GM Perspective on Pre-Competitive Research Needs for Bipolar Plate Development

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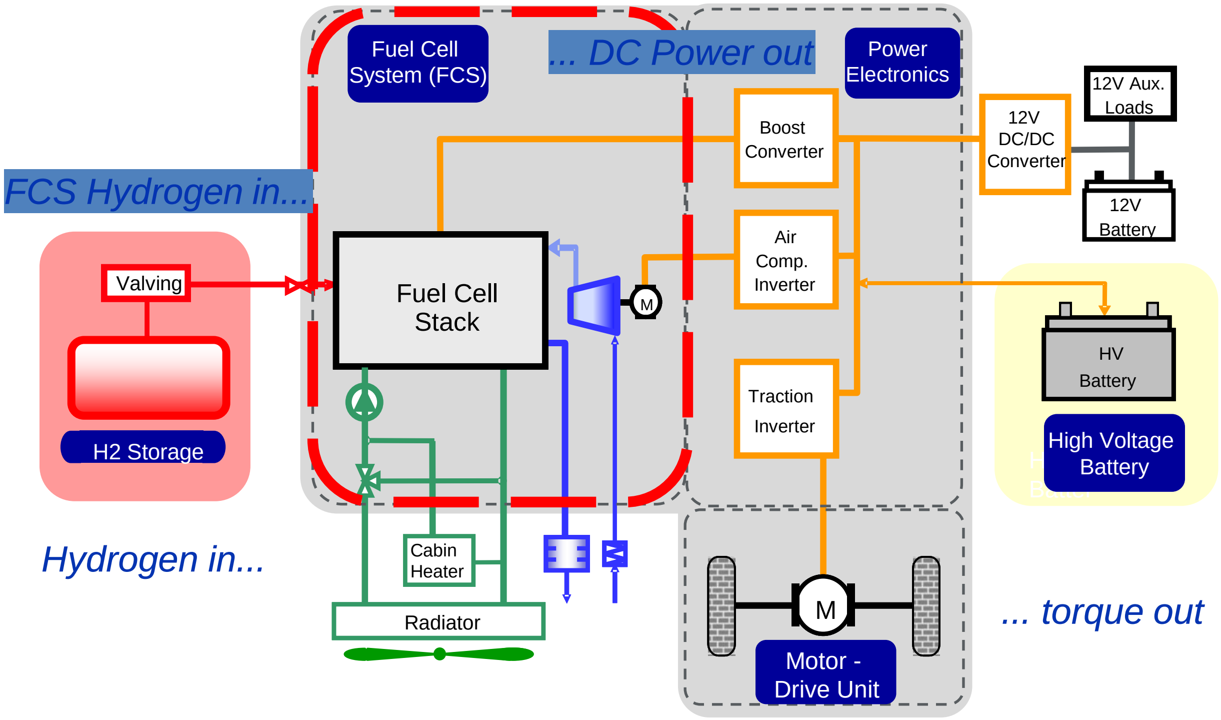
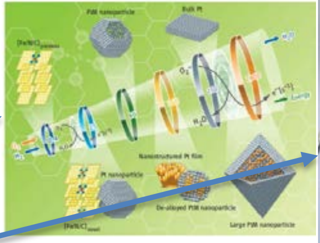
Overview of a Fuel Cell Propulsion System (FCPS)

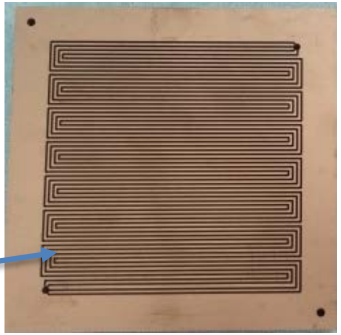


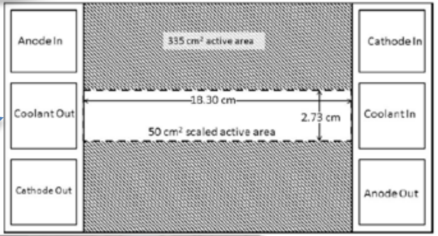
Successful R&D approach accounts for material-to-system interactions
(Fuel Cell Materials ↔ Cell ↔ Stack ↔ FCS ↔ FCPS)

