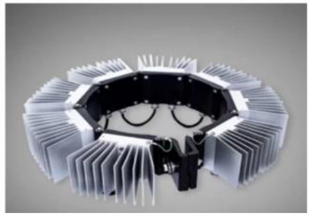
Grid Resilient, Self-Powered, Fuel Flexible, High Efficiency Heating System

Heating System
(Courtesy: A. O. Smith, Corp.)

High Efficiency, Fuel Flexible 3D Printed Burner



High Temperature Thermoelectric Generator (TEG)
(Courtesy: II-VI Marlow)

Heating Systems
(Courtesy A. O. Smith, Corp.)

Gas Technology Institute
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Project Summary

Timeline:

Start date: April 15, 2019

Planned end date: July 31, 2022

Key Milestones

1. Milestone 3.2.3: Burner meets performance targets
2. Milestone 4.2.3: TEG testing complete
3. Milestone 6.2.2: System meets performance targets

Budget:

Total Project $ to Date:

- DOE: $286K
- Cost Share: $176K

Total Project $:

- DOE: $855K
- Cost Share: $288K

Key Partners:

ORNL
Sheetak, Inc.
A.O. Smith Corp.
II-VI Marlow

Project Outcome:

Operational hardware of an integrated system capable of operating with all subsystems together and meets the following metrics:

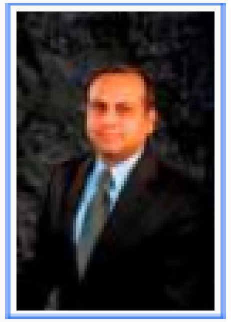
- Drop-in design
- Thermal-to electric conversion to operate independent of the grid

Team

Team Expertise
- High temperature thermoelectric materials
- Thermoelectric material evaluation and selection
- Integration of thermoelectric modules with heating systems
- End-use application

Resources
- State-of-the-art testing laboratory and 3D printing facilities

Partners
- ORNL
- Sheetak, Inc.
- II-VI Marlow
- A. O. Smith Corp.



Sandeep Alavandi
GTI
PI & PM

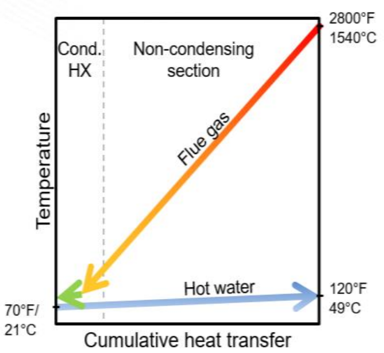
Kyle Gluesenkamp
ORNL

Uttam Ghoshal
Sheetak, Inc.

