# U.S. DOE FE Fuel Cell Program

DOE Hydrogen and Fuel Cells Coordination Meeting

***June 2, 2003***

***Sam Biondo, 35910***

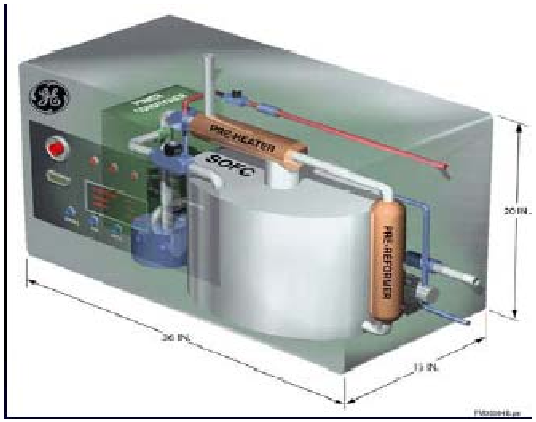
**Fuel Cell and Hydrogen Crosscut**
**(dollars in thousands)**

| Bureau/Program | FY 2001 Actual | FY 2002 Actual | FY 2003 Enacted* | FY 2004 Budget | Description |
|---|---|---|---|---|---|
| **Fossil Energy (FE) Fule Cells** | | | | | |
| **Distributed Generation Systems** | | | | | |
| Innovative Systems Concepts | 3,789 | 26,484 | 33,779 | 23,500 | Continue to develop and test six SECA industry team concept designs for prototype low-to-high temperature, $400/kW systems and continue the supporting SECA Core Technology program. |
| Fuel Cell Systems Development | 30,172 | 13,147 | 9,935 | 6,000 | Conduct re-directed program on advanced systems development and testing. These advanced systems include zero emission and hybrid systems. Also includes various stack designs under SECA and adaptation of SECA for syngas and diesel. |
| Vision 21 Hybrid | 14,592 | 13,152 | 13,412 | 5,000 | Conduct a redirected Vision 21 enabling cost reduction and performance enhancement program to emphasize SECA with low-cost Vision 21 fuel cell /turbine hybrids and V21 zero emissions concepts; and conduct system studies and explore fuel flexibility and in |
| Advanced Research | 2,721 | 3,895 | 3,477 | 10,000 | Continue to fund research at the High Temperature Electrochemical Center to develop a fundamental understanding of processes that limit the performance of high temperature electrochemical systems. This activity also supports SECA core technology material |
| **Total, FE** | **51,274** | **56,678** | **60,603** | **44,500** | |

# Fuel Cell Program Goals

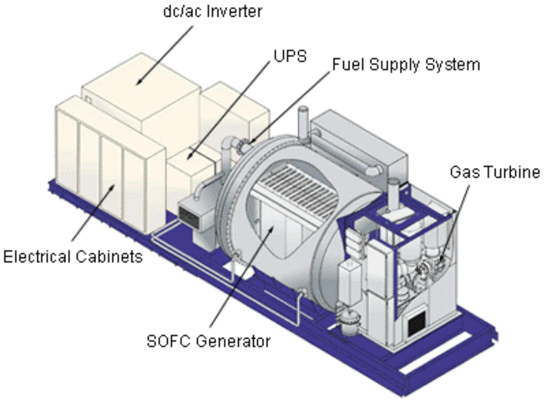

- Ensure the widespread deployment of **affordable clean, efficient** fuel cell technology
- Develop technology that is:
  - Very low cost
  - Widely applicable
  - Highly reliable

# Fuel Cell Program Areas (FY '03 Funding)

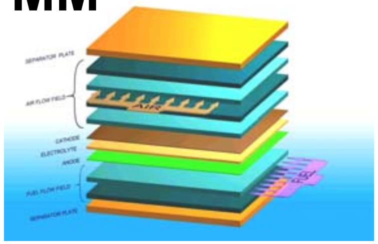



**Innovative Concepts - SECA**
**$33.779MM**

**Fuel Cell Systems -**
**$9.935MM**




**Advanced Research**
**(Electrochemical Engineering)**
**$3.477MM**



**Vision 21 Hybrids -**
**$13.412MM**

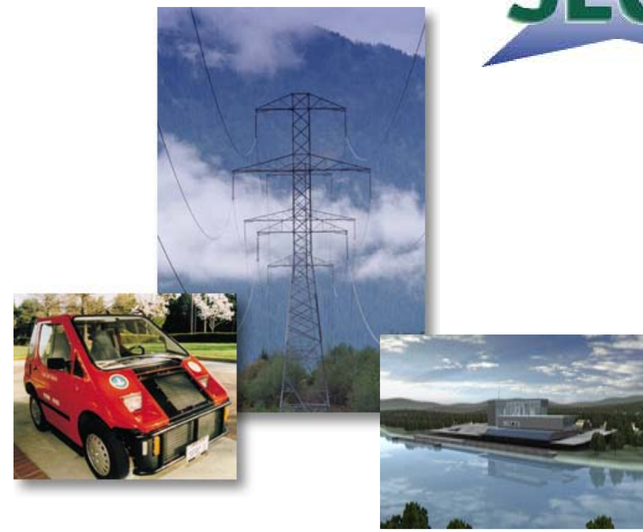
# SECA Applications


**2005**

- **APU Prototypes (Beta)**
  - Long Haul Trucks )
  - RV's
  - Military
  - Premium Power

**2010**

- **$400/kW**
- **Commercial Products**
  - Transportation APUs
  - Residential & Industrial CHP

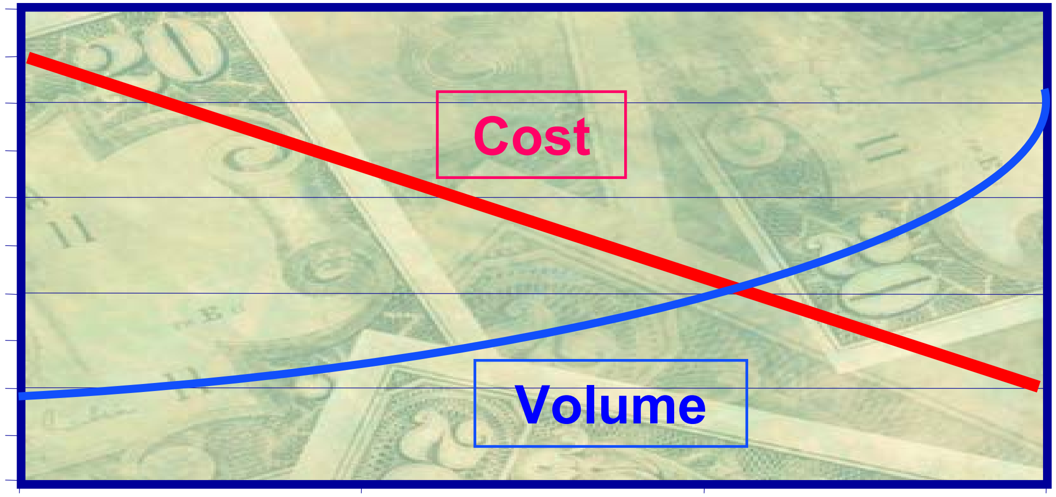


**2015**

- **$400/kW**
- **Hybrid Systems**
  - 60-70% efficient
- **Vision 21 Power Modules**

# SECA Program Strategy

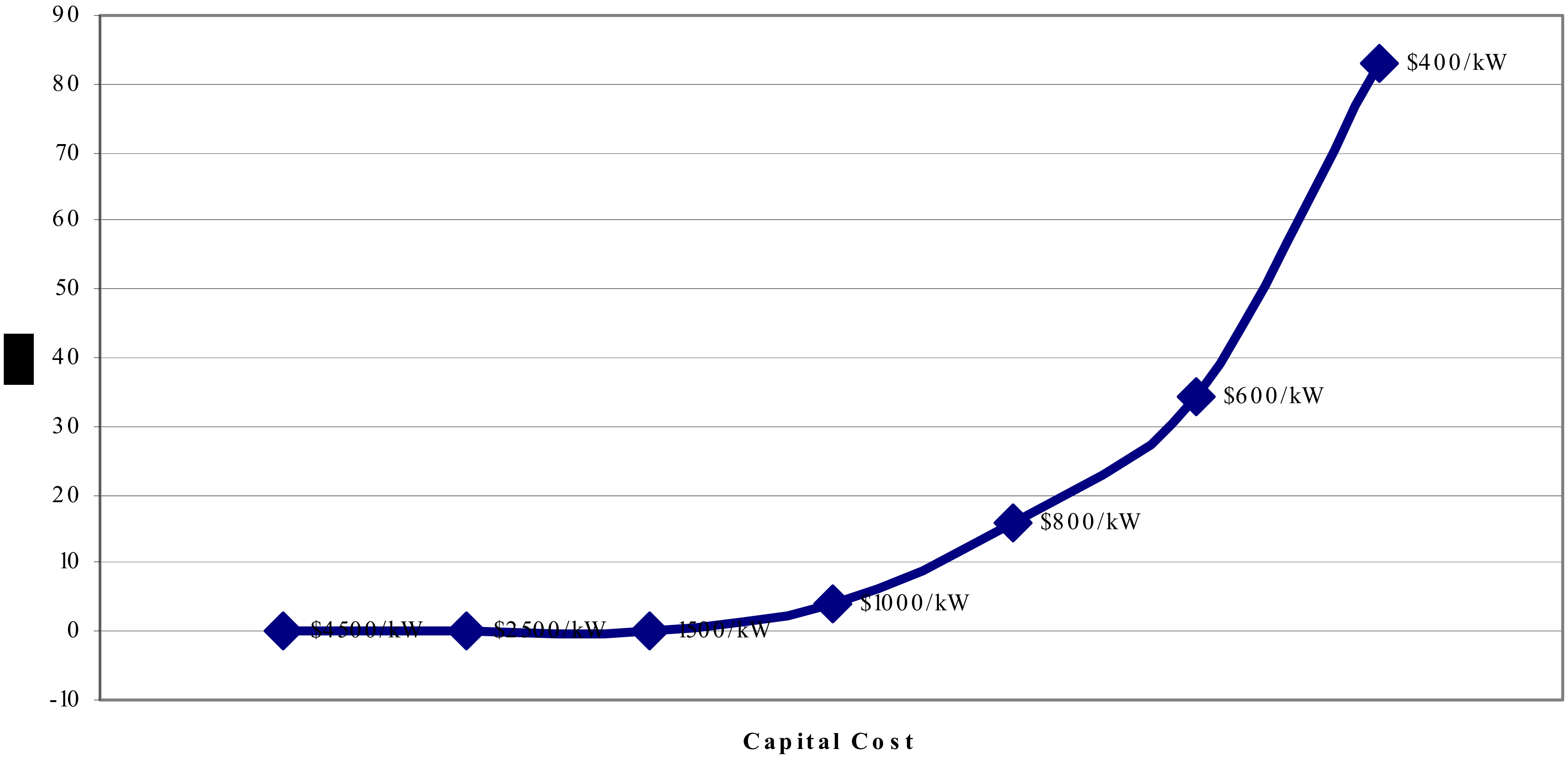
- Make the enormous potential public benefits of fuel cells widely available
- The cost goal is FOB $400/kW or less by 2010
- High-volume / low cost manufacturing technology




Low Cost/High Volume
$400/kW/ > 50,000 units/yr

# Market Penetration of Fuel Cells by 2025

## as predected by NEMS



# SECA Program Strategy

- Multiple markets via mass customization
- Industry teams with different technical approaches and market applications
- Core Technology Program (CTP) to develop common supporting technology
- Leverage funding by cost sharing and encouraging broad participation by other funding organizations

