

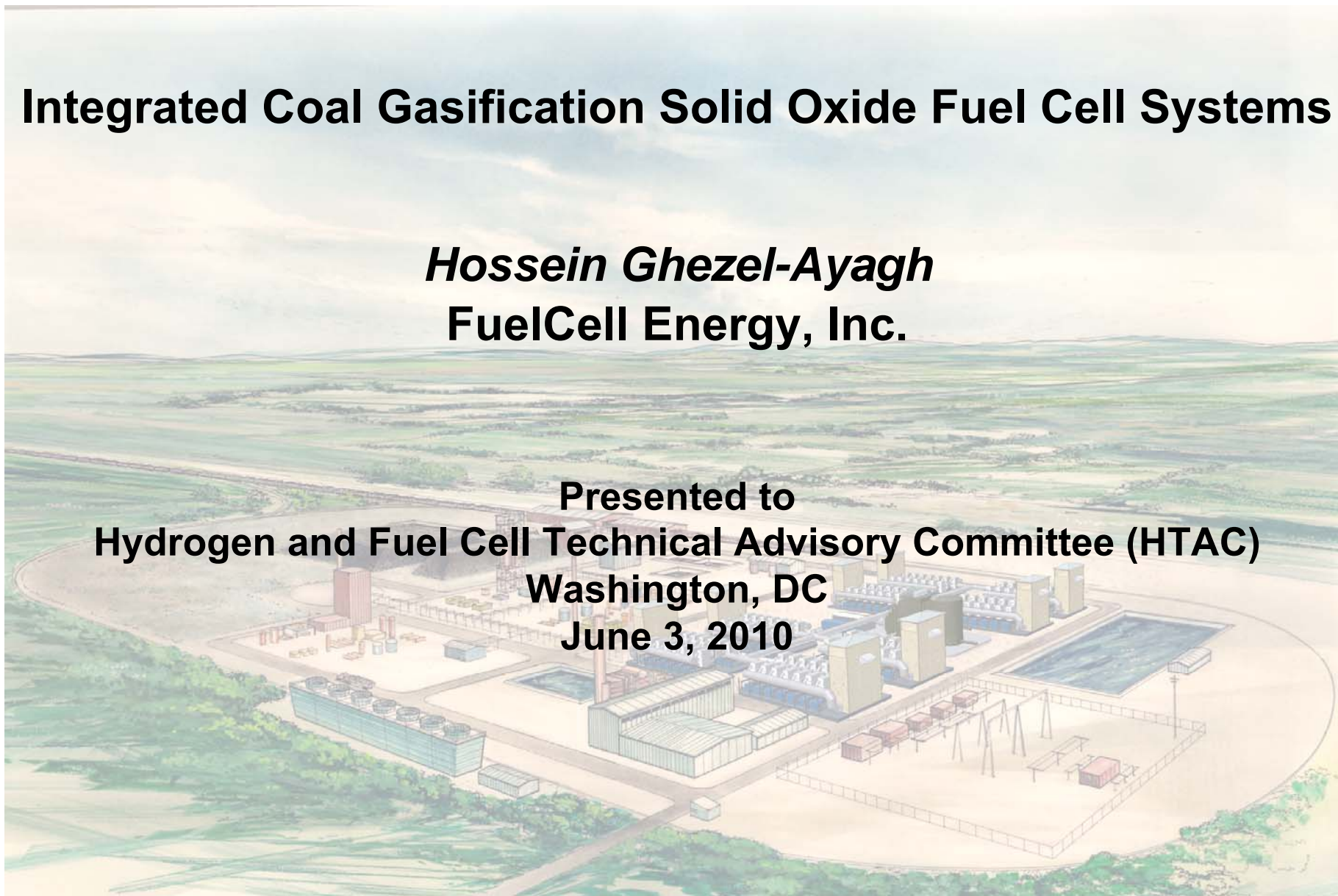


FuelCell Energy

# Integrated Coal Gasification Solid Oxide Fuel Cell Systems

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**FuelCell Energy, Inc.**

**Presented to**  
**Hydrogen and Fuel Cell Technical Advisory Committee (HTAC)**  
**Washington, DC**  
**June 3, 2010**





- Premier developer of stationary fuel cell technology
- Headquarters in Danbury, CT (USA), with 65,000 ft<sup>2</sup> manufacturing facility in Torrington, CT (USA)
- Delivering Direct FuelCell power plants to commercial and industrial customers
- Developing large scale coal-based power plants as well as natural gas distributed generation (DG) systems utilizing planar SOFC
- Established commercial relationships with major distributors in the Americas, Europe, and Asia



Torrington, CT - Manufacturing Facility



MW-Class Fuel Cell Products



## Program Objectives

### **Development of large scale (>100 MWe) coal-based SOFC systems with:**

- At least 50% electrical efficiency from coal (higher heating value)
- Performance to meet DOE specified metrics for power output, degradation, availability, and reliability
- Factory cost <\$400/kW in 2002 USD (\$700/kW, 2007 \$)
- Greater than 90% of carbon capture from coal syngas as CO<sub>2</sub>, for sequestration
- Reduced water consumption as compared to the existing coal power plant technologies

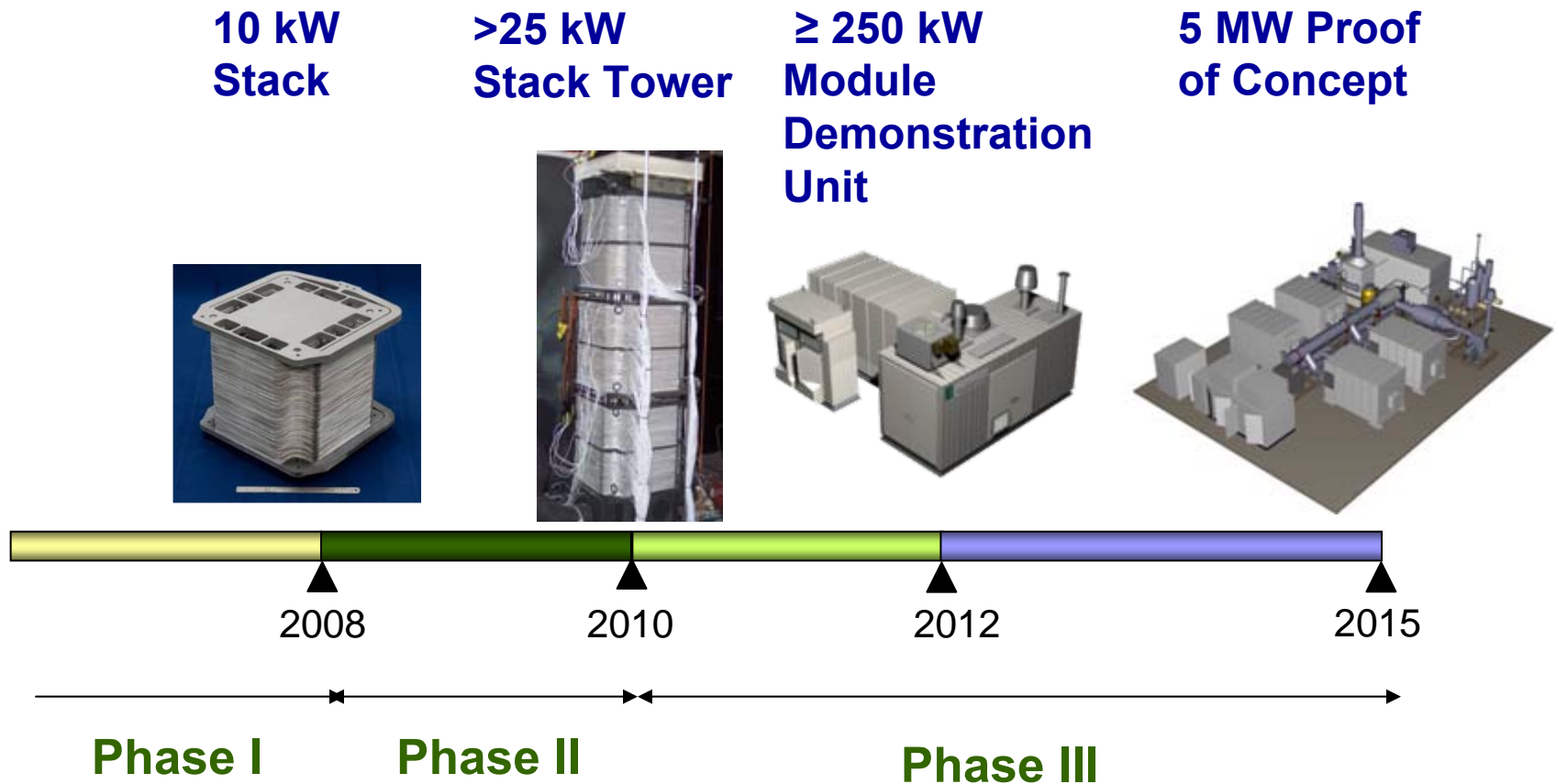
## Program Status

- ❖ FCE team successfully completed Phase I of the Coal Based SECA Program in December 2008.
- ❖ Phase II work is underway to further the development of an affordable, multi-MW size SOFC power plant system to operate on coal syngas fuel, with near zero emissions.



# SECA Coal Based Plan for IGFC Development

- FCE is currently engaged in development of stack tower and SOFC power module configurations suitable for large scale coal based power plants.







**The FCE team is comprised of diverse organizations with expertise in key functional areas:**

### **FuelCell Energy Inc. (FCE), Danbury, CT**

- Manufacturing and commercialization of fuel cell power plant systems in sizes ranging from 250kW to Multi-MW.