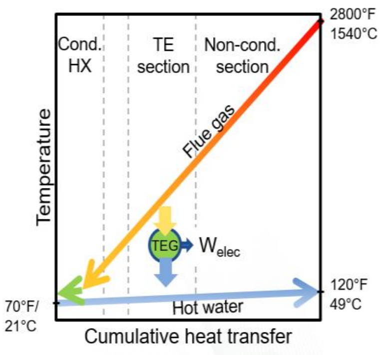
Challenge

Grid resilient heating systems address energy efficiency and power outages

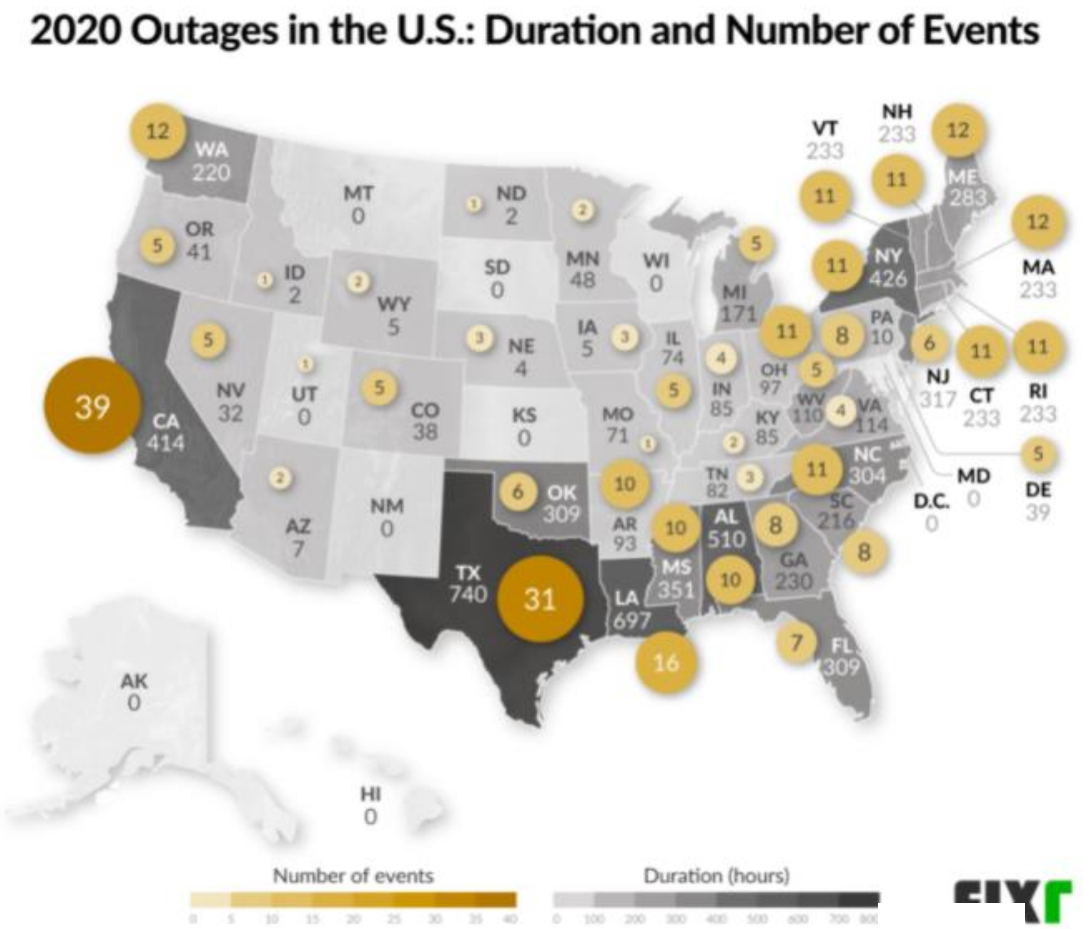
- Climate crisis has led to significant natural disasters leaving infrastructure vulnerable
- Power outages lead to no heat especially in emergency needs
- Significant redundancy to overcome power outage issues
- Waste heat not effectively captured in different heating systems
- Grid failure leads to lower safety



Conventional



Grid-resilient



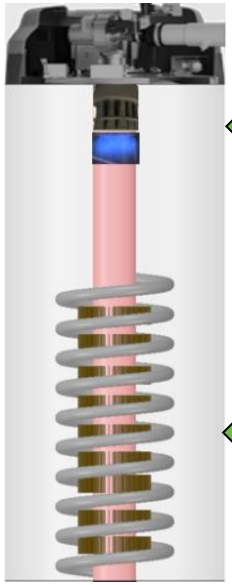
https://www.fixr.com/blog/2021/03/10/u-s-power-outages-2020-map-and-solutions-for-homeowners/

Approach

A grid resilient, self-powered, fuel flexible drop-in integrated advanced burner Thermoelectric Generator (TEG) system for residential and commercial buildings

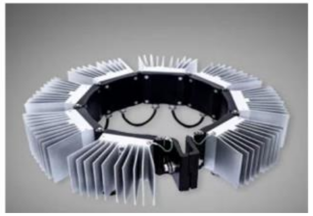
Design, develop, and test an integrated system with GTI's innovative 3D printed high efficiency, fuel flexible burner, and commercially available TEG in an A.O. Smith hot water heater. The integrated design can achieve :

- Coefficient of Performance (COP) >1
- Drop-in capability
- Achieving the electrical demand to make the equipment grid-independent
- Fuel flexible operation with NOx and CO emissions <5 ppm and <20 ppm respectively (@3% oxygen) with a turndown >6 to 1



Heating System
(Courtesy: A. O. Smith, Corp.)

