

Direct Hydrogen PEM Fuel Cell Powertrain Manufacturing Cost Analysis for Automotive Applications

2025 Fuel Cell Seminar



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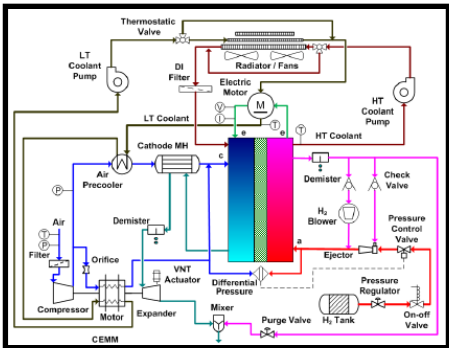
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This approach has been used successfully for estimating the cost of various technologies for commercial clients and the DOE.

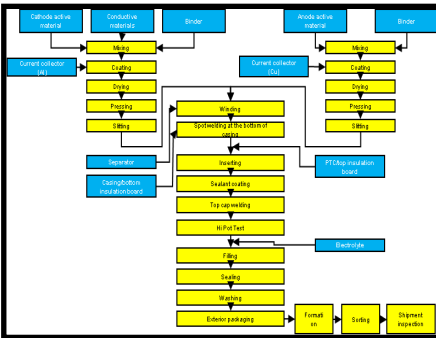
Technology Assessment

- Literature research
- Definition of system and component diagrams
- Size components
- Develop bill-of-materials (BOM)



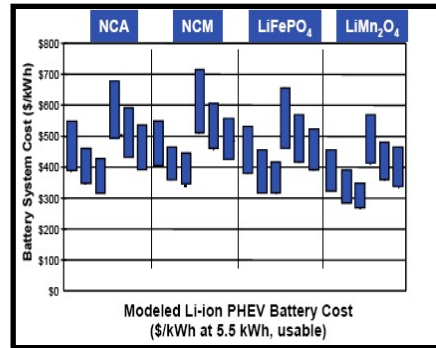
Manufacturing Cost Model

- Define system value chain
- Quote off-shelf parts and materials
- Select materials
- Develop processes
- Assembly bottom-up cost model
- Develop baseline costs



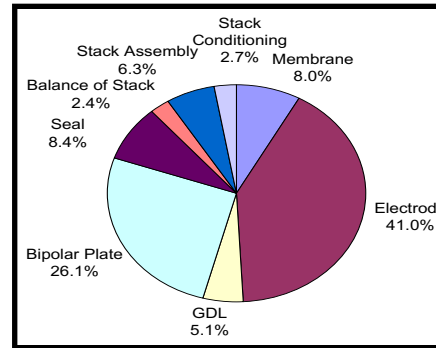
Scenario Analyses

- Technology scenarios
- Sensitivity analysis
- Economies of Scale
- Supply chain & manufacturing system optimization
- Life cycle cost analysis



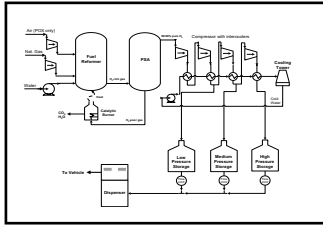
Verification & Validation

- Cost model internal verification reviews
- Discussion with technical developers
- Presentations to project and industrial partners
- Audit by independent reviewers



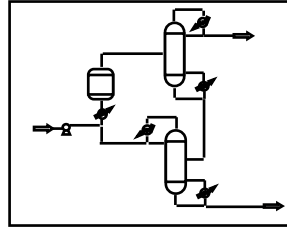
Combining performance and cost models will easily generate cost results, even when varying the design inputs.

Conceptual Design



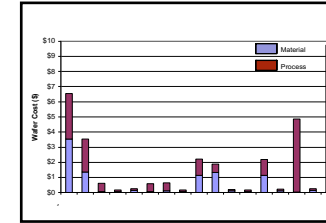
- ◆ System layout and equipment requirements

Process Simulation



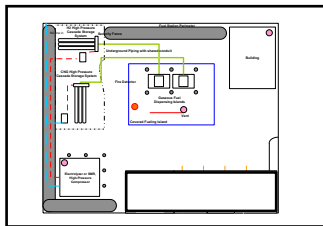
- ◆ Energy requirements
- ◆ Equipment size/ specs

Process Cost Calcs



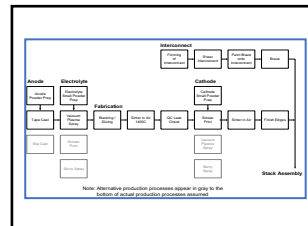
- ◆ Process cost
- ◆ Material cost

Site Plans



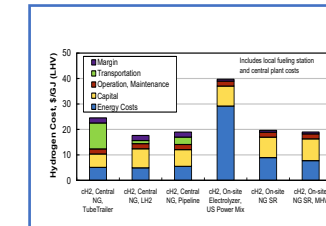
- ◆ Safety equipment, site prep, land costs

