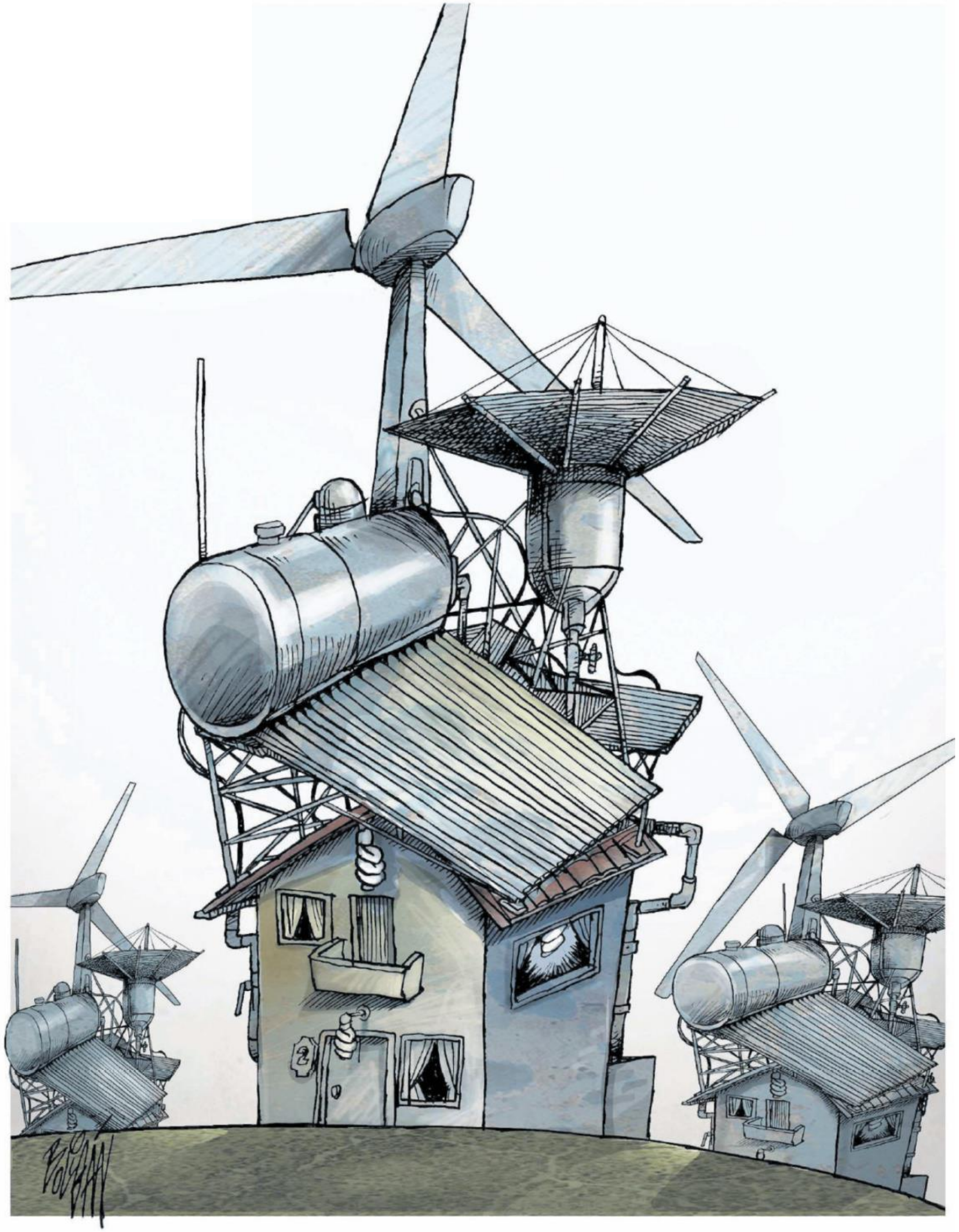
Should we pave the way for CO_2 recycling?