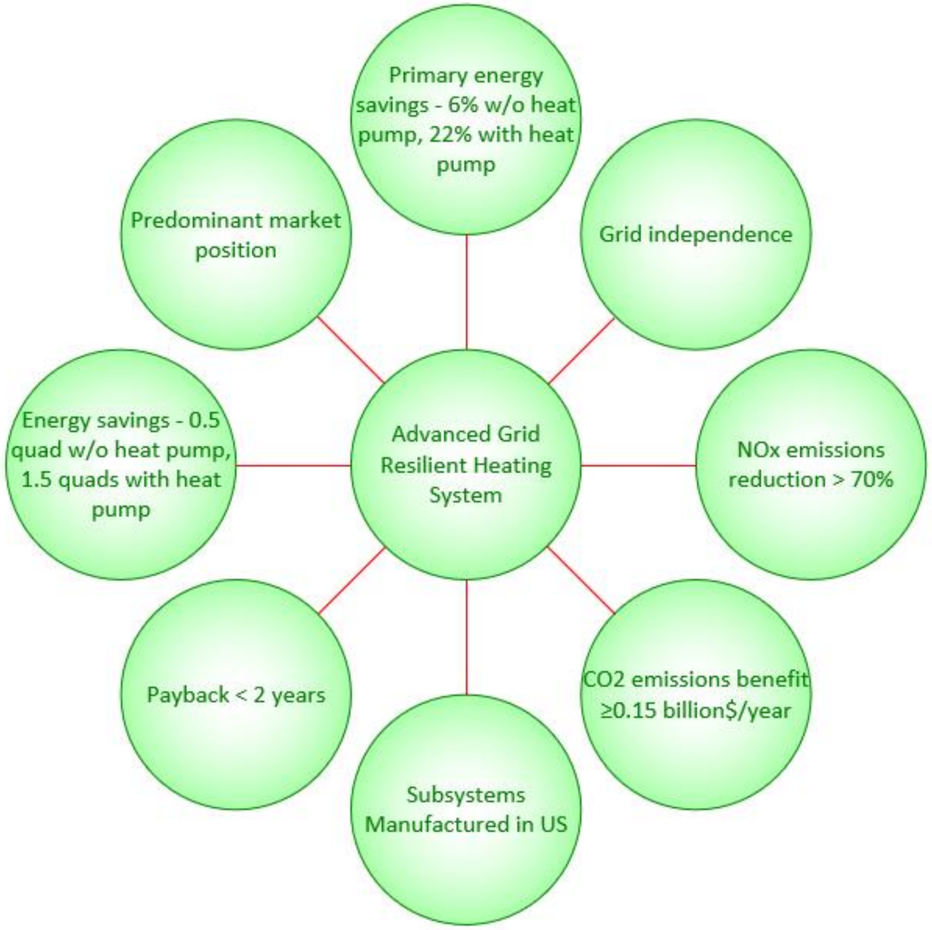
High Efficiency, Fuel Flexible 3D Printed Burner



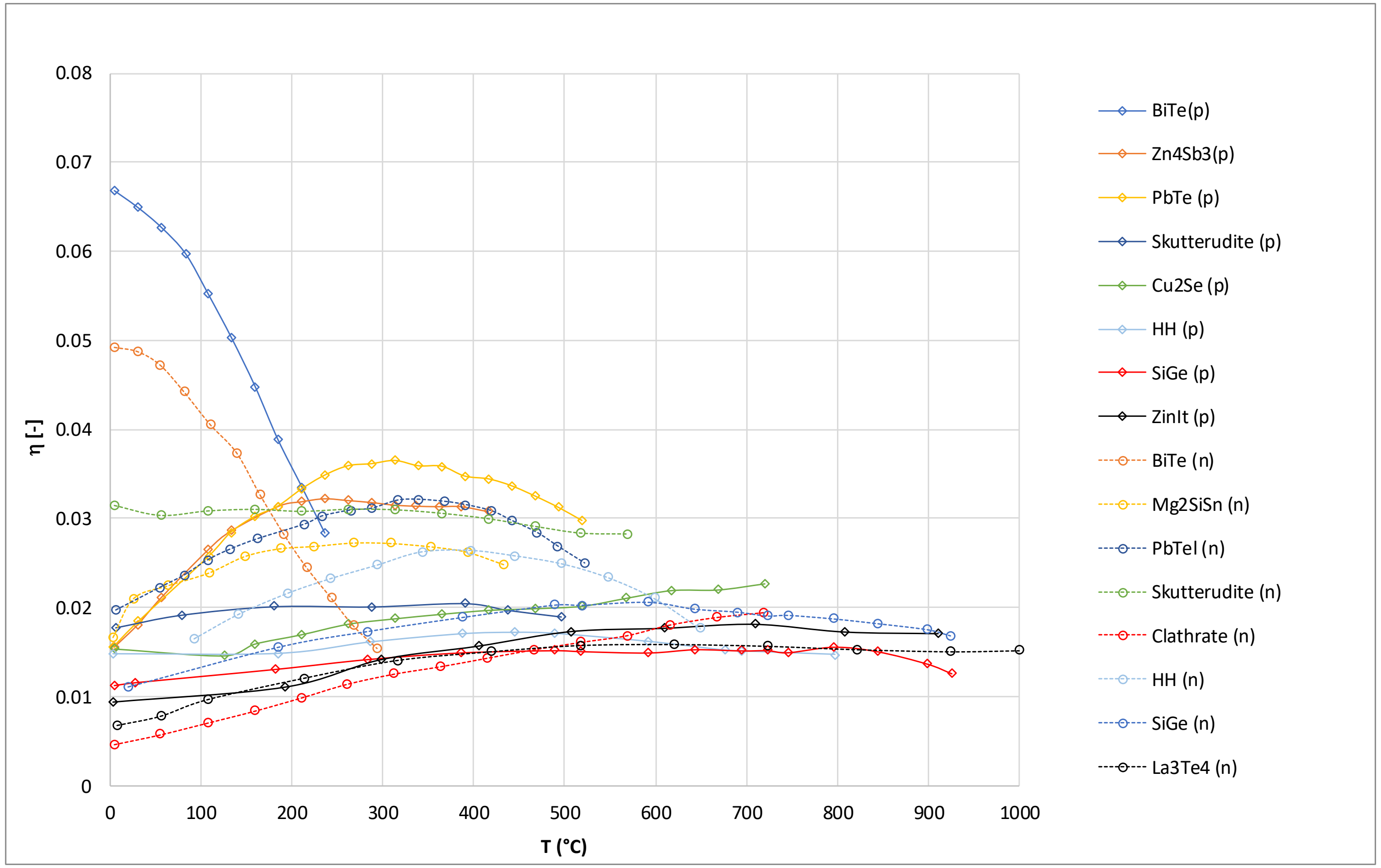
High Temperature Thermoelectric Generator (TEG)
(Courtesy: II-VI Marlow)

