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Integrated Coal Gasification Solid Oxide Fuel Cell Systems

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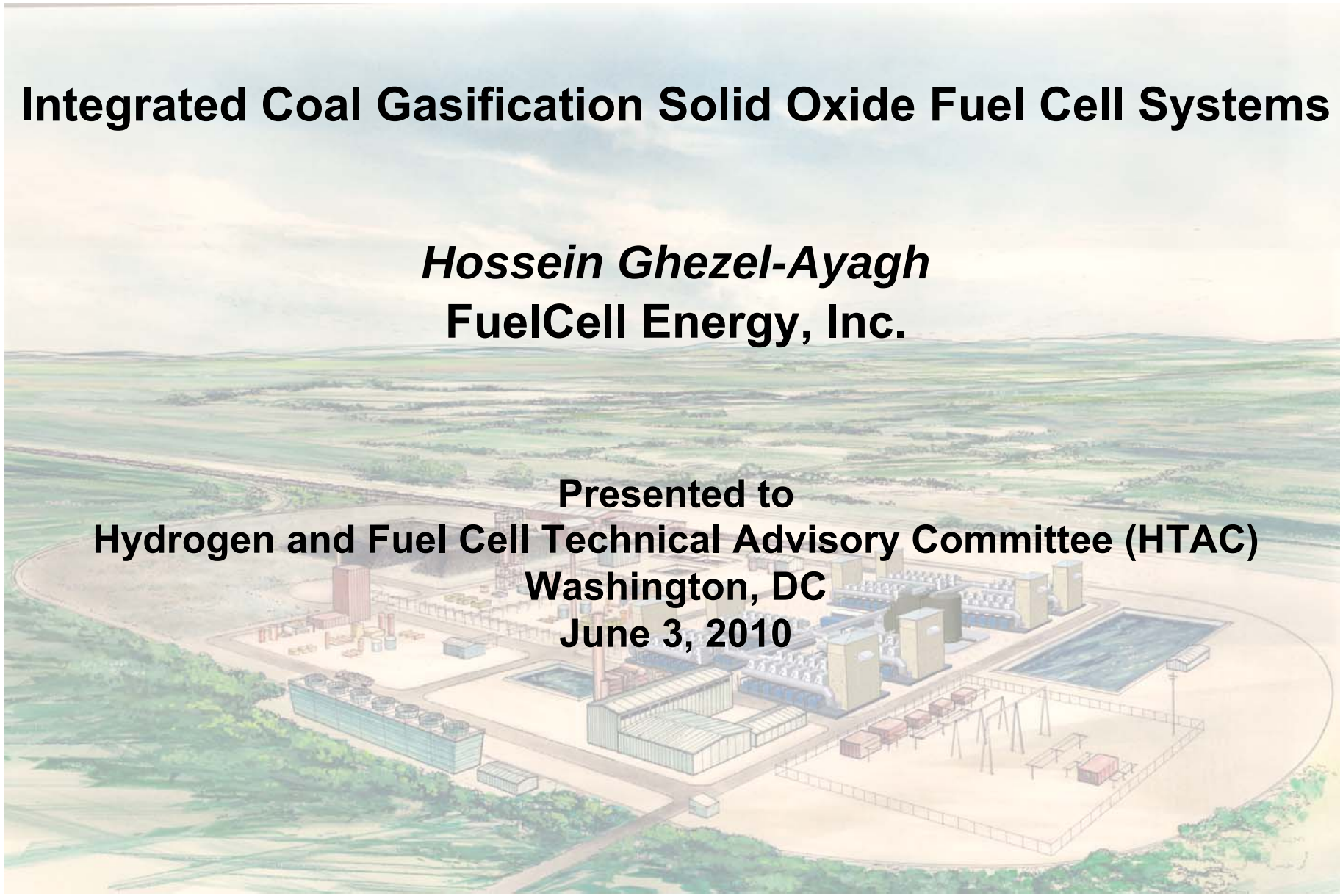
Washington, DC
June 3, 2010



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FuelCell Energy (FCE)

- **Premier developer of stationary fuel cell technology**
- **Headquarters in Danbury, CT (USA), with 65,000 ft^2 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_2, for sequestration
- Reduced water consumption as compared to the existing coal power plant technologies

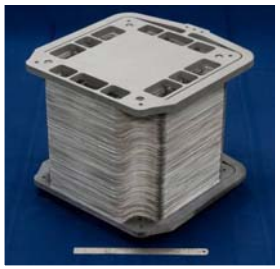
Program Status

- **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.

10 kW Stack



>25 kW Stack Tower

≥ 250 kW Module Demonstration Unit

5 MW Proof of Concept

2008 2010 2012 2015

Phase I **Phase II** **Phase III**

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Phase II SECA Coal-Based Team

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.

Versa Power Systems

Pacific Northwest National Laboratory (PNNL), Richland, WA

- SOFC cell and stack computational modeling.

Pacific Northwest National Laboratory

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.

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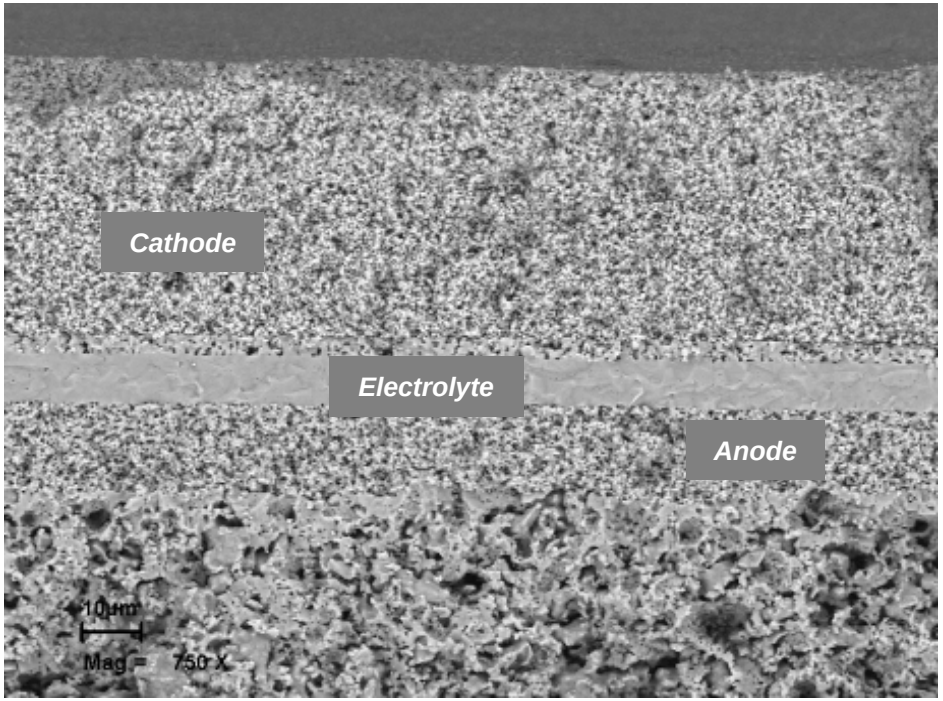
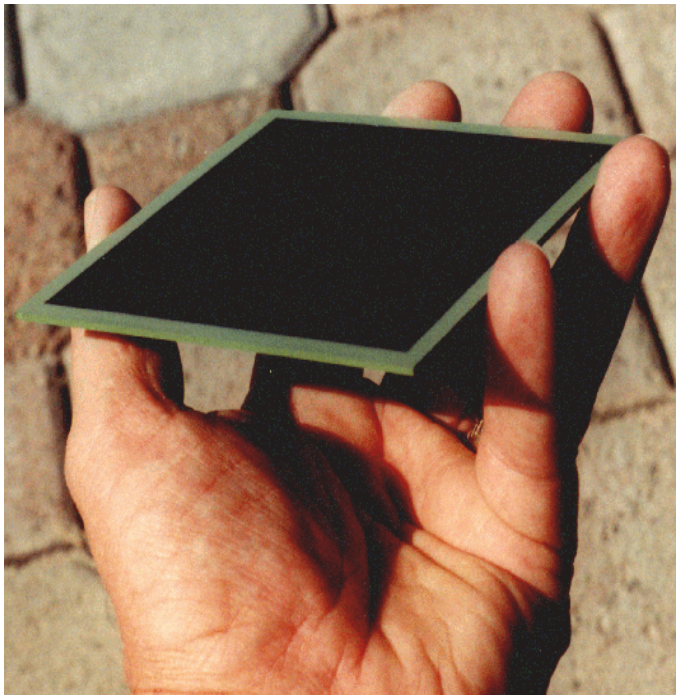
VPS Cell Technology

- **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)*

Versa Power Systems

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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"

Co-Sintering
"C"

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

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Cell Fabrication Status

- **Cell Scale Up**
  - > Cell process development was conducted and process capability was established for cells up to 33 x 33 cm^2 (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^2 cells with 550 cm^2 active area is the current baseline size for SOFC stack fabrication.
  - > More than 5000 cells (25 x 25 cm2) have been fabricated - production yields greater than 90% and volumes of 500 kW (annual) have been demonstrated.

