



Solar Fuels

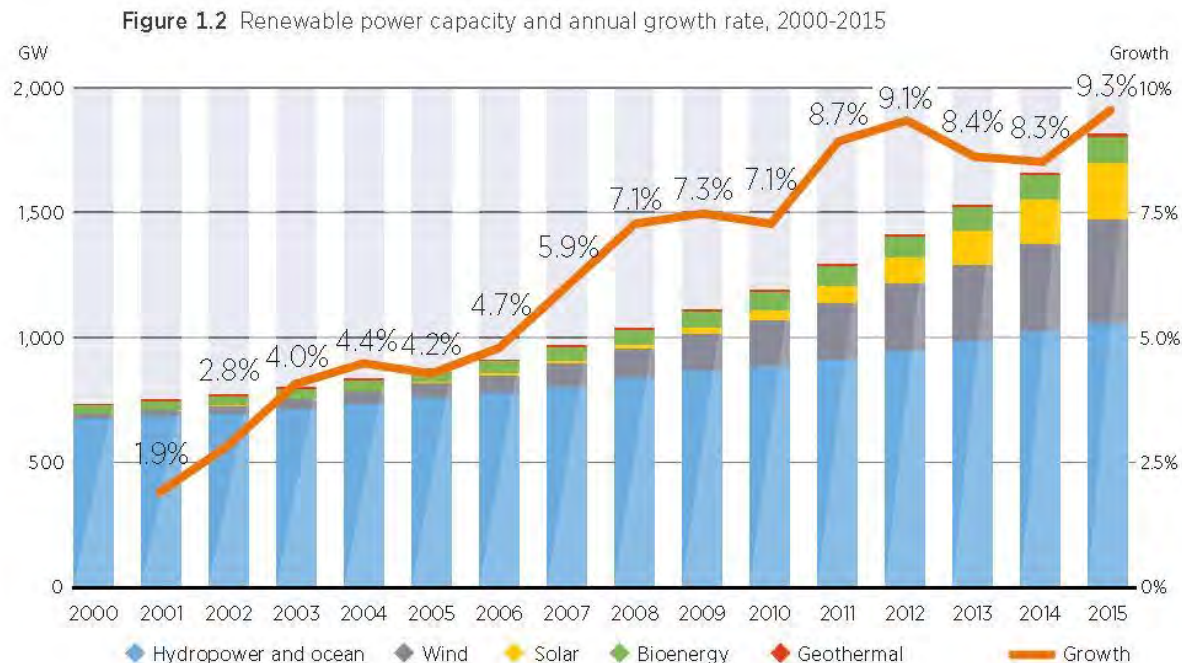
The road ahead

Hans de Neve



Investments in renewable electricity are booming

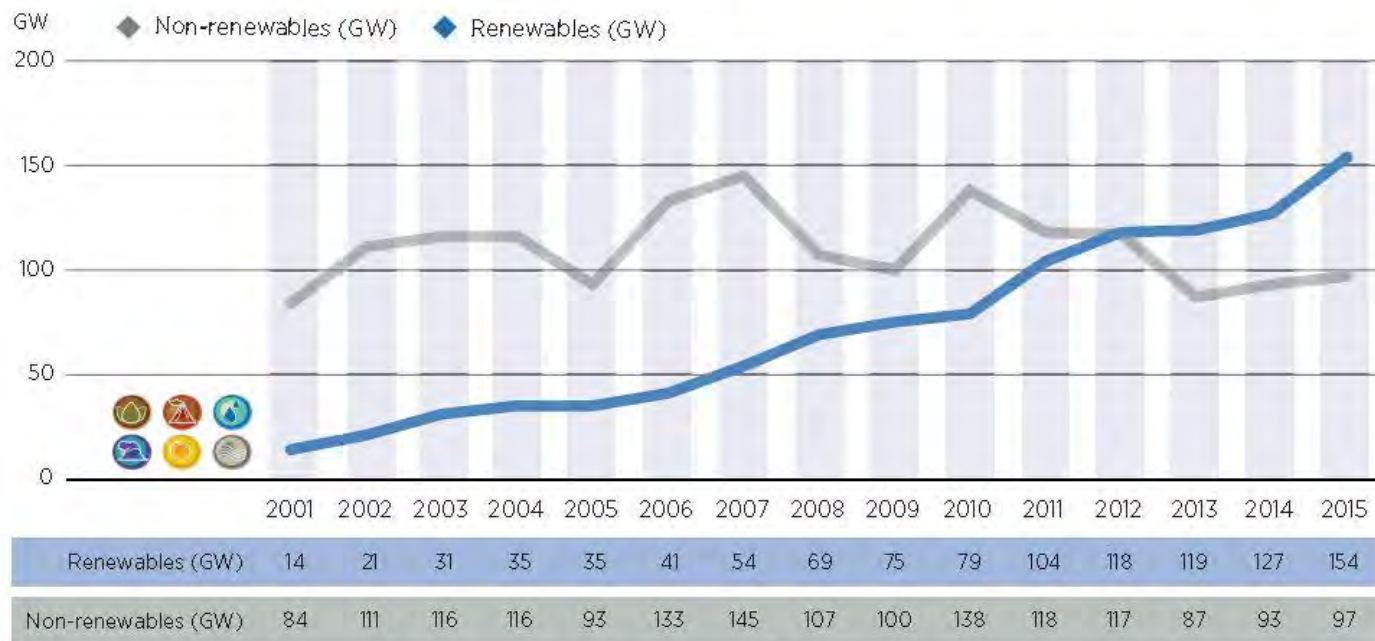
Renewables are now the first-choice option for expanding, upgrading and modernising power systems around the world. Wind and solar power, which commanded about 90% of 2015 investments in renewable power, are now competitive with conventional sources of electricity, as their costs have plunged in recent years. The cost of wind turbines has fallen by nearly a third since 2009 and that of solar photovoltaic (PV) modules by 80%. These developments are reflected in the levelised cost of electricity with some renewable technologies having reached grid parity.



