

Large-scale hydrogen electrolyzer plant design and cost analysis

2023 Fuel Cell Seminar



Yong Yang, President
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Austin Power Engineering LLC
1 Cameron St
Wellesley, MA 02482
USA

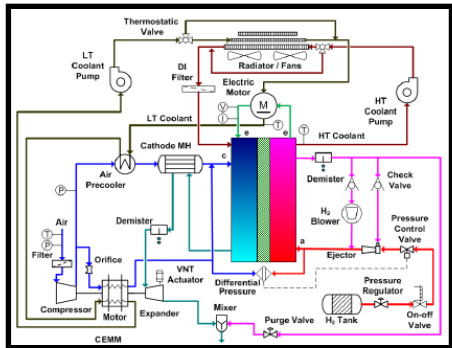
www.AUSTINPOWERENG.com
yang.yong@austinpowereng.com

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

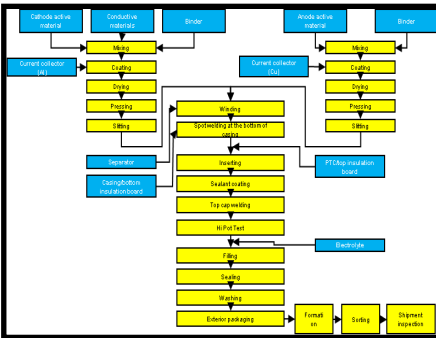
Technology Assessment

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



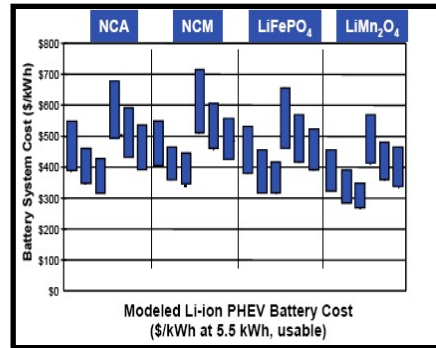
Manufacturing Cost Model

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



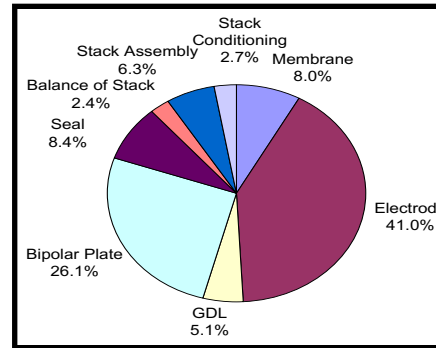
Scenario Analyses

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



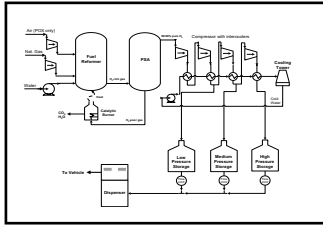
Verification & Validation

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



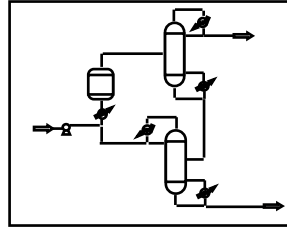
Combining performance and cost models will easily generate cost results, even when varying the design inputs.

Conceptual Design



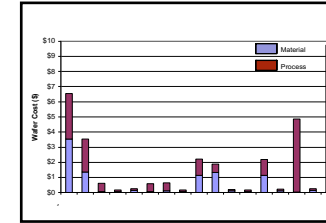
- ◆ System layout and equipment requirements

Process Simulation



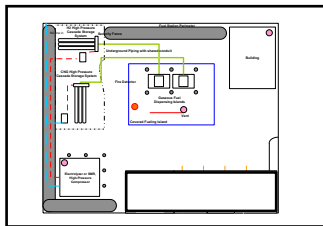
- ◆ Energy requirements
- ◆ Equipment size/ specs

Process Cost Calcs



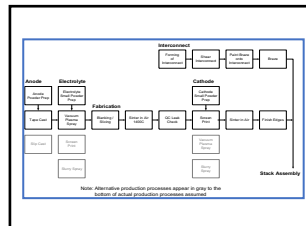
- ◆ Process cost
- ◆ Material cost

Site Plans



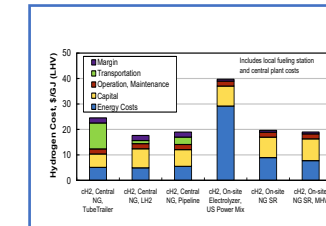
- ◆ Safety equipment, site prep, land costs