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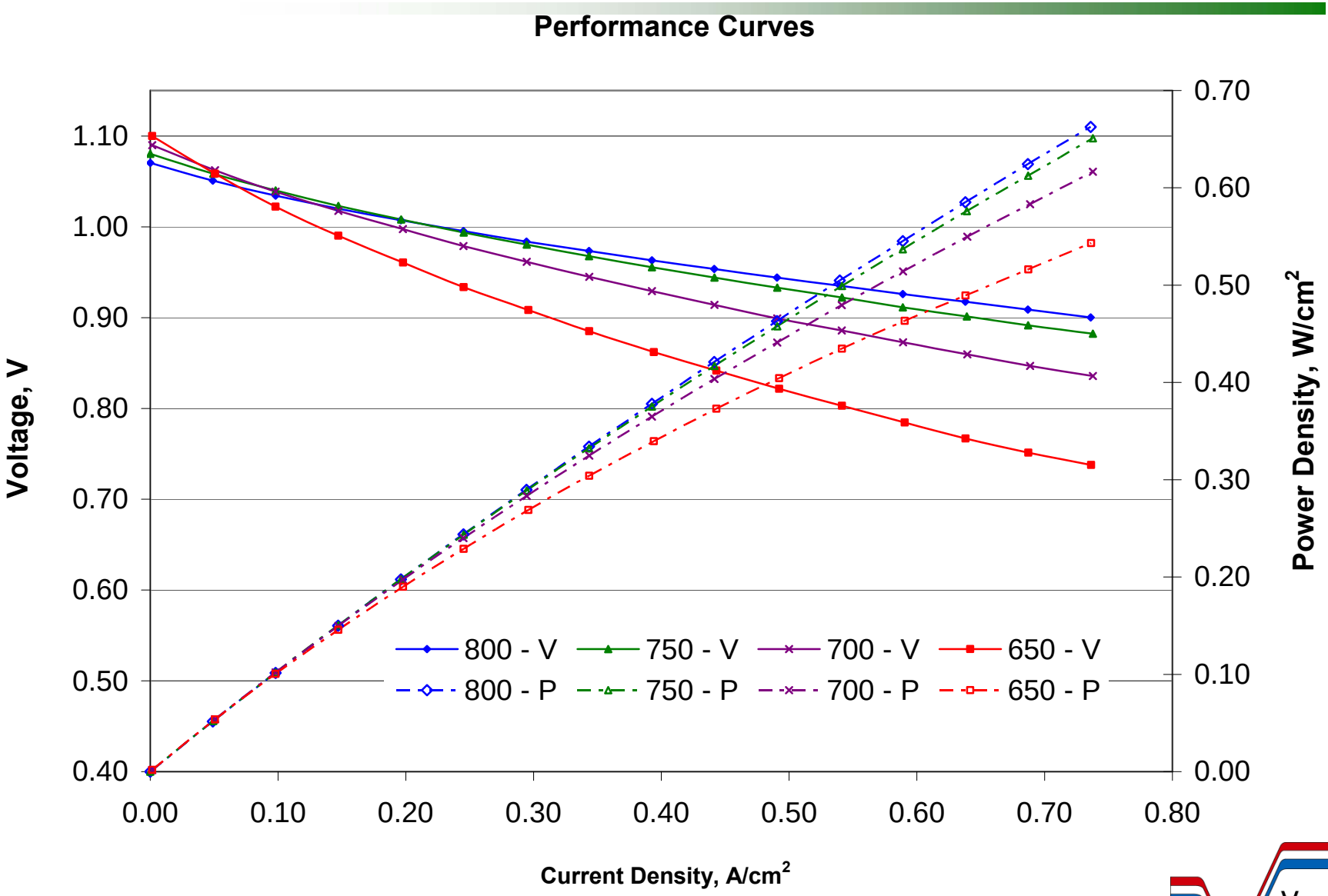
Single Cell Performance Achievements



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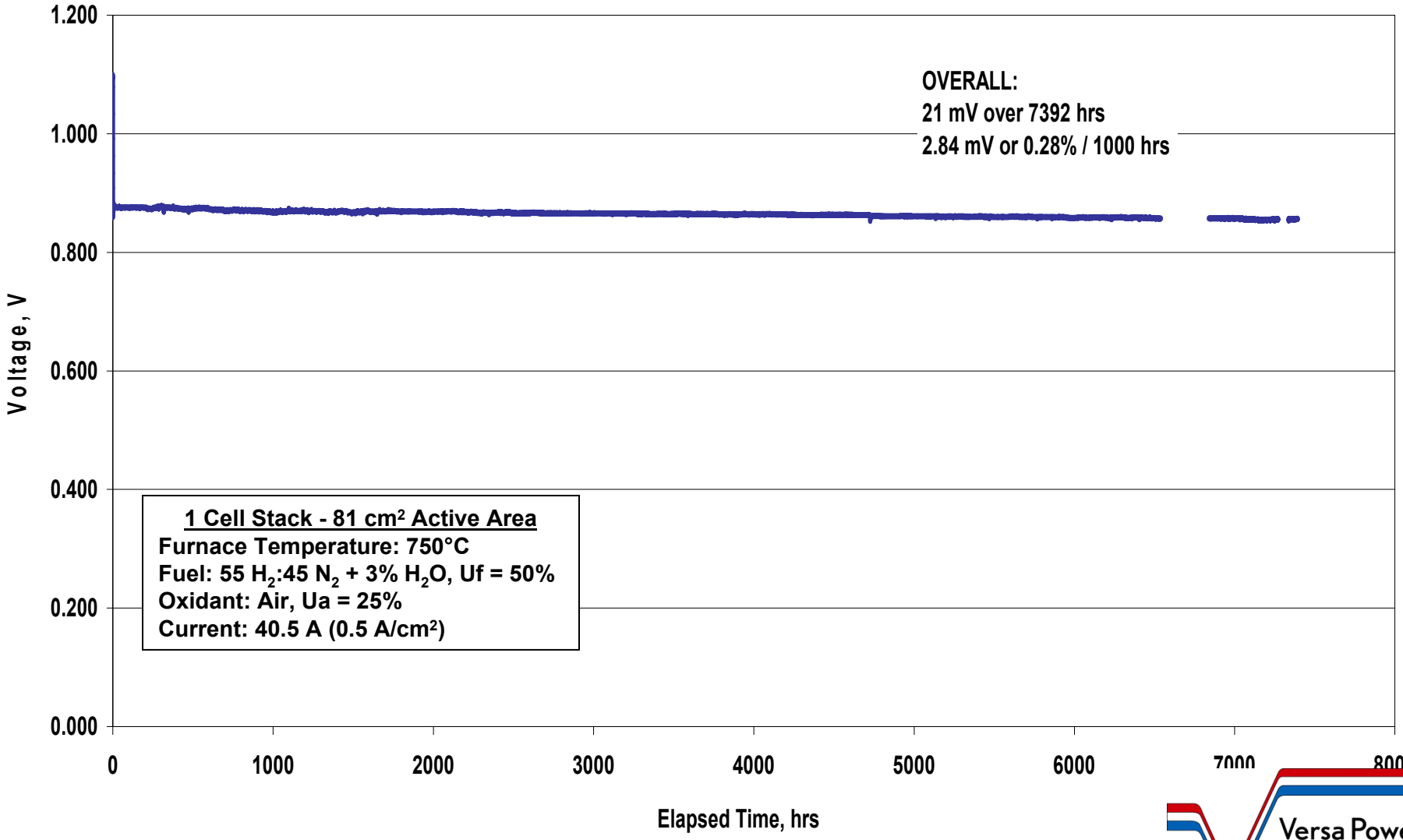
Cell Stability Achievements



