The Equinor way; natural gas reforming and carbon capture and offshore storage (CCOS)

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Climate-neutrality 2050: GHG emissions reduction in Germany
Low Carbon Solutions
Gas is a cost efficient enabler
… to a carbon neutral energy system

Gas displacing more carbon intense fuels in transport, heating and power

Gas combination with renewables (gas and electricity)

Hydrogen and renewable electricity smartly integrated
The Challenge and the Tool-Box

European Energy-Mix 2018

Cost Efficiency EL : MOL
Energy Transport 1 : 10
Long Term Storage 1 : 100

Clean EL

MOLE-CULES

- Affordable
- Reliable and Safe

Green Hydrogen and Power to X

- Electrolyser and Fuel Cell
- CCS

Blue Hydrogen

- Permanent CO2 Storage (CCS)
- Gas Reformer w/CCS

Renewable EL

- Renewable EL
- Improve Carbon Efficiency

Zero Carbon EL

- Nuclear
- Switch from Coal …

Improve Carbon Efficiency

- … to Natural Gas

Hard-to-Decarbonize Industry

Affordable Gas Reformer w/CCS

Improve Carbon Efficiency

- Electric power
- Green Hydrogen and Power to X

High-Carbon EL

- Hydrogen fired EL power
## CCOS and Clean Hydrogen Portfolio

### Market Build
(2019 – First Operations)

<table>
<thead>
<tr>
<th>Year</th>
<th>Project</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>2023</td>
<td>Northern Lights</td>
<td>CCS for industry</td>
</tr>
<tr>
<td>2023</td>
<td>HyDemo Norway</td>
<td>Hydrogen for maritime</td>
</tr>
<tr>
<td>2026</td>
<td>Clean Steel</td>
<td>Hydrogen for industry (steel)</td>
</tr>
<tr>
<td>2026</td>
<td>Zero Carbon Humber</td>
<td>Hydrogen for industry, Chemicals, Synthetic fuels, BECCS, Hydrogen power</td>
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<tr>
<td>2026</td>
<td>Clean Gas Project</td>
<td>Hydrogen power</td>
</tr>
<tr>
<td>2027</td>
<td>H2 Magnum</td>
<td>Hydrogen power</td>
</tr>
</tbody>
</table>

- **Applications:**
  - CCS for industry
  - Hydrogen for maritime
  - Hydrogen for industry (steel)
  - Hydrogen for industry
  - Chemicals
  - Synthetic fuels
  - BECCS
  - Hydrogen power
  - Post-combustion CCS power generation
  - CCS for industry
  - BECCS
  - Hydrogen production

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6 | LCS Strategy Implementation

Confidential | 27 September 2019
## Blue Hydrogen – What Will it Cost?

<table>
<thead>
<tr>
<th>Sector</th>
<th>Price Premium</th>
<th>Compared to …</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>+25%</td>
<td>Grey Hydrogen</td>
</tr>
<tr>
<td>Heat</td>
<td>+50%</td>
<td>Natural Gas</td>
</tr>
<tr>
<td>Power (on demand)</td>
<td>+100%</td>
<td>Natural Gas</td>
</tr>
</tbody>
</table>
H2M – Magnum, Netherlands

- Energy: 8-12 TWh
- CO2 emissions reduction of 2 Mton/year
- Utilise existing gas power plants and gas infrastructure
- Switch fuel from natural gas to clean H2
- Clean, flexible electricity as back-up for solar and wind
- Launch large-scale H2 economy

- Partners: &
Autothermal reforming – an efficient means of hydrogen production

Autothermal reforming (ATR) is a well-established process for large-scale industrial production of hydrogen based on natural gas.

- In this process, the carbon dioxide is put under high pressure. This allows separation rates up to 94%.

- ATR has optimized efficiency due to the combined advantages of two processes: Oxidation (providing energy from heat) and steam reforming (high hydrogen yield) complement each other very well.

