Electrification of the Chemical Industry

Industrial electrification

"Towards a CO_2 neutral process industry"

Robert de Kler

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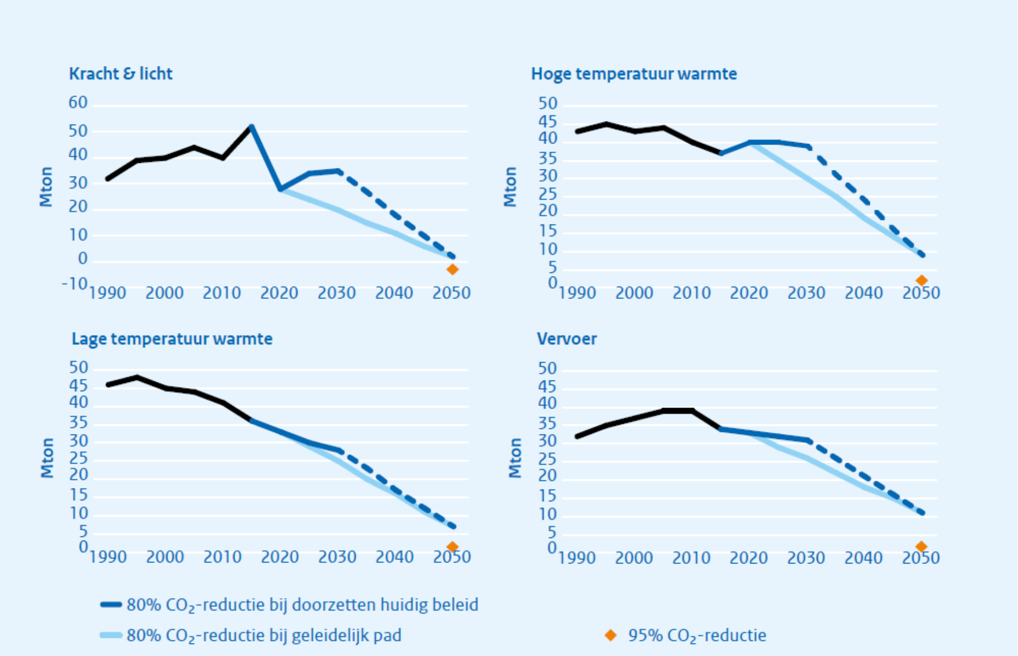
The “energieAgenda” near zero CO_2 emission in 2050

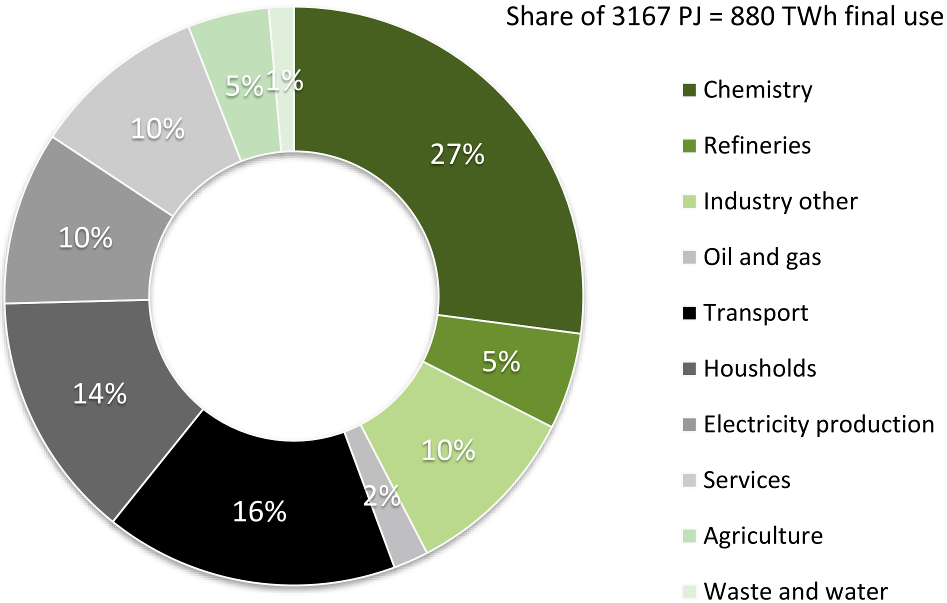
The Dutch “Energieakkoord” has been signed by 47 parties with an action plan up to 2023, with targets on low carbon economy and the roadmap towards 2050. This is documented in the “Energieagenda” which consist of a set of agreements with all relevant stakeholders and industry. As such it is important that investments must be in line with the sustainability targets well-defined in the “Energieagenda”.