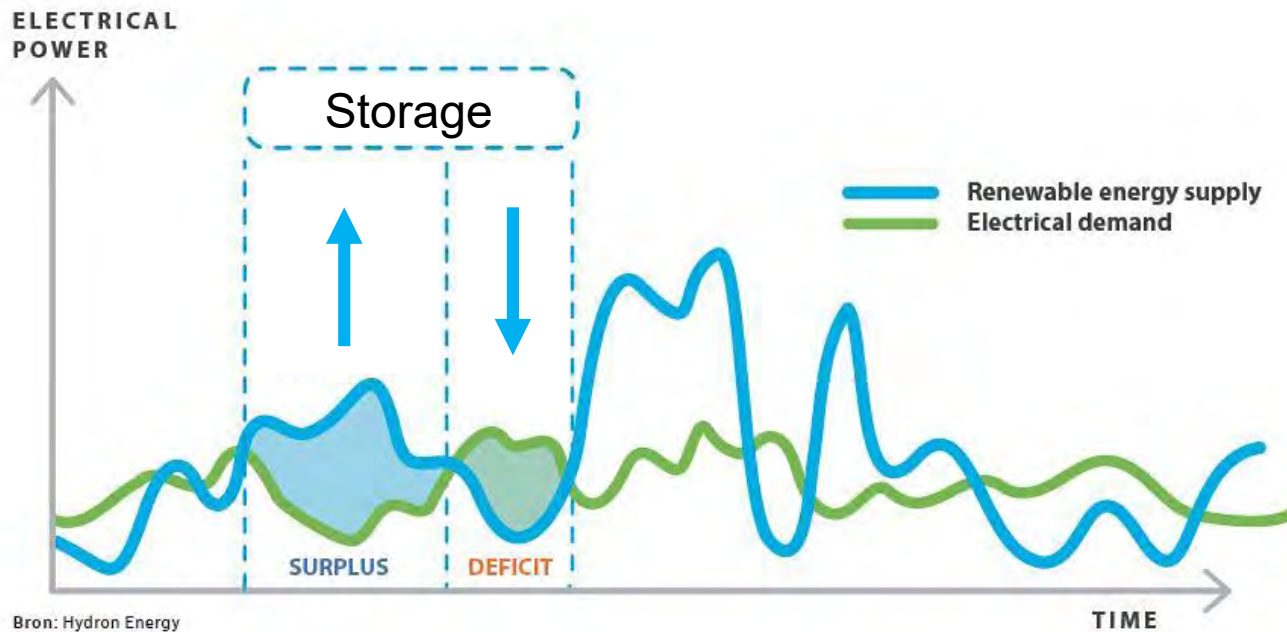
Source: IRENA, 2016b

Cross-over with fossil power plants

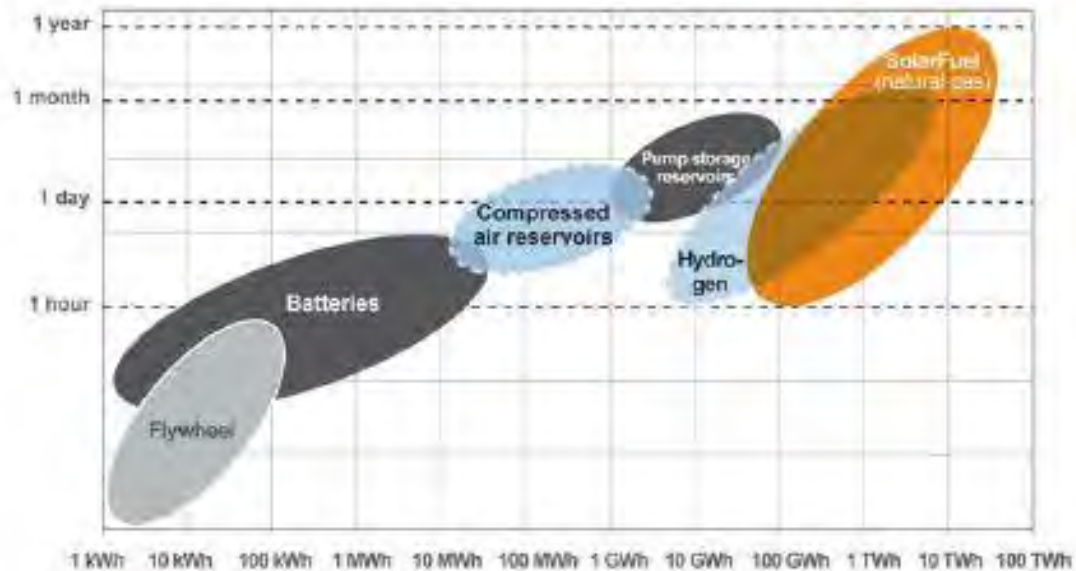
Figure 1.3 Renewable and non-renewable power capacity additions, 2001-2015



Growing need for storage



Different storage technologies



Chemical bonds as storage of renewable electricity

- **Scaleable in size:**

- Chemicals have a high energy density and can easily be stored in huge quantities
 - Investment in a conversion unit
 - Storage volume is very cheap and therefore scaleable

- **Scaleable in time:**

- Chemicals can be stored for very long times



More than balancing the grid

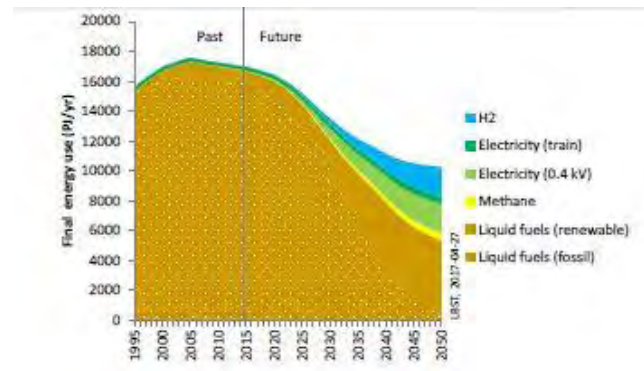
- **Large parts of the transport sector will remain dependent on high-density fuels**