- some remarks and concerns -



Source drawing: NRC-HB, 19 August 2013

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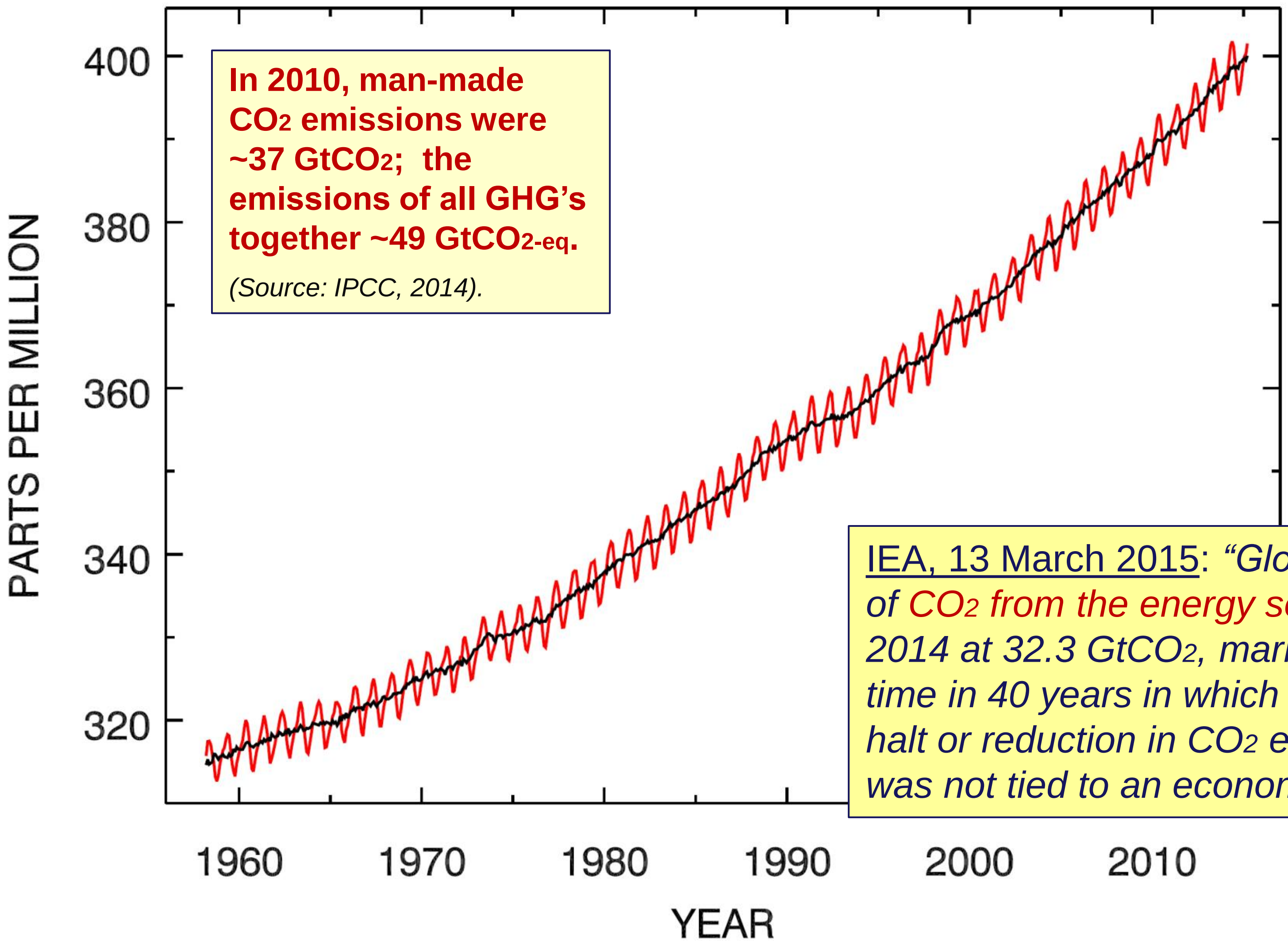
ACHEMA 2015 / session on SCOT
Frankfurt am Main
18 June 2015

Climate Change

Carbon budget, ‘stranded assets’ and CCS

Monthly average CO_2 concentration in the atmosphere at Mauna Loa Observatory (1958 – April 2015)



400 ppm

In 2010, man-made CO_2 emissions were ~37 $GtCO_2$; the emissions of all GHG's together ~49 $GtCO_{2\text{-eq}}$.

(Source: IPCC, 2014).

IEA, 13 March 2015: *"Global emissions of CO_2 from the energy sector stalled in 2014 at 32.3 $GtCO_2$, marking the first time in 40 years in which there was a halt or reduction in CO_2 emissions that was not tied to an economic downturn."*

Source curve: http://www.esrl.noaa.gov/gmd/webdata/ccgg/trends/co2_data_mlo.pdf (visited: 19 May 2015)

Austria’s Pasterze Glacier has retreated hundreds of meters since nations began debating limiting warming to +2°C

