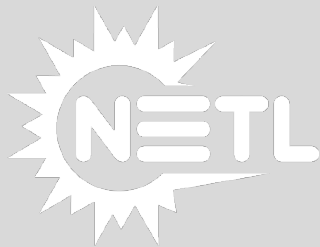


“Scaling Up WATT Fuel Cell’s Additive Manufacturing Process (AMP)”



connect with us

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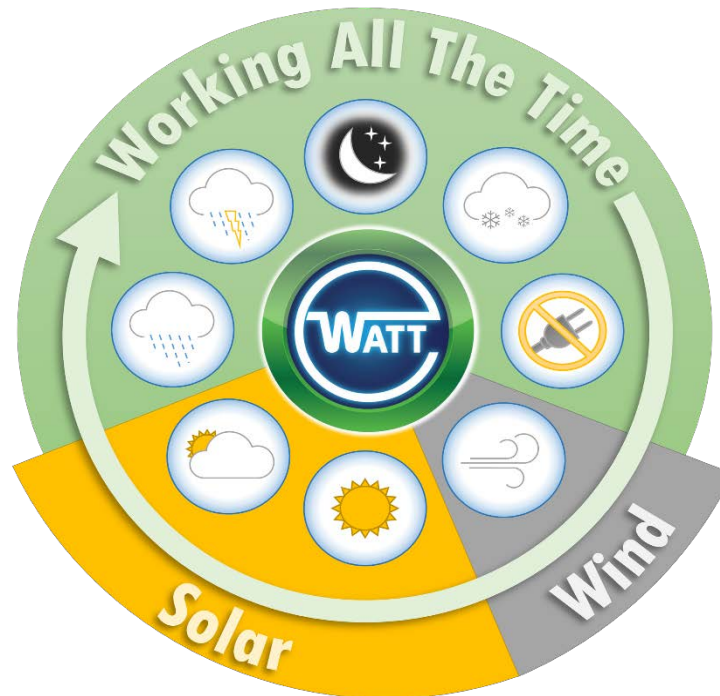


July 14-16 2015

16th Annual Solid Oxide Fuel Cell (SOFC) Workshop

Agenda

- Overview of WATT Fuel Cell Corp
- Progress on WATT's RIF 2013 Contract – AMP Scale Up
- WATT's Commercial Portable Fuel Cell Technology
- Development of portable SOFC liquid-fueled systems for the US military



Who is **WATT** Fuel Cell?



Who is WATT Fuel Cell?

- Tubular SOFC Technology Manufacturer
- Manufacturing and Operations Plant in Mount Pleasant, PA (With offices in Port Washington and the Hampton Bays, NY)
- Marketed towards portable, military and small Distributed Grid (DG) power applications
- 13 filed patents and 23 active patent applications
- Business Model based upon Direct Customer or Strategic Partnership
- Multi-Fuel Processing Flexibility



WATT Owned Subsidiary – Pittsburgh Electric Engines, Inc. (PEEI)

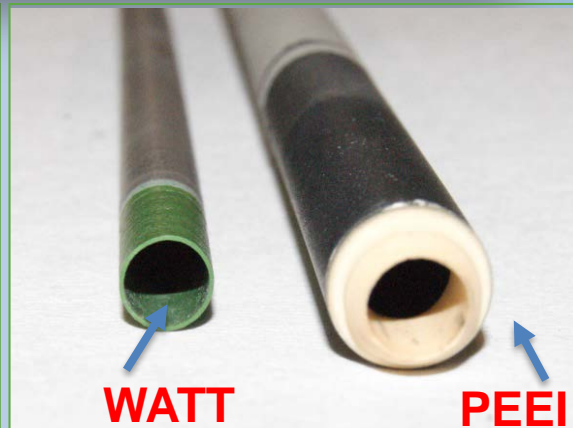


The screenshot shows the PEEI website with a navigation bar containing 'TURBO FUEL CELL ENGINE', 'TECHNICAL CAPABILITIES', 'FACILITIES', and 'CONTACT US'. The main content area features a large image of a truck and a list of 'TURBO FUEL CELL ENGINE BENEFITS':

- ENVIRONMENTALLY CLEAN
- 40% FUEL SAVINGS
- USES CURRENT FUEL SYSTEM
- DROP-IN REPLACEMENT

A 'LEARN MORE' button is visible below the list. Below the truck image, the text reads: 'A DIRECT REPLACEMENT FOR EXISTING DIESEL ENGINES. Over a span of 15 years, Pittsburgh Electric Engines, Inc. (PEEI) developed the only practical alternative energy engine capable of powering heavy highway trucks and military vehicles while saving energy costs and environmental impact.'

Large tubular SOFC (25")



Technology

- Large format - tubular
- Air electrode supported
- 37,000h of test time
 - Stable Operation
- Robust current collection
 - Reliability
- Extrusion based manufacturing
 - Can be manufactured utilizing WATT's AMP process
- Interfaces well with WATT's modular approach

WATT in Mount Pleasant, PA



- 40k sq. ft. of lab and office space between WATT and PEEI
- Full in-house capability
 - Synthesis of materials
 - Cell and stack production
 - Fuel processing
 - Construction of complete fuel cell systems
- State-of-the-art clean room for WATT's AMP (printing multilayered, ceramic and cermet tubular cells)
- Full range of liquid and gaseous fuels testing capabilities



On Site - Analysis and Evaluation Packages



Analytical

- Thermo-gravimetric Analysis
- Laser Diffraction PSD
- Acoustic PSD
- Zeta Potentiometric Analysis
- B.E.T. Surface Area Analysis
- Multiple GC/MS
- Rheometry

