# Report on Equipment Upgrade Incentive Project *December 2024*

Advancing Zero-Carbon Home Heating

National Oilheat Research Alliance
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**Contents:**



NORA was authorized by Congress in 2000 to generate funding, from within the industry, allowing the liquid fuel industry to provide more efficient and more reliable heat and hot water to American consumers. NORA's efforts focus on Energy Efficiency, Environmental Responsibility, Safety, Research & Development and Professional Education, with particular emphasis on transitioning heating oil and its appliances to a highly efficient, low-carbon source of heat and hot water. For more information on NORA's activities go to NORAweb.org or contact NORA at info@noraweb.org


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# Executive Summary

## *Impact to-date of the NORA Equipment Rebate Program*

*December 2024*

## Introduction

The National Oilheat Research Alliance (NORA) has a rebate program in place that aims to increase consumer efficiency and safety by encouraging the replacement of existing equipment with modern, efficient systems. The current program offers rebates on boiler and furnace replacements, storage tanks, and/or burner controls, but rebates may also extend to water heaters, smart thermostats, and other energy-efficient equipment.

The NORA rebate program is administered through state organizations, which are part of NORA and operate within the basic NORA requirements. Details of the program, including rebate amount, are different in each state. All participating organizations, however, as part of the rebate application process, are required to provide information with details of the equipment replaced and new equipment installed.

In December 2021, NORA completed an analysis of the energy savings associated with boiler and furnace upgrades completed as of the beginning of 2021 [1]. This report describes the technical methodology used to develop the energy savings associated with the upgrades. The following section of this report includes a summary of the methodology.

In September 2024, NORA completed an extension of the analysis of the impact of the NORA Rebate program from January 2022 to June 2024 using the same methodology. This report, included here as Attachment I, provides an update on the total impact of the NORA Rebate Program through June 2024, combining the findings of these two efforts.

Both of these rebate analysis reports are combined here to present a more comprehensive review of the impact of the NORA Rebate Program through June 2024.

## Approach to Analysis of Impact

Data on all equipment upgrades are provided to NORA by participating states in a spreadsheet format. Data provided include the make, model, age, and estimated Annual Fuel Utilization Efficiency (AFUE) of the replaced unit. Unfortunately, not all this information has been reported for all sites. The same information, except age, will be provided for the new, upgrade unit.

The age of the replaced units was typically between 25 and 35 years. Many were reported to be 50 years old, and some were reported to be 70-80 years old. The ages of the replaced units are as reported by the installation contractors and it is expected that, in many cases, these are just estimates. In a significant number of cases the age, make, and model were all reported as simply "unknown."

The analysis of fuel savings associated with appliance upgrades has been done using a different methodology for furnaces and boilers. Of the upgrades completed through 2021, 72% were boilers.

For furnaces, the approach started with the use of the AFUE values of the old and new appliances as reported by the contractors through the state forms. The analysis of the data submitted up to 2021, found that the average AFUE increase for furnace upgrades was 19.1% (from 67.7% to 86.8%). This increase represents an energy savings of 22%. However, these contractor estimates appear to provide a low AFUE value for the removed furnaces (67.7%), leading to high estimates of the savings. Considering the minimum required AFUEs for the older equipment at the estimated installation time, NORA has decided to use a more realistic estimate of the energy savings with furnaces of 10% for all cases.

For boilers, the situation is more complex. The AFUE metric has been developed for heating only boilers, but in nearly all cases in the field, boilers also provide domestic hot water. This leads to much greater parts of the year at very low loads where boiler idle losses can greatly influence efficiency [2,3]. As described in Ref. 1 for boilers, NORA developed a 4-level classification of boilers, including steady state efficiency and estimated idle loss. All old and replacement boiler systems were put into classes, and the energy savings estimated in upgrades between classes were prepared. A detailed analysis of pre- and post- fuel consumption and correlation with degree days for 330 specific installations was used to validate the energy savings with this approach. The results were then extended to the larger set of boiler system upgrades. The average fuel use reduction with boiler systems was found to be 20%.

## Achieved Impact of the NORA Rebate Program

In the analysis of more recent rebate data reported to NORA by the states ( 1/2022- 6/2024) a total of 2,744 boiler upgrades and 791 furnace upgrades were reported. However, an additional 826 "system" replacements were also reported, which could be boilers or furnaces. For analysis, these have been assumed to be split between these two appliance categories in the same proportion. This leads to a total of 3,388 boiler upgrades and 973 furnace upgrades for this more recent data set. Combining the units presented in Ref. 1 and this later data set leads to a total of 9,888 boiler replacements and 3,074 furnaces. It should be noted that impacts due to only burner changes or water heater upgrades have not been included here.

In estimating the total impact of the NORA Rebate program to date, a typical baseline home annual oil consumption of 850 gallons and 10% average savings for furnaces has been assumed. For the first set of boilers studied, a 20% average savings for boilers was found. For the second set, which had a different boiler population set, the average savings was found to be 14%. Combining these, the total reduction in annual fuel consumption resulting from the NORA Rebate program over the two time periods analyzed is 1,754,502 gallons. Using a current, average price of heating oil of $3.61/gallon, represents an annual homeowner cost savings of $6,333,752.

For the reduced fuel use associated with the NORA Rebate Program, the reduction in GHG emissions can be estimated using a heating oil emission factor of 209 lbs. $CO_2$e/MMBtu and a fuel higher heating value of 139,000 Btu/gal. For the above fuel savings this yields a reduction of 25,593 metric tons $CO_2$e/year.