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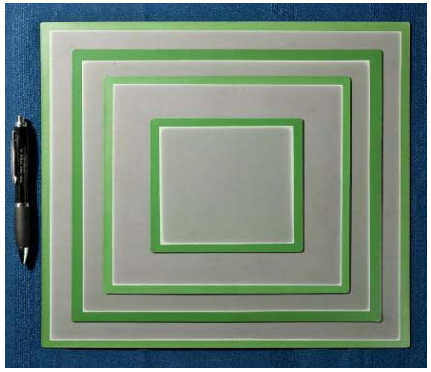
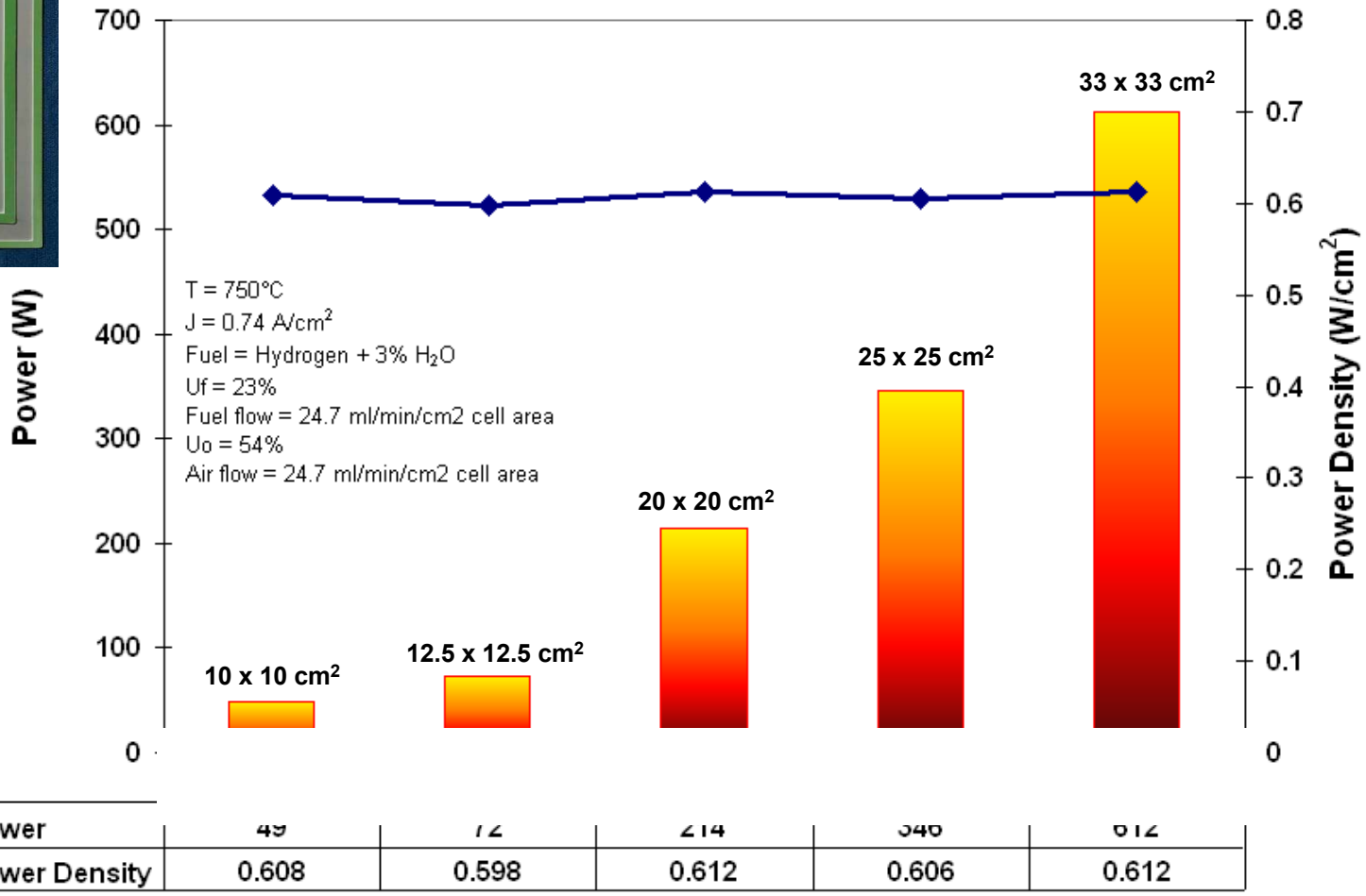
Cell Scale-Up Progress