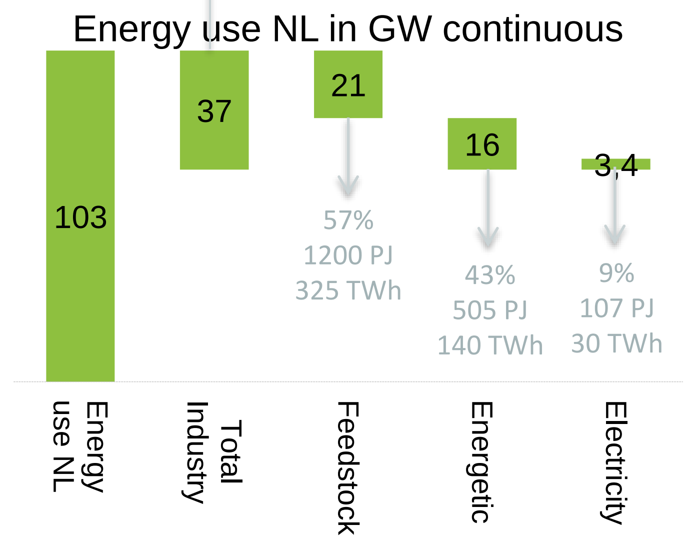
Source: Energieagenda

Energy use in Dutch process industry

Share of 3167 PJ = 880 TWh final use



44% compare: 25% EU



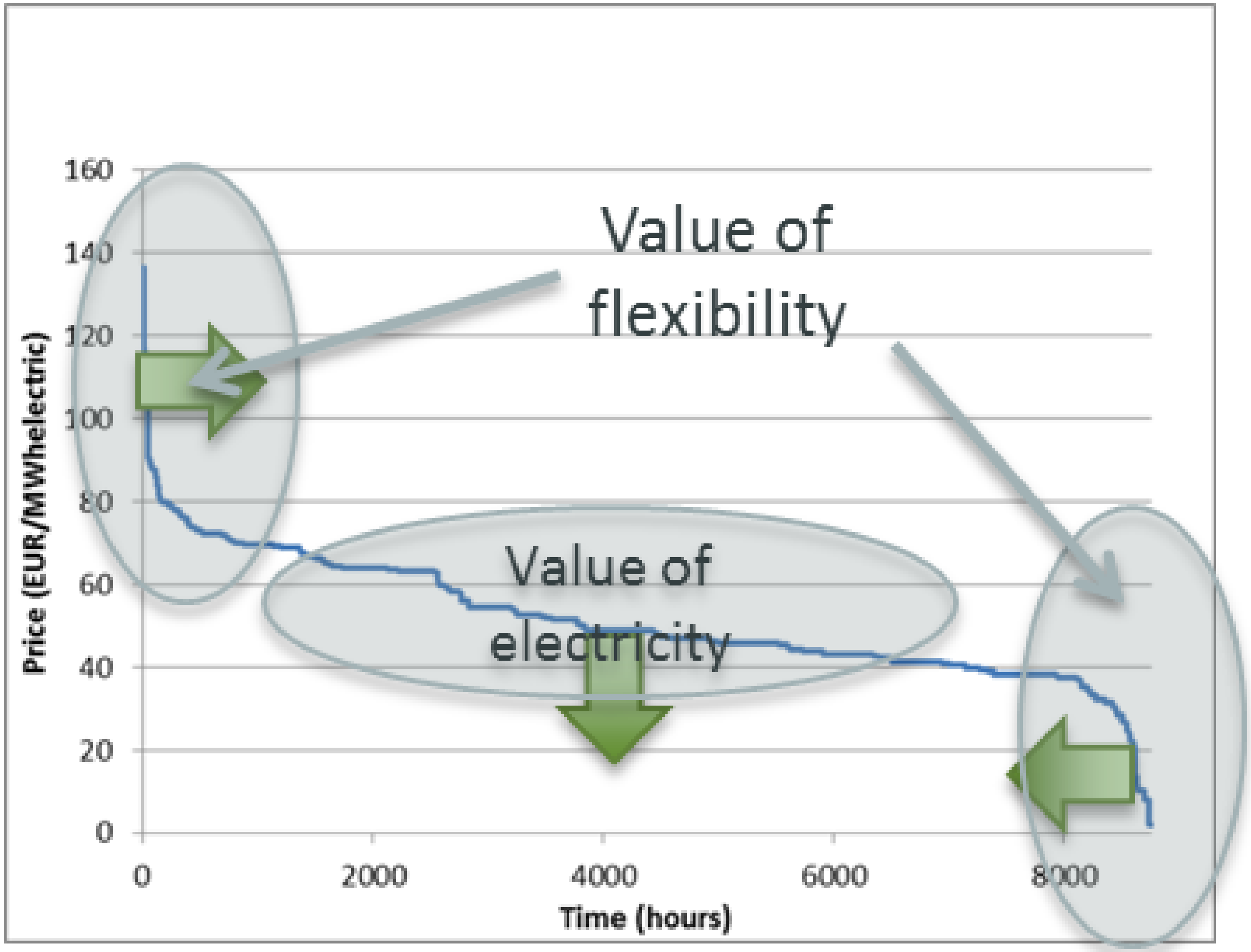
Year	Source	$GW_{eq\ cont}$	$GW_{installed}$
2013	Total electricity generated	13.5	30
2013	renewable electricity	1.4	
2030	Total electricity generated	14.1	
2030	renewable electricity (53%)	7.5	
2030	intermittent solar/wind (87%)	6.5	26

12 TWh = 44 PJ (1.4%)

65 TWh = 236 PJ (~7%)

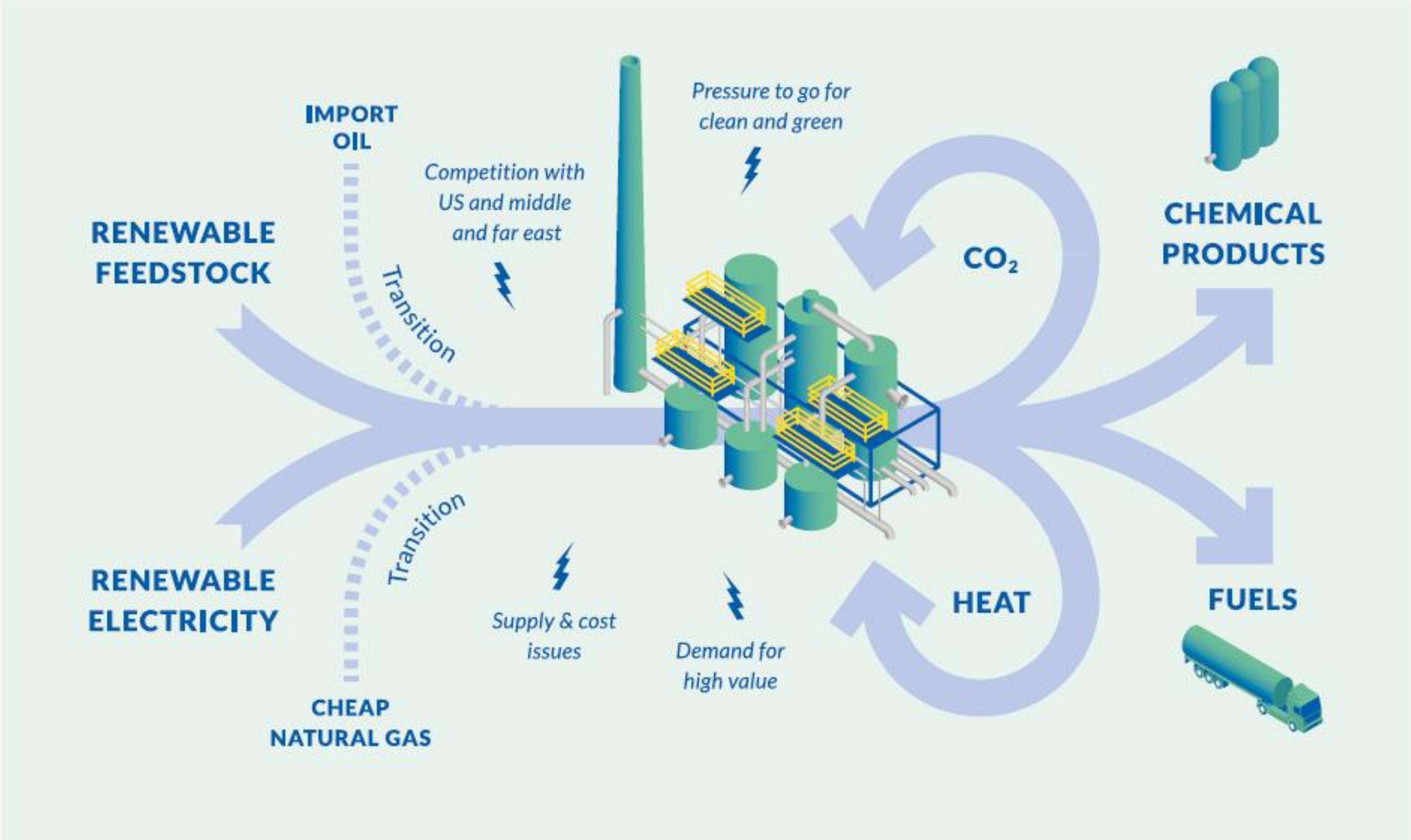
Source: Nationale Energieverkenning, 2014