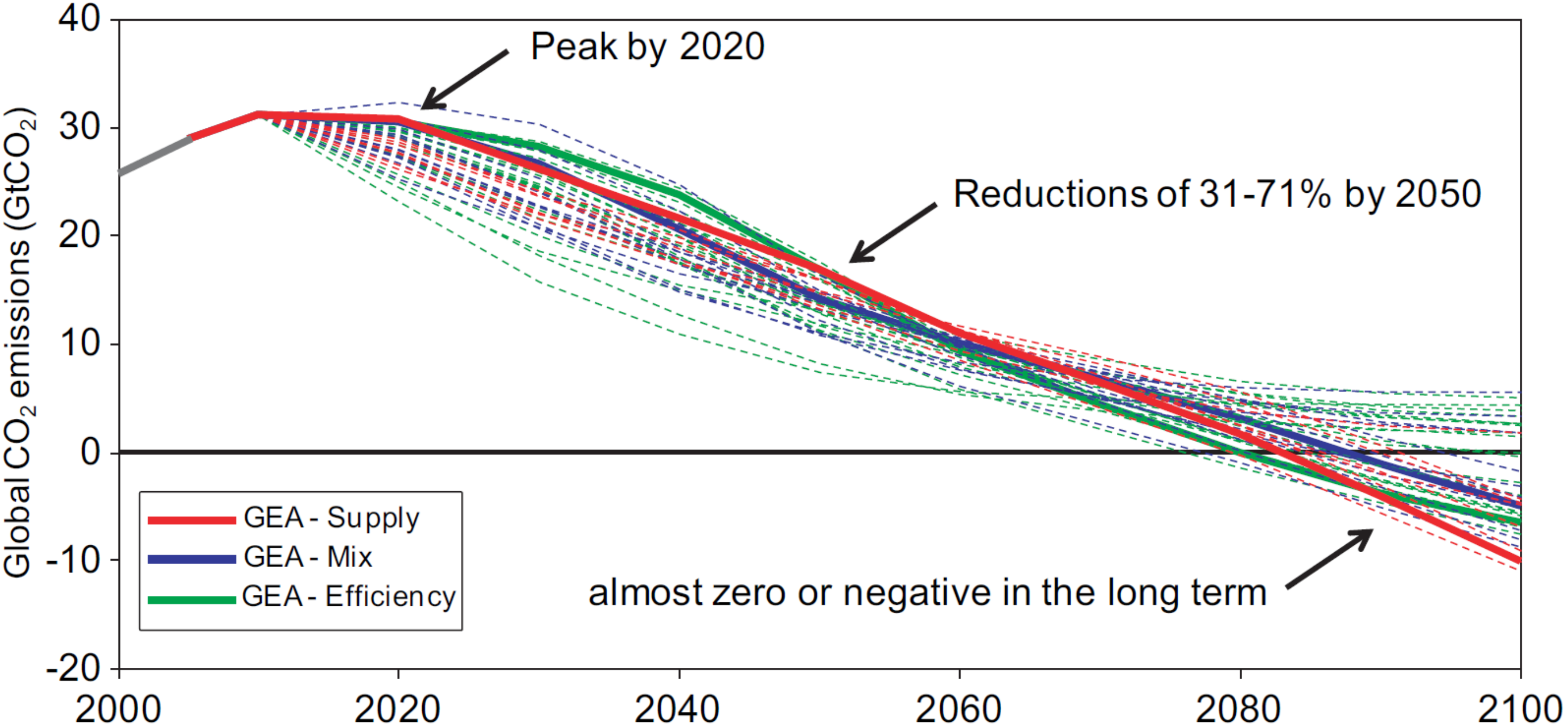
G7 Summit, 7-8 June 2015:
“All countries should (be enabled to) follow a low-carbon and resilient development pathway in line with the global goal to hold the increase in global average temperature below 2°C”.

“The science tells us that 1.5 °C might be considerably better.”
Nature, 2 April 2015

Source: J. Tollefson, ‘Global-warming limit of 2ºC hangs in the balance’, Nature, 2 April 2015, pp. 14-15.

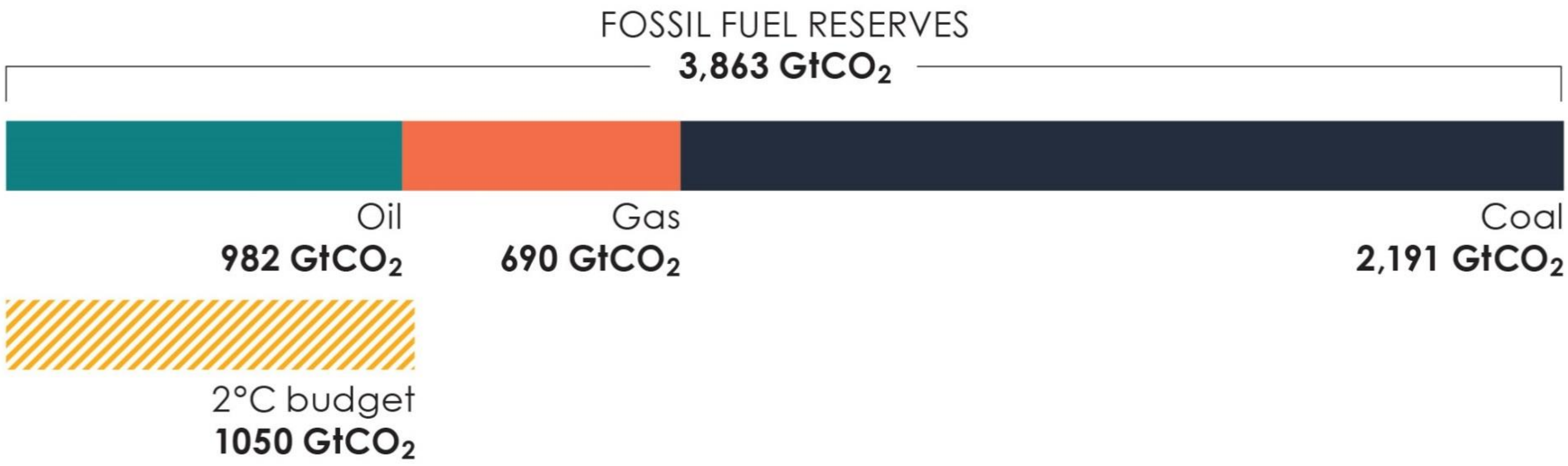
Development of global CO_2 emissions from energy and industrial sources to limit temp. change to below 2°C (prob. > 50%)

- GEA energy pathways toward a sustainable future -



Source: Global Energy Assessment, 2012

Global Carbon budget compatible with limiting global warming to +2°C *versus* fossil fuel reserves



Conventional and unconventional fossil fuel reserves of coal, oil, and gas and the global carbon budget compatible with scenarios limiting global mean warming to 2°C above pre-industrial temperatures (with a 66% probability).

Source of Fossil Fuel reserves: IPCC, 2011 (figure 1.7).
Source of Carbon budget: IPCC, 2013 and IPCC erratum, November 2013.