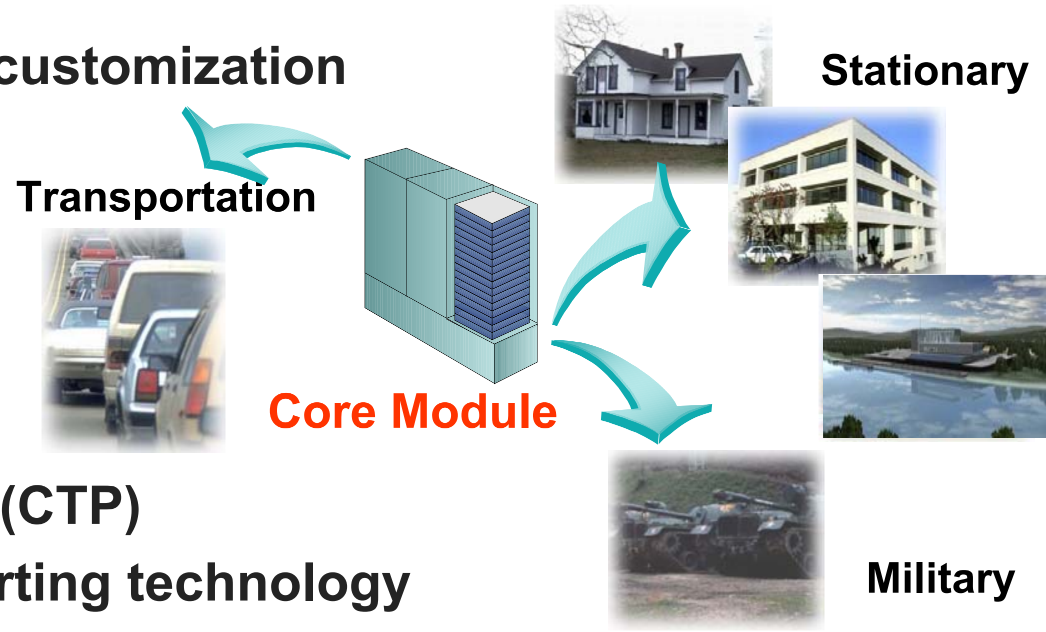


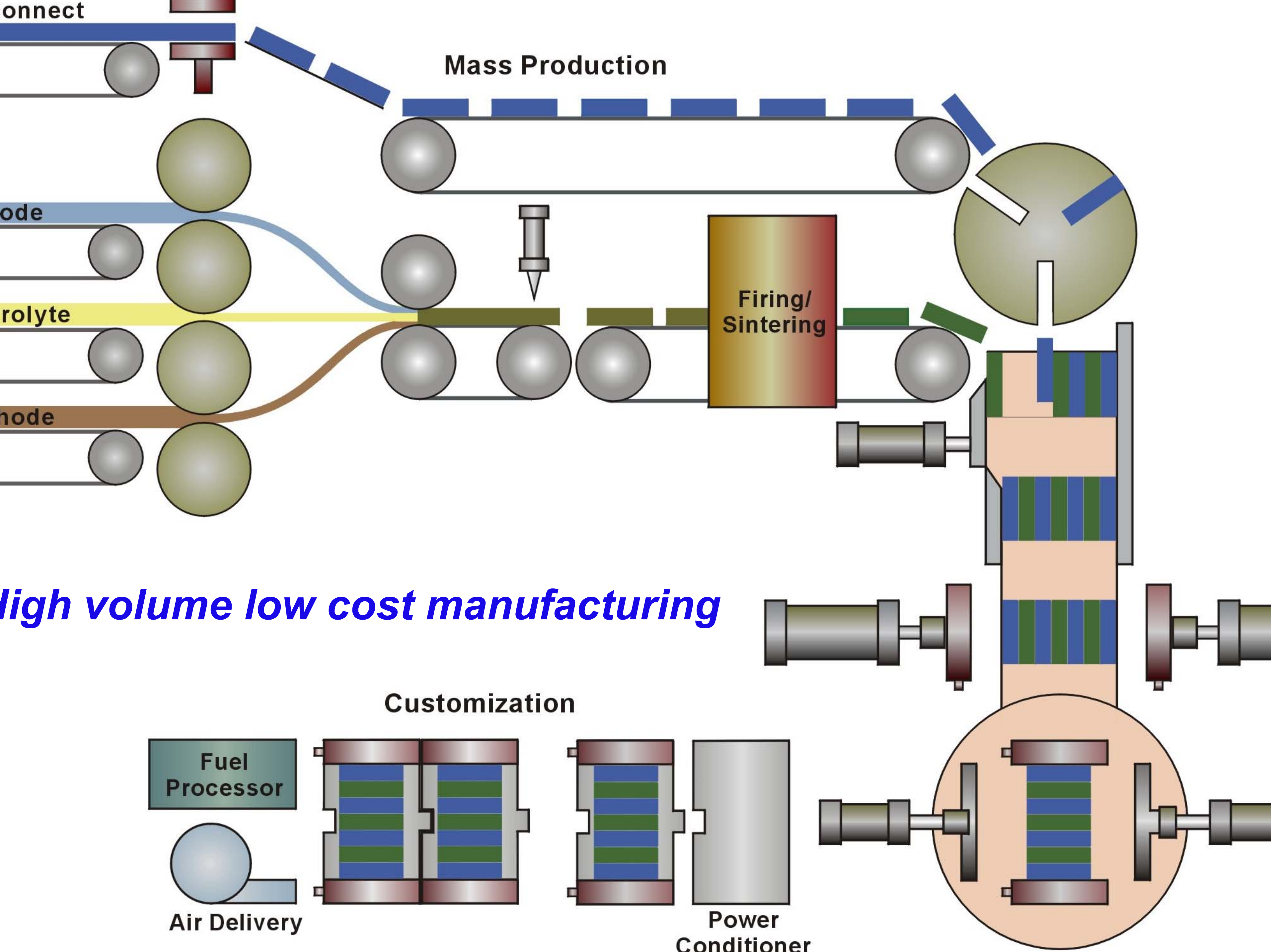
Table 3. Performance Objectives of 3–10-kW SOFC Module

| Phase | I | II | III |
|---|---|---|---|
| **Cost** | * | * | $400/kW |
| **Efficiency** | | | |
| Mobile | 25–45% | 30–50% | 30–50% |
| Stationary | 35–55% | 40–60% | 40–60% |
| **Steady-State** | | | |
| Test Hours | 1,500 | 1,500 | 1,500 |
| Availability | 80% | 85% | 95% |
| Power Degradation per 500 hours | ≤2% | ≤1% | ≤0.1% |
| **Transient Test** | | | |
| Cycles | 10 | 50 | 100 |
| Power Degradation after Cycle Test | ≤1% | ≤0.5% | ≤0.1% |
| **Power Density** | 0.3W/cm$^2$ | 0.6W/cm$^2$ | >0.6W/cm$^2$ |
| **Temperature** | 800 °C | ~700 °C | 700 °C |

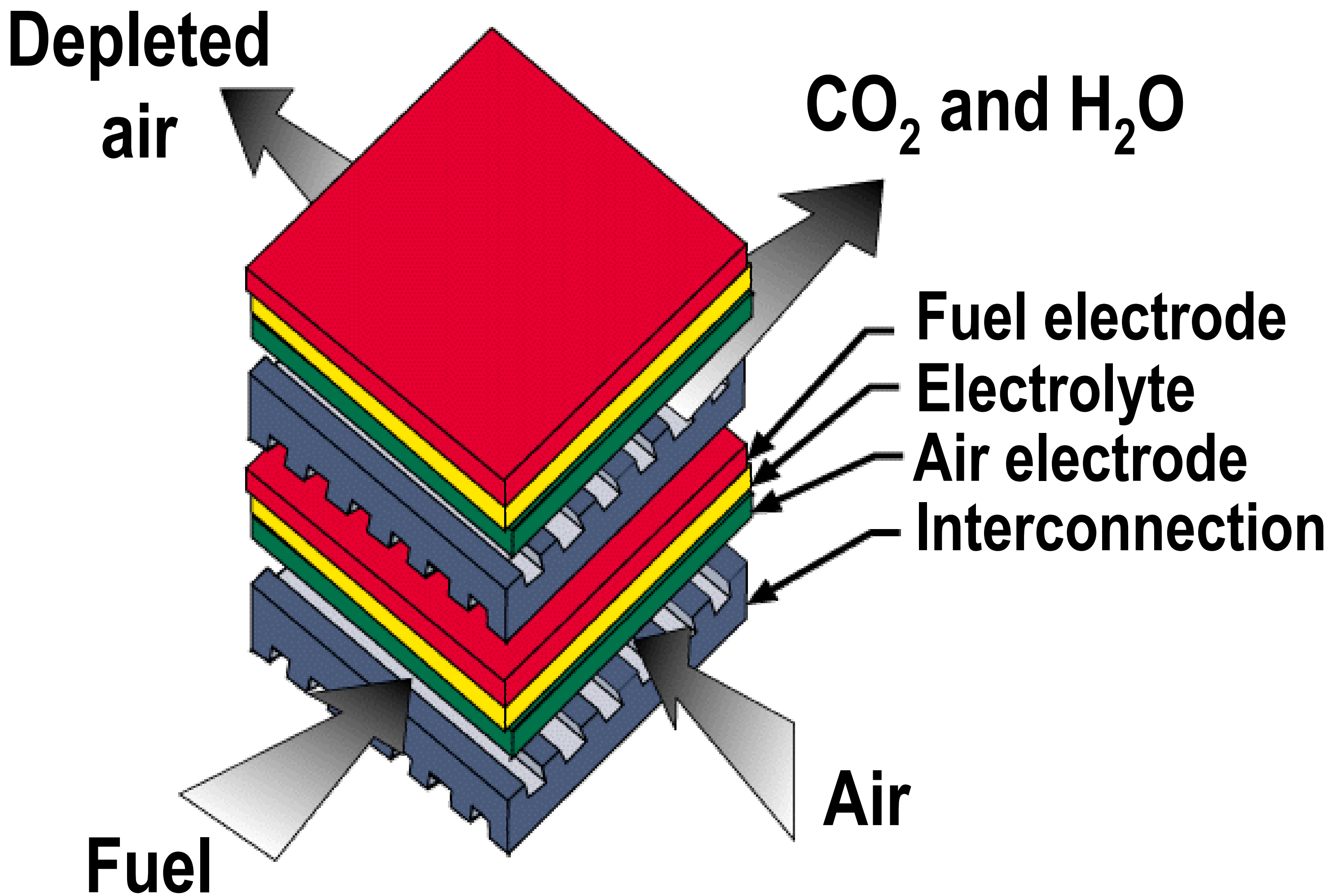
* *Evaluate for potential to achieve $400/kW*

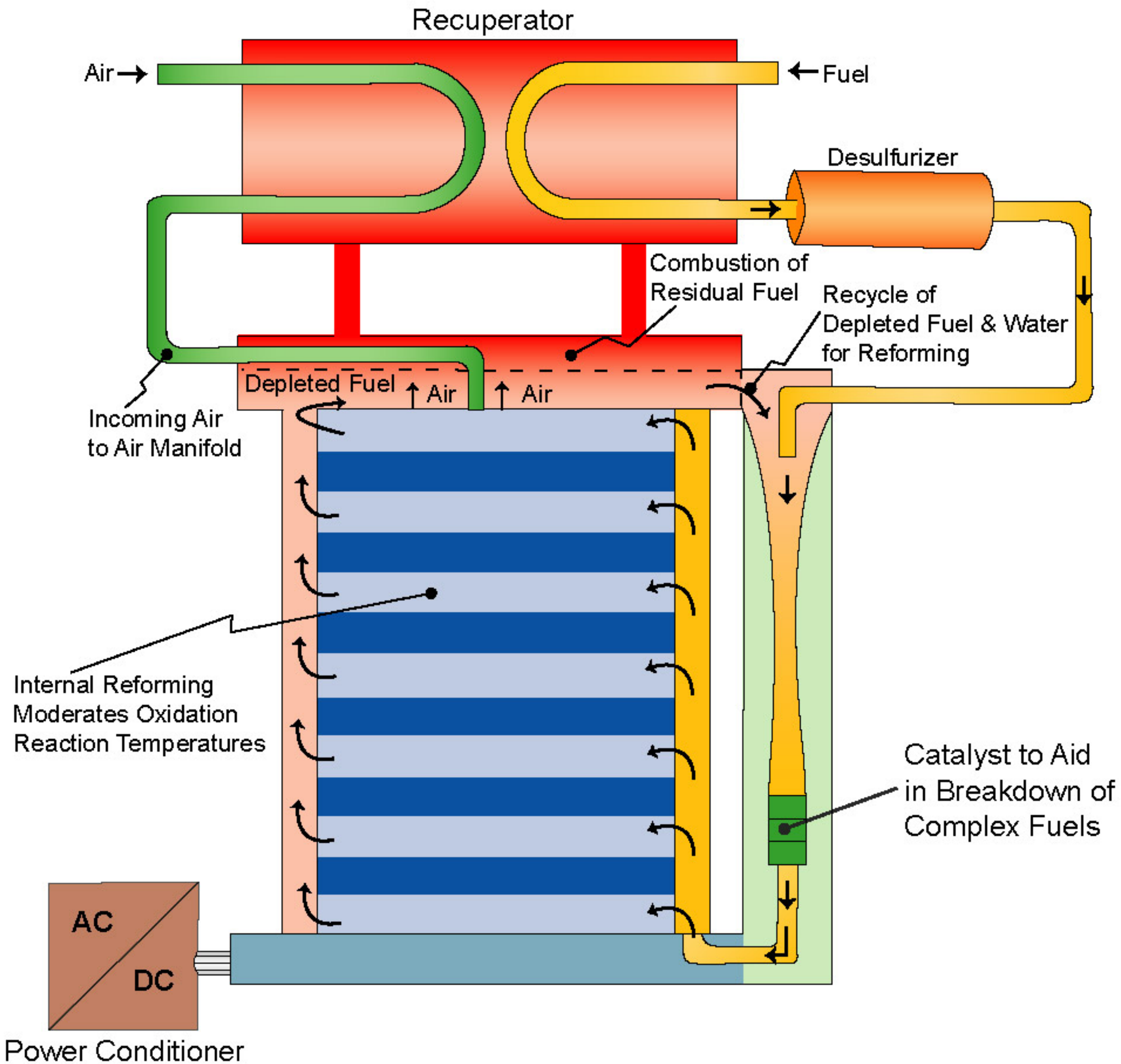
# **Mature** SECA Fuel Cell Systems Cost and Performance Goals

| | Fuel Cell System | Fuel Cell Turbine Hybrid System |
|---|---|---|
| Capital Costs | <$400/kW | <$400/kW (includes turbine) |
| Maintenance Interval | 3000 hrs. | 3000 hrs. |
| Full Load Electrical Efficiency (LHV) | 50% APU<br>60% stationary | 60-70% adaptable to coal gas |
| Design Life | 5000 hrs. APU<br>40,000 hrs. stationary | 40,000 hrs. |
| Emissions of criteria pollutants | Near zero | Near zero |


onnect
Mass Production
ode
rolyte
hode
Firing/
Sintering
ligh volume low cost manufacturing
Customization
Fuel
Processor
Air Delivery
Power
Conditioner

