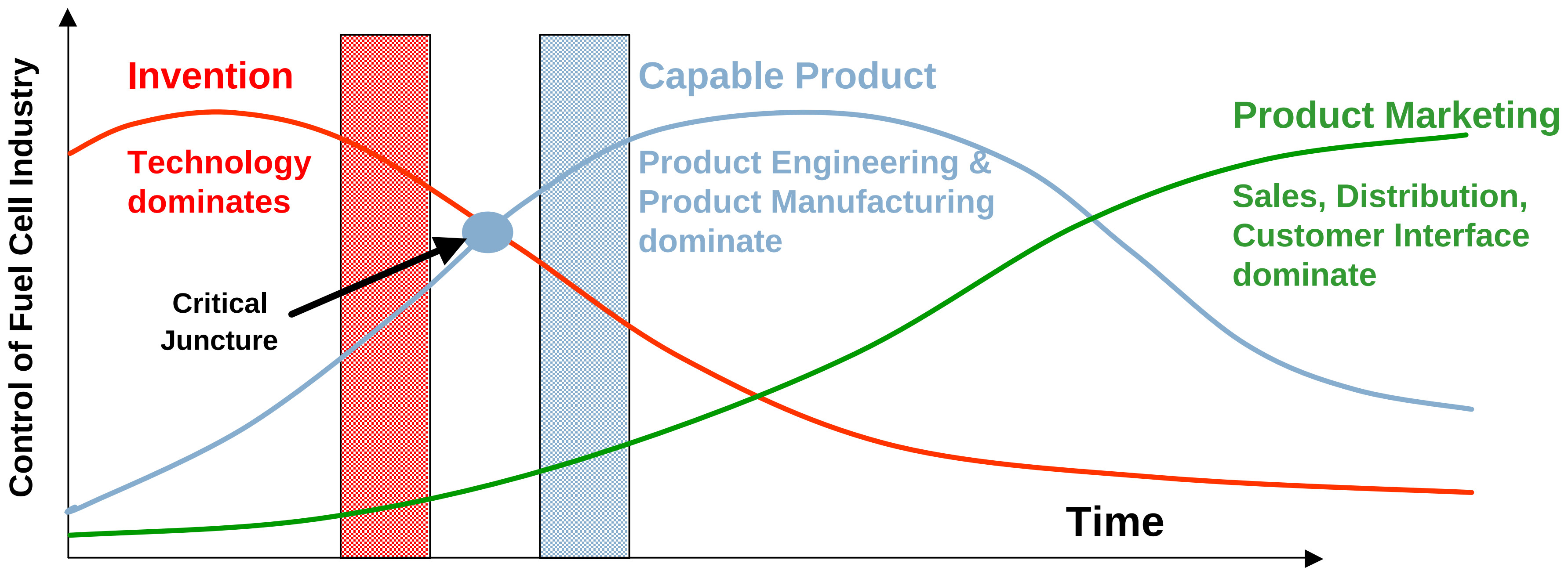
General Motors Fuel Cell Research

Andrew Bosco

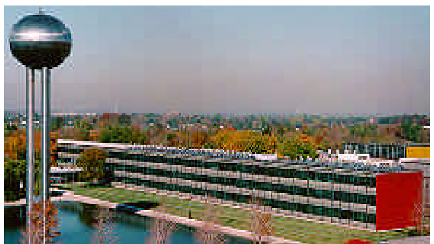
Manager Fuel Cell Stack Research

Fuel cell industry entering a transition phase in which engineering and manufacturing will become as important as technical leadership



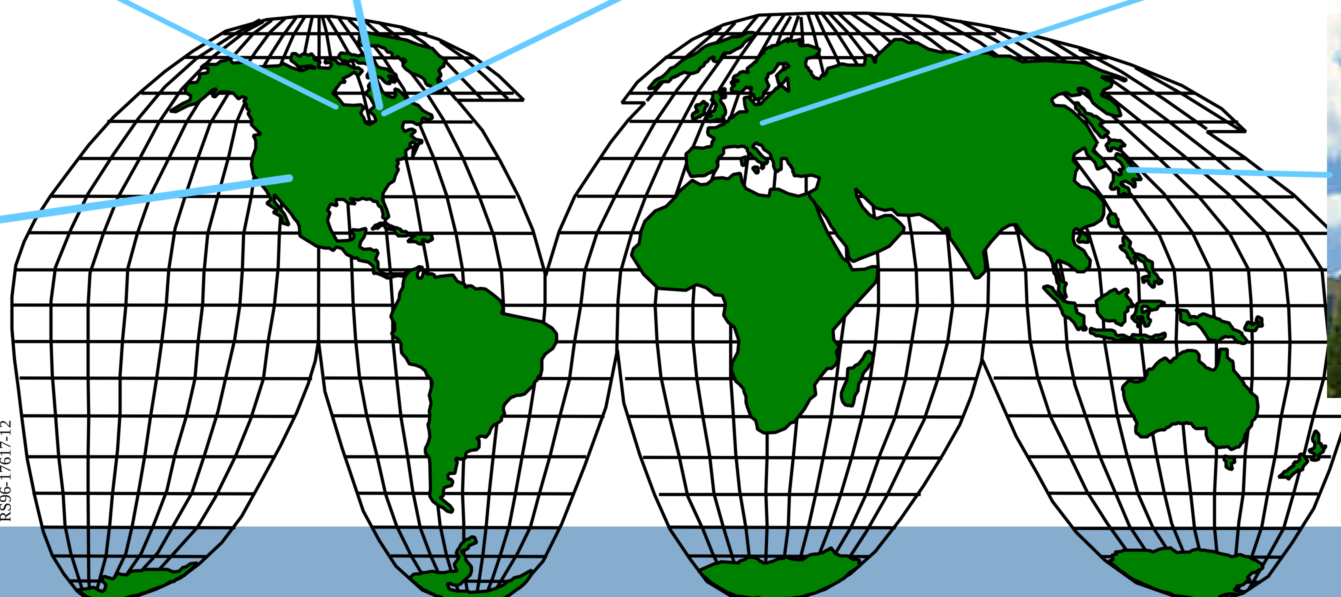
Fuel Cell Activities Formed in 1997
Stack Research Locations

