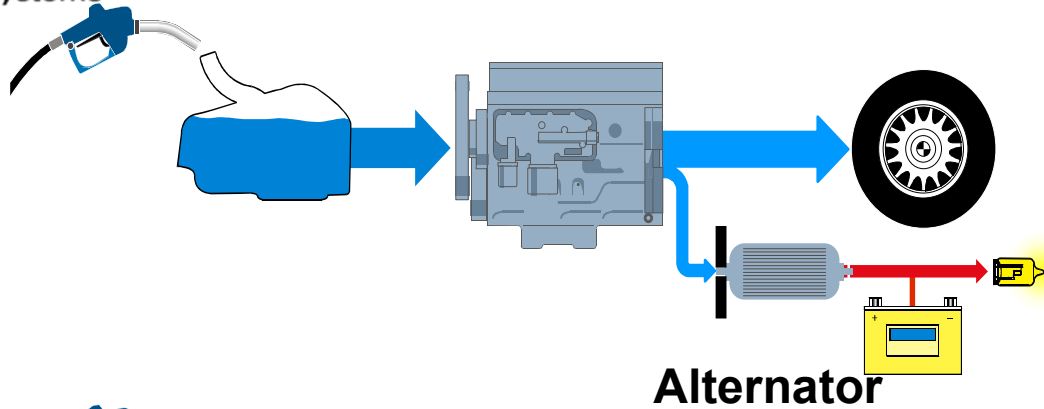


**Chris De Minco & Dr. Subhasish Mukerjee**  
***Delphi Automotive Systems***

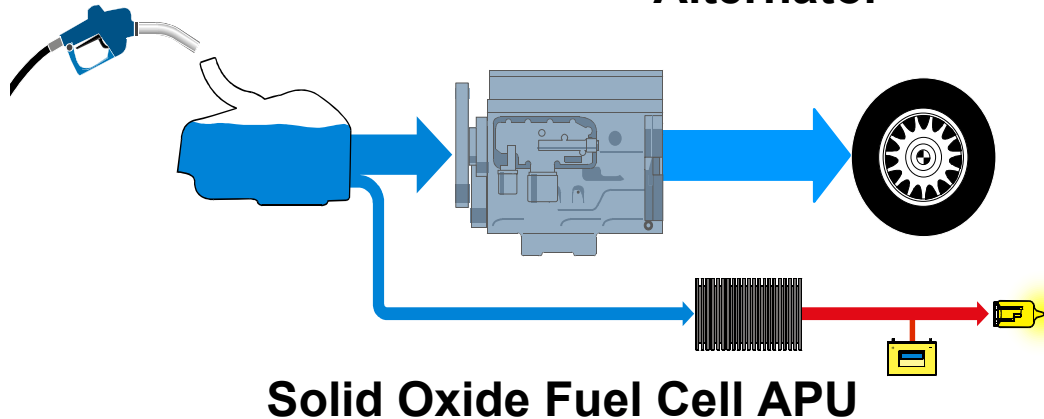
- ◆ Delphi Automotive Systems is developing Solid Oxide Fuel Cell (SOFC) technology for transportation applications - primarily as an on-board Auxiliary Power Unit (APU).
- ◆ Paradigm shift in the supply of electric power for transportation.
- ◆ Highly efficient and low emissions.
- ◆ Consistent with the increasing demands for electrical power in the new era of more comfort and convenience, safety along with low emissions environmental friendliness.

- ◆ Why a SOFC APU
- ◆ SOFC APU System Mechanization
- ◆ Key Subsystem Development
  - ⇒ Stack
  - ⇒ Reformer
  - ⇒ Waste Energy Recovery
  - ⇒ Battery Pack
  - ⇒ BOP
- ◆ Current APU and Technical Challenges
- ◆ Future Vision and Conclusions

**Today:**



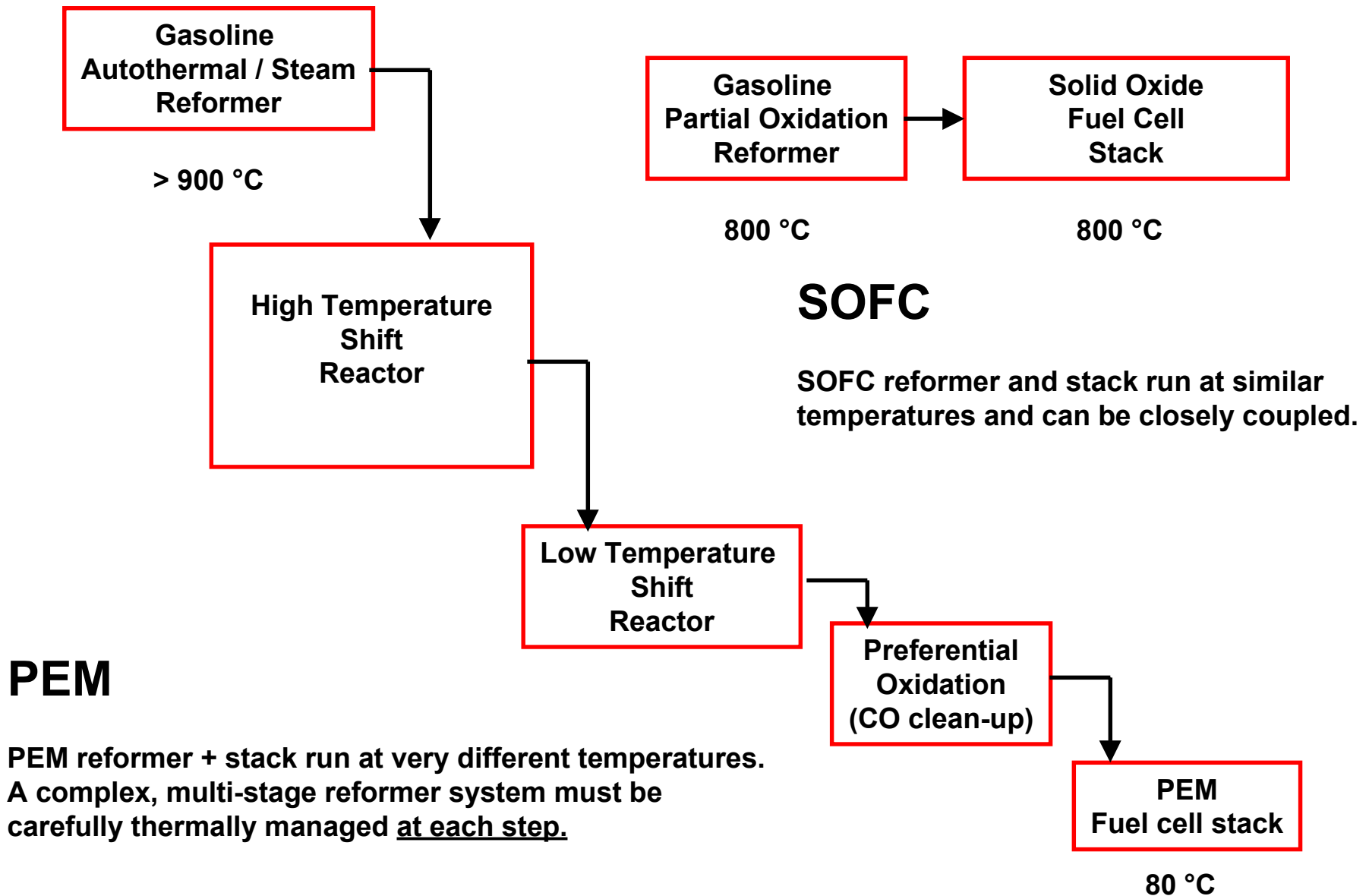
**Tomorrow ?**



**Why a SOFC APU?**

- The APU is not competing with the IC Engine but complements it.
- Highly efficient generator providing power with the engine off
- The SOFC utilizes simple reforming technology
- Less stringent fuel requirements (uses CO as a fuel)

	PEM	SOFC
Electrolyte	Polymer	Ceramic
Operating Temperature	80°C	700-1000°C
Fuels	H <sub>2</sub> / Reformate	H <sub>2</sub> / CO / Reformate natural gas, light HC fuels
Reforming	External	External / Internal
Oxidant	O <sub>2</sub> / Air	O <sub>2</sub> / Air
Efficiency	> 50%	> 50%
Commercial	Ballard, GM, Toyota	Westinghouse [Delphi]
Current Applications	Portable electronics / Automotive / Utility	Utility [Automotive]



