BCCI workshop on 12 November 2020:
Increasing energy efficiency and Hydrogen Economy - the contribution of the chemical industry to a 'climate-neutral economy’

„Green Hydrogen“ as a feedstock for the chemical industry/various industrial sectors and sub-sectors

cefic

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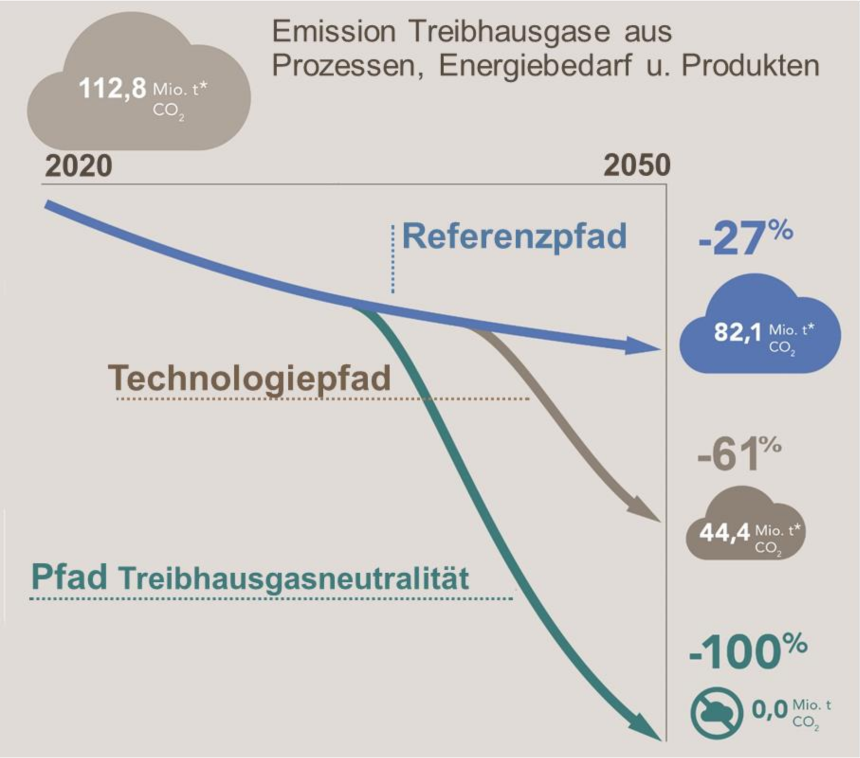
Three pathways towards climate neutrality (example Germany = +/- 25% of EU chemical industry)