Warren (MI, USA):
Bipolar Plate & Catalyst
Diagnostics, Modeling



Honeoye Falls (NY, USA):
Stack Design, MEA, DM, Catalyst,
Diagnostics, Modeling, Freeze

Mainz-Kastel (Germany):
Stack/Vehicle Integration,
Material Development, Modeling



Torrance (CA):
Stack/Electronics
Interface

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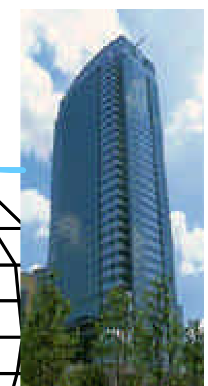


**GM AP,
Tokyo**

Fuel Cell Propulsion System

Fuel Cell Propulsion System (FCPS)

Vehicle Integration: Connections, Controls, Thermal

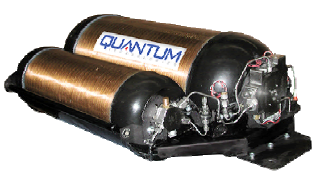
Fuel Storage
(H_2 on board → H_2 to FCPM)

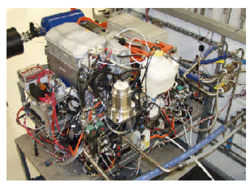
Fuel Cell Power Module (FCPM)
(H_2 in → DC electrical power out)

Traction
(DC in → Torque out)

Liquid

Compressed



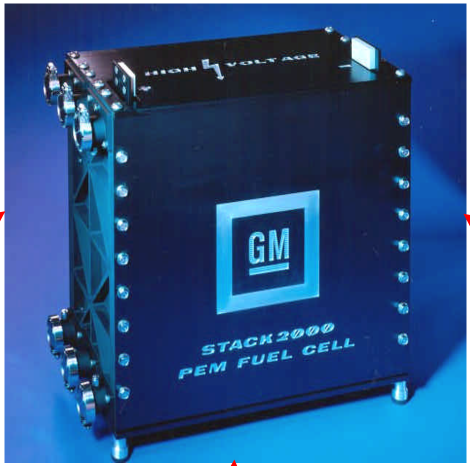


Stack

Stack components

FCPM Subsystems

Automotive Stack Research



Cost

- Stack:
  - Material
  - Processing
  - Assembly
- Low Pressure
- Humidifiaction
- Passive Anode Control

Life

- Durability
- Start/Stops
- Degradation
- Coolant Compatibility

Performance

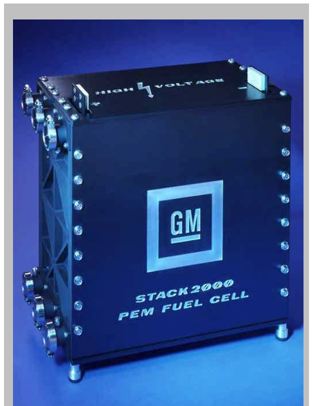
- Volumetric Power Density
- Gravimetric Power Density
- Transients
- Freeze Capable
- High Temperature

Fuel Cell Stack Technology Progress

St 3 - 1997

St 4 - 1998

St 7 - 1999



Stack 2000

Current

	St 3 - 1997	St 4 - 1998	St 7 - 1999	Stack 2000	Current
Max. Power:	37- 41 kW	40 kW	50 - 120 kW	80 - 120 kW	102 kW
Power density:	0.26 kW/l	0.77 kW/l	1.10 kW/l	1.44 kW/l	1.75 kW/l
	0.16 kW/kg	0.31 kW/kg	0.47 kW/kg	0.83 kW/kg	1.25 kW/kg
Active area:	500 cm^2	500 cm^2	800 cm^2	800 cm^2	250 cm^2
Pressure:	2.7 bar	2.7 bar	2.7 bar	1.5 - 2.7 bar	1.2-1.5 bar
Temperature:	80 °C	80 °C	80 °C	80 °C	80 °C

