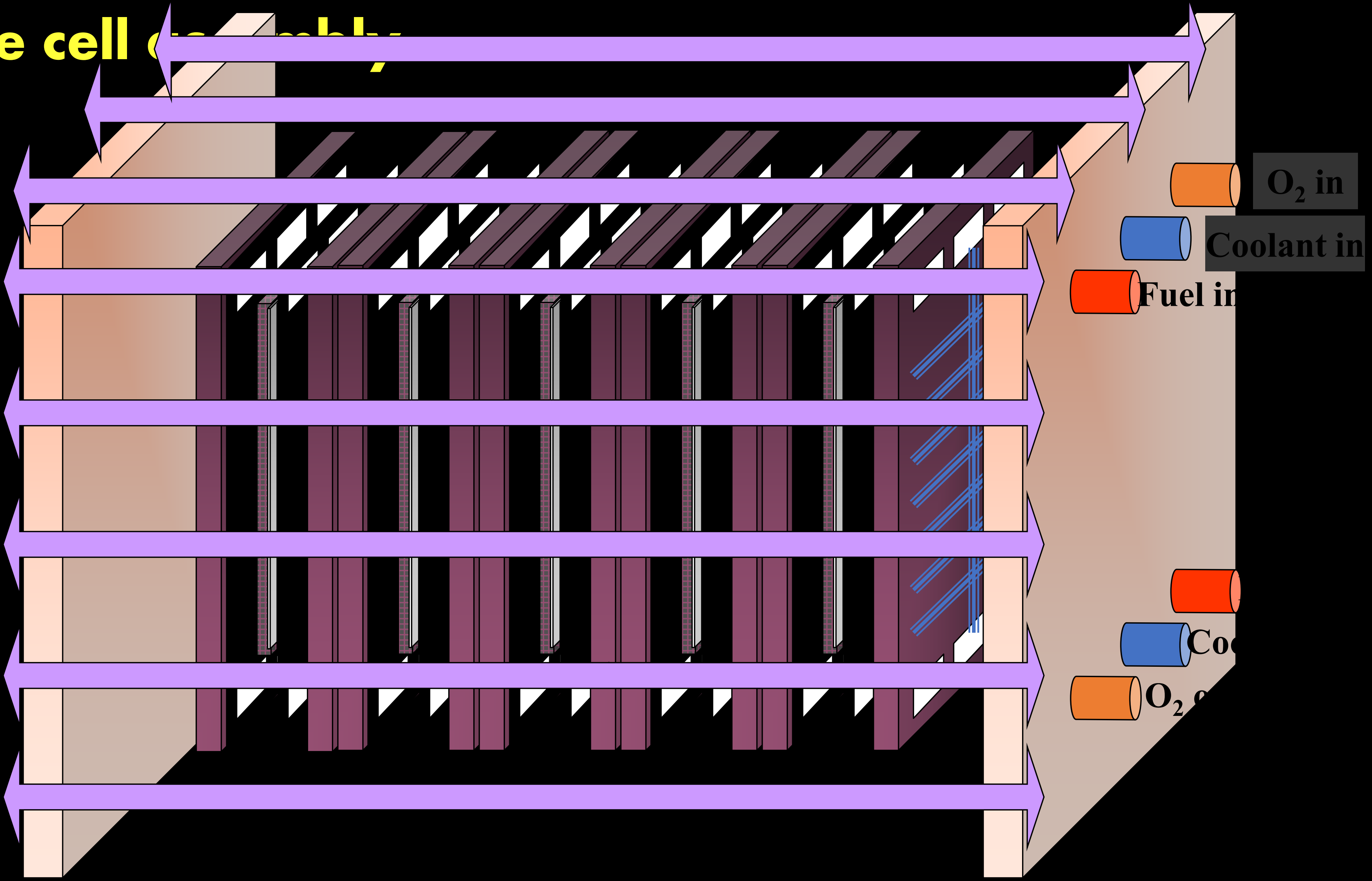
Multiple cell



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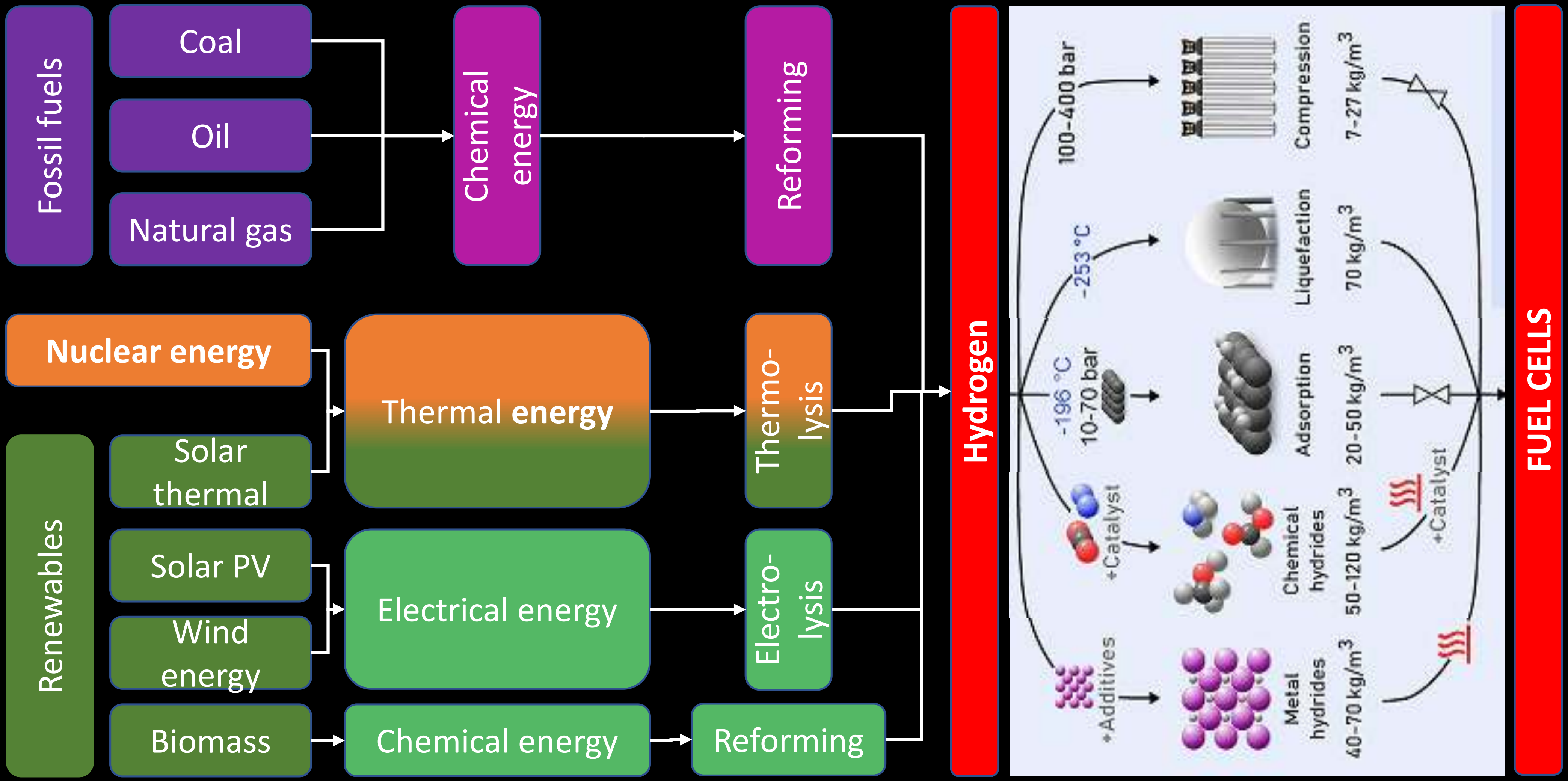
Hydrogen production storage pathways