Capital Cost Estimates



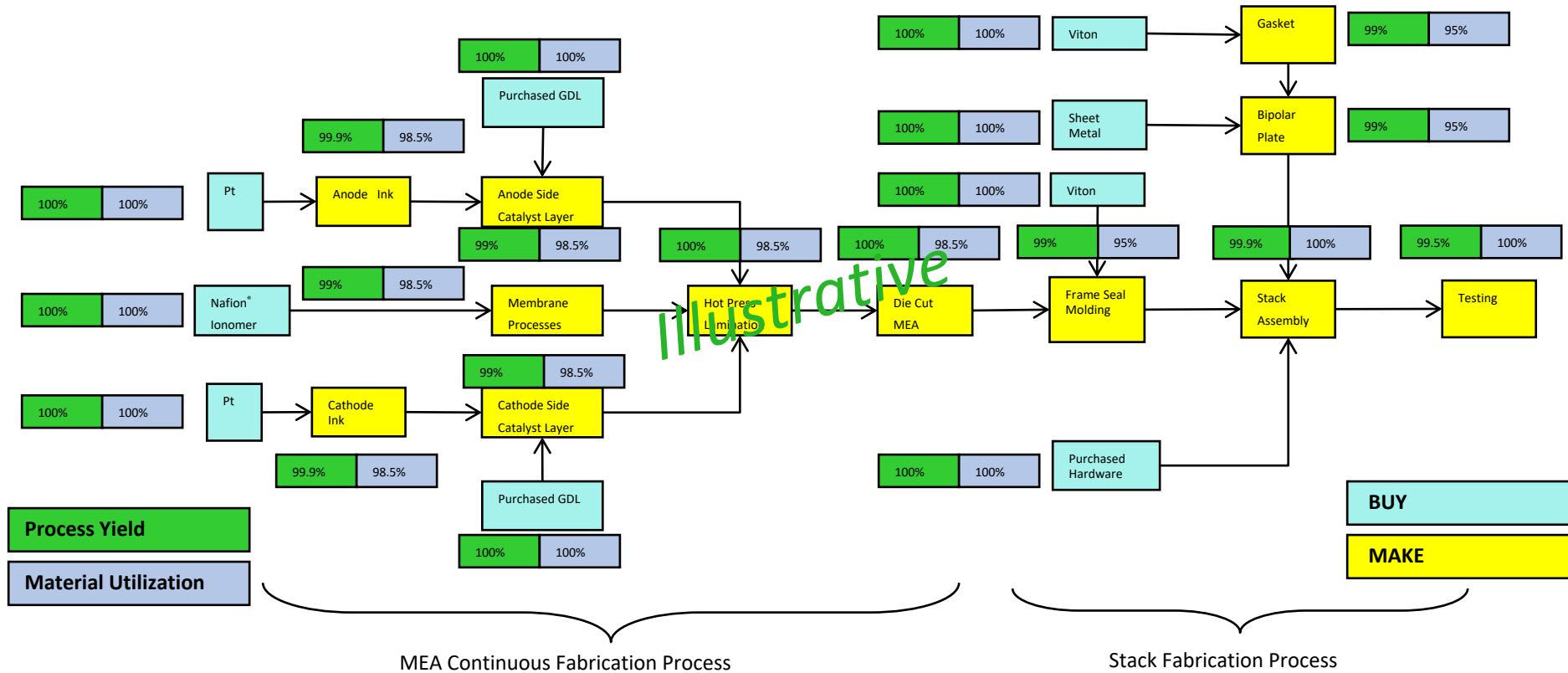
- ◆ High and low volume equipment costs

Product Costs



- ◆ Product cost (capital, O&M, etc.)

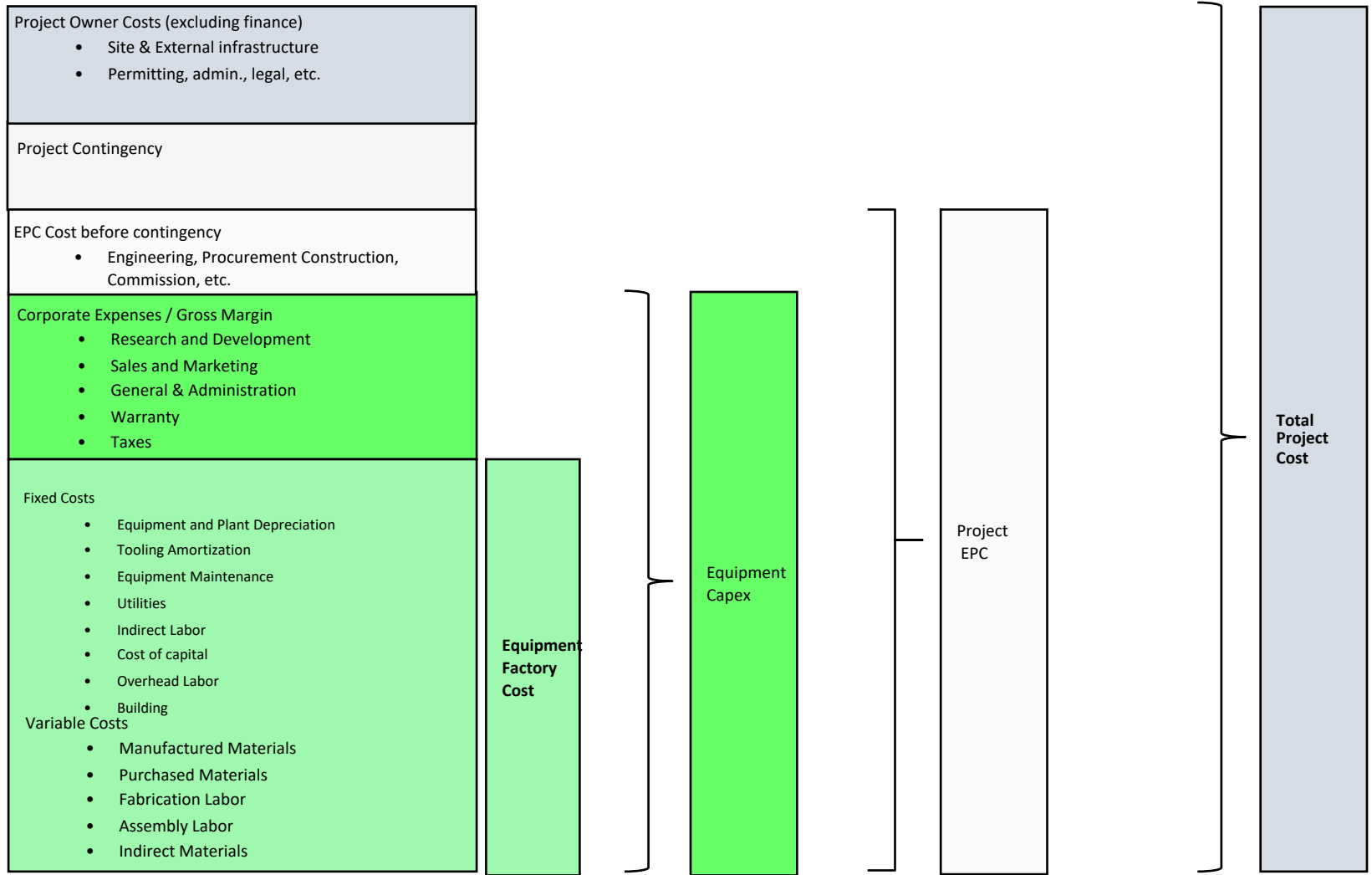
The bottom-up cost approach will be used to capture the manufacturing costs for each fabrication step accurately.