Electrochemical Stack Model

Parameter Space

Bipolar Plates
- Channel/Land dimensions
- Length of flow path

Diffusion Media
- Thickness
- Porosity

Membrane
- Thickness
- Equivalent weight (EW)

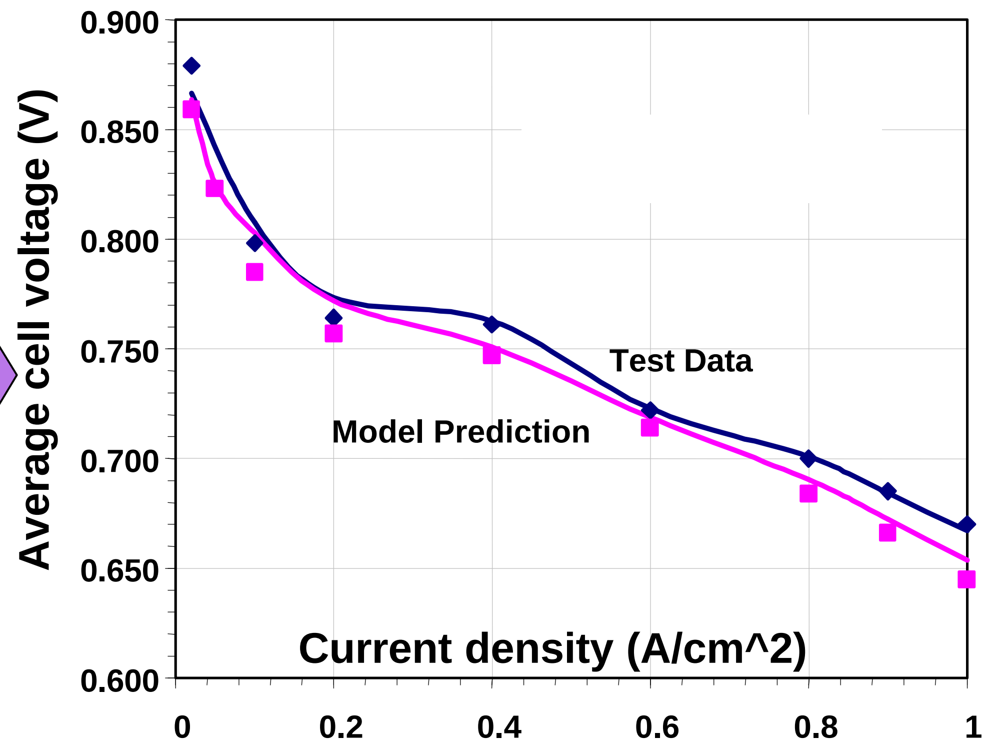
Catalyst Layers
- Loading
- Thickness
- Porosity
- Ionomer volume fraction

Inlet Flow (An/Cath)
- Stoich
- Temperature
- Pressure
- Gas composition
- Humidity (Dewpts)

Control
- Coolant
- Flow orientation

Applied Current Density

Steady State
Non-isothermal Model



- **Reactant concentration profiles**
- **RH profiles and Current distribution**
- **Pressure drop and Temperature variation**

Stack Research Driven by System Interactions & Requirements

	"Device"	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	Anode side pressure system	x	x	x	x	x			x								x	x			x	x											
2	Anode side temperature system	x	o	x	x												x				x		x										
3	Anode side humidification system	x	x	o	x											x	x		x		x		x										
4	Anode side flow control	x	x	x	o												x				x	x	x										
5	Cathode pressure control system	x				o	x	x	x	x	x	x					x	x			x	x											
6	Cathode humidification System					x	o	x	x	x	x	x				x		x		x		x	x										
7	Cathode temperature System					x	x	o	x	x	x	x						x				x	x										
8	Cathode pressurization system	x				x	x	x	o	x	x	x					x	x			x	x											
9	Cathode flow control system					x	x	x	x	o	x	x						x			x	x											
10	Water vapor recovery system					x	x	x	x	x	o	x				x		x		x		x	x										
11	Liquid water recovery system					x	x	x	x	x	x	o				x		x		x		x	x										
12	Water Cleaning system												o								x	x	x	x		x							
13	Heat Rejection system (temperature sink)													o	x	x																	
14	COOLANT FLUID													x	o	x								x	x	x	x						
15	COOLANT FLOWFIELD			x			x				x	x		x	x	o	x	x					x				x						
16	ANODE FLOWFIELD	x	x	x	x	x			x							x	o	x	x														
17	CATHODE FLOWFIELD	x				x	x	x	x	x	x	x				x	x	o		x													
18	DIFFUSION MEDIA-A			x													x		o		x												
19	DIFFUSION MEDIA-C						x				x	x						x		o		x											
20	CATALYST LAYER-A	x	x	x	x	x			x	x			x						x		o		x			x	x						
21	CATALYST LAYER-C	x			x	x	x	x	x	x	x	x	x							x		o	x			x	x						
22	MEMBRANE		x	x	x		x	x			x	x	x			x					x	x	o	x	x	x	x						
23	PLATE MATERIAL												x		x								x	o		x	x						
24	SEAL														x								x		o	x							
25	PLATE COATING												x		x						x	x	x	x	x	o	x						
26	ADHESIVE														x	x					x	x	x	x		x	o						
27	CVU																											o			x	x	
28	BASEPLATES																												o	x	x	x	x
29	SIDEPLATES																												x	o			
30	MANIFOLDS																											x	x		o		
31	INSULATOR PLATES																											x	x			o	x
32	TERMINAL plates																												x			x	o

Anode Subsystem

Cathode Subsystem

Stack

Thermal

Softcomp & Flowfield

Repeatable Hardcomp.