Capital Cost Estimates



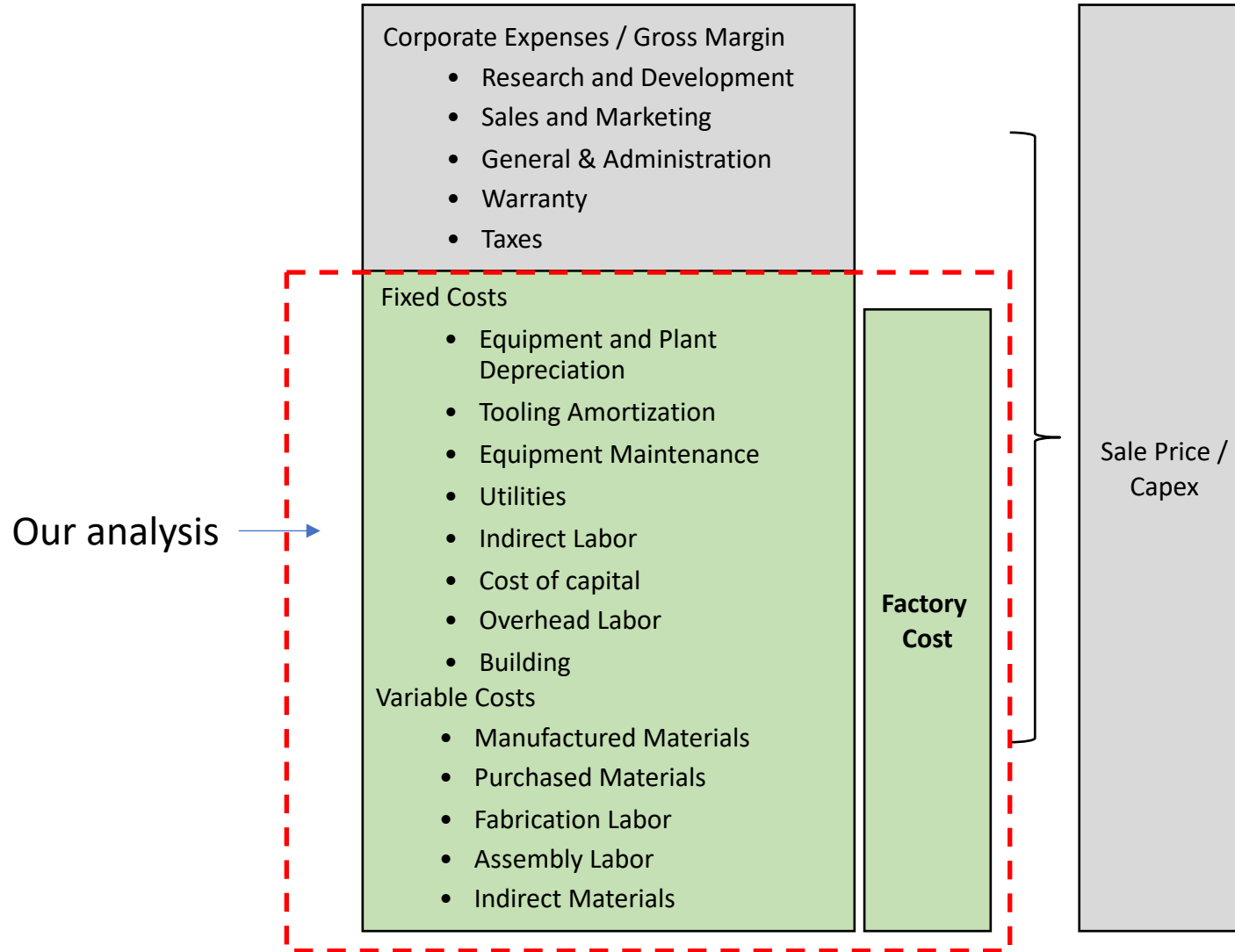
- ◆ High and low volume equipment costs

Product Costs



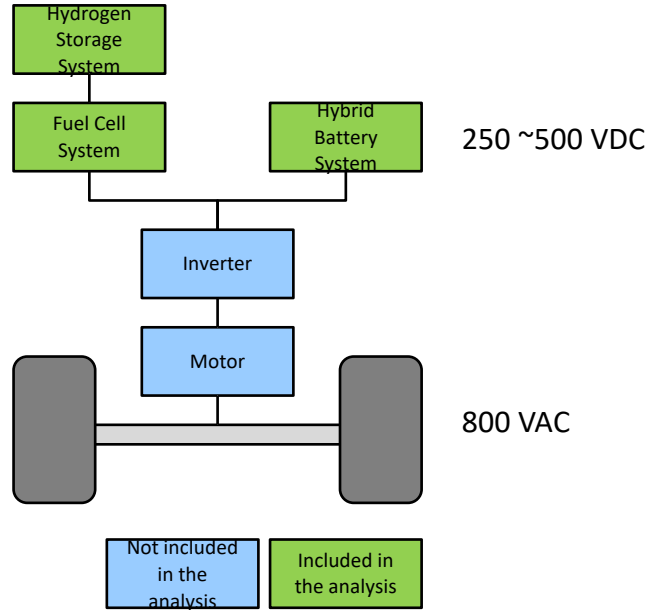
- ◆ Product cost (capital, O&M, etc.)

Cost structures / categories used in our analysis:



Project Scope

Conduct a bottom-up manufacturing cost analysis of a 275 kW_{net} class 8 truck fuel cell power system.



275 kW_{net} Class 8 Long Haul Fuel Cell Truck

Fuel cell power: 275 kW_{net} (EOL)

Battery power: 225 kW

Battery energy: 106 kWh

Motor power: ~500 kWe

H2 storage: 60 kg (2-tank)

H2 storage tank: Cryo-compressed

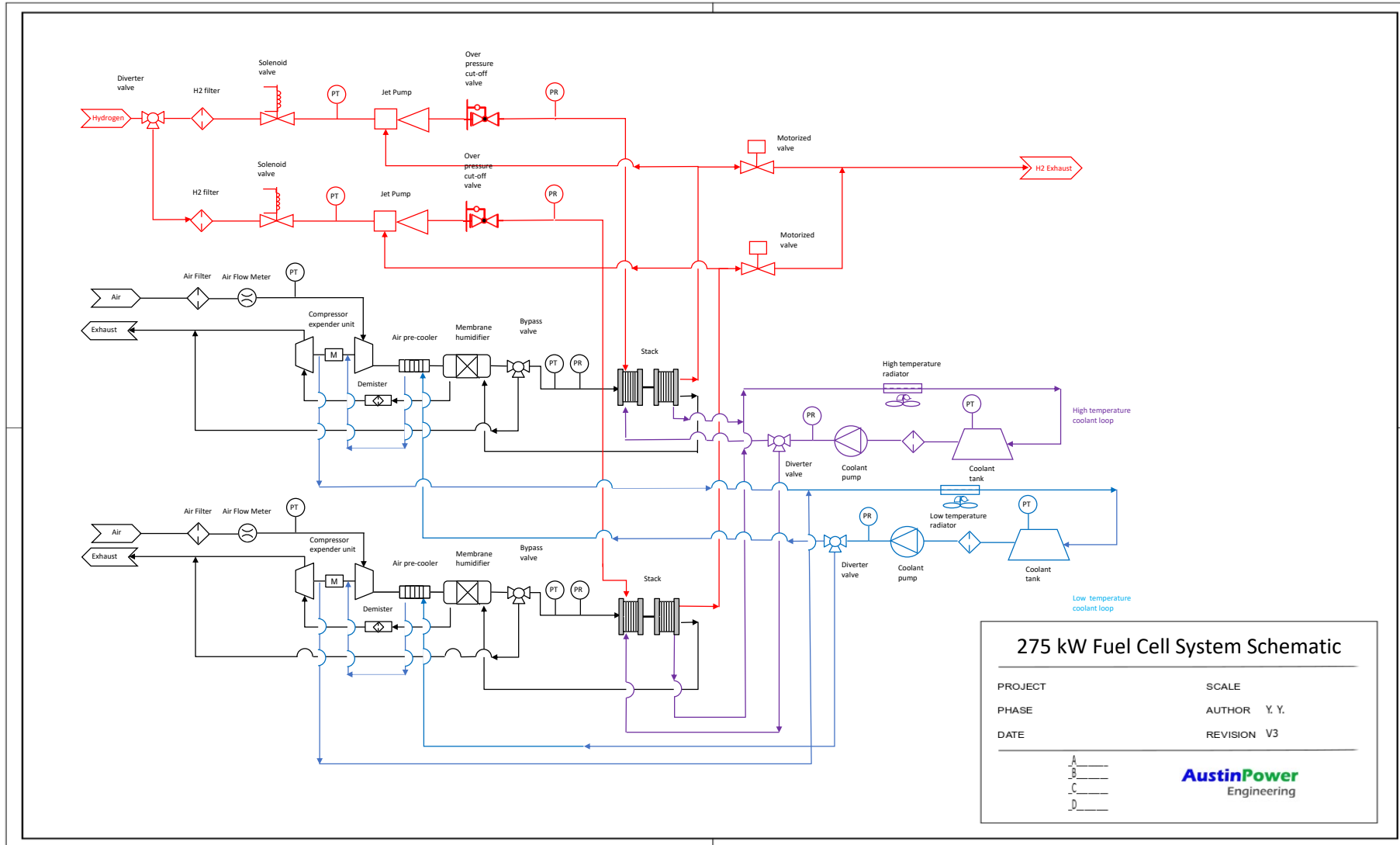
System Components	Class 8 Truck
Vehicle production volume (unit/year)	1,000, 10,000, 50,000, and 100,000
Stack source (four-stack)	Assume 275kW _{net} stacks at the annual production volume of 1,000, 10,000, 50,000, and 100,000 units
H2 storage system production volume	30 kg x 2 cryo-compressed H2 tanks at an annual production volume of 1,000, 10,000, 50,000, and 100,000 units
Battery source	106 kWh lithium-ion battery pack

