NATIONAL RENEWABLE ENERGY LABORATORY

Light-Weight, Low-Cost, Single-Phase, Liquid-Cooled Cold Plate

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Project Duration: FY 11 to FY 12

DOE Vehicle Technologies Program
Advanced Power Electronics and Electric Motors R&D
FY12 Kickoff Meeting

Oak Ridge National Laboratory
Oak Ridge, Tennessee

November 3, 2011

NREL/PR-5400-52808

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

USDRIVE
DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

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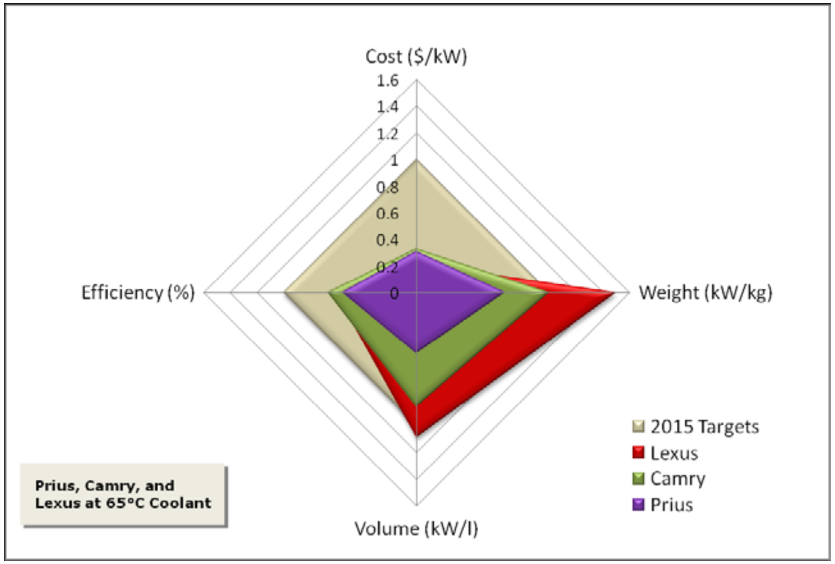
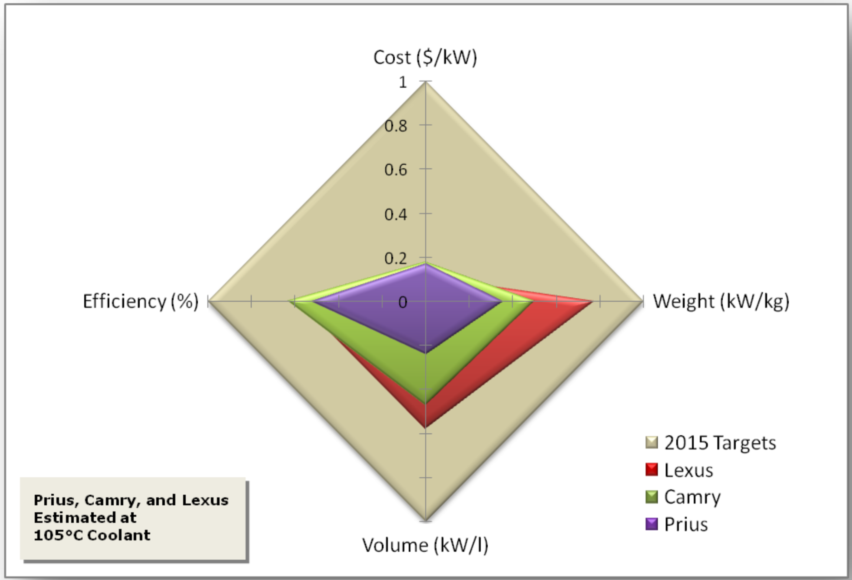
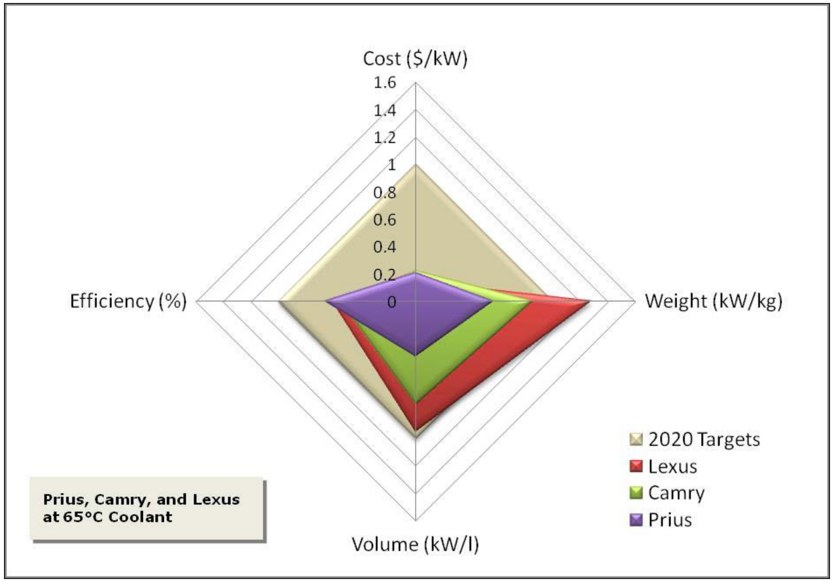
The Problem

- Directly addresses program goals of increased power density, specific power, and lower cost of power electronics components through improved thermal management.