Electricity value vs. Variability value



Price duration curve 2030

Our vision on industrial electrification



TOPSECTOR ENERGIE Empowering the new economy

Topsector Chemie

Holland High Tech High Tech Solutions for Global Challenges

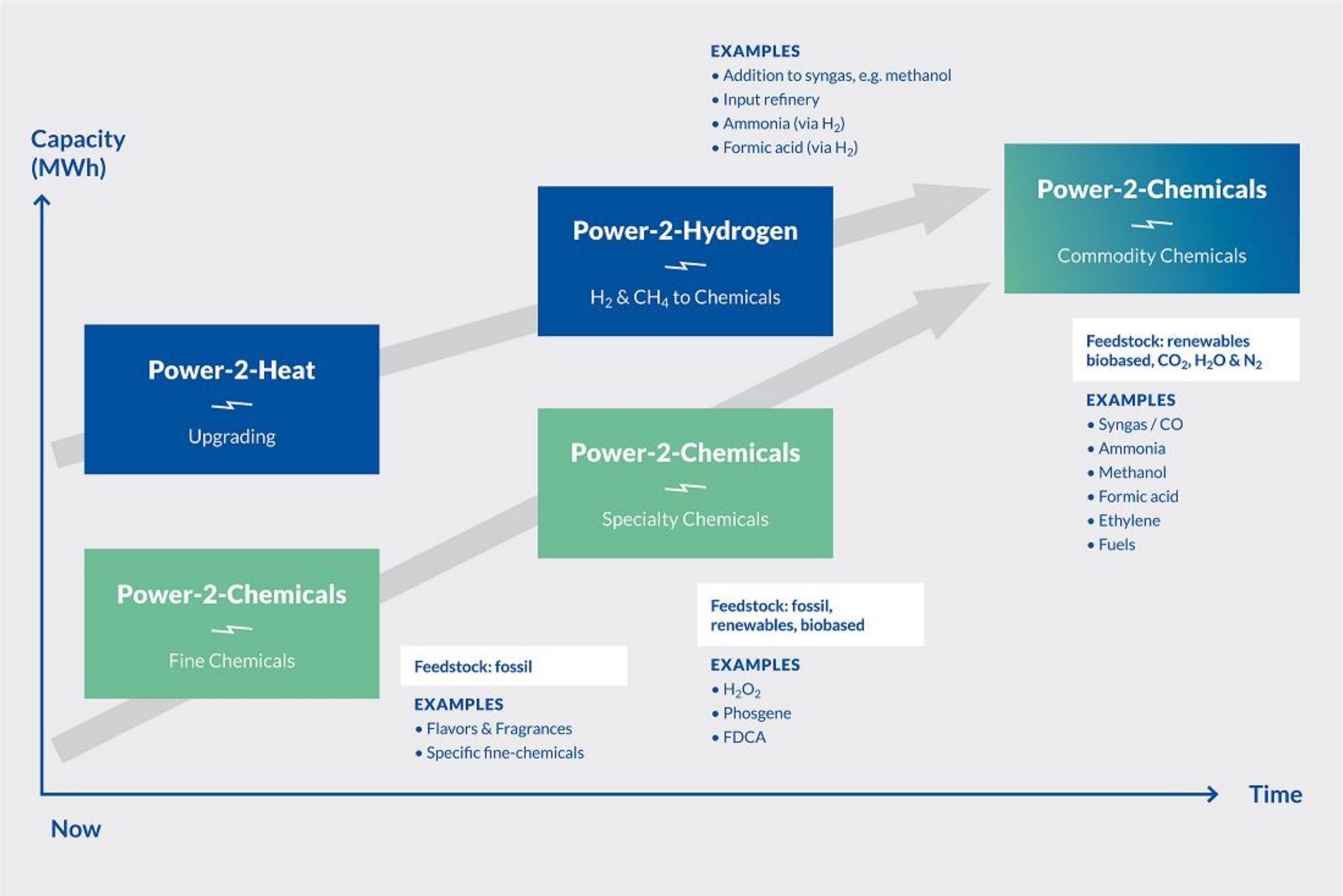
De-carbonization of the (petro) chemical industry

The transition of the energy intensive industry is a high priority societal challenge as demonstrated by Paris COP21 and the EU's Circular Economy Package, setting clear targets on low carbon economy for the future. In line with the “Energieagenda” Port of Rotterdam has supported several industrial initiatives that addresses these challenges, with the added potential for reducing the carbon foot-print and stimulating job creation.

The Wuppertal institute has identified a potential pathway for the Port of Rotterdam energy intensive materials industry towards 2050. This pathway requires a radical and complete shift of the energy demand as well as the resource base of feedstocks to electricity. For this transition, electricity would be used for producing hydrogen and hydrocarbons for feedstock and energy purposes. With increased material efficiency and some share of bio-based materials and biofuels the electricity demand can get much lower. The Wuppertal analysis suggests that electrification of basic material production is technically possible but could have major implications on how the industry and the electric system interact.

The energy transition requires a radical move to emerging zero CO2 emission technologies for the materials industry.

Implementation roadmap



In summary

- Industrial electrification will play an important role in the future
  - The (chemical) industry uses 44% of all energy in The Netherlands.
  - Energy will be more and more dominated by (intermittent) renewables.
  - Step-changes in *technology development*, *societal and market conditions* and *regulations* are to be expected.

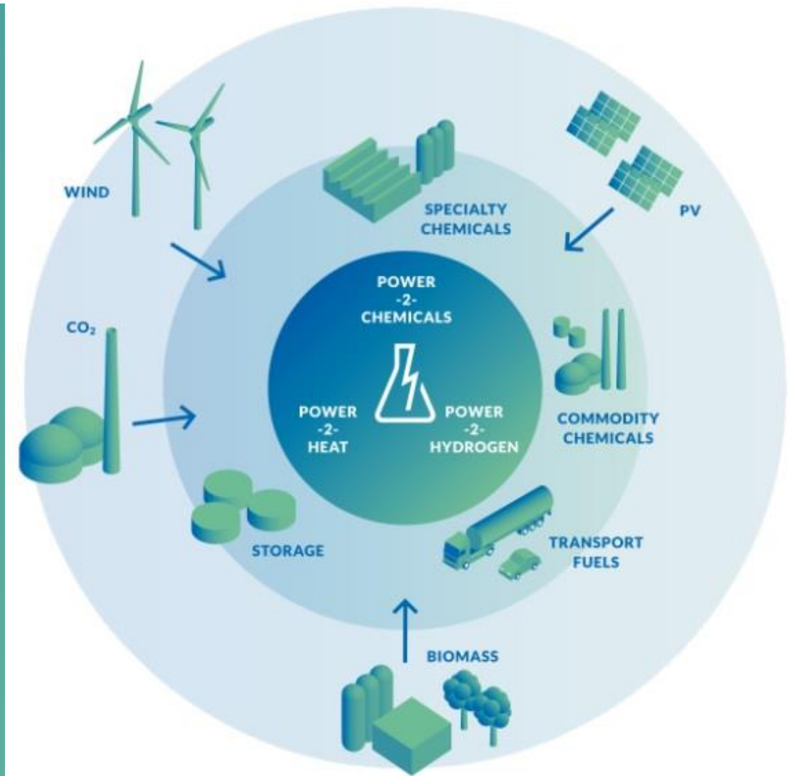
- Short-term opportunities: utilities and flexibility value
  - Power-2-Heat & Power-2-Hydrogen.
  - Positive business-cases depending on regional situation.
  - Challenges in market risks and financing, not R&D.

- Mid/Long-term opportunities: chemicals and product value
  - Power-2-Specialties & Power-2-Commodities.
  - Business-cases very dependent on product and feedstock.
  - Challenges in feedstock price, product value, regulations and R&D progress.

Stelling:

The energy transition requires a radical move to new zero CO2 emission technologies for the materials industry. Renewables will play a crucial role as it is the feedstock of the future.

Want to know more or participate?