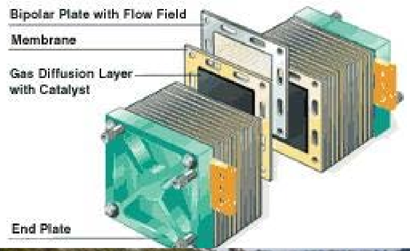
Fuel Cell System Technology Readiness Levels (TRL)

TRL	TRL Definition	Platform	Power
1	**Basic Principle(s)**	Fundamental property, not practical format	0W
2	**Technology Concept**	Practical concept	0W
3	**Proof-of-Concept**	Ex-stu, RDE	0W
4	**Laboratory Demonstration**	50 cm^2 MEA	50W
5	**Full-Scale Demonstration**	Large Active Area	500W
6	**Demonstration in Relevant Environment**	Short Stack	10kW
7	**Demonstration in System Environment**	Mini-module	30kW
8	**System Verification**	Full-module	100kW
9	**System Validation**	Vehicle	100kW









GM has demonstrated real world experience at TRL 9 with 3 million miles accumulated and individual vehicles approaching 150K miles under 8 winter cycles

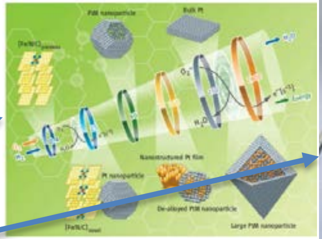
Fuel Cell System Technology Readiness Levels (TRL)

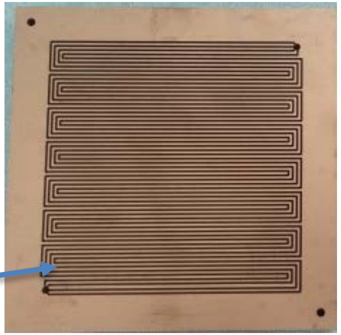
TRL	TRL Definition	Platform	Power
1	Basic Principle(s)	Fundamental property, not practical or na[illegible]	0W
2	Technology Concept	Practical concept	0W
3	Proof-of-Concept	[illegible]st[illegible], RDE	0W
4	Laboratory Demonstration	50 cm^2 MEA	50W
5	Full Scale Demonstration	Large Active Area	5[illegible]W
6	Demonstration in Relevant Environment	Short Stack	10kW
7	Demonstration in System Environment	M[illegible]i-mo[illegible]du[illegible]	3[illegible]kW
8	System Verification	Full-module	100kW
9	System Validation	Vehicle	10[illegible]kW