- Enabler to using high-temperature water-ethylene glycol (WEG) mixture as coolant.







Courtesy: Electrical and Electronics Technical Team Roadmap, 2010
http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/eett_roadmap_12-7-10.pdf

Project Overview

Research Focus Area: Thermal Management

➔ Heat Transfer Technologies, Thermal Systems Integration

Objective

- Demonstrate prototype inverter heat exchanger of lighter weight and higher thermal performance than the baseline heat exchanger; demonstrate potential for reducing cost.

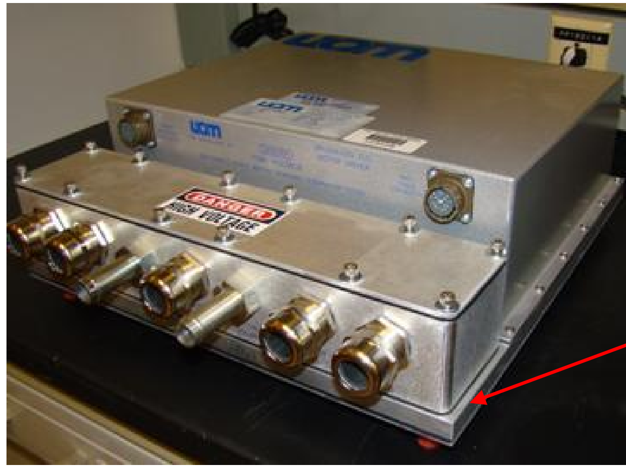
Addresses Targets

- Increased power density, specific power, and lower cost.
- Use of higher-temperature coolant.

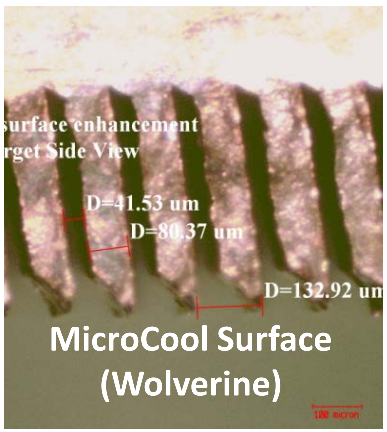
Uniqueness and Impacts

- Combination of microfinned surfaces, single-phase liquid jets, light-weight and low-cost plastic manifold demonstrated on a commercial inverter (UQM) platform.
- Reliability assessment also performed.