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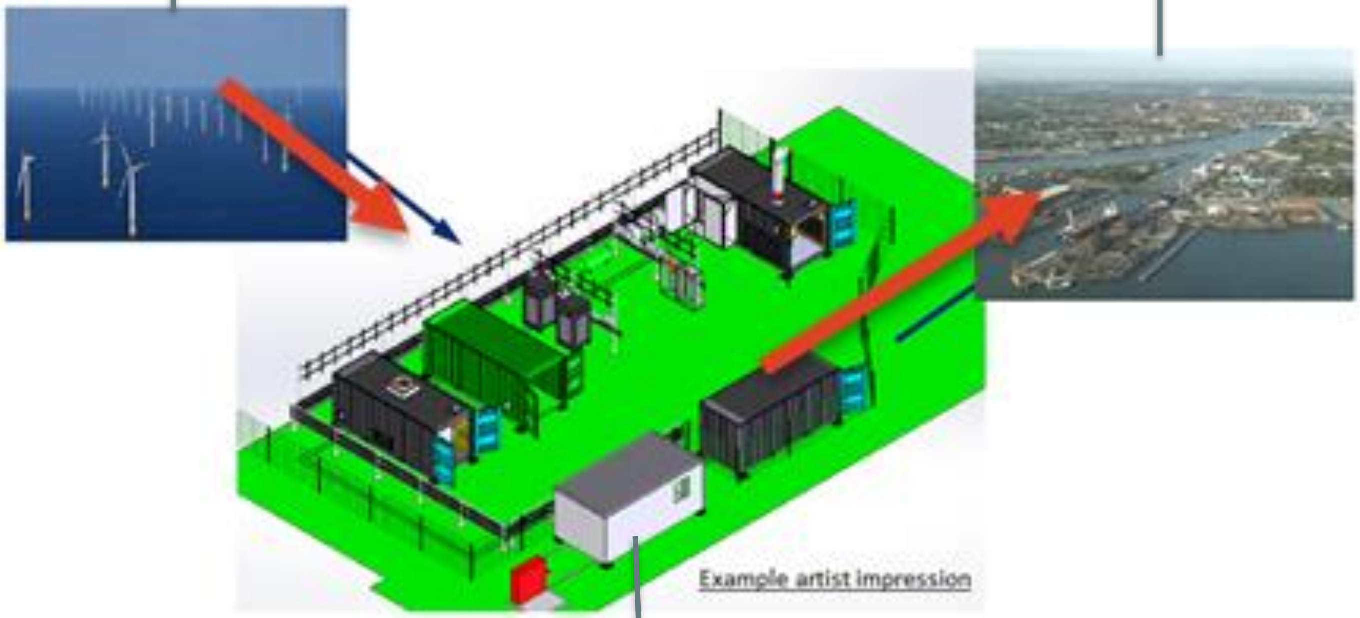
Port of Rotterdam as industrial fieldlab

Future proximity of renewable energy
Need for storage & flexibility

Largest Dutch Energy & Industry cluster
Serious decarbonization objective



Industrial Demonstration & Implementation Power-2-Heat/-Hydrogen.
Pre-competitive Development & Piloting Power-2-Specialties/-Commodities.

Concrete participation options

- Smartport & Community participation.
- Interreg NL/B/UK project Power-2-X.
  - Focus Methanol/DME & FA/CO
  - Your ideas (?)
- New project ideas:
  - Industrial electrification scenario's & policies
  - Power-2-Heat
  - Power-2-Hydrogen
  - Power-2-Chemicals (specialties & commodities)
- Bilateral or multilateral RD&I projects.
- Bilateral or multilateral piloting & demonstration projects.

Power-2-Heat

- Using electricity to generate high-value steam that can be used as utility in chemical processing.

- Applications:
  - Heat integration.
  - Generate heat directly from electricity.
  - Upgrade steam or waste heat.

MECHANICAL VAPOUR RECOMPRESSION BY SHELL

Propylene is an important feedstock in the production of a number of chemical products, including polypropylene. It is produced by distillation separation of propylene and propane in a splitter column. Traditionally, the reboiler is heated by low pressure steam or hot condensate. Since 1995, Shell Pernis uses a propylene-propane distillation column that applies *mechanical vapour recompression* (MVR). In the MVR, an electrical compressor increases the pressure of the top vapours. As the column operates independently of a cooling fluid, the column pressure can be reduced. This results in a better split between the propylene and propane and a purity of 99.5% is reached.

The MVR process has resulted in reduced energy use, reduced use of cooling water and an increase in distillation yield. Energy savings add up to 1.2 PJ yearly, equivalent to 37.8 mln m^3 of natural gas. A very short payback time of two years was realised.

Source: Industrial heat pumps in the Netherlands, IEA Heat Pump Programme Annex 35, May 2014. Photograph by courtesy of Shell.

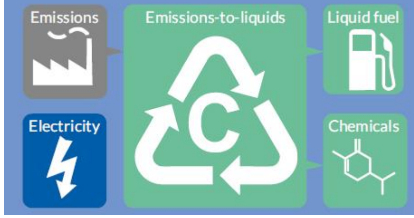
Power-2-Hydrogen

- Conversion of water and electricity to hydrogen using electrolyzer technology.

- Applications:
  - Feedstock for chemicals.
  - Large scale energy storage.
  - Mobility

CARBON RECYCLING INTERNATIONAL IN ICELAND

Applying Power-2-Hydrogen for local use on-site is already being applied by the industry at small scales for specific cases. Carbon Recycling International in Iceland is a good example. It is using local conditions to make a commercially feasible renewable product, namely methanol. Their commercial plant, operating since 2011 and connected to the Svartsengi geothermal power plant, produces 5 million litres of completely renewable methanol per year and recycles 5.5 thousand tonnes of CO_2 emissions per year.



Power-2-Specialties

- Direct conversion of feedstock into *high added value* chemicals using electrochemistry.

- Applications:
  – High selectivity for specialties.
  – Selective conversions in biobased.
  – New decentral applications.

ELECTROCHEMICAL PRODUCTION OF INDUSTRIAL CHEMICALS FROM CO_2 BY LIQUID LIGHT

Liquid Light is a company offering technology to use electricity for not only achieving a cost advantage, but also to contribute to sustainability. Based on the discovery of an efficient and stable electrocatalyst for the conversion of CO_2 to valuable products, such as ethylene glycol, isopropanol and acetic acid, conventional oil and gas feedstocks are avoided and replaced by recycled CO_2 and electricity. While their technology is still to be proven at commercial scale, investors and the industry are confident in its potential, as shown by numerous awards and recognitions.

Source: llchemical.com

Power-2-Commodities

- Direct conversion of feedstock into *commodity* chemicals using electrochemistry.

- Applications:
  - Central platform chemicals.
  - Decentral platform chemicals.
  - Energy carriers / fuels.

DECENTRALISED PRODUCTION OF CHLORINE

CONVE & AVS INC.
"Servicing the Chlor-Alkali Industry"

Chlorine production is probably the most well-known electrochemical process which annually produces 9937 ktonne of chlorine, 9678 ktonne of caustic soda and 298 ktonne of hydrogen within the EU. For safety reasons, most of the chlorine is moved by short distance pipelines, with transportation by road or rail being less than 5% of the total production. Large-scale transportation of chlorine by train in the Netherlands ended completely in 2006.

Skid-mounted chlor-alkali plants avoid transport and handling of liquid chlorine in order to offer a secured supply. Ease of installation and highly automated production are further key advantages under certain circumstances. These circumstances include high labour costs at the plant location, remote production sites, harsh climate conditions, lack of infrastructure, and shortage of skilled labour. Companies such as Conve & Avs Inc. and UhdeNora are developing and optimising these systems, with rated production capacities up to 100,000 tonnes per year.