True-value-mapping analysis virtualizes costs in each fabrication step, breaking costs down into materials, labor, capex, utility, maintenance, etc.

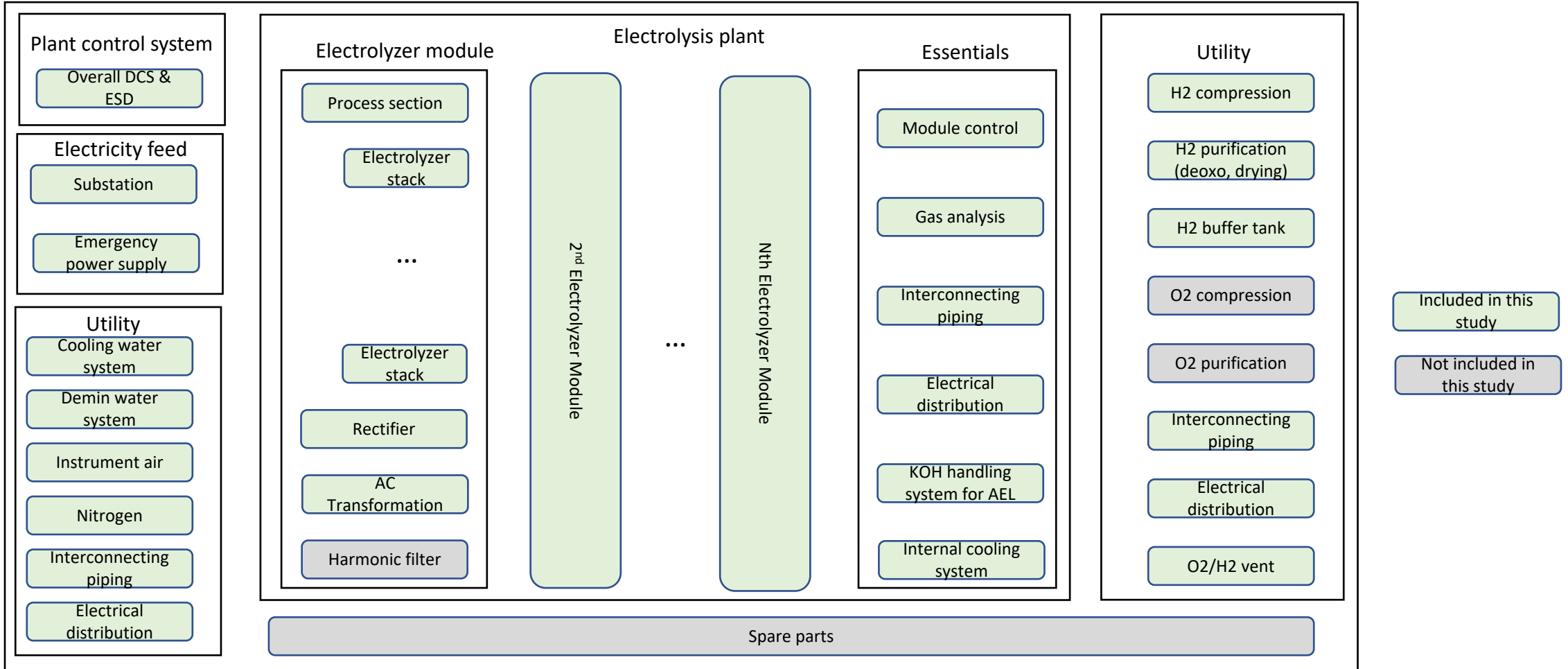
Cost Structures

Cost structures / categories used in our analysis:



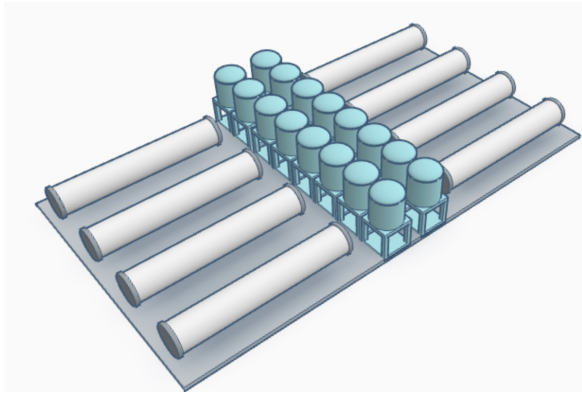
1 GW hydrogen electrolyzer plant boundary limits:

Hydrogen production plant

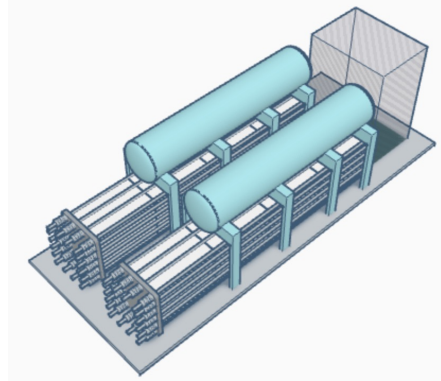


Stack Module Bottom-up Cost Analysis (Using Alkaline Stack as an Example)

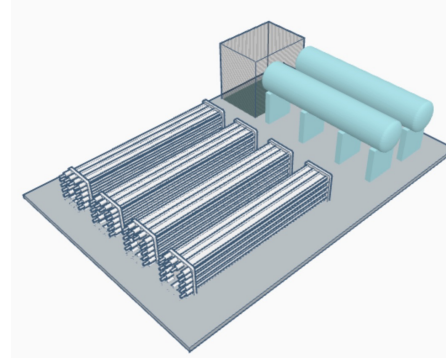
We have developed multiple 18~40 MW stack modules bottom-up manufacturing cost models for scenario analyses.



