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Electronically Filed in TPUC Docket Room on December 16, 2020 at 12: 40 p.m.

December 16, 2020

***Via Email and U.S. Mail***

Executive Director Earl Taylor
c/o Ectory Lawless
Tennessee Public Utility Commission
502 Deaderick Street, Fourth Floor
Nashville, Tennessee 37243

**Re: Piedmont Natural Gas Company, Inc. Petition for an Adjustment of Rates, Charges, and Tariffs Applicable to Service in Tennessee; Docket No.: 20-00086**

Dear Mr. Taylor:

Enclosed please find for filing the original and four copies of the following documents:

Rebuttal testimony and exhibits of:

a. Pia Powers
b. Kally Couzens
c. Quynh Bowman
d. Dylan D'Ascendis
e. Paul Normand

This material is also being filed today by way of email to the Tennessee Public Utility Commission docket manager, Ectory Lawless. Please file the original and provide a "filed" stamped copy of the same via email to my assistant, at denise.guye@wallerlaw.com.

Please do not hesitate to call me if you have any questions.

Very truly yours,

Paul S. Davidson

PSD:cdg
Enclosures
cc: Daniel Whitaker
Bruce Barkley
Pia Powers
James Jeffries

# Before the
# Tennessee Public Utility Commission

## Docket No. 20-00086

**Piedmont Natural Gas Company, Inc. Petition for an Adjustment of Rates, Charges, and Tariffs Applicable to Service in Tennessee**

# Rebuttal Testimony of
# Pia K. Powers

# On Behalf of
# Piedmont Natural Gas Company, Inc.

Piedmont Natural Gas

**December 16, 2020**

**Q. Please state your name and business address.**

A. My name is Pia K. Powers. My business address is 4720 Piedmont Row Drive, Charlotte, North Carolina.

**Q. By whom and in what capacity are you employed?**

A. I am the Managing Director – Gas Rates & Regulatory for Piedmont Natural Gas Company, Inc., ("Piedmont" or the "Company").

**Q. Have you previously testified in this proceeding?**

A. Yes. In this proceeding, I filed Direct Testimony on July 2, 2020.

**Q. What is the purpose of your Rebuttal Testimony in this proceeding?**

A. The purpose of my Rebuttal Testimony is to respond to various matters raised in the Direct Testimony of Consumer Advocate witnesses William H. Novak and David N. Dittemore filed in this proceeding on November 30, 2020.

**Q. What is your position regarding the legal authority of Piedmont's Minimum Margin Agreements ("MMAs")?**

A. Section 5 of Piedmont's existing Tennessee Service Regulations requires that Piedmont's extension of its main(s) to serve a new customer (or customers) be subject to the determination that such extensions are economically feasible. The reason that a determination of economic feasibility is needed in order to extend a main to serve new customers is ultimately to protect the rest of Piedmont's customers. Without that requirement, all other customers could otherwise end up subsidizing the infeasible portion of the investment that is included in rate base. MMAs are utilized by the Company when the economic

feasibility determination is marginal, i.e. when the extension of service is feasible only if the new customer's projected level of usage actually materializes. MMAs are not used for residential customers. They are only used to assure usage levels associated with commercial and industrial customers.

Under MMAs, prospective customers guarantee that they will utilize natural service to at least their projected level necessary to support the extension of service to that customer under Piedmont's feasibility analyses or will pay Piedmont the margin equivalent of such usage. It is fundamentally an economic guarantee to Piedmont that Piedmont will receive the revenues necessary to support the service extension to that customer. Absent an MMA, prospective customers could inflate their predicted usage in order to pass Piedmont's feasibility test. The primary effect of the MMA is to ensure that neither Piedmont nor Piedmont's other customers are left to subsidize service to a new customer if the predicted usage by that customers does not occur.

In terms of service, MMA customers receive service under one of Piedmont's applicable rate schedules at the same Commission-approved rates that all other customers receiving similar service pay and under terms and conditions that are identical to those applicable to other customers in that rate class. In terms of the receipt of natural gas service from Piedmont, customers with MMAs are treated exactly the same as non-MMA customers. Piedmont is

charging only the rates and charges approved by the TPUC to these customers. Should the customer's actual usage in an annual period not achieve the assumed usage upon which service was extended, the MMA customer will be required to make a true-up payment for the difference. Such true-up payment is not associated with the receipt of natural gas service, but rather is associated with the customer's utilization of service at levels below the levels used to justify feasibility of service.

In Piedmont's view, the financial guarantees involved in an MMA do not constitute terms and conditions of natural gas service but are simply financial guarantees upon which Piedmont is willing to extend service that it would not otherwise approve (because the extension is only marginally feasible). It is worth noting that all MMAs are voluntary commitments of the customers involved and that Piedmont uses them in multiple jurisdictions and that the respective Commissions in the States where Piedmont uses them have never asserted jurisdiction over them as gas service agreements. Piedmont believes this treatment is appropriate and that MMAs have two significant beneficial effects on Piedmont and its other customers: (1) they make additional service available on the Piedmont system which helps to reduce each customer's share of system costs, and (2) they avoid the possibility that projects that are only marginally feasible end up as a burden on and subsidized by Piedmont or other customers if usage for those projects is below that predicted.

We are unaware of any negative impacts of these agreements on either the parties thereto or on our customers as a whole. For all of the foregoing reasons, I disagree with Mr. Novak's assertions on page 19 of his Direct Testimony that the MMAs have no legal authority.

**Q. Are there additional points of disagreement with Mr. Novak related to MMAs?**

A. Yes. Mr. Novak's recommends that the Commission order any funds, along with any previous collections prior to the test period, be refunded back to these MMA customers with interest and penalty.[1] I disagree with this recommendation primarily because it is certainly counter to the interest of our customers and would result in subsidization of the MMA customers. The fact that Piedmont was able, through the MMA, to offer service to these two customers under marginal feasibility conditions benefits all customers through the increase in customer base over which the annual cost of service is spread for recovery and through the inclusion in attrition period revenues in this proceeding of the margin from these two customers including that guaranteed by the MMA.

**Q. Do you agree with Mr. Novak's belief that the Company has oversubscribed to its pipeline and storage assets?**

1 Novak Direct Testimony, pg. 19, lines 8 through 10. Also pg. 57, lines 5 through 8.

A. No, I do not. Mr. Novak believes that Piedmont is oversubscribed based on his finding a weather correlation for Piedmont's industrial customers.[2] I see no connection between these two matters. Mr. Novak also mentions that Piedmont has not curtailed the gas usage for any of its interruptible industrial customers since 2015.[3] While it is true that Piedmont has not interrupted customers since the winter of 2014-2015, there is no indication that the cause is an oversubscription of upstream pipeline and storage capacity.

Fundamentally, there is no requirement that interruptible customers have their service interrupted with any frequency or duration. A customer on an interruptible rate schedule simply faces a higher risk of having an interruption of service pursuant to the terms and conditions in our Commission-approved tariff, compared to a customer on a firm rate schedule. In general, the likelihood of interruption of service to interruptible customers increases during periods of colder than normal weather, particularly as the gas system nears design day conditions. Extremely cold temperatures were experienced in the Nashville area during winter 2014-2015. Because of the consequential increase in natural gas demand at that time, system pressures were impacted negatively. In an effort to maintain our system and to ensure continued service to our firm customers, Piedmont's system planning group made the decision to interrupt

2 Novak Direct Testimony, pg. 11, lines 9 through 17.

3 Novak Direct Testimony, pg. 12, lines 4 through 5.

the customers on interruptible rate schedules. Warmer winter temperatures in the intervening years have resulted in Piedmont's natural gas system not experiencing declining pressure issues like those seen in 2014-2015. Consequently, no interruptions have been necessary.

Previous allegations of an oversubscription of upstream pipeline and storage capacity were among several issues that gave rise to the ongoing requirement for an independent Triennial Review of Piedmont's gas supply and capacity plans and transactions. The fifth such Triennial Review is currently underway in Docket No. 05-00165. For these reasons, I see no compelling reason for a separate docket to be opened, as recommended by Mr. Novak on page 56 of his Direct Testimony, on the matter of consideration of the appropriate level of Piedmont's pipeline and storage capacity.

**Q. Do you agree with Mr. Novak's recommendation related to the attrition period expense adjustment for Piedmont's Gas Technology Institute ("GTI") dues?**

A. No, I do not. Mr. Novak argues against the inclusion in rates of Piedmont's proposed $100,000 attrition period expense to support customer-focused research and development activities by the GTI.[4] The basis for Mr. Novak's recommendation is his opinion that Piedmont's participation in GTI's program is not necessary for the provision of utility service by Piedmont and that the

4 Novak Direct Testimony, pg. 47, lines 12 through 19. Also pg. 57, lines 21 through 22.

benefits of the GTI are "illusory at best since any successful research would ultimately be marketed to manufacturers in the distant future."[5]

I find Mr. Novak's recommendation on this matter to be unsubstantiated and misguided. My Direct Testimony explains that most utilities, Piedmont included, cannot independently engage in important research and development work for the ultimate benefit of our customers. The Utilization Technology Development ("UTD") program, which GTI manages and for which Piedmont is proposing cost recovery, leverages the collective strength of 20 utility members and funding from 30 participating States nationally. A study commissioned by UTD in 2016 demonstrated an estimated cost/benefit ratio for UTD developed or improved residential and commercial technologies, averaged across residential and commercial ratepayers located within participant utility territories, of 13 to 1. Many UTD technology impact examples are shown in the opening pages of Rebuttal Exhibit_(PKP-1), which contains UTD's public Annual Report of Research Project Summaries 2019-2020. Many of these UTD technology impacts are already proven in wide practice and many more are at the field demonstration stage. Therefore, contrary to Mr. Novak's opinion, the UTD program has and continues to provide benefits to customers that are neither illusory nor in the distant future. Gas customers and local economies in Tennessee will also benefit from UTD's

5 Novak Direct Testimony, pg. 47, lines 16 through 17.

significant work with the Oak Ridge National Laboratory (Oak Ridge, TN) and with companies such as Stone Mountain Technologies (Johnson City, TN) and manufacturers like A.O. Smith (Johnson City, TN) and Lochinvar (Lebanon, TN). See, for example, in my Rebuttal Exhibit_(PKP-1) the UTD projects listed as 1.11.H (p. 3), 1.13.F (p. 11), 1.16.I (p. 27), 1.19.C (p. 55), 2.18.H (p. 75), and 2.18.B (p. 107). The research and development work that UTD has commissioned since its founding in 2003 has resulted in higher efficiency and lower emissions for residential furnaces and water heaters, commercial rooftop heating units and boilers and commercial food service equipment. All of these technology developments and improvements have resulted in lower energy costs and reliable and clean appliance choices for residential and commercial customers and provide technology choices as our utility plans for a lower carbon future.

Currently UTD is developing and demonstrating the first commercial offerings of residential and commercial natural gas heat pumps which will increase efficiency of natural gas heating appliances from 98% to 140%. One of the developers of this technology is Stone Mountain Technologies in Tennessee. Additionally, the value of the program is enhanced by new technologies being brought to market and UTD actively pursues partnerships with manufacturers so that the benefits of the research and development can be

realized by ratepayers. If the research and development did not get to market, then it would provide little value to consumers.

The UTD program also focuses on customer's safety and health. I reference, for example, UTD's research to assure proper venting of water heaters, improve kitchen indoor air quality, or reduce methane emissions through the burner tip or at compressed natural gas vehicle fueling stations. These are summarized in my Rebuttal Exhibit_(PKP-1) under UTD projects 1.19.J (p. 65), 1.15.G (p. 129), 1.17.H (p. 133), 1.18.F (p. 47), and 2.17.H (p. 155).

Overall, the UTD program is an exemplary research and development collaboration, does a tremendous job in leveraging ratepayer funding and all at a relatively immaterial average proposed cost to customers of approximately $0.0436 cents per month (approximately $0.52 per year).[6] For these reasons, I continue to advocate for inclusion of the $100,000 attrition period GTI program expense.

**Q. Do you have any additional concerns with Mr. Novak's recommendation related to the attrition period expense adjustment for Piedmont's GTI dues?**

A. Yes, there is one other concern which is legal in nature. In its last Tennessee rate case, Piedmont and the Consumer Advocate reached a comprehensive

settlement of all disputed issues in that proceeding. One element comprising the give-and-take nature of those settlement negotiations was that recovery of Piedmont's proposed GTI program participation not be included in the settled cost of service and rates in that proceeding.[7] The Tennessee Regulatory Authority ("TRA") accepted that comprehensive settlement. That approved settlement also bound the Parties to the following commitment:

> "to agree to support this Stipulation and Settlement Agreement before the Authority and in any hearing, proposed order, or brief conducted or filed in this proceeding; provided, however, that the *settlement of any issue provided for herein shall not be cited as precedent by any of the stipulating Parties hereto in any unrelated or separate proceeding or docket before the Authority*…and neither Party waives its right to take position with respect to the matters settled herein in future proceedings before this Authority. This Stipulation and Agreement shall not have any precedential effect in any future proceeding or be binding upon any of the settling Parties in this or any other jurisdiction except to the extent necessary to implement the provisions hereof."[8] [*emphasis added*]

Mr. Novak's statement in his Direct Testimony on page 47 that "[t]his is the same proposal that the Company made in its last rate case that was rejected by the Commission" is not only inaccurate, but also appears to be an attempt to cite as precedent a settlement position from the 2011 rate case, which is an

6 Overall per customer impact calculated as $100,000 attrition period expense spread over approximately 191,000 Piedmont customers in Tennessee.

7 See paragraph 14.i of the approved Stipulation & Settlement Agreement between Piedmont and the Consumer Advocate in Docket No. 11-00144

8 See paragraph 19 of the approved Stipulation & Settlement Agreement between Piedmont and the Consumer Advocate in Docket No. 11-00144

action on Mr. Novak's part that is clearly prohibited by the terms of the TRA-approved settlement agreement in that proceeding.

**Q. Did the Consumer Advocate make any other recommendations related to the recovery of expenses that you disagree with?**

A. Yes, there are several which are addressed in the Rebuttal Testimony of Piedmont witness Quynh Bowman. In addition to GTI dues expense, my Rebuttal Testimony addresses the Consumer Advocate's recommendation related to recovery of expense associated with this rate case proceeding.

With regard to Piedmont's proposal to include and amortize rate case expense in our attrition period revenue requirement, Mr. Novak recommends that "the Commission omit estimated rate case costs and the related amortization from base rates and instead set a separate surcharge to recover these costs in a separate docket."[9] Mr. Novak later in his testimony further clarifies, or rather amends, his recommendation to be "that the Commission open a separate docket for the purpose of evaluating the appropriate level of rate case costs and establishing a separate surcharge for recovery."[10]

Despite his recommendation to entirely move this issue to a separate proceeding, Mr. Novak also shares his opinions about what he feels should be the right level of rate case expense for recovery, presumably in case the

9 Novak Direct Testimony, pg. 39, lines 7 through 9.

10 Novak Direct Testimony, pg. 58, lines 11 through 13.

Commission does not adopt his recommendation to move this issue to another proceeding. In that part of his testimony, Mr. Novak eliminates the costs related to Piedmont's Class Cost of Service Study ("CCOSS") under the premise that since "the Commission has never accepted a CCOSS to set rates", these costs are imprudent and unnecessary and should be excluded from recovery.[11] Mr. Novak also eliminated $60,000 of proposed rate case expense associated with the Company's use of consulting services from Scott Madden Inc. regarding the ARM mechanism.[12] Lastly, Mr. Novak reduced all of the Company's projected legal and remaining consultant costs to 58% of the Company's estimate.[13]

It is important to note that despite Mr. Novak's assertion that the Commission has never accepted a CCOSS to set rates, the Commission's Minimum Filing Requirement for general rate cases calls for a CCOSS to be performed by the Company and submitted in this proceeding; specifically, the Commission's Minimum Filing Requirement No. 42 requires the Company to "[p]rovide a copy of the LDC's Cost Allocation Study and support for any proposed changes in rate design." Therefore, I entirely disagree with Mr. Novak's position that the expense associated with the development and support

11 Novak Direct Testimony, pg. 38, lines 8 through 11.

12 Novak Direct Testimony, pg. 37, Table 12. And pg. 38, lines 13 through 14.

13 Novak Direct Testimony, pg. 38, lines 1 through 6.

of the Company's CCOSS in this proceeding are imprudent, unnecessary and not worthy of recovery through ratemaking.

Legal expenses are incurred by the Company for rate cases because legal expertise is needed to ensure that the case stays on course. Rate case costs also include items not routinely undertaken such as lead-lag, depreciation studies and class cost of service studies, which if not recovered for outside consultants would force the Company to hire employees to perform these functions internally at costs that could potentially exceed the outside costs incurred. Legal costs for a rate case such as this Piedmont one, where a rebuttal case is required, place upward pressure on rate case expense. Note that the Consumer Advocate did not have a basis for their recommended -58% downward adjustment to rate case legal expense, other than noting that the -58% was the difference between Piedmont's estimate of the depreciation study consultant's costs (Alliance Consulting) and Mr. Novak's estimate of the depreciation study consultant's costs.[14]

Piedmont's deferred rate case expense estimate of $982,000 is within the norm of reasonable and accepted rate case expenses, and is lower than the amount accepted for base rate recovery in the most recent litigated gas rate case before this Commission. Specifically, the Commission panel unanimously approved in Chattanooga Gas' 2018 general rate case a deferred rate case

14 Novak Direct Testimony, pg. 38, lines 1 through 6.

expense of $1,241,665; note that their proceeding is similar to Piedmont's current one in that it also required a rebuttal case be prepared.[15] Following Mr. Novak's suggestion herein, which is to entirely move the issue of deferred rate case expense to a separate proceeding, would simply duplicate legal proceedings to handle matters that are routinely and easily handled within the process of a rate case. The deferred rate case expense that was stipulated between Piedmont and the Consumer Advocate in Piedmont's 2011 general rate case, and ultimately approved by the TRA, was approximately $720,000 amortized for recovery through base rates.[16] Piedmont's 2011 rate case was settled, which typically achieves a lower deferred rate case expense for legal costs and consultant costs than rate cases which are not settled. Given the foregoing reasons, it is reasonable to continue with well-established precedent to recover Piedmont's deferred rate case expenses through base rates established in the general rate case.

**Q. Has Mr. Novak recommended that a similar approach be used to estimate Deferred Rate Case expense in any of his prior testimonies before the Commission?**

15 See the TPUC's January 15, 2019 *Amended Order* in Docket No. 18-00017, Section J(5) Deferred Rate Case Expense, pgs. 49 through 52.

16 See the TRA's April 18, 2012 *Order Approving Settlement Agreement* in Docket No. 11-00144, Section Amortization of Deferred Costs, pgs. 4 through 5, paragraph 14.d. Note that $89,983 x 8 years = $719,864 total deferred rate case expense approved for recovery.

A. Yes. In Chattanooga Gas Company's ("CNG") 2018 rate case in Docket No. 18-00017, Mr. Novak excluded consultant costs related to the CCOSS from recovery arguing that CCOSS studies had never been approved by the Commission. Additionally, Mr. Novak eliminated other consultants' costs claiming CGC had not supported such costs through records or testimony. Mr. Novak also recommended that the Commission consider severing Deferred Rate Case expense from the rate case and instead set up a separate docket to determine the appropriate expenditure for this expense.

**Q. Did the Commission adopt Mr. Novak's approach to estimating Deferred Rate Case expense in Docket No. 18-00017?**

A. No. The Commission held that CGC provided sufficient testimony and documentation to justify its Deferred Rate Case expense as reasonable.[17] Therefore, the Commission approved CGC's Deferred Rate Case expense.[18]

**Q. What is the Company's position on Mr. Novak's proposed disallowance of the Company's ARM consultant cost of $60,000?**

A. Regarding Mr. Novak's specific elimination of the Company's $60,000 projected cost for an ARM consultant, I find it acceptable to reduce Piedmont's deferred rate case expense estimate by $60,000 in recognition that the ARM has not been a distinct matter raised in this case (other than Piedmont's request, as

17 CGC Amended Order at p. 51.

18 *Id.* at p. 52.

expressed in my Direct Testimony on page 19, that the Commission in its final order clearly identify the approved methodology as required by T.C.A. § 65-5-103(d)(6)(A)). This proposed $60,000 reduction to the Company's deferred rate case expense is reflected in the updated cost of service computation is represented in the Rebuttal Testimony and Exhibits of Piedmont witness Quynh Bowman.

**Q. Can you describe the Company's position on the Consumer Advocate's recommendation to require Piedmont to have a depreciation study conducted on its indirect common plant that is allocated to Tennessee?**

A. Yes. In his direct testimony, Mr. Novak states that Piedmont has no authorized depreciation rates for indirect plant in service that is allocated to Tennessee.[19] Here Mr. Novak is referring to Piedmont's 3-state joint property (also in prior Piedmont rate cases and in Piedmont report filings sometimes referred to as Corporate Office 3-State Joint Property). These are Piedmont utility plant assets that are used and useful in the provision of regulated gas service to Piedmont's customers in Tennessee, North Carolinas and South Carolina, and of which Tennessee receives an allocated amount for the computation of Tennessee rate base and for the computation of Tennessee depreciation expense. Because Mr. Novak cites that there are no Commission-authorized depreciation rates for this jurisdictional classification of plant, Mr. Novak is

19 Novak Direct Testimony, pg. 29, lines 8 through 9.

recommending that the Commission order the Company to conduct a depreciation study on these assets for consideration in future cases.[20] Nevertheless, Mr. Novak found reasonable to accept and use in his computation of depreciation expense for this proceeding the depreciation rates employed by Piedmont on such 3-state joint property.[21]

Piedmont has always sought and received Commission approval for the depreciation rates applicable to Piedmont's Tennessee direct assets, which represent the significant majority of Piedmont's Total Tennessee Utility Plant in Service. Prior to this rate case, Piedmont presented in its 2011 general rate case a depreciation study by Alliance Consulting, similar to the study presented in this current proceeding which was also prepared by Alliance Consulting.[22] Both the last study and this current study reviewed Piedmont's direct assets in Tennessee and recommended new deprecation rates for Piedmont's direct assets in Tennessee. Commission approval of the deprecation rates applicable to 3-state joint property was never a matter previously raised as a concern by either the Consumer Advocate or Commission, either in the Company's last rate case or any other prior proceeding. I surmise that the reason it was never a

20 Novak Direct Testimony, pg. 29, lines 14 through 15. And pg. 58, lines 6 through 8.

21 Novak Direct Testimony, pg. 29, lines 12 through 13. Piedmont also identified in Mr. Novak's workpapers that he accepted and used in his computation of accumulated depreciation (part of rate base) for this proceeding the depreciation rates employed by Piedmont on such 3-state joint property.

22 See the Direct Testimony and Exhibits of Rhonda Watts filed on September 2, 2011 in Docket No. 11-00144.

prior concern is due to the general nature and relatively small magnitude of cost impact to Tennessee of such Piedmont 3-state joint property.

In Piedmont's 2011 rate case, Tennessee direct assets comprised 95% of Piedmont's attrition period Utility Plant in Service. In this current rate case, Tennessee direct assets comprise 97% of Piedmont's Attrition Period Utility Plant in Service. Of the remaining 3% of Piedmont's Attrition Period Utility Plant in Service that is joint property in this proceeding, the majority is intangible plant (software) and general plant (largely personal computing equipment, customer information system, communication equipment, office furniture, structure and improvements for its call center operations). Given the nature and very small magnitude of Piedmont's 3-state joint property, coupled with the fact that Mr. Novak is accepting for use in this proceeding the deprecation rates proposed by the Company for its 3-state joint property, I see no compelling reason at this time for the TPUC to order that Piedmont conduct and file a depreciation study for these specific joint property assets.

Nevertheless, Piedmont will commit in future rate cases before the TPUC to clearly and separately present for pre-approval changes to the deprecation rates of its joint property assets that it seeks to implement, including support from a depreciation study of these 3-state joint property assets.

**Q. Do the Consumer Advocate and the Company agree on all of the Tariff changes proposed by Piedmont in this docket?**

A. No. Mr. Novak is opposed to one of the Company's proposed Tariff changes. Mr. Novak recommends that the Commission deny Piedmont's Tariff change proposing to eliminate the numerical listing of the base rate on each individual Rate Schedule.[23] Mr. Novak states that he is opposed to this Tariff change because he believes that keeping the base rate listed on each Rate Schedule helps provide clarity to the customer.[24]

I recognize that the Company's proposed Tariff change here is more a matter of form rather than substance. However, I disagree with Mr. Novak's recommendation to deny this proposed Tariff change. I disagree with Mr. Novak because I believe that the Company's proposed change will indeed improve clarity and reduce confusion for customers compared to the current form of the Tariff. And clarity for customers, not confusion for customers, with respect to Piedmont's TPUC-approved rates and Tariff is exactly what I believe Mr. Novak wants as much as I do.

Please be aware that Piedmont was not and is not proposing to entirely eliminate the publication of the base rates from its Tariff. The total billing rate in effect for each Rate Schedule, along with each component of that

23 Novak Direct Testimony, pg. 54, lines 7 through 8.

24 Novak Direct Testimony, pg. 54, lines 9 through 10.

rate, will continue to be published in Piedmont's Tariff as part of Tariff Sheet No.1.[25] Specifically, Column <1> in Tariff Sheet No. 1 lists, by Rate Schedule, the amount of the monthly charge, the base margin rate component per therm and, where applicable, the base margin demand rate component per therm. Tariff Sheet No. 1 additionally shows in columnar format all the other rate components for each Rate Schedule, and a summary column with the total billing rate applicable for each Rate Schedule. By contrast, each individual Rate Schedule in Piedmont's current Tariff identifies the numerical base rate component set in the last general rate case proceeding, not the entire current billing rate that is in effect.

In summary, I continue to advocate for removing the existing numerical rate and charge references shown within each individual Rate Schedule of the Tariff, and to instead simply reference "Tariff Sheet No. 1" therein. I believe that eliminating these duplicative and partial references in the current form of the Tariff will yield a more streamlined and cohesive Tariff, and thereby improve the clarity and understanding of Piedmont's rates and Tariff by its customers.

**Q. What is your position on the Consumer Advocate's recommendation that the Commission should re-endorse its position stated in its 1992**

25 A PDF of Piedmont's current Tariff and Service Regulations, starting with Tariff Sheet No. 1, can be found at: www.piedmontng.com /_/media/pdfs/png/tn-tariffandserviceregulations.pdf?la=en

**Accounting Order in Docket No. 92-16160[26] and confirm that such environmental cost deferrals do not imply such costs will necessarily be recoverable in Rate Base or as Operating Expenses in subsequent Piedmont rate proceedings?[27]**

A. Mr. Dittemore states that the Consumer Advocate has no adjustment to the Company's proposal to recover its deferred environmental costs in this proceeding.[28] The Company defers environmental costs that have been prudently incurred to address environmental matters that are directly related to the provision of regulated natural gas service to its Tennessee customers. I believe that the Commission's prior orders are clear and that the Commission has the right to approve only prudently incurred costs in this and future ratemaking proceedings. Therefore, Mr. Dittemore's suggested re-endorsement of prior guidance associated with deferred environmental costs attempts to remedy a problem that does not exist and is not necessary.

**Q. What is your position on the Consumer Advocate's recommendation that the Commission make clear to the Company that any subsequent approval to enter into an ARM mechanism should be based upon a finding that the regulatory treatment provided to Piedmont is in the public interest and**

26 *Order* dated December 21, 1992 in Docket No. 92-16160.

27 Dittemore Direct Testimony, pg. 37, lines 10 through 13.

28 Dittemore Direct Testimony, pg. 36, lined 5 through 7.

**that the Company has the burden of proof in supporting that conclusion?**[29]

A. I believe this issue is more appropriately addressed in an actual ARM filing by the Company pursuant to T.C.A. § 65-5-103(d)(6)(A)), rather than in this general rate case proceeding.

**Q. What is your position on the Consumer Advocate's recommendation that the Commission, in approving the implementation of interim rates, should ensure the appropriate coordination of the Company's base rate increase with the termination of its IMR surcharge, save for the true-up portion of the charge?**[30]

A. For the most part, I do not have a concern with Mr. Dittemore's recommendation because it aligns with exactly what Piedmont requested in its November 30, 2020 filing to this Commission in Docket No. 20-00130 for an amended IMR surcharge amount effective January 1, 2021. Please note, however, that Piedmont is not requesting in this proceeding nor in Docket No. 20-00130 that its IMR mechanism (Service Schedule No. 317) be terminated. As explained in my Direct Testimony filed on July 2, 2020 in this rate case docket, Piedmont anticipates making a separate filing sometime after the conclusion of this rate case for approval to operate an ARM effective January

29 Dittemore Direct Testimony, pg. 36, lines 15 through 18.

30 Dittemore Direct Testimony, pg. 36, lines 19 through 21.

1, 2022; and with that ARM filing will be a conditional proposal to terminate the IMR mechanism effective January 1, 2022.[31]

**Q. What is your position on the Consumer Advocate's recommendations that the Commission should terminate the provisions contained in its prior orders in Docket No. 96-00977[32] permitting Piedmont to defer pension funding on its books and records?**

A. Mr. Dittemore recommends that the Commission terminate the existing deferred accounting treatment for pension that was originally authorized for Piedmont in Docket No. 96-00977.[33] Should the Commission adopt his recommendation, Mr. Dittemore notes Piedmont can petition the Commission to reobtain approval for deferral of pension funding based upon the specific facts and circumstances it faces at that time.[34]

I do not agree with Mr. Dittemore's opinion that Piedmont should be required to petition the Commission for the authority to defer pension expense each time future pension plan contributions are made. The Commission's guidance concerning the recovery of pension expense has been articulated in numerous orders over a period spanning more than twenty years. The

31 Powers Direct Testimony, pg. 18, lines 18 through 20.

32 *Order* dated February 19, 1997 and *Order Clarifying "Order of February 19,1997"* dated June 9, 1997 in Docket No. 96-00977

33 Dittemore Direct Testimony, pg. 15, lines 20 through 21. And p.36, lines 24 through 26.

34 Dittemore Direct Testimony, pg. 16, line 9 through 11. And pg. 36-37, line 27 and lines 1 through 3.

Commission's directives are clear and should not be replaced by a process that adds no value for customers yet increases the administrative burden for all parties involved including the Commission. Mr. Dittemore recommends this new process on the basis of the future being uncertain.[35] He believes that blanket authority should not be provided regardless of funding status.[36] Mr. Dittemore concludes by suggesting that Piedmont is unique because "the Company no longer exists," plan benefits are frozen, and the plan is currently overfunded.[37] However, none of Mr. Dittemore's assertions should require the type of inefficient case-by-case requests for deferral that is currently recommending.

I believe that Mr. Dittemore's recommendation should not be accepted for the following three reasons. First, specific pension funding is and always has been uncertain because contributions are dependent on market returns and future obligations of the pension fund. There is nothing new or unique in this proceeding concerning this uncertainty. Second, the Commission is currently under no such blanket authorization to approve requests for additions to rate base or operating expenses that it does not deem prudent. Mr. Dittemore's recommendation creates a cumbersome process to solve a problem that does not exist. Finally, the specific terms and status of

35 Dittemore Direct Testimony, pg. 15, lines 25 through 26.

36 Dittemore Direct Testimony, pg. 15, lines 26 through 27; pg. 16, lines 1 through 2.

pension plans are prone to change over time, and while this reality impacts the amount of pension cost to be included in ratemaking proceedings, it does necessitate additional proceedings. It should also be noted that the merger with Duke Energy which was approved by this Commission in 2016 did not cause Piedmont or its workforce to no longer exist.

Q. **Please comment on Mr. Dittemore's assertion that Piedmont is incented to overfund its pension plan.[38] Do you agree that this is credible scenario that requires the Commission's attention?**

A. No, I do not. As stated in my previous answer, the Commission has established clear policies associated with pension accounting and has the authority to amend those policies as it deems appropriate. The scenario described by Mr. Dittemore is detached from the reality of managing a regulated utility such as Piedmont. His theory appears to be that Piedmont has excess funds that it funnels into its pension plan in order to generate credits to its pension expense.

Mr. Dittemore's assertion is not realistic on several grounds. The primary reason that his assertion is nonsensical is that such pension expense credits would be returned to customers through the annual rate proceedings that Piedmont undergoes in South Carolina and through the general rate cases that Piedmont undergoes in North Carolina, because both of these jurisdictions

37 Dittemore Direct Testimony, pg. 16, lines 8 through 9.

38 Dittemore Direct Testimony, pg. 11, line 21.

follow the accounting guidance provided by the Financial Accounting Standards Board for ratemaking. Under Mr. Dittemore's "unhealthy incentive"[39] scenario, Piedmont would inexplicably invest excess funds in its pension fund rather than investing such excess funds in the most attractive investment option available in the marketplace. This scenario is even more unlikely given the fact that over 80% of the potential profits from this alleged scheme would be returned to Piedmont's North Carolina and South Carolina customers through rate proceedings in those jurisdictions. This illogical, unprofitable motivation to overfund its pension plans as a benefit to shareholders has never influenced Piedmont's pension funding decisions and deserves no consideration as the Commission rules on pension matters in this proceeding.

**Q. The Consumer Advocate expresses criticism of Piedmont for its purported failure to identify with specificity the rate case methodology upon which Piedmont may seek to implement an ARM.[40] Do you agree with this criticism?**

A. With respect to a ratemaking methodology that would have applicability under an ARM, I do not see that there is anything to criticize in this proceeding, including in Piedmont's July 2, 2020 filed application and direct witness

39 Dittemore Direct Testimony, pg. 11, line 21.

40 Dittemore Direct Testimony, pg. 6, lines 1 through 7.

testimonies. Piedmont requested in its July 2, 2020 application that the Commission "adopt and approve ratemaking methodologies sufficient to enable implementation of an ARM pursuant to T.C.A. §65-5-103(d)(6) upon subsequent application by Piedmont for adoption of such a mechanism".[41] My Direct Testimony explained that "[w]hile Piedmont is not requesting Commission approval to operate under an ARM or approval of an ARM Tariff in this general rate case, the Company is nevertheless requesting that the Commission in its final order in this rate case clearly identify the approved methodology as required by T.C.A. § 65-5-103(d)(6)(A) so that this rate case can provide the foundation for a subsequent ARM request should the Company decide to make such petition to the Commission in the future."[42] Examples of what Piedmont requests be laid as foundation in the Commission's final order are the Commission's decisions on: capital structure and returns, rate base, billing determinants, weather normalization, depreciation, lead-lag, A&G expense and its components such as incentive compensation and non-lobbying governmental relations expense, uncollectibles expense, other O&M expense, ongoing expense deferral treatment, OPEB rate base treatment, AFUDC, income tax, general taxes, retention factors, class cost allocation, and the like. Most if not all of these matters are typically well articulated in the

41 See Piedmont's July 2, 2020 Petition filed in Docket 20-00086, pg. 8, paragraph 6.

42 Powers Direct Testimony, pg. 19, lines 9 through 16.

Commission's final orders, as par for the course. Therefore, what Piedmont seeks from the Commission in its final order for this rate case is what I believe the Commission would otherwise normally include in its final rate case order for proceedings such as this – an explanation of the methodologies used by the Commission for each of the rate case elements that go into the Commission's final approved rates.

Piedmont does not yet know what the Commission's approved ratemaking methodologies will specifically be for this general rate case. Ultimately, the Commission will know what rate methodologies it approves in this case and will explain them in its final order.

Another reason why I see nothing to criticize in the proceeding regarding rate methodologies for a future ARM is the Commission precedent that exists on this exact matter. CGC, in its 2018 general rate case in Docket No. 18-00017, did not seek approval of an ARM in that proceeding after withdrawing its original filed request for an ARM. However, CGC did indicate in the rate case proceeding that it would seek an ARM in a subsequent proceeding, and like Piedmont in this proceeding, CGC requested that the Commission in its final order clearly identify the approved methodology as required by T.C.A. § 65-5-103(d)(6)(A). CGC did not list all the proposed rate methodologies in any more detail than Piedmont did in this case. The Commission, in its final Order, explained the methodologies used in its

determination of the final, approved rates for CGC, such that the clarity of the rate methodologies in the rate case were appropriately understood for use in CGC's subsequent ARM request and approval in Docket No. 19-00047. I will note that the Commission included in CGC's rate case order the following statement: "If Chattanooga Gas Company petitions for an alternative regulatory mechanism, the forward-looking methodologies adopted in this Order should be reviewed for appropriateness in the determination of service rates pursuant to such annual rate-setting mechanism".[43] The Commission will have the opportunity to include similar language in its order in this general rate case proceeding.

**Q. Piedmont witness Dylan D'Ascendis disagrees in his Rebuttal Testimony with Mr. Dittemore's recommendation that ROE should be reduced if an ARM is approved. Do you agree with Mr. Dittemore's recommendation concerning an ROE reduction?**

A. No, I do not. I believe Mr. Dittemore's recommendation is not supported by the fact that the legislation authorizing alternative regulatory mechanisms in Tennessee, which is T.C.A. §65-5-103(d), makes no mention of such ROE reduction.

The comments made by then-Chairman Roberson in 2009, which are cited on Page 7, Line 1 of Mr. Dittemore's Direct Testimony, were associated

43 See the TPUC's *Amended Order* dated January 15, 2019 in Docket No. 18-00017, pg. 89, paragraph

with legislation that ultimately did not pass.[44] In 2013, when the legislation we currently operate under was considered and ultimately passed,[45] Consumer Advocate representatives appeared in front of a legislative committee to recommend against the passage of legislation authorizing an ARM and to require lower ROE if an ARM were approved.[46] However, then-Chairman James Allison testified before the legislative committee to rebut the claims of the Consumer Advocate representatives.[47] Mr. Allison did not recommend an ROE adjustment for entry to operate with an ARM. Mr. Allison noted at that time that entry into an ARM was discretionary on the part of the utility and the Commission, and that the Commission would consider the utility's ROE along with many other factors to determine whether an ARM was in the public interest. Mr. Allison went further in noting the additional protections available to consumers and stated that a show cause proceeding could be used if ROEs under an ARM got out of kilter with market conditions. TPUC's General Counsel at the time, Jean Stone, further rebutted the Consumer Advocate's objections by commenting that rate setting is inherently a legislative function

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22.

44 The legislative history for HB1349/SB1375 from 2009 is publicly available at http://wapp.capitol.tn.gov/apps/Billinfo/default.aspx?BillNumber=HB1349&ga=106.

45 https://publications.tnsosfiles.com/acts/108/pub/pc0245.pdf

46 House Business and Utilities Committee meeting 3/6/13 video can be found at http://tnga.granicus.com/MediaPlayer.php?view_id=269&clip_id=7320 . Consumer Advocate testimony begins at 11:28

47 Chairman Allison's testimony begins at 31:33

and that it's entirely appropriate for the legislature to set regulatory policy, including any parameters.[48]

The Tennessee General Assembly received all of this input, yet included no mention of an ROE reduction in the legislation it ultimately enacted. Therefore, I believe no such reduction was deemed appropriate by the General Assembly in 2013, and no such reduction should be ordered by the TPUC in this proceeding or in a future proceeding in which Piedmont seeks approval to implement an ARM.

**Q. Does this conclude your Rebuttal Testimony?**

A. Yes, it does. Thank you.

48 Ms. Stone's testimony at 45:51

# Rebuttal Exhibit_(PKP-1)

UTD.
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Technology
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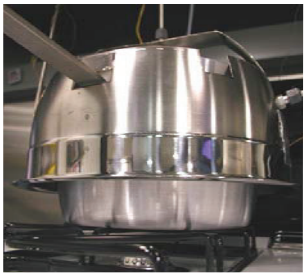
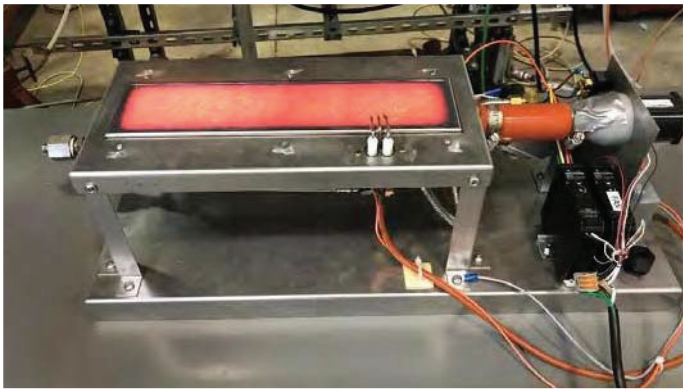
# RESEARCH PROJECT SUMMARIES 2019-2020





# Utilization Technology Development, NFP

# RESEARCH PROJECT SUMMARIES

# 2019 - 2020

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## Letter to Our Stakeholders

The events of the past year underscore the importance of the mission and impact of Utilization Technology Development, NFP (UTD), a non-profit applied research organization of 20 member companies who serve 37+ million customers in North America. National and global efforts to reduce greenhouse gas (GHG) emissions are increasing, but the personal and financial hardships amplified by COVID-19 spotlight the need for an affordable and resilient transition to a lower-carbon energy economy for all.

This report summarizes 70+ UTD research projects that help members serve their residential, commercial, industrial, and transportation customers. These initiatives focus on increasing efficiency, integrating more renewable energy, reducing emissions, and enhancing reliability and safety.

UTD is creating, developing, and demonstrating many new gas-fired products to operate at far higher energy efficiency levels than existing equipment – while maintaining affordability. Notable developments in 2020 include large field demonstrations of new high-efficiency gas-fired heat pump water heaters that are close to commercialization.

UTD's efforts to reduce GHG emissions continue in many ways, such as to develop novel integrated systems that connect on-site renewable energy with gas distribution systems, or by increased use of renewable natural gas or hydrogen. Pairing renewable energy with the underground gaseous infrastructure that offers immense seasonal energy storage retains customer choice and provides a resilient, reliable foundation to improve energy efficiency as consumers cope with bitterly cold winters, hurricanes, and other weather events.

The projects also illustrate how UTD leverages its resources by co-funding research grants from the U.S. Department of Energy, California Energy Commission, New York State Energy Research and Development Authority, and other leading governmental agencies, and maximizes its impact by collaborating with national laboratories, university researchers, and leading manufacturers.

We thank those who support UTD and other applied research to economically address the great needs facing ratepayers and society.

### UTD Members

> APGA Research Foundation
> Atmos Energy Corporation
> Dominion Energy
> DTE Energy
> Duke Energy
> Enbridge Gas
> Intermountain Gas Company
> Louisiana R&D Committee
  - Atmos Energy Corporation
  - CenterPoint Energy, Inc.
  - Entergy Corporation
> National Fuel Gas Distribution Corporation
> National Grid
> New York State Electric & Gas Corporation/ Rochester Gas and Electric Corporation
> NW Natural
> Nicor Gas
> Oklahoma Natural Gas Company
> Pacific Gas and Electric Company
> Peoples Gas, a WEC Energy Group co.
> Southern California Gas Co., a Sempra Energy Utility
> Southwest Gas Corporation
> Spire Energy
> TECO Peoples Gas

Rob Eck
*Chairman*

Ron Snedic
*President*

# UTD IMPACT

UTD
Utilization
Technology
Development

UTD develops and advances economical new products, systems and technologies to save energy, save customers money, integrate renewable energy and renewable natural gas, and help customers maintain safe, reliable, resilient operation with superior environmental performance.

UTD recognizes the economic hardships amplified by COVID-19, and is developing and demonstrating affordable new energy-efficient solutions for all ratepayers as illustrated in the following pages. As a 501(c)(6) non-profit collaboration of forward-thinking utilities, UTD thanks the leading researchers, universities, governmental agencies, manufacturers and others that partner with UTD to make these and other exciting impacts!

Please contact us if you have any questions about UTD.

**Ron Snedic** (1.847.768.0572)

**Rich Kooy** (1.847.768.0512)

UTD's 20 member companies serve more than 37 million natural gas customer accounts in North America.

UTD helps utilities create exciting new products for their customers and maximize the impact of their energy-efficiency programs.

Together we're shaping the energy future with clean, efficient end-use technologies.

**Visit www.utd-co.org for more information.**

## COMMERCIALIZED PRODUCTS

### M-Trigen PowerAire

M-Trigen's PowerAireä provides high-efficiency microCHP with integrated cooling to homeowners, small businesses, and other users. UTD is providing technical support for a notable demonstration by partnering with NYSERDA, National Grid, NJNG, and PERC to independently validate performance. UTD is also supporting M-Trigen in its optimization of PowerAire to minimize emissions, and its development of PowerFurnaceä.

**M-Trigen**
Kevin Robert
713-574-4506 x1018
kevinr@mtrigen.com
www.mtrigen.com

### Sierra™ Engine-driven Gas Heat Pump

Sierra's (formerly NextAire™) 11-ton packaged GHP can efficiently heat and cool commercial buildings (up to 1.4 COP) while reducing electric demand. Also available are 8- and 15-ton GHPs with VRF multizone capabilities. UTD's field studies are supporting best practices for siting. UTD is partnering with NYSERDA and National Fuel in a 2020 field test in NY state.

**Blue Mountain Energy**
Tom Young
702-339-7395
tyoung@bluemountainenergy.com
www.bluemountainenergy.com

## COMMERCIALIZED PRODUCTS (continued)

### Yanmar 3-Pipe Engine-driven Gas Pump

Yanmar's 3-pipe, 14-ton Gas Heat Pump (GHP) with variable refrigerant flow (VRF) offers an important new energy-efficiency option for the North American market by combining heat recovery with simultaneous heating and cooling. In a 2018-20 field test, UTD is validating the quantitative and qualitative performance of an instrumented installation.

**YANMAR America Corp.**
Mike Mehrvarz
770-877-7709
mike_mehrvarz@yanmar-es.com
www.yanmar-es.com

### Dedicated Outside Air System/Rooftop Unit

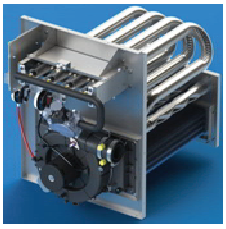
Condensing heating versions of Munters Dedicated Outside Air System (DOAS) and other rooftop unit (RTU) products increase heating efficiency from 80%-81% to 90%-93%. Multiple RTU manufacturers are now offering DOAS with 90+% efficiencies, facilitated by the availability of condensing duct furnace modules first developed with UTD support.

**Munters Corporation**
Larry Klekar
210-249-3883
larry.klekar@munters.com
www.munters.com

### Heat Sponge Economizer for Industrial/ Commercial Boilers

In either condensing or non-condensing configurations, this heat recovery system for commercial and industrial boilers (over 140,000-unit market in U.S.) increases boiler efficiency from 80% to a range of 85%-93% (validated by UTD lab testing). It also saves customers 5%-15% in annual energy costs. UTD completed a field test in Utah to validate energy savings.

**Boilerroom Equipment, Inc.**
866-666-8977
www.heatsponge.com



### Condensing Duct Furnace Modules

High-efficiency condensing heating modules developed with UTD support are now available from Beckett Gas and other OEMs, including Heatco, and are being applied to DOAS and other products including Make-Up Air Units available from multiple manufacturers including Aaon, Daikin, and RuppAir.

**Beckett Gas, Inc.**
Joel Mohar
440-783-7610
jmohar@beckettcorp.com
www.beckettgas.com

### Cannon Boiler Works Ultramizer®

The Ultramizer is an advanced heat-and-water recovery system for larger commercial and industrial boilers, of which there are more than 140,000 in the U.S. It increases boiler efficiency from 80% to 93%—saving customers 15% in energy while also reducing water demand.

**Cannon Boiler Works, Inc.**
Chris Giron
724-335-8541 x414
sales@cannonboilerworks.com
www.cannonboilerworks.com

### S.U.N. Equinox Solar-Assisted Heating System

The Equinox system is a combination solar/natural gas water heating system that uses an efficient evacuated tube design. It can be used in residential, commercial, or industrial locations and is capable of meeting 100% of domestic hot-water and space heating needs. UTD validated its energy performance in a field demonstration.

**Solar Usage Now, LLC**
Thom Blake
260-657-5605
tblake@solarusagenow.com
www.solarusagenow.com

## COMMERCIALIZED PRODUCTS (continued)

### ENERGY STAR® Fryers

Royal Range introduced the high-efficiency RHEF-75 fryer in 2019—building on the success of the smaller-capacity, high-efficiency RHEF-45 fryer that received the National Restaurant Association's Kitchen Innovation Award and GFEN's Blue Flame Product of the Year Award. Independ-ent testing showed 63% heavy-load cooking energy efficiency.

**Royal Range of California**
Robert Lutz
951-360-1600
robert@royalranges.com
www.royalranges.com

### Low-Oil-Volume Fryers

Marketed by Frymaster as Protector® fryers, this equipment increases energy efficiency while also extending cooking-oil quality and life to provide significant customer savings. Field demonstrations completed by UTD have shown an average savings of $4,800 per year per fryer.

**Frymaster**
Linda Brugler
318-866-2488
lbrugler@frymaster.com
www.frymaster.com

### ENERGY STAR Conveyor Oven

ENERGY STAR rated conveyor ovens from Lincoln include an advanced energy-management system to reduce energy con-sumption up to 38%.

**Lincoln, a division of Manitowoc Foodservice**
260-459-8200
www.lincolnfp.com

### ENERGY STAR Convection Oven

This unit showed improved efficiency and 40% energy savings compared to a standard oven during field testing and achieved an ENERGY STAR rating.

**Garland**
905-624-0260
www.garland-group.com

### High-Efficiency Broiler

This broiler features infrared burners and an energy-saving hood that showed an average of 23% energy savings during field testing. It offers more efficient cooking as well as reducing heat gain to the kitchen.

**Royal Range of California**
800-769-2414
www.royalranges.com

### ENERGY STAR Countertop Steamer

A compact, gas-fired countertop steamer for commercial foodservice offers enhanced cooking rates while providing energy savings and reduced water consumption. It was the first gas-fired boilerless steamer on the market and received an ENERGY STAR rating.

**Market Forge Industries Inc.**
617-387-4100
866-698-3188
custserv@mfii.com
www.mfii.com

### Gas Quality Sensor

The Gas Quality Sensor (GQS) uses solid-state infrared light absorption spectroscopy to measure Btu content and composition of natural gas and bio-methane fuels. It provides faster response at much lower cost than a gas chromatograph. It was developed with UTD support and was commercially in-troduced by CMR Group in 2019.

**CMR Group**
Jon Stendebach
724-452-2200
918-407-4005
jon.stendebach@cmr-group.com
www.cmr-group.com

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Jon Stendebach
724-452-2200
918-407-4005
jon.stendebach@cmr-group.com
www.cmr-group.com

## COMMERCIALIZED PRODUCTS (continued)

### Cummins Westport 6.7L Medium-Duty NGV Engine

This 6.7L 240-HP natural gas vehicle (NGV) engine is used in school buses, shuttle buses, medium-duty trucks, and other vocational uses. It went into full commercially production in December 2016. It meets U.S. 2017 EPA GHG requirements and CARB's optional more stringent low $NO_x$ standard of 0.1 g/bhp-hr.

**Cummins Westport Inc.**
Yemane Gessesse
812-377-5000
yemane.gessesse@cummins.com
www.cumminswestport.com

### Cummins Westport 8.9L Near-Zero Emission NGV Engine

This 8.9L 320-HP NGV engine is widely used, with 50,000+ engines sold for transit, refuse-collection, and regional hauling applications since 2007. In 2016, it was advanced to become the first engine certified in North America to meet the 0.02 g/bhp-hr optional Near Zero (NZ) $NO_x$ emissions standard (i.e. 90% lower than the current EPA $NO_x$ limit of 0.2 g/bhp-hr).

**Cummins Westport Inc.**
Yemane Gessesse
812-377-5000
yemane.gessesse@cummins.com
www.cumminswestport.com

### Cummins Westport 11.9L Near-Zero Emission NGV Engine

This 11.9L 400-HP NGV engine is used in large trucks, buses, and refuse vehicles. Engine sales since 2013 are approaching 10,000 units and 25,000+ engines will likely be sold in N.A. by 2020, yielding emissions reductions and $600+ million in annual fuel sales. In Model Year 18, it became CWI's second engine certified to meet NZ $NO_x$ emissions standard of 0.02 g/bhp-hr.

**Cummins Westport Inc.**
Yemane Gessesse
812-377-5000
yemane.gessesse@cummins.com
www.cumminswestport.com

### HyperComp/3M NGV Cylinders

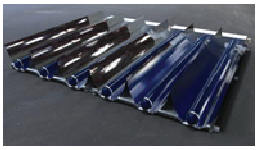
These lightweight Type IV NGV cylinders are manufactured using advanced 3M nanoparticle-enhanced matrix resin technology for high strength and durability. Three tank sizes of 30, 40, and 45 diesel gallon equivalent (DGE) are now offered in nine unique CNG Fuel System Solutions from Momentum Fuel Technologies, including roof mount, saddle mount, and back-of-cab designs.

**Momentum Fuel Technologies**
844-264-8265
www.momentumfueltechnologies.com

### Ultimate CNG FuelMule™

The patented FuelMule™ mobile fueling solution dispenses eight diesel gallon equivalent per minute and fuels 35-50 medium-duty vehicles per delivery. It is used as a temporary starter station, station back-up, or for mobile onsite fueling. It logged 250,000+ miles and almost 6,000 compressor hours delivering natural gas fuel to vehicles across the U.S. in its first five years of operation.

**Ultimate CNG, LLC**
Dennis Pick
703-209-4086
dpick@ultimatecng.com
www.ultimatecng.com

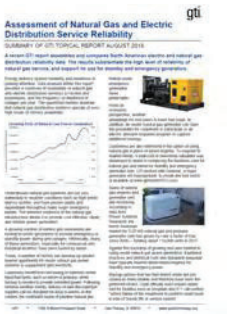


### External Concentration Parabolic Collector

This patented, non-tracking, extremely-low-profile concentrator can achieve 200°C (392°F) solar thermal energy to economically serve commercial and industrial facilities and reduce GHG emissions. It can also be integrated with natural gas as a supplemental energy source. UTD provided technical and product development support and experimental validations over a seven-year period.

**Artic Solar Inc.**
Bill Guiney
904-513-4638
bill@articsolar.com
www.articsolar.com

## KEY INFORMATION & ANALYTICAL TOOLS




### Reliability, Cost and Environmental Impacts of Standby Generation Systems

Generac's website provides technical information related to emissions, reliability and costs of natural gas generators that was developed with UTD's support. For example, UTD researchers published a white paper that provided new data on the reliability of natural gas service and assisted in the development of a Total Cost of Ownership calculator that compares emissions and costs of natural gas vs. diesel-fueled standby generators.

*Available on-line at https://www.gti.energy/wp-content/uploads/2019/02/Assessment-of-Natural-Gas-Electric-Distribution-Service-Reliability-SummaryReport-Jul2018.pdf and https://www.generac.com/Industrial/all-about/natural-gas-fuel*

### Building America

Under five separate projects from 2011 to 2020, UTD has developed key information and tools to support the U.S. DOE's Building America research, development, and demonstration program, which helps accelerate use of best practices by residential builders, remodelers, installers, code officials, designers, raters, teachers, and others. Most recently a simplified combustion safety protocol was introduced.

*Available on-line at https://www.gti.energy/BuildingAmerica and https://basc.pnnl.gov/library*

### Commercial Foodservice (CFS) Equipment Calculator

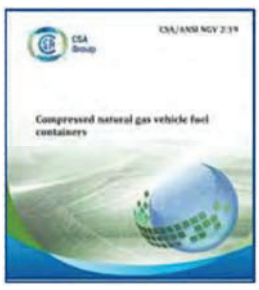
This website provides the restaurant industry and others with information and tools to determine the economic and environmental benefits of using new, more advanced and efficient CFS equipment. The website was developed with UTD support and has been showcased at several restaurant trade shows. Further enhancements are underway in 2020.

*Available online at http://cfscalc.gastechnology.org. For more information, contact Frank Johnson; fjohnson@gti.energy*

### Virtual Test Home

A Virtual Test Home (VTH) in a laboratory was expanded in 2020 with UTD's support. Leveraging the VTH, UTD has helped Navien and iFLOW demonstrate that an advanced forced-air condensing tankless water heater combi system can achieve 30-50% energy savings relative to best-in-class condensing furnaces and water heaters. The VTH is also developing data to help accelerate adoption of advanced gas technologies (such as GHPs, combis and modulating furnaces) in U.S. DOE's EnergyPlus™ and other energy software.

*For more information, contact Tim Kingston; tkingston@gti.energy*

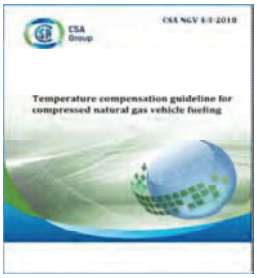



### CSA NGV2 CNG Vehicle Fuel Containers Standard Technical Committee Support

The sixth edition of CSA NGV2 issued in 2019 and contains updated information and requirements for the material, design, manufacture and testing of serially-produced, refillable Type NGV 2 containers intended only for the storage of CNG for vehicle operation. The 2019 revision includes localized fire tests and conformable storage topics. UTD supported participation to lead the Technical Task Force that created the Standard.

*Available online at www.csagroup.org. For more information, contact Ted Barnes; tbarnes@gti.energy*

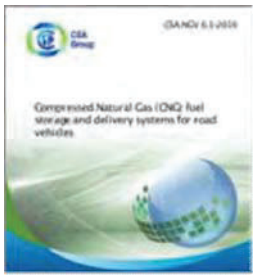
## KEY INFORMATION & ANALYTICAL TOOLS (continued)




### CSA NGV4.3 NGV Storage and Delivery Standard Technical Committee Support

CSA NGV4.3 issued in 2018 and specifies the performance requirements for temperature compensation control used to prevent compressed natural gas (CNG) dispensing systems from exceeding a safe fill level of vehicle fuel storage container(s). It contains safety performance guidelines and field evaluation methods for existing dispensing systems. UTD supported participation to lead the Technical Task Force that created the Standard.

*Available online at www.csagroup.org. For more information, contact Ted Barnes; tbarnes@gti.energy*




### CSA NGV6.1 NGV Storage and Delivery Standard Technical Committee Support

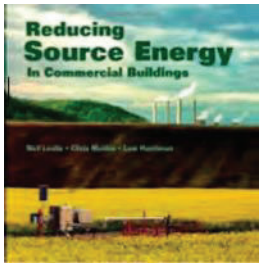
CSA NGV6.1 was introduced in 2016 and defines the requirements for the balance of systems and equipment onboard a NGV, which is not otherwise defined by NGV1 for the receptacle or NGV2 for the storage containers. UTD supported GTI's participation on the Technical Committee.

*Available online at www.csagroup.org. For more information, contact Ted Barnes; tbarnes@gti.energy*

### CSA NGV5.1 and NGV5.2 Fueling Appliance Standard Technical Committees Support

CSA NGV5.1 was introduced in 2015 and updated in 2016, and provides mechanical, physical, and electrical requirements for residential fueling appliances (RFAs) that dispense natural gas for NGVs, including indoor and outdoor fueling appliances that connect to residential gas piping. A complimentary standard, NGV5.2 for vehicle fueling appliances (VFAs) in non-residential locations, has been developed and was published in late 2017. UTD supported participation on both of the Technical Committees.

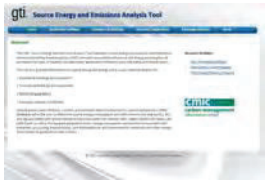
*Available online at www.csagroup.org. For more information, contact Ted Barnes; tbarnes@gti.energy*




### Source Energy Technical Data

Researchers are providing unbiased technical data on the benefits of source energy in reducing energy consumption and carbon emissions in buildings and transportation. Source energy is now included in the International Green Construction Code (IgCC) for high-performance commercial buildings, and in various American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) standards (e.g., Standard 100 for existing buildings, Standard 105 method for comparing building energy performance, Standard 189 for high-efficiency green buildings, and Standard 214 for building energy performance rating).

*For more information, contact Neil Leslie; nleslie@gti.energy*




### Source Energy and Emissions Analysis Tool

The Source Energy and Emissions Analysis Tool (SEEAT) calculates source energy and greenhouse-gas emissions related to point-of-use (site) energy consumption by fuel type for each energy-consuming device. The source-energy and carbon-emission calculation methodology used accounts for primary energy consumption and related emissions for the full fuel cycle for residential and commercial buildings, industrial applications, and light-duty vehicles. SEEAT data is also used in theEnergy Planning Analysis Tool (EPAT), a publicly available resource to help end users assess and minimize their total source energy use.

*Available online at www.cmctools.com and www.epat.gastechnology.org. For more information, contact Neil Leslie; nleslie@gti.energy*

## TECHNOLOGY ADVANCEMENTS

### Gas-fired Absorption Heat Pump Residential Water Heater

A field test of five prototype units of this efficient residential Gas-Fired Heat Pump Water Heater was successfully completed in Southern California during 2020, with support from CEC, UTD, SoCalGas and a prospective manufacturing partner. The unit has a projected Uniform Energy Factor (UEF) of 1.20-1.30 and ultra-low NOx emissions of ≤10 ng/J. A significantly larger and wider field test of prototype commercial production units is being formulated in 2020.

*Project Manager: Paul Glanville*

### Gas-fired Absorption Heat Pump for Space Heating or Commercial Water Heating

A field test of four prototype Gas Absorption Heat Pumps (GAHP) for space heating or water heating applications was successfully completed in WI and TN during 2019 with a prospective manufacturing partner and support from U.S. DOE, UTD and others. Results demonstrated an Annual Fuel Utilization Efficiency of 140% (45% gas savings), ultra-low NOx emissions of ≤14 ng/J, and continued operation under extreme cold weather conditions in WI during the Jan-Feb 2019 Polar Vortex. A larger field test of prototype units is underway in 2020.

*Project Manager: Paul Glanville*

### Ultra-Low $NO_x$ Burner

This innovative firetube boiler technology has more than two years of proven successful operation at a Mission Linen Supply facility in California. It improves efficiency and achieves $NO_x$ emissions below 9 vppm, while avoiding the significant efficiency, capital cost, and/or operating cost penalties if conventional Selective Catalytic Reduction or burner enhancements such as external Flue Gas Recirculation and/or High Excess Air firing were used. UTD's partner Power Flame Inc. is helping businesses in 2020 meet $NO_x$ emission regulations without sacrificing energy efficiency.

*Project Manager: David Cygan*

### Low $NO_X$ Ribbon Burner System

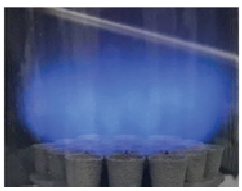
A new combustion system reduces $NO_X$ emissions by 50% in food processing, thermoforming, and other industrial applications and also saves energy. The system was evaluated in bench-scale, pilot scale, and full-scale production settings and has demonstrated transparent operation at an industrial bakery in California. In 2020, post-demo monitoring will continue at the bakery is along with commercialization activities with UTD's partner Flynn Burner Corp.

*Project Manager: Yaroslav Chudnovsky*

### FlexCHP High-Efficiency Ultra-Clean Power and Steam Package

This innovative CHP package allows flexible steam production while meeting stringent California emission levels without a SCR system and across the full range of firing rates — achieving $NO_X$ levels 50% below CARB limits. An installation in California operates with 84+% system efficiency and system emissions well below 9 ppm $NO_X$. UTD has provided long-term support, including efforts to apply the technology for broader application sizes (e.g. to 400 kW / 400 BHP).

*Project Manager: David Cygan*



### Low $NO_x$ Advanced 3D-Printed Nozzle Burner

A novel design for next-generation retention nozzles leverages new additive manufacturing capabilities and equipment. In 2020, UTD is evaluating applications for boilers, water heating and air heating. Laboratory tests have demonstrated a robust, high-efficiency (3-6% increase), ultra-low emissions burner, with >10:1 turndown. It achieved 50%-75% reduction in $NO_X$ emissions compared to current burners, with the potential to reach <5 ppm $NO_X$.

*Project Manager: Sandeep Alavandi*

## TECHNOLOGY ADVANCEMENTS (continued)

### Gas-Fired Warewasher

A new prototype gas-fired warewasher is being developed in conjunction with a leading OEM. The estimated annual savings for restaurant, cafeteria, and other commercial food service operators is $1,100-$9,000 per warewasher (depending on size and type) while also saving energy and chemicals, when compared to electrically-heated warewashers that operate at lower temperature and thus require one-time use and environmental impact of chemicals.

*Project Manager: Shawn Scott*

### Cost-Effective Small-Scale Compressor for Natural Gas Vehicles (NGVs)

A cost-effective small-scale compressor could significantly change the NGV fueling market. With UTD cost share and U.S. DOE funding, GTI and the University of Texas, Austin (using specialty materials from Argonne National Laboratory) developed a novel approach using a linear motor with only one moving piston and operated a prototype successfully in the lab. The technology is currently being scaled up to 50 SCFM capacity with UTD funding.

