1 GW Hydrogen Electrolyzer Plant Design and Cost Analysis

Yong Yang
President

November 7, 2019

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

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

© 2019 Austin Power Engineering LLC
Austin Power Engineering LLC is an independent technology consulting company that focuses mainly on bottom-up technical cost modeling.

Hydrogen Electrolysis

Hydrogen Storage

Fuel Cell

Battery

Hydrogen & Fuel Cell Manufacturing Cost Modeling

Arthur D Little / TIAX

Austin Power Engineering
Project Objective

We will analyze a 1 GW (200,000 Nm³/hr / 500 ton H₂ per day) hydrogen electrolysis plant capex.

* Have done 200 kW, 1 MW, 2 MW, 10 MW, 50 MW, 100 MW, 250 MW, 500 MW hydrogen electrolysis plant cost analysis for various clients.
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
  - Audition by independent reviewers
Combining performance and cost model will easily generate cost results, even when varying the design inputs.

Conceptual Design

- System layout and equipment requirements

Site Plans

- Safety equipment, site prep, land costs

Process Simulation

- Energy requirements
- Equipment size/ specs

Capital Cost Estimates

- High and low volume equipment costs

Process Cost Calcs

- Process cost
- Material cost

Product Costs

- Product cost (capital, O&M, etc.)
1 GW hydrogen electrolyzer plant boundary limits:

- **Capex**
  - Electrolyzer stack
    - Balance of plant
      - AC-DC power supply
      - System control
      - Feed water treatment
      - Gas / liquid loops
      - Compressor (if needed)
      - De-oxygen unit
      - Gas drying
      - Cooling system
      - Piping, fitting, valves, instrument
    - Assembly, conditioning, testing, packaging

- **Peripheral components**
  - Optional additional hydrogen compression
  - Optional hydrogen storage

- **Hydrogen Output**
  - 30 barg
  - Oxygen limit: <5 ppm
  - Moisture content: -65 °C dew point

**Project development**
- Permitting
- Engineering
- Civil works and installation
- Land use
- Selling, general and administrative expenses, margins

Indicative estimated for engineering and project cost is given separately based on textbook factors.

Highly site and situation-specific: Included in analysis
Approach  Cost Reduction Options

Comparing large scale hydrogen electrolysis plant with small hydrogen electrolyzer, cost reduction mainly comes from the following areas:

1. Improve stack performance
   - Increase current density
   - Simplify stack structure
   - Reduce precious metal loading
2. Large scale production
   - Process automation, etc.
3. Increase the stack size
   - Current 1~5 MW
   - Future 5~20 MW
4. System BOP optimization
   - Power supply
   - Mechanical compressors if apply
   - H2 gas purification
5. Low cost region manufacturing

Modular vs Integrated
- Capex
- Project cost
- O&M cost
We screened major electrolyzer manufacturer’s MW level electrolyzer stacks.

**Approach**  Stack Options

**We screened major electrolyzer manufacturer’s MW level electrolyzer stacks.**

**Alkaline electrolyzer**
- Atm. pressure
- Pressurized

**PEM electrolyzer**
- Atm. pressure
- Pressurized

**Hight temperature electrolyzer**
- SOEC
- Proton Conductive SOEC

**Commercial**
- NEL A485 2.3 MW
- McPhy 2 MW Module
- Chinese Manufacturers
  - Peric
  - Jingli
  - Tianjin Continental
- Hydrogenics 3MW
- ITM Power 2MW Module
- NEL/Proton Onsite MW Module
- Giner EXL 1MW
- Siemens 1~2 MW
- >Potential 10 MW stacks

**Pre-commercial**
- ThyssenKrupp
- Asaki Kasei

- NEL/GHW
- Siemens

- >Potential 10 MW stacks

- Tubular
- Planar
The chosen cell voltages and current densities are based on current technology status.

- The chosen cell voltage (1.75V) largely determines the cell efficiency (85% HHV)
- This low cell voltage is used to reflect that such large plants will be optimized for efficiency.
- Assume current atm. pressure alkaline electrolyzer current density is 175 mA/cm²
- Assume current PEM electrolyzer current density is 1,500 mA/cm².

**Relationship between cost and efficiency**

**First “MW” PEM Stack Measured Efficiency**
We must consider the capex, project cost, as well as O&M cost when we design the electrolysis plant project.