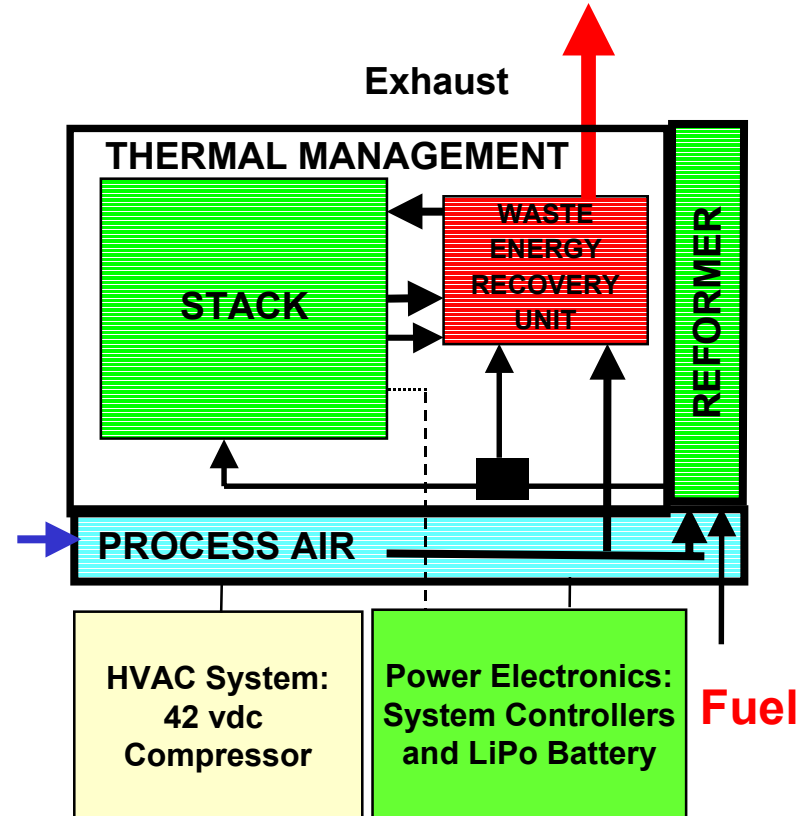
## **Auxiliary Power Unit (APU)**

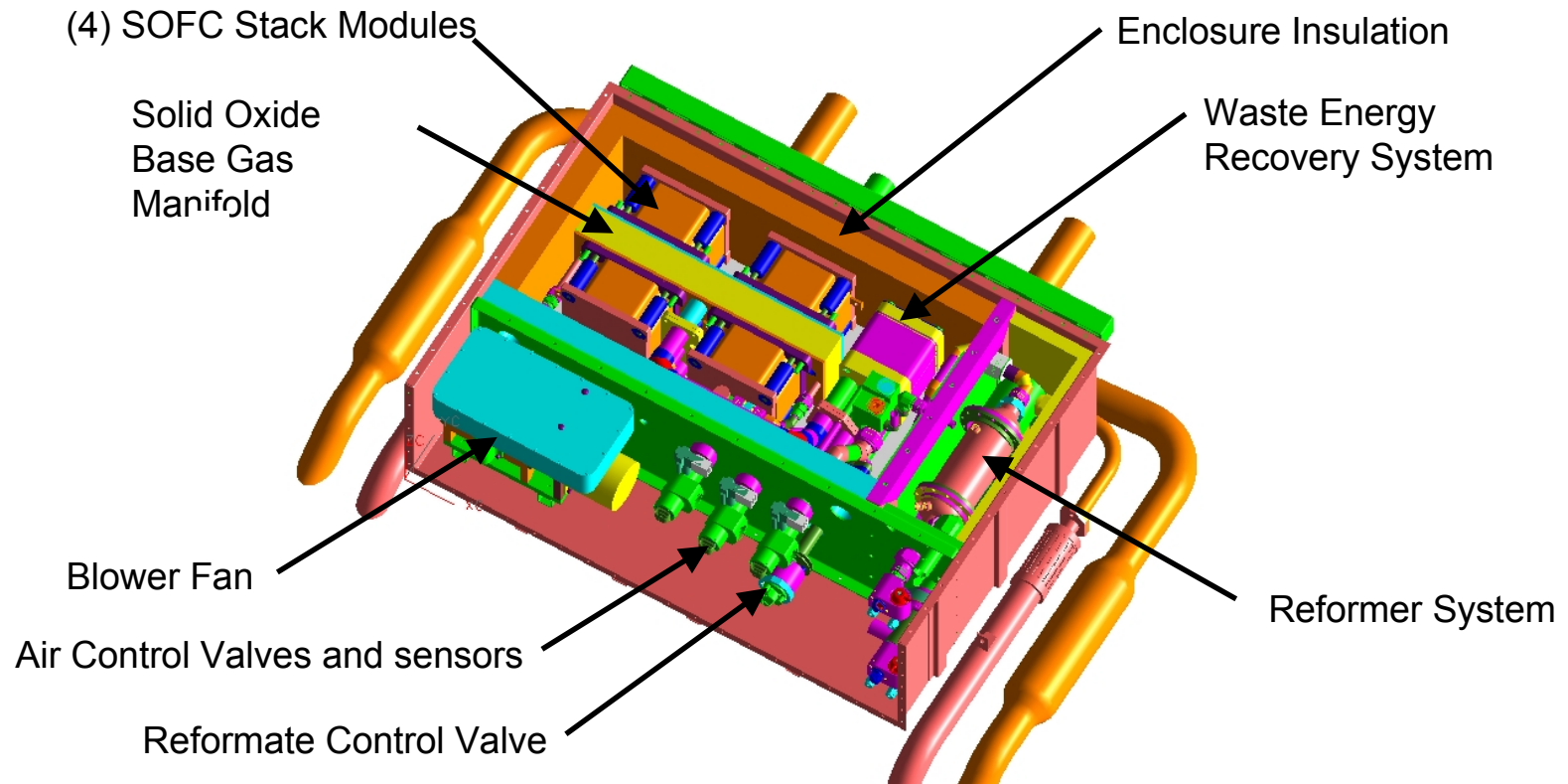
### **Parts:**

- ◆ SOFC Stack subsystem
- ◆ Fuel Reformer subsystem
- ◆ Balance of Plant (BoP)
  - ◆ Process Air Supply
  - ◆ Thermal Management
  - ◆ Waste Energy Recovery
  - ◆ Power Electronics / Controls
  - ◆ HVAC subsystem

### **Expected Customer Benefits:**

- ◆ Can supply electric power with engine on or off, with high efficiency and essentially zero emissions
- ◆ Permits operation of any electrical accessory
- ◆ Possible enabler for high power-consuming advancements (e.g., PVT)

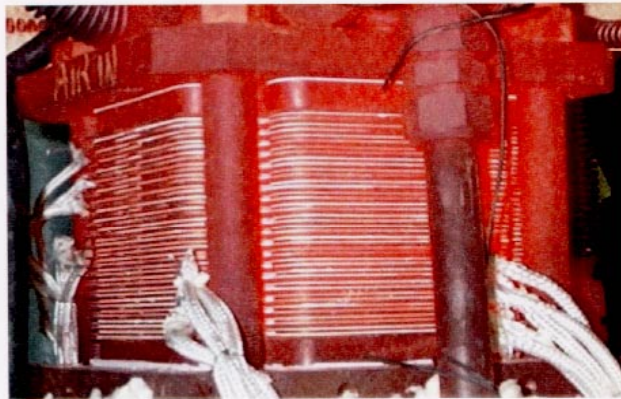




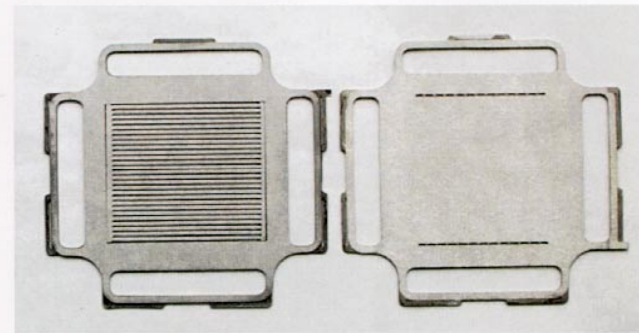


- ♦ Stack developed by Global Thermoelectric
- ♦ Planar anode supported technology for high power density.
- ♦ Metallic interconnects for low cost.
- ♦ Compression seals for thermal cycling.