Electrochemical Evaluation

- Impedance Spectroscopy
- Custom Fuel Cell Test Stands
- Custom Fuel Cell Stack Test Stands
- Custom Fuel Cell System Test Stands

Imaging and Detection

- SEM with EDS
- Video-based microscopes

World Class Manufacturer - WATT Fuel Cell

Cell

- **Additive Manufacturing Process (AMP)**
 - Automated Cell Production – PROCESS CONTROL
 - Rapid Deployment of Modified Designs
- **Capacity to support high volume batch or continuous production**
 - Cost Reduction ↔ Waste Reduction ↔ Recipe Flexibility ↔ Repeatability
- **Alternative Geometries**

Stack

- **Expandable Modular Format**
- **“Seal-less Stack” allows for a range of compliant materials in assembly (i.e. Plastic Manifold)**
 - Cost Reduction ↔ Weight and Size Optimization ↔ Quality/Integrity
- **High Volume Batch Production enables application flexibility**
 - The benefit of high volume production without the capital outlay typically incurred by an inflexible mass production process

BoP and System

- **BoP is the “Foundation of the WATT Stack”**
 - Design for Manufacturing and Assembly (DFM&A)
 - Enhanced Reliability and Performance Predictability
- **Modular Design**



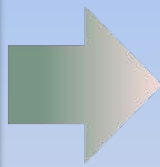
Scale-Up



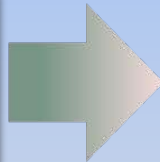
Conventional SOFC Tubular Manufacturing



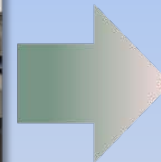
Paste
Preparation



Extrusion



Drying and Tube
Preparation



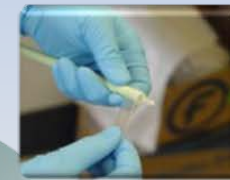
Burn-out and Pre-fire

Separate support formation and coating technologies require more than

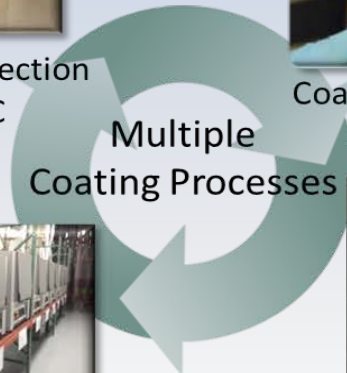
300 hours
of processing time!



Coating Inspection
and QC



Coating Preparation



Coating Sintering

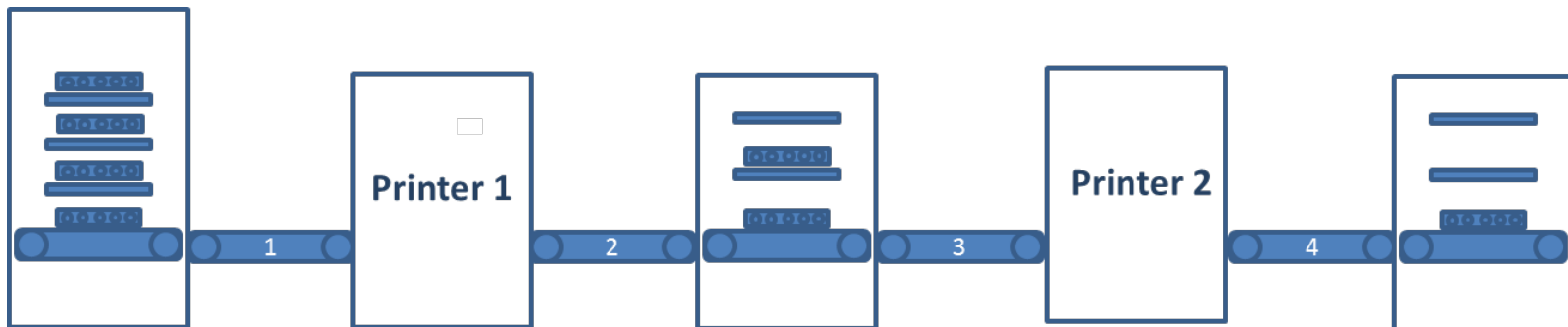


Coating Processes

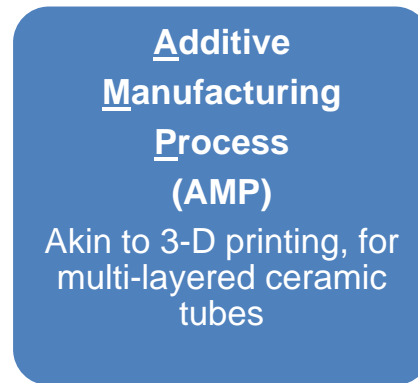
RIF2013 – 2,000 systems per year

2 Year Contract, \$2.1m supported by DoD

- Adapt **WATT's** AMP commercial printing process to scale production of micro-tubular SOFC suitable for military operations.
- Tasks Include:
 - Design and fabricate optimized rack-mount cartridge
 - Design and fabricate auto-loader equipment
 - Design and Optimize software for integrated systems
 - Evaluate the efficiency of manufacturing SOFC technology
 - Design and Validate Mfg. Process to Support 2000+systems/year
 - Build and deliver a TRL-5 SOFC liquid-fueled system



RIF2013 – WATT's Solution for Manufacturing SOFCs



WATT's patented Additive Manufacturing Technology

One technology to manufacture multiple layered ceramic tubes with varying densities

- 60% less energy consumption to create SOFC products
- Precise, repeatable, low cost deposition of layers
- Raw material waste is highly controlled (reduced by 42% to-date!)
 - ✓ Increased Recycle
- Low Cost vs. High Energy Density
- Modular Scalability
 - ✓ Decreased capital cost in machine set-up and commissioning
- Tailored structures using automated controls
- Intrinsically higher part quality
- Increased production rate by ~400%