# Planar Cell Design

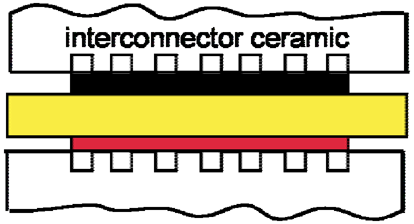





# *Fuel Cell System*

# Planar Cell Designs

**1000°C**



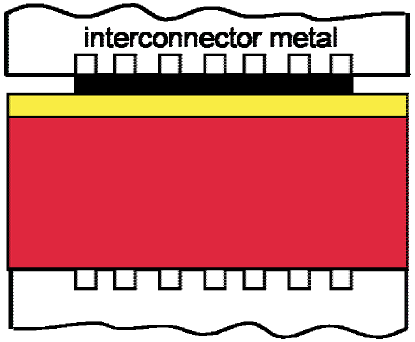

**Electrolyte-supported**

Cathode: 50 μm

Electrolyte: >100 μm

Anode: 50μm

**700-800°C**



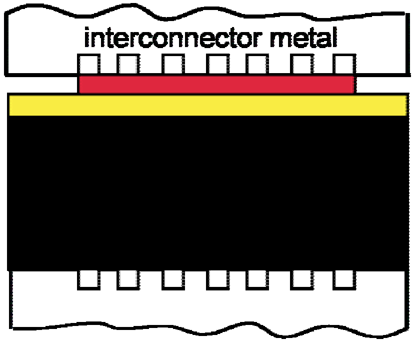

**Anode-supported**

Cathode: 50 μm

Electrolyte: <20 μm

Anode: 500–1500 μm

**700-800°C**




**Cathode-supported**

Anode: 50 μm

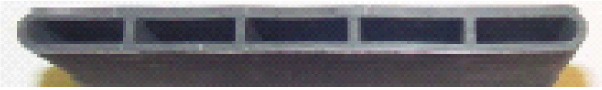
Electrolyte: <20 μm

Cathode: 300–1000 μm

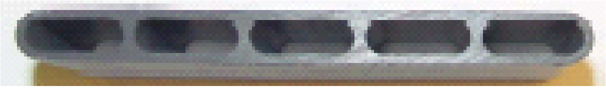
# METAMORPHOSIS OF SWPC TUBULAR DESIGN

Standard Cylindrical

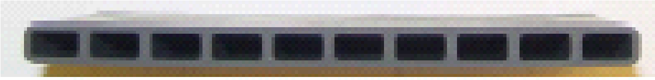
HPD5R0-2002



HPD5R1-2003

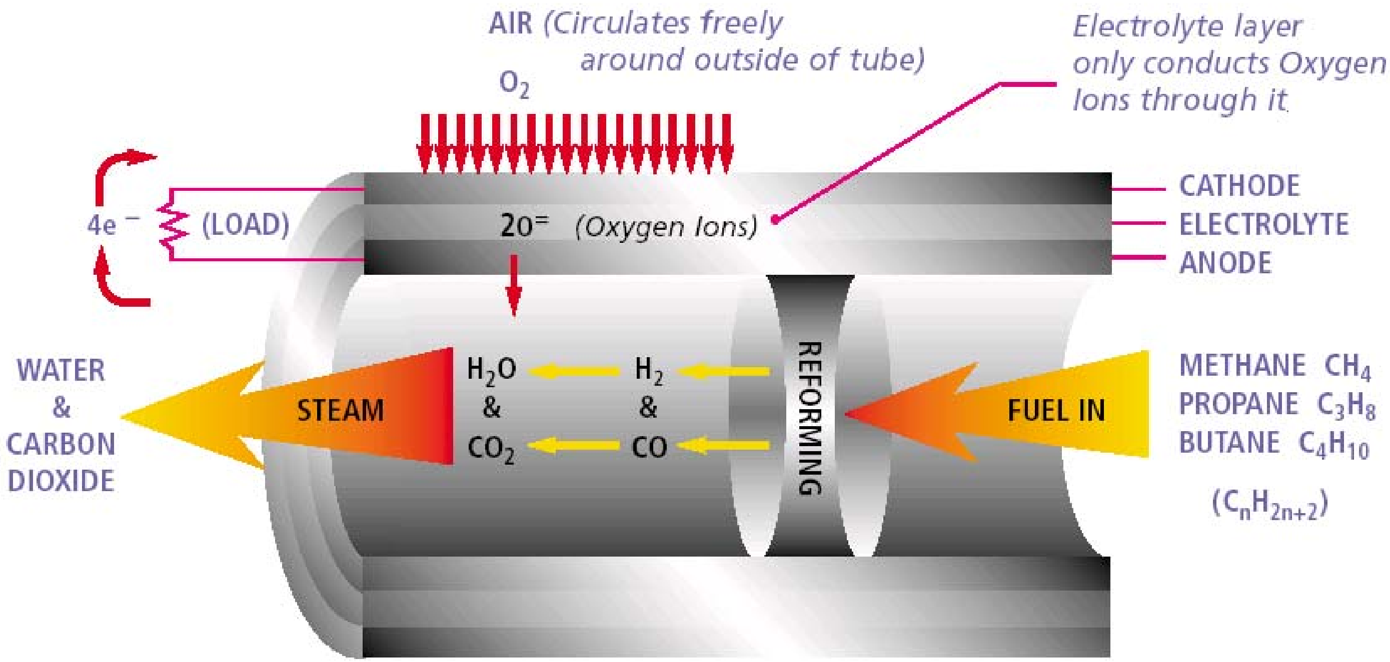


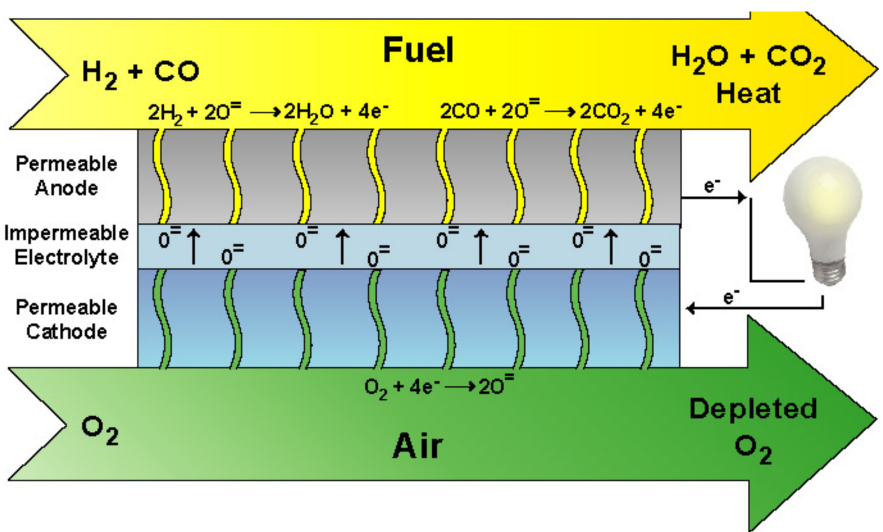
HPD10 >2003



# Standard Tube vs HPD Flattened Tube

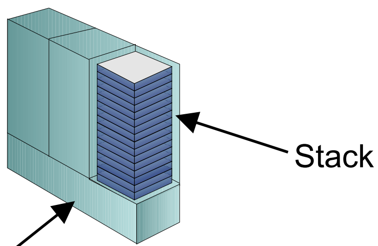
# ACCUMENTRICS MINI CYLINDERS



# Design To Cost Approach

## SECA Core Module

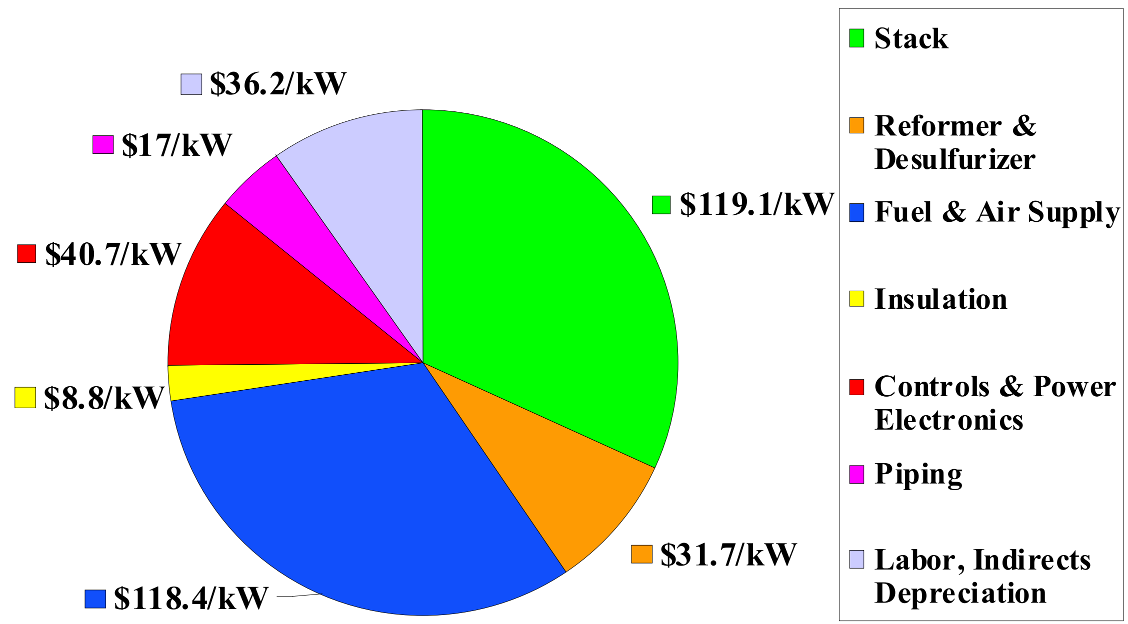



**Balance of Plant**

Reformer
Desulfurizer
Fuel Supply
Air Supply
Controls
Electronics
Piping
Insulation

## 5kW SECA SYSTEM COST BREAKDOWN

**Total Cost: <$400/kW**




**The Stack and Fuel/Air supply are the two largest items.**

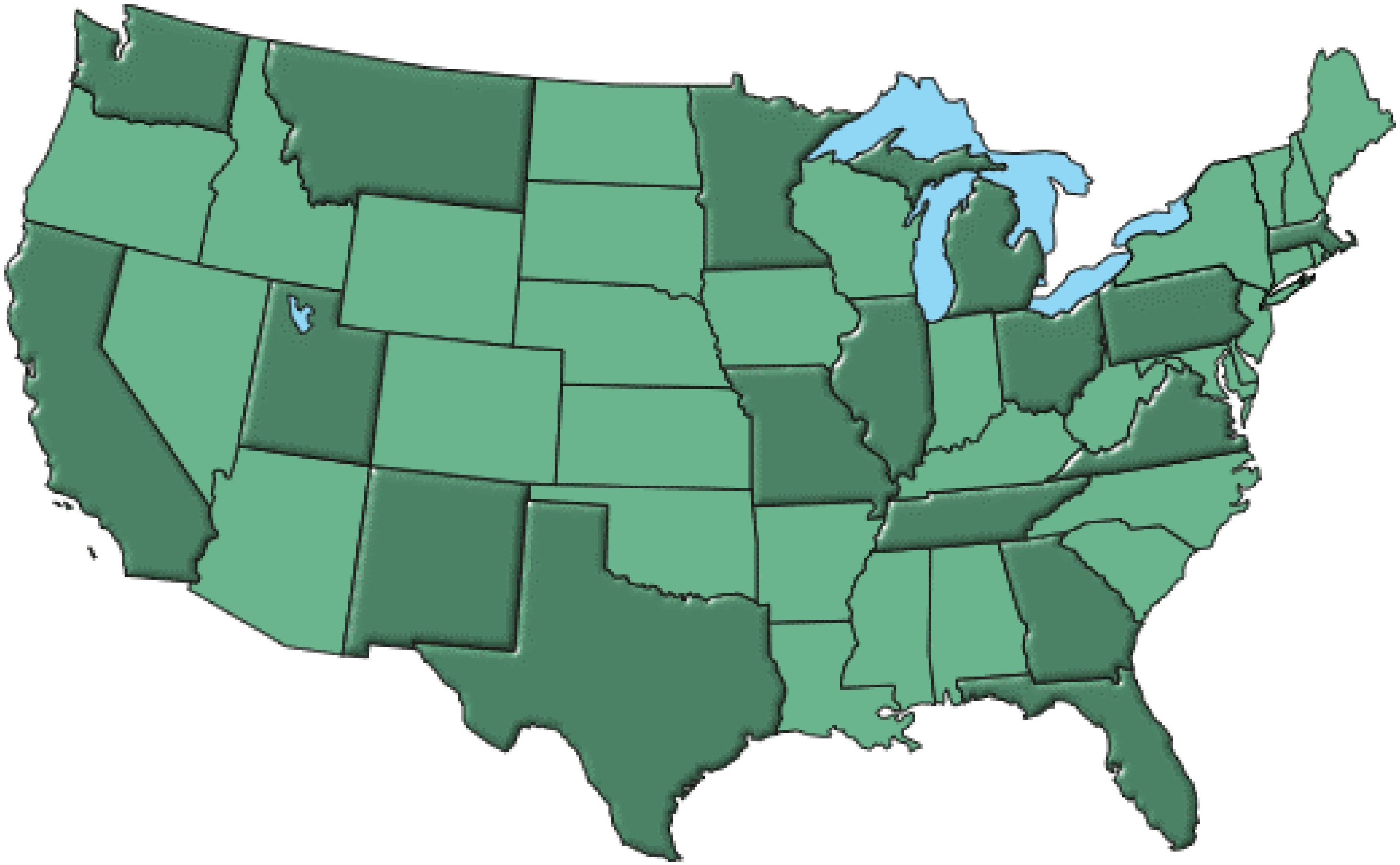
**The Fuel/Air supply slice includes heat exchangers, combustor, blowers, valves.**

**The fuel processor is based on cPox and ZnO absorption.**

**This is DC output straight from the fuel cell only.**

**Study also showed that system volume is strongly dependent on insulation.**

# SECA ACTIVITIES IN THE UNITED STATES



# Current Industrial Team Approaches Applications

## GE - Honeywell
- Low temp (700-800C) internal reforming, electrode supported SOFC
- Large (multi-MW) hybrid systems

## Delphi / Battelle
- Low temp anode supported with external CPOX reforming
- Automotive (trucks) APU applications

## Cummins / McDermott
- Proprietary 850C electrode supported design with unique interconnects (matched materials)
- RVs, portable generators, etc.