## References

1. *Butcher, T., Persch, M., Islam, N., Levey, J., and Huber, J., Report on Equipment Upgrade Incentive Project, NORA Report December 2021. Available at https://noraweb.org/technical-publications/.*
2. *Butcher, T.A., Performance of Integrated Hydronic Heating Systems BNL-79814-2008-IR. 2007 Brookhaven National Laboratory.*
3. *Butcher, T.A. Performance of Combination Hydronic Systems. ASHRAE Journal, 2011 53(12):p 36-41.*

# Update on Equipment Upgrade Incentive Project
## January through June 2024

*December, 2024*
*Santino Decarolis and Dr. Jenny Frank*

## 1. Introduction

The National Oilheat Research Alliance (NORA) rebate program supports energy efficiency in residential homes and light commercial buildings across the United States by encouraging the adoption of energy-efficient heating equipment. The rebate program provides financial incentives to help encourage homeowners to replace outdated, less efficient heating systems with modern, high-efficiency boilers, furnaces, and other heating equipment.

The rebate program has provided rebates to consumers who purchase and install qualifying energy-efficient equipment. The rebate program maintains the goal of reducing the environmental impact of home heating systems by lowering fuel consumption and reducing carbon emissions generation. NORA is helping to contribute to national efforts to combat climate change by making energy-efficient heating options more accessible and affordable.

The NORA Rebate Program offers rebates across many states for boilers, burners, furnaces, heating oil systems (boiler or furnace), tanks, vent alarm whistles, and water heaters. The equipment type and the total number of upgrades and replacements from January 19, 2022, to June 21, 2024, are depicted in Table 1. This report also organizes the data in terms of the number of equipment replacements and upgrades per state. It shows the impact of the NORA Rebate Program across many regions throughout the United States. Figure 1 represents the distribution of equipment replacements and upgrades in participating states. New York achieved the highest number of equipment replacements and upgrades, totaling 2,637. Massachusetts and Pennsylvania followed with 1,870 and 1,643 replacements and upgrades, respectively. Maryland yielded 1,230 replacements and upgrades. Wisconsin, Vermont, and Michigan reported lower numbers, totaling 172, 112, and 41, respectively. Delaware and South Carolina were excluded from Figure 1 due to the low number of replacements achieved during the reported time period of 3 and 2, respectively.

*Table 1. Total equipment upgrades resulting from the NORA Rebate Program across 15 states from January 19, 2022, to June 21, 2024.*

| Equipment Type | Total Equipment Upgrades |
|---|---|
| Boiler | 2,744 |
| Burner | 56 |
| Furnace | 791 |
| Heating Oil System (Boiler or Furnace) | 826 |
| Tank | 4,632 |
| Vent Alarm Whistle | 150 |
| Water Heater | 188 |
| **Total** | **9,387** |

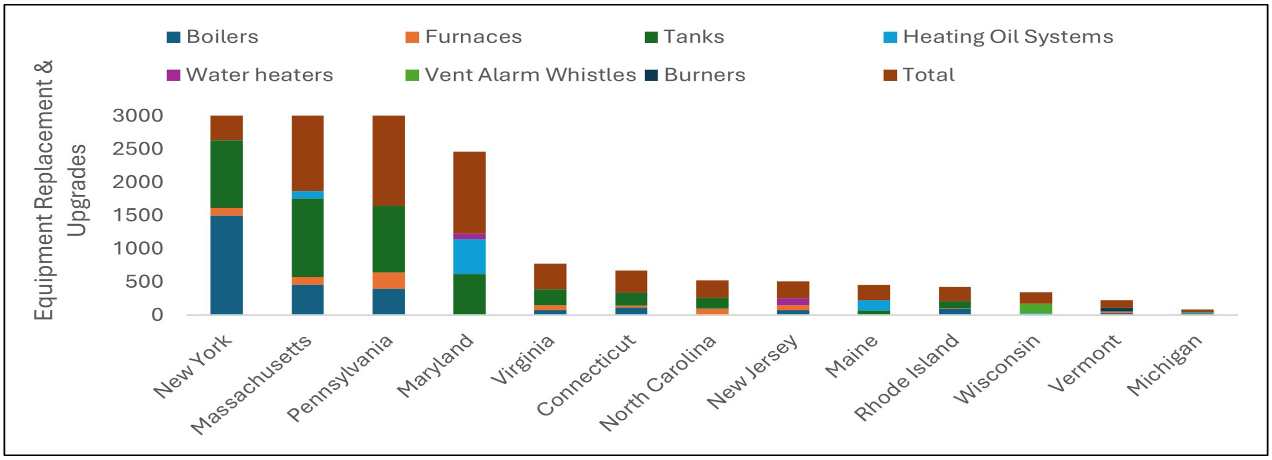



*Figure 1. State-level distribution of equipment replacements and upgrades under the NORA Rebate Program from January 19, 2022, to June 21, 2024.*

This report analyzes the NORA rebate program performance from January 19, 2022, to June 21, 2024, and uses data across 15 states. The report discusses the energy efficiency improvements achieved through the program, including the methodology used to calculate greenhouse gas emission reductions and fuel savings. A state-level analysis overviews the energy savings and environmental benefits achieved from a regional perspective and highlights program participation, equipment replacements, and variations in energy savings and emission reductions. The conclusion summarizes the key findings, assesses the program's impacts, and provides recommendations for improving the future program.