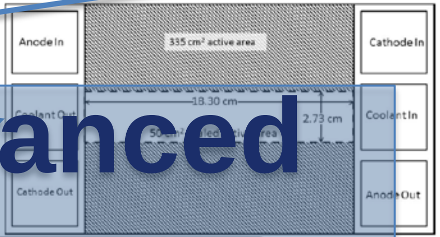
Pre Competitive Research

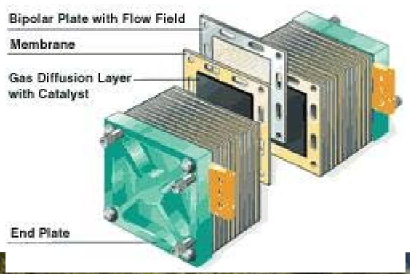
Collaborative Advanced Engineering

Competitive Product Development





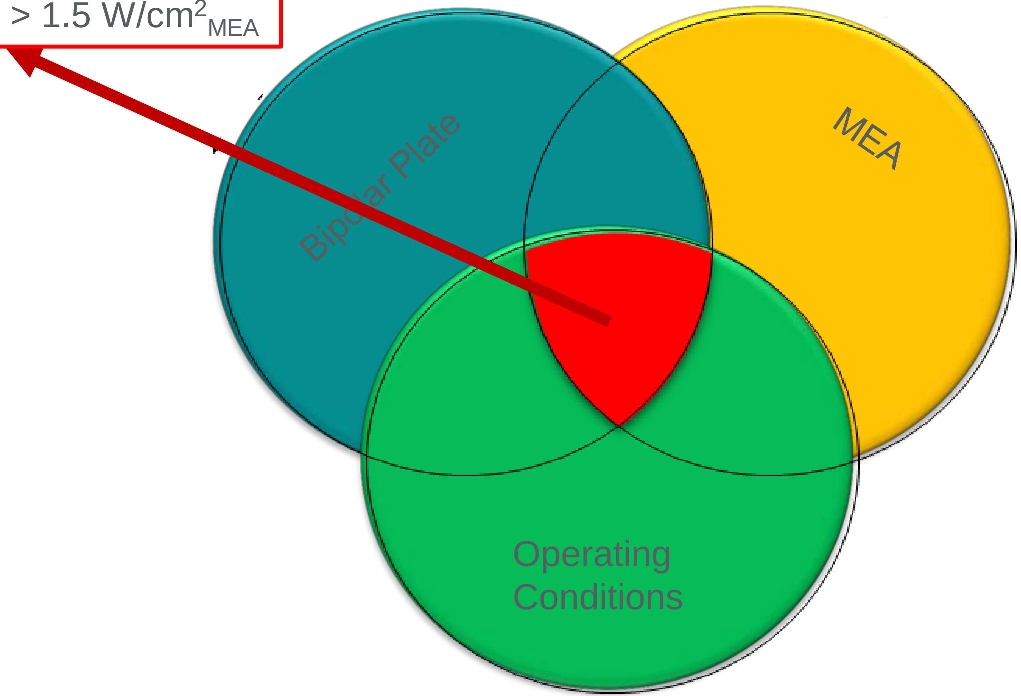




The Fuel Cell community needs to collaborate up to TRL 4 (In – Situ single cell non stack foot print ~ $50cm^2$)
Timeframe for a new material to reach final product after TRL4 proof-point could be 5 to 8 year.
Work on new flow fields and stamping could fall into TRL 5 & 6 and may not be pre-cpmpetitive

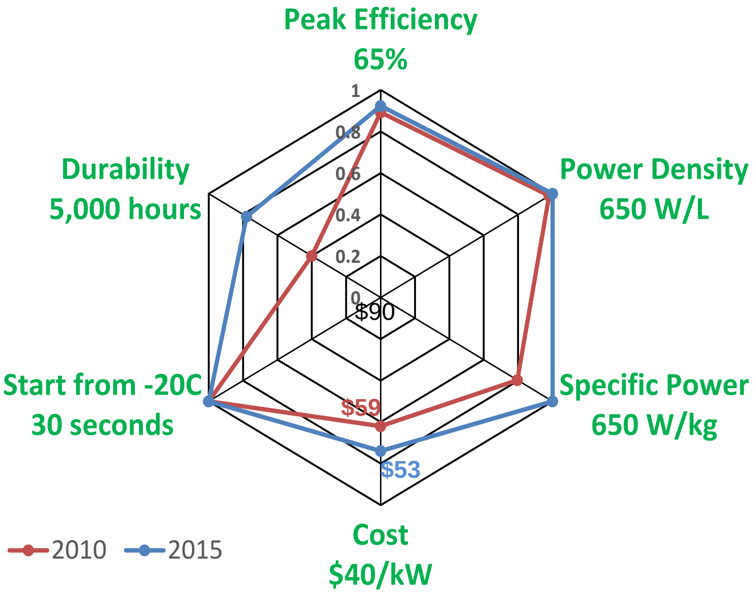
Development Needs

Focus on a combination of technologies that can enable power densities > 1.5 W/cm^2_{MEA}



