

Emissions Reduction Alberta

NON-CONFIDENTIAL Final Report

1.0 Title Page:

- ERA Project ID

Project ID (from ERIMS):	F0160834
Project Title:	Demonstration of Thermally Driven Heat Pumps for Residential Heating Applications
Lead Applicant Organization:	SMTI – Stone Mountain Technologies, Inc.

- Title of Project : Demonstration of Thermally Driven Heat Pumps for Residential Heating Applications
- Name and information of Recipient contact:
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 - Bill Hewa, Product Manager, bhewa@stonemtntechnologies.com
- Name of ERA Project Advisor: Dallas Johnson
- Start date of the Project: 2/17/2021
- Completion date of the Project: 2/28/25
- Technology Readiness Level (TRL) at Project initiation: TRL 7
- TRL at Project completion: TRL 9, commercialized
- Total actual ERA funds are \$943,682.64 on a budget of \$986,250, which is under budget by \$42,567.36 or 4.32%. The breakdown of ERA funds is as follows:

	Milestone 1	Milestone 2	Milestone 3	Milestone 4	Milestone 5	Milestone 6	Milestone 7	Milestone 8	Milestone 9	Total	Budget
Invoiced to ERA	\$26,261	\$171,922	\$62,074	\$40,149	\$29,609	\$323,882	\$160,460	\$121,957	\$7,369	\$943,683	\$986,250

- Total actual Project costs are \$1,887,365.36, on a budget of \$1,972,510 , which is under budget by \$85,144.75 or 4.32%. The breakdown of the total budget is as follows:

	Milestone 1	Milestone 2	Milestone 3	Milestone 4	Milestone 5	Milestone 6	Milestone 7	Milestone 8	Milestone 9	Total	Budget
Total Cost	\$52,521	\$343,844	\$124,147	\$80,298	\$59,218	\$647,765	\$320,921	\$243,914	\$14,738	\$1,887,365	\$1,972,510

- FOR submission date: February 28, 2025

Short Project description with high level results for the ERA website:

This project consisted of a rigorous field trial of pre-production prototypes of the SMTI thermally driven heat pump (TDHP), a gas absorption heat pump with all-natural ammonia water refrigerant. The trial consisted of testing the SMTI 80KBTH TDHP in a residential environment in forced air space heating and domestic hot water applications. The goal was to prove the technology in the bitter cold of Edmonton winter, evaluate performance, and measure system efficiency across seasons. Performance results indicate the system can achieve target efficiency of 140% during portions of data gathered where steady state operation was observed, offering a reduction in carbon emissions and annual energy consumption with higher reductions seen depending upon the legacy gas appliances being replaced. Less quantitative, but equally valuable results yielded important design changes in the equipment to enhance operation, reliability, and efficiency, as well as improve product aesthetics such as sound levels and installation protocol. The field trial also offered the opportunity to enhance contractor training for installation and routine service of the product.

Providing warm comfortable air and hot water, TDHPs are an ideal cold-climate heat pump that do not need supplemental equipment like electrically driven heat pumps. SMTI has developed a cost-effective approach to scalable manufacturing of a well-established thermodynamic cycle (single-effect ammonia-water gas absorption) that makes this technically sound process economically viable.

Five prototypes were fabricated during the project and installed in homes within the Edmonton, Alberta area for the purpose of verifying performance in the local climate as well as optimizing control strategies. Two additional prototypes were created for lab and reliability testing purposes.

The project prepares the technology for market entry into the Canadian market with the opportunity to significantly reduce GHG emissions in residential buildings. Because SMTI's TDHP is aligned with the existing HVAC industry interests and other stakeholders (e.g. gas utilities), the system creates a truly scalable solution for GHG reduction. This project paves the way for an estimated province-wide reduction of 4 million annual tonnes of CO₂e and \$1.2 billion from annual homeowner utility costs by 2050 (using the Medium Growth Case).

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5.0 Executive Summary

The project was to complete design work on SMTI's 80KBTH TDHP, with project partner Napoleon completing design of a matched capacity hydronic air handling unit. Both companies produced prototype units for independent accelerated life testing. The field trial was implemented as the installation of 5 "combi" systems to provide residential space heating and domestic hot water. Each system consists of an 80KBTH SMTI gas absorption heat pump with a Napoleon hydronic air handler and custom hydronic board, and an OEM 80-gallon indirect storage tank. This system was installed in 5 Edmonton homes, in parallel with the legacy gas furnace and gas water heater as potential backup. Installation was handled by a local, SMTI-trained prime contractor, and the prime relied on subcontractors to accomplish some of the hydronic and gas connection work, as well as a rigging company for product placement. A comprehensive Measurement & Verification system was installed and remotely monitored for duration of the field trial.

Results of the trial included independent documentation of high efficiency, a significant number of product design and manufacturing changes to optimize performance and reliability, and significant learnings regarding the qualification and subsequent installation by contractors.

Efficiency was anticipated to be 140%, and in practice ranged as high as 150%. This high efficiency resulted for some sites in significant reduction in gas use for the same comfort level, depending upon the legacy gas furnace and gas water heater being replaced. SMTI's TDHP for this trial witnessed a reduction in carbon emissions up to 15% as the first of several environmental benefits. The decarbonization in the SMTI solution has the added benefits of utilizing an all-natural refrigerant that has zero global warming potential, zero ozone depletion, and no PFAS chemicals. An additional environmental benefit of the SMTI TDHP solution is its low power consumption, enabling the system to be installed without costly upgrade to the home electrical panel, and no stress on the grid like is commonly found with electric heat pump installations. Furthermore, the low power consumption permits the homeowner to operate the system on a small 3000 W generator in areas prone to power disruptions.

6.0 Project Description

Introduction, including an outline of technology or process that is the focus of the Project

A TDHP offers significant primary energy savings compared to furnaces, boilers and water heaters in all climates and vapor compression electric heat pumps (EHPs) in cool-cold climates. SMTI's TDHP design maintains 85% of rated heating capacity and energy efficiency down to -18°C and can operate successfully at least down to -40°C , eliminating the need for back-up heating. Our approach uses a natural refrigerant pair (ammonia + water with a global warming potential of zero), yielding a rating point COP approaching 1.45 at 8.3°C ; and it is poised to replace conventional furnaces, boilers and water heaters (limited to $\text{COP} < 1$). The absorption heat pump cycle (Figure 1) consists of seven specialized heat exchangers and a small solution pump. Thermal energy is used to generate ammonia vapor at high-side pressure in the desorber where it is condensed, expanded to the low-side pressure and evaporated in an air-coupled evaporator. The low-pressure ammonia vapor is then re-absorbed into water in the absorber and then the liquid is pumped back to the high-side pressure to begin the cycle again.

Heat for space or water heating is obtained from the condenser, absorber and condensing heat exchanger. Two internal recuperative heat exchangers (RHX and SHX) are critical for achieving very high COPs, while the rectifier is a small heat exchanger that condenses the small amount of water vapor that exits the desorber with the ammonia vapor so that the evaporator operates at maximum effectiveness.

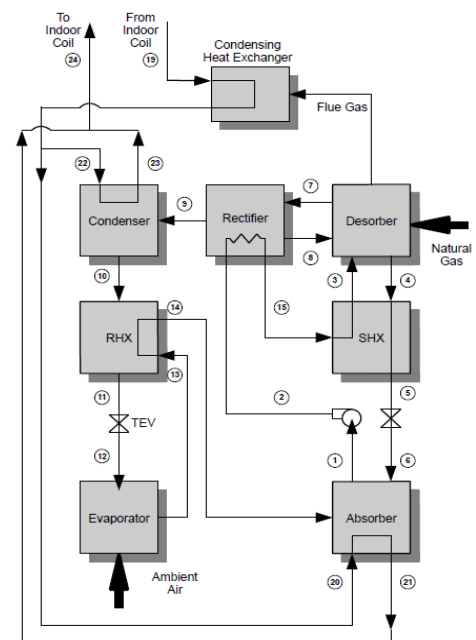


Figure 1: Gas Absorption Cycle

The cycle pulls energy from the outdoor air through the evaporator and “pumps” it up to a higher temperature so that when combined with the combustion energy a net heating efficiency greater than 100% is obtained. For the system’s energy balance, at the 47°F rating temperature (and at 120°F supply water temperature), for every (1.0) unit of gas-combustion energy put into the system, 0.45 units of ambient heat energy are also transferred in from the local environment. Thus, the total heat energy output of the thermal part of the system is 1.45 units. Parasitic electrical energy is approximately 500 watts at design conditions, resulting in a net system COP of 1.40.

SMTI’s TDHP designs are suitable for a variety of residential and small/medium commercial building applications. In a single-family home, the heat pump is installed just outside the building (Figure 2) and is hydronically coupled to an air-handling unit (AHU) positioned inside in the same location as a traditional furnace. It is also optionally coupled to an indirect

storage tank in the same location as a traditional water heater. For a hydronic heating system (with a boiler, not shown), the TDHP directly replaces the boiler (although it is located outside, rather than inside the house) and connects directly to the existing indoor hydronic distribution system. The ammonia-water refrigerant pair remains outside and never enters the building.

The TDHP can operate on any typical thermal fuel, including natural gas, propane, and fuel-oil. It can also operate on any renewably produced fuel, such as renewable gas, hydrogen, synthetic natural gas, biofuels. For a typical home, SMTI’s 80,000 BTU/hr (23 kWh) output capacity TDHP requires a 15-amp, single-phase circuit and natural gas from a 1/2” pipe at 5 inches water (typical) pressure. Condensate can be drained either to a sanitary sewer or, code-permitting, drain directly outside into a small limestone gravel lined pit dug below the freeze line.

It can produce water-supply temperatures as high as 65°C for space heating and can heat an indirect water tank to 60°C. Venting of combustion by-products is direct to the air outside, requiring no special piping. This eliminates the need for indoor flue vent system retrofits and the possible danger of CO poisoning. SMTI’s unique heat exchanger designs allow automated mass production in any size between 10,000 – 140,000 BTU/hr (3-40 kW) heating capacity. For the single-family market, SMTI ultimately expects to produce units as required by the market in the range of 40-140 kBTU. The proposed test unit size was 80 kBTU (output capacity) and represents SMTI’s introductory product.

The single effect NH₃/H₂O absorption cycle was first patented in France by Ferdinand Carré in 1859. The process was used primarily as a cooling cycle, but that application faded as vapor compression became more economically efficient. SMTI formed in 2010 to re-orient and re-engineer the cycle primarily for heating, with a focus on reducing the cost by 50% compared to existing options (European manufacturer). Through a series of grants from the US Department of Energy, the California Energy Commission, and a number of other strategically interested entities (largely gas utilities), SMTI completed the design to position its approach for cost-effective, and globally scalable production and final DFM (Design For

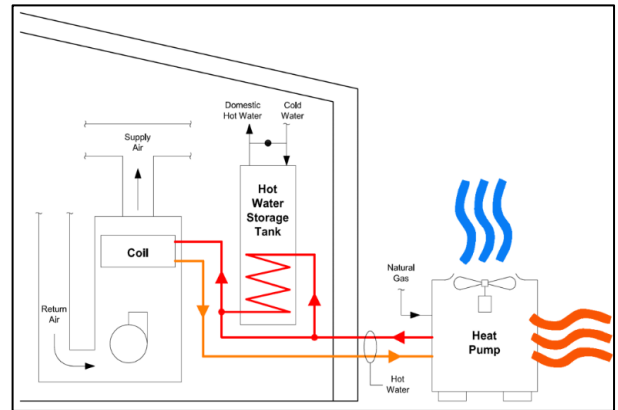


Figure 2: Residential COMBI System

Manufacturing) specifications, as well as consumer and contractor concept-test data for the US market. The completed ERA project has provided critical operating experience, and market acceptance data specific to Canada, enabling SMTI to address the full North American market for cool and cold-climate product applications.

With a 3rd-party-demonstrated 140% AFUE, SMTI's TDHPs go well beyond the COP=1.0 barrier that has previously represented a hard ceiling for gas heating appliances. SMTI's recent DFM project, as well as the manufacturing background of its leadership team means the technology can be cost-effectively scaled at a market-price that maximizes the chance of wide market acceptance.

Background of the Project

The project seeks to prove performance and market viability of TDHPs as an efficient and reliable alternative to traditional gas fired furnaces and water heaters, as well as provide a residential gas heating solution as an answer to fuel switching required of electric heat pumps. Some of the key issues which the project addresses include:

- Reduce gas use – TDHPs provide a means of heating with less gas, while maintaining end user comfort, in an affordable, easily installed solution. SMTI will target replacing gas furnaces and gas storage water heaters with a higher efficiency solution, but the solution is well suited to help consumers keep their gas heating when electrification driven fuel switching is a threat
- Decarbonization – higher efficiency results in lower carbon emission, further reinforcing the continued use of gas for heating, as well as securing the continued use of the paid-for asset in the gas pipeline network.
- Homeowner security – high efficiency, affordable gas heating provides an alternative to electrification when the grid viability to handle higher loads is suspect
- Homeowner comfort - TDHPs offer the comfort that many are accustomed to in gas appliances, particularly when electric alternatives present a significant change to that comfort level
- Homeowner cost reduction - Comparing TDHPs to the alternatives of gas furnaces and boilers, and electric heat pumps, SMTI's technology has the lowest cost per unit of heating capacity. It also has the lowest operating cost of any advanced efficiency (COP>1.0) technology. On a lifecycle cost basis, TDHPs will have the lowest cost compared to any other technology.