Stainless Steel Current Collectors, Cross-Flow Gas Delivery



Power	49	72	214	346	612
Power Density	0.608	0.598	0.612	0.606	0.612

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Building Block Approach

Single Stack

Building block for stack towers

30-100 kW

Stack Tower

Building block for stack modules of ≥ 250 kW

Stack Module

Building Block for a ≥100MWe Integrated Gasification Fuel Cell (IGFC) system

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Stack Scale-up Progression

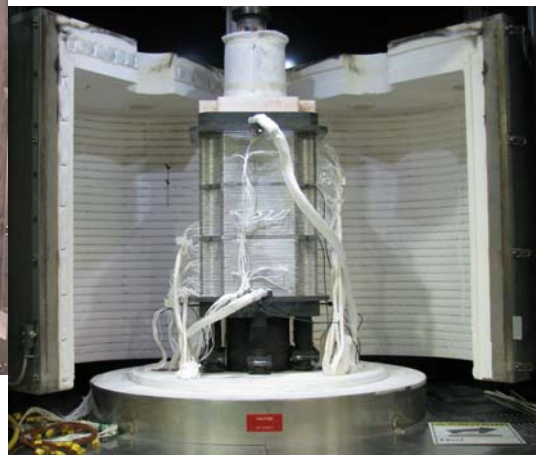
0.16 kW 1-cell

1 kW 6-cell

2.5 kW 16-cell

10 kW 64-cell

18 kW 92-cell



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

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

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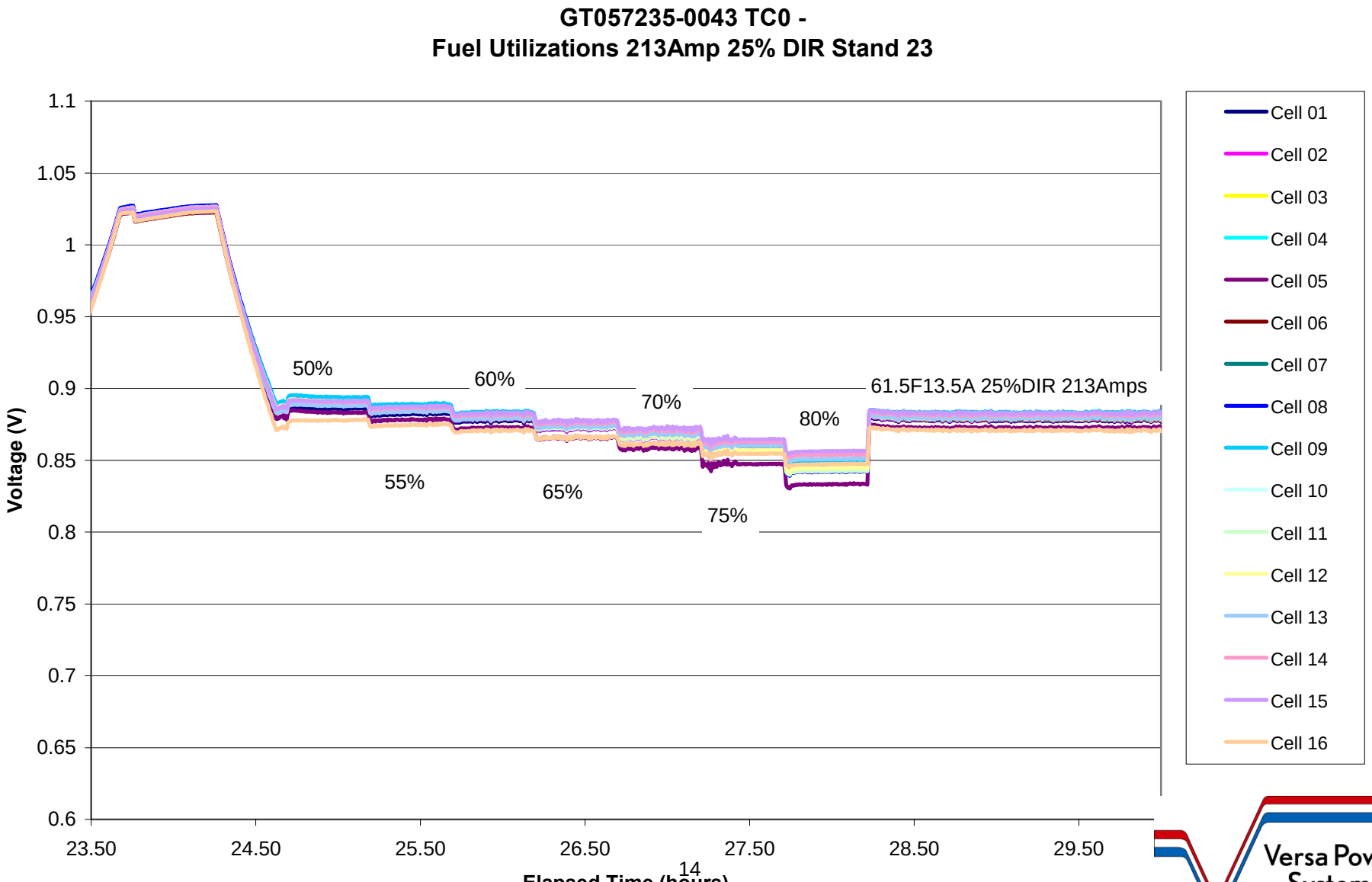
16-Cell Stack with TSC3 Thin Cell



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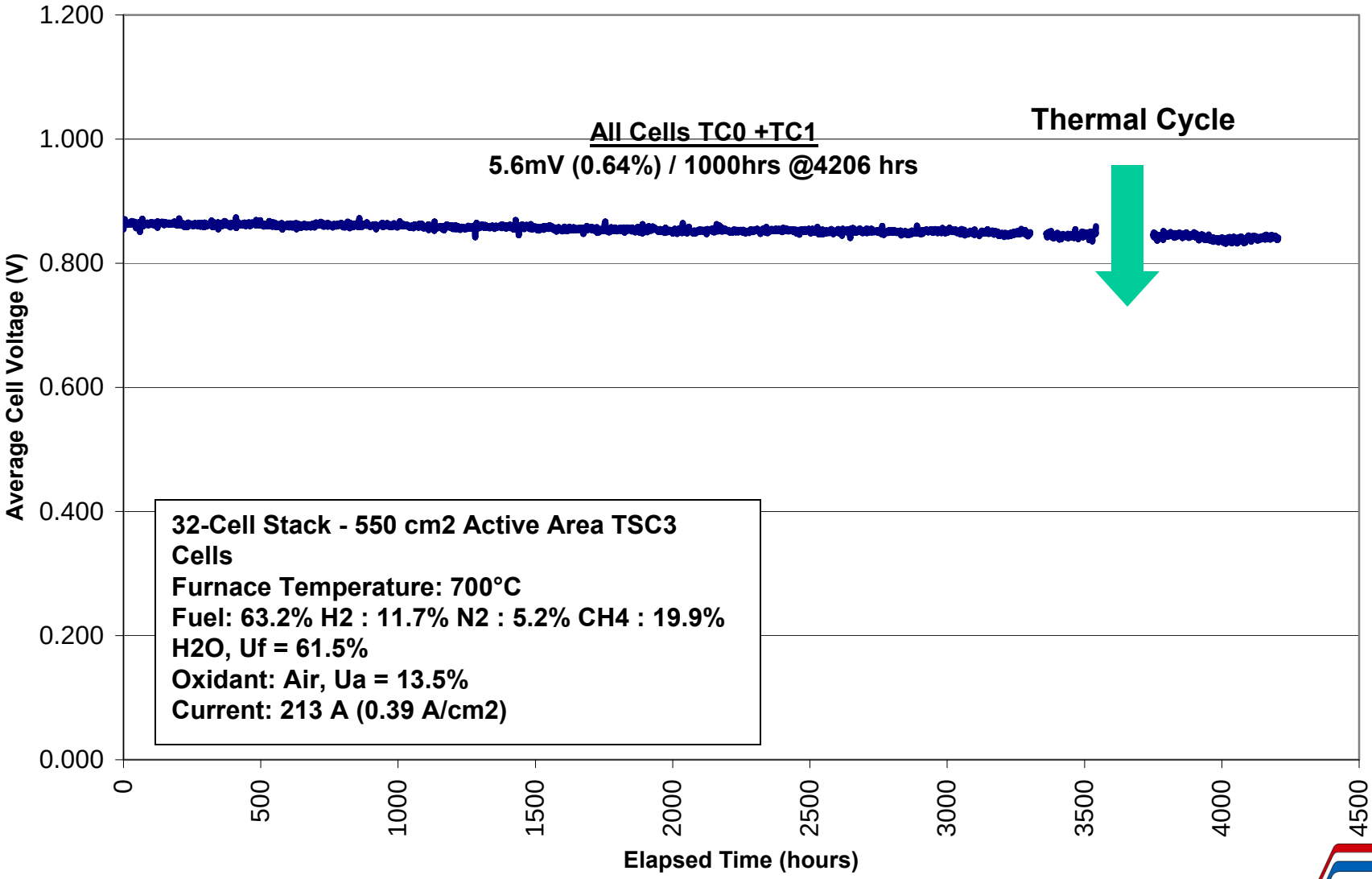
Stack Operational Stability



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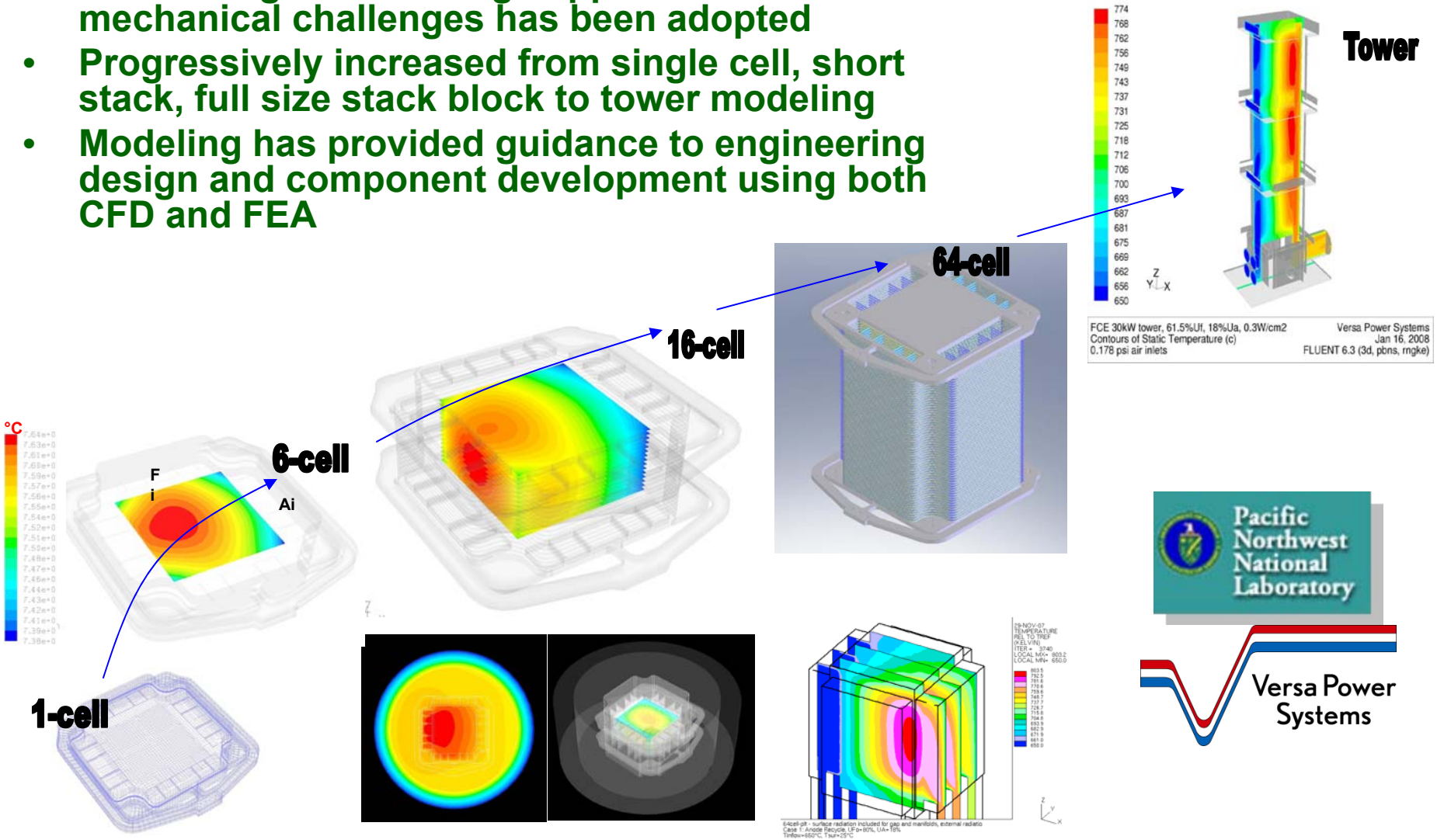
Stack Modeling