### **Versa Power Systems Inc. (VPS), Littleton, CO**

- Solid Oxide Fuel Cell (SOFC) development and manufacturing technologies.



### **Pacific Northwest National Laboratory (PNNL), Richland, WA**

- SOFC cell and stack computational modeling.



### **WorleyParsons Inc. (WP), Reading, PA**

- Design of the power plant, including: integration with gasifier and syngas clean-up technologies, system level costing, and system performance analysis.

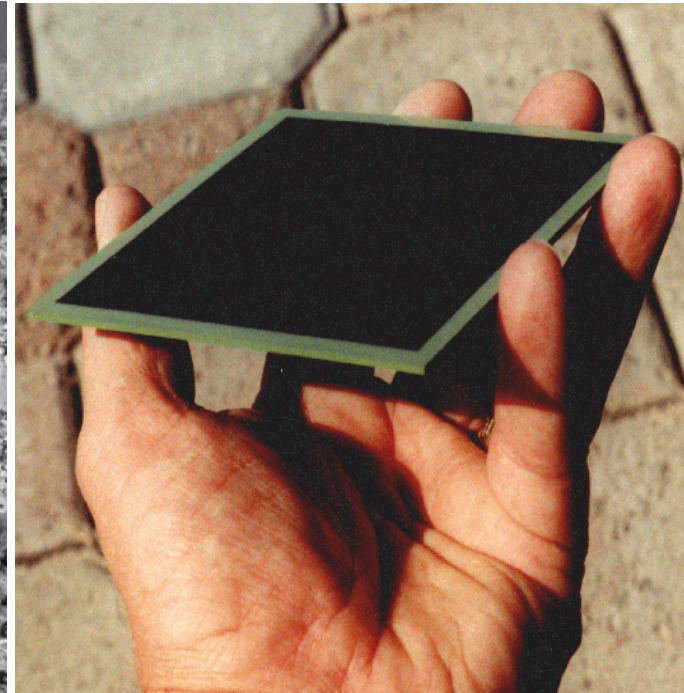
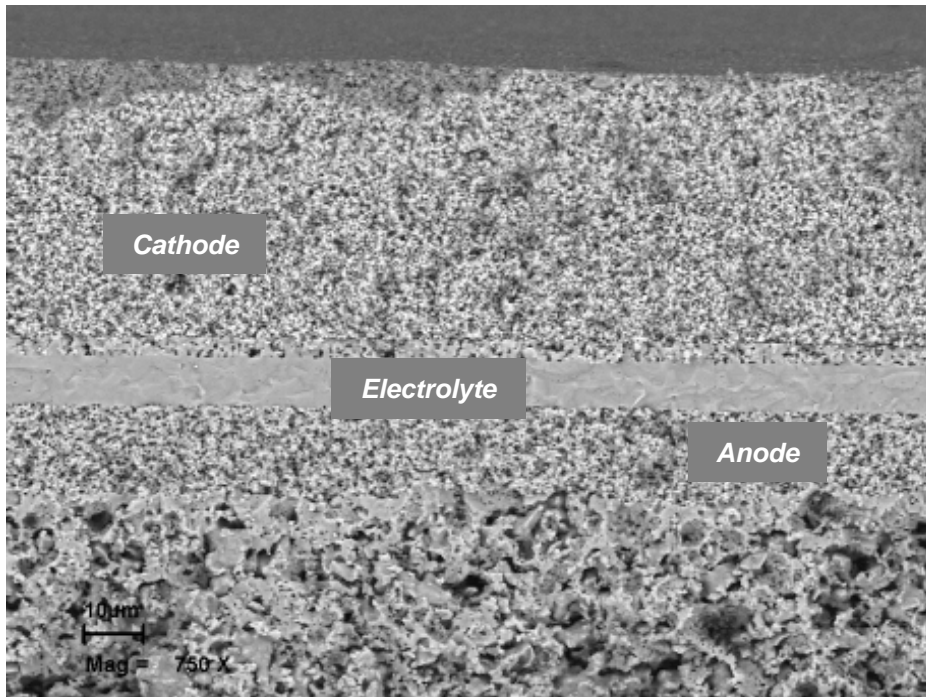


**WorleyParsons**

resources & energy



- FCE utilizes cell and stack design of its technology team partner, Versa Power Systems Inc. (VPS), for coal based system development.



## ANODE SUPPORTED PLANAR CELL DESIGN:

Anode – nickel-zirconia cermet (*~1mm thick*)

Electrolyte – yttria-stabilized zirconia (YSZ) (*~10μm thick*)

Cathode – conducting ceramic (*~ 50μm thick*)



# SOFC Manufacturing

VPS has been developing cost effective SOFC manufacturing procedures since 1998 and has well established processes, quality procedures, and equipment for the manufacture of fuel cells and stacks.



**Tape Casting**  
**“T”**



**Screen Printing**  
**“S”**

The “TSC” process for SOFC component fabrication has proven to be cost effective with high yields and excellent quality.



**Co-Sintering**  
**“C”**



- **Cell Scale Up**

- > Cell process development was conducted and process capability was established for cells up to 33 x 33 cm<sup>2</sup> (largest size that can be made with existing equipment)

- **Cell Fabrication Process Development**

- > Capital equipment for all major process units was added in order to accommodate increased cell size and volume

- **Cell Manufacturing**

- > 25 x 25 cm<sup>2</sup> cells with 550 cm<sup>2</sup> active area is the current baseline size for SOFC stack fabrication.
- > More than 5000 cells (25 x 25 cm<sup>2</sup>) have been fabricated - production yields greater than 90% and volumes of 500 kW (annual) have been demonstrated.