Hydrogen storage: targets

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	2020	2025	ULTIMATE
System Gravimetric Capacity (Wt%)	4.5	5.5	6.5
System Volumetric Capacity (g H_2/L)	30	40	50
Storage system cost ($/kg H_2)	333	300	266
Cycle life (DOD: 75%)	1500	1500	1500
System fill time (min)	3–5	3–5	3–5

700 bar storage vol capacity (g/L)	62.5

Fuel cell stack: targets

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Characteristic	Units	2015 Status	2020 Targets	Ultimate Targets
Peak energy efficiency[b]	%	60	65	70
Power density	W/L	3,000	2,250	2,500
Specific power	W/kg	2,000	2,000	2,000
Cost[f]	$\$/kW_{net}$	53	40	30
Cold start-up time to 50% of rated power				
Startup from -20C	seconds	20	30	30
Startup from +20C	seconds	10	5	5
Durability in automotive drive cycle	hours	3,900	5,000	8,000
Start-up/shutdown durability[l]	cycles		5,000	5,000

Fuel cell system: targets

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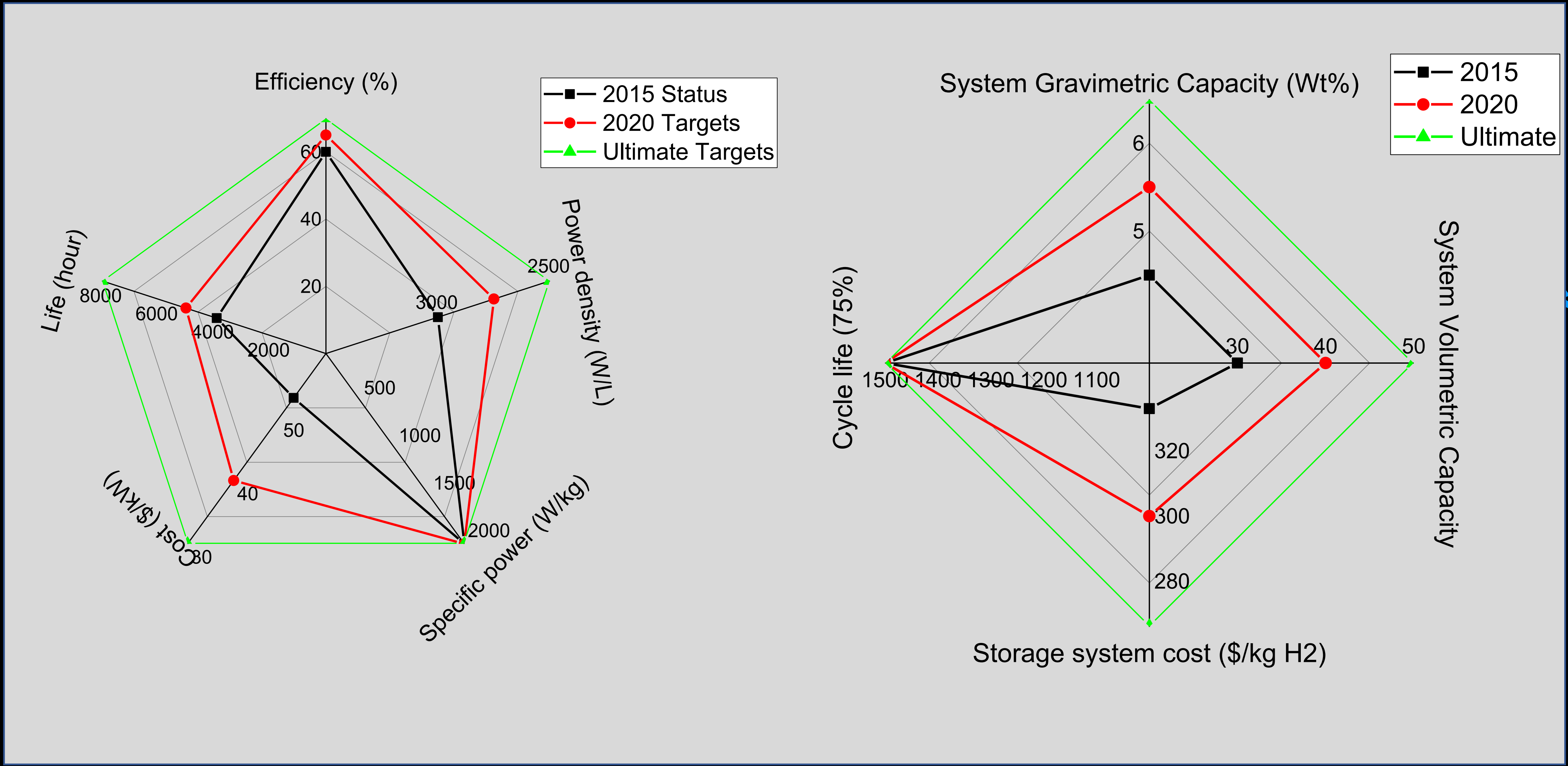
Characteristic	Units	2015 Status	2020 Targets	Ultimate Targets
Peak energy efficiency[b]	%	60	65	70
Power density	W/L	640	650	850
Specific power	W/kg	659	650	650
Cost[f]	$\$/kW_{net}$	53	40	30
Cold start-up time to 50% of rated power				
Startup from -20C	seconds	20	30	30
Startup from +20C	seconds	10	5	5
Durability in automotive drive cycle	hours	3,900	5,000	8,000
Start-up/shutdown durability[l]	cycles		5,000	5,000