System and material assumptions for the cost estimation:

Stack Components	Unit	Current System	Comments
Production volume	systems/year	1,000, 10,000, 50,000, and 100,000	
System net power (EOL)	kW	275	DOE M2FCT
System gross power (EOL)	kW	335	
# of stacks in the system	#	4	
Stack' net power	kW	69	
Stacks' gross power	kW	84	
Cell power density (EOL)	mW/cm ²	642	DOE M2FCT
Cell Voltage (EOL)	Volt	0.7	DOE M2FCT
Durability	Khrs	25	DOE M2FCT
ECSA loss at EOL	%	50%	DOE M2FCT
Active area over sizing	%	69%	DOE M2FCT
Platinum price	\$/tr.oz.	\$1,000	Feb, 2023
Cathode Pt loading (EOL)*	mg/cm ²	0.30	DOE M2FCT
Membrane type		Reinforced PFSA	
Membrane thickness	micro meter	14	
GDL layer		Non-woven carbon paper with MPL layer	
GDL thickness	micro meter	110	@50 kPa pressure
MPL layer thickness	micro meter	45	
MEA gasket material		PET	
MEA gasket thickness	micro meter	100	
Bipolar plate type		Pre-coated SS316	Treadstone; Near term
Bipolar plate base material Thickness	micro meter	100	
Seal material		EPDM	

- Data from M2FCT: Million Mile Fuel Cell Truck Consortium, DOE AMR, 2024, Rod Borup, Adam Webber
- Estimated 50% electrochemical surface area (ECSA) loss after 25,000 hours at EOL on Class 8 Drive Cycle from degradation Model and 69% of active area oversize.

The 275 kW_{net} direct hydrogen PEM fuel cell system configuration:



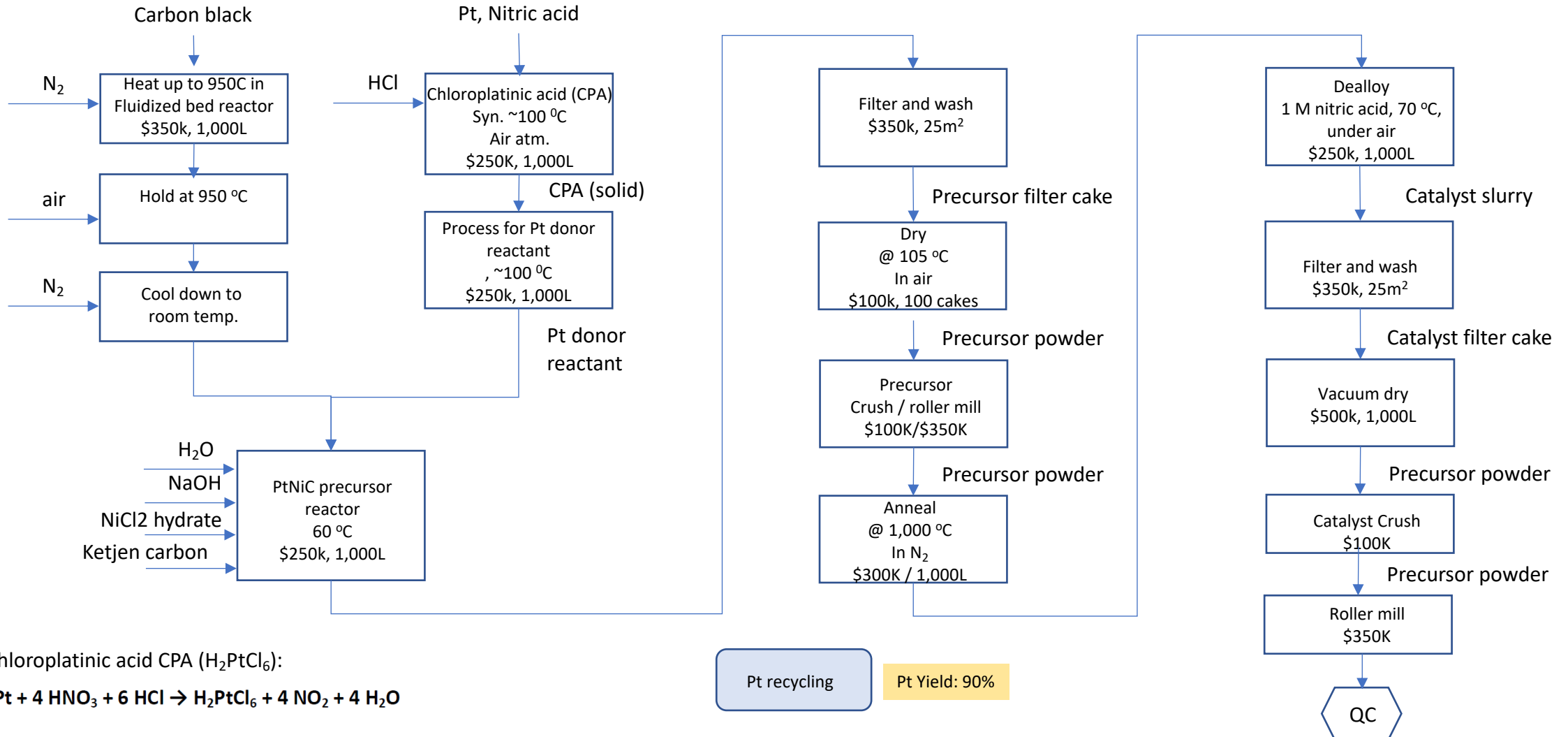
275 kW Fuel Cell System Schematic

PROJECT	SCALE
PHASE	AUTHOR Y. Y.
DATE	REVISION V3

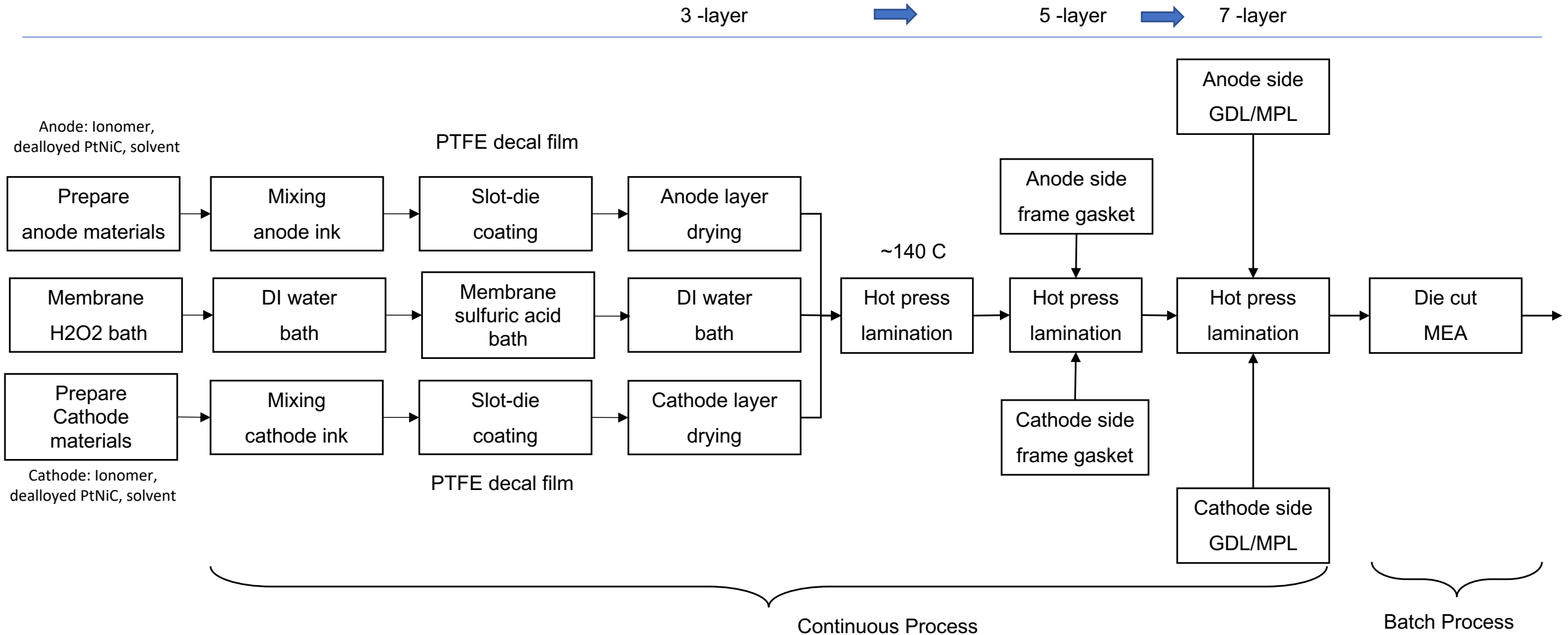
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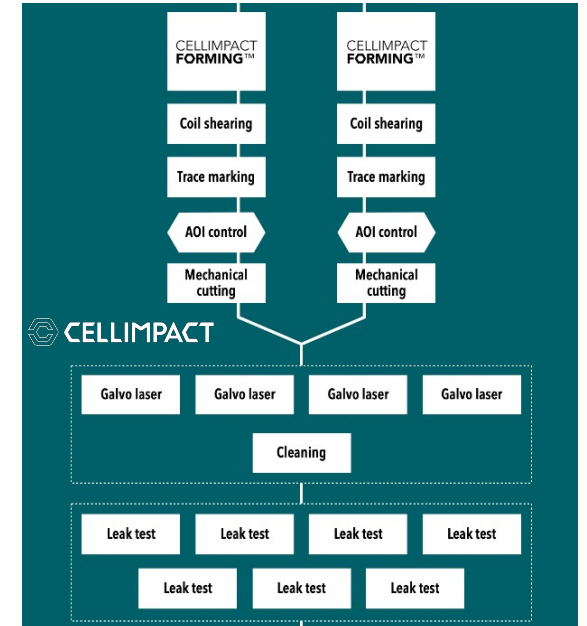
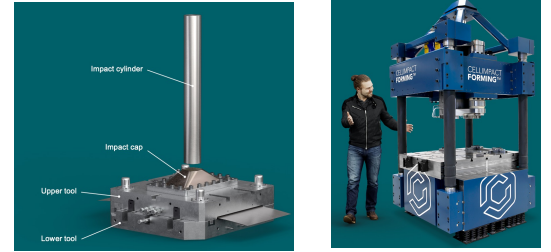
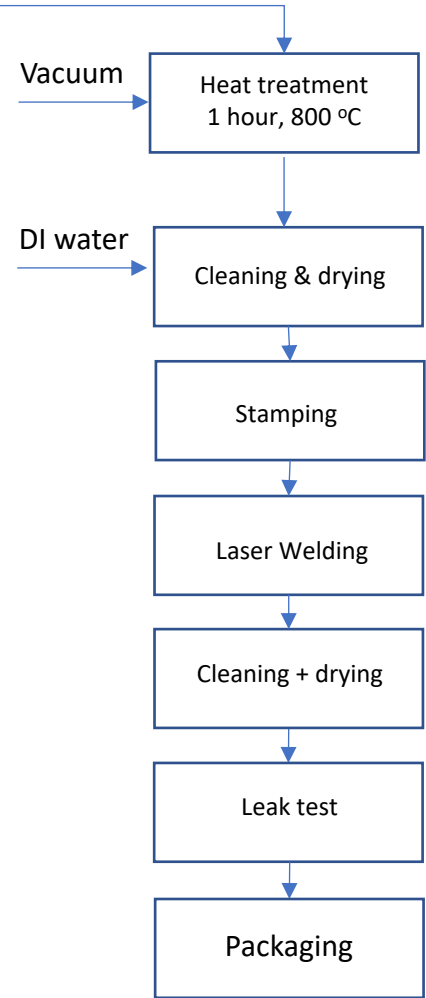
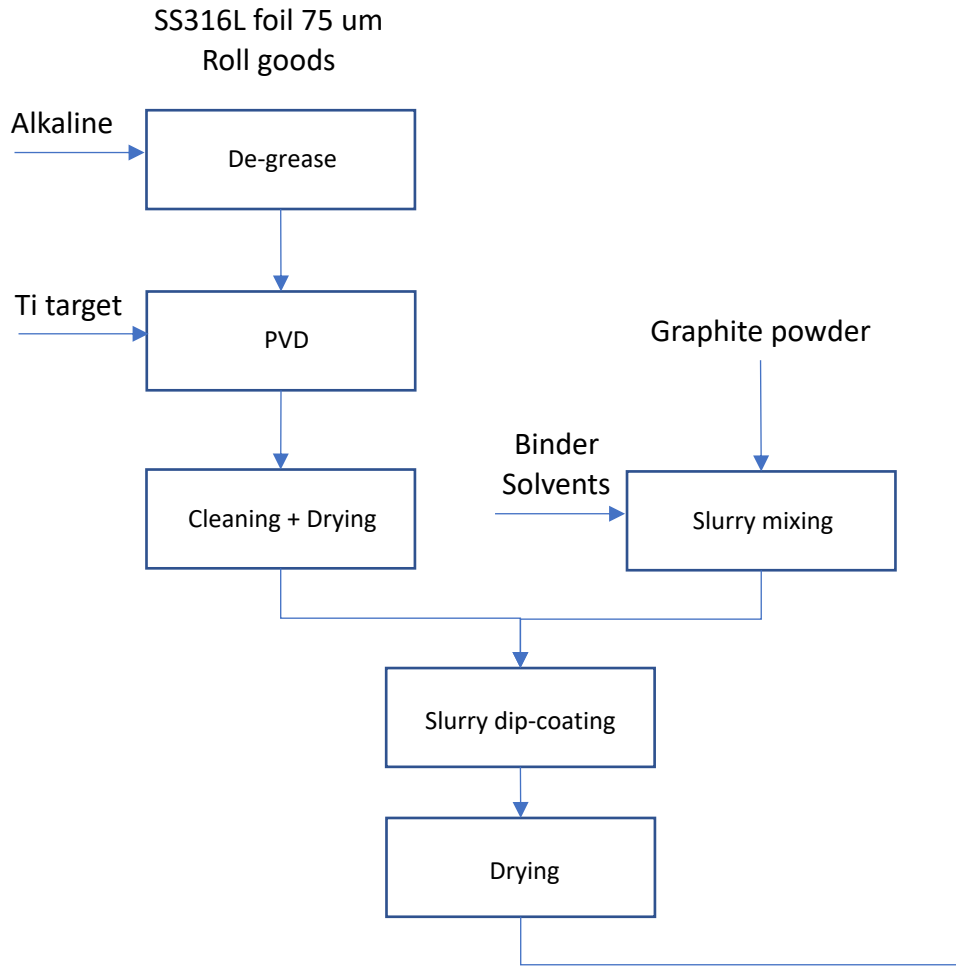
We developed the de-alloyed PtNiC catalyst manufacturing process based on Johnson Matthey patents (US2014/029531) and other literature.