<table>
<thead>
<tr>
<th>BOP</th>
<th>Modular Design</th>
<th>Integrated Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capex</td>
<td>$$$</td>
<td>$$</td>
</tr>
<tr>
<td>Project Cost</td>
<td>$</td>
<td>$$$</td>
</tr>
<tr>
<td>O&amp;M Cost</td>
<td>$$$</td>
<td>$$</td>
</tr>
</tbody>
</table>

Outdoor Modular Design

Integrated BOP Design
### Design Scenarios

#### 1 GW Hydrogen Electrolysis Plant Stack

**Major stack specifications summary:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Alkaline Electrolyzer Current KPI</th>
<th>Alkaline Electrolyzer Future KPI</th>
<th>PEM Electrolyzer Current KPI</th>
<th>PEM Electrolyzer Future KPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant size (MW, DC basis)</td>
<td>957</td>
<td>960</td>
<td>960</td>
<td>960</td>
</tr>
<tr>
<td>Stack size (MW)</td>
<td>2.3</td>
<td>10</td>
<td>2.5</td>
<td>10</td>
</tr>
<tr>
<td># of stacks</td>
<td>416</td>
<td>96</td>
<td>384</td>
<td>96</td>
</tr>
<tr>
<td>Cell voltage (V)</td>
<td>1.75</td>
<td>1.75</td>
<td>1.75</td>
<td>1.75</td>
</tr>
<tr>
<td>Current density (A/cm²)</td>
<td>0.175</td>
<td>0.75</td>
<td>1.50</td>
<td>2.50</td>
</tr>
<tr>
<td># of cells</td>
<td>258</td>
<td>258</td>
<td>258</td>
<td>258</td>
</tr>
<tr>
<td>Stack voltage (VDC)</td>
<td>452</td>
<td>452</td>
<td>452</td>
<td>452</td>
</tr>
<tr>
<td>Stack Current (A)</td>
<td>5,088</td>
<td>22,124</td>
<td>5,531</td>
<td>22,124</td>
</tr>
<tr>
<td>Cell active area (cm²)</td>
<td>29,077</td>
<td>29,499</td>
<td>3,687</td>
<td>8,850</td>
</tr>
<tr>
<td>Actual cell area (cm²)</td>
<td>34,208</td>
<td>34,704</td>
<td>4,852</td>
<td>11,644</td>
</tr>
<tr>
<td>Operating Pressure (barg)</td>
<td>0.02</td>
<td>.06</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Stack production volume (GW/year)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Oxygen limit</td>
<td>&lt;5 ppm</td>
<td>&lt;5 ppm</td>
<td>&lt;5 ppm</td>
<td>&lt;5 ppm</td>
</tr>
<tr>
<td>Moisture content</td>
<td>- 65 ºC dew point</td>
<td>- 65 ºC dew point</td>
<td>- 65 ºC dew point</td>
<td>- 65 ºC dew point</td>
</tr>
</tbody>
</table>
**Design Scenarios** 1 GW Hydrogen Electrolysis Plant BOP

**Major BOP components summary:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Alkaline Electrolyzer Current KPI</th>
<th>Alkaline Electrolyzer Future KPI</th>
<th>PEM Electrolyzer Current KPI</th>
<th>PEM Electrolyzer Future KPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power supply</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>H2 gas/liquid separator</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>O2 gas/liquid separator</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>H2 gas lye scrubber</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>H2 booster compressor</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>De-oxo unit</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>TSA dryer</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>DI water system</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Stack cooling system</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>H2 gas chiller before boost compressor</td>
<td>Included in the boost compressor cost</td>
<td>Included in the boost compressor cost</td>
<td>Included in the boost compressor cost</td>
<td>Included in the boost compressor cost</td>
</tr>
<tr>
<td>H2 gas chiller before TSA dryer</td>
<td>Included in the deoxo unit cost</td>
<td>Included in the deoxo unit cost</td>
<td>Included in the deoxo unit cost</td>
<td>Included in the deoxo unit cost</td>
</tr>
<tr>
<td># set of BOPs in system</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

2019 YY
Current Alkaline: 1 GW Alkaline (2.3 MW stack), 2 sets of BOP, simplified P&ID
Current Alkaline 1 GW Plant Layout

Gas/liquid separation
KOH Scrubber
KOH Scrubber
De-oxo
TSA Dryer
TSA Dryer
Compressor
DI Water
Gas/liquid separation
KOH Scrubber
De-oxo
TSA Dryer
Gas/liquid separation
KOH Scrubber
De-oxo
TSA Dryer