Impact

- 6% primary energy savings without heat pump and 22% with heat pump
- Provide grid resiliency, reduce amount of dispatch power required, and lower peak power plant operation
- Savings of 0.49 quad/year and 1.5 quads/year without and with heat pump respectively across the residential and commercial buildings
- Payback of 2.1 years without heat pump and 1.9 years with heat pump can be achieved
- Advanced 3D Burner - NOx emissions reduction of more than 70%
- Advanced 3D Burner - CO_2 emissions reduction of 21.2 Mt annually leading to ≥ $0.15 billion in emission benefit per year
- 3D printing - Subsystems manufactured and assembled in U.S. and will meet "Manufacturing in America" goals
- Predominant position in the market, becoming the highest primary efficiency water heater available, with the lowest operating cost, and with the ability to provide heat during power outages



Progress



Device Material	TRL Level	Application	Current Status
Bismuth Telluride	9	Waste Heat/Defense/ Telecommunications	Commercially available
SiGe	7	Voyager 1&2 mission	Available
Skutterudite	5	Potential automotive	Long-term performance demonstration needed
PbTe	8	Space missions	Mars 2020 mission
Half Heusler	4	Energy	Long-term performance demonstration needed

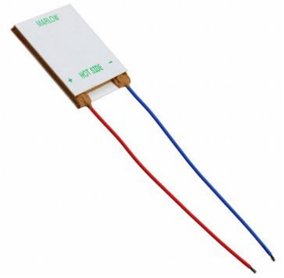
- *zT* data obtained for 16 materials covering entire temperature range
- Conducted detailed numerical analysis for material selection and sizing for the TEG design
- Five different materials chosen based on performance and availability

Progress

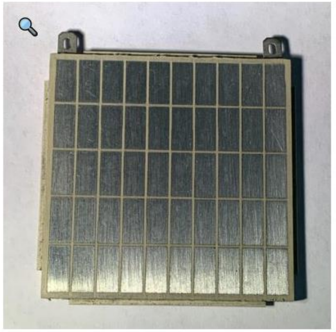
Marlow	Marlow	Hi-Z	Sheetak, Inc.

Marlow

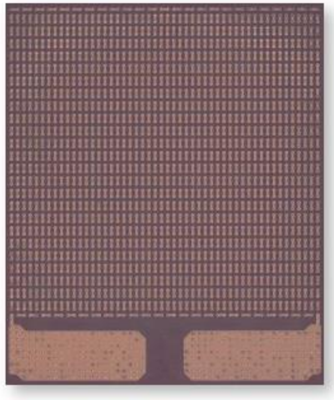
Marlow



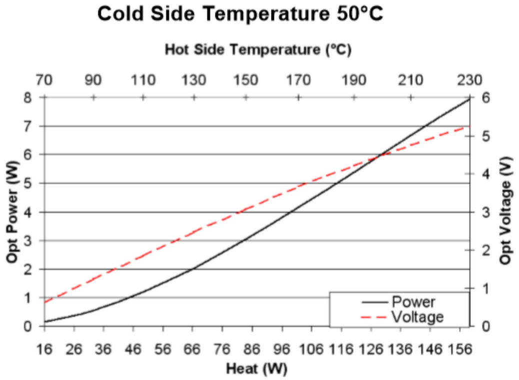
Hi-Z

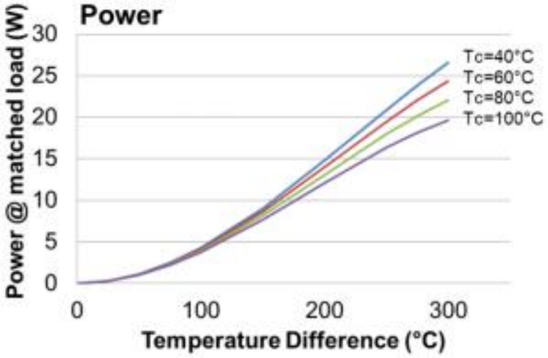


Sheetak, Inc.