Combination of bipolar plate, MEA and operating conditions are required to achieve power densities > 1.5 $W/cm^2_{active\ area}$

Fuel Cell System Level Targets



This 1.0L engine has a power density of ~ 950 W/kg.[1, 2] Engine power densities are expected to increase in the future.[3]

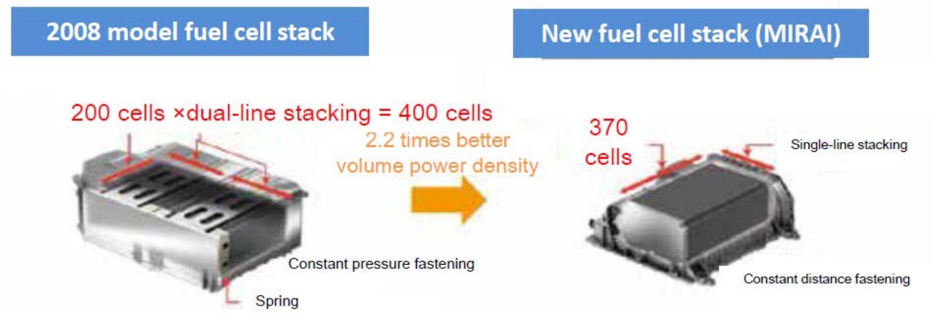
Increase in power density and specific power will enable FC remain competitive to incumbent technologies.

TRL 4 level work for BPP may not be the biggest factor for FCS (TRL 8) level metrics.

Durability no longer a barrier for commercial entry of FCEVs. Cost reduction along with increase in power density is desired to be competitive in the future.

1 → https://en.wikipedia.org/wiki/Ford_EcoBoost_engine#Specifications_2 2 → http://wardsauto.com/2015/2015-winner-ford-10l-ecoboost-dohc-di-i-3 3 → https://energy.gov/sites/prod/files/2016/06/f32/ace000_singh_2016_o_web.pdf

Fuel Cell Stack Level Targets



	2008 FC –advanced	MIRAI FC stack
Maximum Power	90kW	114kW
Volumetric power density	1.4kW/L, 0.83kW/kg	3.1kW/L, 2.0kW/kg
Cell number of cells	400 cells, dual line stack	370 cells, single line stack
thickness of cell	1.68mm	1.34mm
flow channel	straight channel	3D fine-mesh flow field

Table 3.4.4. Technical Targets: 80-kW_e (net) Transportation Fuel Cell Stacks Operating on Direct Hydrogen[a,b]

Characteristic	Units	2015 Status	2020 Targets	Ultimate Targets
Stack power density[c]	W / L	3,000[d]	2,250	2,500
Stack specific power	W / kg	2,000[e]	2,000	2,000
Performance @ 0.8 V[f]	mA / cm^2	–	300	300
Cost[g]	$ / kW_{net}	26[h]	20	15
Durability in automotive drive cycle[i]	hours	3,900[j]	5,000	8,000
Start-up/shutdown durability[k]	cycles	–	5,000	5,000
$Q/\Delta T_i$[l]	kW/ºC	1.9[m]	1.45	1.45
Robustness (cold operation)[n]	see footnote	–	0.7	0.7
Robustness (hot operation)[o]	see footnote	–	0.7	0.7
Robustness (cold transient)[p]	see footnote	–	0.7	0.7

Stack Power Density Targets are set based on current values[1,2]. Stacks need to get lower cost and smaller to remain competitive.[3]