- Airplanes
- Heavy duty road transport
- Ships



THE TRANSPORT [R]EVOLUTION HAS NOT REALLY STARTED YET

While the transition towards 100% renewables in the “traditional” power and heating sector seems well within our grasp, the phase-out of fossil fuels in the transport- and parts of the industry sector are still present major challenges, especially air travel and transport. Oil dominates the global transport system and a switch from combustion engines to electric drives is not possible for example for airplanes.. The



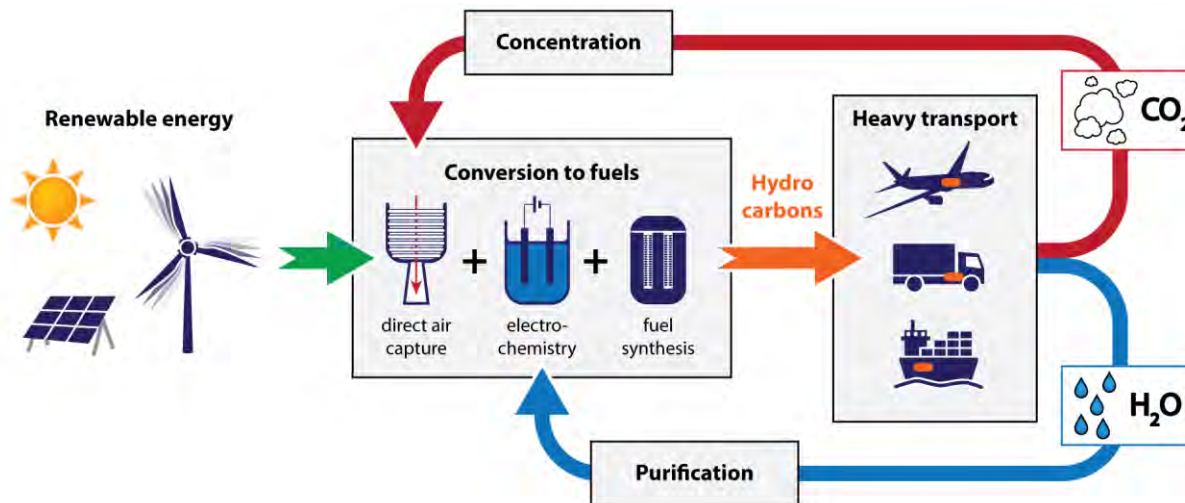
Source DENA-LBST

Chemical industry

- **Chemical industry requires renewable hydrocarbon feedstock to replace fossil oil and gas**
- **For the chemical industry there are few alternatives**
 - Biomass – issues of land use – already constrained by law in Europe
 - Gasification of waste: certainly part of the solution but not sufficient to supply the chemical industry with a renewable hydrocarbon feedstock replacement



Circular economy



Challenges

■ Electrolyser technology is still very expensive

- 1000 Euro/kW_{el} CAPEX costs but could be lower for larger systems (MW range – offers in the range of 500 Euro/kW_{el})
- This is the reason why industrial H₂ today comes from methane crackers
 - Electrolysis: 4 Euro per kg H₂ at industrial electricity tariff of 6 cent/kWh
 - Crackers: 1 Euro per kg for H₂ derived from fossil gas

■ Renewable sources of electricity are intermittent

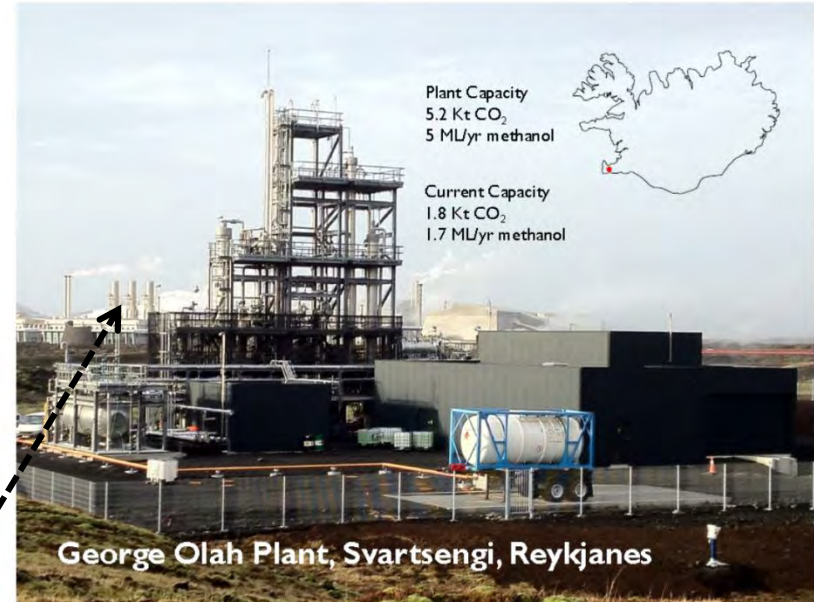
- Not possible to use your CAPEX at 100% capacity
- PV (12%), on-shore wind(40%), off-shore wind (60%), geothermal (100%)