*Project Manager: Jason Stair*

### On-Demand Heat and Power System

This unique new technology has received a remarkable three rounds of funding from U.S. DOE ARPA-E, along with UTD and other co-funding support. This technology captures and stores renewable energy (or other resources, including waste heat), augments it with natural gas as needed, and delivers heat and power on-demand to commercial, industrial, and other users. In 2020, the technology is moving to a pilot field scale-up demonstration in California.

*Project Manager: David Cygan*

### CARB-Compliant Engine-Based Micro-CHP System

UTD researchers are collaborating with the CEC and SoCalGas to advance and commercialize the first-ever engine-based micro-CHP system that complies with California Air Resource Board requirements. A system offered by a major manufacturer in an influential market like California could spark the U.S. micro-CHP market.

*Project Manager: Tim Kingston*

### Energy Recovery Heat Exchanger

UTD researchers are collaborating with CEC to demonstrate in California an advanced recuperator to increase energy efficiency at an aluminum die casting operation. The objective is a decrease natural gas use by 20-40% per ton of melted aluminum (depending if scrap is preheated). The technology has been used in Europe but not yet in North America.

*Project Manager: David Rue*

### ENERGY STAR® Residential Gas Dryer

UTD worked with a major manufacturer to develop one of the first commercially-available gas-fired ENERGY STAR clothes dryers (included at energystar.gov/products/appliances/clothes_dryers). UTD is currently investigating next-generation technologies and developing an early-stage prototype residential gas dryer to substantially further increase operating efficiency.

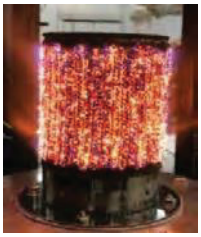
*Project Manager: Shawn Scott*

## TECHNOLOGY ADVANCEMENTS (continued)

### iGEN Self-Powered Furnace

The innovative new iGEN furnace generates its own electric power and contains an integrated battery, providing homeowners with continuous heating even during electricity outages. Initial units produce about 45 MBtu/hr and 1kW of power, with reported 95% heating system efficiency. UTD supported the technical refinement of this new product with laboratory testing, validation, and recommendations.

*Project Manager: Tim Kingston*



### Ultra-High-Efficiency, Combination Heating/Cooling Vuilleumier Cycle Heat Pump

Vuilleumier cycle-based heat pumps could provide a step-change efficiency improvement over vapor absorption- or compression-based cycles, achieving cooling COP > 1 and heating COP > 2. UTD is working with a leading developer to advance key system components using both computational and experimental analysis, to help achieve performance goals in alpha prototype testing funded by DOE, UTD and others. UTD is funding additional research in 2020.

*Project Manager: Alex Fridlyand*

### Next Generation Liquid Dessiccant-based, Heat-Driven HVAC System

Liquid desiccant-based systems can efficiently remove moisture from air and reduce the amount of mechanical energy and water required by conventional HVAC technologies that de-humidify, condition, and re-humidify space air. In cooperation with NYSERDA and others, UTD is testing a novel new non-corrosive, non-toxic desiccant in a gas-driven system that offers a potential 30% increase in COP on a seasonal basis over conventional HVAC technologies.

*Project Manager: Doug Kosar*

### Self-Powered Tankless Water Heater

Tankless water heaters yield higher levels of efficiency than storage-type water heaters but require the added expense of an electrical connection and are susceptible to power outages unless a separate battery back-up system is installed. UTD researchers have assessed leading thermoelectric generator (TEG) technologies, and in 2020 are analyzing opportunities to economically integrate TEG and other technologies into a prototype water heater design.

*Project Manager: Aleks Kozlov*

### Low $NO_x$, High-Efficiency Burners for Commercial Food Service Equipment

UTD is helping manufacturers respond to pending new regulations on $NO_x$ emissions of CFS equipment and simultaneously improve energy efficiency by developing and demonstrating prototype equipment that uses advanced burner concepts or components. Both novel new burner configurations as well as state-of-the-art burner technologies are being evaluated.

*Project Manager: Frank Johnson*

### High-Efficiency Gas-Fired Rotary Heat Pump for Food Processing

UTD is partnering with CEC, SoCalGas, and others to demonstrate an innovative high-efficiency, thermal-vacuum, gas-fired heat pump technology for food drying applications at a commercial food processing company. The new technology has the potential to be about twice as efficient as conventional processes. A prototype system at a field host site will generate performance data during 2020.

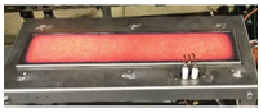
*Project Manager: Yaroslav Chudnovsky*

## TECHNOLOGY ADVANCEMENTS (continued)

**High Efficiency Commercial Clothes Dryer**

An advanced natural-gas-fired commercial clothes dryer is being created and demonstrated at laboratory scale that has the potential to save at least 50% of the energy used in the commercial clothes drying sector. It is being developed in partnership with Oak Ridge National Laboratory and others, with financial support from U.S. DOE and UTD.

*Project Manager: Yaroslav Chudnovsky*



**Next Generation Infrared Burner**

In partnership with a leading U.S.-based product manufacturer, UTD-funded researchers are testing a variety of unique metal foam materials in a laboratory to evaluate their potential performance as next-generation, high-efficiency, rapid-response, low-emission infrared burners that are directly fired with natural gas or renewable natural gas.

*Project Manager: Sandeep Alavandi*

**Residential Furnace Retrofit for High-Efficiency Heating and Humidification**

Tests of a patented Transport Membrane Humidifier (TMH) technology in four homes in Minnesota demonstrated a 14% increase in furnace efficiency while providing humidification without water supply. Interested licensees should contact Rich Kooy at rich.kooy@utd-co.org.

*Project Manager: Dexin Wang*

**Advanced Combustion System for Next Generation mCHP**

An advanced combustion system with thermochemical heat recovery has been created and demonstrated with UTD's support in a laboratory. Applying the system to a Stirling-based micro-CHP system can increase fuel-to-electric efficiency from 12-15% to 30%. Testing in 2019 demonstrated low NOx and CO emissions at ≤9 ppm (at 3% O2, dry).

*Project Managers: Aleks Kozlov*

## WORKING WITH PARTNERS TO CO-FUND UTD INITIATIVES

In 2019, each $1.00 in new UTD funding was leveraged by $4.82 of new direct funding from government and industry partners for related end-use R&D. GTI secured $23.5 million from federal and state government partners and $5.76 million in funding from manufacturing partners and other gas industry resources (outside of UTD). Manufacturing partners also provided significant, additional in-kind co-funding. Examples include:

> U.S. Department of Energy (DOE) funding of $7.6 million for five complementary programs aimed at advanced compressed natural gas and hydrogen fueling station and vehicle technology.

> California Air Resources Board (CARB) funding of $5.8 million for novel low-emission vehicle demonstrations.

> U.S. DOE ARPA-E funding of $1.5 million to further push forward a novel high-temperature heat recovery and storage technology that will increase solar thermal energy integration with supplementary gas.

> South Coast Air Quality Management District (SCAQMD) funding of $1.3 million for an innovative high-efficiency ultra-low NOx ribbon burner system for industrial applications.

> U.S. DOE NETL funding of $1.2 million to develop a unique high energy-conserving heat rejection technology.

> California Energy Commission (CEC) funding of $1 million for advanced high-efficiency through-the-wall furnaces.

> More than $5.4 million in other gas industry funding to advance a range of emerging high-efficiency technologies.

# UTD RESEARCH PROJECT SUMMARIES
## 2019 - 2020

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# RESIDENTIAL AND LIGHT COMMERCIAL, INCLUDING mCHP

# Next-Generation Residential Gas Heat-Pump Water Heater

***A research team designed and demonstrated the first residential gas-fired heat-pump water heater to provide end users with a storage water heater with an efficiency factor of 1.3 of greater. Field demonstrations were recently conducted in California.***

## Project Description

The industry's first residential gas heat-pump water heater (GHPWH) is near commercialization, with two OEM partners and a series of successful field trials advancing the design of each generation of prototypes. In partnership with other research funding agencies, UTD co-funded a team of researchers to develop the residential/small-commercial GHPWH and continue to reduce projected product costs and improve reliability by refining a number of system components.

The initial GHPWH development initiative was funded by the U.S. Department of Energy (DOE). This project is a continuation of that steady development, led by Stone Mountain Technologies, Inc. (SMTI) with commercial OEM partners and Gas Technology Institute.

The first-generation GHPWH units were designed and demonstrated through laboratory testing from 2011 to 2013. Subsequently, six GHPWH units were installed and monitored in the field. Through these initial field tests, critical information was used to improve the GHPWH control strategies and future design improvements (including system sizing).

The most recent phases of this UTD project focused on supporting an additional five field demonstrations in a program sponsored by the California Energy Commission (CEC) with financial support from Southern California Gas Company (SoCalGas) in addition to UTD, with recent activities investigating enhanced options for system diagnostics and grid interactivity.

*One of five pre-commercial GHPWHs tested in California.*

## Benefits / Market Implications

The motivation for developing a GHPWH is efficiency driven. When delivered to the market, the GHPWH will be the only technology and product of its kind with a primary energy efficiency of greater than 100%. The efficiency gains are significant, with project uniform efficiency factors (UEFs) of 1.20 or greater, and consistent field results of 50% or greater energy savings over conventional water heaters, respectively. Results from this project have the potential to reduce the cost, increase the reliability, and more than double the efficiency of the next generation of gas heat-pump water heaters for end users.

## Technical Concept & Approach

The GHPWH units are driven by an air-source single-effect absorption heat pump, itself driven by a gas burner, capable of Coefficients of Performance (COP) of 1.4-1.9. This can yield a UEF of 1.20, more than twice the efficiency of standard gas storage water heaters, which are in 74% of California homes.

Based upon a recent certification, the units are ultra-low-$NO_x$ compliant. The packaged GHPWH heats the 60 to 80 gallons of stored water with a nominal 10,000 Btu/hr output ammonia-water absorption heat pump, driven by a small 6,300 Btu/hr low-$NO_x$ gas burner. With such a small combustion system, the GHPWH offers retrofit installation advantages over other high-efficiency gas products.

Through the broader project funded by the CEC and SoCalGas, the project team is currently focused on the testing of GHPWH units and the development, use, and refinement of advanced fault detection and diagnosis.

For the phase that recently completed, the goal was to demonstrate that the projected delivered efficiencies of 130% or greater are valid, robust, and are not achieved through a loss of user comfort. Researchers estimated the annual energy, operating cost, and emissions savings and solicit feedback from host end users and installation contractors through pre/post surveying.

## Results

Following a laboratory development program, a first prototype gas heat-pump water heater was installed in a Tennessee residence over a 10-month period was investigated. The laboratory-validated performance and preliminary field test data suggested that the 1.20 UEF target is feasible and if achieved during commercialization it can be competitive with other available high-efficiency gas water-heating options.

In 2015, project efforts focused on transitioning the purpose-built prototype from field testing to reliability testing. Reliability testing was completed in 2016.

A report on the initial phases of the project was issued in 2017. In these phases, six GHPWH prototypes were subjected to extended reliability testing. More than 2,500 operating hours were accumulated by these GHPWH units.

Researchers also performed an analysis of how the GHPWH is impacted by relevant codes and standards in the U.S., Canada, Mexico, and Europe.

In 2017, seven new GHPWH units were built: five units for residential field demonstration, one for evaluation at SoCalGas' *Engineering Analysis Center*, and one for proprietary testing by a manufacturing partner.

In 2018, the project team monitored the performance of the five gas GHPWHs installed at the test sites, which continued through June 2019.

Data continue to confirm that ~50% energy savings are achieved on a site-by-site basis and are expected to improve as the ambient temperatures rise.

Data analyses were performed on a weekly basis and shared with the candidate manufacturing partners to provide early feedback.

Baseline monitoring was completed for the initial equipment at all five test sites. Data was data collected, aggregated, and analyzed. The project team also finalized the all deliverables for the project prime project sponsor, CEC, with summaries posted here:

*"We are very pleased to be supporting this initiative. In the next five to 10 years, proposed government performance standards for residential water heaters will increase, necessitating that natural-gas water-heating products meet or exceed these energy-efficiency targets. The performance target established for this product-development program ensures that these requirements will be fulfilled."*

*- Bill Castellan*
*Specialist Energy Solutions - Business Development (retired)*
*Enbridge Gas*

*https://www.gti.energy/enhancing-efficiency-in-space-conditioning-and-water-heating/.*

In 2020, technicians prepared laboratory space for Phase 5 activities. For Phase 4, two fourth-generation GHPWH units were received from California, with one partially installed in the laboratory. Additional preparations were made to initiate standardized and non-standardized efficiency testing.

A draft Final Report was submitted to CEC summarizing the results of the recent program sponsored by CEC, and is in CEC's review process. A final project virtual meeting was held on August 26, 2020.

## Status

COVID-19 slowed the initiation of testing for current phase activities, but progress is now under way. In parallel efforts by others, a larger field trial program is being considered.

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UTD Utilization Technology Development

RESIDENTIAL AND LIGHT COMMERCIAL, INCLUDING mCHP

PROJECT NO. 1.11.M
SUMMARY REPORT

# Evaluation of Whole-House Residential Retrofit Technologies (Building America)

***In a multi-year partnership with the U.S. Department of Energy, researchers are conducting laboratory tests, field studies, and energy analyses to support the adoption of energy-efficient technologies to reduce energy use and costs in existing residential buildings.***

## Project Description

Through this project, UTD provides financial support for the Partnership for Advanced Residential Retrofit (PARR), a U.S. Department of Energy (DOE) Building America team led by Gas Technology Institute (GTI). PARR focuses on retrofit issues in cold climates with high space-heating energy consumption. Building America provides opportunities to present UTD findings promoting intelligent use of gas appliances to reduce source-energy consumption in existing homes.

The project is divided into phases. Phases 1-4 provided cost share for the first five years of the PARR activities, and Phase 5 provides cost share for the 2015-2020 scope, which focuses on managing infiltration, ventilation, and duct system airflows to obtain the best indoor air quality with the lowest energy consumption.

## Benefits / Market Implications

This project is providing data and analysis to support natural gas technology assessment and installation best practices in existing residential buildings. It is anticipated that project results will support the continued use of gas equipment and systems in retrofit situations as the most cost-effective potential single measure or as a part of an energy-efficiency package.

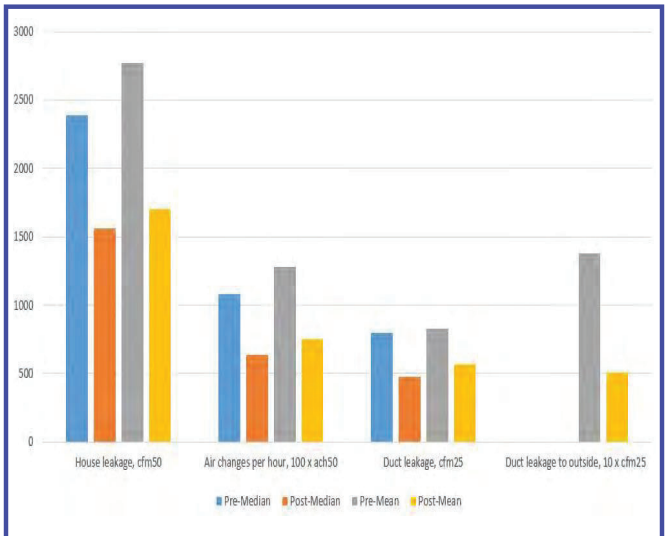
## Technical Concept & Approach

Investigations were completed for several key areas of research:

1. Optimizing gas furnace performance in the field
2. Testing the laboratory performance of furnaces
3. Improving the performance of multifamily buildings that use gas for steam and hydronic heat
4. Measuring the performance of combination heating and water-heating systems
5. Determining the optimum energy upgrade packages for typical midwestern single-family building types
6. Combustion safety for gas appliances using indoor or outdoor air for combustion, and
7. Low-cost methods for mitigating radon.

For the 2015-2020 program, key research areas are:

1. A systems approach to air flow in houses *(ventilation, air tightness, ducted distribution systems, and combustion air requirements)*. This scope includes the adoption of outdoor-temperature-based ventilation strategies, air tightness credits for ventilation, and the interaction between ducted air distribution systems and depressurization in the space. This research is a collaborative effort between GTI, the University of Illinois, and the Midwest Energy Efficiency Alliance. Standard and enhanced measures packages will be evaluated in up to 40 homes. Standard and enhanced measures packages will be evaluated, along with different ventilation approaches.
2. Continued support and advocacy through the Building America program for simplified combustion safety test procedures so that fewer homes are rejected by weatherization teams.
3. Continued focus on approaches for determining zero net energy for mixed fuel house using solar photo-voltaics as the renewable resource.




*Preliminary airflow data show drastic improvements in uncontrolled air*

## Results

- **Optimizing Gas Furnace Field Performance**

  A study of 48 Iowa HVAC SAVE program evaluations showed that homes were losing 9% of potential performance from their furnaces, usually due to restrictive returns and/or filters. In 10 homes that received more in-depth evaluation, diagnostic data showed that 23% improvement in delivered heating energy could be achieved through system tune-ups.

- **Laboratory Performance of Furnaces Removed from the Field**

  Laboratory testing of 12 vintage furnaces removed from the field showed that there was no degradation in performance with time, and the efficiency of the furnaces in the field could be increased an average of 6% through tune-ups.

- **Multifamily Steam Distribution Systems**

  A 10-building retrofit study showed 10% savings in natural gas use, with a five-year payback.

- **Combination Heating & Water-Heating Systems**

  A two-year study of commercialized combination units in the field found up to 20% savings compared to separate space- and water-heating systems.

- **Energy Upgrade Packages for Midwestern Single-Family Homes**

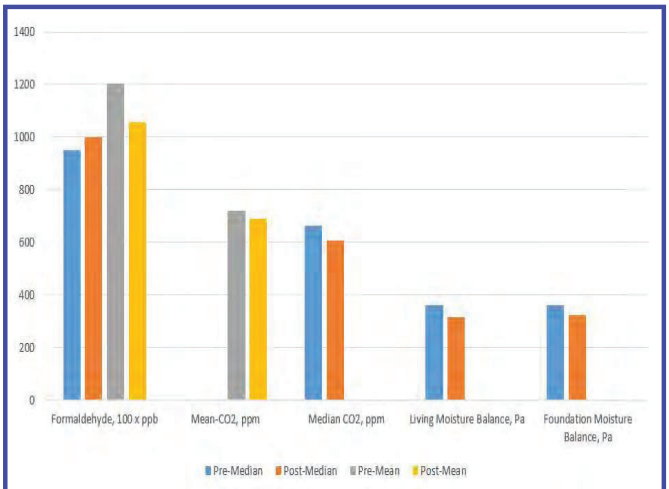
  PARR analyzed cost-optimal energy packages from the Illinois Home Performance program with the ENERGY STAR program as compared to the packages selected by the Building Energy optimization tool for 15 single-family archetypes.

- **Combustion Safety for Gas Appliances Using Indoor or Outdoor Air for Combustion**

  PARR developed a Combustion Safety Measure Guideline published by Building America and developed a simplified test procedure for appliances using indoor air.

- **Radon Mitigation Through Air Sealing**

  PARR studied the impact of air sealing between first-floor and foundation space on the radon levels in the home. Results showed, in many cases, surprising links between hourly measured radon and hourly outdoor temperature. Colder temperatures correlate strongly with lower radon levels. When windows are open, radon is reduced in vented crawl spaces, as expected, as well as in living spaces.




*Preliminary airflow data generally shows that as homes were made tighter and intentionally ventilated, indoor air quality improved.*

## Status

A test plan was developed for a study to compare homes with normal industry practice energy retrofits and a suite of enhanced airflow-control measures.

In 2019, the team prepared a preliminary data analysis for a DOE project review. All of the homes are receiving ASHRAE 62.2-compliant ventilation as part of their retrofits, and so far the data support the expectation that energy efficiency retrofits installed with proper ventilation do not have a negative effect on indoor air quality. $CO_2$ and moisture decreased slightly post-retrofit. Formaldehyde levels were similar and very low both pre- and post-retrofit, likely because these are older homes without out-gassing from recently installed building materials.

A revised test plan was submitted to DOE to evaluate the effectiveness of supply-side ventilation versus exhaust ventilation on the indoor air quality contaminants of concern.

More than 30 homes have enrolled in this study, and the project will be extended through another heating season to finalize data collection.

Field data collection is expected to extend through the third quarter of 2020.

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UTD Utilization Technology Development

# Gas Engine Heat Pump Modeling for Different Climates

***Researchers developed and are applying new models based on the laboratory and field performance of the Yanmar high-efficiency gas-engine-driven heat pump to provide a more accurate prediction of seasonal energy-savings performance for five different climate zones.***

## Project Description

In 2016, Yanmar introduced a 14-ton gas heat pump (GHP) with a three-pipe heat-recovery variable refrigerate flow (VRF) configuration that provides simultaneous heating and cooling, an important new option for the GHP market. In addition to improving the response to building loads, a three-pipe system potentially reduces energy use by recovering heat from zones in cooling mode (e.g., internal loads) and redistributing it to meet heating loads in perimeter zones.

In an early phase of this project, researchers developed GHP models based on field and laboratory data from the NextAire™ 15-ton unit. These results were compared to modeled results for conventional rooftop units (RTUs) and electric heat pump VRF (EVRF). This modeling study provided some valuable results highlighting the importance of part-load performance for VRF systems paired with dedicated outdoor air systems. Measured performance of the NextAire GHP showed reduced efficiency at lower part loads, which adversely impacted the total seasonal performance.

Based on these models, part-load performance of both electric and gas VRF systems, particularly from 20%-40%, was the key indicator of overall system performance.

In this project, researchers will assist gas end users by developing energy models of new GHP technology and providing a more accurate estimate of seasonal performance in different climates. This study will also assist in identifying the most cost-effective target markets for GHPs, as well as performance or cost targets for continued development. The ultimate goal is to expand the use of high-efficiency GHPs by identifying regions and commercial applications where GHPs generate the most energy savings or economic benefits.

## Benefits / Market Implications

Gas-engine-driven heat pumps offer consumers a high-efficiency option. Several of these products have a multi-zone VRF configuration, an increasingly popular option in the small commercial market.

For the customer, the key value proposition for GHPs are lower operating costs due to reduced peak electric demand and low natural gas prices. GHPs significantly reduce peak electric use during periods of high demand, especially peak summer loads, as well as peak winter loads in regions with widespread use of electric heating. GHP operating costs can be 30% less than electric heat pumps. GHPs also offer potential savings in source energy and full-fuel-cycle greenhouse gas emissions.

Another key advantage for GHPs is improved heating performance at low ambient temperatures. Heat recovery from the engine jacket and exhaust is used to supplement heat output, increasing heat capacity at low temperatures and improves heating efficiency. This also allows GHPs to maintain supply temperatures. In contrast, electric heat pumps typically require inefficient resistance heating to supplement heat output at low outdoor temperatures.

## Technical Concept & Approach

Under Phase 3 of this project, researchers will update existing GHP models to incorporate performance data from the Yanmar three-pipe GHP. These models will be used to predict energy savings, operating costs, and reductions in peak electric demand for various climates.

The project team will use existing published models of EVRF configurations and calibrate these models based on measured field data to determine the relative energy savings and environmental benefit of GHPs compared to equivalent EVRF systems.

The project team will update existing GHP models, incorporating Yanmar performance data with respect to ambient temperatures and the range of heating and cooling loads.

Researchers will:

- Select up to five locations in North America in different climate zones
- Conduct hourly energy analysis for three equipment types (GHP, RTU, EVRF), two building archetypes, and up to five climate locations
- Determine the seasonal energy use; specifically gas and electricity consumption, and peak electric demand
- Determine economic benefits of GHP as compared to EVRF systems
- Analyze savings in operating costs and lifecycle costs, and
- Compare source energy and full-fuel-cycle greenhouse gas emissions based on the U.S. average marginal electricity mix.

## Results

A baseline U.S. Department of Energy (DOE) reference building model was developed for a multi-zone office building. Space conditioning loads and energy use were compared to measured field data for validation. An EnergyPlus™ GHP model was developed based on measured data from the NextAire unit to validate the model. The project team also developed a new EnergyPlus model for an alternative GHP VRF system based on manufacturer performance data (Yanmar) and measured field data from UTD project 1.17.G.

Existing EnergyPlus electric heat pump VRF models were revised based on manufacturer performance data for the Daikin IV cold-climate VRF heat pump. These performance curves were adjusted and validated based on measured field data.

*"Southwest Gas has always supported natural gas air-conditioning technology. We are extremely encouraged that more than 350 NextAire gas heat pump units have been installed in our service territory. Using natural gas for cooling saves energy, reduces costs, and lowers greenhouse gas emissions. It's a win-win for all!"*

*- Anthony Hills, PE*
*Director*
*Southwest Gas Corporation*

In 2019, researchers developed a new EnergyPlus model for a GHP VRF system, for a second DOE reference building (Stand-Alone Retail). Custom performance curves were based on manufacturer performance data and measured field data.

Hourly energy simulations were conducted for a standalone retail building in five different climates. A baseline model with a conventional system is being used for comparison. The following climate zones are in the scope of the analysis:

- Chicago, IL
- Helena, MT
- Richmond, WA
- Houston, TX, and
- Los Angeles, CA.

Energy use is being compared to a conventional system across a total of 15 simulations.

## Status

Hourly energy simulations for a second DOE reference building (Retail) using EnergyPlus models are under way to compare gas and electric heat-pump systems with the baseline systems for five climate locations.

Research is being conducted to determine seasonal energy use, specifically, gas and electricity consumption and peak electric demand. Comparisons will be made for source energy and GHG emissions based on the U.S. average marginal electricity mix.

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UTD Utilization Technology Development

# Codes and Standards for Advanced Gas Technologies

***Through interactions with industry associations and code-development organizations, researchers are presenting scientific data and helping refine and update codes and standards so that end users and the environment can benefit from cost-effective advanced gas technologies.***

## Project Description

The introduction of advanced equipment and technologies can be restricted by a variety of issues between the prototype stage and full market adoption. Codes and standards (C&S) issues can sometimes be hurdles to widespread adoption. Advanced technologies are often developed to address issues with existing alternatives; however, new technologies are evaluated using existing criteria which may misrepresent performance, necessitate costly engineering redundancies, and delay market introduction.

The objective of this project is to present scientific data and help technical organizations make consensus-driven refinements and updates codes and standards so that end users and the environment can benefit from cost-effective advanced gas technologies.

## Benefits / Market Implications

Information tools, cost-effectiveness calculations, case studies, technical data, and other products developed through this project will help consumers have more efficient gas technology and product options to benefit the environment and end users.

## Technical Concept & Approach

By supporting technical committees and groups from leading organizations such as the U.S. Department of Energy (DOE), the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Natural Resources Canada (NRCAN), the International Code Council (ICC), the American National Standards Institute (ANSI), and the National Fire Protection Association (NFPA), the research team is helping advanced gas technologies be scientifically characterized and evaluated.

## Results

**Example Consensus Standards Recently Supported**

- *ANSI/ASHRAE Standard 146-2020 Method of Test for Rating Pool Heaters* new standard issued adding gas-fired heat-pump (GHP) pool heaters to the standard. Standard SPC 146-2020 was published with updates including definitions and provisions for fuel-fired heat-pump pool heaters, paving the way for rating GHP-based pool heaters.
- *ANSI/ASHRAE Standard 118.1 Method of Testing for Rating Commercial Gas, Electric, and Oil Service Water Heating Equipment* completed.
- *ANSI/ASHRAE Standard 204P Method of Test for Rating Micro-Combined-Heat-and-Power Devices* completed.

**Other Example Activities**

- Contributed to updates of the ASHRAE Fundamentals Handbook.
- Assisted in development of ASHRAE research projects.

The project team supported technical discussions on the following ASHRAE standards committees:

- ASHRAE Residential Building Committee
- STD 90.1-2019 Energy Standard for Buildings Except Low-Rise Residential Buildings

- TC 1.2 Instruments and Measurements
- TC 1.10 Combined Heat-and-Power Systems
- TC 1.13 Optimization
- TC 2.10 Resilience and Security
- TC 4.1 Load Calculation Data and Procedures
- TC 4.3 Ventilation Requirements and Infiltration
- TC 4.7 Energy Calculations
- TC 6.1 Hydronic & Steam Equipment and Systems
- TC 6.3 Central Forced Air Heating and Cooling Systems
- TC 6.6 Service Water Heating Systems
- TC 6.10 Fuels and Combustion
- TC 8.12 Desiccant Dehumidification Equipment and Components
- TC 8.3 Absorption and Heat Operated Machines
- TC 8.7 Variable Refrigerant Flow
- SPC 40 MOT for Heat Operated Unitary Air-Conditioning and Heat-Pump Equipment
- SPC 62.2 Ventilation and Acceptable Indoor Air Quality in Residential Buildings
- SPC 105 Standard Methods of Determining, Expressing and Comparing Building Energy Performance and Greenhouse Gas Emissions
- SPC 118.2 Method of Testing for Rating Residential Water Heaters
- SPC 227P Passive Building Design Standard
- SPC 228 Standard Method of Evaluating Zero Energy Building Performance
- SPC 124 Methods of Testing for Rating Combination Space-Heating and Water-Heating Appliances
- SPC 146-2011R, Method of Test for Rating Pool Heaters
- SPC 204 Method of Test for Rating Micro-Combined-Heat-and-Power Devices
- SPC205 Standard Representation of Performance Simulation Data for HVAC and Other Facility Equipment
- SPC 228P, Standard Method of Evaluating Zero Energy Building Performance

*"GTI was very instrumental in the final outcome of the soon-to-be-released standard 204-2020, which without their direct influence we would still be working on completing the standard today. GTI assisted on the technical writing of the document, keeping the roster together, and helping keep the chairmen organized and well informed."*

*- Chris Dockery*
*ASHRAE SPC 204 Chairman*
*Chief Operating Officer*
*KI Energy, LLC*

- SSPC 41 Standard Methods for Measurement
- SSPC 41.13P Standard Methods for Fuel Heating Value Measurement
- SSPC 188 Guideline 12 (Legionella).

The project team supported technical discussions on these other committees:

- NFPA 54 National Fuel Gas Code
- ANSI/CSA Joint Technical Sub-Committee on Standards on Gas Air Conditioning Appliances
- ANSI Task Force Z21.40.2/CGA 2.92
- ANSI Task Force Z21.40.4/CGA 2.94
- ASTM Committee E06 on Performance of Buildings
- ASTM Subcommittee C16.30 on Thermal Measurement
- ASTM C1784 Standard Test Method for Using a Heat Flow Meter Apparatus for Measuring Thermal Storage Properties of Phase Change Materials and Products.

## Status

Members of the project team (including from GTI, the Gas Technology Institute) continue to interact with various C&S committees and prepare conference papers and presentations of value to end users, engineers, regulators, and the gas industry.

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UTD Utilization Technology Development

# Innovative Gas Absorption Heat Pump for Space Conditioning

***This project focused on developing and testing a prototype packaged high-efficiency, low-emission gas heat-pump for space-heating applications to serve residential and small-commercial customers.***

## Project Description

Gas-fired absorption cooling at the residential/small-commercial scale has traditionally experienced low market penetration due in large part to high first cost. To meet this market need, low-cost gas-fired absorption heat pumps (GAHPs) in heating applications (air source) are being developed, which may be able to offer substantial efficiency gains over typical non-condensing and condensing warm-air furnaces and hydronic boilers alike, with a project Annual Fuel Utilization Efficiency (AFUE) of 140% versus 80% to 95% for standard boilers and furnaces. Thus, a cost-competitive GAHP could gain market share in the space-heating and/or cooling markets.

This UTD project provided cost-share to a program that received prime funding from the U.S. Department of Energy (DOE). Additional project participants included Stone Mountain Technologies Inc., A.O. Smith Corporation, and Gas Technology Institute (GTI), with subsequent scale-up and design manufacturing with Trane Technologies.

This R&D effort was supported by UTD with cross-cutting efforts across platforms to enhance component reliability and corrosion protection.

## Benefits / Market Implications

Natural gas end users may soon have much greater opportunity to have gas heat pumps for residential and small-commercial space conditioning to compete with traditional electricity-driven vapor-compression heat pumps. One benefit is lower fuel prices relative to other energy sources. Another benefit is efficiency gains. Conservative estimates of GAHP heating COPs are 60% to 90% greater than condensing and non-condensing warm-air furnaces.

## Technical Concept & Approach

Phase 1 of this project involved developing and testing a packaged heat-pump prototype with a nominal capacity of 80,000 Btu/hr at 47°F ambient temperature at a manufacturing cost that supports a simple three- to five-year payback. In Phase 2, efforts were made to advance commercialization by estimating the market potential for multifamily applications and large single-family homes, versus competitive electric systems and decentralized heating. Phase 3 involved the development, fabrication, and installation of a beta GAHP systems in single-family homes.

## Results

- **Combustion System Development**

  Using lessons learned from prior combustion system developments for the gas heat pump water heater (UTD 1.11.H), several scaled-up designs for radial mesh/mat style premix burners were tested for GAHP application, using commercially available gas trains (blowers, valve, mixer.) Additionally, several methods to reduce CO emissions were identified.

- **Evaporator Design Guidance**

  An assessment of the initial evaporator performance and recommendations for right-sizing were made. After component testing and analysis, the system model was updated to improve the accuracy over the traditional heat-exchanger modeling methodologies. With a refined model, the "alpha" evaporator coil demonstrated high performance.

- **Prototype GAHP Tests**

  The packaged GAHP alpha prototype demonstrated high performance, meeting most of its performance goals and delivering an estimated 136% AFUE based on the ANSI Z21.40.4 method. Subsequent field testing validated these projected savings.

- **Building Energy Modeling**

  Several vintages of single-family homes were used to estimate the annual energy savings of the GAHP in comparison to a conventional non-condensing furnace installation.

This experimental program included 12 24-hour (and some 48-hour) tests of the GAHP under separately controlled and automated space-heat and domestic-hot-water loading patterns.

GAHP units were installed at three residential test sites in La Crosse, WI, for next-generation field trials into the 2018-19 heating season.

Primary goals that were accomplished included: 1) build and perform pre-shipment testing on a prototype GAHP combination system; 2) recruit, screen, inspect, and select residential host sites; 3) perform baseline monitoring of host site's HVAC and water heater performance; 4) install and commission a prototype GAHP combination system at the host site; and 5) troubleshoot the GAHP and data-collection system and monitor system performance through end of project.

Based on results from the 2017-18 and 2018-19 heating seasons, the GAHP would provide:

- Energy savings of 35%-49% in space-heating only mode, depending on baseline selected
- Energy savings of 55% for domestic-hot-water only mode, and
- Energy savings of 37%-47% overall, as a combined space/water heating system.

Currently, three GAHP combination space-heating systems continue to operate in La Crosse, WI, with support from both the technology and manufacturing partners. In record-setting cold temperatures (down to -30ºF) and significant snowfall, the performance of the GAHP held up despite these extreme conditions.

For Phase 3, the project team located an additional field test site, developed a field-test execution and monitoring plan, and procured data-collection hardware.

## Status

This project is complete. A Final Report for Phase 3 was issued in October 2019. With a transition to an *Emerging Technology Program*, the project team has continued monitoring three prototypes in Wisconsin, in addition to four new GAHP prototypes installed in Chicago and Toronto with monitoring continuing through 2020.

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UTD Utilization Technology Development

# Investigating Multifamily Infrastructure Challenges

***Researchers are investigating the current challenges and opportunities for the natural gas industry to better serve multifamily new-construction homeowners, architects, and builders.***

## Project Description

There is a significant opportunity for natural gas to better serve the growing multifamily new-construction market; however, there are also significant barriers, many of which have been the focus of research in recent years.

In Phase 1 of this project, researchers investigated national trends regarding gas and electric multifamily market shares, the economics of energy services, building codes, and installation practices.

In Phase 2, the project team provided regional multifamily market paths for advanced products that provide promising opportunities in this sector, a portfolio, and examples and discussion of successful utility initiatives.

Phase 3 recommended implementation of opportunities for specific regions or utilities, including holding utility-sponsored design-planning sessions in the form of charrettes with stakeholders within the development, design, and building communities.

The current Phase 4 focuses on the development of detailed market transformation implementation tools and action plans to optimally connect new development decision-makers with financial, marketing, and technical resources suitable for the multifamily new-construction sector. Deliverables include case studies and economic assessments (customizable with utility logo), a review of emerging gas technologies to better serve multifamily buildings, and continuing education credit curriculum.

## Benefits / Market Implications

Studies on the multifamily market identify key economic issues, code barriers, and product gaps that require investigation and resolution. Addressing these issues, gaps, and barriers will enable more multifamily end ratepayers to benefit from the lowest-cost energy option and improve energy efficiency. This project is highlighting and creating resources that improve existing avenues of support for developers, utilities, and end-users to leverage natural gas as a fuel choice. Key demonstrations of these methods are being summarized in consumer-friendly case studies of successful multifamily developments.

## Technical Concept & Approach

Key tasks include:

- **Multifamily Market Data Collection & Analysis**

  Researchers used census data and other available resources to obtain a 2015 snapshot of builder and developer energy choices in the multifamily new construction market by U.S. region and by building type. The assessment included, to the extent possible, gas and electric utility rates and incentives, the availability of gas service, market trends, and code differences.

- **Multifamily Market Preliminary Recommendations**

  Researchers reviewed the analysis and developed preliminary recommendations for a path forward in each region.

- **Technology Solutions**

  The project team reviewed the market data and up-to-date technical equipment and system information to recommend advanced resource-saving technology solutions.

- **Multifamily Stakeholder Charrette**

  The project team held three stakeholder charrettes in 2018 in targeted geographical regions that showed the greatest need or desire for multifamily development support.

- **Development of Supporting Utility Programs**

  Researchers recommended utility program features and best practices that were observed to be successful.

- **Guidance for Design and Construction Professionals**

  Leveraging the insights from Phase 3, researchers will create tangible market guidance tools tailored for design and construction professionals that can be branded by UTD member utilities.

- **Case Study Development**

  Three case studies will be developed to showcase successful pathways to natural gas inclusion in multifamily developments.

- **Curriculum Development**

  The project team will develop curriculum geared towards design professionals in a one-hour presentation format.

- **Multifamily Emerging Technologies Strategy and Needs Assessment**

  Investigators will identify promising natural gas emerging technologies or innovation needs that can help overcome barriers to using natural gas in the multifamily market.

*"The Multifamily Infrastructure Challenges project has given us a comprehensive insight into customer concerns. We have used this insight to develop outlines and resources to help build a greater understanding of the benefits of natural gas in multifamily developments."*

*- April Arnold*
*Sales Representative II*
*ONE Gas, Inc.*

## Results

The project team held interviews with key national-level players active in the multifamily market, including representatives from industry associations and gas utilities. These discussions covered past activities each of these organizations have undertaken within the multifamily market segment, current challenges, and key concerns of stakeholders. Project representatives also held discussions with many U.S. utilities and performed significant outreach to the building and development community to obtain their perspectives.

Phase 1 research reported on key trends in the housing market, the use of heating fuels, and the use of electricity. The rebounding of electricity as the majority space-heating fuel can be seen in both low-rise (2-4 units) and high-rise (5+ units) buildings, while the volume of gas-heated units shows either modest or no growth. However, this trend is not reflected in water heating, where gas still plays a strong role and has generally kept pace with electricity growth.

In Phase 2, researchers identified the key economic and non-economic factors presently driving the decision behind choosing electric service over gas service in new construction multifamily buildings. U.S. southern states and Atlantic coastal states were identified as particular focus areas for project research.

In 2018, specific UTD members participated in stakeholder charrettes (i.e., focus group sessions) with the goal of garnering feedback and dialogue among participants such as real estate developers, architects, engineers, and others involved with multifamily projects.

A Phase 3 Final Report was issued in January 2019. The report details recommendations to utilities to address codes and standards, economic challenges, and technology-based solutions that UTD members can consider to enhance their service to multifamily stakeholders, architects, builders, and others.

In 2020, dialogues continued with experts in the multifamily new construction market as the project moved into Phase 4 to create actionable tools for UTD members to better serve multifamily homeowners, architects, and builders.

## Status

The project team is recruiting developers to showcase development planning and gas-inclusive projects under way.

Researchers continue to monitor the identified applicable financial structures, as market dynamics shift in the near term. The project team is also reviewing data from market findings on emissions, paybacks, and other non-energy benefits such as emissions and sustainability certifications.

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UTD Utilization Technology Development

# Advanced Systems for Self-Powered Water Heating

***Research in this project focused on developing an advanced technology for gas water-heating applications with the potential to increase the competitiveness of gas-fired water-heating systems for homes and businesses.***

## Project Description

To optimize the natural-gas option for water heating, experts cite the need for cost-effective, mid-efficiency, near-condensing gas water heaters.

In this project, researchers investigated Two-Phase Thermo-Syphoning (TPTS) technology and ultra-low-power gas-water-heater control technology in an effort to develop a prototype "unplugged" high-efficiency water heater.

## Benefits / Market Implications

A TPTS water heater offers the potential for higher efficiency, scalability, rapid startup, long life, minimal standby heat loss, minimal scaling, self-power capability, and low emissions.

The replacement market opportunity for self-powered high-efficiency water heating is approximately 150,000 units per year, representing a savings of eight million therms annually, or $6.4 million in avoided cost for gas customers while mitigating 52,000 tons of $CO_2$.

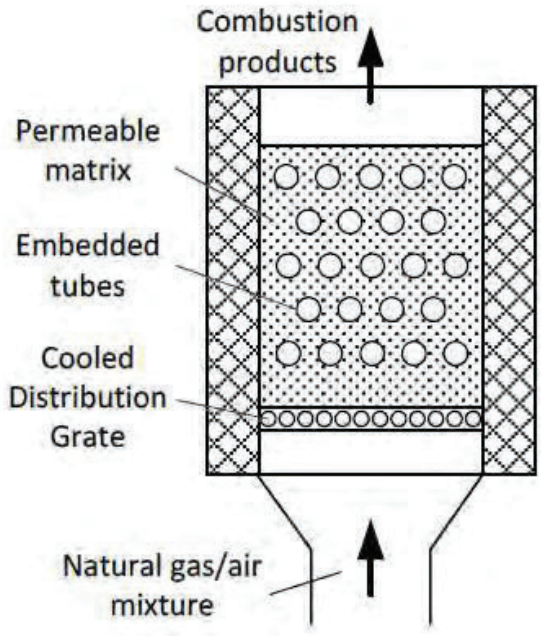
## Technical Concept & Approach

Similar to heat pipes, the TPTS technology is more like a passive, closed-loop, flash boiler. The TPTS technology was initially developed to augment solar water-heating systems.

The key is the integration of three technologies:

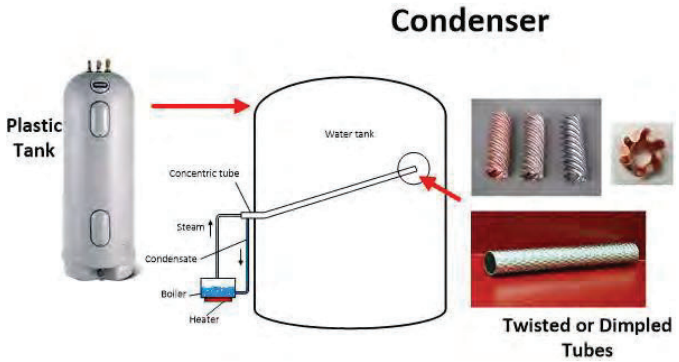
1. **TPTS Technology.** A TPTS loop is evacuated and then partially charged with liquid water. Upon firing, a two-phase (steam/water) flow accelerates from the evaporator up to the submerged condenser. Condensing steam transfers latent heat to the hot water and travels through the condenser coil towards a vertical restriction. This restriction builds up condensate, increasing pressure head for circulation.

2. **Surface Combustor-Heater Concept as Evaporator.** The surface combustor-heater is a combustion heat transfer device that is based on the concept in which the relatively cold heat-exchange surface is embedded in a stationary bed (porous matrix) where gaseous fuel is combusted. As the

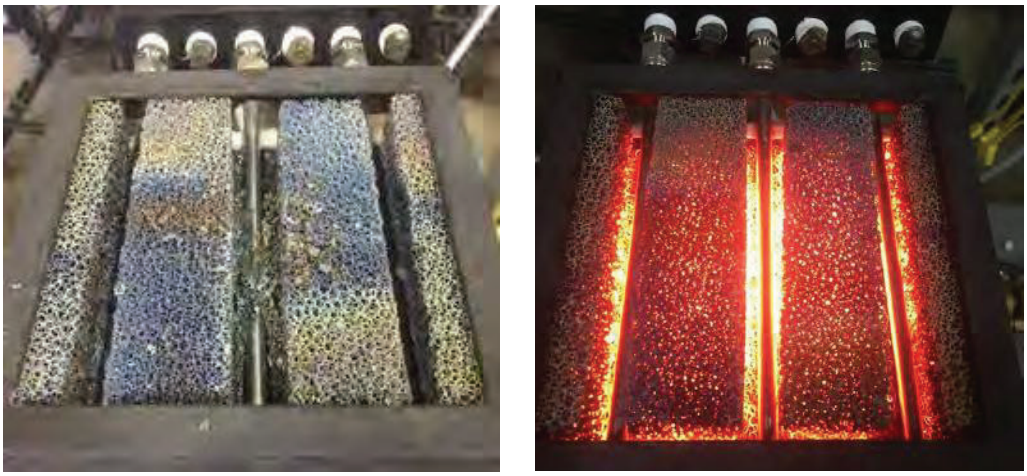



*Surface combustor-heater concept as evaporator.*

*SuperPerm Burner.*




*Condenser with twisted or dimpled tubes.*



*Embedded-tube water heater-evaporator bench-test setup.*

bed is heated by the combustion products, the heat is extracted from the bed by the embedded heat exchanger and is transferred to a working fluid circulating in the tubes.

3. **Dimpled or Twisted Tube Condenser.** The use of dimpled or twisted tubes in the condenser allows for effective, rapid heat transfer with minimal use of materials in a compact space.

## Results

Phase 1:

**July 2014 - February 2015**. The project team conducted a preliminary cost analysis. Fitting the TPTS water-heater product within the spectrum of water heater efficiency, a TPTS would cost between $373 and $752. The analysis also took a look at component costs.

**June 2014- September 2015.** The project team conducted parametric testing of the TPTS technology (1980's design) during this period primarily with $24,000 cofunding provided by the Copper Development Association. Testing determined that the efficiency of the TPTS components were not optimal. The evaporator required a new design. The evaporator was undersized, used too much copper, and was subject to hot spots and burnout. The condenser also required redesign to reduce cost and improve performance at low-load conditions.

**September 2015 – June 2018.** After reviewing alternative paths and approaches for the TPTS concept, the project team proposed a new evaporator design that used a permeable matrix surface combustor-heater with embedded heat-exchanger tubes. The design was highly efficient and offered a significant breakthrough in cost reduction. An earlier proposed approach using thinner walled tubing offered a 30% savings in evaporator material cost. The new surface combustor-heater design offered a potential 80% savings in material costs. At that time it was proposed that the condenser use dimpled or finned tubing to improve heat transfer and reduce size and cost.

Phase 2:

**July 2017 - December 2019.** In 2018, the project team developed a Computational Fluid Dynamics model of the surface combustor with embedded tubes. This model was used to validate and optimize prototype system designs. Preliminary designs were developed for a TPTS evaporator with single- and multi-pass embedded tubes. An alternative approach separating the embedded tubes from the burner was also designed and evaluated. It offers potential advantages in component manufacturing and in-field servicing. It also offers advantages in its design in that it is adjustable and allows for quick iterative testing to fully characterize the technology. At this time, both designs will be explored and validated.

A laboratory test setup was constructed to characterize the prototype evaporator. Delays in sourcing embedded tubes shifted testing to 2020.

## Status

A Phase 2 Final Report was issued in August 2020.

The research team is also pursuing knitted-wire mesh burners with integrated heat-exchanger tubes due to quality issues identified using metal foam.

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UTD Utilization Technology Development

# Next-Generation Advanced Residential Gas Clothes Dryer

***Researchers are investigating next-generation technologies so that a residential gas dryer can economically provide gas consumers with faster drying times, yet 5%-15% higher efficiency than standard drying technologies.***

## Project Description

In this project, researchers are investigating next-generation technologies – including heat recovery, indirect firing, direct venting, and advanced burners – to determine potential efficiency boosts for residential dryers. All of these techniques and technologies have been shown to increase efficiencies in other areas, but scaling them to a residential dryer size, determining the additional cost to the dryer, and quantifying the efficiency increases will help dryer manufacturers determine the best path to further advance gas-fired dryers while minimizing cost increase.

UTD's guiding Technical Project Committee indicated that there is also an interest in reducing drying times if possible. This is an advantage that gas dryers have over electric units: the potential to increase firing rates to reduce drying times. The research team will also study drying times as technologies are evaluated. For instance, modulation may allow a high firing rate in the early stages and a low firing rate later to both reduce drying time and save energy.

The goal is to find a technology to achieve a 5%-15% boost over standard efficiency gas dryers. Project deliverables include an early-stage prototype incorporating the most promising technologies and reports detailing the performance improvement provided by all of the technology options investigated.

## Benefits / Market Implications

Gas-fired dryers have not had many technological advances in recent years and there is potential to enhance the technology. With about 81% of U.S. households having a clothes dryer, the potential improvements in the design of gas dryers represent sizable savings to residential ratepayers.

Although electric clothes dryers represent the majority of U.S. residential dryers, a 2011 study by others indicates that it is not consumer preference for electricity that is the driving force. Although 60% of survey respondents are currently using electricity for clothes drying, only 34% stated that they actually preferred electricity. In contrast, 40% of respondents stated they currently used gas for clothes drying and 53% said they would prefer to use gas. These results indicate that the cause for gas dryer's minority market share is not due to the inherent characteristics of gas as a fuel, but is driven by other factors such as cost, availability, and other regional factors.

*Left: Test dryer in laboratory environmental chamber; right: burner testing.*

## Technical Concept & Approach

The project team is investigating high-efficiency dryer technology options including, but not limited to, heat recovery, modulating burners, indirect firing, direct venting, and advanced burners. Researchers are also investigating the potential for technologies to reduce drying times.

The effect of each technology modification is being tested to standard methods to determine the performance improvement (efficiency, drying time, etc.) in comparison to the baseline unmodified model. The most promising technologies will be incorporated into an early prototype for demonstration.

## Results

Phase 1 of this project focused in part on assembling a test station in an environmental chamber to maintain temperature and humidity to ensure accurate testing. It had become apparent during previous UTD dryer research that room temperature and humidity have a very large effect on the dryer efficiency rating. Although the test standard allows for 40%-60% relative humidity (RH) during the test, a dryer will be much more efficient at 40% RH than at 60% RH. With that in mind, researchers decided that it was necessary to arrange the test in an environmental chamber.

Technicians then completed the first modifications to the dryer. The unit was fully instrumented to allow for testing different design changes, including changes to primary aeration and air-to-fuel ratio, followed by potential heat-recovery options. Designs to recover heat from the flue were implemented and show promise for improved efficiency in testing. Overall, the heat recovery appears promising while providing a small cost added to the dryer, but still potentially making it appealing to consumers.

Researchers attempted many different configurations for sealing the dryer to maintain stable combustion, and investigated simple heat-recovery options with many different alterations. In the end, it was determined that a novel heat-recovery setup, along with a newly configured and sealed dryer combustion chamber, showed the most promise, with a 4% boost to the dryer efficiency while adding very little cost to the dryer.

For the study, a total of 42 temperature sensors, five gas sample points, a gas meter, and electric power meter were fitted to the dryer.

In Phase 2, researchers are investigating additional heat-recovery options, modulation techniques, indirect-fired methods, direct venting, and alternate burners.

Researchers set up a new dryer in the test stand in the environmental test chamber. The project team also set up a new washer test stand to provide clothes with the needed temperature and remaining moisture content for dryer testing.

In 2019, the research team developed a slightly modified test procedure to provide repeatable results that will allow comparison to technology improvements on a common basis. After this modified procedure was adapted, baseline testing was completed. Researchers also investigated the effect of firing rate on the dry time and efficiency.

It was noticed from previous dryer research that results of dryer efficiency testing according to the U.S. Department of Energy (DOE) test procedure can vary based on a few factors. The current standard requires allowing the automatic moisture sensor to automatically stop the load. An issue is that the moisture sensor can create significant variability in the test results based on when it determines the load is dry. In many instances, the load is fully dry, but the dryer keeps running before the moisture sensor eventually shuts it off. Researchers need good repeatability to compare the baseline testing of a standard dryer to each technology that is being tested to improve efficiency.

The project team was able to achieve good repeatability by creating a slightly modified test procedure that measured flue RH and determined when the clothes were dry based on the flue RH.

Testing at four firing rates showed around a 2% boost consistently with lower firing rates. The dryer was insulated and sealed to test potential boost from better sealing and allow for implementing heat recovery. After several variations, technicians were able to achieve a 5%-6% increase in efficiency with insulation and sealing as well as a 6% reduction in drying time. The insulation and sealing also allowed researchers to implement an innovative heat-recovery design.

## Status

Testing heat-recovery performance will be initiated once the laboratories are opened again after the COVID-19 shut down.

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# Gas-Fired High-Efficiency Liquid Desiccant Air Conditioning and Humidity Control

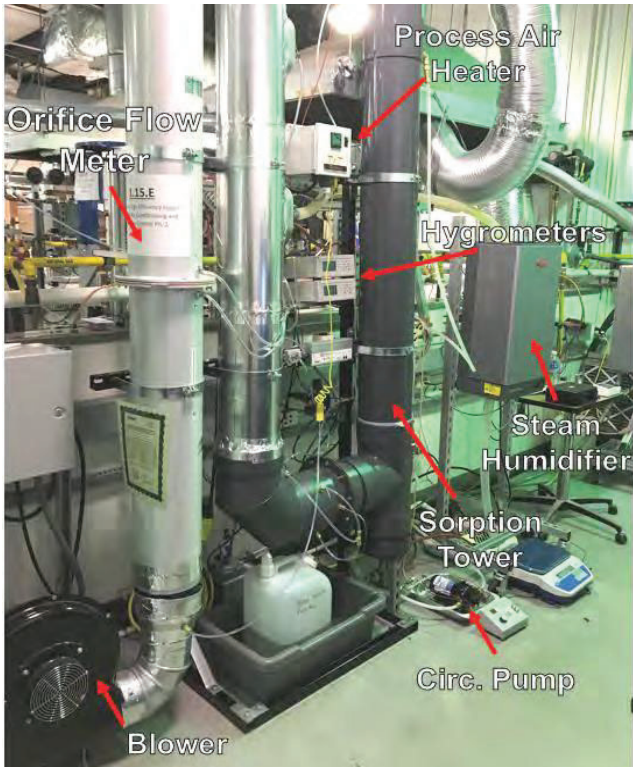
***A research team is partnering with a chemical manufacturer, two HVAC manufacturers, and others to develop and demonstrate a very-high-efficiency gas-fired liquid-desiccant-based air-conditioning and humidity-control system that uses a novel, non-corrosive, non-toxic desiccant.***

## Project Description

The goal of this project is to develop a gas-fired liquid-desiccant dedicated outdoor air system (LDDOAS) that addresses many of the critical issues now facing owners and operators of commercial HVAC systems.

The LDDOAS is designed to significantly reduce primary energy consumption, on-peak electrical demand, and water use for air conditioning in commercial buildings. The system can deeply dry a building's ventilation air without inefficient overcooling or reheating, which will enable advanced HVAC solutions (e.g., chilled beams, displacement ventilation, and other approaches) to essentially eliminate fan power for recirculating air within buildings.

In this project, a research team is partnering with a manufacturer to compare the current state-of-the-art LDDOAS technology to other advanced systems, including a concept involving a sub-atmospherically-regenerated LDDOAS system with internal water recovery and reuse capabilities.




*Laboratory test rig.*

The current Phase 2 involves demonstrating a novel technology in a laboratory to determine its value to potential end users. In Phase 2, the project team will design and experimentally evaluate a breadboard LDDOAS test rig rated at approximately 100 CFM capacity using a novel non-corrosive, non-toxic desiccant initially evaluated and characterized in Phase 1 of the project.

## Benefits / Market Implications

New cooling designs that integrate desiccant drying and indirect evaporative cooling in compact cost-effective configurations have the potential to be competitive with electric options in residential and commercial markets.

For a summer design day, the LDDOAS' primary energy Coefficient of Performance (COP) is 18% higher than the conventional alternative. This advantage is projected to increase to 30% when averaged over a cooling season. The effective COP for the LDDOAS is estimated to be 2.77 (where the LDDOAS is credited with energy savings for the advanced HVAC systems that it enables). The LDDOAS can eliminate water use for air conditioning in the more humid eastern U.S. The burden that air conditioning now imposes on electric grids can be eased as peak loads drop by approximately 75%, from about 1.01 kW/ton-hour to 0.26 kW/ton-hour of cooling.

## Technical Concept & Approach

Desiccant-based dehumidification and air-conditioning systems can employ an open drying cycle wherein a humid gas (generally, air) comes into contact with a desiccant and is dried. The dried air continues to subsequent processes (e.g., sensible cooling), and the desiccant is regenerated by a thermal input. The desiccant loading and regenerating is performed in a cycle, allowing for continuous dehumidification.

The two major system types are liquid and solid desiccants. While solid desiccants have a larger established market presence, the liquid-based systems have gained interest in applications for active dehumidification, enhanced evaporative cooling, and indoor air quality.

These liquid desiccant systems, also known as open absorption systems, have had limited market presence due in large part to the inefficiency of current regenerating components and difficulties in handling the caustic strong salt desiccant solutions.

Phase 2 will provide an important next step towards developing a commercial product. Successful completion of Phase 2 is expected to lead into follow-on construction and field trials of alpha LDDOAS prototypes.

Building on the team's initial experimental experience with uncontrolled supply or scavenger air, the project team will develop and implement an experimental test plan to 1) optimize the LDAC regenerator and conditioner designs, 2) integrate the two into the first recirculating breadboard test rig, and 3) evaluate LDAC breadboard performance over a range of simulated conditions.

The specific objective of Phase 2 is to prove the LDDOAS' system operation in the laboratory and determine its value to potential end users. In Phase 2, the project team will design and experimentally evaluate a breadboard LDDOAS test rig rated at approximately 100 CFM capacity (approximately 1/10th scale for small RTUs) using the novel non-corrosive, non-toxic desiccant initially evaluated and characterized in Phase 1. Researchers partnered with the New York State Energy Research and Development Authority (NYSERDA), a chemical manufacturer, and two HVAC industry partners in Phase 2.

## Results

In Phase 1 of this project:

- An experimental gas-fired liquid-desiccant air-conditioning (LDAC) system was constructed from inexpensive materials.
- A fluid was demonstrated to operate as a desiccant over a useful range of process air dew points (for space conditioning) and could be regenerated at low temperatures (<200°F).
- The absorption/regeneration tower operated as designed (~0.5-2 lb/hr moisture movement at 50 cfm).
- During regeneration, with heated liquid and cool regeneration air, 50% of the enthalpy rise in the air was latent. This result was within the expected order of magnitude.

In Phase 2, the project team:

- Initiated upgrades to one tower test rig.
- The single-tower apparatus was fully instrumented to measure temperatures, pressures, and flow across the tower to allow completion of the initial test plan.
- The preconditioning system for simulating outdoor air temperature and humidity levels was completed and tested.
- A refractometer was acquired and an empirical calibration curve was successfully developed for the desiccant concentration based on its refractive index.
- Single-tower experiments were initiated, with tests focused on characterizing the uniformity of desiccant distribution inside the tower.
- Liquid desiccant distribution tests in the single tower were completed, and continuous regeneration tests and batch conditioning tests, along with comparative wettability tests are ongoing.

The single-tower experiments were shut down in April 2020 due to the coronavirus. There was also a delay in testing due to a failed chilled mirror hygrometer used to measure the dew point temperature at the inlet of the tower. This combined set of circumstances precluded researchers from concluding several tests as planned per the original project timeline.

Researchers returned to the laboratory in late June 2020 (with additional pandemic protocols in place) and progress was then made on characterizing the desiccant distribution in the tower by varying nozzle configurations for distributing the liquid at the top of the tower. The purpose of these tests was to identify the optimal nozzle to use and determine whether tower-wall effects were present.

## Status

Activities in the current phase focus on optimizing the design and operation of the single-tower experiment. Parametric analysis will be conducted with respect to regeneration operating conditions to map out the performance of the tower in continuous regeneration mode, in order to calibrate a theoretical model for the system to be used to design a dedicated absorption tower. Integrated system (dehumidification and regeneration) testing will be used to scale the results to a practical-sized system for a techno-economic analysis.

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UTD Utilization Technology Development

# Maintenance-Free Approaches for Tankless Water Heaters

***In this project, researchers investigated maintenance-free approaches to hard-water remediation on heat exchangers for tankless water heaters in order to improve energy efficiency, reduce maintenance costs, and extend equipment life.***

## Project Description

Condensing tankless water heaters eliminate the stand-by energy loses associated with tank-type heaters, offering consumers significant increases in efficiency – a 95 Uniform Energy Factor (UEF) compared to a 59 UEF for a minimum-efficiency tank-type water heater. However, tankless products have compact copper heat exchangers, and in areas of hard water they are susceptible to scale and mineral accumulation.

Scale is about 400 times less conductive of heat than copper per unit thickness, so if left untreated, the daily efficiencies can dip down to 72%. Furthermore, this scale and mineral accumulation can reduce equipment life to as short as 1.6 years.

Tankless water-heater market penetration has had limited adoption in the U.S. gas-water-heater market. Combination space- and water-heating boilers are still limited in application as well. Addressing water-quality issues and identifying the correct remedy is critical to enabling broad adoption of these technologies in the U.S. and maintaining the effectiveness of energy-efficiency programs aimed at tankless water heaters.

In Phase 1 of this project, researchers investigated various low-cost, maintenance-free approaches to hard-water remediation on tankless heat exchangers. Phases 2 and 3 investigated various coatings in coordination with major OEMs.

## Benefits / Market Implications

Scale buildup on heat exchangers as a result of hard water is shown to reduce equipment performance and life. This issue could have a detrimental effect on equipment energy efficiency, natural gas savings, and ultimately market penetration.

## Technical Concept & Approach

Specific project tasks:

- Identification and prioritization of maintenance-free approaches
- Prototype heat exchanger development

- Hard-water testing, and
- Coatings testing.

## Results

In Phase 1:

- A literature review was conducted of maintenance-free approaches for tankless heaters. Select vendors providing near-commercial or commercially available technologies were contacted for further information.
- A Nickel-Teflon® (Ni-PTFE) coating was selected for prototype heat-exchanger development. The project team employed recipes from literature to demonstrate and become familiar with a recommended coating process. Researchers collaborated with a coating manufacturer to coat the interior surface of copper tube samples to be used in the hard-water test loop and to plan for future coating processes for the interior of an entire copper tube heat-exchanger bundle.
- A test plan was developed and executed. A hard-water test loop was built. Six copper tube samples (three coated and three uncoated) were installed in the test loop and tested for 45 days, after which the samples were removed and analyzed. Due to mixed results and degrading condition of the experimental setup, the test was terminated after 45 days in favor of re-scoping the project to incorporate testing of multiple coatings under control conditions to provide more statistically significant results.

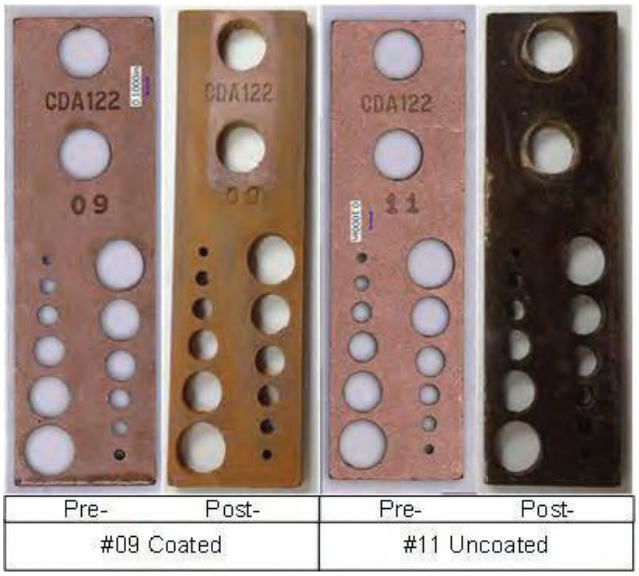
In Phases 2 and 3, a hard-water test loop was designed and built to accommodate an accelerated scale test where six sets of coupons, each set containing a coupon with an anti-scale coating and an uncoated coupon, were subjected to accelerated conditions for 1,171 hours, representing 20 years of scale buildup.

Hard-water test loop conditions included:

- Water-hardness characteristics of 423 mg/l or 24.7 gr/gallon
- Water pressure of no less than 40 psi
- Temperature of no less than 160°F± 4.33, and
- Water flow rate at 3.0 GPM ± 0.15.

All coupon sets were weighed and photographed periodically throughout the test.

Coupon Set #4 exhibited the greatest visual difference between coated and uncoated and was chosen for further analysis under the microscope and energy-dispersive X-ray spectroscopy.