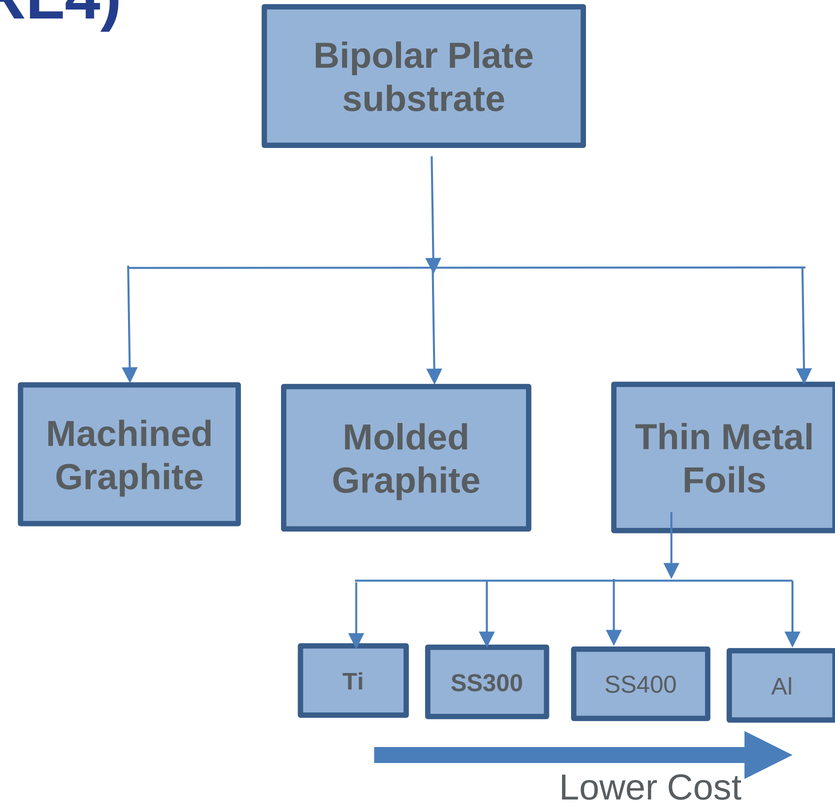
TRL 4 level work for BPP is critical for achieving stack level targets for power density and specific power.

Incumbent technologies are getting cheaper and getting there faster due to economies of scale. FC stack targets should be revisited to remain competitive.

1 → https://energy.gov/sites/prod/files/2016/10/f33/fcto_myrdd_fuel_cells.pdf 2 → https://www.electrochem.org/dl/interface/sum/sum15/sum15_p45_49.pdf 3 → https://energy.gov/sites/prod/files/2016/06/f32/es000_howell_2016_o_web.pdf

Fuel Cell Stack Level Targets (@ TRL4)

				2020 Targets	
	Characteristic	Units	2015 Status	MYRDD / DoE	GM Proposal
Plate	Cost	$/kW	7	3	2
Plate	Plate weight	kg/kW	<0.4	0.4	0.15
Material	Flexural strength	MPa	>34	>25	>60
Material	Forming elongation	%	20-40	40	40
Coated Material	Corrosion, Anode	µA/cm2	No active peak	<1	<1
Coated Material	Corrosion cathode	µA/cm2	<0.1	0.05	0.05
Coated Material	Electrical conductivity	S/cm	>100	>100	>100
Coated Material	Areal specific resistance	ohm cm2	0.006	<0.01	<0.01



- Research focused on developing new substrates and coatings can enable high power density plates
- Plate design that approach > 0.75 $W/cm^2_{total\ plate}$ important to improve FC technology competitiveness

Summary

- Pre-competitive work on bipolar plates limited to TRL 4.
- Work on flow field design and water management impinges on competitive areas, hence not suitable for funding.
- Need to increase focus on materials and processing of thin metal foils to meet power density and cost requirements.
- Since processing costs can be higher than the material costs, it is critical to understand process flow and cost models prior to determining whether to pursue a new technology.
- Low-cost coatings that can be stamped are preferred for high volume manufacturing.

- http://www.uscar.org/commands/files_download.php?files_id=348

BACK UP