Source figure: ECF, “Statement by leading climate and energy scientists”, 2013

Unburnable Carbon and Stranded Assets

- Not the use of fossil fuels but the emission of CO_2 (at present ~37 Gton/yr globally) is the problem!
- The website *Carbon Tracker,* and groups like *Urgenda* in NL, discussing stranded assets, don't give enough attention to the potential of CCS. Applying CCS can have a large impact (*storage capacity ~2,000 GtCO$_2$ till 2100*) on 'unburnable carbon'.
- But: within about 20 years we can't allow **any** new investment in **unabated use** of any fossil fuel (given 'max +2°C), having **huge consequences** for e.g. energy companies. Therefore National Roadmap on CCS are urgently needed, for each country!
- Note also the statement of the EC (Dec. 2011): *"No new investments in fossil fuel power plants after 2030 without CCS".*

Removal of CO_2 from power plants

- **CCS: a proven technology that today securely stores 25 Mt CO_2 per year.**
- **There are 21 large-scale projects in operation or construction, all expected to be online by 2016. These will have the capacity to capture up to 40 Mt CO_2 per annum.**

- In Saskatchewan (Canada) the first commercial scale operation of CCS at a power plant started October 2014: the *Boundary Dam project* (Shell involved).
- It's a coal-burning plant that generates 110 MW and would emit more than 1 Mt of CO_2 per year. Its operators say, the project is "exceeding expectations."

Aerial Photo of SaskPower's Boundary Dam Project near Estevan, Saskatchewan

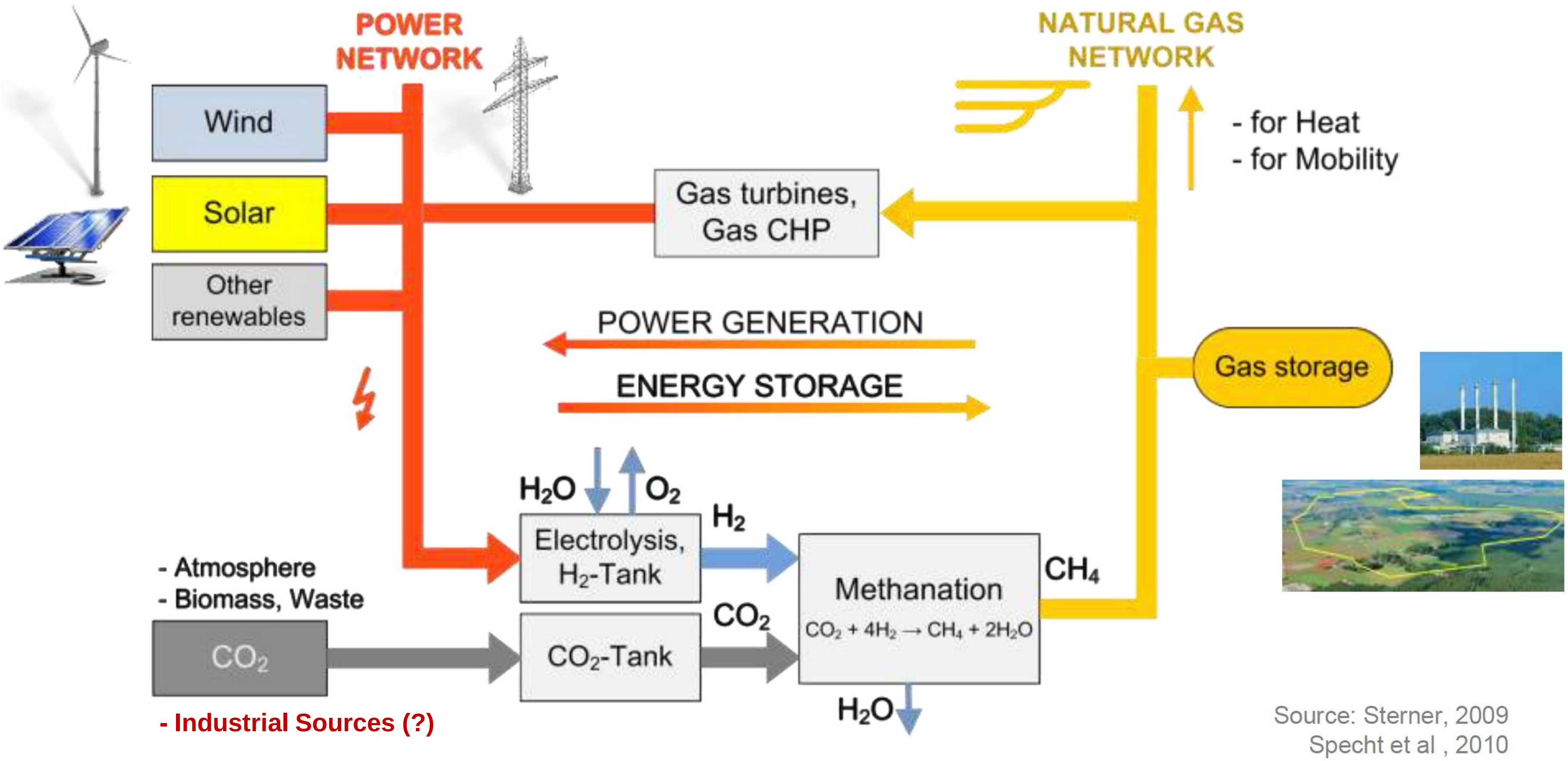
- Shell/Cansolv and SSE are looking to develop the world's first full-scale gas CCS project – the *Peterhead Project* (Scotland), with support of the UK Gov't

Sources: GCCSI, 2014 // SaskPower, 2015 // Shell UK, 2015

Misunderstandings about P2G and re-utilization of CO_2

Power-to-Gas (H_2 and/or CH_4)

Energy storage by coupling electricity and gas networks



- Industrial Sources (?)

