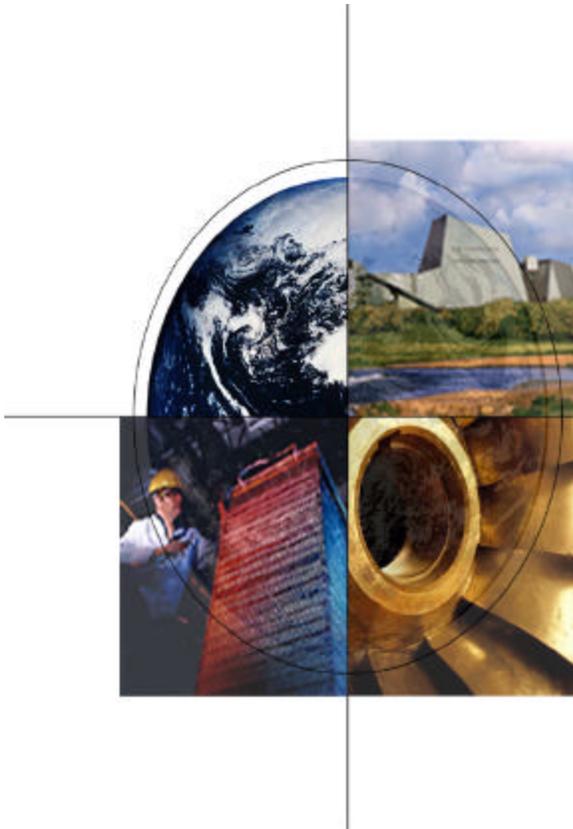


# DOE Hybrid Systems Program



*DOE / UN International  
Conference and Workshop  
on Hybrid Power Systems*

*April 16, 2002*

*Rita A. Bajura, Director*

**National Energy Technology Laboratory**



[www.netl.doe.gov](http://www.netl.doe.gov)



---

# Hybrid

*Oxford English Dictionary, Second Edition*

hybrid ("halbrld, "hlbrld), *n. and a.*

Offspring of two animals or plants of different species, or (less strictly) varieties; a half-breed, cross-breed, or mongrel

**1601 Holland *Pliny* II. 231. . . and verily such hogs in old time they called Hybrides, as a man would say, halfe wild**

**1623 Cockeram, *Hibride*, a Hog ingendred betweene a wilde Boare and a tame Sow**



# Working Definition

## *Hybrid Fuel Cell System*

**Combined-cycle power generation system containing a high-temperature fuel cell plus a**

- ✓ **Gas turbine**  
*or*
- ✓ **Reciprocating engine**  
*or*
- ✓ **Another fuel cell**



# Hybrid History

**Mid 1970s**

Fuel cell / turbine hybrids conceived

**1995 & 1996**

Workshops at NETL

**1998**

Hybrid Solicitation

**1997**

Westinghouse  
Contract Signed



# 1998 Hybrid Solicitation

## *Program Research and Development Announcement*

- Feasibility / systems studies
- < 20 MW
- Near-term
- 70% efficient
- Operate on natural gas
- Contain HT fuel cell
- COE 10-20% < conventional plants



## 1998 Hybrid Awards

<b><i>Fuel Cell Manufacturer</i></b>	<b><i>Turbine Supplier</i></b>	<b><i>Type of Fuel Cell</i></b>
<b>Siemens W</b>	<b>Rolls-Royce</b>	<b>Tubular SOFC</b>
<b>Siemens W</b>	<b>Caterpillar/Solar</b>	<b>Tubular SOFC</b>
<b>McDermott</b>	<b>NREC</b>	<b>Planar SOFC</b>
<b>FuelCell Energy</b>	<b>Rolls-Royce</b>	<b>MCFC</b>
<b>M-C Power</b>	<b>Rolls-Royce</b>	<b>MCFC</b>