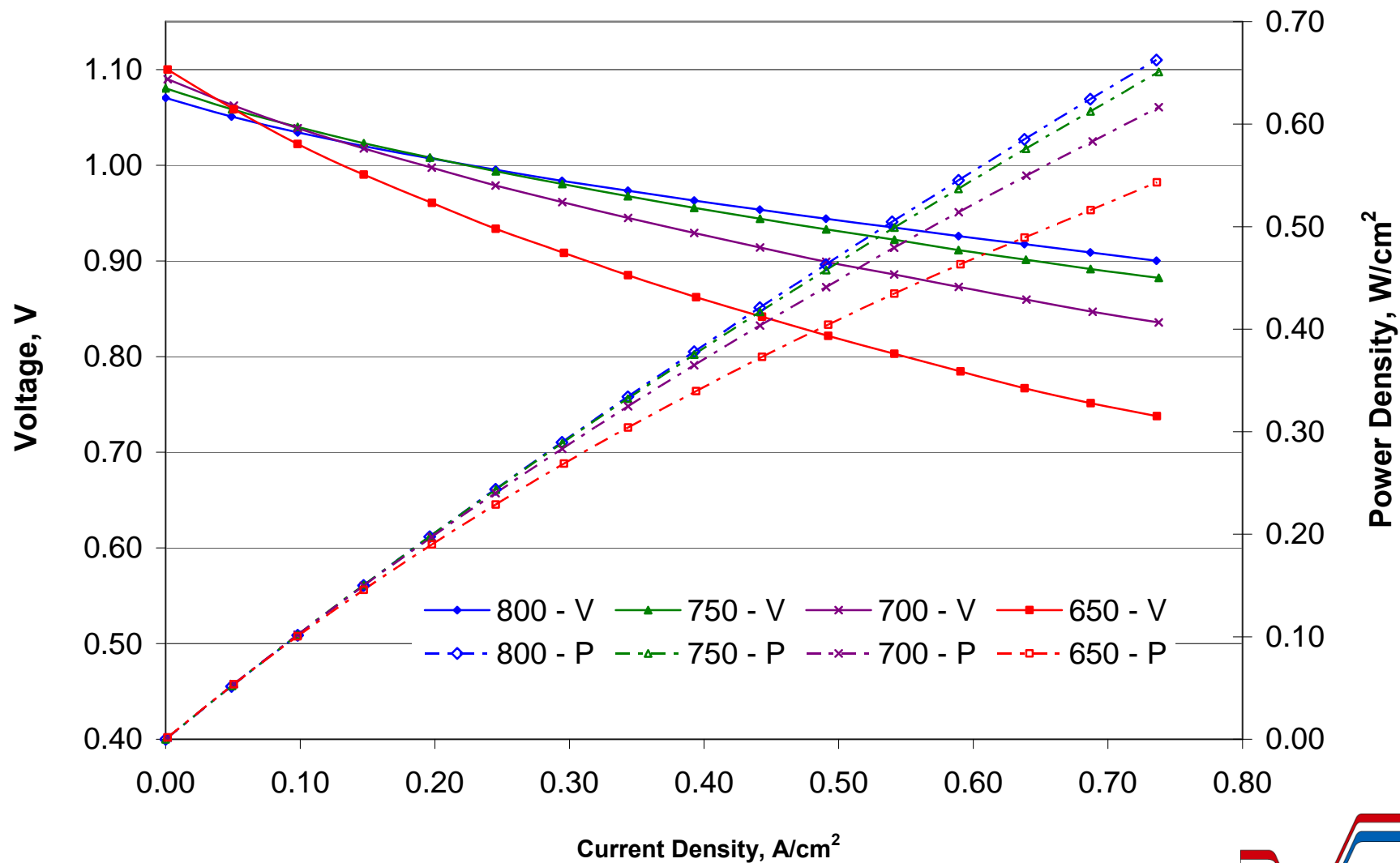






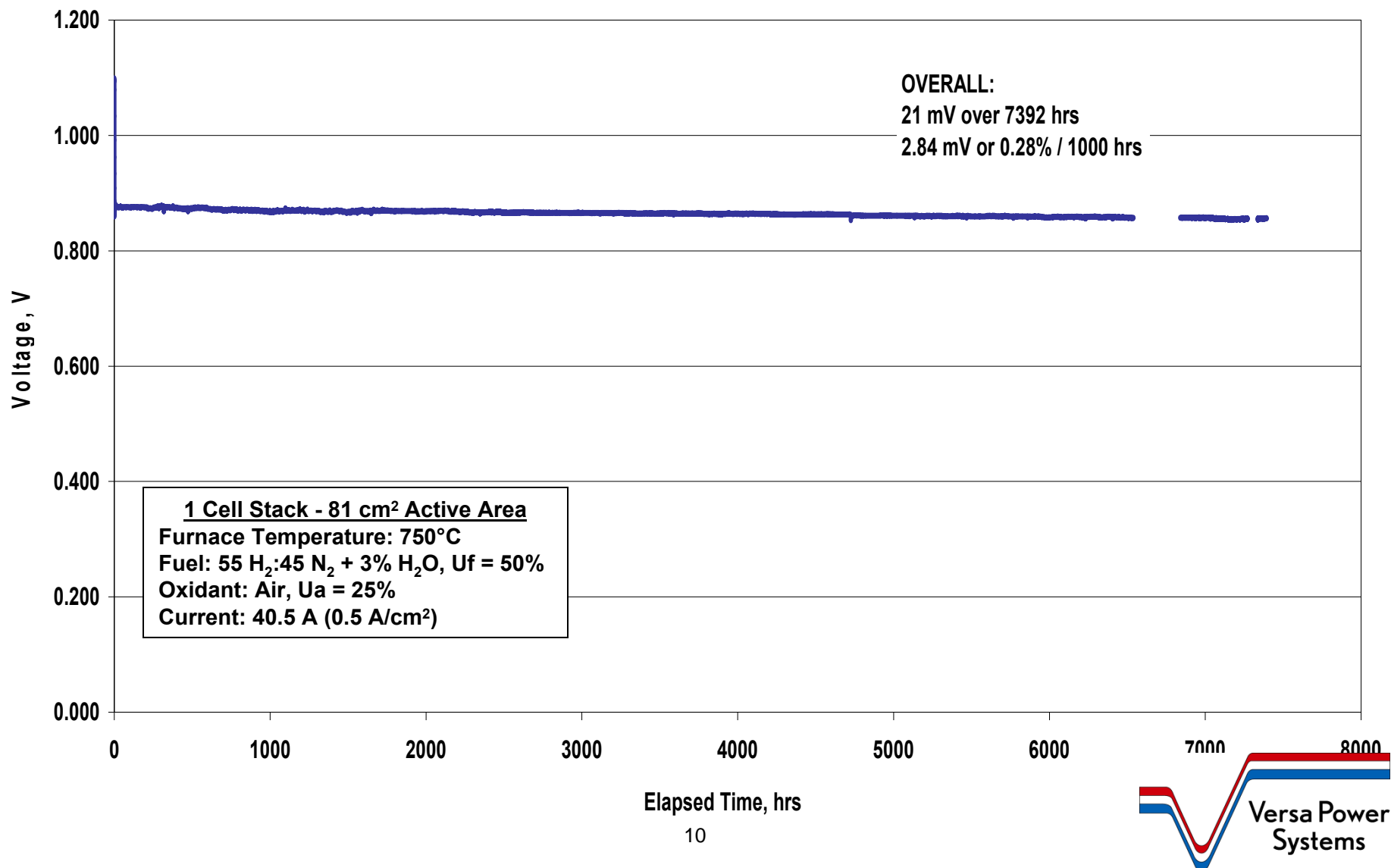
# Single Cell Performance Achievements

Performance Curves



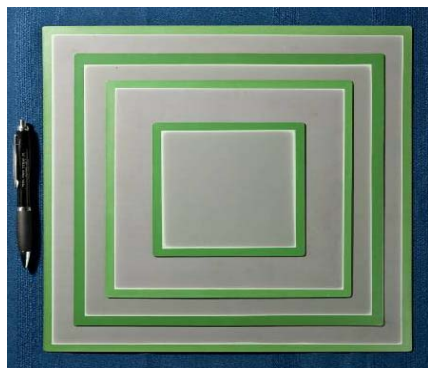


# Cell Stability Achievements

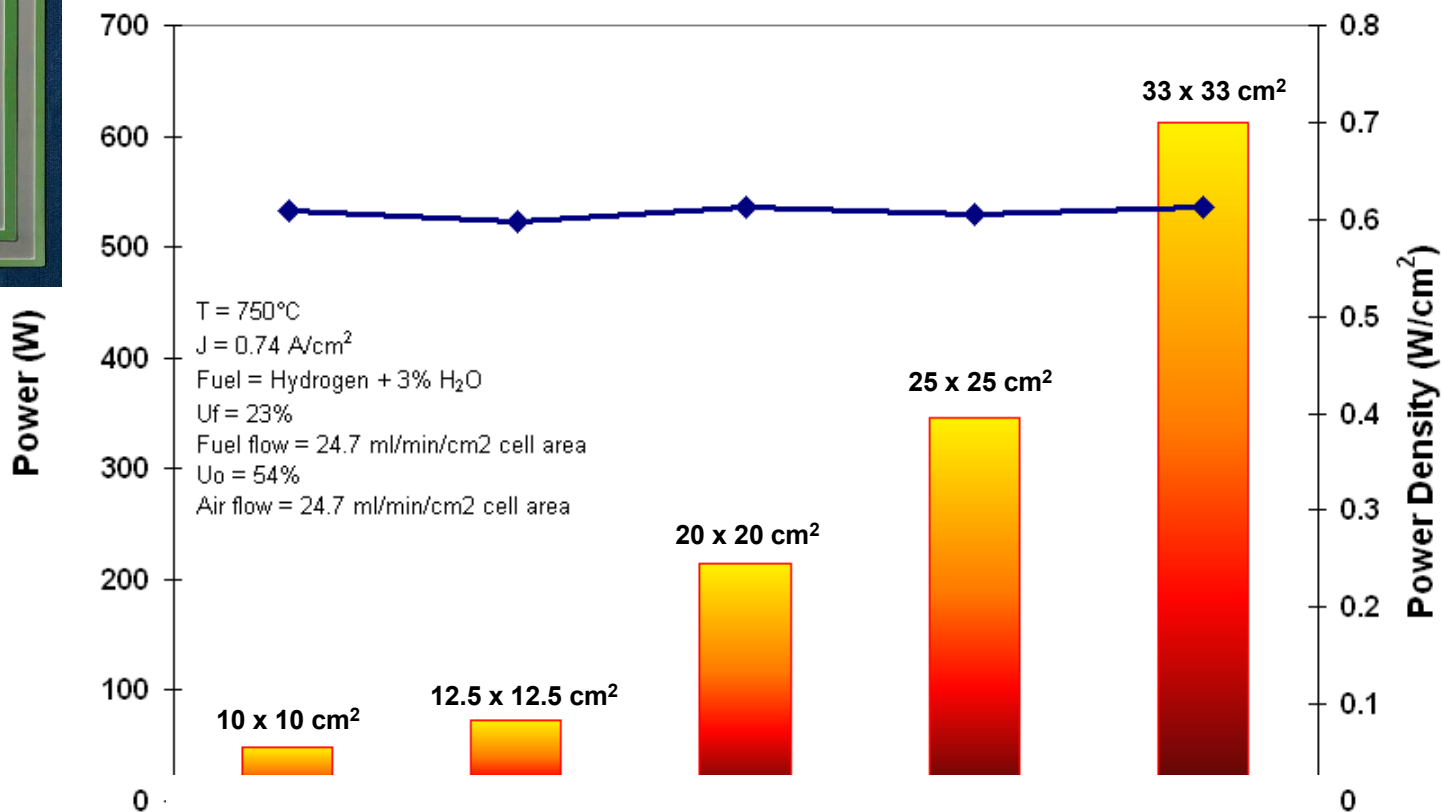




# Cell Scale-Up Progress



**Stainless Steel Current Collectors, Cross-Flow Gas Delivery**



Power	49	72	214	340	612
Power Density	0.608	0.598	0.612	0.606	0.612

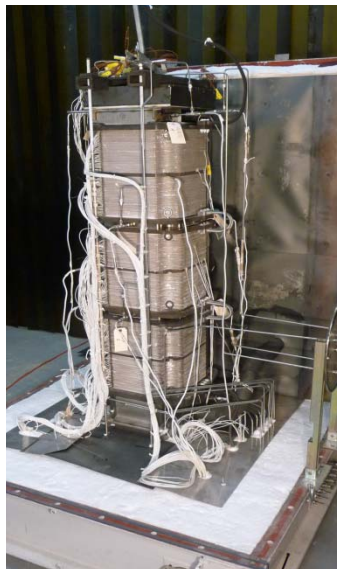


## *Single Stack*



**Building block  
for stack towers  
30-100 kW**

## *Stack Tower*



**Building block for  
stack modules of  
 $\geq 250$  kW**

