Pre-Commercial Scale Up of a Gas Absorption Heat Pump

Stone Mountain Technologies, Inc., IR-Trane, Gas Technology Institute
Michael Garrabrant, President & CEO
(423) 735-7400  mgarrabrant@stonemtntechnologies.com
Project Summary

Timeline:
Start date: January 1, 2018
Planned end date: December 31, 2019

Key Milestones
1. Milestone 3.1; 4 GAHPs tested at SMTI with COP at design of at least 1.40
2. Milestone 8.1.1; Benchtop demonstration of automated assembly of Absorber and Condenser
3. Milestone 9.2; ANSI Z21.40.1 Testing Complete, pass 90% of requirements
4. Milestone 9.4; ALT of prototype for at least 4000 hours
5. Milestone 9.6; Pre-commercial prototype testing completed with COP at design of at least 1.40

Key Partners:
- Ingersoll Rand-Trane
- Gas Technology Institute

Budget:
Total Project $ through 28 Feb 2019
- DOE: $1,214,026
- Cost Share: $7705,937

Total Project $:
- DOE: $1,881,537
- Cost Share: $822,523

Project Outcome:
Advance the maturity of SMTI’s 80 kBTU/hr residential space/water heating GAHP from the current engineering prototype stage to pre-production readiness by addressing remaining manufacturing, balance of system design, installation, cost reliability and field application questions.
Team

**Stone Mountain Technologies, Inc**
- Michael Garrabrant, PI
  - Absorption Heat Pump Innovation and R&D
  - Gas Appliance Design & Volume Manufacturing Expertise

- Dr. Christopher Keinath, Dir. Engineering
  - 10 years experience investigating absorption heat pumps
  - Fundamentals, Modeling, Experimental Expertise

- Scott Reed, VP Marketing and Strategy
  - Advanced technology marketing and commercialization
  - Business development and strategy expertise

**Ingersoll Rand-Trane**
- Leading Global HVAC Manufacturer, Product Engineering, Volume Manufacturing, Marketing and Sales Distribution

- Jason LeRoy, Dir. Advanced Solutions

**Gas Technology Institute**
- Paul Glanville, R&D Manager
  - Gas Appliance R&D, Innovation, Natural Gas Industry Representation
  - HVAC-Water Heating Field Test Expertise
Challenge – Improve Efficiency of Heating

What We Use For Gas Heating Has Not Changed Much in 50+ years

Furnaces | Boilers | Water Heaters

Non-Condensing Models Are 75 – 83% Efficient
Condensing Models Are 90 – 98% Efficient

BUT

We are getting close to changing that with

Gas Absorption Heat Pumps

Condensing, 4:1 Modulation, 140% AFUE
Outdoor Installation, SCAQMD NOx Compliant, GWP = 0

- Reduce Operating Cost by 30-50%
- Maintain a High Level of Comfort
- Reduce Carbon Footprint by 30-50%
- Target Total Installed Cost <$7,500
- Simple Payback 3-5 Years
Background: SMTI Business Model

- Thermal Compressor
- HVAC & WH OEMS

- Partners, not competitors
- Maximize existing brand & marketing power
- Least-cost, Fastest-to-market, Lowest-risk pathway to Product Differentiation

End Use Products
80 kBtu/h GAHP Development Timeline

- **EE0006116**
- **80K Breadboard**
  - COP: 1.27 (no CHX)
- **80K Alpha 3**
  - COP: 1.35
- **80K Beta 1**
  - COP: 1.41
- **80K Beta 3**
  - COP: 1.44

**Time in development**

- **Private Funding**
  - Engineering Prototypes
  - 3rd Party Performance Verification
  - Initial Field Demonstrations

**This Project**
Approach of This Project

End Goal: Advance Development to Commercial Readiness

- Design for Manufacturing and Cost
  - Sealed System
  - Balance of System
  - Integrated Control Board
- Fabricate & Test Four Prototypes of DFM Design
  - Cold-Climate Field Demonstration
- ANSI Certification Tests
- Direct Manufacturing Cost and Capital Equipment Required
  - Benchtop Automated Assy Demonstration
- Techno-Economic Analysis
- Reliability Test Plan
- Market Research
  - Quantitative and Qualitative
  - Consumers & Contractors
  - Five Year Sales Estimate
- Codes & Standards Review & Analysis
- Fabricate & Test Two Commercial-Ready Prototypes