Referenzpfad

0 Mrd. € zusätzliche Investitionen

54 TWh Strombedarf pro Jahr

Technologiepfad

15 Mrd. € zusätzliche Investitionen

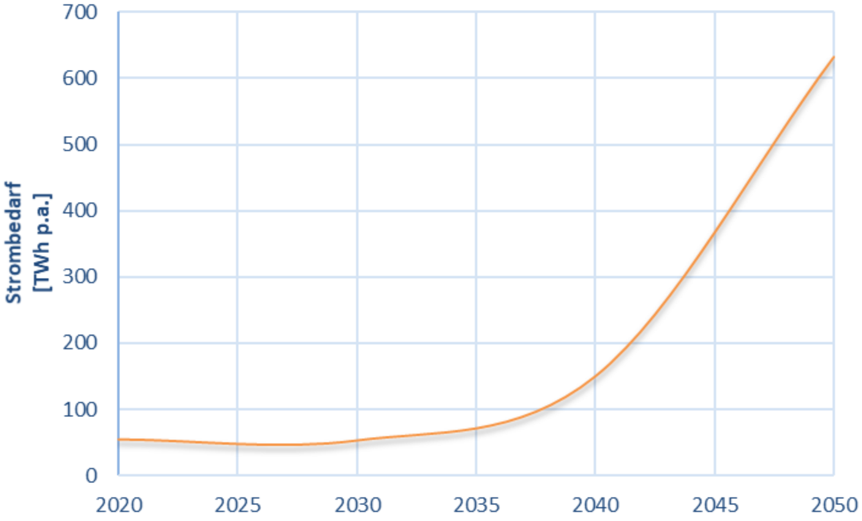
224 TWh Strombedarf pro Jahr

Pfad Treibhausgasneutralität

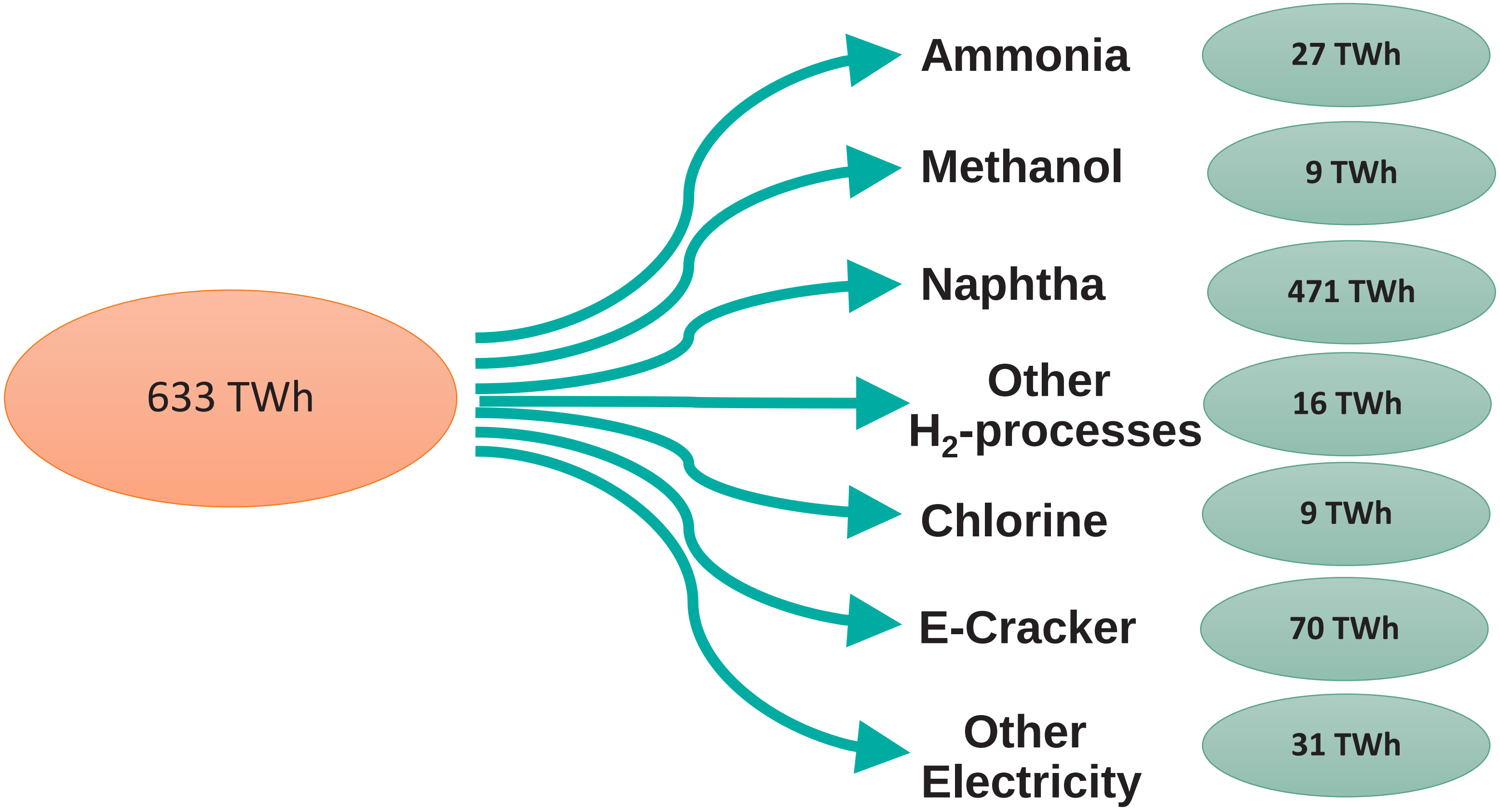
45 Mrd. € zusätzliche Investitionen

628 TWh Strombedarf pro Jahr

Electricity-/H2 needs Climate Neutrality (Germany)



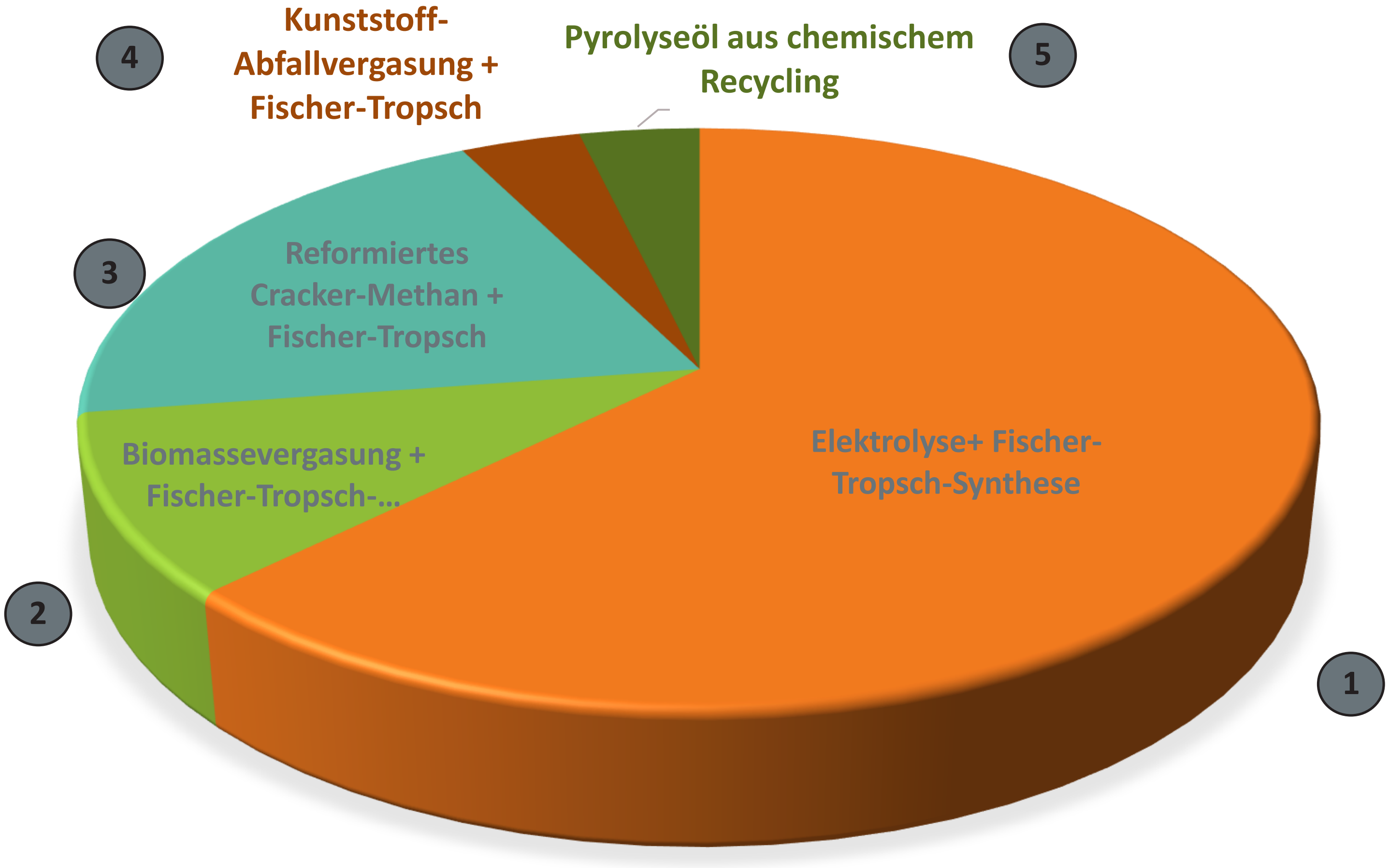
Electricity flows for Climate Neutrality (e.g. Germany)



