

Thermoelectric Generator Development Efforts at the Maine Maritime Academy



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Setting a Course for Thermoelectric Applications





Why Look at Marine Applications For TEGs?



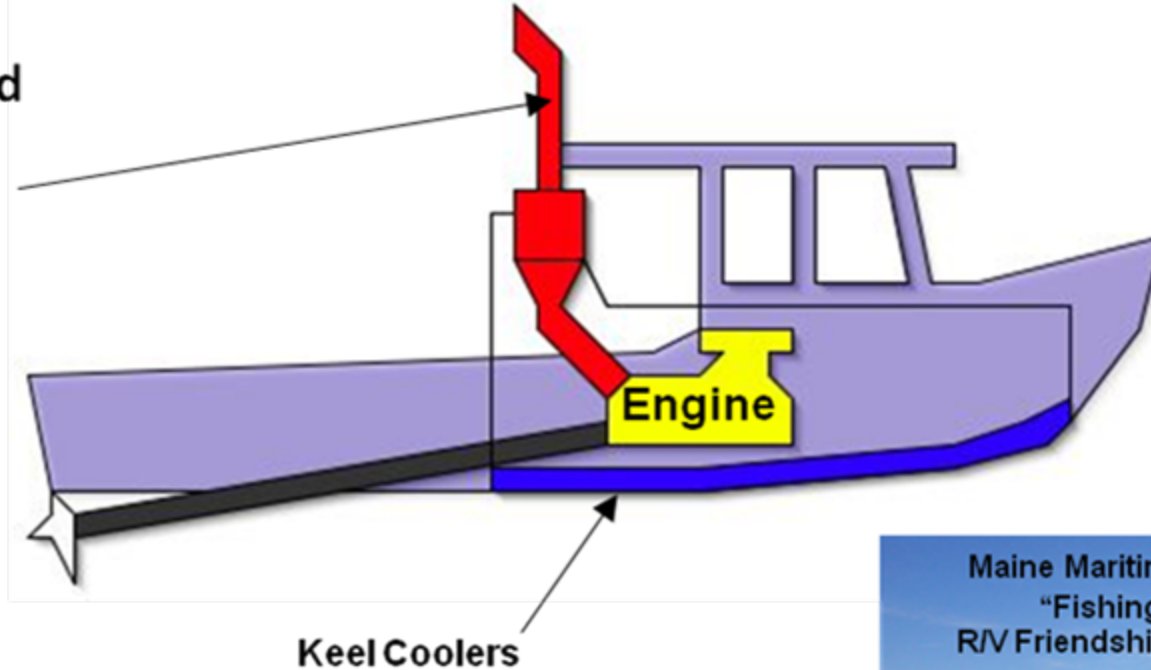
- Marine Applications not Sensitive to Weight and Size Constraints
- Efficiency Improvements are of Critical Importance to Industry
- Shipping Industry can be an Early Adopter of this Enabling Technology
- Ships have Onboard Infrastructure for Electric Power Generation.
- Provides an auxiliary generator using waste heat only
- Opportunity of reduce CO₂ emissions (Green Technology)
- Low emission vessels are needed NOW: Port of Los Angeles Hybrid Tug Boat



General Concept



Seawater Cooled
Exhaust Stack
T/C Generator



Maine Maritime Academy's
"Fishing Vessel"
R/V Friendship 47 Feet LOA



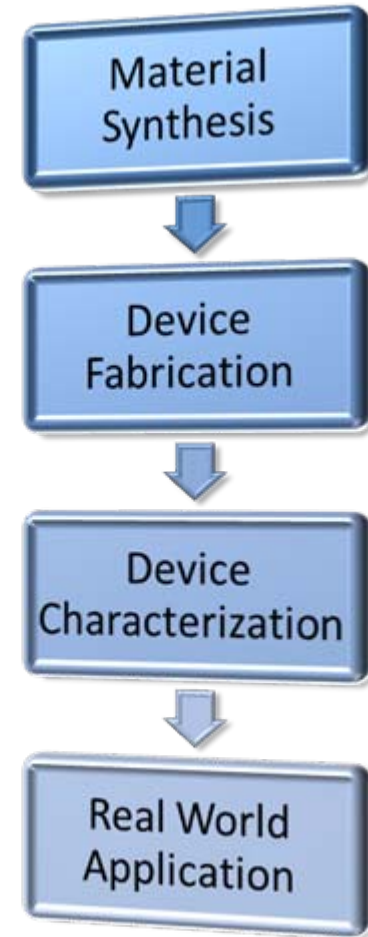


TEG Fabrication Effort



Objective:

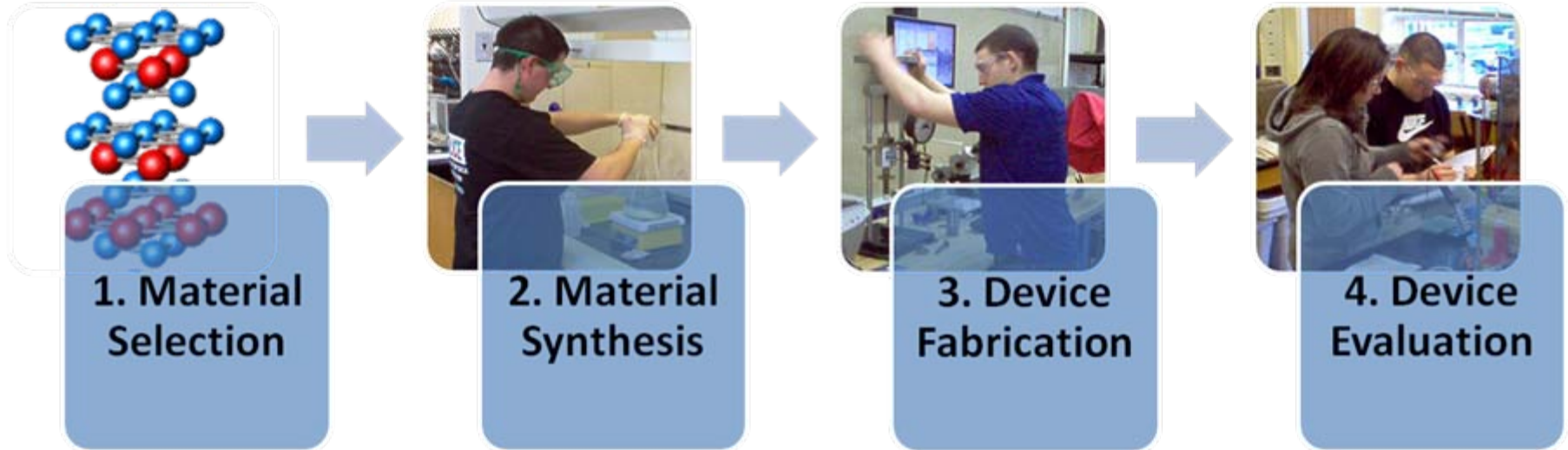
- Fabricate experimental thermoelectric devices
- Evaluate experimental devices in real world applications
- Optimize devices primarily for marine industry