Source: Michael Sterner, 'The impact of the next big thing: (Solar) energy storage', OTH Regensburg, 2014

TKI-Gas (NL)

Industrial research 'Power2Gas and the power of methane'

Project partners:
- *DNV.GL*
- *Stedin Netbeheer*

Source:
TKI-Gas (website, October 2014)
http://www.tki-gas.nl/projecten/tkig01015

Union of Chemical Industries in the Netherlands (VNCI) on re-utilization of CO_2 *(CCU / Circular Economy)*

● CO_2: a raw material for methanol

"A nice example of Carbon Capture and Usage is the utlization of CO_2 as a raw material to produce methanol, being a feedstock of e.g. gazoline."

"Methanol in brandstoffen bijmengen kan een grote impact hebben en niet alleen door een iconische waarde van de oplossing. Bestaande installaties in Japan en Korea hebben een capaciteit van respectievelijk 100 ton per jaar en 3.000 ton per dag."

● CO_2: a raw material for polymers

"The goal is to use CO_2 as a raw material for polymers. There are many industrial processes where CO_2 is produced as a waste product."

"Bayer en RWE onderzoeken de mogelijkheden om CO_2 af te vangen en te gebruiken voor de productie van PU (Polyurethaan). Novomer en DSM hebben een systeem commercieel beschikbaar om CO_2 te gebruiken als grondstof voor polymeren."

Source: VNCI, 'Road Map Chemistry 2030', 2013

The CO_2 Forum, April 2015:

“The chemistry and technologies are available to reuse CO_2 as a carbon source for well-known commodity chemicals, particularly liquid and gaseous synthetic fuels. CO_2 released by large scale industrial sources could be captured and immediately fed to a conversion unit that turns it into marketable carbon derivatives.”

“CCU (or CDU) could complement CCS with large-scale conversion units closely integrated with primary emission sources like power utilities, refineries, cement, chemicals or steel works.”

4th Conference on CO_2 as Feedstock for Fuels, Chemistry and Polymers (29 - 30 Sept. 2015, Essen, Germany):

"Everyone is fascinated to hear about it for the first time: We can use various technologies to produce gaseous and fluid fuels (e.g. methane, petrol, diesel, kerosene) from captured CO_2 and renewable energies like solar or wind energy. With the same technologies, we can also produce chemical building blocks that can supply basically all chemical and plastics industries."

?

Ellen MacArthur Foundation, ‘Towards the Circular Economy’, 2014:

“Through the lens of circularity, the economic justification for Carbon Capture and Storage (CCS) projects, arguably a key technology we still require at scale to address CO_2 pollution from new coal power stations, can be transformed. CCUS projects (Carbon Capture, Use, and - if needed - Storage) become driven by the economics of the revenue stream generated by the potential use of the CO_2 in new industrial applications.”

“Large-scale energy producers with chemical feedstock companies would ideally join forces in converting their CO_2 into polymer-based products.”

Power-to-Gas (H_2 / CH_4)

- From the perspective of climate change, the production of CH_4 using H_2 from solar/wind and captured CO_2 **can only be an option if it doesn't result into an increase of the CO_2 concentration in the atmosphere**!
- Also: Electrochemical production of **H_2 is very expensive** (*about 5-10€/kgH_2*). Also ~20-25% of the kWh-energy will be lost, but in practice at present ~40-50%).
- **Methanation** would enhance the energy loss and add costs.

(Note: Captured CO_2 from a coal fired plant cost at present ~80$/tCO2).

-
- There is a need to develop a H_2 production technology with (much) lower energy losses and production costs.

DIFFER (2013): *"An interesting approach might be plasmolytic H_2 production"*

step 1: plasmolytic production of CO from CO_2 ($CO_2 \rightarrow CO + ½\, O_2$)
step 2: water-gas shift reaction ($CO + H_2O \rightarrow CO_2 + H_2$)
step 3: separating H_2 from CO_2 and re-use CO_2 in step 1

Misunderstandings about re-utilization of CO_2

- Re-utilization of captured CO_2 from fossil fuel power plants is more and more promoted (*see e.g.: www.co2-chemistry.eu*).
- **But: From the perspective of climate change it can only be an option if the emission of CO_2 to the air is reduced, and about 25-30 years from now completely avoided. (Thereafter CO_2 emissions should become even negative!)**

<u>Consequently</u>:

- Re-utilization of fossil CO_2 in horticultures: not a permanent solution when striving for zero GHG emissions.
- Re-utilization of CO_2: no problem with CO_2 from sust. biomass.
- Re-utilization of fossil CO_2: only in on ongoing circular approach (which can hardly be realized), or combined with mineralization!
- Massive application of methanation of H_2 only with air capture of CO_2. Cost CO_2 ~$600/tonne *(Source: Am. Phys. Soc., 2011).*

How to deal with intermittent renewables (wind / solar-PV)