## 2. Energy Efficiency & Greenhouse Gas Emissions for Furnaces

The Annual Fuel Utilization Efficiency (AFUE) metric was used to quantify furnace energy efficiency improvements achieved through the rebate program. AFUE represents the quantity of fuel (%) effectively converted into usable heat by a heating system, with the remaining percentage lost during the conversion process. This report assesses the improvement in energy efficiency resulting from the furnace upgrades by comparing the AFUE values of old and newly installed furnaces.

### 2.1. Efficiency Improvement Calculations

The AFUE of the old furnace is compared to that of the new furnace to measure efficiency improvements. This report utilizes the following formula to calculate a percentage increase in efficiency, which depicts efficiency upgrades of the new furnace compared to the old system. For example, if an older furnace has an assumed AFUE of 70% and is replaced by a new furnace with an assumed AFUE of 90%, the efficiency improvement would be calculated according to equations (1) and (2):

$$(1)\ Efficiency\ improvement = \frac{new\ AFUE - old\ AFUE}{old\ AFUE} \text{ x } 100$$

$$(2)\ Efficiency\ improvement = \frac{90\% - 70\%}{70\%} \text{ x } 100 = \sim 28.6\%$$

### 2.2. Energy Savings Calculations

The energy savings achieved were determined by calculating the reduction in fuel consumption due to the improved efficiency of the new furnace. The following formula is utilized to calculate the fuel savings:

$$(3)\ Fuel\ savings = fuel\ usage\ x\ \left(1 - \frac{old\ AFUE}{new\ AFUE}\right)$$

The calculation estimates the amount of fuel that was saved as a result of efficiency improvements. For example, if an old furnace with an AFUE of 70% used 850 gallons of heating oil annually and was replaced by a furnace with a 90% AFUE rating, the estimated fuel savings would be calculated as follows:

$$(4)\ Fuel\ savings = 850\ gallons\ x\left(1 - \frac{0.70}{0.90}\right) = {\sim}189\ gallons\ of\ heating\ oil\ saved$$

## 2.3. Greenhouse Gas Reduction Calculations

This report calculates the GHG emission reductions achieved for furnaces. The fuel used in the heating system and their corresponding emission factor were identified to calculate the reduction values. This emission factor indicates the amount of $CO_2$ or $CO_2$ equivalent emissions produced per unit of fuel burned. The reduction in fuel usage was attributable to the increase in efficiency of the newly installed equipment. This was calculated by comparing the old and new systems' AFUE.

Once the fuel savings were determined, the GHG emissions reduction was calculated by multiplying the fuel savings by the fuel energy content and dividing by the old AFUE. This value was then multiplied by the fuel's emission factor. The GHG reduction equation is depicted below:

$$(5)\ GHG\ reduction = \left(\frac{fuel\ savings\ x\ fuel\ energy\ content}{old\ AFUE}\right) x\ emission\ factor$$

Continuing with this example, equation (4) calculated the fuel savings as ~189 gallons of heating oil and assumed 0.139 MMBtu/gallon as the fuel energy content. This value was then divided by the old AFUE value of 70% (0.70). This resulted in 37.53 MMBtu/year of energy saved. The exact equation is depicted below:

$$(6)\ Total\ energy\ saved = \frac{189\ gallons\ x\ 0.139\left(\frac{MMBtu}{gallon}\right)}{0.70} = 37.53\frac{MMBtu}{year}$$

Equation (6) calculated the total energy saved as 37.53 MMBtu/year. Using the assumed emission factor of 209 lbs. CO2/MMBtu, the total GHG emissions saved would be calculated utilizing the following equation:

$$(7)\ GHG\ reduction = 37.53\frac{MMBtu}{year}\ x\ 209\ lbs\ \left(\frac{CO2}{MMBtu}\right) = 7{,}843.77\ \left(lbs\frac{CO2}{year}\right)$$

This value was converted into metric tons, where one metric ton is equal to 2,204.62 lbs.:

$$(8)\ GHG\ reduction = \frac{7{,}843.77\ lbs\left(\frac{CO2}{year}\right)}{2204.62\ lbs} = 3.56\ metric\ tons\ \left(\frac{CO2}{year}\right)$$

## 2.4. Total Energy Savings Calculations

NORA conducted an analysis to examine the potential energy savings associated with furnace replacements and upgrades. Initially, the total energy savings and emission reductions were based on the AFUE values submitted by the original data requests. There were potential issues with the data, as some AFUE values reported fell outside of the legal minimum standard for AFUE ratings. NORA conducted a secondary calculation using AFUE assumptions. This calculation assumed a conservative 78% AFUE rating for old equipment and an 87% AFUE rating for new equipment. This report assumed a baseline value of 850 gallons of fuel consumed annually per site to calculate the energy savings values. These calculations were based on the AFUE values provided in each submission. This report found that 87.9 gallons per site was achieved regarding the average annual fuel savings. The average fuel savings per site were then multiplied by the total number of furnaces replaced during the reporting period of the program, totaling 791 replacements and upgrades. Using these values, it was calculated that the program achieved a total annual fuel savings of 69,528.9 gallons. These savings demonstrate the program's impact in reducing overall fuel consumption of furnaces in the United States.

$$(9)\ Fuel\ savings = 850\ x\left(1 - \frac{0.78}{0.87}\right) = \sim 87.9 \text{ gallons of heating oil saved}$$

## 3. Average Efficiency Improvement for Furnaces

The NORA Rebate Program's data was used to evaluate the average efficiency improvements resulting from furnace upgrades across the United States. The percentages depicted in Figure 2 were obtained by calculating the improvement for each submission and then taking averages across all the percentages. It should be noted that the analysis in this report only accounted for submissions containing both the new and old AFUE ratings. Submissions lacking either of these data points were excluded from this analysis.