The project has enabled SMTI to demonstrate a complete “white label” TDHP with Napoleon (and other OEMs) and allows Napoleon to develop and field test an air-handler and associated controller that matches the specific performance characteristics of a GAHP and combi system so that they can offer a complete heating system through their distribution channel.

Project objectives

SMTI has developed a cost-effective residential GAHP from proof-of-concept to pre-commercial readiness and has commercialized this, along with an AHU designed and manufactured air handling unit for delivering effective space and water heating to a residential home with an indirect storage tank, closed hydronic loop, control algorithm. Over the course of this project, SMTI and Napoleon collaborated to

modify Napoleon's air-handler and indoor control systems to allow optimum TDHP performance and home-owner comfort, build and laboratory test the resulting system design and then field test 5 systems in Alberta homes to verify performance, evaluate home-owner satisfaction, and identify design or control changes required before commercialization. Additionally, contractor and home-owner market research was completed in order to identify product attributes necessary for commercial success and estimate the market potential in Alberta and greater Canada. This research has guided our decisions in product design, installation protocol, sales channel development, and pricing strategy.

Performance/success metrics identified in the Contribution Agreement

Table 1: Performance Metrics Summary

Success Metric	Commercialization Target	Project Target	Achievements to Date
COP at design condition	1.43	1.43	1.43
Average heating season COP on gas basis in Alberta climate	1.3	> 1.25	>1.25 in Wisconsin, USA climate
Maintain home-owner comfort	90%	90%	Using M&V data regarding home temperature, and feedback from home owners during and after field test, access comfort level so that control algorithms can be optimized if necessary
Hot water availability	100% at less than 200 gal/day	90% at less than 200 gal/day	Using M&V data regarding home temperature, and feedback from home owners during and after field test, access comfort level so that control algorithms can be optimized if necessary

Discussion on any changes in the Project during the lifecycle of the ERA funded Project scope

SMTI's team has grown and changed significantly over the span of the project. The leadership now includes:

- Michael Garrabrant, Founder & CEO
- Douglas Coates, Chief Financial Officer
- Dave Monk, VP of Engineering & Operations
- Jack Sinkler, Executive VP of Sales & Marketing
- Scott Reed, VP of Regulatory & Business Affairs

The company has expanded from an 11,000 square foot development site, to a 160,000 square foot production and engineering building.

Technology risks

Technology risks throughout the project have included the following, most of which were recognized as potential challenges at the outset, and which have been effectively dealt with for the commercialized product:

- Cost effective and reliable manufacturing –
- Product design to mitigate sound, in order to comply with local codes, effectively compete with well-established electric heat pumps, and to meet homeowner expectations.
- Refine our installation protocol and options for effective condensate removal, particularly in extreme cold conditions. The Edmonton homes offered various options for effecting condensate removal, including draining direct to a pit, as well as indoors to sanitary drain. We adapted our training and protocol to ensure a robust solution down to -40F/C.
- Communications connectivity to field installed product. While we began the project with Wi-Fi connectivity directly to the TDHP, we found the challenges and barriers to operating on the homeowner’s “network” we resolved via a direct cellular connection.

7.0 Project Work Scope

The project work scope can be simply summarized as the production of two white label 80KBTH TDHP units for accelerated life testing, and the subsequent manufacturing of 5 pre-production units for field testing in Edmonton residential applications. SMTI white label ALT units were tested and summarized in the M5 report, along with our partner Napoleon’s ALT test report on their air handler units in their lab. The field test of SMTI 80KBTH TDHP with Napoleon Air Handling Units, Napoleon designed and provided hydronic control boards, and SMTI selected HTP 80-gallon indirect storage tanks were summarized in M7, and the test protocol conformed with the anticipated protocol at the project outset.

Additional details are provided in Section 9, by Milestone.

8.0 Commercialization

During the span of the ERA project, SMTI has transitioned from an 11,000 square foot design center to a 160,000 square foot full production facility with extensive lab development and test space. SMTI launched the production 80KBTH TDHP with a custom designed matched hydronic air handler, in early 2024.

Over the span of the ERA project, SMTI has taken our 80K BTH TDHP solution from a TRL7 level to TRL9, effectively completing full commercialization of the solution. The path to commercialization benefitted greatly from the learnings of the ERA field trial.

Through a number of field trials in both Canada and the US over the past 3+ years, SMTI has achieved success in meeting performance metrics in production equipment. Both the HP80 TDHP and SMTI's custom AH1400 AHU are Intertek certified, and are commercialized in both Canadian and US markets.

9.0 Lessons Learned

Milestone 1:

Subtask 1.1 – Canadian TDHP Combi System Engineering Specification

SMTI and Napoleon worked together to complete a specification document that outlined the performance characteristics for all components and sub-systems contained within the TDHP Combi System. This document was used as a guide for sourcing components under sub-tasks 2.2 and 6.3.

The specification document included coverage for:

- TDHP performance, firing rates, hydronic flow rate and fluid requirement, electrical requirement, physical size, refrigerant charge, and maximum / minimum operating conditions.
- AHU heat exchanger performance, air flow rates, maximum pressure losses, physical dimensions, hydronic I/O specification and minimum control functionality.
- IST capacity, materials, control, fluid I/O specification.
- Hydronic loop component specifications and ratings.
- Minimum thermostat capability.

Subtask 1.2 – Multi-speed Hydronic Air Handler Design

The TDHP modulates the firing rate to maintain a target hydronic supply temperature to the air handler (AHU) or indirect storage tank (IST), based on an ambient reset curve when in space heating mode. The reset curve is set to minimize the supply water temperature (maximizing efficiency) while at the same time providing a comfortable supply air temperature from the AHU (maximizing comfort), by increasing the supply water temperature as the outdoor temperature decreases. The hydronic coil capacity for the air handler was selected based on the indoor blower running at high speed and SMTI's 80 kBth TDHP heating output and target hydronic supply temperature at an outdoor temperature of –5 °F, which is about 60,000 btu/hr and 125 °F respectively. The target AHU air flow rate at high speed was selected to be 1400 cfm, slightly higher than the cooling flow required for a 3RT air conditioner.

At the minimum load condition (warm day), TDHP modulated down to 25% firing rate at a target supply water temperature of 108 °F, the low AHU air flow rate was selected to be 700 cfm.

Working with hydronic coil and AHU blower manufacturers, Napoleon sized and selected an appropriately sized hydronic coil, blower and hydronic circulator based on the expected pressure losses of the TDHP, hydronic coil, and hydronic connecting lines.

Milestone 2:

Subtask 2.1 – Combi System Controls Development

After SMTI and Napoleon collaborated and finalized the control board specification, a board development company was selected, and detailed board development began. After several reviews and revisions, 1st spin prototypes of the board were ordered and were delivered to the board developer around late July 2021. Once received, the board developer began their hardware/circuit testing and wrote the firmware based on SMTI's control logic.

Upon receipt of the boards the developer traveled to SMTI to assist with board testing in-situ on the COMBI system tested as part of Milestone 3. After Napoleon and SMTI approved the board/software and board hardware changes were made, 2nd spin prototypes were ordered for the field test units.

The following are a few key features of the board:

- The use of push-in style connectors to allow for quick and easy field installation for the various components within the Combi System.
- A Bluetooth / Wi-Fi chip that allowed the contractor/ homeowner to remotely connect and control the appliance via an app (which was not developed until after the field trial was finished).
- A master Modbus port (for TDHP) and 2 slave Modbus ports for a secondary zone control board or an external display.
- A push-button to clear timers & errors as well as reset the Wi-Fi chip.
- DIP switches which allow for multiple board configurations.
- The capability of controlling many extra components commonly found within a forced air system but not needed for these field trials (Dehumidifier, Air Cleaner, Auxiliary Heating Elements, etc.)

Subtask 2.2 – Fabricate & Assemble Two Combi Systems for Lab Testing

In mid-June 2021, SMTI quickly finished assembly of the unit and installed it into one of their environmental chambers to begin undergoing testing. The unit completed “shake-down” testing where various components were dialed in for optimal performance near mid-July and began steady-state performance testing soon after. The second prototype scoped under Task 2.2 received its last remaining parts around mid-July and the build was completed soon afterwards. After shakedown testing was completed on the second unit in SMTI's second test chamber it was coupled to Napoleon's custom AHU and hydronic board assembly to begin COMBI testing with a PLC to confirm that SMTI's control logic functioned properly. This gave a necessary baseline before the functional PCBs were tested on the system.

Napoleon completed assembly and testing of the first AHU in June 2021. Following blower testing, the cabinet design was optimized, and new parts were ordered. These new cabinets arrived at their facility and the final prototype that was to be used for Combi testing at SMTI was assembled and shipped.

Parts arrived near the end of July and were installed on the exterior of SMTI's test chamber in preparation for the COMBI testing.

To simulate a pre-assembled and packaged hydronic flow and control system for field testing, a hydronic control board was developed to make installation easier on the contractors. All components within the

hydronic loop between the TDHP and AHU were located on this board. Therefore, the contractor would only be required to mount the board and run hydronic lines between the TDHP, AHU, and indirect storage tank. Napoleon received all necessary components to build this first board prototype and shipped the completed board to SMTI for testing with the AHU near the end of July 2021.

Milestone 3:

Subtask 3.1 – TDHP Performance Lab Testing

The TDHPs were installed in SMTI’s environmental chambers and underwent an array of steady state tests. This was the first set of TDHPs that were built and tested using SMTI’s custom printed circuit board for the primary control logic. As such the initial “shakedown” testing took longer than anticipated as SMTI worked with the board manufacturer on software revisions and improvements to optimize performance. The plot in Figure 3 below shows that SMTI successfully achieved a COP on a gas basis (heating output ÷ gross gas input on HHV basis) above 1.4 at the design condition (47 °F ambient, 100 °F hydronic return), with a measured value of 1.404. Note at full-fire, the nominal hydronic temperature rise is 20 °F (11 °C), so the hydronic supply temperature for the curves in Figure 3 are nominal 20 °F higher than the listed hydronic return.

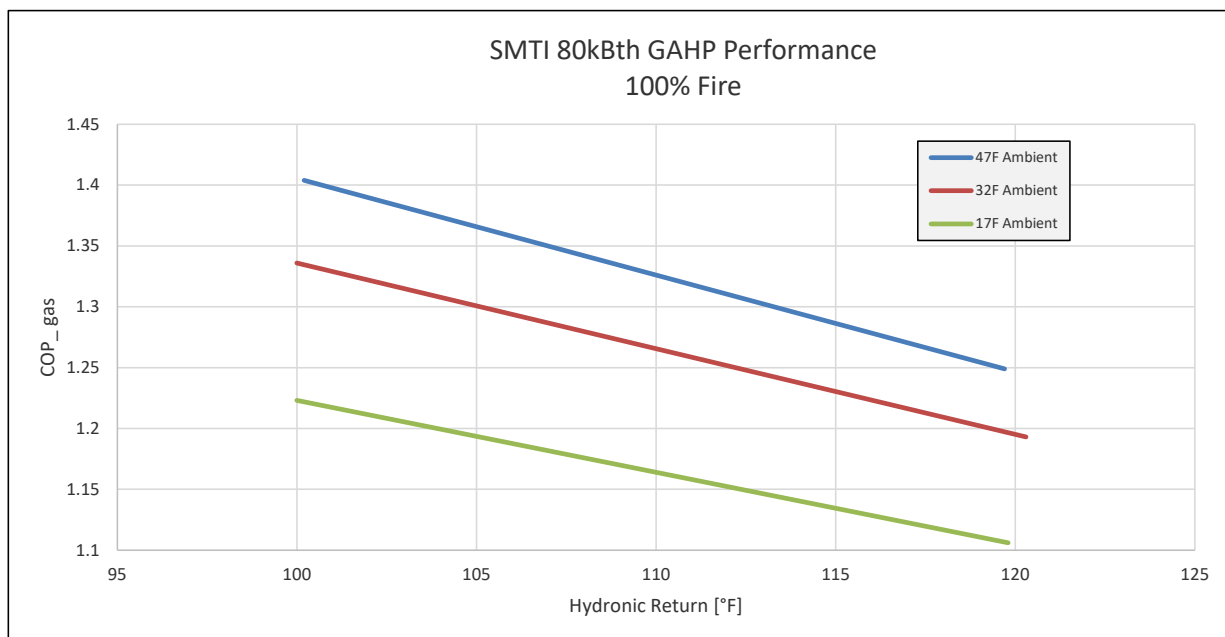


Figure 3: Steady State Testing Results

Testing continued with performance characterized across three different ambient temperatures (47 °F, 32 °F, & 17 °F or 8.3 °C, 0 °C, -8.3 °C) and two different hydronic return temperatures (100 °F & 120 °F, or 38 °C & 49 °C). Testing was completed at different modulation points of the combustion system. Figure 4 shows that performance was consistently at or slightly above 1.4 at the design condition across the majority of the modulation range.