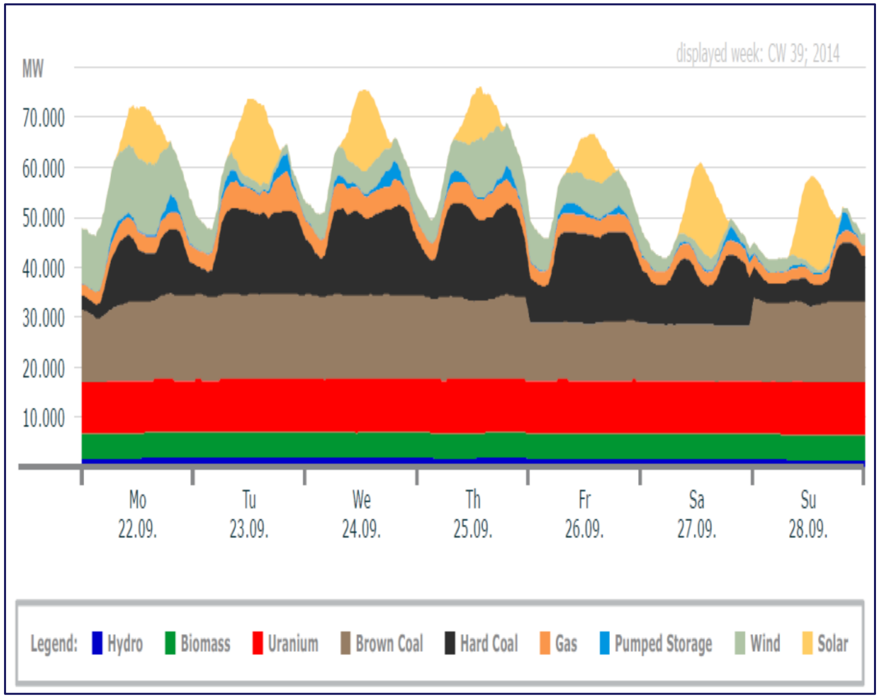
- What might be the role of P2G ? -

Integrating intermittent renewables

Electricity production in Germany

2014, Week 39 (22-28 Sept.)

- by solar PV, wind, pumped storage, conventional capacity, biomass and hydropower -

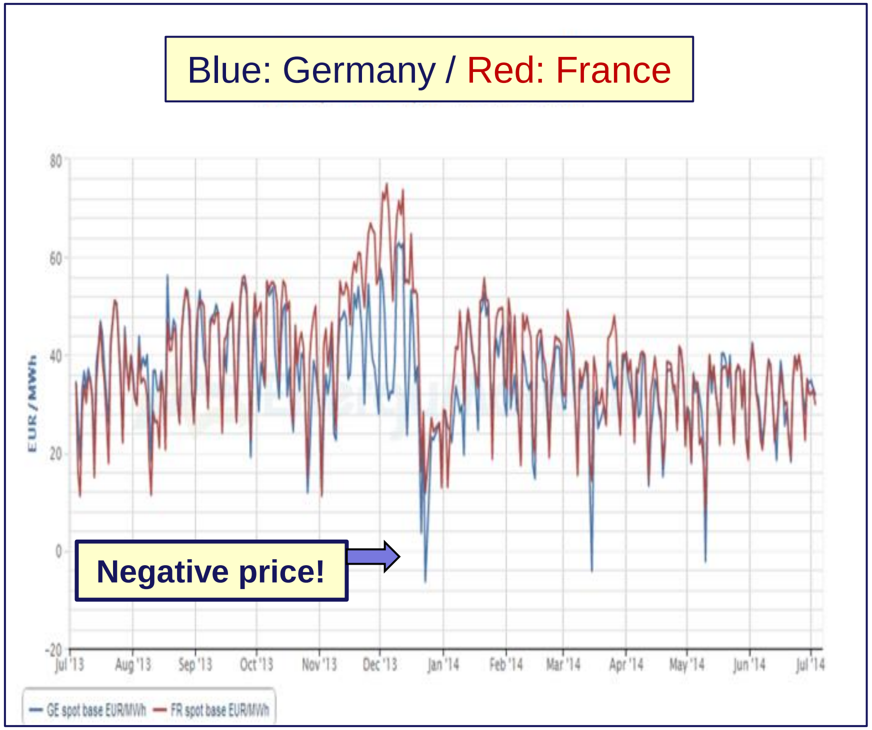


Source: Bruno Burger, Fraunhofer ISE, 2014

Spot price of base load electricity

July 2013 – July 2014

(EUR/MWh)



Source: Energy Market Price, 3 July 2014

Options to balance the fluctuating supply from wind and solar-based electricity

In random order:

- Temporary curtailment of variable electricity generation sources;
- Exchanging electricity surpluses with other countries;
- More flexible utilization of part of the *electricity* demand (demand side response);
- Flexible electrification of *energy* demand (e.g. Power-to-Heat);
- Use of dispatchable gas-based electricity generation units (using natural gas or biogas, also combined with CCS);
- Implementation of some type of electricity storage, such as Pumped Hydro, Compressed Air Energy Storage (CAES) and batteries (in homes / electric vehicles);
- Converting electricity into a gaseous energy carrier (P2G).