*Coupon Set #4 pre- and post-high-contrast photographs.*

The following was observed:

- Scale formation on the uncoated coupon averaged 30% thicker compared to the coated coupon and
- At the thickest observed scale formations, the uncoated coupon was 73% greater than the coated coupon.

Regarding key performance indicators and goals:

- Coating adherence to the copper coupon was maintained throughout testing
- A sampling of five areas of the coated coupon determined that scale buildup was minimal, and
- Researchers were not able to predict anti-scale coating performance over time.

## Status

The project is complete. A Phase 2 and 3 Final Report was issued in August 2020.

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# High-Performance Building Initiative

***Researchers developed and communicated design approaches for mixed-fuel houses that meet or exceed the criteria for high-performance-home programs, and supported utilities in their efforts to assist architects, builders, and homeowners.***

## Project Description

The U.S. Department of Energy (DOE) has several initiatives to develop technology for high-performance houses and recognize builders of high-performance houses.

In its Building America program initiative, DOE is investing in measures that reduce the energy used by new houses by 50% from a 2006 baseline. This program includes thermal envelope improvements, ventilation standards, equipment options, and the development of the BEopt modeling tool that offers cost-based tradeoffs to select the optimal set of measure packages to drive energy efficiency.

In the DOE Zero Energy Ready (ZER) Home Program, builders are recognized for building homes that are 40%-50% more energy efficient than a typical new home. This generally corresponds to a Home Energy Rating System (HERS) Index in the low-to-mid 50s. A HERS index of 100 is the baseline for standard homes (first introduced in 2006), and an index of 0 means the houses uses a total of zero purchased energy over a year.

While natural gas remains the most cost-effective fuel for many new and existing buildings, it is often left out of the high-performance-home design process because of the difficulty in applying electricity-based renewables to natural gas consumption and the challenge in identifying and installing cutting-edge hardware. Also, in some cases, the tools for the analysis of natural gas system benefits are insufficient.

The objective of this project was to develop an approach to be used for supporting mixed-fuel high-performance buildings, covering several fronts, including: zero net energy (ZNE), renewables, clean power, modeling engines, application guidelines, demonstration houses, and case studies.

In Phase 1, various programs were reviewed and cataloged. Phase 2 focused on the methodologies and analysis tools for high-performance homes, home designs that meet the goals of the leading methodologies, and case studies from selected climate zones. In Phase 3 of the program, researchers are exploring strategies for gas utilities to better support high-performance home program initiatives.

## Benefits / Market Implications

This project helps homeowners, ratepayers, regulatory agencies, and others achieve goals for high-performance or ZNE homes by developing best practices and tools and identifying gaps and barriers. It also provides market-based information to guide R&D and utility energy-efficiency programs in the near future.

This focus on the high-performance-home market helps homeowners and builders address environmental goals and respond to legislative initiatives (in states like California) moving all houses toward becoming high performance or ZNE.

## Technical Concept & Approach

In Phase 1 of the project, researchers cataloged programs that focus on high-performance housing, addressing criteria for inclusion of the program, the number of houses that qualify, design tools used, equipment selection, and other criteria. The project team also developed a best-practices guide for high-performance

mixed-fuel houses. The project team conducted a member webinar introducing a variety of high-performance building programs, and another webinar reviewing design best practices for mixed-fuel high-performance homes.

In Phase 2, researchers investigated tools and methods to design ZNE homes and developed options for high-performance mixed-fuel homes in different climate zones. Researchers evaluated metrics and energy simulation software used to analyze high-performance homes, with a focus on those relevant to key programs identified in Phase 1. Then, in cooperation with five builders, the project team developed energy models and case studies for high-performance mixed-fuel homes in diverse climates throughout the United States. UTD member CenterPoint Energy also sponsored a training session for homebuilders in its Shreveport, LA, territory to share best practices and results from a local design study.

The focus of Phase 3 was on advancing utility involvement to promote high-performance home programs.

## Results

This project explored design tools and metrics for high-performance mixed-fuel homes. Research suggests that the recipe for a high-performance mixed-fuel home include:

- A tight, well-insulated building envelope. While some high-performance homes employ unconventional wall systems to achieve super-insulated walls, a good envelope can be achieved at reasonable cost using 2x6 or 2x4 framing, advanced framing techniques, careful attention to air sealing, and a layer of exterior rigid foam insulation to reduce thermal bridging.
- Ducts in conditioned spaces, either routed within living spaces, or though sealed, conditioned attics and basements.
- A right-sized space-conditioning system with appropriately-sized ductwork.
- An efficient hot-water distribution system paired with a condensing tankless gas water heater, or efficient gas storage water heater.
- High-efficiency LED and CFL lighting and energy-efficient appliances.
- Photovoltaic and (less commonly) solar thermal systems for homeowners looking to further reduce their energy and emissions footprint.

A Final Report for Phase 2 was issued in June 2019. Phase 2 produced the following additional deliverables:

- An assessment of metrics and residential energy simulation software packages for designing high-performance mixed-fuel homes
- Five case studies demonstrating appropriate energy-efficiency measures for high-performance mixed-fuel homes in diverse climates in North America, and
- A presentation on design methodologies and case studies shared in a member webinar.

For Phase 3, researchers investigated gas utility-efficiency program support for high-performance home programs and developed a White Paper summarizing common strategies and best practices. The team also conducted energy modeling to assess the potential impact of various emerging gas technologies for high-performance homes at each of the five design study sites identified in Phase 2.

## Status

The project team completed modeling of emerging technologies for high-performance mixed-fuel homes. A Phase 3 Final Report was completed in August 2020.

The High-Performance Mixed-Fuel Homes Best Practices Guide developed in Phase 1 was updated to incorporate additional content developed during later project phases. This guide is a primer on high-performance natural gas homes for UTD member utilities and their stakeholders.

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# EnergyPlus™ Models for Advanced Gas Space-Heating Systems and Combination Systems

***In this project, researchers developed models of advanced gas space-heating equipment and combination systems in an EnergyPlus simulation engine to expand choices to evaluate these advanced, energy-efficient technologies by architects, engineers, facility managers, and others.***

## Project Description

EnergyPlus™ is a whole-building energy-simulation program developed through the U.S. Department of Energy (DOE) that engineers, facility managers, researchers, and others use to model energy consumption for heating, cooling, ventilation, lighting, and plug-and-process loads as well as water use. However, the limited capability of EnergyPlus to simulate advanced residential gas-heating systems makes it difficult to accurately compare advanced systems with other HVAC options.

Data indicate that current models in EnergyPlus are inadequate for estimating the dynamic efficiency of condensing furnaces, gas absorption heat pumps (GAHP), and combination systems. Having no module in EnergyPlus to estimate the performance (or, even worse, to do it incorrectly) would significantly limit choices by users to consider advanced, energy efficient systems during initial screenings to evaluate HVAC options. It was the objective of this project to address these limitations in EnergyPlus and to provide decision makers accurate and reliable simulation tools for advanced residential heating systems in order to enable equitable comparison with competing technologies and to advance the integration of gas and renewable energy.

Specific tasks included:

- Develop mathematical models and performance maps for condensing furnaces, gas absorption heat pumps, and combined space- and water-heating technologies
- Perform a technical and economic potential analysis on the above systems for the U.S. national single-family housing market, and
- Disseminate the results through peer-reviewed journal publications.

In Phase 1 of this project, researchers leveraged technology-performance data for burners and gas heat pumps collected as part of other projects to develop functions in EnergyPlus, and then used them to estimate energy savings potentials.

In Phase 2, the project team focused on a more expansive market analysis and further function refinements for combined space- and water-heating systems.

*Advanced heating systems modeled in EnergyPlus, including tankless combination units, gas heat pumps, and advanced condensing furnaces.*

## Benefits / Market Implications

Through this project, researchers developed EnergyPlus built-in models for advanced furnaces, gas heat pumps, and combination systems to allow the general users to adjust the parameters such as system size, performance curves, or design features, which are necessary to describe any of such gas systems from any manufacturer.

It is anticipated that the simulation results using these models will be used to estimate annual energy savings for each type of system, which can support gas utilities to provide further incentives in energy-efficiency programs.

## Technical Concept & Approach

In Phase 2 of this project, researchers updated and refined the prototype EnergyPlus models for advanced condensing furnaces, GAHPs, and combination systems, and conducted an expansive technical and economic potential analysis for North America.

Advanced gas-heating models refined in Phase 2 are expected to be disseminated in a future EnergyPlus release, along with the other advanced residential heating-system models developed.

## Results

To achieve the project objectives, the current limitations of the furnace and GAHP models were reviewed and a new approach for modeling was developed, taking advantage of extensive part-load performance data collected on five condensing furnaces from a single manufacturer and prototype GAHP units.

In Phase 1, researchers leveraged extensive data collected in a Virtual Test Home to advance EnergyPlus simulation capability for condensing furnaces and GAHPs. Using simulations of modern homes in mild and cold climates, the new approach helped demonstrate how a modulating furnace can consistently save 10% on the natural gas consumption annually compared to single- and multi-stage furnaces, and an additional 2% if it is right-sized for the home.

In the new construction analysis, the GAHP combination system was compared to an electric heat pump with three different water-heater alternatives (gas, electric, and electric heat pump water heater) with a condensing furnace and a premium water heater as the baseline. It was demonstrated that the lower-capacity GAHP combination systems were competitive with electric heat pump and electric heat-pump/water-heater alternatives in the milder climates of Seattle and Portland, with respect to source energy savings and operating cost savings ($100-$200 per year). The GAHP combination system was the only option offering energy and operating cost savings in the colder climates of Spokane and Helena. With further reductions in the electricity consumption of the GAHP, even better all-around savings for the GAHP are possible.

Major accomplishments of Phase 2 included:

- Development of a whole new mathematical framework for simulating tankless-based combination units. The existing methods used in EnergyPlus were found to be inadequate. An extensive energy and cost-savings analysis demonstrated the efficacy of the novel framework and how advanced tankless combination units can produce energy and cost savings comparable to condensing furnace/water-heater alternatives.
- The GAHP combination model was refined with new data for the latest pre-commercial prototypes. The major conclusion was that the GAHP is the best and most cost-effective option right now (and for the foreseeable future) for reducing $CO_2$-equivalent emissions in the majority of locations around the U.S.
- Public dissemination of the results of this project has begun through conference presentations and journal articles being prepared for 2020-2021.

The recommended next step is to push the results of Phase 1 and Phase 2 out to the public through peer-reviewed journal articles which can support direct updates to EnergyPlus. Additionally, a review of how current modeling and simulation tools are being used has highlighted a need for even simpler tools and calculators for estimating the energy consumption of advanced gas-heating systems.

## Status

This project is complete. A Final Report was issued in March 2020.

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# Commercial Gas-Fired Heat Pump Water Heater

***This project is developing an economical, high-efficiency gas heat pump to serve commercial water-heating applications and end users. Researchers are leveraging recent residential gas heat technology developments, optimizing controls and components, and beginning field trials.***

## Project Description

While the commercial water-heating market is smaller in volume than the residential market, it is no less competitive for high-efficiency gas technologies, whose product prices are often 15 times that of common residential products. The market drivers are the same: federal requirements, ENERGY STAR ratings, and the test method for rating equipment.

Historically, a key advantage to end users of gas water heating over electric water heating in the U.S. was operating cost savings. With a typical restaurant consuming 30 times the hot water of an average single-family home, the operating cost savings of natural-gas versus electric-resistance heating is readily understood by business owners and property management companies. However, with the advent of electric heat pump water heaters – with operating efficiencies two to three times that of the resistance-heating products, federal/utility incentives, and the option to integrate with grid-interactive thermal storage programs – electric products have increased in popularity. New gas-fired heat pump water heaters (GHPWHs) would provide commercial customers the option of even higher efficiencies and lower emissions on a source energy basis.

This project involves the development of a commercial GHPWH and field evaluations at small commercial facilities.

## Benefits / Market Implications

The motivation in developing a GHPWH is efficiency-driven. When delivered to the market, the GHPWH will be a cost-effective technology with a primary energy efficiency of greater than 100%. The efficiency gains are substantial – with Energy Factors of 1.5 or greater (88% to 140% greater than condensing and non-condensing water heaters, respectively). Continued regulatory pressure and incentives for high-efficiency water heating will likely help this new gas-fired product be an attractive new option for end users.

*Prototype residential GHPWH prototype at Evanston, IL, site.*

Unlike residential water heating, where the vast majority of the products are sized for stand-alone service, commercial water-heating installations have a wide range of installation sizes, often requiring multiple products installed in parallel or for higher-temperature "boost" installations in a series. The challenge for a heat-pump water-heating installation (electric or gas) is the baseline/peaking relationship of the heat pump to the backup/boost conventional heating. As a result, system installations are often site-specific and require prior knowledge of peak loads and load shapes. The sizing of heat pump/conventional components and their arrangement (e.g., parallel, series, include "free" cooling) make for a large design space.

## Technical Concept & Approach

This effort involves preparation for a commercial water-heating application of the gas heat pump, focusing on commercial hot-water and pool-heating applications. Field evaluations of the technology are part of this project.

Specific tasks are:

- **Development of a System Design Model**

  The project team is developing a sizing and system design tool that will consider peak/average load patterns, installation cost, North American regional climate, local utility costs, and other factors.

- **Design of Commercial-Grade GHPWH Controls**

  The team is developing and test modifications to the gas heat pump controls to better facilitate operation as part of a commercial GHPWH system.

## Results

In 2019, the project team performed an extensive site-selection survey, inspected a site, and finalized a field-test agreement with a six-unit multifamily building in Evanston, IL. The team gained access to the site's utility data and performed a preliminary assessment of space heating and domestic hot water (DHW) energy consumption.

The site has a heating load such that the gas heat pump (GHP) will supply 20% to 50% of the peak load, sizing the GHP as a nominal 140kBtu/hr unit.

Technicians monitored the heating season at the Evanston site. Performance was adequate; however, multiple instances of servicing were required. Continued monitoring and analysis was completed in February 2020.

## Status

In 2020, the unit required servicing during the COVID-19 shutdown and between site access restrictions.

The project team is developing draft design guidelines for retrofit and new-build boiler/GHPWH hybridization.

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UTD Utilization Technology Development

# SuperPerm Burner for Water Heaters

***Efforts in this project focus on validating a novel, efficient, compact, low-emission ceramic-coated foam-metal-matrix burner design for next-generation water heaters in both un-humidified and humidified combustion-air conditions.***

## Project Description

Hot-water use in commercial service is application-specific. From continuous flow rates (both high and low volumes) to large-volume dumps over a short time period, manufacturers have many models to meet the specific needs of a customer's application.

Adding complexity to the number of models are the different regional and local requirements, which adds cost not only to the low-$NO_x$ burner, but to business infrastructure expenses such as stock keeping, inventory tracking, and certification.

In response, researchers evaluated a permeable metal foam burner with superior performance that includes ultra-low emissions, increased heat transfer, increased flue-gas dew-point temperature, and condensing efficiency at lower cost than the current commercially available power burners. Called the SuperPerm™ burner, the patent-pending burner is the result of research conducted in collaboration with the Institute of Chemical Physics for the Russian Academy of Sciences in Moscow.

The objective of this current project is to develop the ceramic-coated foam-metal-matrix burner design at commercial scale for application in a commercial water heater (down-fired firetube heat exchanger) in both un-humidified and humidified combustion-air conditions.

In Phase 1 of this project, researchers completed a numerical analysis of a volumetric permeable matrix burner design. Testing with flat-plate metal foams of varying porosity, density, and metals was conducted to develop baseline characteristic data on metal foams for both volumetric and flat-plate burner designs. For benchtop testing, the project team designed and fabricated a single-burner design.

In the current Phase 2, the project team is testing and characterizing at least three higher-density (15% to 20%) metal foams, coated and uncoated, for use in flat-plate and volumetric burner designs; fabricating and installing the burner in a commercial water-heater simulator; analyzing results; and refining the burner design for water-heater integration.

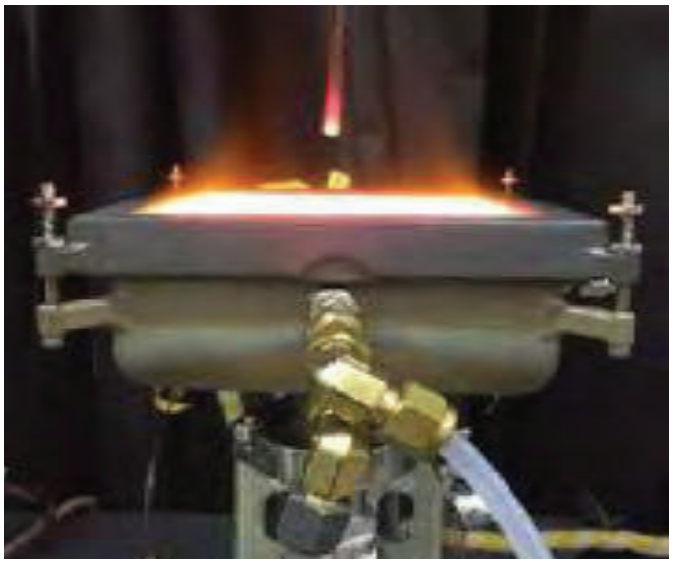
The key burner features to achieve are:

- Surface stabilized combustion on a high-conductivity metallic permeable matrix coated with a low-conductivity ceramic material that increases the temperature of the matrix surface and therefore radiant flux at the surface of the material (i.e., increased thermal radiation efficiency by more than 20%)
- Operation at low flame temperature and low excess air (10%-15%), with reduced $NO_x$ emissions to 3-5 vppm while maintaining low (10-20 vppm) CO and unburned hydrocarbon emissions, and
- Higher thermal efficiency attributed to decreased excess air.

## Benefits / Market Implications

The goal of this project is to provide lower-cost, high-efficiency condensing technology for water heating by developing an advanced burner with:

- 20%-30% increased radiant heat transfer
- Increased thermal efficiency (excess air ratio $\alpha$=1.1)
- Potential for ultra-low $NO_x$ (<3vppm), and
- Potential for ultra-low CO (<5vppm).



## Technical Concept & Approach

The approach for this project is to first characterize and optimize key operating principles of the radiant burner at bench scale and to confirm the original experiments performed. Key design features (e.g., mix distribution pattern, distance to cold wall, and power density) will be optimized at bench scale. A custom built burner design will be used to accommodate the larger metal matrix burners (5"x5") of varying thicknesses.

A metal, water-cooled calorimeter measures the total heat flux given off of the burner and simulates the cold wall of a water heater. A dedicated emission-sampling probe, a radiation flux meter, and an infrared imaging camera are used to characterize the surface variation in emissions, radiant heat flux, and temperature.

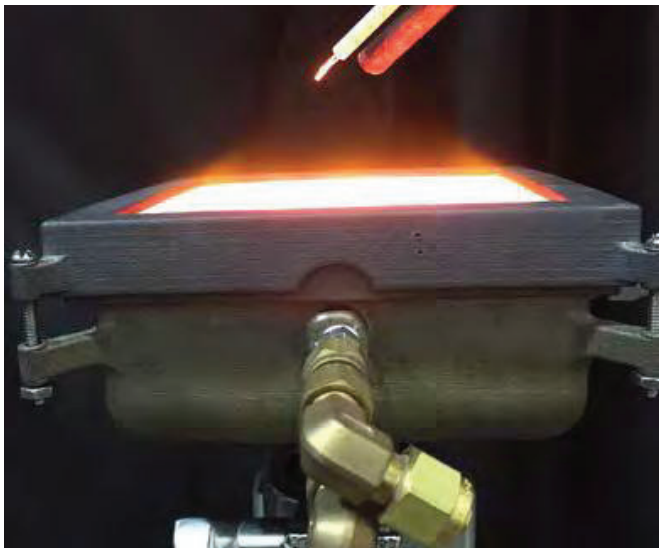
Based on the lessons learned and optimal design configuration achieved for the bench-scale burner, a volumetric burner was built and tested.

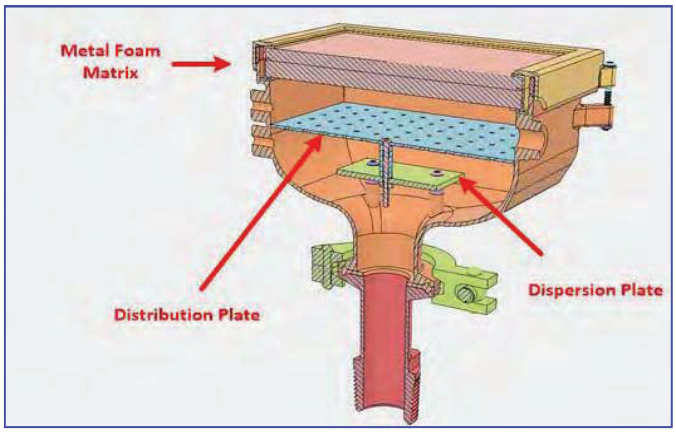
## Results

In validation testing, the project team confirmed that:

- Differences in test results of Russian and U.S. samples compared with the findings of Semenov Institute were due to differences in foam materials properties (density, porosity, etc.) and burner geometries, and
- Exploitation of the SuperPerm technology to extend the range of the burner operation (power density) and generate consistently low pollutant emissions requires better characterization of foam material properties and burner geometry.

In Phase 1, research confirmed that the SuperPerm technology performed very well, with stable combustion and low pollutant emissions ($NO_x$ and CO) over a wide range of the burner power density. Metal foam






performance varies widely from manufacturer to manufacturer in materials properties (porosity, relative density) and geometry.

A flat plate benchtop burner design was developed and researchers explored the performance limitations of metal foams for surface combustion. Investigators validated the use of reverberatory screens to stabilize surface combustion at higher power densities, and to lower pollutant emissions. Researchers also validated methods to reduce or eliminate the risk of auto ignition and flashback in SuperPerm burners operating at high air-preheat temperatures, up to 1,562°F.

In Phase 2, the project team completed characterization of the SuperPerm technology by validating an operational range from 17 to 65 W/cm2, ultra-low-$NO_x$ emissions, and superior performance of coated metal foam over uncoated metal foam.

Other Findings:

- 60 ppi metal foam product was well-developed (e.g., met product specifications).
- <60 ppi and >60ppi metal foam products were not well-developed; samples purchased were not uniform in air-fuel mixture flow as well as surface combustion, and were missing quality control for the porous material uniformity. More research and development is necessary by the product manufacturer to ensure consistent product specifications.

## Status

A Phase 2 Final Report is under development. A patent for the technology is pending.

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UTD Utilization Technology Development

# Elevated-Gas-Pressure Water-Heater Market and Technical Evaluation

***Research was conducted to evaluate the market, technical opportunities, and barriers to operating appliances at elevated gas pressure in order to reduce appliance cost, increase efficiency, and enhance self-powered resiliency.***

## Project Description

Using elevated-gas-pressure infrastructure in residential and commercial buildings could help reduce the incremental cost and complexity for builders to construct mixed-fuel Zero Net Energy homes and meet both customer preferences and regulatory compliance.

In addition to the infrastructure savings, there may be cost, emissions, and efficiency benefits to operating appliances at elevated pressure. In this project, research was conducted to 1) define the current market opportunities and barriers to operating elevated-gas-pressure appliances in residential and commercial buildings and 2) assess the technical feasibility and benefits by operating both non-condensing and condensing gas storage and tankless water heaters at elevated gas pressures.

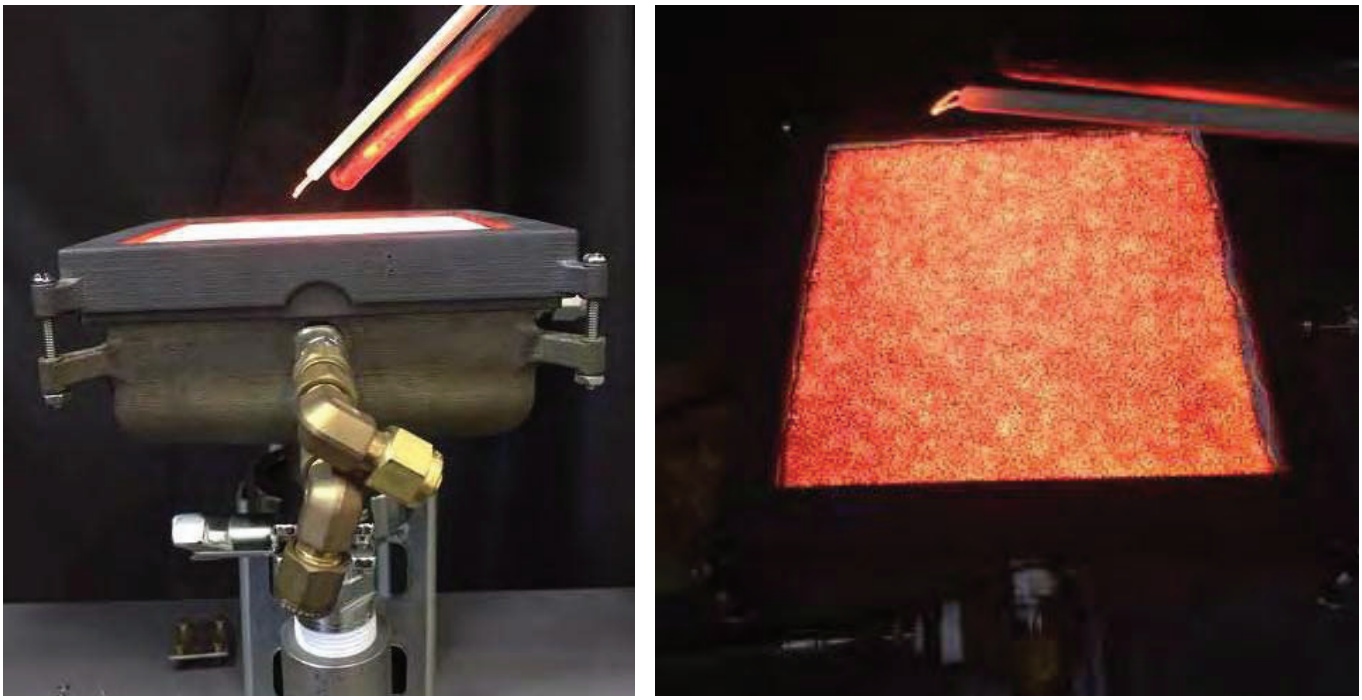
Phase 1 research focused on codes and standards, market and institutional barriers, and technical validation of existing atmospheric burners (the lowest-cost burner approach) operating at elevated gas pressures.

Phase 2 research activity included evaluating if operating at elevated gas pressure could eliminate the powered blower on a condensing water heater to achieve a 30% component cost reduction for condensing appliances.

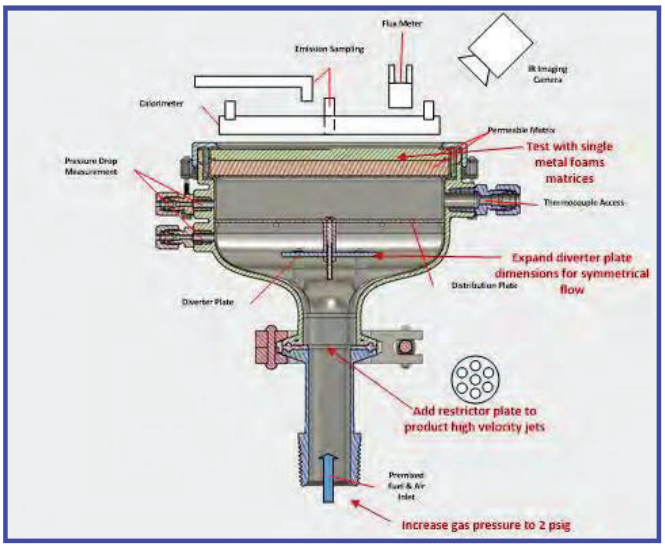
In recent years, a number of technical changes have occurred that may affect the benefits of operating at elevated gas pressure. These changes include:

- The minimum water-heater efficiency requirements increasing from an Energy Factor of 0.54 (2003) to a unified Energy Factor of 0.62 (2015)
- New burner technology emerging on the market with metal porous matrix styles, and
- Electronic circuitry, including power-harvesting technology, that has come down in price and electronic components that consume less power.

The ability of the appliance to be self-powered, free from a powered connection, is a desirable feature that will be examined in this project. An “unplugged” appliance can offer lower installation costs, operate continuously in a power outage, and minimize the contribution of overall energy use in the home.



*Metal foam burner laboratory testing.*




## Benefits / Market Implications

Elevated gas pressure has the potential to lower costs and simplify gas-system installations inside buildings by allowing for the use of smaller-diameter rigid and flexible gas piping with manifold or parallel branch pipe layouts. Flexible gas piping reduces the number of fittings by changing direction easily within walls and floors or around appliances, and the smaller diameter allows more length for each roll of pipe. Additionally, the elevated-pressure layout can more readily integrate future expansion for pool heaters and other emerging technologies.

## Technical Concept & Approach

Specific tasks for this project included:

- A review of the market, manufacturers, codes, opportunities, and barriers for a 2 psig infrastructure with elevated gas appliances
- A residential water heater baseline evaluation
- Elevated-gas-pressure combustion systems development, and
- A modified residential water-heater testing and analysis.

## Results

In Phase 1, research validated that existing atmospheric burners (the lowest-cost burner approach) can be adapted or modified to run on elevated gas pressures. The 3G burner (used in atmospheric water heaters to meet California emission requirements) performed well at 2 psig with little modification.

In Phase 2, research focused on eliminating the blower on a condensing water heater, which is necessary to achieve the 30% component cost reduction for condensing appliances. Researchers analyzed the use of an ejector for mixing and found that at 2 psig there was not enough buoyancy and momentum to exhaust flue gas.

A turbo-compressor concept was investigated to eliminate both the blower and the appliance gas valve/ regulator. Initial numerical analysis tended to confirm that this design would be able to provide the momentum and buoyancy for safe flue gas venting, although a much more rigorous analysis is required.

Calculations were performed to determine whether using 2 psig gas supply pressure would eliminate the need for a blower in a combustion system of a high-efficiency water heater. In such a system, the natural gas jet acts as a pump to push all combustion products out of the building. Theoretical calculations were performed for a simplified burner geometry (i.e., 3G or pancake), where the gas supply pressure is increased while keeping the overall firing rate at ~40,000 Btu/hr. As an alternative approach, researchers evaluated transforming elevated gas pressure to another form, either mechanical or electrical, to create an air pressure booster to overcome exhaust backpressure.

A turbo-generator plus fan configuration was estimated to have 15% efficiency, but is not able to deliver more than 1 in. w.c. of static air pressure, deeming it insufficient for a direct vent system. An off-the-shelf hydro-base generator was unsuccessful in delivering power at 2 psig gas pressure without significant modification. A turbo-compressor configuration was estimated to have an efficiency as high as 85%, and able to deliver more than 3 in w.c. of static pressure consistently at all excess air levels. No product on the market that can perform the outlined functions, so one must be prototyped and evaluated.

## Status

This project is complete. A Phase 2 Final Report was issued in June 2020.

It is recommended that a turbo-compressor configuration be designed, prototyped, and tested to validate the ability to eliminate a component fan under 2 psig operation. Leveraging small micro-turbine technology development for military applications may provide fast track development.

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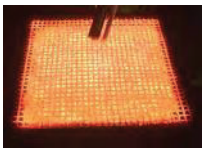
# Thermoelectric Generator for Self-Powered Water Heater



***Researchers validated that a Thermoelectric Generator Heat Exchanger (TEG-HX) device can generate enough electric energy to power a tankless natural gas water heater. The overall goal is to develop a self-powered, gas-fired tankless water heater to save ratepayers money and energy while enhancing resiliency.***

## Project Description

Many consumers are embracing tankless gas-fired water heaters for their high efficiency and compact size, including significant adoption in Europe. According to Persistence Marketing Research, tankless water heaters sales will grow at an annual rate of 5.3% from 2016 to 2024.

Currently, all gas tankless water heaters require a connection to an electrical supply to maintain operation. Unlike gas storage water heaters, tankless heaters do not hold reserve hot water that can be used during a power outage. However, advances in thermoelectric generators (TEG), low-power components, energy harvesting, and energy storage may make it possible to develop an unpowered gas-fired tankless water heater for the residential market.

In previous efforts, researchers evaluated the potential for thermoelectric concepts for water-heater integration. All of the concepts used a water-cooled TEG device for gas-to-liquid thermoelectric power generation. While difficult to implement in a gas storage water-heater design, the water-cooled TEG concept may be ideal to implement in a tankless water heater where electronics, heat exchangers, and water flow are in close proximity to each other. Components such as the spark ignitor, a gas valve, a flue damper, and energy harvest and storage circuitry may have additional application in the development of a self-powered tankless water heater.

The initial objective for this project was to validate that a Thermoelectric Generator Heat Exchanger (TEG-HX) device can generate enough electric energy to power a tankless natural gas water heater.

Now in Phase 3, efforts are under way to develop and prove the concept of a novel self-powered natural-gas-driven tankless (instantaneous) water heater with ultra-low emissions (<5 ppm $NO_x$) and with excess power capability by incorporating a novel new heat pump configuration with a TEG-HX design.

## Benefits / Market Implications

A self-powered tankless water heater would preserve one of the key value propositions that traditional gas storage water heaters offer to its customers – hot water availability during a power outage.

A TEG-HX-based condensing system would provide an enabling platform for higher efficiency self-powered gas appliances and serve end users with greenhouse-gas emissions reductions and energy assuredness in disasters.

A successful TEG-HX component can also improve the efficiency of traditional storage water heaters by eliminating the energy consumed by the standing pilot light. At 400 Btu/hr, the water heater pilot light in a non-powered gas storage water heater consumes 35 therms per year, or 16% of the total energy consumption of a typical gas water heater.

The novel self-powered tankless water heater offers an identified energy savings potential of 20.9% over typical new natural-gas-driven water heaters and 73.2%

*New radiant burner tested with thermoelectric generator and TEG-HX.*

*"Our organization supports the development of self-powered natural gas appliances. The technology is something needed in the market today."*

*- Chris Latch*
*Gas & Water Manager*
*City of Corinth Gas & Water Department*

over typical new electric water heaters – which translates into a total of 0.4 quads saving in primary energy and a reduction of 20 Mt of $CO_2$ emissions per year in 2030.

## Technical Concept & Approach

The key to developing a self-powered tankless water heater is to generate enough energy to power a combustion air blower while harvesting and storing additional power for start-up operations. This project focuses on the design and development of the TEG-HX power generating component.

The TEG device generates electricity by converting heat (temperature differences) directly into electrical energy. Water-to-water, gas-to-water, and thermal fluid-to-water are three methods of heat transfer that this project investigated to generate electric power from the heat of combustion for a self-powered tankless water heater. Daily hot-water demand creates flows in both hot and cold water. Hot water, gas, or thermal fluid flow through the hot side of the TEG-HX and cold water flows through the cold side of the flow through the TEG-HX.

The TEG efficiency at the temperature difference range is about 1%-3%, or heat flow through a TEG to achieve 1W of power is 30-100 W. This is rather small compared to the enthalpy flow of hot water (10-25 kW), thus showing potential for this concept.

The project began with a Phase 1 that characterized through technical evaluation both the power requirements and operational constraints of a tankless water heater. Capabilities were demonstrated through numerical and analytical models.

Phase 2 validated this capability through technical analysis and benchtop testing.

The current Phase 3 builds upon the knowledge and technology developed in prior phases to develop the critical components and prove the concept that a TEG-HX could power a condensing tankless water heater.

## Results

During the project, a technical analysis of three selected TEG-HX designs to generate electric power from the heat of combustion was conducted. The project team identified that the most effective and reliable heat-exchanger design for thermoelectric generator is gas-to-water TEG-HX. Based on Phase 1 project results, researchers identified the preferred electrical energy-storage mechanism and proposed modifications that reduce the power requirements of a tankless water heater, specifically, a new radiant burner was used with the TEG-HX for tankless water heating, which allows effective harvesting power from natural gas combustion for self-powered operation of the water heater while achieving ultra-low $NO_x$ emissions (<5ppm).

The project team developed, designed, fabricated, and tested the TEG-HX device in a laboratory environment and at simulated tankless water-heater conditions. This was done in close cooperation with a leading manufacturer of TEG devices.

The capacitor was chosen as a preferred energy storage mechanism based on cost, dimensions, and research experience in the energy-storage mechanisms for water-heater operation.

With the new burner, the opportunity for a 20%-50% electric power reduction was identified.

Based on the project research results, it was concluded that the TEG module and developed TEG-HX design together with the new burner can provide enough electricity from the TEG module to cost-effectively power a tankless water heater.

Phase 2 of this project was completed in June 2019 with the release of a Phase 2 Final Report.

## Status

The project team continues development and optimization of the thermoelectric system design during Phase 3. Critical tankless water heater components designs are being made to optimize performance, minimize power consumption, and provide ultra-low emissions. Components include: TEG-HX, advanced burner, primary and secondary heat exchangers and energy storage.

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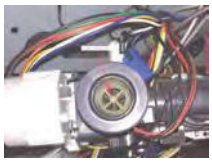
UTD Utilization Technology Development

# Gas Heat Pump Combination Space/ Water-Heating System Design



***Through this project, a research team is developing best practices for end users to utilize gas heat pumps (including absorption, adsorption, vapor-compression, and other technologies) in order to maximize economy and efficiency for end users.***

## Project Description

UTD has a long history of supporting the analysis, evaluation, and development of combined space- and water-heating systems ("combi" systems) for residential applications. The greatest challenge with combi systems is the proper integration and control of forced-air distribution, most commonly via an air-handler unit (AHU) and a separate water heater. For combis that use traditional condensing water heaters, inducing condensing operation while delivering adequate space heating comfort from the AHU can be especially difficult. Heat pump water heaters have a similar problem.

In Phase 1 of this project, researchers performed targeted experimental testing and simulation, and outlined best practices for gas heat pump (GHP)-based combi system design.

Phase 2 involves the development of a smart hybrid combi controller that infers the properties of a heat pump and/or water heater and hydronic air handler, and then optimizes the system performance for efficiency and comfort.

Goals for Phase 2 are to:

- Reduce to practice a provisional U.S. patent application for a hydronic heating hub (H3) controller for combination space- and water-heating systems, and
- Design/build an alpha prototype that utilizes the H3 controller either built into the AHU (or as a hub between an AHU and water heater) to automate otherwise field-engineered methods for maximizing combi efficiency and delivered comfort.

To accommodate these goals, researchers designed and built an advanced combi AHU constructed programmable control board of off-the-shelf parts. The AHU was outfitted with a micro-processor and minimal control components such a relays to switch fan speed and temperature sensors. The micro-processor was programmed with novel control logic that will maximize the performance of hybrid combis given dynamic outdoor air-temperature input and simple design capacity metrics, basic heat-pump performance, and coil performance. A chilled water coil was used as the hot water heating coil because it has appropriate coil capacity to induce condensing tankless operation. The system automatically controls water flow and air flow, and switches between gas tankless water heating and electric heat-pump heating to maximize heating efficiencies across the spectrum of ambient conditions.

Some important considerations for GHP-based versus conventional gas water-heater/boiler-based combi systems are:

- **"Higher mass" system:** In a way, GHPs have more in common with high-mass boilers than tankless water heaters and low-mass boilers commonly used in conventional combi systems. Particularly for thermally-driven GHP systems, bringing up the GHP to temperature and starting the "heat pumping" process can take several minutes and the system controls must account for this.
- **Low turndown ratio:** Similarly, GHPs are limited to dual-stage or even 4:1 turndown, unlike the 20:1

turndown common for tankless water heater-based conventional combi systems. As a result, and to meet the refrigerant-to-DHW heating ANSI requirement of a "double wall," an indirect storage tank is required for the majority of GHP-based combi systems.

- **Influence of operating conditions:** As a heat pump is installed most commonly outdoors, the operating efficiency and capacity are influenced by ambient *and* heating loop temperatures. This influences the use of setback curves and hardware sizing.
- **Using split media:** In some cases, the GHPs are more akin to an electric heat pump, as a direct-expansion system. Space heating and DHW are provided by separate media (refrigerant/water-glycol, respectively) and considerations for combi system best practices are affected accordingly.
- **Engineered systems:** With these operating characteristics taken into account, it is possible a unique engineered system (tank, coil, GHP) is required as is used with "all-in-one" multi-function electric heat pumps.

## Benefits / Market Implications

The development of advanced combi systems supports the broad commercialization of these technologies, including GHPs for single- and multi-family buildings. GHP technologies can offer 30% or greater savings to ratepayers over condensing gas heating products and, with year-round operation as a combi system, the financial payback can be as low as three years. Other benefits include a simplified installation, ratepayer energy savings, and carbon savings associated with the direct use of natural gas year-round as well as potential integration of solar thermal energy.

## Technical Concept & Approach

- **Best Practices for GHP-Based Combi System Design**

  This effort involves a review of literature on combi systems and GHP equipment, and development of a database of laboratory and field combi system performance data to establish baseline for: typical and extreme space/DHW heating loads, the dynamics of conventional combi systems, and opportunities to refine component design (coil, storage tank, etc.).

- **Design and Testing of "Smart" GHP-ready Combi Controller**

  To enable a lower cost, non-engineered system approach to GHP-based combi systems, researchers will develop and prove the concept of a "smart" GHP-ready combi controller. The controller will use onboard sensors to infer properties of the major components (GHP, tank, coil) and optimize performance while allowing for setback controls, safety monitoring, and user-defined operating modes (high efficiency, high output, etc.). The combi controller will be tested with a simple simulation tool.

## Results

Testing involved a tankless water heater and a standard air handler. Researchers investigated the potential "hacking" of this testing unit to 1) read and respond to the internal flow sensors, 2) read/write to the thermostat setting, and 3) read and respond to internal temperature measurements. Results indicate that read/write of the temperature setting is feasible; however, best achieved with external actuation of the inputs.

In 2018-19, the project team completed the design and assembly of the hydronic heating hub. This involved the completion of custom parts and assembly and installation in the laboratory, including integration with a tankless water heater and hydronic air hander. Researchers finalized and executed an experimental test plan and a learning framework for the controller.

The project team assembled a flexible breadboard on a 19-inch portable rack system with final parts to be assembled through automated machining. This first alpha prototype of this controller will be assembled in this manner to allow for flexible adjustments to system hardware, in addition to software.

Results from breadboard testing are being used to develop an alpha prototype combi controller that implements control features for achieving 90%+ gas efficiencies down to 5% part-loads and 100%+ hybrid efficiencies in an integrating energy systems approach.

In 2020, the project team developed controls concepts and a prototype design for the integrated systems configuration. A test setup was completed in the laboratory.

## Status

Shelter-in-place orders due to COVID pandemic has limited progress in the laboratory.

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UTD Utilization Technology Development

# Combination Heating/ Cooling Vuilleumier-Cycle Heat Pump

***This project is supporting the development of an innovative gas-fired Vuilleumier heat pump to substantially increase efficiency over current gas heat pumps that operate using vapor-absorption and vapor-compression (engine-driven) cycles.***

## Project Description

This project supports the development of a gas-fired heat pump based on the Vuilleumier cycle – a closed-loop system similar in nature to the Stirling cycle – that uses a working fluid (helium) driven across a number of heat exchangers that interact with the environment. The working fluid flow is driven through two linked displacers located in opposing cylindrical ends known as the "hot end" (where heat input to the cycle occurs) and the "cold end" (where heat removal from the environment occurs). Competitive to an absorption cycle heat pump, the gas-fired Vuilleumier-cycle heat pump (GVHP) shows potential for a greater coefficient of performance (COP).

The objective for this project is to support the development of the GVHP, which, if commercialized, would represent a step-change in efficiency over the current gas heat pumps that operate with vapor-absorption and vapor-compression (engine-driven) cycles, with a cooling COP of greater than 1.0 and a heating COP of greater than 2.0.

## Benefits / Market Implications

It is estimated that the lifetime fuel savings of a GVHP over a condensing furnace is $9,760, with the potential for cooling-season cost savings as well. Using a benign working fluid (helium) with cost-effective design to accommodate higher working pressures (~1,450 psia), the GVHP may offer a premium gas heat-pump product with compelling emission and cost savings for future gas ratepayers.

## Technical Concept & Approach

Efforts focused on moving towards simulated-use testing of an alpha version of the GVHP prototype, sized for light commercial/large residential applications.

Combustion system prototyping and full-system testing were conducted to enable direct comparisons to conventional gas-heating equipment, combined space/water-heating system, conventional and advanced electric HVAC technologies, as well as to more mature competing gas heat-pump technologies (vapor absorption and engine-driven vapor compression).

The project team helped update the design of key components from prior R&D programs for incorporation within the alpha GVHP (e.g., fuel/air mixer). Components were fabricated and bench-tested individually within an existing simulator.

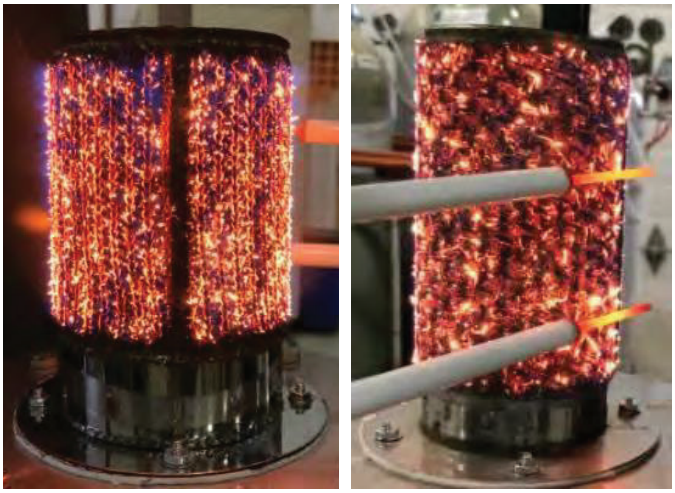
## Results

In Phase 1, the project team:

- Identified air-fuel preheat limits for a recuperator that would help avoid auto-ignition
- Defined design guidelines for air-fuel mixing strategies for the GVHP
- Engaged with five burner manufactureres to find a compatible burner for the operating regime
- Validated hot-end heat-exchanger design and demonstrated >50% efficiency
- Demonstrated overall hot-end efficiency of >70%, and
- Identified that the recuperator design was undersized by 30%.

Phase 2 includes:

- Providing technical support for the redesign of the combustion system and novel combustion controls
- A codes and standards review to help with field certification of initial prototypes, and
- Testing of subcomponents and the full system in 2020-2021.



*Initial air-preheating test setup with example burners.*

In 2020, a fourth-generation prototype was built and is undergoing shakedown tests in preparation for early field trials and testing. The GVHP manufacturer has noted good thermodynamic cycle performance, but additional opportunities to optimize the heat transfer are being identified.

In parallel, a partnering manufacturer is making an effort to develop and certify combustion controls.

In preparation for whole-system testing, a comprehensive test plan for the system was prepared and the test apparatus is being built.

## Status

Next steps include:

- Installation and testing of the hot-end assembly, including an evaluation of the new combustion controls and
- On-site support for emissions testing.

The project team anticipates testing and further development of a fourth-generation prototype in 2020.

But due to the COVID-19 outbreak, progress on this project was delayed, and the timing for whole-system testing is to be determined.

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# Yanmar Three-Pipe Gas Engine Heat Pump Field Study

***Researchers evaluated the field performance and economics of the Yanmar three-pipe gas heat pump (GHP), the first to provide simultaneous heating and cooling. The ultimate goal is to expand the application of these high-efficiency GHPs by commercial building owners and operators.***

## Project Description

Natural gas engine driven heat pumps (GHPs) combine high-efficiency heating and cooling to significantly reduce peak electric demand and electricity use with potential savings in life-cycle costs as compared to electric heat pumps or conventional HVAC equipment.

In 2016, Yanmar America Corp. Energy Systems introduced a 14-ton GHP with a three-pipe heat-recovery variable refrigerant flow (VRF) system, the first GHP in the U.S. market with the capability to provide simultaneous heating and cooling. This option improves the response to building loads by recovering heat from zones in cooling mode (e.g., internal loads) and redistributing it to meet heating loads in perimeter zones. This technology provides a unique energy-efficient option, and opens up new markets where in the past electric systems were the only options for simultaneous heating and cooling.

*The Yanmar three-pipe GHP provides simultaneous heating and cooling.*

As an emerging technology, GHPs face economic and market barriers, including high installed costs, which potentially can be offset by savings in operating costs. The need for additional engine maintenance and limited service networks are other potential barriers for this technology. Engine emissions pose another barrier for some markets. While natural gas is a very clean-burning fuel for engines, the primary environmental concern is $NO_x$ emissions.

GHPs have a significant share of Japanese and European space-conditioning markets, but are relatively new to the U.S. market. The Yanmar product line includes two-pipe VRF systems from 8 to 14 tons in addition to a 14-ton three-pipe unit.

For this project, researchers expanded on previous developments with GHPs in laboratory and field demonstrations to evaluate the field performance and economics of the Yanmar three-pipe GHP.

## Benefits / Market Implications

Historically low gas rates are a key driver for the adoption of GHPs to reduce operating costs in areas with high electric rates and demand charges. These operating-cost reductions include not only energy costs but also water costs associated with electric chiller, which can be significant in hot, dry regions such as the southwestern U.S.

Peak electrical demand has been growing in the commercial sector, mainly due to the high cooling requirements of commercial buildings. GHPs offer a cost-effective and environmentally-friendly option to reduce peak electricity demand.

## Technical Concept & Approach

Specific tasks included:

- Site Selection and Field Test Plan
- Site Monitoring and Data Analysis, and
- Optional Laboratory Testing.

## Results

For the demonstration, the project team selected the Lawrenceville Public Works (LPW) facility in the service territory of the Municipal Gas Authority of Georgia (MGAG). In 2016, the MGAG launched a GHP incentive program to support market transformation for GHPs.

Six GHP systems provide zoned heating and cooling for the Lawrenceville facility. A tempering energy recovery ventilator provides ventilation to each zone during occupied hours and conditions outside air to space neutral conditions. The conditioned outside air is distributed directly to each zone through separate ductwork with fixed dampers.

One of the six GHP VRF systems at LPW was selected to be studied in the demonstration. The GHP outdoor unit and corresponding fan coils were instrumented to monitor energy use and performance. The GHP system was monitored from November 2018 to October 2019 to evaluate its performance across the full range of ambient conditions and equipment operation.

Due to the field site's warm climate, the GHP operated in cooling mode for the majority of time, with limited runtime in heating mode. Simultaneous heating/cooling operation occurred only during mild temperatures. Based on this field site, the GHP had lower annual energy costs and reduced peak electric demand compared to equivalent all-electric VRF systems or conventional multi-zone roof top units (RTUs).

**Part-Load Operation:**

The GHP system was over-sized for this installation. While this is common practice for sizing HVAC equipment, the resulting low part-load operation impacted both heating and cooling performance. The GHP achieved rated efficiencies up to and exceeding 1.3 COPg during extended steady-state runtimes; however, overall GHP efficiency was reduced during low part-load operation. Measured seasonal efficiency was 1.18 COPg heating and 0.95 COPg cooling, excluding simultaneous operation.

Throughout the demonstration period, the GHP operated at very low part loads, ranging between 15% and 30% during heating or cooling. During simultaneous operation, the net load on the GHP outdoor unit (i.e., the difference between the heating and cooling delivered) ranged from 5%-20% part load.

**Simultaneous Operation:**

Simultaneous heating/cooling operation is an important feature of three-pipe VRF systems that improves comfort but adversely impacted overall efficiency due to cycling losses and low part-load operation. These results suggest that two-pipe VRF systems may in some cases be more cost effective than three-pipe systems.

*"The Municipal Gas Authority of Georgia is excited to see one of its members, the City of Lawrenceville, participate in testing the Yanmar system, which we think will help solidify market acceptance of GHPs. Low natural-gas prices have created a tremendous market opportunity for GHP technology. Through our Emerging Technology Rebate Program, many of our member natural gas systems are currently supplying natural gas for GHP installations."*

*- Rodney Dill*
*Director, Member Services & Communications*
*Municipal Gas Authority of Georgia*

Fan coil placement and set points may also impact performance in simultaneous operation. Careful commissioning is needed to eliminate cycling or false loading of adjacent fan coils.

**Economic Assessment:**

The GHP had lower annual energy costs compared to an equivalent multi-zone RTU or an all-electric VRF system. Savings in energy costs were driven by reductions in peak electric-demand and associated demand charges.

Despite reduced performance due to over-sizing, the field-site GHP had lower life-cycle costs compared to an all- electric VRF with a simple payback of eight years based on regional energy prices. With current incentives ($700/ton), GHPs would have an immediate payback compared to electric three-pipe VRF with more than $14K life-cycle cost savings over the 15-year life of the equipment.

## Status

A Final Report for this field demonstration was issued in May 2020. A two-page case study of the Yanmar three-pipe GHP field study was also developed and is publically available.

Efforts are being made to identify an alternate approach to obtain performance data for the Yanmar GHP in place of the planned laboratory evaluation.

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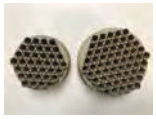
# Advanced Nozzle Burner for Commercial Water Heaters



***Researchers are developing an advanced economical nozzle burner for commercial water heaters with a high-efficiency, ultra-low emissions, good turndown, superior stability, and compactness.***

## Project Description

Current commercial water-heater burner designs are not able to achieve all the technology targets of ultra-low emissions, high efficiency, good turndown, and reduced first costs and payback periods. They also often have retrofit-ability limitations and are not scalable.

The advanced nozzle burner being developed in this project has the ability to overcome some of the key challenges and be an enabling technology for gas-driven commercial and residential water heaters. This project will demonstrate the advanced nozzle technology in a water heater and review results with leading manufacturers to move towards commercialization.

Key performance indicators and goals to measure the success of this project will be:

- Improve efficiency by 2%-4% for the same emissions
- $NO_x$ emission of <5 ppm and CO emissions of < 20 ppm corrected to 3% O2, and
- Achieve turndown of 10:1.

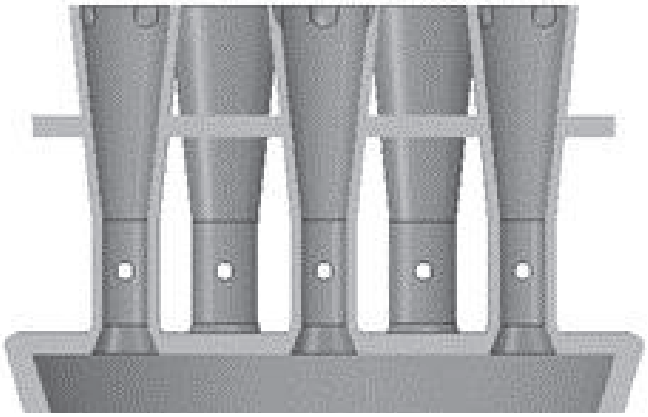
## Benefits / Market Implications

Forty-four percent of the 225,000 commercial water heater units sold annually are gas driven, with associated positive impacts on source energy efficiency. Similarly, data shows that 42% of commercial buildings heat water with natural gas. Low-cost, low-emission, compact commercial gas-driven burners could further reduce source-energy use.

The technology to be advanced in this project can substantially reduce energy consumption in commercial buildings. Of the 40 quads used by U.S. buildings, 9% is utilized by the water heaters. An average 3% improvement in efficiency will lead to at least 0.12 quads of annual energy savings.

Other benefits of the advanced, patent-pending nozzle burner technology are expected to be:

- Scalable to multiple designs and capacities
- Significant reduction in $NO_x$ emissions >75%, turn-down of 10:1 with CO emissions of < 20 ppm
- Simple and robust, with potential lower first costs
- Installer- and manufacturer- focused
- Reduced weight and size of the water heater, hence lower cost and easier installation in tight locations
- Improved manufacturing ease and significantly reduced time to market
- Reduced noise (hence, more comfort), and
- Capable of integrating smart controls for smart-building applications.



## Technical Concept & Approach

In this project, researchers 3D printed and tested the advanced nozzle burner design for use in a commercial water heater.

Specific tasks included:

- **Baseline Test of Conventional Burner in a Commercial Water heater**

  The project team evaluated the baseline existing burner and reviewed the performance and operability benefits and challenges to compare and improve the current advanced nozzle burner.

- **Adapt and Install the Advanced Nozzle Burner in the Commercial Water Heater**

  The project team designed the advanced burner to adapt to the commercial water heater. The dimensions were matched to be a drop-in design to replace the original burner. The advanced nozzle was installed within the water heater. Modifications to the water heater for measuring emissions, oxygen concentration, and temperature at a certain location were performed. Shakedown testing of the air and fuel flows and ignition device were conducted prior to firing up the burner to ensure smooth and safe operation. Pressure drop, firing rates, emissions, and temperature recording was performed.

- **Evaluate Ignition, Emissions, Stability, and Turndown**

  Researchers tested the advanced burner to evaluate its performance for various key parameters, including efficiency, emissions, turndown, and reliable and smooth ignition. After performing shakedown testing of the burner, multiple ignition tests were performed to ensure that the burner ignites reliably and at variable firing rates. This determined the reliability and repeatability of the ignition process, even though the water heater usually operates at a constant firing rate.

  After successful ignition testing, performance testing was performed. The burner was started at a certain (lower) firing rate and then gradually ramped up to a higher firing rate. This helped to determine the operability and turndown characteristics of the advanced nozzle burner. The testing was performed for different firing rates and different air/fuel ratios to evaluate the emissions and efficiency characteristics. The firing rate was varied to ensure operability and oxygen concentrations were varied for evaluating emissions and efficiency performance.

- **Implement Prototype Improvements**

  During testing of the burner, design changes were made. Researchers performed design review and analysis to address operability and performance concerns, and modified and adapted the design for desired improvements.

## Results

In 2018, technicians completed installation of the conventional burner in the commercial water heater, added instrumentation to measure key parameters, and reviewed the factory settings to conduct performance testing. Preliminary shakedown testing was performed. In addition, the research team initiated a review of the design modifications required to install the advanced nozzle burner in the commercial water heater.

In 2019, bench-scale testing of the 3D-printed burner was conducted to evaluate emissions, turndown, and overall stability. Three different burner designs were developed. A test rig was built to perform burner testing with water-heater controls and blower assembled.

In 2020, researchers reviewed improvements for beta prototype burner design and methods to reduce pressure drop while maintaining emissions and performance. Computational Fluid Dynamics simulations were performed to improve certain key design aspects.

## Status

The first phase of the project is near completion and a Final Report for this phase is being developed. A next phase was proposed to move the technology towards field testing and commercialization.

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# Integrating Thermal Energy Storage in Advanced Gas/Renewable Homes

***This project expanded the thermal energy storage capabilities in a virtual test home in order to more rapidly develop, test, and optimize thermal energy storage options that increase energy efficiency and reliability, reduce energy costs, and better integrate natural gas with renewable energy in homes in all climates.***

## Project Description

The residential rooftop solar market continues to outpace expectations and transform how homes are powered. As a result of the decline in both photovoltaic (PV) module and installation costs, residential PV capacity and output has increased considerably in the U.S. (increasing capacity by nearly four times since 2014 to 2017). These trends continue despite uncertainty regarding incentives, net-metering policy, and other market interventions that were instrumental in PV's initial success.

In this project, a research project team expanded laboratory capabilities of a virtual test home to be able to test a thermal energy storage network to simulate loads and advanced heating equipment using representative 24-hour heating loads based on building energy modeling and prior field data collection. In parallel, researchers built and calibrated analytical capabilities to extrapolate results from the experimental program.

*Tankless water-heater module.*

The ultimate goal of the virtual test home is to evaluate solutions with gas-fired heating equipment (e.g., gas heat pumps), micro-CHP equipment, and a PV array with simulated climate conditions and building loads.

In this effort, the primary research questions are:

- What is the minimum level of thermal energy storage required for a given set of HVAC and micro-CHP equipment?
- Is standalone domestic hot water (DHW) equipment required?
- Are there opportunities for latent energy storage in addition to sensible energy storage?
- Can chilled water energy storage enable gas-fired chillers for air conditioning at residential scale?
- Over what timescales is thermal energy stored and deployed?

## Benefits / Market Implications

This project was a system-level technology development program to demonstrate methods and technologies to effectively integrate gas-fired equipment with on-site renewable generation. Future benefits include system-integration strategies and building practices that will facilitate the expanded integration of gas and renewable energies in homes.

## Technical Concept & Approach

The virtual test home (VTH) approach consists of multiple test rigs and associated control algorithms that simulate as-installed conditions in a controlled, repeatable laboratory environment. The VTH approach can be used for gas and electric space heating/cooling, water heating, and power-generation equipment. Testing protocols

were created for this VTH approach to map the equipment performance to better understand system behavior and operating range in multiple climate zones across the U.S. Coupled with building energy modeling, the VTH provided estimates of as-installed equipment performance and energy savings.

In this project, researchers built and tested experimental controls with an integrated tankless water heater, boiler, and gas heat pump water heater (HPWH). In parallel, the project team built a calibrated simulation tool for modeling different combinations of thermal storage with other heating equipment in a gas/renewable home.

Specific tasks included:

- **Design and Construction of Thermal Storage Experimental Test Stand**

  Researchers framed the range of thermal loads expected for the simulated gas/renewable homes and developed the range of homes simulated by the test stand. A range of specifications for thermal energy storage equipment was also developed.

- **Commission the Test Stand and Evaluate DHW Technologies**

  The project team analyzed test data and refined control strategies iteratively, coupled with micro-CHP and HVAC considerations.

- **Develop and Calibrate Simulation Tool**

  Using building energy simulation software, the project team created several model gas/renewable homes and generated baseline performance for multiple equipment configurations. Upon completion of testing, researchers calibrated experimental findings with baseline equipment (e.g., tankless water heater).

## Results

The project team developed a test plan and initiated implementation of the test rig modifications, including procurement of additional controls and instrumentation.

The VTH allows investigators to determine the impact of gas-fired, electric driven, renewable, and resilient integrated systems technologies on the environment, utility distributions, homeowners, and comfort. In addition to estimated energy consumption, building energy modeling tools support investigations into proper equipment sizing.

The main features of the expanded VTH infrastructure are:

- Thermal storage capabilities for both indirect and direct tank systems
- Independent mCHP electric circuit to interact with auxiliary HVAC systems and simulated electric loads
- Outdoor bay for hybrid evaluation, on-site field demonstration/VTH loads
- Two independent integrated systems bays with space heating and cooling and water-heating capabilities
- Simulated return air and city water temperatures for space- and water-heating simulations
- 200 MBH modulating heat rejection controls to simulate part-load heat loads in hydronic systems, and
- Thermal fluid management loops between mCHP, gas heat pumps, and thermal storage

Features of the VTH infrastructure allow for systematic testing and product development for integrated system with dual-fuel, thermal storage, power-generation, off-grid capabilities for space heating, and cooling and hot water.

## Status

This project is complete. A Final Report was issued in March 2020.

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# Field Evaluation of Central Condensing Tankless Water Heaters for Energy Savings

***A field evaluation of central condensing tankless water-heating systems at two multifamily buildings in Minnesota is quantifying energy savings and developing tools, guidance, and measures to support this emerging high-efficiency technology for more ratepayers.***

## Project Description

Central condensing tankless water heaters (CCTWHs) were recently commercialized by several manufacturers as novel standalone packaged systems or as extensions of more prevalent residential tankless water heating systems ("racking" systems).

A field evaluation of CCTWHs in this project will develop important datasets concerning energy savings, system performance, installation barriers, and end-user/contractor feedback. If successfully demonstrated, the team will develop assessment tools, industry guidance, and recommended potential measures/ incentives to support this emerging technology.

As a replacement to conventional central hot water systems, CCTWHs primarily yield energy savings by two methods: 1) minimizing standby heat losses and 2) maximizing the "condensing" efficiency of the thermal engine. For multifamily buildings, schools/ universities, and hospitality, occupancy is highly variable with peaks in daily and monthly loading patterns. As a result, standby heat losses from the hot-water storage tanks and circulation loops can make up a large fraction of total energy consumption. CCTWHs largely eliminate standby losses by removing storage.

A well-known issue with recirculating boilers and, to a lesser extent, commercial water heaters is that the equipment rated for "condensing" efficiency (90% or greater) do not always operate in a condensing, high-efficiency mode. For a central water-heating system with storage (unless the system is meeting a significant demand wherein the storage tank is partially or wholly cold and the return water to the boiler is below 120°F, the equipment rated for 90%), efficiency will operate in a non-condensing mode (85% or less). By contrast, CCTWHs are able to operate consistently in a condensing mode. Through consistent condensing operation and a reduction in standby losses, retrofitting to CCTWHs from boiler/commercial storage water heating systems may result in significant natural gas savings.

The objective for this project is to perform a field demonstration of the CCTWH at two multifamily buildings in Minnesota to quantify the energy savings potential of CCTWH over conventional direct-fired gas storage and indirect (with dedicated boiler) systems in this application. Under this field evaluation, a project team will quantify the performance and cost effectiveness over an eight-month period. Results will be compared to the existing baseline equipment and extrapolate findings to other building types and loading patterns. Since recognizing the energy savings from the CCTWH and the resulting economics will be heavily influenced by installed conditions and building type, the project team will also develop a sizing and assessment tool for CCTWHs when applied to multifamily housing, hospitality, and schools or universities.

