Green hydrogen production using low temperature water electrolysis
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Greening High-Temperature Manufacturing
BU-ISE/ITIF Workshop
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Hydrogen is expanding its areas of application

The H2 opportunity

- Conventional industries represents “traditional” hydrogen markets
- Steady demand for hydrogen

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<th>CONVENTIONAL INDUSTRY</th>
<th>MOBILITY</th>
<th>POWER-TO-X</th>
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<td>Food Industry</td>
<td>Mobility (transportation)</td>
<td>Power-To-X (renewable hydrogen)</td>
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<td>Glass Industry</td>
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<td>Polysilicon Industry</td>
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<td>Steel Industry</td>
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<td>Power Industry</td>
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<td>Life support</td>
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- Key market going forward – both within hydrogen production and fueling
- Heavy duty sector developing faster than anticipated – hydrogen now relevant fuel for all forms of mobility
- Decreasing cost of renewables & electrolysers is accelerating market
- Vast opportunities within existing & new sectors

Steady growing market
Markets expected to see fast growth going forward
Nel Hydrogen
Pure Play Hydrogen Company Providing Entire Production/Delivery Value Chain

- Strong technology, field experience & manufacturing capacity

**PEM electrolysers**
Wallingford, USA

- Systems delivered: 2,700+
- Nameplate capacity: ~40MW/year

**Alkaline electrolysers**
Notodden/Herøya, Norway

- Systems delivered: 800+
- Nameplate capacity: ~40MW/year → ~500 MW/year in 2021 → ~2GW/year if fully expanded

**Hydrogen refuelling stations**
Herning, Denmark

- Stations delivered: 80+
- Nameplate capacity: ~300 HRS/year
**Electrolyzer History**

**Cost & Product Context**

**Nel (Norsk Hydro)**
Glomfjord / Norway
1953 – 1991

Largest Nel electrolysis plant built: 135 MW

KOH developed at scale for industrial applications **from the beginning**

Designed for efficiency and low operating cost

Drove low current densities (passive atmospheric system also limits bubble removal)

PEM originally used for **life support** (O₂) in closed environments: Optimized for **very high reliability**

Initial commercial products at small scale
<200kW capacity until 2014

Drove high current densities for low capital cost
Commercial Electrolysis Comparisons

How They Work

- Liquid Alkaline:
  - Liquid electrolyte
  - Enables non-noble metals
  - Lower current density
  - 1 MW stack = ~20 m$^3$

- PEM-based:
  - Solid electrolyte enables H$_2$ at pressure
  - Reliability at scale = KOH
  - Room for cost/efficiency growth
  - 1 MW stack < ~0.5 m$^3$

Traditional Cell

```
H$_2$    O$_2$
```

“Zero Gap” Cell

```
H$_2$    O$_2$
```

- Porous separator
- Electrodes
- Cell Plates
- KOH

- Separator plate
- Flow field
- Porous layer
- Anode catalyst
- Membrane
- Cathode catalyst
- Porous layer
- Flow field
- Separator plate
Scaling of Low Temperature Electrolysis

Cost Reduction through Product Design Scale

**Alkaline**

- 2.5 MW
- 5 MW
- 20 MW
- 100's of MW

**PEM**

- < 10 kW to 0.2 MW
- 2.5 MW
- 10 to 25 MW
Technology directions

Historical CAPEX/OPEX relationship between ALK and PEM technology

- PEM more efficient than alkaline at equivalent current density (CD)
- PEM CAPEX too high low CD
- Potential for lower OPEX
- Reduction in CAPEX through technology development

- Alkaline strategy: increase output, maintain efficiency
  - Leverage chlor-alkali industry knowledge for higher rate

- PEM strategy: increase efficiency, maintain output
  - Leverage fuel cell industry knowledge

Future Result:
Alkaline operates at higher current density
PEM operates at higher efficiency

H₂ Production per Fixed Amount of Energy

H₂ Production per Fixed Electrolyzer Size

Alkaline

PEM

Decreased CAPEX

Decreased OPEX
Cost and Efficiency Tradeoffs*

- Balance-of-plant sourced from standard industries and cost reduction addressed through scale