We choose a 7-layer MEA structure, and the final MEA is laminated by a roll-to-roll process.

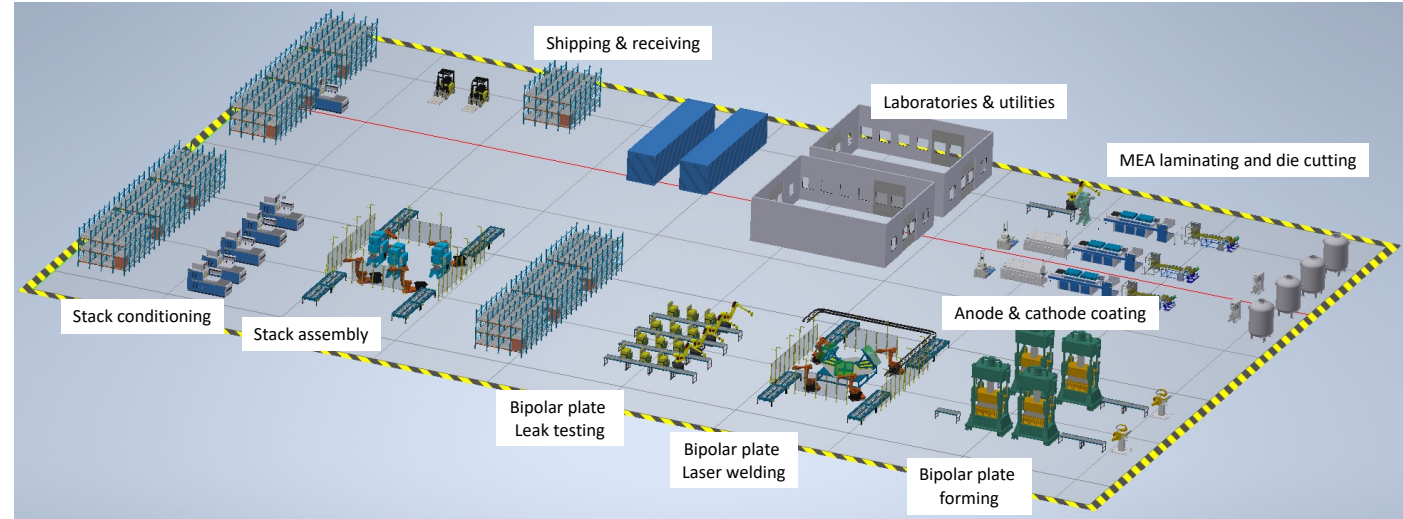
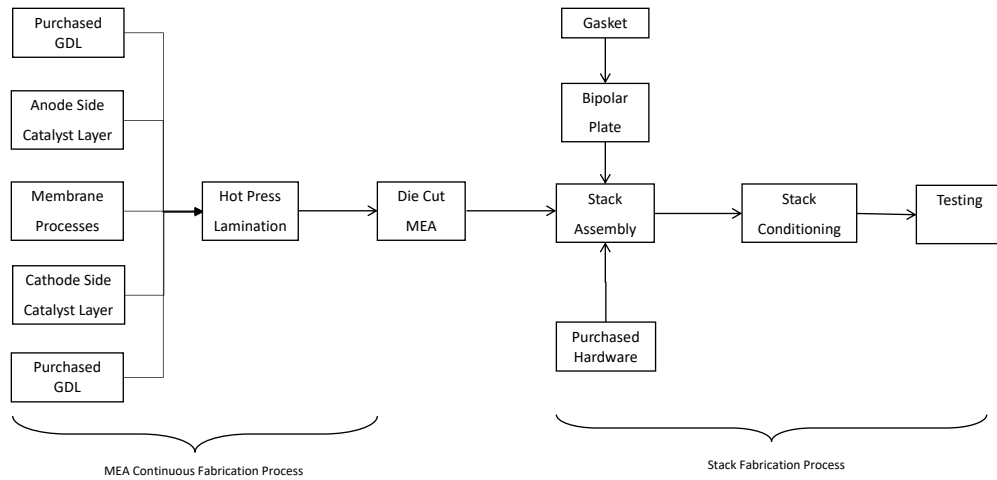


We developed the precoated bipolar plate fabrication process based on Treadstone, Cell Impact technologies.