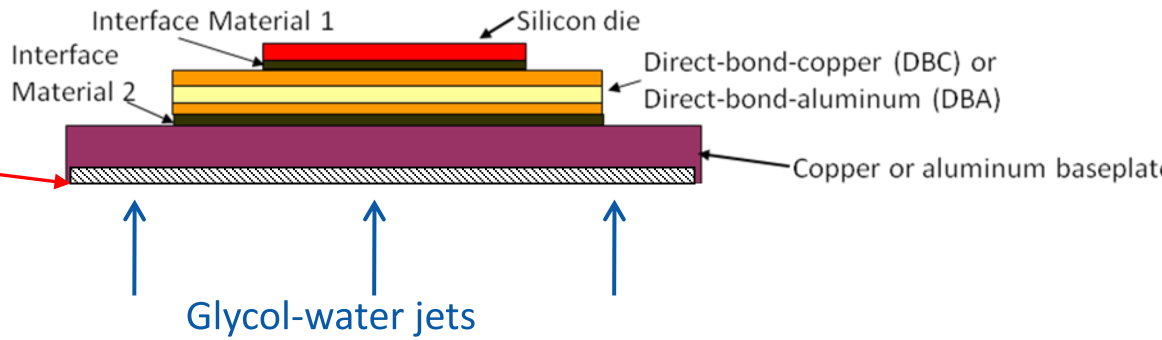
Description of Technology/Approach



Credit: Sreekant Narumanchi, NREL



Credit: Mark Mihalic, NREL

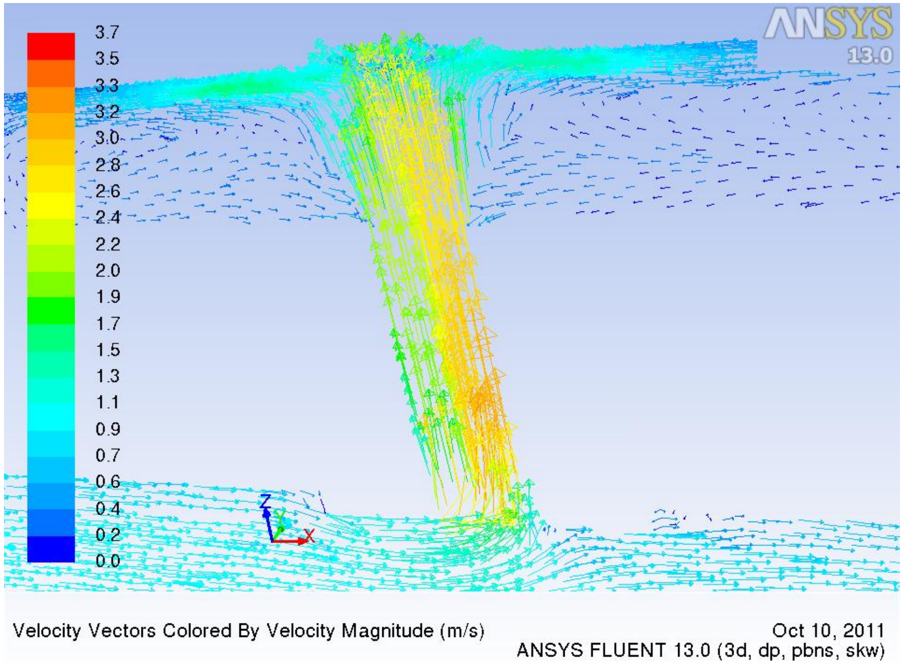


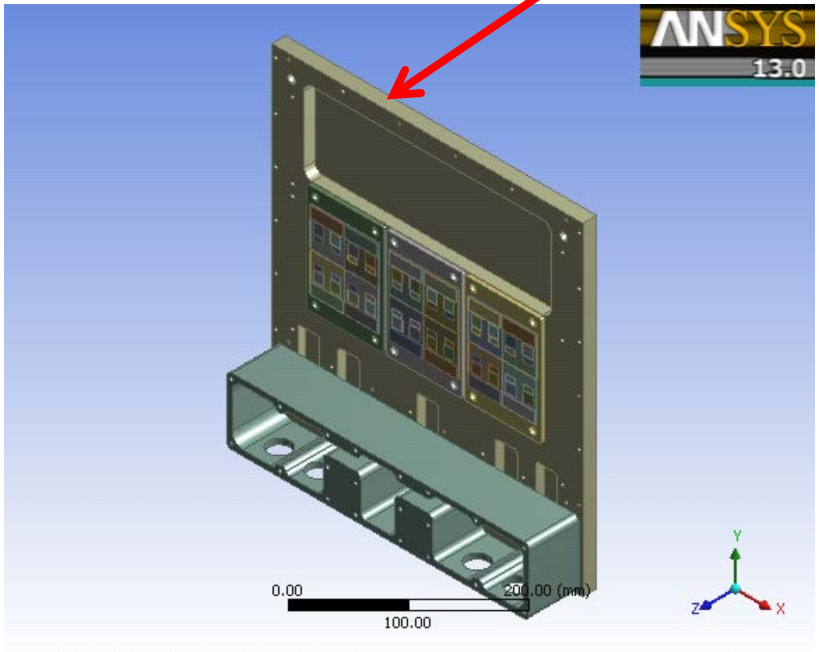
- Reduce thermal resistance, increase heat transfer rates through impingement on enhanced surfaces, and use light-weight, low-cost plastic fluid manifold.
  - Demonstrate increased power density, specific power, and lower cost.
- Characterize thermal performance based on steady-state and transient/realistic loading conditions (dynamometer testing).

Heat Exchanger Design

Credit: Sreekant Narumanchi, NREL

- A jet plate designed using computational fluid dynamics (CFD) with WEG coolant (50–50% mixture by volume).
- A glass-fiber reinforced nylon plastic material envisioned for the bulk of the fluid manifold (replacing aluminum).
- Microfinned structures on the copper base plate on which the jets impinge.

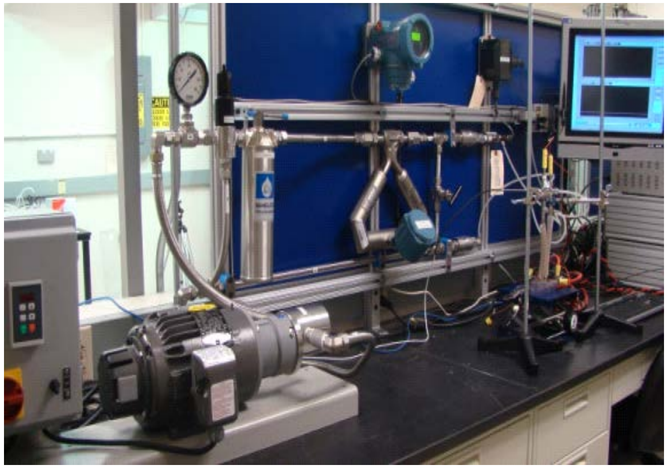




Validation of CFD Modeling for Baseline Heat Exchanger

Flow rate (m^3/s)	Pressure drop (Pa)		Average temperature in diodes (°C)	
	Experiment	CFD	Experiment	CFD
0.336e-04	1,076	1,079	84.9	84.0
1.667e-04	19,374	16,988	82.8	82.9

- 105.3 W dissipated in four diodes in the center power module.
- WEG mixture (50–50% by volume) at 70°C used as coolant.
- Junction temperature in the four diodes measured using the transient thermal tester during the steady-state heating.
- Reasonable match between modeling and experimental results.



