Decarbonisation of Natural Gas
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ENERGETIKA Nov 14 2018
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EU Decarbonisation Targets

- Ambitious EU Targets
- 2050 low carbon economy target relies on renewables producing electricity, replacing gas/coal/oil
- Strategy, an electrically powered EU for all sectors Res/Com, industry, powergen, transport, heat
- EU believes gas (CH₄) has no long term future without CCS
- EU strategy could strand large quantities of gas and infrastructure assets

EU climate targets

By the year:
- 2020
- 2030
- 2050

- 20% reduction in GHG emissions³
- 20% EU energy from RES
- 20% improvement in energy efficiency
- >40% reduction in GHG emissions
- >27% EU energy from RES
- 27% improvement in energy efficiency
- 60% reduction in GHG emissions
- 80-95% reduction in GHG emissions

³ GHG emission reduction targets from 1990 levels (source: Eunergas)
US NETL Study: CO2 avoided cost $94/te, Capture 71$/te (75% of cost)

- CCS projects are limited globally
- EU CCS projects are expensive
- Low EU ETS CO₂ prices hampered CCS
- Typically CCS is post combustion
- CCS reduces powergen efficiency and is expensive
- Capture element 75% of the cost
- NETL study:
  - 601 MW F-class CCGT in USA
  - CO₂ capture & compression 28MW
  - Auxiliary power demand increase +31 MW
  - Total power for CCS 59MW (9.8% of 601MW)
  - Efficiency w/o CCS 51.5%*
  - Efficiency with CCS 45.7%*
  - Efficiency loss CCS 5.8%*
- Avoided CO₂ cost $94/te ~10 times higher than EU ETS CO₂ price
CCS Summary

- Clean energy investment over 100 times CCS

- CCS post combustion is expensive
  - Low flue stack pressure increases CO2 compression requirement for injection
  - Flue stack has a high (N₂) content which requires rejection
  - CO2 gathering system required and typically offshore pipelines or CO2 ships to a reservoir/ re-injection sink

- The capture element of CCS accounts for the majority of the cost in the CCS chain.*
  - “In power generation, for example, 70-90 % of the overall cost of a large-scale CCS project can be driven by expenses related to the capture & compression process”

Source: *Global CCS Institute THE GLOBAL STATUS OF CCS | 2016
https://www.globalccsinstitute.com/
Steam Methane Reforming (SMR)

- SMR production of H₂ is a mature technology
- Most H₂ produced globally is from natural gas
- H₂ cost depends heavily on the feed gas price/cost
- H₂ produced by electrolysis is typically uncompetitive
  - Requires 1.3-2.0 kwh of electricity for 1 kwh of H₂
  - If electricity for electrolysis is generated from CH₄ it requires 2.5-4 kwh of gas for 1 kwh of H₂
  - SMR requires only ~1.2 kwh of CH₄ to produce 1 kwh of H₂
SMR Produced $H_2$ Export Concept

- Construct SMR & CCS in Yamal/Nadym-Pur-Taz region or onshore NL
- $H_2$ supply to EU or local NL market when NL stops exporting
- Inject CO$_2$ bi-product into depleted fields or use for enhanced oil recovery
- Potential for other pipeline gas producers: Norway, Algeria, Libya supplying Europe
- SMR limited* at LNG regas terminals unless CO$_2$ re-exported by ship

*As 2.5 tonnes CO$_2$ are produced per tonne CH$_4$ , liquefied CO2 export requires many additional ships than the unladed/ballast return voyage
H₂ Competitive with RW/Nuclear

- Offshore wind power generation is promising but still “out of the money” at current EU ETS CO₂ prices
- H₂ with zero CO₂ at the burner tip can compete using existing powergen plant
- Hydrocarbon based power generation loses competitiveness vs RW if CO₂ prices increase as expected

"German & UK wind auction

Bundesnetzagentur (BNetzA) announced successful bids in first auction for offshore wind farms 1,550 MW. "Avg. price 4.4 ct/kWh (44€/MWh) 13 April 2017

ScottishPower Renewables received planning approval for the East Anglia offshore windfarm up to 1,200 MW. Price £119/MWh (€131/MWh). Competitive auction process run by the British government. (7th August 2017)