## Siemens-Westinghouse
- Flattened tubes (to reduce costs)
- Residential applications

# Current Industrial Team Approaches & Applications

## Accumentrics

- Ceramic mini-cylinders designed for exceptional ruggedness and quicker start-ups (10 min. or less); applicable for residential markets, military applications, broadband communication networks, and auxiliary power for heavy-duty trucks

## FuelCell Energy

- Expected to combine fuel cell manufacturing capabilities and electrochemical expertise to produce lower temperature (700 C), low-cost widely deployable products.

| Team | Approach | Manufacturing | Markets |
|---|---|---|---|
| Delphi/Battelle | 5-kW module<br>Anode supported<br>Low temperature<br>Ultra compact system<br>50 liter envelope<br>Rapid transient capability<br>cPox reformer | Tape casting<br>Screen printing<br>Two-stage sintering | Automotive/heavy truck APUs<br>Stationary DG<br>Niche military applications |
| General Electric | 5-kW module<br>Anode supported<br>Low temperature<br>Hybrid compatible<br>Internal reforming | Tape calendering<br>Two-stage sintering | Residential applications<br>FC/T hybrid applications<br>Eventual tie-in to coal-based systems |
| Cummins Power Generation/ McDermott | 4-kW module<br>Electrolyte supported<br>Intermediate temperature<br>Unique co-sintered design<br>Thermally matched materials<br>Seal-less (co-sintered) stack | Tape casting<br>Screen printing<br>Co-sintering | RV APUs<br>Commercial vehicle APUs<br>Emergency telecommunication APUs |
| Siemens Westinghouse | 5- to 10-kW module<br>Cathode supported<br>High temperature<br>Redesigned tubular<br>Reduced manufacturing steps<br>Seal-less stack | Extrusion<br>Plasma spray | Residential CHP<br>Automotive APUs |
| Acumentrics | 10-kW module<br>Anode supported<br>Intermediate temperature<br>Soda straw sized tubes | Extrusion | Residential application<br>Military applications<br>Broadband communications<br>APUs for heavy trucks |
| FuelCell Energy | 10-kW module<br>Anode supported<br>Low temperature<br>MCFC seal and interconnects<br>Novel non-YSZ materials | Tape Casting<br>Screen Printing | Target stationary power first<br>Expand to military and APU markets |

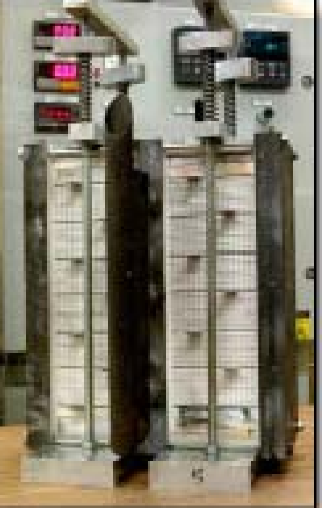
# Different Approaches!

| *Team* | *Design* | *Manufacturing* |
|---|---|---|
| Cummins-SOFCo | • Electrolyte supported<br>• 850 C<br>• Thermally matched materials<br>• Seal-less stack | • Tape casting<br>• Screen printing<br>• Co-sintering |
| Delphi-Battelle | • Anode supported<br>• 750 C<br>• Ultra compact<br>• Rapid transient capability | • Tape casting<br>• Screen printing<br>• 2–stage sintering |
| General Electric Company | • Anode supported<br>• 750 C<br>• Hybrid compatible<br>• Internal reforming | • Tape calendering<br>• 2–stage sintering |
| Siemens Westinghouse | • Cathode supported<br>• 800 C<br>• Redesigned tubular<br>• Seal-less stack | • Stack extrusion<br>• Plasma spray |

# Two New Different Approaches!

| *Team* | *Design* | *Manufacturing* |
| --- | --- | --- |
| Acumentrics Corporation | • Anode supported microtube<br>• 850 C<br>• Thermally matched materials<br>• Robust & rapid start-up | • Extrusion<br>• Dip processing<br>• Spray deposition |
| FuelCell Energy, Inc. | • Anode supported<br>• < 700 C<br>• Low cost metals | • Tape casting<br>• Screen printing<br>• Co-sintering<br>• Electrostatic deposition |

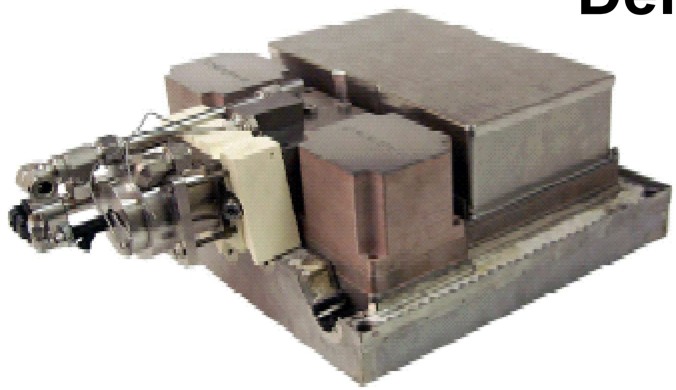
# Cummins



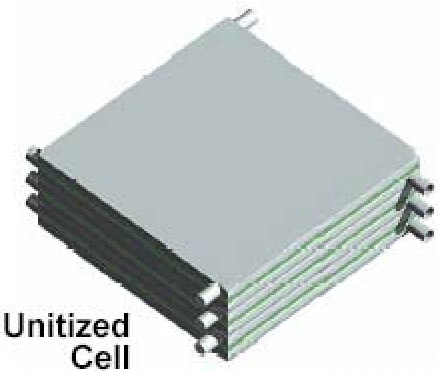
Two 60-cell Stacks

Core Module without Insulation

# Delphi



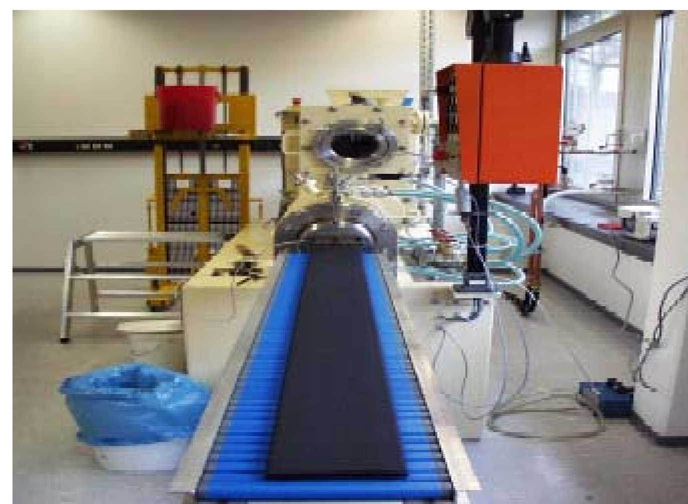
# GE



Unitized Cell

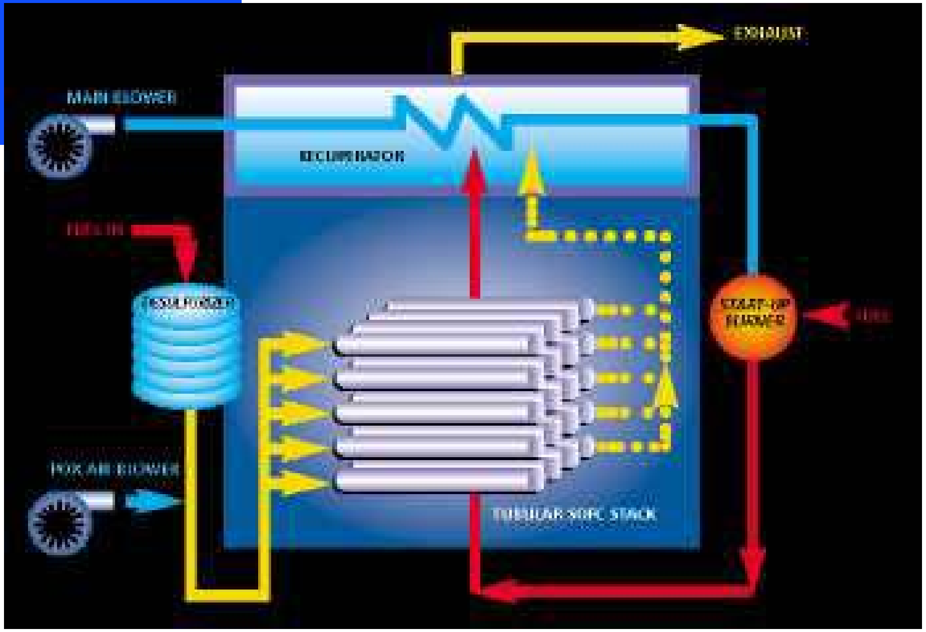
# SWPC

Extrusion of HPD Tubes



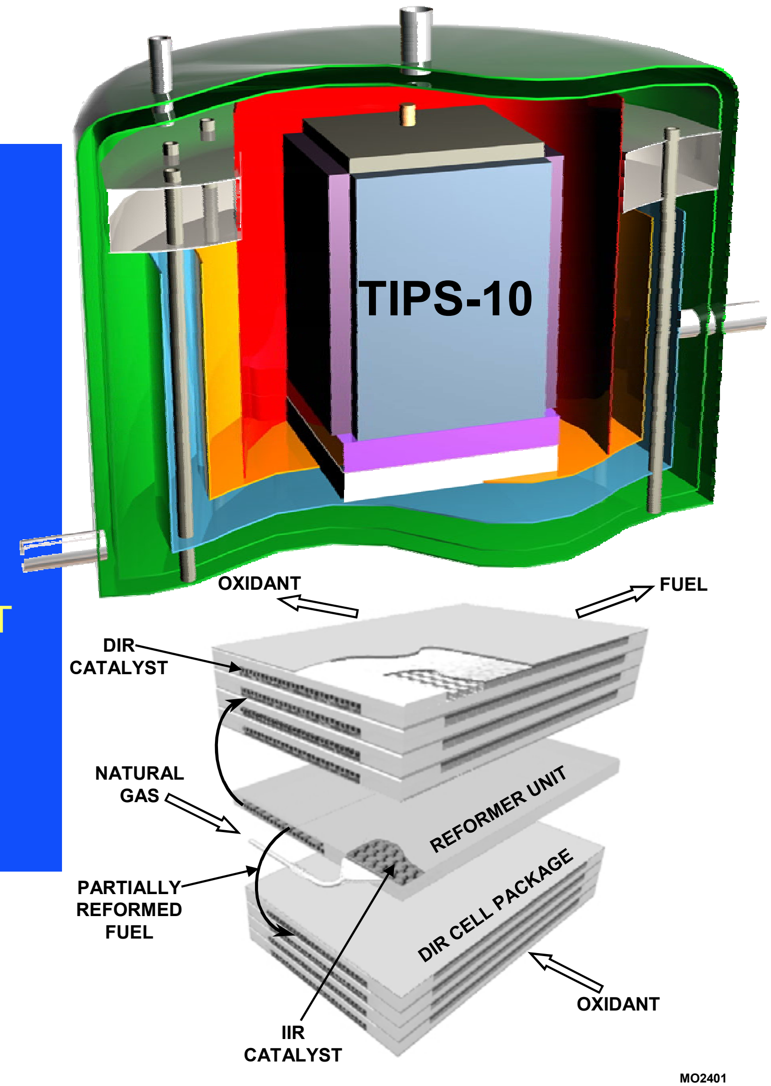
# Acumentrics Corporation

- **10 kW Tubular SOFC Generator**
  - Natural Gas, Propane & Diesel for stationary, transportation, and military markets
  - Rapid start-up at 10 minutes
- **Team members**
  - General Dynamics, Taunton, MA
  - Aspen Systems, Marlborough, MA
  - Boston University, Boston, MA