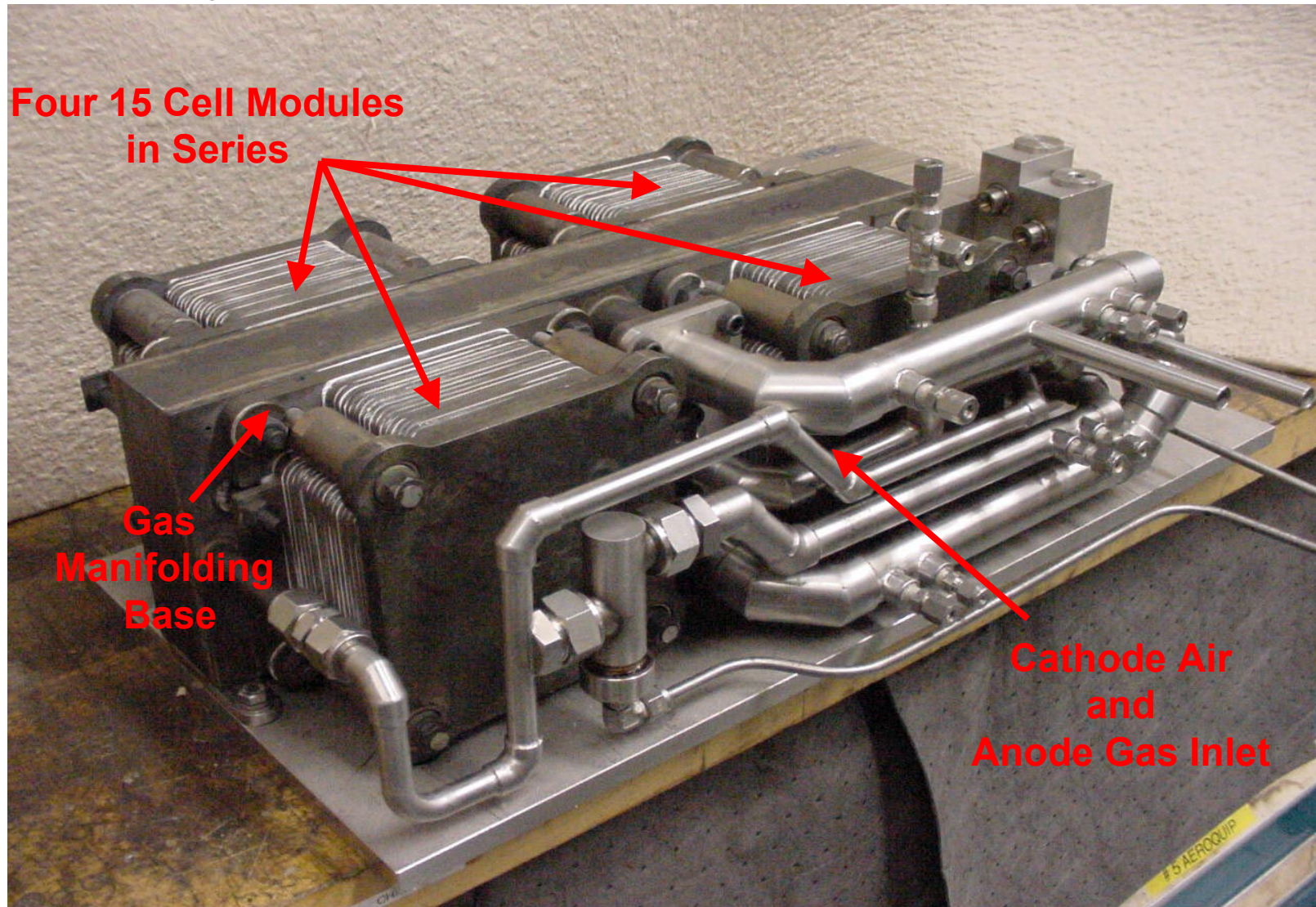
**20 Cell - 800 deg. C.**



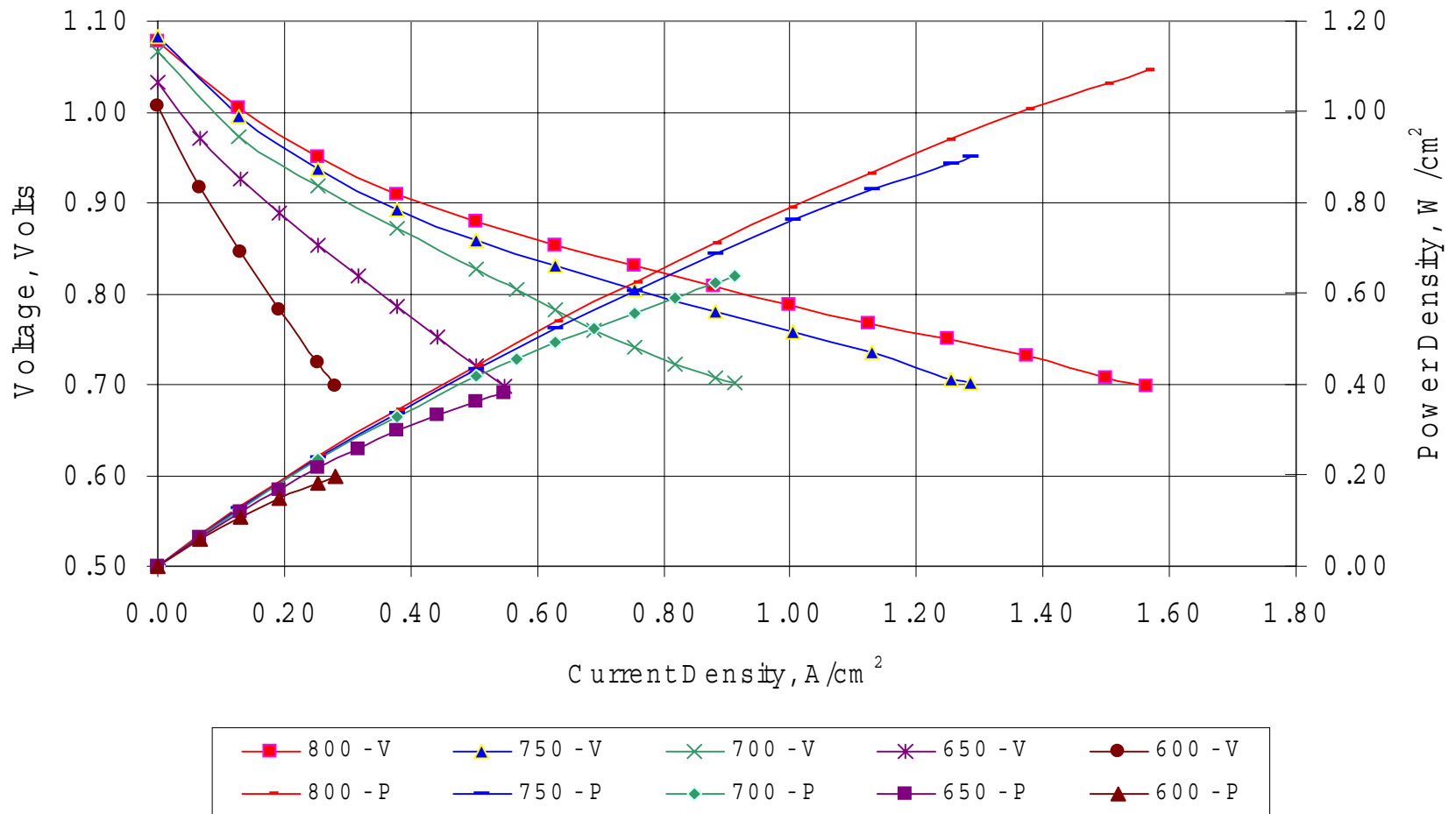
**Metal Interconnect Plates**



**Source: Global Thermoelectric**

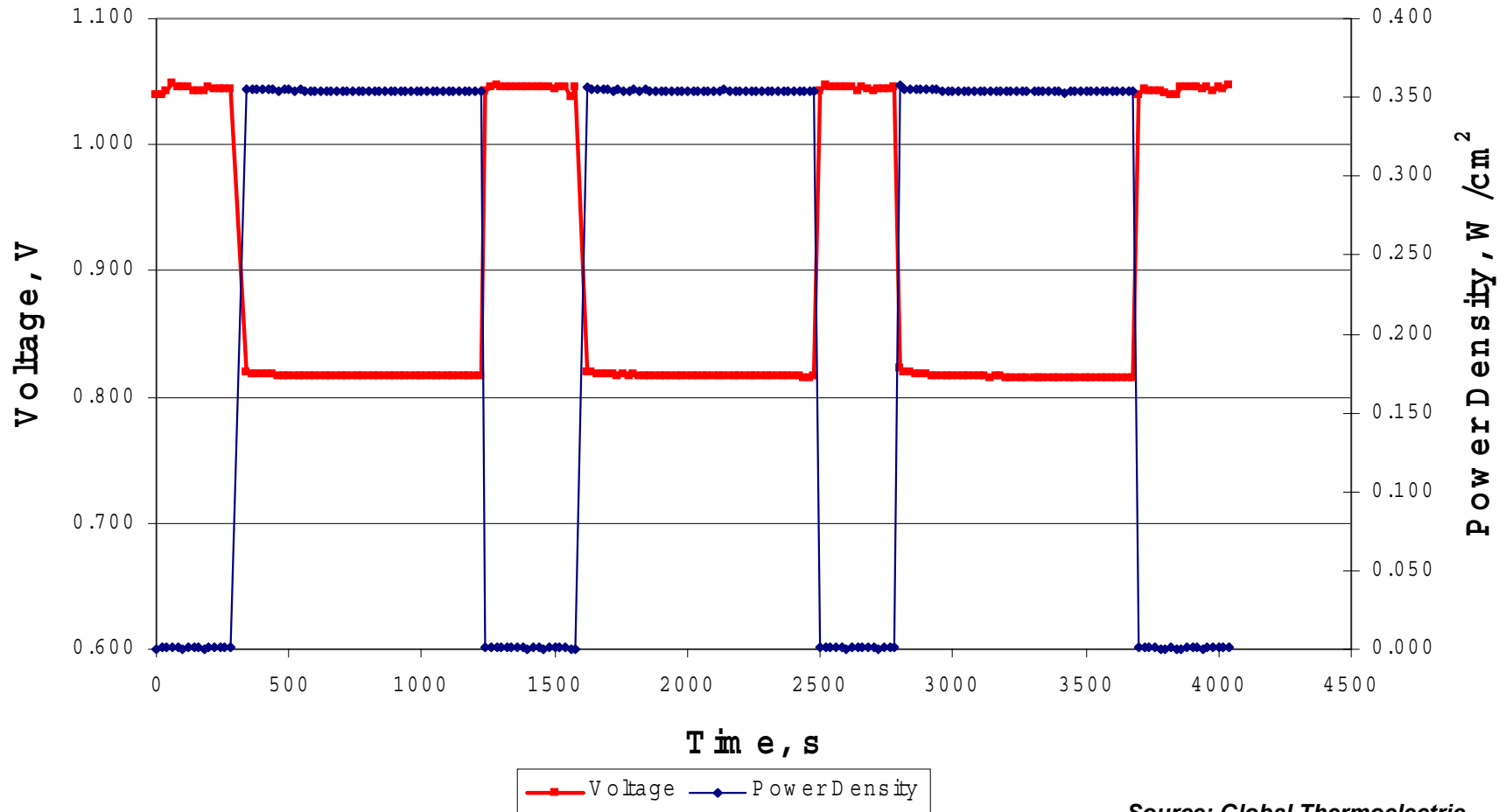


Fuel = hydrogen



Source: Global Thermoelectric

**T=750°C, Fuel = 45%hydrogen,rest argon; Fuel Utilization 60%**

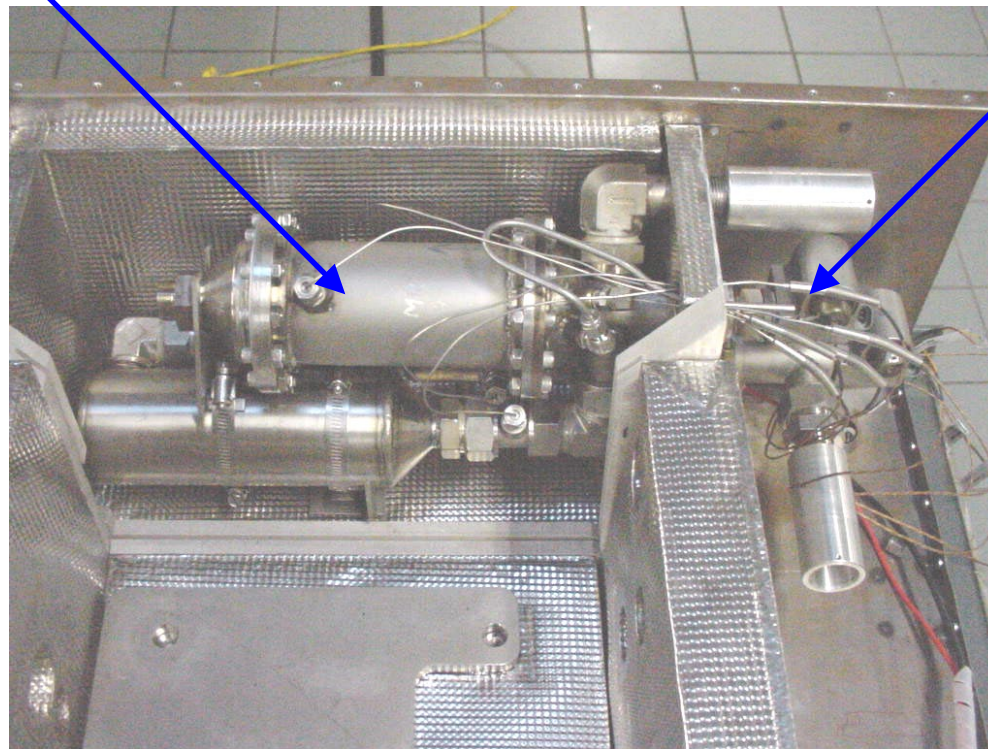