Targets for fuel cells



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Fuel cell components & challenges

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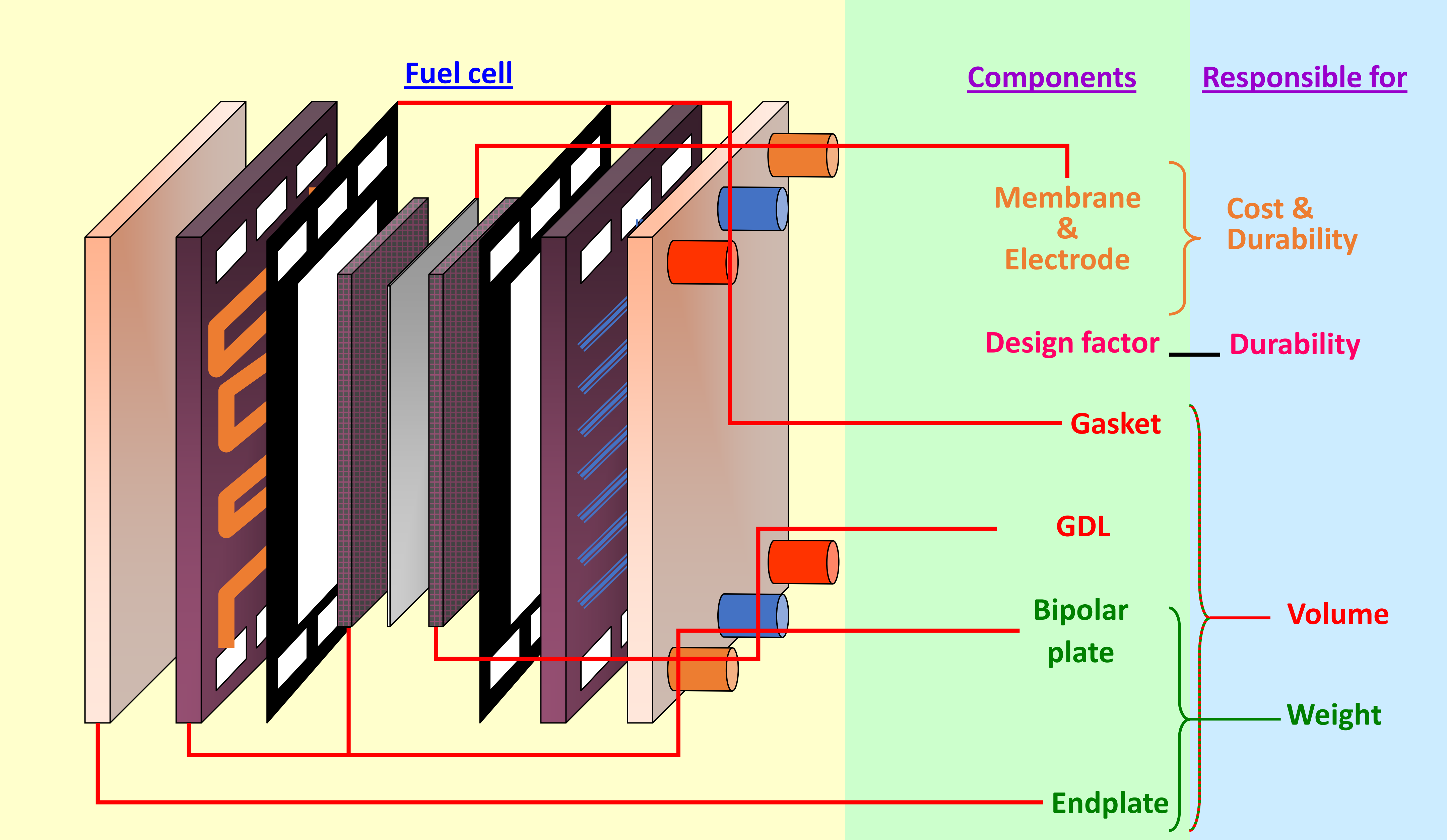