Figure 2 contains the average efficiency improvements for furnace upgrades across nine states. These values represent the percentage increase in the AFUE ratings from the old furnace to the new furnace values. The data in Figure 2 demonstrates that the NORA Rebate Program has had a varying impact on furnace efficiency improvements across different states. North Carolina is depicted as having the largest average furnace efficiency improvement at approximately 52%, followed by Virginia at ~22.6%. States such as New Jersey, Massachusetts, and Vermont depict more modest efficiency improvements. This variation demonstrates the importance of continued efforts to target areas with less efficient equipment and to support the adoption of high-efficiency furnaces to maximize efficiency improvements across all states involved in the NORA Rebate Program.

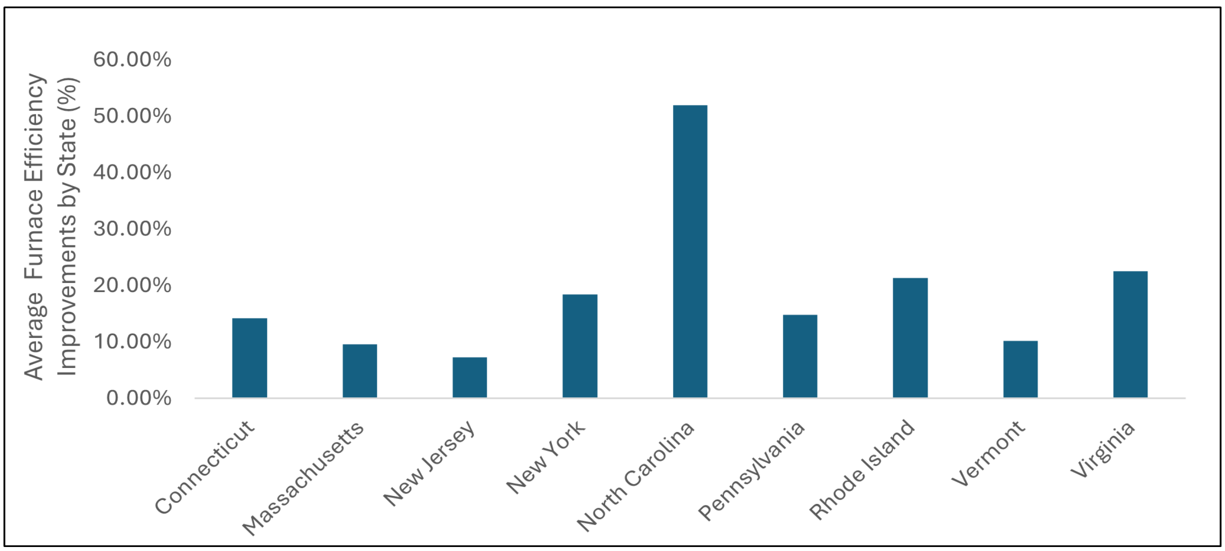



*Figure 2. State-level average furnace efficiency improvements based on data from the NORA Rebate Program.*

### 3.1. Fuel Savings from Furnace Upgrades

This report calculates the fuel savings provided by furnace upgrades. The analysis is based on the average AFUE values for old and new furnaces and assumes an annual usage of 850 gallons of heating oil consumed per home. Submissions lacking either the old or new AFUE data points were excluded from this analysis. This methodology provided a basis for estimating the actual fuel savings in gallons and depicted the direct benefit of the energy efficiency improvements achieved by the NORA Rebate Program.

The stated-based calculated fuel savings depict the impact of upgrading to higher-efficiency furnaces under the NORA Rebate Program. State-based fuel savings per site are depicted in Figure 3, with North Carolina achieving the largest savings. Figure 3 depicts the importance of targeting equipment and upgrade replacements in regions with older, less efficient systems.

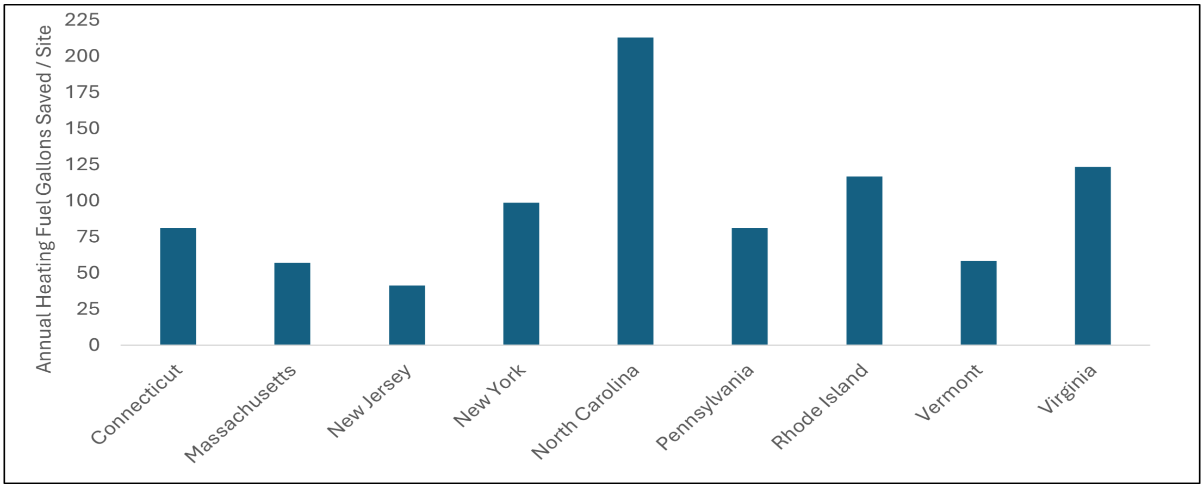



*Figure 3. Annual heating fuel gallons saved per site from January 19, 2022, to June 21, 2024.*