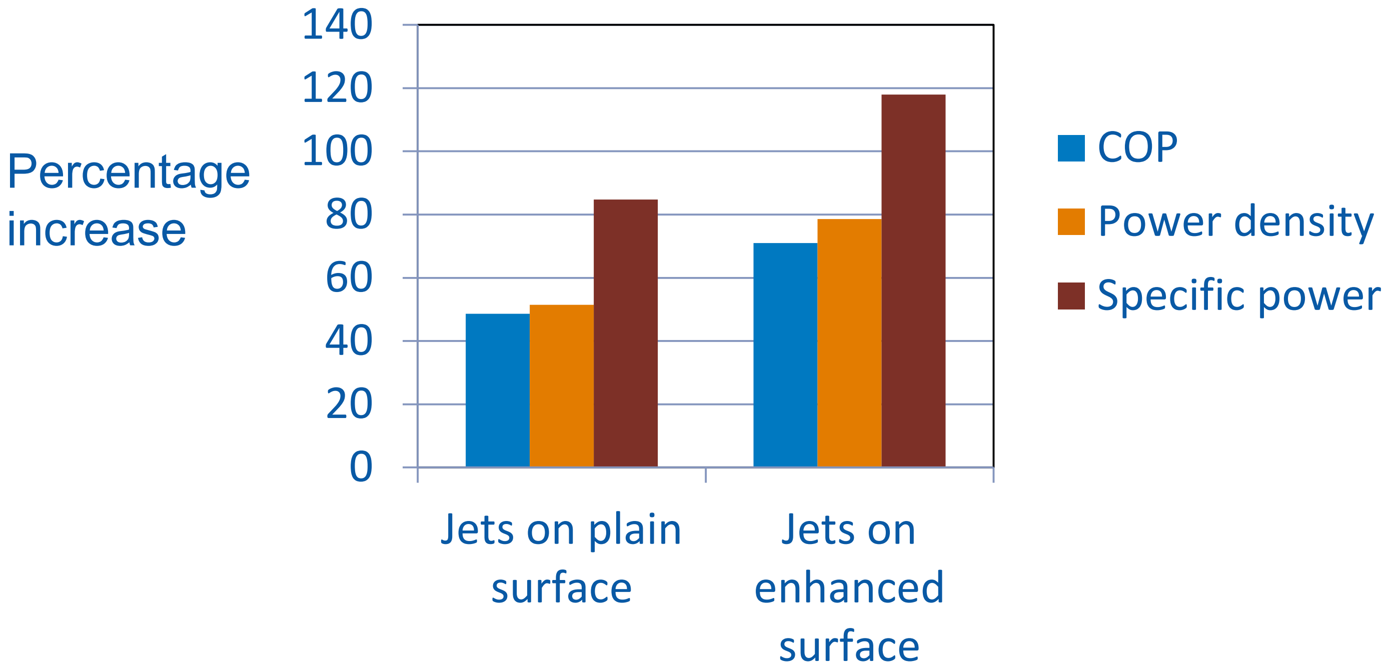
Credit: Sreekant Narumanchi, NREL

CFD Modeling Results for New Heat Exchanger

Parameter	Baseline (channel flow)	Jets impinging on plain surface	Jets impinging on microfinned surface
ΔP (Pa)	16,858	17,458	17,458
$R_{th, ja}$ (K/W)	0.294	0.191	0.166
Isothermality (^0C)	2.7	0.3	0.15

- Design case with 2.5-kW heat dissipation spread over 24 insulated gate bipolar transistor (IGBTs) (72 W in each IGBT) and 24 diodes (33 W in each diode).
- WEG at 70°C as coolant, thermal resistance based on 4 diodes in the center module: $R_{th, ja} = (T_{4diodes, avg} - T_{coolant})/q_{4diodes}$.
- For similar parasitic power as the baseline
  - Jets on plain surface yield **34%** lower thermal resistance
  - Jets on enhanced surface yield **44%** lower thermal resistance compared to baseline.