# FuelCell Energy, Incorporated

- **10 kW Planar SOFC Generator**
  - Natural Gas for stationary markets
  - Propane & Diesel for remote and transportation markets
- **Team members**
  - Versa Power Systems, Des Plaines, IL
    - Electric Power Research Institute, Palo Alto, CA
    - Gas Technology Institute, Des Plaines, IL
    - Materials & Systems Research, Inc., Salt Lake City, UT
    - University of Utah, Salt Lake City, UT
  - Dana Corporation, Toledo, OH
  - EPRI PEAC Corp., Knoxville, TN
  - Pacific Northwest National Laboratory, Richland, WA

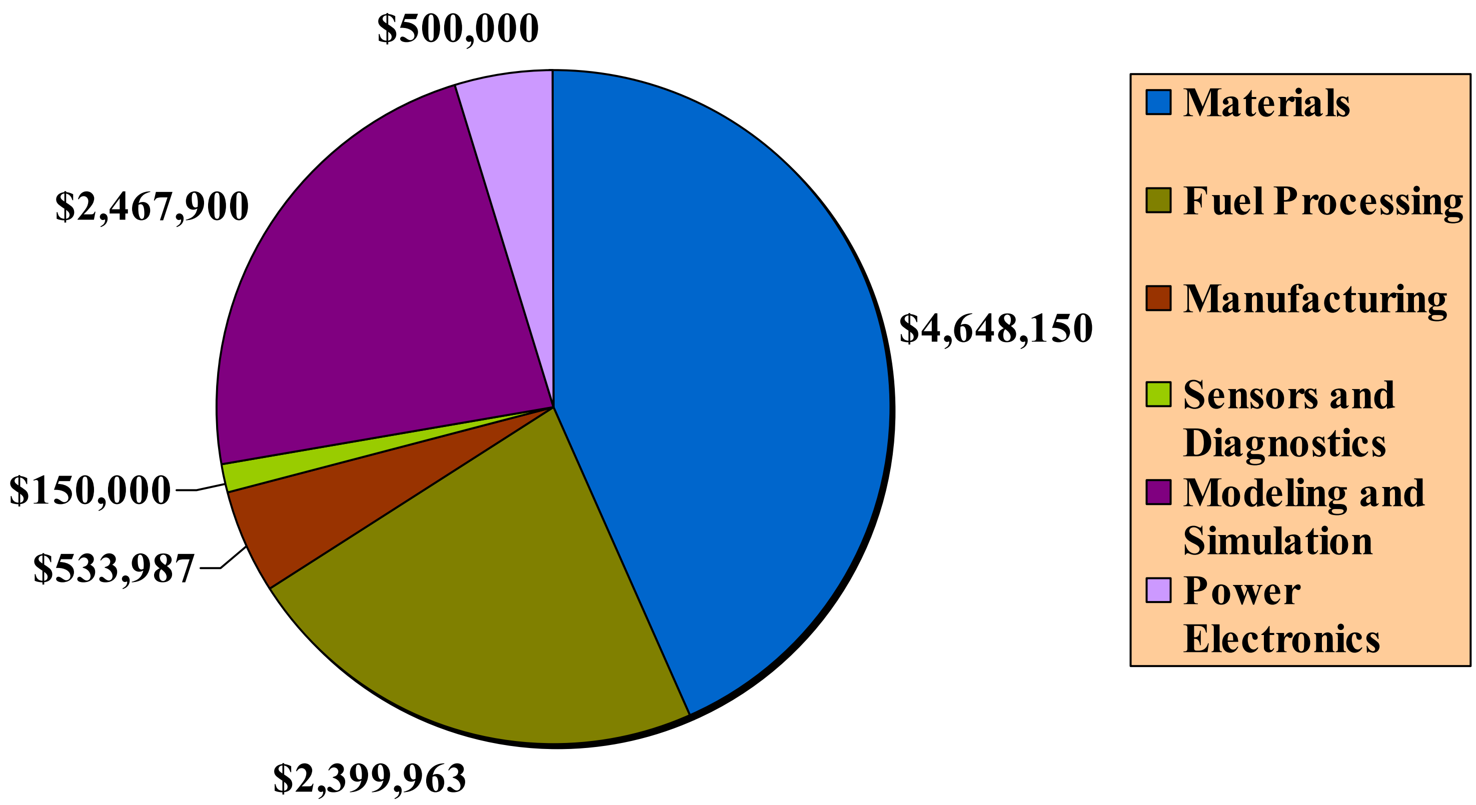


# Current Core Technology Participants

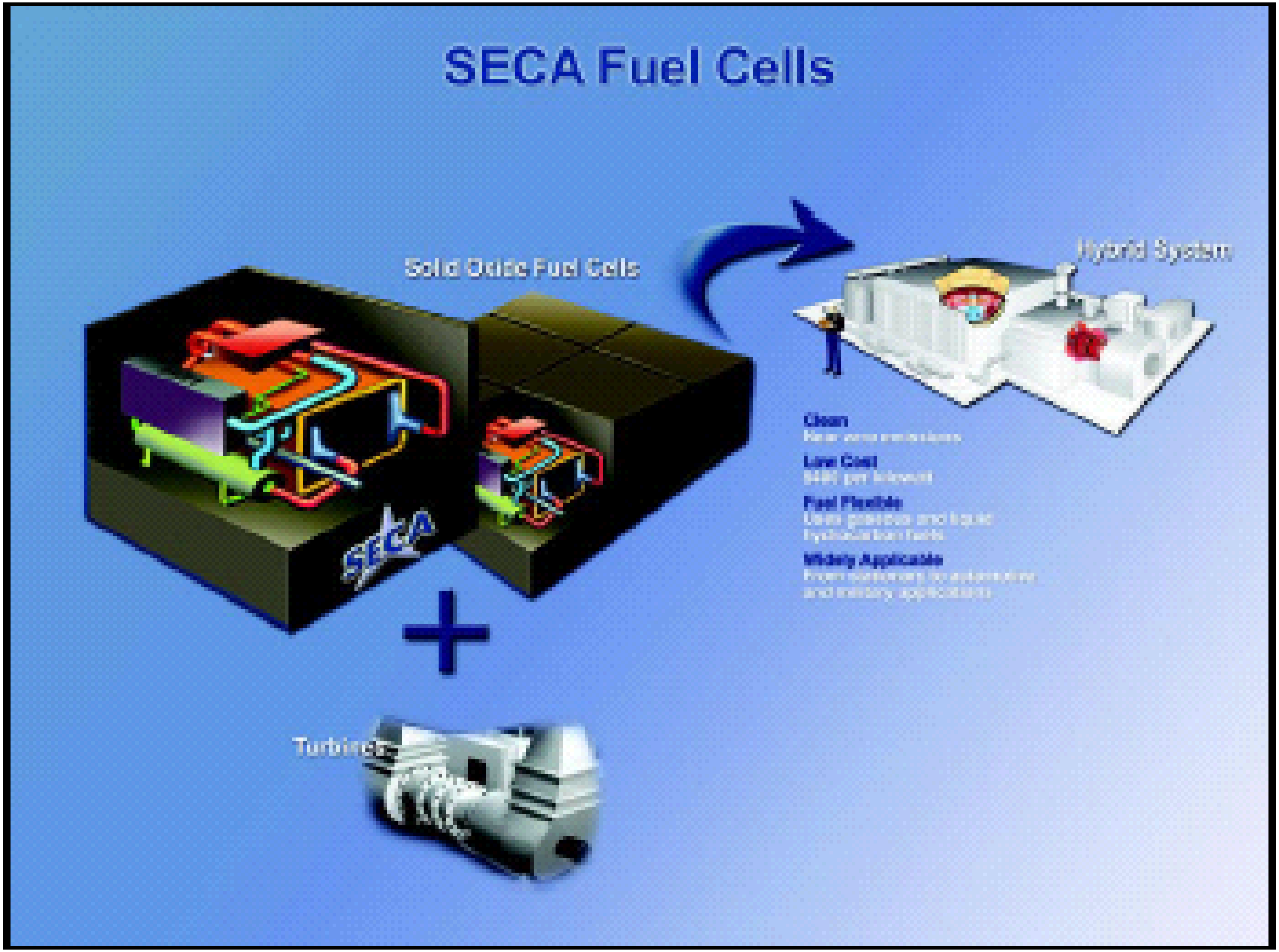
- Argonne National Laboratory
- National Energy Technology Laboratory
- National Fuel Cell Research Center
- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory

- Gas Technology Institute – Des Plaines, IL
- Georgia Tech Research – Atlanta, GA
- Lawrence Berkeley National Laboratory – Berkeley, CA
- Los Alamos National Laboratory – Los Alamos, NM
- Montana State University – Bozeman, MT
- Northwestern University – Evanston, IL
- Southwest Research Institute – San Antonio, TX
- Texas A&M University – College Station, TX
- University of Florida – Gainesville, FL
- University of Illinois – Chicago, IL
- University of Missouri – Rolla, MO
- University of Pittsburgh – Pittsburgh, PA
- University of Utah – Salt Lake City, UT
- University of Washington – Seattle, WA
- Virginia Tech – Blacksburg, VA