Case Study: Improvement (performance and cycle time) of Anode Support Manufacturing Process (Cost and Efficiency Opportunities)

Define

- Decrease cycle time (capacity)
- Improve Cell Performance
- Stable Operations
- Reduce Variability

Measure

- Physical measurements (length, wall thickness, mass, etc)
- Structure
- Cell Performance (Power, OCV)

Analyze

- Variability in physical measurements
- Variability in performance
- Manufacturing process steps
- Machine Configurations
- Identify root causes

Improve

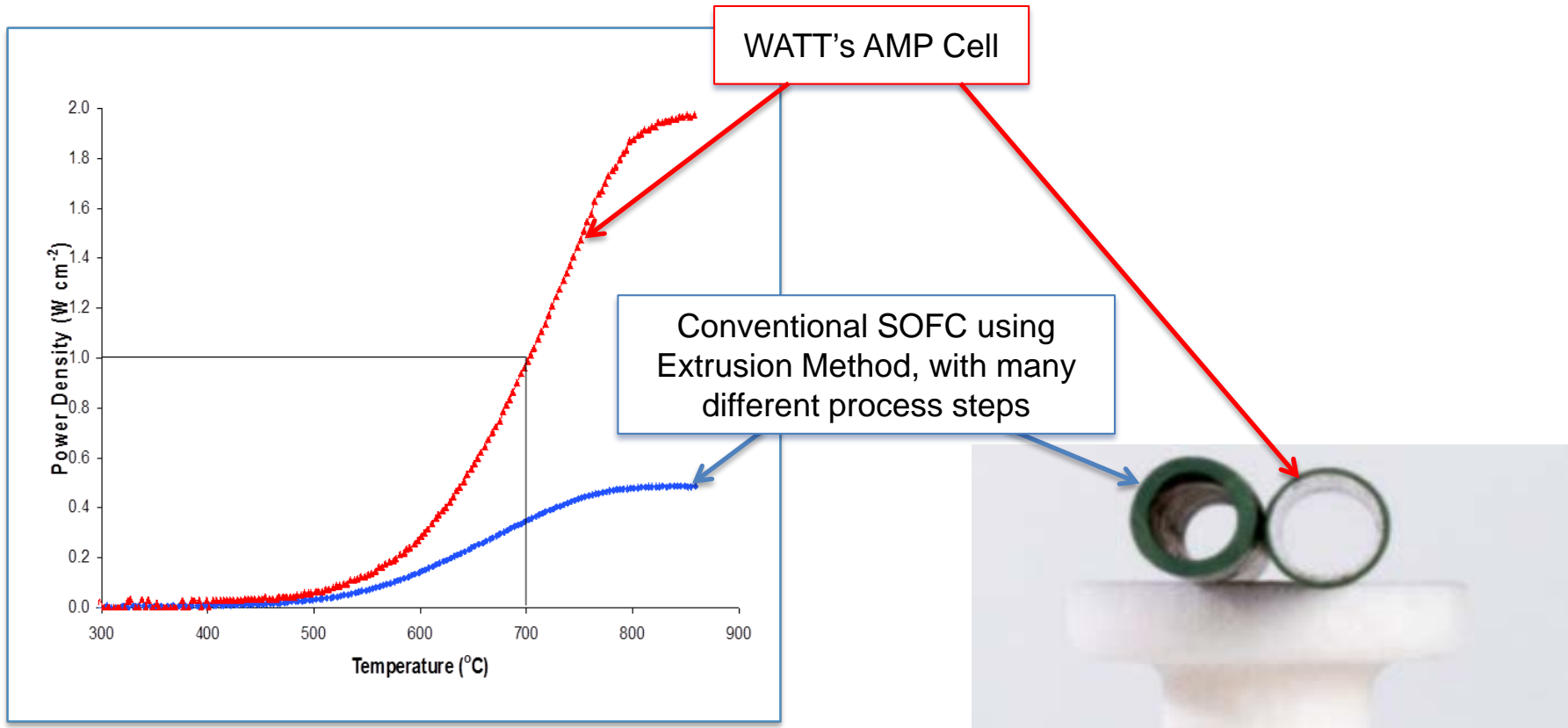
- Machine configurations
- Process Documentation
- Handling Steps
- Material Sets
- Recipes

Control

- Process Control Cards (Machine Recipes)
- Ink Recipes
- Process Documentation
- Testing Procedures
- Process Automation