## *Stack Module*



**Building Block for a  $\geq 100$ MWe  
Integrated Gasification Fuel  
Cell (IGFC) system**





# Stack Scale-up Progression

0.16 kW  
1-cell



1 kW  
6-cell



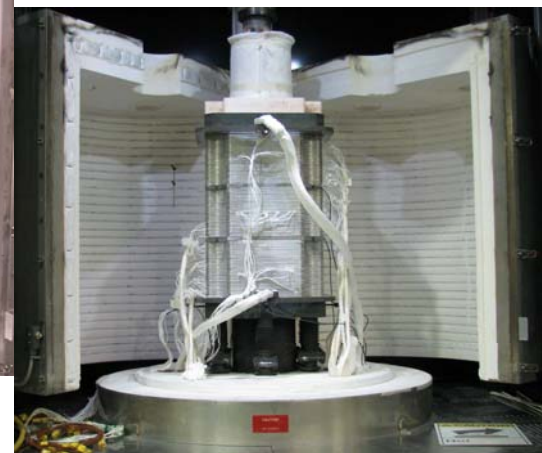
2.5 kW  
16-cell



10 kW  
64-cell



18 kW  
92-cell



Phase II

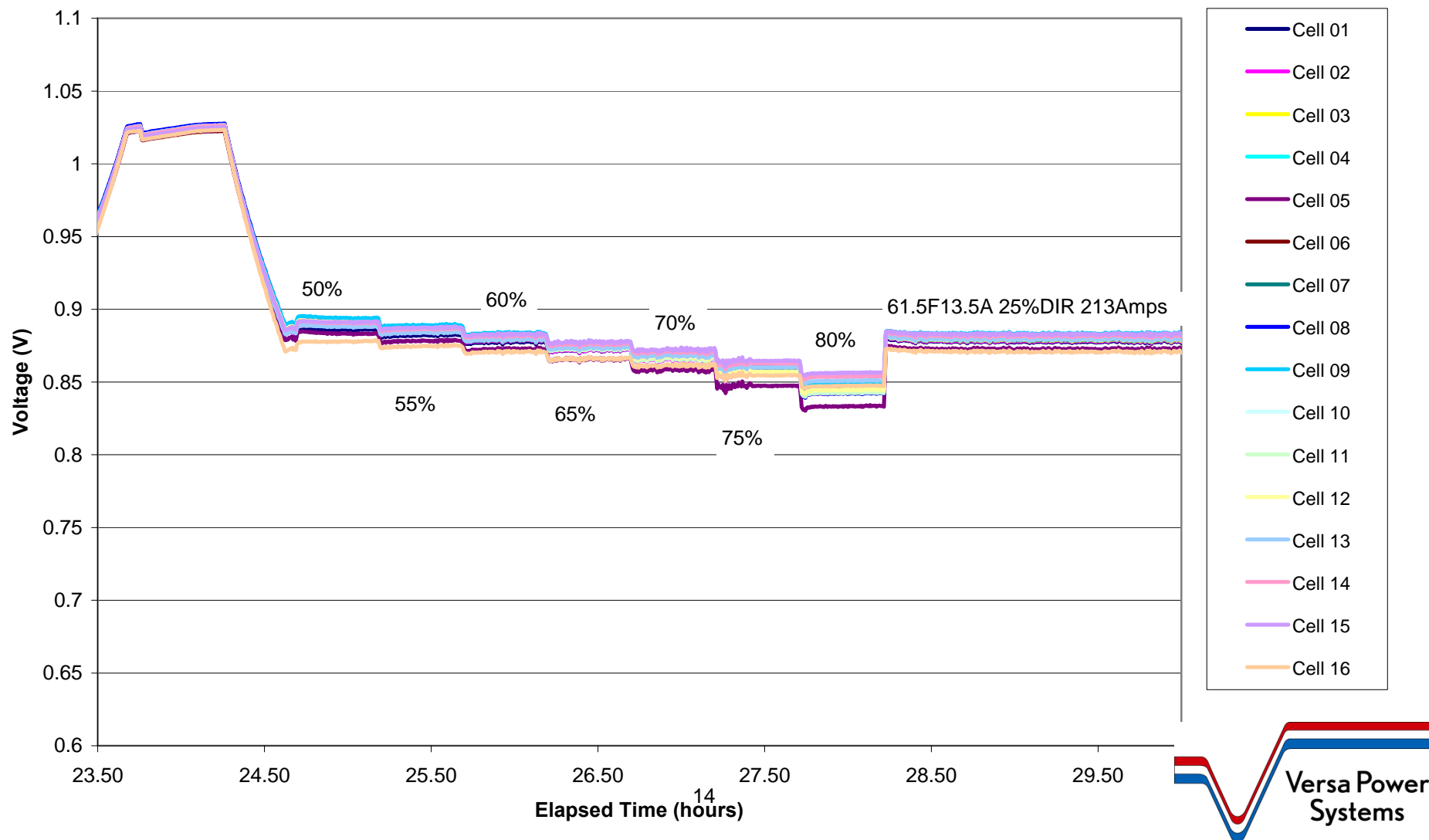
Stack Design	Power (kW/stack)	Quantity	Total Power (kW)
16 cells	2.5	38	95
32 cells	5	1	5
92 cells	18	6	108
Total		45	208

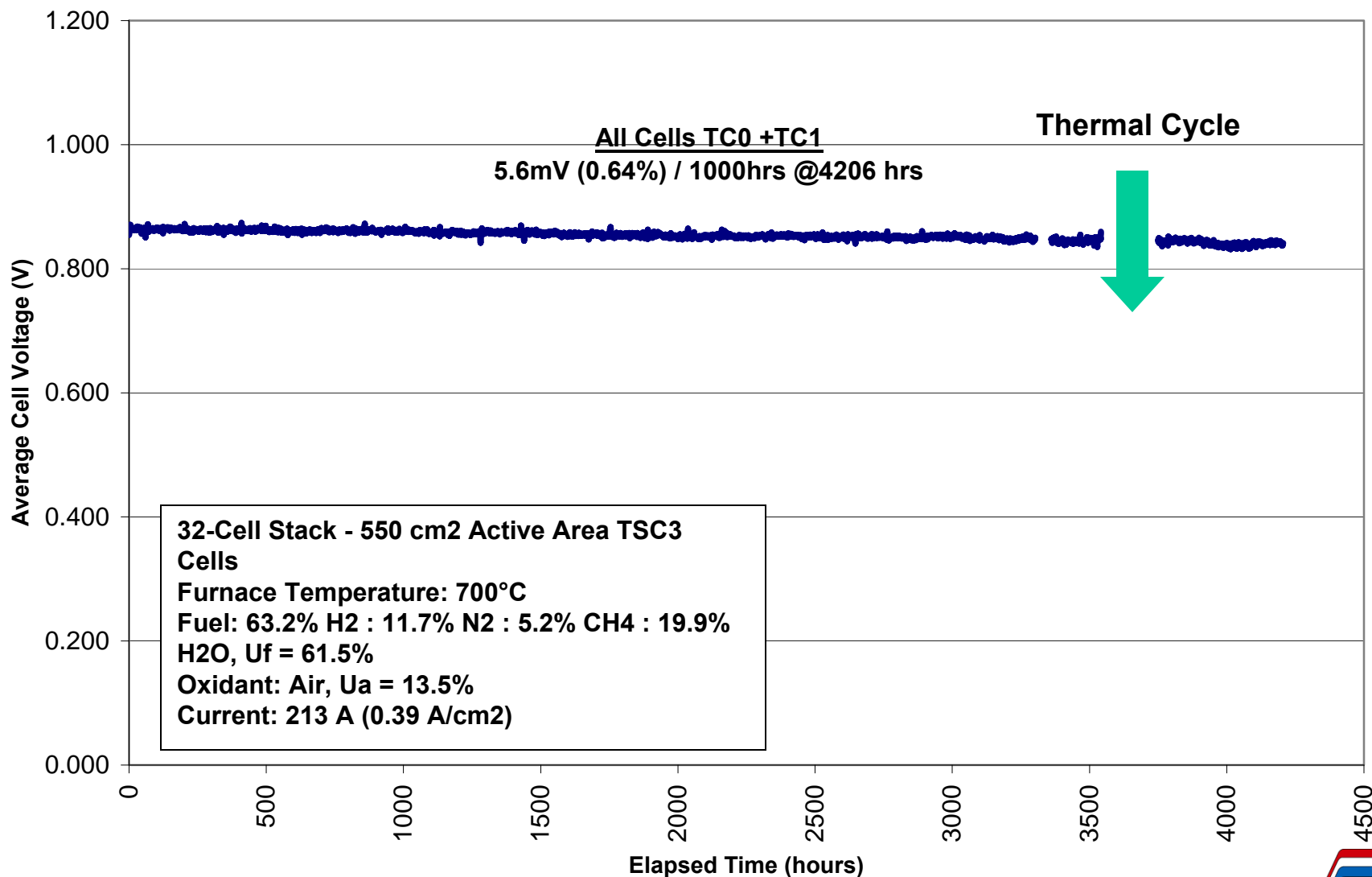
Stack Design	Power (kW/stack)	Quantity	Total Power (kW)
6 cells	1	21	21
16 cells	2.5	18	45
64 cells	10	6	60
Total		45	126