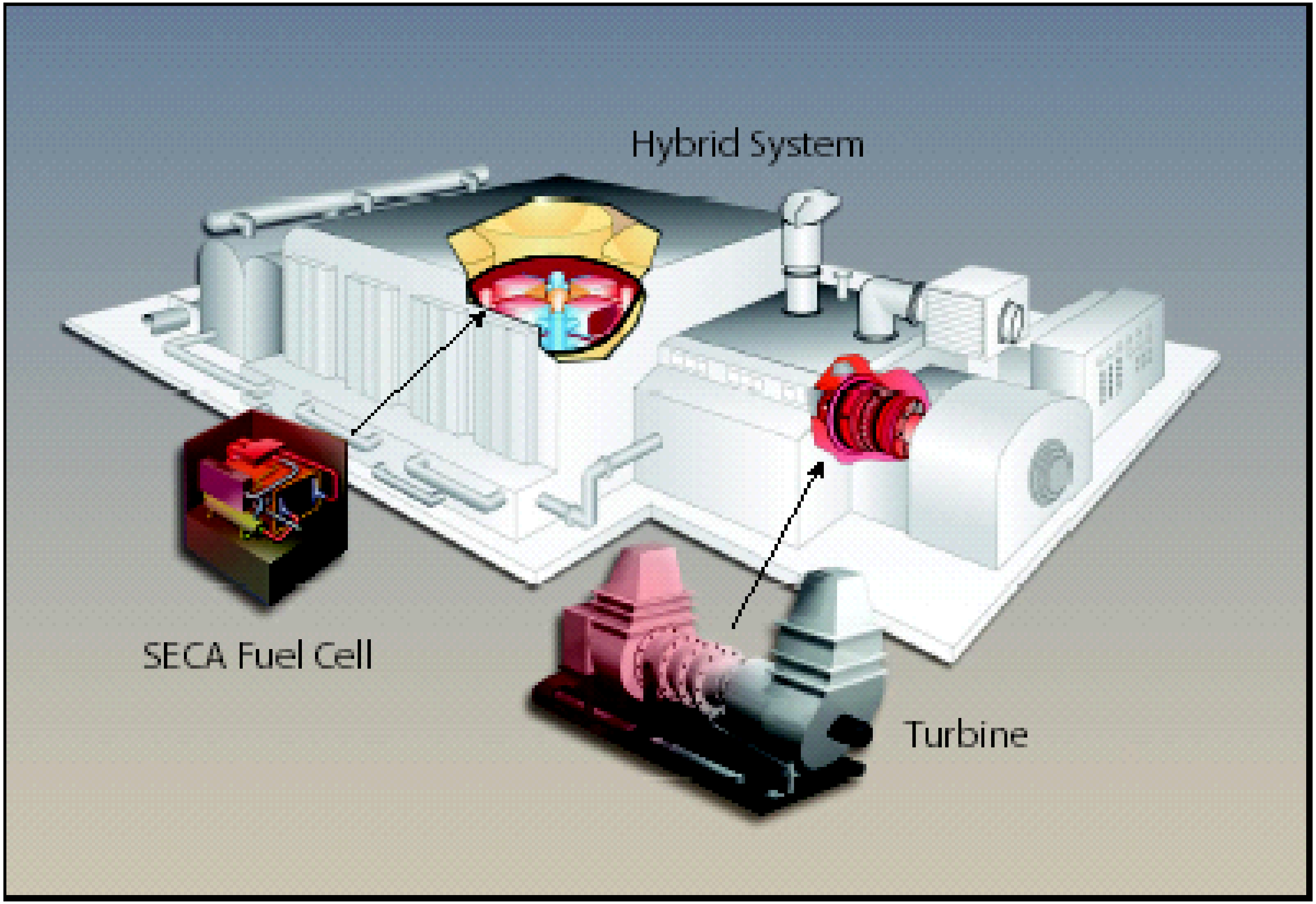
# Core Technology Program FY 2003



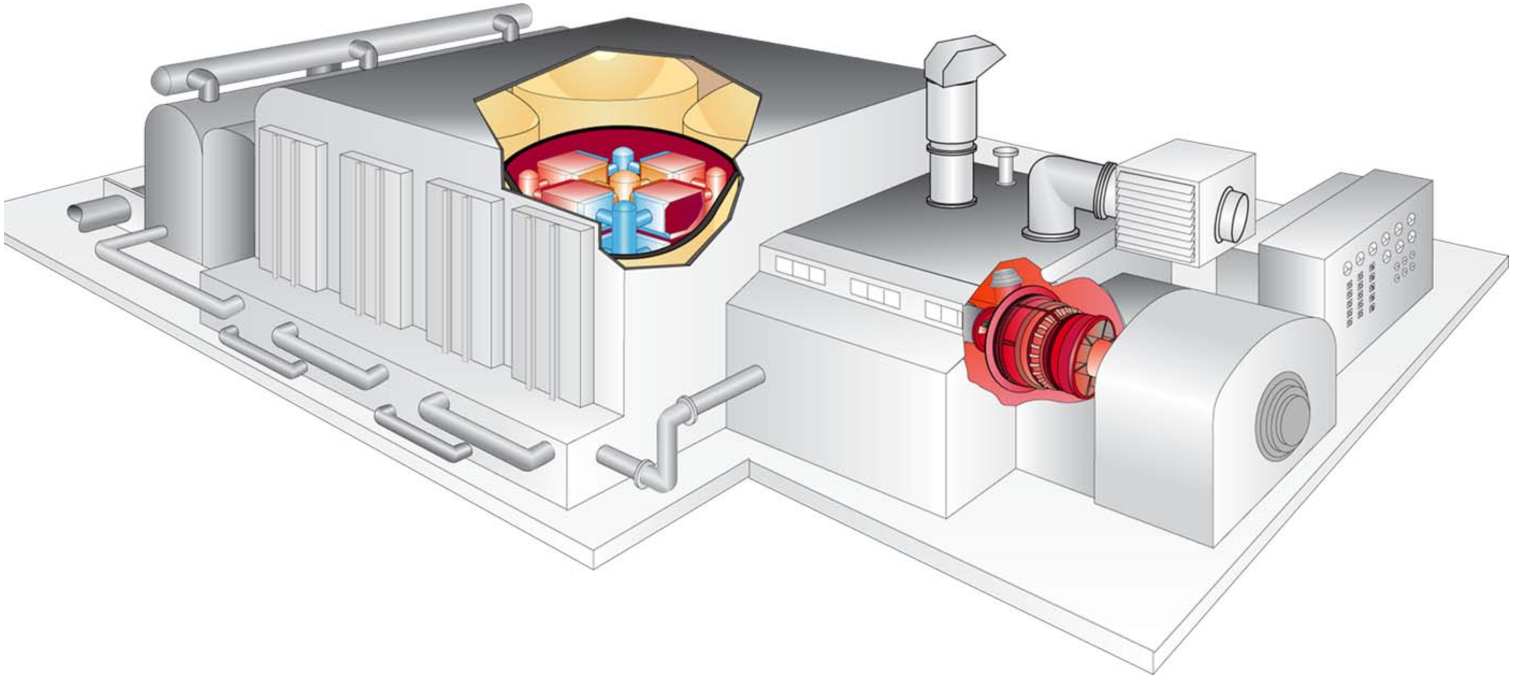
# SECA FC/T Hybrid



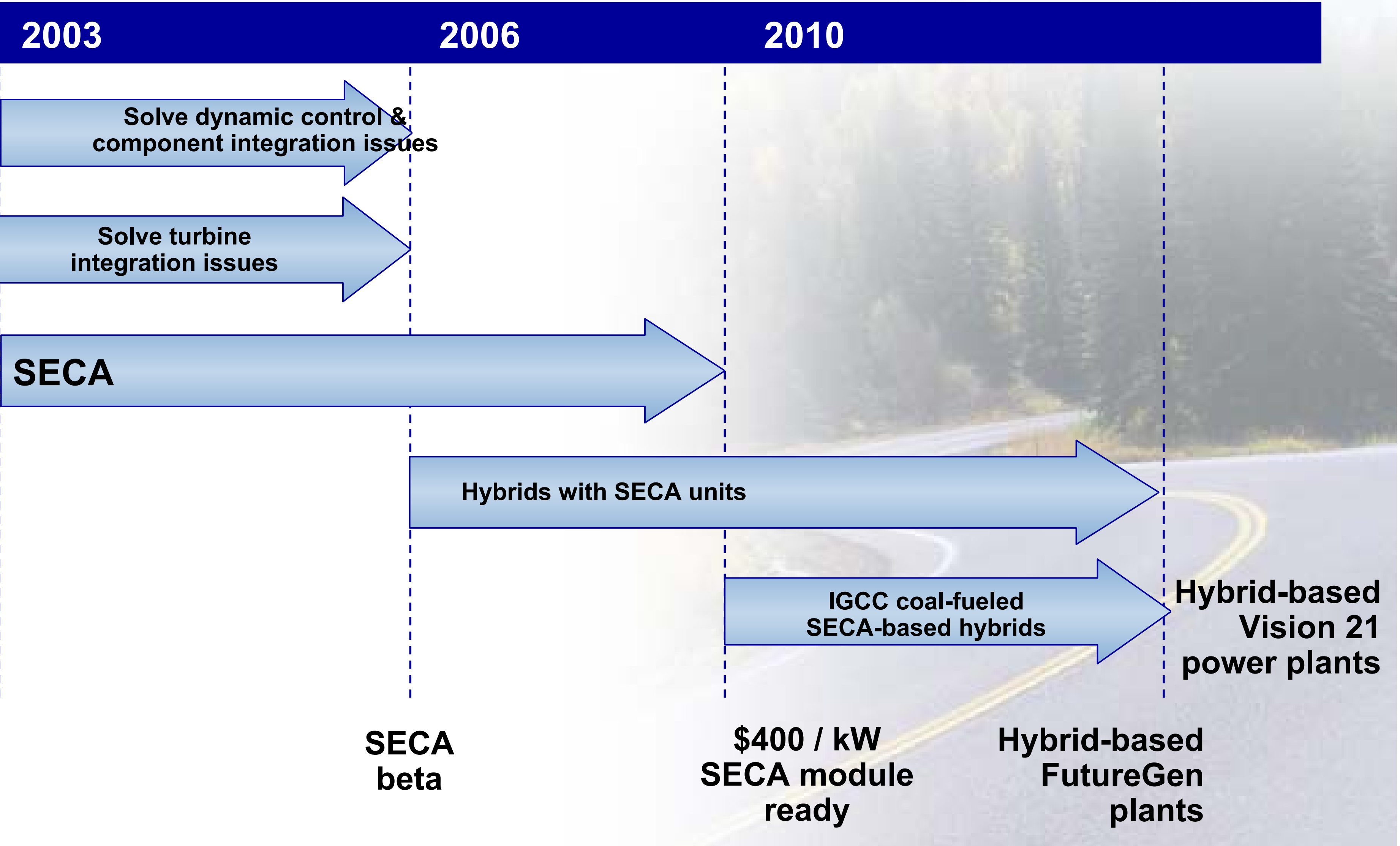
# SECA FC/T Hybrid System



# SECA TURBINE HYBRID

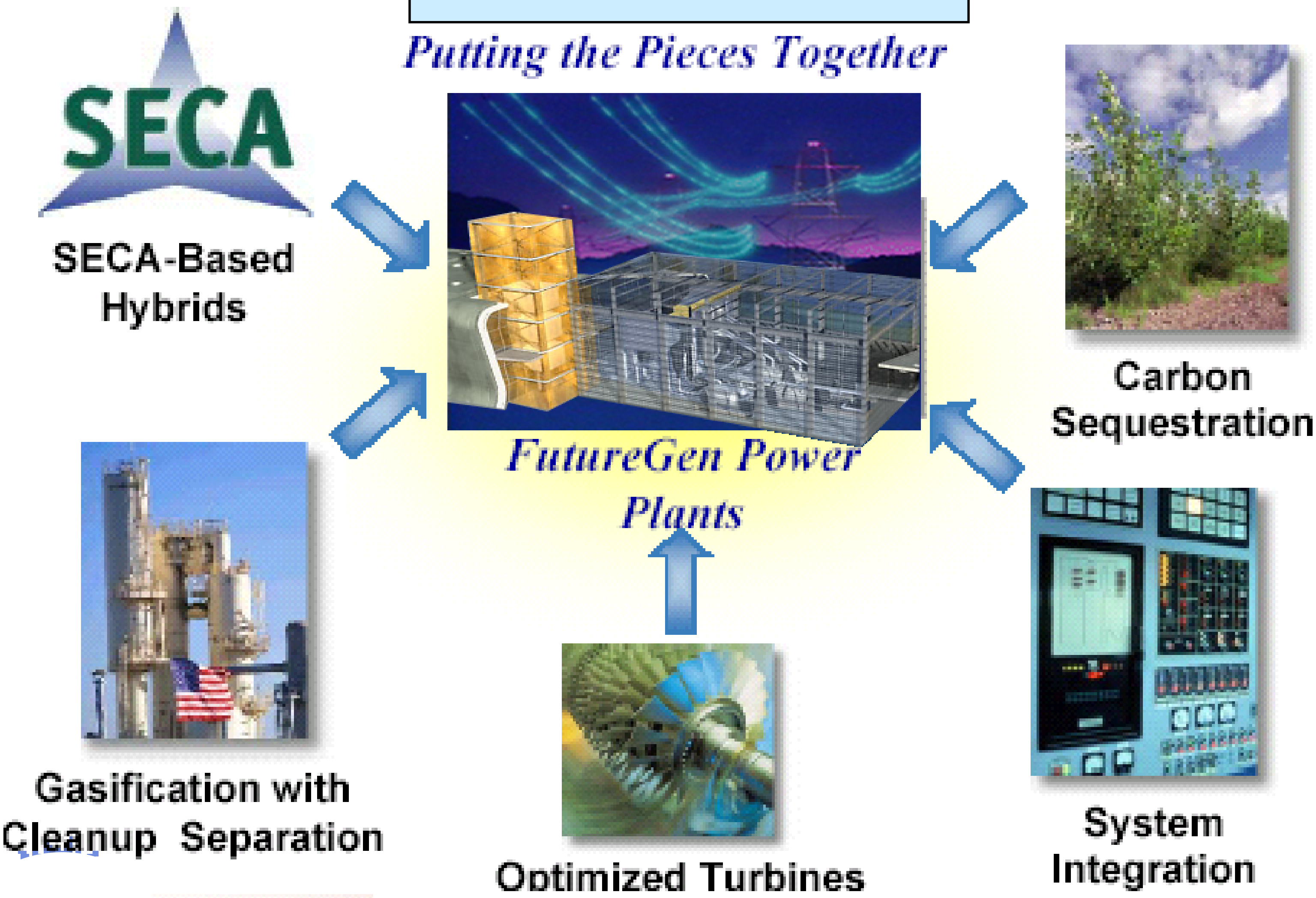


# Technology Road Map for SECA & Hybrid Power Systems



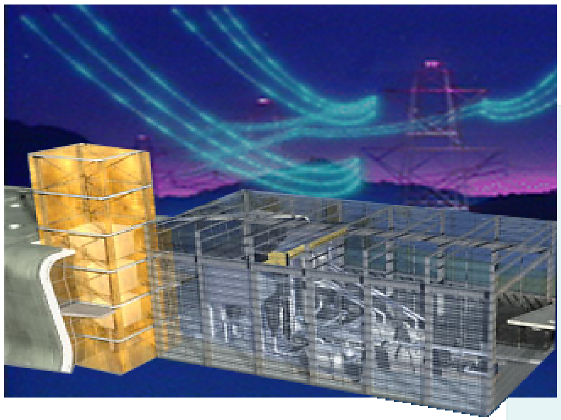
# SECA and FutureGen

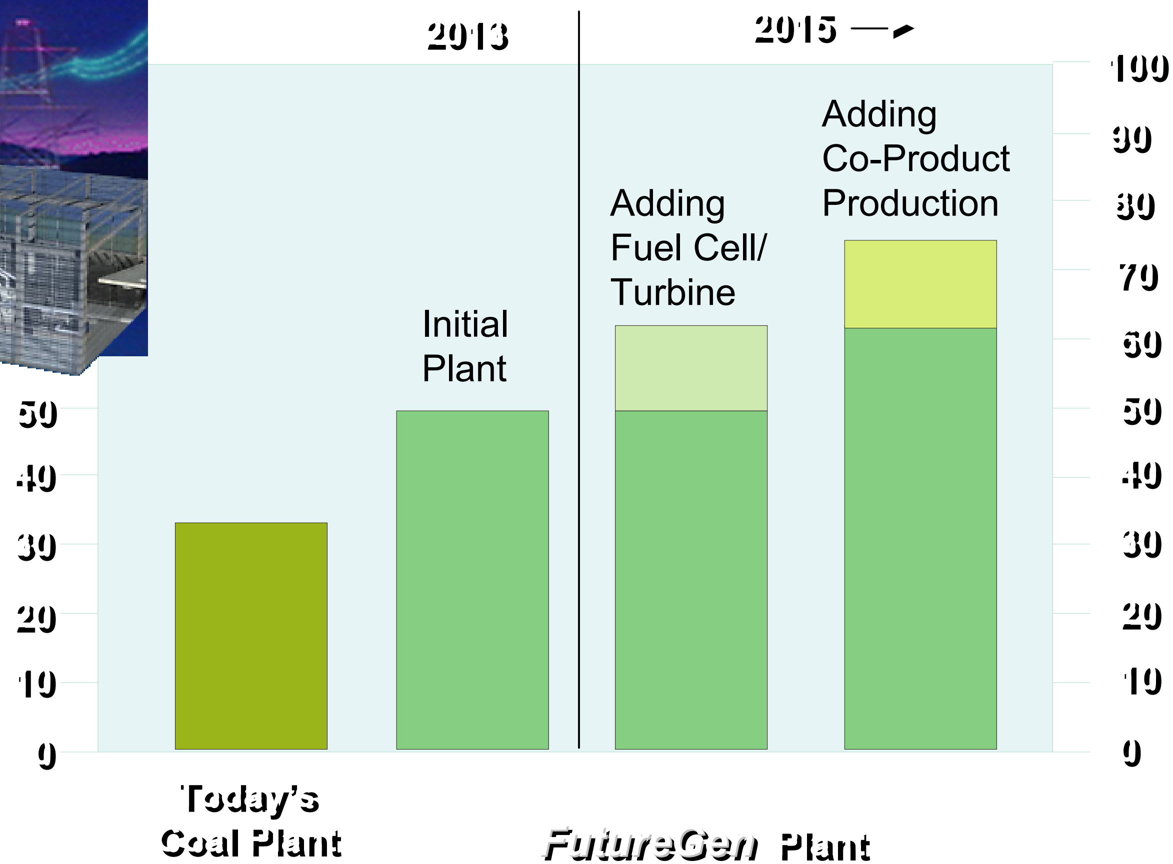
*Putting the Pieces Together*



# *FutureGen*

## The World's Most Energy-Efficient Power Plant

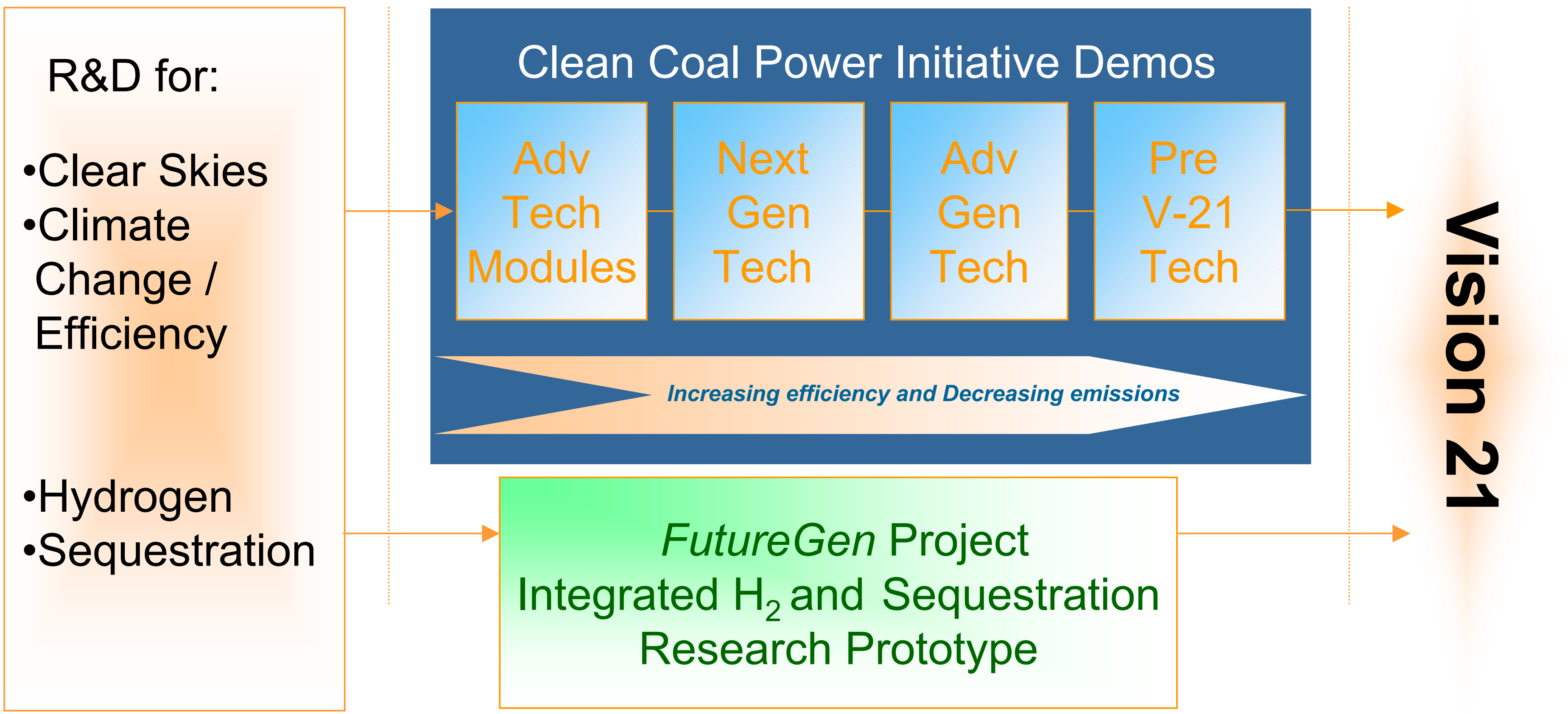





Boosting power plant efficiencies is first step toward reducing greenhouse gases

# Role of *FutureGen*

## In the Coal Research Program



# Vision 21

## *Putting the Pieces Together*

**SECA-Based Hybrids**

*Hybrid-Based Vision 21 Power Plants*

**Carbon Sequestration**

**Gasification with Cleanup & Separation**

**Optimized Turbines**

**System Integration**

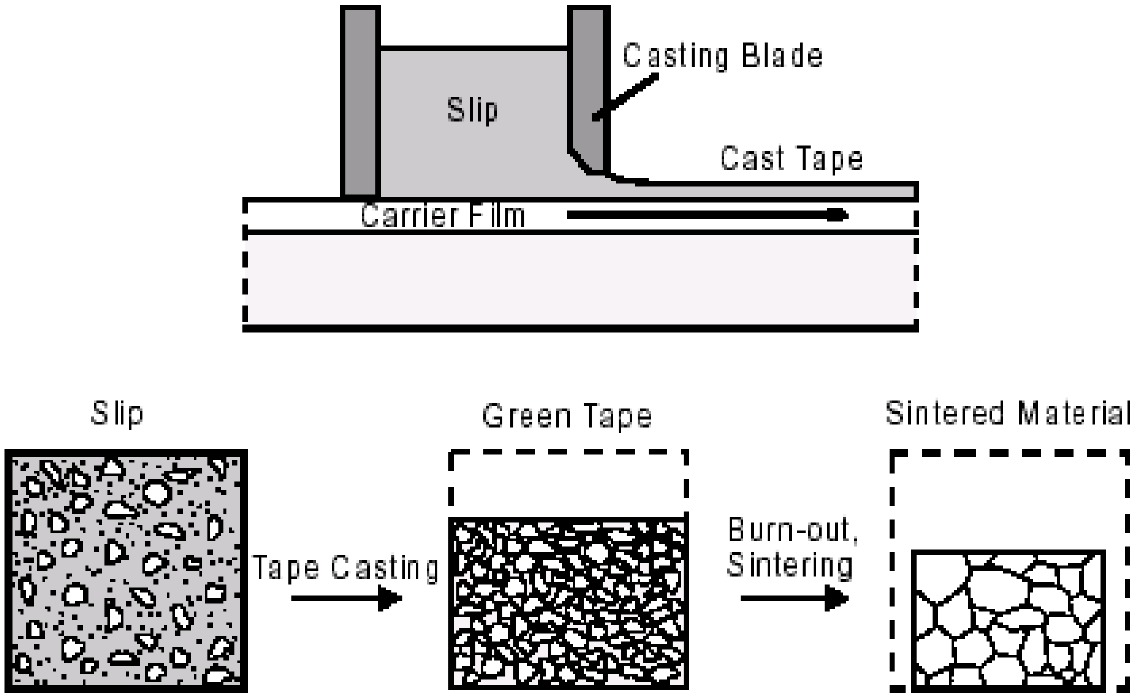
# Advanced Research – High Temperature Electrochemical Energy

- **Initiated July 2002 via FWP with PNNL-5 Tasks**
  - Establish unique measurement and diagnostic capabilities to support fundamental research studies of non-ohmic performance limiting electrode processes
  - Conduct reversible fuel cell studies to guide the selection of anode material compositions that are best suited to minimize the overpotentials (related to efficiency losses) associated with hydrogen oxidation and steam electrolysis