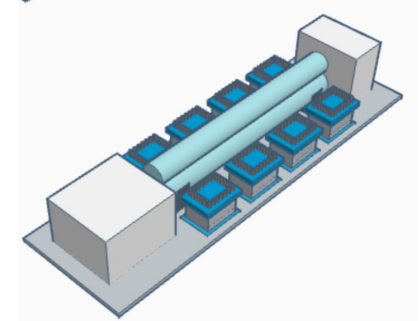
Current 18 MW Stack Module
(Baseline)



Future 20 MW Stack Module



Future 40 MW Stack Module



Current 20 MW PEM Stack Module
(Baseline)

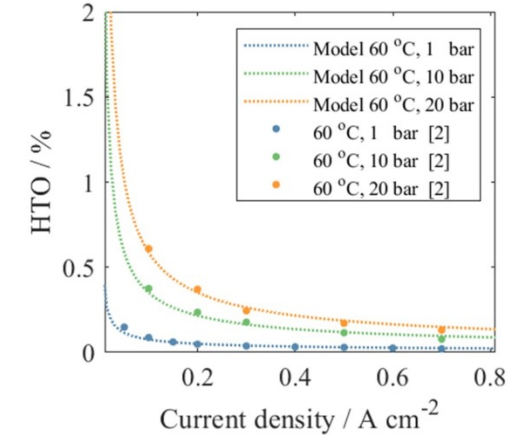
Alkaline Stack Modules

Project	1,000 MW Alkaline	1,000 MW PEM
Stack	AEL Current	PEMEL Current
Stack size	2.25 MW	2.5 MW
Stack module size	18 MW	20 MW
Stack pressure	Atm. Pressure	30 bar
Output capacity (Nm ³ /h)	210,000	197,815
Output capacity (kg H ₂ /day)	454,054	427,709
H ₂ gas output	99.99% Pure; O ₂ < 5ppm; H ₂ O: -65 C Dew Point; 30 bar	99.99% Pure; O ₂ < 5ppm; H ₂ O: -65 C Dew Point; 30 bar
System BOP*	1,000 MW integrated	1,000 MW integrated
Project region	Western Europe	Western Europe

Stack / System Pressure Selection at The Large Scale (Using Alkaline Stack as an Example)

8~10 barg range might be a good pressure range for future alkaline electrolyzers in large-scale project.

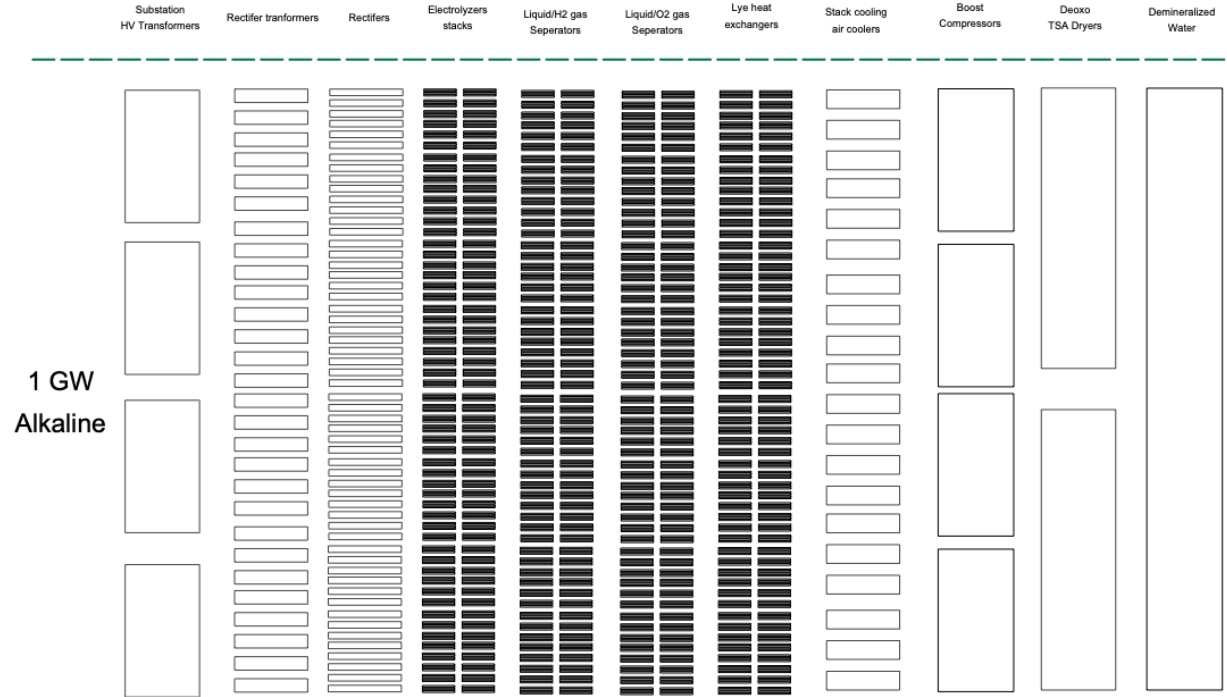
Stack Pressure	Atmospheric	8 ~ 10 bar	30 bar
Stack shape	Rectangle possible ~20% direct material saving	Rectangle possible ~20% direct material saving	Circular
Boost compressor for H2 purification	Yes Difficult from 0.1 barg	No	No
Step-up compressor (100~200 bar)	Yes	Yes	Yes
Minimum turn-down ratio ¹	Low	Low	Medium
Ramp-up speed (from warm)	Slow	Medium	Fast
Stack cost	No significant impact	No significant impact	No significant impact
Stack essential components cost ²	Low	Low	high
Boost compressor cost ³	~\$50/kW	No	No
Plant safety	Better	Better	Good
Overall cost	5~15% lower than others		



1. Challenges and Opportunities in Scaling Up Alkaline Water Electrolysis, T. Groot, 2022 Gastech conference in Milan (The minimum load of an electrolyzer is determined by the gas crossover of hydrogen to oxygen.)
2. Gas/liquid separators, H2 scrubbers, HX, circulation pumps, filters, valves, piping,
3. Based on the project size power, at the large scale.

