Levelized Cost of Electricity

Source: IRENA Renewable Cost Database and Auctions Database.

IRENA, January 2018, Renewable Power Generation Costs 2017
5 GW Mohammed Bin Rashid Al Maktoum Solar Park in Dubai

• 700MW CSP, 15 hours storage
• $3.9 billion investment
• Central Tower
• Parabolic Troughs
• Auxiliary solar PV
• Tariff 7.3 ct/kWh
• PPA 35 years
• Dispatch: between 4pm and 10am

100 MW
3x200 MW
4x33 MW
7.3 ct/kWh
35 years
Surface needed to produce all the world’s energy 556 EJ = 155,000 TWh

10% SOLAR AUSTRALIA

1.5% WIND PACIFIC OCEAN
Tokyo Olympic Games 2020

Hydrogen Pipelines (~2035)

Hydrogen Shipping (~2025)
Offshore Wind Development Germany
Eemshaven; The Energy Harbor

Norned Cable 700 MW
Cobra Cable 700 MW (2019)
Gemini Offshore Wind Farm 600 MW
Onshore Wind Farms > 275 MW
Nuon Magnum power plant 1,320 MW
RWE Coal fired power plant 1,560 MW
Engie Gas fired power plant 2,450 MW
Cable Inland 4,000 MW
Expansion to 5,610 MW
Electricity and Gas Transport Grid

Capacity 20 GW HV + 6 GW MV

Capacity 350 GW
Hydrogen backbone the Netherlands 2030

- Low caloric gas pipelines will become available, because the Groningen gas field has to reduce production to 0 in 2030
- 1 Transport pipeline capacity about 10-15 GW
- New hydrogen pipeline connections to offshore wind farms
- Connections to Germany (Ruhr-area, Bremen-Hamburg and Belgium (Antwerp, Zeebrugge)
- European connections to France, Austria, Italy, etc.

Existing gas pipeline
Retrofitted compressors
New hydrogen pipeline
Industrial cluster
Hydrogen storage in salt cavern
# Hydrogen production

<table>
<thead>
<tr>
<th>Source</th>
<th>Process</th>
<th>Efficiency Today</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>Steam reforming</td>
<td>70-75%</td>
</tr>
<tr>
<td>Bio Gas</td>
<td>Auto-thermal reforming</td>
<td>&gt;75%</td>
</tr>
<tr>
<td></td>
<td>Solid Oxide Fuel Cell</td>
<td>80% (40-40)</td>
</tr>
<tr>
<td>Coal/Oil</td>
<td>Gasification</td>
<td>56%+ (=syngas)</td>
</tr>
<tr>
<td>Biomass</td>
<td>Gasification</td>
<td>44%+ (=syngas)</td>
</tr>
<tr>
<td>Electricity + Water</td>
<td>Electrolysis</td>
<td>75-80% (90% exp.)</td>
</tr>
<tr>
<td></td>
<td>Alkaline and PEM</td>
<td></td>
</tr>
<tr>
<td>Sunlight + Water</td>
<td>Photoelectrochemical</td>
<td>14% (lab)</td>
</tr>
</tbody>
</table>
20 MW Alkaline Electrolyser

<table>
<thead>
<tr>
<th>5 MW module</th>
<th>20 MW module</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design capacity $\mathrm{H}_2$</td>
<td>1000 Nm$^3$/h</td>
</tr>
<tr>
<td>Efficiency electrolyser (DC)</td>
<td>$&gt; 82%_{\text{e}}$</td>
</tr>
<tr>
<td>Power consumption (DC)</td>
<td>max. 4.3 kWh/Nm$^3$ $\mathrm{H}_2$</td>
</tr>
<tr>
<td>Water consumption</td>
<td>$&lt; 1/\text{Nm}^3$ $\mathrm{H}_2$</td>
</tr>
<tr>
<td>Standard operating window</td>
<td>10% - 100%</td>
</tr>
<tr>
<td>$\mathrm{H}_2$ product quality at electrolyzer outlet</td>
<td>$&gt; 99.99%$ purity (dry basis)</td>
</tr>
<tr>
<td>$\mathrm{H}_2$ product quality after treatment (optional)</td>
<td>as required by customer, up to 99.9999%</td>
</tr>
<tr>
<td>$\mathrm{H}_2$ product pressure at module outlet</td>
<td>$\leq 500$ bar</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>up to 95 °C</td>
</tr>
</tbody>
</table>

* NWV – calculated with reference to higher heating value of hydrogen.
All values may vary depending on operating conditions.
IMAGINE THE WALLS OF YOUR HOME COULD GENERATE CLEAN ENERGY
Gas and electricity consumption in the Netherlands

Solar power production in Germany

**SOLAR POWER GENERATION IN GERMANY 2015**
Solar energy sets a new all-time summer record and beats peak power output

- 36.8 bn kWh in 2015
- 34.9 bn kWh in 2014
- Summer record 14.1 bn kWh
- Peak power 25.8 m kW

Source 2014, 2015: Fraunhofer ISE, EEX
Hydrogen storage in Salt Caverns

Salt formations and caverns in Europa

1 salt cavern can contain 6,000 ton hydrogen
Equivalent of 240 GWh or 17 million home batteries (14 kWh)

Red colored caverns in use for natural gas storage
Green Hydrogen Markets

Chemical

Feedstock/Steam

Electricity Balancing

Residential area

- Water
- H₂ production
- Excess Electricity
- In case of shortage
- H₂ refueling

Transport

Heating

NUON Magnum power plant

Town gas Utrecht 1862–1959

> 50% hydrogen in town gas

Leeds city gate H21

TU Delft
The Future is Electric!

Tesla Model S

Toyota Mirai
Fuel cell cost

Fuel cell cost @ 500,000 units

FC System Cost ($/kWnet)

- 2006: 124
- 2007: 106
- 2008: 81
- 2009: 69
- 2010: 59
- 2011: 57
- 2012: 55
- 2013: 55
- 2014: 55
- 2015: 53
- 2020: 40
- Ultimate: 30

Targets:
- Weight: -48%
- Volume: -43%
- Power: +26%

TOYOTA

2008 FUEL CELL STACK

2016 FUEL CELL STACK

Future Energy Systems
Hydrogen versus petrol safety

0 seconds
Hydrogen          Petrol

3 seconds (ignition)
Hydrogen          Petrol

60 seconds
Hydrogen          Petrol

90 seconds

Town Gas production Utrecht 1862-1959

> 50% hydrogen in town gas
Remeha Hydrogen Boiler
Ene Farm: Home Fuel cell systems Japan

- Japan 200,000 sold 2017
- Aim 1.4 million end 2020
- Panasonic with Viesmann started sales in UK and Germany in 2017
- Kyocera makes systems for restaurants, hotels, etc.
The Hydrogen Cycle

ELECTROLYSIS

SOLAR WIND HYDRO

ENERGY IN

H₂O

O₂

ENERGY OUT

H₂O

O₂

H₂

H₂

H₂

H₂

TRANSPORT & STORAGE

COMBUSTION/ FUEL CELL

Future Energy Systems
Defying Death Valley
Further reading about hydrogen
www.profadvanwijk.com