Sources: GEA, 2012 // REP, 2012 // RWE, 2013 // ECN, July 2014 // UU, 2015

Integrating flexible renewables (solar-PV and wind) into a reliable electricity supply system

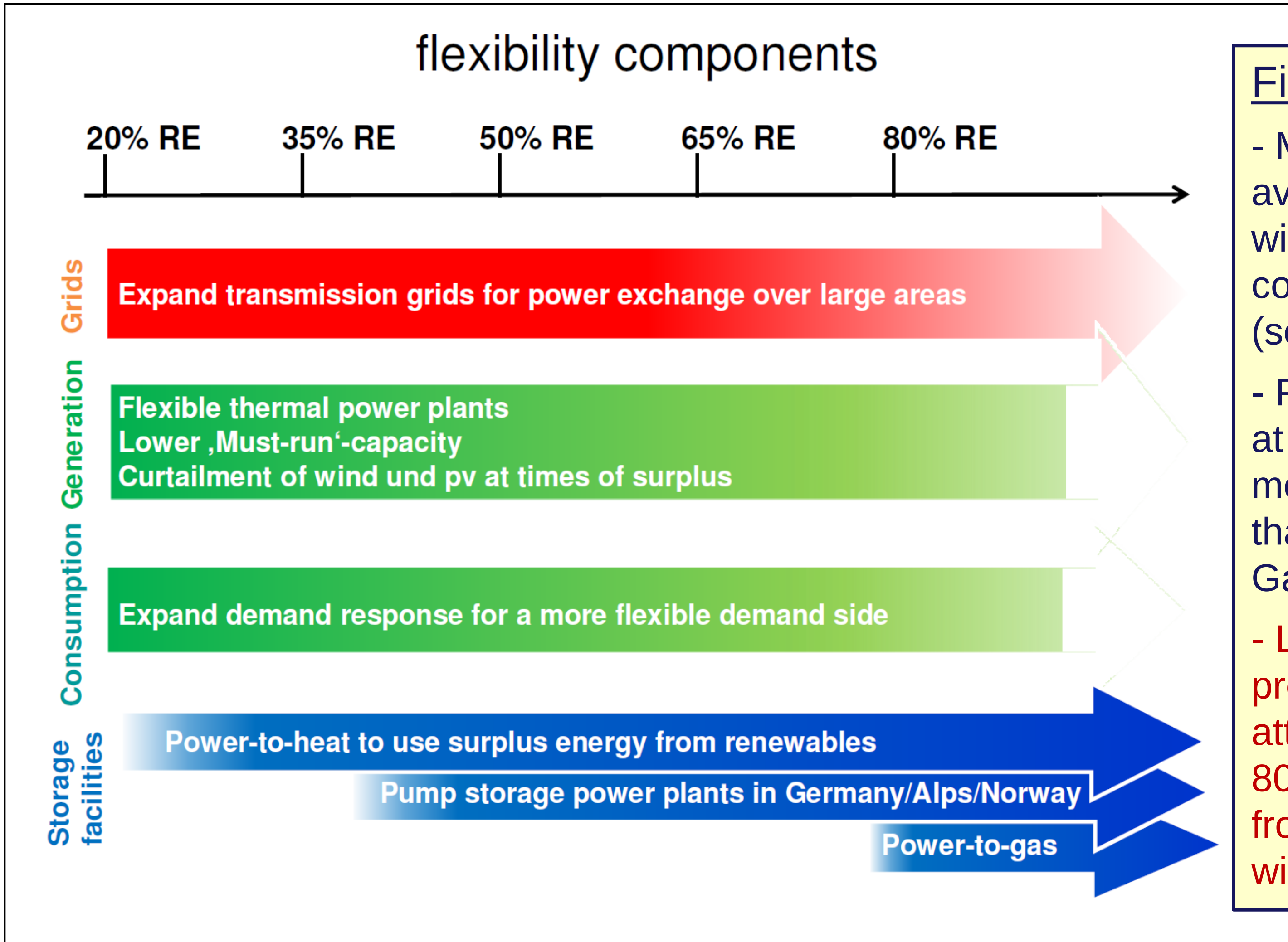


Figure shows:

- Many options available to deal with flexibility components (solar-PV & wind).

- Power-to-Heat at present far more attractive than Power-to-Gas (P2G).

- Large scale P2G probably not attractive below 80% contribution from solar-PV and wind!

Source: Steering Committee of the Renewable Energy Platforms, Germany, 15 Oct. 2012

Report RWE-AG and Frontiers Economics (2013)

'Is Energy Storage really the missing link in the Energy Transition?'

In 2013, RWE AG and Frontier Economics investigated the future economic efficiency of different storage options in Germany until 2050.

Main conclusions:

- Large-scale storage facilities cannot be expected to boom in Germany in the short to medium term (before 2040). **The future role of storage will be much less significant than is often assumed.**
- It is only under favourable conditions, with more technological progress and a very high share of renewable energy (above approx. 60%), that some storage technologies could be commercially viable.
- New pumped-storage plants are at the commercial viability threshold in the medium to long term.
- **Power-to-Gas (producing H_2 and CH_4)** involves high conversion losses. Up to two thirds of the electricity can be lost. **Even under optimistic costs assumptions, P2G will not become commercially viable before 2050.**

Source: F.D. Drake et al. (2013), "Sind Speicher wirklich der fehlende Baustein zur Energiewende?", Energiewirtschaftliche Tagesfragen, 63 Jg, Heft 8, pp. 34-38.