Source: www.conveavs.net/projects

Upcoming technologies

Inspiring international examples for Power-2-X

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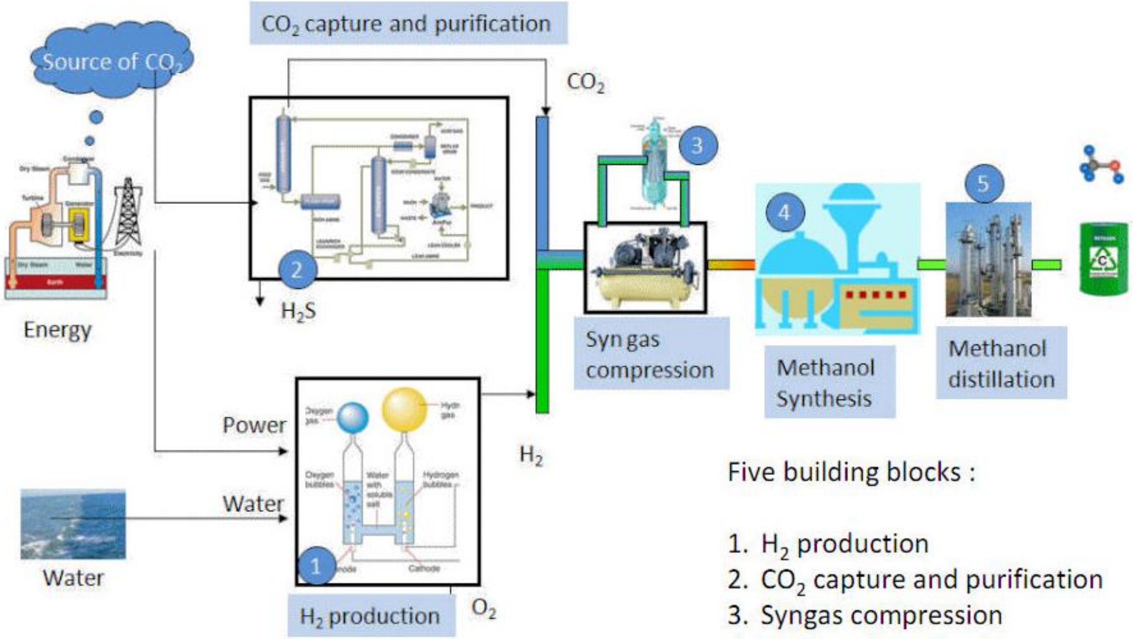
Power to Methanol

Approximately TRL 8 (out of 9)

Demo plant, CRI, Reykjanes (Iceland)



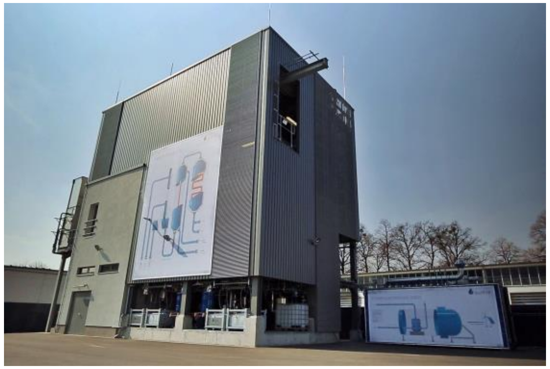
Five building blocks :

1. H_2 production
2. CO_2 capture and purification
3. Syngas compression
4. Methanol synthesis
5. Methanol distillation

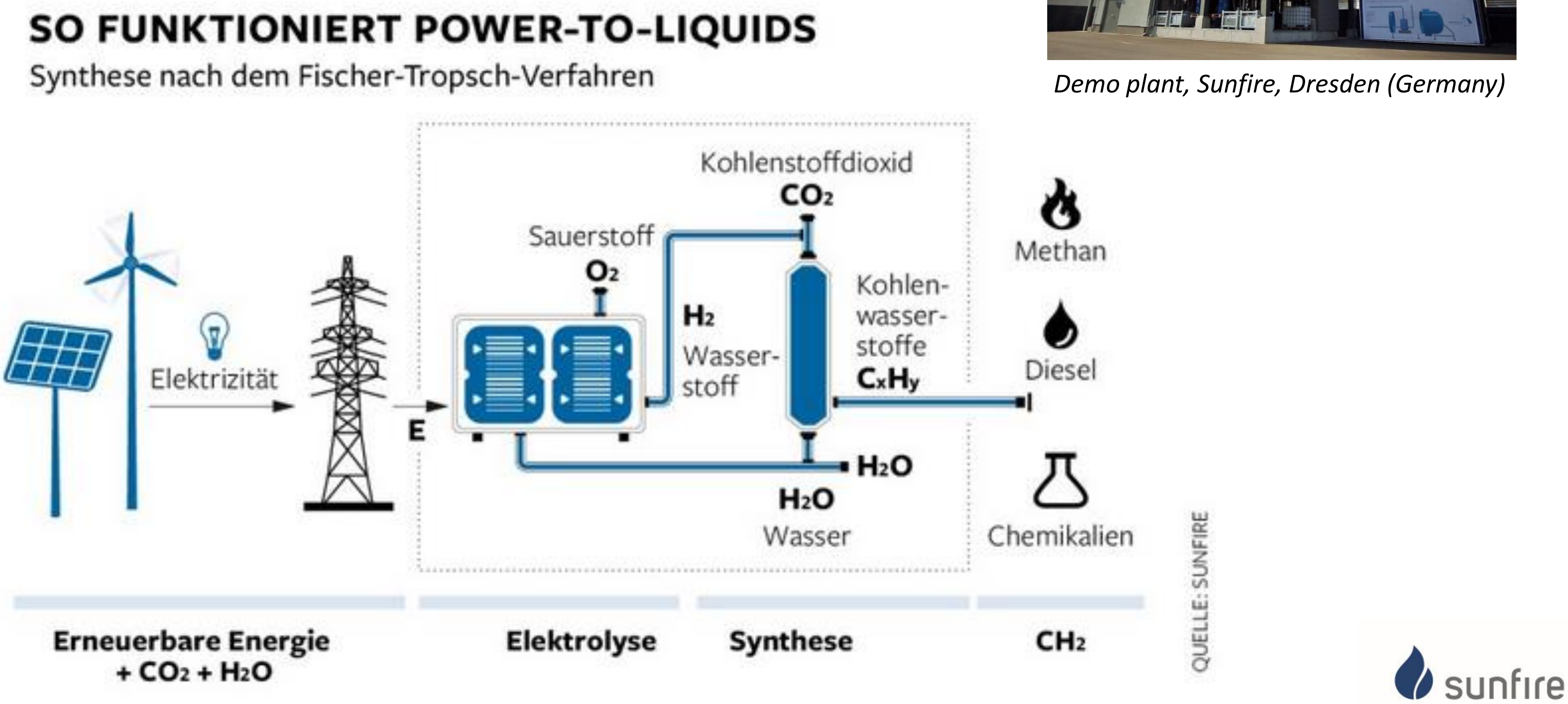
CARBON RECYCLING INTERNATIONAL

Power to FT-liquids

Approximately TRL 7 (out of 9)