Membrane & electrode challenges: Cost

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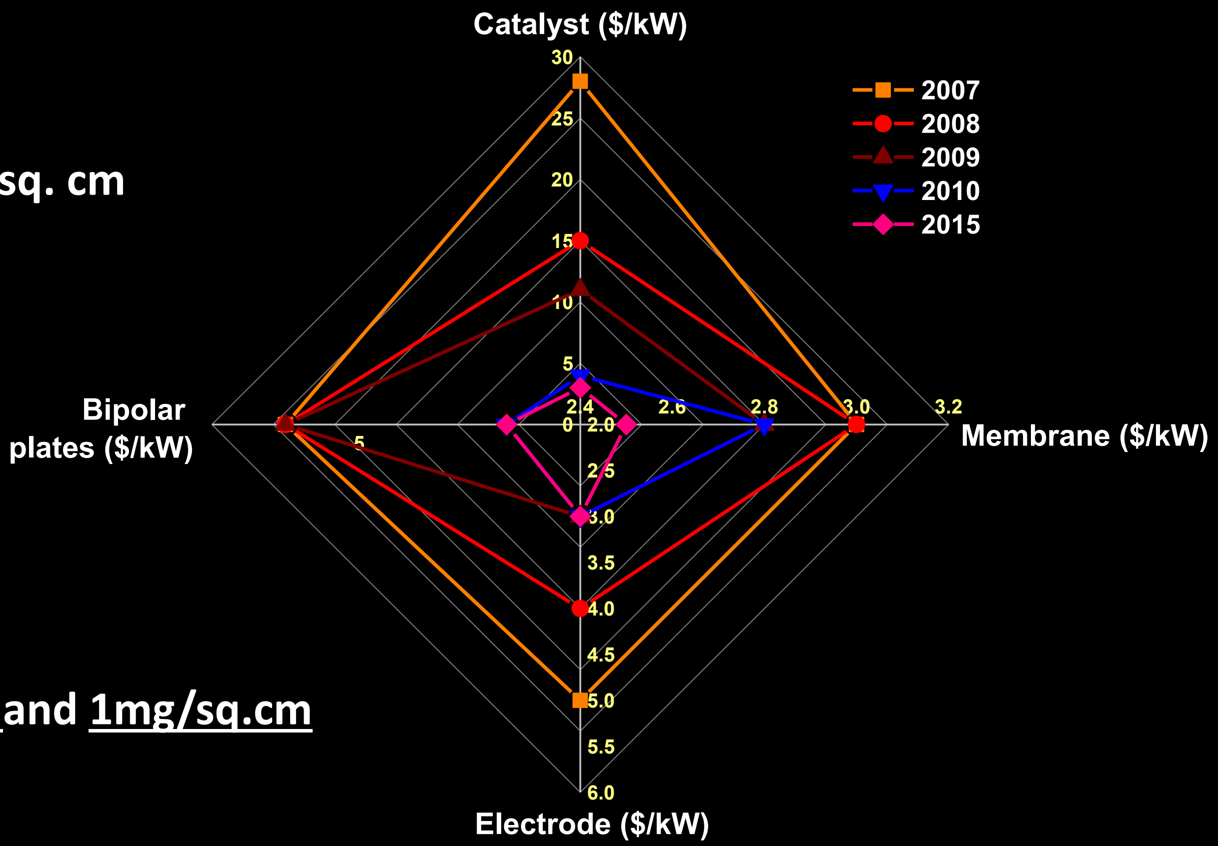
Membrane

- Type: Sulphonated (Nafion)
- Cost: ~200 US$/sq. m
- Area/kW: 2000 sq. cm @0.5 W/sq. cm
- Cost/kW: 40 US$



Catalyst

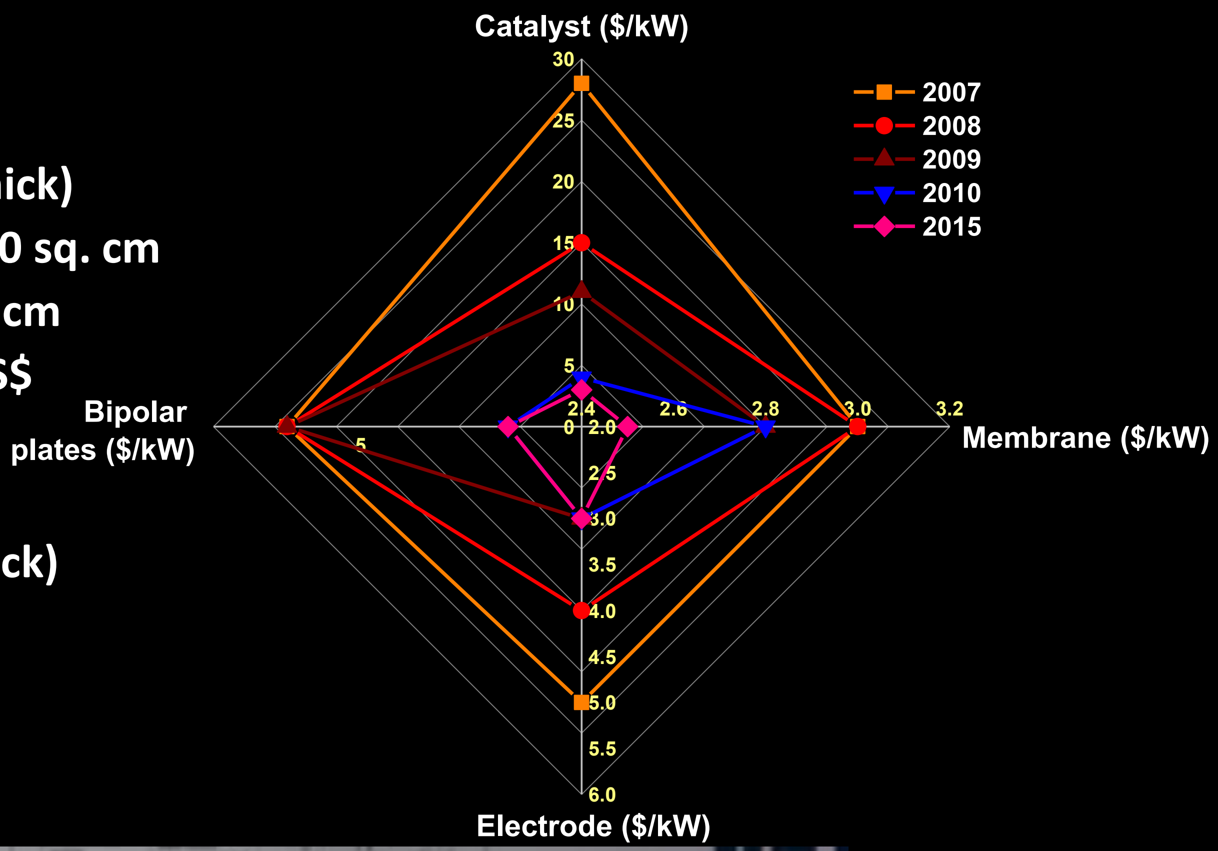
- Catalyst type: Platinum
- Cost: ~30 US$/gm
- Loading/kW: 2 gm @0.5 W/sq. cm and 1mg/sq.cm
- Cost/kW: 60 US$

IS PLATINUM REALLY CULPRIT !