Pipe Diameter	6”
Number of Facets/Strap	5**
Strap Outer Diameter (in)	15.5
Weight (lbs.)	13
Max Power Output /Strap (W)***	7.4
Max Short Circuit Current /Strap (A)***	1.02
Max Open Circuit Voltage (V)***	28.7





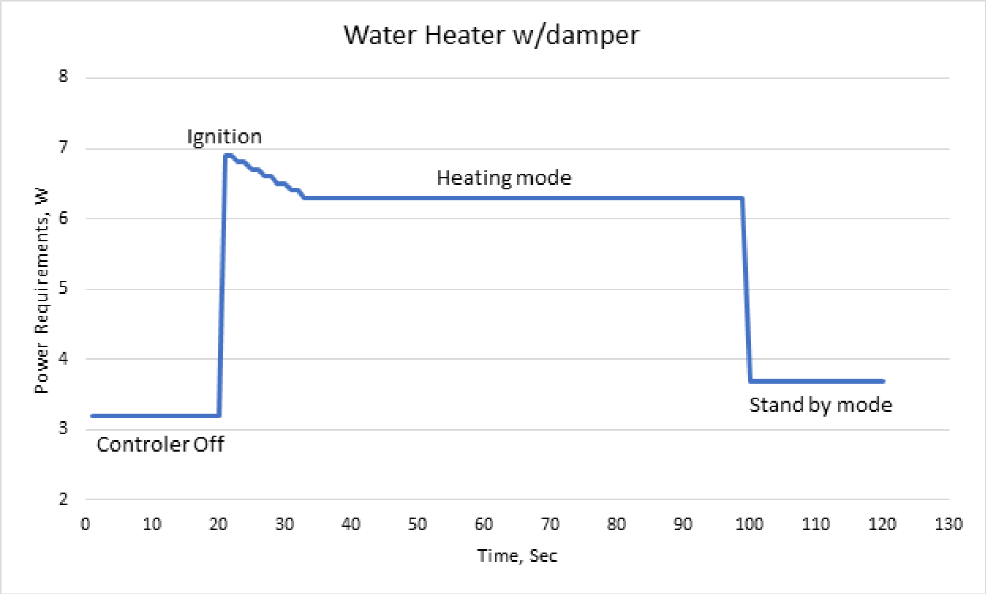
https://sheetak.com/

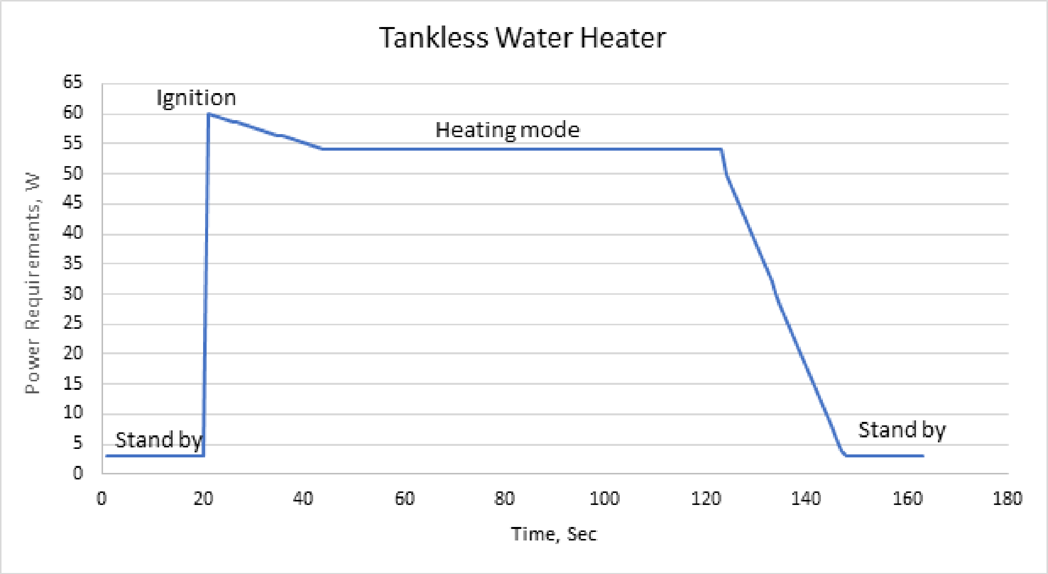
https://ii-vi.com/product-category/products/thermoelectrics/power-generators/
https://cdn2.hubspot.net/hubfs/547732/Data_Sheets/EHBMS.pdf?t=1523036106184

https://hi-z.com/products/

- Tested different thermoelectric hardware for performance mapping

Progress





Courtesy: A. O. Smith, Corp.