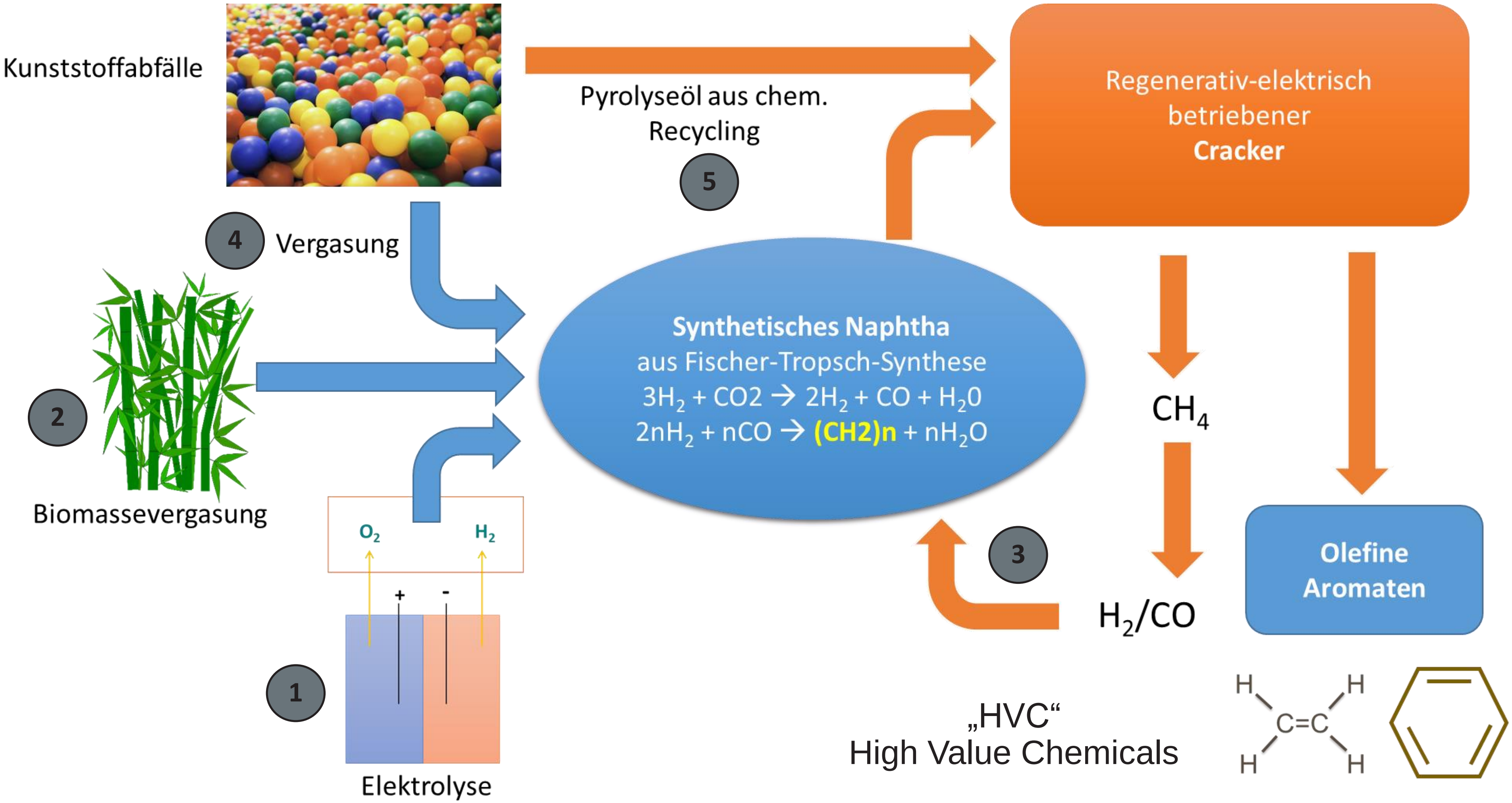
633 TWh

Ammonia	27 TWh
Methanol	9 TWh
Naphtha	471 TWh
Other H_2-processes	16 TWh
Chlorine	9 TWh
E-Cracker	70 TWh
Other Electricity	31 TWh

Technology mix for providing synthetic Naphtha in 2050



Pathways for Olefin/Aromatics production with electrified cracker



Kunststoffabfälle

Pyrolyseöl aus chem. Recycling

⑤

Regenerativ-elektrisch betriebener **Cracker**

④ Vergasung

Synthetisches Naphtha
aus Fischer-Tropsch-Synthese
$3H_2 + CO2 \rightarrow 2H_2 + CO + H_20$
$2nH_2 + nCO \rightarrow (CH2)n + nH_2O$