BPP challenges: Cost

Bipolar plate

- Type: Graphite based (3 mm thick)
- Cost (machined): ~140 US$ per plate @ 300 sq. cm
- Area/kW: 2000 sq. cm @0.5 W/sq. cm
- Cost/kW: 140x6.5 US$ = ~1000 US$



Alternative solutions

- Material type: Metallic (0.1 mm or 0.15 mm thick)
- Channel: Hydroforming
- Cost: ~3 US$ per plate @ 300 sq. cm
- Area/kW: 2000 sq. cm @0.5 W/sq. cm
- Cost/kW: 3x6.5 US$ = ~20 US$

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Platinum Recovery: Economics

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Factors to be considered

- In-use loss of platinum during the fuel cells life
- Process loss of platinum during recovery operations
- Operational costs incurred during recovery
- Inflation in platinum price

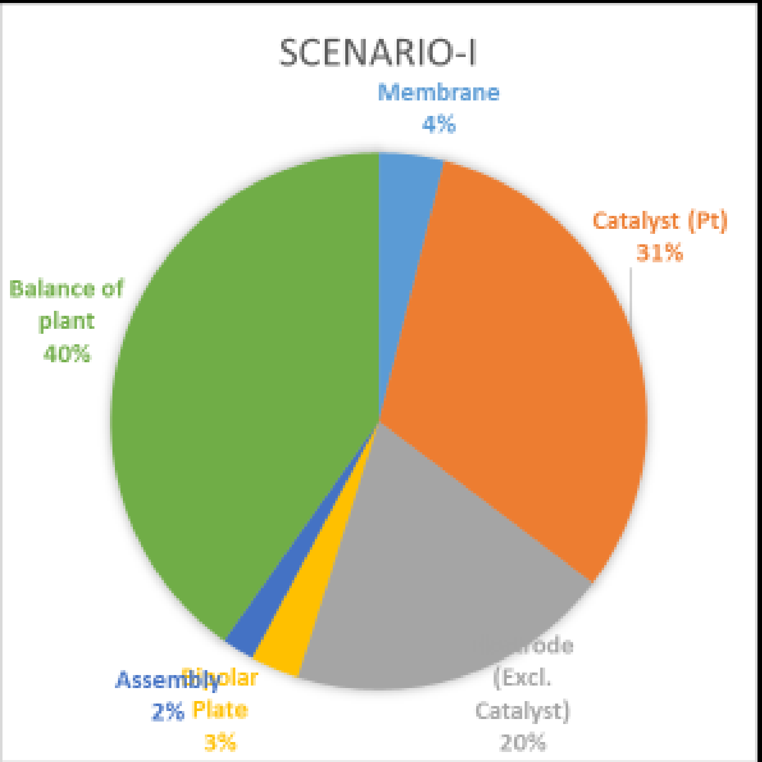
Ref: Kromer et al. *Internationl Journal of Hydrogen Energy*, **34**, pp. 8276–8288, 2009.

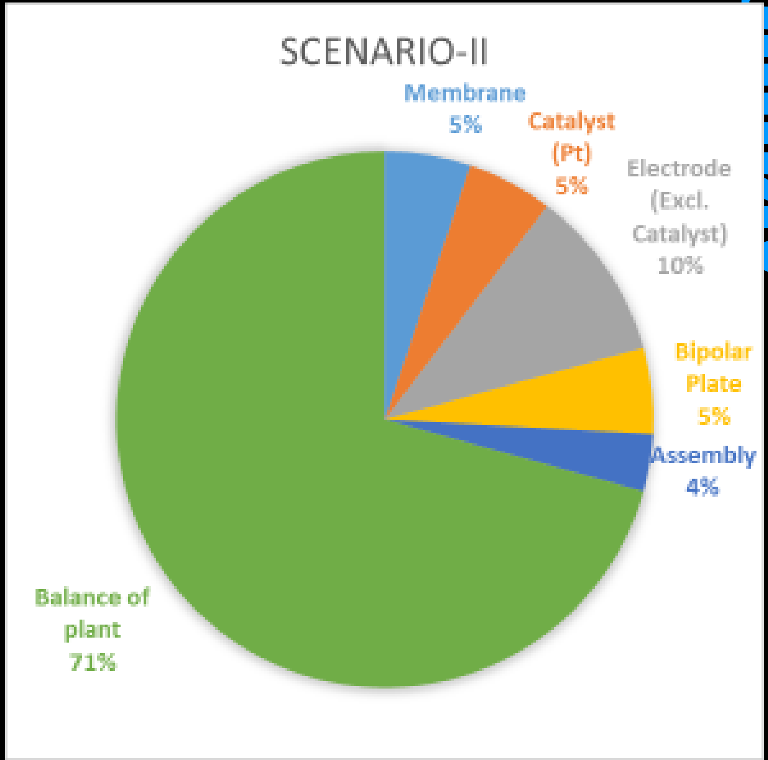
Loss mechanism	Description	Estimated loss
In-use loss	Platinum degradation in the fuel cell stack	~1%
Process loss	Metal losses in the secondary supply loop	8-10%
Recovery costs	Cost of recovering metal	4–9%
Total		**13–20%**

$$K_{salv,FC,Pt} = P_{FC} \cdot Pt_{load} \cdot k_{pt,f} \cdot f_{pt,rec} \cdot \left(\frac{1+i_g}{1+r}\right)^n$$

Fuel Cell Cost with different scenarios

	Cost (US$ kW^{-1})	
	Scenario-I	Scenario-II
Membrane	4	3
Catalyst (Pt)	32	3
Electrode (Excl. Catalyst)	20	6
Bipolar Plate	3	3
Assembly	2	2
Balance of plant	41	41
Complete system	102	57
Power density (W cm^{-2})	0.4	1
Pt loading (mg cm^{-2})	0.8	0.2
Platinum cost (US gm^{-1})	29	20





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Ref: Stone J Harry, 'Economic analysis of Stationary PEM Fuel Cells', Project ID #48 (for DOE), 2005.