**Source: Global Thermoelectric**



**Gasoline Reformer Subsystem**

**Air / fuel Delivery  
Subsystem**

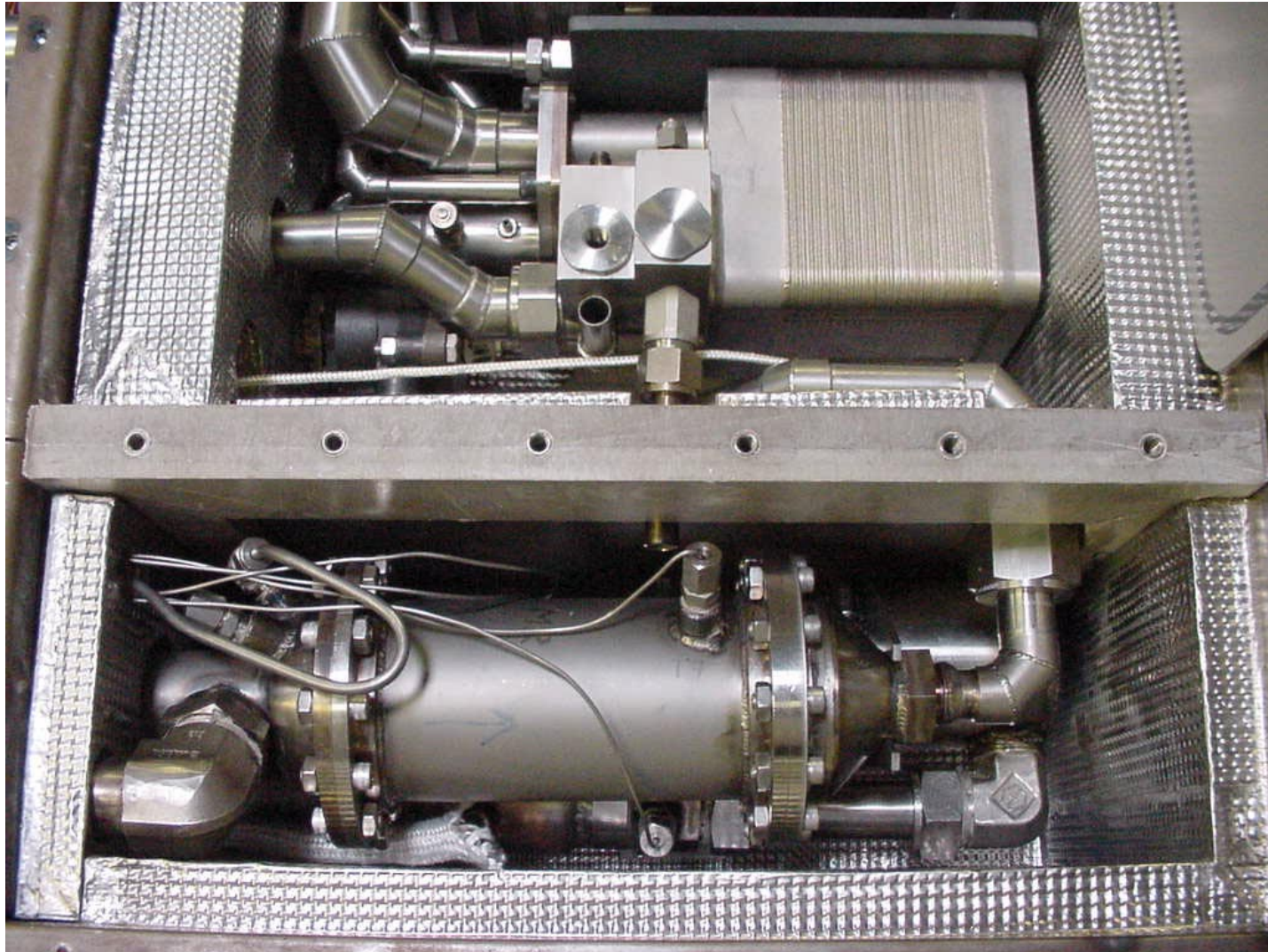


**Capacity: 10 kWt Reformate**

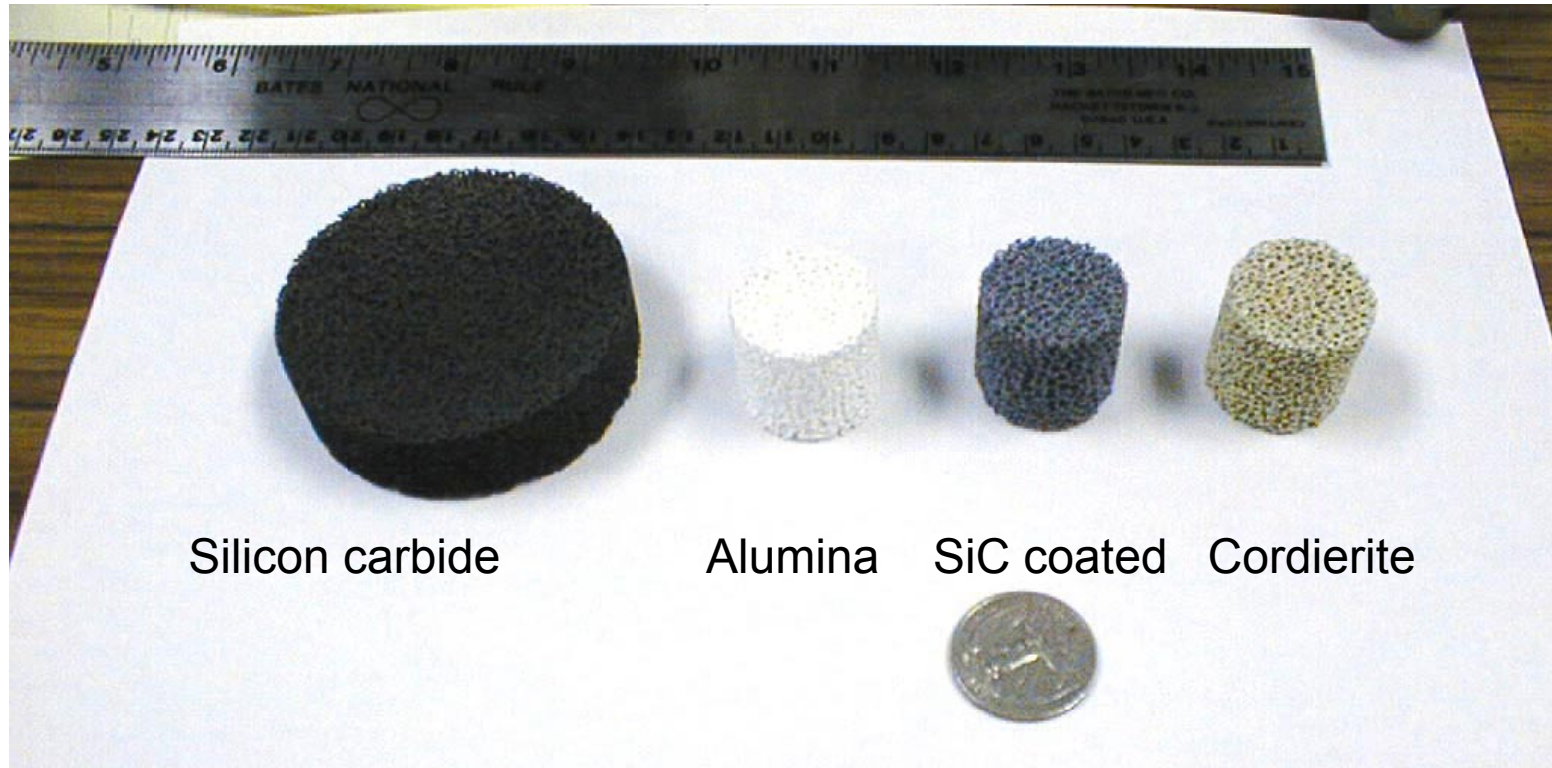
**Catalysts: Automotive Derivative**

**Air / Fuel Actuators: Standard Automotive**

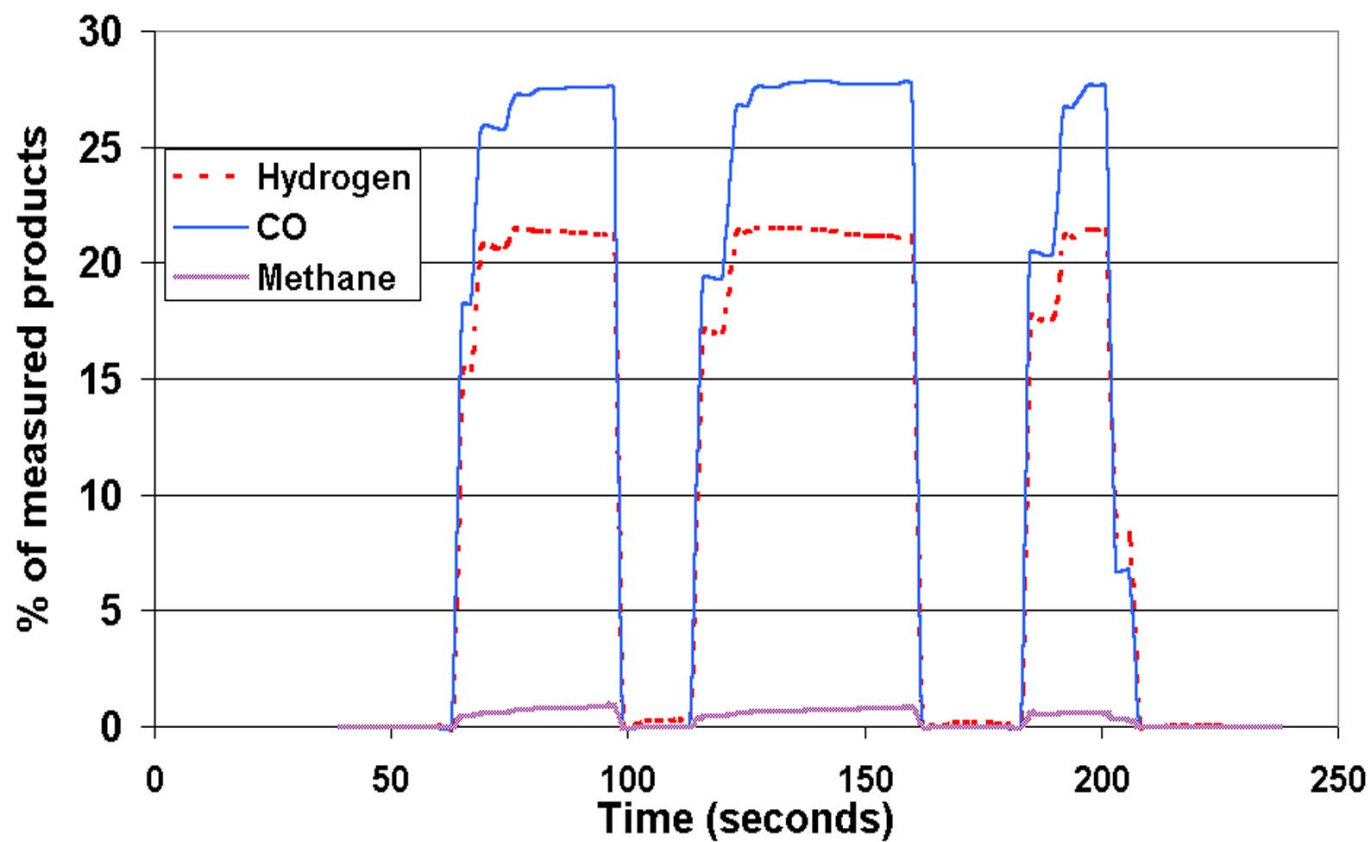