Engineering rule of “6/10’s”

- Cell stack cost reductions being addressed through roadmap activities

CAPEX

- Largest efficiency losses due to membrane
- Addressed through:
  - Advanced materials (thinner, higher strength)
  - Higher operating temperatures
- These efficiency improvement approaches can have inverse effect on operating lifetime

OPEX

*Values are illustrative only
Electrolysis Cost Reduction Opportunities

PEM Electrolysis Example

Room in all major areas for significant improvement:
First three require materials and process understanding

Analogous Technology Cost Reduction Roadmap Defined for ALK as well
Example of 80% Component Cost Reduction

Fundamental R&D to Prototyping

Component modeling

Accelerated embrittlement

Plate manufacturing

Products from kW to MW scale

Nel scale up and commercialization: MW stack based on same platform
Cost Reduction through Higher Volume Manufacturing
Taking Technology Advancements to Large Scale

• Planned capacity expansion at Herøya
• Fully automated and designed according to lean manufacturing principles
• Large production line improvements already identified, name plate capacity up from ~360 to ~500 MW/year, with further potential
• Test production in new line Q2 2021, start of ramp up Q3 2021
• Room to expand to ~2 GW/yr

• Similar plant capacity plans being contemplated for PEM
Low Temperature Electrolysis Cost Reduction

- PEM
  - Significant cell stack cost reduction achievable through advanced materials and process development
  - Leveraging fuel cell R&D and supply chain
  - Balance-of-Plant (BoP) reductions through product design/scale
- Alkaline
  - Incremental cell stack design improvements to drive output/unit area
  - Investments in manufacturing volume scale up including advanced manufacturing processed & automation
- Power matching
  - Optimization of cell stack size (current & voltage) versus power rectifier specs
  - Interfacing with variable renewable sources
- Supply chain still underdeveloped/immature
  - Not optimized for electrolyzer material requirements
  - Products driven/developed largely by small companies

- U.S. funding programs mainly small and focused ($1-2.5 million/project)
- Have made great progress but not sufficient for integration
- Components must work together to function in the device
- EU making much more investment in supply chain and prototypes
number one by nature
Extra Slides
Already engaged in key projects for the major, future markets
Selected by Iberdrola as preferred supplier for a 20 MW green fertilizer project in Spain

In final negotiations to deliver a 20 MW PEM electrolyser solution to Iberdrola

- Iberdrola, one of the largest electricity utilities in the world, has together with a world-leading fertilizer manufacturer Fertiberia launched a project to establish the largest green hydrogen plant in Europe
- Project includes 100 MW photovoltaic plant, a 20 MWh battery and a 20 MW electrolyser
- Will use hydrogen to produce green fertilizer commencing in 2021
- Nel in final negotiations to deliver a 20 MW PEM solution for the first phase
- Contract award is subject to mutual agreement on the final terms and conditions, technical details, and board approval
Signed letter of intent (LoI) with Statkraft for green hydrogen project in Norway

Up to 50 MW electrolysis to support fossil free recycling steel production

- Statkraft, the largest renewable energy company in Europe partnered up with Celsa Armeringsstål (Celsa), a leading steel producer
- Facility in Mo i Rana which produces reinforced steel from recycling of scrap metal
  - Current production: 700,000 tons/year (equal to two Eiffel towers per week)
  - By exchanging natural gas with hydrogen, CO₂-emissions can be reduced by >60%
- Nel and Statkraft has entered into a LoI for 40 – 50 MW of electrolyser capacity
Supplying electrolysers to HYBRIT, the fossil-free steel project in Sweden

Supplying electrolysers to the currently most advanced fossil free steel project

• Nel has received a purchase order for a 4.5 megawatt alkaline electrolyser which will be used in a pilot plant for fossil free steel production.

• Hybrit Development AB (HYBRIT) is a joint venture owned equally by SSAB, LKAB and Vattenfall.

• The steel industry accounts for 7% of global and 10% of Swedish CO2-emissions.

• Pilot plant will operate in Luleå, Sweden from 2021 – 2024, with target of full-scale implementation by 2035.

Photo: Vattenfall