## Results from 1998 Solicitation

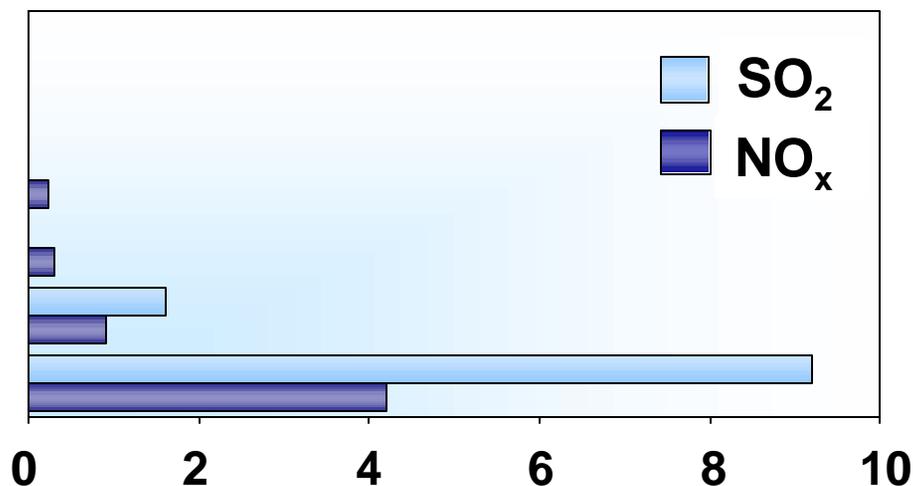
- Efficiencies of  $>70\%$  possible
- ~ 65% efficiencies produce a lower COE
- Program should start with sizes  $\ll 20$  MW
- Off-the-shelf turbines poor fit for larger hybrids



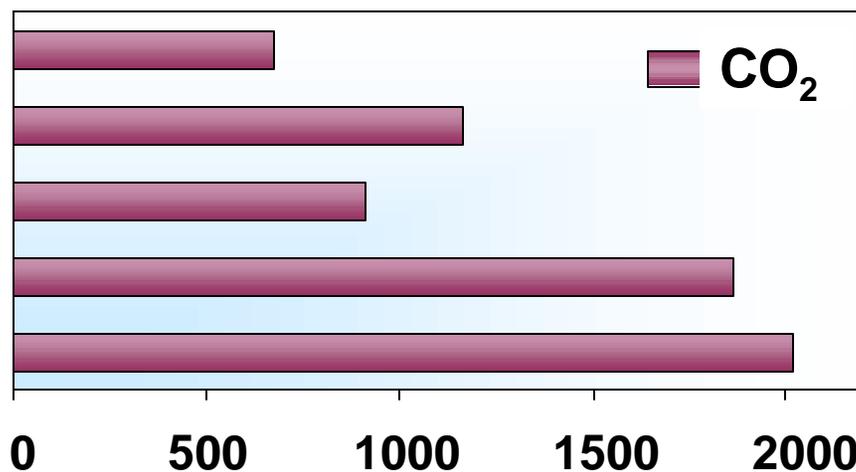
# Hybrid Efficiency Leads to Low Emissions

*lb/MWhr*

**Hybrid**  
**Fuel Cell**  
**Gas Turbine CC**  
**Microturbine**  
**“Clear Skies” Plant (2018)**  
**US. Fossil Fuel Plant (2000)**