**Start-up time: < 10 minutes (to SOFC purity reformate)**



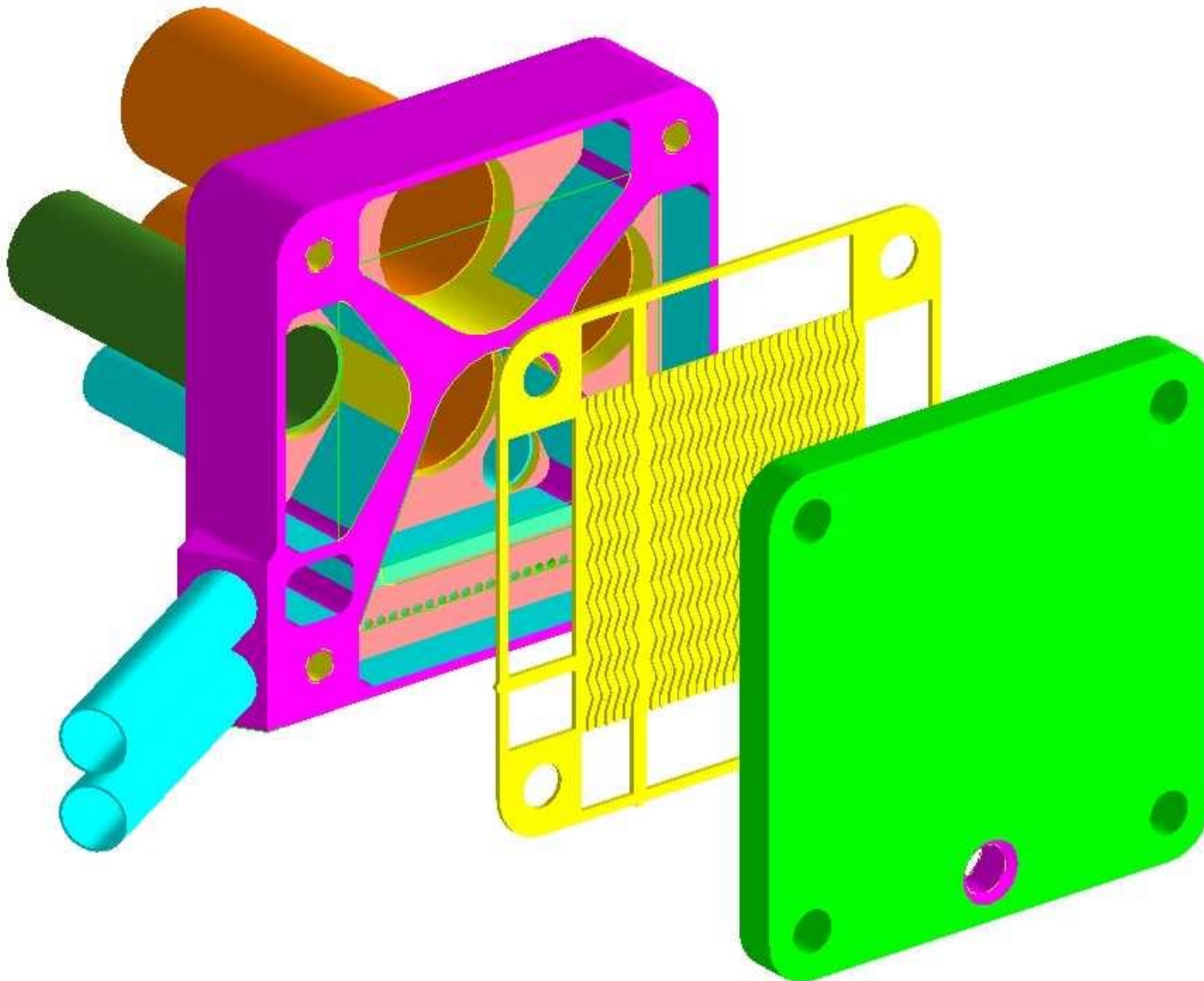


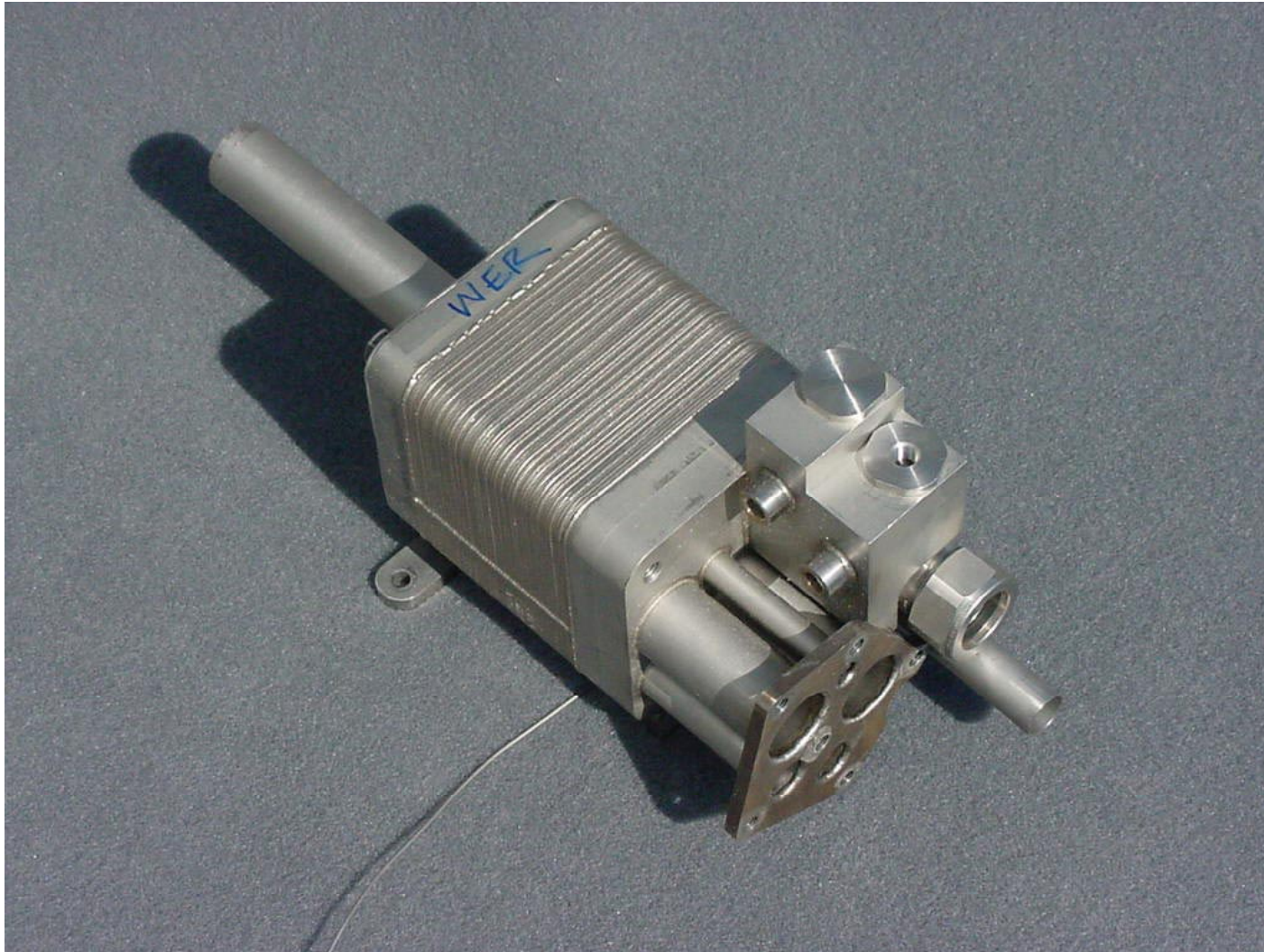


- ◆ Catalysts and Supports are Being Developed at Lab Scale within Delphi.
- ◆ Lab Scale Reactors Support Catalyst Development (For Both SOFC and PEM)
- ◆ Full Scale System Integration and Controls Labs Support Reformer System Development