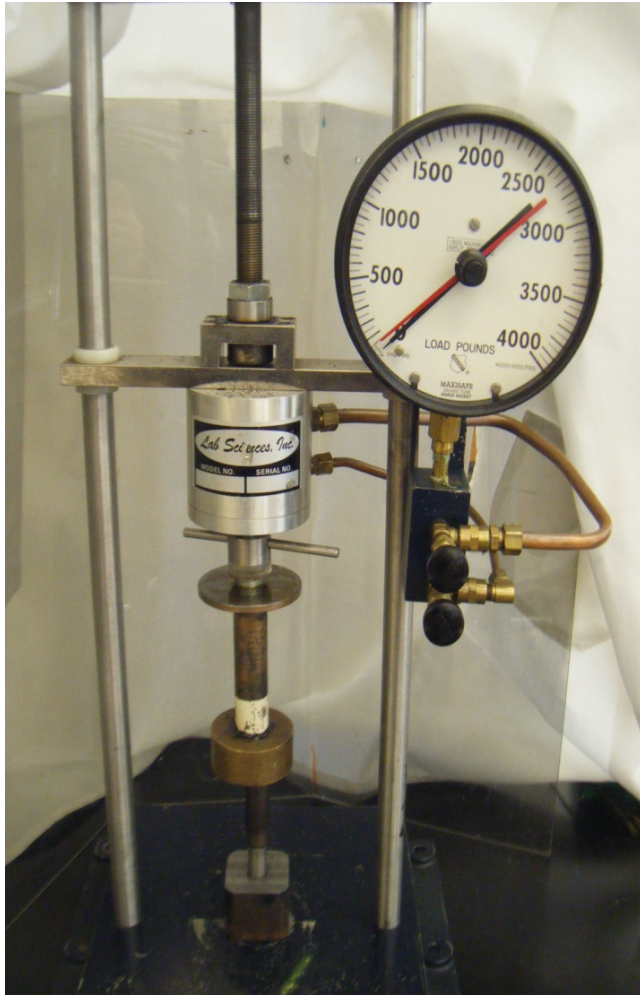
Plan for Module Development

Goal: Develop a working module from raw materials





Device Fabrication



Press Conditions¹

Room Temperature(25°C) for 15 minutes

Pressure 60 MPa

Press Conditions²

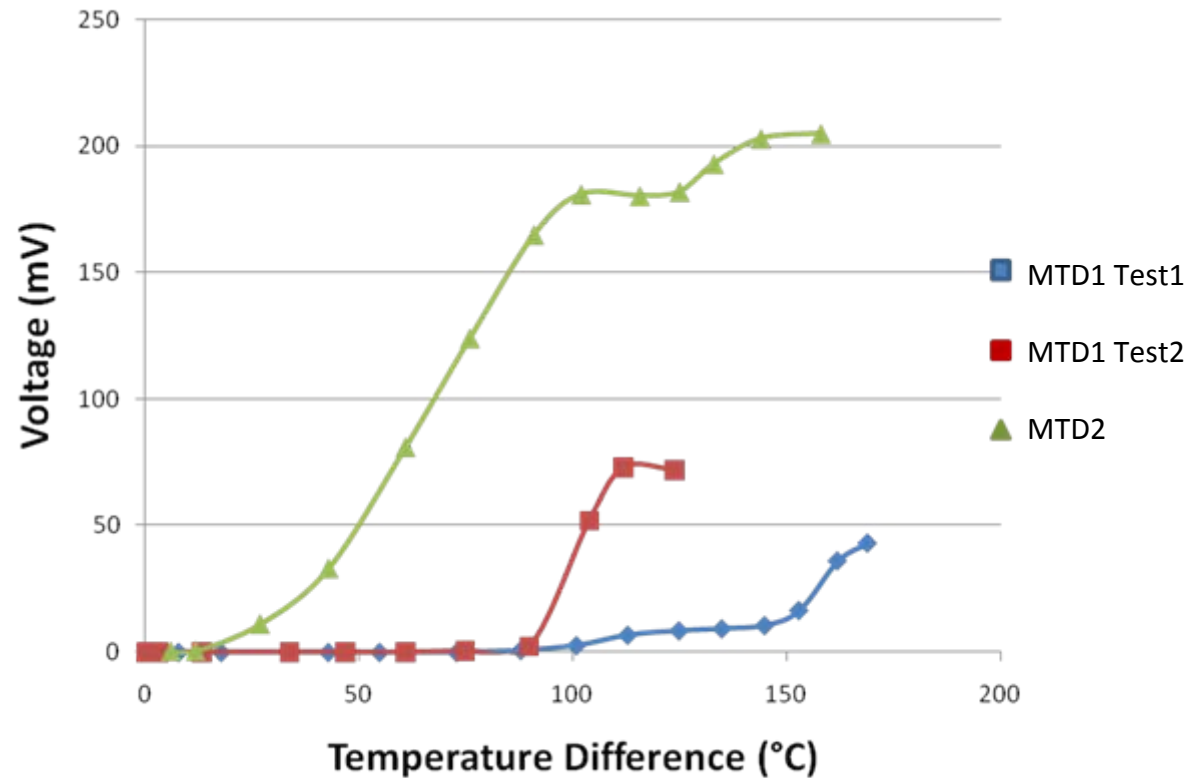
Heated (125°C) for 30 minutes

Pressure 60 MPa

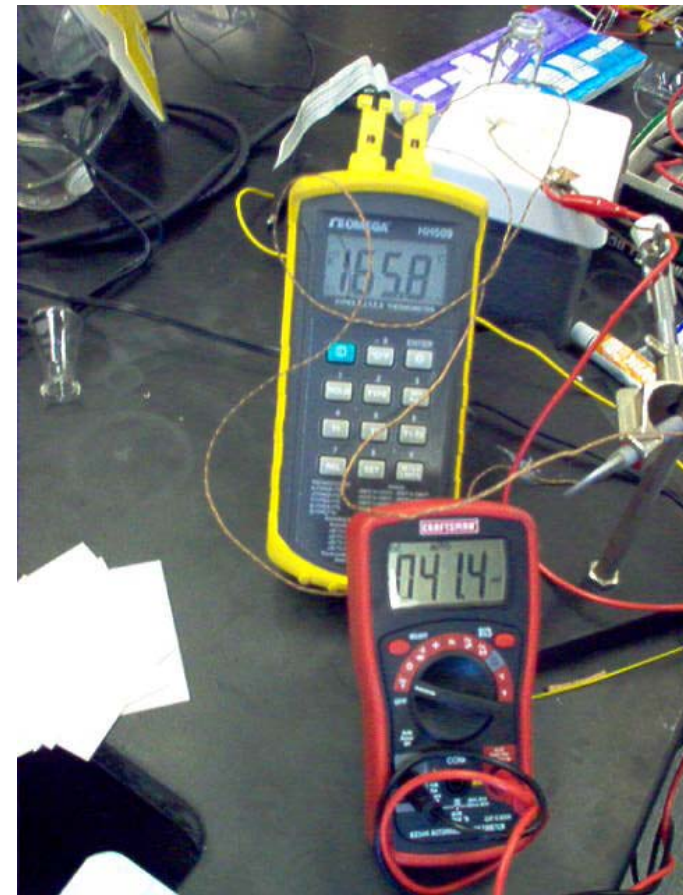




Material Characterization



Best result was ~18% of Hz-2, based on amount of materials used



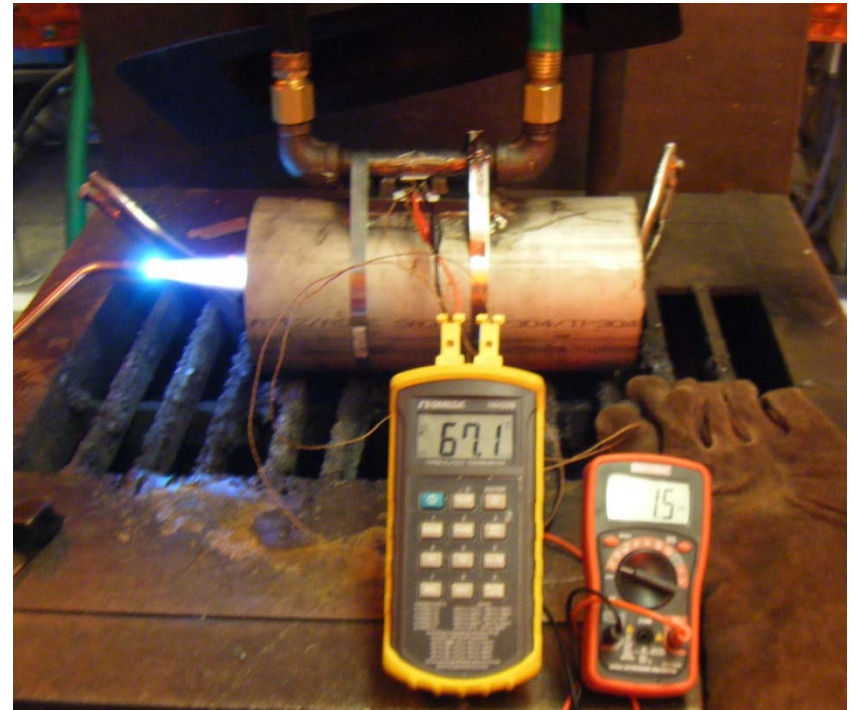
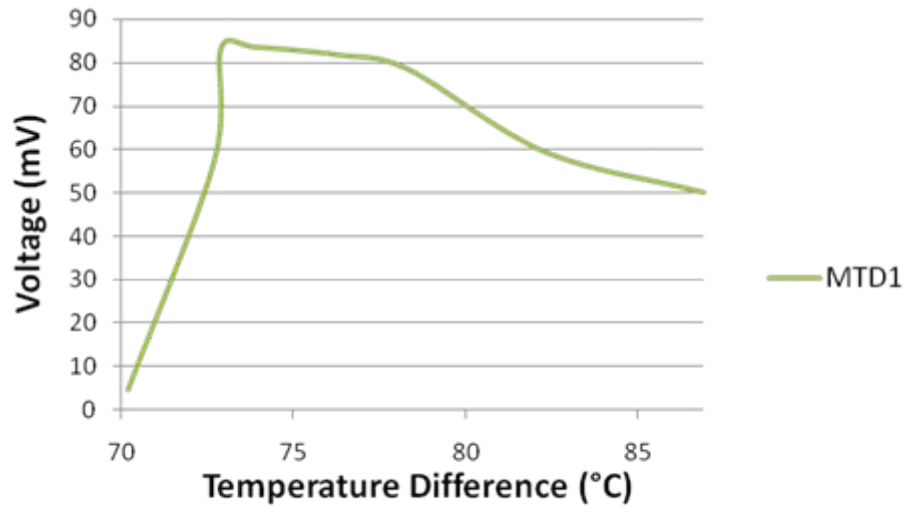
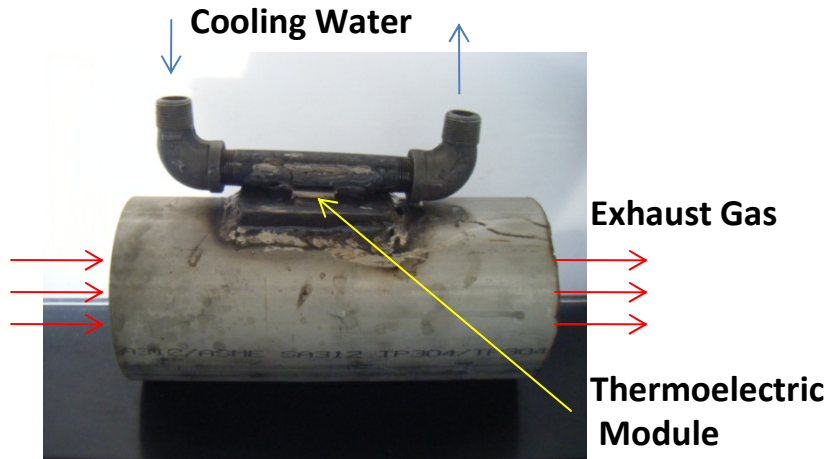


Platform for Gas Turbine Testing

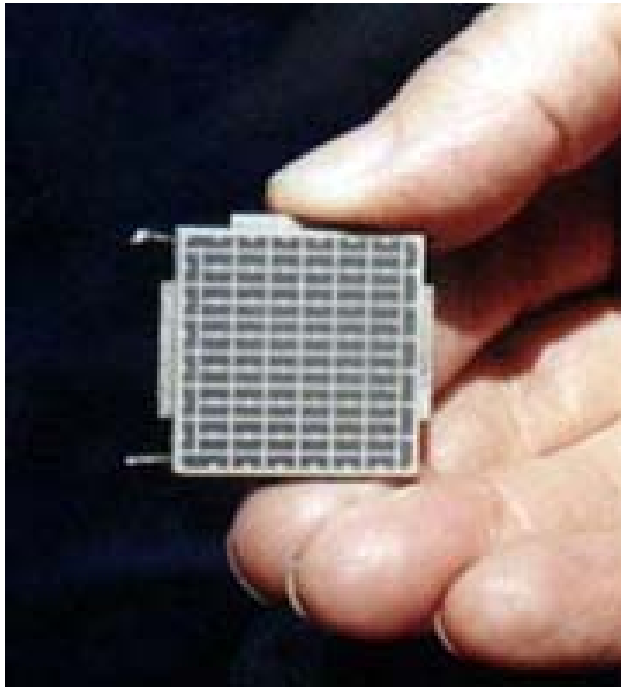




Gas Turbine Simulation



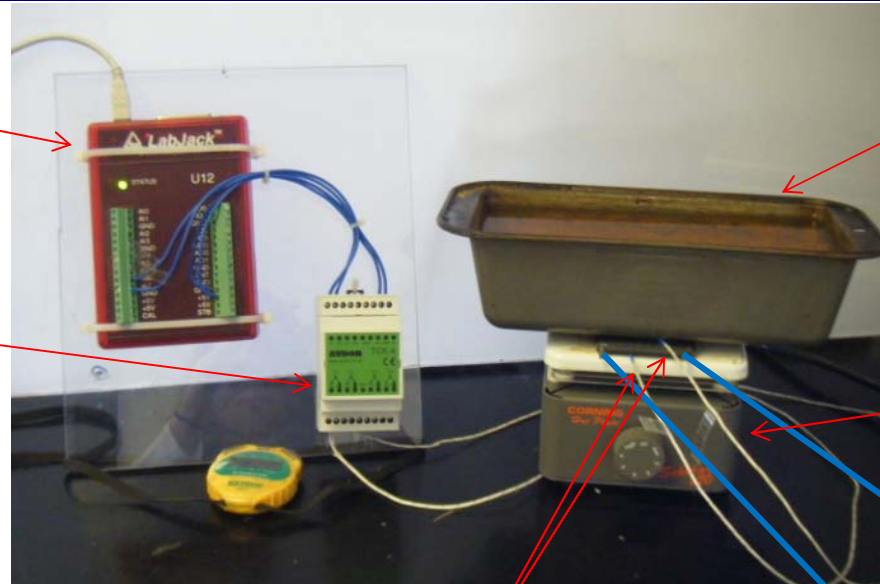
Commercial Modules Hi-Z



Hi-Z 2 Thermoelectric Module

Properties of the 2½ Watt Module, HZ-2	
Physical Properties	
Width & Length	1.15" (2.90 cm)
Thickness (Special Order)	0.2" (0.508)
Weight	13.5 grams
Compressive Yield Stress	3 ksi (20 MPa)
Number of active couples	97 couples
Thermal Properties	
Design Hot Side Temperature	230°C (450°F)
Design Cold Side Temperature	30°C (85°F)
Maximum Continuous Temperature	250°C (480°F)
Maximum Intermittent Temperature	400°C (750°F)
Thermal Conductivity	0.024 W/cm*K
Heat Flux	9.54 W/cm²
Electrical Properties (as a generator)	
Power	2.5 Watts
Load Voltage	3.3 Volts
Internal Resistance	4.0 A
Current	0.8 Amps
Open Circuit Voltage	6.53 Volts
Efficiency	4.5 %