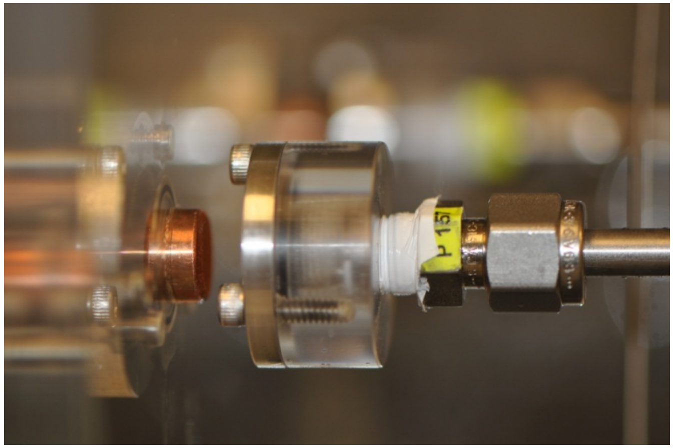
Impacts on Coefficient of Performance (COP), Power Density, Specific Power and Cost



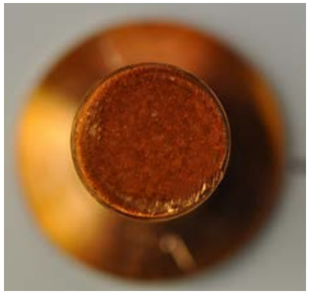
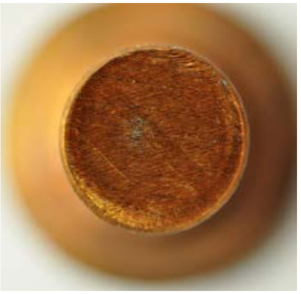
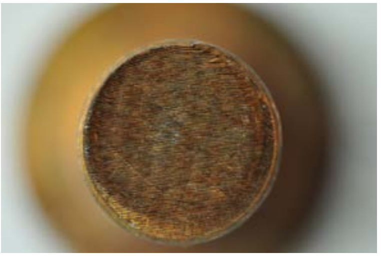
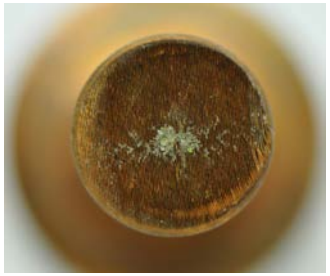
- Up to **71%** increase in COP.
- Up to **79%** increase in power density.
- Using plastic results in approximately 2.9 kg (6.3 lb) or 50% weight reduction of the heat exchanger
  - Results in up to **118%** increase in specific power.
- Cost likely to be competitive with respect to aluminum baseline heat exchanger.

Experimental Reliability Assessment of Jet Impingement

- Tests initiated with WEG impinging on microfinned surface (on 12.5-mm-diameter copper target surface).
- Evidence of oxidation on surfaces (no initial coating/plating on the surface).

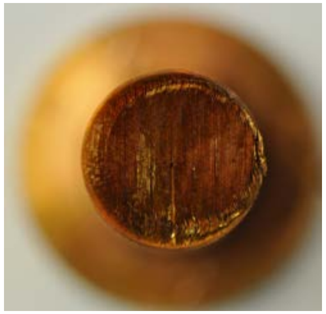
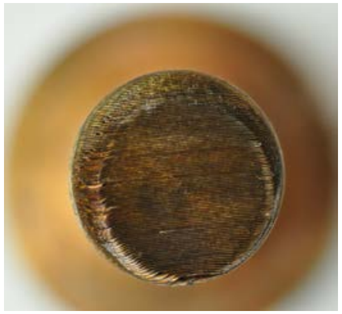
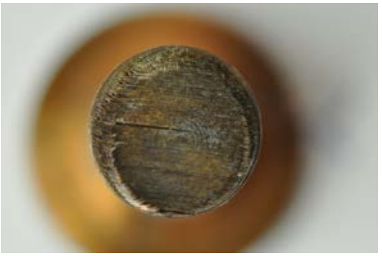
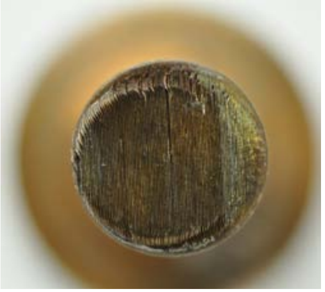


Sample W1 (7 m/s jet velocity)

t=0 t= 30 days t= 60 days t= 90 days

Sample W2 (2 m/s jet velocity)