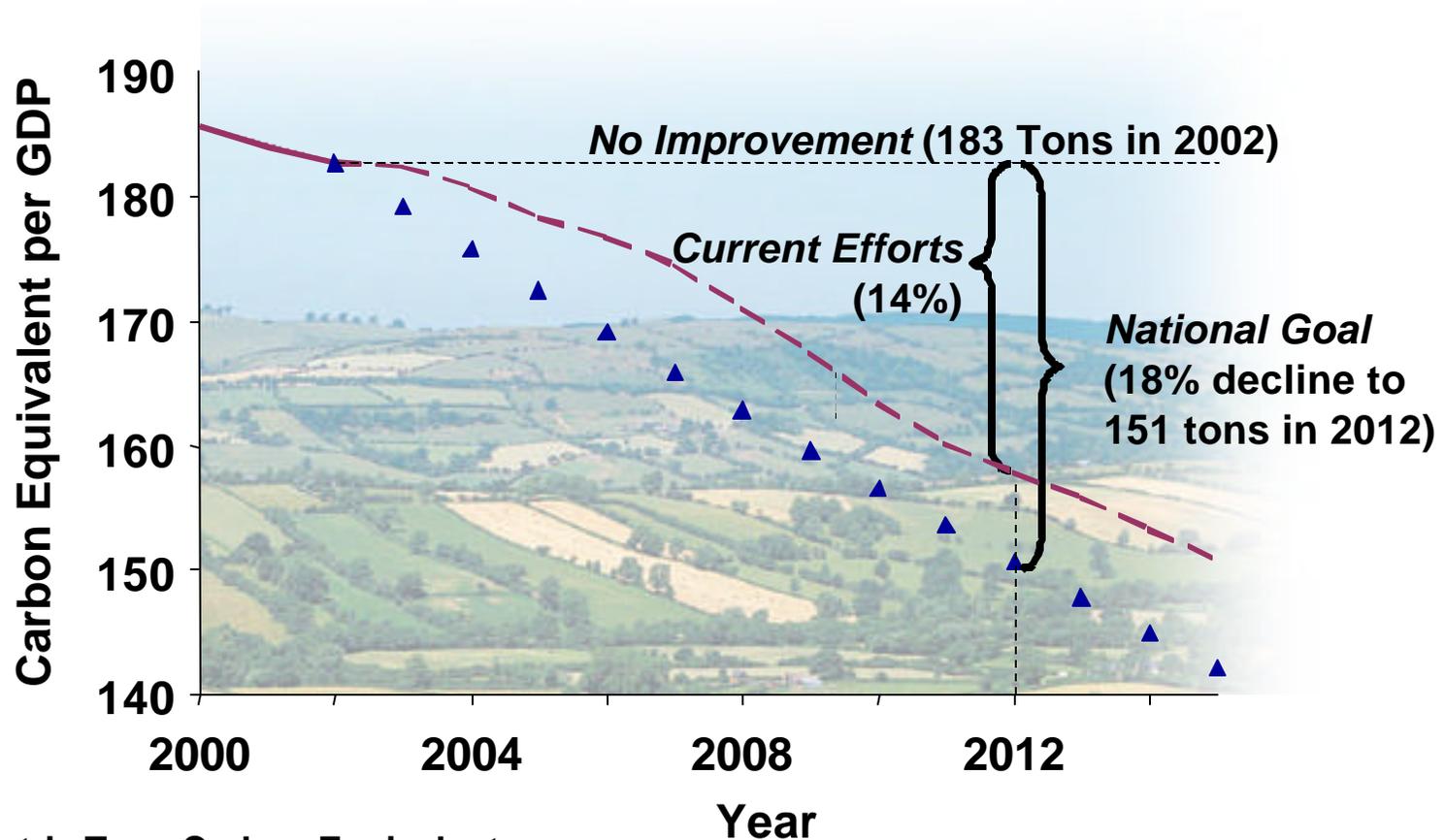


**Hybrid**  
**Fuel Cell**  
**Gas Turbine CC**  
**Microturbine**  
**US. Fossil Fuel Plant (2002)**



*Plant Estimates: D. Smith, NETL*  
*Hybrid Estimates: L. Berkshire, NETL*  
*Other Technology Estimates: S. O'Brien, UTC Fuel Cells*