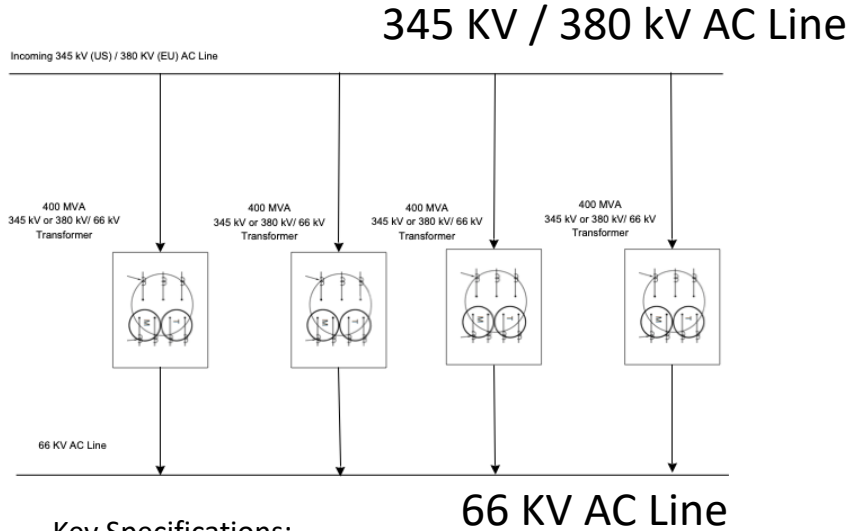
System Balance of Plant Components Modular Design (Using Alkaline System as an Example)

Overview of major BOP components required in a 1 GW alkaline electrolyzer project.



Components	Substations	Rectifier transformer	Rectifier	Stack module	Liquid/H2 separator	Liquid/O2 separator	Lye heat HX	Stack cooling wet water cooler	Boost compressor	Deoxo – TSA dryer	Demin. water
Description	380 kV / 66 kV 1,600 MVA	42 MWAC	452 V	8x 2.25 MW = 18 MW	For 18 MWDC stack module	For 18 MWDC stack module	For 18 MWDC stack module	Wet water cooling tower	Oil lubrication compressor with 12 ppb oil recovery	H2 purification	for H2 production
# of modules x capacity	4 X 25%	28	18 MWDC x 56	2.25 MW x 8 x 56	448	448	448	22	4 x 25%	2 x 50%	1 x 100%

1 GW (DC) Water Electrolysis Project – 1,600 MVA Substation (baseline scenario with grid connection).



Key Specifications:

Substation

- 345 kV (US) or 380 kV (EU) / 66 kV
- 400 MVA x 4 =1,600 MVA

of transformer

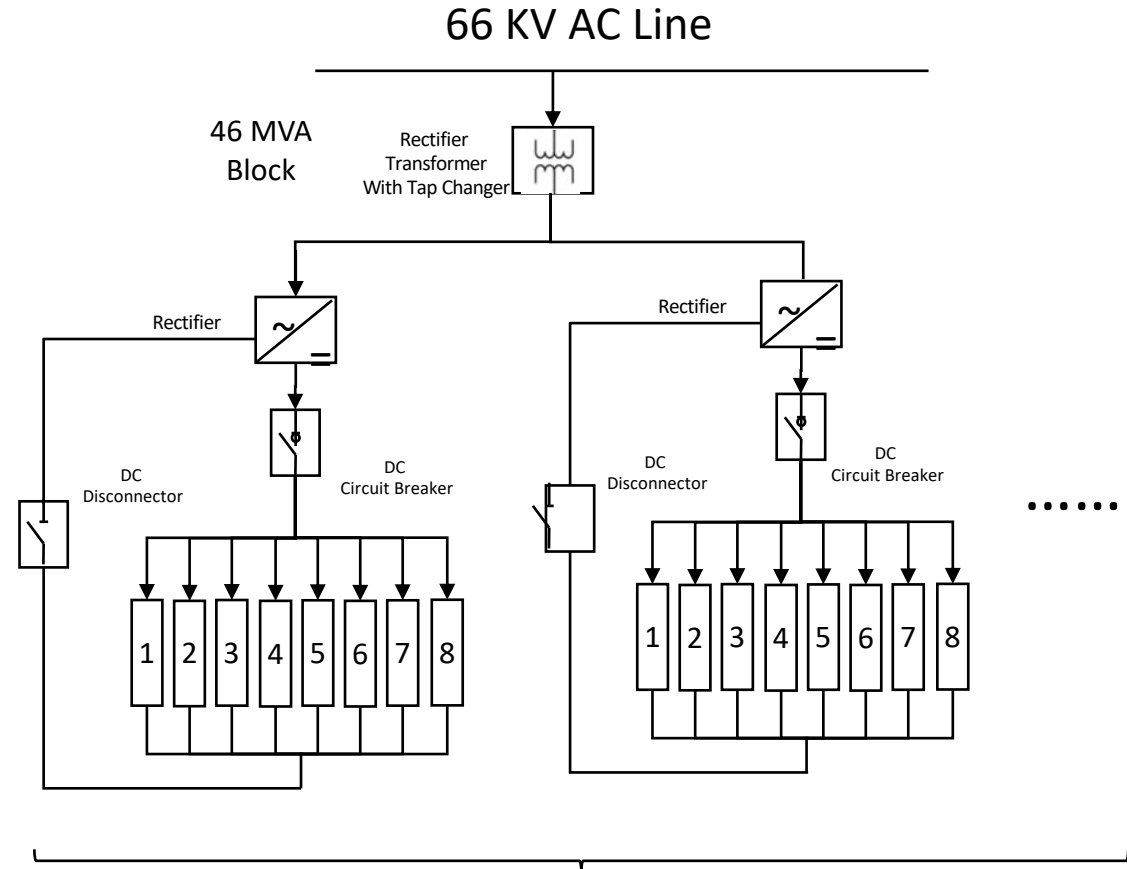
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Transformer capacity

- 400 MVA each
- Three transformers are online for 100% load, and one is standby/maintenance.