ScottishPower price double current market prices, as is the Hinkley Point C nuclear facility at 98.5£/MWh (~111€/MWh)

Headline prices are not comparable due to German grid paying for the offshore transmission connections
An EU All Battery Electric Vehicle (BEV) Future Costs

<table>
<thead>
<tr>
<th>Capital cost 2018 monies Trillion €</th>
<th>High</th>
<th>Low (50%)</th>
<th>Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional RW Powergen</td>
<td>0.8</td>
<td>0.4</td>
<td>375 GW, 2Bn€/GW, 15% vehicles charge/day @10 kw</td>
</tr>
<tr>
<td>Strengthen Power Transmission</td>
<td>0.1</td>
<td>0.1</td>
<td>375 GW, 0.3Bn€/GW</td>
</tr>
<tr>
<td>Strengthen Power Distribution</td>
<td>0.1</td>
<td>0.1</td>
<td>&quot;</td>
</tr>
<tr>
<td>Batteries for 250 million vehicles</td>
<td>7.5</td>
<td>3.8</td>
<td>Battery 300€/kwh(installed), 100kwh(~400km range)</td>
</tr>
<tr>
<td>Public charging stations</td>
<td>0.04</td>
<td>0.04</td>
<td>1 million points, 40,000€/point (fast 100kw, 1 hr charge)</td>
</tr>
<tr>
<td>Home charging Stations</td>
<td>0.1</td>
<td>0.1</td>
<td>~100 million points, 800€/charging point (10 kw)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8.6</strong></td>
<td><strong>4.4</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Capital cost €k/vehicle</strong></td>
<td><strong>34.4</strong></td>
<td><strong>17.4</strong></td>
<td>250 million BEVs in EU</td>
</tr>
</tbody>
</table>

- Transport is a key sector (~25% of EU CO₂), reduction essential to meet EU target
- An all electric BEV future in EU is likely to be very expensive, requiring additional RW powergen, transmission/distribution and charging points
- Majority of the 8 trillion € capital cost for an all BEVs future is the battery cost
- Battery cost is a function of the battery size (Tesla model S is ~100kwh), many vehicles will have smaller batteries, but trucks/busses require larger batteries

Comments:
- Considers only vehicle battery cost not the whole cost of the vehicle (IC vehicles would be replaced over time)
- BEV battery cost may decline, short range vehicles battery may require 50 kwh
- Trucks/busses etc. (15% of EU vehicles) require larger batteries than cars
- Additional RW Powergen assumes no additional electricity storage, modulation provided by existing powergen
- Additional grid scale battery storage would reduce additional RW Powergen requirement
- Additional strengthening transmission/distribution and RW powergen if gas & oil heat sectors electrified
- Transmission/distribution costs estimated from UK National Grid data, each EU country may vary significantly

Sources: Eurelecric, Lazard, Nation Grid Study, Tesla, Plugincars.com, Greenbiz
BEV Lithium/Cobalt cost vs $H_2$ Fuel Cell

- Raw Lithium & Cobalt prices have increased with demand
- BEV battery raw material costs may not decline, even if production costs decline
- Without battery cost reductions, $H_2$ fuel cells become more attractive
- Tesla battery (~550kg) is ~7,000 AA batteries, intelligently packaged
- BEVs are a very large bet on the future
- A 2017 KPMG survey found “most senior automotive executives believe BEVs will ultimately fail, with $H_2$ offering the true breakthrough for electric mobility”

Fuel Cell Electric Vehicles (FCEVs)

- Major auto manufacturers produce FCEVs
  - Toyota Mirai, Hyundai Nexo, Honda Clarity
- Lack of a H₂ grid/infrastructure & high H₂ prices have limited FCEV introduction

<table>
<thead>
<tr>
<th></th>
<th>£/kg</th>
<th>€/mbtu</th>
<th>€/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>10</td>
<td>84</td>
<td>287</td>
</tr>
<tr>
<td>High</td>
<td>15</td>
<td>126</td>
<td>430</td>
</tr>
</tbody>
</table>

IHS forecasts that by 2027 the number of FCEVs available on market will increase to 17
IHS forecasts production of FCEVs will rise at a CAGR of 31% from 2016 to 2027