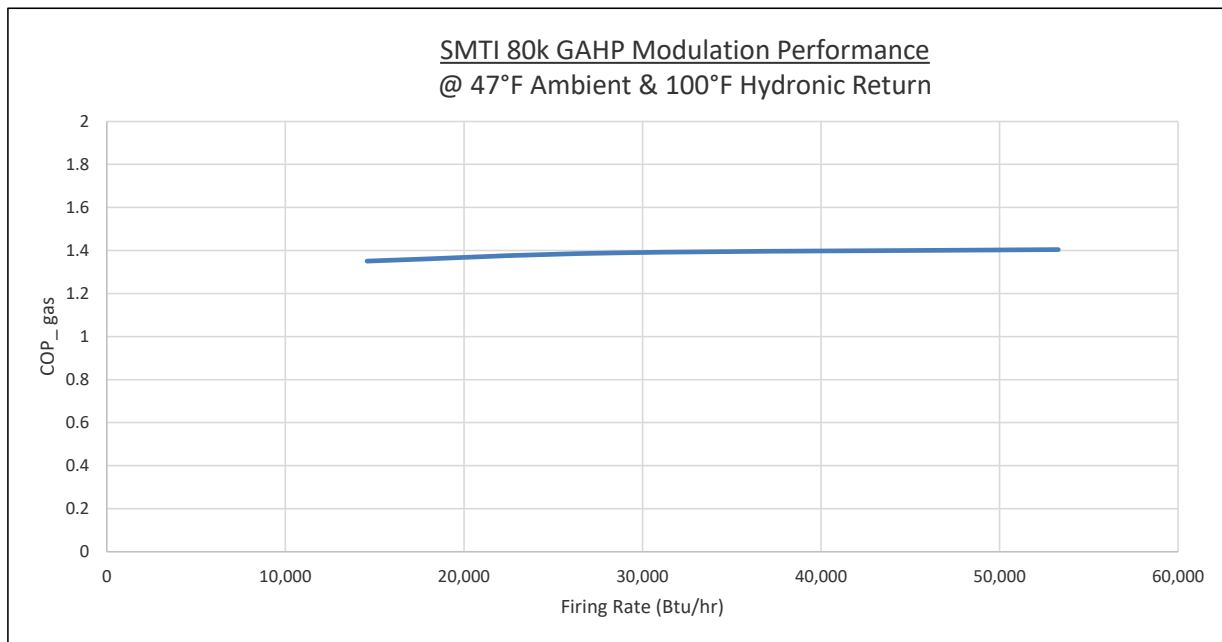


Figure 4: Modulation Test Results

Subtask 3.2 – Combi System Lab Testing

Following the steady state testing completed in subtask 3.1, one of the TDHP's was connected to Napoleon's custom hydronic air-handling unit (AHU) and hydronic pump-control board. The AHU control board (PCB) developer travelled to SMTI to assist with installation of the custom printed circuit board and the team began testing and troubleshooting the control logic. The project team stepped through every possible path of the control logic by manually forcing various heating calls and disconnecting sensors to confirm the error logic worked accordingly. As issues or "bugs" in the firmware were identified, the software engineer made modifications, and the new version was retested. The result was a fully functional firmware revision that SMTI has been using to continue running the TDHP since this initial round of testing was completed. The following is a list of the various modes tested, and a brief description of a few control logic checks performed:

- Space Heating Only
 - W1 heating call (stage 1) sets blower to LOW speed and after a preset amount of time the blower would transition to the next appropriate speed settings.
 - W2 heating call (stage 2) sets blower to HIGH speed.
 - Controls correctly transition between W1 & W2 logic mid-run.
- Water Heating Only
 - Water heating call via the Aquastat would energize the diverter valve and ensure the blower is turned off.
- COMBI (Water + Space Heating)
 - The hydronic flow is diverted between the AHU & indirect storage tank appropriately.
 - The logic would switch into and out of COMBI mode based on any order of heating call (i.e. W1 then water heat, water heat then W1, simultaneously, etc.).

- End of Heating Cycle
 - Blower reduced speed and continued running for either the predetermined amount of time or until another heating call was received.
- AHU Decay
 - Heating calls were removed to TDHP.
 - Blower speed reduced to low and ran for either the predetermined amount of time or until the hydronic temperature had reduced to the target parameter.
- Errors
 - Forced parameters in the code to induce an error and confirm that the system behaved as it was intended.

Along with testing the logic of the printed circuit boards, the air handler coil was tested in-situ with the TDHP and using the PWM blower control of the PCB. It can be seen in Figure 5 that the AHU blower reached the target maximum airflow of 1400 cfm with room to spare. After confirming that the airflow was adequate, SMTI tested the AHU at various hydronic supply temperatures to characterize the capacity curves for the system. During testing the team found that the hydronic-side pressure drop was slightly higher than anticipated based on initial coil sizing calculations at the maximum flow rate of 8.5 gpm. During the field-testing phase, additional hydronic loop pressure loss was expected due to the use of flow meters. To compensate for this in the field test phase, an extra pump was added to the hydronic board design. As seen in Figure 6, it was plumbed in a manner that allows the use of only one pump if the actual field test site pressure drop proves to be acceptable. It should be noted that this added pump is one of the reasons behind increased electrical consumption. SMTI's production AHU was specifically sized to have a significantly lower hydronic pressure drop and a larger pump to prevent the need for multiple pumps in most applications.

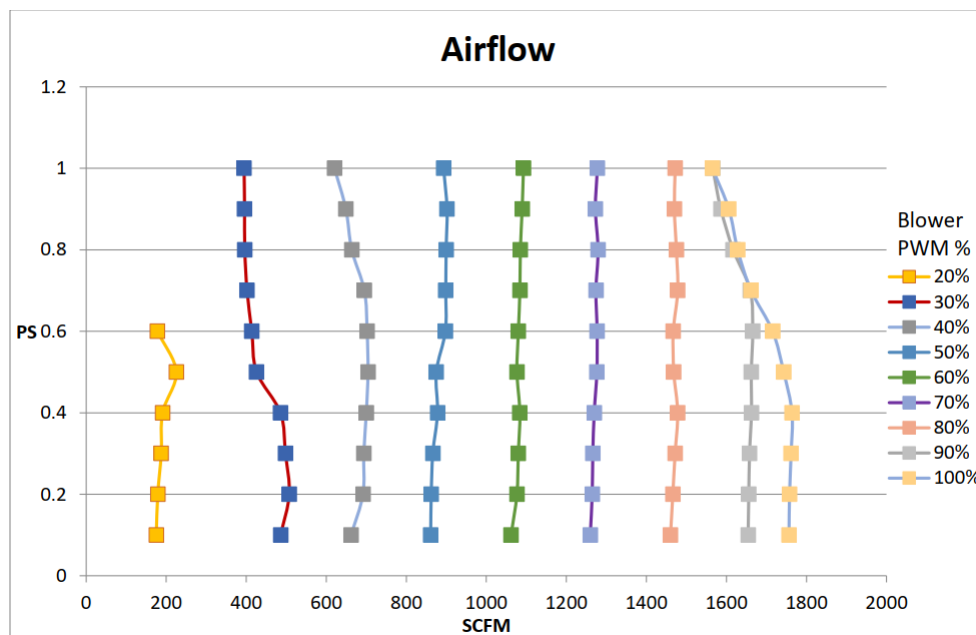


Figure 5: Napoleon AHU Blower Curves

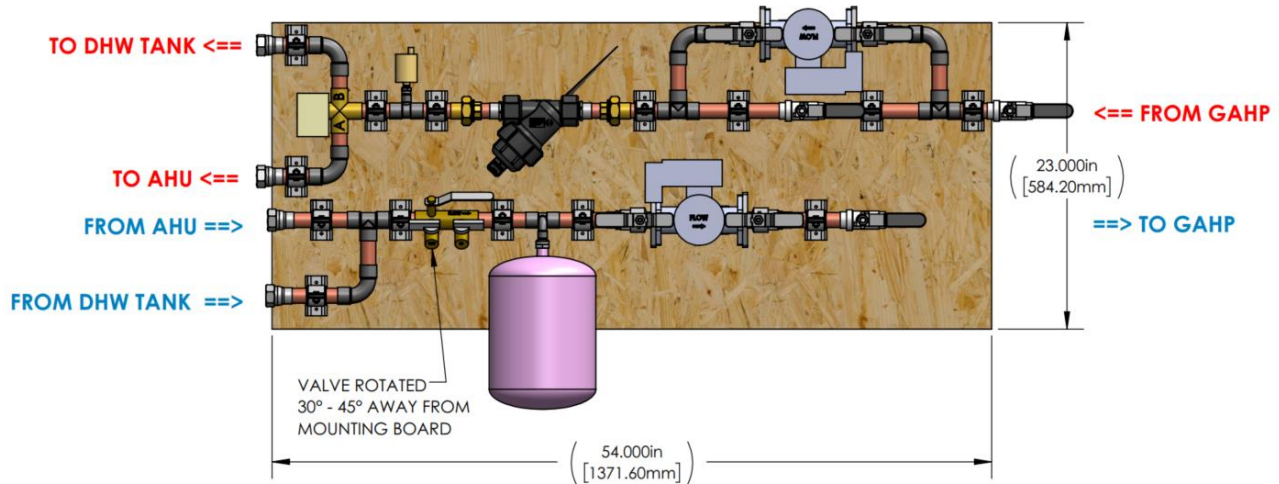


Figure 6: Napoleon Hydronic Board Modification

Once airflow and hydronic flow had been dialed in SMTI began performing tests at various hydronic supply and return air temperatures to characterize the AHU coil with a 35% glycol mix. The results can be seen in the following Figures 7 & 8. The measured capacity was slightly below target at 125 °F (51.7 °C) when calculated on a hydronic-side basis [$Q_{hyd} = m \cdot hyd_cp \cdot (T_2(\text{Hyd Supply}) - T_1(\text{Hyd Return}))$], but at target with 135 °F (57 °C) hydronic supply. Future design revisions of the coil increased the number of passes (to reduce the hydronic-side pressure loss) while increasing the capacity vs supply temperature.

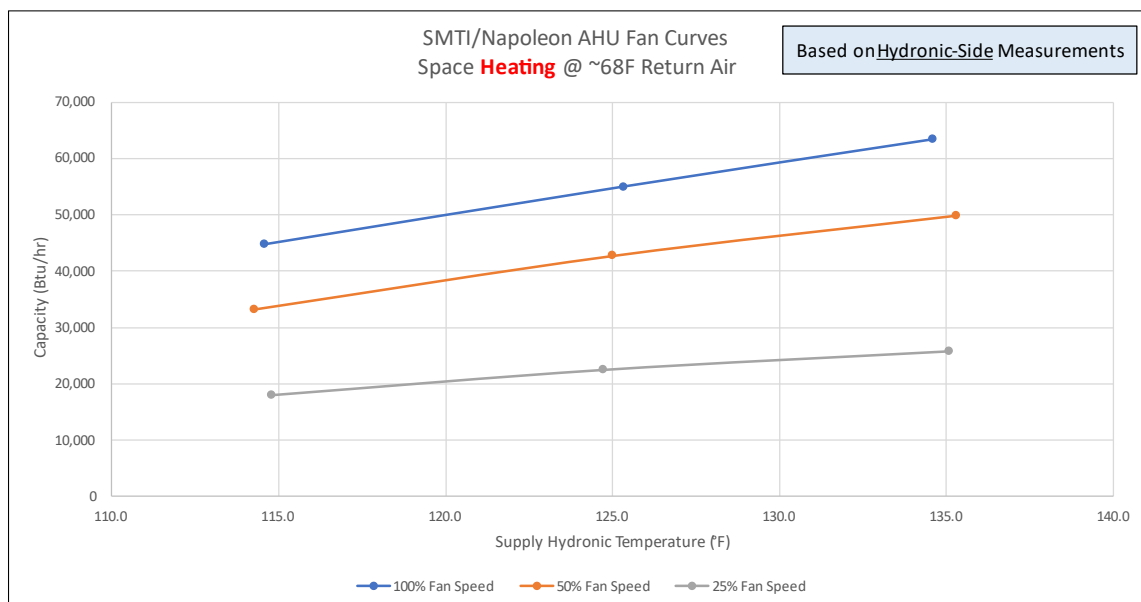


Figure 7: Hydronic AHU Curves - 68F Return Air

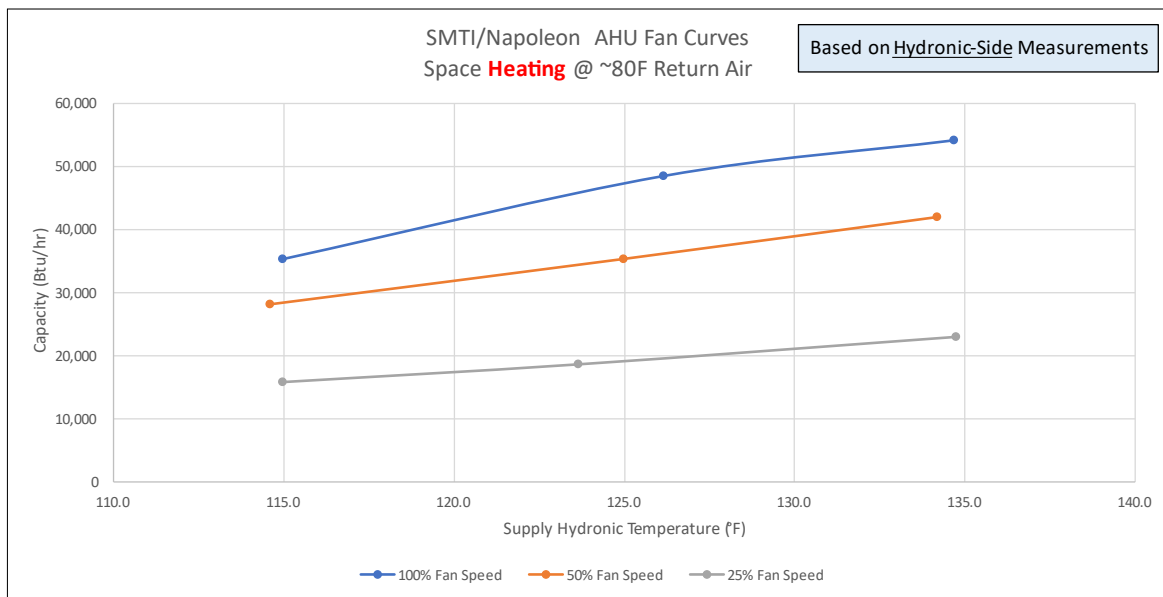


Figure 8: Hydronic AHU Curves - 80F Return Air

The performance testing allowed SMTI and Napoleon to determine the best default speeds for the air handler (low, medium, high) for the field trials

Milestone 4

Subtask 4.1 – Reliability Test Physical Preparation



Figure 9: GAHP Life-Test Installation #1

SMTI completed the setup of GAHPs and AHUs in November 2021. Figure 9 shows the first unit running during some of the cooler weather for the Eastern Tennessee region. Soon afterwards the 2nd unit was installed alongside the first to begin reliability testing as seen in Figure 10. Each GAHP was connected to Napoleon's AHUs to manage heating loads and reject



Figure 10: GAHP Life-Test Installation Final



Figure 11: SMTI – Indoor Installation

heat into SMTI's facility over the winter heating season, as seen in Figure 11. A Wi-Fi booster was also added to enable remote connection to a cloud server for data monitoring and troubleshooting. Each heat pump was linked to a thermostat programmed for almost continuous operation, allowing for periodic off-cycles.