CH_4

H_2/CO

③

② Biomassevergasung

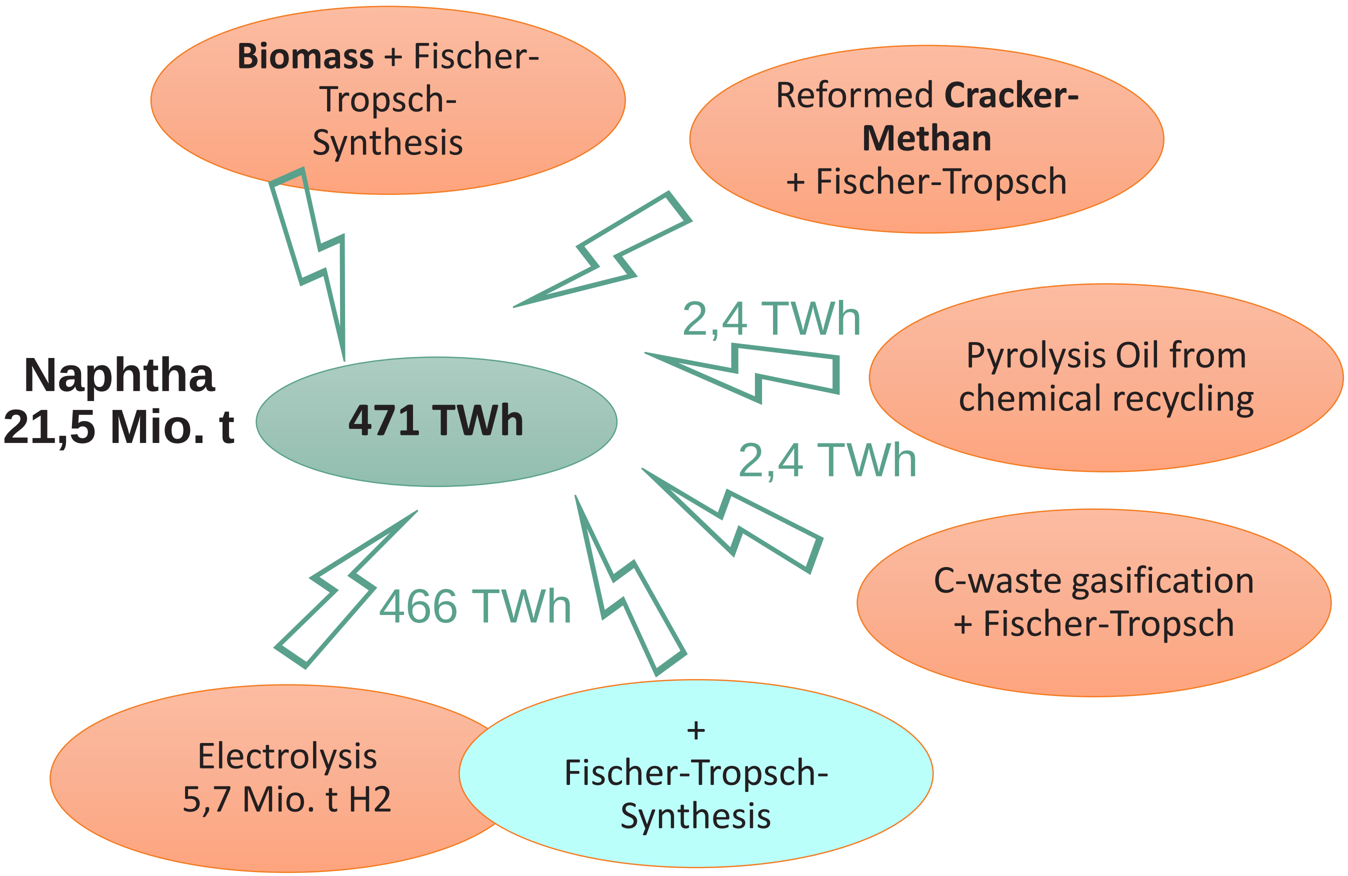
Olefine Aromaten

① Elektrolyse

„HVC“
High Value Chemicals

Chemistry 4 Climate

Energy flows with synthetic Naphtha in 2050



Biomass + Fischer-Tropsch-Synthesis

Reformed **Cracker-Methan** + Fischer-Tropsch

2,4 TWh

Pyrolysis Oil from chemical recycling

Naphtha
21,5 Mio. t

471 TWh

2,4 TWh

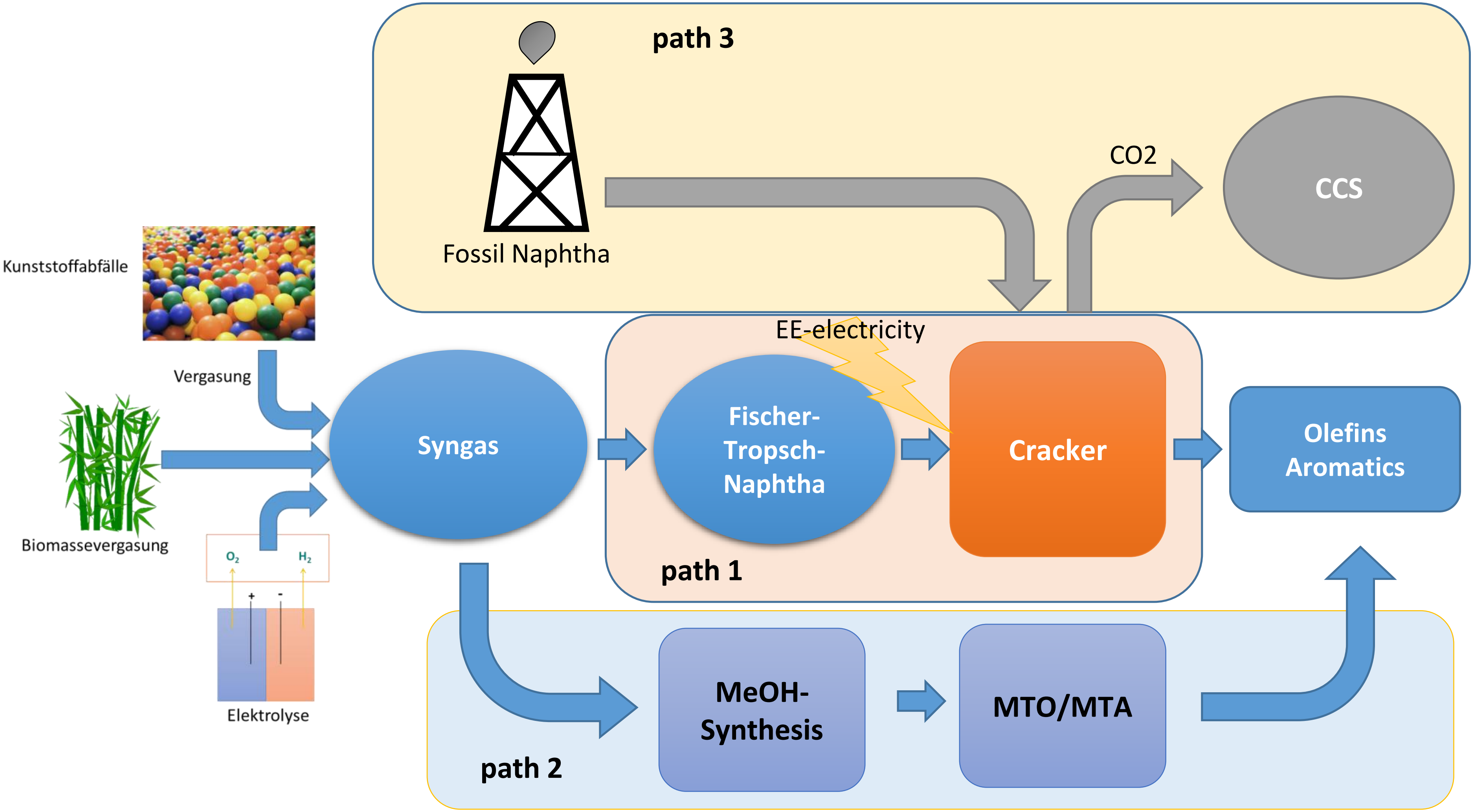
C-waste gasification
+ Fischer-Tropsch

466 TWh

Electrolysis
5,7 Mio. t H2

+
Fischer-Tropsch-Synthesis

Three options towards HVC



Energy losses from non usable products

Ammonia

$N_2 + 2\ H_2 \rightarrow 2\ NH3$

Produced H2 completely in Product

Methanol

$CO_2 + 3\ H_2 \rightarrow CH_3OH + H_2O$

produced H2 partly in by-product

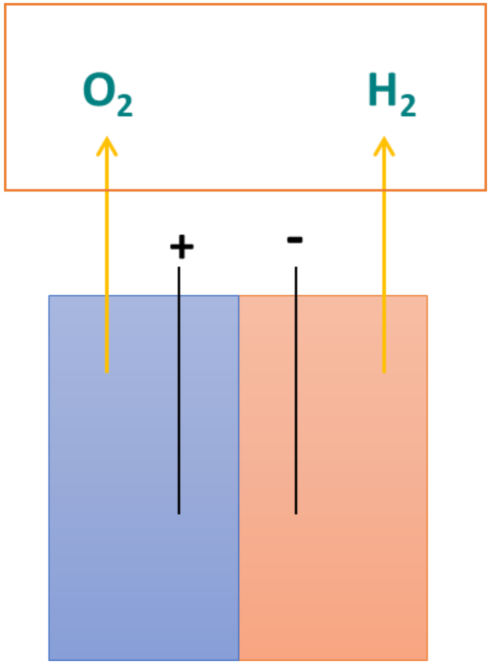
Depending on process energy for H2 production that does not completely transfer into desired product

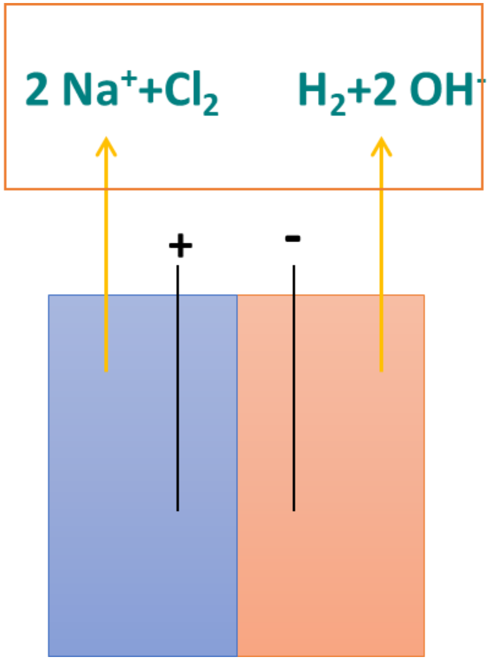