Phase I



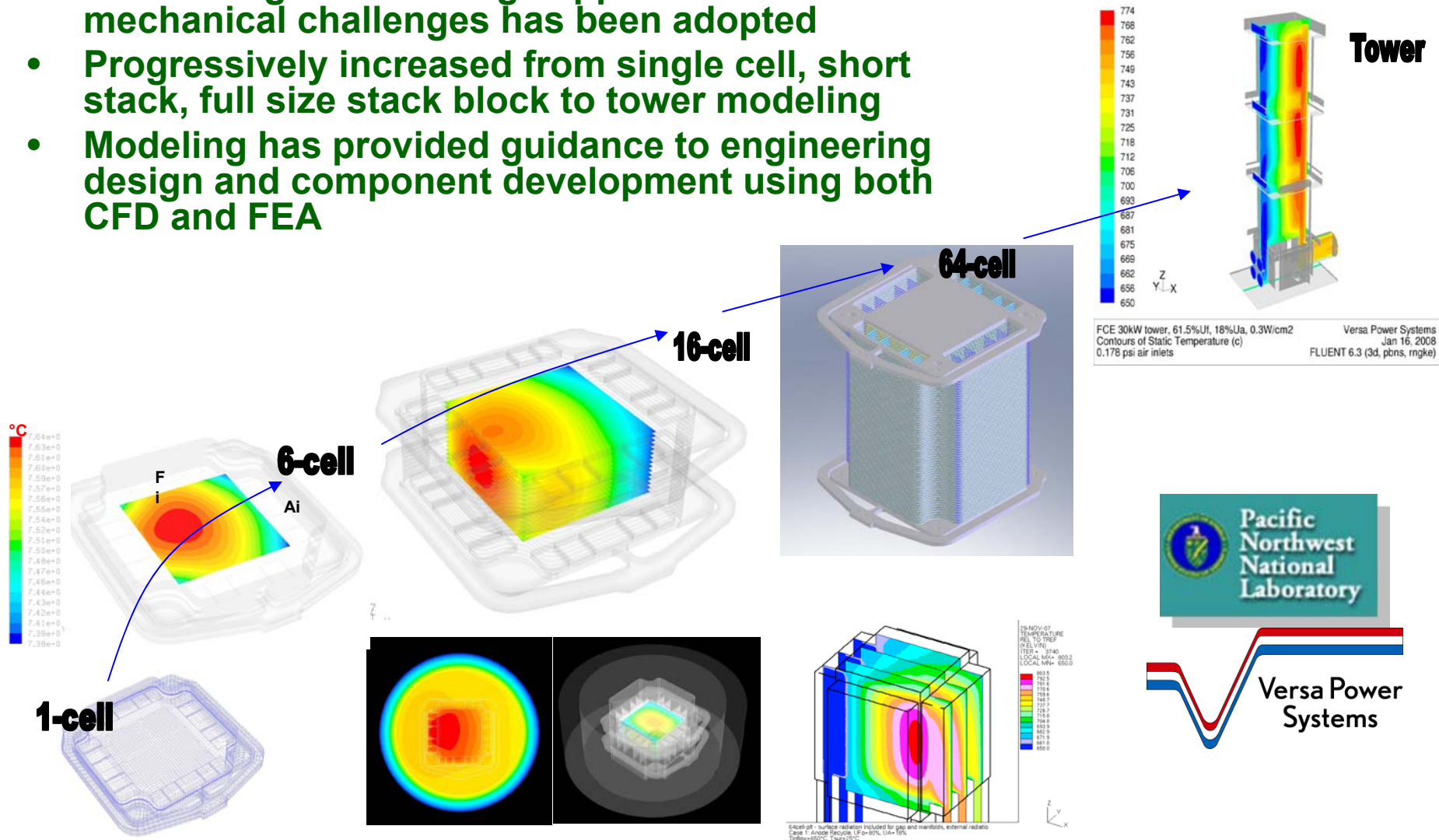
**GT057235-0043 TC0 -  
Fuel Utilizations 213Amp 25% DIR Stand 23**







- A modeling-driven design approach for thermo-mechanical challenges has been adopted
- Progressively increased from single cell, short stack, full size stack block to tower modeling
- Modeling has provided guidance to engineering design and component development using both CFD and FEA







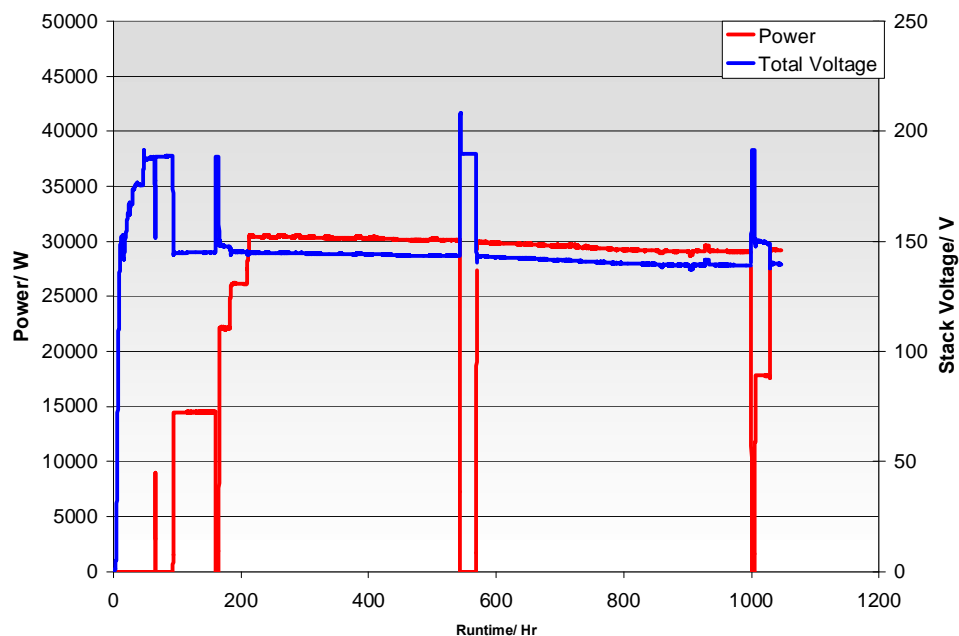
Cell Size	25 x 25 cm <sup>2</sup>
Active Area	550 cm <sup>2</sup>
Number of Cells	92

Operating Conditions	
Fuel Utilization	68%
Air Utilization	14%
In-Stack Reforming	25 – 70%
Stack Current	250 A (455 mA/cm <sup>2</sup> )
Gross DC Electrical Power	~18 kW





## Stack Tower (SO-30-3) Test



- Demonstration of a stack tower operation in a simulated power plant environment was performed using 2x92-cell fuel cell blocks.
- A Power Rating of 30 kW was established during the operation.



## POWER GENERATION SUMMARY

	kW	% Q input	% MW gross
Fuel Gas Expanders Gross Power @ 20 kV	52,307	5.15%	8.49%
Fuel Cell Inverter AC Gross Power @ 20 kV	515,126	50.76%	83.57%
WGPU Off Gas Expander Gross Power @ 20 kV	9,361	0.92%	1.54%
Steam Turbine Gross Power at Generator Terminals @ 20 kV,	39,599	3.90%	6.42%
<b>Total Gross Power Generation @ 20 kV</b>	<b>616,393</b>	<b>60.74%</b>	<b>100.00%</b>
<b>Total Auxiliary Load</b>	<b>56,152</b>	<b>5.53%</b>	<b>9.11%</b>

## Net Power Output at 230 kV

**560,241      55.21%      90.89%**

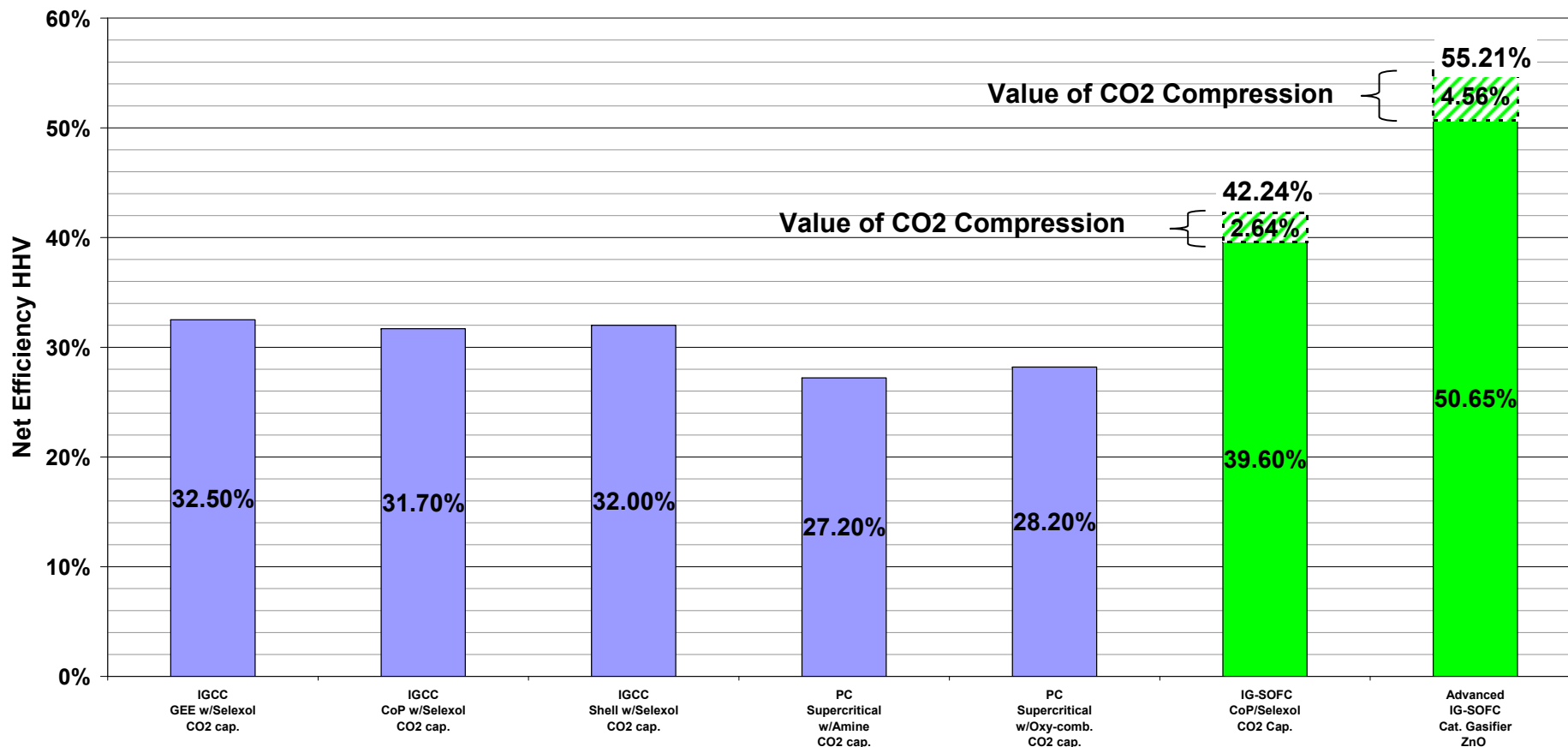
## Net Efficiency Excluding CO2 Compression & Thermal Input