The original intent for the reliability units was to monitor system metrics live with our data acquisition system. However, it was later found that there were issues with the DAQ system that prevented gathering the necessary data, so regular inspections were performed instead and a list of issues found and resolved are listed in Milestone 5. Performance post reliability testing for comparison to data recorded in Milestone 3. This information can also be found in Milestone 5.

To increase wear & tear on the GAHPs they were set to target hydronic supply temperatures of 140F which would force the GAHP to operate at higher pressures.

Napoleon's reliability test setup (Figure 12) monitored the following:

1. Inlet Water Temperature
2. Outlet Water Temperature
3. Ambient Temperature
4. Supply Air Temperature
5. Inlet Water Pressure
6. Water Flow Rate
7. Blower Amperage
8. A-coil Temperature during heat cycles

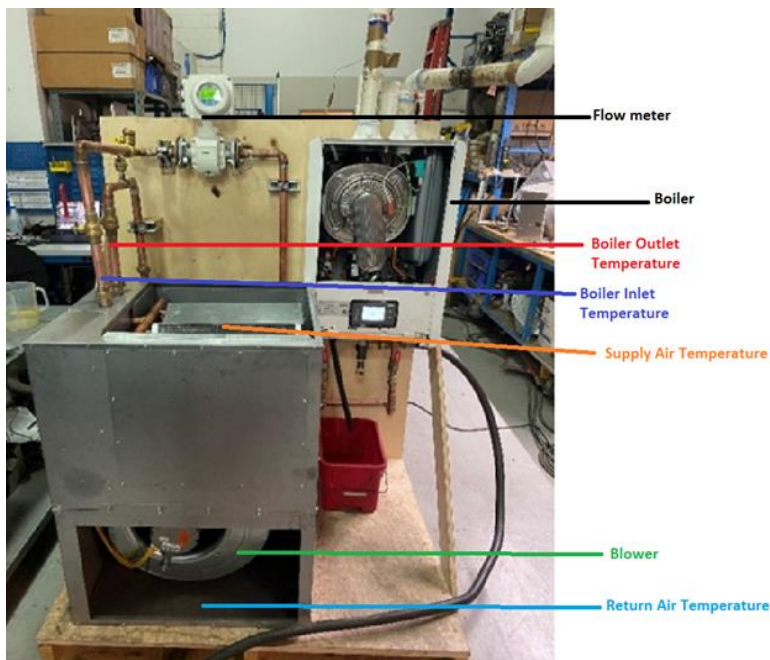


Figure 12: AHU Life-Test Installation at Napoleon

A general overview of their heating cycle to thermally shock the coil was as follows. The air handler unit and boiler were installed in a closed loop with constant water flow. The inlet temperature of the boiler was set to 120F and then heated 60 degrees for a hydronic supply temperature of 180F. The outlet water temperature was cooled through the heat exchanger inside the AHU before circulating back through the boiler.

The blower operated at 500 CFM during the heat

cycle for 5 minutes; once the cool cycle was initiated, the boiler shut off and the blower ramped to 1200 CFM to cool down the AHU coil until it reached the laboratory ambient temperature, which took approximately 5 minutes. In total, the cycle time lasted about 11 minutes. Therefore, the target of 10,000 cycles was expected to be reached in approximately 90 days of operation.

Milestone 5

Subtask 5.1 – Reliability Testing

SMTI tested the 80K GAHP reliability units as part of this Milestone.

Throughout the duration of the field trial there was an array of service items that were found and addressed. This reliability testing was ongoing during several field trials being conducted across much of Canada, including the 5 units part of this project in Edmonton, AB. The list below summarizes all improvements that were identified and made to the GHP design prior to launching into production thanks to this reliability & field testing.



After testing was completed and the GHPs were decommissioned WL04 was installed in one of SMTI's test chambers to repeat steady state testing at conditions similar to what was done during Milestone 3.1. Figure 14 below

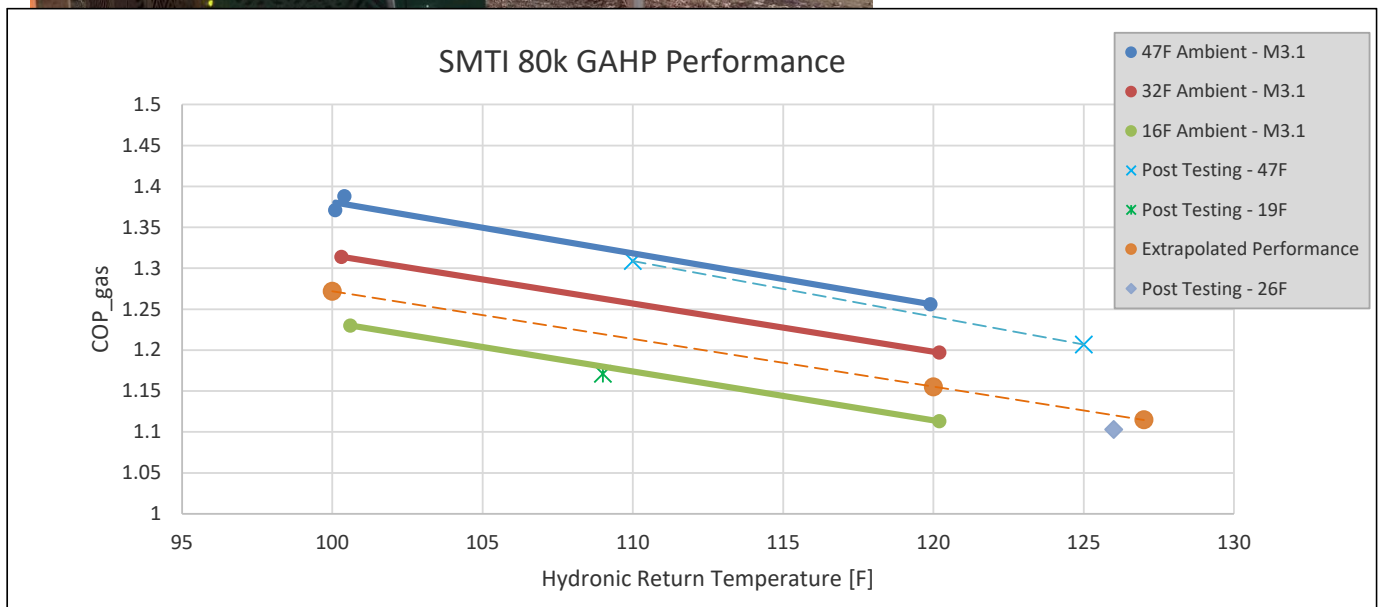


Figure 14: Performance Testing of 80k GAHP – Pre & Post Life Testing

shows performance in line with previous results, within the expectation of measurement accuracies. A performance trendline needed to be extrapolated to compare results for 26F since that testing was not done previously, however once complete it could be seen that results were less than 2% of expected results.

The Napoleon Air Handling Unit (AHU) comprised of several key components already well tested.

The Napoleon Air Handling unit successfully completed accelerated life testing. Reliability testing was further validated during the scheduled field testing as part of Milestone 7 where no air handler issues were observed. Proving that reliability testing conducted in Napoleon's lab was sound and results could be correlated with operation when connected with a GAHP instead of a boiler (operating at lower temperatures and reduced thermal shock to the coils).

Milestone 6:

Subtask 6.1 – Identify Field Test Sites & Installation Contractor

The original set of potential field trial homesites was developed from an ATCO provided list, with assistance from Napoleon and a prime contractor). There were significant challenges in the identification of 5 field trial sites as a result of COVID. Of the five originally chosen sites, one dropped out (after having signed the contract and had time spent on site survey details) due to a fear of COVID exposure from contractor's staff. This site was subsequently replaced by selecting from remaining options in the ATCO list of potential sites. To further compound challenges, the replacement site dropped out due to their selling their home (again, after having signed contract and site survey work time spent). The third selection of a 5th site again was made from the ATCO list and picked from a home previously surveyed and a homeowner who remained interested in the project over the span of several months. This final selection of the 5th site was deemed possible after the homeowner agreed to allow moving their legacy gas water heater under a stairwell adjacent to the equipment room, thereby making room in the equipment room for the field trial indirect storage tank and hydronic board.

Additional challenges were faced in working with the field trial homeowner sites due to access and resources. Contractor staff tested COVID positive and had to delay work in field trial homes. One home had a newborn child home delivery, resulting in delay of work. Another home was difficult to access due to homeowners not being physically present due to multiple homes, travel, and a job change. This challenge was eventually overcome by providing a key to a neighbor, for contractor access. Overall, other challenges were due to equipment placement, weather restrictions on access, and tight fit for equipment both indoors and outdoors, all of which while having been nothing unexpected, were a valuable learning experience.

Subtask 6.2 – Measurement & Verification

The primary contractor installed baseline equipment by early February 2022. The M&V technician commissioned baseline equipment the week of 02/14/2022. All baseline equipment for 4 sites recorded baseline data as needed. (Note: when one of the field trial sites backed out of the project, the team decided to only record baseline for 4 sites so that data acquisition planning could continue.) The M&V execution included collected baseline on 4 of the 5 sites, with full M&V data collection for GAHP operation on all 5 sites, beginning 12/2/22 and extending through the completion of the project.

Subtask 6.3 – Fabricate and Assemble Combi Systems

SMTI shipped out the first three GAHPs to contractor the week of 3/29/2022. The second set of two GAHP units shipped to contractor 7/8/22. Because of prior damage (cosmetic) to one of the first 3 shipped, SMTI covered the last shipment with heavy wooden frames, which appeared to work well in protecting the units in transit. SMTI also delivered the Indirect Storage Tanks sourced through a third-party supplier.

The Napoleon team delivered all 5 Air Handling Units and customized-per-site hydronic control boards.

Subtask 6.4 – Field Test Installation

The contractor team partnered smoothly to affect the installation of all equipment. The first 3 field trial sites were installed by 8/31/2022. The final 2 field trial sites were installed by 12/19/2022, with the delay installing being driven by equipment availability as well as homeowner access (for site #4,) and by the twice cancelled 5th site finally being settled shortly after the last equipment arrived in Edmonton.

Items of note during the installation process:

- SMTI has developed an extensive list of “lessons learned” throughout the installation of the Edmonton field trial units. The most important observations are noted below:
 - Shipping damage incurred on at least one Edmonton site GAHP, which was mitigated in future shipments to ALL SMTI customers through addition of a 1x6” protective wood frame surrounding the equipment for LTL transport (not full truckload).
 - Hydronic loop length must be closely evaluated pre-installation and the potential need for a booster pump considered for long hydronic loops to ensure adequate flow rate.
 - WiFi signal strength/repeater was a challenge for several homes; repeaters should be available at installation time to include as needed to ensure adequate signal strength.
 - Condensate drain tube slope must provide adequate drainage to avoid combustion issues.
 - Condensate drainage location was a challenge, particularly where space constraints exist such as proximity to property lines.
 - Heat trace must be properly routed along the entire section of flue and condensate drainage. Insulation must also cover this entire portion. If any sections are left exposed condensate will freeze in the extreme cold seen in the Edmonton region. This results in an inability to light the gas as eventually the frozen condensate restricts all flue gas airflow.
 - IST connection labeling is needed to ensure appropriate connections are made.
 - Hydronic pump flow direction and flow rate are critical to proper operation; labelling may facilitate contractor installation.
 - Gas valves are factory set “rich” to facilitate initial startup; it is critical to appropriately “dial in” the proper combustion for local conditions (ambient, altitude, barometric pressure, etc.).
 - Sound levels have been monitored, and noted that they comply with requirements in other Provinces (Alberta/Edmonton do not have sound ordinances).
 - Proximity GAHP to property line, home, must ensure adequate service access and avoid rain/snow drip/drift from roof eave.

It should be noted that for the Edmonton installations, SMTI developed a Commissioning Checklist to guide contractors through all the steps to ensure an installation is ready to start. Following this list, with proper attention in advance of system startup, ensures best use of time and resources.