- Autothermal reformers take up less space than steam reformers.
Decarbonization Process - Selected Technologies

**ATR and Amines**

*Hydrogen Plant*

- Air Separation Unit
- Natural Gas Purification
- Syngas Generation (ATR)
- CO Shift and heat recovery
- CO₂ Removal (activated MDEA)
- CO₂ Liquefaction

**Inputs:**
- Air
- Natural Gas

**Outputs:**
- Nitrogen
- Hydrogen
- Liquid CO₂

**Utilities incl. heat and power**
Natural Gas Compression and Desulphurisation

- Increasing the gas pressure to meet $H_2$ delivery pressure
- Cleaning out impurities from the gas that will harm the process
ATR - Reforming process (Syngas generation)

H₂ production:
- Natural gas, steam and Oxygen reacts forming Syngas (CO+H₂)
- Followed by CO conversion to CO₂ and H₂ and heat recovery (steam)
- ASU – Air Separation Unit (Oxygen and Nitrogen) – high power demand
- Steam is used for power generation

Ending up with a mix of H₂ + CO₂
CO₂ Removal and CO₂ Liquefaction

Separate the CO₂ from H₂:

- Amine CO₂ removal technology uses an amine based solvent to absorb CO₂ from the process gas

- The CO₂ is recovered and sent to the CO₂ liquefaction unit meeting the transport specification before going into storage waiting for transportation
Hydrogen Distribution and Export

- Hydrogen used in the hydrogen plant to produce heat and power and for process recycle

- Hydrogen to “Gasunie” for further distribution to Magnum and/or pipeline to cavern and 3rd party
Norther Lights - a European “open source” network for CO2 removal and permanent offshore storage
Northern Lights - Project status & future

• **Transport, intermediate storage & pipeline**
  FEED to be delivered Q3 2019

• **Storage**
  – Use permission Nr 001 given for “Aurora” south of Troll
  – Confirmation well to be drilled November 2019, subsea equipment is being built

• **Potential beyond anchor customers**
  In dialogue with 15 possible users in 8 European countries

• **Investment decisions**
  Planned for December 2020 (State budget)

• **Operational 2023**
  Then all emitters have a storage solution – start capture!
Northern Lights: a solution for European heavy industry

Large potential in energy-intensive industrial sectors:
• Hydrogen and power from natural gas
• Waste incineration
• Cement
• Biomass and biofuel
• Steel
• Refinery

Equinor and Heidelberg Cement: signing of the Northern Lights MoU

Northern Lights is within reach of about 350 of the most ‘attractive’ European facilities amounting to 300 million tons of CO2
H21 North of England

System approach to decarbonise residential heating and distributed gas

Energy: ~85 TWh (12.5% of UK population) / 12 GW hydrogen production

CO2 emissions reduction: 12.5 Mt CO2 pa

CO2 storage offshore UK / Norway

8 TWh (seasonal) hydrogen storage

CO2 footprint 14.5 g/KWh

Unlimited system coupling

CAPEX: £23 billion
H21 NoE supply concept

Greenfield Hydrogen Facility
- Location: Easington
- Capacity: 12 GW
- Configuration: Multi train, self-sufficient with power

Hydrogen Storage
- Location: Aldbrough
- Capacity: 8 TWh
- Configuration: 56 caverns at 300,000 m³

CO2 Storage
- Location: Bundter
- Capacity: +600 Million @ 17 mtpa
- Configuration: Saline aquifers
# H21 - What will it cost?

## 2035 Residential Prices

<table>
<thead>
<tr>
<th>Source</th>
<th>Price 2035 (BEIS Projection)</th>
<th>CO2 Footprint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>£200/MWh</td>
<td>50 g/KWh</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>£50/MWh</td>
<td>200 g/KWh</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>£75/MWh (H21)</td>
<td>15 g/KWh (H21)</td>
</tr>
</tbody>
</table>
Zero Carbon Humber

Our vision
H2morrow: Building a platform for clean hydrogen in Germany
H2morrow pilot region

Why Nordrhein Westphalen?

• Well developed gas infrastructure
• Parallel L-gas and H-gas pipelines
• Available salt caverns for storage
• The Rhein with access to the North Sea
• Industrial heartland of Germany
• Industry well aquainted with H2
• Already a large market for grey H2
• Large CO2 emissions to be abated
• Strong will to retain industry & jobs
• Huge H2 market potential in other sectors
• More than 10 million people in pilot region
• Vantage point for further expansion to the south and southeast
CCS Projects:
Northern Lights - Decarbonising industry
H21 North of England – Decarbonising heat
H2M-Magnum – Decarbonising electricity
Zero Carbon Humber - Decarbonising industry
H2morrow – Decarbonising the Ruhr area

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