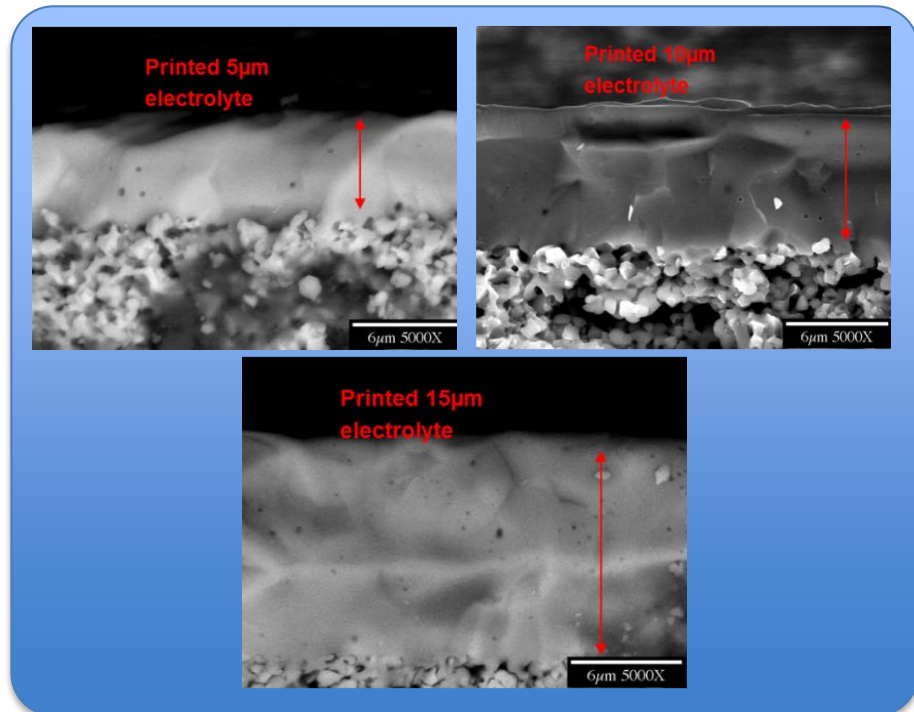
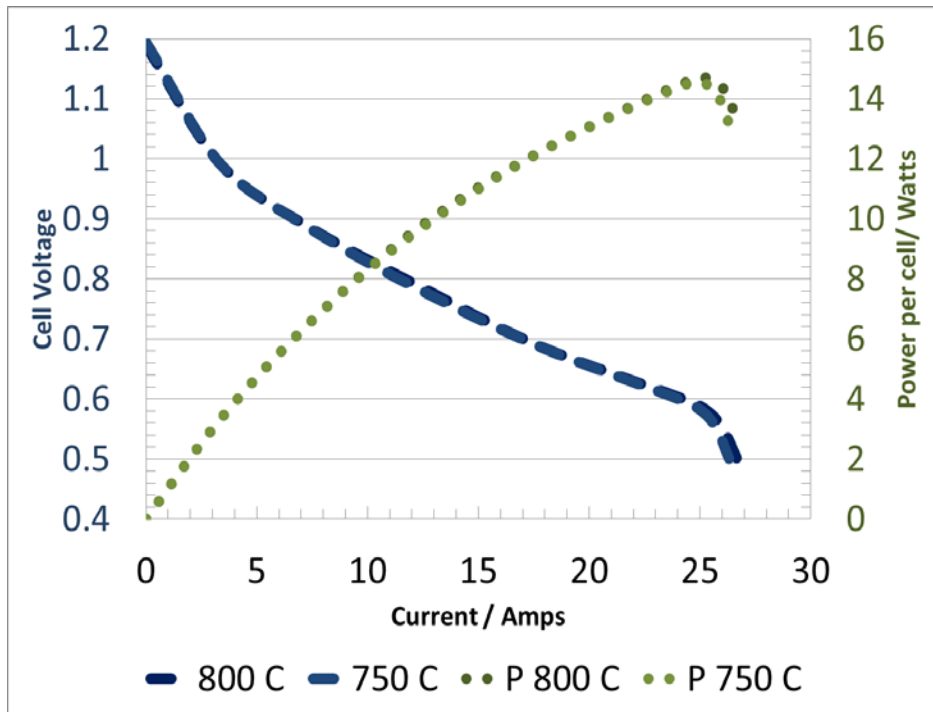
Outcome: 62.5% decrease in cycle time
6% increase in overall First Pass Yield (FPY)
7% and 9% increase in performance (Power and OCV, respectively)

Cell Performance using AMP



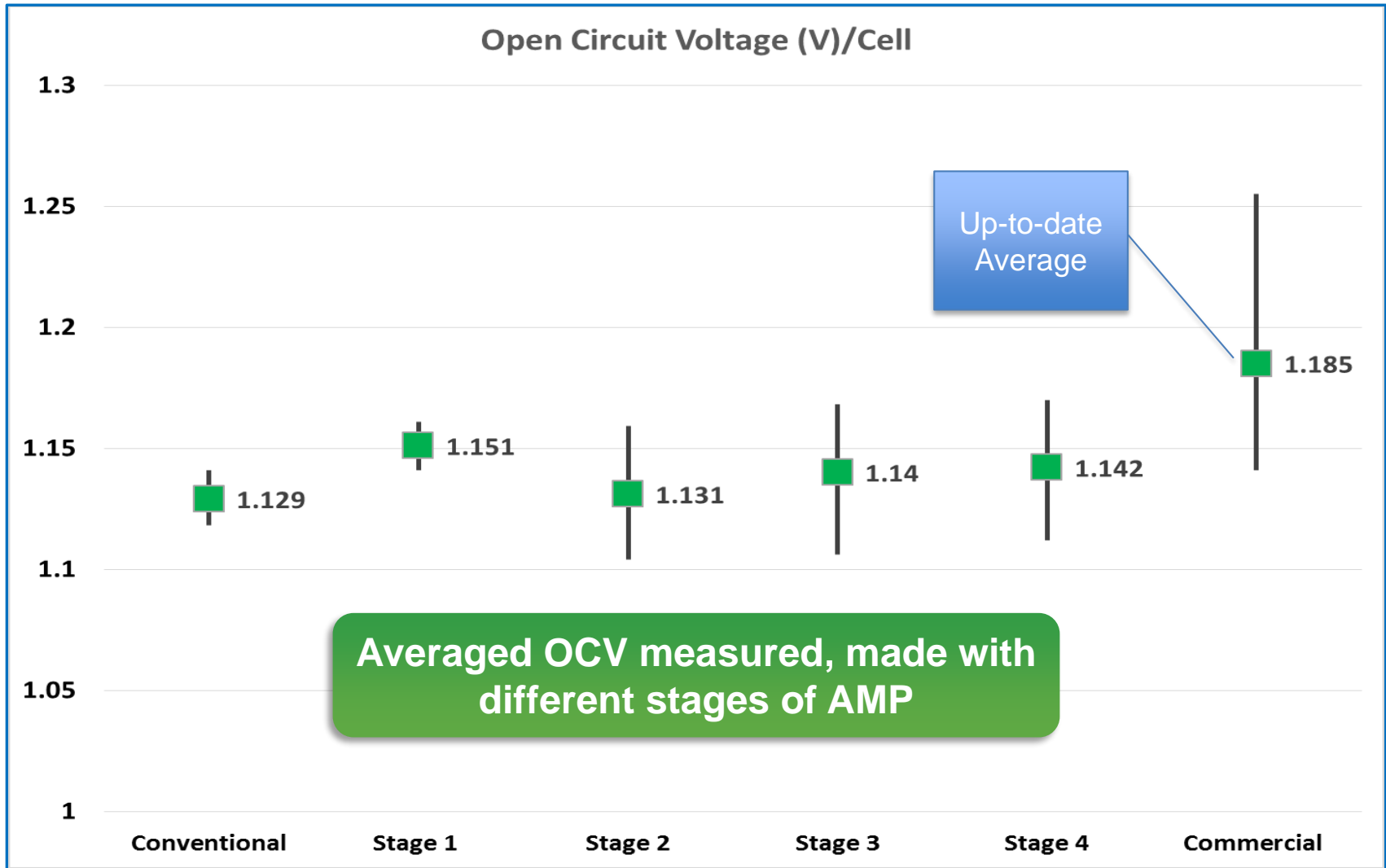
Increased power density. Less mass, time to manufacture, handling, energy consumed in manufacturing, and reduced Cost of Goods (COGs)