- Napoleon
 - o Service kits with various parts and components of both the AHU and Hydronic boards were sent to Edmonton in case of any malfunction with the Napoleon provided components.
 - o Two updated air handling circuit boards were sent to Edmonton to be replaced

At the outset of the project, SMTI trained the contractors who were involved in system installation. Much of this was completed remotely via online meeting software, with the use of PowerPoint slides. As a result of working with contractors in Edmonton (and across Canada in general), SMTI formulated a training curriculum which is more detailed and methodical than the originally provided training courses. As a result, we have shifted from topic-based training, to instead offering a multi-tier curriculum which focuses on the skillsets needed for various levels of product support. This training, which SMTI has characterized as Anesi 101, 201, 301, and 401 courses, separates the tasks with which contractors must be familiar. The first two courses will ensure a contractor is familiar with the solution and can successfully perform basic installation. The latter two courses focus on service and repair procedures, particularly on the refrigerant sealed system. We have additionally expanded from only online training, to now hosting train-the-trainer sessions for our reps in Piney Flats TN, as well as in person and recorded training sessions available online. In addition, we have hired a professional trainer as our Customer Service manager, and an assistant, to keep up with the growing demand for training.

One challenge experienced in Alberta and discussed below in Milestone 7 (site 4), and a situation which appears to be common across the provinces, is sourcing ammonia for recharging the sealed system. While SMTI had already designed and sourced the ammonia-rated valves and connectors to enable a charging system, actually getting ammonia in an appropriately sized container for contractor use proved difficult. However, through negotiations with a supplier, Linde, who has Canadian-wide coverage, SMTI is able to secure the small tanks ideal for our contractors, and long term these will be staged at SMTI's Canadian rep locations for contractor pickup and return of tanks.

Milestone 7:

Subtask 7.1 – Field Test Monitoring (Nov 2021 – Aug 2023)

Reliability and Maintenance Summary

Site 1

- GHP cabinet was damaged during shipping but remained functional. This led to a design change for SMTI when shipping systems via LTL. A crate is now built to protect the systems from all angles. Since damage in this case was due to something falling on top of the unit during transit.

Site 2

- GHP solution pump speed fault near end of the project, it was disabled since it was not necessary for GHP operation and the unit continued heating. This was tied to an issue with the hall sensor being displaced but these systems were installed with belt driven solution pumps which were transitioned away from as explained in Milestone 5. The hall sensor is now rigidly mounted to the direct driven pumps.
- There were many issues with the remote thermostat that was used. Instead of hard-wiring a new thermostat in (since the original was still tied to the existing equipment for backup heat during the trial) this remote communicating thermostat was used at all sites. It utilized a radio signal to communicate between the indoor thermostat and a control module wired directly to the AHU control board. If communication was lost the system would not receive any heating calls and no heat would be provided. This resulted in “outages” or loss of heat events multiple times throughout the trial.

Site 3

- GHP accumulated ice on the fan blades due to heat trace for condensate line running next to the evaporator fan on top of the cabinet.
- Condensate drainage problem caused multiple ignition failures.
- Frozen glycol during December 2022 due to incorrect concentration prevented operation until outdoor temperatures warmed enough to gain hydronic flow again.
- The error signal relay between the GHP and AHU began to sporadically malfunction. The relay would stick closed resulting in an outage because the AHU perceived this as a fault when in reality the GHP was sitting idle. This relay was needed for the field trials but control board designs were updated so that it is no longer necessary for production systems.
- After the measurement period had ended but the system was still operational leading into the 2nd heating season the solution pump bearings failed. This was found to be an issue with shaft tolerancing and was heavily investigated and redesigned for the direct driven pump transition. Instead of replacing the pump and continuing with the 2nd heating season the participant chose not to continue since there were sound complaints due to the failing bearing that resulted in a louder pump.
 - Even though increased sound levels were due to bearing wear in the pump, efforts were also made to implement damping features on the new direct driven pumps to further reduce sound pressure levels for production systems.

Site 4

- GHP experienced an ammonia leak at the non-condensable vent, causing it to shut down. The leak was due to corrosion on an internal surface. The vent has since been redesigned to use stainless steel components to prevent corrosion and leakage. The goal was to source ammonia in Canada and recharge the system, however, there were several months of delay in receiving ammonia. Once finally received and taken onsite it was found that the tank provided by the ammonia vendor was not full. This resulted in too little ammonia to fully recharge the system, and it was another 3-month lead time before more could be sourced. Due to this the unit could not be repaired in time to continue the trial.

Site 5

- The GHP solution pump locked up and was replaced. This was due to a design issue with the bearing fits with the drive shaft. The design is obsolete since the pump has been redesigned for direct coupling

to the motor instead of a belt drive. Bearing fits and retention have been optimized for reliability in the production design.

General

- Wi-Fi connectivity for remote access to the GHPs & AHUs was an issue, this resulted in a shift to cellular communication for the control boards on production systems.
- Condensate drain solutions are unique to each site and must be considered in the initial cost as well as long term operation. Several sites were not installed with adequate slope, or enough insulation / heat trace in appropriate locations. This resulted in frozen condensate causing occasional outages and poor performance until resolved, as there would be some gas use to try and light but no heat being provided to the home.
- Thermostat setup and communication is important. The issue seen often at site 2 with the remote communication dropping out was also seen to varying degrees at other sites as well. This was done for ease of installation during field trials but a production system swap out would utilize the existing thermostat. This issue would either cause no calls or intermittent calls to the heating appliance resulting in short cycling which is problematic for all types of heating appliances but is more difficult on a GAHP. Logic has been added into the AHU to try and extend runtimes for the GAHP to help limit this impact for production systems.

Performance Summary

Baseline data recording was completed for 4 of the 5 field test sites for approximately 2 months. Data for the GHP system was recorded for sites 3, 4, and 5 for 8 months and sites 1 and 2 for 12 months. The measurement and verification contractor has provided a summary report of the recorded data.

A few comments/observations about the data collected and presented below:

- It should be noted that baseline data was recorded from February 21, 2022 to April 17, 2022. The data shown below does not clearly outline the time of year for which comparison between upgrade and baseline data is compared (if not outlined as HDD, specifically Figure 20). Even if excluding the colder months of runtime the upgrade system experienced, which in December of 2022 dropped as

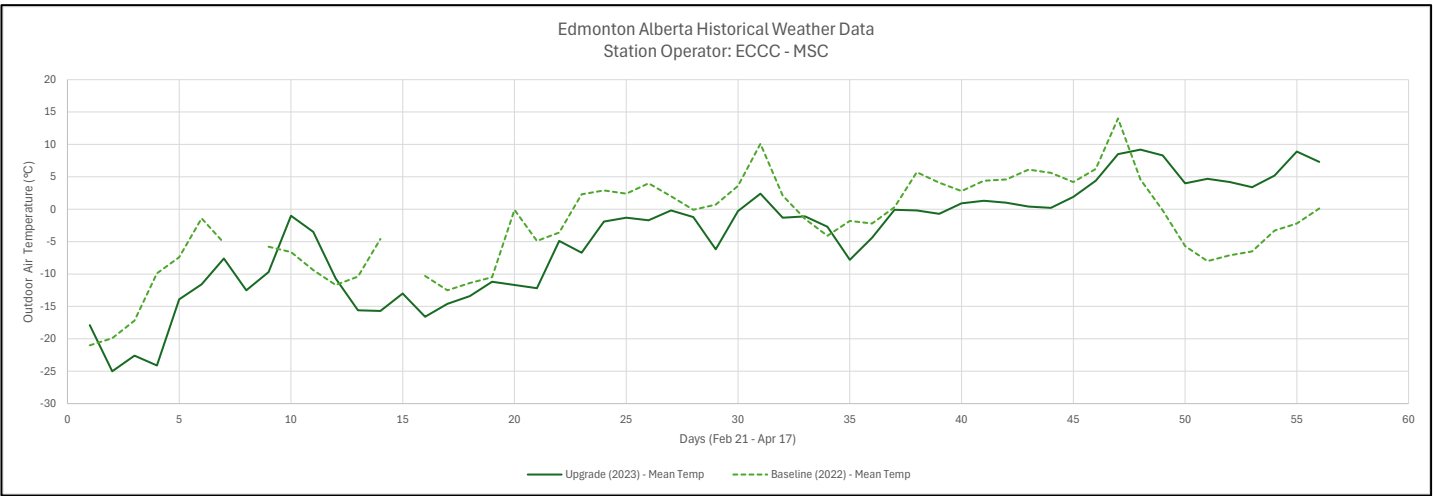


Figure 15: Edmonton Alberta Historical Weather Data – Mean OAT

low as -40°C, outdoor air temperatures (OAT) during the upgrade period 1-year later (Feb 21, 2023 – Apr 17, 2023) were consistently lower, as seen in Figure 15. This would have resulted in a larger heat loss from the buildings and required more heat to be provided from the appliance.

- Thermostat and DHW setpoints were not consistent from baseline to upgrade period. Most thermostats had their night-time setbacks removed during the upgrade period which would result in running more often at night. The thermostat setpoint was also changed slightly during occupied and unoccupied periods, some sites setting them slightly higher and some lower.
 - Site 5 utilized 2 heating units for different (communicating) zones of the house. During the upgrade period the second zone's thermostat was reduced substantially which would have forced the GHP to heat an area of the home that it may not have been ducted or designed to achieve, resulting in longer runtimes to try and keep the house warm compared to baseline.
- There was unattributed gas use at the sites both during GHP operation and while idle. This was later realized to be the backup water heater for Site 2 being used in parallel with the IST installed during the upgrade period, but there were also fireplaces installed at some sites that may have been used and contributed to added gas use which would have negatively impacted GHP performance measurements.
 - **Daily results with significant amounts of unattributed gas were excluded from efficiency calculations. Although it is possible that the lower volumes of unattributed gas could be used in the GAHP calculations. This could cause some inaccuracy within the results.**
- DHW Efficiency: There are several factors that play into DHW performance, some of the more important ones are listed below.
 - The GAHP is designed to operate at a maximum of 50% fire when operating in DHW only mode to extend the runtimes and try to prevent very short cycles. As mentioned above, given the GAHP requires about 10 minutes to ramp from zero to full efficiency at cycle start, the 10 minutes of lower than maximum efficiency is a higher percentage compared to longer cycles obtainable for space heating and combi mode.
 - If the tank Aquastat is set to a 15 degree differential then even operating at 50% capacity will still heat the 80-gallon tank back to the setpoint within 15 minutes so it is very difficult to get longer runtimes when only heating the tank.
 - If the tank temperature is set above 130F then the GHP will modulate down to minimum fire for the remainder of the heating cycle. This is to keep high-side pressure down as we heat to higher hydronic temperatures. At the minimum firing rate, the delta between the

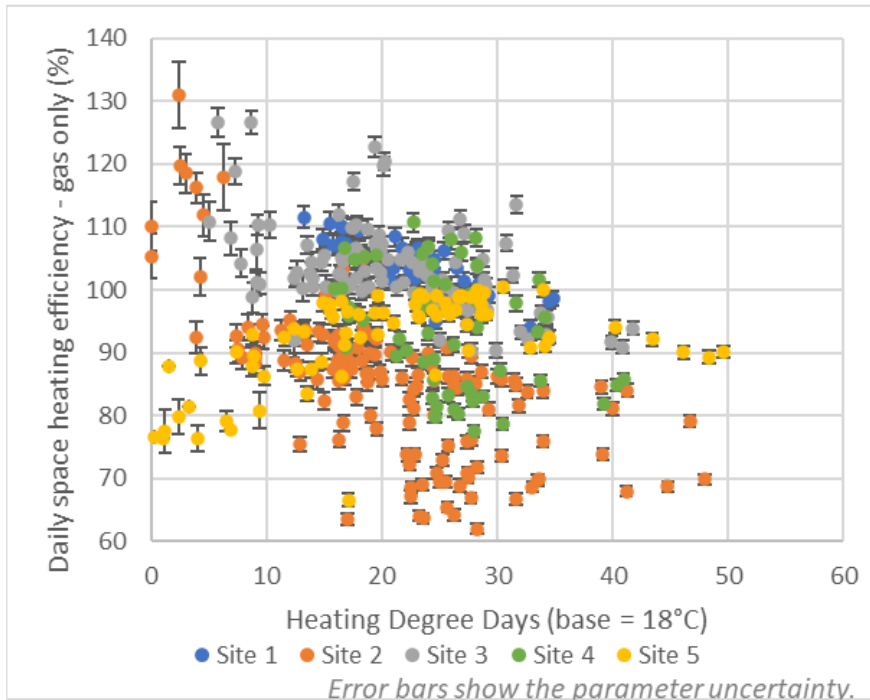
hydronic supply and return temperatures is very low, 3-4 degrees. At this low of a delta, if there are any inaccuracies in the measurement sensors, it can significantly impact the performance calculation. An error of 1-degree F from both return and supply sensors could result in an error of as much as 50%, which is why accurate field measurements at low fire can be difficult.