A lion share of the energy input is however being passed into desired molecule

Diversifying H2 production?

National and EU H2 Strategies focus on green H2

- Transformation role for other H2 proveniences
- H2 electrolysis vs. Chlor-Alkali-Elektrolysis

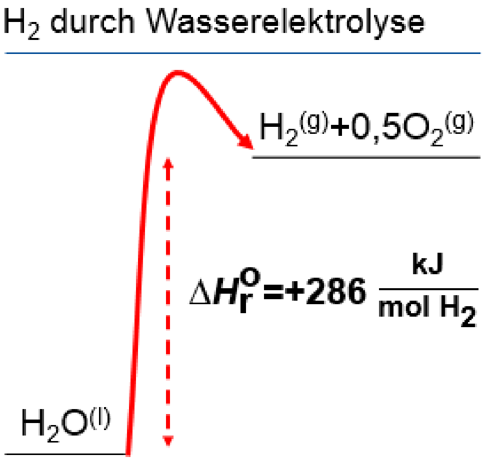


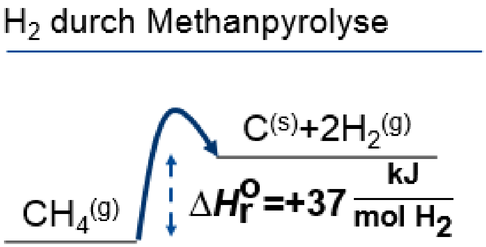


Diversifying H2 production?

- Sustainability assessment of H2-production according to ghg footprint
- Methanpyrolysis (in future)
- CCS/CCU
- Biomethane reforming

Possibly electricty demand reduktion

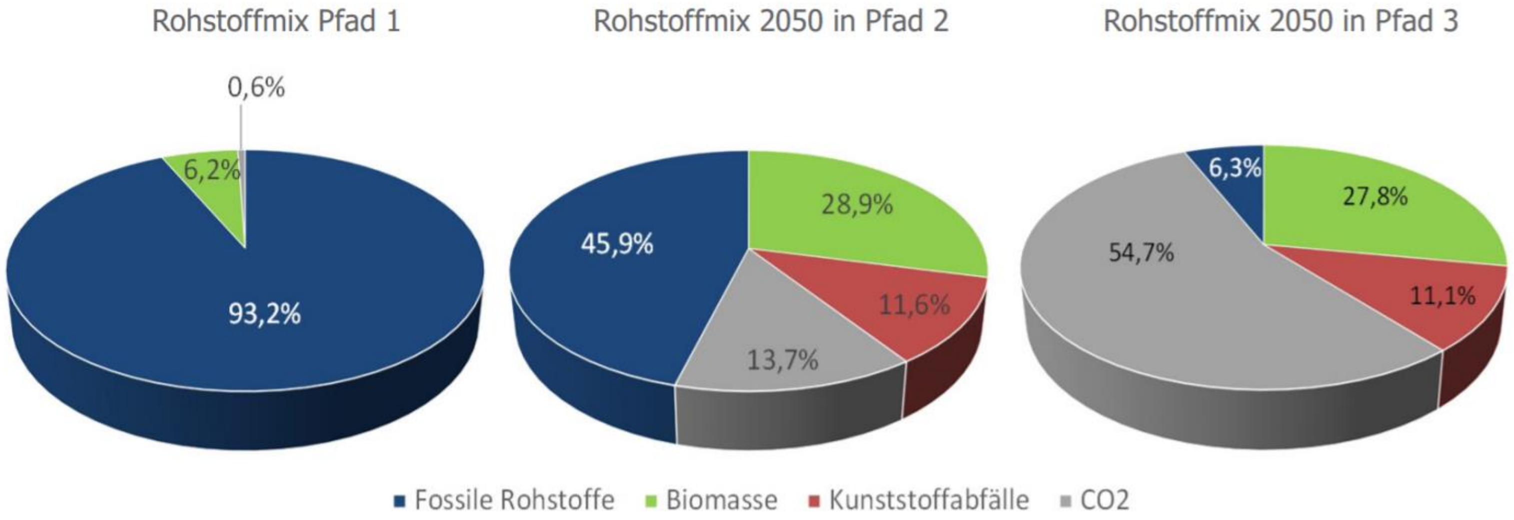




Technology mix for synthetic Naphtha in 2050

Nr.	Technology	Technology share (%)	Mass [t]
1	Elektrolysis+ Fischer-Tropsch-Synthesis	62,6%	13,46
2	Biomass gasification + Fischer-Tropsch-Synthesis	10,0%	2,15
3	Reformed Cracker-Methan + Fischer-Tropsch	20,0%	4,30
4	Plastics waste gasification + Fischer-Tropsch	3,7%	0,80
5	Pyrolysis oil from chemical recycling	3,7%	0,80
	Total	100,0%	21,50