- 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



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New Generation of Stack Blocks (Phase II)

Cell Size	25 x 25 cm^2
Active Area	550 cm^2
Number of Cells	92

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

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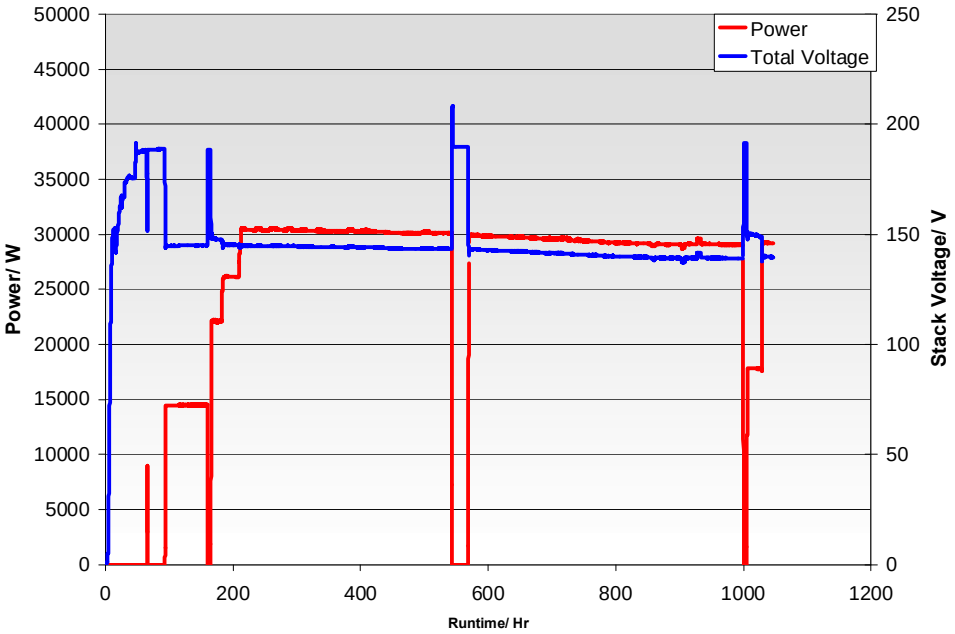
Stack Tower (SO-30-3) Test



- 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.

Coal-Based SOFC System with Catalytic Gasification

POWER GENERATION SUMMARY	kW	% Q input	% MW gross
Fuel Gas Expandors Gross Power @ 20 kV	52,307	5.15%	8.49%
Fuel Cell Inverter AC Gross Power @ 20 kV	515,126	50.76%	83.57%
WGCU 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%
Total Gross Power Generation @ 20 kV	616,393	60.74%	100.00%
Total Auxiliary Load	56,152	5.53%	9.11%
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%
Net Plant Efficiency (HHV)	**55.21%**		

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

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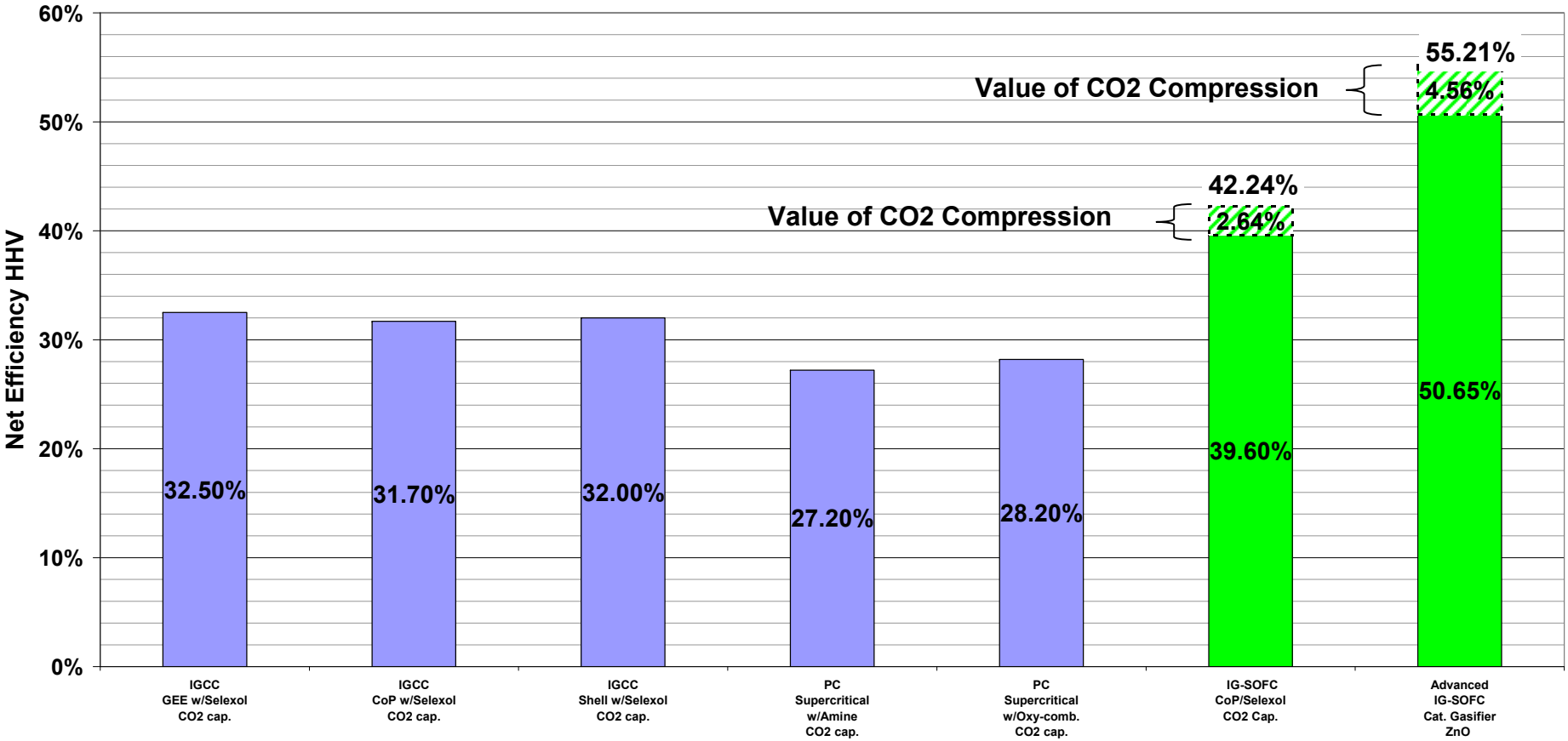
Baseline SOFC Power Plant Efficiency vs. Competing Technologies