Electrolyzer plant DC power requirement

- 1 GW DC



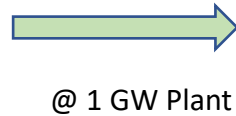
40MW block total: 40 MWDC x 24= 960 MWDC

PEM Scenario

Compact wet water cooling towers will replace dry air coolers for stack cooling at the 1 GW plant.



Example dry air cooler – 720 kW cooling capacity

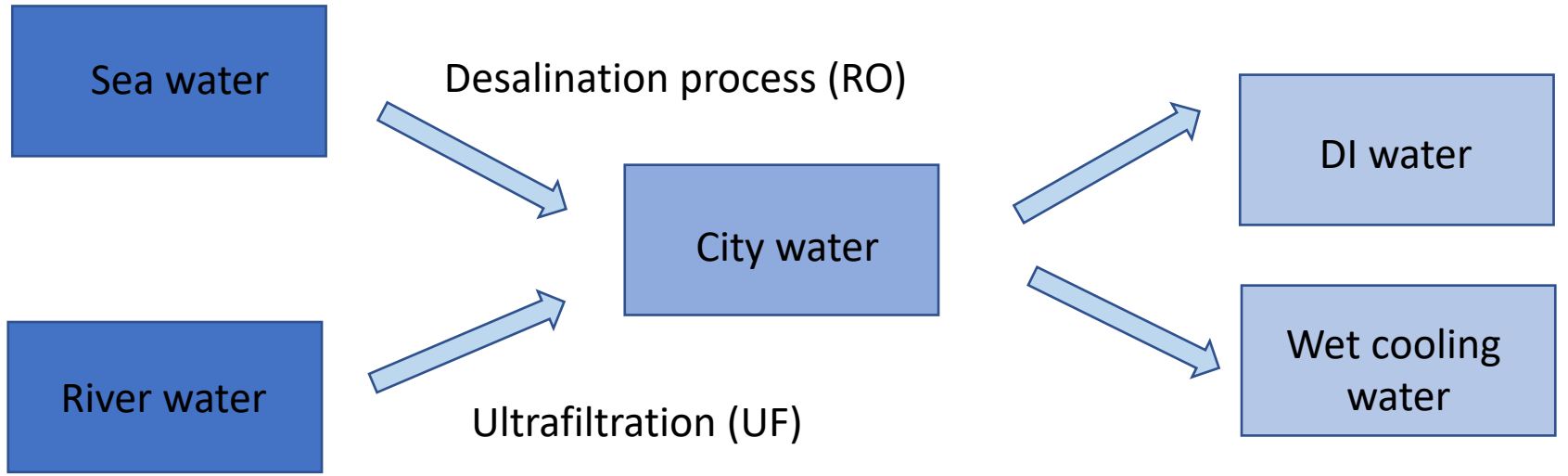


Example wet water cooling towers

Project	500 MW	1 GW	5 GW
H2 produced (ton/day)	200	400	2,000
Raw water usage (ton/day)	13,000	26,000	130,000

Wet cooling towers require a significant amount of freshwater (~ 7 times theoretical hydrogen production water consumption) compared to dry air coolers.

Wet cooling towers require a significant amount of freshwater (~ five times direct hydrogen production water consumption) compared to dry air coolers.



Electrodeionization (EDI) for PEM
 < 0.1 MICROSIEMENS(conductivity) or
 >10 MEGOHM/cm2 (resistivity)

Reverse Osmosis (RO) for Alkaline
 < 4 MICROSIEMENS(conductivity) or
 > 0.25 MEGOHM/cm2 (resistivity)