From: Cell Impact

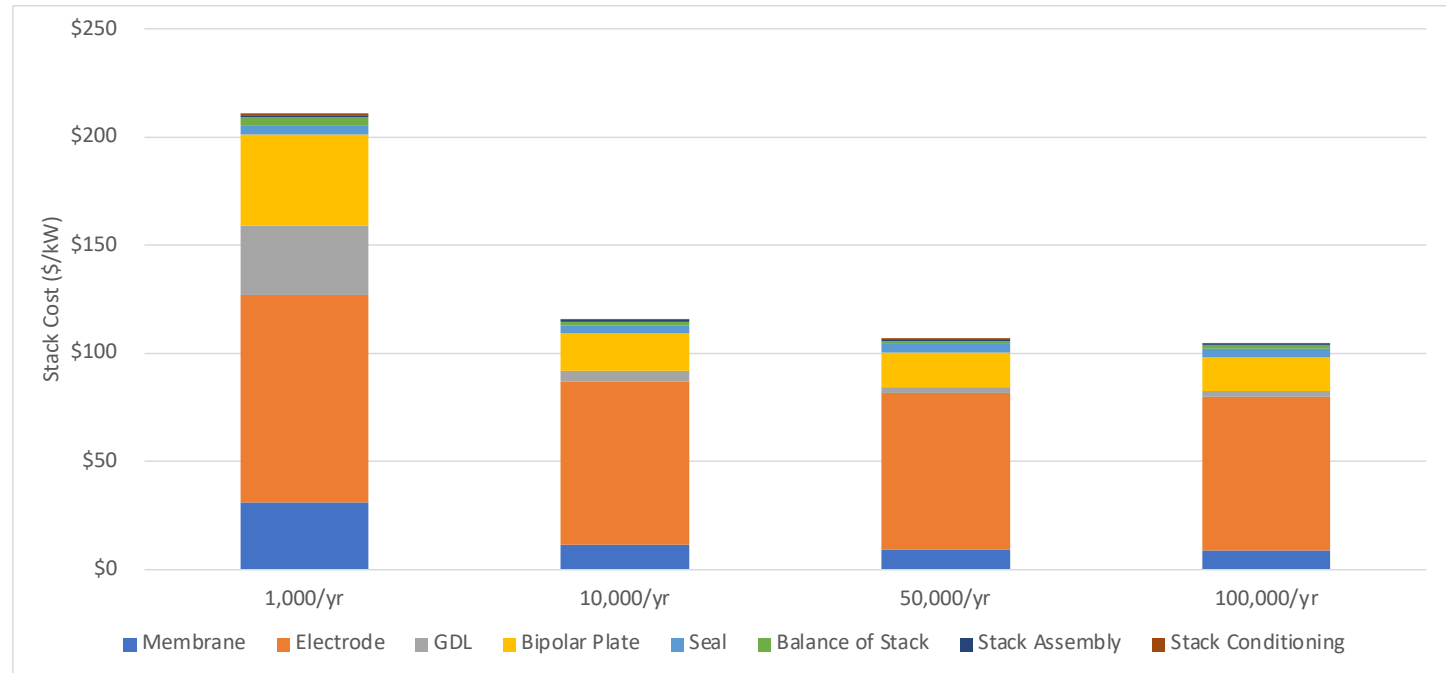
Robotic arms are used in automated stack assembly cell.



Fuel Cell Stack Cost

Considering stack EOL and increasing cell active area to prevent stack ECSA loss will significantly increase the stack cost.

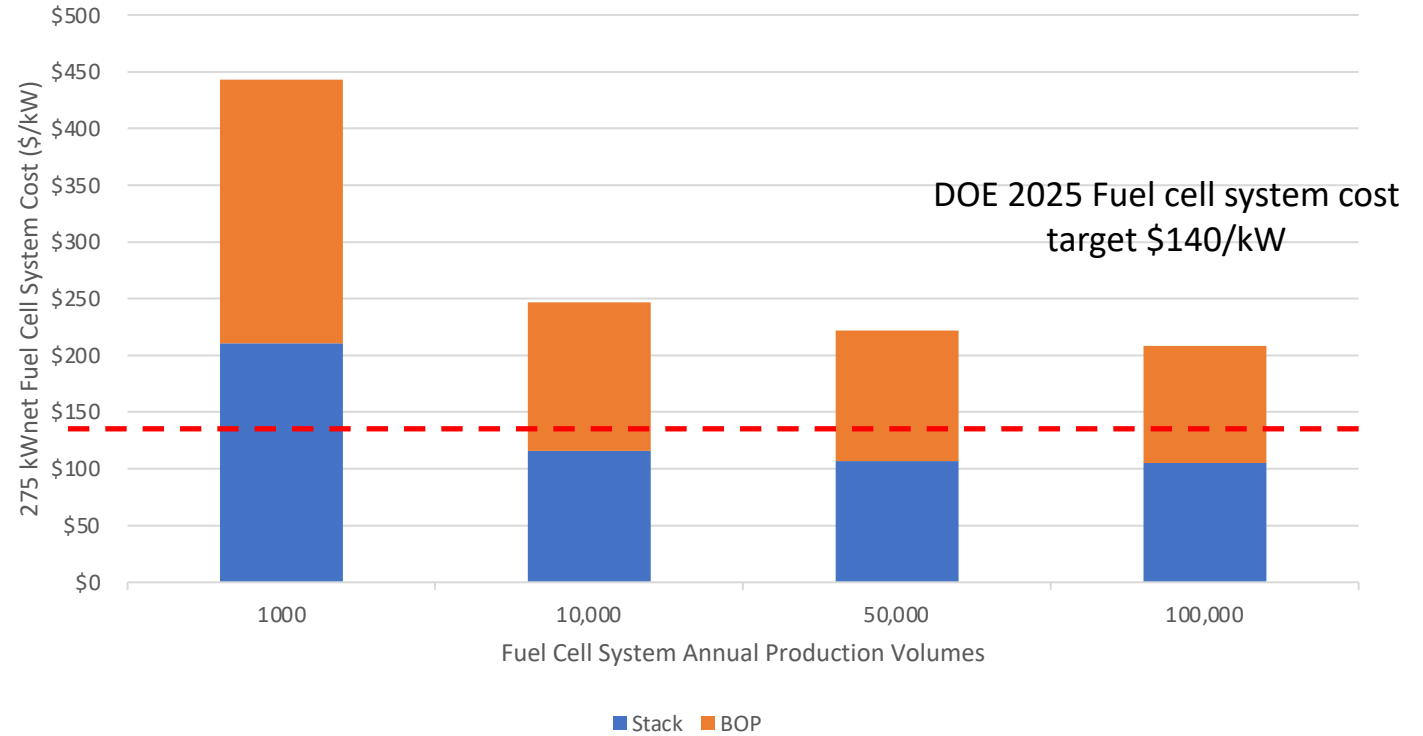
Stack Cost (\$/kW)	1,000/yr	10,000/yr	50,000/yr	100,000/yr
Membrane	\$31.16	\$11.48	\$9.39	\$9.04
Electrode	\$95.81	\$75.49	\$72.15	\$70.80
GDL	\$31.98	\$4.89	\$3.02	\$2.81
Bipolar Plate	\$42.32	\$17.20	\$15.83	\$15.72
Seal	\$4.16	\$3.99	\$3.98	\$3.97
Balance of Stack	\$3.83	\$1.61	\$1.44	\$1.43
Stack Assembly	\$1.09	\$0.82	\$0.78	\$0.77
Stack Conditioning	\$0.52	\$0.41	\$0.40	\$0.40
Stack total	\$210.88	\$115.89	\$106.99	\$104.95