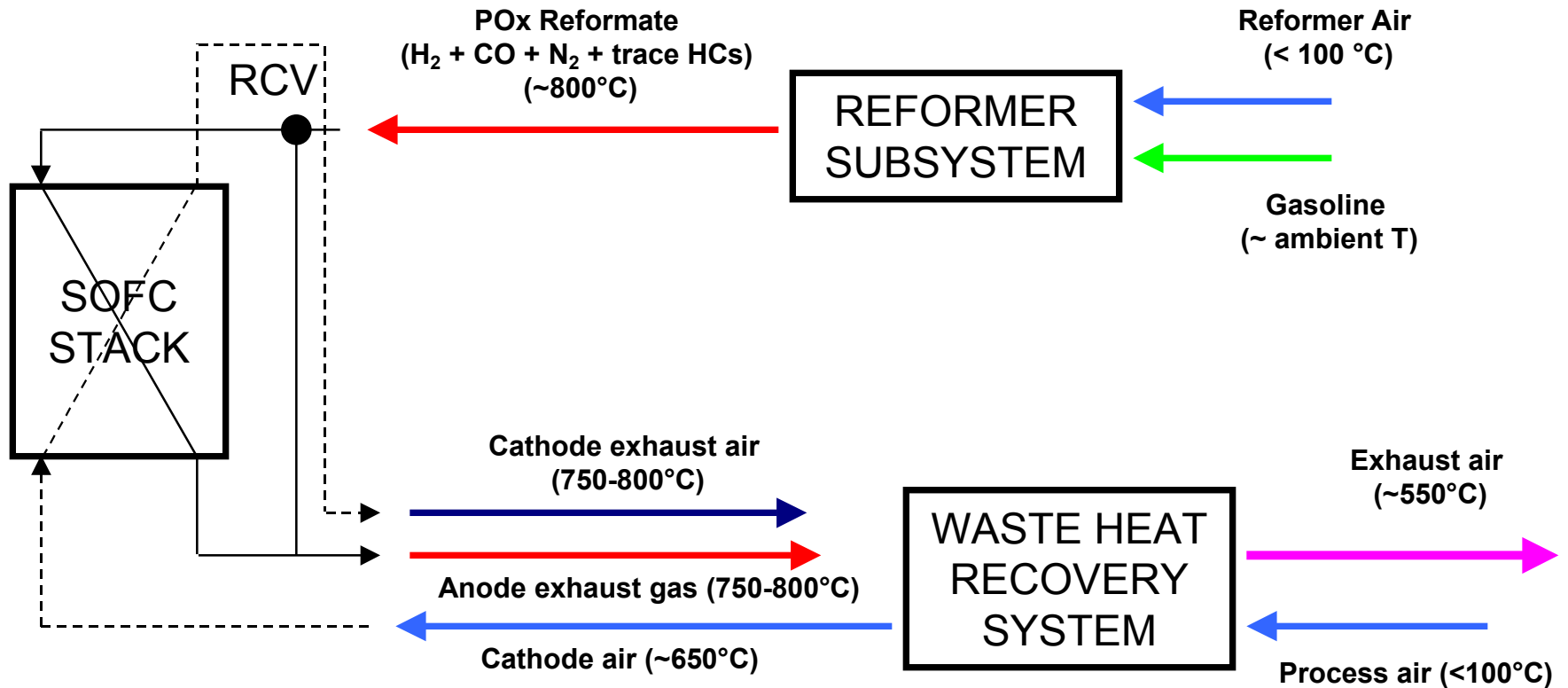




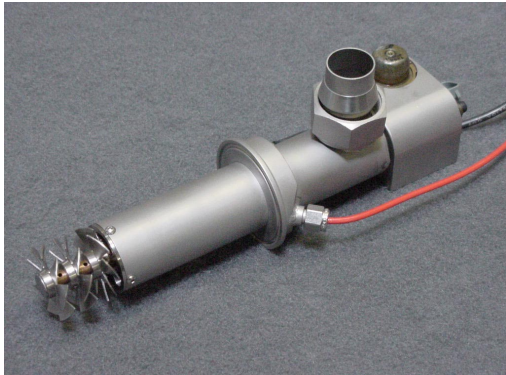




## Reformer / Waste Heat Recovery Integration







**PTC Fuel and Air preheating,  
mixing and vaporization**

**Reformer catalyst inlet flame  
arrestor / radiation shield**



**Catalyst formulation, loading  
and substrate development**