Green = Complete or Nearly Complete; Blue = In Process or Pending
## Impact

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAHP:</td>
<td>140% AFUE</td>
</tr>
<tr>
<td>Gas Furnace Min:</td>
<td>80% AFUE</td>
</tr>
<tr>
<td>Gas Furnace Max:</td>
<td>97% AFUE</td>
</tr>
<tr>
<td>Energy Savings:</td>
<td>30 – 50%</td>
</tr>
</tbody>
</table>

### For 80 kBth GAHP
- **Total Installed Cost:** < $7,500
- **Typical Payback:** 3–5 yrs (for HDD>4000)

### Residential Space Heating Market
- 3.4 million gas furnaces sold annually
- ~2.2 million in HDD > 4000 climate zones
- 20% Market Share = 440,000 units annually

Therms Saved per home per year: 400 - 800

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### Method and Assumptions
- 2,700 sqft home
- 4 occupants
- Space-heating load only
- eGrid 2016
- Performance: mfr data except GAHP (prototype test data)

http://epat.gastechnology.org/
Impact

Source CO2e by Technology and Geography

(vs. Standard EHPs)
Impact

Source CO2e by Technology and Geography
(vs. Cold-Climate EHPs)

CCEHP HSPF 13
GAHP 140%
Progress – DFM

• Sealed system
  – Integration of several components
  – Elimination of ~6 tube runs
  – Elimination of ~20 weld joints
  – Reduction in part count
  – Simplification of design
  – Reduced width by 2.5 inches

• Balance of system
  – Tech Transfer to Commercialization Partner
  – Commercialization Partner controls development and integrated circuit board design
  – Combustion system supplier controls and component design & development
  – Cabinetry based off commercialized products

Apologies for blurred pictures due to confidentiality
Progress – Prototype Testing

- Four (4) prototype fabricated and tested at SMTI
  - Significant DFM design revisions
  - Commercialization partner GAHP controls
  - Combustion supplier controls and combustion assembly
  - Initial ANSI Certification Testing Completed (combustion)

✓ Q4 Milestone - COP of at least 1.4 at design confirmed

- Two (2) units sent to field test in WI
- One (1) unit sent to CP facility in TX
## Progress – Field Demonstration

<table>
<thead>
<tr>
<th>Site</th>
<th>Home Details</th>
<th>Occupants</th>
<th>Existing HVAC</th>
<th>Existing DHW Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>Two-story, 1973 build, 2,451 sf</td>
<td>2 – 2 Adults</td>
<td>Gas Furnace, Dual stage, 100 kBtu/h input, 96.7% AFUE</td>
<td>Standard Gas Storage, 40 kBtu/h, 40 gal.</td>
</tr>
<tr>
<td>Site 2</td>
<td>Two-story, 1978 build, 1700 sf, full basement</td>
<td>2 – 2 Adults</td>
<td>Gas Furnace, Single stage, 80 kBtu/h input, 78% AFUE</td>
<td>Standard Electric Resistance, 80 gal</td>
</tr>
</tbody>
</table>

Some Images courtesy of GTI
Progress – Codes and Standards Reviewed

GAHP Performance and Test Standards
- ANSI Z21.40.4/CGA 2.94
- ASHRAE 40
- EN 12309
- CAN CSA P.9-11
- ANSI/AHRAE 124-2007 (R2016)

Product Safety
- ANSI Z21.40.1/CGA 2.91
- ASHRAE 15
- IIAR-2

Installation and Maintenance
- NFPA 54,
- IMC
- Condensate (outdoor) handling
- NH3 disposal
- Double-wall heat exchangers (hot water heating)

Shipping
- 49 CFR 173.306
- 49 CFR 173.307
- 49 CFR 173.154

Emissions
- EPA
- SNAP
- CARB
- SCAQMD
- California AB 32
- Canadian Carbon Levy

No major roadblocks with codes and standards are expected in the commercialization and roll out of a GAHP product
Research Design

The following five research phases were conducted:

1. Contractor In-Depth Interviews
   - 90-minute web camera interviews with 11 residential heating & cooling contractors who work in U.S. zones with 4001+ Average Annual Heating Degree Days (HDD) and have at least $500K in annual sales.
   - In-depth reaction to the Next Generation GAHP was obtained to identify possible areas of confusion, as well as to uncover potential barriers and key selling points for promoting the product to their customers.