“FCEVs offer shorter refuelling times and longer ranges than battery electric vehicles but must overcome infrastructure issues to turn those advantages into a strong presence in the mainstream market”

- FCEVs offer new sector demand for SMR produced H₂. EU road transport 290 mtoe 2014~1/3rd of EU total final consumption
- Transportation market for H₂ extends to busses and trains
H₂ SMR Capital Costs

- US study estimates large scale SMR capital cost at ~200$/kg/d
- Capital cost translates to PV10% ~4.8$/MWh or 1.4$/mbtu of H₂
- Efficiency 65-70%
- CH₄ feed gas, opex, CCS and transportation to market are additional (see example)
- Feed gas and transport costs vary by location
- CCS cost assumed onshore similar to NETL study
- SMR capex ~25Bn$ for 40 mta H₂, equivalent to 150 BCMA CH4 export to EU

### Example H₂ cost PV10%

<table>
<thead>
<tr>
<th></th>
<th>H₂ $/te/yr</th>
<th>$/MWh</th>
<th>$/Mbtu</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMR Capital Cost</td>
<td>4.8</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>CO₂ storage @20$/t</td>
<td>3.6</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Opex (5% capex)</td>
<td>2.3</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Feed CH₄ (2$/mbtu)</td>
<td>7.1</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>Transport (estimate)</td>
<td>6.8</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td><strong>Total Delivered cost</strong></td>
<td><strong>24.7</strong></td>
<td><strong>7.2</strong></td>
<td></td>
</tr>
</tbody>
</table>
SMR H₂ Production & CCS Pre-Combustion Benefits

• An all-electric renewable EU future risks putting “all the eggs in one basket” with inherent natural disaster and cyber threats to the grid

• SMR is a mature technology, large scale CCS/SMR brings economies of scale

• CO₂ sinks nearby (depleted reservoirs) in Russia. No expensive offshore pipelines for CO₂ injection (needed in Norway) or CO₂ ships

• No N₂ rejection from post combustion gases for a rich CO₂ stream for injection

• Cost effective CO₂ injection with high pressure CH₄ supply >100+ bar vs CO₂/N₂ post combustion ~1bar

• H₂ will command a “clean” premium vs CH₄, CCS may qualify for EU CO₂ credits

• Low cost methane feedstock & fuel gas Russia vs EU

• H₂ supply utilises existing investments in powergen, industry, households

• H₂ grid could facilitate growth in FCEVs, or supply clean zero emissions powergen for BEVs if BEVs become mainstream
De-carbonisation of Natural Gas

Issues

- Technical solution (inhibitors/coating etc.) to manage H₂ pipeline embrittlement (town gas was ~60% H₂)
- Reduction in p/l capacity (H₂ vs CH₄) due to lower H₂ mbtu/vol density
- Underground storage compatibility
- Long term SPAs needed to support investments
- Low EU ETS CO₂ price
- Conversion of end user equipment
- Managing parallel CH₄ & H₂ systems during a transition
Potential Study Deliverables

- €/mbtu of H₂ produced via SMR
- Identify technical solutions for H₂ pipeline embrittlement
- CCS pre-combustion costs & potential reservoir sinks (Bn t/yr CO₂)
- H₂ pipeline embrittlement technical solutions and costs
- Market for H₂ powered vehicles (BCMA CH₄ & H₂)
  - Road transport EU demand is ~300MTA (500 BCM CH₄)
- Potential time scale to convert to H₂
  - If faster than RW/BEV route, identify saving in billion tonnes/CO₂/yr vs RW implementation
- Total cost (€Bn) of SMR/CCS vs an all-electric future
- Breakeven H₂ vs RW powergen cost, incl’ network upgrades for power transmission, distribution and storage etc.
- Optimal mix of RW & SMR/CCS
Conclusion

An all electric renewable future will likely strand billions of €s of gas reserves in Russia, Norway, NL & UK etc. and existing plant/infrastructure, requiring substantial RW powergen/power infrastructure investments.