Courtesy: US Boiler Company

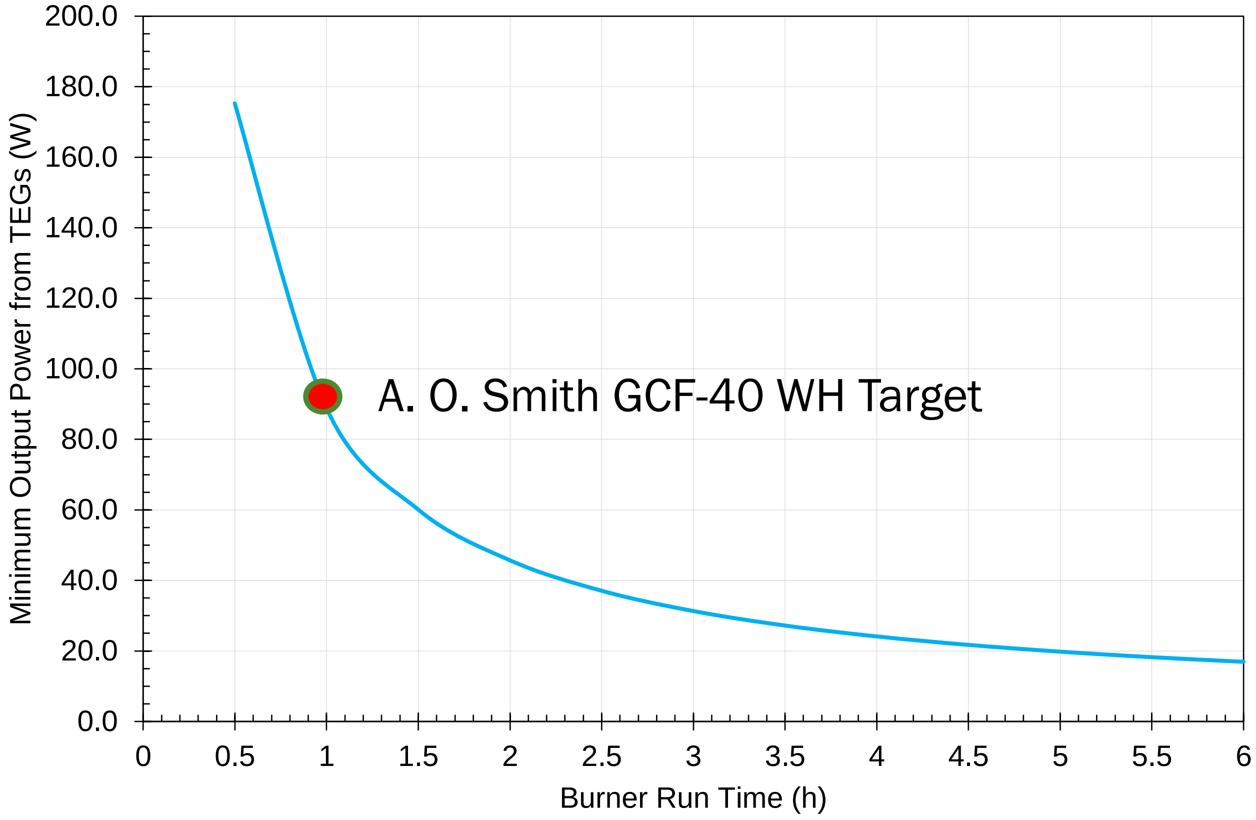
Courtesy: Goodman

Courtesy: A. O. Smith, Corp.

Courtesy: A. O. Smith, Corp.