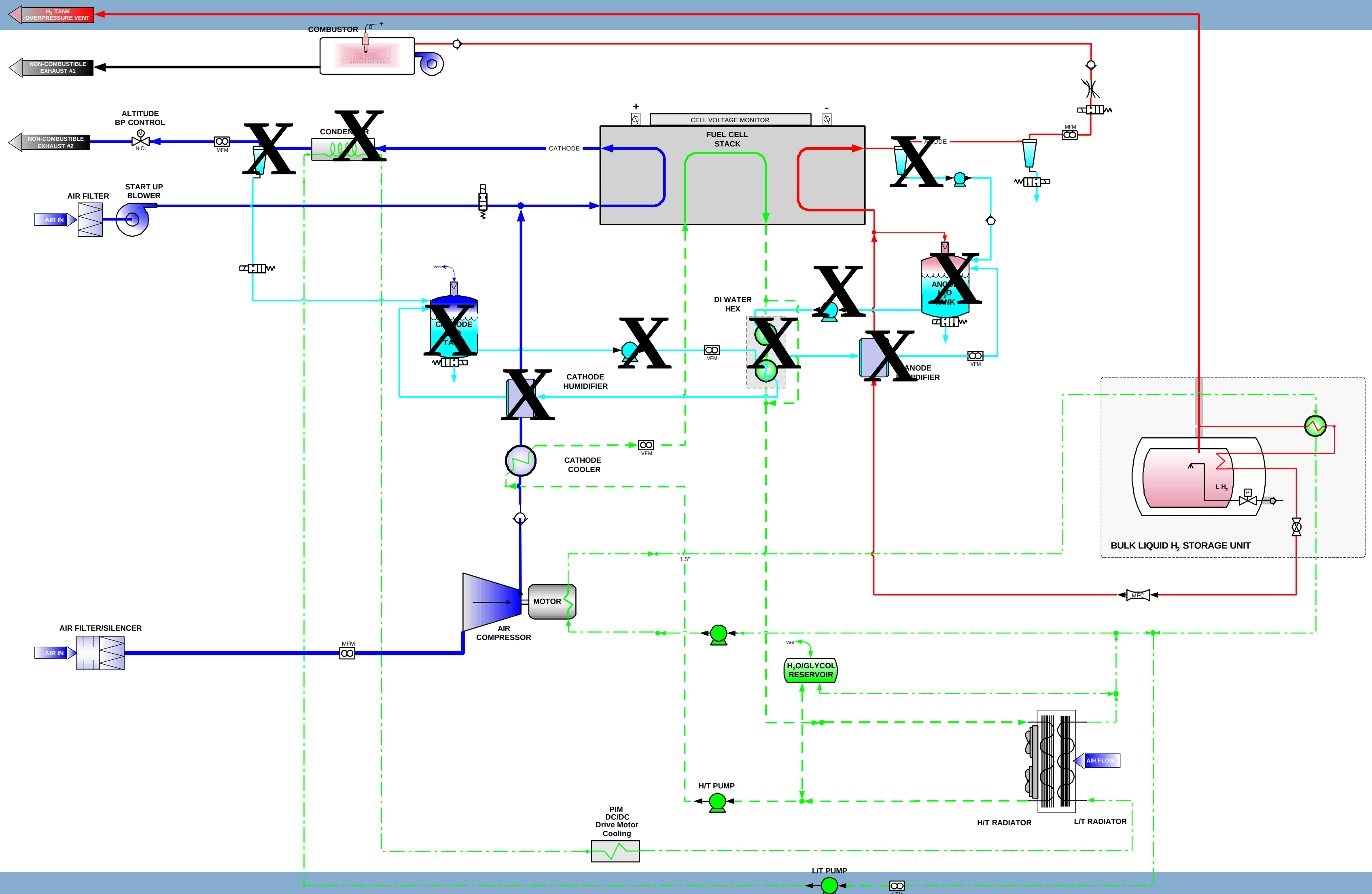
Non-repeat Hardcomp.