# Reduce Greenhouse Gas Emission Intensity by 18% Over Next Decade



Metric Tons Carbon Equivalent per Million \$ GDP, 2001 Dollars



# Vision 21

## *Ultra-Clean Energy Plant of Future*

### *Energy Plants for Post-2015*

- Coal and other fuels
- Electricity and possible co-products



*Goal*  
**Eliminate  
Environmental  
Concerns from Use  
of Fossil Energy**



### *Approach*

- **Maximize efficiency**
  - 60% coal
  - 75% natural gas
- **Near-zero emissions**

# Market Potential for Hybrids

## *Up to 2005*<sup>1</sup>

- 8.2 GW market
- 15 – 25 MW size
- \$1000-1600/kW

## *2006-2009*<sup>1</sup>

- 60 GW market
- \$600-\$1100/kW

## *DOE's Industries of the Future*<sup>2</sup>

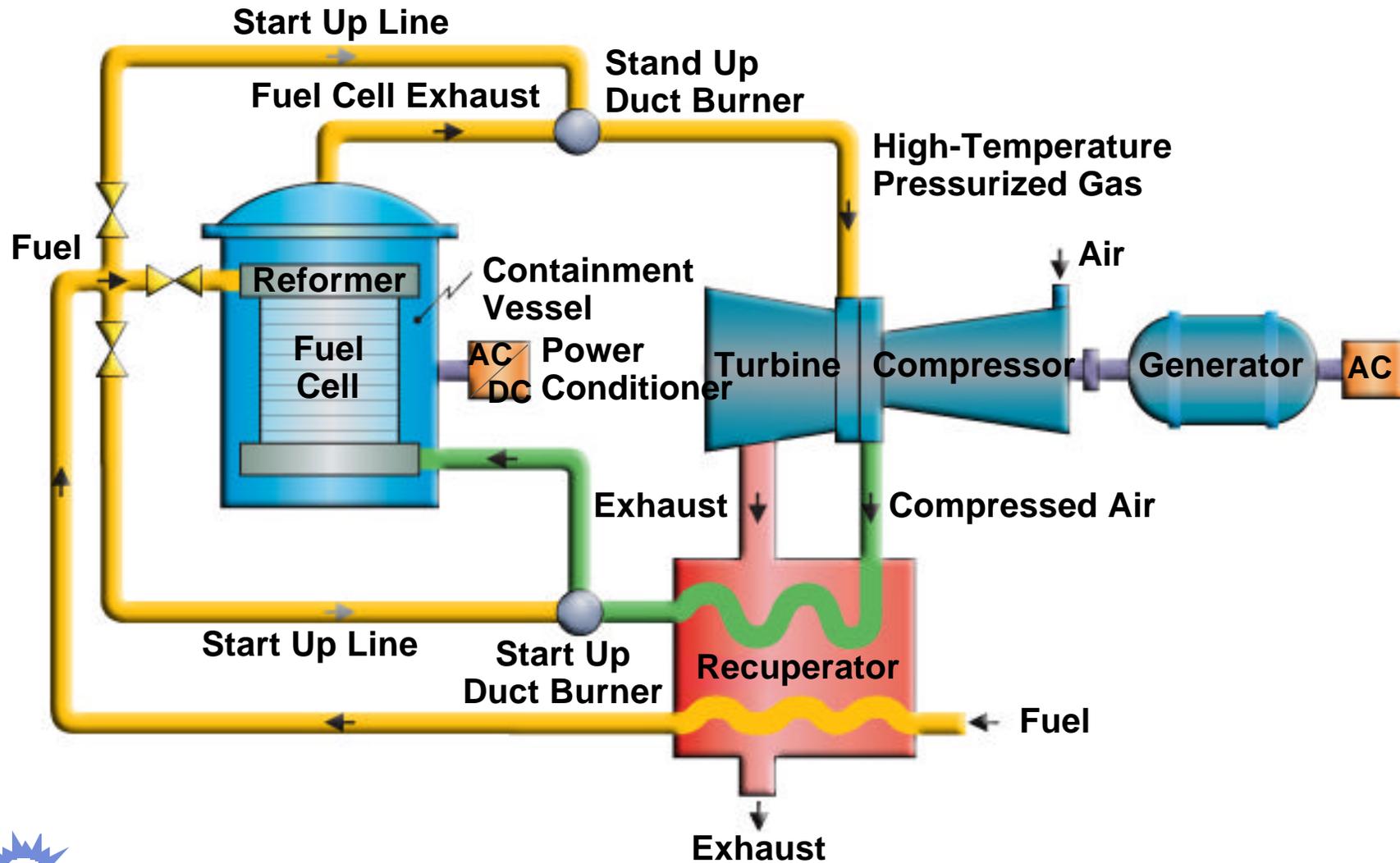
- 70 GW “addressable market” by 2010
- 0.25 – 20 MW size