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

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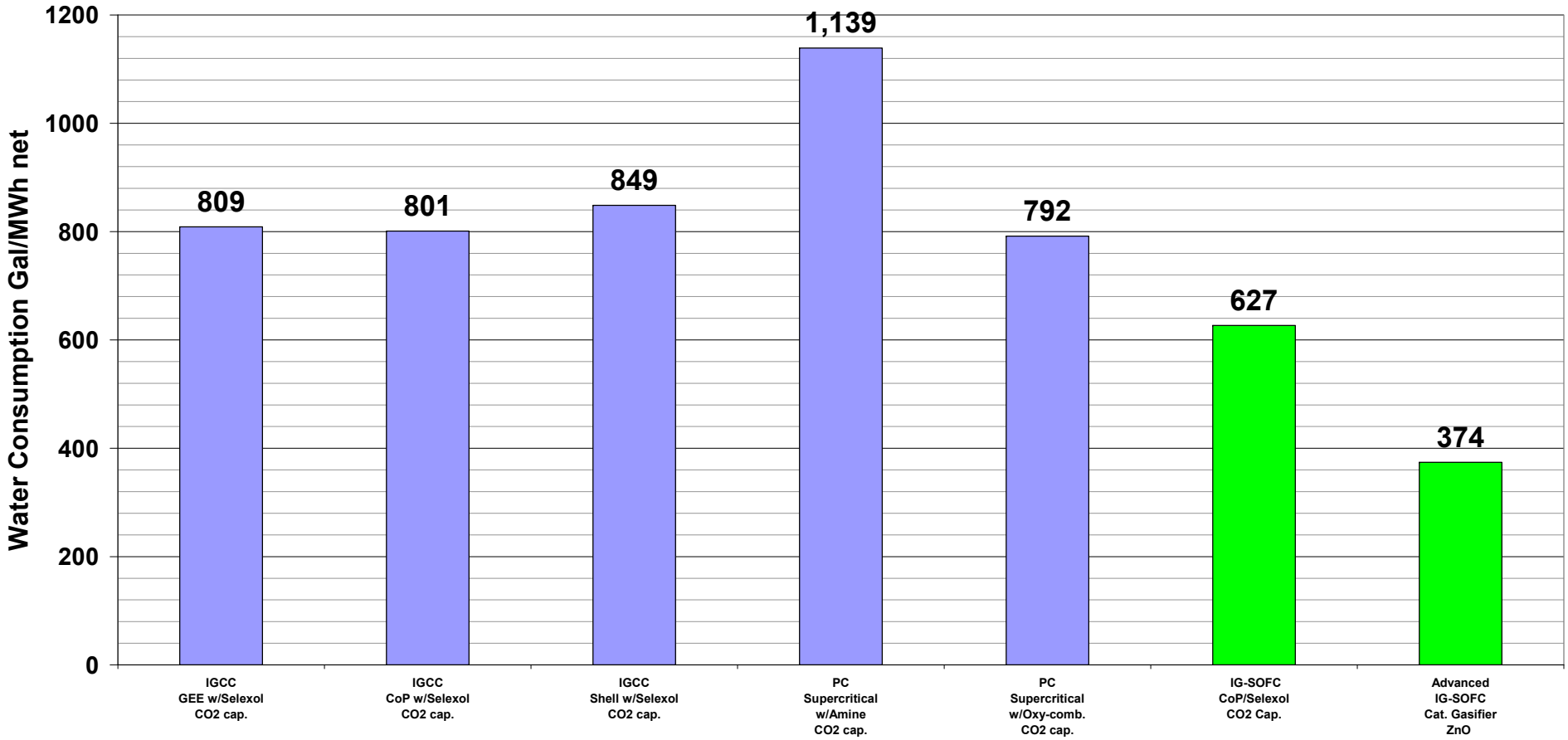
Baseline SOFC Power Plant Water Consumption vs. Competing Technologies



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

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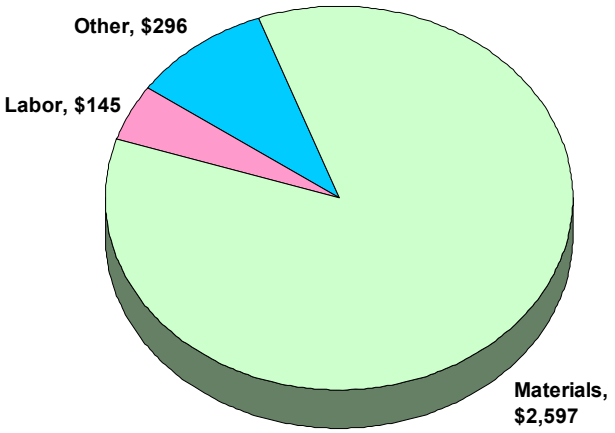
Stack Costing (Q3, 2009)

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



Stack Block Cost by Category (Phase II Interim)

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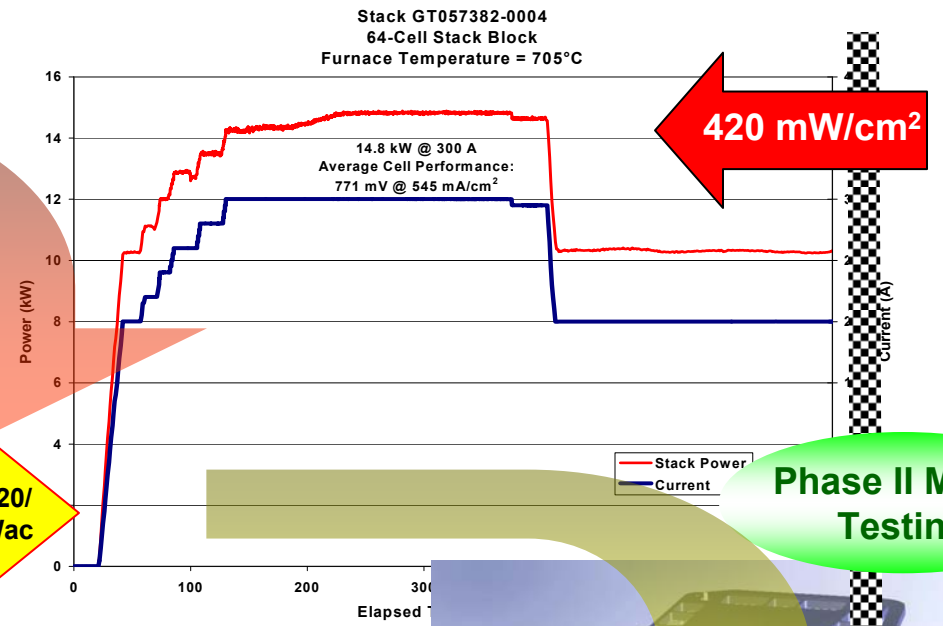
Stack Cost Reduction Path

$197/ kWac

Higher Power Density



420 mW/cm²

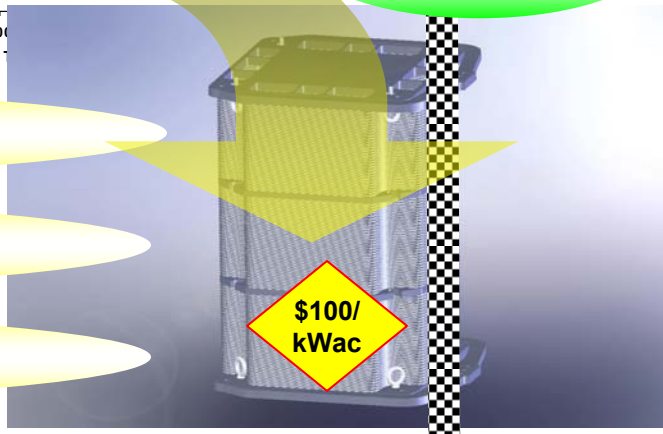
$120/ kWac

Phase II Metric Testing

Stack Block Scale Up

Thin Cell Development

Stack Materials Reduction

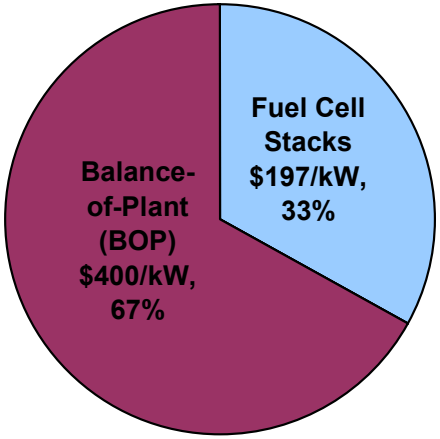


$100/ kWac

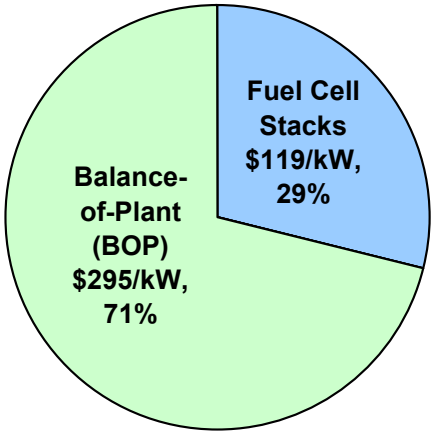
Q4 2008 | Q1 2009 | Q2 2009 | Q3 2009 | Q4 2009 | Q1 2010 | Q2 2010 | Q3 2010 | Q4 2010