Experimental Set-up



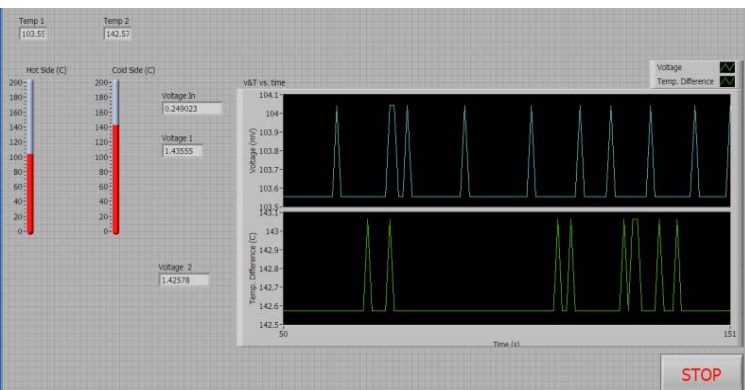
LabJack U12

Ice Bath

Audon TCK-4 Amplifier

Corning Hot Plate

National Instruments LabView 8.2



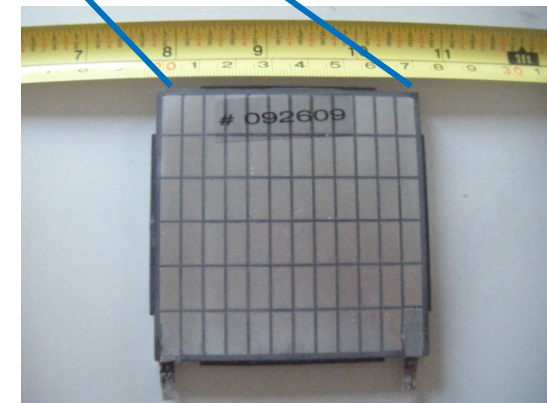
2 Type K Thermocouples

Hi Z modules

Hz 2

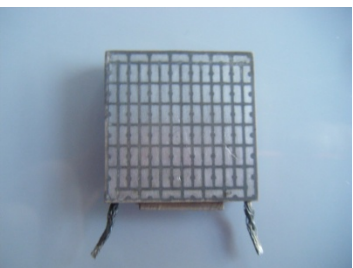
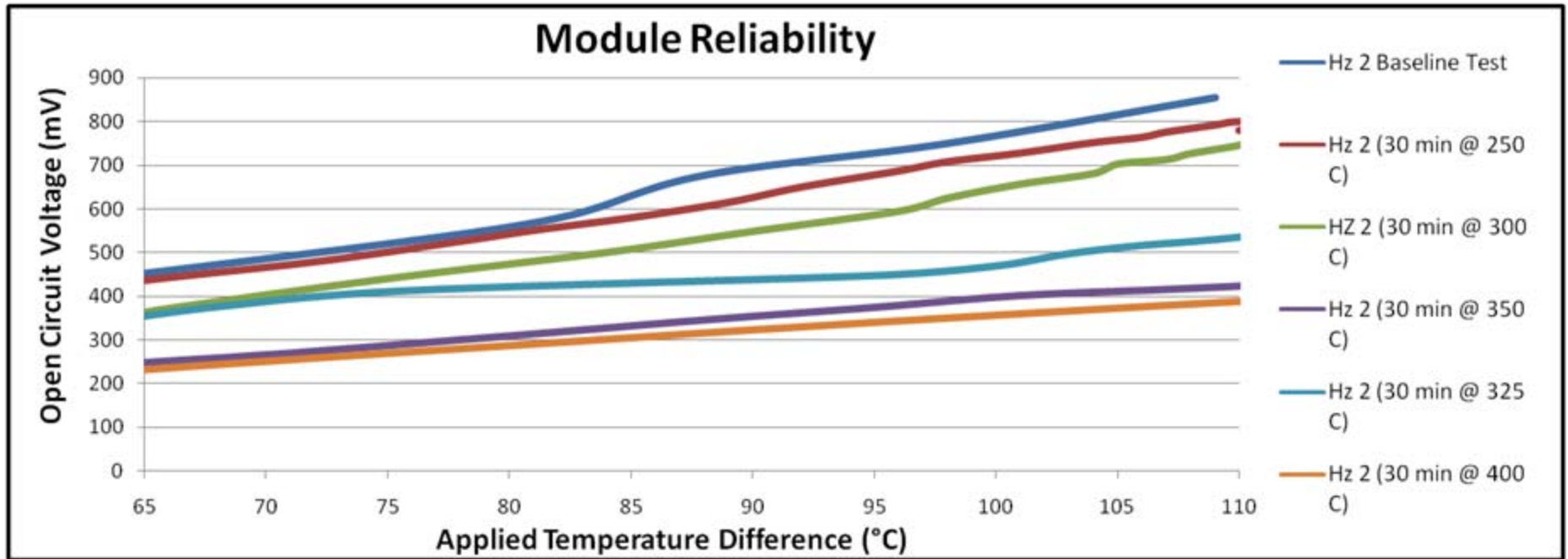
Hz 14

Hz 20 (Right)





HZ 2 Module Testing



250°C



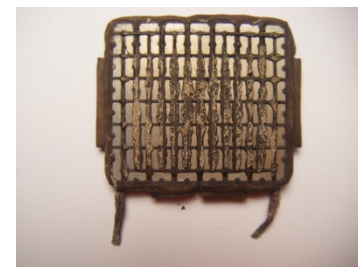
300°C



325°C

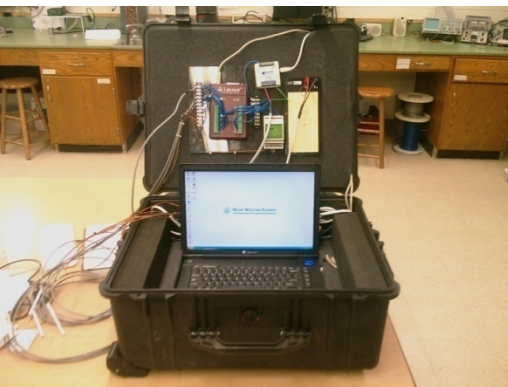


350°C



400°C

Overview of the Testing Program for the Marine Thermoelectric Generator

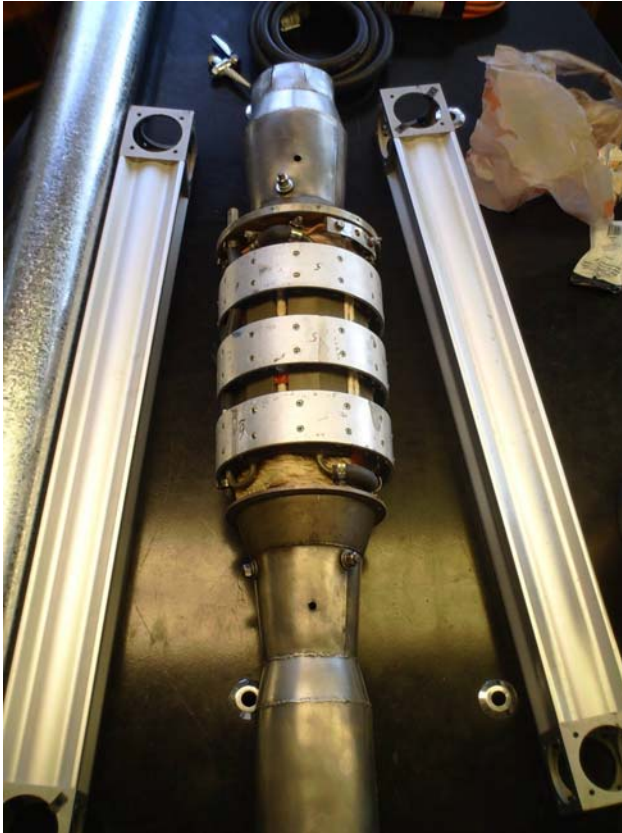


- Bench top lab tests
- Gas turbine tests
- Sea trials –
R/V Friendship
- Data acquisition system



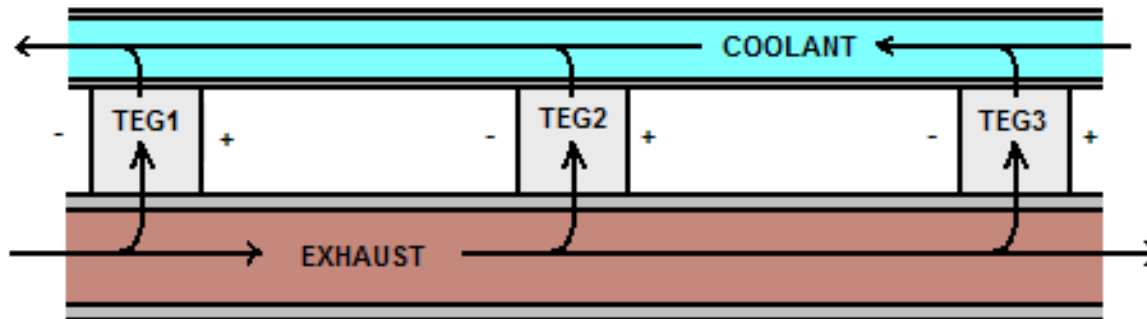


Hi-Z's 180W thermoelectric unit



Acquired from Hi-Z Technology, Inc. (Hi-Z), the thermoelectric unit consists of 18 HZ-14 modules connected in 2 parallel circuits. Maximum temperature values were supplied as 250 °C for the exhaust side.