As Fed Coal feed, lb/h	291,667		
HHV (AF), Btu/lb	11,872		
Thermal Input, kWth	1,014,809	100.00%	164.64%
<b>Net Plant Efficiency (HHV)</b>	<b>55.21%</b>		

**Combined with high methane producing gasification, coal based SOFC systems are capable of achieving ~ 55% efficiency and 98% carbon capture.**



# Baseline SOFC Power Plant Efficiency vs. Competing Technologies



➔ **Baseline coal based SOFC system is >18 percentage points more efficient than IGCCs and Pulverized Coal (PC) Steam Turbine power plants.**

References for Competing Technologies:

\* Cost and Performance Baseline for Fossil Energy Plants, Volume 1 - Bituminous Coal and Natural Gas to Electricity, DOE/NETL-2007/1281, Revision 1, August 2007

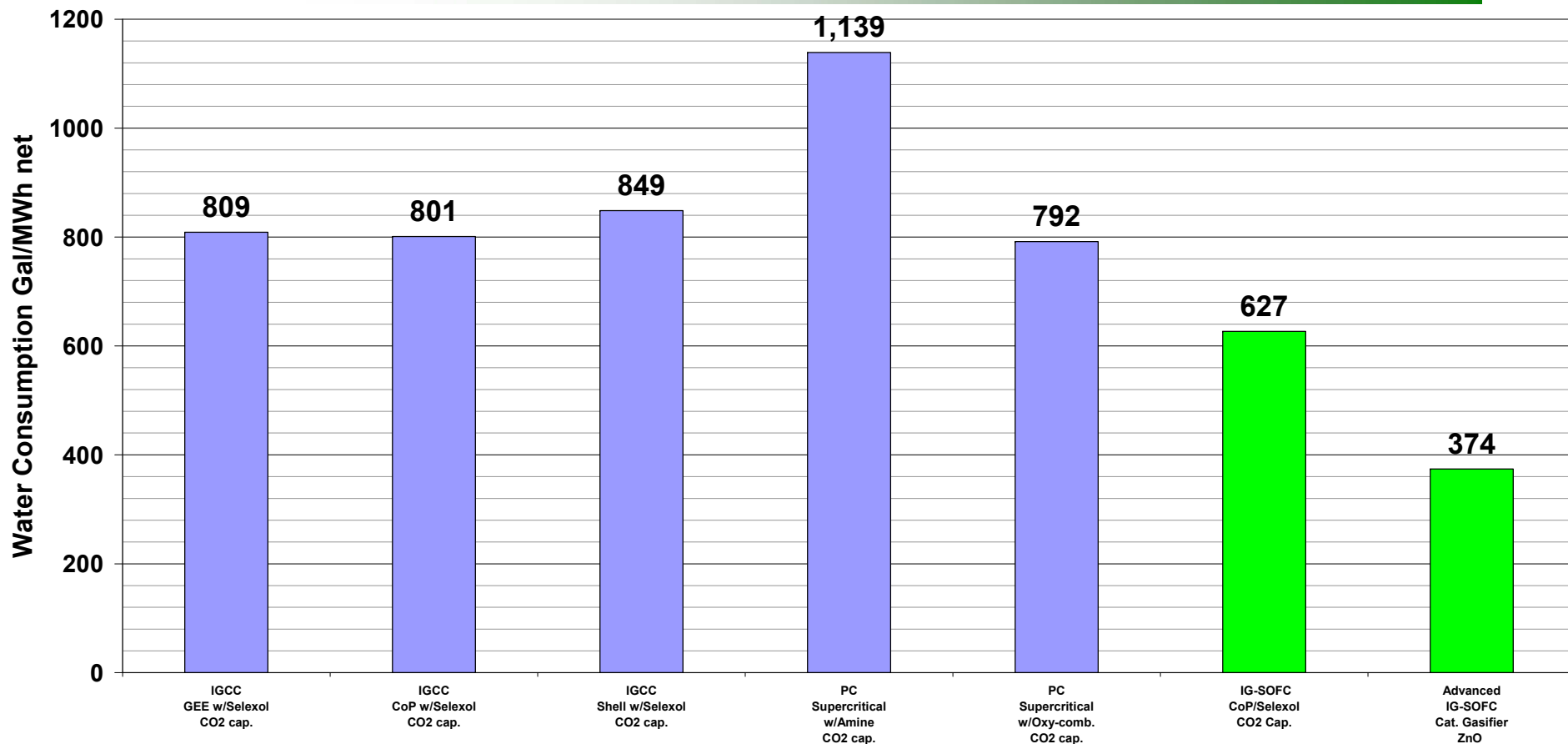
\*\* Pulverized Coal Oxycombustion Power Plants, Volume 1 - Bituminous Coal to Electricity, DOE/NETL-2007/1291, Final Report, August 2007







## Baseline SOFC Power Plant Water Consumption vs. Competing Technologies



➔ **Baseline coal based SOFC system requires significantly less water than IGCCs and Pulverized Coal (PC) Steam Turbine Power Plants.**

References for Competing Technologies:

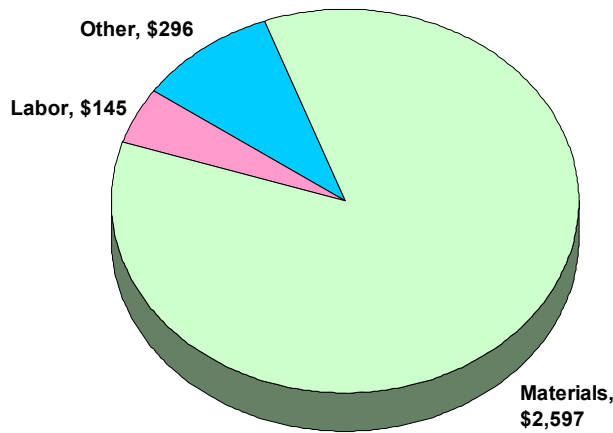
\* Cost and Performance Baseline for Fossil Energy Plants, Volume 1 - Bituminous Coal and Natural Gas to Electricity, DOE/NETL-2007/1281, Revision 1, August 2007

\*\* Pulverized Coal Oxycombustion Power Plants, Volume 1 - Bituminous Coal to Electricity, DOE/NETL-2007/1291, Final Report, August 2007





- **92-cell stack block**
  - > 18 kW nominal, 19.87 peak
  - > 0.393 W/cm<sup>2</sup>
- **Cell dimensions**
  - > 550 cm<sup>2</sup> active area
  - > 645 cm<sup>2</sup> cell substrate
  - > 1.0 mm thick
- **1036 MW/yr production volume**
  - > 57,600 stack blocks
  - > 5,299,200 cell repeat units
  - > 341,900 m<sup>2</sup>
  - > 1,711,000 kg, cells