■ We need air-capture of CO₂ to close the loop

- For the time being limited to CO₂ waste streams – OK as long as it is used as intermediate solution
- Direct-air capture technology is under development and very promising!

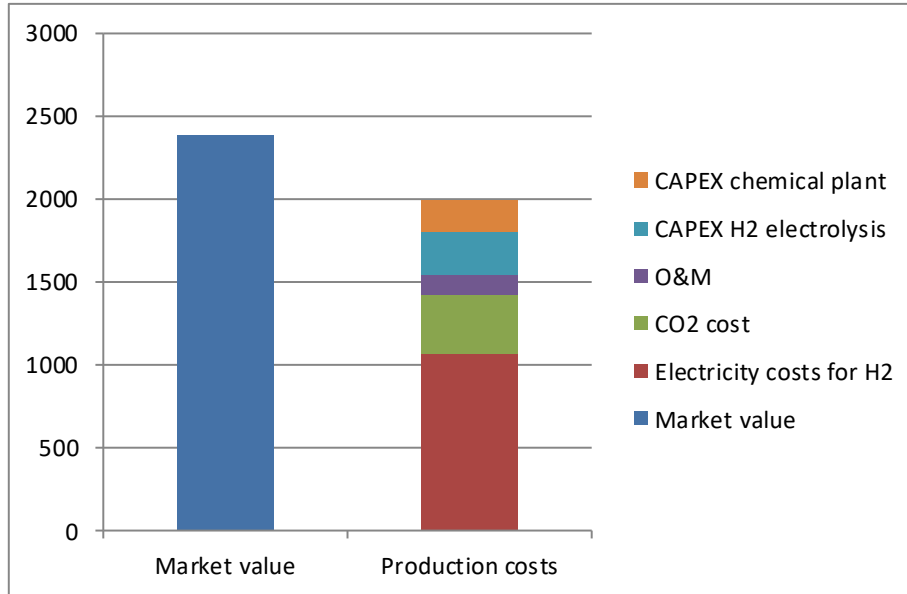
Renewable methanol plant in Iceland

- **Methanol production based on H_2O , CO_2 and (geothermal) renewable energy**
- **Carbon Recycling International**
- **Operational since end 2011**