UTD's partner and co-funder in this project is the State of Minnesota Center for Energy and Environment (CEE).

## Benefits / Market Implications

CCTWHs have several advantages over other high-efficiency gas technologies as they build on a mature, high-volume technology which has achieved cost effectiveness in the residential water-heating market. Specifically, "racked" CCTWHs can adapt product modules and components from the high-volume (~450,000/year) U.S. residential gas tankless market. Coupled with the competition amongst several large, mature manufacturers, this reduces the price of CCTWHs to yield competitive system paybacks.

*Examples of commercially-available racked (left) and packaged (right) CCTWHs.*

Manufacturers of CCTWHs claim energy savings of up to 40% over baseline equipment by eliminating large storage tanks and having high system turndown (achieved through modular design), to consistently operate in the high-efficiency "condensing mode" and sharply reduce system standby heat losses.

In the residential gas water heating market, a cost comparison across products has resulted in condensing efficiency with tankless water heating gaining significant market penetration, while adoption of condensing gas-storage water heaters has been more limited due to high equipment costs. If demonstrated through this project, CCTWH products might get expanded support from utility energy-efficiency programs in order to accelerate the transformation of markets such as 1) mid-/high-rise multifamily housing, 2) hospitality, and 3) schools and universities.

## Technical Concept & Approach

The overall project scope is:

- **Field Demonstration Planning and Preparation**

  In this task, the project team will develop a test plan; perform a literature review and manufacturer interviews; and solicit, screen, inspect, and finalize two field demonstration sites in the Minneapolis/St. Paul region.

- **Baseline Monitoring**

  The project team will perform a eight-month baseline monitoring on existing equipment, deploying high-resolution data-collection/analytical methods to assure transient energy/water/waste is quantified.

- **CCTWH Demonstration**

  The project team will specify, procure, install and commission CCTWH systems at two multifamily sites, with aggregate output between about 800-1,400 kBtu/hr.

- **Measure Assessment and Knowledge Transfer**

  The research team will finalize the CCTWH modeling and assessment tool, extrapolate savings and performance to other building types and regional locations, and summarize project results as a draft measure for utility energy-efficiency programs and to support end-use ratepayers.

## Results

The research team engaged a CCTWH manufacturer, recruited a host site, and formulated the test plan. The manufacturer provided specific installation/sizing guidance and pricing of its CCTWH products to support site recruitment. Sites were selected and baseline monitoring equipment was installed at two multifamily buildings in St. Paul, MN.

Monitoring of the baseline equipment has been under way since February 2019. Initial data indicate that for the 40 units at the two sites have an average usage rate of 30 gallons per day per unit, 4.9 therms per day per site, and an annual system efficiency of 0.61. The team continued receipt and analysis of incoming baseline monitoring data and it is being incorporated into the development of the CCTWH Assessment Tool, which is based on a simplified central hot-water system model. The pre-installation surveys for the host site tenants, owners and installation contractor were completed, and findings are being analyzed.

The racked condensing tankless units for both sites were delivered to the installation contractor. However, field installation progress slowed due to executive orders delivered by the Governor of Minnesota for businesses and residents to voluntarily comply with COVID-19 shelter-in-place orders.

## Status

Field installation, commissioning, and instrumenting were slowed due to executive orders due to COVID-19, but the installation and commissioning of the CCTWHs at each site was completed in May 2020. The CCTWH systems will be monitored through approximately November 2020.

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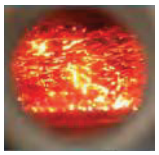
# Mitigating Methane Emissions from Tankless Water Heaters



***Research is being conducted to quantify the amount of emissions and determine the conditions under which tankless water heaters may release unburned hydrocarbons into the atmosphere in order to identify best practices or design features to reduce methane emissions.***

## Project Description

Some appliances are coming under increased scrutiny due to field-measured emissions of unburned hydrocarbons Of specific focus are high-input compact burners (e.g., tankless water heaters). However, field-derived emissions measurements are difficult to perform accurately and representatively.

In principle, tankless water heaters (TWHs) modulate directly in response to end-user loads. In order to maintain outlet temperature stability while handling variable inlet water temperature and flow demands, these units ramp up and down their firing rate quickly, with 20:1 turndown ratios common for products available (unusual for most gas-fired equipment). This is achieved in a number of ways.

Staging multiple cassette burners is the most common method. Several burners (~16) are staged in groups, on and off, as sequenced by proportional gas valves. This allows for the highest possible turndown.

A single ceramic "plaque" or flat woven/knitted fiber mesh, large enough and with an adequate thermal mass to permit such a wide turndown ratio, is added to the burner. As the tankless water heater shifts to the load, either rapidly staging burners on/off or modulating the single plaque/mesh burner, temporary loss of flame stability and delayed ignition can lead to temporary emission of unburned methane. While this transient effect is present with all cycling gas-fired equipment, tankless water heaters by their nature are constantly adjusting the flame through staging or rapid and drastic modulation.

Tankless water heaters offer high efficiencies and are increasingly popular, but could be subject to future regulations or regulatory scrutiny due to methane emissions. This scientific research can help inform public dialogue on this topic.

Currently, tankless gas water heaters, the second most popular type of gas water-heating equipment, representing more than 10% of gas products sold in North America and more than 50% in the Europe.

This project established the first known technically-sound greenhouse gas emission rate for tankless gas water heaters using a laboratory analysis and methodology. The objective is to quantify the amount and determine the conditions under which tankless water heaters release unburned hydrocarbons into the atmosphere in order to identify best practices or design features to reduce methane emissions.

Models from three different manufacturers of tankless water heaters were tested under specific operating conditions and representative use patterns.

*Tankless water heater undergoing testing in a laboratory.*

## Benefits / Market Implications

Over the past 15 years, TWH sales have grown from less than 1% to more than 12% of gas water-heater sales in North America. The ability to clarify and mitigate the impact of TWHs on greenhouse gas emissions would protect the continued market availability of this technology. Any potential restrictions that limit ratepayers' options to use this type of high-efficiency device should be based on sound scientific study and consider product and technical advancements to minimize and mitigate potential releases.

## Technical Concept & Approach

A project team completed a literature review on unburned methane release from appliances. Input was solicited from TWH manufacturers regarding system operation, compact burner modulation/ignition methodologies, and system controls with respect to the emission of unburned fuel.

Researchers developed methods to accurately measure the dynamic emission rate of methane from a modulating TWH and represent end-user behavior through various dynamic tests.

Three TWHs were used for testing, representing a range of combustion system designs and the most popular models and manufacturers. The units were tested using steady-state, "step ramp-up," and simulated use patterns to establish typical methane emissions across products and combustion system designs.

Through data analysis, researchers identified tankless designs, features, and operating conditions that can produce some methane emissions. A list of recommendations for detection and mitigation of such conditions was developed.

The project team compiled and reported results to a cross-section of TWH manufacturers via a webinar, reviewing methods and results.

## Results

In this project, researchers initiated two tasks in parallel: 1) developing the test plan including specifications for the methane-analyzing methodology and 2) procuring and installing both a non-condensing TWH and a condensing TWH. Plumbing and system controls were put in place to operate the TWH units.

The team reviewed recent methane emissions studies and procured a methane analyzer suitable for this project. Additionally, the project team engaged with a major university regarding the test plan as a complement to field sampling of TWHs.

In 2019, researchers finalized the TWH test stand and acquired the tankless water heaters for testing. The test stand was commissioned and shaken down, and initial data-collection tests initiated. Initial runs revealed necessary modifications of the test setup and the analyzer. The draft test plan underwent internal review and modification.

Findings showed that the tested TWHs produced measurable methane emissions:

- "Puffing" at ignition/extinction, universal
- During modulation, depending on the burner design (ignition/extinction of stages)
- During steady-state operation, depending on the burner design and firing rate, and
- During off periods.

Both steady-state emissions (in g/hr) and ignition/extinction emissions (in g/event) generally showed similar order of magnitude results as in prior field studies.

Project findings were publicly presented at the American Council for an Energy-Efficient Economy's 2020 Hot Water Forum during a virtual meeting session held on July 22, 2020.

## Status

Testing is complete, with reporting to utility stakeholders, academic partners, and TWH manufacturers.

Researchers are investigating various approaches to mitigate emissions, including:

- Multi-point ignition/flame sense
- Modulation controls
- Radiant vs. "blue-flame" mode combustion system
- Other in-situ sensors
- Improved heat management and quench minimization, and
- Post-combustion treatment (e.g., catalysts).

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UTD Utilization Technology Development

# Integrating Gas Heating and Cooling in Advanced Gas/Renewable Homes

***This project expanded advanced gas-heating and cooling capabilities in a Virtual Test Home to more rapidly develop, test, and optimize options in system-based solutions that increase energy efficiency and reliability, reduce energy costs, and better integrate natural gas with renewable energy in homes in all climates.***

## Project Description

The objective of this project was to expand the advanced gas heating and cooling capabilities in a Virtual Test Home in a laboratory to more rapidly develop, test, and optimize advanced options in system-based solutions that increase energy efficiency and reliability, reduce energy costs, and better integrate natural gas with renewable energy in homes in all climates.

In this project, researchers designed, commissioned, and tested space-conditioning options, which included integration with a laboratory environmental chamber for simulated indoor/outdoor environments, equipment for controlling transient hydronic loads for 24-hour periods, integration with forced-air heat distribution for hydronic air-coil-equipped and furnace-based systems, and test stations for gas heat pumps (GHPs) and low-capacity warm-air furnaces. In parallel, the project team built and calibrated analytical capabilities to extrapolate results from the experimental program, focusing on the HVAC equipment.

This project included a three-pronged approach:

1. The evaluation of solutions and design practices to assure that high-efficiency, low-impact gas-fired heating technologies are able to maintain thermal comfort in all-climates

2. The development of solutions to deploy and store thermal energy, the primary connective tissue from efficient gas-fired heating to the home's other systems, and

3. The development of sizing guidance and system controls to balance on-site micro-combined heat and power (mCHP) with available renewable resources and thermal energy needs.

This approach is expected to illustrated and inform how the direct use of natural gas in modern homes support policy pushes towards Net-Zero Energy (NZE) building designs, including through the widespread deployment of both on-site renewable PV electricity generation and integration of smart devices with HVAC equipment through mobile software platforms.

*An integrated systems bay that supports a Virtual Test Home analysis.*

## Benefits / Market Implications

When some advocates imagine a NZE home or a home with significant on-site renewable power generation, they often imagine a home with a large rooftop PV array, electric heat pumps for domestic hot water (DHW) and HVAC, and smart electric appliances (including cooking). This may be due to the lack of robust, peer-reviewed analyses and case studies demonstrating that mixed-fuel homes can reach similar levels of emissions reductions and renewable energy utilization but at lower cost and higher reliability and resiliency for ratepayers. There is also a lack of market-ready equipment and system-integration strategies to demonstrate the effectiveness of coupling on-site renewable generation with efficient gas-fired heating equipment.

This effort is intended to address the latter by developing and demonstrating equipment designs, controls, and system-integration architectures through experimental integration of PV generation, mCHP, ultra-high-efficiency gas heating, and thermal energy storage.

This represents a system-level technology development program to demonstrate to industry and homebuilders methods and technologies to effectively integrate gas-fired equipment with on-site renewable generation while economically achieving efficiency and GHG reduction goals.

## Technical Concept & Approach

The focus of this project was on building the space-conditioning portion of an integrated natural gas/ renewable test stand with thermal energy storage and mCHP/PV integration. This space-conditioning portion includes integration with environmental chambers for indoor/outdoor conditions, hydronic and forced-air load control, test stands for furnaces and GHPs, and a link to thermal energy storage.

The project team built and tested experimental controls for this portion and tested its capabilities with GHP equipment, a combination system through integration with DHW/mCHP equipment, and a low-capacity furnace. In parallel, researchers built a calibrated simulation tool for modeling space-conditioning equipment as part of a building energy simulation for hourly heating/ cooling loads, including multiple types of GHP and low-capacity heating equipment with or without thermal energy storage integration.

Using building energy simulation software, the project team created several model gas/renewable homes and generated baseline performance for multiple equipment configurations.

## Results

The project team leveraged an opportunity to build GHP testing capacity in support of the Virtual Test Home through adding 1) capabilities to test low-load gas heat pumps, 2) improved calibration of hydronic measurements, and 3) expanded sensible and latent heating control of the climate chamber. This effort was performed in parallel with the laboratory evaluation of a 6 kW (20 kbtu/h) output gas absorption heat pump. This opportunity accelerated some of the changes to the virtual test home while the low-load GHP was on-site during the reporting period.

Testing was successful, with the chamber alterations permitting operation at 7°C, 2°C, -7°C, and -15°C.

Additionally, the project team built capabilities in a separate, cold-climate chamber to evaluate performance of combustion equipment at temperatures as low as -20°F (-29°C), and developing instrumentation, controls, and best practices for testing at these low temperatures.

The expanded build-out is complete. Simulation regarding interactive effects between elements in different installation scenarios is also complete.

## Status

This project is complete. A Final Report was issued in March 2020.

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# Economical High-Efficiency Residential Gas Absorption Heat Pump with Integrated Cooling

***This project focuses on adding cost-effective cooling to a low-cost gas absorption heat pump pre-commercial product that currently provides only heating and domestic hot water. An economical, integrated single unit that provides air conditioning as well as high-efficiency heating can help more end users benefit from this emerging high-efficiency product.***

## Project Description

A gas absorption heat pump (GAHP) can provide low-cost whole-house heating with significant improvements in efficiency over condensing furnaces and boilers. In addition to cost-competitive therm savings of up to 45% over conventional residential gas heating equipment, the GAHP delivers stable, comfortable temperatures without the need for auxiliary heating or backup and is projected to be ultra-low-$NO_x$ compliant with all combustion occurring outdoors.

This project builds on other UTD efforts to bring to market a new heating-only, low-cost GAHP for the residential market.

One issue that might limit its adoption is that it currently doesn't provide cooling. The economics of the heating-only GAHP (sized at nominal 80 kBtu/h output), with the aggressive equipment cost target of $5,000, are generally suitable in cold climates and for large, single-family homes. For example, as a simple estimate, in a space-heating-only application, the GAHP would have a five-year simple payback over a condensing furnace in homes that have an average monthly heating bill of $200 or greater during the heating season. This may be feasible in cold climates, for large homes, or both, with economics of combination systems improving; however, the economics worsen in mixed or cooling-dominated climates, especially in the U.S. southeast. As a result, cost-effective cooling is necessary for this product to succeed broadly and serve many ratepayers.

The all-weather system will offer an Annual Fuel Utilization Efficiency (AFUE) of >140% and a Seasonal Energy Efficiency Ratio (SEER) of >16.0 to end users, exceeding the majority of electric or gas-fired options.

While GAHPs offer high efficiency and low emissions, existing GAHPs commercial products tend to be costly and have seen limited adoption in the Americas. While GAHPs are available with integrated cooling, the approach in this project will advance a new hybrid arrangement, wherein the GAHP would have an electrically-driven compression cycle that uses an ultra-low charge of ammonia vapor, and shares internal heat exchangers with the absorption heat-pump sealed system. This could provide a simple payback of less than three years for a hybrid system. The project team seeks to demonstrate an economical GAHP with integrated cooling for a projected target equipment price of $5,000.

*Heating-only GAHPs in field trial.*

This system would be designed for low-load homes; however, scaling up or down at a later date to fill out the product family is not expected to be problematic.

This project leverages co-funding from the Canadian Gas Association (CGA) and moves from the development/design stage to a laboratory version proof of concept of a packaged alpha prototype.

## Benefits / Market Implications

Of all U.S. single-family homes, 73% have central A/C. Early feedback from contractors and homeowners on the heating-only GAHP is that very few homeowners will permit having two large pieces of HVAC equipment outdoors, which may limit the application of the heating-only GAHP.

The hybrid GAHP with A/C is intended to broaden the energy and emissions savings potential of the GAHP, expanding the benefits of this technology for end users by providing applicability for mixed and cooling-dominated climates.

The advantage offered by operating with a chilled-water loop for A/C, using the single indoor coil, is that this is not a direct expansion system. This significantly reduces the refrigerant charge volume as it is only contained within the hybrid GAHP unit, helpful in preventing fugitive greenhouse-gas emissions and minimizing risks with an ultra-low-charge ammonia system. In addition, many HVAC manufacturers are looking to refrigerants at higher pressures or with moderate flammability, which is challenging for conventional split A/C systems.

## Technical Concept & Approach

This project is similar in scope to a previous effort to commercialize a gas-fired heat pump water heater (GHPWH) developed and supported in conjunction with UTD Project 1.11.H, scaling up the same absorption heat pump technology by an eight-fold factor.

## Results

In 2020, the project team held a kickoff meeting. The scope of the hybrid GAHP device was defined for the purposes of modeling. A modeling plan (assumptions, boundary conditions, etc.) was developed and simulation was executed. In parallel, the team is discussing other future tasks regarding system design and prototype laboratory assessment.

Researchers agreed on the operational parameters of the GAHP hybrid as it pertains to the initial building energy modeling task, using the heating GAHP modeling assumptions developed under prior efforts and absorbing modeled performance curves. In terms of the home modeled, the project team is developing the baseline equipment and home type (vintage, size, location, etc.) as part of the modeling plan.

## Status

The project team has run models of single-family homes for several representative metropolitan areas, covering multiple climate zones and housing types (size, construction, occupancy) and performing annual energy assessments of hybrid GAHPs. Investigators are considering multiple baseline scenarios (all-electric, high/low efficiency, etc.).

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# Gas Heat Pump RTU Cold-Climate Performance Assessment

***This project is demonstrating and analyzing the installed performance of a gas-engine-driven heat pump incorporated in a packaged rooftop unit to determine its cold-climate performance, reductions in peak electric and peak gas demand, and environmental benefits.***

## Project Description

Gas-engine-driven heat pumps (GHPs) are an important gas cooling option for the small-commercial market when considering electric-demand reduction initiatives. Preliminary modeling indicates that GHPs can reduce peak electric demand by 6 kW to 15 kW, compared to conventional rooftop units (RTUs) or electric variable refrigerant flow (VRF) systems, respectively.

GHPs can also reduce peak gas demand. GHPs have high heating efficiency due to the use of engine heat recovery to boost performance during the winter. This increased heating efficiency will reduce peak gas demand, generate energy savings, and reduce full-fuel-cycle greenhouse gas (GHG) emissions when compared to a baseline standard-efficiency packaged RTU. The extent of this peak gas demand reduction and overall efficiency gain will be analyzed in this project.

Compared to electric-driven heat pumps, GHPs have two key advantages in heating operation for cold climates. GHPs use engine heat recovery to: 1) avoid a defrosting cycle and 2) maintain heating capacity and supply temperatures. Electric heat pumps require periodic defrosting at ambient temperatures below 40˚F. Conventional defrosting by reverse cycling has an inherent energy penalty because it removes heat from the indoor air during the defrosting period. GHPs avoid the need for a defrosting cycle by controlling the flow of the recovered waste heat from the engine and maximizing the heat-recovery process.

A second advantage is to avoid supply temperatures which can result in the “cold blow” effect (delivery of air at less than body temperature) that compromises indoor thermal comfort. GHPs use engine heat recovery to supplement heating output in order to maintain both indoor supply temperatures and heating capacity. In cooling and moderate heating mode conditions, engine waste heat can also be directed to an optional supplemental water heater, maximizing system efficiency.

This field demonstration will evaluate the GHP-RTU energy performance, reliability, and economics.

This project is being conducted in partnership with the New York State Energy Research and Development Authority (NYSERDA) and National Fuel Gas Company.

Image credit: Blue Mountain Energy

*Blue Mountain Energy’s packaged rooftop gas-engine-driven heat pump.*

## Benefits / Market Implications

GHPs are expected to provide environmental, economic, and resiliency benefits for commercial buildings and ratepayers.

- Environmental benefits for the customer include life-cycle cost savings due to reduction in time-of-use rates or electric-demand charges.
- The reduction of peak electric demand offered by GHPs provides regional utility benefits and may provide opportunities to retire one or more power-generation plants.
- Environmental benefits include the reduction of source energy and full-full-cycle GHG emissions through high-efficiency operation compared to conventional HVAC equipment.

## Technical Concept & Approach

- **Site Selection and Baseline Monitoring**

  This market includes health clubs, gymnasiums, hospitals, retail buildings, and restaurants.

- **GHP-RTU Installation and Demonstration Plan**

  The project team developed the demonstration plan for the selected site, then specified, installed, and commissioned the instrumentation and data-acquisition system for the GHP-RTU.

- **GHP-RTU Performance Monitoring**

  Researchers will monitor the performance of the GHP-RTU for a full heating and cooling season to determine annual energy use and costs across the full range of possible operating conditions.

- **Data Analysis**

  The project team will analyze measured data to determine heating and cooling delivered, energy consumption, reduction in peak electric demand, GHG emission reductions, and energy cost savings relative to baseline. Researchers will also estimate paybacks, life-cycle cost savings, and cost/benefit ratios based on current costs and projected mature market pricing. A real-time dashboard was added to provide better insight into system performance.

## Results

In 2019, the project team selected a field site in Buffalo, NY, for the GHP-RTU demonstration. The field site is a small gas station/grocery store with extended hours of operation. The GHP-RTU was installed in place of the existing conventional RTU using a rooftop curb adapter. Supplemental heating (a gas-fired duct furnace) was installed to ensure adequate heating capacity during the demonstration.

The demonstration GHP was installed and operational in November 2019. Commissioning of the system and instrumentation was completed in January 2020.

Mild winter conditions in 2020 and significant internal heating loads at the field site (e.g., a bread oven and refrigeration cases) limited the heating runtime of the GHP-RTU.

To reduce cycling, a remote sensor for the thermostat was installed behind the cashier in March 2020 to prevent the controlling thermostat from being impacted by the GHP supply air. In addition, the GHP-RTU controls were revised to extend heating runtime and minimize cycling. Monitoring of the GHP-RTU heating performance will be extended through the 2020/2021 heating season to demonstrate the optimized heating performance of the unit.

The project team analyzed preliminary cooling performance data from May through July 2020. Daily cooling operation ranged from 1.65 to 20.9 hours, averaging 14.3 hours per day. Average part-load operation, based on cooling delivered vs. rated cooling output, ranged from 48% to 73%. Part-load operation had minimal impact on the GHP-RTU cooling efficiency, indicating effective control strategies can meet the cooling load while minimizing cycling losses. During this time period, the daily average cooling efficiency ranged from 0.99 to 1.90 COPg. These promising results demonstrate the high-efficiency cooling performance of the GHP-RTU and the potential for a cost-effective gas cooling rooftop design.

## Status

The project team will continue to monitor the GHP heating and cooling performance through 2021. The GHP-RTU outside air damper will be adjusted to increase the ventilation and space-conditioning loads to more closely match the GHP-RTU heating and cooling capacity.

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# Integrated, Self-Powered, High-Efficiency Burner System

***Researchers are developing a grid-resilient, self-powered, fuel-flexible, high-efficiency Advanced Burner Thermoelectric Generator (ABTEG) that can be installed into many types of residential and commercial building space- and water-heating systems.***

## Project Description

Research over the past two decades to develop self-powered gas appliances for grid independence have not resulted in commercially successful products due to increased capital costs and customized designs preventing drop-in installation.

The objective for this project is to develop and demonstrate a grid-resilient, self-powered, fuel-flexible, high-efficiency Advanced Burner Thermoelectric Generator (ABTEG) as an integrated system that can be installed in many types of residential and commercial building space- and water heating-systems.

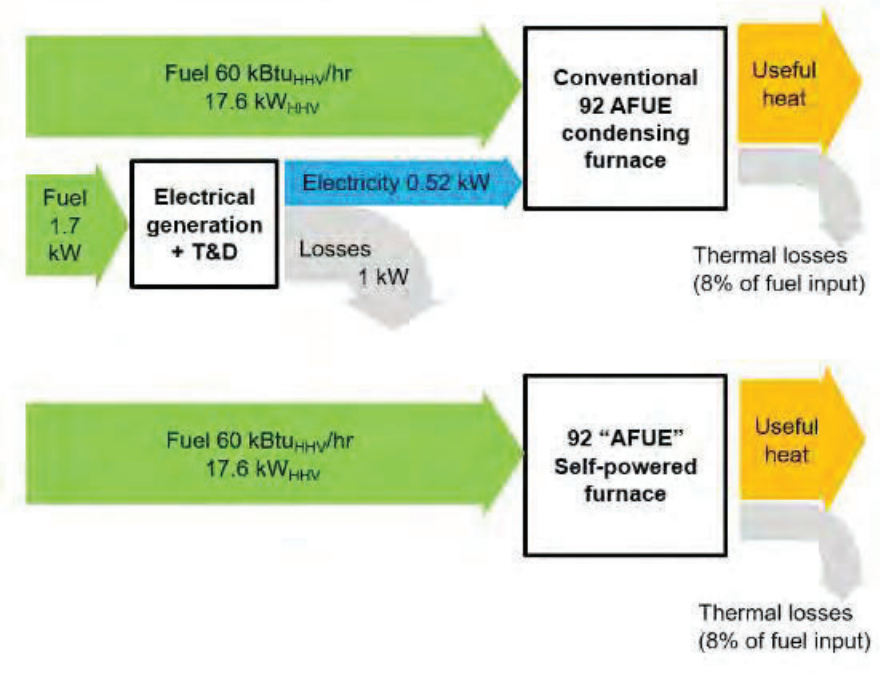
The integrated system consists of two key subsystems: 1) a 3D-printed high-efficiency, ultra-low-emissions, fuel-flexible, modulating burner integrated with 2) a commercially available low-cost, high-efficiency, high-operating-temperature TEG. The integrated design will result in a drop-in retrofitable, fast payback (<2 years) system that is self-powered and grid independent.

The design and integration of a combustion-driven TEG power system that is interconnected and interdependent on thermal characteristics and efficiencies has not been addressed before this project and no commercial designs are available to end users.

This UTD project is co-funding a prime contract from the U.S. Department of Energy (DOE) Buildings Technologies Office.

## Benefits / Market Implications

The market for residential and commercial gas water heaters in the U.S. alone is greater than $3 billion and $0.5 billion respectively. The technology being developed in this project can provide 22% energy savings, leading to significant cost benefits to the ratepayer. Furthermore, the national savings potential can be 94 trillion Btu per year for the self-powered, no-heat pump option, and at 354 trillion Btu per year savings for the self-powered with the heat pump option. In addition, the



*Left: Primary energy savings of 1.18 kW (6%) with a self-powered system with PER=0.92 (bottom) compared to conventional system with PER = 0.86 (top). Right: Representation of integrated 3D-printed burner.*

technology is targeted to provide $NO_x$ emissions reduction of more than 70% compared to current designs.

The technology will ensure safe, reliable, and resilient operation and expand options for distributed generation/ electric demand response or for gas-demand response. The technology can also integrate with renewable energy sources.

For the water-heater market, these benefits translate into a savings of 0.09 quad per year without a heat pump and 0.35 quad per year with a heat pump. As the technology expands to space heaters, boilers, and furnaces, the total savings potential is 0.38 quad per year without a heat pump and 1.39 quads per year with a heat pump. An additional savings of 0.11 quad per year from retrofitting the higher-efficiency burner may be achieved, thus leading to a total of 0.49 quad per year and 1.5 quads per year without and with heat pump, respectively, across the residential and commercial sector. A simple payback of 2.1 years without heat pump and 1.9 years with heat pump is targeted.

The value of the technology is in its grid-independence, self-powered, high-efficiency feature, but one or more of the other features (e.g., ultra-low emissions) may be equally or more attractive to certain market segments.

## Technical Concept & Approach

The ABTEG system is a transformative power-conversion technology to improve the efficiency of gas-driven systems. In this project, researchers will design, develop, and test a first-of-its-kind highest-efficiency drop-in burner/thermoelectric generator integrated system capable of achieving ultra-low emissions while being grid independent.

The following tasks will be performed:

- **Subsystem Specifications and Design**

  Researchers will evaluate, assess, and finalize design and specifications for each subsystem to be integrated. Down selection of the TEG to meet electrical demand, thermal requirements, location, and complexity to adhere to the drop-in design specifications will be addressed. The instrumentation and controls required to measure, modulate, and monitor the TEG output will be finalized. In addition, the water heater to be used for testing will be selected. After the subsystems and the system architecture are finalized, the designs for each of the subsystems will be finalized.

- **Burner Fabrication**

  Investigators will optimize the burner configuration as defined by the trade-off studies to achieve the lowest cost, while meeting emission requirements.

- **Burner Testing**

  The project team will install the burner in a simulated water-heater test rig to evaluate the performance. Flame-stability characteristics, operability, and lean blow-out will be evaluated to map the operating envelope of the new burner in comparison to the past burner.

- **Testing Integrated ABTEG System Architecture**

  After installing the subsystems with the controls, testing will be performed for the ABTEG system at different firing conditions that are representative of typical water-heater operation. The project team will investigate different options for starting the water heater from cold conditions.

## Results

The team performed a detailed analysis to down-select three different materials for the TEG. In addition, three different water heaters were reviewed.

In 2020, researchers performed Computational Fluid Dynamics analysis for the fuel-flexible burner and generated a solid model for 3D printing. The model was sent to project partner Oak Ridge National Laboratory (ORNL) and 3D printed there.

Two different water heaters were installed in the laboratory for power-consumption and thermal-characteristics testing. A test rig was set up for operation with hydrogen with the appropriate interlocks and improved exhaust system.

## Status

Next steps are to test electrical power consumption and thermal characteristics of the water heaters. A 3D burner design is being developed.

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# Comparative Assessment of Heat Pump Water Heaters in Virtual Test Home

**The objective of this project is to compare natural-gas/liquid propane and electric-driven heat pump water heaters on a level basis by characterizing equipment part-load, year-round performance across five climate zones in a Virtual Test Home. Results from this research will support decision making by designers and end users.**

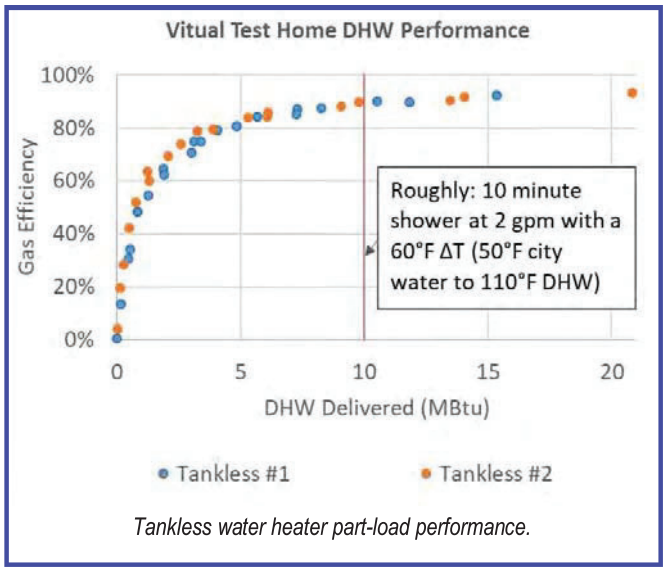
## Project Description

Potential changes in the direct use of natural gas and liquid propane gas (LPG) in modern homes may shape a pivotal shift in building water-heating and HVAC design. However, such a shift may neglect essential aspects of effective building energy designs, including seasonal-equipment efficiencies, associated source-energy and greenhouse-gas (GHG) emissions, cost effectiveness, and energy resilience.

In this project, researchers are investigating the potential real-world implications and limitations of heat pump water-heating technologies by comparing natural gas/LPG water heating and electric heat pump water heating on a level basis by characterizing equipment part-load performance in a Virtual Test Home (VTH).

Goals include:

- Characterizing at least two electric heat pump water heaters (EHPWHs) in the VTH. (Gas water heaters have already been characterized in other UTD projects.)
- Implementing the characterizations in EnergyPlus™ building energy modeling software to quantify relative annual water-heating energy consumptions and GHG emissions in 15 cities across five climate zones, and
- Authoring a peer-reviewed technical paper for public dissemination that informs readers on predicted energy and environmental impacts of electric, gas/LPG, and hybrid water and space heating.




*Tankless water heater part-load performance.*

Researchers use the VTH to determine real-world performance of water-heating and space-heating equipment. Rather than characterize equipment with single rating points, equipment performance is characterized across a range of conditions where the systems normally operate. This UTD project was co-funded by the Propane Education and Research Council (PERC).

## Benefits / Market Implications

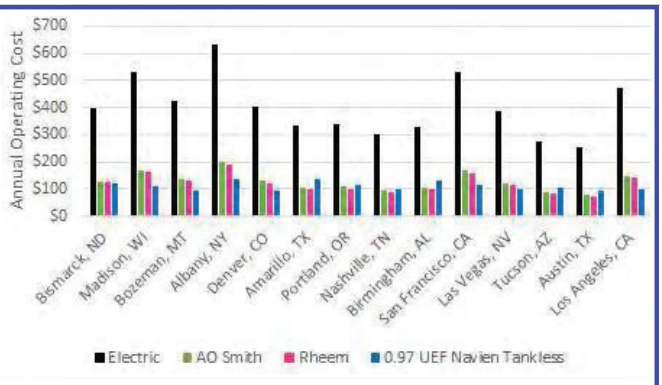
The results are expected to provide a data-based, scientific analysis of real-world, annualized performance of equipment options to support accurate decision making by consumers, the energy industry, and others.

## Technical Concept & Approach

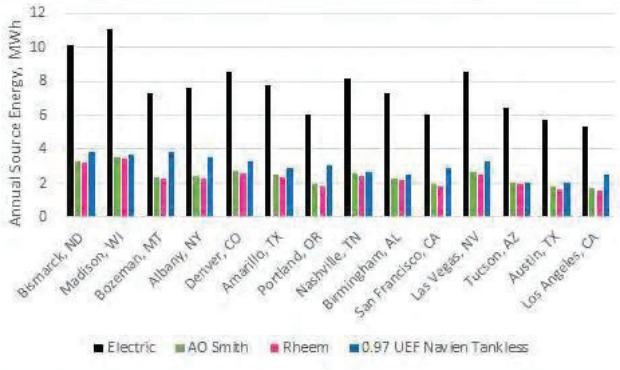
Researchers developed a series of evaluations in the VTH that characterize and predict EHPWH part-load performance. The approach will account for thermal storage since EHPWHs have tanks, unlike on-demand thermal water heaters. The characterizations in EnergyPlus will then be implemented to assess relative energy and the environmental impacts of gas/LPG, electric, and hybrid water-heating technologies.

Investigators procured two best-in-class EHPWHs sized for residential application. Evaluations were planned to be conducted of EHPWH performance in the VTH in order to understand operating nuances of the heat pump and resistive-heating elements of the EHPWHs.

Due to limited access to a laboratory during the COVID-19 pandemic, an alternative approach was used to achieve the goals of this project. Third-party published data from controlled environment evaluation procedures were used to develop performance mapping equations for the two EHPWHs. The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) performed evaluations similar to




*Annual operating cost for various systems.*




*Annual source-energy utilization for various systems.*

the ones scoped in the test plan for this project. Building energy models were used to corroborate the performance mapping equations against test profiles, NREL controlled laboratory evaluations, and two third-party field demonstration data.

The project team will use the VTH performance characterizations from laboratory testing to quantify relative annual water-heating energy consumptions, efficiency, and resulting GHG emissions for representative single-family housing stock. Analyses will be conducted for 15 cities across five climate zones, including: Texas, North Dakota, Alabama, Montana, Illinois, Colorado, Nevada, California, Arizona, Wisconsin, Oregon, and New York.

## Results

Researchers developed laboratory test methods to characterize equipment performance across a full range of operating conditions. In addition, building energy modeling methods are being developed that use those characterizations to quantify annual energy, emissions, and operating costs. These methods are the basis for the VTH.

Industry experts recognize that while single rating points for equipment serve manufacturers' basic rating purposes, they do little to help consumers or the energy industry quantify annual energy use in various buildings in various climates with various equipment. The VTH does just that, and researchers use it to characterize equipment performance and quantify annual energy, emissions, and operating costs for a myriad of residential gas and electric appliances. VTH research is particularly important as it provides a way to understand real-world performance of gas/LPG, electric, and hybrid space-heating and water-heating equipment.

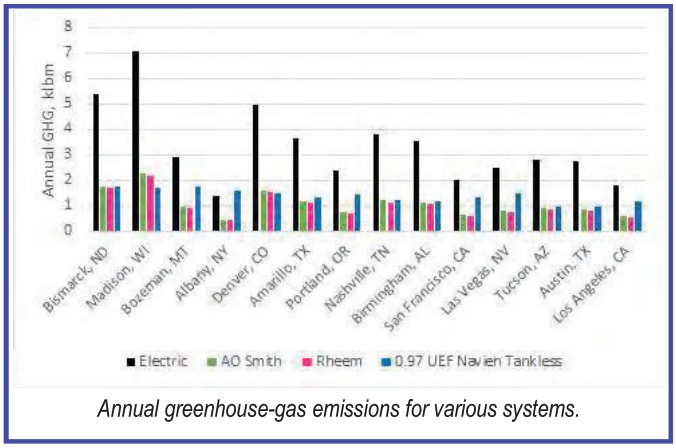
This project was initiated in July 2019. The project team developed a test plan to expose EHPWHs to a diverse set of simulated heat-pump entering air temperatures and humidity and daily domestic hot water loads corresponding to typical installations in different regions across the U.S. Traditional and ducted installation operation were also accounted for the performance characterization.

Two best-in-class EHPWH systems were selected for the evaluation. The performance characterization for the two EHPWHs were developed and validated with published data, NREL controlled environment 24-hour profiles, and third-party field-demonstration data, including both traditional and ducted installation.

## Status

A Final Report is being prepared.

Researchers plan to present a technical paper at the ASHRAE 2021 Annual Conference summarizing the research results and the energy and environmental impacts of gas/LPG, hybrid systems, and all-electric approaches to water heating and combination space/water heating.




*Annual greenhouse-gas emissions for various systems.*

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# Sequestering Non-Condensable Gases for Enhanced Gas Absorption Heat Pump Reliability

***Researchers are developing non-condensable gas isolation modules and providing research and development support to employ novel, low-cost, aluminum heat exchangers to increase system reliability, enhance system safety, and reduce the cost of any absorption-type heat pump.***

## Project Description

A major issue concerning the cost effectiveness of absorption heat pumps (which represent the most technologically mature option for thermally-driven heating and cooling systems) is the need for corrosion protection. The problem is inherent to the technology, where the ammonia-water or a strong salt absorbent/refrigerant pair often create high-temperature, high-pH environments that 1) have a tendency to form hydrogen (a non-condensable gas that degrades system efficiency) and 2) can attack steel surfaces, promoting stress corrosion cracking and failure.

With introduction of low-cost technology on the horizon in multiple segments, it is imperative that the project team seek to minimize the impact of non-condensable gases on long-duration performance and reliability. The goal of this project is to design and develop non-condensable gas isolation (NCGI) modules and provide research and development support to employ novel, low-cost aluminum heat exchangers to increase system reliability and safe operation, and reduce the cost of any absorption-type heat pump.

The project team plans on demonstrating the performance of the technology in a prototype gas absorption heat pump (GAHP).

## Benefits / Market Implications

The natural gas industry has identified GHPs as strategically important for society to achieve short-term (e.g., energy efficiency) and long-term (e.g., decarbonization) goals.

This project seeks to ensure optimum long-term performance, economy, and reliability of these new product categories for end users.

Current gas heat pump (GHP) heat exchangers use carbon steel tube/aluminum fin evaporator coils due to limitations in the manufacturing process of lower-cost components and the fact that copper coils are not suitable given operating issues with ammonia-water solutions. As such, the evaporator coils of GHP systems are the heaviest and most expensive part of the system. By shifting to an aluminum evaporator, provided that corrosion issues are within control, the GHP can significantly reduce the cost and weight. The evaporator coil in a standard 80 kBtu/h GHP weighs about 150 pounds; however, an all-aluminum coil could weigh just 25 pounds and might save perhaps $375. Also, an additional estimated benefit is the air flow can also lowered by 20%-30% for the same effectiveness, reducing power consumption and noise.

The primary target market impacted by this technology will be absorption-type heat pumps at residential or light commercial scale (space conditioning or water heating) because, for example, they may not receive annual service maintenance. Another market that would benefit is absorption-type heat pumps at a larger commercial scale.

## Technical Concept & Approach

This project focuses on the development and demonstration of solutions to address non-combustible gases (NCG) through isolation, storage, or both. Isolation will be performed by a selective membrane.

Much of the development of hydrogen membranes has been for hydrogen production from coal. Hydrogen permeability through palladium is fairly high at 700°C,

*GHP corrosion test rig.*

*Coupon sample vessel.*

but decreases sharply with decreasing temperature. Several other metals, including vanadium, niobium, and tantalum have much higher permeabilities at these lower temperatures. The metals themselves embrittle at room temperature in the presence of 100 psig hydrogen, but several alloys of these metals are non-embrittling, making them good candidates for hydrogen purification membranes. For a similar size membrane, the flux can be 10 times higher than with palladium silver, at temperatures of 300 °C and below.

To achieve cost/weight reductions, the project team will perform corrosion testing of alloy samples in an ammonia-water solution at standard and elevated pressures and temperatures to investigate the potential of aluminum evaporators and, if possible, aluminum absorbers as well.

Specific activities involve:

- A literature survey regarding NCG generation in absorption heat pumps (AHP), including a review of manufacturer and research data from prior AHP evaluations, storage/venting of NCGs in other applications, and challenges with hydrogren transport and storage in other applications.
- An outline the design requirements of the NCGI module, including operational requirements (e.g., ambient temperatures), design requirements (e.g., maximum allowable size within enclosure), safety requirements (e.g., protection in the event of damage or fire), and expectations regarding NCGI module cost.
- Development of a preliminary NCGI module specification, sized for existing AHP sizing categories, including 3kW, 6kW, 12kW, 23kW, and 41kW output units. Additionally, project representatives will outline options for the NGCI module concerning gaseous versus adsorbed storage and venting versus non-venting solutions.
- Development and evaluation of options for hydrogen-selective membranes using a membrane system developed for nuclear-fuel applications. The project team will collect hydrogen permeation data in the membrane unit under a controlled laboratory environment for the membranes selected. Initial tests will be performed using hydrogen and helium gases to obtain hydrogen permeability data.

Technicians will modify a corrosion test rig as required per test plan. Sample coupons will be tested and analyzed.

The team will provide technical support for finned-tube evaporator modeling, air-side computational fluid dynamic simulation, and experimental evaluation.

This project provides co-funding to a prime contract funded by the U.S. Department of Energy with the general goal of reducing the cost and improving the reliability of residential and light commercial-sized GHPs.

## Results

An initial kickoff meeting was held with the participating manufacturer and academic partner to outline project goals and compare experimental capabilities. Subsequently, a test matrix was developed for the initial corrosion test program. With the literature review complete, the project team agreed upon an experimental test design and execution plan, with technicians currently modifying an existing corrosion test stand to accommodate the unique requirements of this project.

## Status

The project team is commissioning a modified test plan to initiate corrosion testing in the second half of 2020.

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# Yanmar Three-Pipe GHP Cold Climate Case Study

**In this effort, a project team will evaluate the performance and economics of the Yanmar three-pipe natural gas engine-driven heat pump (GHP) in a cold climate. Researchers are targeting a 50% reduction in peak electric demand and a 10% reduction in source-energy consumption compared to baseline HVAC systems.**

## Project Description

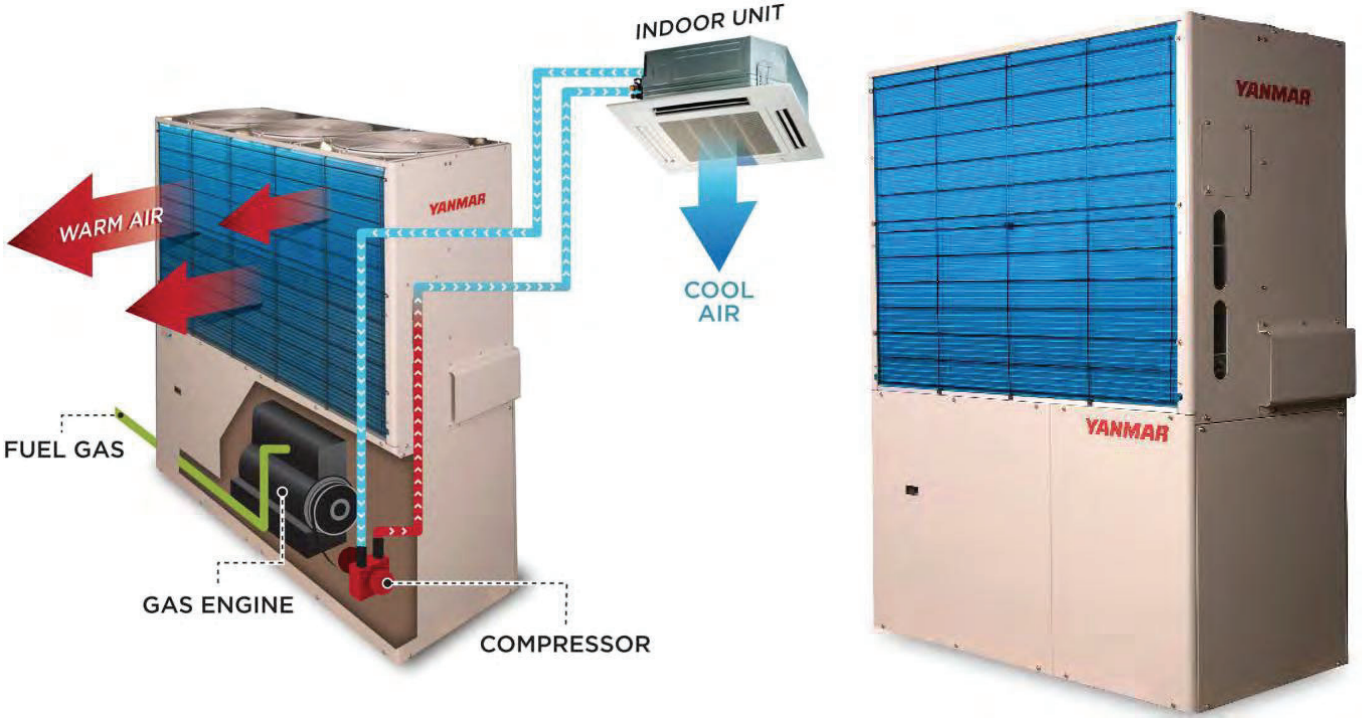
Gas heat pumps (GHPs) provide space heating and cooling using an advanced natural gas engine in place of an electric motor. GHP engines have a demonstrated long life and extended maintenance intervals of about 10,000 hours.

GHP heating output is supplemented by heat recovered from the engine cooling jacket and exhaust, similar to a combined heat-and-power system, increasing overall system efficiency. In contrast, electric heat pumps typically require backup heating to supplement the heat pump output at low outdoor temperatures.

GHPs combine high-efficiency heating and cooling (1.0-1.4 coefficient of performance) to significantly reduce peak electric demand and electricity use with potential savings in operating and lifecycle costs, as compared to electric variable refrigerant flow (VRF) heat pumps or conventional HVAC equipment.

Multiple field demonstrations have reported significant reductions in electric usage, demand charges, and water use, generating cost savings that more than offset the initial cost premium. According to one manufacturer, GHPs reduced operating costs by up to 30% and electricity usage by up to 80% compared to electric heat pumps. Compared to water-cooled chillers, air-cooled GHPs reduce water use by up to 17,000 gallons per year for each 15-ton unit. Based on the results from a current warm-climate demonstration (UTD 1.17.G), the Yanmar three-pipe GHP reduced peak electric demand by 8 kW (98%) in heating and 10 kW (96%) in cooling as compared to an electric three-pipe VRF. The GHP reduced peak electric demand by 11 kW (96%) in cooling as compared to an electric multi-zone rooftop unit.

GHPs have a significant share of the Japanese and European space-conditioning markets, and only recently became available in the U.S. Yanmar introduced its GHP product line to the U.S. in 2016. Yanmar offers a range of VRF systems, from 8 to 14 tons. These products are two-pipe systems that can operate




GHP product images courtesy of Yanmar.

operate either in cooling or heating mode. Yanmar's 14-ton GHP has a three-pipe heat-recovery VRF system that provides simultaneous heating and cooling.

With Yanmar's headquarters in Adairsville, GA, a key initial target market is in the Southeast U.S., near existing service networks for its marine engines in Georgia and Florida. Yanmar's case study of an Adairsville installation reported an estimated savings in operating costs of $17,000 per year.

As an emerging technology, GHPs face technical and market barriers. Compared to electric motors, GHPs require additional engine maintenance for reliable performance and minimized wear. So additional maintenance and establishing service networks are other potential barriers for this technology.

Another potential barrier is engine emissions. While natural gas is a very clean-burning fuel for engines, the primary environmental concern is $NO_x$ emissions.

An additional current barrier for GHPs include high installed costs, which potentially can be offset by savings in operating costs. As such, early market targets include public sector customers, which are often more willing to accept higher upfront costs based on lifecycle cost savings.

The primary target markets for the technology will be:

- Multi-zoned commercial buildings, such as office buildings, retail, schools, hotels, health clubs, nursing homes, and mid/high-rise multifamily residences
- Facilities that can benefit from lifecycle savings, such as commercial offices, government facilities, schools, and owner-occupied buildings, and
- Electric-grid-constrained markets or regions with relatively high electricity prices and/or high demand charges.

## Benefits / Market Implications

This demonstration will help end users assess the value of gas engine driven heat pumps while expanding customer choices and quantifying the benefits of direct use of natural gas in buildings.

The project team is targeting a 50% reduction in peak electric demand and a 10% reduction in source-energy consumption (with lower GHG emissions) compared to baseline HVAC systems. Researchers are also targeting 20% energy-cost savings through reduced demand charges and higher source-energy efficiency compared to electric heat pumps.

## Technical Concept & Approach

The project team identified an existing Yanmar three-pipe GHP installation in Delaware as a potential demonstration site. The GHP system will be instrumented to monitor energy use and performance.

The demonstration site will be monitored for a minimum of one year. Performance data will be uploaded via a cell phone and analyzed to determine monthly energy use. Using measured and baseline data, researchers will determine net energy savings and economics based on natural gas consumption, electricity use, and electric demand. A Final Report will describe qualitative benefits of the technology along with recommendations.

Deliverables will include a two-page case study highlighting key results of the field demonstration, including performance and cost benefits.

Key performance objectives are to: 1) achieve efficient heating and cooling performance, 2) demonstrate efficient part-load performance, and 3) demonstrate capacity and efficiency under cold ambient conditions.

## Results

The host site submitted the GHP commissioning report, Test and Balance report, and runtime data on all eight GHPs installed on site. Based on the submitted drawings, specifications, and the runtime data, the project team selected the Yanmar GHP-3 to be monitored for the demonstration. The GHP-3 was also selected for the demonstration based on the indoor fan coil sizes and ease of monitoring. The unit has the second highest runtime among the GHPs at 5,768 hours and has a total of 10 indoor coils. Also, all the indoor units are ducted, which will allow for more accurate measurement of return and supply air.

## Status

A demonstration plan was completed for GHP-3 at the site in Delaware. Necessary instrumentation and data-acquisition equipment are being ordered, but installation and other project next steps may be impacted by COVID-19.

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# Comparative Assessment of Space-Heating Systems in Virtual Test Home

***The objective of this project is to compare natural gas/liquid propane and electric-driven space-heating systems on a level basis by characterizing equipment part-load performance across five climate zones in a Virtual Test Home to support decision making by designers and end users.***

## Project Description

Researchers developed laboratory test methods to characterize equipment performance across a full range of operating conditions and building energy modeling methods that use those characterizations to quantify annual energy, emissions, and operating costs. These methods are the basis for the Virtual Test Home (VTH).

Industry experts recognize that while single rating points for equipment serve manufacturers' basic rating purposes, they do little to help consumers or the energy industry quantify annual energy use in various buildings in various climates with various equipment. The VTH does just that, and researchers use it to characterize equipment performance and quantify annual energy, emissions, and operating costs for a myriad of residential gas and electric appliances.

This project focuses on a comparison of natural gas/liquid propane gas (LPG) space heating and electric heat pump space heating on a level basis by characterizing equipment part-load performance in the VTH, and was co-funded by the Propane Education and Research Council (PERC).

Goals include:

- Characterizing at least two air-source cold-climate electric heat pumps (ccASHPs) in the VTH, and leveraging the characterization of gas space heating, including furnaces and combination units completed in other UTD projects.
- Implementing the characterizations in EnergyPlus™ building energy modeling to quantify relative annual space-heating energy consumptions and greenhouse gas (GHG) emissions in 15 states across five climate zones.
- Authoring a peer-reviewed technical paper for public dissemination that informs readers on predicted energy and environmental impacts of electric, gas/LPG, and hybrid water and space heating.

*The electric heat pump and air handler laboratory installation.*

## Benefits / Market Implications

The results are expected to provide a data-based, scientific analysis of real-world, annualized performance of equipment options to support accurate decision making by consumers, the energy industry, and others.

Predictions based on previous gas-heating systems and preliminary baseline electric heat pump (EHP) evaluations indicate all-electric water heating will result in lower annual source-energy efficiencies, higher GHG emissions, and higher operating costs to consumers. Predictions based on regional electricity grid emissions data indicated baseline EHPs will produce more GHG emissions across a heating season than best-in-class gas equipment in nearly all of the 15 cities analyzed.

ASHRAE SPC124 Committee voted to explore adopting the VTH method of testing to evaluate combination space- and water-heating performance on combination systems.

## Technical Concept & Approach

Researchers use the VTH to determine real-world performance space-heating equipment. Rather than characterize equipment with single rating points (e.g., HSPF, SEER, and AFUE), researchers can characterize equipment performance across a range of conditions where the systems normally operate.

In this project, researchers developed an automated simulated-use approach in the VTH that characterizes and predicts ccASHP part-load performance. The approach accounts for outdoor and indoor ambient conditions, including temperature and relative humidity, as well as cycling and other part-load scenarios. The project team will implement the characterizations in EnergyPlus to assess relative energy and environmental impacts of gas/LPG, electric, and hybrid space-heating technologies.

The project team procured best-in-class ccASHPs, including central and mini-split-systems with variable refrigerant flow capabilities. Technicians conducted evaluations of two ccASHPs and one baseline EHP performance in the VTH in order to understand operating nuances of heat-pump systems, including defrost cycles, standby power consumption, and capacity range. A test plan was developed based on what was learned from the initial evaluations.

The project team uses the VTH performance characterizations from laboratory testing to quantifying relative annual space-heating energy consumptions, efficiency, and resulting GHG emissions for representative single-family housing stock. Analyses are being conducted for 15 cities across five climate zones, including: Texas, North Dakota, Alabama, Montana, Illinois, Colorado, Nevada, California, Arizona, Wisconsin, Oregon, and New York.

## Results

In 2019, researchers developed a test plan for characterizing the performance of EHP systems using the VTH. Two ccASHPs and one baseline EHP system were selected for evaluation. The goal was to compare complex features of two ccASHPs relative to a baseline EHP system.

Building of the testing infrastructure was initiated in late 2019. The data-acquisition system was designed for monitoring the daily performance of the three systems during the 2020 winter and spring weather loads. This testing infrastructure includes three six-ton ductwork units for space heating/cooling simulations and power distribution for outdoor equipment installation. The ductworks have airflow, temperature, and relative humidity measurement, and air pre-conditioning capabilities. The power panels were instrumented to measure electrical consumption and power rates for the electric heat pump system components. Additionally, data-acquisition systems are installed to monitor and collect data from the electric heat pump systems.

Investigators collected performance data for two cold-climate and baseline heat-pump systems operating in the VTH. The data was collected and post-processed in order to develop performance mapping equations for the three electric heat pump systems. Building energy models were made to evaluate the performance equations. Modeling results were corroborated with third-party field demonstration data. Energy and greenhouse emissions levels were computed and compared to an ultra-efficient gas-fired system.

A peer-reviewed technical paper was presented by the project team at the ASHRAE 2020 Winter Conference to provide information to end users about electric heat pump performance characterization in multiple U.S. climate zones.

## Status

A Final Report is being prepared.

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UTD Utilization Technology Development

# Investigation of Venting Requirements for Ultra-Low-$NO_x$ Residential Storage Water Heaters

**Researchers demonstrated adequate performance of the in-situ venting capacity to accommodate market-available ultra-low-$NO_x$ storage water heaters. The analysis was in response to proposed rules governing allowable $NO_x$ emission levels, and supports broader adoption of these low-emission units.**

## Project Description

In this project, investigators demonstrated the reduced-emissions performance of market-available ultra-low-$NO_x$ (ULN) burner technologies designed for the residential storage water-heater market in response to proposed rules governing allowable $NO_x$ emission levels. The goal was to help to continue the widespread adoption of this next-generation technology to wider regions outside of existing rule-governing regions as an ULN alternative to existing technologies.

The project provided feedback to rule-making bodies on the necessary venting required for stable combustion of next-generation ULN burners over existing standards used for the installation of traditional "pancake"-style burners. Existing manufacturer-prescribed installation requirements for venting for the traditional burners are specific to the type of burner and expected flue-gas temperatures, as to provide adequate buoyancy of the flue gases for proper outdoor natural draft ventilation. There are potential concerns that the existing as-installed venting will not be sized correctly for the use of next-generation ULN burner technologies. This project demonstrated that existing storage water heaters can be replaced by ULN units via in-situ installation while maintaining use of the installed venting.

This research built on previous efforts in this area, such as the validation of the next-generational ULN capabilities of a variety of burner types. Additional R&D involved a comparison of traditional burners to ULN variants in the context of residential gas-fired furnaces. Research included analysis of ULN burners as installed in commercially-available furnaces via retrofit to determine the effects of these new burners on whole-system performance and safety standards.

## Benefits / Market Implications

This work supports the continued market adoption of ULN residential storage water heaters typically rated ≤ 75MBH. In particular, this analysis was relevant to new units under jurisdiction of the State of Utah's Administrative Code §-307.230 *$NO_x$ Emission Limits for Natural Gas-Fired Water Heaters.*

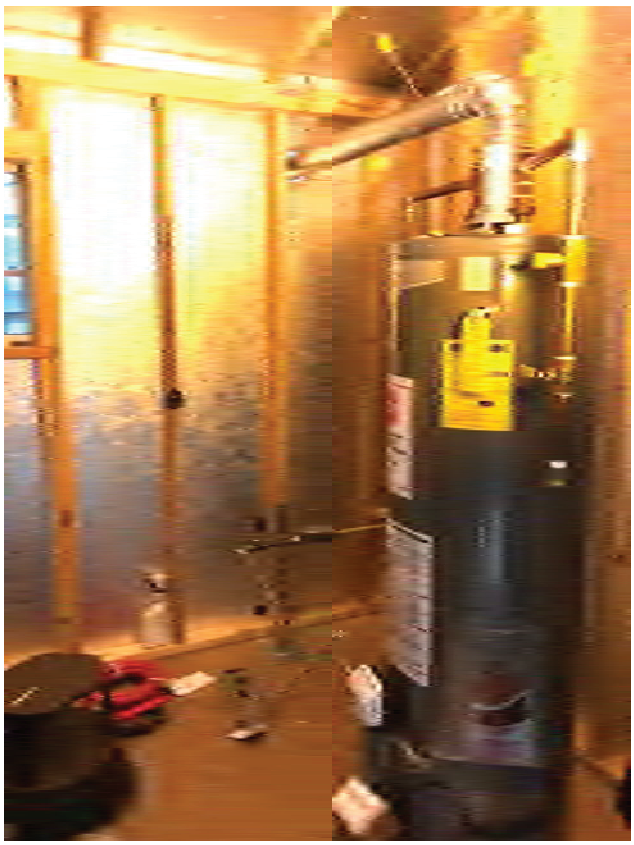
## Technical Concept & Approach

This project focused on testing the venting requirements of market-available ULN residential storage water heaters as compared to existing storage water heaters typically installed.

Researchers tested the efficacy of a ULN option using existing venting typically installed within the region.

Researchers performed a search of typical existing residential storage water heaters as installed within the affected region, as well as existing venting standards as prescribed by both manufacturers and local codes.

Contacts at manufacturing partners, involvement with local coding jurisdictions, and contacts of region-specific installers were used as primary references to ensure appropriate models and venting requirements are used for comparisons.



*In-situ test home laboratory.*

The units were operated under a variety of conditions to achieve a holistic view of typical operation and a high degree of confidence in expected venting operation.

## Results

Researchers conducted a study to determine the effects of introducing a ULN residential water heater unit for in-situ testing using the venting requirements of the 40ng/J traditional units. Investigators also studied the effects of new technologies on ensuring that stack emissions can be properly vented without modification to supporting venting systems while maintaining sub 10ng/J or 15ppm $NO_x$ formation.

The study encompassed four commercially-available non-condensing water heater units. Overall research was comprised of the installation of a non-ULN unit for a given venting category within a simulated residential home, with installation in accordance to manufacturer specifications while adhering to regulations published by the State of Utah. ULN units were then installed in-situ with the same venting setup as installed for non-ULN units, with the goal of the study to measure operational changes using a ULN unit within the installation of a non-ULN setup.

The study concluded that while there is a limited shift in exhaust conditions in terms of temperature and stack constituents, there are no detrimental effects to the system and surrounding residential atmosphere to replacing the previous generation storage water heaters with the next-generation ULN units through demonstration of successful testing of a number of commercially available units. Additionally, the ULN units maintained the requirement of sub 10ng/J or 15ppm $NO_x$ formation across all testing.

Utilizing a test home constructed through appropriate standard-practice techniques in residential settings (such as insulation, wall dimensioning, and ceiling construction), the units were installed in a similar manner to a typical residential setting. The test home is a small house built to standard construction codes, as opposed to a standard laboratory bay. Exhaust construction followed both manufacturer prescribed orientations and lengths which coincided with code outlined in the Utah Residential Code. The installations outlined for non-ULN exhaust systems were also used for the ULN units in order to replicate a retrofit option.

Due to the nature of the project and its analysis of venting between traditional 40ng/J NOx water heaters as compared to the 10ng/J NOx ULN units, a direct comparison of the two categories was reported with the potential to infer comparison between the two categories as needed. Each of the test points were reported on a case- by-case basis in terms of testing protocols in the context of each of the venting categories. Heating values of natural gas supplied were taken at the onset and outset of the testing of the four units, with an average value of 1,038 Btu/$ft^3$ used for calculations.

Overall, between the test units of the two venting categories, there are deviations in how the units operate both in overall temperature profiles and emissions. A review of the data indicates that there are no immediate concerns of installing an ultra-low-$NO_x$ storage water heater unit with venting requirements prescribed for a non-ULN unit.

The similarities in measured stack pressure indicate that the stack effect of the ULN units installed within the context of a non-ULN venting structure remains sufficient to overcome any potential for insufficient venting of post-combustion products. This is in-line with a similar measured stack temperature profile and buoyed through calculations using the available stack pressure using the reduced temperature output of the ULN setup as a reference. A review of the results presents one significant unresolved area of interest for installation within the state of Utah: operation under decreased atmospheric pressure due to elevation. The work presented did not have the opportunity to simulate this elevation; therefore, results presented are under conditions of ambient pressure of the laboratory site located approximately 642 feet above sea level. While in practice this may not have an effect on the overall results, it may be relevant for future consideration and further work. However, there is confidence in conveying the success of the results due to relative similarities between the ULN and non-ULN units at the lower tested elevations when compared to the fact that currently, and historically, non-ULN units have shown safe operation within the higher elevation of Utah.

## Status

This project is complete. A Final Report will be issued in September 2020.

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# Test and Demonstrate M-Trigen Micro-CHP Systems

***Researchers are evaluating new M-Trigen micro-CHP systems to confirm performance, develop information to help building owners and stakeholders identify the most impactful initial applications, and support the continued technical development of these innovative, high-efficiency products.***

## Project Description

Micro-CHP systems (mCHP – combined heat and power) still represent a niche product in the U.S., partially due to historically high initial costs, poor matching of thermal and electrical loads at some sites, and the complexity of distribution and installation. For many mCHP applications, producing only hot water and electricity is not enough to make these products viable in the marketplace. However, if the mCHP system can also produce cooling, it provides opportunity in more applications and for longer runtimes, thus improving economics. While there are dozens of mCHP systems available, only two have integrated cooling. One of these is a technology from M-Trigen, Inc.

M-Trigen is developing two micro-combined cooling, heating, and power (mCCHP) systems under the PowerAire™ product line that produce about 6 kW and 10 kW of power. The smaller unit can produce about 60 MBH of heat and five tons of cooling. The larger unit can produce more than 100 MBH of heat and 10 tons of cooling. The M-Trigen system is the only system in the North American market that can generate power, space heating, air conditioning, and hot water; but it is the cooling attribute that makes the M-Trigen system stand out for greater mCHP potential in North America as well as abroad.