  - Investigate new materials and structures for use in thermoelectric generators which can produce electricity directly from waste heat
  - Actively seek to collaborate with universities, industries and other research laboratories, including student and faculty internships at PNNL from universities, other national labs, and industry
  - Establish a satellite Center at Montana State University for research in high temperature electrochemical systems.

# Advanced Research – High Temperature Electrochemical Energy

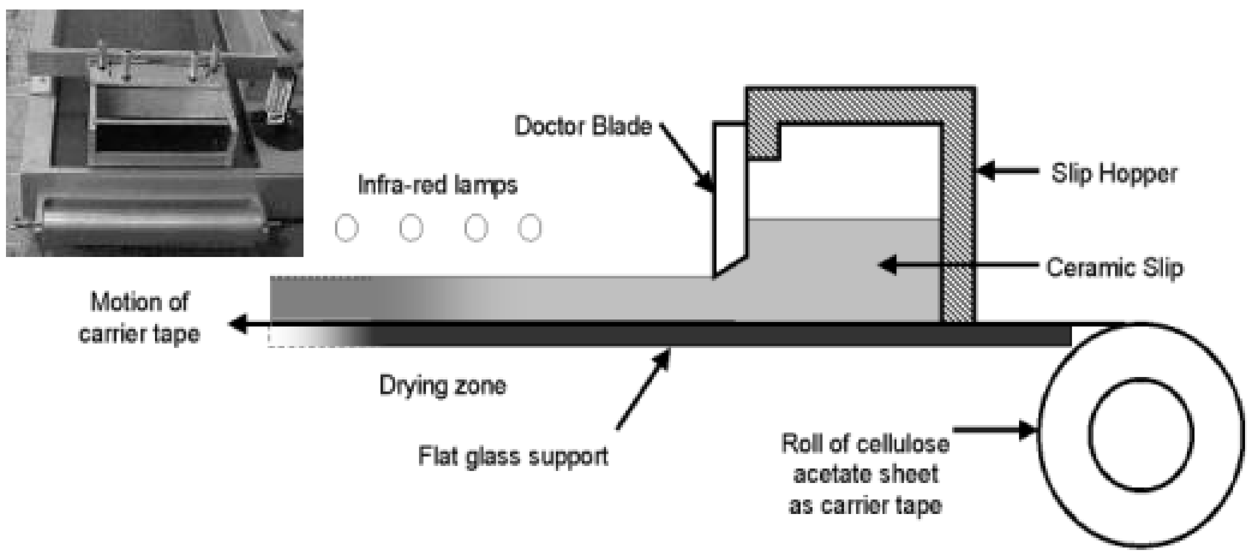
- **Montana State University Research in High Temperature Electrochemical Systems**
  - Use advanced synchrotron-based X ray techniques to characterize fuel cell materials
  - Develop large-area filtered arc plasma ion deposition technologies (FAPSID) to deposit electronic ceramics, and generate corrosion-resistant coatings for bipolar plates
  - Conduct studies focused on fuel cell power response characterization, modeling and monitoring.
  - Conduct research on power electronics control devices for high temperature electrochemical devices

# *Tape Casting*



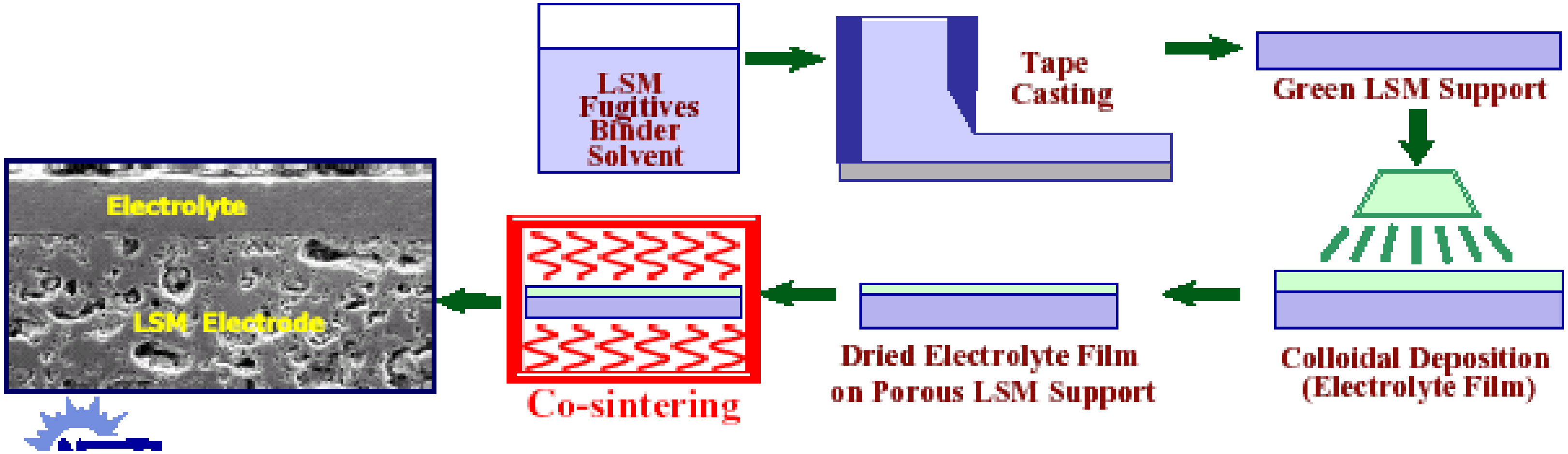

The top schematic drawing illustrates tape casting. The bottom sketch shows the different stages during the processing: the slip consisting of water, ceramic particles and binder; the cast, dried green sheet; and, finally, the microstructure of the sintered material.

