LEADING THE ENERGY TRANSITION

HYDROGEN-BASED ENERGY STORAGE SOLUTIONS
Electrolysis & Flexibility

SBC Energy Institute
IEA Workshop on Hydrogen Technology Roll-Out in Europe
10th July, 2013
Electrolysis & Flexibility

More than a storage carrier, hydrogen is a bridge between energy systems

SIMPLIFIED VALUE CHAIN OF HYDROGEN-BASED ENERGY CONVERSION

Note: Simplified value chain. End uses are non-exhaustive. Note that the power and gas grids are the main supplier to the residential and commercial end-uses (lighting, heating and cooling, cooking…)

Source: SBC Energy Institute analysis
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Electricity price spreads are too small to enable significant hydrogen production cost reductions through price arbitrage.

LEVELIZED COSTS OF HYDROGEN FOR A GRID-CONNECTED ELECTROLYSIS PLANT

$/MWh_{ch}$

- Reference plant with price arbitrage strategy
- CAPEX - 20% with price arbitrage strategy
- Efficiency + 10% with price arbitrage strategy
- Reference plant buying electricity at annual spot mean

**Assumed electricity price distribution**

($)MWh_{el}$

Annual spot mean: $77/MWh

**Assumed electricity price distribution**

($)MWh_{el}$

- Hourly prices ranked in chronologic order
- Hourly prices ranked in ascending order
- Cumulated average of the hourly prices ranked in ascending order

**Production excess monetization**

- Plant load factor / utilization rate (operational hours in % the year)
- Baseload

**Note:** Illustrative example based on 8.5MW$_{ch}$ electrolysis (5 alkaline stacks of 1.7MW$_{ch}$ each), with total installed system CAPEX: $765/MWh_{ch}$, Efficiency: 79%HHV, Project lifetime: 30 years and real discount rate after tax: 10%.

**Source:** SBC Simulation based on US DoE H2A Model

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Injection of hydrogen into gas networks provides a large end-market in the short to mid term for electrolytic hydrogen

HYDROGEN INJECTION INTO THE GAS NETWORK: GERMAN POTENTIAL AT 5VOL.% BLENDING

Note: Order of magnitude for 5% blending in volume (i.e. ~1.5% in energy) where it does not affect the grid nor the end-use applications. It takes into account the dynamic of the seasonality of the grid (lowest demand in summer of 58 GW_{ch}) for the injection rate (58 GW * 1.5% = 0.870 GW). Electrolyzer could act as negative control reserve (9GW in Germany currently, including 7.6 GW of Pumped Hydro)

Current Electric Storage capacity corresponds mainly to Pumped Hydro Storage capacity, on top of the Hunthorf Compressed Air Energy Storage Facility.

Source: SBC Energy Institute analysis
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Synthesis of methane is promising but constrained by affordable CO₂ sources

SIMPLIFIED MASS FLOW CHART OF HYDROGEN-ENRICHED BIOMETHANE PLANT
kg/h

<table>
<thead>
<tr>
<th>Component</th>
<th>Flow Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>1MW_e</td>
</tr>
<tr>
<td>Electrolysis</td>
<td>19.5 kg/h H₂</td>
</tr>
<tr>
<td></td>
<td>106.7 kg/h of CO₂</td>
</tr>
<tr>
<td></td>
<td>38.8 kg/h of CH₄</td>
</tr>
<tr>
<td></td>
<td>54.5 dry kg/h of biomass residues</td>
</tr>
<tr>
<td>Biogas unit</td>
<td>110 ha. of land</td>
</tr>
<tr>
<td></td>
<td>60 kg/h water</td>
</tr>
<tr>
<td></td>
<td>140 dry kg/h of biomass</td>
</tr>
<tr>
<td></td>
<td>87.2 kg/h of H₂O</td>
</tr>
<tr>
<td>Methanation</td>
<td>77.7 kg/h of CH₄</td>
</tr>
<tr>
<td></td>
<td>~ x2</td>
</tr>
<tr>
<td>Waste Heat</td>
<td>230kW_th</td>
</tr>
</tbody>
</table>

Notes: 1: Biomass feedstock is a maize silage of 5kWhch/kg of dry matter, cultivated with a land yield of 0.63MWch per km². 2: The anaerobic digestion of maize silage requires heat and has an total efficiency of 68.7%; 3: Thermochemical methanation at 300°C and 77.7% hydrogen-to-methane efficiency