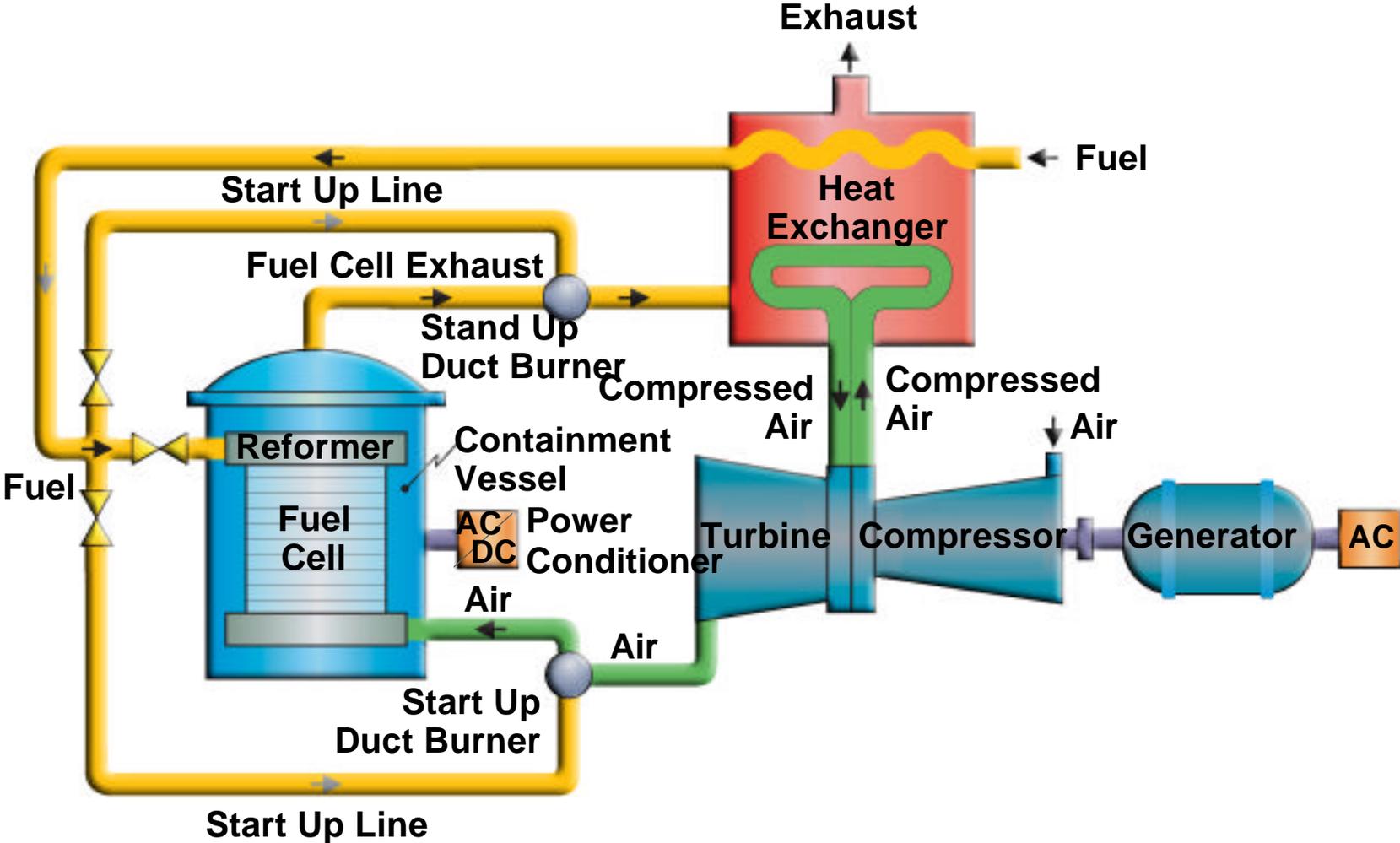
<sup>1</sup> Resource Dynamics Corp

<sup>2</sup> AD Little

# Direct-Fired Hybrid



# Indirect-Fired Hybrid



## Characteristics of Hybrids

	<i>Direct</i>	<i>Indirect</i>
<b><i>Fuel Cell:Turbine Power Ratio</i></b>	~4:1	~10:1
<b><i>Flow Rates &amp; Pressure Ratio</i></b>	More difficult to match	Easier to match
<b><i>Efficiency</i></b>	↑ ↑ ↑	↑ ↑
<b><i>Thermal Duty</i></b>	High-temperature recuperator	High-temperature heat exchanger