Svartsengi Geothermal
Power Plant

Production costs for renewable methanol – case 1



Prices per ton of H₂



■ Geothermal

- continuous
- Average cost of 20 Euro/MWh

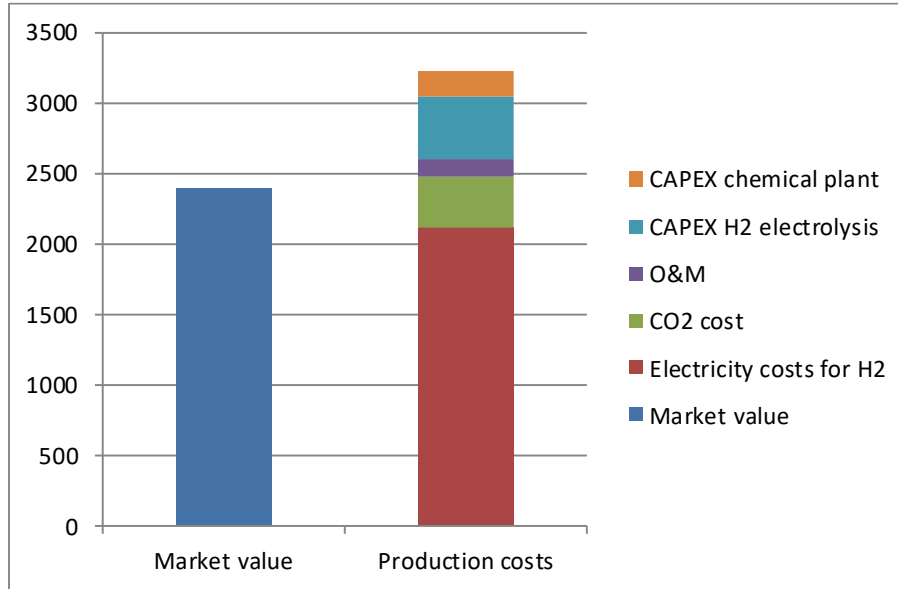
■ H₂ CAPEX 500 Euro/kW_{el}

- Quote for larger systems (MW range)

■ CO₂ priced at 50 Euro/ton

- Also quoted for direct-air capture technology

Production costs for renewable methanol – case 2



Prices per ton of H₂



- **Off-shore wind**
 - 60% intermittency
 - Average cost of 40 Euro/MWh
- **H₂ CAPEX 500 Euro/kW_{el}**
 - Quote for larger systems (MW range)
- **CO₂ priced at 50 Euro/ton**
 - Also quoted for direct-air capture technology

Factor 1,3 more expensive than fossil alternative

Renewable methanol – crossing the gap

▪ Renewable electricity financially supported by society

- Market price for fossil electricity is 4 Eurocent/kWh
- Residential PV systems get 24 Eurocent/kWh (factor of 6!)
- Solar parks get 14 Eurocent/kWh (factor 3,5!)

▪ Renewable electricity is great but it does not get us all the way

- We need renewable hydrocarbons to turn chemistry and transport into 100% renewable sectors
- We need renewable hydrocarbons to ensure supply of electricity during longer times of poor wind and sun conditions
 - store renewable electricity for larger time spans and in larger quantities
- With off-shore wind on the North Sea it is only a factor 1,3 more expensive than the fossil alternative
- What are we waiting for.....

Is this not very inefficient?

- **Converting renewable electricity to renewable methanol: 50% (including direct-air capture of CO₂)**
 - Elon Musk called hydrogen (or derivatives) the stupiest idea ever....
- **The problem is not a shortage of sun and wind**
 - Renewable electricity will soon be a cheap and abundant commodity product
 - Exponential growth – we will largely overshoot our global energy needs
- **The challenge is to store and convert it**
 - Batteries are half of the story
 - Hydrocarbons are the other half