Source: SBC Energy Institute Analysis

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Fuel synthesis from water, electricity and carbon, extends the market potential for electrolysis

**POWER-TO-SYNFUELS' PATHWAYS FOR H-C-O SYNFUELS PRODUCTION**

- **ELECTROLYSIS**
  - CO₂ + H₂O electrolysis
  - CO₂ + H₂ co-electrolysis
  - H₂O electrolysis

- **CO₂ HYDROGENATION**
  - Formic acid synthesis
  - Methanol synthesis
  - CO₂ Methanation

- **OXYGENATED SYNFUELS**
  - Formic acid (HCOOH)
  - DME (CH₃OCH₃)
  - Methanol (CH₃OH)

- **HYDROCARBON SYNFUELS**
  - Methane (CH₄)
  - CnH₂(n+1) liquid hydrocarbon

Source: SBC Energy Institute Analysis

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Hydrogen is an essential energy carrier to facilitate the energy transition

- **Hydrogen is an enabler for high intermittent renewable penetration:**
  - Balance deficit (directly or coupled with gas)
  - Ensure security of supply with massive storage
  - Monetize intermittent surplus

- **Hydrogen facilitates the decreased carbon intensity of fossil-fuel based energy systems:**
  - Hydrogenate fossil fuels and maximize land use for biofuel / biogas production
  - Recycle carbon captured from CCS
  - Leverage current infrastructure

- **Hydrogen business cases are not yet profitable in the absence of green supports except for a few early markets:**
  - A few early markets can provide short-term business cases (e.g. back-up for telcom towers)
  - Costs reduction on electrolysis side are a pre-requisite (learning curve, manufacturing…)

Source: SBC Energy Institute analysis
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SBC Energy Institute is a non-profit organisation that promotes understanding of key global energy issues

INSTITUTE IDENTITY

- Focused on crossover technologies related to the energy space
- Registered as a non-profit organization: all studies publicly available
- Governed by its own Board Members, including external people:
  - Claude Mandil, Former Executive Director of the International Energy Agency
  - Dr. Adnan Shihab-Eldin, Former OPEC Acting Secretary General.

HYDROGEN STUDY

- One year effort on electrolytic hydrogen
- Release expected Q4 2013
- For more information:
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Appendix
Wind and Solar PV are challenging to integrate on the power grid

WIND & SOLAR GENERATION VS. DEMAND IN NORTHERN GERMANY
MW, December 2012 on the 50Hertz Operated Grid

Source: SBC Energy Institute Analysis based on 50Hertz data archive (Wind and Solar Actual In Feed 2012, Control Load 2012)
Electricity price spreads are too small and not frequent enough to enable significant hydrogen production cost reductions through price arbitrage.

**LEVELIZED COSTS OF HYDROGEN FOR A GRID-CONNECTED ELECTROLYSIS PLANT**

€/MWh\(_{ch}\), based on EPEX Spot price 2012 for Germany

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**Note:**

EPEX SPOT intraday trading “index price for each hour of 2012. Intraday SPOT and day-ahead SPOT auctions have been found to give very similar price duration curves. Electrolysis assumptions is based on the US for a 10MW alkaline plant with total installed system CAPEX: $848/MWh\(_{ch}\). Efficiency: 78%. Project lifetime: 30 years. Real discount rate after tax:10%.

**Source:** SBC Simulation based on EPEX Market Data, US DoE H2A Model
Due to a poor round-trip efficiency, power-to-power is likely to be limited to niche applications.

LOSSES ALONG THE RE-ELECTRIFICATION VALUE CHAIN OF A H₂-BASED STORAGE
In MWh, based on a 100MWh storage system, with no hydrogen transport.

![Diagram showing round-trip efficiency of different storage technologies.]

- **84% eff.** Underground storage (95% eff.)
- **77% eff.** Pressurized tanks (85% eff.)
- **60% eff.** Turbine
- **30% eff.** Fuel Cell

- **75% Pumped hydro storage (today)**
- **55% Compressed air energy storage (today)**
- **48% Hydrogen, forecast**
- **20% Hydrogen, today, low range**

**Round-trip efficiency**