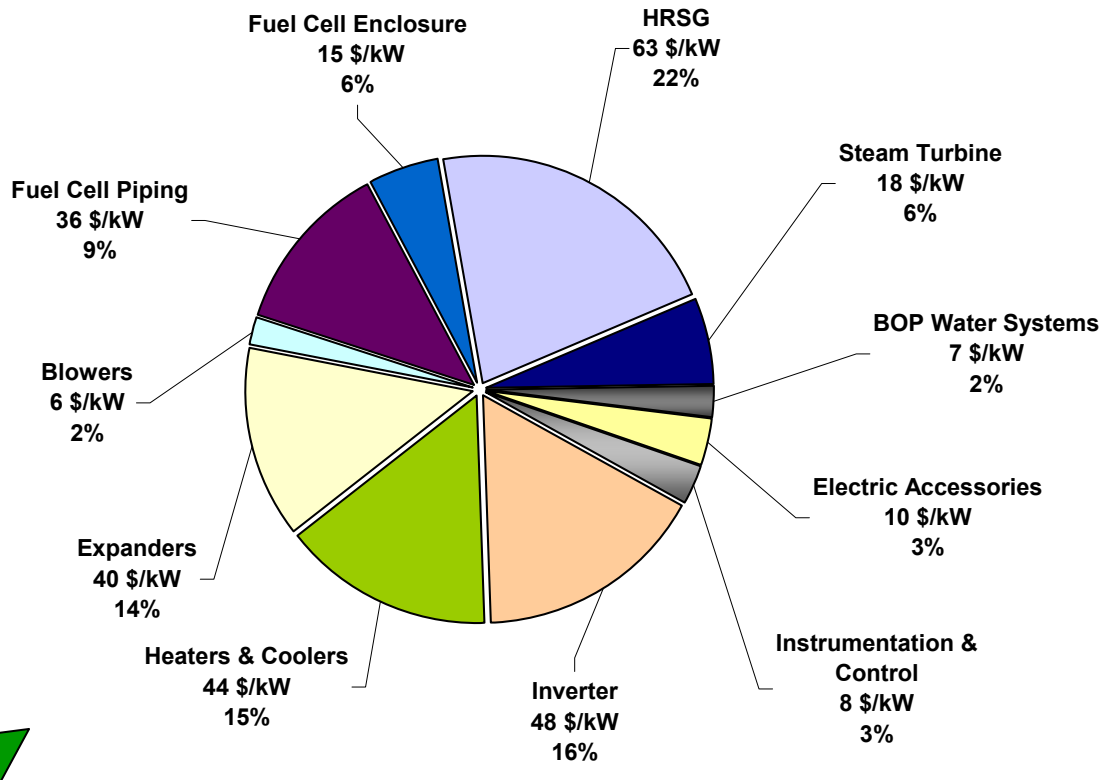
Factory Equipment Cost Estimate

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_2 separation/compression systems.

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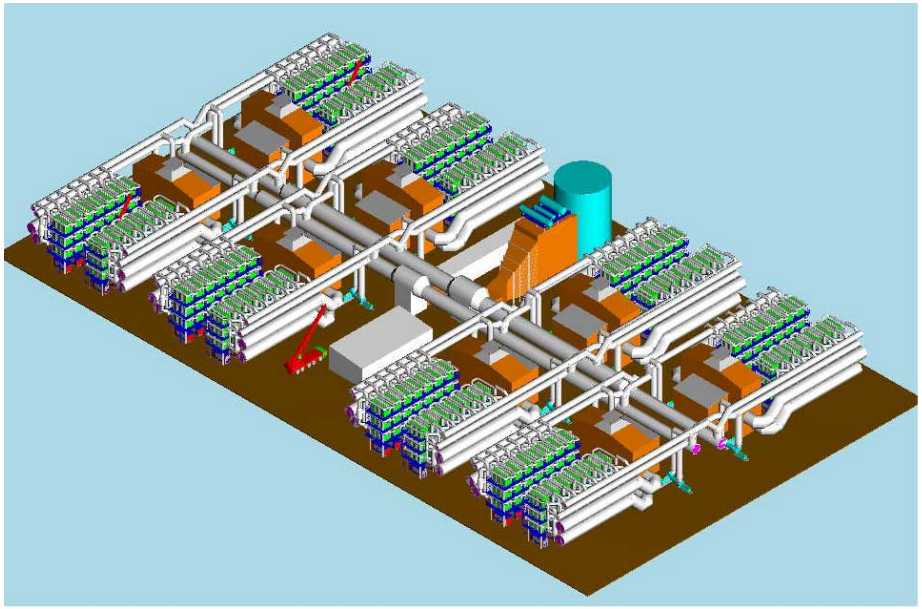
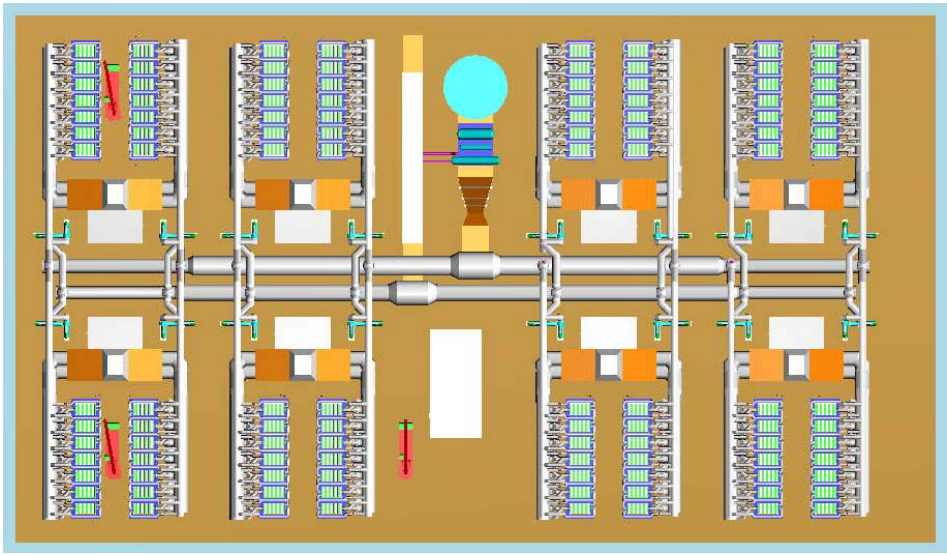
Baseline System Power Island Layout