Conclusion

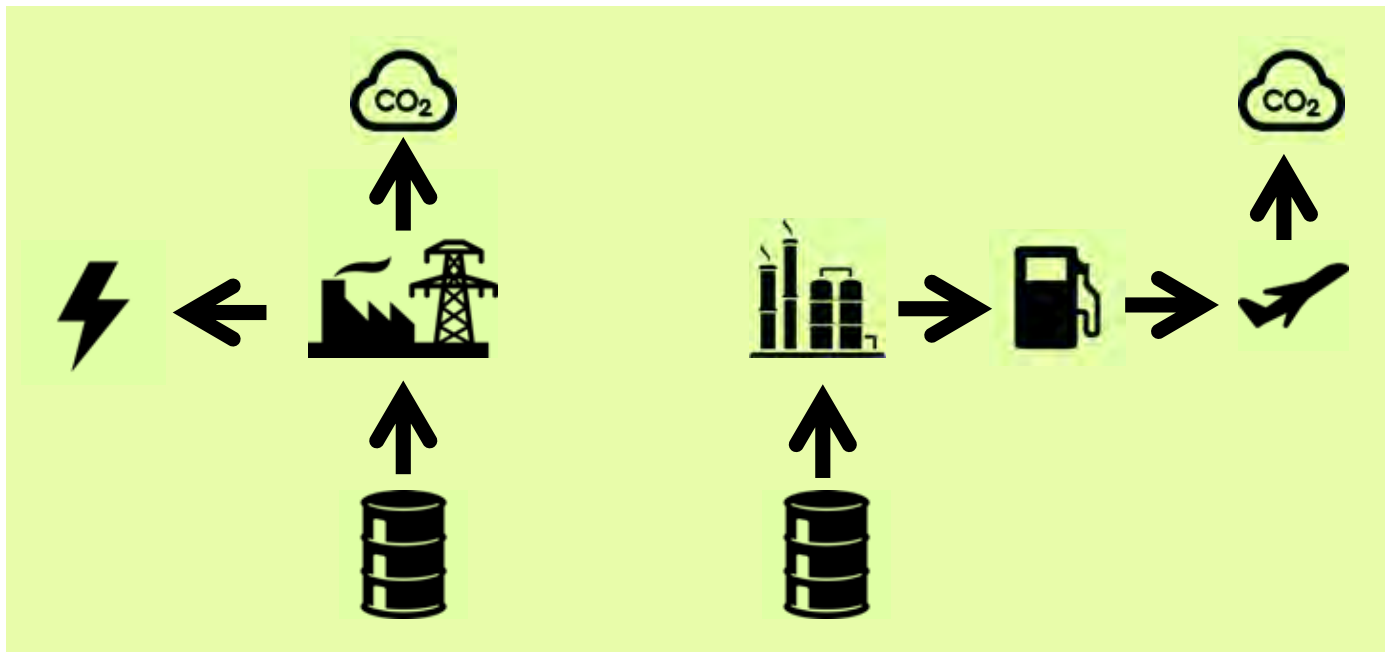
- **Conversion of renewable electricity into chemical bonds is the key enabler of a CO₂-neutral economy**
 - Required for grid balancing/storage at large scale
 - Required for transport
 - Required for chemistry

- **The problem has shifted from generating renewable electricity to storing and converting it**