## 4. Boiler Overview

Boiler efficiency was calculated utilizing methodology based on the 2021 Report on Equipment Upgrade Incentive Project. Boilers were assigned a boiler system class based on their steady state efficiency (%) and idle loss (%). Their annual reduction in fuel consumption (%) was assigned based on their respective upgrade case. Table 1 presents the boiler system classifications utilized for this report. Table 2 shows the annual reduction in fuel consumption (%).

*Table 1. Boiler system class classification based on steady state efficiency and idle loss values.*

| Boiler System Class | c | b | a | C | B | A |
|---|---|---|---|---|---|---|
| Steady State Efficiency (%) | 78 | 80 | 84 | 84 | 86 | 87 |
| Idle Loss (%) | 2.5 | 1.5 | 1 | 1 | 0.8 | 0.1 |

*Table 2. Upgrade cases depicting annual reductions in fuel consumption*.

| Upgrade Case | a to C | a to B | a to A | b to C | b to B | b to A | c to C | c to B | c to A |
|---|---|---|---|---|---|---|---|---|---|
| Annual Reduction in Fuel Consumption (%) | 0.0 | 3.8 | 10.0 | 8.2 | 11.7 | 17.5 | 16.6 | 19.8 | 25.0 |

### 4.1. Greenhouse Gas Emission Reduction Calculation for Boilers

To calculate the annual GHG emission savings, this report assumed that each site utilized 850 gallons of heating oil. The calculation included the heating oil emission factor of 209 lbs. $CO_2$/MMBtu and a fuel energy content value of 0.139 MMBtu/gallon. Then, the average annual reduction was calculated as approximately 14%. These values were utilized along with the 2,204.6 lbs. as a conversion factor. The equation is noted below:

$$(10)\ \text{GHG reduction} = \frac{((fuel\ usage\ x\ emission\ factor\ x\ fuel\ energy\ content)\ x\ annual\ reduction)}{2204.62\ lbs}$$

$$(11)\ \text{GHG reduction} = \frac{\left(850\ gal\ x\ 209\ lbs\frac{CO2}{MMBtu}x\ 0.139\frac{MMBtu}{gallon}\right)x\ 0.14}{2204.62}$$

$$(12)\ \text{GHG reduction} = \sim 1.6\ metric\ tons\ \frac{CO2}{year}$$

Figure 4 shows Virginia yielded the lowest annual average $CO_2$ emission savings per site for boilers at 1.4 metric tons of $CO_2$/year. Connecticut, New Jersey, and New York were each responsible for 1.6 metric tons of $CO_2$/year. On the other hand, Massachusetts, Pennsylvania, and Vermont yielded the highest annual average GHG emission savings per site for boilers at 1.7 metric tons of $CO_2$/year.

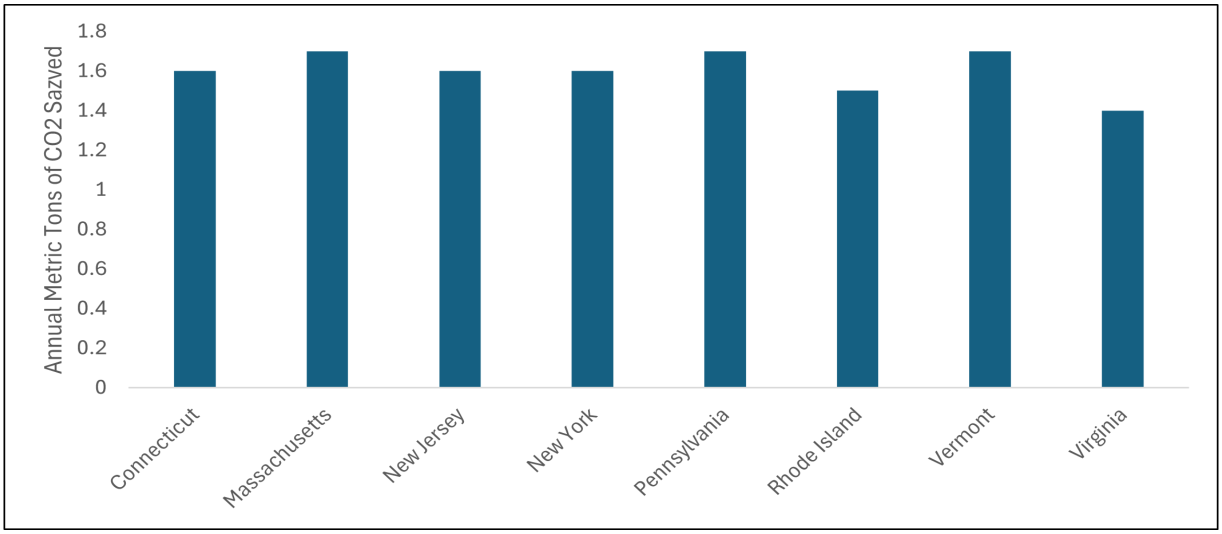



*Figure 4. Annual state-based metric tons of CO2 saved per site due to boiler upgrades and replacements received under the NORA Rebate Program.*

## 5. Conclusions

This report demonstrates the importance of the NORA Rebate Program in supporting energy efficiency initiatives across all participating states. The program's impact, as depicted by the results of this report, is significant in terms of fuel savings and reduced GHG emissions.