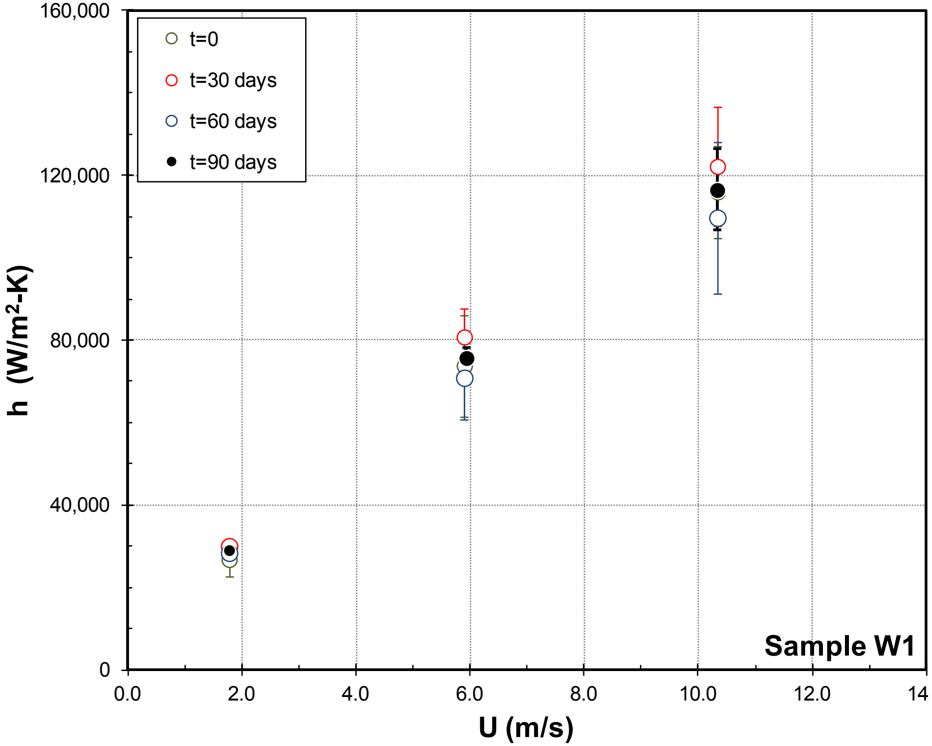





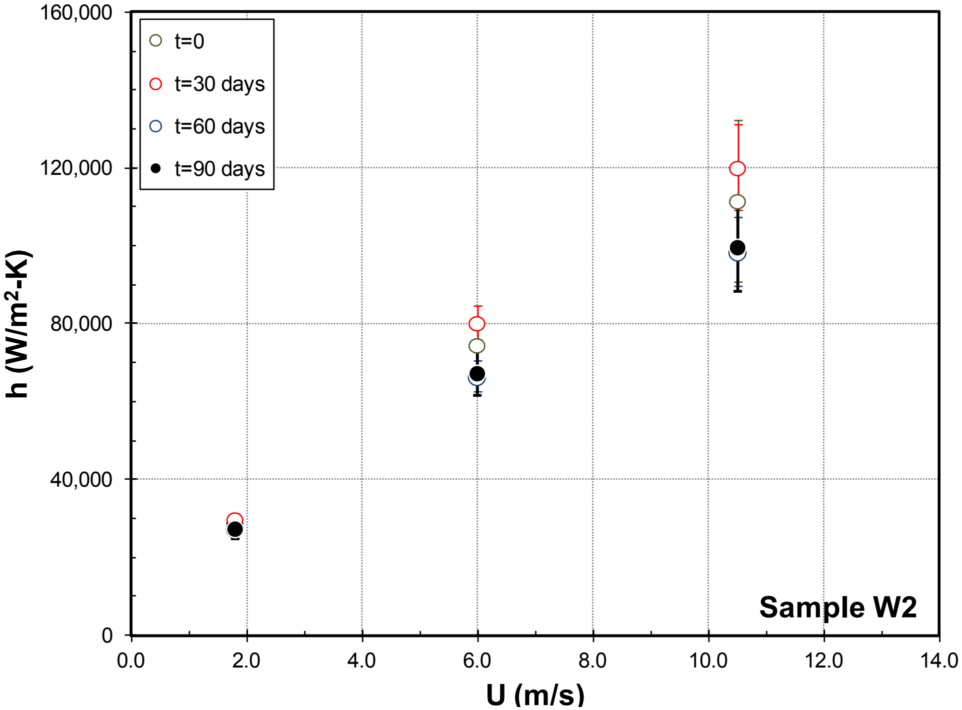
Credit: Gilbert Moreno, NREL (all photos)

Experimental Reliability Assessment of Jet Impingement

- Change in thermal performance of the surfaces over time (90 days of impingement) within the 95% confidence intervals (CI).

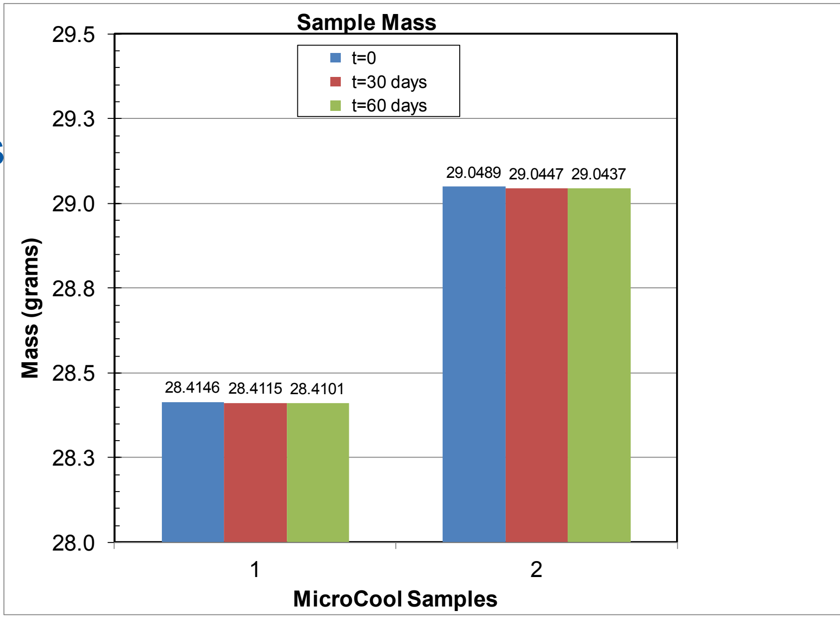
Error bars: ± t s / √n
t = student t-distribution (95% CI)
s = sample standard deviation
n = number of tests (3-4 typical)