Historical price of platinum

Source: http://www.platinum.matthey.com/prices/price-charts

Pt NPSV for different economies

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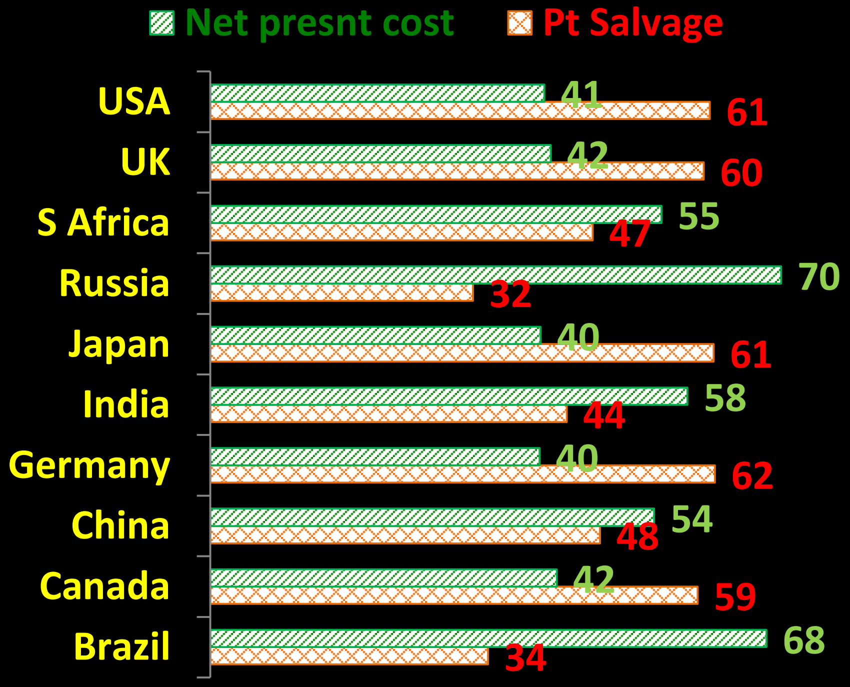
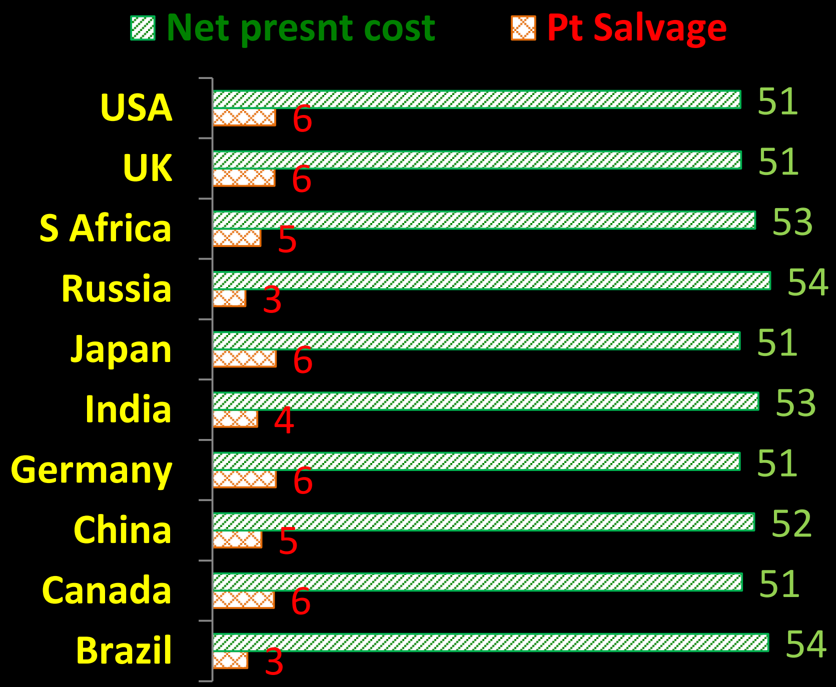
Investment year: 2000; f_{ptrec}: 0.85

life: 5 years; i_{Pt}=18%;