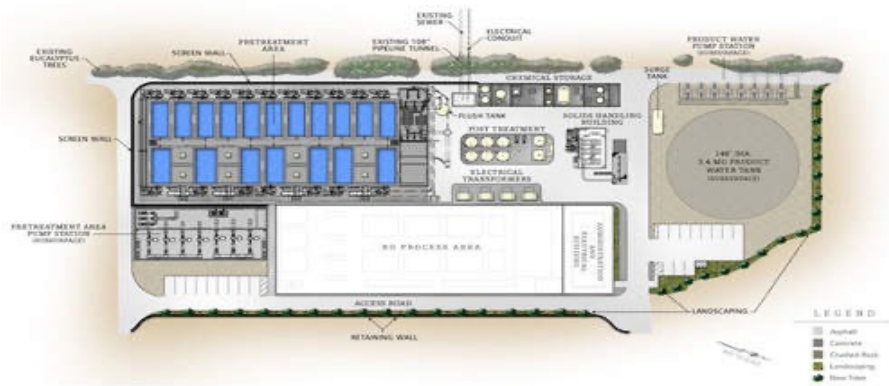


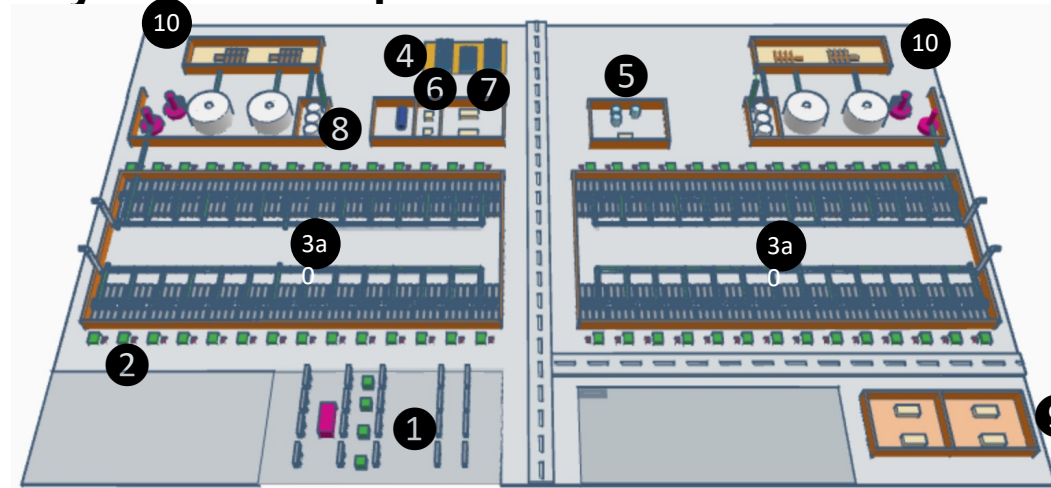
Image courtesy Poseidon Resources Corporation

Carlsbad desalination project	Specification
Location	San Diego County, California US
Capacity	50 million gallon per day
Capacity	189,000 ton/day
Investment (USD)	A few hundred millions
Commission date	2015
Space (m ²)	16,187
Service	300,000 ~400,000 people water usage per year

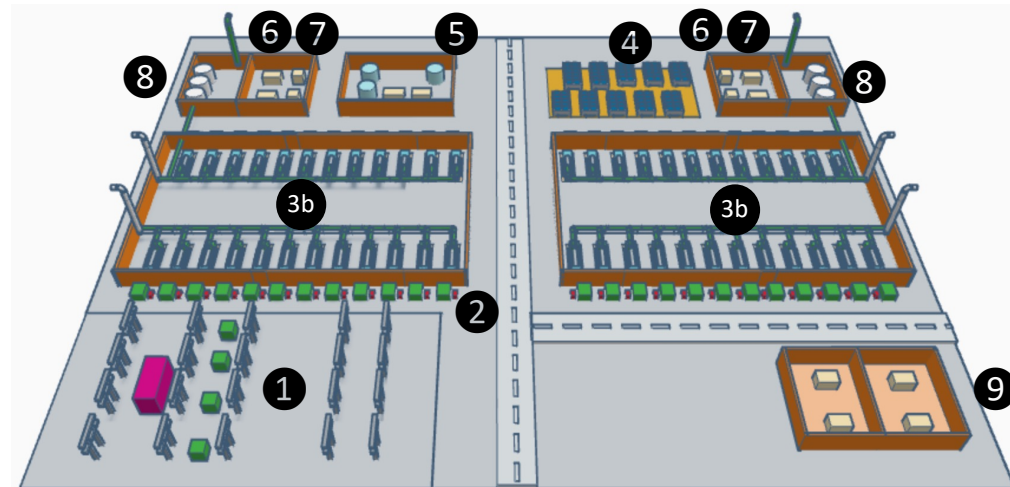
1 GW PEM Electrolysis Plant and 1 GW Alkaline Electrolysis Plant Layouts

1 GW PEM electrolysis plant (no boost compressors, compact stacks, etc.) size is about 40% of the 1 GW alkaline electrolysis plant size using our system assumptions.

- ① Substation
- ② Transformer / Rectifier
- ③a 18 MW alkaline stack module x 56
- ③b 20 MW PEM stack module x 48
- ④ Stack cooling water tower
- ⑤ DI water
- ⑥ Compressed air
- ⑦ Nitrogen generation
- ⑧ H₂ purification
- ⑨ Control
- ⑩ Booster compressor