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





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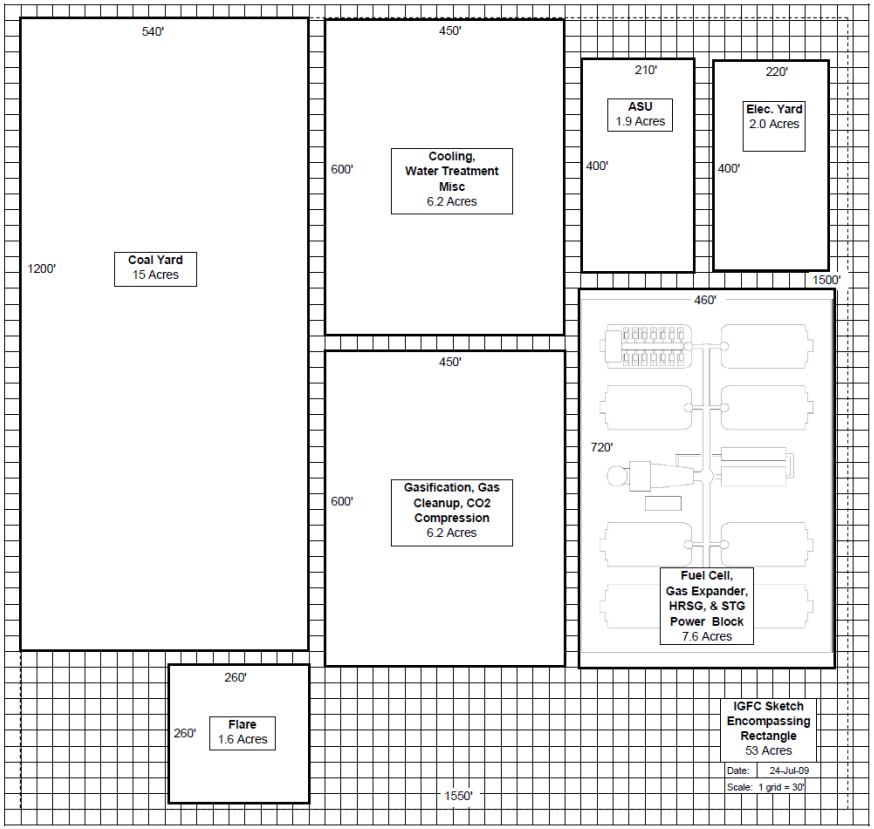
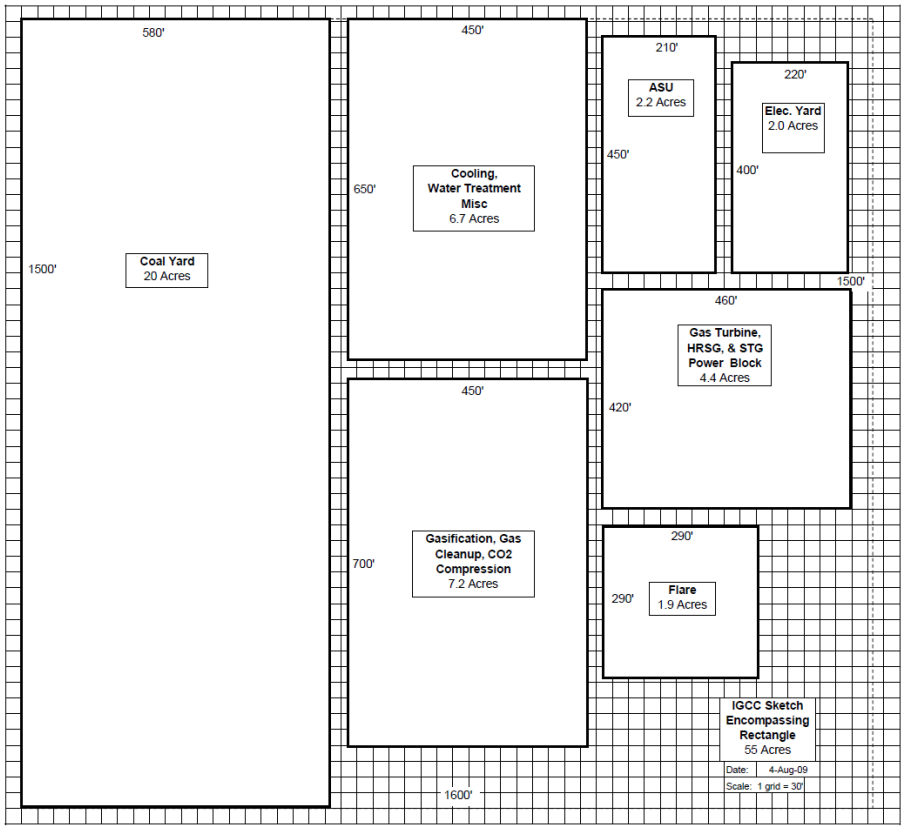
Representative Foot Print Comparison: IGFC & IGCC

IGFC



IGCC



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

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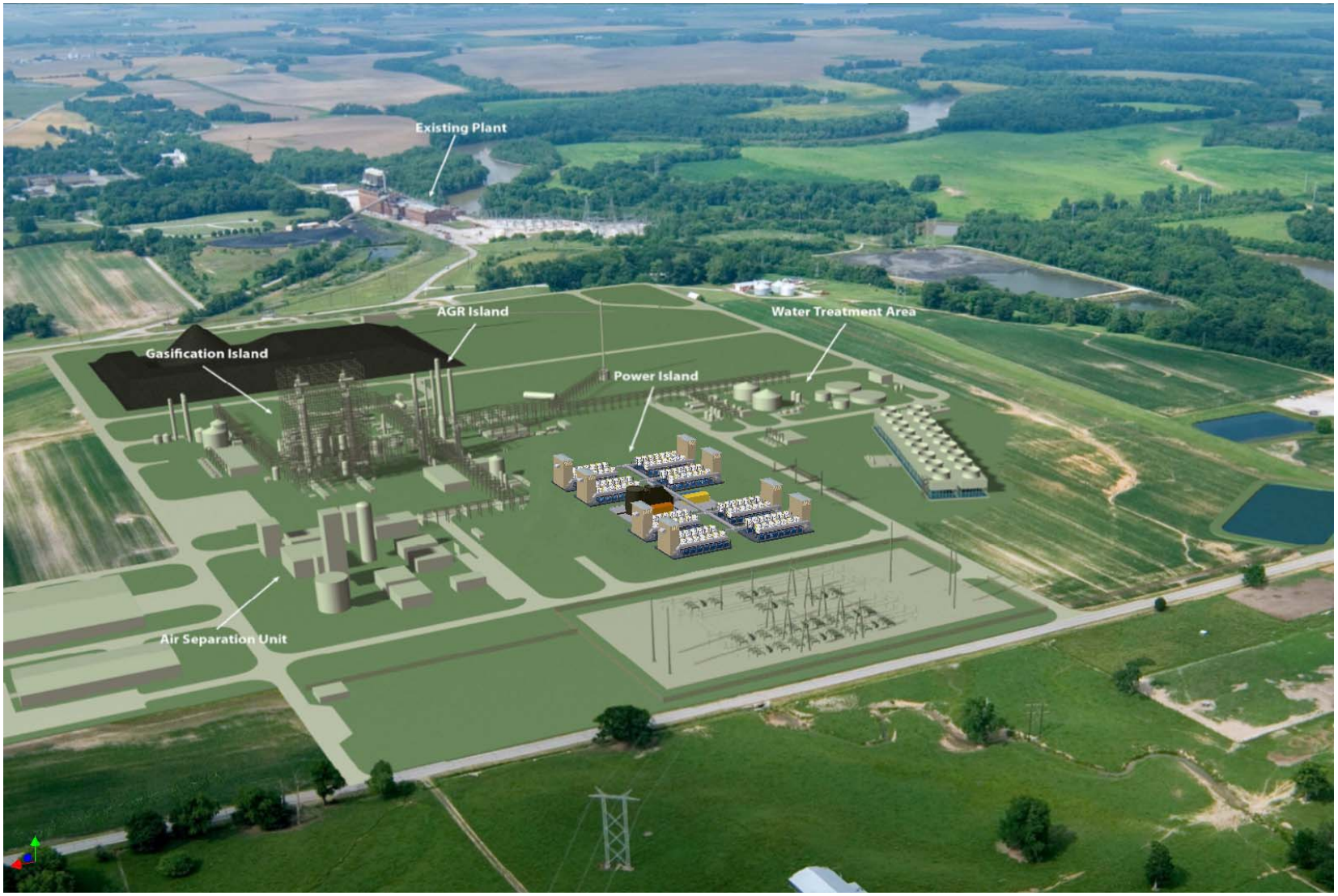
IGFC Site Layout



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Summary of Recent Achievements

- **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.

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Acknowledgement

- **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!