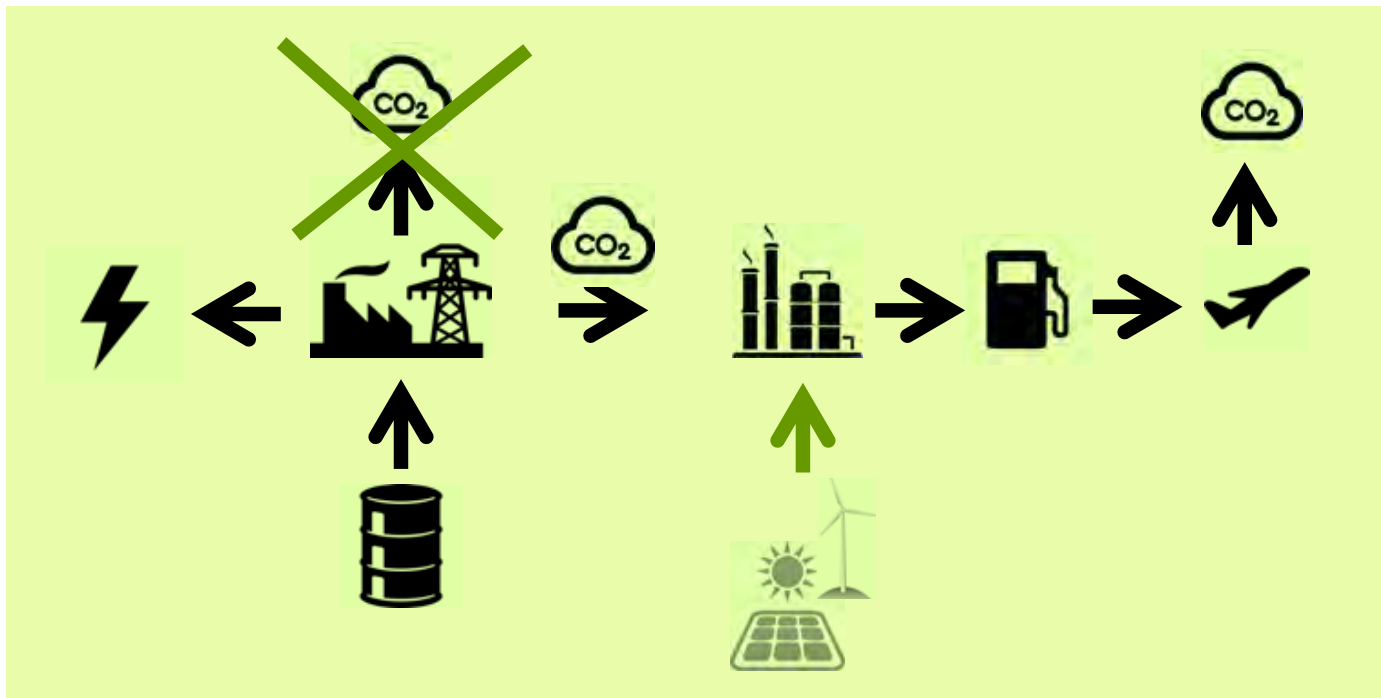
Back-up



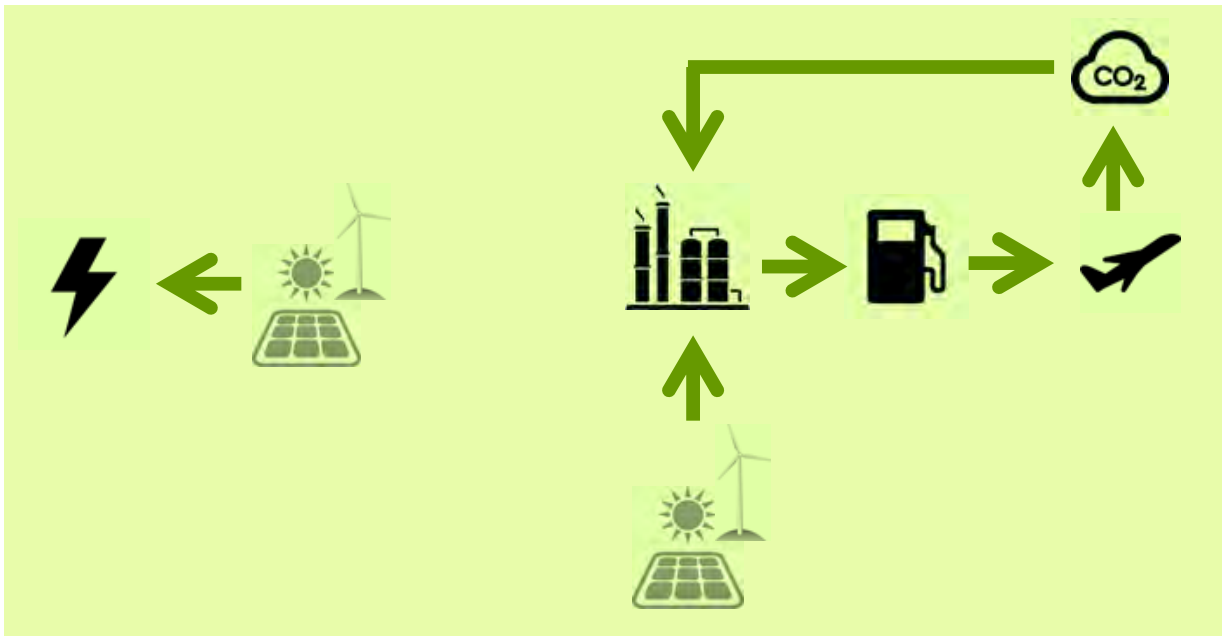
Transition: current situation



Transition: first step



Transition: final step



Fuelliance

- **Collaboration between industrial sectors**
 - TKI energy
 - TKI chemistry
 - TKI HTSM
- **Collaboration between regions**
 - Noord-Brabant: high-tech machine manufacturing
 - Chemelot: chemical engineering R&D
 - Rotterdam: chemical cluster of companies
- **Single point of contact for political stakeholders and media**