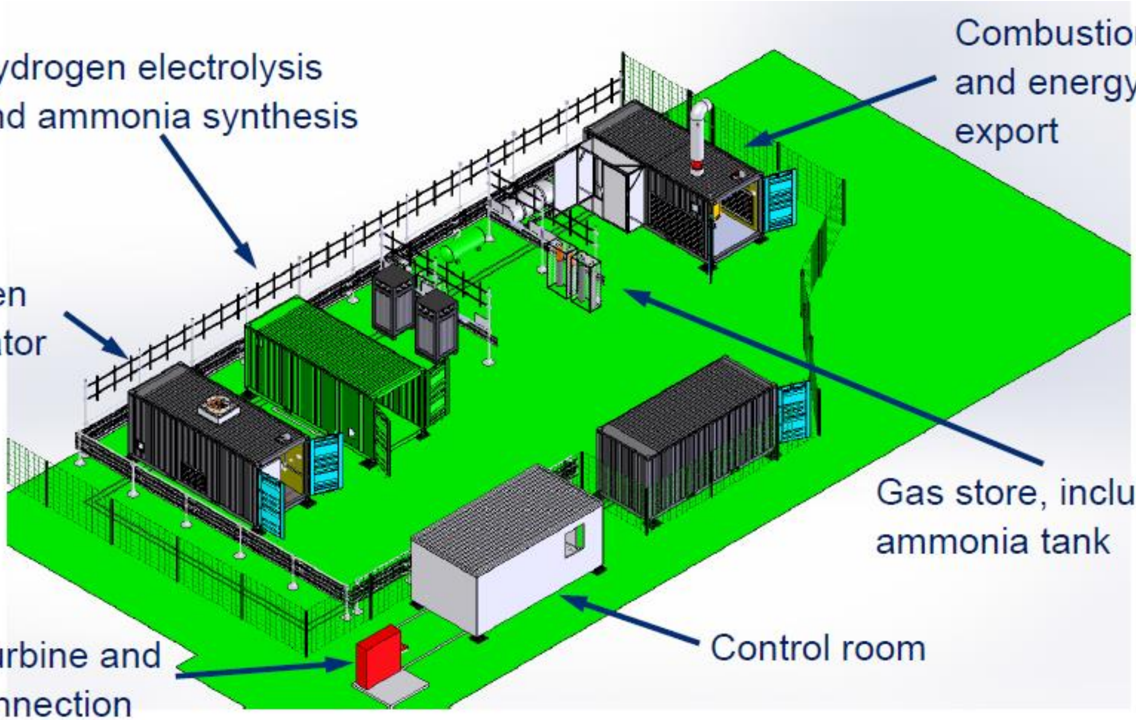
Demo plant, Sunfire, Dresden (Germany)



Power to Ammonia

Approximately TRL 6 (out of 9)

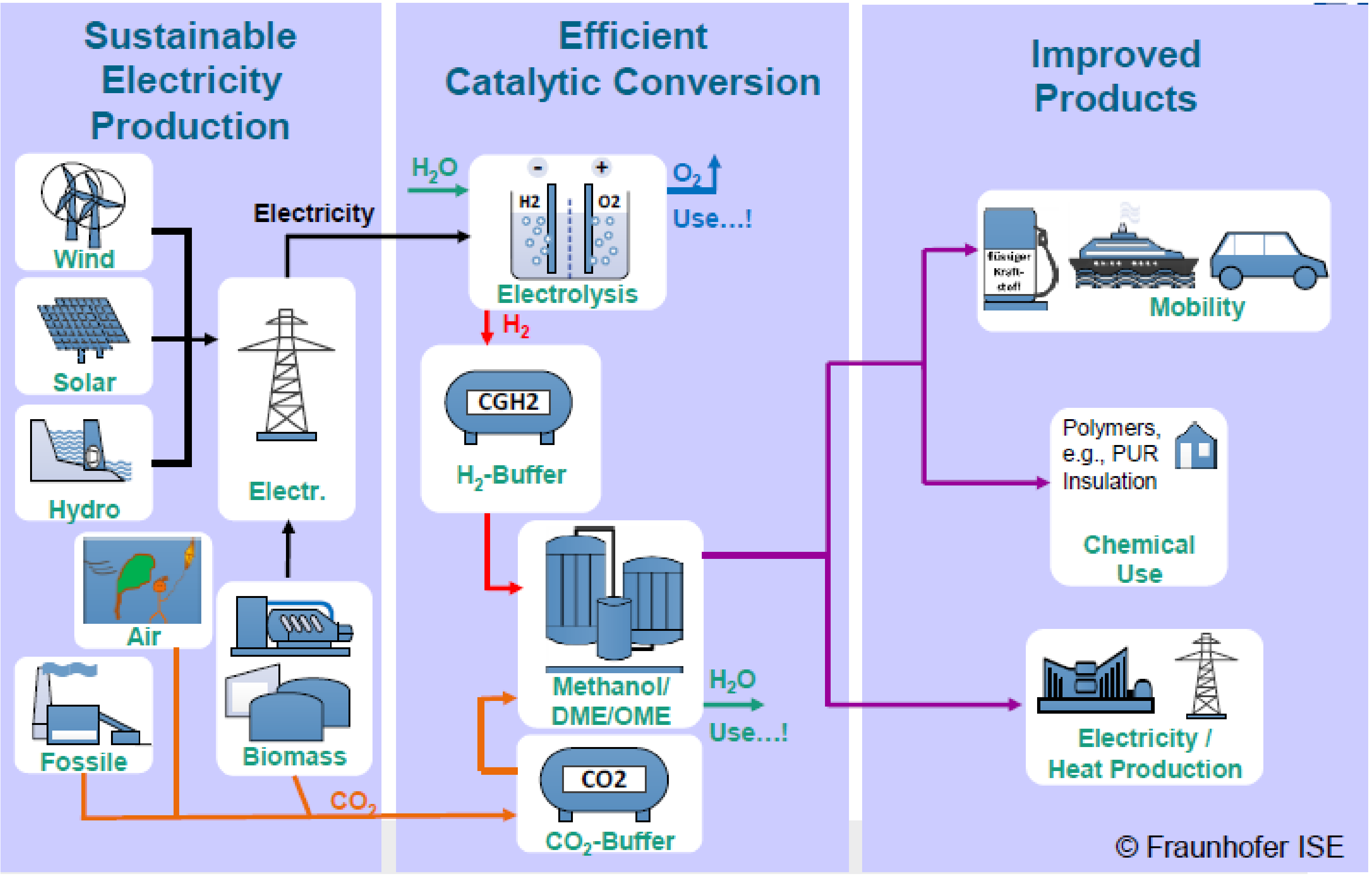
Pilot plant [2017], Siemens, Oxford (UK)