Bulk Parameter Finite Element Solver

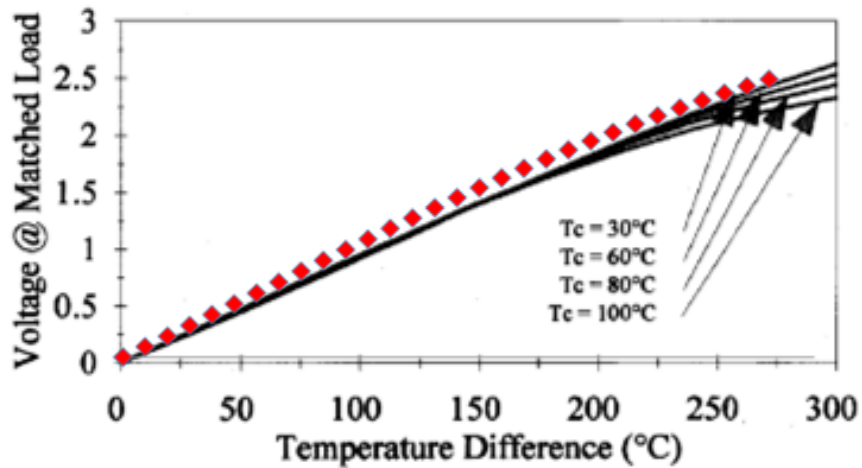


Thermoelectric Configuration

*Arrows indicate heat flow

Module Code Validation

Voltage

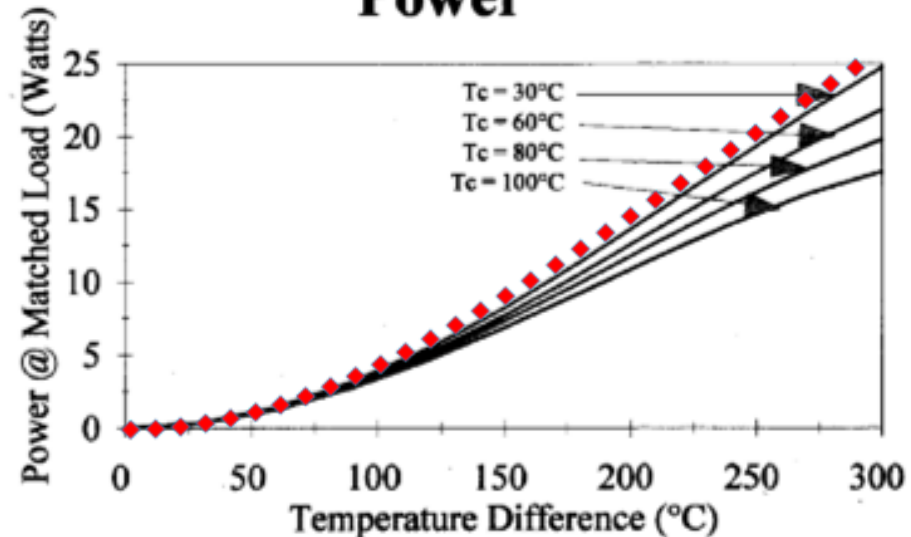


Module Test run at $T_c = 30^\circ\text{C}$

Data Points from MATLAB Model

Data Curves from Hi-Z Specification sheet
On HZ-14 Modules

Power



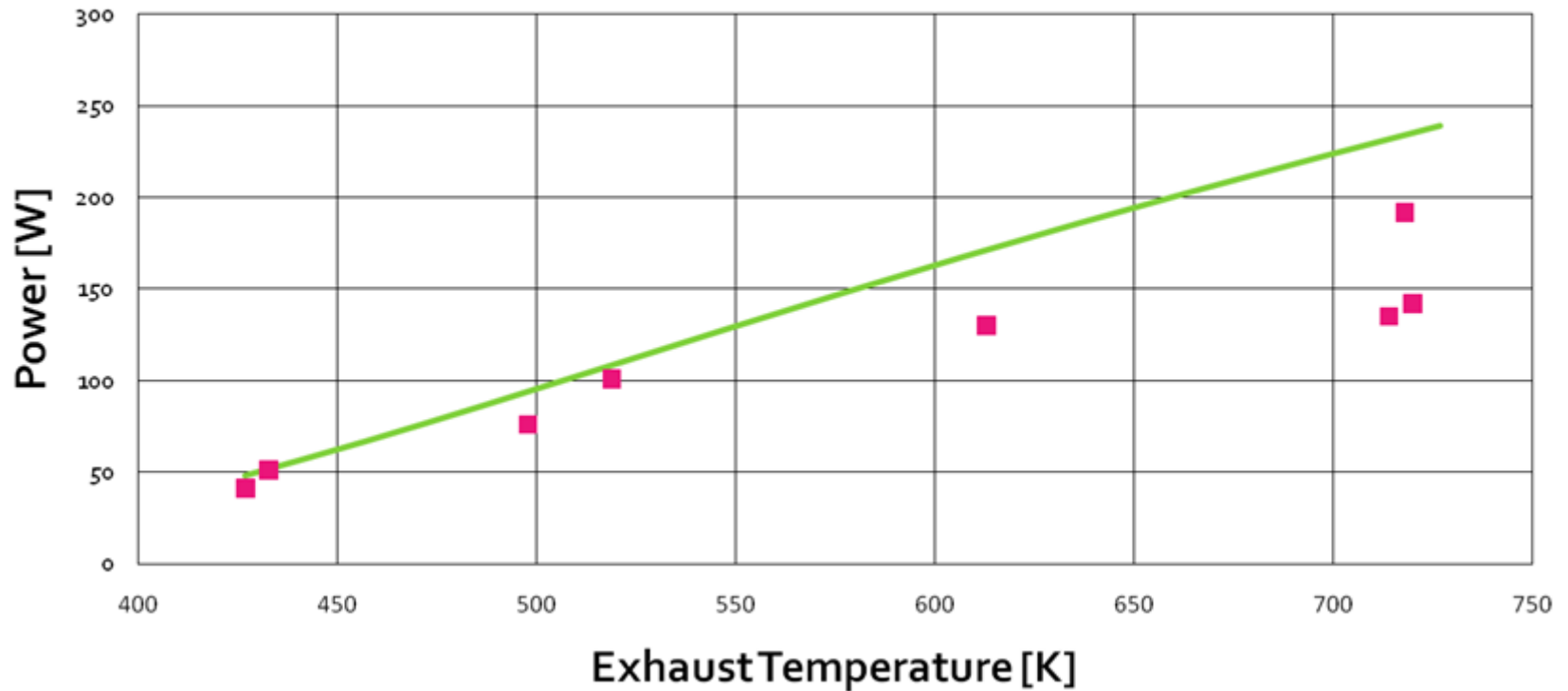


Test Bench For Model



Unit Model Validation