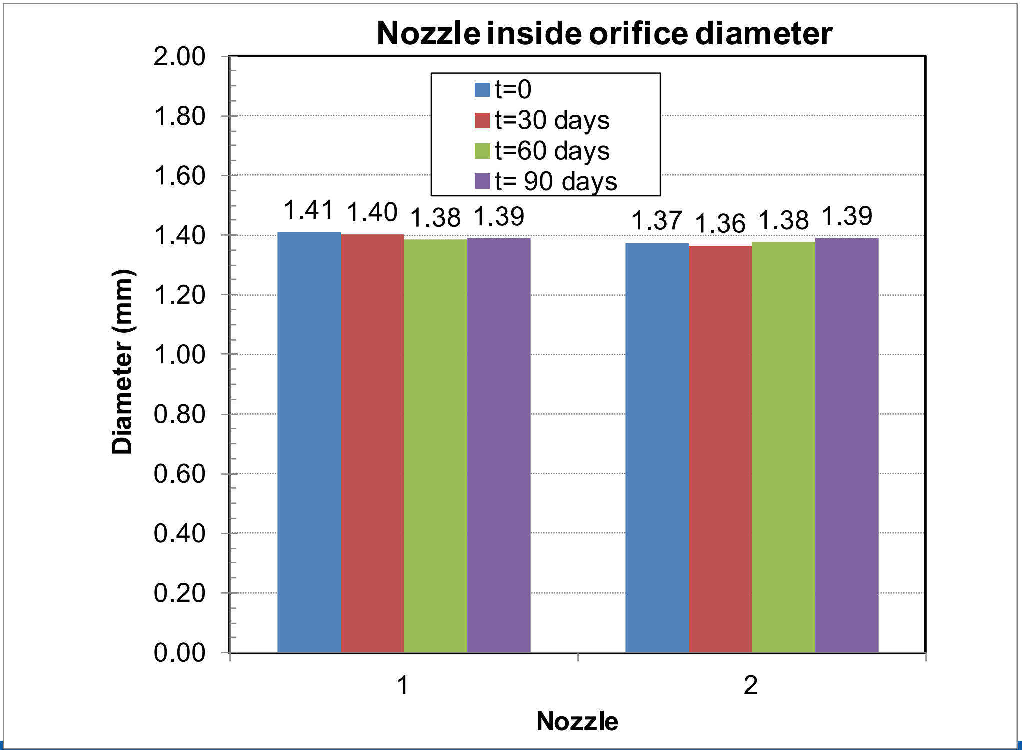


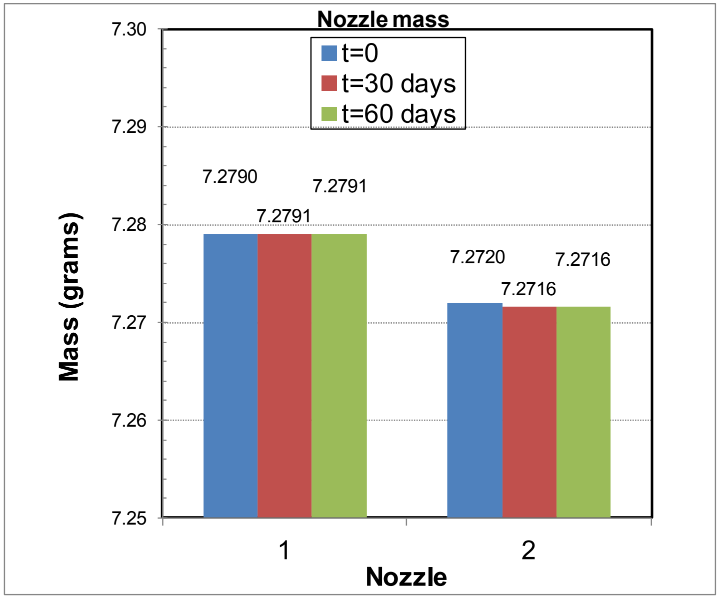


Experimental Reliability Assessment of Jet Impingement

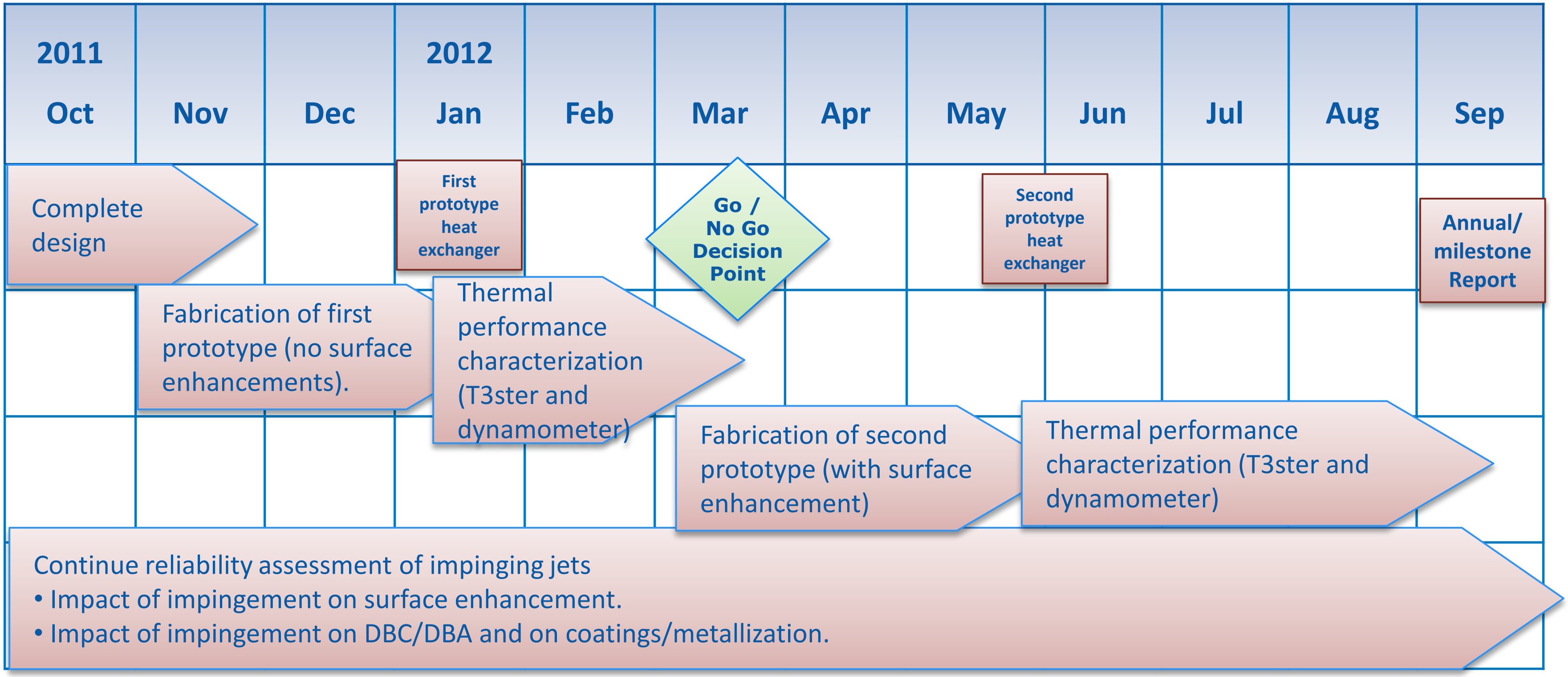
- Negligible change in mass of the enhanced surface samples and the nozzles after 60 days of nearly continuous impingement.
- Negligible change in jet nozzle diameter after 90 days of nearly continuous impingement.







FY12 Approach and Challenges



Go/No Go Decision: **Assess whether performance improvements from the first prototype (jets on plain surface) merits fabrication of second prototype (jets in conjunction with enhanced surfaces).**

Challenges/Barriers:

- **Various aspects of reliability of the system have to be proven.**
- **Performance improvements specific to this inverter configuration.**
- **Inferring cost benefits for a large number of units is a challenge.**

FY12 Approach Highlights

- Two prototype heat exchangers will be fabricated and performance demonstrated.

- Modeling results indicate up to 71% increase in COP, 79% increase in inverter power density and 118% increase in specific power as compared to the baseline
  - Novel impingement configuration which also eliminates thermal grease from the system.

- Cost likely to be competitive with respect to the baseline heat exchanger.

FY12 Approach Highlights

- Results for reliability of the system will be obtained
  - Initial results suggest thermal performance of the enhanced surfaces do not degrade after three months of continuous impingement.

- Dynamometer testing of the inverter with the baseline and enhanced heat exchangers.

Beyond FY12

- Project in current form ends in FY12.

- FY13-FY15
  - Low-cost, light-weight, reliable, high-thermal performance concepts could be proposed with single-phase liquid flow configurations for alternative power electronics packaging configurations.
  - With the constant trend towards reducing the footprint of components, concepts related to miniaturization of cold plates will be investigated.

Acknowledgments:

Susan Rogers and Steven Boyd,
U.S. Department of Energy

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Gilbert Moreno

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