1 GW Alkaline Plant: 600 m x 400 m



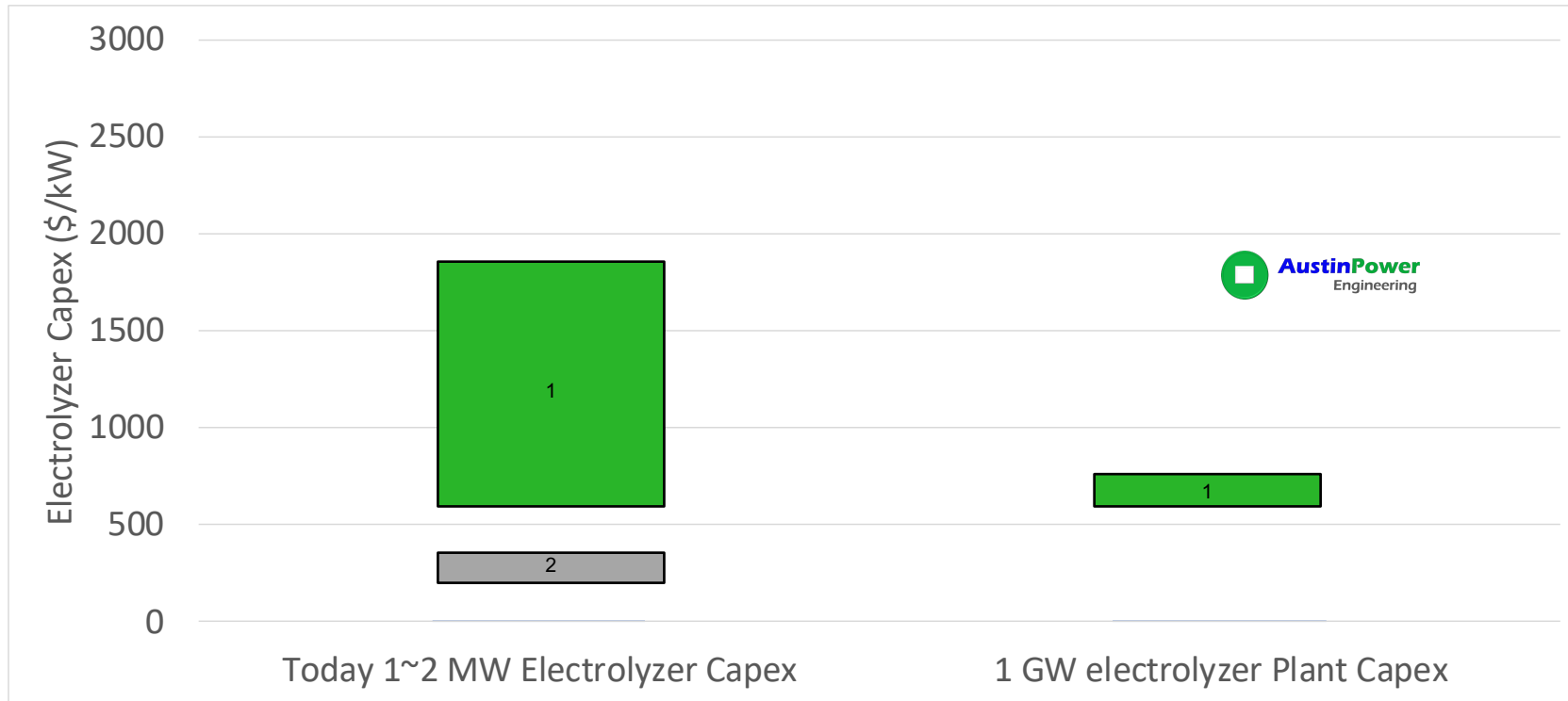
1 GW PEM Plant: 360 m x 280 m

Project EPC and owners' costs ("soft" cost) typically are much higher than equipment Capex in Europe and USA.

EPC	Owner's Cost
<ul style="list-style-type: none">• Engineering and supervision	<ul style="list-style-type: none">• Service facilities (installed)
<ul style="list-style-type: none">• Purchased-equipment installation	<ul style="list-style-type: none">• Permit, licensing, legal expense
<ul style="list-style-type: none">• Instrumentation and controls (installed)	<ul style="list-style-type: none">• Contractor's fee (pre-engineering, contract drafting,etc.)
<ul style="list-style-type: none">• Piping (installed)	<ul style="list-style-type: none">• Financing cost
<ul style="list-style-type: none">• Electrical (installed)	<ul style="list-style-type: none">• Contingency
<ul style="list-style-type: none">• Buildings (including services)	<ul style="list-style-type: none">• Land Cost
<ul style="list-style-type: none">• Yard improvements	
<ul style="list-style-type: none">• Construction expense	

The estimated 1 GW electrolyzer plant capex falls between \$550/kW and \$650/kW.

- Today 1~2 MW electrolyzers' capex ranges from \$600/kW to \$1,800/kW
- Modelled 1 GW electrolyzers' capex ranges from \$550/kW to \$650/kW¹

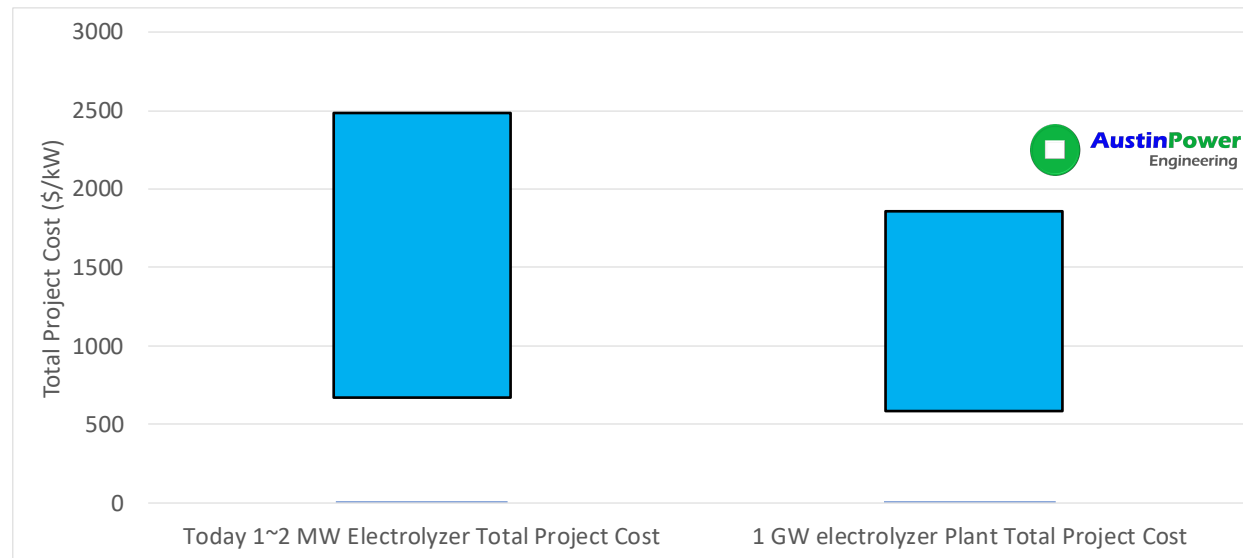


1. Made in western Europe countries; output H2 gas purity is 99.99% at 30 barg
2. Alkaline units made in China ranges \$250~350/KW

1 GW Project Total Project Cost Summary

Total project cost also includes project “soft” cost, which is highly site and situation-specific.

- Container-based 1~2 MW electrolyzers’ project cost is minimum
- 1 GW electrolyzer plant total project cost ranges from \$600/kW to \$1,800/kW, which is the same as our estimation presented in the 2019 Fuel Cell Seminar.



A robotic assist semi-automated alkaline stack assembly line was assumed for stack assembly.

Electroplating lines



Stack assembly



Industry stack assembly examples

Thank You!

Contact: Yong Yang

Austin Power Engineering LLC

1 Cameron St,
Wellesley, MA 02482
USA

+1 401-829-9239

yang.yong@austinpowereng.com

www.austinpowereng.com