# Recommended Practices

## Background:

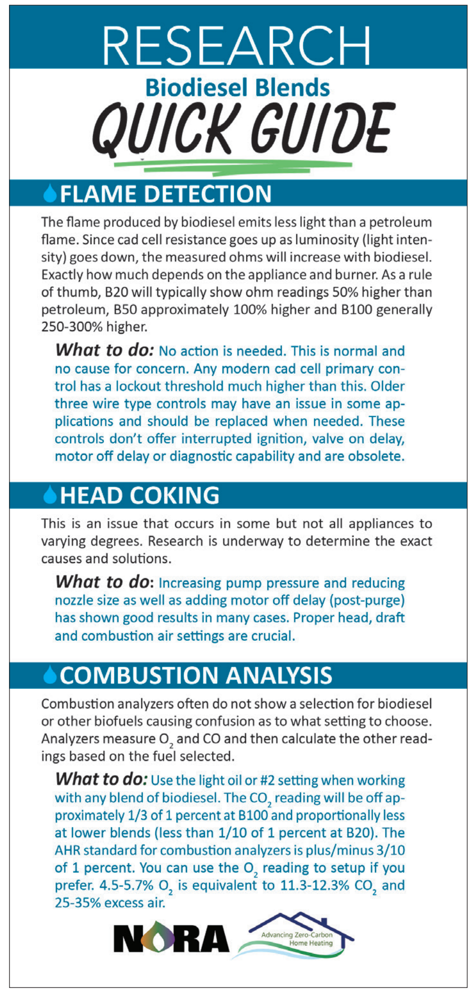
Through its research and field-testing activities, the NORA uncovers information that is both beneficial and actionable by field personnel in their jobs. NORA believes that information that can be of immediate benefit to consumers, should be disseminated as rapidly as possible.

## Goal:

To have a plan in place to distribute useful information on a timely basis in various formats to the individuals and companies that can gain from implementation.

## Approach:

To be flexible and handle the approach on a case-by-case basis dependent on the recommendation and its impact. For example, as NORA has learned more about high biodiesel blends and recommended practices in deploying them, an in-person and online training module titled *Bioheat Technical Guidance* was developed. NORA believes this information is so vital, it is a prerequisite to any certification renewal or upgrade. The in-person presentation is about 90 minutes long, however, a shorter and more concise version was developed to fit a 40-minute period. An accompanying card handout was produced to summarize the important points and is available online for download. This provides multiple avenues to circulate this information.



RESEARCH

Biodiesel Blends

QUICK GUIDE

FLAME DETECTION

The flame produced by biodiesel emits less light than a petroleum flame. Since cad cell resistance goes up as luminosity (light intensity) goes down, the measured ohms will increase with biodiesel. Exactly how much depends on the appliance and burner. As a rule of thumb, B20 will typically show ohm readings 50% higher than petroleum, B50 approximately 100% higher and B100 generally 250-300% higher.

***What to do:*** No action is needed. This is normal and no cause for concern. Any modern cad cell primary control has a lockout threshold much higher than this. Older three wire type controls may have an issue in some applications and should be replaced when needed. These controls don't offer interrupted ignition, valve on delay, motor off delay or diagnostic capability and are obsolete.

HEAD COKING

This is an issue that occurs in some but not all appliances to varying degrees. Research is underway to determine the exact causes and solutions.

***What to do:*** Increasing pump pressure and reducing nozzle size as well as adding motor off delay (post-purge) has shown good results in many cases. Proper head, draft and combustion air settings are crucial.

COMBUSTION ANALYSIS

Combustion analyzers often do not show a selection for biodiesel or other biofuels causing confusion as to what setting to choose. Analyzers measure $O_2$ and CO and then calculate the other readings based on the fuel selected.

***What to do:*** Use the light oil or #2 setting when working with any blend of biodiesel. The $CO_2$ reading will be off approximately 1/3 of 1 percent at B100 and proportionally less at lower blends (less than 1/10 of 1 percent at B20). The AHR standard for combustion analyzers is plus/minus 3/10 of 1 percent. You can use the $O_2$ reading to setup if you prefer. 4.5-5.7% $O_2$ is equivalent to 11.3-12.3% $CO_2$ and 25-35% excess air.

NORA Advancing Zero-Carbon Home Heating

## Project Benefits:

- Turns research and field testing into recommendations that can be immediately implemented.
- Efficiency benefits from latest technology and techniques
- Reduce costs
- Reduce fuel use
- Use technology more effectively.
- Respond more quickly to innovations.
- Facilitate faster transition to renewable liquid fuels

# Building Performance Institute & Environmental Protection Agency Projects

## Background:

NORA recognizes that the demands of the industry are changing and new educational programs must be added to NORA's offerings, particularly in the areas of efficiency and decarbonization.