*M-Trigen PowerAire™ mCHP system.*

In Phase 1 of this project, researchers tested a new M-Trigen PowerAire mCCHP system to confirm performance and develop information to support market entry. In Phase 2, researchers are evaluating the M-Trigen PowerFurnace™, a CHP-only (no cooling) system designed around the same platform. M-Trigen has set their go-to-market price for the PowerFurnace at an extremely competitive target. However, as with the PowerAire, its emission levels are higher than competing technologies.

The project team partnered with M-Trigen to:

- Develop an emissions-control solution for the M-Trigen platform and evaluate the solution in the laboratory
- Evaluate the performance of the PowerFurnace in a laboratory , and
- Develop solutions/improvements to the PowerFurnace based on laboratory results.

The M-Trigen PowerFurnace 10 and 20 are packaged 10kW and 20kW systems, respectively, that also provide uninterruptible power, space heating, and hot water. The product is powered by the same engine as the PowerAire, but has significant design characteristics that make it less expensive than the PowerAire.

Researchers evaluated the PowerAire in a laboratory and made significant contributions to its development. The project team will do the same with the PowerFurnace through similar laboratory evaluations and subsequent development in collaboration with M-Trigen.

This project is being co-funded by NYSERDA (the New York State Energy Research and Development Authority), New Jersey Natural Gas, the Propane Education and Research & Council, and M-Trigen.

## Benefits / Market Implications

Potential benefits to end users and the environment are significant. In 2013, a mCHP manufacturer commissioned a study to determine the current and potential market for mCHP. It determined that the total number of mCHP units installed in North America at the time was no more than 200, and these were typically smaller units (<5 kWe) in high-end homes and multifamily apartments. The report also stated more than 370,000 light-commercial buildings could benefit from use of an mCHP system with a potential 1% compound annual growth rate. This translated into a potential annual volume of 5,300 units for new and replacement markets 10 years after introduction, at a total market value of $164 million. If retrofit opportunities are included, these numbers increase significantly.

*"The M-Trigen is one of the most potentially transformational products for the gas industry in decades. It's a single product that provides highly-efficient heating, cooling, and electric power for the mass market. It's energy savings for our customers, business growth, peak-demand management for gas and electricity, and reduced greenhouse-gas emissions in one incredible package."*

*- Christopher A. Cavanagh*
*Principal Program Manager*
*Innovation and Development - Complex Demonstration Projects*
*National Grid*

## Technical Concept & Approach

The M-Trigen PowerAire and PowerFurnace can serve the dual function of stand-alone power (black-start capable) and grid parallel operation. Heat is scavenged from the internal combustion engine and sent to an external heat exchanger connected to a buffer tank for hot water storage. Stored hot water can then be used for domestic hot water, or space heating via an air-handler unit with a hydronic coil. The PowerAire has a refrigerant compressor used in a vapor-expansion cycle for space cooling. Refrigerant can then be used together with a standard outdoor condenser, expansion valve, and an air handler A-coil for cooling. A generator coupled to the engine produces electricity, which is used on site and for battery charging.

Laboratory testing in Phase 1 verified PowerAire performance targets, and subsequent field testing is under way with NYSERDA to further confirm performance of a fully-integrated system.

In Phase 2, researchers will procure a PowerFurnace system to be installed and laboratory-evaluated. Testing will focus on confirming power, space heating and cooling, and hot-water output capacities; determining efficiencies and emissions levels; and assessing general functionality, including on- and off-grid operation.

## Results

Supplemented by grid power, the M-Trigen PowerAire unit was able to provide 6 kW of gross power (over and above its internal power for HVAC). It was limited to 5 kW of net power output when islanded in heating mode at 40°F ambient, and 3.5 kW of net power output when islanded in cooling mode at 95°F. Its maximum cooling capacity at 95°F was about five tons, and maximum space heating capacity was about 52 MBH at 40°F ambient. During heat pump operation, the PowerAire 65 produced over 60 MBH of hot water at 40°F ambient, and up to 75 MBH at 95°F ambient with onboard radiator operation. Total system efficiencies ranged from 85% to nearly 100%.

M-Trigen entered the mCHP market with its PowerAire system – a packaged combined heating, cooling, and power. In Phase 1 of this project, researchers evaluated and helped develop the PowerAire system in partnership with M-Trigen.

The PowerFurnace is a sister product of the PowerAire 10 series. The PowerFurnace does not produce space conditioning, and thus has significantly lower cost. In Phase 2 of this project, researchers are evaluating the PowerFurnace and supporting its further development.

The project team completed commissioning of an M-Trigen PowerAire 65 in Brooklyn, NY, in 2019. Preliminary data were collected with about 45 hours of run time. Overall efficiency of the mCHP system across that period was about 66%. Average output was about 3.6 kW.

## Status

Due to the COVID-19 pandemic, researchers developed an alternative plan with M-Trigen to evaluate the PowerFurnace system remotely in the manufacturer's facilities.

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# iGEN Self-Powered Furnace

***The objective of this project was to support the development of the iGEN self-powered furnace through laboratory breadboard testing and continued technical refinement. The iGEN unit could provide users with a self-powered hydronic forced-air space-heating system at a reported 95% total efficiency.***

## Project Description

In recent years, the North American energy infrastructure has been exposed to frequent and extreme weather events leading to extended power outages. As such, the need for energy resiliency has become an increasingly important issue for many end users.

As tested, the prototype iGEN system was a drop-in furnace with 45 to 80 MBH heating capacity that generates one kilowatt (1 kW) of power to: charge an on-board battery pack; power its blower, compressor, and exhaust fan; and provide nominal surplus power to an on-board power strip that can be used to power minor loads. Essentially, the iGEN could provide users with a self-powered residential space-heating system at a reported 95% total efficiency that is fed by the highly-reliable natural gas distribution system.

The iGEN product is in a pre-commercialization state with prototype units under way in field trials in Canada. The company has a patent for a novel method of generating heat and power in a vapor-expansion cycle as part of an air-handler unit (furnace). It uses a vapor-expansion cycle which includes a typical compressor, condenser, and evaporator. However, the iGEN unit employs a custom expander instead of a typical thermal expansion valve. The expander recovers energy from the refrigerant expansion process and converts it to 1kW of power.

During a power outage, the iGEN system runs when there are calls for heating and also to charge the batteries. When the furnace is not running during a power outage, the batteries would provide power until they are uncharged (estimated 2 to 10 hours depending on charge at outage and external loads).

The objective of this project was to support the development of the iGEN system by conducting laboratory testing of prototypes and help the developer advance this new technology for end users.

## Benefits / Market Implications

As with other heating technologies, the iGEN self-powered space-heating system is certainly more attractive in heating-dominant climates than in cooling. iGEN reports an incremental installed cost of about $1,500 compared to a traditional condensing furnace, which would serve similar markets. In a cold climate, the furnace typically runs for about one-third of the time during heating months; the furnace on-time might be about 1,500 hours per year. At 1 kW of power, electricity savings would be 1,500 kWhrs; and at 12 cents per kWhr, electricity cost savings would be about $180 per year.

While there are electricity cost savings associated with the iGEN, there is also quantitative and qualitative value from improved home energy resiliency. Consumer demand for emergency generators has grown substantially during the past decade – at costs on the order of $400/kW to $600/kW. Netting out $400-$600/kW as a reliability premium drives the incremental cost down, and brings simple paybacks for this self-powered furnace technology close to about five years for users in many cold climates. In addition, further optimization of the iGEN unit may reduce the incremental cost.

*As was previously done with traditional furnaces, the iGEN-i2 was evaluated in a laboratory Virtual Test Home to determine its efficiency.*

## Technical Concept & Approach

Technicians instrumented the internal components of prototype iGEN units and conducted bench-scale testing. The primary goal was to gather initial data for the air, refrigerant, water, and power cycles in order to evaluate performance and provide recommendations for further development. A second prototype was then provided.

## Results

The project team tested and supported the development of two generations of iGEN units.

In 2018, iGEN announced it acquired all assets related to the micro-combined-heat-and-power mCHP business of UK-based Flowgroup. Following that acquisition, iGEN provided the project team with an initial bench-sale prototype iGEN unit which also included a boiler. The bench-scale unit was tested by the project team in support of demonstrating proof of concept.

*"Working with UTD has been valuable to iGEN, as it has supported the testing and validation of our i2, and helped us share the results of this important work within the energy industry. The UTD team is ideally structured to support iGEN as we continue growing our early-adopter sales and innovating our products. We look forward to continued collaboration with the UTD team."*

*- Michael Chatzigrigoriou, CEO*
*iGen Technologies Inc.*

A second provide unit was provided and was readied for simulated use testing in a Virtual Test Home (VTH). For the second prototype, project team researchers coupled the iGEN unit with an hydronic air handler to provide hydronic forced-air operation. The air-handler heating capacity was rated at about 35-45 MBH with supply water at about 120°F. The system produced about 45-50 MBH of usable heat off the air handler with about 400 watts of supplemental power that could be used to power the air handler plus other nominal loads. Total operating efficiencies were about 90% with electrical efficiency at about 4%-5%.

Because the iGEN produces electricity on site, evaluations in the VTH included thermal and electrical energy produced and consumed. Based on part-load performance evaluations for this project, the iGEN-i2 exceeded the performance of a traditional non-condensing furnace from site- and source-energy perspectives and, therefore, would likely generate substantial space-heating energy savings relative to that baseline. On the other hand, its performance fell short of the traditional condensing furnace in terms of overall energy efficiency. However, a key advantage the iGEN-i2 would have over the condensing furnace is continued operation during a power outage. Also, continued development of this innovative product may identify additional opportunities to increase efficiency for end users while also offering resilient operation.

## Status

This project was completed with the issuance of a Final Report in October 2019.

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# Ultra-High-Efficiency Natural-Gas-Fired Combustion Systems for mCHP

***Research is under way to develop and validate ultra-high combustion efficiency (90%) and ultra-low emissions for highly-advanced residential micro-combined-heat-and-power appliances. This research project developed and tested near-term efficiency (65%) combustion systems to support further advancements.***

## Project Description

This goal of this project is to develop prototype combustion systems for an ultra-high-efficiency, ultra-low-emission, economical, micro-combined-heat-and-power (mCHP) appliance for the home, with capacity modulating between 0.5 kW to 2.5 kW to better meet market demand.

This UTD project is built upon a recent related research project funded by the U.S. Department of Energy ARPA-E, which completed development of a thermo-chemical heat-recovery (TCHR) hybrid recuperator. This UTD project supported a near-term development focus on lowering the cost of a Stirling-engine combustion system for mCHP and remote power appliances. The near-term development targets were a combustion efficiency of ~65%, an equivalent fuel-to-electric efficiency of 20%, and compliant with California Air Resources Board emissions requirements.

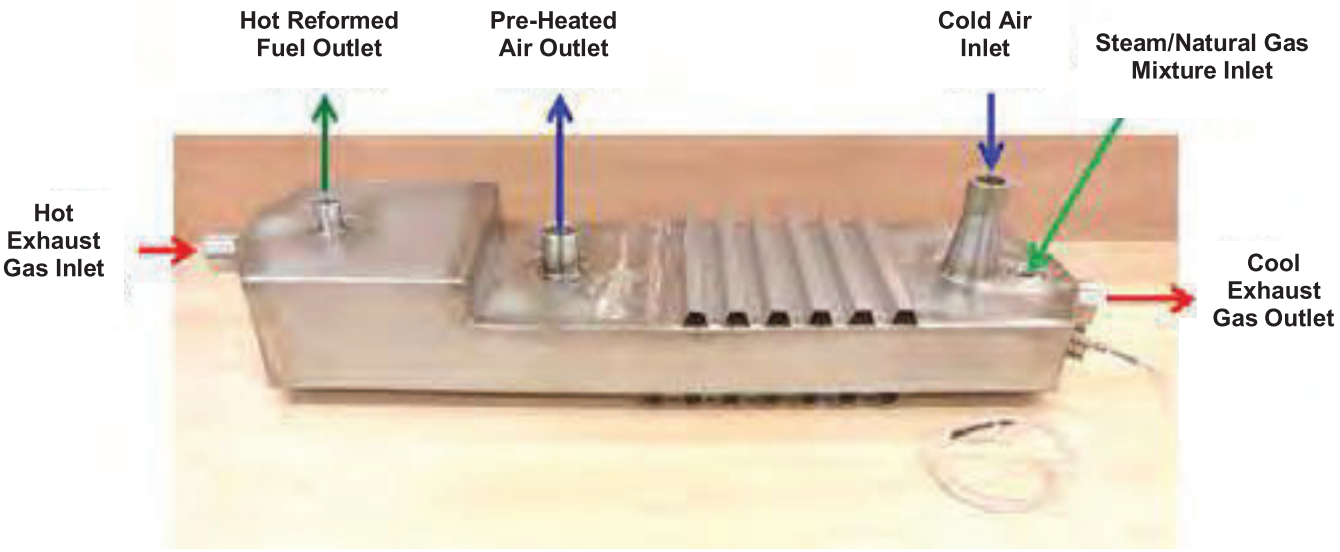
## Benefits / Market Implications

A 1kW nominal capacity natural-gas-fueled mCHP system could provide most U.S. household's electricity and hot water.

Currently, 70 million U.S. homes (61%) have access to piped-in natural gas. The widespread adoption by these homes would result in both energy and environmental savings that include:

- Saving ~five quads in energy through efficient on-site generation
- Eliminating ~200 million tons, or 10%, of annual $CO_2$ emissions generated from U.S. electric generation, and
- Reducing ~8% of the annual fresh water withdrawal used in U.S. electric generation.

*The prototype near-term burner being tested under high fire. The inconsistent color in the metal foam sections under fire are indicative of poor manufacturing quality control in pore size and density.*




*Hybrid recuperator.*

Near term, a lower-cost combustion system allows the Stirling engine to be competitively used in early-entry markets – such as remote power, backup power, and battery recharge – while the mCHP appliance is fully developed and tested.

## Technical Concept & Approach

**Design Burner to Fit Within the Existing Housing Assembly Current Used By the Manufacturer**

- Develop burner specifications that integrate with existing recuperation for use in a tubular-type heater head Stirling engine design
- Confirm ultra-low emissions through analysis
- Target Stirling engine performance:
  - 65% combustion efficiency
  - 20% fuel to electric efficiency
  - CARB 2007 compliant, and
- Design, engineer, and fabricate the burner; and validate the design and performance specifications through laboratory testing.

**Manufacturer Integration, Testing, and Validation**

- Provide manufacturer with the burner for integration with a prototype Stirling engine for testing and evaluation.

## Results

In 2019, structural components for a near-term burner were fabricated, assembled, and tested at two firing levels. Under a high fire of 12.3 kW, the pressure drop across the burner was 0.75 in w.c. and $NO_x$ emissions measured 8 ppm @ 3% $O_2$. Under low fire of 5.2 kW, the pressure drop across the burner was 0.05 in w.c. and $NO_x$ emissions measured 5 ppm @ 3% $O_2$.

During testing by a manufacturer, the burner performed as efficiently as the currently-used burner, but testing exposed a known sensitivity in the axial positioning of the burner – a slight misalignment impacts performance dramatically. Emission levels were high and not able to meet CARB 2007 targets.

Researchers conducted a failure analysis and found no oxidation on the metal foam burner surface, suggesting that the burner was not operated at design conditions. The quality in the metal foam may have contributed to improper combustion and high emissions. The mass and proximity of the reverberatory stiles may have contributed to a flame-quenching effect on the tubular heater head design. In addition, burner misalignment and fallen heater head insulation may also contributed to quenching.

Researchers identified and secured some new pressed-wired burner material for a more robust burner design for testing and evaluation.

## Status

The project is complete. A Final Report was issued in June 2020.

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UTD Utilization Technology Development

# Integrating Micro-CHP and PV in Advanced Gas/Renewable Homes

***The capabilities of a Virtual Test Home were expanded in order to more rapidly develop, test, and optimize system-based solutions (such as incorporating photovoltaic panels and micro-cogeneration) that increase energy efficiency and reliability, reduce energy costs, and better integrate natural gas with renewable energy in homes.***

## Project Description

The objective was to expand the advanced gas heating and cooling capabilities in a laboratory Virtual Test Home (VTH). Laboratory research was complemented with building energy modeling techniques to provide an opportunity to properly quantify potential energy savings from hybrid gas-fired systems in various building types and climate conditions.

Researchers analytically demonstrated that a mixed-fuel home – using electric and gas-fired equipment for HVAC, domestic hot water, and on-site power – can provide similar or better emissions reductions over typical homes as compared to the all-electric home. Moreover, the mixed-fuel home could require the lowest operating and capital costs, and be the most effective in heating-dominated climate regions.

This project builds on analytical and case studies, to:

- Develop solutions for the design of individual components (e.g., mCHP) to facilitate better integration in a gas/renewable home and
- Evaluate those solutions in an experimental VTH, coupling gas-fired heating equipment (e.g., heat pumps), mCHP equipment, and a photovoltaic (PV) array with simulated climate conditions and building loads.

## Benefits / Market Implications

Zero Net Energy (ZNE) homes are attracting increasing market interest, and many homebuilders are opting for an all-electric approach. However, there are principal drivers for including gas in mixed-fuel ZNE and other high-efficiency homes. In terms of cost-effectiveness, gas enables lower-cost ZNE implementations by allowing smaller PV arrays to offset source energy use, and also provides key resiliency benefits.

Peer-reviewed analyses indicate mixed-fuel homes can reach similar levels of emission reductions and renewable energy utilization as all-electric ZNE homes.

In this project, a goal was to develop system integration and control strategies with a portfolio of near- or

*Space heating/cooling simulators. Three-ton capacity (left) and five-ton capacity (right)*

market-ready equipment to demonstrate the effectiveness of integrating onsite gas and renewable generation with efficient gas-fired heating equipment and energy storage.

## Technical Concept & Approach

Specific tasks included:

- Micro-CHP pilot house assessment and experimental Plan
- Design and construction of integrated energy system (IES) in a VTH, and
- Evaluation of the IES.

## Results

In this project, researchers developed a systematic approach to evaluate gas-fired and electrical-driven HVAC, hot water, and power-generation residential equipment in as-installed-conditions for homes in different climates zones.

The VTH provided a holistic approach that helped to identify alternative paths to develop gas-fired systems with renewable-ready capabilities to provide heating, cooling, and hot water at low operating cost and greenhouse-gas (GHG) emissions with respect to all-gas and all-electric baselines.

The following features of the VTH infrastructure allows for systematic testing and product development for integrated systems with dual-fuel, thermal storage, power generation, and off-grid capabilities for space heating and cooling and hot water:

- Simulated hot-water use up to 10 gpm draws with controlled entering water temperatures
- mCHP/renewable 5kW 120/240VAC micro-grid
- Outdoor bays for VTH/field demonstration hybrid evaluation
- Simulated outdoor air for outdoor unit VTH evaluation
- Hydronic loops for hot water management across mCHP and gas heat pump integrated systems bays
- Hydronic heat rejection for up 22-ton systems with a 25°F process water/glycol system
- Battery bank system for self-powered HVAC evaluations, and
- 120 or 240VAC 5kW load bank for electrical load simulations.

As part of the research, researchers teamed with manufacturers to further develop a combination system that integrates electric and gas equipment and dynamically monitors air and water temperatures and modulates water flow to maximize efficiency and comfort.

The integrated systems represent alternative paths to reducing operating cost and GHG emissions, taking an integrated systems-based approaches to existing technologies. With advanced heat pump technology, the concept with optimized controls will maximize operation even for hot-water application during the cooling season. With high electric consumption associated with hydronic loop pump operation, the operating cost and GHG emission reduction is based on lowering gas consumption. Hydronic loop controls, space-heating modulation strategies, heat-pump sizing relative to peak heating loads, and storage tank size and thermostat calls are key parameters to further reduce electric consumption and minimize short-cycling.

Limitations associated with hot-water production shedding in heating and cooling seasons are key to optimize the system efficiency. Modulation strategies for space heating could be further improved by splitting the load between hot-water production and electric heat-pump heating.

Modeling indicates an integration of these systems would result in a more efficient and reliable system than traditional gas equipment or all-electric equipment. For example, the current model would use a small 1.5 kW mCHP system isolated from the grid, an electric heat pump, a tank-type water heater, and a hydronic air handler unit. In the winter, the heat pump would be off and the mCHP system would supply heat to the tank water heater for space heating and DHW. The mCHP power would be used for the air handler, water pump, and small water-heater power demands. In the summer, the heat pump is used for air conditioning. Off-grid PV is supplemented by the mCHP system to supply power to the heat pump, air handler, water pump, and tank.

## Status

This project is complete. A Final Report was issued in March 2020.

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# Micro-CHP Characterization and Demonstration

***Researchers characterized key mCHP technologies in an effort to increase market adoption of highly-efficient mCHP by providing the market with qualified, well-established, and cost-effective systems.***

## Project Description

The primary barrier to widespread adoption of micro-combined heat-and-power (mCHP) systems is cost. While a downward trend in cost is expected as new technologies penetrate the market, significant declines in cost are generally only seen after high-volume production occurs, with numerous manufacturers offering competitive products.

With consistently low gas prices and rising electricity prices, there are now many manufacturers positioning for the small-scale CHP market. However, high-volume production has yet to be seen. Qualified technology supported by a major manufacturer in an influential market such as California could help to spark the North American market and expand the global market.

Industry experts recognize the energy efficiency and end-user benefits for mCHP. However, with dozens of mCHP technologies coming into play, it is difficult to determine the technologies that are best to pursue. To gain a comprehensive understanding of the technical and economic viability of mCHP, many factors need to be considered, including thermal-electric ratio of the technology, regional- and application-specific co-incidental power and thermal loads, quantitative and qualitative value of standby power, time-of-use energy rates, net-metering legislation, and the incremental costs of mCHP relative to traditional costs for retrofit and new construction equipment.

There were two components to this project:

1. Updating UTD's 2012 *Technical & Market Analysis for Residential and Commercial Micro-CHP*. The Final Report for that project provided the industry with a snapshot of emerging mCHP technologies and a detailed, practical assessment of the market potential for them.

2. Laboratory testing in support of a much larger research project funded by the California Energy Commission (CEC). The CEC project is funding the development and demonstration of two mCHP systems.

The objectives for this project were to characterize key mCHP technologies and determine regional, technical, and economic viabilities of those technologies and increase market adoption of mCHP by providing the California market with qualified, well-established, and cost-effective systems.

## Benefits / Market Implications

The mCHP landscape has changed significantly in recent years, and the long-term projected price of natural gas in North America has substantially declined. There are now at least six new 10kW-50kW engine-based mCHP products suited for the commercial sector, and a wide assortment of new technologies less than 10kW for the residential and light commercial sector.

*A wide variety of m-CHP systems were evaluated.*

## Technical Concept & Approach

The first component of this project was to identify the most attractive opportunities for end users to benefit from mCHP, by first characterizing the technologies and then putting them through a battery of energy and economic analyses.

Economic analyses were conducted for at least seven climate regions and included:

- **Commercial**: Near-grid-efficiency mCHP applied to the U.S. Department of Energy commercial reference building models, including full-service restaurants, small hotels, outpatient healthcare, and midrise apartments, and
- **Residential**: Above-, near-, and below-grid-efficiency mCHP applied to a residential homes based on the National Renewable Energy Laboratory housing stock characteristics database.

The second component of this project partially co-funded the CEC project to 1) perform systems tests to verify electric and thermal efficiencies and 2) facilitate third-party stack emissions testing to collect emission test data in compliance with CARB testing procedures.

Laboratory testing and demonstration of two mCHP systems addressed the Distributed Generation Certification Regulation (DG-Cert) requirements under the California Air Resources Board (CARB) Distributed Generation Program. The DG-Cert sets the bar for exceptionally clean and efficient distributed generation, and would position these manufacturers for expanded market offerings elsewhere.

## Results

A Final Report for this project provides a comprehensive technical and economic assessment of five specific residential and commercial mCHP technologies and operating strategies in seven regions.

Technologies included:

- The 6kW M-Trigen PowerAire gas-engine-driven heat pump mCHP system (because of its space cooling capability)
- A 1.0W fuel cell
- A 2.3kW BRASH Pllus boiler-to-mCHP conversion system
- A 1.5kW Aisin Coremo internal combustion engine mCHP system
- A 24kW Lochinvar mCHP system.

Three residential mCHP systems were configured for modeling purposes with off-the-shelf electric and gas HVAC and water-heating appliances, along with novel controls in a way that reduced operating costs and greenhouse-gas emissions. A fuel cell rated at 1.0 kW was configured to operate baseloaded at about 400 watts. The 1.5 kW Aisin system was configured to come on for HVAC thermostat calls. The BRASH Plus boiler system was configured to come on for water heating. Analyses indicated that a more than 20% energy cost savings could be achieved in most cases with an all-gas integrated energy solution that produces space heating and cooling, domestic hot water (DHW), power, and dehumidification.

Modeling and analyses of two commercial-scale systems was conducted. The Lochinvar system was configured to operate thermally, supplying 3,000 to 4,000 gallons per day of hot water service demands in plus hydronic space heating as an option. The M-Trigen PowerAire system was configured to operate on HVAC thermostat calls providing space heating and cooling along with DHW. Each system was modeled in a way that potentially reduced operating costs and improved energy resilience for customers. Analyses varied widely across regions and natural gas and propane fuels. In some cases, paybacks of less than five years could easily be achieved regardless of tax incentives or if the mCHP system was black-start capable.

In 2019, results of testing with the 25kW mCHP system indicated emissions were controlled well below CARB limits with the new catalyst, while work is still being conducted to determine if an aged catalyst will maintain the emissions. As a result of this research, the project team has shown that mCHP can help retain a high-efficiency role for natural gas and propane in the residential forced-air and commercial hot water heating markets with a variety of mCHP Technologies.

## Status

This project is complete. A Final Report was issued in April 2020.

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# Triathlon™ 2030 Five-Ton Cold-Climate GHP

***Researchers are assisting in the prototype design of a new five-ton natural gas engine-driven cold-climate gas heat pump (GHP). The system will provide water heating, space conditioning, power generation, and off-grid operation in one unit.***

## Project Description

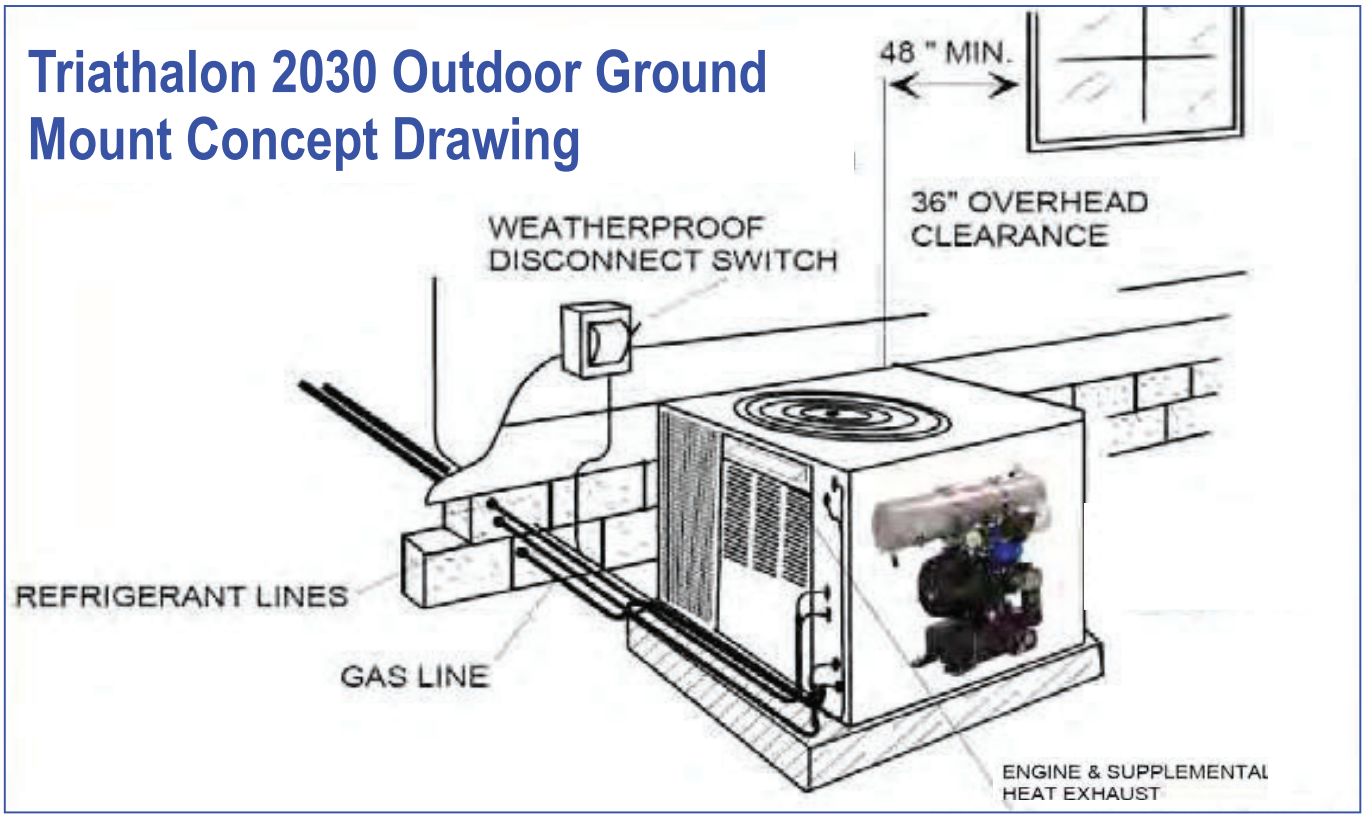
Over the last 20 years, there have been several advances in gas-engine heat pump (GHP) design and components, including condensing coils, refrigerants, motors, and fans. This combination of new developments with a proven, high-reliability/low-emission engine provides a low-risk path to achieving the project goals for a high-performance and low-cost heat-pump design.

This effort builds on prior five-ton GHP designs first developed in 1995 that used off-the-shelf components, leaving much room for incremental improvement. The most recent design was built and tested in 2015 and optimized for the hot, dry climate of the southwestern U.S. (e.g., Nevada and Arizona). The project achieved its goals for combined water heating, space conditioning, power generation, and off-grid operation: 1.2 cooling coefficient of performance (COP); 1.5 heating COP; 80% primary energy savings for water heating; and a five-year payback based on $8,000 product cost and at 1,000 units/year production volume.

The objective for this new project is to assist the project team in developing and testing a new five-ton natural gas-engine-driven cold-climate heat pump prototype. UTD researchers are supporting the efforts of a project sponsored by the New York State Energy and Research Development Authority (NYSERDA) led by Syracuse Center of Excellence by providing technical support.

Key performance indicators and metrics to measure project success include meeting the targets of the NYSERDA NextGen HVAC Challenge:

- Lower energy source consumption compared to current baseline technology
- Lower greenhouse-gas emission levels compared to current baseline technology
- Clear peak-demand reduction compared to current baseline technology, and



- Achieve average annual COP >2.0 with emphasis on cold-climate heating capacity and efficiency.

Initial product cost targets are <$5,000 per unit based on a production volume of 500 units/year.

## Benefits / Market Implications

The GHP design will provide the following benefits:

- Achieving high heating efficiency and the ability to operate at significantly lower outside temperatures than electric heat pumps
- Expanding customers' competitive choices of product offerings and fuel options
- Reducing electrical energy and demand savings for end users
- Improving the use and resilience of the power grid
- Deferring investments to increase grid capacity, and
- Avoiding rate increases associated with capital projects to increase power grid capacity.

Five-ton HVAC rooftop units are ubiquitous and can be found on most commercial buildings under 200,000 square feet.

## Technical Concept & Approach

The first stage of this project is to develop a product design to determine the performance, reliability, serviceability, and cost targets. The Triathlon 2030 design focus is on heating and cooling applied to small commercial building load profiles, including office, lodging, restaurants, fitness, health care, box retail, strip malls, light commercial, and education.

The Triathlon 2030 is being designed as a reliable, drop-in replacement with a similar footprint to conventional five-ton rooftop units. The major technical design challenge is to redesign and improve engine-heat recovery for cold-climate operation. The multifunction power-generation and water-heating capability incorporated in the GHP design will be eliminated to reduce both manufactured and installed cost.

If a successful proof of concept is achieved, the NYSERDA-sponsored project team will build demonstration units, install them in field sites, and monitor their performance.

The NYSERDA project team will also develop energy and economic system models that will predict simple payback and life-cycle costs, utility avoided cost value, source energy savings, and reduced greenhouse gas emissions. The model will be updated after each laboratory test and as field-demonstration data becomes available.

*Triathlon heat pump in 1995.*

The NYSERDA project team will update performance as well as energy and economic models. The team will also meet with utilities and end-use customers to build awareness with stakeholders and to select at least two end-user sites for initial installations.

## Results

In Phase 1, the project team developed the modeling approach for the preliminary energy and economic assessment of the five-ton Triathlon 2030 GHP design. Three building types (small office, strip mall, and full-service restaurant) were selected to represent the best applications for a light-commercial five-ton GHP split system. Actual weather data was used for three locations (New York City, Buffalo, and Binghamton) corresponding to ASHRAE climate zones 4A, 5A, and 6A, respectively. Detailed electric and gas utility rates for each location were updated.

## Status

To complete Phase 1, the project team will develop a detailed design for the Triathlon 2030 and its value proposition for New York state. NYSERDA will issue a Go/NoGo decision prior to Phase 2 development and testing of the breadboard design.

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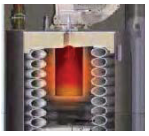
# EnviroPower 6kW SmartWatt and BRASH 3kW Plus mCHP Boilers – Laboratory Test



***A research team is evaluating the 6kW EnviroPower and 3kW BRASH Plus mCHP self-powered hydronic HVAC boiler systems in a laboratory in order to support their technical development. When fully commercialized, these products will offer end users high efficiency and high resiliency.***

## Project Description

In recent years, frequent and extreme weather events exposed the North American energy infrastructure to extended power outages. As a result, energy resilience has become increasingly important. The high reliability of natural gas delivery addresses this problem.

In this project, a research team is evaluating prototype products from EnviroPower and BRASH that fall into a specific mCHP category of self-powered hydronic space heating. Their primary target markets are drop-in boiler replacements and residential/light commercial customers (e.g., heating capacities up to 175 MBH), especially those that value service reliability. The electrical efficiencies are low relative to other mCHP systems, but they are packaged devices with all balance-of-plant necessities integrated into one system. The supplemental power these systems generate over and above their operating parasitic power needs can be used to serve heat distribution and other critical loads in residential and commercial applications. Essentially, these systems enable residential and light/commercial self-powered mechanical equipment rooms at a reported 85% total efficiency.

The EnviroPower SmartWatt and BRASH Plus systems are modified Rankine steam cycles each using their own novel approach to making steam and generating power. In their thermodynamic cycles, heat from combustion is transferred to the water to create steam, which in turn drives an expander such as a turbine. A generator is fixed to the expander to produce power. As steam is condensed, it transfers heat to a hydronic loop for space heating and/or domestic hot water.

EnviroPower indicates the 6kW SmartWatt boiler will be priced similar to a traditional boiler and that it can meet the emissions standards for California Air Resources Board Distributed Generation Certification based on preliminary test results.

*BRASH (left) and EnviroPower (right)*

*"Commercial success in the home heating and power sector doesn't happen unless independent testing is done that builds trust with stakeholders and consumers. Knowing this, BRASH turned to UTD to help us refine and bring to market what we feel is a significant advancement in home energy efficiency and resilience."*

*- Michael Brookman*
*President*
*BRASH Power*

BRASH's mCHP system is based on a patented air-steam hybrid technology that can be installed as an accessory to an existing boiler or as a turnkey mCHP system. The BRASH system is a 900W to 2.3kW, 33 to 82MBH thermal system. BRASH has UL-certified Plus units in initial production. BRASH also indicates its mCHP system will be priced similar to a traditional boiler.

In this project, researchers will evaluate the 6kW EnviroPower and 3kW BRASH Plus mCHP self-powered hydronic HVAC boiler systems in the laboratory and support their development by validating performance and other competitive analysis benchmarking.

Project goals include:

- Developing specific test protocols with EnviroPower and BRASH guided by newly developed ASHRAE SPC204 mCHP Methods of Testing
- Evaluating the EnviroPower SmartWatt and BRASH Plus performance, including power and thermal production, efficiencies, and emissions in the laboratory, and
- Providing subsequent development support as needed based on performance results.

If this project proves successful, it will result in two demonstration-ready mCHP boilers that provide self-powered hydronic HVAC. The project will document the performance of the EnviroPower SmartWatt and BRASH Plus and assess the benefits of self-powered HVAC systems for end-use customers.

## Benefits / Market Implications

The value of energy resilience is often overlooked when assessing the feasibility of combined heat-and-power (CHP) systems because of the difficulty quantifying the benefits of the technology. Recent UTD-supported analysis (2.12.F) helped the gas industry quantify the supply reliability advantage of natural gas. Self-powered units such as BRASH and EnviroPower build on this gas industry differentiator to provide high heating reliability.

By some estimates, poor energy reliability and power quality costs the U.S. about $79 billion per year and traditional backup generators fail about 15% of the time. Microgrids are a major trend shaping the future of distributed energy resources. The technology can be a non-infrastructure grid-balancing solution as deeper penetrations of intermittent renewables are realized.

## Technical Concept & Approach

Laboratory testing will focus on confirming power and thermal output capacities, determining efficiencies and emissions levels, and assessing general functionality, including on- and off-grid operation.

The newly developed ASHRAE SPC204 mCHP Method of Test will be used as a guide for developing the test plans with EnviroPower and BRASH.

A battery of laboratory tests will be developed to determine performance at steady state and in transient electric and thermal loading scenarios. Typically, mCHP systems are evaluated at 40°F, 59°F, and 95°F ambient conditions. However, since these self-powered hydronic heating systems are intended to replace indoor boilers, the tests will be conducted at typical indoor conditions designed to simulate space-heating and water-heating loads.

## Results

The project team will evaluate the BRASH Plus mCHP system first. Researchers are developing a test plan for the 3kW unit. BRASH is preparing operating and installation manuals.

Due to the COVID-19 pandemic, researchers developed an alternative plan with BRASH to evaluate its BRASH Plus system remotely in the manufacturer's facilities.

## Status

Researchers are developing a test plan for BRASH system and specifying instrumentation and data-acquisition equipment. The project team is interacting with BRASH to make sure instrumentation and data-acquisition equipment is installed properly.

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# LARGE COMMERCIAL AND INDUSTRIAL, INCLUDING CHP

UTD Utilization Technology Development

# Enhanced Gas Space Conditioning for Greenhouse and Vertical Farming

***This project is assessing technology needs and opportunities to integrate value-added features of gas-driven space-conditioning and power systems to better serve greenhouse and indoor/vertical farming end-use customers.***

## Project Description

This project focuses on integrating value-added features for gas-driven space-conditioning and power systems for use in greenhouse and indoor/vertical farming.

Attractive features of vertical farming include increased yield per unit area and multiple crop cycles annually. The growth in the legal cannabis agribusiness is driving indoor growing innovation in environmental control, energy use, and crop-production optimization. As the industry continues to expand, increased competition is affecting profitability, putting pressure on operating costs. Natural gas and propane can and are playing important roles in energy-cost reduction. Innovation in indoor cannabis growing can serve as a technology roadmap for other value crops, such as microgreens grown in indoor/vertical farming environments.

In this project, researchers are conducting a techno-economic assessment of integrating features for use in systems employed in greenhouse and indoor/vertical farming. This UTD project is being co-funded by the Propane Education and Research Council (PERC).

The goals of this project include:

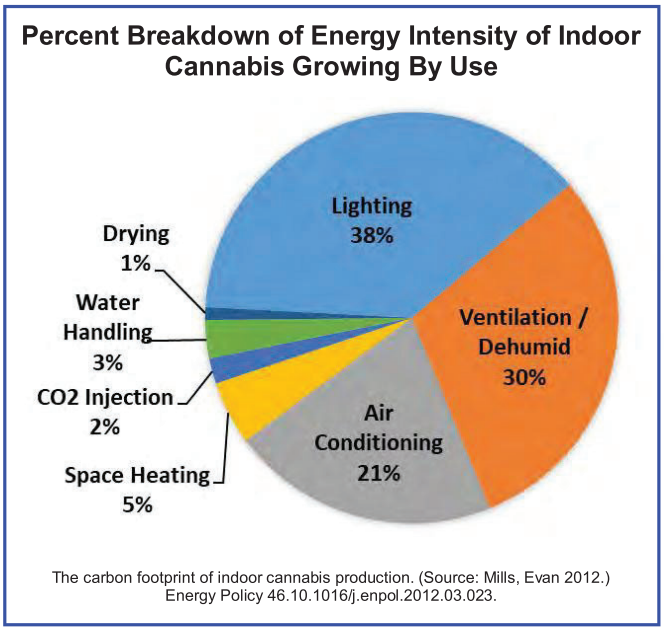
- Segment and define the Controlled Environment Agriculture (CEA) agribusiness, growth potential, and value by crop and region
- Define current and best practices
- Determine energy use, costs, and efficiency opportunities
- Identify technology needs and opportunities
- Identify gas-based technology solutions that can impact the efficiency and productivity of CEA farming for end users
- Determine the pros and cons of each technology solution
- Determine the economic benefit, and
- Identify research and development needs.

## Benefits / Market Implications

Gas-based technology options (fossil or renewable) have the potential to decrease energy costs while boosting production performance for these customers.

Legal cannabis growing, both medicinal and recreational, has a market value of $10 billion (2018) and is expected to grow to $23 billion in 2024. The collective market value of other indoor/vertically farmed crops is $700 million (2018) and expected to grow to $3 billion (2024). This project also addresses greenhouse operations and aquaponics.

With energy costs representing 30%-50% of total operating costs, natural gas- and propane-driven gas heat pumps (GHPs) and combined heat-and-power (CHP) systems are increasingly serving indoor/vertical farming operations.




The carbon footprint of indoor cannabis production. (Source: Mills, Evan 2012.) Energy Policy 46.10.1016/j.enpol.2012.03.023.

Currently, growers typically inject $CO_2$ into a growing room during lockout periods to raise the $CO_2$ levels between 800-1,200 ppm to accelerate plant growth. Growers typically use $CO_2$ tanks over natural gas- and propane-based methods as $CO_2$ tanks offer greater injection control without adding humidity. Existing gas technologies such as direct-fired dedicated outdoor air systems and make-up air units have the ability to raise the $CO_2$ levels.

It may also be possible to add capabilities to existing GHPs and CHP systems to enhance their value for these customers. A review of $CO_2$ separation technologies suggests that it may be possible to develop low cost add-on processes to extract $CO_2$ from natural gas and propane combustion exhaust and decouple the $CO_2$ from other flue gas constituents including water.

## Technical Concept & Approach

This project will clarify the indoor/vertical farming markets, opportunities, and technology needs of gaseous fuel customers. Researchers will provide an annotated review of available information on emerging markets in indoor/vertical farming and value crops as defined by: 1)agribusiness growth and value potential, 2) energy use and costs, 3) agribusiness economics, and 4) technology needs.

The project team will conduct stakeholder interviews to validate and further clarify the growth potential for indoor/vertical farming.

Key performance indicators and metrics to measure project success include:

- Interview at least six indoor/vertical farming owner/operators
- Interview at least six equipment suppliers (and/or subject matter experts) to greenhouse and indoor/farming operations on code and market issues, opportunities, and needs
- Identify and discuss technology issues with at least two leading architects and engineer of vertical farming facilities in North America, and
- Identify at least four key technology development needs or opportunities related to use of gaseous fuels to better serve customers in greenhouse and indoor/vertical farming markets.

## Results

The project team attended key conferences to discuss issues with industry experts, and performed a detailed literature review.

Interviews were initiated with key contacts with agricultural owners/operators, subject matter experts, architects and engineers, and equipment manufacturers/suppliers.

The team has been researching various growing structures. Initial drafts of one-sheet publications were made for different crops and/or growing structures.

## Status

The project team is completing final interviews and the Final Report, in addition to final one-sheets for different crops and/or growing structures. The Final Report is expected to be delivered to sponsors in September 2020.

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UTD Utilization Technology Development

# Reliability Assessment of Natural Gas for Standby Power Generation

***Researchers are developing data, providing technical information for standards updates, and supporting a website in order to provide credible, scientifically-sound information on the value of using natural gas for standby power generation. End users benefit from more choices and the opportunity to leverage the 10X higher reliability of gas vs. electric supply.***

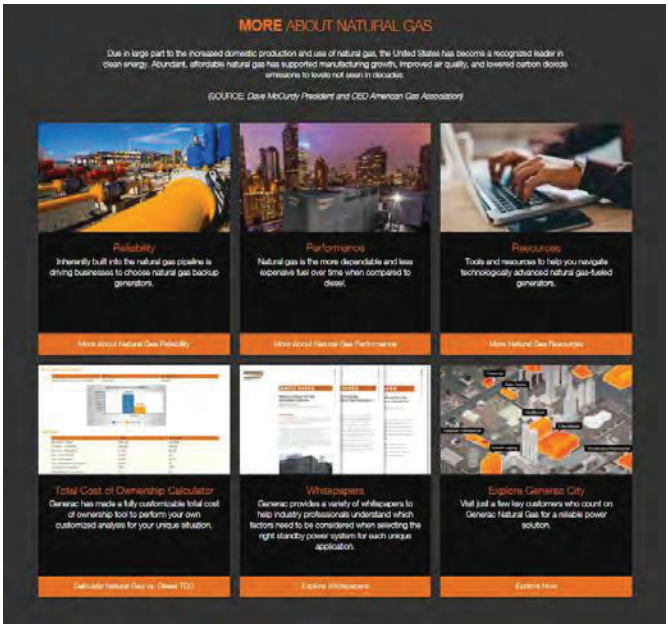
## Project Description

Although the market for emergency power supply systems (EPSS) is dominated by diesel-fueled generators, natural gas systems are gaining market share in the U.S. due to technical advances, low fuel costs, notable severe weather events, and regulations. For voluntary non-code-driven EPSS installations (typical of residential or small commercial applications) the natural gas market share is about 70%. In the EPSS commercial market, where volume is driven by code requirements, the natural gas share is only 20%-30%.

The initial phase of this project focused on identifying the degree of customer need for a typical 50kW natural-gas-fueled distributed generation (DG) system. This study found that some technical codes and standards issues presented a significant hurdle for natural gas code-driven EPSS due, in part, to historical developments and perceptions regarding the reliability of utility natural gas supply.

A traditional perception is that diesel engines with on-site fuel storage are the most reliable equipment for all backup power applications. Despite their widespread use, diesel generators (gen-sets) are not without reliability concerns. Power outages associated with major weather events highlighted diesel gen-set vulnerability to inadequate fuel-maintenance practices and to the difficulty or impossibility of fuel replenishment in the midst of extended major outage events. On the other hand, the natural gas infrastructure is highly reliable. Underground supply pipelines are less likely to be compromised during major disasters than above-ground electrical infrastructure, and there may be insufficient on-site diesel storage to address a multi-day service outage. The reliability of natural gas supply has been the focus of several recent studies due to the growing dependency of power generation on natural gas.

The overall goal of this project is to help inform end users and reduce barriers for natural gas backup power generation, such as by supporting consensus refinements in codes and standards. An additional goal is to gather technical information showing that standby generation using natural gas by pipeline can be as or more reliable than onsite diesel fuel storage. Broad dissemination of data on the reliability of the natural gas supply, especially during simultaneous power outages,



can support code officials as they consider permitting natural gas utility supply for emergency power generators.

In the current phase of the project, the research team is developing technical information on natural gas reliability and the benefits of natural gas EPSS, and supporting proposed changes to applicable standards.

## Benefits / Market Implications

Natural gas DG and EPSS provide cost-effective options that increase energy resilience while providing environmental benefits. These advantages, coupled with historically low natural gas prices, provide significant benefits to end users, the environment, and infrastructure reliability.

Supportive research on natural gas reliability will aid consumers, the gas industry, and regulators in understanding the benefits of natural gas as compared to diesel for backup generators. This collected research will also lay the groundwork for a change in industry perception and potential consensus updates in applicable technical codes and standards for backup generation.

## Technical Concept & Approach

In early phases of this project, researchers evaluated natural gas DG applications using various criteria, including: capital cost, system efficiency, reliability, serviceability, maintenance cycles, product life, exhaust emissions, noise emissions, systems integration, and modes of operation supported.

In the current phase of the project, activities focus on the dissemination of data on the reliability of the natural gas supply to address regulatory barriers for the natural gas EPSS market.

Generac Power Systems, Inc., is partnering with the project team to provide industry insight on barriers regarding the natural gas generator market and to disseminate information.

## Results

The project team collected technical content on natural gas standby generation, and provided technical support for a member of the NEC/NFPA 70 technical committee. Similar efforts by others led to the acceptance of "off-site fuel sources" for emergency generators in Canadian Standards Association's CSA C282 ("Emergency Electrical Power Supply for Buildings") in 2007.

The project team partnered with Generac by providing technical content for Generac's public website, (*www.reliablenatgasgen.com*), the Natural Gas Knowledge Center. The website disseminates technical content on natural gas reliability and other data to help the gas industry, authorities having jurisdiction, engineers, and customers make well-informed decisions when selecting fuel(s) for back power generation.

The Natural Gas Knowledge Center continues to be improved as researchers enhance tools and add content. The website includes condensed, readily-available, supporting data on reliability and other advantages of natural gas-fueled EPSS. The website also offers online tools, performance data, information on applicable codes, and case studies. One online tool, the Total Cost of Ownership calculator, compares natural gas standby generation to diesel in terms of economics and full-fuel-cycle emissions.

As part of this effort, researchers collected aggregate historical natural gas outage data from several utilities to quantify the reliability of the natural gas supply. These results show that natural gas distribution reliability is an order of magnitude greater than the reliability of the electric distribution service. This assessment was publicly distributed in July 2018 as a Gas Technology Institute (GTI) topical report, *Assessment of Natural Gas vs. Electric Distribution Service Reliability*, to substantiate the high level of reliability of natural gas service and to support its use for standby and emergency generators. Generac's public website also includes GTI's white paper *Reliability Assessment of Diesel vs. Natural Gas for Standby Generation*, an overview of natural gas EPSS and a comparison of natural gas vs. diesel systems.

Researchers presented a webinar in April 2020 to UTD members to summarize developments in onsite power generation and demand response.

## Status

The project team continues to provide technical content for the Natural Gas Knowledge Center website and gather and document additional data regarding natural gas reliability.

Economic case studies are being developed for new non-emergency-certified EPSS installations that can use demand response, including potential life-cycle cost benefits relative to natural gas and diesel emergency-only EPSS.

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UTD Utilization Technology Development

# Ribbon Burner Improvements

***An innovative cost-effective, low-$NO_x$ ribbon burner combustion system that can be used for a wide variety of industrial processes was developed and demonstrated. Results of a prototype unit in a full-production field test demonstrated 50% $NO_x$ reduction and approximately 5% energy savings.***

## Project Description

The heating, drying, and baking of food products is accomplished extensively by conventional gas-fired ribbon burners, which are also widely used in other industrial processing and surface-treatment applications. These combustion systems are coming under stricter emissions regulations in many regions of the United States, especially in California. Reducing $NO_x$ emissions is critical for end users to continue benefitting from ribbon-burner combustion systems across a wide spectrum of industrial and commercial applications.

In response, researchers developed and demonstrated an advanced low $NO_x$ (ALN) ribbon-burner combustion system directly applicable to the business and environmental concerns of the California bakery industry. Considering the broad application of ribbon burners, the ALN combustion system has the potential to support the wholesale baking industry in meeting and exceeding more stringent emission requirements while increasing efficiency and maintaining product quality and economy.

In 2015-2018, researchers conducted a technology demonstration project in a full-scale production environment at a wholesale commercial bakery in California. UTD's project partners included the California Energy Commission and SoCalGas.

## Benefits / Market Implications

According to the American Bakers Association, there are more than 700 baking facilities and baking suppliers nationwide. A typical mid-size bakery might have three production lines and consume about 7 million cubic feet of natural gas per month, resulting in approximately 0.6 Tcf of annual natural gas consumption by the U.S. baking industry.

Reaching the target of 50% reduction in $NO_x$ production (< 15 vppm at 3% $O_2$) could lead to significant reductions of pollutant emissions from ribbon burner installations. Considering the broad application of ribbon burners for industrial processes, the ALN ribbon-burner concept has the potential to help end users meet more stringent emission requirements without sacrificing efficiency, major design, or process control.

If a 30% market penetration in the baking industry is achieved, then the emissions reductions in California alone are estimated as follows:

- Natural gas reductions of 1.3 million to 1.5 million therms per year
- Carbon emission reductions of 7,500 to 10,000 tons per year, and
- $NO_x$ emission reductions of 200 to 300 tons per year.

## Technical Concept & Approach

This project involved the following tasks:

- Selection of qualified host site and quantification of baseline performance
- Specification, design, and engineering of demonstration system

*Ribbon burner.*

*"The technology has been successfully demonstrated at a large-volume industrial baking facility. The production rate is 22,800 bagels an hour. The oven operates 24/7, with minimum downtime. At long last, a commercially viable $NO_X$ reduction technology for premix ribbon burners is now available. It can be easily applied to both existing and new ovens."*

*- Joe DiGiacomo*
*Vice President*
*Flynn Burner Corporation*

- Technology installation and shakedown at the host site
- Data collection and analysis
- Post-demonstration monitoring, and
- Technology outreach and initiation of commercialization activities.

## Results

The ALN ribbon burners combustion system demonstrated a 50% $NO_x$ reduction potential in a full production environment. This brings emission levels well below the new air quality regulation emissions in Southern California which are the most stringent across the United States.

The demonstrated approach assumes a portion of exhaust gas (which is laden with $CO_2$) is mixed with the combustion air to reduce the $O_2$ content in it and, therefore, to reduce the $NO_x$ emissions produced by industrial ribbon burners or other types of burners with partially premixed flames. This approach was demonstrated in a full-scale wholesale bakery, confirming that it can meet new regulations limiting $NO_x$ emissions without the need for expensive modification to the burner systems. For situations when the $NO_x$ reduction is critical and replacing the conventional ribbon burner is not possible or is cost-prohibitive, the demonstrated technology can become a viable option, especially in light of the strengthening of federal and state environmental regulations.

Results of experiments and computational fluid dynamics modeling demonstrated that the dilution of the combustion air with $CO_2$ can result in significant reductions in $NO_x$ formation.

Quantifiable fuel savings of approximately 5% compared to the baseline run were demonstrated during the project. Emissions and fuel consumption data was determined by an independent third party as part of a measurement and validation report. Bagel production was successfully accomplished with the modified system with no loss of production.

A Final Report that summarized the results of the completed project phases was issued in April 2019.

The results of the technology demonstration and the potential benefits for the wholesale baking operations were presented to a number of U.S. and international baking industry operators and equipment suppliers.

## Status

The technology was presented at the Baking Industry Equipment Manufacturers annual meeting in March 2020 and promoted at the IBIE (International Baking Industry Expo) in Fall 2019.

A U.S. Patent for the technology was granted in April 2019. Licensing discussions are in progress with a potential commercialization partner.

*Demonstration oven at the participating industrial baking host site.*

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UTD Utilization Technology Development

# Field Validation of Gas-Quality Sensor for Natural Gas

***Field evaluations are under way to demonstrate a new, reliable, low-cost gas-quality sensor that can detect changes in gas quality (heating value, hydrocarbon, and carbon-dioxide concentrations) in real time and provide valuable data to operators and end users.***

## Project Description

Natural gas is priced by total energy delivered (in Btus or therms). However, Btu content cannot be easily measured, so a common practice is to measure the volumetric flowrate at the point of use, and to determine total energy used by multiplying this number by the average energy content (Btu per standard cubic foot) measured at a central location. While this approach is typically adequate for billing residential, commercial, and most industrial customers, there are industrial combustion processes (e.g., processes for glass and fertilizer production) and power-generation equipment (e.g., dry low-$NO_x$ gas turbines and lean-burn internal combustion engines) that have stricter limits on gas quality and composition.

Some large-volume end-user applications have in-line equipment to continuously monitor gas quality to obtain measurements that can be readily converted to heating value, methane number, or Wobbe Index. The introduction of shale gas and upgraded biogas from anaerobic digesters into the gas-transmission network is increasing the importance to more accurately and more regularly measure the heating value of the gas for many of these large-volume customers.

The most common equipment used today for continuously measuring natural gas heating value is the gas chromatograph (GC). Although GCs provide accurate Btu values based on direct measurements and compositional data, they have several drawbacks, including:

- Long response times (often four minutes or more)
- High capital costs (in excess of $20,000), and
- Regular calibration required (a recurring operating cost).

To address the issue, researchers developed and extensively tested in a laboratory a heating-value sensor on natural gas, biogas, and producer gas. Testing in the field was also conducted for biogas applications. The sensor is expected to be significantly lower in cost (under $5,000) than gas chromatographs and will address other limitations of the GC.

The objective of this project is to continue to develop and demonstrate in actual field-operating conditions a practical, reliable, and low-cost gas-quality sensor (GQS) that can detect changes in gas quality (e.g., heating value, hydrocarbons, and carbon-dioxide concentrations) in real time and provide this data to natural gas pipeline operators and end users of natural gas.

## Benefits / Market Implications

Gas distribution companies and large-volume gas consumers that are sensitive to variations in gas quality will benefit from the faster, lower-cost new Btu sensor. Industrial customers can operate equipment more efficiently with lower emissions when real-time fuel heating-value data are available. Operators of natural-gas-fueled turbines and internal combustion engines can have enhanced control of equipment performance and protection.

Specific advantages of the GQS include:

- The sensor needs to be calibrated just once for the application

- Simple to use; no special training is needed
- Measurements can be taken at high gas pressures
- Measurements can be taken continuously, allowing trending and controls operation, and
- In-line configurations are possible.

## Technical Concept & Approach

The GQS uses the infrared light-absorption properties of hydrocarbon gases to measure the Btu content and composition of a natural gas mixture. It has been shown that this sensor technology can be used to measure the air/fuel ratio in air/hydrocarbon gas mixtures delivered to combustion equipment. The accuracy of heating-value measurements made by this new instrument can closely match those of a GC, but at a much lower cost.

Technicians will prepare, calibrate, and install a GQS prototype at utility sites to monitor the heating value and composition of natural gas for 12 months. GQS measurements will be conducted side-by-side with a gas chromatograph to verify accuracy of the GQS measurements. The gas-quality data will be provided to the pipeline operators and/or end users in real time.

The project team will provide support to the licensee of the GQS technology as the project moves pre-production gas-quality sensors through customer testing. UTD members will have the opportunity to be in the first group of pre-production field testers.

## Results

This project began with the procurement of a new GQS spectrometer that was integrated with the GQS hardware. The GQS software was modified to allow the GQS controls to communicate with the new spectrometer. The extended-range spectrometer enables higher accuracy and repeatability of natural gas monitoring.

An experimental apparatus was used to calibrate and test the GQS after upgrades and modifications. The experimental setup consists of a blending station and a certified mixture of methane, ethane, propane, butane, and carbon dioxide. The composition of the blend supplied to the GQS was varied by diluting the certified blend with nitrogen. In 2017, testing of beta prototypes was performed using 12 gas mixtures with compositions covering the range of anticipated real-world biogas and natural gas.

GQS developments include:

- Software integration: The new spectrometer can read high wavelength data and, therefore, collect carbon dioxide data directly. Software was modified to collect and process this data.
- Details of the dimensions, utility requirements, and other aspects of the enclosure (inlet and outlet ports, temperature range, etc.) to hold the GQS for demonstration testing were made.
- The enclosures wer received, and the team completed assembling the GQS inside the enclosure. Two sensors were installed. One sensor followed a prototype design using a spectrometer and the other sensor is a commercial prototype built by the commercializing partner and using an interferometer.
- Field demonstrations were arranged for sites in Oklahoma and North Carolina. All sensors were installed in enclosures and prepared for testing per safety requirements of the two host sites. Data was collected in Oklahoma in early 2019 and in North Carolina during the summer of 2019 from two versions of the gas quality sensor connected in series in both enclosures.

The project team will use a mobile hot spot to collect and transmit data during the demonstration period.

The project team decided to add a second sensor to the demonstration unit. This unit is a beta prototype of the interferometer-based gas quality sensor build by commercialization partner. The two gas-quality sensors are connected in series. This change will enable the project team to gather data from two sensors in the same demonstration test.

Data collection is complete. The team is now processing all data.

## Status

Researchers are finishing calculations of gas composition from collected gas-quality sensor data.

A Final Report is being prepared.

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UTD Utilization Technology Development

# On-Site Electrical Generation

***This research is focused on photovoltaic technologies suitable for converting thermal radiation into electricity. The goal is to design, build, and test an innovative thermal photovoltaic concept for combined heat-and-power generation at a 1-2kW scale to economically maximize the energy efficiency of homes and small businesses.***

## Project Description

In this project, research is focused on thermal photovoltaic (TPV) technology to advance on-site gas-powered electrical generation. Recent advances in gallium-based cells offer the potential for achieving significantly higher conversion rates for high-efficiency TPV-based combined heat-and-power (CHP) systems. While TPV is ideal for CHP applications, the technology is also applicable for power generation alone.

For this project, researchers designed, built, and tested an advanced TPV concept for CHP generation. The results were used to develop a performance model for the selection of appropriate TPV cells and a conceptual design for a TPV-based power generator with the potential for 70% power-generation efficiency.

## Benefits / Market Implications

TPV CHP systems offer several advantages over conventional technologies:

- The systems have almost no moving parts, are practically noise free, and have low maintenance and long life
- The TPV power-generation component can be directly integrated into a variety of thermal equipment to maximize performance, which is a distinct advantage over separate power-generation systems, and
- Significantly fewer pieces of equipment are required, resulting in a reduced footprint and weight.

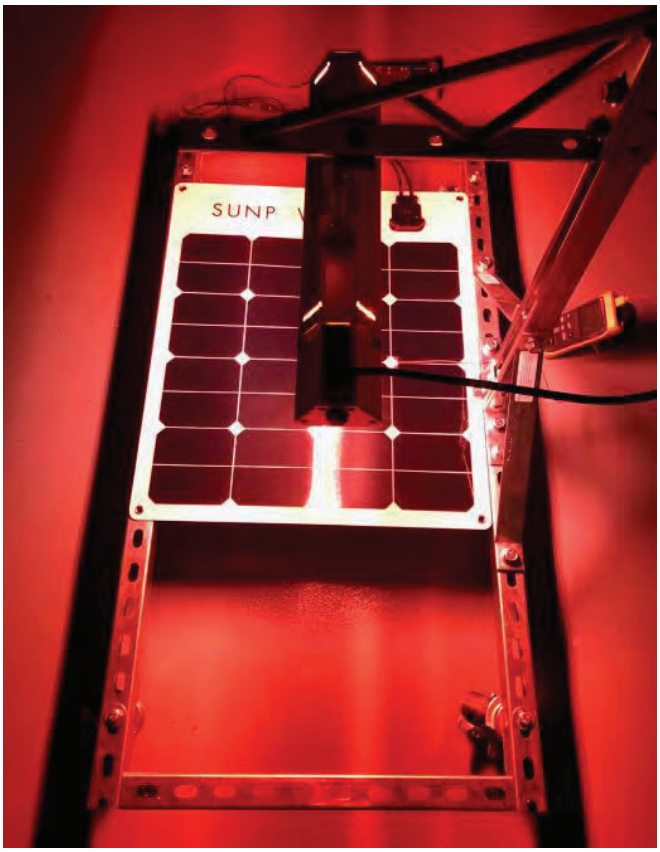
## Technical Concept & Approach

Similar to conventional solar cells, TPV cells can convert radiant energy into electricity via photons, offering an opportunity to directly generate electricity using radiant burners and TPV cells. Both approaches involve a thermal emitter (sun or radiant burner) and a photovoltaic (PV) diode cell designed to match the wavelength of the emitter. The key differences are the emitter temperature and its distance from the cells.

In recent years, partly because of accelerated investments in high-temperature concentrated PV solar technologies, this research area is attracting more interest for both stand-alone power-generation systems for remote applications as well as for CHP. However, current approaches do not adequately address the key efficiency and cost challenges, making near-term prospects for commercial products unlikely.

One of the core technologies being developed is a low-cost, gallium-based high-temperature and high-efficiency solar diode, which provides an excellent match for a natural-gas-fired infrared emitter.

Researchers conceptualized an innovative approach to address both the efficiency and cost issues of current technologies to significantly boost power conversion efficiency to more than 30% and system efficiency over 80%, while keeping costs within the range of alternative CHP technologies.