<b><i>Catalytic Oxidizer</i></b>	No	Yes
<b><i>Fuel Cell</i></b>	Pressurized	Non-pressurized



# Current Hybrid Projects

- National Fuel Cell Research Center
- Rolls-Royce (2)
- Siemens Westinghouse
- FuelCell Energy
- Honeywell GE



# National Fuel Cell Research Center

## *Systems Integration Methodologies*

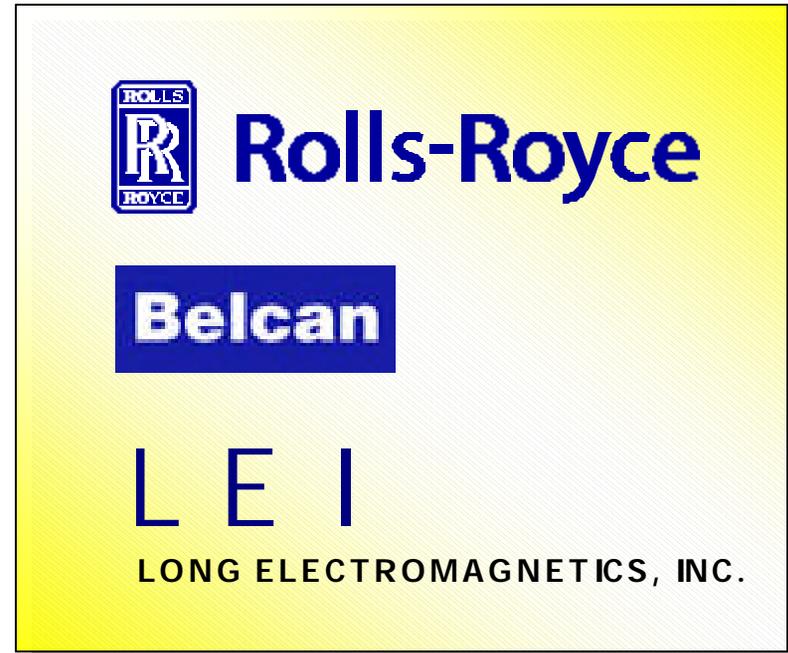
- Identify coal- and natural-gas-based systems to meet Vision 21 goals
- Develop tools to simulate steady-state and dynamic performance of hybrids