Feedstock mix of the future

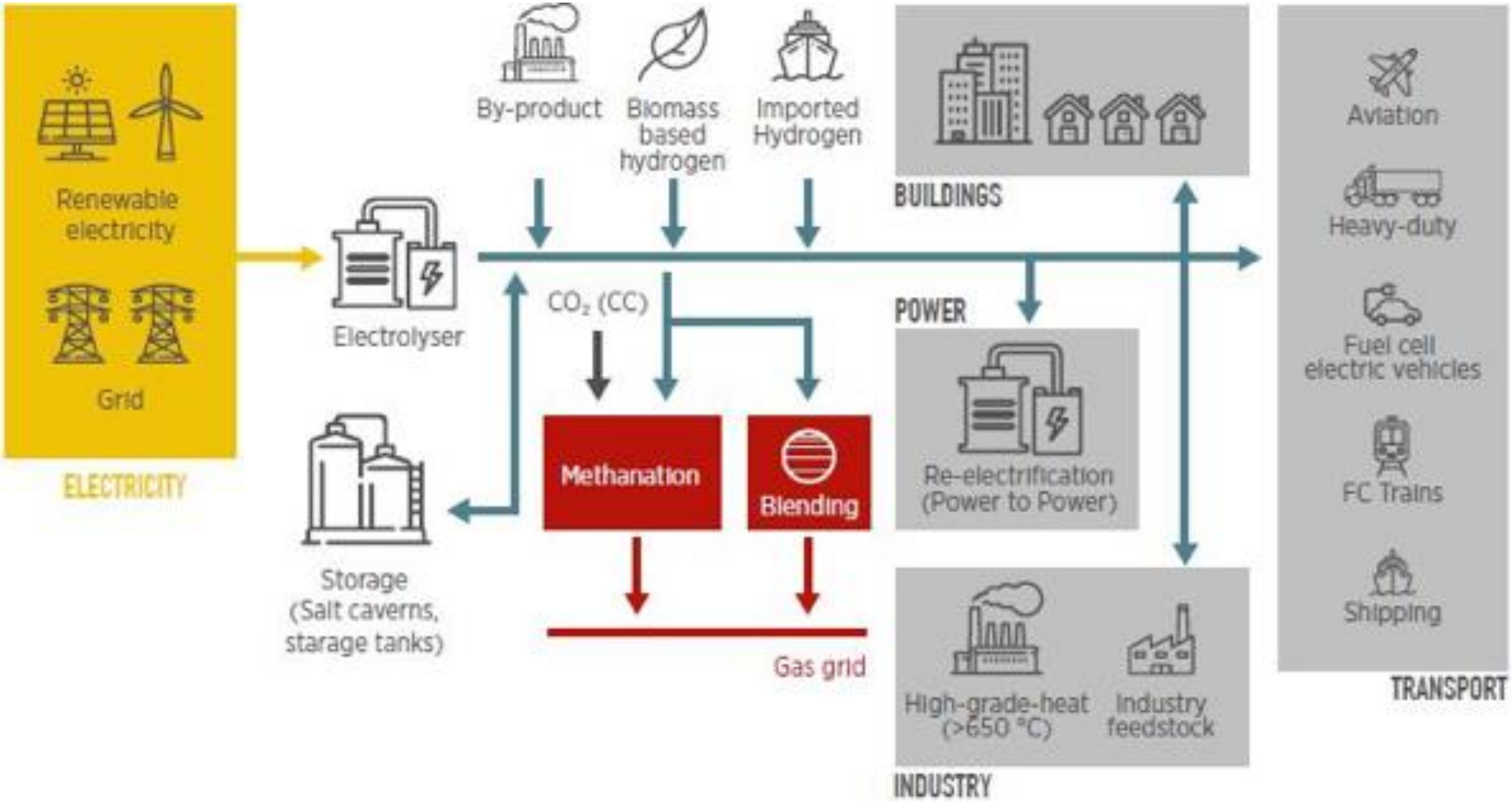


Rohstoffmix Pfad 1

Rohstoffmix 2050 in Pfad 2

Rohstoffmix 2050 in Pfad 3

Hydrogen and sector coupling



How to decarbonise several sectors: H_2 versus other options

Electricity versus H_2

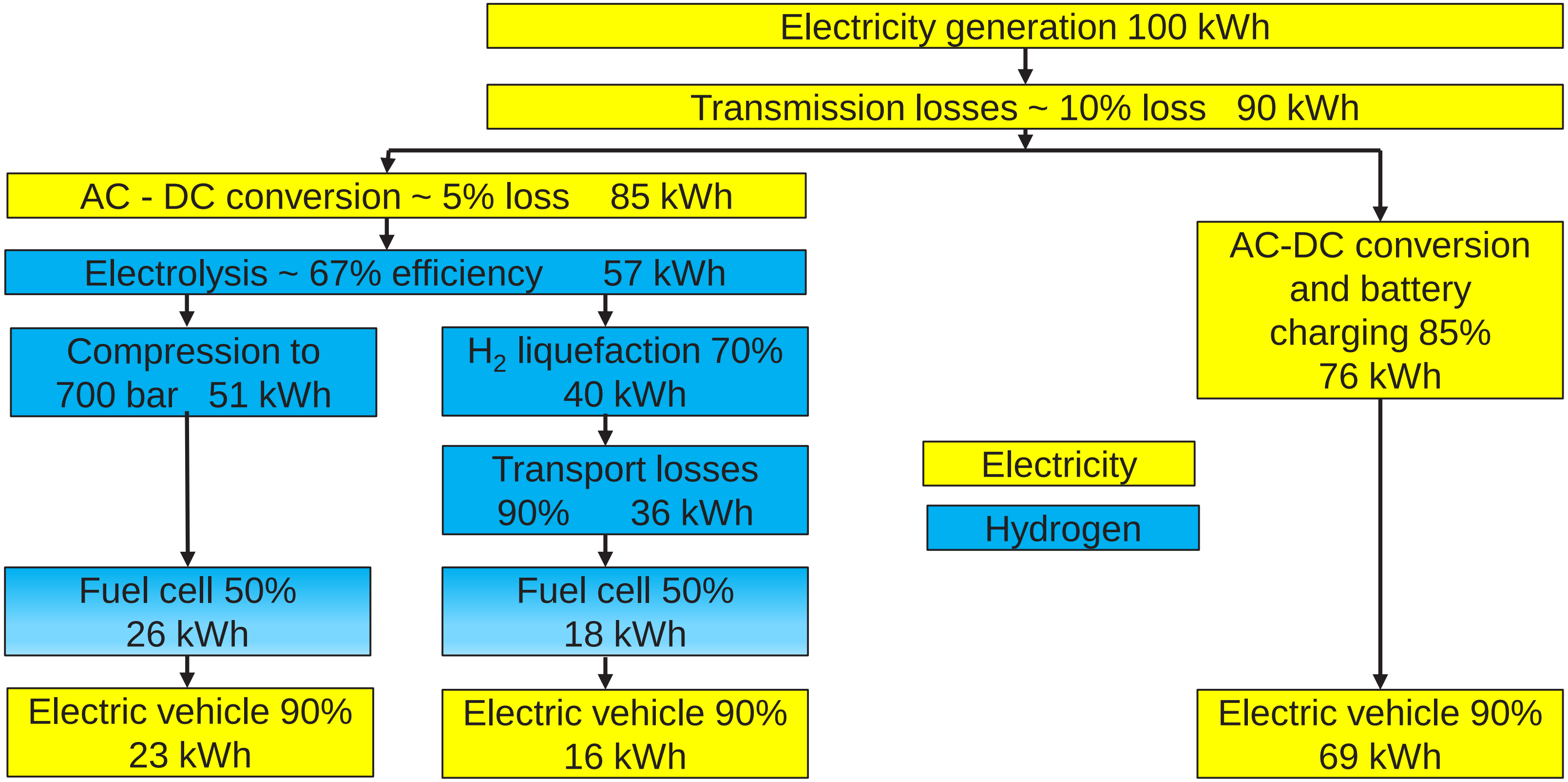
Transportation

“Electrification” of transport either direct (via battery) or via H_2 and fuel cells

- Electrification for passenger cars via batteries seems more efficient
  - Via batteries: 3.5 – 4.5 km/kWh
  - Via H_2 and fuel cells: 0.8 – 1.5 km/kWh (H_2 via water electrolysis)
- For heavy duty, the picture is a bit different

Electricity versus H_2

Transportation: Is hydrogen efficient?



Electricity generation 100 kWh

Transmission losses ~ 10% loss 90 kWh

AC - DC conversion ~ 5% loss 85 kWh

Electrolysis ~ 67% efficiency 57 kWh

Compression to 700 bar 51 kWh

H_2 liquefaction 70% 40 kWh

Transport losses 90% 36 kWh

Fuel cell 50% 26 kWh

Fuel cell 50% 18 kWh

Electric vehicle 90% 23 kWh

Electric vehicle 90% 16 kWh

AC-DC conversion and battery charging 85% 76 kWh

Electric vehicle 90% 69 kWh

Electricity

Hydrogen

100 - 150 km

80 - 100 km

350 - 450 km

Electricity versus H_2

Transportation

- Passenger cars
  - Europe has 286 million passenger cars and they drive on average 12000 km/year.
  - If they were all electrified before 2050; they would need…
    - Via batteries 760 - 980 TWh
    - Via H_2 34 - 38 million ton H_2 (if produced via electrolysis 2300 - 4300 TWh needed)

- What about other transport: trucks, busses, ships, planes?