Fuel Cell System Cost

For the HDV 275 kW_{net} truck fuel cell system cost about \$208/kW at the annual production volume of 100,000 units.

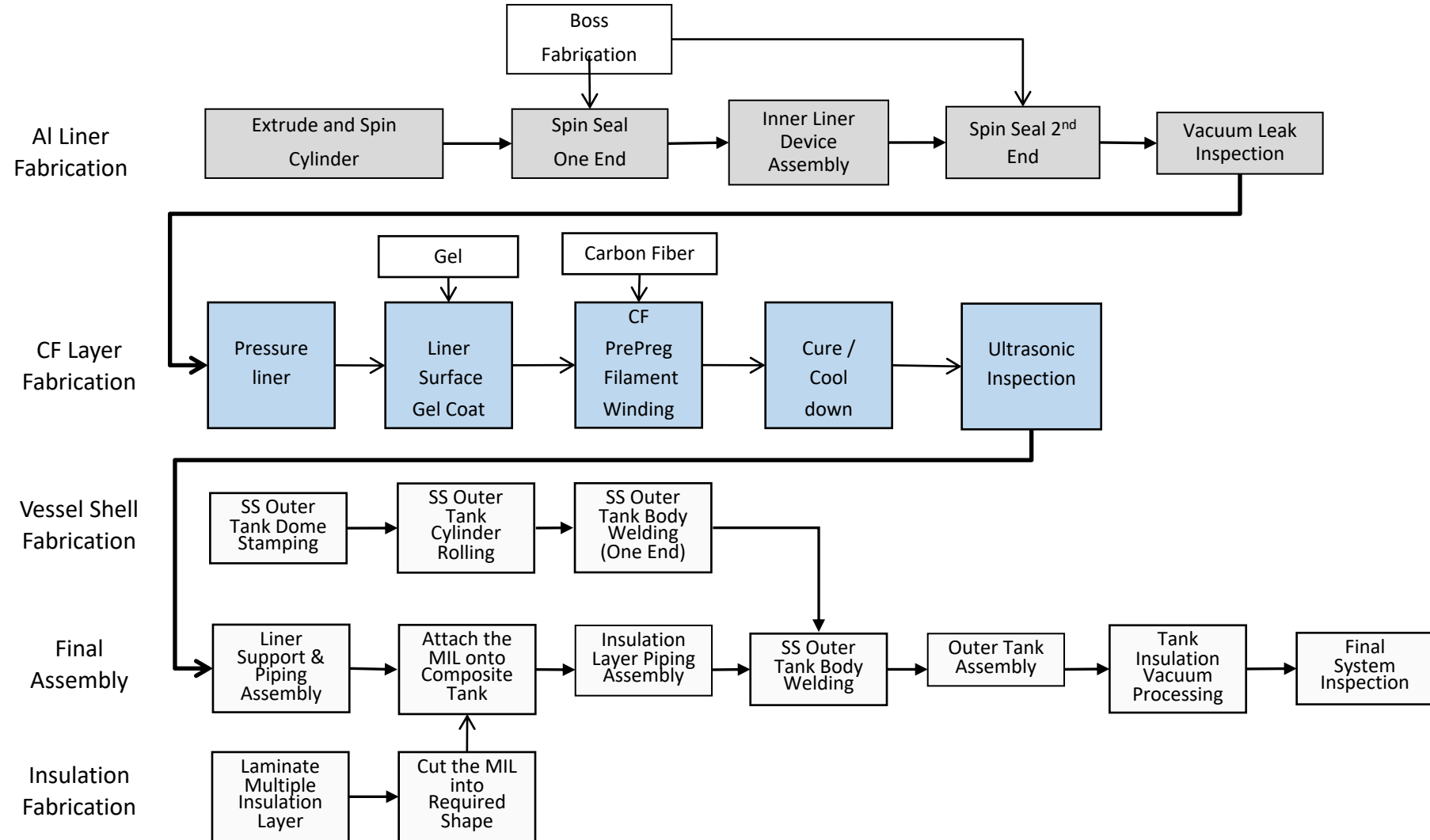
Annual production volumes	Stack cost (\$/kW)	BOP cost (\$/kW)
1000	\$211	\$232
10,000	\$116	\$131
50,000	\$107	\$115
100,000	\$105	\$103



Cryo-compressed On-board Hydrogen Storage System

A vertically integrated manufacturing process is assumed for the tank and BOP components.

Stack Components	Unit	Class 8 Truck
Usable hydrogen	Kg	30
Total H2 in the tank	Kg	33
Tank type		III
Tank max pressure	PSI	5,000
# of tanks	Per System	2
Safety factor		2.25
Tank length/diameter ratio		3:1
Liner material		Al
Carbon fiber type		Toray T700S
Carbon fiber cost	\$/lbs	12
Carbon fiber vs. resin ratio		0.68:0.32
Carbon fiber translational Strength factor		81.5%
Outer layer		SS304



Fuel cell system and hydrogen storage cost analyses are typically done separately and use different measures, but we wanted to compare them jointly to batteries.