Sample Performance Metrics - WATT SOFC



1. Cell Production Rate: 3,128 per Q
2. Controllable layer thickness: 0.5 µm
3. Average OCV: 1.185 Volts
4. Low Standard Deviation, OCV
5. Max power per cell ~ 15 Watts

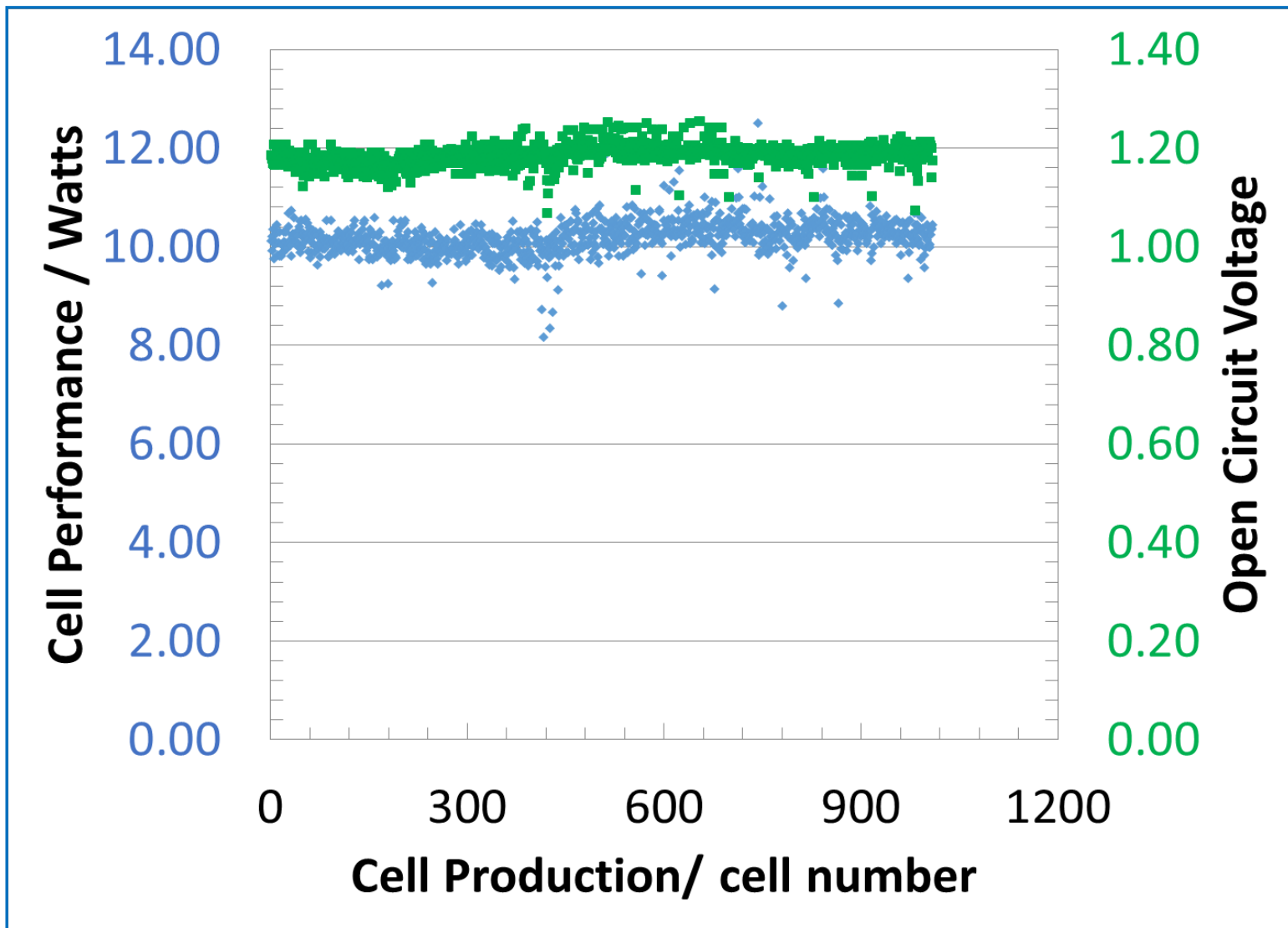
Demonstrated Feasibility of AMP



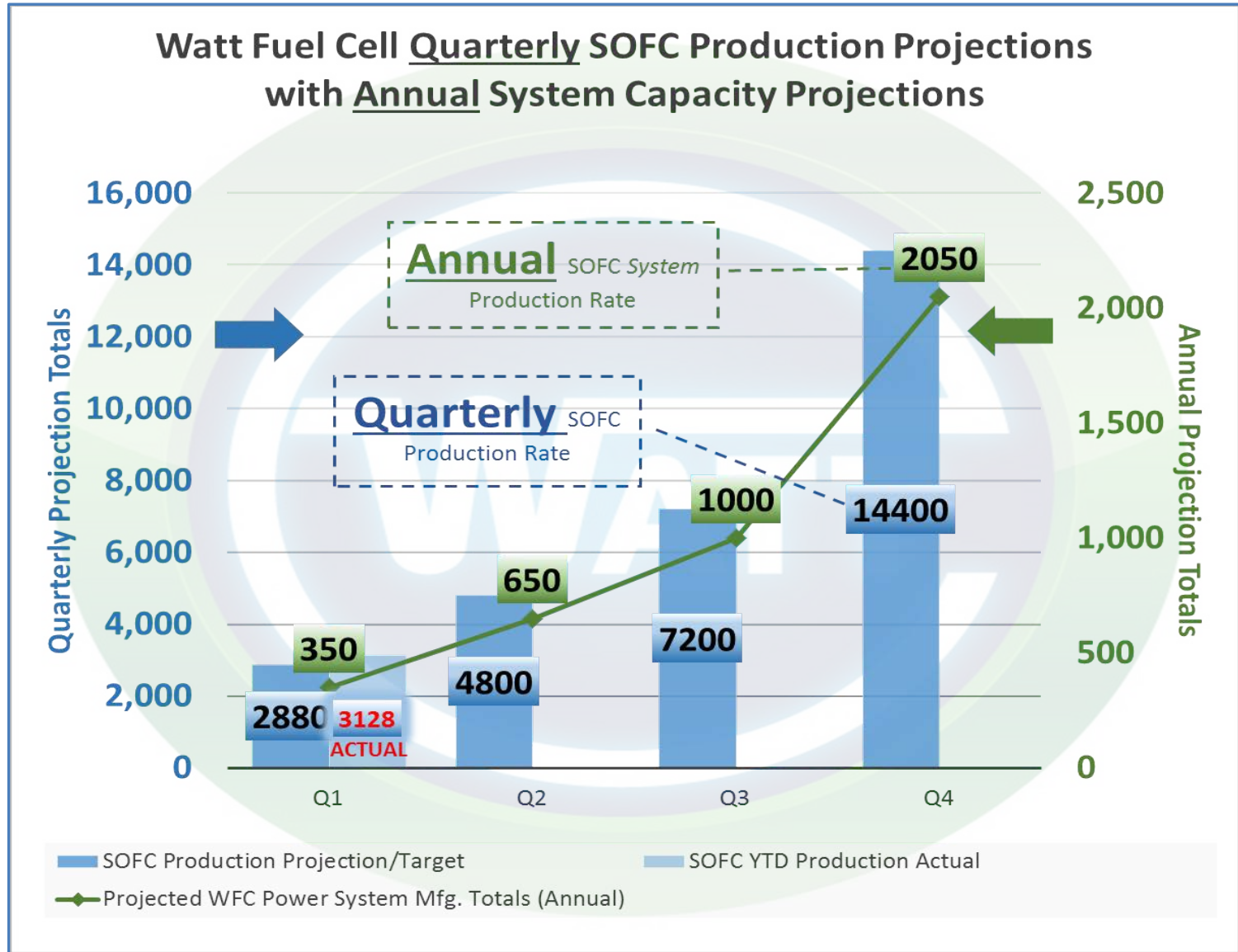
Results from feasibility study showing comparing OCVs, QC Check



Preliminary Results – 1,000+ Samples, SOFC Performance Data



Preliminary Results – 2015 SOFC Production



Project Status

Summary:

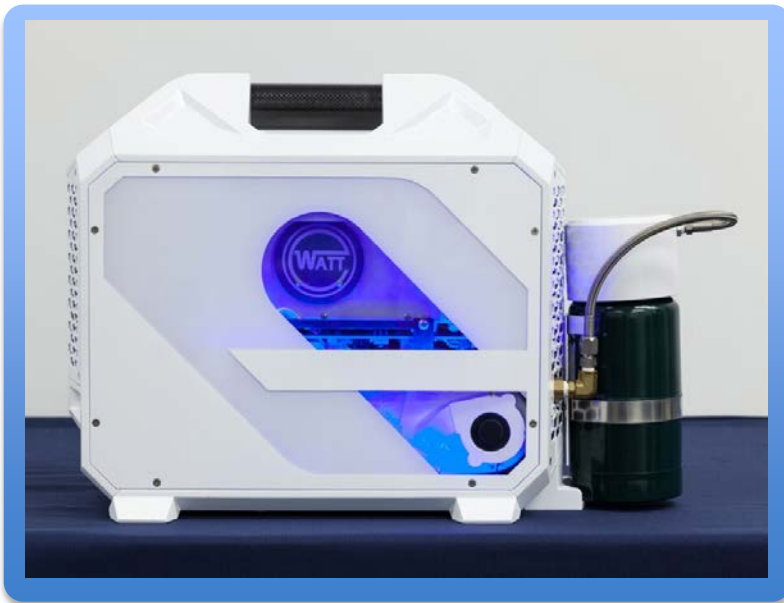
- Project is 39% complete and is progressing on-schedule
- Commercial Printer 1 and 2 Tested and Commissioned
- 24/7 SOFC production commissioning in Q3 2015
- Manufacturing Cycle Time successfully reduced by ~400%
- New printing cartridge, enabling a 2x increase in capacity, is designed.
- On/under budget for each reporting period
- Power and OCV 'pass' metric exceeded (with stability and repeatability) by ~7% and ~9%, respectively
- Environmental controls are being developed to decrease variability
 - Implementation Q3 2015