- Evaluated heating systems for thermoelectric generator design

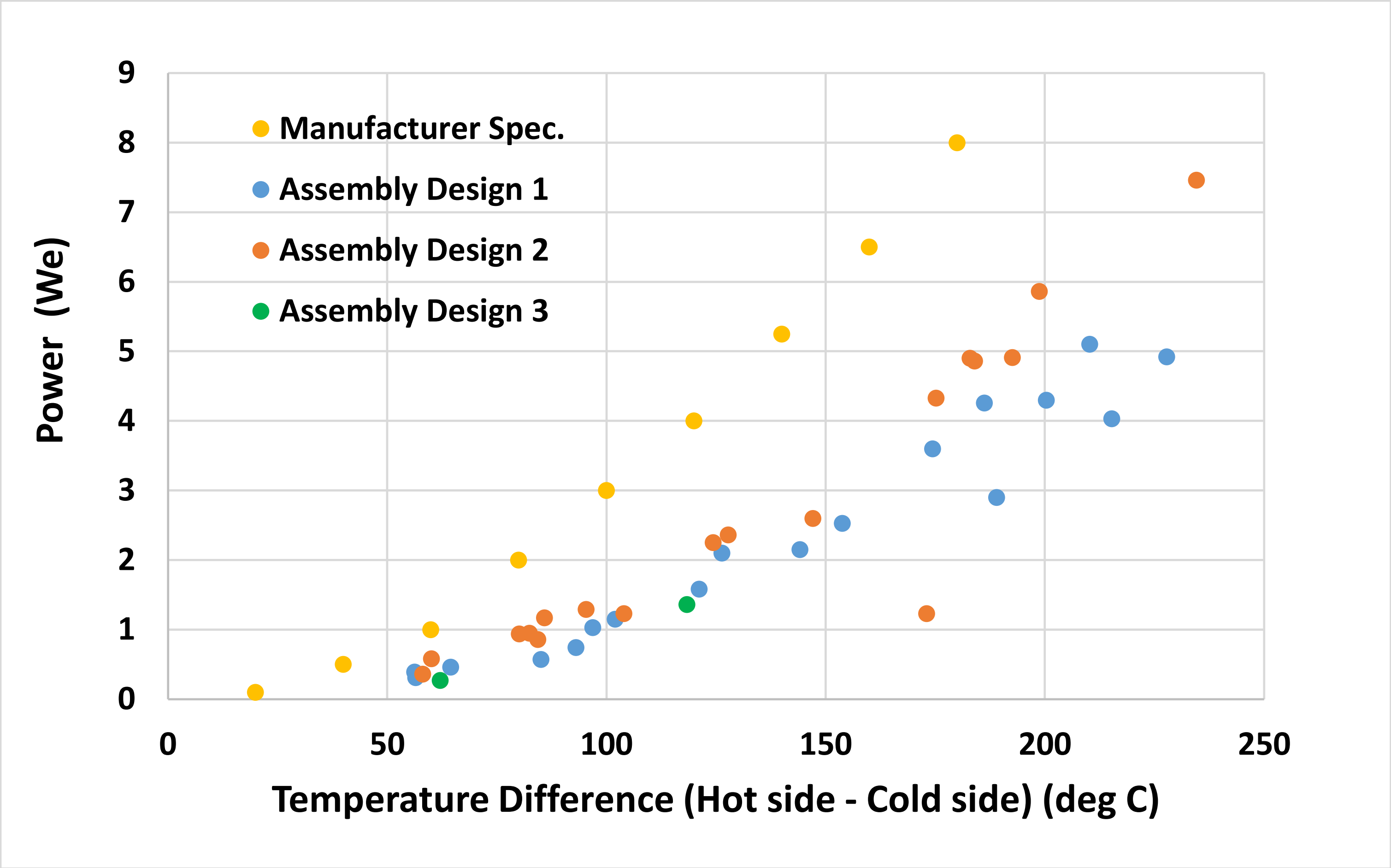
Progress



AO Smith GCF-40 WH Status	Power Demand (We)	Energy Demand (Wh) (over 24-hours with 1 hour burner operation)
Idle, Plugged into Wall, Gas Control Valve On, Burner Off	3.6	82.8
Burner On, Igniter on	6.9	0.061
Burner On, Igniter off	6.1	6.1
Total	88.9 (over 24 hours)	88.9