  - If they would have to operate on H_2 this would require approx. 33 - 47 million ton H_2 (if produced via electrolysis 2500 – 3600 TWh needed)

Transport with H_2 would decrease energy efficiency but if H_2 is produced from fossil with CO_2 capture it would give a relief in the demand for renewable electricity

Electricity verus H_2

Heating of houses and other buildings

- Several options possible
  - Using heat-pumps: might only be feasible for newer well-insulated houses
  - Using direct electrical heating
  - Using hydrogen, biomethane, or artificial methane (from CO_2 and H_2)
  - Using hydrogen via fuel cells: benefit: producing heat and electricity
  - Using “waste heat” of industry, etc.

Electricity versus H_2

Heating of houses and other buildings

Heat-pump (requires very well insulated building)

- Electricity generation 1 MWh
- Transmission losses 10%
- Heat pump seasonal COP 2.7
- Heat generation 2.43 MWh

Efficiency 243%
(the heat comes from cooling surrounding air or the ground)

Direct electrical heating

- Electricity generation 1 MWh
- Transmission losses 10%
- Electrical heating 95% eff
- Heat generation 0.855 MWh

Efficiency 85.5%

H_2 from electrolysis

- Electricity 1 MWh
- Transmission losses 5%
- Electrolysis 67%
- H_2 transport loss 5%
- Boiler 90%
- Heat generation 0.544 MWh

Efficiency 54.4%

- Electricity 1 MWh
- Transmission losses 5%
- Electrolysis 67%
- H_2 transport loss 5%
- Fuel cell 50% E and 40% heat
- Heat generation 0.302 MWh and Electricity .242 MWh