WATT's Commercial Portable Fuel Cell Technology



Portable Alpha System



Automated Battery Tender System Specs:

- 220W (expandable to 440W)
- 12 or 24 VDC
- < 20 lbs
- Propane fueled
- Startup time – 25 min to nominal run
- Fuel Consumption – 6 hrs per lb.
- Over 850 Wh/kg wet based on 20lb fuel tank

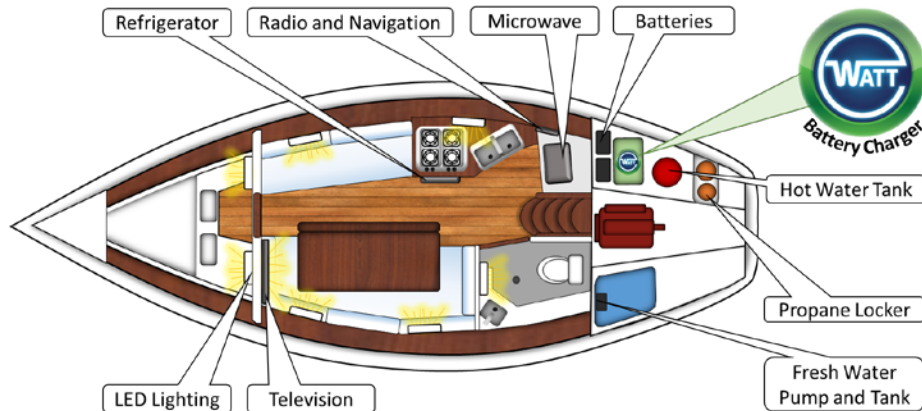


Portable Alpha System



Functionality:

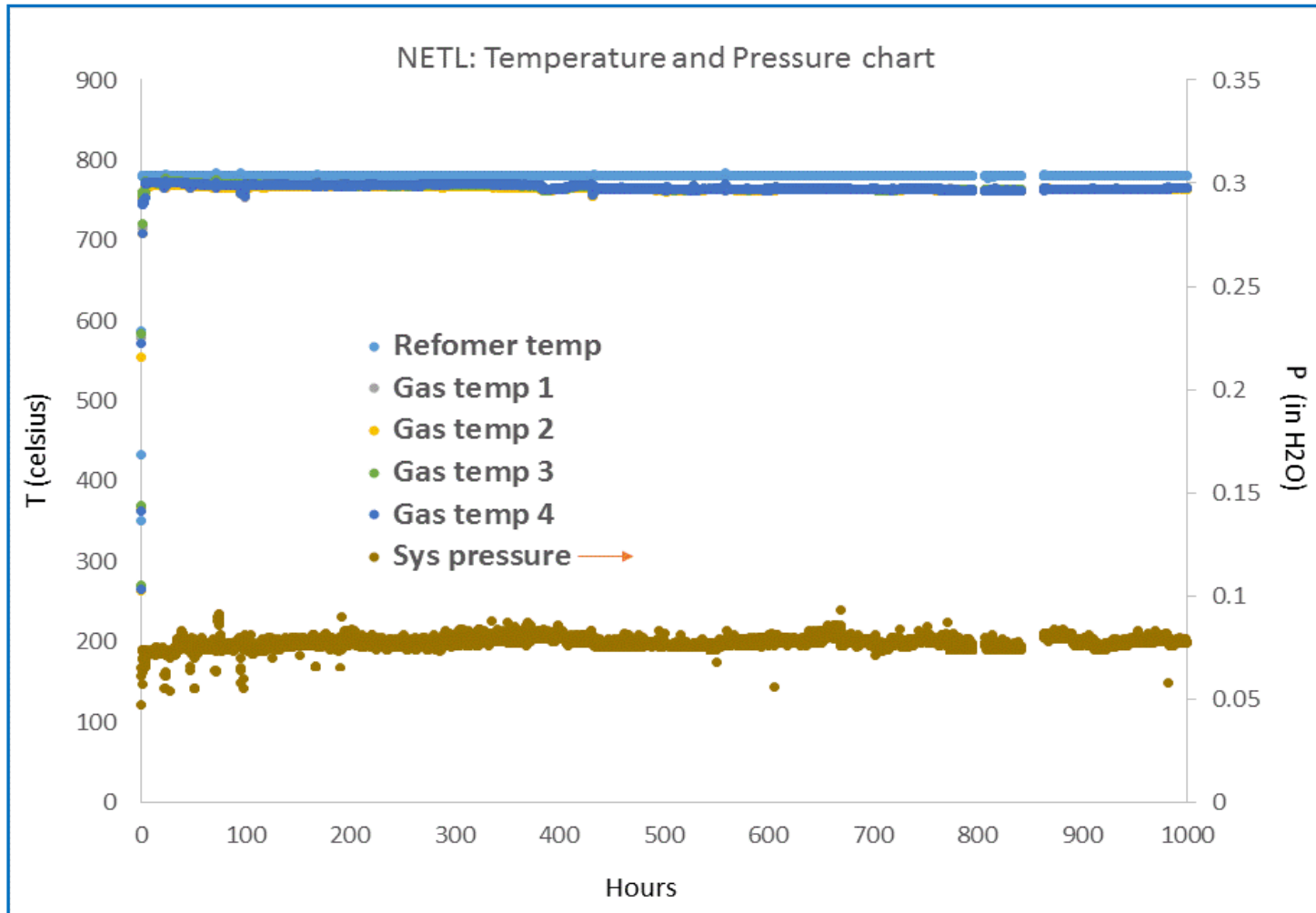
- Capable of charging dead battery bank
- Maintains charge level of bank, switching on automatically as State of Charge (SOC) drops to preset threshold
- System warns user and shuts down safely if battery disconnected
- Targeted to serve:
 - Marine
 - RV
 - Emergency Backup
 - Remote Power