The building shell and its performance are critical to reducing energy consumption, lowering greenhouse gas emissions, and ensuring the comfort and safety of residents. Building Performance Institute (BPI) a private certification organization in energy efficiency and home performance focuses on building science principles and the interaction of all the systems in a home working together to provide a safe and efficient environment. Testing to confirm that changes in one aspect of the system do not negatively affect another is key. Some rebates are available under the Inflation Reduction Act of 2022 (IRA) that require adherence to BPI 2400 standards, having personnel certified in these standards will be critical in implementing this energy saving program.

The U.S. Environmental Protection Agency (EPA) requires that technicians who maintain, service, repair, or dispose of heating equipment that could release refrigerants into the atmosphere must be certified. Equipment containing refrigerants include air-conditioners and heat pumps. Many service companies that participate with NORA install and service both of these types of equipment.

Technicians are required to pass an EPA-approved test to earn Section 608 Technician Certification. The tests are specific to the type of equipment the technician seeks to work on. Tests must be administered by an EPA-approved certifying organization. NORA was approved in April 2023 to administer training and testing for the 608 exam both in person and online formats.

## Goal:

To expand NORA educational initiatives to include efficiency and decarbonization training and certifications and to offer these to all in the liquid fuels industry to improve efficiency, reduce energy costs and enhance the safety of residents.

## Approach:

NORA has been approved to offer 608 testing and has certified and has an on-going certification process. NORA has also been approved by BPI to be approved to offer testing for Building Analyst-Technician and Building Analyst- Professional and is developing a training curriculum for both of these certifications as well as Building Science Principles certificate, the first sessions will be held in Q1 2025.

## Project Benefits:

- Support efficiency and decarbonization efforts of state and federal governments.
- Allow consumers who use liquid fuels greater access to state/federal efficiency programs and incentives.
- To reduce consumer carbon emissions through increased efficiency and weatherization.
- Expand the pool of trained technicians.
- Broaden the skill set of existing technicians in hybrid systems and building performance.
- Assure safe handling of refrigerants with high GWP (Global Warming Potential).

# High Efficiency Liquid Fuel-Fired Heat Pump

## Background:

NORA, and the liquid fuels industry, are exploring the development and market introduction of fuel-fired heat pumps. These offer the potential for achieving dramatically higher thermal efficiency—the equivalent of ~140% from fuel input to thermal energy output - while running on 100% renewable fuel.

NORA has explored a number of options for this in the past, including several European manufacturers. Currently, NORA is collaborating with Stone Mountain Technologies, Inc. (SMTI) in Tennessee which has developed an interesting ammonia/water absorption system. The SMTI system has been developed for use with natural gas and has undergone several successful field trials. SMTI reports that commercial production of gas-fired products has started. It is our understanding that DOE has supported this work for natural gas. Given the similarity with the combustion process, NORA saw this as an opportunity to piggyback on this important work. Additionally, the New York State Energy Research and Development Authority (NYSERDA) provided additional funding with the goal of having a highly efficient renewable fuel application available in the extreme cold of New York.

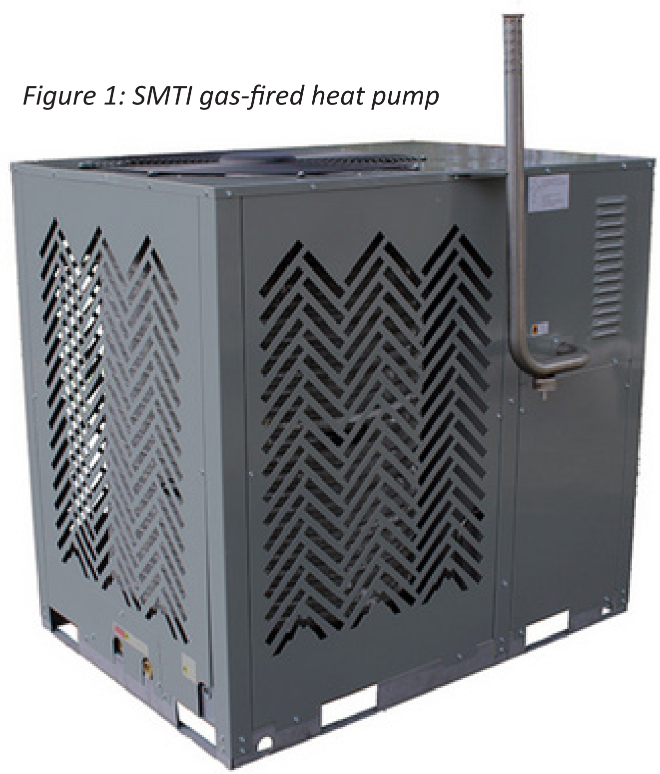
In collaboration with NORA, SMTI has completed a set of customer focus group sessions and done system configuration cost studies. They have concluded that the optimal system with liquid fuels would be a heat-only absorption heat pump paired with a conventional refrigerant, compression air conditioning system for space cooling.

The SMTI system is hydronic and would deliver heat to the home with a hydronic coil in an air handler, a radiant floor heating system, or a panel radiator system designed for the supply temperature. It could replace current furnace or boiler heaters. The heat pump absorbs heat from the outdoor air in the winter and the entire unit is located outdoors.

From a liquid fuel burner perspective, this is considered a very challenging application. The heat from the burner is applied in a vertical, cylindrical chamber with a tube assembly to thermally separate the ammonia and water ("desorber"). Key challenges include the very small combustion chamber (5-inch diameter), back pressure associated with the tube assembly, a very low firing rate range, an up-fired arrangement, and the need to modulate the burner. Without modulation, the off-cycle heat loss from the thermal mass in the heat pump system would significantly lower thermal efficiency.