Key features of the concept are:

- Use of high-efficiency, low-cost, standard-size, and mass-producible gallium-based TPV cells to reduce costs and increase conversion rate.
- Use of economical backing material on the cells to maximize heat transfer and facilitate adhesion to heat-exchanger surfaces.
- Integration of TPV cells directly into the heat-transfer interface to minimize heat losses and maximize cooling (keeping cells cool increases conversion efficiency and cell-adhesive life.)
- Use of mirrors with oxide coating for selective transmission of desired wavelengths and reflection back to the radiant surface of undesired wavelengths to maximize conversion rate and keep cells cool, maximize efficiency, and extend life.
- Use of radiant emitter with integrated heat recovery to maximize system thermal efficiency and prevent contamination of TPV surfaces.
- Use of high levels of internal recirculation to increase temperature uniformity, eliminate hot spots, and minimize $NO_x$ generation.

## Results

In this project, researchers demonstrated the viability of the concept of using back-reflective TPV cells to achieve high-efficiency conversion of natural gas energy to power. The results of bench-scale experiments show potential for designing a compact natural-gas-fired TPV CHP system that provides >55% power-generation efficiency and allows wide variations in the ratio of power and thermal energy (hot water) generated.

The project team designed and built a test facility consisting of a one-inch-diameter gas-fired radiant tube with burners and heat-recovery devices on both ends. The tube was surrounded by a cylindrical reflector to simulate back-reflecting TPV cells. The experimental effort focused on developing the gas-fired infrared (IR) emitter surrounded by a highly-reflective enclosure, since the integrated performance of various TPV cells could then be modeled relatively easily to estimate heat and power generation.

Test results show the possibility of achieving radiant tube emitter temperatures in the range of 2,400°F by increasing the firing rate, reducing the excess air levels, and increasing the regenerative bed volume. The $NO_x$ emissions during the tests were high; however, these can be reduced to acceptable levels by additional equipment modifications.

Adjustments were made to the test system and performance testing was conducted. The team was able to demonstrate stable combustion up to 5 kW input and also demonstrated the potential for using back-reflecting PV cells to increase TPV CHP efficiency.

The project team was able to:

- Achieve stable flames over a range of air/fuel ratios and firing rates, when firing from either end of the radiant tube
- Achieve self-sustained reversing operation without the need for an external ignition source, and
- Acquire proof-of-performance data (air and fuel flow rates, system pressure drop, air and exhaust gas temperatures, reflector temperature, etc.).

The project team explored design concepts for a 2kW TPV CHP system to facilitate test planning, and initiated development of the test plan for evaluating its performance.

In 2020, the project team tested panels with a short-wave IR burner fueled with conventional natural gas. The height of the burner relative to the PV panels was adjusted to obtain measurements of power output as a function of burner distance from the PV panels. The short-wave metal foam IR radiant burner was operated at 11,000 Btu/hr.

## Status

This project demonstrated at a prototype level that cost-effective, large-area, back-reflective, back-contact PV panels can generate reasonable power without water cooling, forced-air cooling, or the need for vacuum when irradiated by an IR source that contains enough of the radiated light spectrum with energy. Preparation of a Final Report is under way.

For the purpose of constructing an optimal TPV system, a more sophisticated burner could be developed with improved confinement and directional control of the radiation as well as potentially improved spectral emissivity.

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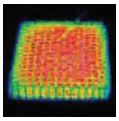
UTD Utilization Technology Development

# Next-Generation Infrared Burner



***In this project, researchers evaluated gas-fired infrared burners that use advanced metal foam material to offer end users new high-efficiency products. The project team is collaborating with material and burner manufacturers to advance the technology.***

## Project Description

Using gas-fired infrared (IR) heaters instead of electric-driven IR heaters can significantly reduce both source energy emissions and end users' operating costs. The goal of this project is to build on earlier developments to advance a gas IR burner for commercial and industrial use.

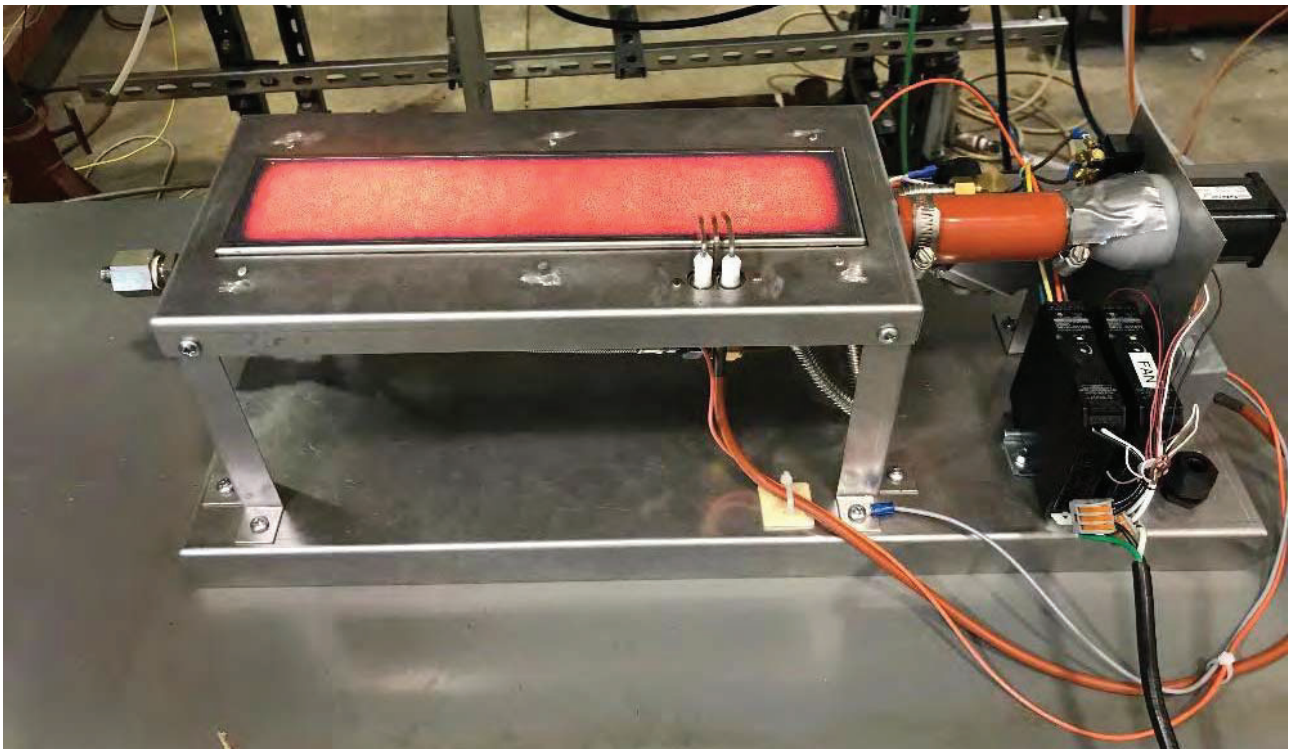
Unlike conduction or convection, IR heating uses radiative heat transfer, which transfers heat through electromagnetic radiation (light). As IR light is absorbed by the load material, its surface is heated. This surface-heating phenomenon can be highly efficient by avoiding the unnecessary thermal load of heating surrounding air.

The IR-heating industry divides IR heaters into short-, medium-, and long-wave products. The associated emitter temperatures as well as its radiant portion increase significantly at shorter wavelengths, while the response time decreases. While electric heaters are available across the IR spectrum, gas IR is available primarily in the medium wavelength range. Catalytic gas-fired heaters are also available in the long-wavelength range. The short response times allow precise control of work-zone temperatures with the short wavelength electric heaters. Electric IR also typically offers significantly greater turndown range compared to gas-IR and shorter response times for heating and cooling.

In this project, researchers investigated advanced metal foam IR burners, with better material properties. In the current phase of the project, the research team will design, build, and test in the field a prototype next-generation, high-response, higher-efficiency IR burner.

## Benefits / Market Implications

Currently, nearly 75% of the IR-heater market in commercial and industrial applications is occupied by electric units. Development of an advanced gas-fired IR burner that can meet market specifications will increase customer choice and save energy on a source basis by increasing the direct use of clean, affordable natural gas.



## Technical Concept & Approach

Specific tasks included:

- **Burner Design**

  The project team designed a laboratory-sized 35,000 Btu/hr burner with sensors, control, and valves with advanced material. This unit has broad flexibility and is well instrumented so a wide range of parametric tests can be conducted and data used to optimize design and operating conditions.

- **Laboratory Testing**

  A range of IR burner tests were conducted to demonstrate safe and stable operation, collect valuable data for burner optimization, and investigate the effect of all independent variables on the performance of the advance IR burner.

## Results

Researchers selected and tested multiple commercial IR burners to evaluate operational and emissions performance. Different materials and original equipment manufacturers (OEMs) were chosen for the testing to provide a spectrum of performance data. The key performance indicators for the burner testing were turndown, emissions, start-up and shutdown characteristics, and temperature uniformity.

Testing showed the advantages and key limitations of these burners. The high-throughput burners could provide high output; however, these led to high emissions and potential material degradation. Burner materials such as ceramics led to cracking due to thermal cycling and were difficult to form into different shapes. Other materials such as metal fibers lead to non-uniform mixing, non-uniform temperature profiles, and loss of fiber material due to high-temperature zones.

Metal foam materials testing showed promise in certain aspects, such as adapting to different shapes and layouts, more robust design, and improved thermal cycling characteristics. This material showed the potential to replace a majority of the materials and be able to provide a long-term solution to gas-fired IR.

Emissions and performance testing showed that the non-uniform mixing and high local temperatures led to increased $NO_x$ emissions (>20 ppm @ 3% O2). In addition, the start-up time for a gas-fired IR was high (>7 seconds) with burner material choice making a significant impact.

In 2018, the project team completed preliminary testing of a burner and discussed the results with partners. More extensive testing was suggested to completely evaluate the burner performance.

*Four initial test samples included in the early stages of testing.*

Based on the testing of all the burners and in discussion with OEMs, some materials show great promise but also challenges to be considered, such as:

- Low backpressure can make air/fuel distribution difficult across a large burner face
- Life expectancy may need to be demonstrated
- Semi-rigid – material can tear or fracture if bends are too sharp
- Safe mode of failure if subjected to extreme temperature must be demonstrated
- Eliminate or reduce potential for backlighting
- Material can be subject to oxidation, and
- Material may trap particulates.

In 2019, emissions and temperature measurement testing were conducted at different axial locations from the burner surface. A report was issued in July 2019 that summarizes the differences in burner configurations tested.

In 2020, researchers teamed with a burner manufacturer and an advanced material manufacturer to resolve key issues to move the technology to the market.

## Status

Project work has been slowed by COVID-19, but progress is being made to advance this high-efficiency, high-performance new product for end users.

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UTD Utilization Technology Development

# Energy-Recovery Heat Exchanger

***This project involves designing and demonstrating at full industrial scale in North America an advanced, compact, and economical recuperator technology to preheat furnace combustion air that has been proven in Europe. Operators of commercial and industrial furnaces can use this technology to achieve large energy savings.***

## Project Description

A common way to increase the efficiency of commercial and industrial furnaces is to use a heat exchanger to transfer heat from hot exhaust gas to combustion air. While preheating combustion air can lower natural gas demand by 10%-40%, many furnaces do not employ this simple means of energy savings because the higher equipment costs make payback times too long to justify the investment.

This project addresses this issue by demonstrating a technology known as the Radiative Recuperator with Secondary Emitters (RRSE) – a technology that has been found to be more compact, less expensive, and more efficient than heat exchangers currently available in North America. The RRSE's shorter payback time can enable this technology to be installed on many commercial and industrial furnaces that currently have no cost-effective means to recoup exhaust-gas heat to save energy and reduce emissions.

The objective of this project is to demonstrate the capabilities of the RRSE in a real-world setting in North America.

The RRSE was developed at the Center for Energy Efficient Technologies (CEET) of the National Academy of Sciences, Ukraine. The RRSE has undergone significant development, modeling, laboratory testing, and initial industrial testing. But despite extensive testing and impressive performance results, the RRSE has never been deployed outside Eastern Europe. The demonstration supported through this project provides an opportunity to demonstrate how this advanced heat-recovery device can benefit many industrial end users.

The RRSE is supplied with flexible inserts known as secondary emitters inside the tubes along the full length of the system. The arrangement has been demonstrated to be superior to existing recuperator designs equipped with spiral inserts (turbolators). Compared to conventional heat exchangers, the RRSE has:

- Increased heat transfer from flue gas to combustion air
- Higher combustion-air preheat temperature
- Decreased heat-transfer surface area
- Lower total weight of recuperator metal, and
- Lower wall-surface temperatures (leading to longer service life).

This UTD project supports and co-founds a larger industrial demonstration project with prime funding provided by the California Energy Commission (CEC) on an aluminum-melting furnace.

## Benefits / Market Implications

This project addresses a large potential market for furnaces that are not yet using combustion-air preheating. These furnaces are found in industry (die casting, foundries, minerals and ore processing, various chemical processes), agriculture (drying, roasting), and commercial cooking (bakeries, general cooking, chips, brewing). Equipment sizes are different from one industry segment to another, but the RRSE is highly adaptable and can easily be sized for a wide variety of commercial and industrial applications.

*Re-designed recuperator in the laboratory.*

The RRSE can provide cost-effective energy savings on a wide range of furnaces. To illustrate one large potential group of end users who could benefit from RRSE heat exchangers, the North American Die Casting Association estimates there are more than 400 die casters in the United States; most do not presently use any exhaust-gas heat-recovery devices. Saving 30% energy on 30% of the die-casting furnaces alone would reduce U.S. gas demand by 60 million SCF per year.

## Technical Concept & Approach

Specific tasks for this project include:

- **RRSE Design**

  The full-sized design serves as a template for design of various sizes and configurations.

- **Fabrication**

  An industrial configuration of the RRSE will be fabricated specific to the field test demonstration site furnace capacity.

- **Industrial Installation**

  The RRSE will be installed on the exhaust duct of an aluminum-melting furnace at a die-casting company in California. This will be part of a larger installation of equipment designed to demonstrate energy savings on this furnace.

- **Demonstration Testing**

  Independent variables to be evaluated include number of secondary inserts, temperature of preheated air, velocity of exhaust gas and air through the RRSE unit, and volume of exhaust gas processed. Results will be used to optimize the system design and to validate the technology in preparation for commercial roll-out of the technology in North America.

## Results

Researchers are using a recuperator design with a stacker for scrap preheating to maximize heat recovery. Researchers found that potential energy savings of 19% can be obtained with air preheating alone. When scrap preheating is combined with air preheating, energy savings as high as 34% can potentially be achieved.

Several rounds of preliminary RRSE designs were carried out to reach a design that fits the geometry of the space available without interfering with furnace operation.

Computation Fluid Dynamics calculations were completed for the three-pass design, showing that the recuperator design is able to provide the heat recovery desired for the RRSE. Also, calculations showed that the insulation is sufficient to keep the recuperator surface temperature at a low, safe value.

To date, activities included project planning and execution; completion of the air-quality permit modification; recuperator modeling, design, and fabrication; and furnace refurbishment.

The furnace was restored, new insulation brick installed, and the burners mounted. A new control panel using a modern micro-processor was installed and programmed.

Fabrication was completed in 2019 and the furnace was installed at the host site in early 2020.

## Status

The team found the installed burners were unacceptable for this application. An investigation found a different burner that is suitable for this furnace. COVID-19 has slowed that activity, but that activity is in progress in the third quarter of 2020. Data will be collected and analyzed once the furnace is operating.

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# Recovery of Water from Humid Exhaust Gas to Save Water and Energy

***Researchers are investigating a novel new thermal ejector technology to recover useful process water from humid exhaust gas, which in turn can increase overall efficiency. The project involves a field demonstration at a large industrial facility in California.***

## Project Description

Industries that use large volumes of water to cool natural-gas-fired furnaces could save money if water from hot exhaust gases can be economically recovered and returned to the plant for cooling and other uses. Toward this end, this project is focused on thermal ejector technology that uses the low-level heat in exhaust gas to recover usable, room-temperature water, which in turn can increase overall efficiency.

In this project, a research team is demonstrating an innovative self-regulated ejector cooling system that generates colder water at a manufacturing plant. This project is being conducted in collaboration with the California Energy Commission.

The thermal ejector technology to be demonstrated in this project is the first practical technology that can recover room-temperature water that can immediately be returned to a plant and used for process cooling.

*California host site facility.*

## Benefits / Market Implications

Operators of drying, curing, commercial cooking, and other agricultural and industrial processes with humid exhaust gases are strongly positioned to realize large benefits from utilizing thermal ejector technology. This technology offers the opportunity to reduce the huge water demand at power plants. Overall, freshwater savings are estimated at one billion gallons per year in California if deployed for example on 50% of applicable industrial and commercial furnaces.

The technology has the potential to provide additional service and economic benefit for the same amount of gas combustion. Some sites can also save significant amounts of natural gas when warm water produced by a unit displaces ambient temperature waster supplies. Carbon dioxide emissions would also decrease at sites where recovered warm water reduces natural gas demand.

## Technical Concept & Approach

For this project, a demonstration of thermal ejector technology will be conducted at a major industrial host site in California. The project team will attach a demonstration scale unit to the humid exhaust gas of equipment at the facility, and recover water from a portion of that exhaust gas. The demonstration system will be based on the laboratory-tested prototype, but will have production capacity of one ton of water per hour (~241 gallons/hour).

Using the remaining thermal energy in the humid exhaust gas from the facility's drying kiln will help to conserve water (a very valuable resource in California) and enable the plant to receive an added benefit from the same natural gas already being burned in the kiln, thereby also conserving natural gas.

Project work will begin with modeling and design of the demonstration unit. Plant information will be used to model and design the demonstration unit. The unit is expected to recover water from 10% of the kiln exhaust gas. After modeling and design calculations, a skid-mounted system was designed.

Demonstration testing will be carried out over a period of at least six months. A full set of performance data will be collected. When the demonstration testing data is available, the project team will develop a technology transfer strategy, including a product-readiness plan.

## Results

Initially, project representatives visited the demonstration site to meet the project team, initiate the air quality permit modification process, and address developments for the water-recovery unit. Information from the visit was sufficient to plan the positioning and size of the skid-mounted demonstration unit.

The site host provided exhaust gas data for a furnace similar to the one to be used for the demonstration. This data confirmed the anticipated range of exhaust-gas compositions, including water content, to be expected. Data on exhaust gases confirmed the anticipated range of exhaust gas compositions, including water content, to be expected.

The process layout and fabrication drawings were completed, and the full materials and equipment list with vendors and prices was completed.

Additional research focused on modifying and simplifying the demonstration system design.

The final system design has one quarter the footprint of the first system and is much more reasonable for scale-up. Assembly of the demonstration unit will begin when all heat exchangers and other components are received.

In the final system design, no external water is required and the power demand was greatly reduced. Components are reasonable in size because there are no gas to gas heat exchangers in the system.

Final design and system layout for the improved water-recovery system were completed with assembly details for the electric boxes, wiring, and sensor locations.

The system will be placed on a single skid with a footprint of 31 x 8 feet.

Data from the host site confirmed the anticipated range of exhaust gas compositions, including water content, to be expected. The water content in the 256ºF exhaust gas is 43 volume percent (32 weight percent). While the project goal is to demonstrate water recovery of 100 gallons per hour, the amount of water recovered will depend on ambient air temperature which changes from day to night and around the year. Review of historical weather data shows that although temperature can reach 117ºF on summer days, the average year-round temperature is 73ºF. This data has been used to design a demonstration unit producing 100 gallons per hour of water at 73ºF. Water recovery will be lower at higher ambient air temperatures.

The project team developed a simplified design. Detailed fabrication drawings were completed. All equipment was ordered with attention turned to assembly and final heat-exchanger fabrication.

The skid framework and electrical boxes were completed. All components were installed on the skid frame. Wiring and sensors were installed and checked for proper installation and accuracy. The skid is complete and ready to be moved to the host site for installation.

## Status

The skid was ready to be moved in February 2020 but the pandemic prevented this move. All project activities have been on hold until the skid can be installed. In late August 2020, the host site announced the skid can now be moved and installed. Installation is being coordinated through the host site and will be completed in September 2020. Shakedown and startup will then take place. Data collection is anticipated to start by the beginning of November 2020.

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UTD Utilization Technology Development

# High-Efficiency Thermo-Vacuum Commercial Clothes Dryer

***The goals of this project are to develop and demonstrate an advanced prototype gas-fired commercial clothes dryer. The technology has the potential to save at least 50% of the energy used in the commercial laundry sector, while also reducing drying time and water consumption.***

## Project Description

The most common commercial clothes-drying method uses a combination of electricity-driven centrifuge with consequent moisture evaporation by heated air. Research suggests that the integration of a thermal-driven ejector vacuum system into a commercial dryer can provide significant a performance enhancement along with substantial fuel savings and reduced water consumption.

The goals of this project are to develop an advanced clothes dryer concept and demonstrate the technical and economic benefits of an innovative ejector-based technology, which can minimize heat losses and speed up the drying process up to 10 times due to the simultaneous thermal and vacuum effect on moisture removal from the capillary fibers of the laundry being dried. At the same time, the heat used for vacuum-ejector operation is then used to heat the mass of wet laundry.

## Benefits / Market Implications

Using only one thermo-vacuum dryer with a one-time load of 50 pounds of dry laundry results in an annual savings of approximately $8,000. The annual savings from the use of new drying technology across the nation has a potential to reach over $2.5 billion.

Due to improved efficiency, the technology being developed in this project is expected to have the potential to save at least 50% of the energy used for commercial clothes drying.

Preliminary estimated benefits of the clothes-drying concept under development are:

- Higher Combined Energy Factor (CEF): 5-6 (estimated) versus 3-4 (ENERGY STAR, conventional)
- $6K-8K annual savings (payback period under two years)
- Drying-time reduction 5-10 times (depending on the fabric type and selected drying conditions), and
- At least 20% reduction in water consumption.

The primary target markets impacted will be commercial laundry markets, including on-premise laundries (OPL), multi-family housing, dry cleaners, industrial, and coin-operated facilities. OPL facilities typically include laundries in healthcare, lodging and resorts, and educational sectors, among others.

## Technical Concept & Approach

The main element of the thermo-vacuum drying system is an ejector, which simultaneously provides a dynamic vacuum and moisture removal from the drying chamber.

The operation relies on the heat produced by the gas-fired boiler circulating mostly in a closed cycle between the vacuum ejector and the rotary drum. This leads to continuous heat recuperation, which makes the process highly energy efficient.

This technology should not require replacing existing laundry equipment completely; it can be used to upgrade existing dryers to a new technology level. In addition, this technology may allow combining both washing and drying processes into one unit in new installations. This will simplify the system design, reduce the cost of the drying process, and reduce the operation footprint.

In Phase 1 of this project, researchers performed a commercial market review along with a preliminary cost/benefit analysis and estimation of a simple payback period.

UTD's Phase 2 efforts co-funded a 24-month project with prime funding provided by the U.S. Department of Energy to:

- Characterize a refined concept and experimentally define the driving curves for three test fabric types
- Specify key components of the prototype to be tested
- Develop a test plan and matrix, and
- Identify applicable protocols.

## Results

In Phase 1 of this project, researchers conducted a bench-scale evaluation of the technology concept and proved its feasibility. A numerical simulation and energy balance analysis of the concept was performed. A bench-scale system was then constructed by modifying a commercially available residential clothes dryer with an integrated heat exchanger and steam-driven ejector.

Preliminary testing was completed with encouraging results. The removal of the main part of the moisture is conducted at high entrainment ratio values. Low pressure in dryer intensifies moisture evaporation and removal. That indicates a possibility of either reduced drying time or increased throughput.

A thermodynamic analysis of the thermal vacuum drying cycle showed that the overall efficiency of using heat energy increases by a factor of two or even more.

The heat transfer coefficient from condensable steam through the wall to the wet laundry in the perforated rotating drum decreases as drying progresses, but this does not adversely affect the heat and mass transfer process due to a sharp decrease in the heat and mass flow of steam at the final stage of drying.

Bench-scale experimentation for drying of selected fabric samples was conducted. Drying curves serve as a basis for the prototype unit design.

A full U.S. patent application was filed in December 2019.

The commercial product lines were assessed and evaluated by the project team. Outreach to major equipment OEMs was conducted, with promising and ongoing discussions. A 50-pound system was defined as the most popular benchmark for the design and performance evaluation.

A commercial/industrial laundry facility was visited and a commitment obtained for a potential follow-on field demonstration.

## Status

The feasibility study and bench-scale evaluation demonstrated the superior performance of the technology and provided promising results for moving the technology forward:

- Heat consumption is reduced by more than three to four times, heat loss is minimized, the waste heat is returned back to the drying cycle while recovered water may be reused in the wash cycle.
- Drying time decreased by five to 10 times compared to convective heated air drying cycle.
- Thermo-vacuum-dried laundry has lower stiffness and no observed deterioration of the fabric. The final temperature in the drying cycle can be varied over a wide range; if necessary, it can be maintained at any level by adding a portion of heat from steam after ejector system.

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UTD Utilization Technology Development

# Long-Term Performance and Reliability Assessment of CHP and DG Systems

***Researchers are analyzing the long-term reliability and performance of high-efficiency gas-fueled combined heat-and-power (CHP) or distributed-generation (DG) technologies. The goal is to identify potential opportunities to further improve the performance and reliability of CHP/DG systems for end users.***

## Project Description

Combined heat-and-power (CHP) applications typically improve energy efficiency, reduce operating costs, and enhance energy resilience for both individual customers as well as the regional power grid. Likewise, natural gas distributed generation (DG) or micro-grids have the potential to generate power during widespread outages or to be dispatched by electric utilities during periods of high electric demand to relieve local grid stress and prevent brownouts.

The configuration of CHP systems vary widely in capacity, efficiency, fuel type, and prime mover. In this project, researchers are analyzing the performance of existing natural-gas-fueled power CHP or DG technologies based on available data from select sources.

The ultimate goal is to identify potential opportunities to further improve the performance of CHP/DG systems for facility managers and other end users.

For this project, researchers are analyzing long-term monitored performance data on hundreds of CHP installations in multiple states and are currently working with The New York State Energy Research and Development Authority on a CHP re-commissioning program.

## Benefits / Market Implications

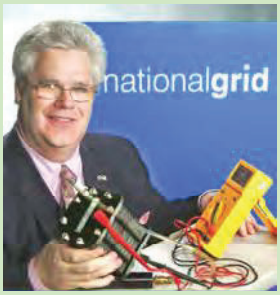
CHP is recognized as a proven technology for improving energy efficiency. Twenty-three states include CHP in one form or another as part of their Renewable Portfolio Standards or Energy Efficiency Resource Standards. A number of states – including California, New York, Massachusetts, New Jersey, and North Carolina – have initiated specific incentive programs for CHP.

This project is analyzing the baseline operational reliability of CHP/DG systems, ranging from micro-CHP systems under 50 kW to industrial CHP applications. Facility managers, researchers, manufacturers, and utilities can use this information to identify potential improvements in the operational reliability of CHP/DG systems. An established baseline will also allow current and potential users to benchmark the reliability of natural gas CHP systems.

## Technical Concept & Approach

For this project, researchers are reviewing and summarizing available reliability data on current operational CHP or DG systems. The team is also exploring how performance can be used to infer traditional operational reliability parameters. CHP operation reliability data is

*A variety of CHP and DG equipment types were studied.*




*"National Grid is a member of the DOE's Better Buildings CHP for Resiliency Accelerator and is happy to support a project like this that can advance CHP and DG technology. We have long known the potential for CHP and DG systems to support our customers. Utility networks are large and scalable, but rely on reliable equipment operating efficiently at high load factors. This research promises to make this a reality."*

*- Christopher A. Cavanagh*
*Principal Program Manager*
*Innovation and Development*
*National Grid*

being collected from multiple sources, including the Department of Energy's (DOE) CHP Technical Assistance Partnerships, DOE CHP Installation Database, and others.

The project team created a detailed CHP database of 275 sites and more than 300 prime movers. The database consists of multi-year performance data from installed CHP systems, ranging from microCHP systems under 50 kW to larger commercial applications such as multifamily residences, hospitals, office buildings, and educational facilities. CHP prime movers include reciprocating engines, micro-turbines, fuel cells, and gas/steam turbines. The database includes measured power production and runtime, as well as calculated parameters that indicate the long-term reliability of CHP systems.

This analysis will quantify the reliability of a wide range of CHP technologies and identify typical outage or failure modes. This study will allow current and potential users to benchmark the reliability of natural gas CHP, and identify any potential research needed to improve the long-term performance of CHP systems.

Data is being grouped into technology categories for comparison based on key parameters, such as prime mover type, capacity, and application (e.g., continuous, thermal led, and peak shaving).

## Results

The project team developed methodologies to determine an operating strategy based on existing CHP data and a statistical approach to predict planned vs. unplanned downtime as an indicator of system reliability. This approach includes the development of custom software algorithms to compare the time of outages to the same time of day within a given time period. The project team also developed an approach to account for scheduled maintenance based on prime mover type.

Algorithms were modified to improve the handling of missing data. Algorithms were further refined by analyzing a subset of 40 systems with known operating strategies to validate algorithm results.

The CHP database is grouped into technology categories for comparison based on key parameters, such as prime mover type, capacity, and application (e.g., electric led, thermal led, peak shaving, etc.). The algorithm is then used to analyze CHP performance data within each category to identify the equipment types, applications, operating modes, or other parameters that impact CHP reliability.

The project team identified key metrics based on the *IEEE Guide for Electric Power Distribution.* These metrics will be used to quantify reliability and identify key parameters that influence reliability, such as prime mover type, size, building application, and operational strategy.

Several prime mover types (including reciprocating engines, micro-turbines, fuel cells, and gas/steam turbines) were analyzed with capacities ranging from under 50 kW to large commercial applications of more than 2,000 kW. The operational strategy for each system is categorized as thermal load following (TLF) or non-thermal load following (non-TLF), such as electric load following or baseload operation.

## Status

Researchers are assessing the validity and robustness of the methodology using power data to identify and classify outages or unexpected equipment failures. Results will be compared to manufacturer data, operation and maintenance logs, and known parameters to continue refining the algorithm to identify unplanned outages and quantify long-term operational reliability.

The project team is summarizing results and completing the Final Report for distribution.

The research team continues to conduct detailed analysis to identify parameters that may impact CHP long-term reliability. These metrics will be used to quantify reliability and identify key parameters that influence reliability, such as prime mover type, size, building application, and operational strategy.

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UTD Utilization Technology Development

# High-Efficiency Ultra-Low-$NO_x$ Commercial Boiler Burner

***A field test has successfully demonstrated a commercial prototype high-efficiency, economical, natural-gas-fired burner to meet ultra-low-$NO_x$ emission requirements in California and future requirements anticipated elsewhere. To date, a commercial laundry host site has documented 9% savings in fuel use during more than 10,000 hours of real-world conditions, with emissions <9ppm $NO_x$.***

## Project Description

Current state-of-the-art burners are able to achieve <9 vppm $NO_x$, but with high levels of excess air, which reduces boiler efficiency. Options for achieving low emissions for burners in the commercial sector are to either install Selective Catalytic Reduction (SCR) or Flue Gas Recirculation (FGR). However, SCR systems are expensive and require additional permitting for ammonia slip and added maintenance costs, floor space, and expendable costs (urea and aqueous ammonia). The FGR systems also require additional equipment (e.g., a hot fan, insulated ducting, and controls). In addition, a high level of recirculated gases may present challenges to achieve single-digit emissions. A cost-effective, high-efficiency low-emission burner would eliminate the need for SCR and FGR.

Through previous UTD studies, a method was developed for improving flame stability and mitigating combustion noise, a major issue with low-emission burners. In this project, the technique is being incorporated into the burner design.

A pre-commercial prototype burner was designed in collaboration with Power Flame, Inc., a major U.S. burner manufacturer. The burner demonstrated the ability to achieve <9 vppm $NO_x$ emissions with 4:1 turndown. $NO_x$ emission requirements of 9, 12, or 20 vppm are satisfied through adjustment of excess oxygen, allowing the same burner to operate across a wide spectrum of U.S. boiler markets.

In comparison to conventional ultra-low-$NO_x$ (ULN) burner technologies operating at <9 vppm $NO_x$, the prototype burner provides a 2.3 percentage point gain in efficiency for operation at <9 vppm $NO_x$ (83.6% versus 81.3% efficiency).

The objective for this project is to field test and deploy a commercial prototype high-efficiency, low-emission, natural-gas-fired burner to meet current requirements in California as well as expected future requirements in non-attainment areas throughout the world. The ultimate goal is to commercialize a high-efficiency commercial burner that is economically and operationally more attractive to end users than current boiler systems.

*Installation at California commercial laundry facility.*

*"Having been in the ultra-low-$NO_x$ market for years, we quickly saw the benefits of a non-FGR, high-efficiency, single-digit $NO_x$ emissions burner. It has the potential to change how we view combustion to significantly improve the quality of the air we breathe"*

*- Robert Rizza*
*VP Sales & Marketing*
*Power Flame, Inc.*

The project team secured a clear path to market through its partnership with Power Flame. This project is being cofounded by the California Energy Commission.

## Benefits / Market Implications

The burner offers a cost-competitive alternative – in an easy-to-operate and simple design – to currently available equipment for the commercial hot-water/steam-generation market, and a means for achieving compliance in several major markets. Monitoring the performance of a commercially-integrated low-emissions boiler/burner system, complete with controls package, will provide critical data needed to facilitate its commercialization.

## Technical Concept & Approach

This project specifically focuses on incorporating advanced control systems and combustion stability techniques into a burner design. The project team is addressing the remaining technical requirements for the pre-commercial burner technology through support and monitoring of a field demonstration at a linen supply company in California.

The technology is unique in its ability to achieve ultra-low emission levels and increase boiler efficiency compared to conventional burners. The burner incorporates dynamic flow geometry to achieve induced entrainment of cooled products of combustion, providing greater spatial uniformity in the distribution of the reacting species, heat release rates, and temperatures. Also, the technology allows for staging of combustion reactants within the combustion chamber, providing further thermal distribution within the boiler chamber. These features minimize localized high-temperatures regions within the flame, limiting the production of thermal $NO_x$ in a simple and robust design.

In the demonstration, a 125 HP burner/boiler system supplies steam to the commercial laundry facility. The goal is to evaluate the boiler/burner system performance over an extended monitoring period at the demonstration host facility. Technicians will make necessary modifications to the burner design and facilitate demonstration of a first commercial deployment of the burner.

## Results

The monitoring system for the pre-commercial boiler/burner system was installed in early 2018 at the commercial laundry facility. The boiler/burner consistently achieved emissions <9 vppm $NO_x$ without the need for costly and complex SCR, external FGR, or operation at high-excess-air levels. Extensive evaluation of the technology for over 10,000 hours of real-world conditions proved the burner capable of meeting low-emission levels while operating with relatively low excess air and high efficiency levels.

The host site demonstration documented a 9% savings in fuel usage as compared to the baseline boiler.

In addition to the continuous year-long operation and the energy savings, the host site operations manager noted that: 1) The control panel display provides the operator with a clear, concise readout of the operating parameters, 2 Operating conditions are stable and stay consistent with set points, and 3) The data-logging system provides operator knowledge for troubleshooting issues that may arise.

Operating emissions are much below the regulatory threshold, with significant fuel savings when compared to the previous installation.

A commercial burner was shipped to the host site in 2019. Updated emission regulations sets a new stricter emission limit for units of the size proposed on or after January 1, 2020. The South Coast Air Quality Management District considers the replacement burner as a "new" unit installation and required a new emission limit of 9 ppm $NO_x$ beginning January 1, 2020. A permit was issued in mid-February.

## Status

Burner installation and commissioning was scheduled for mid-March of 2020 but was delayed due to the COVID-19 pandemic and shelter-in-place directives in both California and Illinois.

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UTD Utilization Technology Development

# Cost Optimization of 3D Printing of Advanced Burners for CHP and Distributed Generation

***Research is being conducted to provide manufacturers a low-first-cost, high-efficiency, low-emissions advanced nozzle burner with improved performance and economy by using new 3D printing techniques and optimizing the design, material selection, processing, and other factors.***

## Project Description

Manufacturers and the natural gas industry are looking at methods to reduce first costs for end users and rate-payers, improve system efficiency, reduce emissions, and provide products and services with greater market acceptance and improved customer satisfaction.

Additive manufacturing (AM) or 3D printing provides key benefits to offset these challenges and is making manufacturing more competitive and attractive. In addition, using AM opens up new design opportunities to produce on-demand components and can significantly improve efficiency and reduce emissions, while reducing spare parts inventories.

Three-dimensional printing has gained traction in multiple industries. However, it is important to manufacture the product by Designing for Additive Manufacturing (DfAM). Increasing part value through intelligent optimization helps significantly lower the part cost. Effective DfAM can result in a reduction of support structures, material, part weight, inventory, maintenance, and assembly labor, leading to considerable cost savings and a product that performs better and is more competitive.

Researchers designed, developed, and tested a 3D-printed advanced nozzle in a previous UTD project. This design incorporates beneficial complex, unique features that are impossible or very difficult to manufacture using traditional methods.

Low-volume costs, reduced lead-time, complex designs, and customizable parts are the key benefits of 3D printing. However, for larger-volume production, the cost is not yet competitive with traditional manufacturing. In this project, researchers are evaluating large-volume manufacturing costs using 3D printing and other techniques to significantly reduce this cost.

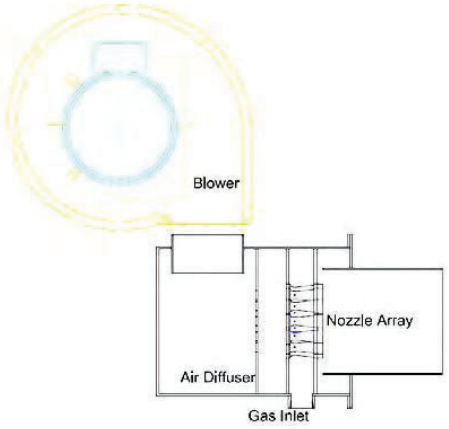
Specific project goals are to:

- Design and develop a 200kW ultra-low-emissions 3D-printed burner capable of achieving the performance metrics (< 5ppm $NO_x$, < 10 ppm CO, and turndown of > 6 to 1) for combined heat and power (CHP) applications
- 3D print the burner with the key complex features, and
- Test the scaled-up burner at atmospheric pressure to demonstrate the performance and operability, discuss test results with partners, and develop a plan to perform pre-commercial testing in a single-burner test rig.

## Benefits / Market Implications

The insights gained from this research are expected to benefit users of a wide variety of gas-fueled equipment that can utilize the advanced nozzle burner.

Current 3D-printing costs already show a potential 25%-50% reduction in the cost of current commercial water-heater burners, for example, while achieving superior efficiency, operation, and emissions reductions. As the technology progresses and better and faster 3D-printing machines are introduced, the economies of scale will have a significant impact on the final cost of the burner.




*Design for testing.*

These cost benefits will directly or indirectly help customers and natural gas users. Improved efficiency with low first-cost, reduced lead-time, and reduced GHG, $NO_x$, CO, and other emissions can have a positive affect of safety, reliability, and affordability while enhancing environmental protection.

## Technical Concept & Approach

The project evaluates techniques to improve performance while lowering first costs for the advanced nozzle 3D-printed burner design for combustion turbines that can be used in CHP and distributed generation.

Specific tasks include:

- **Design and Process Improvements to the Advanced Nozzle Burner**

  Researchers will identify and adapt the design and process changes. One of the key aspects is to lower the build time that will lower the cost of the component. Other key parameters are 3D-printing machine selection (i.e., binder jetting). Also, machines that can produce the parts at the lowest energy input will be evaluated. Researchers will also review different low-cost materials available for this design.

- **3D Print Design and Evaluation Performance**

  After selecting the 3D-printing machine, along with the design and process parameters, the project team will 3D print the advanced nozzle burner. Researchers will evaluate and document the cost. Further, burner testing will be performed with a scaled-up burner at atmospheric pressure to evaluate efficiency, emissions, turndown, and overall performance.

- **Review, Report, and Discuss 3D-Printing Costs with Manufacturers**

  Researchers will showcase the benefits and challenges of the technology with respect to cost parameters. This will enable a dialog with end-use equipment manufacturers that will provide key inputs to evaluate the advanced nozzle as a design for multiple applications and 3D printing as a manufacturing method.

## Results / Status

Initially, researchers reviewed the design and investigated methods and techniques to lower the build time and other aspects of the design without sacrificing performance using 3D printing. The project team is examined methods to conventionally manufacture the advanced nozzle for comparison, trade-off analysis, and impact on performance.

Researchers are also reviewing a design for air-heating applications, which can be extended to CHP and distributed generation applications as well.

In 2019, researchers designed a burner and an individual nozzle was fabricated to evaluate the burner features. In discussions with partners, researchers identified a test rig for performing the burner testing. Drawings were made for the fabrication and assembly of the burner unit in a furnace for evaluation. Technicians identified blowers and other equipment required to perform the testing. The team built hardware for the outer air entry section and the burner assembly and fabricated the outer assembly for the air inlet section.

In 2020, the project team completed partial fabrication of the test rig and the scaled-up burner was 3D printed. Computational Fluid Dynamics analysis for the improvement of the air/fuel mixing in the plenum and within the burner is being performed to reduce $NO_x$ and CO emissions.

## Status

Researchers are completing a cost comparison and analysis.

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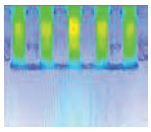
UTD Utilization Technology Development

# Advanced Immersion Tube Burner



***A research team is designing, building, and testing a prototype low-cost, high-efficiency immersion tube burner that is simple to control and has low emissions. The burner will be capable of meeting increasingly stringent environmental regulations for end users in the food-processing industry and many other applications.***

## Project Description

Gas and electric immersion heaters are common for heating liquids in a variety of applications, including food processing such as frying and pasteurizing.

There are an estimated 25,000 or more immersion tube burners in use in the U.S. This does not include a much larger number of these units used in the oil and gas industry. For comparison, oil and gas operations in Alberta, Canada, alone, use an estimated 20,000 to 40,000 immersion tube burners, according to 2005 analysis performed for Petroleum Technology Alliance Canada.

Electric heaters have advantages in terms of ease of installation, turndown, compactness, and onsite efficiency, while gas-fired heaters have lower fuel costs. Electric heater controls are also generally simpler and easier to operate. In gas-fired designs, the bath liquid achieves elevated temperatures by firing natural gas through a metal tube immersed in liquid. The tube could be of a variety of configurations (straight through, U-shaped, W-shaped, circular etc.). Because of large variations in tube configurations and the very high cross-sectional firing intensities required, combustion improvements are difficult and current burners continue to have limitations with combustion stability, turndown, emissions, and controls.

Immersion tubes are generally 1-1/2 inches to eight inches in internal diameter, with firing capacities of 24,000 to 8 million Btu/hr. Assuming an average size of 1.5 million Btu/hr, and a 50% duty cycle, the total natural gas used is estimated at 4.4 billion Btus annually.

The focus of this project is on developing a low-emission, high-efficiency advanced immersion tube technology. Besides immersion tubes, the technology may have applications in water heaters, firetube boilers, steam generators, duct heaters, gas turbines, air heaters, absorption chillers, thermal oxidizers, synthetic gas combustion, and combined heat and power systems.

Project efforts will help end users meet increasingly-stringent environmental regulations while retaining an easy-to-operate natural-gas-fired unit.

*Examples of immersion tube burners available from various manufacturers.*

## Benefits / Market Implications

The technology being developed in this project would be applicable to immersion tubes over a wide size range and offers a number of benefits, including:

- Reduced $NO_x$ emissions to <10 ppm, compared to common levels of 35-40 ppm. This would translate to 1,200 tons/year $NO_x$ reduction, assuming a 50% capacity factor. State-of-the-art low-$NO_x$ burners suitable for this application often claim <25 ppm $NO_x$ at 3% O2, but available actual test data can be limited.
- Increased efficiency to >80%.
- Potential lower costs due to increased manufacturing/production efficiency by using advanced 3D manufacturing techniques.
- Applicable to a wide range of immersion tube burners and designs in current use, and in some cases on a retrofit basis.

## Technical Concept & Approach

Researchers tested a burner concept developed in part during a prior UTD project. The burner, with prototypes manufactured by UTD research partner Oak Ridge National Laboratory, has the potential to provide a very high turndown ratio, uniform heat flux, and low $NO_x$ levels. It also has simple controls. Once set, it only needs to control combustion airflow to meet the demand. The design inherently allows the air/natural gas ratio to self-regulate over the turndown without the need for external controls.

In laboratory tests, the burner achieved less than five ppm $NO_x$ (at 3% O2) with low CO on an un-insulated and un-cooled combustion chamber. In an immersion tube application, it could potentially generate comparable $NO_x$ levels at significantly lower excess air conditions. This project seeks to further develop this technology and:

- Achieve 10:1 turndown, <5% excess air for high efficiency, and <10 ppm $NO_x$ and <50 ppm CO over the turndown range
- >80% efficiency over the entire turndown range
- Demonstrate stable combustion and reliability
- Secure a commercial manufacturing partner and the first potential licensee of the new technology, and
- Demonstrate cost-performance benefits for end users.

## Results

Researchers designed a burner suitable for common entry-level products. Designs for the multi-nozzle burner for sizes up to 8 million Btu/hr were developed to facilitate test planning. Based on these designs:

- A 3 million Btu/hr burner will have an approximately seven-inch inside diameter. The design incorporates flow-straightening vanes in the air inlet to improve distribution of combustion of the aspirated natural gas to the nozzles.
- An 8 million Btu/hr burner will have an inside diameter of about 12 inches. The $NO_x$ emissions with the larger nozzles could be slightly higher at comparable excess air levels.

Researchers completed a plan for evaluating the burner performance over a range of operating conditions. This includes a test matrix, schedule, duration, and anticipated measurements.

In 2019, researchers initiated a detailed design of a 100,000 Btu/hr burner for laboratory testing in a simulated immersion-tube environment. Researchers evaluated different design specifications for the immersion tube burner and finalized the design of a 200,000 Btu/hr burner for 3D printing. The burner was designed to use a blower and controls from a commercially available immersion tube burner. The burner hardware was subsequently 3D printed and inspected. Computational Fluid Dynamics analysis to assess velocity and pressure profiles using for cold flow modeling was conducted.

The project team evaluated different immersion tube burner design configurations for impacts of the nozzle configuration, size, throat diameter, number of nozzles, and the included angles of the converging and diverging sections of the venturi nozzles.

A delay from a fabricator – combined with delays related to COVID-19 – significantly impacted progress. A transition occurred and efforts reside with an alternate fabricator to maintain progress on this project.

## Status

Testing was originally scheduled for March-April of 2020, but has been delayed due to COVID-19.

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UTD Utilization Technology Development

# Sheet Metal Surface Burner Evaluation

***Researchers evaluated a novel sheet metal surface combustion burner through laboratory testing in order to validate the performance of the burner in a current boiler, assess best applications for ratepayers, and identify broader uses and opportunities.***

## Project Description

In this project, a novel sheet metal surface combustion burner developed in Europe was evaluated. The technology features a three-dimensional surface fabricated from a single layer of sheet metal. The formed raised features in the sheet metal reportedly provide a slight elevation of the flame above the service. The result of this elevation has been described as allowing improved flame stability, very high turndown ratios, and performance at low and high firing rates.

The manufacturer claims that the burner:

- Provides a reduction in emissions (up to 50%) compared to currently widespread employed surface combustion burner technology
- Has a high modulation ratio (40:1) with high flame-retention performance while maintaining the flame above the burner surface for increased burner lifetime, and
- Is less expensive than current metal fiber burner designs.

The use of low-cost formed sheet metal components without the additional aid of metal fiber coating could provide a path for lower-cost burner designs with improved lifetimes.

While the burner design currently being utilized for high-efficiency boiler applications may have multiple other applications, the primary target applications would most likely be small-diameter combustion-chamber applications.

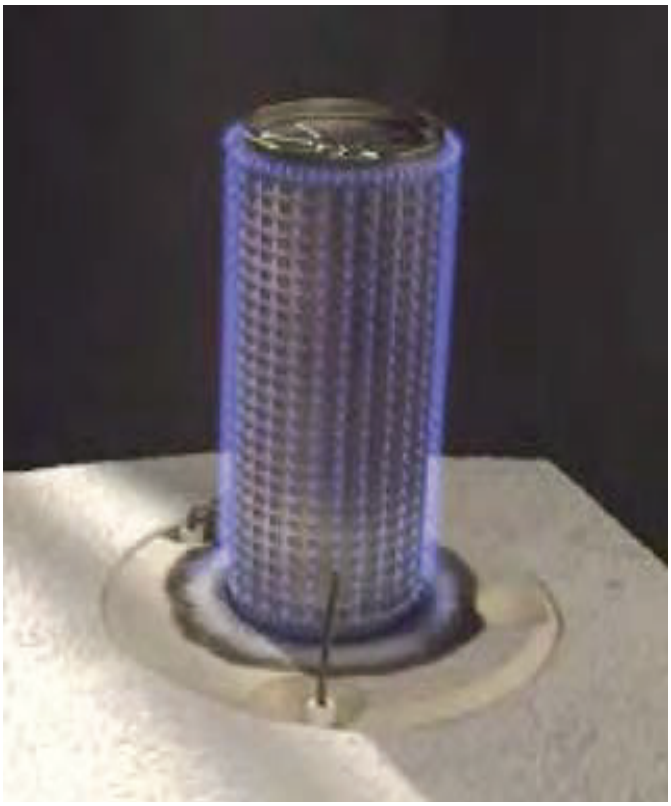
## Benefits / Market Implications

Advanced low-cost burner designs are essential for the continued development of a wide range of commercial and industrial gas-fired equipment for applications such as fluid or material heating.

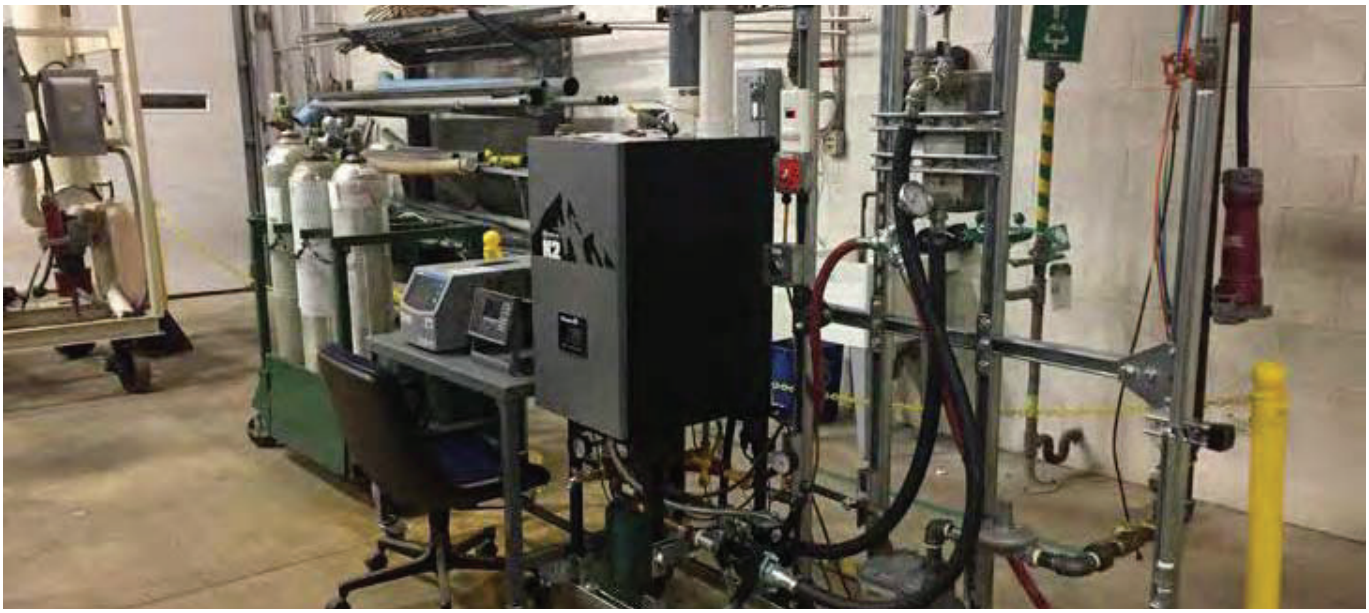
Increases to the output modulation of available burner technology will improve efficiencies by:

- Enabling continued progress in the design of new gas-fired equipment with improved energy efficiency and performance
- Enabling a wider burner operating range to better follow actual heating load
- Reducing cycling through burner shutdown and restart, thus eliminating reheating losses, and
- Allowing for the use of advanced control technology (e.g., auto-adaptive controls).

Development and use of higher turndown gas-fired burner designs provides a path for increased development of efficient and higher performance natural gas equipment. Utilization of advanced burner controls coupled to high turndown burners provide improved load matching, resulting in increased efficiency and reduced emissions.



*Example of sheet metal surface burner.*



*The test cell for the boiler installed in the laboratory.*

## Technical Concept & Approach

The project team designed and developed a test cell to evaluate and verify burner operating performance. A boiler that uses the subject burner was installed into the test cell. Operation of the boiler and test cell was verified to ensure proper operation prior to performance testing.

The project team developed and implemented a test plan capable of accurately assessing the burner performance. Testing of the burner included evaluation of the modulation ratio, sheet metal temperature, and emissions.

## Results

This evaluation substantiated the performance claims of this burner technology. The burner demonstrated a high modulation ratio with outstanding flame-retention performance. Emissions compared favorably to the current low-$NO_x$ emission surface combustion burner technology commercially available and responded favorably to several approaches to possible further reductions in $NO_x$ emissions.

The burner's manufacturer, Sermeta, was started in 1993 by Joseph Le Mer based upon its development of simple hydro-formed stainless-steel heat exchangers for condensing boilers. The Bluejet® burner was developed as the reference burner for use on these heat exchangers due to its modulation capacity and flame-retention performance.

During the completion of this project, Sermeta began supplying to the commercial and industrial boiler manufacturers, utilizing scaled-up versions of both the burner and the heat-exchanger technology, and targeting outputs up to six million Btu. The heat exchanger being supplied is configured to allow a four-pass recovery from the flue gas with a maximum of 97.5% thermal efficiency across the operating range, and designed for size and weight reduction compared to other condensing technologies at this output size range. The Bluejet burner is used in this design to provide turndown ratio of up to 30 to 1, which greatly reduces the number of ignition cycles. New, larger condensing boiler products are currently being introduced to the North American market based on this technology from major U.S. manufacturers including Bryan (BFIT series), Raypak (XFIIRE), HTP (Elite XL), and others that continue to be introduced.

Projects using this type of burner appear to merit consideration for more widespread ratepayer application or utility energy-efficiency program support based on the test results.

## Status

This project is complete. A Final Report was issued in January 2020.

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UTD Utilization Technology Development

# Capstone C200S Micro-Turbine Laboratory Evaluation

***The objective of this project is to evaluate and characterize the performance of the Capstone C200S 200kW Signature Series micro-turbine in order to scale-up the novel, highly-efficient FlexCHP technology to benefit the large market of universities, hospitals, manufacturers, and other end users.***

## Project Description

To succeed in today's marketplace, combined heat-and-power (CHP) systems must achieve high efficiency and low emissions in a cost-competitive package that is capable of broad deployment throughout existing market segments. The FlexCHP technology developed with support from UTD satisfies these needs for those installations that need 65 kW demand and 80 boiler-horsepower (BHP). The technology has the potential to be adopted within commercial and industrial steam-generation markets because of its ability to achieve high steam-production rates and efficiencies that are unmatched by any other competing turbine-based CHP approach.

The FlexCHP technology uses exhaust from a turbine generator as an oxidant for downstream combustion with supplemental natural gas to generate steam in a firetube boiler. While some competing CHP technologies recover heat from the high-temperature turbine exhaust (~600°F) by delivering the exhaust through a Heat Recovery Steam Generator (HRSG), this approach fails to maximize the quantity of recoverable heat because the exhaust excess oxygen levels are not reduced. The FlexCHP maximizes efficiency by reducing the exhaust oxygen levels from 17.7% in the turbine exhaust to 3% in the boiler stack through supplemental combustion. In comparison to simply delivering the turbine exhaust through a HRSG, the FlexCHP technology provides an efficiency gain of more than 30 percentage points (~60% increase).

FlexCHP is the only CHP technology that demonstrated high steam output and efficiencies of 84% without post combustion clean-up (e.g., selective catalytic reduction or other expensive after-treatment). Further, it is the only technology capable of attaining compliance with air-quality regulations in key non-attainment regions.

Evidence for the potential of the FlexCHP technology includes: 1) much customer interest, 2) a pending license agreement for the technology, and 3) support from the U.S. Department of Energy and state-level agencies. However, end users are requesting larger-capacity CHP systems.

While the FlexCHP systems has been successfully developed and field demonstrated at a capacity of 80 BHP and 65 kW electricity (by being integrated with a Capstone C65 micro-turbine), the economics of the technology favors larger-capacity installations, and thus there is need to develop and demonstrate a scaled-up version. The development of an integrated turbine/burner/boiler product that offers the additional advantage of grid-independence for reliable operation will advance the adoption of CHP solutions if the development team is able to transition from 65 kW to larger units.

The potential customer base for the larger Capstone C200S far exceeds that of the C65, and customers with even higher load demands can be satisfied by coupling multiple C200S units to achieve the required output. In summary, the objective for this project is to evaluate and characterize the performance of the Capstone C200S 200kW Signature Series micro-turbine in order to scale-up the novel, highly-efficient FlexCHP technology to benefit the large market of universities, hospitals, manufacturers, and other end users.

C200S product image courtesy Capstone Turbine Corp.

*FlexCHP system.*

## Benefits / Market Implications

Successful commercialization and deployment of the FlexCHP technology will have a transformative impact on commercial and industrial steam markets. Rather than purchasing a standard boiler with a conventional burner, end users will have the option of investing in a FlexCHP unit to generate on-demand steam and electricity. Customers will realize significant cost savings through reductions in electricity purchased from the grid. Ultimately, greenhouse-gas and criteria pollutant emissions will be significantly reduced.

For steam boiler customers for whom the price differential between electricity and natural gas rates exceeds a ratio of 4 to 1 on a per-unit-energy basis, the economics will likely be such that customers can anticipate payback of less than three years by purchasing a FlexCHP unit, with significant long-term benefit (assuming operation five days a week, 48 weeks per year). For customers paying electricity rates that are six times that of their gas rates (as is the case in key markets including California and the Northeast), customers can achieve payback in less than 1.5 years. As the FlexCHP is deployed more widely and equipment prices are reduced, the economic benefits of the technology will increase further.

As an example, consider a customer with a steam demand of 200 BHP and electricity load of 200 kWe. This customer could install a standard 200 BHP boiler that consumes gas at a rate of 8.5 million Btu/h and purchase electricity from the grid. Alternatively, the customer could install a FlexCHP rated at 200 BHP/200 kWe to generate the required quantity of steam and self-generate 200 kWe of electricity, consuming gas at a rate of 9.3 million Btu/h. If the customer rates for electricity are four times that of their rates for natural gas, on a per-unit-energy basis, the customer could reduce its energy costs by 18% annually by installing a FlexCHP unit. At the same time, greenhouse gas emissions would be reduced by more than 16% based on a source energy analysis of a representative installation site.

## Technical Concept & Approach

Activities in this project fit within a broader research program to develop and demonstrate an advanced FlexCHP technology at larger capacities which is 1) capable of operating on both turbine exhaust gas and air and 2) is packaged as a fully-integrated commercial product across load scales for deployment by the manufacturing partner.

Project efforts focus on logistics, procurement, installation, and testing of the C200S micro-turbine. A test plan was developed to characterize system performance across a broad operating range, and data will be compared to the manufacturer claims. This will provide insight and knowledge for determining the optimal burner configuration to be used for scaling the technology to larger capacities.

## Results

The research team has worked closely with Capstone and Capstone's distributors. In addition, the research team has contacted end users such as a major university that has four 200kW engines operating (which are designed to burn low Btu 600 Btu/scf landfill gas) and a site where two model C200 turbines are in place.

Project efforts have slowed as a result of the COVID-19 pandemic and Capstone's significant workload resulting from the rolling electrical blackouts within California, but progress continues such as further information sharing and discussions with Capstone, its distributors, and customers regarding the next project activities.

## Status

A testing/data collection agreement is being finalized.

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# Direct-Contact Flue Gas Heat Exchanger with Innovative Particle Thermal Storage

***A promising high-temperature (up to 1,000°C) thermal storage technology is being field-demonstrated at 50kW scale at an industrial facility in California to enhance renewable energy integration with natural gas and showcase high-temperature energy recovery for numerous applications.***

## Project Description

This project will demonstrate at pilot scale the direct-contact heat exchange between process exhaust flue gas and a novel heat-transfer particle system. The 50kW prototype will provide a step-up in scale from earlier laboratory to demonstration pilot, moving towards the overall commercial goal of one megawatt.

In earlier efforts, a research team designed, built, and tested a particle-based thermal energy storage and recovery loop, and developed and assessed a natural-gas-fired direct-contact particle heater design concept through computer fluid dynamics modeling.

The tests on the particle storage loop proved its performance. It achieved particle thermal fluid temperature of 580°C and showed no flow-path abrasion, no particle degradation, no problematic accumulation of particles, and no changes in heat-transfer rates and system pressure drops over many charge/discharge cycles. Follow-on testing on an integrated system with prototype concentrated solar collectors achieved particle thermal fluid temperatures approaching 700°C.

After assessing fluidized-bed and other potential approaches for gas-fired particle heating, the team selected the cyclone particle separator, which will not only allow very fast heating of the particles, but also provides separation and storage of hot particles within the same unit. Through standard cyclone performance calculations, the preliminary cyclone design was specified and shown to capture particles at over 90% efficiency. The basic cyclone separator design was then modified to allow natural-gas firing and its performance was assessed.

To simplify calculations, combustion products were simulated by hot air. The results demonstrated the cyclone was able to rapidly heat the particles to more than 650°C. The cyclone was also found to be able to achieve these results for a range of air-inlet velocities, particle-to-air loading ratios, and particle sizes, which would allow considerable flexibility in its design.

The overall objective is to supplement intermittent solar thermal energy or waste-heat recovery and provide integrated thermal storage, which can help economically justify higher-efficiency, base-loaded equipment

such as combined heat-and-power (CHP) systems and expand the integration of solar thermal energy with natural gas or renewable natural gas at large industrial scale.

This technology has received significant R&D funding from the U.S. Department of Energy Advanced Research Projects - Energy (ARPA-E)

## Benefits / Market Implications

The U.S. industry uses about 24,000 trillion Btu (TBtu) of energy, of which natural gas represents about 7,600 TBtu or 7.6 trillion cubic feet (TCF). Of this, an estimated one-third or more, representing about 2.5 TCF, is lost as waste heat in the form of hot exhaust gases, cooling water, and surface losses. Recovery and reuse of waste energy from industrial manufacturing therefore offers an attractive opportunity to manage energy demand and improve productivity, without adding to emissions. Combining the particle-based storage technology with direct-contact natural-gas-fired particle-heating technology would allow for a continuous supply of particles at desired temperatures for process heating and power generation.

The particle-based thermal transfer and storage technology can potentially recover and store energy at up to 1,000°C for on-demand generation of heat and/or power. It can recover and store energy from exhaust gases of natural gas fired equipment, even those that are cyclic or batch processes, which are challenging for conventional heat-recovery approaches. If the technology opportunities identified can recover and reuse 5% of available waste energy from industrial natural gas use, the amount of energy saved annually would be about 100 BCF of natural gas. Additional benefits would accrue from customer productivity improvements and emissions reduction. Annual $CO_2$ emissions would reduce proportionally by more than six million tons. This will help manage natural gas demand and can expand solar thermal production while making an attractive total integrated system for end users.

The primary target markets for the technology are natural-gas-fired systems, especially batch type or cyclic processes, that generate variable exhaust gas flow rates and temperatures. Currently there is no commercially available technology that can effectively recover and reuse waste heat from these types of processes.

This technology is also an excellent alternative to air preheating, as it avoids the higher $NO_x$ levels that result from using higher air temperatures.

Another key application is the use of particles heated solely by natural gas in process-heating applications, without the solar component.

Additional markets include: solar thermal systems at industrial/large commercial scale; heat treating; food processing (drying, browning, toasting, frying, etc.); coating and surface treating; thermoforming of plastics; drying of paper and textiles; gypsum calcining; and CHP generation.

The technology is targeted at a 10%-20% reduction in greenhouse gas emissions and more than a 50% reduction in $NO_x$ emissions.

## Technical Concept & Approach

Specific project tasks include:

- **Design and Manufacture of Particle Heater**

  The project team will design a direct-contact, natural-gas-fired 50kW cyclone particle heater.

- **Test Particle Heater Performance**

  Researchers will test the performance of the particle heater using an existing 650°C Generation 2 particle transport and storage loop.

- **Demonstrate Particle Heater on Solar Loop**

  The research team will incorporate and test the particle heater in the 50kW solar thermal particle loop for demonstration in California. The particle heater will supplement solar energy to enable continuous thermal energy supply to the process.

## Results / Status

The solar process heating system (consisting of a high-intensity solar collector and the particle thermal transport and storage loop) will be installed at a host site in California to add thermal energy to the site's primary process kettle. The piping and instrumentation approach were identified.