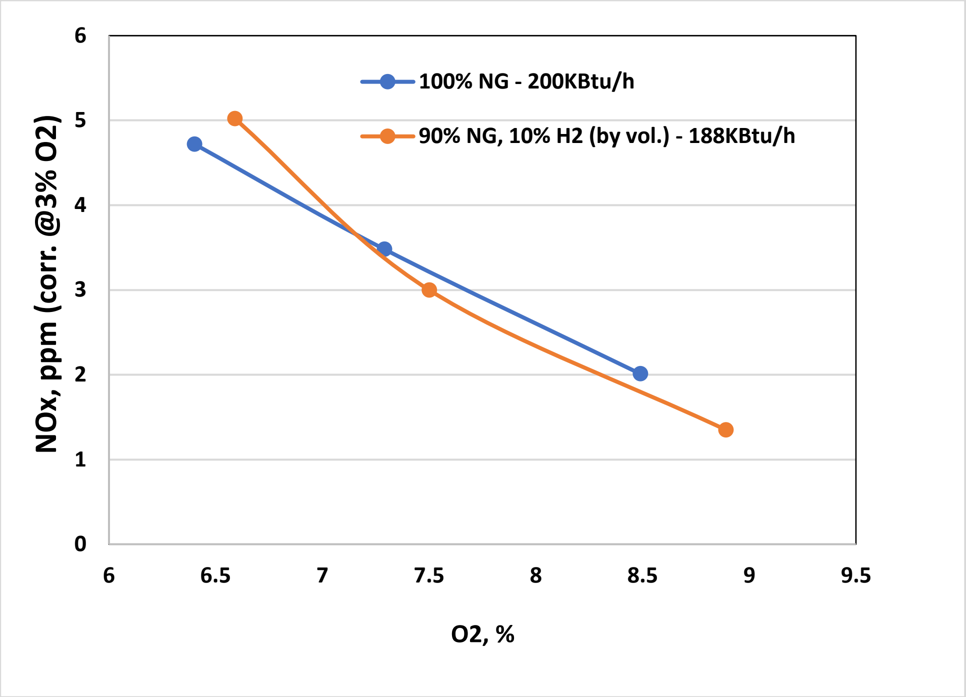
- Electrical power demand for A. O. Smith, Corp. water heater - thermoelectric integration and battery sizing

Progress



- High thermal-to-electric conversion for different assembly designs

Progress



- Ultra-low emissions of <5 ppm NOx and CO emissions <30 ppm with hydrogen

Stakeholder Engagement: Mid–Stage Project

The project is currently in mid-stage:

On-going discussions with thermoelectric generator and heating system OEM's

Reports and Publications

- Presented "Material Selection and Sizing of a Thermoelectric Generator (TEG) for Power Generation in a Self-Powered Heating System"
- Preliminary discussion of techno-economic analysis with stakeholders

Feedback from Stakeholders –

CenterPoint Energy (Jim Tilley, Manager):

- "During a power outage we had to cater to 30,000 customers. This is a great project"

Cold Climate Housing Research Center (Alaska) (Tom Marsik, Research Director) :

- "Do I understand it well that you will be developing a heating system that continues to operate during power outages because it is producing its own electricity using a thermoelectric generator? Such a heating system would have a lot of applicability in Alaska"

Remaining Project Work

FY 2020 –

- Complete testing of the advanced 3D burner in a simulated environment

FY 2021 –

- Demonstrate integrated thermoelectric hardware in a heating system
- Discuss results with OEM

Future project:

- Demonstrate long-term feasibility and durability of the thermoelectric design and assembly

Thank You

Gas Technology Institute, ORNL and Sheetak, Inc.

Sandeep Alavandi, Sr. Engineer

847-768-0571, salavandi@gti.energy

REFERENCE SLIDES

Project Budget

Project Budget: $1.14 MM
Variances: None
Cost to Date: $462K (including cost share, no FFRDC)
Additional Funding: None

Budget History					
FY 2019 (past)		FY 2020 (current)		FY 2021 (planned)	
$179K	$101K	$207K	$97K	$219K	$89K
$175K	$116K	$111K	$60K		

Project Plan and Schedule

April 2019 to July 2022

Task Number	Task Name
	Budget Period 1: System Architecture and Subsystem Design
1.0	**Define System Architecture**
1.01	Finalize system architecture
M1.1.1	System architecture finalized
1.02	Finalize subsystem specs and design
M1.2.1	System specs and design finalized
1.03	Develop model for system performance
M1.3.1	Model for system performance developed
	GO/NO-GO System architecture and design ready
	Budget Period 2: Subsystem Fabrication and Testing
2.0	**Burner fabrication, installation and testing**
2.1	Fabricate 3D printed burner
M2.1.1	3D printed burner fabrication complete
2.2	Burner installation and testing
M2.2.1	Test results show burner meets performance targets
3.0	**TEG fabrication and testing**
3.1	Fabricate TEG
M3.1.1	TEG fabrication complete
3.2	TEG testing
M3.2.1	TEG testing complete
	GO/NO-GO Results demonstrate performance targets met
	Budget Period 3: System assembly and testing
4.0	**ABTEG Integrated System Testing**
4.1	Integrate water heater-ABTEG system
M4.1.1	System assembly complete
4.2	Testing ABTEG System
M4.2.1	System meets performance targets
5.0	**Detailed performance analysis**
M5.0.1	Detailed techno-economic analysis complete
	GO/NO-GO System meets performance targets