2. Consumer Online Bulletin Boards
   - One-on-one bulletin board interviews were held among n=24 homeowners who reside within 4001+ HDD climate zones and who were either recent purchasers or are intending to purchase a new gas-fueled heating system.
   - In-depth reaction to the Next Generation GAHP was obtained for further refinement in quantitative testing, as well as uncover potential barriers and key selling points to purchasing the product.

3. Contractor Concept Test
   - 300 interviews among decision-makers within residential HVAC contractor firms who sell gas or propane furnaces within 4001+ HDD climate zones.
   - Current furnace sales and pricing methods were explored and in-depth reaction to the Next Generation GAHP was obtained, to assess contractors' expectations for sales of the new product and to identify potential key selling points when offered to consumers.

4. Consumer Discrete Choice Study
   - 1,014 interviews among homeowners within 4001+ HDD climate zones who would be open to gas or propane as a fuel source if obtaining a new furnace.
   - A discrete choice approach was used to assess homeowners' likelihood to purchase the new Next Generation GAHP vs. current non-condensing and condensing gas/propane furnaces and to identify the optimal price point for both maximum demand and maximum revenue.

5. Volumetric Forecasting
   - Inputs from the consumer quantitative conjoint study analysis and the quantitative contractor concept test, as well as sales data, market roll-out plans, advertising and marketing support plans, and other pertinent material provided by SMI and Trane data from Decision Analyst’s American Home Comfort Study were used to forecast the projected annual number of units sold for years 1 to 3 after product deployment.

Findings from these phases were used to inform the development of the quantitative surveys and to refine the concept for optimal communication in the surveys.

Findings from these phases were used in the Volumetric Forecasting analysis, along with pertinent marketplace and marketing inputs that would impact the new product roll-out.

*A heating degree day (HDD) is a measurement designed to quantify the demand for energy needed to heat a building. It is derived by multiplying the number of days that the average temperature falls below 65°F by the number of degrees to which it falls below 65°F.
Total Respondents

- Overall, *Annual Operating Cost* constitutes 62% of the decision to purchase a heating system. *Total Installation Cost* is second most important, accounting for 32% of the decision.
- Homeowners prefer the *Next Gen (GAHP)* furnace followed by the *Higher Efficiency* furnace.

### Attribute Importance

- **Annual Operating Cost**: 62%
- **Total Installation Cost**: 32%
- **Brand**: 7%

### Furnace Preference

- **Next Gen Efficiency** *(AFUE = 140%)*: 229
- **Higher Efficiency** *(AFUE = 92-95%)*: 125
- **Highest Efficiency** *(AFUE = 96-98%)*: 46
- **Medium Efficiency** *(AFUE = 80%)*: 0.17

**Notes:** Values in the bar chart illustrate the relative preference for each product type. The raw level utilities are rescaled to the average preference (index = 100) across all product types. The higher the index, the more preferred the product type.
Total Respondents

- Overall, demand is maximized at $7,000 for the Next Generation GAHP total installed cost. Demand decreases by about 40% as Total Installation Cost increases from the lowest cost of $7,000 to the highest cost of $10,500.

The black line reports the Preference Share, which is the percentage of consumers who would purchase the product. The Demand In (solid blue line) is the indexed Preference Share of the Next Gen (GAHP) furnace across the price points tested. A Demand Index of 100 represents the Preference Share at the middle price point, $8,750.