A preliminary cyclone design was generated based on modeling output. Researchers are completing heat-exchanger modeling.

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# Zero $CO_2$ Emission Combustion at Commercial or Industrial Scale

***Research is being conducted to evaluate methods to cost-effectively capture $CO_2$ from commercial and industrial processes. The goals are to determine if the costs of existing approaches can be lowered and to identify new processes with lower capital and energy costs.***

## Project Description

A large body of research was conducted over the last several decades on carbon capture and sequestration. Much of the R&D in the U.S. was sponsored by the U.S. Department of Energy, with studies ranging from laboratory evaluations of processes to full-scale demonstrations and carbon capture from power plants.

A much smaller body of research has considered industrial carbon capture, specifically a low-cost means to capture a moderate amount of carbon from industrial or large commercial facility exhaust gases. Two examples include 1) the CleanO2 process to generate sodium carbonate and 2) carbon capture using easily-regenerated activated carbons. These processes and others are being evaluated in this project.

The goals for this project are:

- To evaluate processes suited for commercial and industrial scale
- To determine if the costs of existing approaches can be lowered, and
- To identify new processes with lower capital and energy costs.

## Benefits / Market Implications

The primary target markets impacted will be:

- Commercial/industrial boilers > 4 MMBtu/h (100 HP)
- Food processors of grains, vegetables, and fruits
- Metal processors (forging, heat treating, etc.)
- Chemical processes
- Industrial heating processes
- Industrial furnace operators such as steel, glass, aluminum, and cement
- Small-scale die casters, and
- Commercial cooking facilities such as bakeries.

Benefits to ratepayers and the environment are expected to include lower carbon emissions at a cost that keeps industrial and large commercial operations competitive.

Specific benefits are targeted to include:

- Identified industrial carbon-capture approaches can

*Target markets include commercial and industrial boilers, food processors, metal processors, industrial furnace operators, and commercial cooking facilities.*

save industry money when carbon taxes or other incentives are in place. A $5 net saving of cost-to-capture over carbon taxes with 25% carbon capture would save about 1.5% of natural gas costs.

- Superior environmental performance can be achieved in a cost-effective manner. Moderate $CO_2$ capture of 10%-40% can meet upcoming emissions targets and help reduce overall emission of greenhouse gases.
- The identified carbon-capture technologies can easily integrate alternative gas sources. Capture of $CO_2$ is not contingent on the fuel source. If tax and energy benefits are realized using renewable gas supplies, application of these identified approaches to carbon capture will provide even more savings to industrial customers.

## Technical Concept & Approach

The project approach is to identify and characterize promising low-cost processes for recovering moderate levels of $CO_2$ from industrial and commercial end-user exhaust gases. This will be carried out through literature and internet searches, reviews of technical papers and patents, and discussions with technology developers. Other project activities include modeling and cost/benefit analyses of the most promising identified processes.

Researchers will rank processes by cost and industrial applicability. Anticipated approaches include liquid sorbents, solid-phase sorbents, carbon and activated carbon sorbents, membranes, and possibly more exotic approaches such as magnetic fields, pressure-swing absorption, or temperature-swing absorption. The identified technologies will be ranked based on a number of factors including maturity, cost, level of $CO_2$ removed, cost per ton of $CO_2$ , etc.

Follow-on work beyond the scope of this project may involve a demonstration.

## Results

A comprehensive review on approaches to carbon capture was conducted. This study has led to defining categories or broad groups of approaches to carbon capture. Matches with the capacities, available heat and temperatures, and emissions levels of commercial and industrial processes were reviewed. This comparison has led to selecting best potential approaches for carbon capture and zero carbon emission modified processes.

Categories of research include activated carbons, modified carbon surfaces, zeolites, metal organic frameworks, and other adsorbents and options. More than a dozen broad approach categories were identified.

## Status

Activities currently under way include:

- Providing further details on identified classes of carbon-capture approaches, starting with activated carbons and other adsorption approaches
- Eliminating classes of carbon-capture approaches considered impractical for commercial and industrial processes
- Reviewing the list of classes of promising carbon-capture approaches to identify and rank the most promising approaches, and
- Making a deeper investigation of specific technologies within the potentially attractive carbon-capture categories.

The next area of research will involve looking at the selected, promising approaches more closely. Before ranking them, the project team will study specific technologies and their costs and performance more closely. This will include as many processes as possible, including processes still in early-stage development.

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UTD Utilization Technology Development

# Distributed Generation/CHP for Electric Demand Response

***This project is assessing opportunities to expand peak electric demand response from distributed generation and combined heat-and-power system installations in order to support increased integration of renewable energy with the gas distribution and storage network.***

## Project Description

On-site power generation or distributed generation (DG) systems are used nationwide by a variety of residential, commercial, and industrial customers to avoid disruptions due to power loss. These units serve a vital role during electric power outages. Combined heat-and-power (CHP) systems are other options to provide uninterrupted power during a grid outage.

In addition to standby operation, DG and CHP systems can be operated during periods of peak electric demand to reduce the use of grid power for financial benefits, either by demand-side management (DSM) or as part of a utility-sponsored demand-response (DR) program. DR incentives and DSM operation can monetize onsite power generation required for reliability and resilience. As participants in a DR program, DG/CHP systems operate in response to a curtailment signal in exchange for financial incentives. Alternatively, a facility can independently operate its onsite power generation to decrease the facility peak electric demand and reduce the corresponding electricity costs. Energy cost savings from DSM operation or peak shaving can reduce energy costs, resulting in lower life-cycle costs for onsite power generation.

In this project, researchers will review available DR programs and DSM options and evaluate the potential for life-cycle cost savings for DG or CHP systems. The objective is to develop a technical and economic assessment of opportunities for peak electric DR that can be achieved from DG and CHP installations.

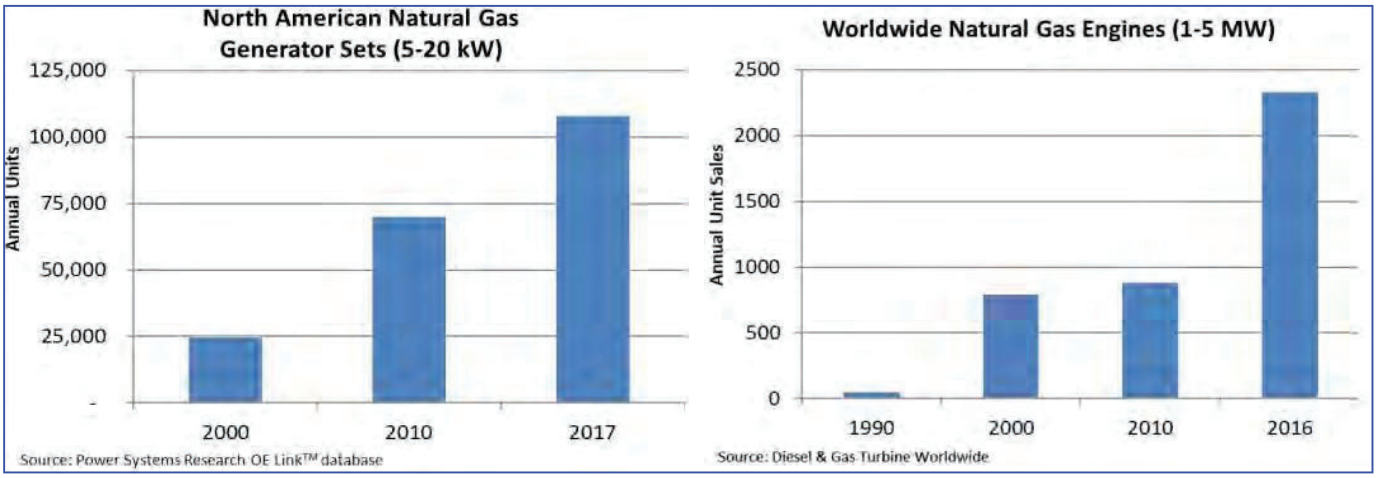
## Benefits / Market Implications

Researchers will investigate the following potential benefits:

- Options for DG/CHP to support electric demand response and expand the integration of natural gas with renewable natural gas, solar energy, ground-source heat pumps, hydrogen/power-to-gas systems, and the onsite power generation of micro-grids
- Reduced life-cycle costs for standby power generation
- DR customers ability receive advanced warning of unstable grid conditions, including blackouts and brownouts, and
- DR/DSM programs that help support the power grid resilience and reliability and potentially reduce emissions from marginal power generation.

The assessment of DR and DSM opportunities will identify operating strategies and other approaches that provide economic benefits for DG and CHP systems. Growth in DG units and micro-grids could improve the resilience for individual facilities and support the reliability of the electric infrastructure and its ability to react to increasingly “peaky” generation from increasing amounts of renewable energy. On-site power generation is a rapidly growing market due to concerns with electric grid reliability and the growing number of extreme weather events. This is evidenced by the

*Examples of current commercial DG product offerings from Generac and Cummins.*




increasing sales of natural gas engines and generator sets. According to data from Power Systems Research, the North American market for 5kW-20kW generator sets (both natural gas and liquid propane gas) has grown by more than a factor of four since 2000 – totaling about 110,000 units in 2017. Internationally, sales of larger natural gas engines are also growing. In 2016, natural gas engines commanded more than 15% of the market share in the 1-5 MW range (the balance being diesel engines) compared to only 4% in 1990. Likewise, there continues to be growth in commercial and industrial CHP systems. Commercial-sized CHP systems have increased by more than 70% since 2005.

This project builds upon work conducted under a previous UTD project (2.12.F) on natural gas on-site power generation, which included the development of an online calculator to compare the total cost of ownership for natural gas and diesel standby power systems.

The primary target markets impacted will likely be:

- Regions with high demand charges or time-of-use electricity rates
- Power-grid-constrained markets or regions with unreliable grid power, and
- Facilities that require standby power systems for resilience and operational continuity.

## Technical Concept & Approach

This assessment will review current DR programs and identify key markets and types of end users that can benefit from these options. In addition, the assessment will highlight regions or applications with favorable energy-pricing structures for peak shaving or DSM.

Specific areas of focus include

- **North American Demand Response Programs**

  Researchers will review and summarize current demand-response programs across North America and identify the key criteria and potential economic benefits for specific DG and CHP applications. This task will also review applicable technologies, including CHP configurations suitable for DR operation. The team will identify key manufacturers and assess technology-related issues or gaps.

- **DSM Operation**

  Researchers will identify regions with favorable energy pricing for DSM operating strategies for commercial DG and CHP. This will include case studies or examples to illustrate the economic benefits for commercial facilities.

- **Codes and Standards**

  Researchers will review and summarize applicable codes and standards for onsite power generation, CHP, and DR/DSM operation, including requirements for installation, startup, and periodic testing, in addition to exhaust emissions and runtime specifications.

## Results / Status

The project began in the first quarter of 2020, and work is in progress.

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# FOOD PREPARATION AND SERVICE

UTD Utilization Technology Development

# Commercial Foodservice Tools and Calculators

***In this project, a research team analyzed tools and/or calculators used by the commercial foodservice industry and combined information from various sources into a single web-based resource that helps end users determine the economic and environmental benefits of using new, more advanced equipment.***

## Project Description

Results from a UTD commercial foodservice (CFS) audit and survey showed the growing importance of addressing sustainability in the CFS industry. Sustainability includes elements such as environmental compliance, recyclable packaging materials, material usage, energy usage, water usage, and disposal. The North American Association of Food Equipment Manufacturers (NAFEM) developed a spreadsheet that calculates many of these values; however, the calculator does not fully address the source-energy consumption and air emissions for CFS appliances.

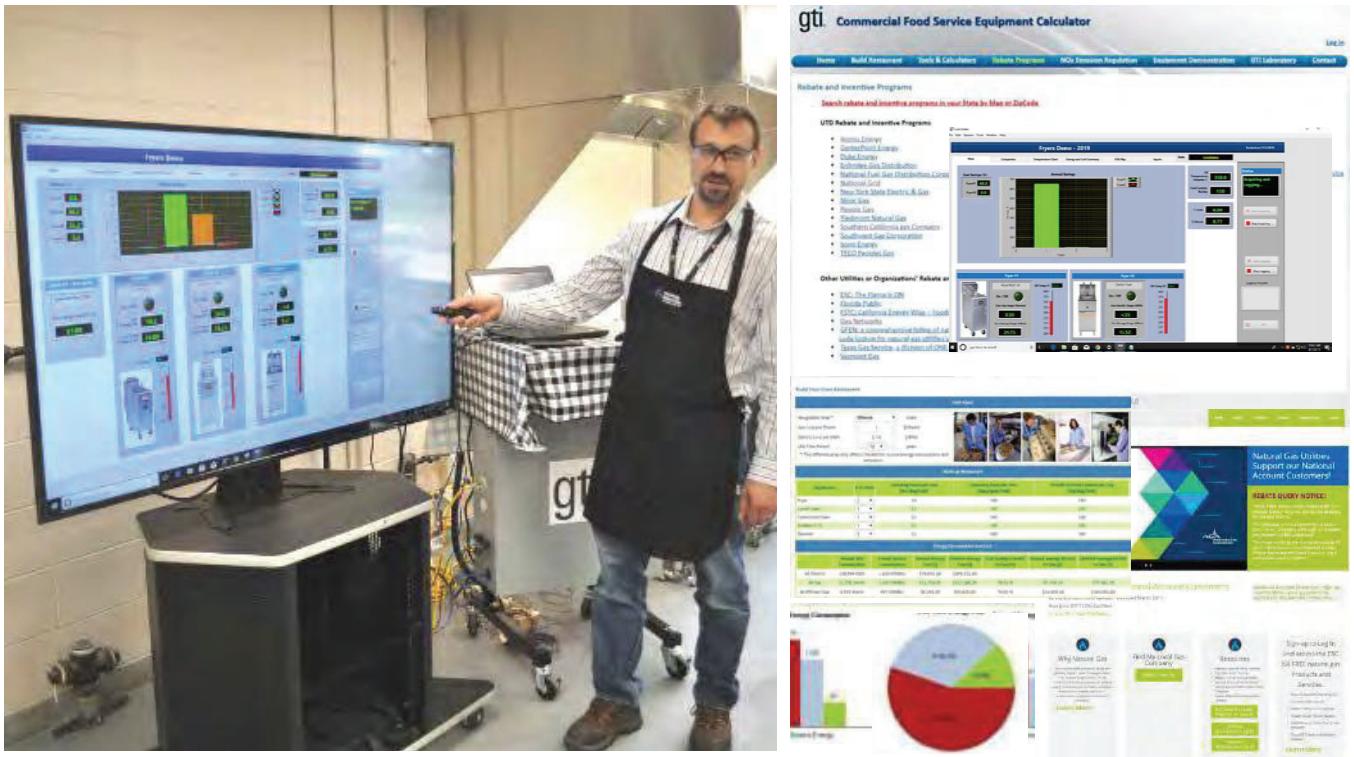
The focus of this project is to create tools and/or calculators that combine information available from various sources that can be used by CFS end users to determine the economic and environmental benefits of using more advanced, more efficient CFS equipment. The tools and calculators show the potential energy and cost benefits of energy-efficient equipment.

For this effort, the project team developed a website with links to energy calculators and easy access to a wide variety of information on commercial foodservice equipment.

## Benefits / Market Implications

CFS owners and operators have traditionally been hesitant to replace functioning equipment or buy new, more efficient equipment because of first costs. The objective of this project is to identify and simplify access to different calculators and tools for CFS industry end users to obtain information and data that can demonstrate the energy and cost savings of replacing outdated or under-performing equipment with energy-efficient models.

Tools and calculators can also show how rebates and long-term cost savings will reduce the burden of increased purchasing costs of new equipment.




*The commercial foodservice website provides easy access to valuable information for restaurants and gas industry representatives.*

## Technical Concept & Approach

In the initial phase of the project, researchers interacted with various organizations to evaluate existing calculators and determine the elements that are useful to the CFS industry. Available databases for the stock efficiency of CFS appliances, information for available rebates in North America, and ENERGY STAR ratings were compiled into a website. The web interface includes a list, explanation, and links to other calculators that could be of use to end users.

## Results

A Commercial Food Service Equipment Calculator webpage was created to consolidate available information from different sources for CFS into a single location. The information and tools are organized into a web-based interface and a calculation page allows the comparison of standard vs. energy-efficient equipment usage in typical restaurants.

The project team developed links to various tools, calculators, and general information, including:

- FSTC: The Energy Efficient Kitchen Tool
- GFEN: Comparison of Natural Gas versus Electric Rates for Foodservice Operations
- ENERGY STAR: Guide for Restaurants
- ENERGY STAR: Savings Fact Sheet
- ENERGY STAR: CFS Program Administrator Guide for Utilities
- NRA: Conservation Guide Rebate and Incentive Information
- GFEN: Utility Pricing and Rebate Information
- ENERGY STAR: Commercial Food Service Equipment Incentive Finder
- Consortium for Energy Efficiency: High Efficiency Incentive Guide
- U.S. DOE: Database of State Incentives and Renewables & Efficiency Energy Cost Calculators
- FSTC: Life-Cycle $ Energy Cost Calculators
- NAFEM: Equipment Life Cycle/Total Cost of Ownership
- ENERGY STAR: Commercial Kitchen Package Resources Other Calculators, and
- ESC: Commercial Carbon Calculator

An added feature to the website allows for a comparison of efficient vs. existing appliances with a “Build Your Own Restaurant” page. On the page, a population of different appliances with energy-efficient options can be chosen and the energy savings calculated.

In 2018, a one-day cooking demonstration was conducted for end users, showing the energy usage for an energy-efficient fryer, a standard gas fryer, and an electric fryer using a new CFS tool developed for this project. The to

ol had a live display that showed the energy usage of each fryer as food was cooked and displayed the estimated lifetime energy costs and savings of using an energy-efficient fryer.

In 2019, information on $NO_x$ regulations and rebate information was compiled and a beta page developed. Based on feedback, a list of new features is being developed and added to the website. This includes information of available rebate programs and summaries of UTD-funded demonstration projects.

Efforts were made to increase the awareness of the website via presentations at CFS-related events and other distribution avenues. The website was demonstrated in booths at SoCalGas Commercial Foodservice Expo, the Louisiana Foodservice & Hospitality EXPO in New Orleans, and the Oklahoma Restaurant Association in Oklahoma City. The site was also used in presentations for webinars and workshops.

## Status

Existing tools and the calculator webpage are being maintained and updated with new information as it becomes available.

The webpage is publicly available at:

*http://cfscalc.gastechnology.org/*

The current phase of the project includes adding cooking demonstration videos and $NO_x$-emissions information, and demonstrating the website at commercial foodservice demonstrations and other events.

Researchers are also designing an energy-monitoring tool for use at a demonstration kitchen. The tool will be capable of monitoring energy use and calculating annual energy costs of an entire cookline or for a side-by-side energy usage comparison of up to five units.

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UTD Utilization Technology Development

# Next-Generation Commercial Foodservice Burners

***This project focuses on designing, developing, and testing prototype higher-efficiency, lower-emission commercial foodservice appliances using advanced burner concepts proven for other markets and products (e.g., residential furnaces and water heaters).***

## Project Description

While controls, construction materials, and insulation have improved products for the commercial foodservice (CFS) industry, burner designs have varied little. Most of the efficiency gains for gas-fired CFS burners over the past few years have been attributed to the structural design of the unit (e.g., enlarged heat-transfer surfaces and the use of insulation). However, with increased emphasis on efficiency and potential emissions concerns, interest in new burner technologies has grown.

Through this project, researchers are investigating existing higher-efficiency and lower-emission burner technologies developed for other markets (e.g., residential furnaces and water heaters) and working with CFS equipment manufacturers to adapt them to CFS appliances.

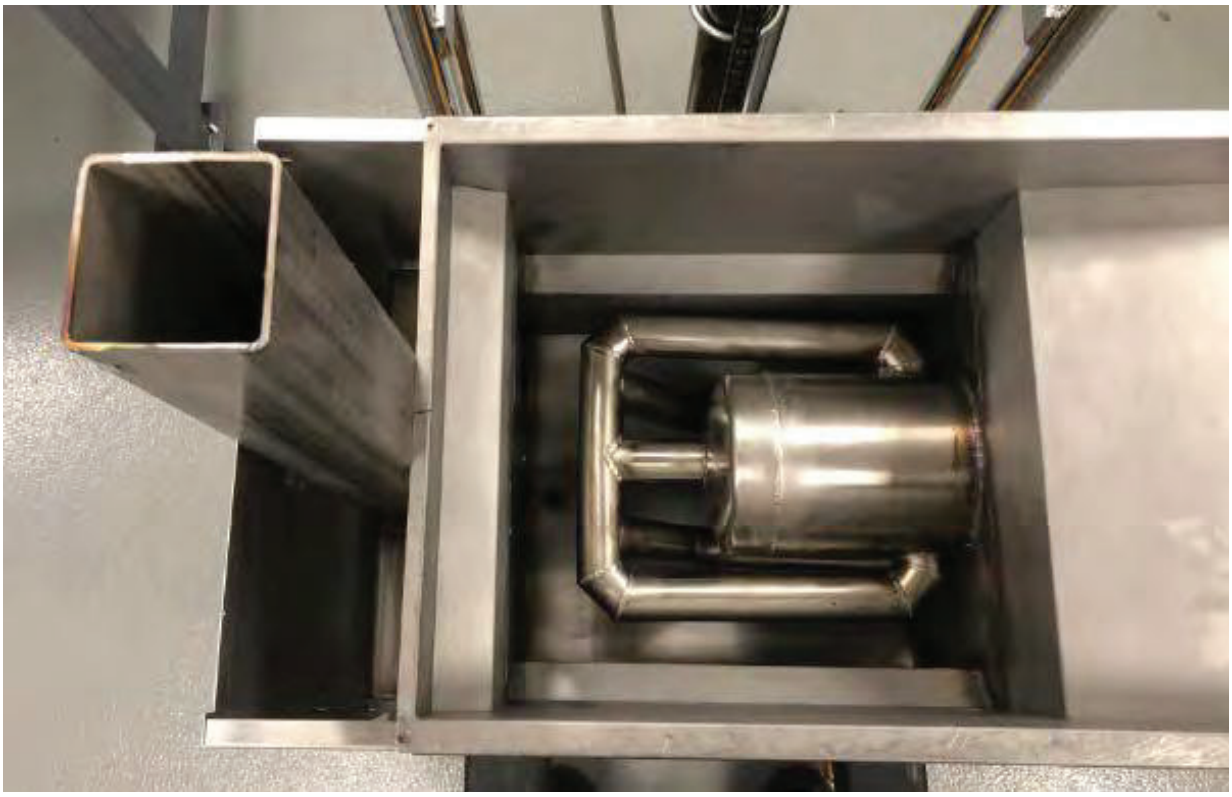
The objective is to design and test prototype CFS appliances using an advanced burner concept based on designs proven in other markets.

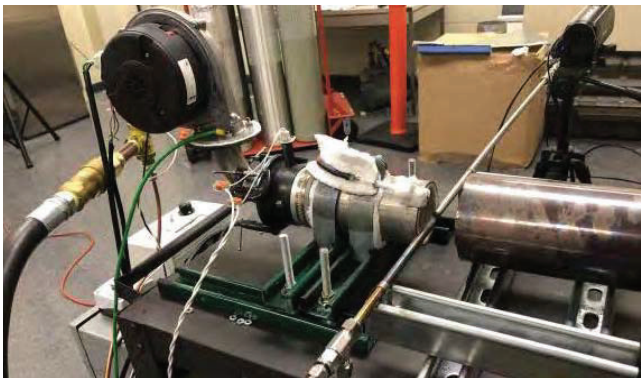
## Benefits / Market Implications

The reason CFS appliances are not approaching the efficiencies of other gas-fired appliances with similar firing rates is partially due to the fact that the burner technology is not as advanced as other appliances. Generally, the market has been unwilling the pay the cost of advanced technologies. However, this project is addressing the growing emphasis of "green" technologies by adapting existing advanced burner technology and concepts to CFS equipment designs.

## Technical Concept & Approach

In previous phases of this project, researchers investigated existing higher-efficiency and lower-emission burner technologies such as metal mesh and foam burners with a combustion blower. The current phase involves incorporating an advanced burner technology into a new design for CFS equipment, and testing of other novel low-emission burners.





*Burner for prototype fryer.*

*"I was involved in the fryer testing program, and I found the fryer to be beyond superb. It takes frying to the next level. I have never seen a fryer that can attain, retain, and sustain its temperature the way it does. All the while, its energy-saving features alone make it a hit. Great machine!"*

*- John Proctor*
*Chef*
*New Orleans Mission*

## Results

Because of the immediate need to assist the CFS industry with $NO_x$ emissions concerns, this project is focusing more on burners that are typically used in the types of appliances in the 2016 South Coast Air Quality Management District (SCAQMD) of California Air Quality Management Plan (AQMP).

Researchers teamed with a major range manufacturer to design a new fryer. The new product design was able to improve efficiency to 54%, thus qualifying as ENERGY STAR. Since its introduction, the fryer was awarded the 2016 Blue Flame Award by GFEN (Gas Foodservice Equipment Network) as innovative product of the year and a KI (Kitchen Innovations) Award.

Project team representatives visited a manufacturer that developed a low-$NO_x$ burner that might have applications in CFS. The manufacturer built a set of burners with a typical firing rate for CFS equipment. Testing showed the burner capable of achieving $NO_x$ emissions of less than 10 ppm and 10 ppm CO (both corrected to 0% $O_2$) at firing rates in the range of 40,000 to 70,000 Btu/hr.

The project team investigated available burners that claim to be low $NO_x$ for potential use in CFS applications. Burners were tested for a series of firing rates, air-to-fuel ratios, configuration of the gas supply, spacing for the fuel supply to the burner, and burner lengths. Testing for $NO_x$ characterization of rangetop burners demonstrated a measurable difference in the emissions characteristics of the back burner compared to the front burner. Testing was also conducted to characterize the $NO_x$ emissions from the pilot lights for each burner.

The project team was approached by a CFS manufacturer for assistance with evaluating combustion technologies for a new appliance for a major chain account. Researchers tested two burners: a radiant metal mesh burner and a metal foam burner. The burner was set up in a test stand to measure emissions as well as firing rate and temperature distribution of the burner with a metal plate and thermocouples located above the burner.

In 2019, the project team initiated a new SCAQMD-funded project for the development of two ultra-low-$NO_x$ (ULN) fryers. One fryer was based on an existing fryer and another was a new prototype design using a burner tested in this project.

Laboratory testing was completed for more than 20 different burner designs. $NO_x$ testing was completed at five manufacturers sites. Data from this testing was analyzed and will be included in the Final Report, to be issued in the third quarter of 2020.

## Status

Testing at CFS manufacturers sites was completed and the project team is in the process of analyzing data and completing test reports. The combustion system is also being modified to allow testing for different firing rates and air-to-fuel ratios.

A ULN fryer prototype was built with the heat exchanger, the burner system, and electronics installed in the fryer body. Final combustion testing of the fryers was almost completed when laboratories were closed due to COVID-19.

The final steps before cook and $NO_x$ testing will be determining the settings for the control system to ensure safe ignition and operation of the unit, adding insulation, and setting the final natural gas supply pressure and firing rate to optimize efficiency and $NO_x$ emissions.

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UTD Utilization Technology Development

# Commercial Foodservice Equipment Demonstrations

***Through restaurant and commercial-cooking field demonstrations, researchers are gathering valuable data to quantify the operating and efficiency benefits of gas-fired commercial foodservice equipment in real-world situations.***

## Project Description

Researchers and gas-industry representatives are conducting demonstrations of gas-fired commercial foodservice (CFS) equipment to quantify the benefits of the equipment in real-world situations.

Demonstrations are designed to address the reluctance of some CFS operators to replace existing equipment with newer models because of concerns with costs and the uncertainty that the new equipment will be able to prepare the food as expected. Chain restaurants – which represent about 50% of the CFS industry – are recognizing the long-term cost benefits of newer equipment; however, this information is not generally available to the rest of the industry.

In UTD-supported CFS demonstrations, technicians test selected equipment in the laboratory and/or at commercial demonstration sites and document performance. Testing is being conducted with some of the industry's most recent market introductions, including a steam kettle, range, wok, conveyor oven, convection oven, boilerless steamer, low-oil-volume fryer, and griddle. Any other appliance of particular interest could be targeted for laboratory performance testing or field demonstrations.

Activities are focused in two areas: The first area focuses on single-day demonstrations at test kitchens and trade shows showing how well specific equipment performs. The second area focuses on long-term demonstrations in restaurants.

## Benefits / Market Implications

Verifying the performance of a CFS technology in the laboratory or the field will demonstrate the advantages of specific technologies and provide valuable performance information.

This project provides end users and utilities with the ability to quickly evaluate appliances, whether a gas-fired or electric-driven, and understand the true performance of the appliance.

## Technical Concept & Approach

The appliance performance and feedback from the test sites were incorporated into a report detailing the benefits and performance of the systems.

Opportunities for demonstrations are being identified at other utilities as additional project funding is provided. The time and cost varies based on the appliance and scope of the tests.

## Results

Whole-kitchen assessments (WKA) were conducted at:

- A 120-seat restaurant that serves a wide variety of dishes and is especially known for its extensive dessert menu of pies. **Findings:** Replacing the existing fryers, convection ovens, and griddle with energy-efficient models would save 2,597 therms ($1,346) per year of energy usage. Assuming an operational life of 12 years, the total savings is 31,164 therms and $16,152.
- A full-service caterer. **Findings:** Replacing the existing convection oven, combination oven, and griddle with energy-efficient models would save 668 therms ($349) per year of energy. Assuming an operational life of 12 years, the total savings is 8,016 therms and $4,188.
- Two counter restaurants with menus that focus on hot dogs, burgers, sausages, and French fries. **Findings:** Replacing the existing fryers and griddle with energy-efficient models would save 2,721 therms ($2,535 per year) of energy. Assuming an operational life of 12 years for both appliance types, the total savings is 32,652 therms and $30,420.

Overall, the WKAs showed the potential savings of 109,000 therms and $85,716 over a 12-year appliance lifespan if the standard equipment used in just these four locations were replaced with existing energy efficient options.

A fryer comparison demonstration was initiated at a casino. The demonstration compare three different models from different manufacturers. Three baseline fryers were monitored. After about a month of monitoring, the baseline fryers were replaced with ENERGY STAR equivalents from three different manufacturers.

In 2018, a cooking demonstration was conducted in Tulsa, OK, where the energy usage for four fryers were compared with each other and with standard gas and electric units. Annual energy cost savings for the highest-efficiency fryer tested was $540 per year when compared with a standard gas fryer and $785 per year when compared with an electric fryer.

An initial evaluation was conducted in a fryer demonstration in Oklahoma. Data collected during the demonstration showed that a CFS facility could achieve significant operational savings by using energy-efficient natural gas-fired equipment compared with standard gas-fired and electric equipment.

A one-day cooking demonstration for energy-efficient fryers was conducted in 2018. The cooking demonstration provided the energy usage for an energy-efficient fryer, a standard gas fryer, and an electric fryer. Based on these results, several utilities approached the project team about doing future demonstrations or helping to design a system for use at their facilities.

The project team is identifying sites for conducting WKAs within the sponsors' territories.

In 2019, a new demonstration site was identified and evaluated for replacing an electric fryer with an energy-efficient gas unit. The entire menu is prepared in the kitchen equipped with an electric fryer, oven, and rangetop.

Researchers conducted a demonstration of a gas-fired vs. electric fryer in Louisiana Gas Association booth at the 2019 Louisiana Restaurant Association Expo.

The project team also initiated planning of the data-collection system for a new test kitchen currently being built. The system will be able to monitor and record and display data on the performance of various cooking appliances being used at the same time and how they compare to each other.

## Status

Researchers are ordering needed equipment and beginning to assemble a new remote energy-monitoring system for demonstration kitchens and shows.

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UTD Utilization Technology Development

# Demonstration of High-Production Fryers

***In this project, commercially available high-production fryers are being evaluated in a test kitchen and in operating restaurants to compare their performance to alternative gas and electric models in order to support decision making by end users.***

## Project Description

High-energy-density electric-powered fryer models are capable of delivering more heat in a given amount of frying space than gas-fired fryers on the market. However, today's advanced gas heat-exchanger designs can transfer more heat from a burner in a given frying space than electric models, allowing gas models to better serve end users who need high-production capacity.

To demonstrate current technology, in this project a research team is testing and evaluating two high-production fryers at test kitchens, followed by demonstrations at field sites.

Sites within the sponsors' territories are chosen to demonstrate the efficiency, cost, and production benefits of commercially available gas fryers.

## Benefits / Market Implications

The continued production of high-performance gas-fired fryers will maintain gas fryers as the leading option in commercial kitchens. Generally, gas-fired models will save end users money and reduce emissions (on a source-energy basis) versus their electric counterparts. Producing high-production models that cook well and deliver even greater cost savings will further serve end users in the fryer market.

## Technical Concept & Approach

Leading high-production gas fryers are being compared to standard electric and gas fryers. Sites are being sought to show the energy efficiency and performance advantages of high-production fryers and include baseline monitoring of previous fryers to demonstrate

demonstrate the potential cost savings. Sites with both legacy electric and gas fryers are being sought to assess the benefits over older-generation models.

Energy monitoring will determine energy and cost savings, while site surveys will obtain direct feedback from users on the performance advantages of the new system.

## Results

In 2018, the research team conducted a field demonstration of a high-production fryer in Oklahoma, with a one-day test demonstration comparing four different fryers. A public document summarizes the energy-efficiency results. The fryer was installed at a field test site and data and results are being collected.

A high-production fryer was demonstrated in collaboration with UTD CFS demonstration project 1.14.B. This high-end gas fryer was compared in a test kitchen one-day evaluation with a low-cost ENERGY STAR gas fryer, a baseline gas fryer, and an additional standard gas fryer the site had on hand (as well as a comparison to an estimated electric fryer). Energy usage was monitored real time with gas and electric meters, while also measuring recovery time with thermocouples in the oil. Results showed that the unit saved 56% energy use while also recovering quicker and cooking the food faster than the baseline gas model. The unit also saved 32% over a low-cost ENERGY STAR gas model.

The project team purchased one of these same fryers for installation at a barbeque restaurant in Tulsa that had already been baselined. In 2019, the new fryer was delivered and installed in Tulsa. Monitoring is being conducted.

A second site was found in Detroit. Researchers expected the installation of the new high-production fryer in spring 2020 at this test site; however efforts were halted in March due to COVID-19.

At the test sites, detailed energy usage, cost analysis, and usage profile reports will be produced to demonstrate the benefits of high-production gas fryers. The high-production gas fryers are being compared to standard electric and gas fryers.

In 2020, researchers continued monitoring of the high-production fryer in Tulsa.

## Status

Researchers continue baseline monitoring of the electric fryer in Detroit and performance monitoring of the fryer in Tulsa.

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# Residential Kitchen Cooking Ventilation Effectiveness

***A research team evaluated existing residential ventilation systems for their effectiveness at capturing and exhausting heat and airborne particles in residential applications. Researchers also analyzed designs for improving the performance of these products for end users and issues related to gas cooking.***

## Project Description

There is a growing concern by certain entities about the effect that cooking has on indoor air quality. Some publications in public forums suggest that emissions from cooking can negatively affect a home's indoor air quality. Specific emphasis has often been put on combustion emissions and strongly suggests electrical cooking results in better air quality than cooking with gas. However, a comparative study of the volume of emissions produced from the food, whether cooked using electric or gas equipment, to the emissions from the gas burners has not been fully scientifically addressed. Also, published information sometimes does not point out that effective ventilation systems remove emissions from the cooked food as well as gas combustion emissions.

*Residential kitchen ventilation laboratory test setup.*

In this project, researchers evaluated the effectiveness of existing ventilation systems at capturing and exhausting heat and airborne particles in residential applications. In addition, the project team developed designs for improving the capture effectiveness and methods to improve the system performance. The project team also reviewed scientific literature and prior studies of cooking emissions.

## Benefits / Market Implications

Emissions from gas-fired cooking are not fully understood and quantified for combustion products and cooking by-products.

A properly designed residential ventilation system should allow for the preparation of food while maintaining safe indoor air quality. The systems effectively remove heat and food emissions from the residential environment.

## Technical Concept & Approach

The project team identified typical designs for residential ventilation systems. Each design was tested in the laboratory to determine the capture rate of heat, food emissions, and combustion emissions. Subsequently, researchers determined the effectiveness of each design for a residential kitchen ventilation system and developed improved redesigns.

## Results

Researchers constructed a residential kitchen ventilation test setup that is specially designed for quantifying the capture effectiveness of the hoods. In 2017, technicians installed a shadowgraph system to quantify capture effectiveness and a data-acquisition system for measuring temperature, emissions, and energy usage.

The project team collected data to measure the emissions profile of each burner and determine the capture effectiveness of the hood for combustion emissions. The team tested several methods for measuring the capture effectiveness of the emission from the burners.

The following is a summary of the results:

- The range hood performance was evaluated using the flow visualization apparatus and procedures outlined in the test method. The shadowgraph image was used to determine the amount of capture or spillage of the thermal plumes as a fractional assessment of the projected image. Trace amounts of smoke were also used as a seeding mechanism.
- The hood capture and containment performance evaluation was completed for five burners on a standard range. In general, the hood captured and contained the thermal plumes from the rear burners and failed to capture the thermal plume from the front burners. Sensitivity testing showed a cooking pot positioned on the front burner did not require a reduction in the firing rate to maintain capture and containment.
- When the thermal plume from the front burners spilled, a visual assessment of the shadowgraph image determined that the plume volume spilled 20%-40% along the front edge of the hood and 10%-20% along the sides of the hood. The poor hood performance of the front burners was due to the amount of set-back of the hood over the range.

*Shadowgraph image of residential range.*

In 2018, the initial evaluation of heat capture using the shadowgraph test setup was completed for all the burners on the rangetop. The hood was modified and retested to improve capture effectiveness by adding side shields and an extension to the front of the hood. Analysis of both configurations suggests that the changes to the hood made some improvement in terms of capture effectiveness, but not as much as expected. These results were discussed with manufacturers of residential kitchen ventilation units to help inform their design of new products to improve ventilation in all home kitchens.

Researchers also investigated the advantages and issues with adding a feature that automatically turns on the hood when the oven is in operation. Unlike commercial kitchen ventilation units, some residential units are limited in effectiveness because they are not manually turned on.

In 2019, researchers also considered issues raised in public forums about residential indoor air-quality concerns of cooking with natural gas as the primary heat source by conducting a thorough review of the existing scientific literature and analysis. A complete list of references is included in the project's Phase 1 Final Report, issued in June 2019. Based on established scientific practices and in the opinion of the project team, many of the public forum articles had questionable conclusions on $NO_x$ and asthma, specifically making conclusions about the relationship between cooking with natural gas and asthma that appeared to be more coincidence than causality. The articles also tended to use implied results from several studies to make a single conclusion against natural gas when none of the articles make a definitive claim on the causes of asthma and in contrast stated that more research is needed. An almost universal conclusion from the reviewed articles was that proper ventilation for both gas and electric cooking greatly improved indoor air quality.

## Status

The project is complete. The Final Report was issued in August 2020. Discussions with manufacturers to improve new kitchen ventilation products on behalf of ratepayers are ongoing.

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UTD Utilization Technology Development

# Commercial Foodservice Codes and Standards

***This project supports the consensus refinement and development of codes and standards for gas-fired commercial foodservice (CFS) equipment. The project team serves as a voice for natural gas ratepayers by providing scientific and technical information associated with gas-fired CFS equipment to relevant codes and standards organizations.***

## Project Description

Compared to other commercial gas-fired products, commercial foodservice equipment has fewer regulations, codes, and standards for efficiency, emissions, and other operational features. However, with the push for more efficient technology and lower emissions (especially in California), newer codes and standards are being developed and implemented by organizations such as ASHRAE, ASTM, and air-quality management districts in different areas of North America.

The objective of this project is to support this development and provide scientific and technical information associated with codes and standards for gas-fired, commercial foodservice (CFS) equipment.

The goal is to help ensure a fair and equitable analysis of all fuels for ratepayers by preparing and supporting scientific and technical information that could help inform the consensus basis of new or refined codes and standards.

## Benefits / Market Implications

Restaurant industry equipment sales in the U.S. are estimated at $863 billion for 2019. The majority of the appliances use natural gas as the fuel source. However, concerns with new codes and standards as well as some misunderstandings about equipment performance have influenced a number of equipment choices. In some cases, the advantages of electric equipment justify their use; however, in many cases gas-fired equipment would still have the advantage in terms of cooking performance and energy costs and impacts.

## Technical Concept & Approach

This project assists CFS industry end users by addressing issues or concerns with gas-fired equipment during the process of refining or developing codes and standards through direct interaction with manufacturers and customers, published articles and presentations at CFS industry events, and membership/participation at codes and standards organizational meetings.

A research team identifies issues and concerns associated with existing or potential new codes and standards relevant to CFS in North America. The team serves as a voice for gas consumers at codes and standards meetings for ASTM, ASHRAE, the North American Association of Food Equipment Manufacturers (NAFEM), and other organizations.

## Results

The project team actively interacted with the gas industry, CFS equipment manufacturers, and other CFS organizations to help them respond to meet new and pending regulations on $NO_x$ emissions of CFS appliances in southern California. Of specific interest were new $NO_x$ emissions regulations being proposed by California's Southcoast Air Quality Management District (SCAQMD).

The project team identified at least 15 issues and topics associated with existing or potential new codes and standards relevant to the CFS in North America and

*"UTD's representation for the Commercial Cooking Equipment $NO_x$ Characterization Study has been invaluable to SoCalGas as we create emission testing protocols. The guidance enabled us to make significant progress with hood design and the development of new emission-sampling techniques."*

*- Jason Wang*
*Engineer, Engineering Analysis Center - Applied Technologies*
*Southern California Gas Company*

globally. Detailed information on all the different codes and standards issues was developed. Along with meetings with individual CFS manufacturers, the project team attended and provided representation for gas consumers at codes and standards meetings such as ASTM, ASHRAE and NAFEM.

One large topic reviewed in this project was to prepare for $NO_x$ emissions regulations in southern California. Researchers were able to help CFS gas-fired equipment manufacturers respond to these developments and prepare equipment innovations to meet new regulatory requirements.

The project team assisted with a SCAQMD-funded project to quantify the existing $NO_x$ emissions of several categories and types of CFS equipment.

Team members met with engineers at a sponsoring utility to discuss results for the $NO_x$ testing of available CFS equipment, including fryers, ovens, and griddles. These tests will be used to develop protocols and procedures for $NO_x$ testing of CFS equipment and the data will be used to help inform the establishment of new $NO_x$ emissions regulations.

A project member remains an active participant in ongoing discussions about ENERGY STAR products spearheaded by NAFEM. Of interest to the gas consumers are proposed changes to ENERGY STAR testing that would make it increasingly difficult for CFS manufacturers to obtain an ENERGY STAR listing.

In 2018 and 2019, the project team and CFS manufacturers made efforts to determine $NO_x$ emissions from CFS equipment and what changes will be needed to comply to new $NO_x$ emissions standards, including completing onsite emissions measurements at five locations.

The project team is contributing to consensus revisions to some ASTM standards, such as to address issues with changes in natural gas heat content which may impact the accuracy of certification testing results.

A project team member accepted an invitation to join NAFEM's Environmental Working Group and Energy Working Group as a subject-matter expert.

A project team member supported ASHRAE Technical Committee 5.0 for the testing and development of standards for commercial kitchen ventilation.

Researchers provided a $NO_x$-emissions update at an ASTM F26 meeting and the NAFEM Technical Liaison Committee meeting for CFS.

In 2020, efforts continued with a focus on $NO_x$ regulations for CFS in California and continued technical support for leading technical committees.

Four $NO_x$ evaluation reports for manufacturers were completed.

## Status

Researchers are conferring with CFS equipment manufacturers to determine their $NO_x$ emissions and what changes will be needed to comply to new $NO_x$ emissions standards. Researchers are continuing to support technical committees in ASTM, ASHRAE, NAFEM, and other organizations.

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UTD Utilization Technology Development

# Residential Cooking Pollutants and Indoor Air Quality

***Researchers are conducting an analytical and laboratory investigation on pollutants contributed by gas and electric residential cooking. The objectives are to determine the impact on indoor air quality and the implications for range hood design.***

## Project Description

Commercial foodservice facilities are required to operate most equipment under a ventilation hood that captures food and grease emissions and exhausts heat from the kitchen. However, residential cooking does not have the same requirements.

Despite the fact that most home kitchens have a ventilation system above the stove, most homeowners do not use the system unless excess smoke is being produced. Also, many existing residential ventilation system are not maintained and/or are ineffective at capturing food and combustion emissions. Another issue is that the emissions for gas-fired ovens and foods being cooked are not fully understood and quantified for combustion and cooking emissions. These factors have led to growing concerns about the effect that cooking has on residential indoor air quality.

Current studies being conducted by others have questioned if gas cooking is a safe and viable option for use in tighter, more efficient homes. Some of these conclusions on the surface appear to lack a scientific basis and overestimate the emissions from combustion compared with heat and water generated during residential cooking.

In this project, researchers are conducting an analytical and laboratory investigation on the pollutants ($NO_x$, acrolene, 2.5 micron particles) contributed by gas and electric residential cooking, the impact on indoor air quality, and the implications for range hood design. In addition, two special reports were developed to address recent air-quality articles.

## Benefits / Market Implications

With increased concerns about tight homes (or, Net Zero Energy homes), data is needed to fully understand the impact that residential cooking has on indoor air quality and what changes may be needed to existing residential oven designs to meet consumer's needs.

## Technical Concept & Approach

In this project, a research team is evaluating and quantifying residential cooking emissions and further evaluating existing residential ventilation systems and ovens for their effectiveness at capturing exhaust heat, airborne particles, and other emissions in residential applications.

*Rangetop burner emissions capture hood.*

## Results

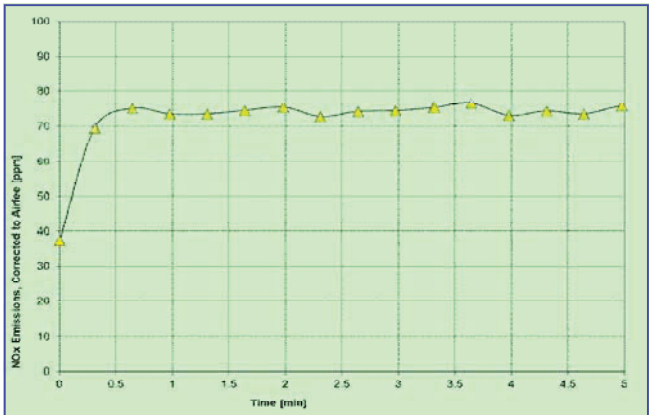
In 2017, an initial evaluation of heat capture using a shadowgraph test setup was completed for all the burners on the range top. A Residential Kitchen Ventilation Test Setup was specially designed for quantifying the capture effectiveness of the hoods. The setup was built using standard residential construction practices and accurately represents a typical residential cooking area. The team also installed a data-acquisition system for measuring temperature, emissions, and energy usage.

The range-hood performance was evaluated using a flow-visualization apparatus. The shadowgraph image was used to determine the amount of capture or spillage of the thermal plumes as a fractional assessment of the projected image. Trace amounts of smoke were also used as a seeding mechanism. The hood evaluation was done at the high-speed air-flow rate on burners separately and in combination.

In general, the hood captured and contained the thermal plumes from the rear burners and failed to capture the thermal plume from the front burners. At maximum firing rate, the hood captured the thermal plume from the rear burners when they operated separately (i.e., 5,000 Btu/hr or 12,000 Btu/hr) or in combination (17,000 Btu/hr). If the firing rate of the front burners was turned down to a dial setting of 2 or 3, then the hood would capture and contain the thermal plume from the front burners. Sensitivity testing showed a cooking pot positioned on the front burner did not require a reduction in the firing rate to maintain capture and containment. When the thermal plume from the front burners spilled, a visual assessment of the shadowgraph image determined that the plume volume spilled 20%-40% along the front edge of the hood and 10%-20% along the sides of the hood.

Researchers also reviewed more than 30 articles that were published in journals or conference proceedings with a focus on $NO_x$ being an asthma cause or trigger. The main articles were Lin 2013, Krasner 2019, Belanger 2013, Singer 2016, HEET 2019, and Garrett 1998 (the latter being the most referenced). The best comprehensive article was “Clearing the Air” from the National Academy of Medicine (Institute of Medicine, 2000) which used proven data analysis to review the information.

Based on established scientific practices and in the opinion of the researchers, many of the publications had questionable conclusions on $NO_x$ and asthma – specifically making conclusions about the relationship between cooking with natural gas and asthma that appeared to be more coincidence than causality. The articles also tended to use implied results from several studies to make a single conclusion against natural gas when none of the articles make a definitive claim on the causes of asthma and all stated that more research is needed. Specific to Singer 2016, the report did not include $NO_x$ emissions data from the oven and data on how $NO_x$ disperses from the oven into the living environment. Basically, no attempt was made to correlate the $NO_x$ emissions from the oven to total value of measured $NO_x$ in the home. Another almost universal conclusion from the reviewed articles was that proper ventilation for both gas and electric cooking greatly improved indoor air quality.



*Rangetop burner $NO_x$ emissions.*

Based on this review, the project team developed a test plan to acquire data to address concerns that have been published about the potential dangers of cooking with natural gas. This plan is included as part of the next phase of this project.

## Status

A Final Report with the literature review and evaluation of the results was issued in June 2020.

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# High-Efficiency Smart Convection Oven

***Efforts are under way to develop a prototype high-efficiency smart convection oven that increases efficiency by at least 5% and integrates superior smart operating controls to maximize food preparation quality and consistency.***

## Project Description

Commercial convection ovens utilize a high-temperature cooking process, which means the flue products need to leave the system at no less than the oven set point temperature of 350ºF-500ºF. Convection ovens by design also constantly flow heat out of the oven (with the fan flowing air across the oven and then out the flue) as they operate, which results in high standby energy use.

There are currently 36 gas ENERGY STAR convection ovens available, but they deliver a mere 44%-55% cooking efficiency. In this project, researchers are incorporating a heat exchanger to recover heat from the flue and feed it back into the combustion air. The objective is to develop a prototype high-efficiency smart convection oven that increases efficiency by at least 5%, and also integrates superior smart operating controls to maximize food preparation quality and consistency.

Earlier, researchers investigated a high-efficiency oven design, showing that this design in bench-scale tests was able to achieve a 3% improvement to cooking efficiency and a 10% improvement to preheat energy use despite not being fully optimized. Based on these results and areas for improvement that were found in that initial design, the project team anticipates that a 5%-10% cooking efficiency should be achievable once the design has been optimized. In addition, a targeted 10%-20% reduction in $NO_x$ and CO emissions are expected.

## Benefits / Market Implications

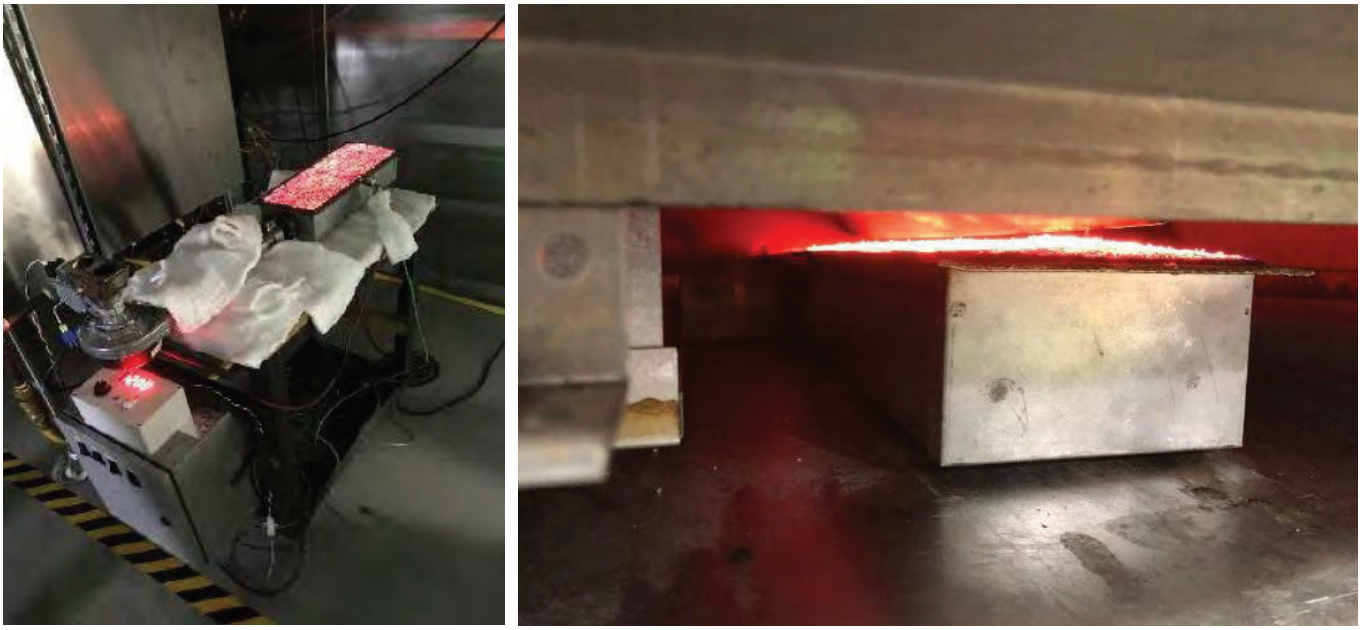
The population of convection ovens in the US is estimated to be around 650,000-700,000, according to a 2015 U.S. Department of Energy study. About 32% of commercial foodservice operations have at least one standard convection oven.

Convection ovens currently use 800 therms annually according to the ENERGY STAR calculator tool. A 2013 California Energy Commission analysis found that replacing existing convection ovens with even 44% minimum ENERGY STAR level ovens resulted in an average energy use reduction of 40% across three field test sites.

The proposed design is targeted to be 10% more efficient than current ENERGY STAR designs. When compared to installed ovens, it could save more than 50% of the energy use, over 400 therms per year. A 50% savings translates to $300 in savings annually for the customer (assuming $0.75 per therm) compared to baseline existing ovens. It would be expected to pay back in one to two years with the cost premium estimated at around $300-$400.

The project team is also incorporating potential "smart" system controls for end users to enhance the quality and consistency of food preparation. Smart system controls may also provide a useful data stream to a manufacturer for enhanced warranties, customer service, and future product marketing and development.

*Modified conventional commercial oven in laboratory analysis.*



*Premix burner installed on the bottom of an oven.*

## Technical Concept & Approach

This project focuses on the development and laboratory demonstration of a prototype next-generation, high-efficiency, smart convection oven. An innovative heat-recovery heat exchanger and burner design will be modified and optimized with the goal of reaching 5%-10% improvement to the cooking efficiency and standby energy use of the oven. In addition, the project team will determine what sensors can be incorporated to make the oven smarter.

## Results

Baseline testing of a current ENERGY STAR oven was completed. A computational fluid dynamics model was made to model several different heat-exchanger designs that could be applied to this oven design. Several heat-exchanger designs and variations were created and researchers began modeling their performance.

## Status

Researchers are completing heat-exchanger modeling and determining the specific best design(s) to move forward. Subsequently, the preferred heat-exchanger designs will be fabricated and installed into the oven in the laboratory. The anticipated completion date for this project is July 2021.

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# Gas-Fired Warewasher

***Efforts are under way to develop a prototype gas-fired door- or conveyor-type warewasher in the laboratory. When commercialized, consumers could achieve significant energy and cost savings by using a new option of gas warewashers as compared to electric units.***

## Project Description

Most commercial dishwashers (also called warewashers) are electric driven and many electric warewashers use chemicals (i.e., "chemical warewashers") rather than high temperature, which further increases environmental impact.

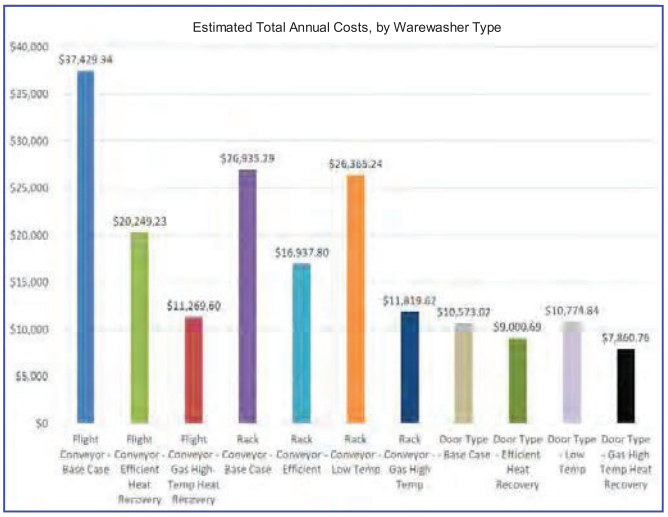
The goal of this project is to provide a reliable, new gas-fired warewasher option for consumers. The primary benefits are to save consumers money, improve energy efficiency, and increase equipment and energy choices for consumers.

Commercial dishwashers are available in four designs for the washing and sanitizing of plates, eating and cooking utensils, and other items. The types include flight type, rack conveyor, stationary door, and undercounter. Flight-type and conveyor warewashers are used for high-volume applications. Door types are the most widely used commercial dishwasher, and undercounter are for very low-usage situations. Commercial dishwashers in each class can be further broken down into either:

1. Chemical low-temperature machines that clean by the use of 120ºF-140ºF water with additional chemicals to sanitize or
2. High-temperature machines, which clean by using 160ºF water to wash and 180ºF water to sanitize.

In this project, a research team will develop a working prototype of a gas-fired door-type or conveyor-type warewasher in the laboratory to demonstrate a viable and reliable product design that meets the potential needs of a manufacturing partner.

*Examples of conventional commercial door-type (left) and conveyor-type (right) warewashers.*



*Example of conventional commercial flight-type warewasher.*

## Benefits / Market Implications

Warewashing equipment is a significant part of commercial foodservice equipment loads, with global equipment capital costs estimated to be approximately $4 billion per year. There are more than 100,000 conveyor-type warewashers in the U.S. A reliable gas warewasher would provide large savings to a commercial foodservice facility and reduce both source-energy and chemical use.

Initial estimates indicate a site will only use one-third of the energy with a gas warewasher compared to alternative technologies. Even a low-usage restaurant with only 1,100 therms of annual usage, would reduce the carbon footprint of the restaurant from 49,610 pounds of $CO_2$ per year with electric units to 16,088 pounds of $CO_2$ per year. In addition, it would cost the restaurant three times more using national average gas and electric prices to run that warewasher on electricity instead of gas. The restaurant would save more than $1,900 a year on operating costs with switching to a gas warewasher.

## Technical Concept & Approach

In this project, researchers will develop a gas-fired warewasher prototype by modifying a current electric design.

A different heat-exchanger design and advanced parts, burners, and controls can all be used and modified as needed to meet the potential needs of a manufacturing partner. These technologies can be applied to both door- and conveyor-type warewashers. Cost additions over standard electric warewashers will be kept as low as possible while still achieving reliable performance.

A functional prototype will be tested for combustion efficiency and emissions standards in the laboratory. Researchers will also test reliability with a short-term continuous operation test in the laboratory.

This project will demonstrate and validate a new design for a gas-fired warewasher. A follow-on project could be to apply the design to additional models or to field test the design and prove its performance and reliability in the field.

## Results

Previously, researchers created a Computational Fluid Dynamic model and modeled the performance of seven different heat-exchanger designs. The project team reviewed previous modeling results and was able to further refine the designs. Researchers are assembling the burner, blower, and gas valve assembly for the combustion system to be installed within the prototype warewasher.

## Status

Technician will assemble the heat exchanger, install it on a tank, and begin testing the combustion system.

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# TRANSPORTATION

UTD Utilization Technology Development

# Free-Piston Linear-Motor CNG Compressor Scale-Up

***A research team is designing a large-scale free-piston linear-motor compressor for use as an inexpensive, energy-efficient, low-maintenance, and oil-free alternative to traditional reciprocating compressors used for natural gas vehicle fueling, in order to reduce operating costs for vehicle owners.***

## Project Description

While the natural gas vehicle (NGV) industry has been growing rapidly, there are still many issues challenging fleet owners and station owners, including station cost, maintenance, and gas contamination. These issues are heavily influenced by the compressor used at fueling stations.

Existing compressors for NGVs consist of multi-stage reciprocating compressors that use a rotating motor to drive a lubricated crank shaft that drives multiple pistons that may or may not be lubricated. These units suffer from high manufacturing costs, high mechanical parasitic losses, relatively high maintenance costs, and relatively short operational lifespans.

Previously, researchers successfully developed a prototype small-scale Free-Piston Linear-Motor Compressor (FPLMC) for at-home NGV refueling that showed promise for reducing the cost of these appliances. This project builds on that work.

The team is using commercial linear motors to build a 50 standard cubic feet per minute (SCFM) compressed natural gas (CNG) compressor. The project has demonstrated control of the motors using off-the-shelf pistons compressing air. The team is now redesigning the fluid end and motor housing to operate with natural gas.

## Benefits / Market Implications

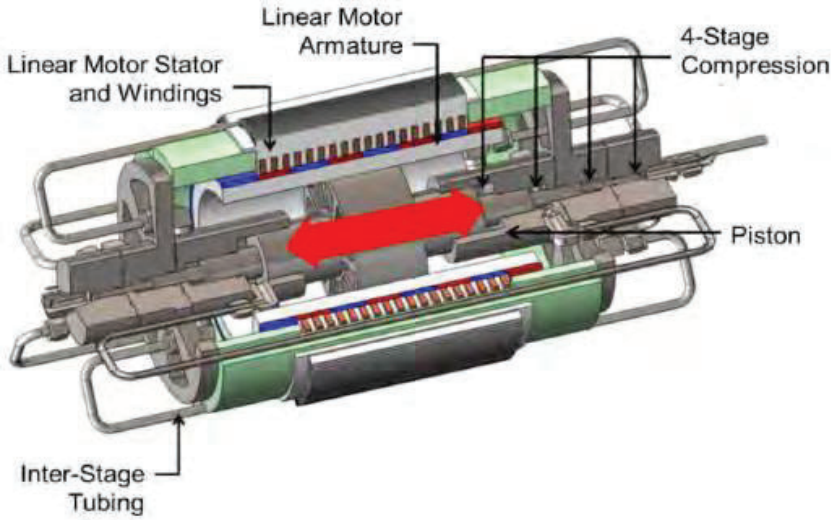
The FPLMC design was developed to improve compressor durability and system efficiency, while significantly decreasing costs of the overall system, including installation and maintenance of compressors.

The FPLMC design eliminates all but one moving part of the compressor and has the potential to significantly reduce capital and maintenance expenses associated with refueling stations, as well as eliminating issues associated with gas contamination and oil carryover (the FPLMC is completely oil free).

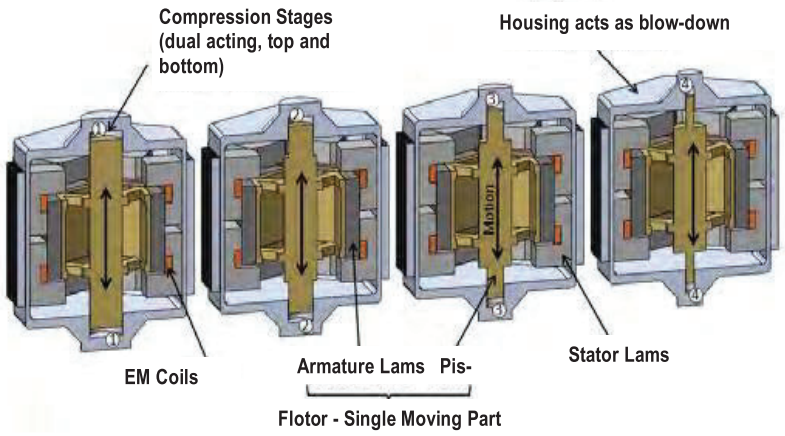
The FPLMC can also be used as a two-in-one compressor and booster to increase storage utilization and fill rates.

## Technical Concept & Approach

The FPLMC concept consists of a compression piston or pistons directly driven by a linear motor. This approach uniquely combines the functions of the compressor and motor into one device with a single major moving part, thus eliminating the inefficiencies inherent in converting rotary motion into linear motion, and eliminating the risk of oil carryover that is inherent with any lubricated crankcase.




*The conceptual linear motor compressor directly drives the multi-stage piston with a linear motor, resulting in a greatly simplified design.*




***Four free-piston linear-motor compressors make up four stages of gas compression.***

***This arrangement allows for independent operation of each stage, and thus stages three and four could be used during vehicle fueling operations and/or to save energy.***

The design has fewer wearing components, reduced parasitic friction, and, consequently, increased compressor durability, improved reliability, and reduced maintenance for end users.