System & Stack Trade-offs

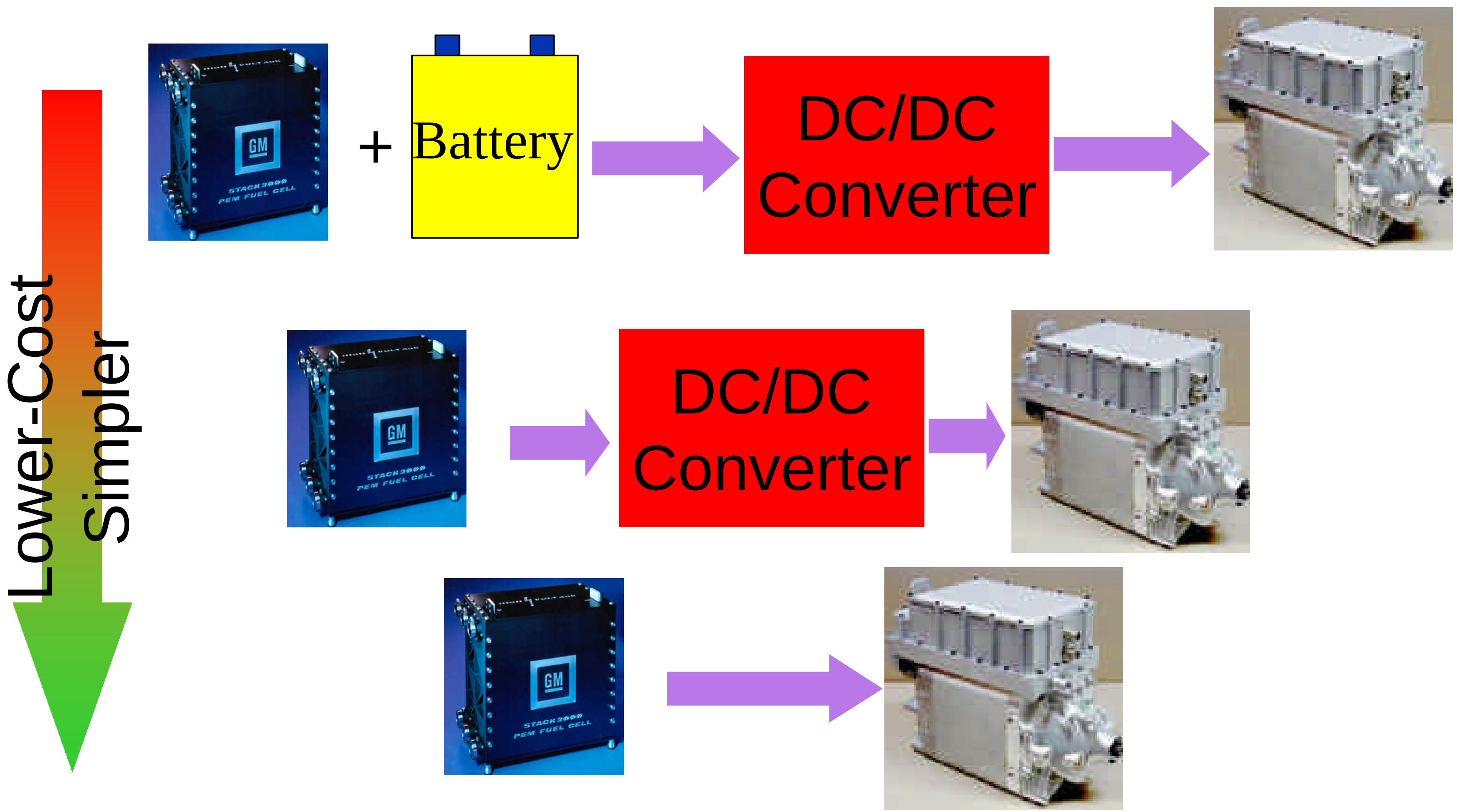
	impact on system			requ'ment	
	weight	volume	complexity	system	stack
Operating pressure	**X**	**X**	**X**	**low**	**high**
Operating temperature	**X**	**X**		**high**	**med**
Reactant stoichiometry	**X**	**X**	**X**	**low**	**high**
Inlet Relative Humidity	**X**	**X**	**X**	**low**	**high**
Stack weight	X			low	low
Stack volume		X		low	low
Stack voltage			X	high	low
Stack Efficiency (cell voltage)	X	X		high	high
Durability				high	high
Start time @ freezing temps			X	low	low
Cost				low	low