Note: Results shown assume 100% awareness and 100% distribution.
Base: Total Respondents (n=1,014)
Source: Advanced Analytics
Stakeholder Engagement

➢ Top 3 HVAC Market Share OEM Commercialization Partner

➢ Natural Gas Utilities
  ➢ NW Natural, CenterPoint Energy, ConEd, National Fuel (all providing cost share)
  ➢ Confidential Major Gas Utility - Seed Investor in SMTI
  ➢ Gas Technology Institute (Major Sub-Contractor)
    ➢ Constant communication path to gas utilities
  ➢ Gas Utility Working Group for Gas Heat Pumps
    ➢ 14 major gas utilities (U.S. and Canada)
    ➢ Goal of helping accelerate market adoption of gas heat pumps

➢ Other Industry Stakeholders
  ➢ Northwest Energy Efficiency Association (NEEA) – providing cost share
  ➢ Propane Education and Research Assoc (PERC) – providing cost share
  ➢ Energy Solutions Center (ESC) – presenting at TMAF in June
  ➢ Center for Energy Efficiency (CEE) – helping us work with EnergyStar
  ➢ ACEEE – multiple presentations at Hot Water Forum (2018 and 2019)

➢ International
  ➢ GRDF/Engie (France) - sponsored R&D, helping enter EU market
  ➢ NRCan – testing SMTI prototype, evaluation for Canadian climate

➢ ASHRAE
  ➢ Presentations (with GTI) at conferences

➢ NREL
  ➢ Selected to “pitch” at Industry Growth Forum (May, 2019)
Remaining Project Work

**Demonstration (Task 7)**
- Continuation of the field test through the end of the project

**Manufacturing Process and Demonstration (Task 8)**
- Assembly Demonstration (Absorber, Condenser, Desorber & Solution Pump)
- Process, Tooling, Equipment definition for production GAHP
- *Final direct manufacturing cost for Sealed System and Final Heat Pump Assembly*

**Reliability Assessment (Task 9)**
- Final ANSI Z21.40.1 Testing and Evaluation
- ALT of prototype GAHP, 4000 hours of operation
- Development of a long term reliability test plan
- Fabrication and testing of two (2) pre-commercial GAHPs

**Techno-Economic Analysis (Task 10)**
- Modeling of different Homes, Regions and Equipment
- Energy, cost, emissions, payback and other analyses
Thank You

Stone Mountain Technologies, Inc.
Michael Garrabrant, President
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REFERENCE SLIDES
Project Budget:

Project Budget: $1,881,537 (Fed) + $822,523 (CS) = $2,704,060

Variances: Currently Under Budget

Cost to Date: Federal: $1,214,026 of $1,881,537 (64.5%)
             Cost Share: $705,937 of $822,523 (85.8%)

Budget History

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<th>DOE</th>
<th>FY 2018 (past)</th>
<th>FY 2019 (current)</th>
<th>FY 2020 – 12/31/19 (planned)</th>
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<tr>
<td>Cost-share</td>
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<td>$344,237</td>
<td>$438,286</td>
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# Project Plan and Schedule

## Project Schedule

**Project Start:** January 1, 2018  
**Projected End:** December 31, 2019

<table>
<thead>
<tr>
<th>Task</th>
<th>Q1 (Oct-Dec)</th>
<th>Q2 (Jan-Mar)</th>
<th>Q3 (Apr-Jun)</th>
<th>Q4 (Jul-Sep)</th>
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<th>Q4 (Jul-Sep)</th>
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<th>FY2019</th>
<th>FY2020</th>
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<tr>
<td><strong>Past Work</strong></td>
<td>Completed Work</td>
<td>Active Task (in progress work)</td>
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<td>M1.0: IPMP Signed and Submitted</td>
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<td>M3.3: Field Test Baseline M&amp;V Report</td>
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<td>M2.4: Cold Climate Gas Valve Demonstration</td>
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<tr>
<td>M3.1: Prototype COP_gas of 1.4 at design conditions</td>
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<td>M7.1: Prototype testing at CP, COP_gas of 1.4</td>
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<td>M8.1.1: Benchtop Assembly Demonstration of Absorber/Condenser</td>
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<td>9.2: ANSI Z21.40.1 Testing, 90% pass</td>
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<td>M8.1.3: Benchtop Assembly Demonstration of Solution Pump</td>
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<tr>
<td>M9.6: Pre-commercial prototype testing with COP of at least 1.40</td>
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### Milestone/Deliverable (Originally Planned)
- Use for missed milestone/deliverable when met on time.

## Timeline

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