It puts “all the eggs in one basket” with inherent natural disaster and cyber threats to the grid

It’s a bet on large cost reductions in BEV technology, RW powergen & grid battery storage (RW interruptibility)

Gas needs effective advocacy

SMR H₂ production combined with pre-combustion CCS, collocated with large gas production should be studied

“Do not go gentle into that good night” Dylan Thomas, 1914 - 1953
Mark James

Mark has over 40 years’ international experience in the upstream and midstream oil, gas and power business, focusing on gas and LNG, origination, infrastructure, long term contract price review negotiation and international arbitration. He has advised and managed business strategies, transactions, and dispute resolution matters involving market, commercial, financial, and regulatory issues for gas, LNG, helium and conventional electricity generation. He has broad experience with negotiation and commercial analysis including government fiscals and Tax Pay on Behalf (TPoB), international arbitration and testimony for gas and LNG disputes heard before international arbitration panels.

Mark has led/advised on numerous LNG and gas negotiations, price reviews/arbitrations and 2 helium negotiations, with most of the major LNG and gas companies in Europe and worked closely with many of the European and US consultancies and law firms.

Prior to joining BRG, Mr James spent over 35 years with ExxonMobil in various international positions, the last 8 of which were advising RasGas, an ExxonMobil joint stock company with Qatar Petroleum and major LNG and Helium producer. Before that he spent 3 years at Schlumberger as a wireline General Field Engineer in the Middle East and Colombia. He has lived and worked in Europe (UK, Norway), USA, Saudi Arabia, Qatar, Colombia, Pakistan, Dubai, Kuwait and Iran.

Mark has Engineering Science Masters from Oxford University and is a member of the ICC, LCIA & AIPN.

Summary of LNG, gas, infrastructure & power negotiation and modelling analysis

- LNG & gas long term contract negotiation, origination and renegotiation analysis and strategy. This includes assessing the embedded value of optionality, price formulae and projections of the total value of the contract, including fiscal and Tax Pay on Behalf (TPoB) analysis of pipeline gas and LNG projects like Qatargas II (QG II 15 mta LNG contract to UK South Hook) and Shtokman Russian LNG

Large infrastructure projects like:
- Core Venture 1 (Saudi Arabia) a 25$bn investment for power and desalination, including fiscal and Tax Pay on Behalf (TPoB) regimes.
- Gassled 5$Bn Norwegian gas pipeline system merger, revenue, valuation and sale
- Sale of Etzel gas storage facility in Germany with Norwegian tax
Thank You
Back up
Carbon Capture and Storage (CCS) Global Projects

- CCS projects are limited globally
- EU CCS projects are expensive
- Low EU ETS CO₂ prices have hampered development
- Typically CCS is post combustion

![Map of global CCS projects](https://www.globalccsinstitute.com/)

**Figure 3** A significant task for CCS deployment is required by 2040 under the IEA 2DS

**Global Status of CCS**
November 2016

- 38 large-scale CCS projects – combined CO₂ capture capacity of approximately 70 Mtpa:
  - 21 projects in operation or construction (40.3 Mtpa)
  - 6 projects in advanced planning (8.4 Mtpa)
  - 11 projects in earlier stages of planning (21.1 Mtpa)

Source: [https://www.globalccsinstitute.com/](https://www.globalccsinstitute.com/)
Tesla Model S: 75 or 100kwh UK Price

- Tesla Model S battery options provide an insight into the commercial cost of the battery, which is much higher than many articles

<table>
<thead>
<tr>
<th>Model S</th>
<th>75 kWh Battery</th>
<th>100 kWh Battery</th>
<th>75 kWh Battery</th>
<th>100 kWh Battery</th>
<th>75 kWh Battery</th>
<th>100 kWh Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paint</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof &amp; Wheels</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Interior</td>
<td></td>
<td></td>
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</tbody>
</table>

**Model S: 75 kWh Battery**
- 75 kWh battery
- £70,950

**Model S: 100 kWh Battery**
- 100 kWh battery
- £93,150

<table>
<thead>
<tr>
<th>UK Cash £</th>
<th>75</th>
<th>100</th>
<th>100 vs 75</th>
<th>£/kwh</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70,950</td>
<td></td>
<td></td>
<td>93,150</td>
<td>22,200</td>
</tr>
<tr>
<td>888</td>
<td></td>
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</tr>
</tbody>
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*Please note: All prices include VAT. End of year delivery, subject to availability.