GM

System Simplification – No External RH



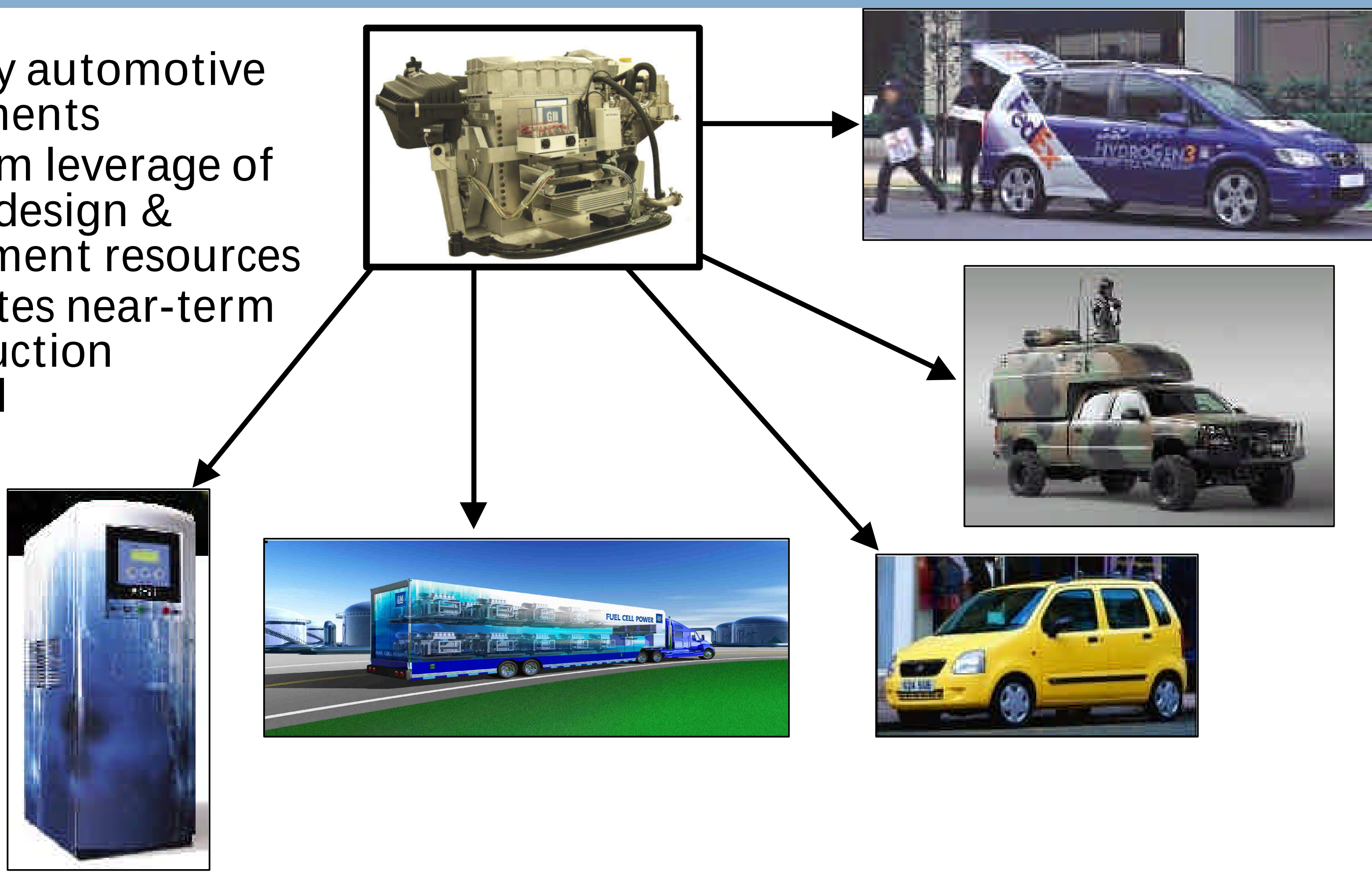
System Simplification - Power Management



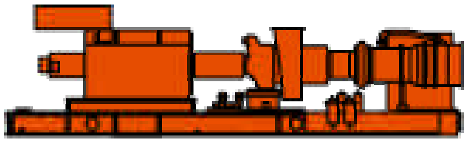
Engineering Focus

Single module development approach across product applications

- Driven by automotive requirements
- Maximum leverage of product design & development resources
- Accelerates near-term cost reduction potential