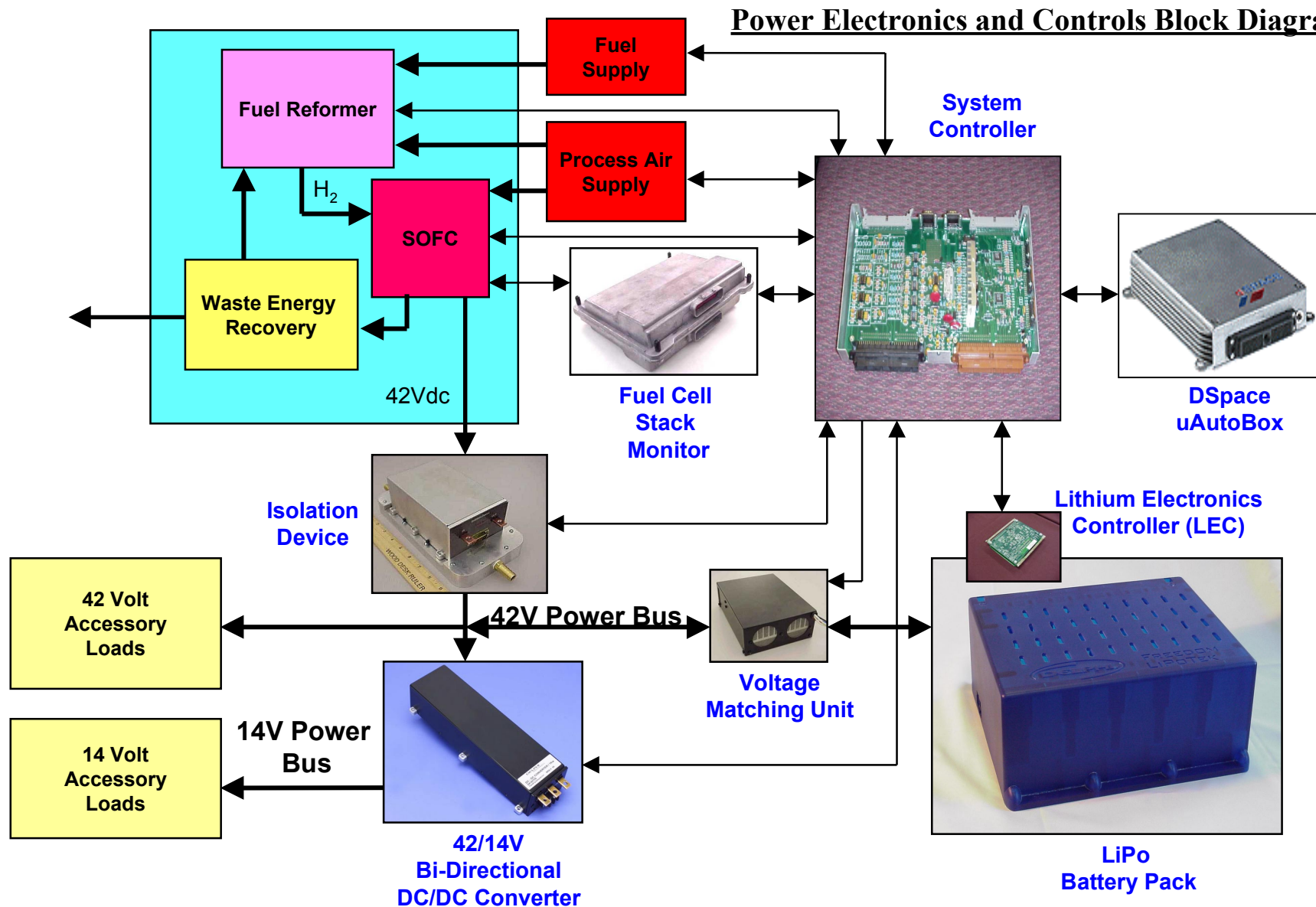


**Electrically heated catalyst and  
start-up strategy development**

**Fuel metering, vaporization  
and mixing assembly**

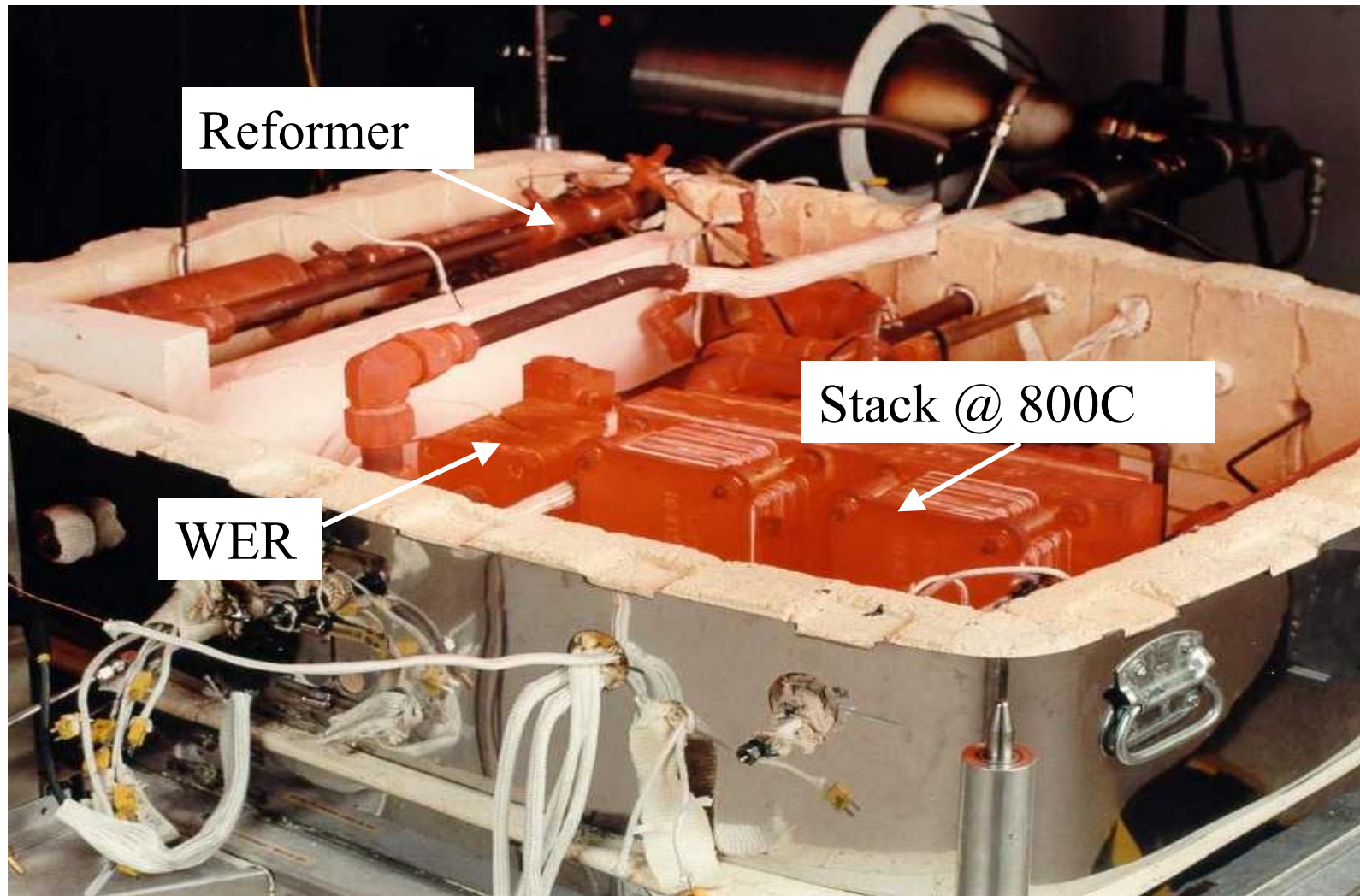


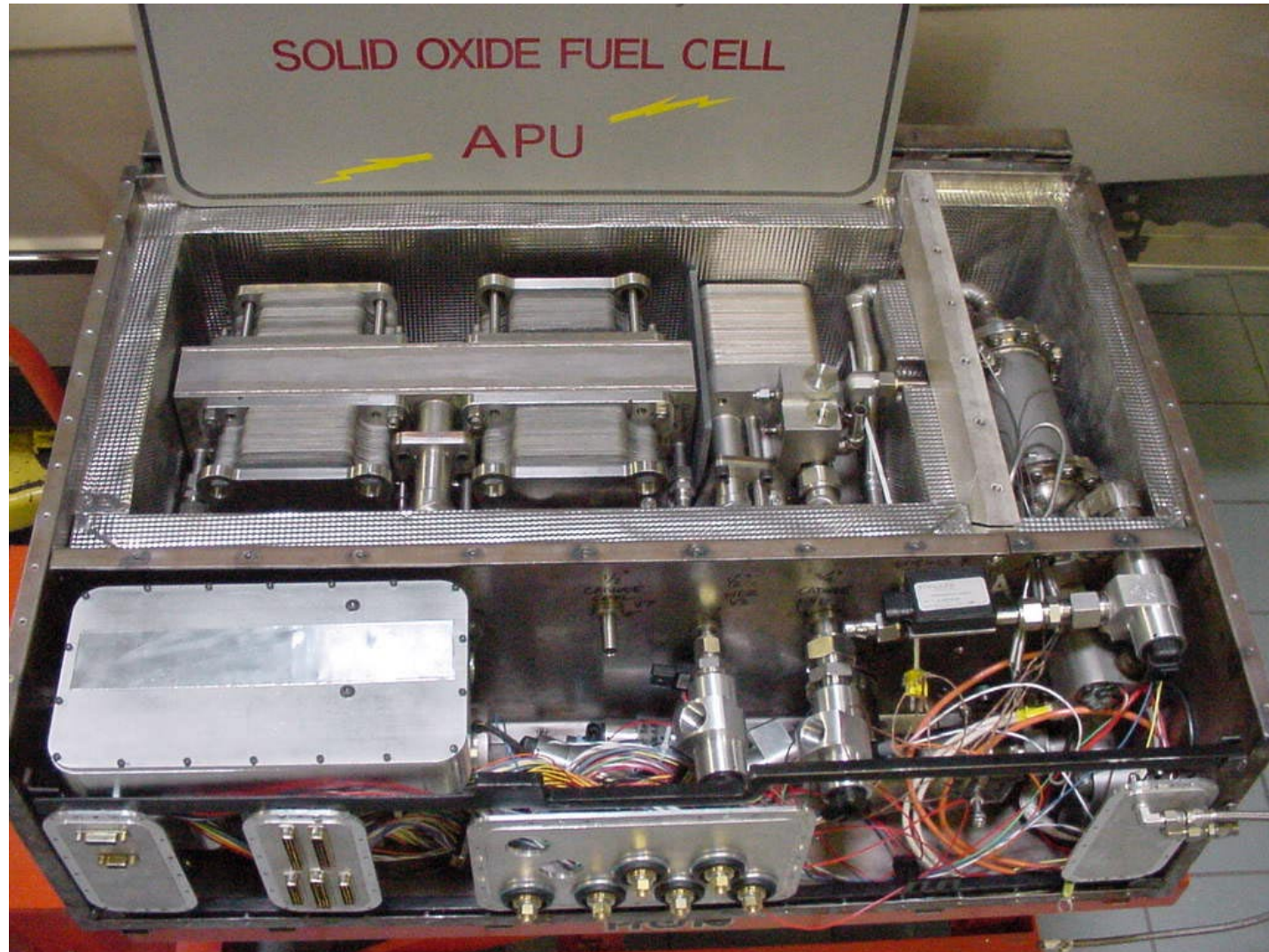
Power Electronics and Controls Block Diagram