Indoor

230KV Substation
System Control & Offices

Indoor

Total area: 172 m x 450 m = 77,400 m²
Indoor area: 48,880 m²

40 meter
450 meter
60 x 30 meter

100 meter
10 meter

42 meter
150 meter
40 meter
Atmospheric pressure alkaline electrolyzer design:

**Key Parameters**

**Diaphragm**
- Zirfon Perl ® diaphragm
- 0.5 mm thickness

**Anode Electrode**
- Substrate: 0.3 mm Ni Mesh
- Coating: NiAl (56/44)wt; 90 µm

**Cathode Electrode**
- Substrate: 0.3 mm Ni Mesh

**Frame / Structure Ring**
- Machined Carbon steel with PTFE coating

**Cell gasket**
- EPDM
- 1 mm thickness

**Separator Plate**
- Ni coated carbon steel
- 2 mm thickness

US patent: 9,556,529
Anode, cathode, and bipolar plate fabrication processes:

**Anode:**
- SS Mesh Sheet
  - Laser Cutting
  - Press Stamping
  - Sand Blasting
  - Vacuum Plasma Spraying
  - HCl Etching

**Separator Plate**
- Laser Cutting
  - Machining
  - Nickel Coating
  - Assembly
  - Inspection

**Cathode:**
- Ni Mesh Sheet
  - Laser Cutting
  - Press Stamping
Diaphragm and cell frame fabrication processes:

Frame:
- Carbon Steel
  - Plasma Cutting
  - Bending (round)
  - Welding
  - Turning
  - Milling
  - Plasma Cutting II
  - Frame Assembly

Membrane Support Ring:
- Carbon Steel
  - Laser Cutting
  - Nickel Coating
  - Inspection

Membrane:
- Water Jet Cutting
  - PPS Felt
  - Membrane O-ring
Other Stack Scenarios Overview

We designed the stacks based on patents and public available information, etc.

Future Alkaline Scenario:
10 MW Atm. Pressure Alkaline Electrolyzer Stack

Current PEM Scenario:
2.5 MW 30 Barg PEM Electrolyzer Stack

Future PEM Scenario:
10 MW 30 Barg PEM Electrolyzer Stack
We assume there are two sets of BOP systems which make the system easy to maintain and give the benefit of resiliency.

### Major BOP Components

<table>
<thead>
<tr>
<th>Major BOP Components</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power supply</td>
<td>230KV Substation; N+1 transformer design</td>
</tr>
<tr>
<td>H2 gas/liquid separator</td>
<td>Integrated</td>
</tr>
<tr>
<td>O2 gas/liquid separator</td>
<td>Integrated</td>
</tr>
<tr>
<td>H2 gas lye scrubber</td>
<td>Integrated</td>
</tr>
<tr>
<td>H2 booster compressor</td>
<td>~20,000 HP x 2</td>
</tr>
<tr>
<td>De-oxo unit</td>
<td>Pt on Al2O3 pellets at 108 C⁰</td>
</tr>
<tr>
<td>TSA dryer</td>
<td>UOP Molesieve pellets</td>
</tr>
<tr>
<td>DI water system</td>
<td>Electric conductivity, &lt;1 Siemens/cm for PEM; &lt;5 Siemens/cm for Alkaline</td>
</tr>
<tr>
<td>Stack cooling system</td>
<td>~20,000 cooling tons</td>
</tr>
</tbody>
</table>
Estimated 1 GW electrolyzer plant capex fall into the range of between $400/kW and $600/kW.

- Today 1~2 MW electrolyzers’ capex ranges from $600/kW to $2,000/kW
- Modelled 1 GW electrolyzers’ capex ranges from $400/kW to $600/kW\(^1\)

1. Made in US or western Europe countries; cell efficiency is about 85%; output H2 gas purity is 99.99% at 30 barg
2. Units made in China and sold in China only; as low as $200~300/KW
Total Project Cost Discussion

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 (additional 50%~200% project “soft” cost)

• Typical Project “Soft” Cost
  • Permitting
  • Building (including service facilities)
  • Engineering & supervision
  • Installation
  • Legal expense
  • Contract fee
  • Contingency

* Units made in China and sold in China only; as low as $200~300/KW
Thank You!

Contact: Yong Yang
Austin Power Engineering LLC
1 Cameron St,
Wellesley, MA 02482
+1 781-239-9988
+1 401-829-9239
yang.yong@austinpowereng.com
www.austinpowereng.com

Online research report store: http://austinpowereng.com/store.php