End users requirements have outgrown current technology solutions

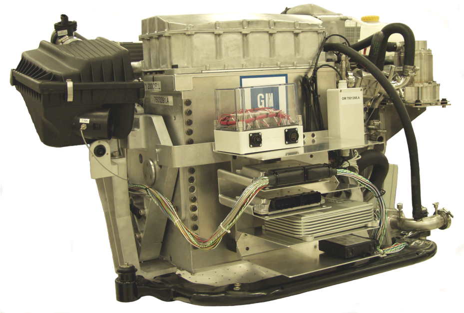


Gas Turbines
Very difficult to site

Reciprocating Generators
Noisy and dirty

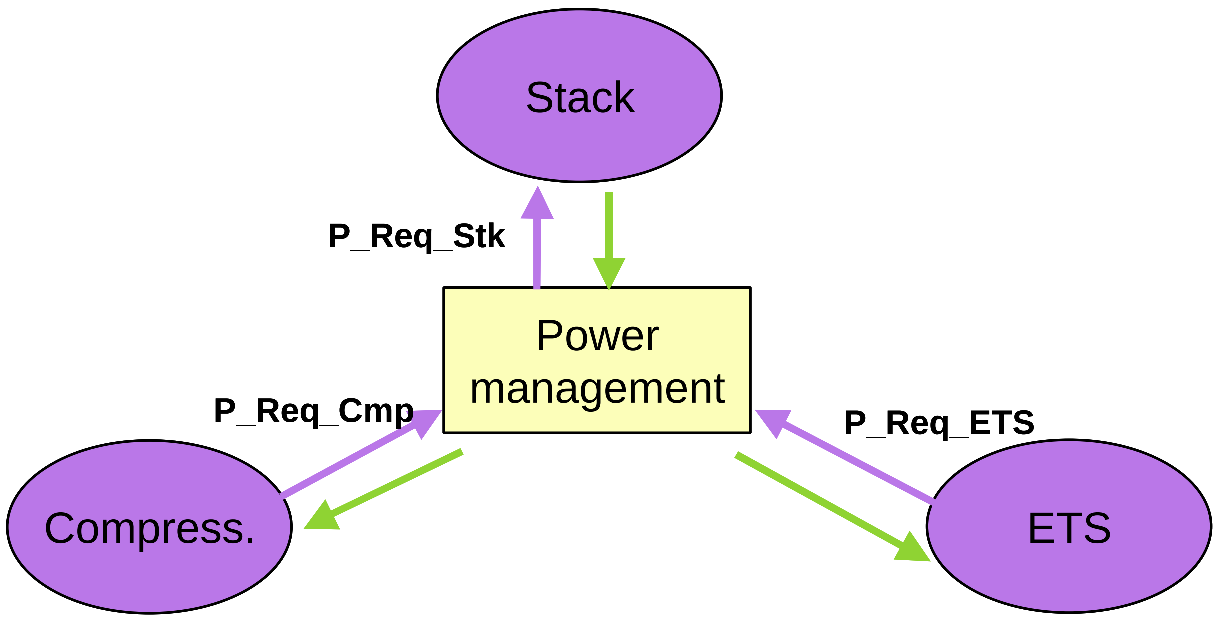
Uninterruptible Power Supplies
Battery failures and expensive

Fuel Cell solutions exploit vulnerabilities of existing technologies



Interactions

- Key interfaces that exist in Fuel Cell Systems



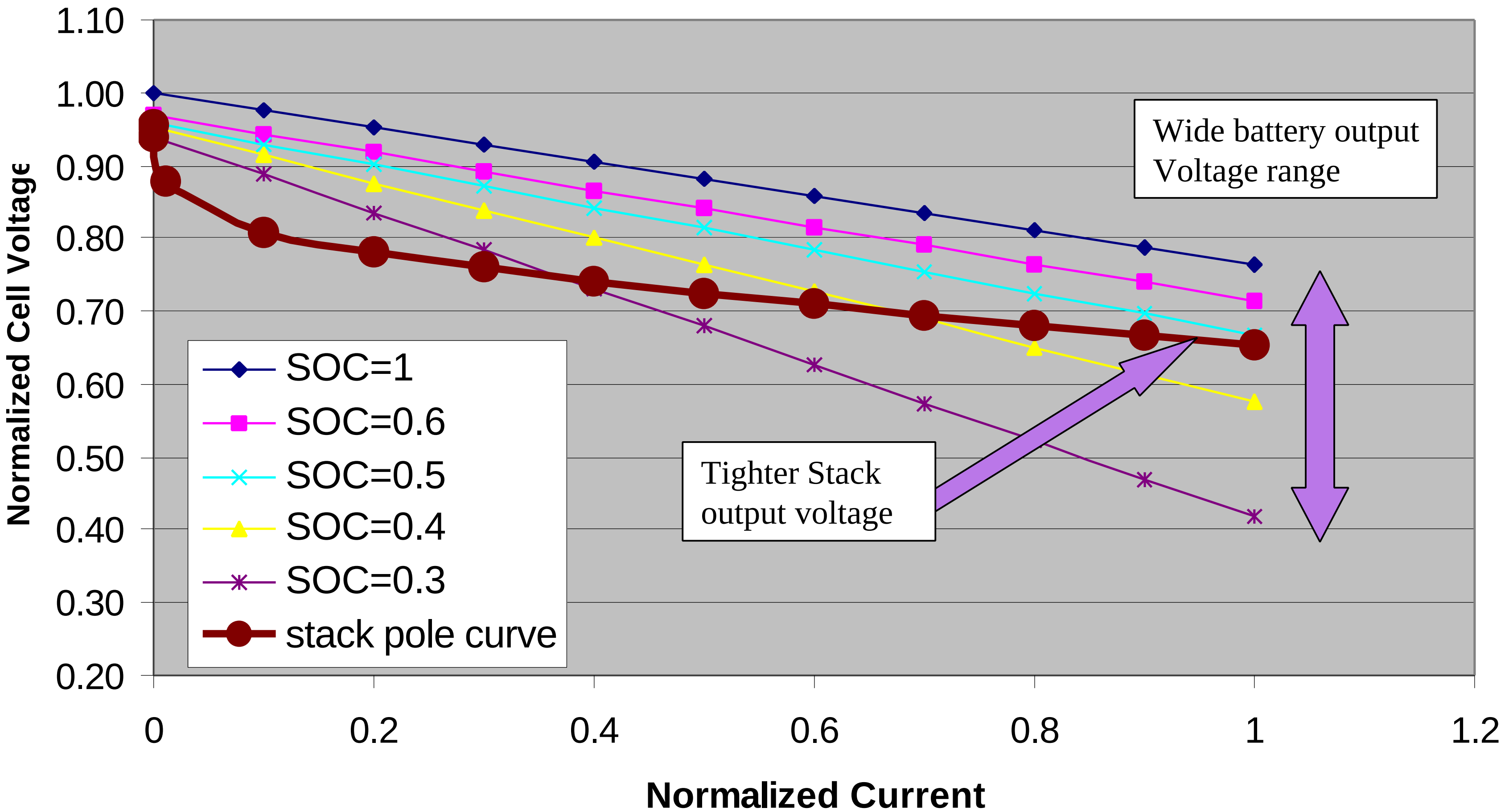
- Batteries and Fuel Cell Stacks have different voltage characteristics