NETL Catalyst



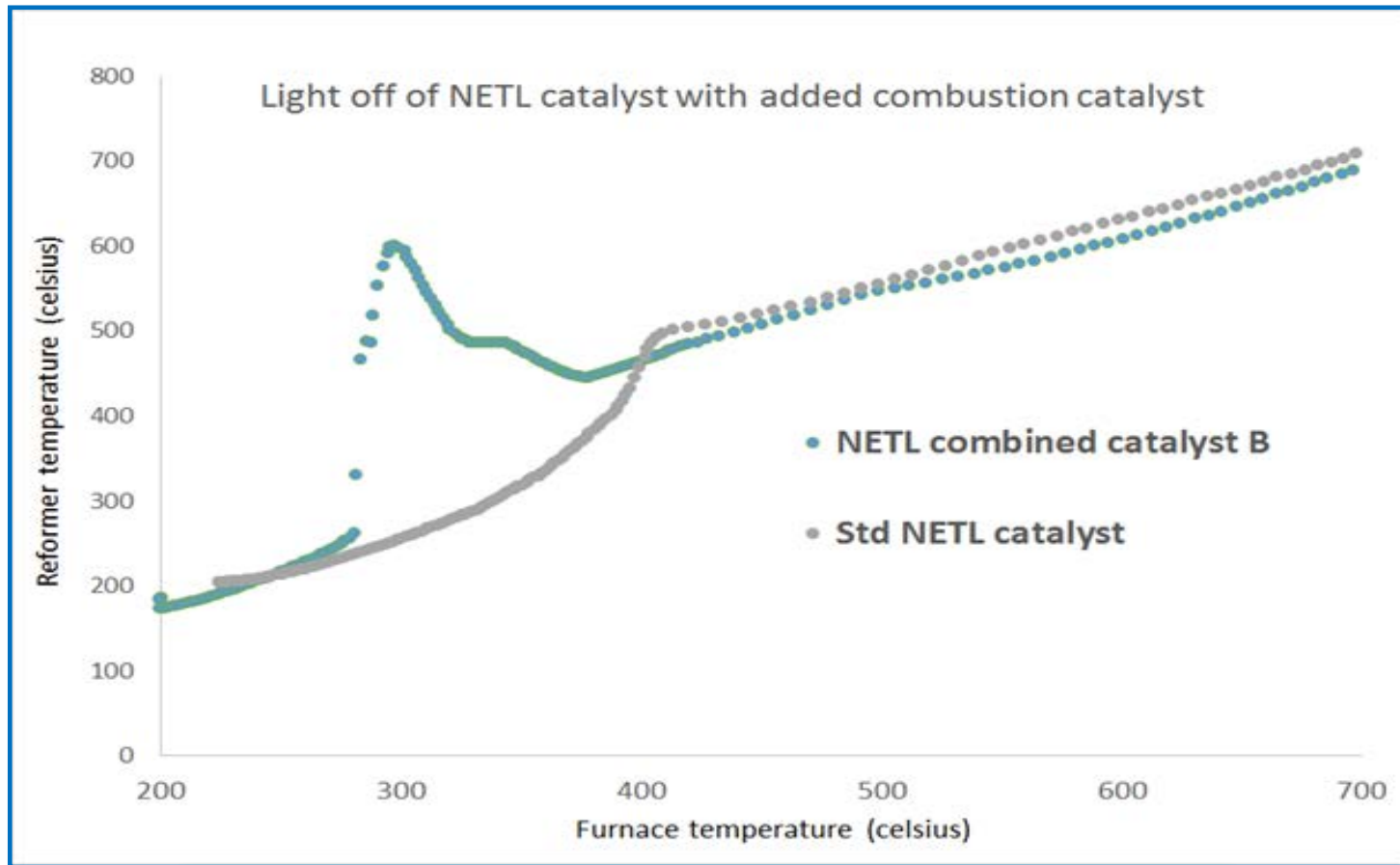
Reforming - LOGISTICS FUELS



**Modified NETL catalyst stable on liquid fuels
Tested > 1000 hrs**



Reforming - LOGISTICS FUELS



- Increased thermal stability
- Increased fuel processing capacity
- Reduced coke formation
- Higher tolerance to redox
- Improved light-off of NETL catalyst (consistent after cycling)

CONCLUSION

- Commissioning of State-of-the-Art Manufacturing Facility is Complete
 - Stable Operations
 - Process Optimization
- Scale-up Stage 1 Successful
 - High Volume Batch Production
 - Advanced Manufacturing Process Tested and Implemented
- Scale-up Stage 2 Begins Q3 2015
 - Increased capacity
 - >2x per production run
 - Continuous (24/7 capability) Operation and Production Pilot

WATT has designed a modular manufacturing process. Stage 3 of scale up is an expansion of the modular system.

Each module is designed to optimize demand capability while reducing inventories.