Similar results are found in a recent study by Utrecht University, simulating sustainable (mainly renewable) electricity supply systems in Western Europe in the year 2050 *(A.S. Brouwer et al., 2015)*

Report ECN and DNV.GL (July 2014)

'Exploring the role for P2G in the future Dutch energy system'

Main conclusions:

- In the long run P2G can contribute to the integration of the fluctuating supply from wind and solar-based electricity generation. **However, P2G is not the first option in terms of lowest societal costs.**
- Due to the capital intensity of P2G and its inherent efficiency losses, **deployment of P2G for the sake of providing system flexibility is not sufficient for a positive business case**.
- Even the low – or possibly even negative – electricity prices that may arise for short time periods by an abundant supply of electricity from intermittent sustainable sources, are insufficient to compensate for the relatively high capital cost per produced unit of hydrogen or synthetic methane.
- **Case studies show that a solid positive business case is hard to realize in the short to medium term for P2G (before 2030-2040).**
- However, it is not inconceivable that a positive business case is possible in specific situations.

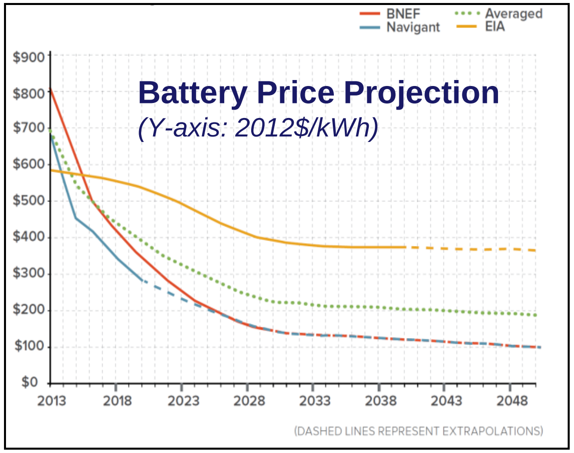
Source: J. de Joode, "The role of Power-to-Gas in the Future Dutch Energy System", ECN, July 2014

P2G has to compete with other options when storage needed

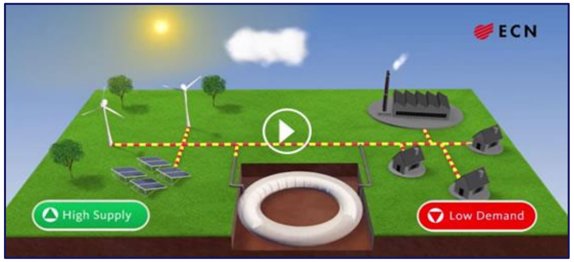
New technologies and approaches are being developed. Some examples:

- New batteries: *"Aluminum battery from Stanford offers a cheap and safe alternative to conventional batteries".*
  Source: Nature (Stanford University), 6 April 2015.

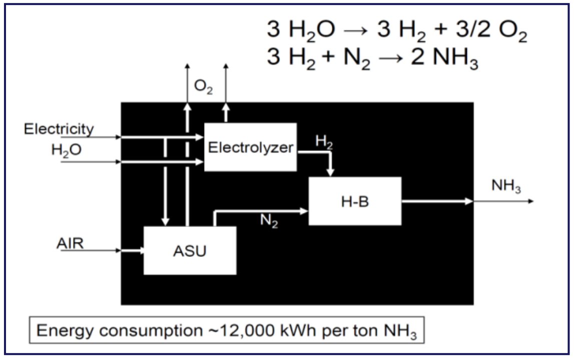
- Distributed solar-plus-battery-systems = 'Utility in a Box': "*Can make the electric grid optional for many customers within 30 years*".
  Source: RMI (et al), 'The Economics of Grid Defection', 2014.



- 'Energy train', a new concept developed by ECN (NL) to store large amounts of electricity: *"With this enormous underground train in a vacuum tunnel we can store 10% of the Netherlands' daily electricity at a very attractive cost."*
  Source: ECN, website, 13 May 2015.



- Renewable energy based ammonia production (combining H_2 with N_2) for transmission, storage and usage as fuel or fertilizer or for de-NOx.
  Source: B. Leighty, Ammonia Fuel Association, 21-24 Sept. 2014.



Conclusions on P2G and re-utilization of CO_2

Conclusions on P2G and re-utilization of CO_2

- Re-utilization of grey CO_2 from industrial sources to produce gas (methane), liquids (like methanol) or polymers will in general be in conflict with the urgent need to solve the climate problem. Consequently: a very bad idea!
- At present, further development of CCS is urgently needed, not CCU. When developing CCU it should contribute to zero or negative CO_2 emissions.
- P2G is a very expensive and inefficient approach to store electricity from intermittent sources (solar-PV and wind). Smart and well-targeted R&D projects are needed to improve this situation largely.
- For many decades to come, P2G is not needed when striving for a reliable and sustainable electricity supply system. Other options are available and that can be applied at (much) lower or even negative costs.
- Most probably a massive use of P2G in sustainable electricity systems is not cost-effective up to at least 80% contribution of from solar-PV and wind to the total electricity demand.
- Consequently, a positive business case for large-scale P2G is hard to realize before 2040-2050.
- Nevertheless, it is not inconceivable that a positive business case can be achieved in very specific situations (on a small scale).

Thanks!

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