SIEMENS

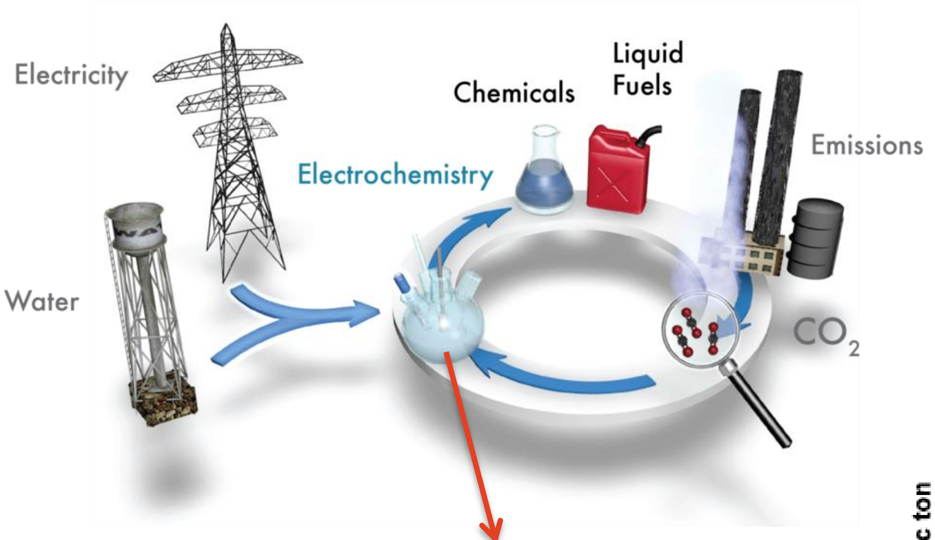
Power to MeOH/DME/OME

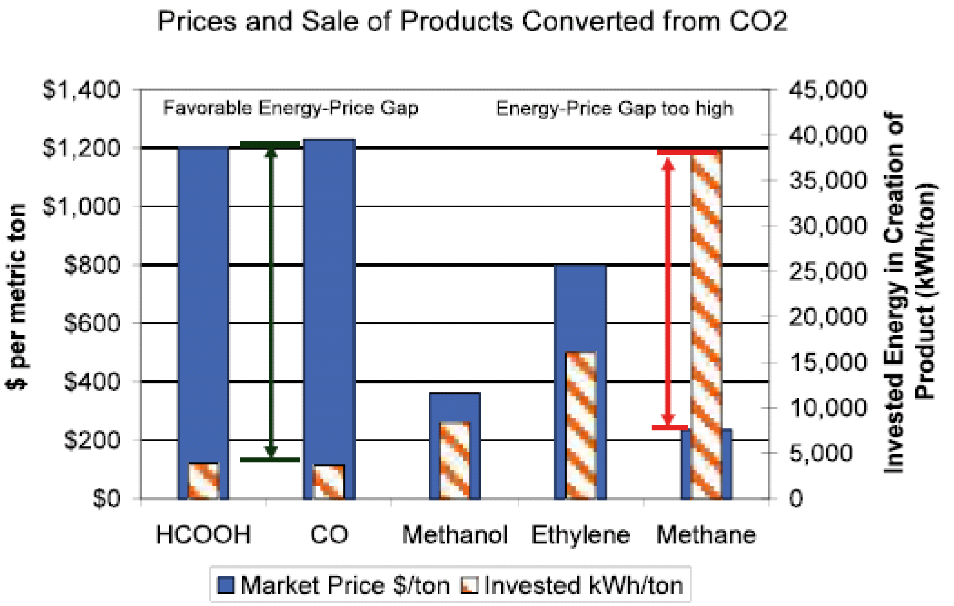
Approximately TRL 3 (out of 9)



Power to Hydrocarbons (from CO_2)

Approximately TRL 1 (out of 9)





Business cases for electrification

Examples of business case calculations

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Business case for Power-2-Heat

Steam recompression as an example

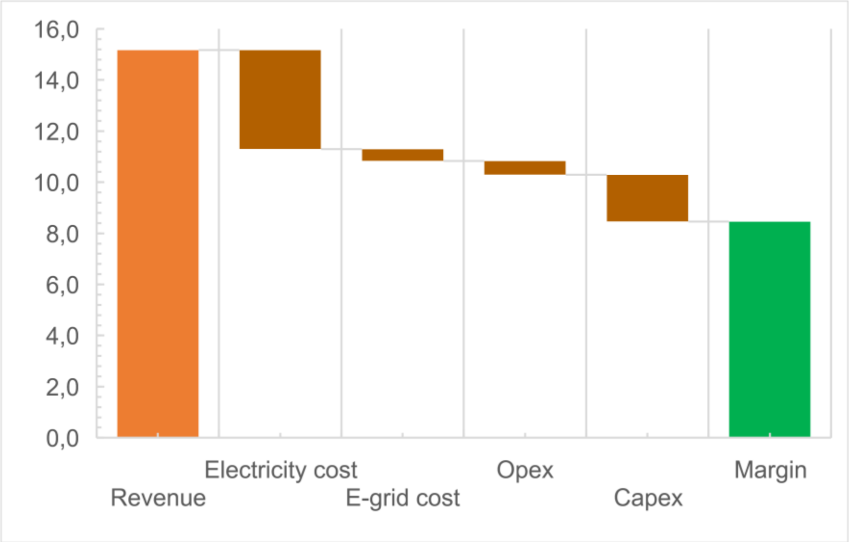
Process
- Mechanical energy is used to upgrade low quality steam to be used in industrial processes

Key parameters
- COP of 6 with temperature lift of 60 ºC from waste steam at 120 ºC
- 10 MW capacity
- Base load operations (96% on in base case)
- Lifetime of 80,000 hours with yearly extension maintenance

Business case is positive at all price scenario's. Base case cumulative NPV is positive after 3 year.

Scenarios based on the report "Scenarios for the Dutch electricity supply system: A report prepared for the Dutch Ministry of Economic Affairs", Frontier Economics, September 2015.

Base case scenario cash flow



Results for various scenarios are for all scenarios positive

Business case for Power-2-Hydrogen

Methanol conversion as an example

Process

- H_2 produced by electrolysis when electricity prices below threshold
- H_2 subsequently combined with CO_2 to produce methanol

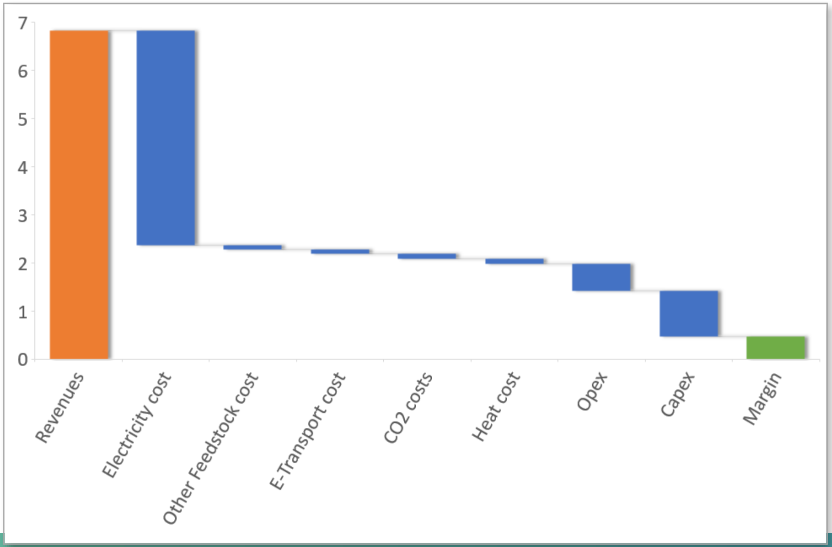
Key parameters

- Future PEM electrolysers (90% efficiency)
- 10 MW capacity (~ 6100 ton MeOH per year)
- Flexible operation (~80% on with base case)
- Lifetime of 80,000 hours with yearly extension maintenance

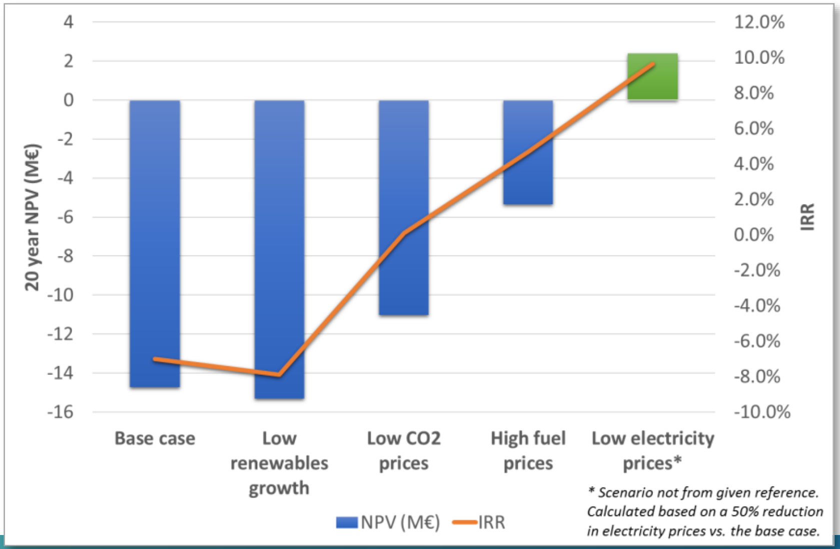
Business as usual (base case) does not result in a positive business case, but decreasing CO_2 prices or increased fuel prices both give positive IRRs. Electricity cost is the main factor.