***Solid Oxide Fuel Cell APU***  
***30 cell Stack / WER Combustor / Reformer***

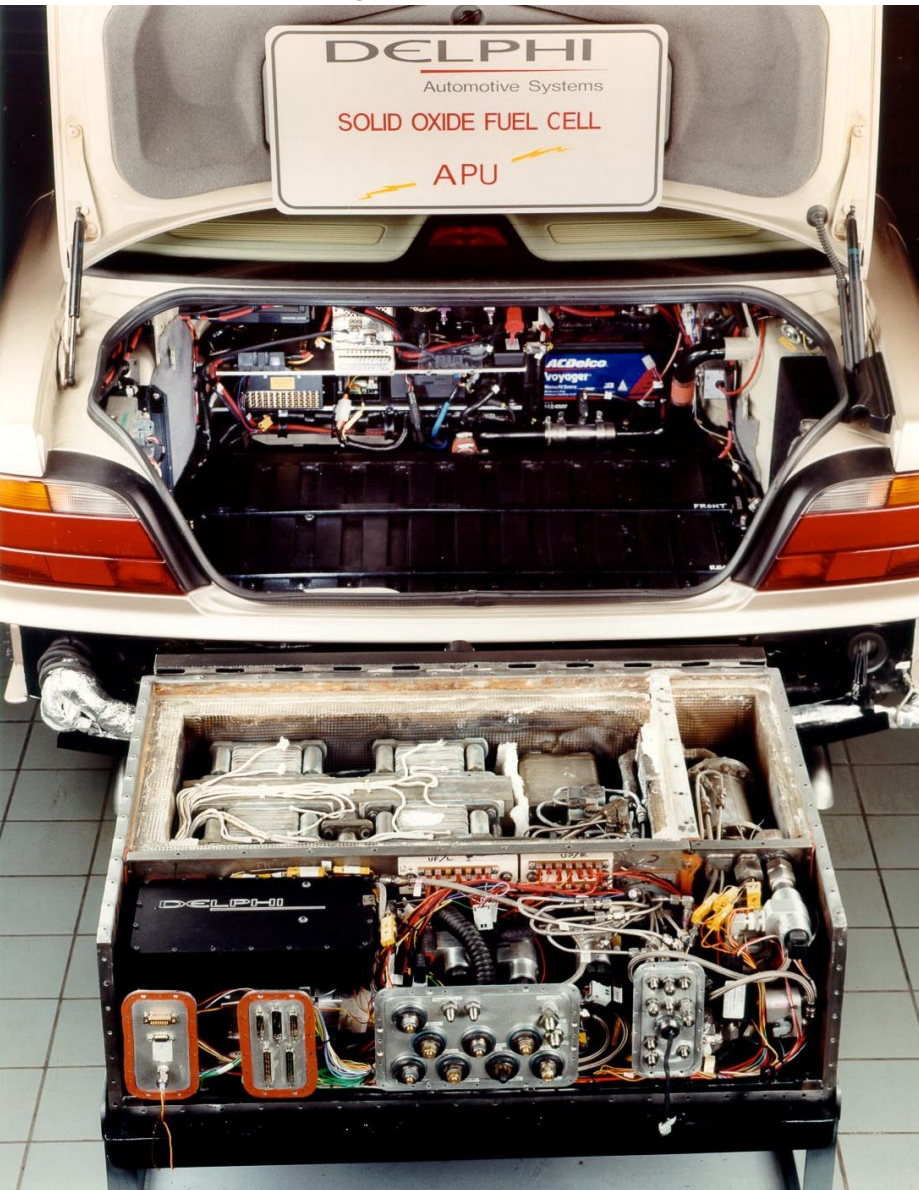




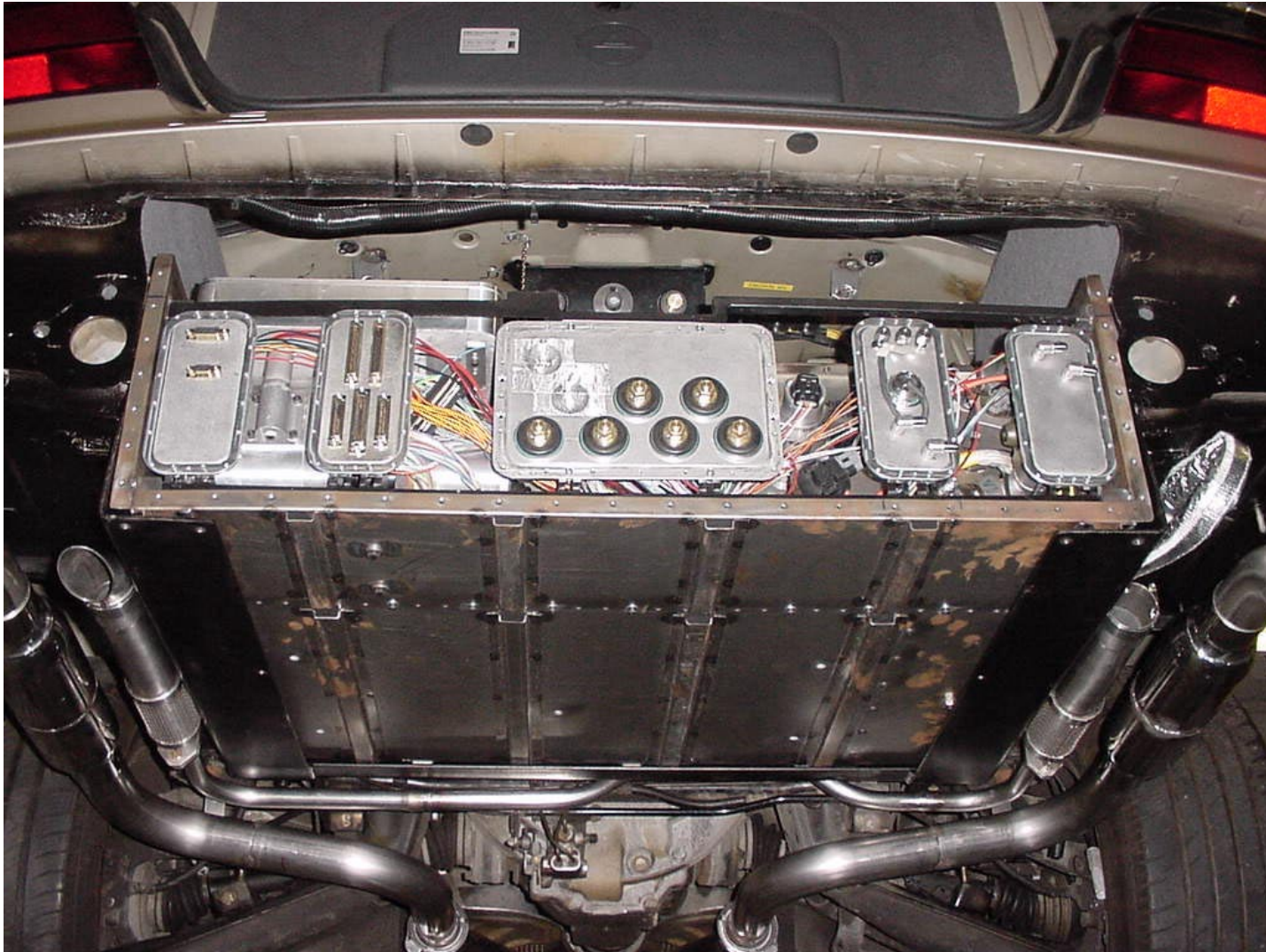






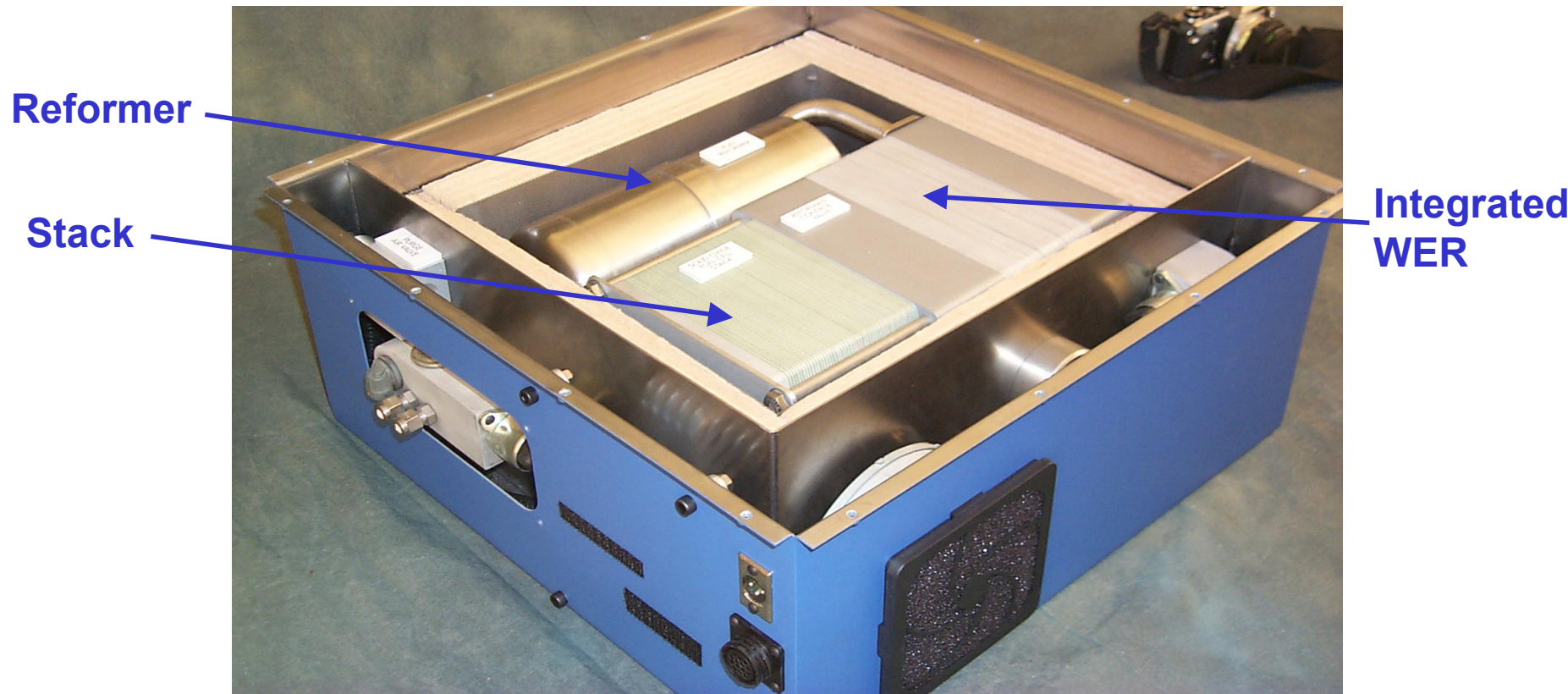






## SOFC Has Many Challenges To Be Viable As An Automotive Technology:

- ◆ Cost, Cost, Cost.
- ◆ Power density
- ◆ Higher efficiency.
- ◆ High performance, low cost insulation.
- ◆ Robust balance-of-plant components.
- ◆ Fast startup and thermal cycling.
- ◆ Automotive levels of robustness.



◆ APU / generator

- ⇒ high efficiency electric power with engine on and off
- ⇒ super low emissions (engine off)
- ⇒ enabler for electric accessories

◆ APU / generator / reformer

- ⇒ high efficiency power with engine on and off
- ⇒ enabler for electric accessories
- ⇒ enabler for very high engine efficiency
- ⇒ enabler for zero emissions with an internal combustion engine (ICE)

◆ Series hybrid range extender

- ⇒ compact, quiet efficient APU
- ⇒ waste heat for cabin heating
- ⇒ super low emissions



- ◆ SOFC is an attractive ,efficient, alternative source of power generation for : transportation,military, remote and distributed power. It will enter the market as an APU - a paradigm shift in supply of electric power .
- ◆ It is not likely to replace the ICE but will complement it.
- ◆ It has other future mechanizations which support the trend to essentially zero toxic emissions and much reduced CO<sub>2</sub> emissions

Delphi Automotive Systems with its partners are working toward bringing this key technology to the various market.