180W Unit Power Curve

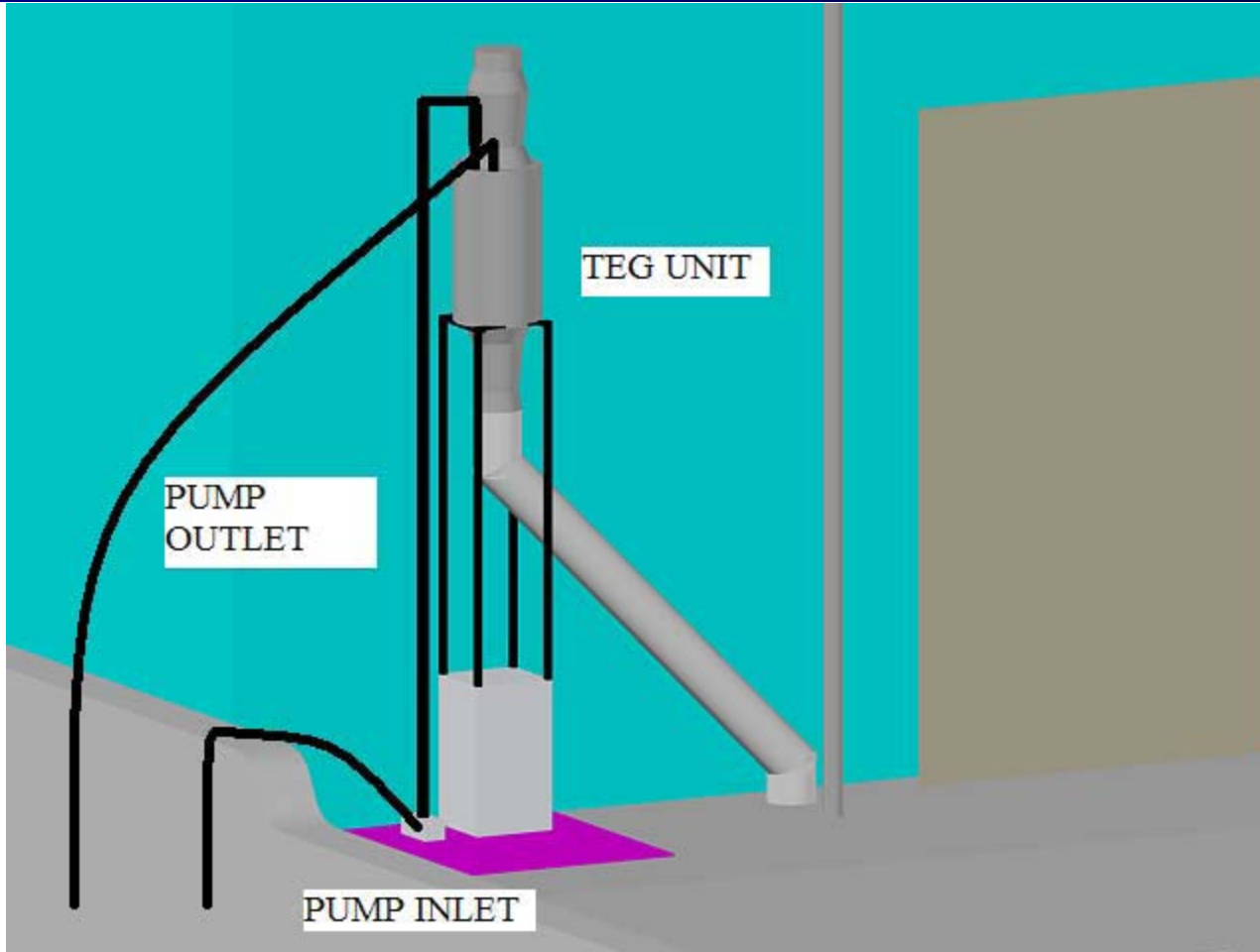


Green Line – Model Prediction

Red Points – Experimental Data



R/V Friendship Setup

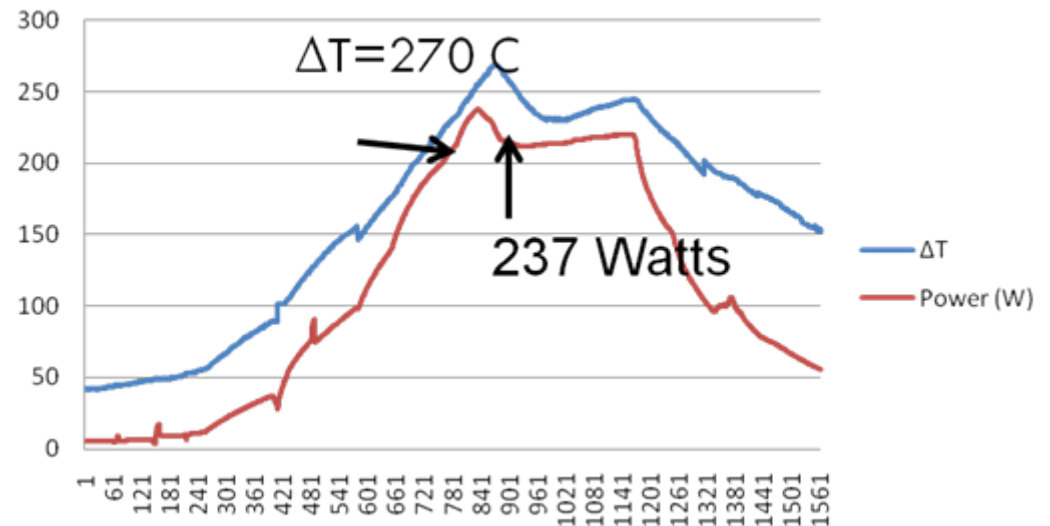




R/V Friendship Setup



Power Developed by R/V Friendship





Gas Turbine Test Platform



SR30 Gas Micro Turbine





Gas Turbine Test Platform



TEG Unit with Air Diffuser Removed

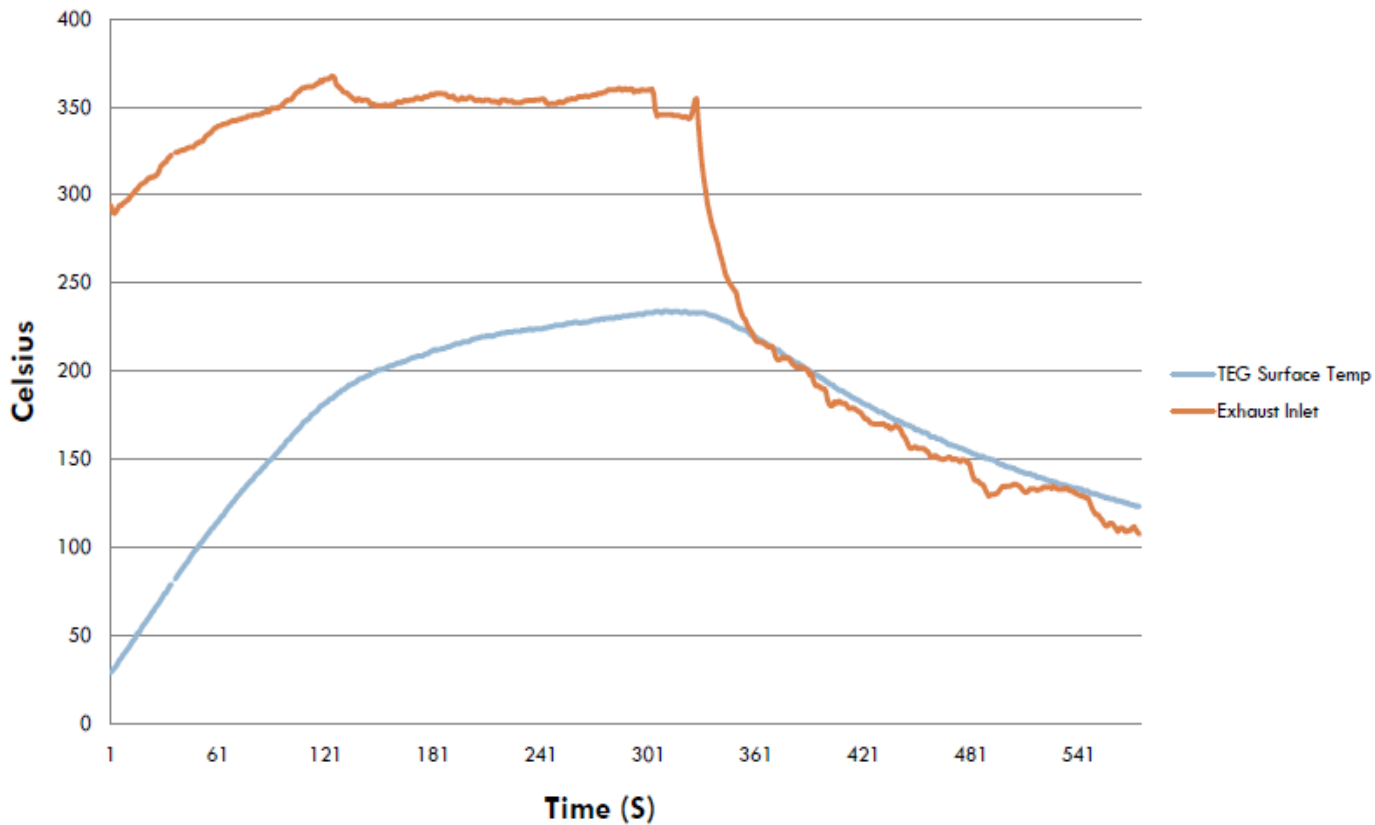




Gas Turbine Test Platform