The project team will develop and test a 50 SCFM gas compressor to demonstrate the commercial feasibility of using the linear motor compressor concept for larger-scale CNG station applications, such as to serve a fleet of Class 5-7 delivery trucks. This compressor will be laboratory-tested to demonstrate the performance, efficiency, and durability of the linear motor design under continuous, long-term operation.

## Results

In Phase 1 of this project, researchers confirmed the feasibility of a scaled-up linear motor compressor by validating that it was possible to design and build a high-power reluctance or permanent magnet linear motor. Theoretical designs were developed for both motor types in excess of 100 kW. To make progress in the selection process, the project team evaluated commercial motor options to determine if there were any cost-effective designs that could drive the development forward, identifying several commercial motor variants.

Researchers investigated the performance of the scaled-up FPLMC by modifying the existing dynamic models that were developed and validated for the small-scale FPLMC. The performance of the compressor was analyzed over a range of operating conditions.

In 2018, researchers conducted a detailed engineering analysis of the commercial motor and controller performance to determine their limits within the linear compressor application. The project team made progress towards validating that commercial motors and controllers can be used for compression.

In 2019, the project team validated air compression using commercial motors and validated the accuracy of the simulation. The team designed a hermetically-sealed motor housing to enable compression using natural gas. The design uses gas bearings to eliminate friction and wear on the design. This motor housing will directly connect to the high-pressure fluid ends of the compressor.

Researchers are developing a test rig to verify that the bearing design used in the motor frame will operate as intended.

## Status

The project team has been in regular dialog with compressor-component manufacturers for design input, quotes for compression stages, and exploratory commercialization discussions.

The linear motor preliminary design is complete. The bearing test rig fabrication is nearly complete. Assembly and testing was planned for the first quarter of 2020. However, the COVID-19 pandemic forced the team to delay testing while facilities are closed.

The research team used the time during the lockdown to develop alternative designs that can be compared to the original design. When the lockdown is lifted, the designs will be compared and evaluated for cost, ease of fabrication, probability of success, etc., to determine which design will be used moving forward.

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UTD Utilization Technology Development

# CNG Fuel Station Best Practices

***In this project, researchers collected information on assessment tools and assembled them into a user-friendly software webpage application to help CNG fueling-station operators achieve best practices and meet the requirements of applicable codes and standards.***

## Project Description

Natural gas has gained more use in the transportation sector in the past decade than ever before, due largely to the low cost of compressed natural gas (CNG) versus traditional fuels. There has also been an increased number of state incentive programs to supplement incremental costs for natural gas vehicles (NGVs) and stations, as well as increased focus on the environmental benefits of NGV fleets.

Because of the rapid growth, there are many new companies that are investing in CNG infrastructure. While new investments expand the cumulative benefits of the NGV industry, less-experienced companies that enter the market may be unaware of industry best practices and have limited technical capabilities to verify station performance.

There are times when unsatisfactory performance of a station cannot be corrected until root cause(s) are determined. This can require specialized tools, collection and/or measurement devices, and instruments that are not commonly available or may not exist.

This project collected and compared operating practices to support the universal adoption of best practices and help ensure longevity, reliability, and safe operation of fueling stations.

The project team also created a software webpage application to recommend and record maintenance activities for CNG fueling stations. The application will provide best practice information.

## Benefits / Market Implications

The transportation market is by far the most concentrated energy sector in the United States, with more than 27 quads of energy use almost entirely from petroleum. This represents an enormous potential for beneficial use of natural gas as a transportation fuel and opportunities for consumers to save money and reduce greenhouse gas emissions.

The U.S. Department of Energy forecasts growth in natural gas use in the transportation industry from approximately 40 Bcf in 2011 to 84 Bcf in 2020.

The most important impact of this project is to ensure customer and public safety. Another important value is to improve customer satisfaction with the fueling experience. The development and distribution of performance-assessment tools will greatly relieve some of the burden that is placed on the fleets when developing fueling station requirements.

*Compressed hydrogen station installation showing required fencing and guard posts.*

## Technical Concept & Approach

Phase 1 of this project involved collecting and collating information relating to safety, performance, and best practices of CNG fueling stations. The product of this investigation is roughly 80 pages of material which can provide great value to CNG fueling station operators. However, the quantity of information presented posed problems with effectively distributing this information. Therefore, in Phase 2 researchers developed a website application to effectively place this vast source of information at the fingertips of the station maintenance team.

In Phase 2, the project team created software in three main stages:

1. Software architecture and content
2. Programming, and
3. Software beta testing at a fueling station four weeks.

## Results

In Phase 1 of this project, information was developed on the following areas:

- **Safety**

  This included information from applicable codes and standards as well as details on conducting safety reviews.

- **Station Performance**

  A series of tools and troubleshooting guides were developed to evaluate station performance.

- **Station Best Practices**

  Items surrounding a station that require regular maintenance were included in this analysis. Periodic maintenance checklists were created based on best practices found around the industry. A software tool integrating maintenance checklists with trouble-shooting guides was included in the software. It can be the basis to allow notifications to be issued when some maintenance data deviates from trends. This can provide an early-warning system to maintenance personnel.

In Phase 2, the above information was incorporated into a mobile webpage application which includes data entry interface for the compressor, dryer, and dispenser. The application also includes troubleshooting guides to provide ready access to the information necessary to ensure safe and reliable CNG station operation. Since it is a web page, a different page can be created for each station as the website is expanded.

*Canopy designed to prevent gas accumulation.*

Application developers programmed the application over the course of three months. Some of the challenges were incorporating deadline tracking and allowing the flexibility for correcting erroneous entries. The application was used to log maintenance data at a representative CNG fueling station. This testing experience highlighted a few key issues, including an issue with scrolling on mobile devices. These issues were resolved, and the was application completed and prepared for release.

A generic site was created at the link here for demonstration purposes. It can be accessed at:

*http://tnt.gastechnology.org:5445/login.*

## Status

The project is complete. A web-based application was developed with the ability to operate over almost any device and not limit the storage of information to that specific device. The application allows data entry, storage and display of data in tables, notification of upcoming maintenance, and storage of troubleshooting guidelines.

The project team created and released a free software application to recommend and record maintenance activities for CNG fueling stations.

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UTD Utilization Technology Development

# CNG Composition Impacts on Engines and Fuel-Delivery Systems

***Researchers developed a test protocol to collect and analyze natural gas and liquid contaminants found at NGV fueling stations and evaluate the efficiency of different liquid-contaminant removal systems and mitigation solutions. Best practices and guidelines were developed to further enhance NGV engine reliability for end users.***

## Project Description

Some engine and vehicle operating issues reported by operators of large natural gas vehicle (NGV) fleets are suspected to be a result of heavy hydrocarbon contamination (usually as a result of compressor oil carryover). However, heavier hydrocarbons and oils are some of the most difficult substances to accurately measure because they often drop out of test samples when improper procedures or equipment are used, leading to misleading or misinterpreted results. To address the issue, this project focused on developing appropriate protocols for fuel-quality sampling and testing in order to quickly obtain solutions when operational issues arise.

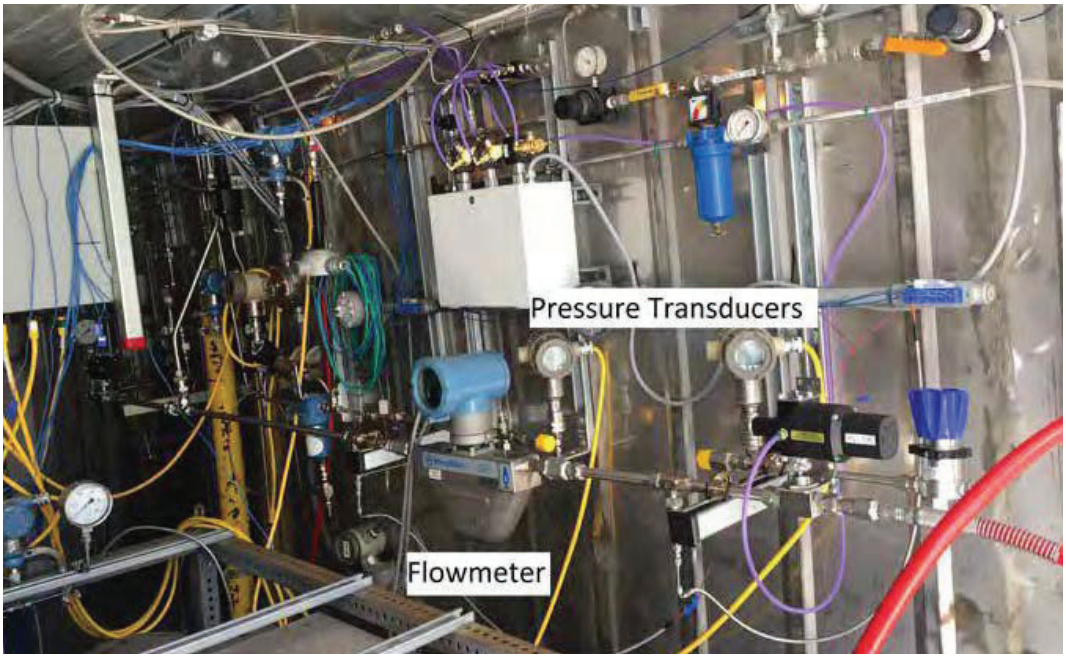
Investigations during Phase 1 of this project found that a significant portion of reliability issues in compressed natural gas (CNG) vehicles can be traced to the contamination of the fuel with heavy hydrocarbons, either from compressor oil or from compounds in pipeline natural gas. These hydrocarbons are present either as a vapor or an aerosol in the CNG as it is transported onto the vehicle.

Phase 1 successfully demonstrated a test protocol, but it also highlighted the lack of available filter testing at CNG pressures. Phase 2 addressed this need by: 1) developing a test protocol to evaluate and rate the performance of coalescing filters or any other components designed to remove aerosols from high-pressure natural gas streams, and 2) developing guidelines to design and apply methods to remove aerosol contamination from CNG downstream of the compressor in a natural gas fueling station.

## Benefits / Market Implications

The protocols developed through this project will provide industry stakeholders (fleets and other end users, station owners, utilities, etc.) with consistent, accurate procedures that can be widely applied.

Generation of performance data for coalescing filters and adsorbents will enable design improvements to enhance the user experience with NGVs. Guidelines will provide station designers with the ability to confidently design stations which include components




*Laboratory testing apparatus.*

based on testing done with high-pressure CNG instead of low-pressure compressed air. These guidelines include critical information to assist in the selection of adsorbent material, in particular their capacity to remove heavy hydrocarbons and odorant from the gas stream, which are currently poorly understood.

Ultimately, results from this research will allow end users to further reduce the capital cost of building CNG fueling infrastructure and improve NGV user experiences.

## Technical Concept & Approach

In Phase 1, researchers investigated the root causes of some reported vehicle issues (clogged injectors, regulators "freezing," liquids in filter housings and storage containers, etc.). The investigation involved a literature search as well as discussions with vehicle and engine OEMs and fleets. Liquid samples were collected from nine different sites that were experiencing vehicle operational issues suspected to be due to CNG quality. When possible, liquid samples were collected from the low- and/or high-pressure coalescing filters on the vehicle. Additionally, liquid samples were taken from fueling station filters or dryers whenever possible.

In Phase 2, the project team designed, built, and commissioned a test system to evaluate the performance of coalescing filters. Design and application guidelines were determined from the data obtained during the testing program. An economic analysis was also conducted to determine the cost savings these solutions could provide to fleets and fueling-station operators.

In Phase 3, a similar program was conducted with adsorbent filters instead of coalescing filters. Researchers modified the high-pressure apparatus to enable measurement of the vaporized oil in the gas stream. This was used to evaluate the performance of several different methods for measuring and removing oil vapor and provide guidelines to the industry for design of these devices.

## Results

The review of vehicle contamination issues and causes revealed that the most common cause of vehicle reliability issues was contamination of the gas with compressor oil. Several instances of natural gas liquids contamination at CNG fueling stations were found, but these were predominantly upstream of the compressor and not the direct cause of the vehicle reliability issues.

Two test methods to detect (and/or measure) the presence of these heavy hydrocarbons were developed and tested.

The Phase 2 test apparatus construction was completed in 2019. The system was designed to provide flow rates up to 250 SCFM to accommodate larger filters. Testing showed that some filters are not appropriately rated for operation at CNG pressures. Some guidelines for filter application were developed based on results.

Two commercially available filter element grades were tested simultaneously. The filters were tested over a range of pressures from 750 psig to 2,300 psig. At each pressure, the system was allowed to equilibrate for 45 minutes, then oil was drawn from each filter twice, once at 90 minutes and once at 135 minutes. To calculate filtration efficiency, the mass of oil removed from each filter was measured and compared to the mass delivered to that filter.

The adsorbent test bed was completed in 2020. Testing was completed in June and included the confirmation of results with a large adsorbent, as well as testing typical liquid-phase adsorbent sizes. The test system disperses octane directly into the high-pressure gas stream. The octane vaporizes once in the gas. The system was found to completely vaporize the injected octane. As the gas pressure is decreased to 150 psig after the adsorbent bed, the octane that is not captured in the adsorbent condenses into a liquid phase that is captured in a coalescing filter and collected in a tube where the amount of octane present is measured with a level transmitter.

Testing of two adsorbent sizes was completed at various flow rates. The first adsorbent was a typical gas-phase activated carbon, with 4x8-inch mesh sizes. The relatively large size is effective only if the diffusion rate of the adsorbing species is very high. In the high gas density CNG environment, that diffusion is much lower than in typical low-pressure vapor applications. Therefore, the team also tested a typical water filtration activated carbon, with 12x40-inch mesh size. The results showed that the smaller, liquid-phase adsorbent was able to perform well with twice the gas velocity through the bed as the gas-phase adsorbent. Full implementation guidelines were developed for adsorbent filters.

## Status

All testing was completed. The Final Report for Phase 3 is currently under review.

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UTD Utilization Technology Development

# Modular CNG Storage System Investigation

**Researchers investigated the development status, governing codes, and certification needs for various conformable CNG storage systems that have the potential to provide a 40%-55% reduction in weight, a 20%-30% reduction in space, and a 20% reduction in cost compared to their conventional counterparts.**

## Project Description

The current state-of-the-art vessel for storing compressed natural gas (CNG) is a cylinder with either a metallic or non-metallic liner reinforced by a carbon or glass fiber wrap. However, this type of storage can result in an inefficient use of the space on a vehicle.

In response, the U.S. Department of Energy Advanced Research Projects Agency - Energy (ARPA-E) created a program to investigate conformable storage for CNG in order to increase the on-board fuel capacity of CNG storage while simultaneously reducing cost and weight.

In this ARPA-E program and with UTD cofounding support provided in this research project, researchers identified several candidate technologies and investigated the status, related codes, and certification needs for various conformable storage systems being developed.

## Benefits / Market Implications

Conformable storage for CNG vehicles has the potential to significantly reduce the storage volume, weight, and cost of high-pressure onboard CNG storage for natural gas vehicles (NGVs). These improvements could provide greater benefits to end users of CNG as a transportation fuel, providing longer range, lower cost, lighter weight, and less bulky CNG storage.

Transformative improvements not only positively impact the light-duty NGV market, but can also further service the long-hauling truck market. By storing more fuel in a lighter configuration, Class 8 trucks can easily travel from station to station while still maximizing the weight of cargo they can carry.

## Technical Concept & Approach

This project included an evaluation of various conformable and modular storage designs to determine their

*Researchers investigated various products and technologies in development for improved CNG onboard storage.*

market potential, status, barriers, and needs. The project team also helped to determine the best ways to accelerate testing and commercialization of these technologies for end users.

Specific tasks included:

- **Product Evaluation**

  Select conformable tank designs were identified as having the best potential for success as a transformative solution for CNG storage on vehicles. The evaluations included a review of test results, validation of theoretical design calculations, a review of design assumptions and safety code compliance, and an assessment of the manufacturer's capabilities to advance its product to market. Interviews were conducted with each technology provider and subject matter expert to either validate the approach as sound or eliminate it from further consideration.

- **Barrier Reduction**

  After selecting the most promising technology or technologies, the project team met with the manufacturer(s) to identify any technical or industry barriers currently preventing commercialization.

- **Search for Additional Funding**

  The project team assisted manufacturers in securing additional funding from various state, federal, and private industry sources. This additional funding was used for technical development, testing, and other barrier-reduction initiatives.

## Results

Four companies were identified that are either currently developing conformable CNG storage tanks or have developed them significantly in the past and are still looking for customers, applications, and development partners. The project team also looked at a couple of bulk CNG transport companies that interestingly rely the same design concepts that conformable tank technologies typically leverage.

Among the four conformable CNG tank development companies that are actively promoting their products, none of them have commercially available products that are certified for meeting applicable engineering standards, although there are two companies that have prototypes currently undergoing select tests from the NGV 2-2019 standard.

Without any products being certified and in commercial production, it is impossible to know definitively what storage performance the final commercial product will have. A prototype may, for example, fail a certification test, proving that it needs to be made of different materials or with greater mechanical strength, and, therefore, be heavier, reducing storage efficiency of the eventual commercial product compared to the prototype. On the other hand, overbuilt features or opportunities for further design optimization may be discovered, resulting in commercial products with superior performance. Finally, the benefits of mass production invariably result in declining manufacturing costs, although it can be difficult to predict the extent. Among the four conformable technology developers, each has only developed enough prototypes for internal testing and certification testing efforts.

Representatives of the four conformable tank developers were interviewed about the level of storage performance achieved by their prototypes and the approximate product cost they were targeting. The results are summarized in the Final Report.

Qualitative designations were assigned to indicate the degree of conformability of each technology based upon the shape forming versatility of each design and its potential to achieve high volumetric efficiency when used in installation spaces that are narrow/thin, highly irregular in shape, or closely associated with other structural components of the NGV.

However, the largest and most challenging barrier to further development was identified as the inability to certify conformable tank designs. As a result, a joint development proposal between Gas Technology Institute (GTI) and CSA Group was accepted by ARPA-E to refine the CSA/ANSI NGV2 standard to accommodate conformable storage. Representatives from the project team served on the committee to revise the NGV 2 standard, and an updated standard which acknowledges conformable tank designs for the first time was published in early 2019.

## Status

This project is complete. A Final Report was issued in March 2020.

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# NGV Codes and Standards Monitoring, Development, and Support

***Through this project, researchers are supporting the consensus development or refinement of relevant natural gas vehicle codes and standards. Efforts are focused on helping create or modify important codes and standards by participating on select technical committees and working groups, or through review and formal comment.***

## Project Description

This project addresses the need to respond to new technologies, clarify coverage between existing standards, and expand coverage to all necessary applications. Project representatives are participating in relevant natural gas vehicle (NGV) codes and standards developments and supporting the consensus creation or modification of important codes and standards.

In light of the need for a temperature compensation standard for natural gas fueling, representatives from this project led a separate compressed natural gas (CNG) task force to develop the CNG fueling temperature compensation standard. The now-published requirements for temperature compensation devices allow CNG dispensing systems to adjust for full fill of vehicle fuel storage containers under all surrounding outdoor ambient temperature conditions and variations in natural gas composition.

The new fueling appliances standards developed with support from this project assist local code enforcement officials by minimizing the potential of different interpretations of "appliance" requirements, and thus simplifying and clarifying the local approval process for these qualifying devices. In addition, the NGV 4.3 and NGV 6.1 standards will ensure more consistent safeguards against over-filling of NGVs and improper fuel storage and delivery system installations onboard NGVs.

## Benefits / Market Implications

Knowledgeable and logical input into the consensus-building process under the rules of standards development bodies is critical to ensuring proper application and safety to protect users and the general public.

This project also aids end users by supporting the introduction of new NGV fueling appliances, dispensers, and onboard vehicle products into the marketplace that can improve on incumbent technologies and practices. Continuous monitoring of potential improvements to keep pace with changes in technology is a critical need and significant challenge.

One of the key goals of this project is to help shape the definition of performance and safety aspects of new technologies, ensuring that commercial offerings are reliable and safe.

*"CSA recognizes the input and insight that our committee members provide on NGV technical subcommittees. Through participation in the standards-development process, UTD contributes to the deployment of safe and reliable components, equipment, and practices for the industry."*

*- Julie Cairns*
*Sr. Project Manager, Alternative Energy*
*CSA Group*

## Technical Concept & Approach

Participation in the codes-and-standards development process on behalf of the natural gas industry and ratepayers has been critical in establishing confidence in safe and progressive NGV use. Through this project, industry representatives continue to participate as voting members in the technical advisory groups for CSA NGV 5.1 and NGV 5.2. In addition, project representatives were able to lead the NGV 4.3 Task Force and contribute to NGV 6.1. Efforts to update Interim Requirements (IR 7-16) for ANG fueling devices and NGV2 *Natural Gas Storage Containers* are under way.

The project team is monitoring standards development activities that impact the NGV industry and seek to identify any gaps or inconsistencies in coverage. Although the primary focus is on U.S. and Canada coverage areas, harmonization efforts with international NGV codes and standards is taking place as well.

Project representatives participate in monthly discussions scheduled by CSA Group involving stakeholders (including product manufacturers, gas utilities, testing organizations, vendors, and code developers) to monitor and support the progress of new standards, as well as modifications to existing standards.

Periodic reporting to UTD members is provided for the project to summarize and analyze the consequences of the standard(s) developed and key impacts or issues.

## Results

Representatives for this project:

- Continue to chair the NGV4.3 Task Force on Temperature Compensation Requirements. The temperature compensation guideline for CNG vehicle fueling is undergoing a major overhaul to include testing for new dispensers as well as updates to better reflect accurate temperature compensation. Project personnel are developing the base technical case for the change process. Researchers prepared several presentations and documents to continue the technical discussions. Additional discussions around temperature compensation of mobile pipeline trailers continued in parallel with the NGV 4.3 discussions.
- Participated on the Harmonization Committee to identify inconsistencies and recommend changes to CSA B108, the International Fuel Gas Code, and the International Fire Code to recognize CSA NGV 5.1 and 5.2.
- Participated in the ANSI/CSA NGV 5.2 Compressed Natural Gas Vehicle Fueling Appliance Standard development process.
- Participated in the CSA/NGV 6.1-CNG Fuel Storage and Delivery Systems for Road Vehicles committee.
- Participated on the CSA Technical Committee for ANSI/NGV 4.1 (CSA 12.5) NGV Dispensing Systems Standard. In 2018, researchers presented to the committee information on communications and fueling algorithms for CNG dispensing.
- Participated on a Common Issues Task Force comprised of the chairs of all Technical Committees and Task Forces related to NGV-based standards to reconcile any differences that may exist among standards.
- Monitored the research being conducted on a new adsorbed natural gas (ANG) storage container standard ANG-2, as well as a low-pressure version of NGV5.1 specific to use with ANG vehicle storage under the Interim Requirement IR 7-16.

In 2019, NGV2 2019 (CNG Fuel Containers) was published that includes localized fire tests and conformable storage.

CSA NGV 4.8 – Compressors for Natural Gas Vehicles Fuel Stations Technical Subcommittee – is in review and several modifications, clarifications, and terminology changes are proceeding to make the standard more universal, allowing for more than just reciprocating compressors, and unified with other standards.

The National Highway Traffic Safety Administration is considering fuel system integrity requirements for medium-duty and heavy-duty CNG and liquefied natural gas vehicles to update FMVSS No. 303.

## Status

Evaluation of a variety of additional standard review cycles is under way.

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# NGVAmerica Technology Committee Participation and Representation

***This project provides technical information and resources to advance the safety, economy, reliability, low emissions, and best practices for users of vehicles powered by compressed natural gas or renewable natural gas. Activities are conducted in coordination with the NGVAmerica Technology Committee.***

## Project Description

NGVAmerica (NGVA) coordinates a broad base of support for identifying the technical needs of natural gas vehicle (NGV) end users. Through NGVA, the NGV industry can mount a coordinated effort to set priorities and promote technology.

NGVA is dedicated to the development of a growing and sustainable market for vehicles powered by natural gas or renewable natural gas (RNG) to benefit consumers and the environment. The organization represents more than 200 companies, environmental groups, and government organizations interested in the promotion and use of natural gas and RNG as transportation fuels. Its members produce, distribute, and market natural gas and RNG across the country; manufacture and service natural gas vehicles, engines, and equipment; and operate fleets powered by gaseous fuels.

NGVA's Technology & Development Committee was created in 2015 to interact with industry stakeholders and federal agencies on NGV technology development, codes and standards, best practices, and other industry issues. NGVA working groups were created to support critical issues and needs, and revised over time to keep pace with the changing priorities of the industry. The organization relies largely on the voluntary efforts of member companies and their representatives to address the issues of most importance and interest. NGVA acts as a coordinator and facilitator to unite interested stakeholders.

Through this project, UTD provides representation on the NGVA Technology & Development Committee in order to advance the safety, economy, reliability, low emissions, and best practices for users of vehicles powered by compressed natural gas or renewable natural gas.

## Benefits / Market Implications

UTD's representation on the NGVA Technology & Development Committee is critical to address the needs of end users and to further advance the benefits of NGV technologies. Each of NGVA's working groups focus on topics identified by the industry as the top priorities to position the consumer and the industry for the future. Speaking with a single voice backed by the consensus of stakeholders is a more powerful way for NGVA to set technical priorities for research and development for the consumer and industry.

## Technical Concept & Approach

The project team leverages its significant body of knowledge, expertise, and relationships developed over many years of focus on NGVs, and participates actively to support the activities of the Technology and Development Committee. The team also solicits periodic requests for input from UTD's Transportation Working Group and designated representatives to ensure that a broad base of opinions and thoughts are leveraged to help support the NGV Technology Committee's decision making.

*"The NGVA Technology Committee largely relies on the voluntary efforts of member companies and their representatives to address the issues of most importance. UTD's support to provide representation on the Committee and our working groups has been instrumental in the many achievements to date."*

*- Daniel Gage*
*President*
*NGVAmerica*

## Results

Representatives participated with groups addressing:

- Incident Investigation and Root Cause Analysis
- Gas Quality
- Compressed Natural Gas (CNG) Fuel System Inspection
- Codes and Standards
- Maintenance Facility Modifications
- Emissions/Environmental
- Liquefied Natural Gas (LNG) and Marine and Rail
- NGV Manufacturing Facility Best Practices/ Training, and
- NGV R&D Priorities.

Representatives participated on the Alliance to Save Energy "50 By 50 Commission: Heavy Duty Transportation Technical Committee" by providing technical information for the gaseous fuels section of the report. The Emissions Working Group conducted conference calls to address issues surrounding methane slip/fugitive emissions and, secondly, the accuracy and treatment of NGVs in the most commonly used emissions impact modeling tools. The Working Group also developed a White Paper titled *Understanding Global Warming Potential - and Other Greenhouse Gas Emission Metrics.* In conjunction with the RNG Coalition, the group created an infographic to show the vast quantity of RNG that is being used as a transportation fuel. The infographic can be downloaded from the following link:

*www.ngvamerica.org/wp-content/uploads/2019/04/RNG-Driving-Down– Emissions.pdf*

Project representatives provided a detailed natural gas R&D topic list to NGVA and to the U.S. Department of Energy (DOE) for consideration for its upcoming natural gas research funding initiatives. The project team supported NGVA in the development of a Cold Weather Advisory Bulletin to ensure safe operations of NGVs in cold weather, and also released a CNG fuel system inspection guidance document that can be found at the following link:

*www.ngvamerica.org/wp-content/uploads/2018/03/CNG-Vehicle-Fuel-System-Inspection-Guidance.pdf*

In 2019, NGVA submitted a 10-page letter to the DOE titled *Natural Gas as a Transportation Fuel – A Strategic Opportunity for U.S. Energy Security Enabled by Innovation and Advanced Technology* in response to the Office of Energy Efficiency & Renewable Energy's request for input on NGV R&D needs and barriers.

Increases in the use of RNG is a main focus of NGVA's mission. In 2019, updated data was released on RNG use in NGVs. Many of the project team's technical efforts support the advancement of RNG.

The project team presented several current projects at the 2020 Natural Gas Vehicle Technology Forum Annual Meeting in February.

## Status

The project team continues to provide technical staff members to Chair the NGVA Technology Committee and staff its Working Groups. Researchers also provide specific technical support to the industry response to NGV safety incidents.

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# US Hybrid ISL8.9 Charge-Sustaining Hybrid Truck Retrofit and Demonstration

***Research was performed to develop and demonstrate a fully integrated and optimized natural gas hybrid-electric Class 8 vehicle to advance the performance, fuel efficiency, and competitiveness of natural-gas-engine hybrid-electric systems.***

## Project Description

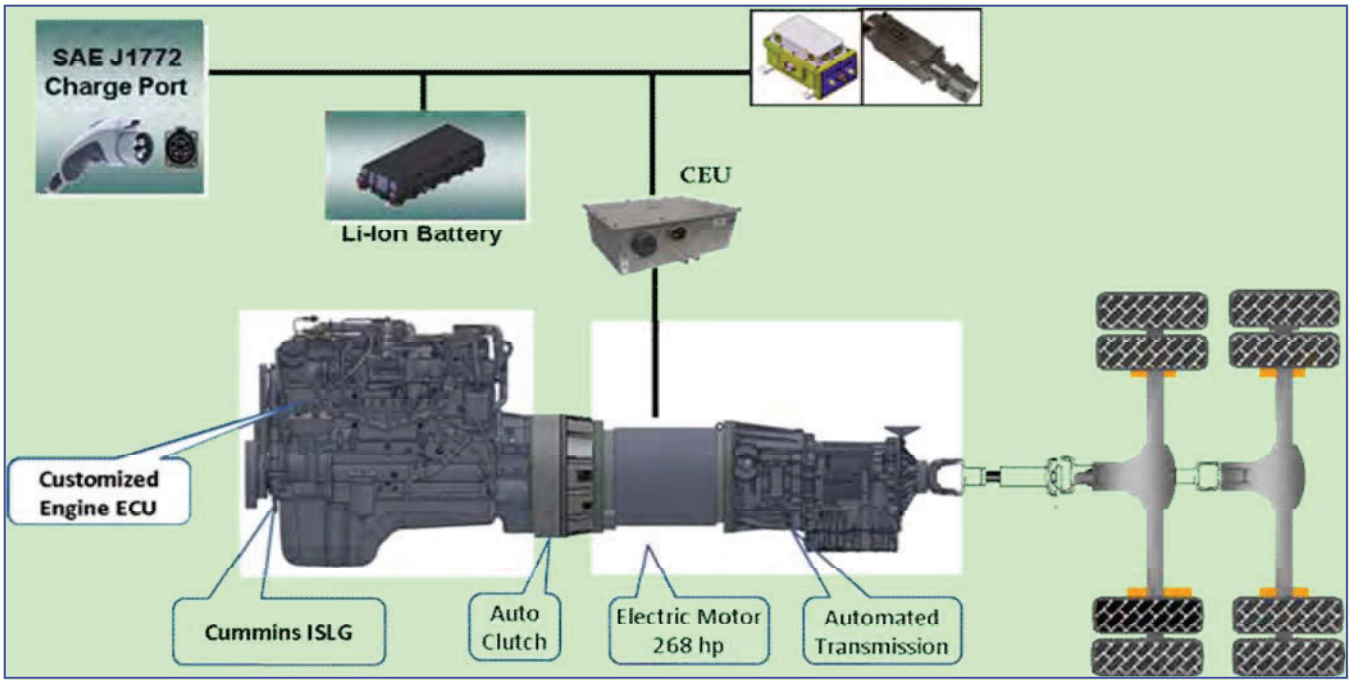
Hybridization is a proven means for reducing fuel consumption for conventional vehicles; however, if not properly integrated, the hybrid-electric vehicle will exhibit performance difficulties. Sub-optimal operations may include the inability of the engine to operate at its ideal efficiency by avoiding low-power operation and rapid-throttling events. Several past heavy-duty hybrid evaluations have also shown an increase in $NO_x$ emissions for the hybrid vehicle compared to the non-hybrid version, as well as some instances with no increase in fuel economy. To improve the competitiveness of natural-gas-engine hybrid-electric systems, hybrid functionality, engine integration, engine controls, and exhaust after-treatment need to be addressed.

The objective of this project was to develop and demonstrate a fully-integrated and optimized natural gas hybrid-electric Class 8 vehicle with advanced performance, improved overall system efficiency, and reduced emissions.

The optimization was applied to an existing plug-in hybrid Class 8 truck platform that includes an electric-drive system with 80kWhr lithium ion battery capacity and a 240kW electric-drive motor. A hybrid configuration was used for the vehicle that allows the Cummins Westport Inc. (CWI) ISL8.9 G engine to drive the truck during cruising for best efficiency and allows the electric motor to supplement the power to provide superior acceleration and energy recovery during regenerative braking. In hybrid mode, the total available power exceeds 500 HP, providing performance similar to that of a 15-liter diesel engine, while significantly reducing emissions and increasing fuel economy. The truck was designed to be able to operate in electric-only mode for zero-emission driving for short durations.

The results from dynamometer and emissions testing incorporated in this project provides evidence that a plug-in, hybrid-electric, liquefied natural gas vehicle is nearly ready for commercialization. This project could result in a significant advancement of the hybridization technology towards a cost effective near-zero emission commercial offering.

UTD's project partners included the California Energy Commission (CEC), which provided the prime funding for this research. Additional UTD partners included US Hybrid Corp. and the University of California, Riverside.



Commercial natural gas engines are currently available to fleet owners; however, the options are extremely limited. Commercialization of US Hybrid's technology will build upon CWI's ISL platform to bring a second near-zero option into the market, introducing a natural-gas/electric hybrid offering where none exists today. This advancement would allow for completely renewable operation using either renewable electricity or renewable gas.

## Technical Concept & Approach

The scope of this UTD project was based on the structure of the CEC prime contract agreement, which also included technical tasks for UC Riverside and US Hybrid that included component design, analysis, and testing, as well as vehicle integration, optimization, and chassis dynamometer testing.

Specific tasks included:

- **Evaluation of Project Benefits**

  This task included estimating energy use, greenhouse gas and criteria pollutant emissions reductions, benefits to the targeted market sector, and implementation costs. This information was gathered during the course of the project.

- **Technology and Knowledge Transfer Activity**

  This task resulted in the development of a Technology and Knowledge Transfer Plan that includes making the knowledge gained available to the public, a description of the intended use of the technology, a discussion of any relevant policy developments, and copies of any fact sheets, journal articles, or press releases prepared during the project.

- **Production Readiness Plan**

  This task resulted in the development of a Production Readiness Plan that included discussion of critical processes, equipment, facilities, personnel, or support systems needed for a commercially viable product. In addition, it includes the costs of production and the expected investment needed to launch the commercial product.

## Results

This demonstration project utilized a commercially available, 2010 certified, dedicated natural gas CWI ISLG 8.9L engine and enhanced the system to make it representative of an engine meeting optional low $NO_x$ near-zero standard.

Both the commercially-available, 2010 certified, CWI ISLG 8.9 and newly certified engine technologies were reviewed and evaluated at UC Riverside to provide an in-depth characterization of emissions formation and fuel consumption results. The UC Riverside emissions test laboratory was upgraded in order to quantify such low-emission factors where ambient concentrations represent more than 50% of the diluted sample concentration.

Two primary observations were identified during the review: 1) up to 90% of the emissions are the results of either rapid engine speed transients (i.e., hot-start tests) or cold starts emissions and 2) the impact of transient and cold start emissions is more critical at the lower near-zero emission standard (0.02 g/bhp-hr) when compared to the 2010 certified, ISL G standard. This suggests emissions differences may be significant between drivers, vocations, and vehicle configuration (automatic transmissions vs manual transmissions).

Potential opportunities to improve the control of the vehicle systems – including fuel monitors and battery-management systems – were identified. The demonstration showed that there was a path to ultra-low emissions with some further optimization work to eliminate low-torque operational conditions via better control and anticipation of power needs. The project team explored multiple pathways to modify the engine-control system, vehicle components, or the hybrid module.

The project team integrated and demonstrated the hybrid truck on a chassis dynamometer at UC Riverside's facility. The hybrid-electric truck was tested following five different drive cycles. Results showed the hybrid-electric truck could easily move twice the load of the non-hybrid truck with reduced emissions.

## Status

This project is complete. A Final Report was issued in December 2019.

Future deployment of hybrid technology should take advantage of this engineering success. This includes the commercial CWI Near-Zero (NZ) natural gas engines, which are superior to the engine used in this research project. It is recommended to develop a hybrid demonstration with the advanced ISL G 8.9 NZ engine utilizing the same chassis platform. This platform would demonstrate the best-available technology for hybrid integration.

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# CNG Station Methane Measurement Investigations

***Research in this project involves developing techniques to quantify the leaks and losses of natural gas from CNG vehicle fueling stations by evaluating station operations and advanced compression technologies, and providing guidance on methods to monitor station leakage performance and minimize leaks and losses.***

## Project Description

While natural gas vehicles (NGVs) have demonstrated significant reductions in many criteria pollutants and ozone-forming emissions, one component that was not included in most past regulations is methane. Although methane is not present in gasoline or diesel fuel, it is the predominant compound in natural gas and therefore even relatively small amounts of methane leakage at a compressed natural gas (CNG) fueling station can cause concern. New U.S. Environmental Protection Agency greenhouse gas (GHG) standards are expected to regulate total GHG emissions, including methane emissions.

Fortunately, some advanced compressor technologies have come on the market that are capable of reducing or eliminating methane emissions from compressors. These enhanced compressors are starting to be implemented, and evaluating their performance compared to baseline compressor methane leakage rates would be extremely helpful in accelerating industry adoption.

An additional need that has been described by several CNG station owners is that there are frequently difficulties in reconciling the metered inlet gas to CNG stations with the gasoline gallon equivalent (GGE) dispensed. A method to account for all sources of gas flows in and out of a station, along with explanations of how the precision and accuracy of various metering devices compare, would assist in properly characterizing vented gas, station economics, and the environmental impact from station operations.

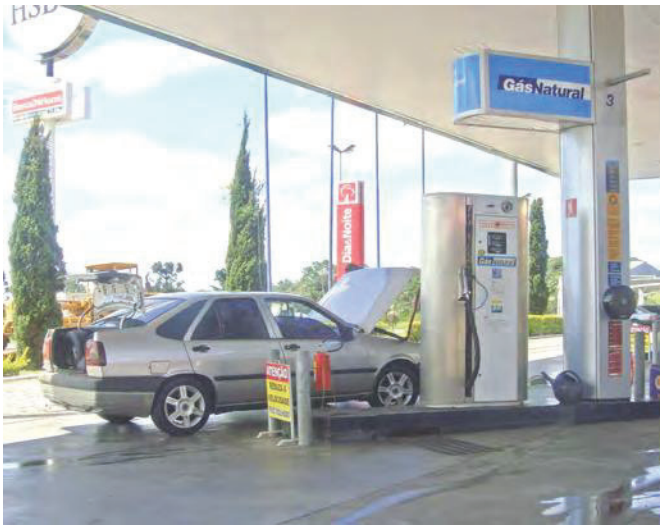
The objectives of this project are to quantify the leaks and losses of natural gas in the CNG fueling process within a CNG fueling station, evaluate advanced compression technologies, and provide guidance on tracking methods to monitor station leakage performance.

## Benefits / Market Implications

The potential for increased regulations to minimize these losses, coupled with the environmental GHG consequences of methane releases from the same situations, prompts the need for data on state-of-the-art technologies and the potential impacts from CNG station operations. In addition, identifying and assessing the performance of new or upcoming technologies to reduce CNG fueling station emissions will be another important result.

In a related development, the U.S. Department of Energy (DOE) is investigating losses associated with high-horsepower gas compression facilities – one aspect of which is the increased energy consumption associated

*Instruments used to detect and quantify methane emissions. From left to right 1) a SENSIT Gold G2 combustible gas indicator, 2) a Bacharach Hi Flow detector, and 3) a FLIR GF-320 Infrared Camera,.*




with leaks and venting of natural gas in midstream and downstream transmission.

Reducing the errors in measurement used to determine leakage and accounting discrepancies can advance station operations and the understanding of environmental impacts.

## Technical Concept & Approach

This project is leveraging the activity of a separate research project funded by the California Energy Commission (CEC) that is quantifying full-value-chain methane emissions, including CNG fueling stations. This study will provide information on common sources of gas losses, methods to mitigate those losses, and practical methods to monitor stations for losses in an effort to quickly catch poor station performance, enabling prompt detection of significant station emission sources.

The CEC project team plans to visit approximately 30 CNG stations in California. A session of more intensive data collection under more controlled conditions will also be conducted at a fueling station in Illinois to complement the CEC data.

Specific tasks include:

- Assisting with data interpretation of the CEC project results
- Coordinating a literature review and reconciliation with other prior studies, and
- Developing a method for monitoring station gas losses.

For this project, CNG fueling-station leaks are being detected via three methods, including a specialized infrared camera, a portable combustible gas-leak detector, and a Hi Flow Sampler™. The infrared camera visualizes the leaking methane by taking advantage of the unique physical and chemical properties of fugitive gas leaks. Utilizing a radiant contrast between the surrounding background and the gas leak plume, the camera will detect and display the leak as a black plume on the thermal image. The thermal image can be viewed on the camera viewfinder, allowing a properly trained operator to quickly locate methane emissions sources.

## Results

In 2018-2020, the project team collected a significant amount of leak data from about 30 CNG vehicle fueling stations, using the three separate leak detection and measuring techniques. A significant literature review was also conducted to support this study.

Researchers also carried out experimental tests to quantify the volume of gas contained in the gas lock between the CNG dispenser hose nozzle and NGV fueling port connection. The code requirements involving the volume of the dispenser nozzle and hose were also studied, helping to create an estimate of the volume of gas contained in the gas lock between the dispenser hose nozzle and car receptacle connection. This small volume of gas tends to escape each time an NGV is fueled.

The project team verified that typically the largest source of methane emissions from a given CNG station is the leakage that occurs around the rod seals of the reciprocating compressors used to boost the gas up to fueling pressures, although undetected pipe-fitting leaks can also make a significant contribution if they are particularly severe.

A literature review revealed promising technological advancements made over the last few years that claim to dramatically reduce the emissions from the compressors during their operating cycles.

Although progress of this project has been at times limited by the pace of data collection of the concurrent CEC study, investigators anticipate leveraging their effort will result in a robust data set for this project.

## Status

Researchers are completing the Final Report for this project.

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# Cost-Effective CNG Pre-Cooling Technologies

***In this project, a research team is investigating and designing an innovative, cost-effective system to pre-cool compressed natural gas (CNG) prior to being dispensed into a natural gas vehicle in order to achieve full fills and improve operating range and user experience.***

## Project Description

Pre-cooling compressed natural gas (CNG) before it enters a CNG vehicle is essential to achieving a full fill under most fueling and ambient conditions. This need is driven by the heat of compression occurring during a CNG fill that causes the tank to significantly gain heat, resulting in the pressure limit being reached prior to transferring the total mass that defines a full fill.

Under-filling of CNG vehicles directly impacts the cost and range of the vehicle, negatively impacting the perception and payback period for end users who operate natural gas vehicles (NGVs).

The largest capital-cost barrier for CNG adoption and the increased consumption of natural gas is the high cost of CNG storage cylinders onboard NGVs. Type 3 and 4 cylinders are typically used for North American markets to limit the weight penalty on many vehicles; however, these cylinders come with a high cost compared to steel tanks used in many other parts of the world. For example, the incremental price increase for a heavy-duty CNG class 6 or 7 truck requiring 150 diesel gallon equivalent or greater fuel storage is about $50k to $75k, depending on the total volume of the CNG storage system.

There are industry efforts under way to directly reduce the cost of composite storage vessels; however, the issue of under-filling directly impacts the volume of storage required on a vehicle. By providing consistent full fills, a vehicle requires a smaller fuel system, reducing the cost and weight of the vehicle's CNG system. This improves the vehicle's range, economics, and the user experience of operating a CNG vehicle.

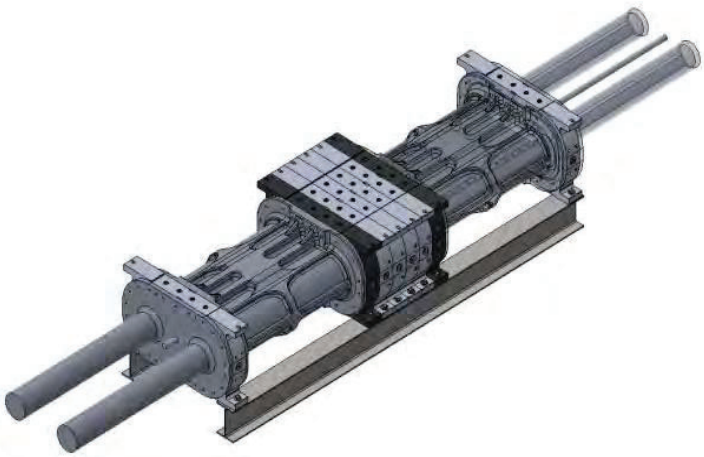
Research has been ongoing to improve full fills by developing improved dispenser algorithms, investigating vehicle-to-dispenser communication, and analyzing pre-cooling systems. These activities have led to the conclusion that some form of pre-cooling is necessary to guarantee a full fill, as well as providing some direction towards the best method to use to achieve the pre-cooling.

The most obvious method for pre-cooling is to use a vapor-compression chiller to cool the CNG being delivered to the vehicle. This method is being used for some virtual pipeline filling stations, but is too expensive for most CNG vehicle filling stations. Research is currently determining whether the system design and operation can be optimized to bring down costs. Results to date indicate that there may be opportunities to reduce costs as these systems become more common; however, they also become disproportionately more expensive for smaller stations as the chiller must be sized to handle the full flow.

Alternatively, the existing CNG compressor could be used to drive a Joule-Thomson cooling loop that is used to store cooling capacity between vehicle fills, and then use that cooling capacity to pre-cool the CNG going into the vehicles during a fill. This strategy has the advantage of reduced capital cost as it uses existing CNG station equipment, but will add run time, complexity, and maintenance cost to the CNG compressor. A detailed analysis is being conducted to estimate the annual increase in compressor run time to accomplish the required pre-cooling. This analysis can be used to determine if the increased compressor run time is worth the reduced capital cost of the equipment.

It is also possible to improve a CNG fill by using a turbo-expander or similar device to pull energy out of the gas as it is flowing into the vehicle. An expander causes the gas to get colder than it would with Joule-Thomson cooling, allowing more gas to enter the vehicle before the pressure limit is reached.

Expanders show the most promise as they do not require any additional energy input to achieve the desired



pre-cooling. The largest issue with these types of devices is that they are not commercially available for CNG's high pressures, requiring a device to be designed specifically for this application.

Overall, the expander development seems to be the most promising path forward due to the ideal thermodynamic performance and efficiency. Ideally, the expander would result in a lower capital cost, as well as a lower operating cost because it does not require additional power.

The objective for this project is to design, build, and demonstrate a novel expander to pre-cool CNG in order to achieve full fills of CNG storage tanks on NGVs and, thus, increase effective storage capacity by 20%-25%.

This UTD project is leveraging significant prime funding from the U.S. Department of Energy.

## Benefits / Market Implications

The use of pre-cooling would improve the safety of the fueling procedure since gas temperature would be controlled by the station and less variable than in existing fueling procedures.

A lower-cost option is necessary if pre-cooling is going achieve widespread adoption, making under-filling an issue of the past.

## Technical Concept & Approach

The project includes a comparison of the available cooling strategies, a selection of the preferred strategy, and a preliminary design of the pre-cooling system and operation.

The project will end with a pre-cooling system design that has the best chance for making a transformational impact on the CNG filling process.

The project team will perform a preliminary design analysis of the selected pre-cooling strategy. The design will include detailed models, simulation, and schematics of the selected technology that estimate the expected cooling performance and how much it impacts CNG full fills, as well as the estimated capital and operating cost of the technology in a simulated station.

## Results

In 2018, the project team proposed the development of a free piston linear expander to the U.S. Department of Energy as the preferred approach to achieving isentropic expansion and pre-cooling of gaseous fuels, including CNG and hydrogen. Subsequently, the project was awarded, and contracts finalized.

The project team is developing a design for the free piston expander. Researchers need to determine the best method for energy rejection from the gas being cooled. Options being considered are electricity generation and/or gas compression. The research team has also focused on developing an understanding of the tradeoffs related to operating stroke vs. frequency, diameters, and other guiding characteristics.

Efforts are under way to enhance a simulation of the free piston expander to better estimate the performance of the system. The simulation will be used to optimize stroke, frequency, and other relevant design parameters. The immediate goal is to simulate an "ideal" expansion cycle at nearly 100% efficiency, then start adding system losses into the simulation to accurately represent the expected expander performance. The simulation is being used to determine how the expander attributes such as stroke length and piston diameter impact the efficiency.

The design of the expander frame is similar to the linear motor frame being designed for the alpha compressor because both designs have similar requirements. They must be hermetically sealed and accurately support the moving "flotor" that will connect to compression and/or expander pistons.

In 2020, the CNG expander geometry was finalized. The project team is developing custom valves that can be actuated by the expander piston. By using the piston to actuate the valves, they should actuate fast enough to achieve the desired performance.

## Status

The project team is evaluating various motor frame designs in order to evaluate the best path forward.

Researchers are testing commercial valves, finalizing a custom valve design, verifying the bearing design, studying the works as intended in the linear motor frame, and comparing linear motor design variations to select the preferred design for full-scale testing.

The COVID-19 pandemic temporarily halted progress on the development of a test rig, which has slowed recent progress in the research laboratory.

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UTD Utilization Technology Development

# CNG Dispenser – Tank Communication

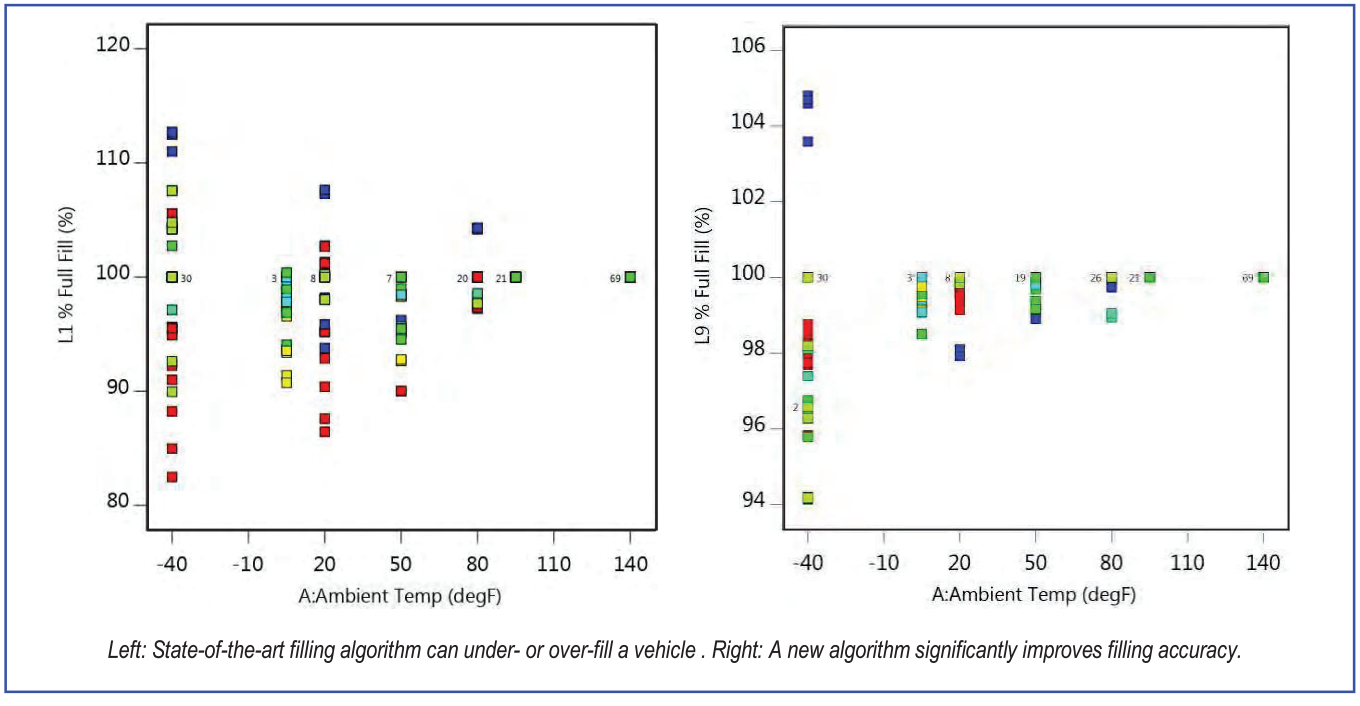
***Researchers will design, build, and demonstrate a prototype compressed natural gas (CNG) station that includes a smart CNG dispenser and a smart natural gas vehicle (NGV). Pre-commercial prototype hardware and protocols will be designed to enable the vehicle and station to communicate about the vehicle's fuel system to deliver safer, fuller fills for end users.***

## Project Description

Research is under way to improve natural-gas-vehicle (NGV) full fills using a multi-tiered approach. This includes the development of an improved dispenser algorithm, a preliminary look at vehicle-to-dispenser communications, and an investigation into various pre-cooling technologies. Improvements in all three areas are necessary to deliver a full fill. Moreover, pre-cooling has been receiving more attention lately as fleets become aware of under-filling drawbacks. While it is simple (although expensive) to add a pre-cooling loop into the fueling process, over-filling of storage systems can occur if the algorithm does not account for the below-ambient gas temperature. It is very important that a filling algorithm be developed that can take pre-cooling into account.

In response, researchers developed an advanced full-fill algorithm that was shown to accurately fill vehicles to nearly 100% full across a range of test conditions. However, this algorithm requires information about the vehicle's real-time pressure and temperature. This means that communicating that information to the vehicle is essential to improving full fills. In addition, pre-cooling is necessary to achieve full fills on warm days. However, pre-cooling alone will not ensure that the vehicle is filled accurately or safely. Again, this is where communications are necessary to fully utilize any investment made in pre-cooling equipment.

Development of a smart compressed natural gas (CNG) dispenser and vehicle enables vehicle sensors, which already exist and are currently installed on most NVGs, to transmit temperature and pressure to the CNG dispenser. This system can also be programmed with the age and volume of the vehicle's CNG cylinders, improving accuracy and safety of the fill. This smart CNG equipment uses low-cost, off-the-shelf data transmission hardware to guarantee that NGVs receive the maximum amount of gas possible during every filling event. By maximizing the volume of gas received, the volume of the NGV fuel system can be minimized, saving cost and weight of the vehicle.




*Left: State-of-the-art filling algorithm can under- or over-fill a vehicle . Right: A new algorithm significantly improves filling accuracy.*

The objective is to design, build, and demonstrate a prototype CNG station that includes a smart CNG dispenser and a smart NGV. A project team will develop pre-commercial prototype hardware and protocols to enable a vehicle and station to communicate information about the vehicle's fuel system (e.g., real-time pressure and temperature, tank volume, and age of the CNG fuel system). This information will allow safer, fuller fills while also enabling fleets to more accurately track their vehicle's fuel consumption.

## Benefits / Market Implications

Improving full fills using communications can lower the cost of an NGV by up to 10%. The lower cost per vehicle reduces the risk of adoption for fleets considering CNG, and reduces costs for end users.

Active communications also improves the safety of a CNG fill. Testing of existing algorithms demonstrated that it is unlikely, but possible, to over-fill a vehicle. Using communications, researchers developed a filling algorithm that should never result in an over-filled vehicle.

The primary target markets impacted will be NGVs with a focus on heavy-duty trucks. Secondary applications may include virtual pipeline gas transport, locomotives, and some marine ferries.

Objectives are to:

- Reduce the cost and weight of NGV fuel systems
- Increase NGV adoption
- Reduce emissions, and
- Improve safety due to the ability for block filling of expired tanks and prevention of over-filling.

## Technical Concept & Approach

This project involves the development and testing of a smart NGV and dispenser capable of using an advanced full-fill algorithm to maximize a full fill. The smart vehicle and dispenser will be tested with an isentropic expander to demonstrate a complete smart CNG station solution that guarantees full fills of NGVs.

The project team will refine and test a software protocol for identifying an NGV at a CNG station, verifying that the NGV is connected to the correct dispenser, and establishing a secure connection. This is the first step in verifying that wireless hardware can be utilized for this application.

A standard that defines how a smart vehicle and dispenser should transmit data during a filling event will bed developed.

The project team will build a prototype smart CNG dispenser and vehicle based on the protocol and standard requirements developed. Performance of the smart dispenser and vehicle will be tested, demonstrating that the vehicle receives the maximum fill possible across a wide range of filling conditions.

The project will occur over 36 months. The first 24 months involve the development of a standard, settling on a data-transmission type, and establishment of a connection protocol. The last 12 months will be dedicated to testing across a range of filling conditions.

This UTD project is co-funding a $2.6 million smart CNG station research project award from the U.S. Department of Energy's National Renewable Energy Laboratory.

## Results

In 2019, the project team identified commercial communications modules that may be suitable for adapting to CNG full fills.

Researchers supported the consensus development of a modified version of NGV standard 4.3, that will hopefully include provisions for improved temperature compensation and communications-based fills. The NGV 4.3 committee developed new tests for certifying non-communication-based dispensers. The committee is also planning on incorporating language related to pre-cooling and communications to enable improved fills.

The team and manufacturers are trying to determine the capabilities and limitations of controllers and if they are suitable for the short-term and long-term needs of the application.

## Status

Activities continue on the development of an embedded smart vehicle and dispenser solution, as well as a revised NGV 4.3 standard.

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# Distributed Generation for EV Charging

***Research was conducted to determine if the demands of the rapidly-expanding electric vehicle (EV) charging infrastructure can be supported in part by gas-powered distributed power generation solutions. Key technical issues and needs were addressed.***

## Project Description

In this project, researchers evaluated the potential for gas-powered distributed generation (DG) solutions to serve the rapidly-expanding electric vehicle (EV) charging infrastructure.

Researchers evaluated the fueling loads of various EV fleets and current EV charging infrastructure to assess how power-generation solutions may support these growing needs.

This project focused on defining key attributes (i.e., geographic locations, power ranges, environmentally sensitive areas, high demand charges, technology solutions, etc.) that may be the most advantageous for end users.

Clean solutions evaluated included advanced generator sets, turbines, fuel cells, and combined heat-and-power opportunities to support EV charging infrastructure growth. This UTD project was co-funded by the Propane Education and Research Council (PERC).

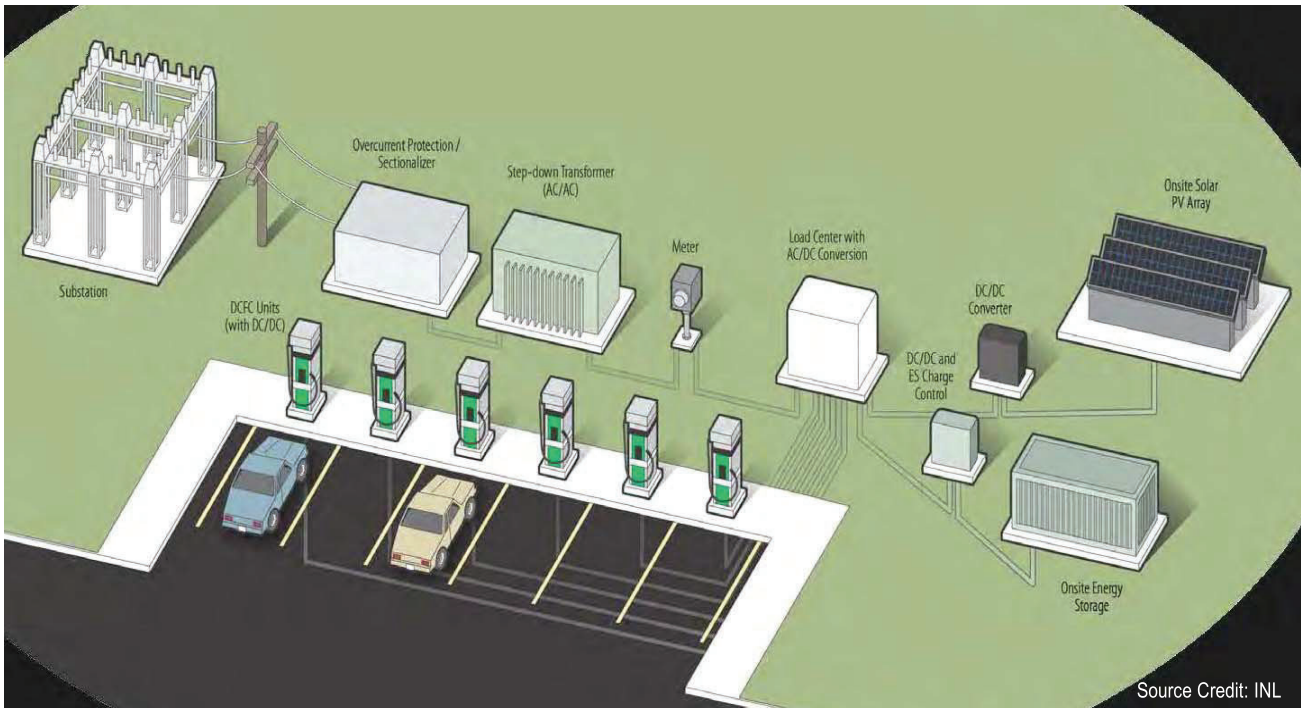
## Benefits / Market Implications

DG can reduce the load on the electric grid while also decreasing emissions in several areas of the United States, or allow EV charging stations to grow in areas with limited electrical distribution.

While it is clear that the vast majority of EV charging locations will be served by the electric grid, there appears to be regions or locations where gas-fired DG can support the growth of EV charging infrastructure and the adoption of EVs.

## Technical Concept & Approach

This project focused on determining appropriate technology solutions and designs for distributed power and EV charging equipment. Researchers evaluated natural gas and propane power-generation options and potential technology development needs, as well as the unique attributes of EV fueling cycles. Additional emphasis was placed on finding "sweet spots" that maximize the advantages of natural gas and propane where the electric grid has its greatest challenges.




*Direct-charge fast-charging complex design considerations.*

Another solution that was evaluated is a skid-mounted, "mobile" charging station that could be deployed at sites that are beginning an evaluation of EVs (but are not ready to commit to major infrastructure costs), performing a short-term demonstration, promotional events, or during sustained power outages. A skid-mounted system could provide a quick, flexible solution that could be relocated as needed.

Conversations with EV fleets led to additional inputs on issues and concerns. An analysis of the "balance of plant" of the EV charging infrastructure allowed for a system-level understanding of the equipment downstream of the power generation.

The team assessed state-of-the-art DG solutions that could provide clean, flexible power for the EV charging infrastructure. A focus of this task was to look for technology needs or development opportunities that will support this unique application.

Research analysis focused on understanding high-level system design requirements for a DG charging station as well as determining ideal locations for natural gas or propane solutions. Efforts included determining potential market applications and key consumer benefits. Results include a report on suggestions for potential representative sites and next steps.

## Results

In 2019, the project team identified more than 40 case studies and reports related to commercial EV deployments and identified products using 350kW-500kW fast chargers.

The project team participated in the Society of Automotive Engineers' Commercial Vehicle Conference in September of 2019. A key topic of the conference was electrification of commercial on-highway and off-highway vehicles. Numerous vehicle, component, and infrastructure providers presented the challenges and opportunities for the commercial EVs. The key takeaway was that the nearest-term opportunity for electrification is in the public transit and school transportation services.

Initial discussions with industry leaders indicated that the soft costs associated with project siting, permitting, and interconnection is a bigger challenge than the hardware itself.

Recent government funding activities indicate that economics are a barrier for EV charging deployments, and incentives are required to continue developing the charging infrastructure. The California Energy Commission issued a notice of intent to release a $22 million funding opportunity titled *Distributed Energy Resource Solutions for Medium- and Heavy-Duty Electric Vehicle Charging*. The notice resulted in a significant amount of feedback from the industry and stakeholders (e.g., local utilities, fleet operators, developers, and manufacturers), indicating significant interest and anticipation for DG technology applications for EV charging. The project team summarized the feedback in the Final Report and will monitor research funding opportunity announcements.

Discussions with station developers, operators, and micro-grid developers indicate high interest, but low short-term energy demand and challenging business cases.

The project team held discussions on the market needs and opportunities with a successful operator of more than 75 gas stations/convenience stores in the United States, finding that the company does not see a business case supporting short-term growth in demand for EV charging, mostly attributed to low EV registrations and low petroleum cost. With anticipated business growth into more urbanized territory, they may revisit EV charging for their stores.

The project team discussed market opportunities with a successful national developer of complex microgrids with experience in 1MW-scale industrial applications (food processing, indoor farming, healthcare). The company evaluated some transit bus charging opportunities in the past, but the spark-spread and economics were not favorable.

## Status

A Final Report is being prepared.

The report summarizes:

- Findings from discussions with EV infrastructure developers to understand the opportunities from their perspective
- The analysis of available DG technologies and potential customer needs
- Current designs and architectures of EV charging and DG systems
- Researched market needs and opportunities, and
- Recent government grant opportunities related to DG systems and EV charging.

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