Total cost 102 US$ kW^{-1}



Total cost 57 US$ kW^{-1}

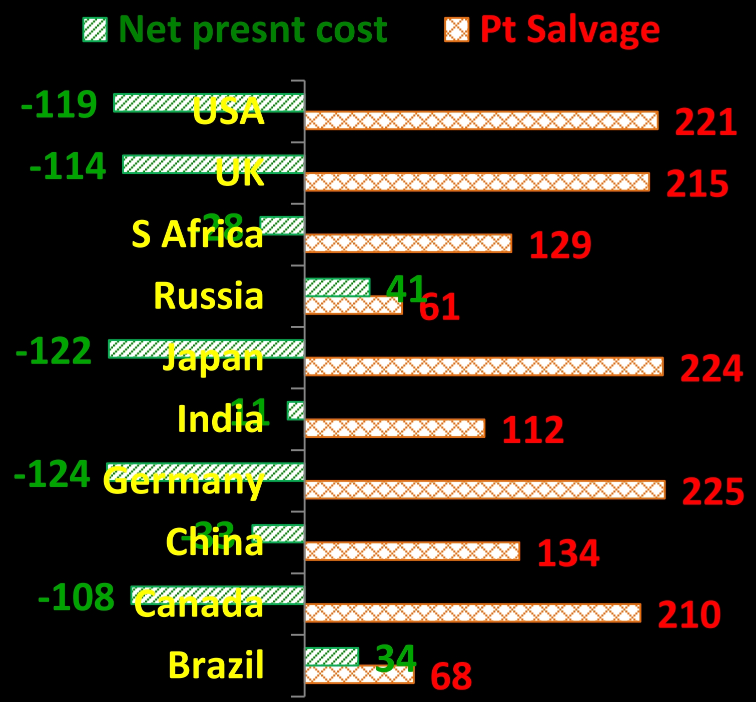


Pt NPSV for different economies

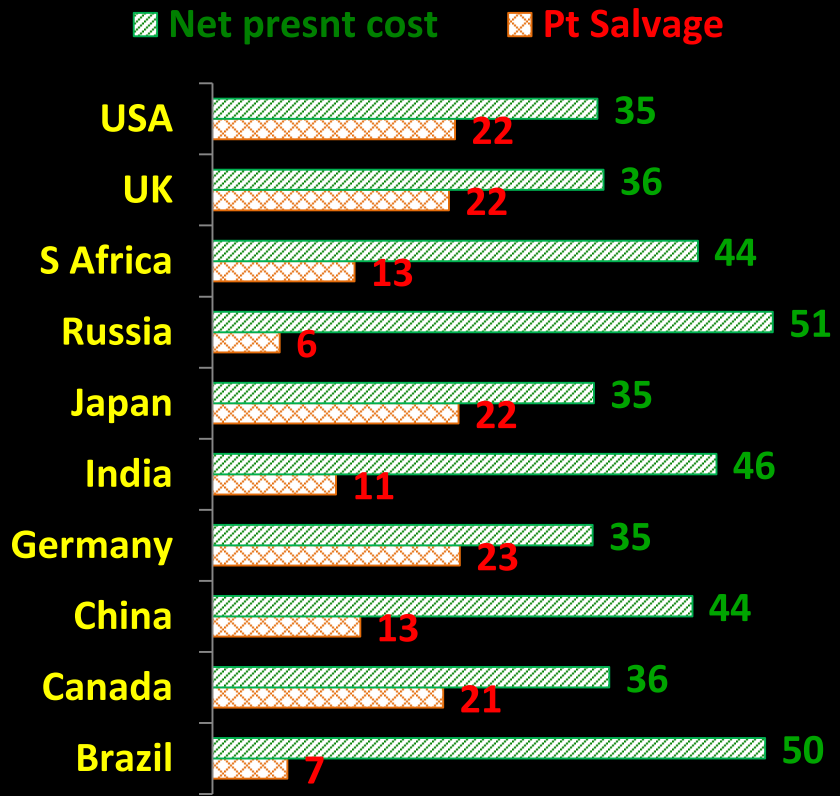
Investment year: 2000; f_{ptrec}: 0.85

life: 10 years; i_{Pt}=23%;

Total cost 102 US$ kW^{-1}



Total cost 57 US$ kW^{-1}



Pt NPSV for different economies

Investment year: 2000; f_{ptrec}: 0.85

life: 15 years; i_{Pt}=11%;

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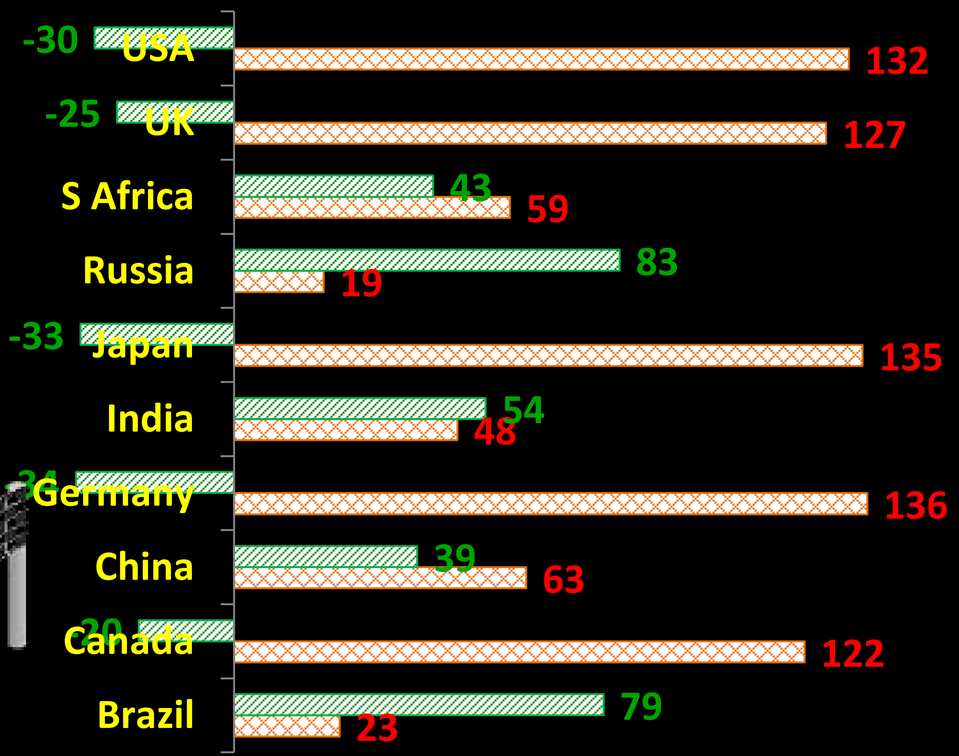
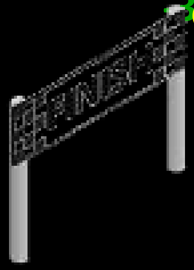
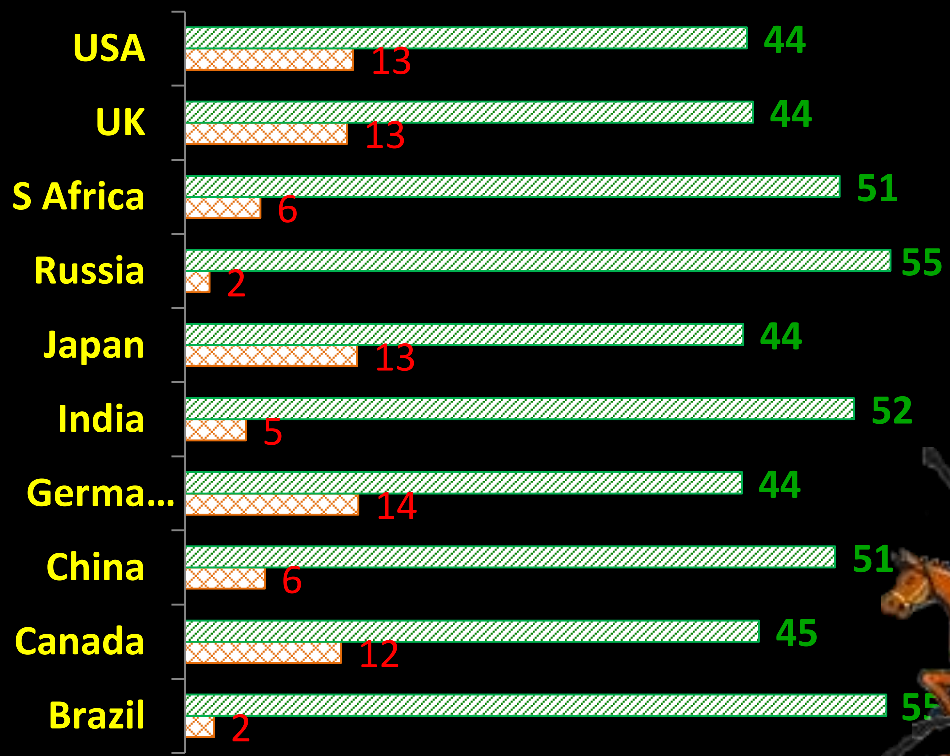
Total cost 102 US$ kW^{-1}