**Stack Block Cost by Category (Phase II Interim)**



## Stack Cost Reduction Path

\$197/  
kWac

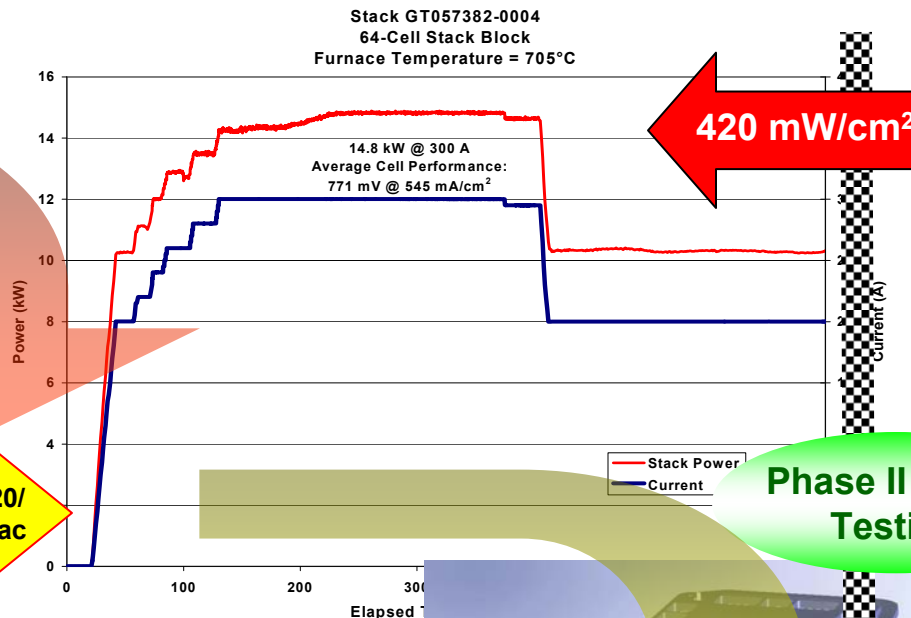
Higher Power Density

\$120/  
kWac

Stack Block Scale Up

Thin Cell Development

Stack Materials Reduction



Phase II Metric  
Testing

\$100/  
kWac

Q4 2008

Q1 2009

Q2 2009

Q3 2009

Q4 2009

Q1 2010

Q2 2010

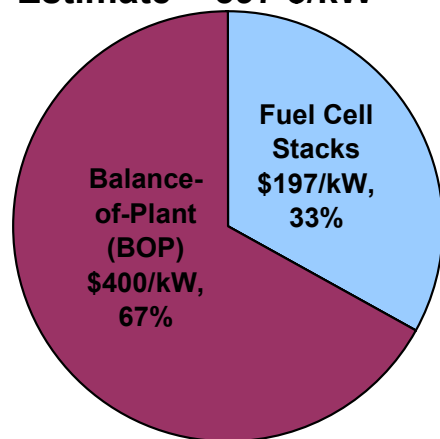
Q3 2010

Q4 2010

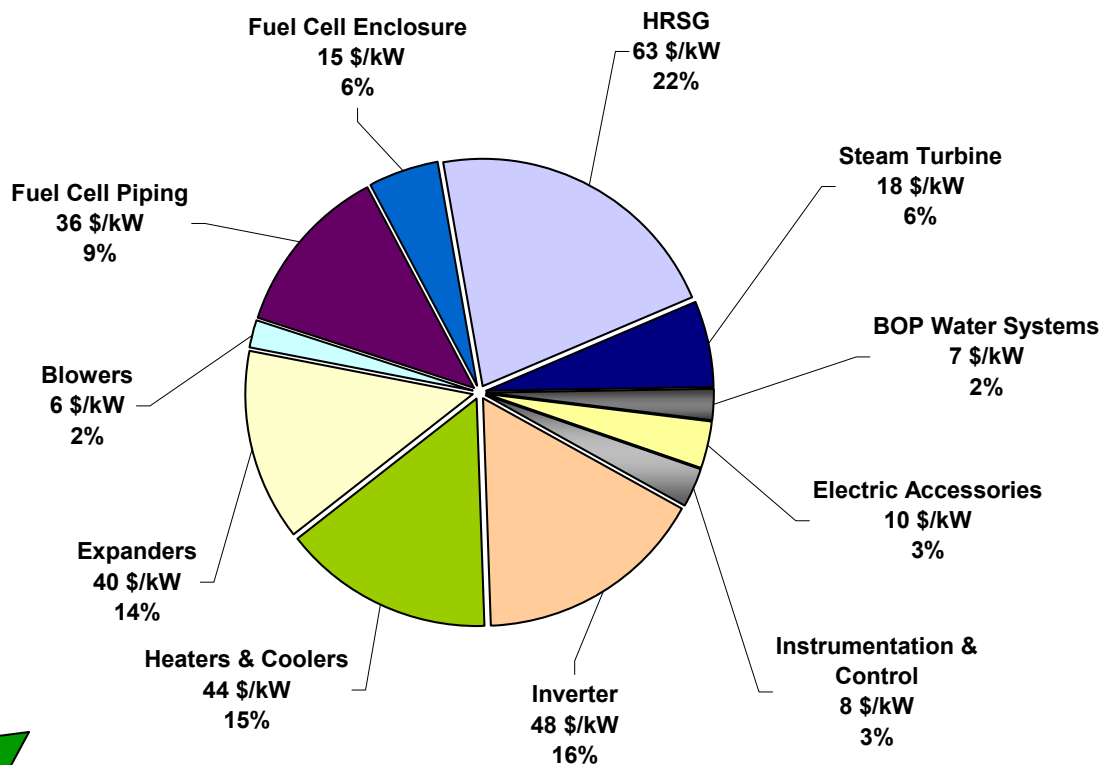
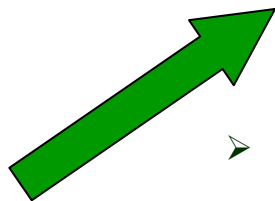
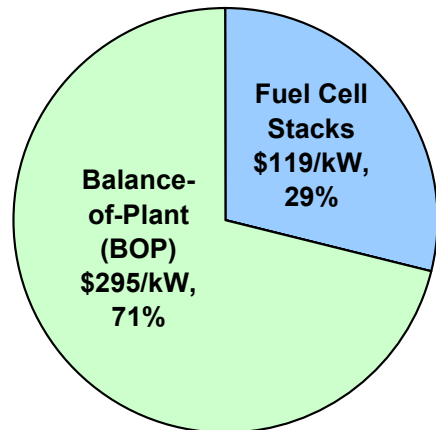


# Factory Equipment Cost Estimate

## Phase I Cost Estimate = 597 \$/kW



## Phase II Interim Cost Estimate = 414 \$/kW



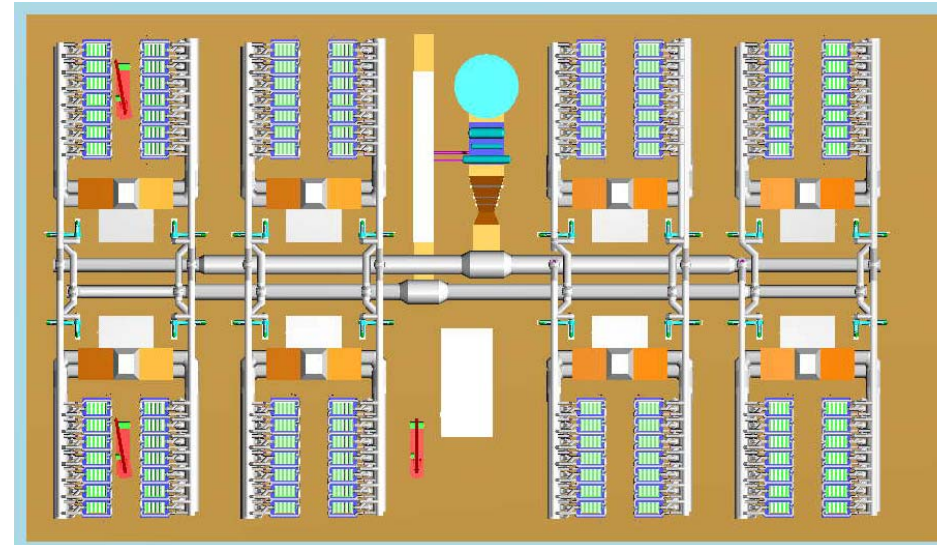
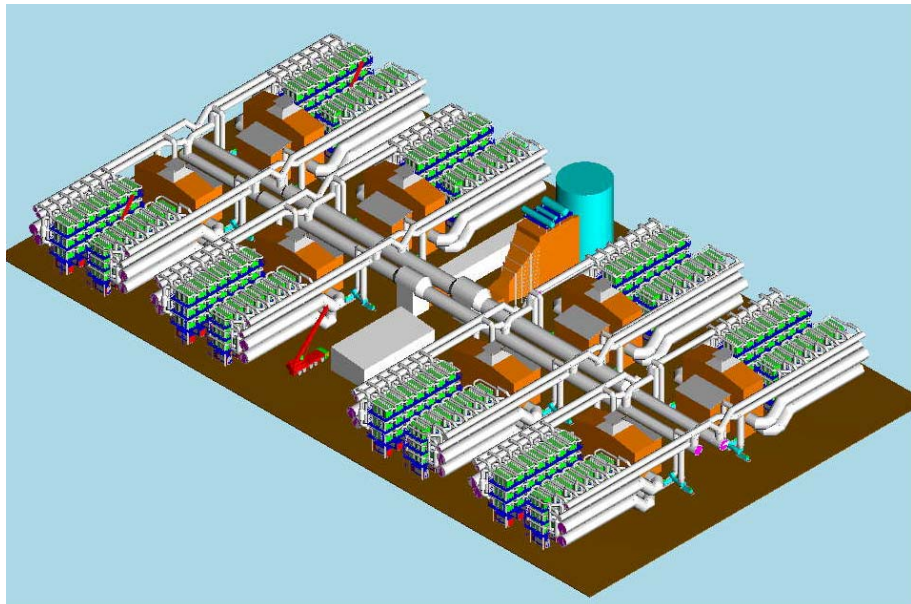
- Cost estimation is based on two nominal 560 MW power plants manufactured per year (2002 USD).
- Estimate includes Factory Equipment costs for the Power Island, exclusive of gasification, syngas cleanup, and CO<sub>2</sub> separation/compression systems.