DC Source Resistance

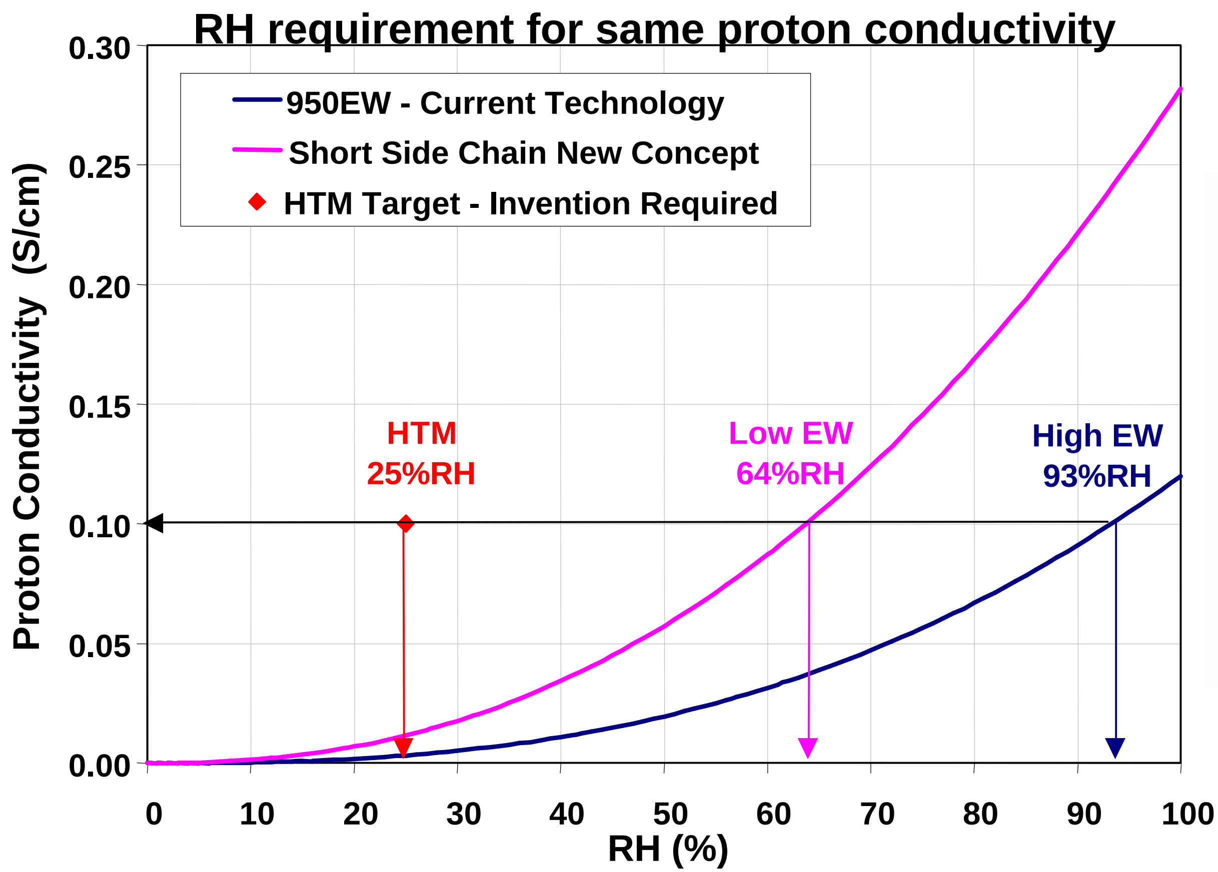
DC Resistance		
Battery		Fuel Cell Stack
SOC	Resistance (Ohms)	Resistance (Ohms)
0	0.789	0.160
0.1	0.718	
0.2	0.656	
0.3	0.522	
0.4	0.374	
0.5	0.293	
0.6	0.254	
0.7	0.239	
0.8	0.227	
0.9	0.229	
1	0.237	

- The DC source resistance for a battery is dependant on it's State of charge
- Stack Resistance is constant, and is dependent on materials development

Comparing Stack and Battery
"Polarization Curves"



Material & System design can impact fuel cell stack resistance



- New material Reduces the RH required to achieve the same stack performance
  - ® Simpler System
- Durability tests in progress

Voltages

Voltages				
Battery			Fuel Cell Stack	
SOC	Open Circuit	Full Load	Open Circuit	Full Load
100%	1.00	0.76	1.00	0.65
30%	0.93	0.42		

- The output voltage for a battery will depend on its state of charge.
- At full load the battery output voltage as function of SOC can vary as much 55%
- Battery full load voltage is 64% lower than that of a stack

Summary

- General Motors Research is Focused on Fundamental Material & Design Development
- Traction System, Power Conditioning & Stack Development Required to meet Automotive Targets

GM