- It is difficult to measure performance for water heating and compare results between lab and field data. During space heating the system reaches quasi-steady state performance once the hydronic supply target has been met and the indoor air handler reaches a fixed blower speed. Alternatively, when viewing the “steady-state” data grabbed for water heating, the hydronic supply and return temperatures are constantly increasing as the water in the storage tank is heated. As these temperatures climb there is a mass-time derivative term missing from the calculation (mass of the system times dT/dt) that cannot be easily measured. This will result in a slightly lower calculated output than is actual.
- Mass of the system includes the glycol, hydronic piping/fittings/valves/meters, and the heat pump itself. In a space heating cycle, the mass of the system heats up fairly quickly and then reaches a steady-state condition. A portion of these “losses” are re-captured during the cool-down part of the cycle (after the gas is turned off but the hydronic flow and AHU fan remain on for several minutes...aka “free heating”).
 - In water heating, the system mass continuously heats up very slowly, so the dT/dt energy component never goes away. Effectively, energy produced by the heat pump being used to heat the system mass up is not captured by the COP calculation, nor is it captured during the “free-heating” portion of the cycle after the gas shuts off at end of cycle. For this reason, it is basically impossible to get an accurate water heating COP using a steady-state measurement/calculation technique.

For space heating, sites 1, 3, and 4 generally had efficiencies over 100%. Sites 2 and 5 had lower efficiencies. The low efficiency for site 5 could be due to the solution pump beginning to fail. Site 2’s lower efficiency could have been tied to the higher quantity of unattributed gas use that could have inadvertently made it into the calculations if not significant enough to be flagged.

Figure 16: GHP Space Heating Efficiency below shows the space heating efficiency for each site vs heating degree days over the measurement period.

Figure 16: GHP Space Heating Efficiency



M&V contractor summarized the range of space heating energy output as follows:

- Space heating energy needs offer a good correlation with the HDD during the baseline and upgrade periods.
- Space heating energy needs were similar for sites 1, 2, and 4 during each measuring period; sites 3 and 5 required more energy compared to the other sites, especially during the upgrade period. A portion of site 5 building is heated with an additional dedicated unit. Its setpoint had been reduced during the upgrade period to favor operation of the GHP.

- Space heating on site 3 decreased about 12% during the upgrade period compared to the baseline, as well as the night setback temperature which was 2 °C lower or nonexistent.
- Space heating on site 5 increased about 40% during the upgrade period compared to the baseline; the indoor air temperature was kept constant when the house was unoccupied instead of having a setback of almost 5 °C. The GAHP also likely heated the second zone building (see previous points).
- Different setpoints or strategy controls were used by the homeowners during the baseline and upgrade periods, which caused fluctuation of the space heating energy requirement for the building. Three sites did not program a nighttime setback during the entire upgrade period or for a part of this period; the setpoint was no longer reduced when the building was unoccupied for site 5.

For domestic hot water (DHW), efficiency varied widely but was generally higher with higher daily water usage. This ties in with the bullet point noted above about short cycling and it's ties to performance. It could be assumed that the higher daily water usage would be tied to longer runtimes instead of an increase in shorter draws scattered throughout the day. M&V contractor reports DHW efficiency compared to daily water usage but does not report it vs outdoor ambient temperature. The baseline equipment, being conventional water heaters, has efficiencies that do not vary with outdoor temperature. However, the GHP efficiency does vary with outdoor temperature. Figure 17: GHP DHW Efficiency shows the DHW efficiency vs daily water usage. Figure 18: Baseline DHW Efficiency shows the baseline DHW efficiency vs daily water usage.

The efficiency of both configurations was lower at low water usage. Site 5 was often unoccupied, so it used much less DHW than the other sites. With low DHW consumption, the cycling and standby losses are a higher percentage of the gas usage than with high DHW usage. The GHP DHW efficiency also varies because the same system handles both space heating and water heating. It will “top up” heat to the indirect storage tank at the end of a space heating cycle to prevent a dedicated water heating cycle.

Combining space heating and water heating in the same GHP cycle improves efficiency by reducing cycling losses.

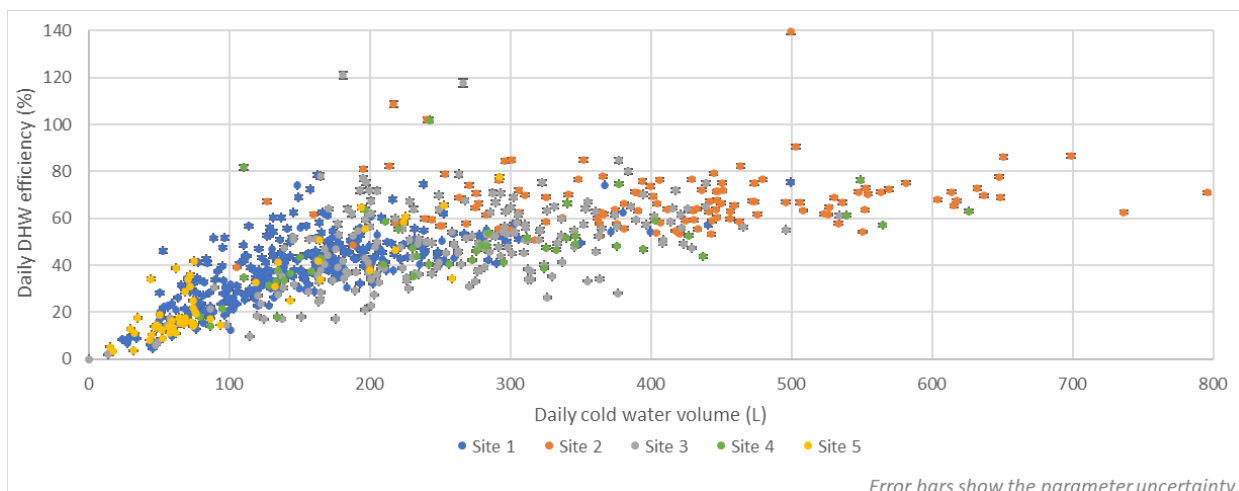


Figure 17: GHP DHW Efficiency

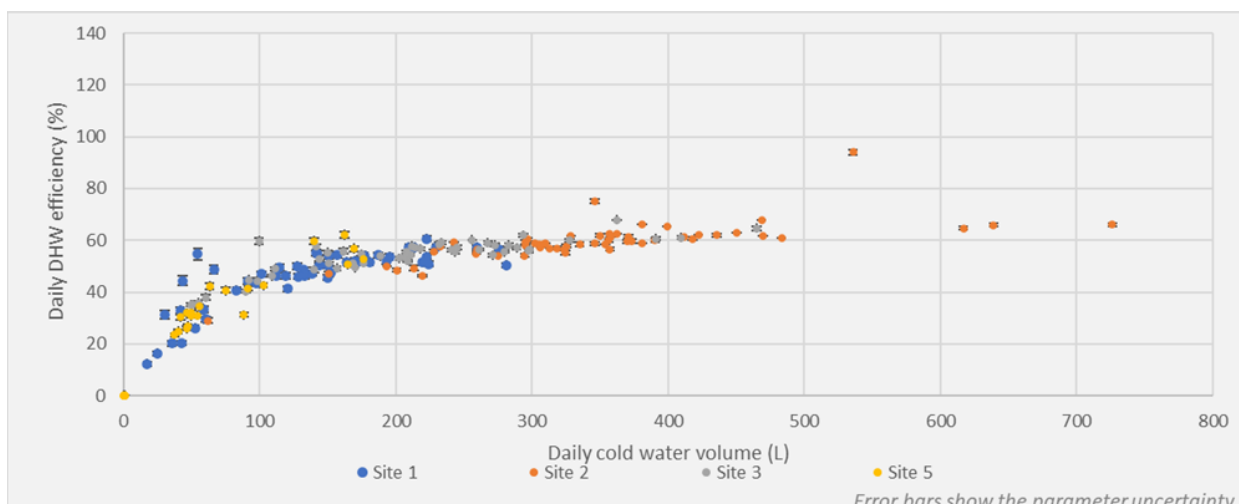


Figure 18: Baseline DHW Efficiency

Electricity usage was higher than baseline with the GHP equipment due to the power consumption of the GHP, hydronic circulating pumps, and condensate heat trace. Figure 19 shows the combined total efficiency of the GHP equipment over the measurement period. This includes electric power and gas consumption for both space heating and water heating. During the summer, efficiency drops when the GHP is only used for water heating.

Hydronic loop length and number of bends is critical to ensure adequate flow, and supplemental pumps may be needed to ensure adequate flow rate but will also increase electricity usage.

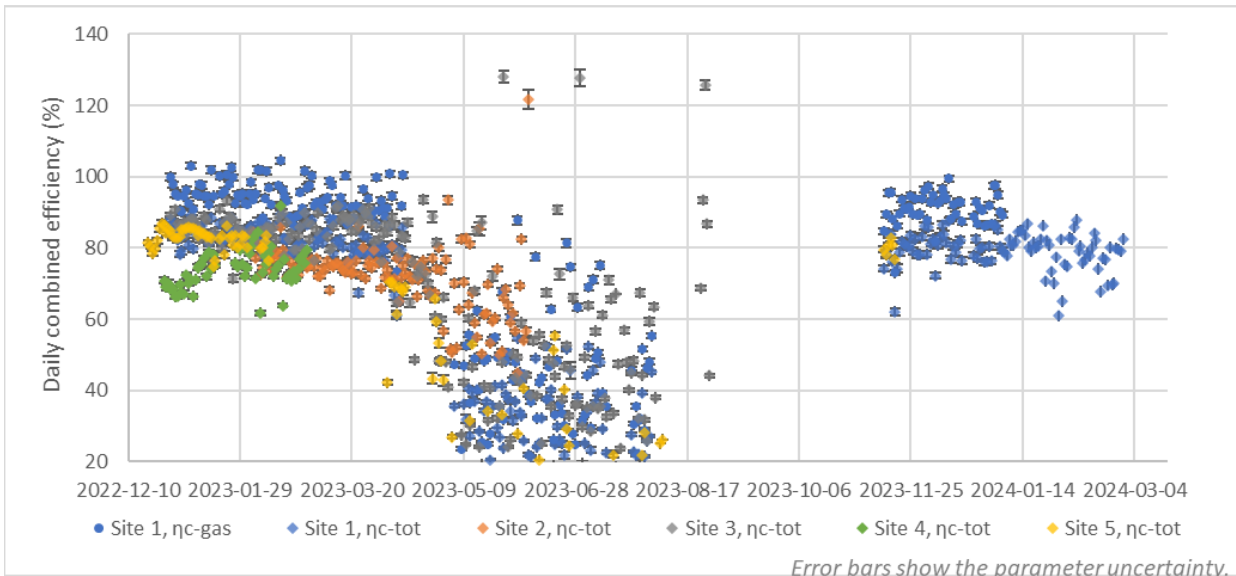


Figure 19: Combined Total Efficiency

M&V contractor estimated the annual energy usage for the demonstration sites and compared the expected efficiencies of the baseline equipment and the GHP configuration. Because one site had no baseline data, there is no comparison for it. For the other four sites, the two that had low efficiency baseline equipment would save energy annually with the GAHP configuration and the two with higher efficiency baseline equipment would use slightly more energy. M&V contractor noted that the energy usage at the sites differed between the baseline period and the demonstration period, which may affect the predictions. See Figure 20.

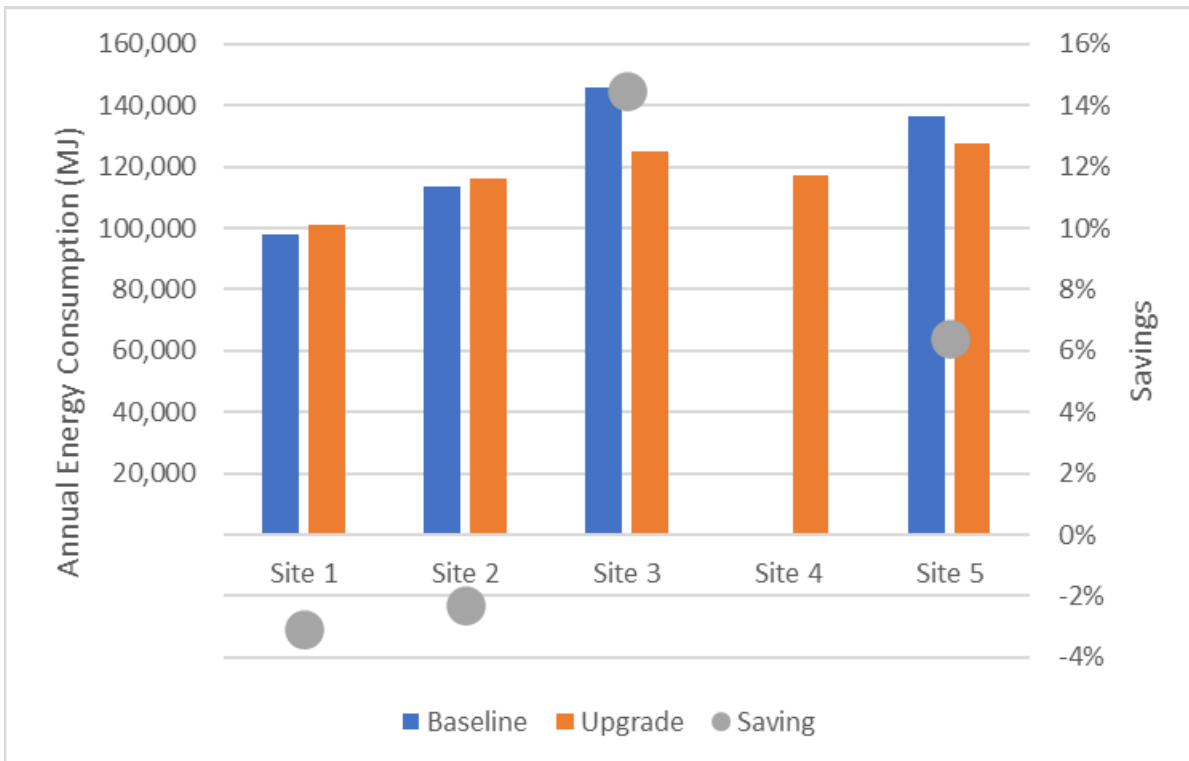


Figure 20: Annual Energy Consumption Comparison

In terms of customer comfort air supply temperatures provided by the GAHP tended to be between 45°C and 55°C. This is inline with SMTI expectations and provides homeowners with significantly warmer air at the duct registers compared to competing electric heat pumps. Data collected for supply air temperatures across all 5 sites can be seen in Figure 21 below.