# FuelCell Energy Baseline System Power Island Layout

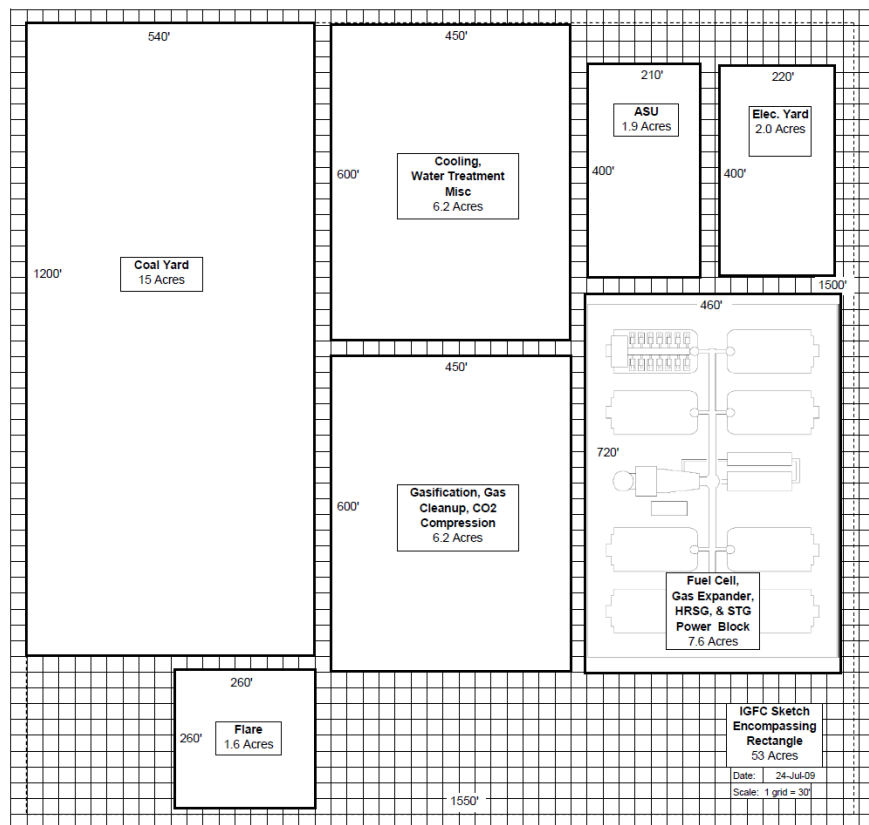
- ➔ SOFC power island includes:
- > 8 Sections of 42 fuel cell stack modules
  - > Steam turbine
  - > Two syngas expanders



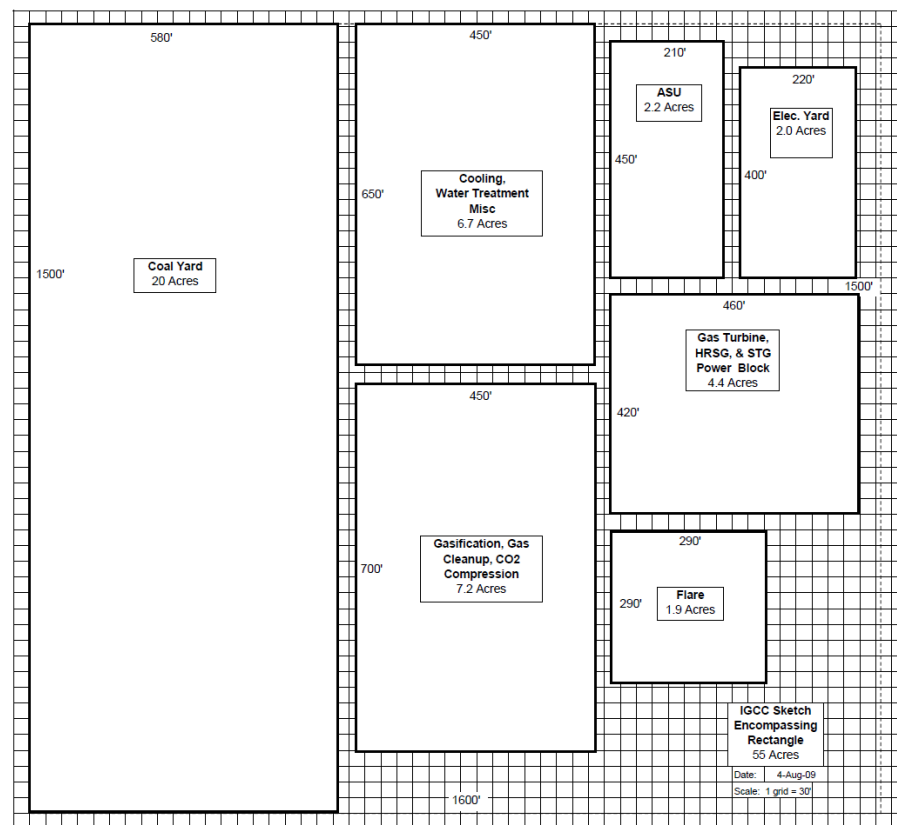


# Representative Foot Print Comparison: IGFC & IGCC

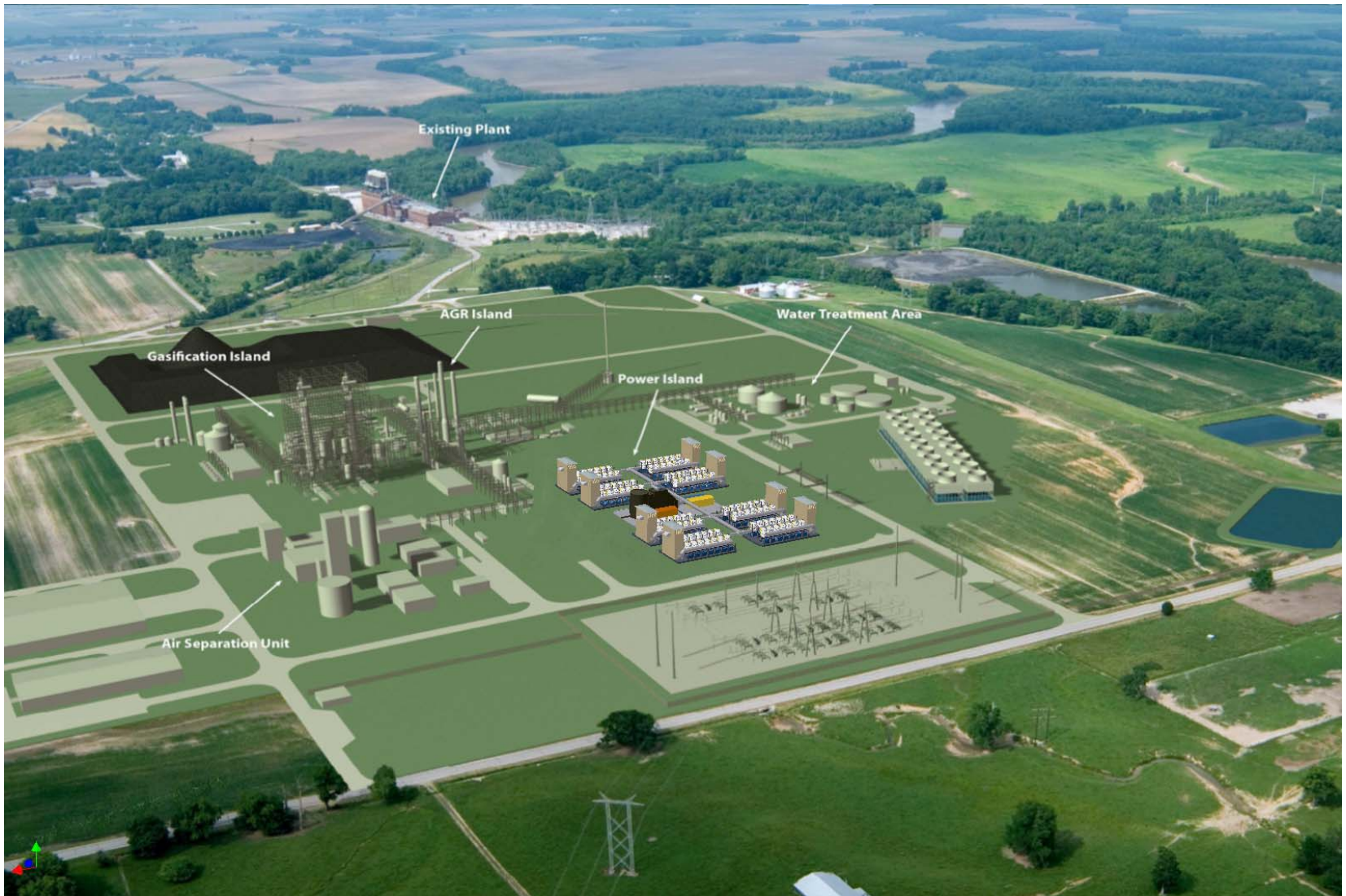
IGFC



IGCC



- A similarly sized (MW) IGCC and IGFC will be comparable in real estate requirement.







## ⇒ **Cell Technology:**

- Fuel cell manufacturing processes were developed to achieve the new scaled-up cell (33 cm x 33 cm).
- Cell materials development continued to improve performance and endurance.

## ⇒ **Scale-up of stack size:**

- Manufacturing of the scaled-up stack blocks was accomplished to establish the building blocks for multi-MW power plants.
- Improved stack design and component advancements resulted in high power densities suitable for large scale coal plants.

## ⇒ **Baseline IGFC System:**

- A Baseline System with Catalytic Gasifier was developed which could achieve efficiency (HHV) of >55% and be able to remove greater than 98% carbon from syngas.
- Baseline 560MW IGFC power plant layout and factory cost estimates were developed resulting in a cost estimate of ~\$400/kW (in 2002 dollars) for the SOFC power island.
- The developed IGFC system showed significantly lower water consumption as compared to IGCC and other coal fueled power plants.



- **Support for FCE's SECA Coal Based Program provided by the US Department of Energy (DOE) through the co-operative agreement DE-FC26-04NT41837**

**Thank You!**