In earlier work on this concept, NORA partnered with a manufacturer of air-atomized modulating burners for military cooking applications to adapt this for the heat pump. After some effort, they were not able to meet the needs and withdrew. Primary issues were firing orientation, back pressure, and difficulty in achieving good combustion with biodiesel. NORA technical staff took this challenge in-house and worked on the use of a more conventional burner with pressure atomization.

*Figure 1: SMTI gas-fired heat pump*



## Goals:

To develop a practical burner approach which can operate with biodiesel from B0 to B100 with a 3/1 modulation range within the geometry and backpressure constraints of the SMTI absorption heat pump.

## Progress:

- 2022 – During 2022, NORA focused on the development of the basic burner platform with some collaboration with one of the major residential burner manufacturers. The burner developed included a pressure-swirl atomizer; separate variable speed, higher-air-pressure blower; compact burner head designed for lower firing rates; and a European modulating pressure fuel pump. Extensive testing was done at the NORA lab with a simulated heat pump desorber unit provided by SMTI. The unit was found to ignite and run very well firing B100 in an upfired configuration, within the heat pump combustion chamber geometry. With the pressure modulation range of the European pump a 2/1 firing rate range was achieved. This was extended to 3/1 using a short on/off firing protocol for the lowest firing rate range. Based on data shared with SMTI they concluded this would likely meet the needs of their absorption heat pump geometry. All testing to date has been done using 100% biodiesel because that is considered to be the most challenging fuel. The system could run with renewable diesel or other similar fuels. NORA will also evaluate whether ethyl levulinate could work in such a system, which would potentially increase greenhouse gas reductions by 20-40%.
- 2023 – During 2023 NORA worked to develop a programmable controller-based control system that would accept a firing rate request signal from the existing SMTI system control board and use that to control ignition, fuel pressure, and air flow rate to automate the operation and modulation of the burner. The system has been packaged for testing at SMTI. Following successful prototype testing, it is expected that SMTI would integrate all control functions into a single programmable controller.

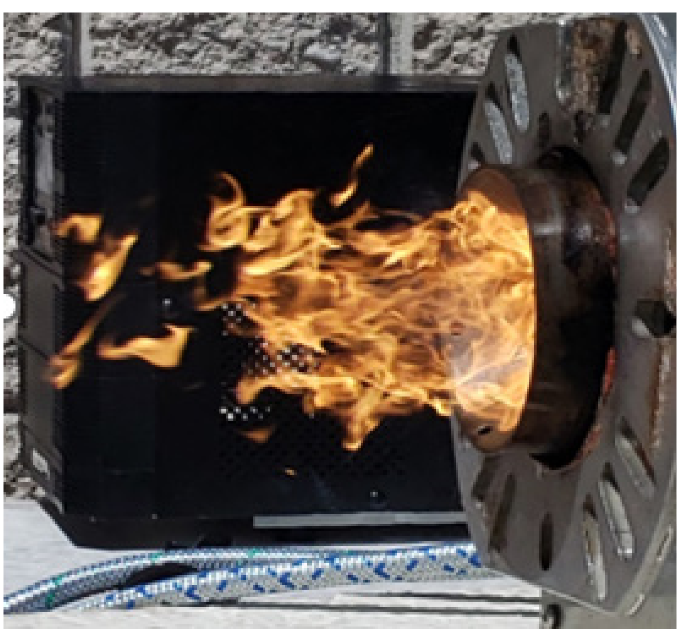


*Figure 2: B100 burner flame (L)*
*Figure 3: Burner operating inside of SMTI desorber simulator (R).*

*Testing done at NORA Liquid Fuel Research Center, Plainview, NY*

## Key Findings:

The work of this project in 2022 and 2023 has demonstrated the technical feasibility of using a renewable liquid fuel in a very high efficiency fuel-fired absorption heat pump. This unit is moving forward commercially with natural gas firing providing encouragement that the liquid fuel concept would be viable in the market.

## Planned Future Work:

NORA is in discussion with SMTI at present regarding the transfer of the burner to their test lab in Tennessee and basic testing in an actual absorption heat pump. Following this, the unit would be operated in its normal outdoor environment for a heating season. The next steps would involve commercialization.

## Project Benefits:

In a 2018 study of source energy, operating cost, and $CO_2$e savings of several replacement technologies for a conventional boiler and furnace in the Northeast were estimated [1]. Results showed the combination of the fuel-fired heat pump and a conventional A/C unit to offer excellent economics compared with other options and in all cases payback periods less than 4 years for a boiler replacement and 5.1 years for a furnace replacement. Annual $CO_2$e savings were found to be the best with this option ranging from 1,429 to 2,206 lb./year depending on location. This was based on a petroleum-based fuel, while a renewable fuel has the potential to substantially increase these reductions.

## References:

*Keinath, C., Butcher, T., and Garrabrant, M., Energy, Cost, and CO2E Analyses of Reversible, Hybrid and Heating-Only LF-AHP (Liquid Fuel Air Source Heat Pump) in the Northeast, ASHRAE Conference Proceedings, HO-18-C038, Houston, June 2018, available at: https://www.techstreet.com/ashrae/standards/ho-18-c038-energy-cost-and-co2e-analyses-of-reversible-hybrid-and-heating-only-lf-ahp-in-the-northeast?product_id=2016649#product.*