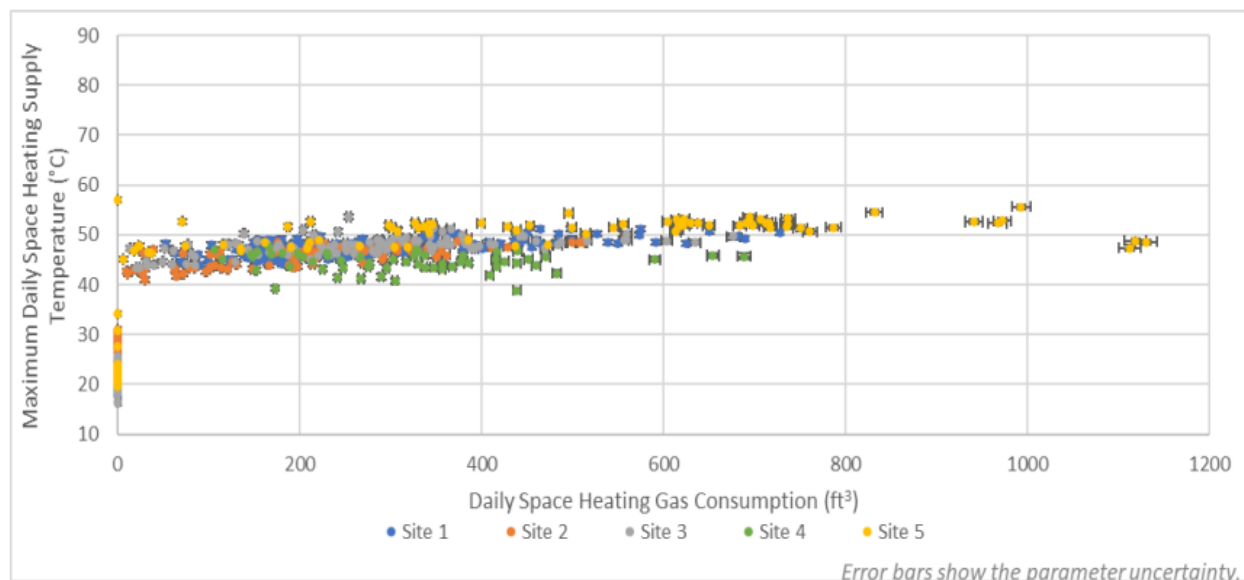


Figure 21: GHP Supply Air Temperatures

Milestone 8:

Subtask 8.1 – Contractor Research

The Contractor Research results show that:

- 96% of the contractors surveyed had a “very” or “somewhat” favorable impression of the Next Gen (GAHP) furnace concept, with 47% being “very favorable”.
- About 2 in 5 (44%) contractors report they “definitely would” be likely to offer the Next Gen (GAHP) furnace concept to their prospective customers who have gas and/or propane available as a fuel source.
- Contractors cited “dramatic energy and cost savings of 30% to 50%” (23%), and “pay back the initially higher cost with utility bill savings” (16%) as their top two most important selling points to customers. 42% cited the payback period on energy savings is extremely important (9-10 on a 10-point scale).

The market research contractor recommended that SMTI communications with contractors should stress the following action items, in order to motivate them to consider adding this new product to their lineup for their gas and propane customers:

- Demonstrate how the new system provides the high level of energy-efficiency benefits promised.
- Explain how to translate those energy-efficiency benefits into language the end-user consumers can understand.
- Place emphasis on the favorable payback period that homeowners will realize if they choose to install this new system.

- Detail the expected lifespan of the product (e.g., how long would it last, after how long does the product need to be replaced).
- Provide a clear explanation about the installation process, in order to allay any concern about the difficulty, cost, or manpower needed to install the new system when replacing another type of furnace unit.
- Furnish information that will assuage any concern about the durability and reliability of the new system.

Subtask 8.2 – Consumer Research

The Consumer (Homeowner) Research indicated the following:

- Homeowners who are open to gas- and/or propane-fueled furnaces react very favorably to the concept as presented, with just under half (47%) giving the GAHP concept a “very favorable” rating, and a further 42% giving the GAHP concept a “somewhat favorable” rating,.
- In general, these homeowners claim they place a great deal of importance on their home’s energy efficiency, with half (49%) rating this issue at least a “9” on a 10-point scale.

Key findings of the Homeowner Choice Modeling Exercise include the following:

- The Preference Share of the Next Gen (GAHP) technology ranged from 18-33%, depending on the total installed cost at which it was offered (cost range of \$12,500 to \$9,500).
- Overall, Annual Operating Cost is the most important attribute considered when deciding to purchase a heating system (53%), followed by cost (total installed or lease to own cost) at 32%.
- A lease-option transaction model appears to increase the market adoption rate of the Next Gen (GAHP) technology significantly, (by an average of 19% across price models) all other factors being equal.

The research contractor recommends that SMTI provide collateral materials for contractors to use when selling the Next Gen (GAHP) system to their potential homeowner customers should do the following:

- Provide a clear and compelling illustration of the dramatic energy and cost savings (30% to 50%) that the system can deliver.
- Explain how the system further ensures operational cost savings by not needing any backup which is required with a typical electric heat pump system.
- Point out that the optional hot water heater – purchased at the same time or in the future – provides another way the homeowner can potentially save on energy costs.
- Assure customers that the installation process will not be disruptive or destructive to their home, nor create new infrastructure/upgrade costs.
- Address any homeowner concerns about the system’s durability and reliability, possibly by offering a longer-than-typical warranty period.
- Provide clear language around leasing, as homeowners are highly sensitive to increases in the monthly price to lease the equipment.

10.0 Environmental Benefits

10.1 Emissions Reduction impact

TDHPs generally reduce GHG emissions by using 30-50% less natural gas for the same amount of heat, depending on local circumstances and what equipment they are replacing. However, for purposes of estimating overall GHG reductions in Alberta, we will assume the home heating loads on average require 172 GJ (1,631 therms) per year of delivered heat for both space and domestic water heating. For calculation purposes, we assume a space-heating equipment AFUE of 85% (reflective of the entire replacement fleet average, not any one location) and an average UEF rating of 0.62 for water heaters to establish the baseline of 211 GJs (1,998 therms) of natural gas consumed per year. For TDHPs in

Alberta's climate, we will conservatively assume a slightly lower-than-standard AFUE (130%) owing to the relatively colder climate. The average water-heating COP (1.25) includes standby losses from the indirect tank. However, because some DHW heating cycles will occur during space-heating calls, overall efficiency benefits because the TDHP equipment (already being on) will avoid cycle-startup losses. As reflected in Figure 22, a total of 134 GJs (1,273 therms) of natural gas would be consumed by the TDHP, for a net average savings of 77 GJs (725 therms) per home per year (36%).

ENERGY ASSUMPTIONS	Units	Baseline Furnace	TDHP Furnace
Building Heat Loads			
Annual Space-heating Load	GJ	153	
Annual Water-heating (DHW) Load	GJ	19	
Total Building Heat Loads	GJ	172	
Energy Efficiency			
Space-heating Average COP	AFUE	85%	130%
Water-heating (DHW) Average COP	UEF	0.62	1.15
Required Annual Fuel			
Space-Heating	GJ	180	118
Water-Heating (DHW)	GJ	31	17
Total Annual Home Heating Fuel	GJ	211	134
Annual Fuel Savings per Home	GJ		77
<i>Average Savings Rate</i>			<i>36%</i>
Parasitic Electricity			
Electricity Consumption Rate	kWh / GJ delivered heat	3.6	7.8
Total Electrical Consumption	kWh	624	1,349

Figure 12: Energy Assumptions

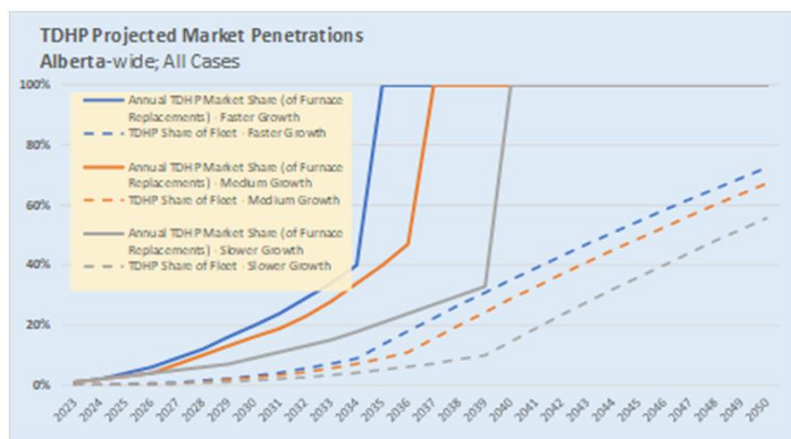


Figure 23: Projected Market Penetrations, Alberta

standard furnaces (AFUE 80%), and their operating condition. Since the rule-change was adopted, it is likely that today's average efficiency is actually less than 85%. However, with time, the average will increase, owing to the reduction of the total percentage of 80% efficient furnaces in the fleet.

SMTI uses GHG emissions rates for the consumption of natural gas and electricity at 64 kg/GJ (149 lbs/mmBTU) and 309 lbs/MWh, respectively. The natural gas figure is provided by the Gas Technology Institute (GTI) in Chicago, representing a full value-chain (well-head to final burner tip) analysis for gas. More information may be found in their Energy Planning Analysis Tool (www.epat.gastechnology.org)

GHG emissions for Alberta are estimated as part of SMTI’s market penetration analysis using a Faster/Medium/Slower case methodology for a reasonable range of GHG reduction outcomes, depending on how fast the product is taken up in the market. Specific to Alberta, Figure 23 indicates the Annual TDHP Market Share under the three scenarios. This chart does not presume that SMTI sells all the TDHPs, but it does indicate the overall market penetration of the category. Canadian energy policy is likely to mandate heating equipment COP>1.0 sometime in the mid-2030s, and a range of outcomes is reflected in the three scenarios. Associated with each market penetration curve is the resulting Share of Fleet (dotted lines), reflecting the total percentage homes in the entire building stock of the province operating with a TDHP. As shown, between 55% and 75% of all Alberta homes would be using TDHPs by 2050.

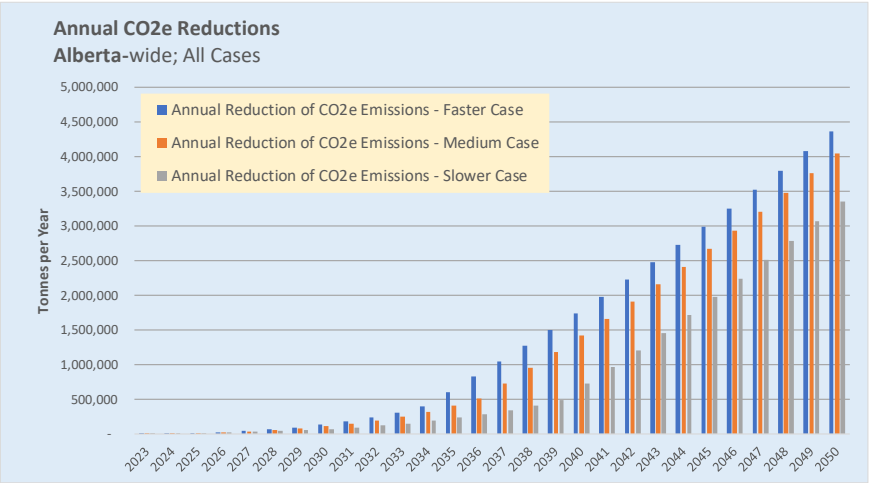


Figure 24: GHG Reductions, Alberta

Driven by the above assumptions, Figure 24 shows the total GHG emissions expected that are specific to Alberta.

Across Alberta, the commercial scale implementation of TDHPs will result in the GHG reductions reflected in Figure 24. Since the technology is applicable globally where-ever there are significant winter heating loads, Canada is an appropriate initial market target, and is likely to be a strong early adopter. Thus, the Canada-wide analysis is developed using a similar Faster/Expected/Slower methodology (Figure 25).