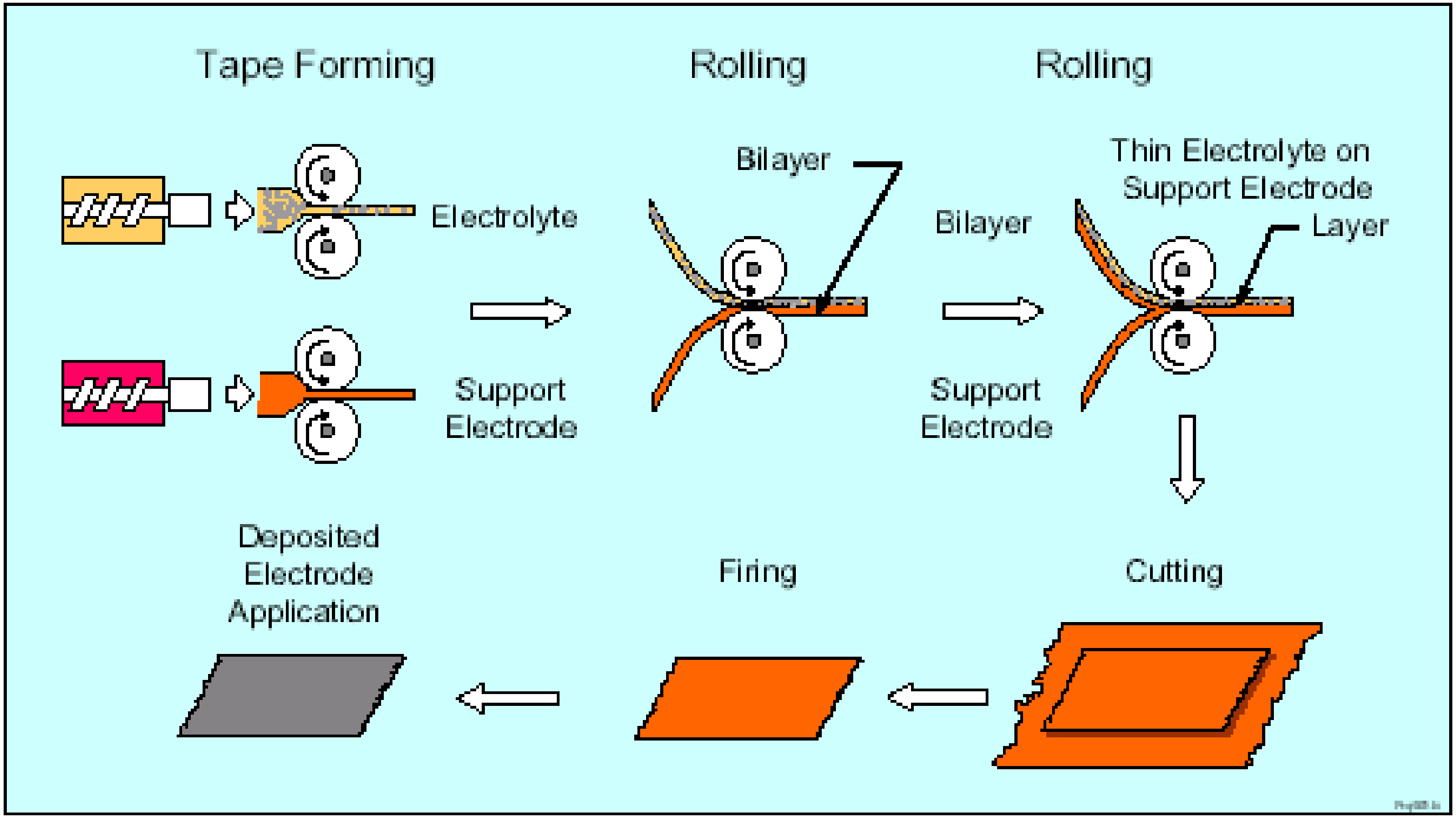
| | |
|---|---|
| **Advantages** | **High production rate. Ideal technique for making flat components such as ceramic substrates.** |
| **Disadvantages** | **Commercial systems usually contain environmentally unfriendly solvents. Technique limited to flat, thin components.** |



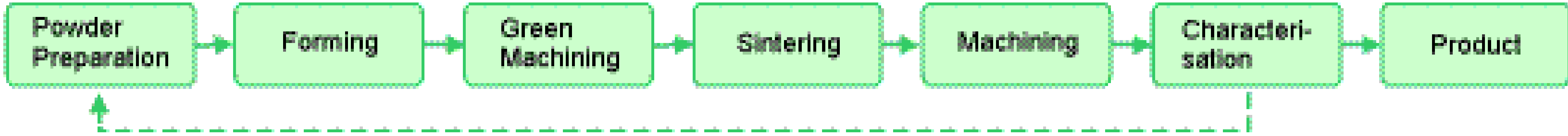

*Schematic diagram of a form of the tape casting process. The particulate slurry is drawn out beneath the doctor blade by the relative motion of the carrier film. The height of the blade above the film controls the thickness of the tape. The-inset photograph shows an end-on view of the tape caster at Cranfield showing the blade in position lying on the carrier film.*

Develop multi-layer ceramics manufacturing processes similar to computer board and chip making






*Tape Calendering Manufacturing Process*




*Typical process steps in the manufacture of a ceramic product*

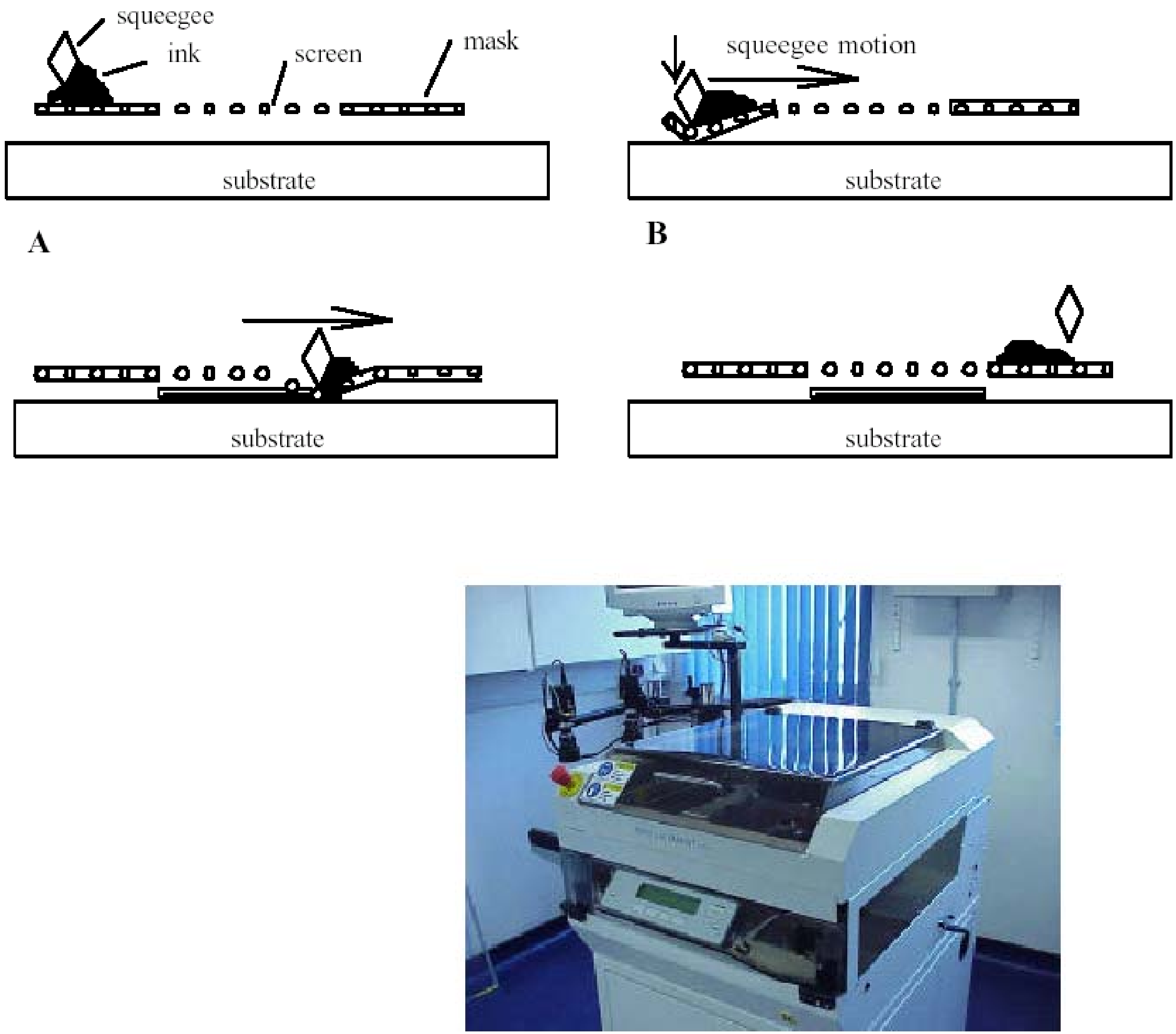
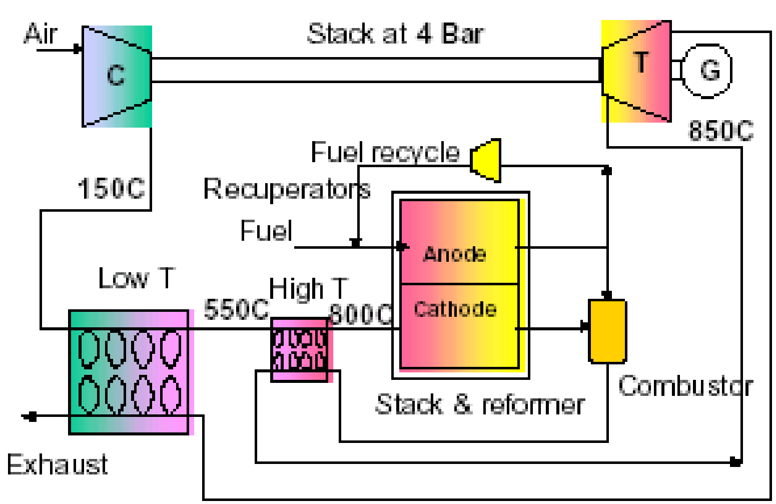
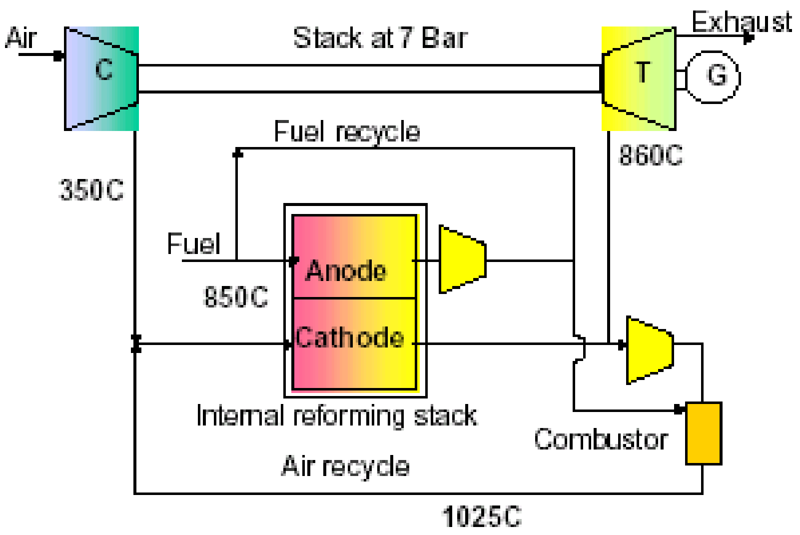



**Figure 1: Four consecutive stages of the screen printing process and a screen printer**


Air
C
Stack at 4 Bar
T
G
850C
Fuel recycle
150C
Recuperators
Fuel
Anode
Low T
High T
550C
800C
Cathode
Combustor
Stack & reformer
Exhaust


Air
C
Stack at 7 Bar
T
G
Exhaust
Fuel recycle
860C
350C
Fuel
Anode
850C
Cathode
Internal reforming stack
Combustor
Air recycle
1025C