Scenarios based on the report “Scenarios for the Dutch electricity supply system: A report prepared for the Dutch Ministry of Economic Affairs”, Frontier Economics, September 2015.

High fuel price scenario cash flow



Results for various scenarios



VOLTA CHEM

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Business case for Power-2-Specialties

FDCA for PEF as an example

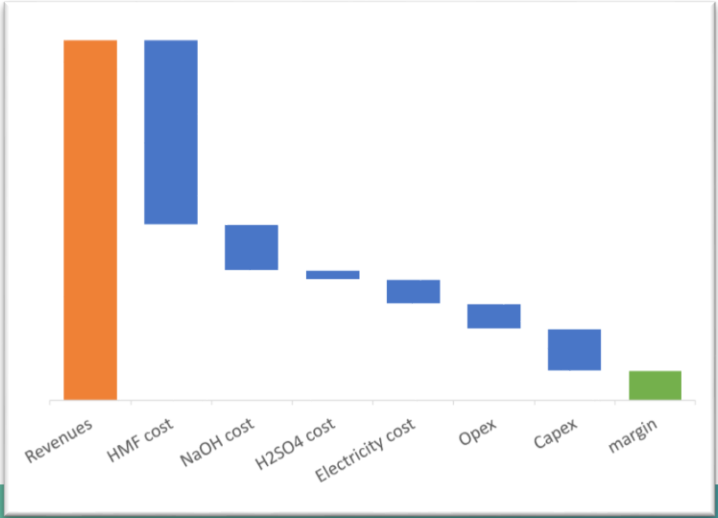
Process
- Selective oxidation of HMF to FDCA at the anode
- FDCA precipitates by PH-shift by adding sulfuric acid

Key parameters
- Based on a laboratory system using Nickel-based electrodes (50 mA current density@current efficiency of 80)
- 4000 ton FDCA produced per year (~ 11.6 MW)
- Base load operation
- Revenues based on PTA price with 50% premium
- Lifetime of 80,000 hours with yearly extension maintenance

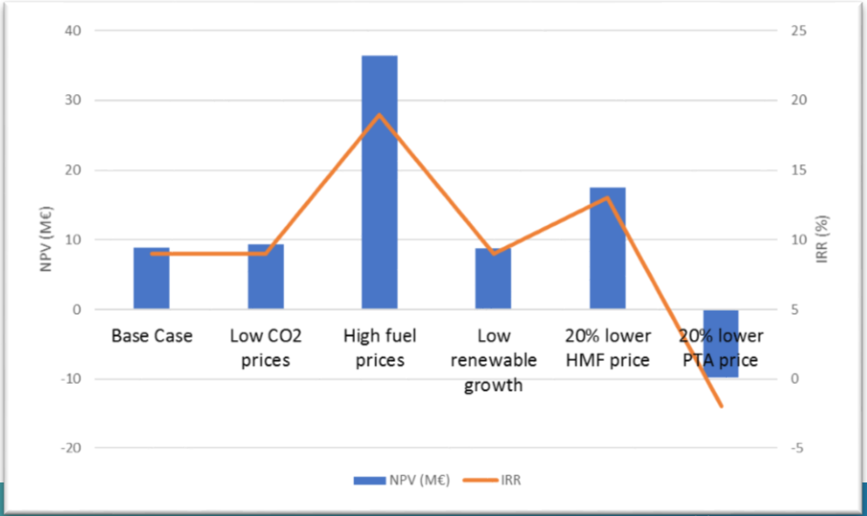
The future HMF price and PEF price have a large impact on the business case. The cost of electricity is insignificant for this power to specialties case.

Scenarios based on the report "Scenarios for the Dutch electricity supply system: A report prepared for the Dutch Ministry of Economic Affairs", Frontier Economics, September 2015, and the future HMF price variations are based on the paper "Techno-economic analysis of dimethylfuran (DMF) and hydroxymethylfurfural"

Base case scenario cash flow



Results for various scenarios



Business case for Power-2-Commodities

CO_2 to CO as an example

Process
- Direct electrochemical reduction of CO_2 to CO
- H_2 produced simultaneously from reduction of water

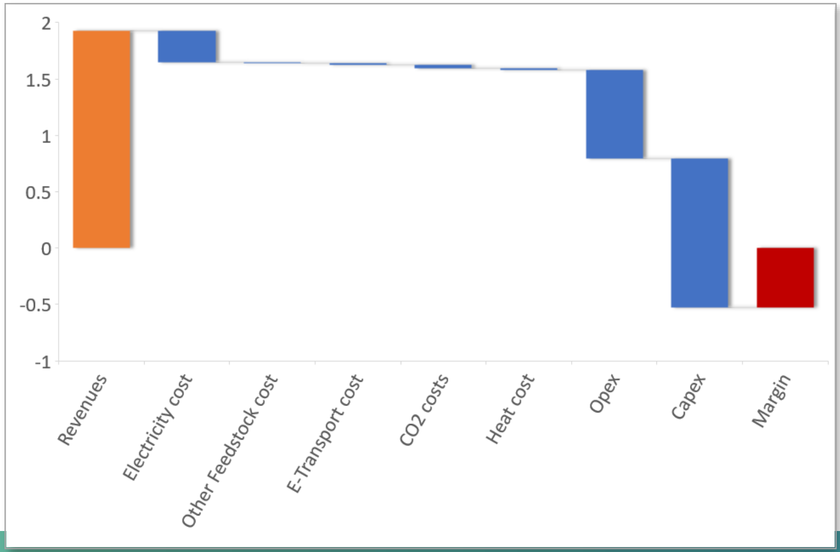
Key parameters
- Based on laboratory system utilising copper-based electrodes (current density of 6 mA/cm^2 @ 90% efficiency)
- 0.7 MW capacity (1 Mton CO per year)
- Base load operation
- Lifetime of 80,000 hours with yearly extension maintenance

Business as usual (base case) does not result in a positive business case. The capital investment is the most important factor and can be decreased by increases in current density and system lifetime.

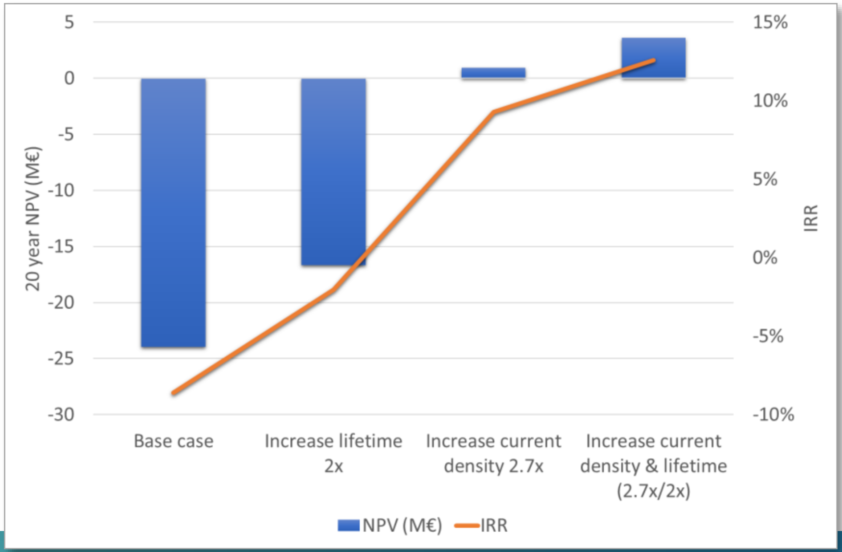
An increase in current density by a factor of 2.54 gives a breakeven NPV at year 20.

Base case scenario based on Frontier Economics, 2015.

Base case scenario cash flow



Results of sensitivity analysis



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