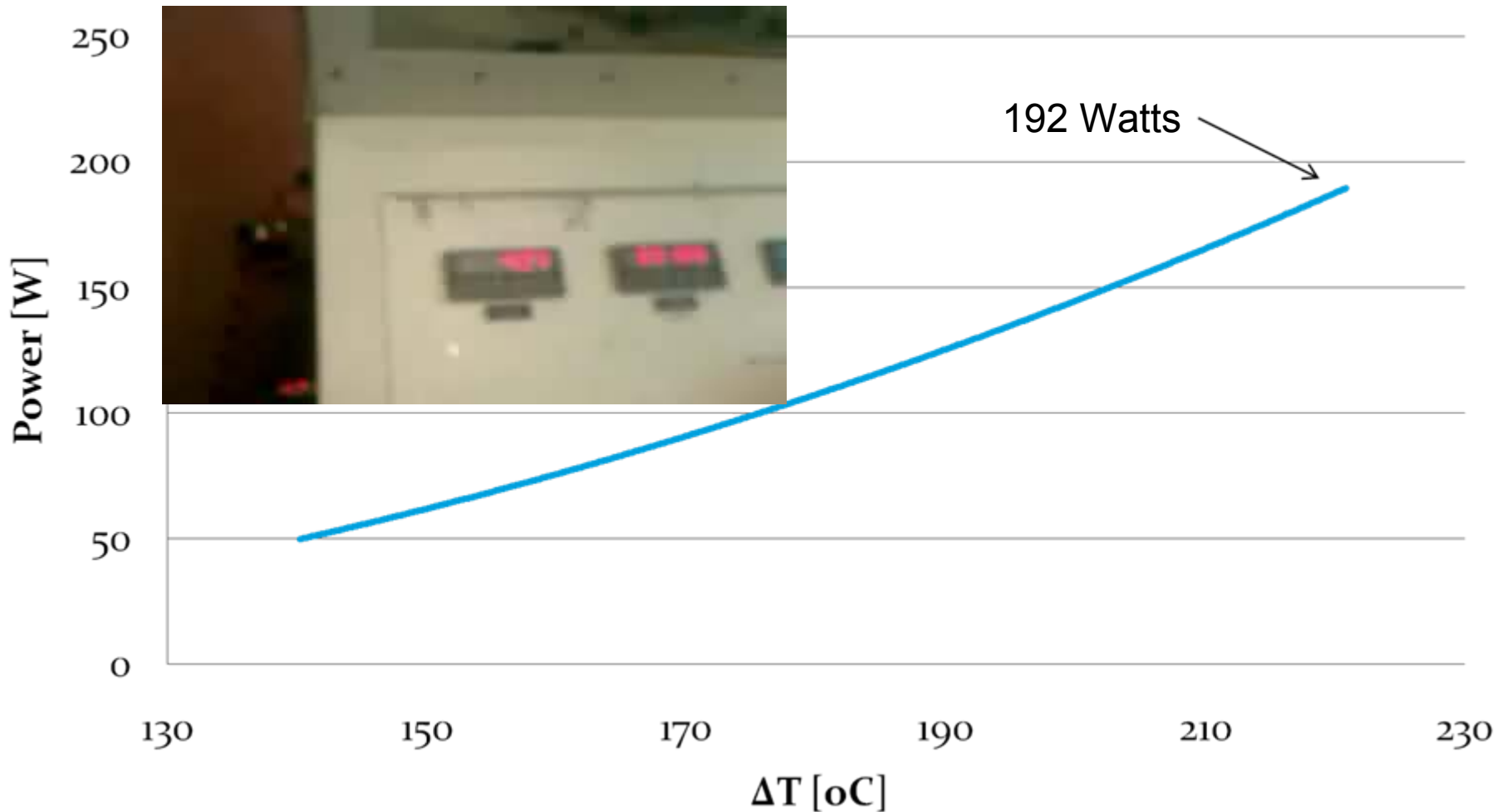
SR30 Gas Micro Turbine Results
Exhaust Inlet vs TEG Surface Temperature





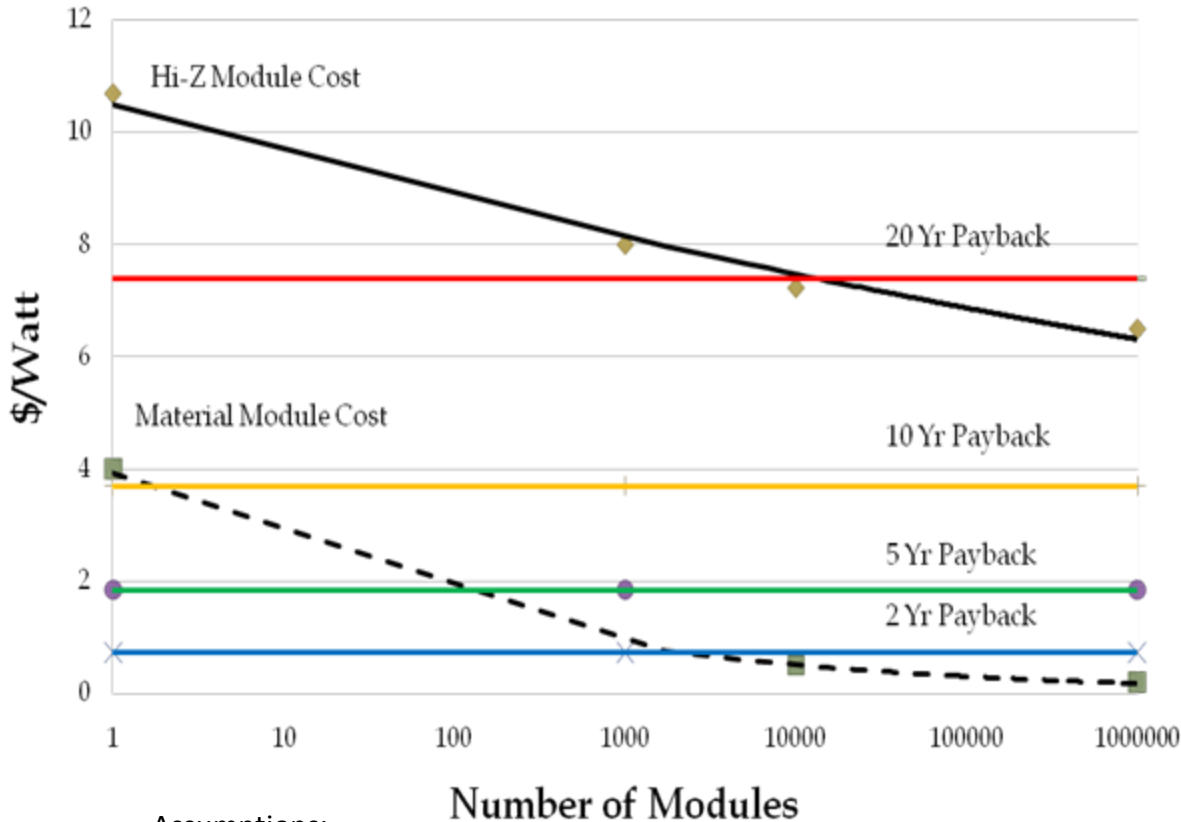
SR30 Results

Power Developed by MMA SR30 Micro Gas Turbine





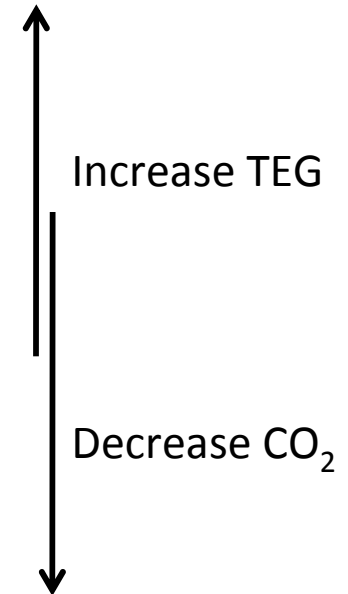
Economics vs. Environment



Assumptions:
80% Duty
 $\eta=0.45$

LHV=42000kJ/kg

Fuel Cost=\$1/gal



Marine Diesel 0.5-1.5Mw Power plants and Gensets are everywhere!