# Rolls-Royce

## *Small Turbogenerator Technology for DG*

- Conceptual design
- Scalable 0.5 - 5 MW
- >40,000-hour life
- Cost target \$400/kW



# Rolls-Royce

## *Market Assessment and Early Adopter Study*

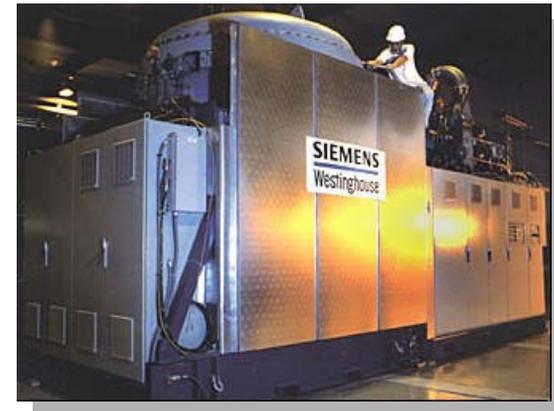


- **Most potential for larger hybrids**
  - 15 - 40 MW
- **Potential >\$30 billion in net savings to hybrid users**
- **Small hybrids needed for market entry / early adopters**
  - 0.1 - 5 MW

# Siemens Westinghouse

## *Solid Oxide Fuel Cell / Gas Turbine*

- Direct-fired configuration
- 200 kW demonstration
- Located at NFCRC
- 53% efficiency
- Operated > 1,000 hours
- 300 and 550 kW demos planned



# FuelCell Energy

## *Molten Carbonate Fuel Cell / Gas Turbine*

- Indirect-fired configuration
- Operated 4,700 hours
- Electrical efficiency of 52%
- Design of 40-MW hybrid plant



# Honeywell GE

## *SECA-Based Fuel Cell Hybrid*

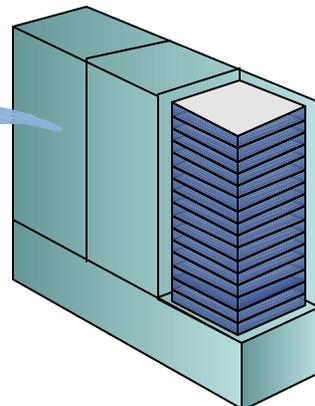
- Planar SOFC and direct-fired turbine
- Estimated efficiency 67%
- First SECA-based hybrid



# Solid State Energy Conversion Alliance

## *Core Module for Multiple Applications*

**Transportation**



**Core Module**



**Stationary**



**Military**



# SECA Goals and Applications



## 2005 Beta Prototype

- **\$800/kW**
  - Premium power
  - Auxiliary power in long-haul trucks
  - RVs
  - Military



## 2010 Product

- **\$400/kW**
  - Residential & industrial CHP

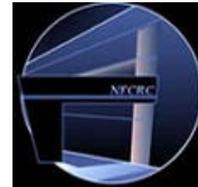
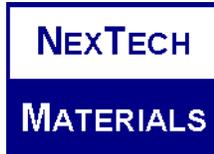
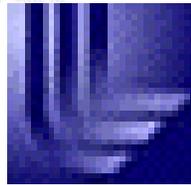
## 2015

- **Vision 21 power plants**
- **Hybrid systems**



# SECA Players

*Universities, National Labs, Industry*



Automotive Systems





# A Vision for 2015

*Putting the Pieces Together*



**SECA-Based Hybrids**



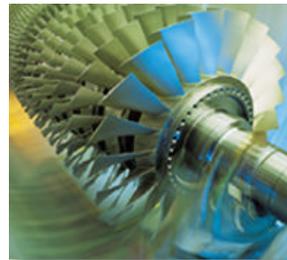
*Hybrid-Based Vision 21  
Power Plants*



**Carbon  
Sequestration**



**Gasification with  
Cleanup & Separation**



**Optimized Turbines**



**System  
Integration**