Fuel cell system costs are measured in \$/kW

Current Class 8 truck fuel cell systems cost \$208~\$443/kW by production volumes

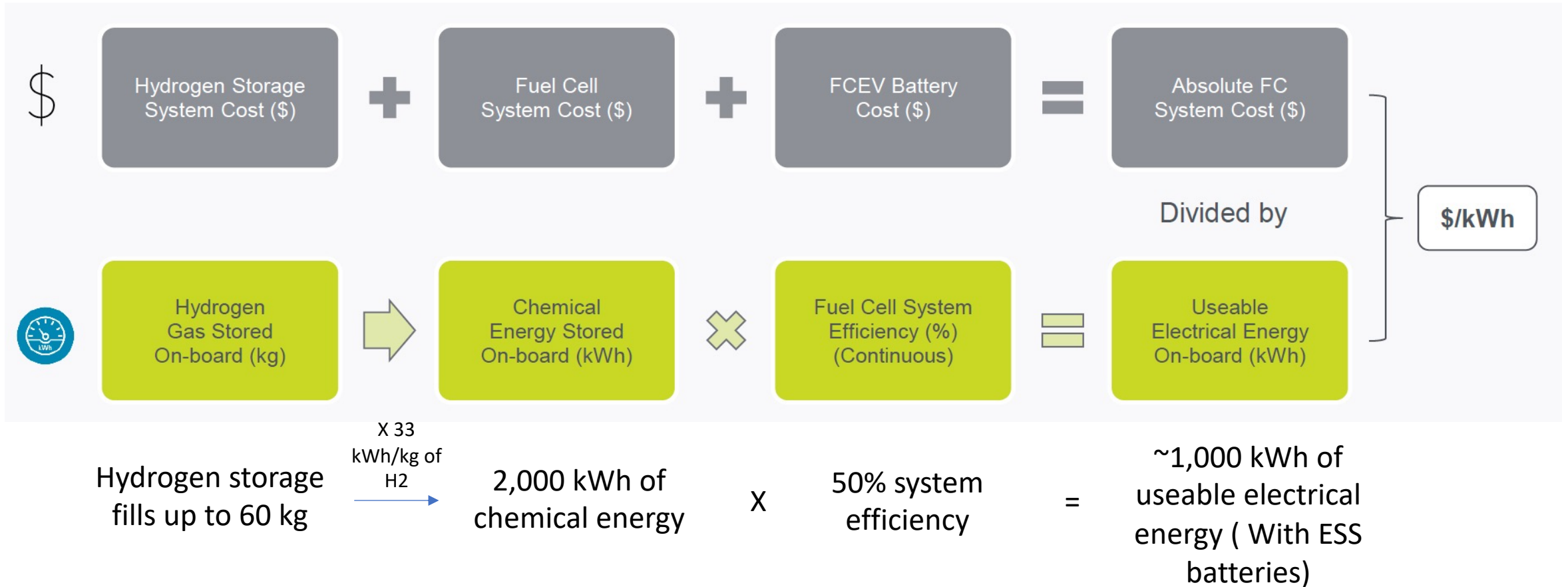
Hydrogen storage system costs are measured in \$/kWh like batteries.

Current on-board hydrogen storage systems cost \$15~25/kWh by production volumes

How can we combine the costs so we can compare them jointly to batteries?

Jointly Comparing Fuel Cell System and Hydrogen Storage Costs

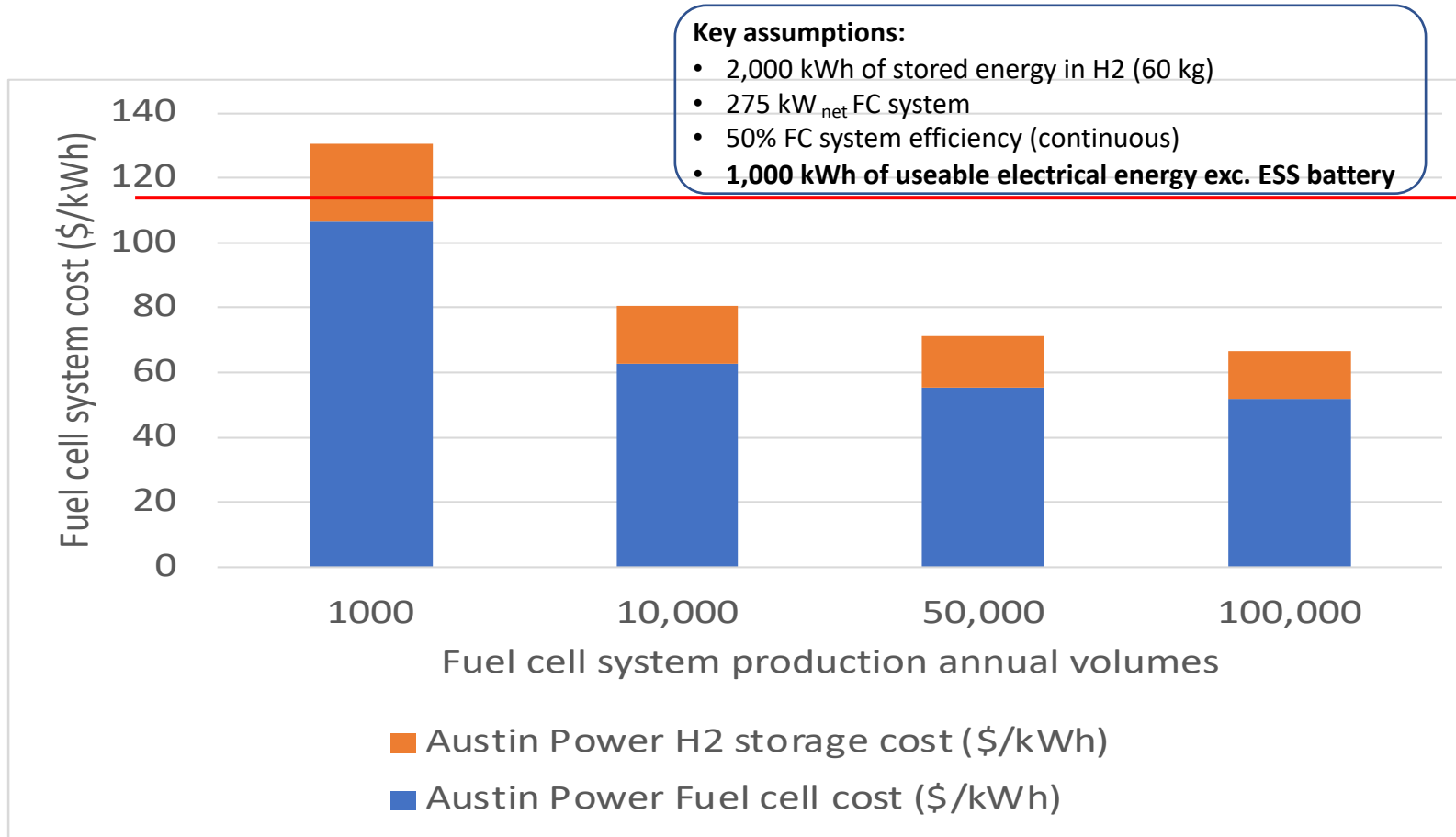
Method to get the fuel cell and hydrogen tank system costs in \$/kWh.



Collaboration with Advanced Propulsion Centre UK, Luke Bates, 2022

Jointly Comparing Fuel Cell System and Hydrogen Storage Costs

If we look at the combined cost of the fuel cell system and hydrogen storage system in \$/kWh, we have a better cost advantage than batteries.



2024 EV battery pack average \$115/kWh by Bloomberg

- <https://batteryindustry.net/ev-batteries-now-cost-115-usd-per-kwh-on-average/>

Thank You!

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