High Duty cycle/
Fuel cost matters

Size/Weight Compatible

Low Maintenance desirable



Offshore Gensets



Workboat/Tug Propulsion



Ship Gensets



Stationary Gensets

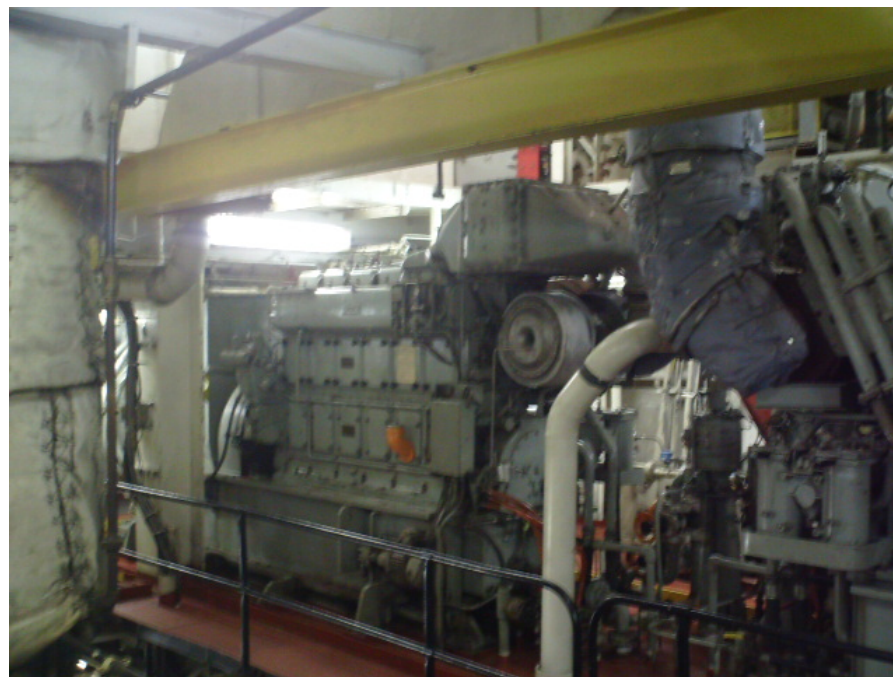
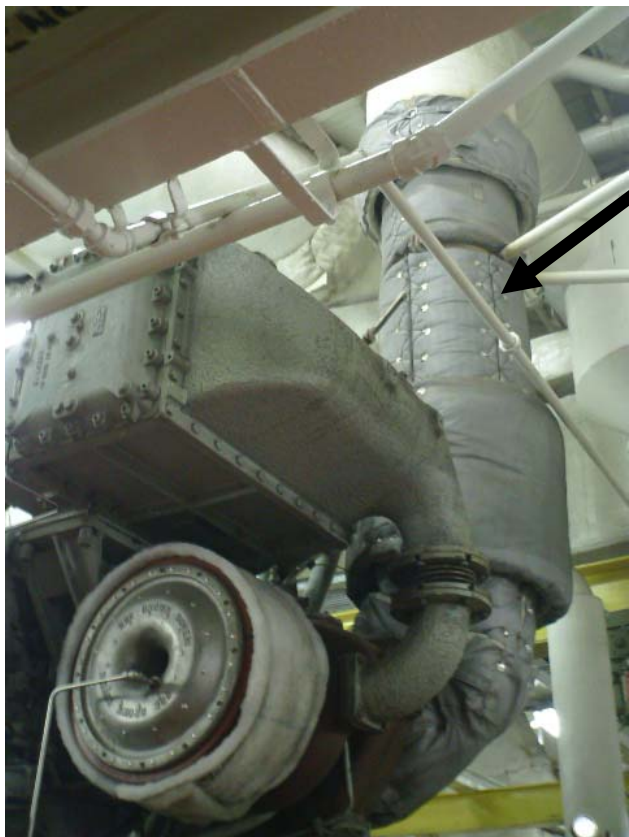
Plans for Phase II





Proposed Phase II Application: Full Scale TEG for SSDG Exhaust Heat Recovery

SSDG Exhaust Stack



MAK332 Diesel Generator Set



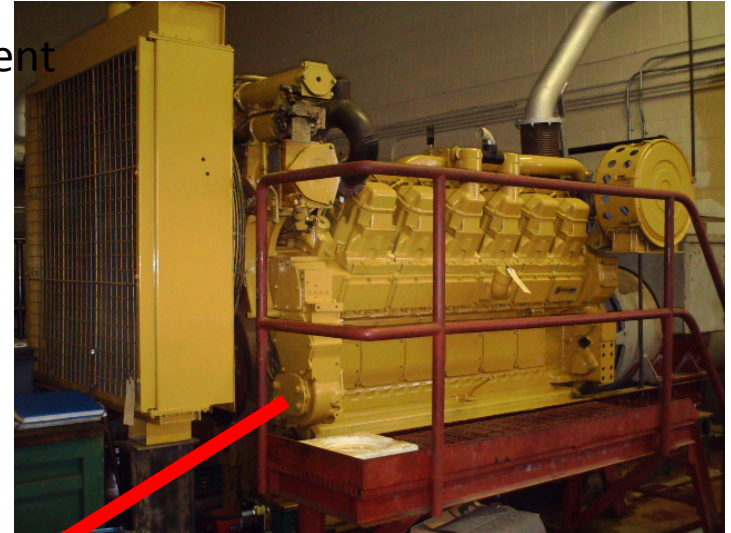
MMA Diesel Lab Facilities and Prototype Development

Gas Turbine Test Stand

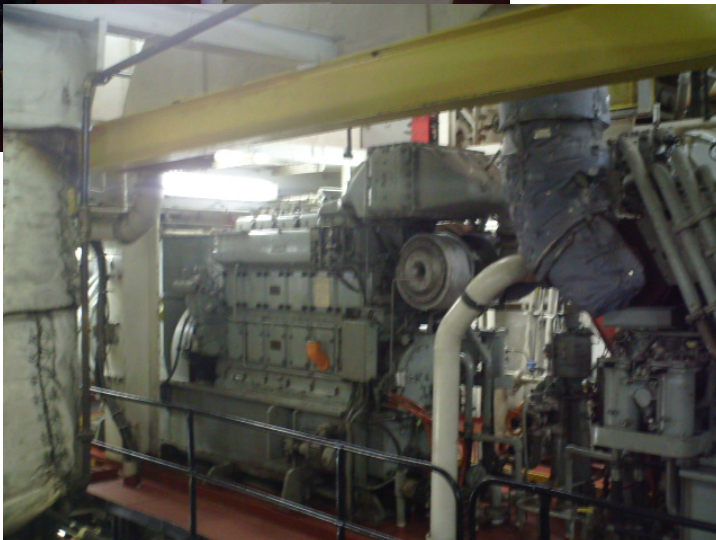
Stationary Diesel Genset



Unit Development



Test full scale TEG in lab



Transfer to ship SSDG



Testing at Sea

TSSOM Shipboard SSDG



Conclusions and Future Plans:

Early results show that Thermoelectric Power Generation is promising for applications in the Maritime Industry

Numerous challenges are involved in scale up, power regulation 440 V, testing advanced materials (beyond Bi_2Te_3)....

- Summer 2009 Data Collection on TS State of Maine
- Fall 2009 Development and configuration of test labs and computer model
- TEG Design and development Fall 2009/Spring 2009
- Construction of TEG prototype Spring/Summer 2010
- Lab Testing Fall 2010
- Install on TSSOM Spring 2010
- Test on Cruise 2010
- Acquire additional vessels for TEG installation
- **Position MMA to be a leader in the field of TEGs in the Marine industry**



Acknowledgments



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