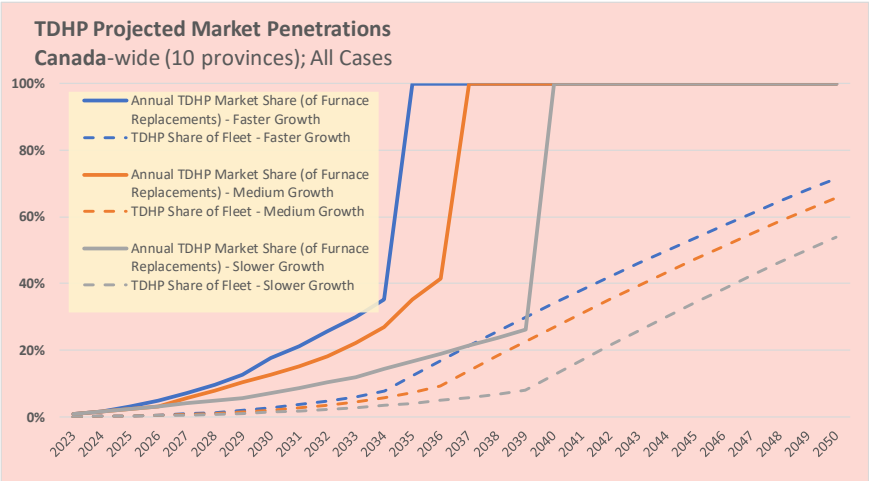


Figure 25: Market Projections, Canada

The resulting GHG reduction benefits are shown here in Figure 26. Since NRCan policy is expected to mandate COP>1.0 well before 2050, the GHG reduction benefits from SMTI’s TDHP technology beyond

2050 may be extrapolated by the trends shown, as they are, at that point, a function of the speed of annual furnace replacement, which is not expected to change.

Figures 27 and 28 show the cumulative GHG reductions for Alberta and Canada as a whole projected using the above assumptions. Accumulated savings beyond 2050 may be extrapolated by the trends as shown.

TDHP technology enables direct emissions savings through immediate reduction of natural gas usage for the same amount of heat and comfort provided compared to current technologies. There are no indirect or enabled GHG impacts contemplated in this analysis.

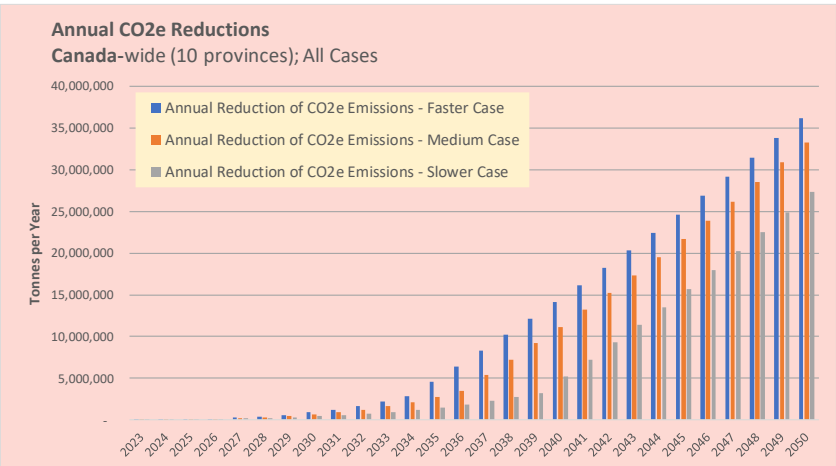


Figure 26: Annual GHG Reductions, Canada

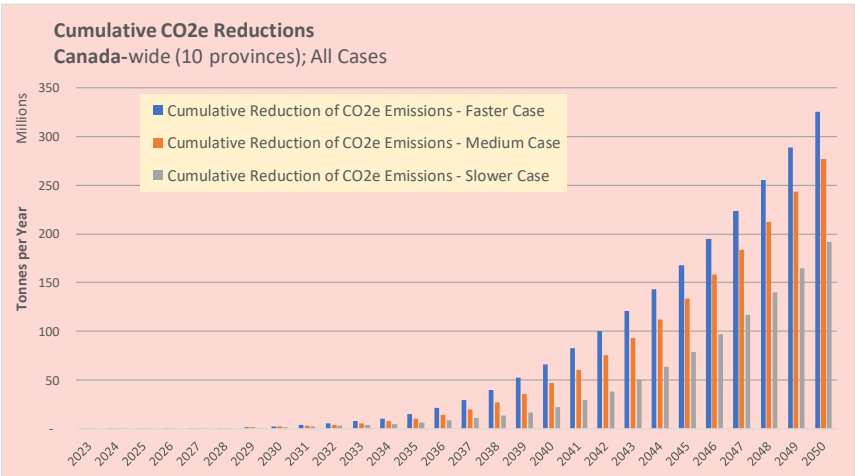


Figure 27: Cumulative GHG Reductions, Canada

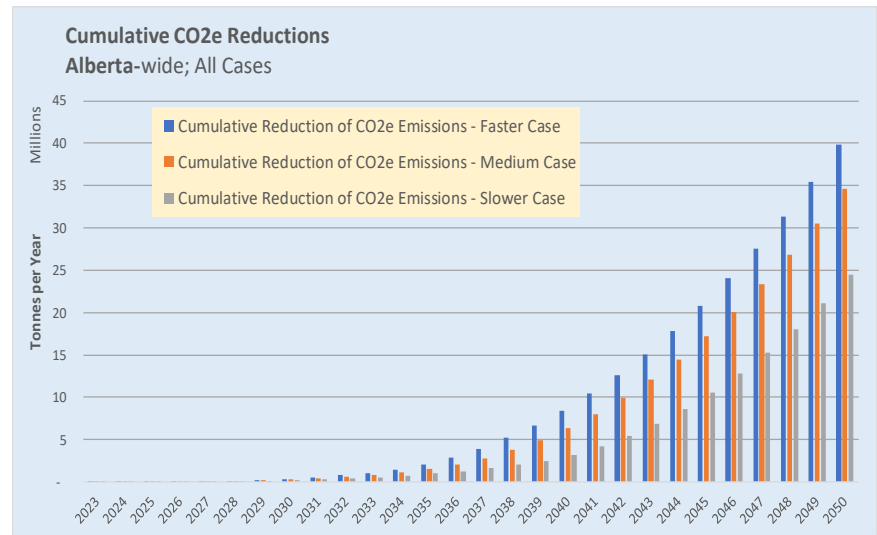


Figure 28: Cumulative GHG Reductions, Alberta

10.2 Other Environmental impacts

SMTI's TDHP uses 100% natural refrigerants with a Global Warming Potential of zero, a stark contrast to electric heat pumps which use synthetic refrigerants with high GWP. Due to future phase out programs of higher GWP refrigerants, electric heat pump OEMs are currently re-designing their products for use with non-optimum, but lower GWP refrigerants which will increase product cost. SMTI's TDHP also has no PFAS chemical to pose a long-term threat to our environment.

Ammonia as a refrigerant has been safely used in small residential cooling and refrigeration applications for over 70 years. Current building codes allow ammonia-water absorption heat pumps to be installed adjacent to residential and commercial buildings as long as the total ammonia charge is less than 24 pounds (SMTI uses 11 pounds in the 80K TDHP model). Additionally, small ammonia-water refrigerators are commonly and safely used in hotel rooms (because they are silent) and in recreational vehicles (operating on propane).

In addition to decarbonization, SMTI's TDHP solution meets the strict Ultra-Low NOx emission standards required of California (and other) Air Quality Management Districts, for reducing nitrogen oxide and nitrogen dioxide emissions to improve air quality and lower nitrogen pollution.

TDHPs allow the movement of the heating/water heating combustion process from inside the building envelope to outside. This eliminates any concern about flue products entering the home and this feature has tested well in previous market research.

11.0 Economic and Social Impacts

Alberta homeowners will realize significant savings off their annual utility costs from TDHP technology. According to the analysis, this starts at \$388,000 in the first year of full commercialization and increases to \$1.8 billion annually by 2050 in the Medium Adoption case (assuming 2.5% annual utility cost inflation). Compared to typically sized HVAC projects, TDHP technology would increase the revenue and potential profit for contractors, all while providing reduced costs and a strong payback for homeowners.

The immediate impact on employment for Edmonton involved a handful of contractors providing installation, maintenance, and transport/removal services specific to the project. More broadly, employment in Alberta or Canada generally would not directly increase from the implementation of TDHP technology at commercial scale. Existing HVAC contractors are expected to sell and service these units, which amount to an additional product offering to their consumers.

However, HVAC contractors and technicians will gain experience and knowledge with a new generation of heating equipment. Motivated by making more money, they will become Alberta's skilled workforce enabling a transition to a sustainable, low-carbon solution for building heat loads.

At the local utility level as well as throughout the natural gas value chain, the gas industry needs focus on the encroachment of its market share for fundamental loads such as building heat. This is a long-term threat which must be addressed with technologies to compete effectively with electric-based solutions, currently the topic of popular discussion. However, TDHPs at scale, by offering comparatively better economics and emissions, help protect that market share with a rational alternative through the continued use of natural gas for home heating, with improved public favorability by virtue of the higher efficiency of our product with reduction in GHG emissions for the same comfort. In addition to increased perception of gas for heating, and an overall general improvement in the perception of fossil fuel use will be facilitated by improved efficiency.

Another economic benefit is in the maintenance of contractor trades required for the installation of the SMTI solution, which might be otherwise lost to electrical trades. Our TDHP solution requires a combination of various trades, and we expect to see growth in the number and skill levels of contractors capable of completing the full installation, a combination of plumbing, gas fitting, sheet metal (ducting) and electrical trades are all facets of the system installation.

12.0 Scientific Achievement

- N/A

13.0 Overall Conclusions

Project outcomes included the following:

- Validation of performance via commercialized CoP 1.4, for units tested in the laboratory setting. Performance was maintained after many 1000's of hours operating on SMTI's accelerated life test loop.
- Performance in the field was measured and saw total energy (gas + electricity) reduction up to 15% depending upon the traditional gas appliance(s) being replaced.
- The combi system (GHP + AHU + IST) consistently provided warm supply air temperatures between 45°C to 55°C and maintained occupant's DHW temperatures between 50°C to 55°C.
- Verification of application proof of concept in real market conditions as a furnace and gas water heater replacement: This was achieved in the field trial through successfully installing and operating the SMTI "combi" solution consisting of the SMTI TDHP, Napoleon AHU, and OEM indirect storage tank. Learnings included design changes for simplification and sound reduction in the TDHP, thorough understanding of the challenges in implementation of the Napoleon AHU with hydronics board, and a technical and market analysis of options for the IST resulting in eventual selection of a much lighter weight and affordable tank choice for all North American markets.
- Significant production improvement in design and manufacturing as a result of project learnings as referenced in the many improvements made outlined in Milestone 5 of section 9. These many changes to the product resulted in more reliable operation, simplified installation, enhanced performance, and an overall quieter product.
- Development and enhancement of product training required for contractors, to include a 4-tier curriculum available in person, or via live or recorded video. This approach will ensure quality

installations and avoid pitfalls by having contractors who have a thorough understanding of the product, application, installation, routine maintenance, and any service procedures.

- Establishment of sourcing means for ammonia in Canadian markets

14.0 Next Steps

SMTI commercialized and launched the 80K TDHP which was trialed in the ERA project in early 2024. A significant benefit of the ERA project was a number of design changes suggested by the project learnings. While SMTI spent much of 2024 refining the manufacturing process, we were able to ship units, which are being installed in market pilots as the next step in product development. For 2025 we will expand our sales channels across Canada and the US, and plan to significantly increase our volume of sales and installed units.

Going forward, SMTI is developing companion products in the TDHP product line which will utilize the same technology. Eventually we will have a full portfolio of TDHP capacities for residential and commercial applications. We are also manufacturing a custom hydronic Air Handling Unit which was developed in part from the ERA project learnings of utilizing the Napoleon AHU. We came to understand that the discrete components which are routinely required to be added to a traditional AHU, are required in all installations. By combining these additional components into a monobloc hydronic AHU, we simplify installation for the contractor and homeowner. This solution is also commercialized with similar volumes from 2024.

Plans for 2025 and beyond include development and testing, in a planned follow up project, a smaller capacity TDHP targeting select Canadian and US markets and applications. SMTI is also developing a combined heating and cooling solution, as well as commercial water heating applications. All of these prospective products will offer similar reductions in gas use and corresponding decarbonization. In terms of partnerships, SMTI has partnered on another project with Napoleon subsequent to the ERA field trial, this one being a combined TDHP and electric heat pump, capable of switching heating mode between gas and electric heat pump technologies, based upon fuel cost and heating requirements.

15.0 Communications plan

- Prime contractor – in addition to training materials, there was a great deal of one-on-one communications regarding service procedures and troubleshooting. The ability for SMTI to remotely access the field trial equipment proved valuable in this process, as our technicians and engineers were able to remotely diagnose issues, communicate corrective actions and/or component replacement to the contractor, and then while online with the contractor, observe the resulting performance changes. Additional communication with the prime contractor involved future opportunities, as well as training feedback and improvement.
- LDC base – some communication of trouble resolution, design and/or manufacturing changes, occurred and continues with the LDC base. An incredible amount of learning resulted from the project, and when this resulted in product or procedural changes, this was often communicated to LDCs who have been following SMTI's product development.

Plans for communicating information about the Project, Project findings, and results or the underlying technology with third parties, including a description of communication tools that will be used.

- Future communications regarding the project and findings will likely be communicated via SMTI's website and social media, primarily in an effort to generate product interest in the specific geographies and LDCs involved. A more broadly defined communications strategy to include SMTI technology and product development, will also utilize our sales channel partners, contractor base, trade show networking, and limited broadcast media in addition to the website and social media mentioned. (Contractors are the "boots on the ground" with our prospective customer base, so the base of contractors we build through training will also serve well to employ direct email and social media to help drive product knowledge and promotion of project results.)

16.0 Literature reviewed.

Not applicable