Total cost 57 US$ kW^{-1}



Thematic R&D areas

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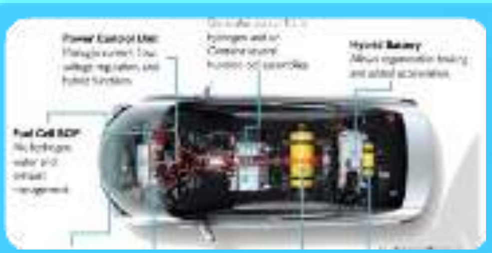
Fuel Cell Stack (FCS)

Development of Fuel Cell Stack with high volumetric and gravimetric power density

Hydrogen Storage system (HSS)

Development of high pressure (700 bar) Type IV Compressed Hydrogen Storage system | Metal Hydride Storage



Balance of Plant

Development of balance of plant for the complete system to integrate FCS and HHS system

System Integration & Demonstration (SID)

System integration and demonstration of fuel cell system and Hydrogen Storage system.

Themes for R&D

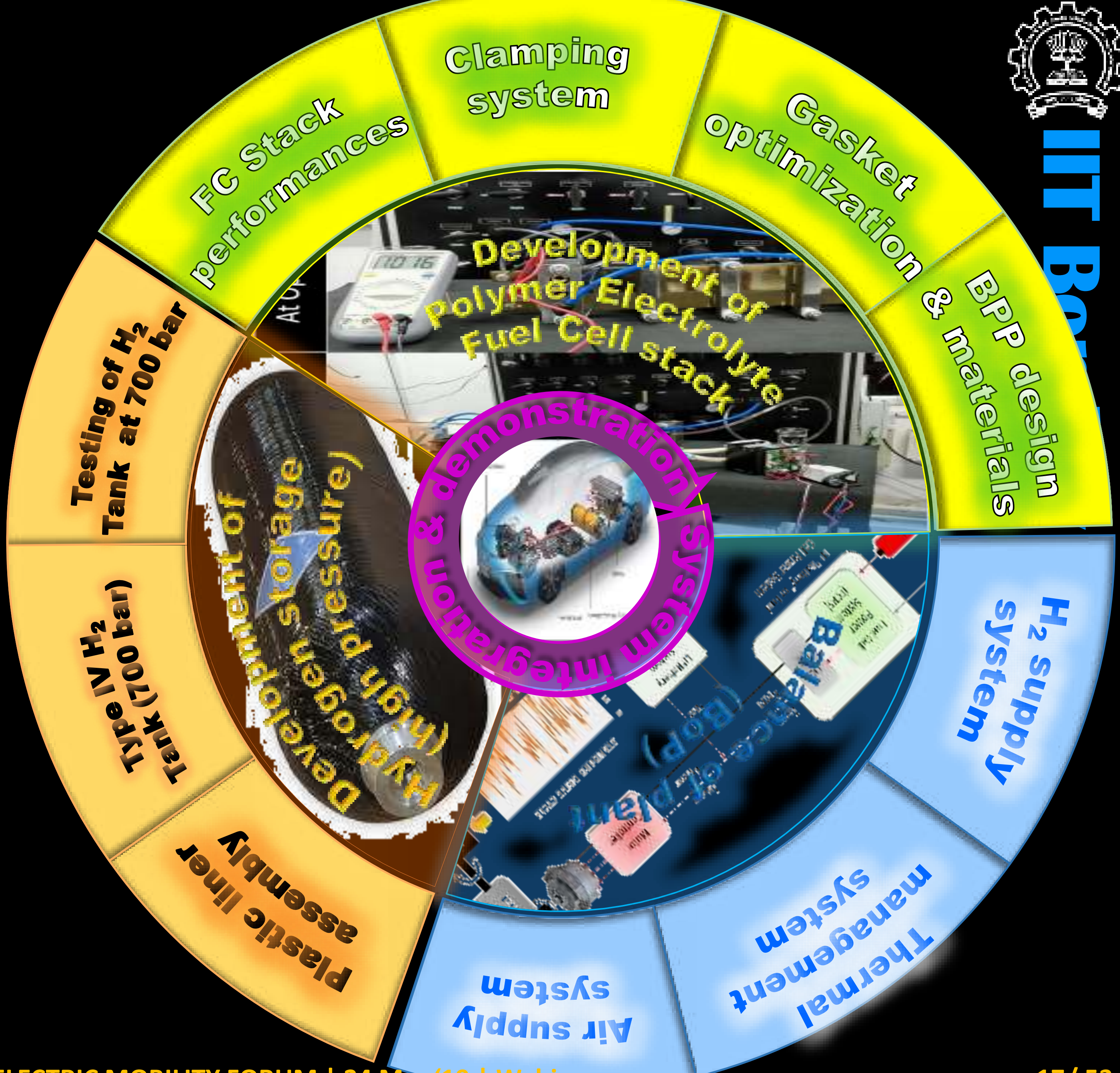
The thematic areas of R&D interest are as follows:

(i) Fuel Cell Stack (FCS)

(ii) Hydrogen Storage system (HHS)

(iii) Balance of plant (BoP)

(iv) System integration and demonstration (SID)



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Conclusions

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- High cost of Pt should not be blamed
- High cost of Pt should promote PEFC business
- Appropriate business model is necessary
- Pinch based design space methodology for sizing hydrogen storage in reformer based fuel cell system
- Reformer turndown ratio plays an important role in sizing
- Reformer turndown ratio dictates the optimum reformer size for minimum storage capacity

Thank you!

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