Efficiency 54.4%

Electricity versus H_2

Heating of houses and other buildings

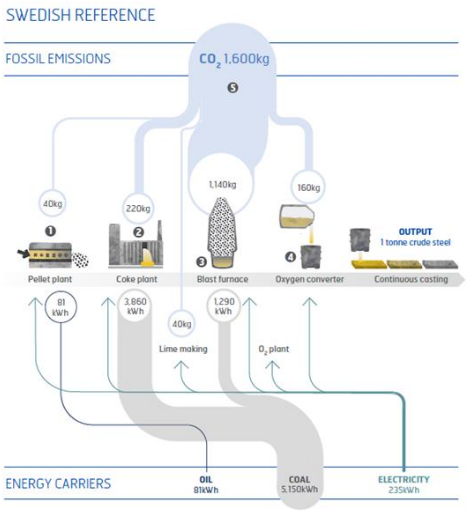
- Households and services use approx. 300643 ktoe (equals to 3500 TWh)
- Several options possible
  - Using heat-pumps, might only be feasible for newer well-insulated houses, would reduce energy consumption to 1440 TWh (as electricity)
  - Using direct electrical heating would require approx. 3500 TWh (as electricity)
  - Using hydrogen produced with electricity would require approx. 6450 TWh producing approx. 94 million ton H_2
  - Using hydrogen produced with electricity and using fuel cells would require approx. 11600 TWh on electricity to produce 178 million ton H_2 but fuel cell deliver back 2800 TWh

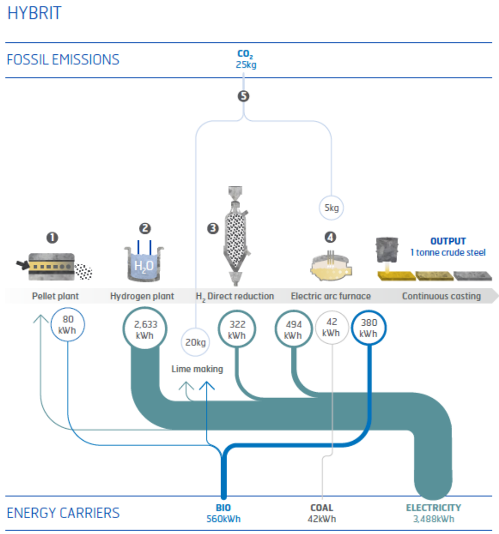
Heat Pumps would be the ideal solution, but requires extremely well insulated buildings (what is the effect of extracting heat from air and/or ground??), Direct heating via electricity is second best; H_2 (from electrolysis) to be used as fuel or being used in a fuel cell does not seem to be a realistic/efficient option.

Electricity versus H_2

Steel industry

- European steel industry produces 98 million (?) ton steel from ore
- Today this is a large CO_2 emitter





All numbers per tonne of crude steel.

Electricity verus H_2

Steel industry

- One of the options to reduce emissions is by making use of H_2 produced via electricity this requires 3.8 MWh/ton
  - Total demand on electricity 373 TWh
    - Of which 255 TWh for H_2 (4.2 million tons)

- Other options are
  - Making use of CCS
  - Direct electrolysis

Electricity versus H_2

Industry, heating requirements

- Industry uses 172003 ktoe (equals to 2000 TWh) as energy (excl. electricity)
- Energy could be replaced by hydrogen, biomethane, artificial methane, bio-mass, direct electricity heating
  - This would require 50.5 million ton H_2.
    If produced via electrolysis, it would require 3300 TWh of electricity
  - Direct electrical heating would require 2000 TWh (possible at high temp?)

Direct heating via H_2 from electrolysis does not seem to be an efficient option if the H_2 is produced via electrolysis.

Electricity versus H_2

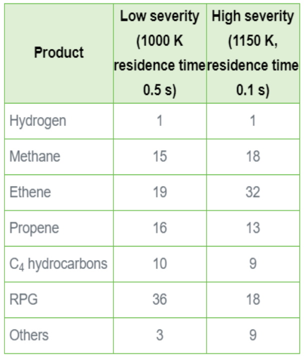
Industry, replacing feedstock

- Industry uses 97865 ktoe (4097.4 million GJ; equals to 1140 TWh) as feedstock
- To maintain or to replace by alternatives via H_2 + CO_2 ?
- Some examples:
  - Production of methanol approx. 1.5 million ton/year
    - Today based on mainly methane; requires 37.5 million GJ (0.9% of feedstock demand)
    - Alternative production out of CO_2 and H_2; requires 0.281 million ton H_2 this requires approx. 18 TWh on electricity (= 65813 TJ = 65.8 million GJ); 1.8 times the energy amount compared to starting from methane as feedstock
  - Production of NH_3 approx. 17 million ton/year
    - Traditional steam reforming of methane to produce H_2 and that reacts with N_2 to NH_3; feedstock requirement 21 GJ/ton NH_3; Yearly feedstock demand 357 million GJ (8.7% of feedstock demand)
    - Alternative H_2 from N_2 and H_2: requires 3 million ton H_2/year or 195 TWh of electricity (702 million GJ); approx. 2 times more feedstock energy

Electricity versus H_2

Industry, replacing feedstock

- Production of ethylene and propylene; ethylene 22 million/year and propylene 17 million ton/year.
  - Today mainly by cracking of naphtha delivers a range of products (propylene, ethylene, benzene, toluene, xylene, and gas (used to heat the process)).
    - Ethylene/propylene is approx. 35-45% of the output
    - So for 22 million ton ethylene and 17 million ton propylene approx. 86 -111 million ton of naphtha is required, delivering besides the ethylene/propylene approx. 30% other valuable products. Approx. 30% is used as energy.
    - Based on the HHV of naphtha the total energy input is approx. 4700 million GJ
  - Alternative production from methanol (produced from H_2 and CO_2);each ton of propylene or ethylene requires 2.28 ton of methanol, or 0.429 ton of H_2 or 25.75 MWh. On top of that there is some energy required for the process. According Dechema the average energy demand for this process is 95.6 GJ/ton so for 67 million ton of HVC the total energy demand 6405 million GJ or 1.4 times more



Product	Low severity (1000 K residence time 0.5 s)	High severity (1150 K, residence time 0.1 s)
Hydrogen	1	1
Methane	15	18
Ethene	19	32
Propene	16	13
C_4 hydrocarbons	10	9
RPG	36	18
Others	3	9

Table 2 Product yields/% by mass from the steam cracking of naphtha.

https://www.essentialchemicalindustry.org/processes/cracking-isomerisation-and-reforming.html

Electricity versus H_2

Industry, replacing feedstock

- Replacing feedstock via all kinds of new chemical routes would require approx. 2000 TWh.
- This is mainly based on routes via CO_2 and H_2
  - Approx. 30 million ton H_2

Summary

H2 plays a major role in the chemical industry:

- Biggest industrial user
- Climate-neutral chemical production technologically possible by 2050

H2 plays a key role:

- Enables CO_2 to become a raw material (c- provider)
- Can be used energetically (e.g. in high temperature processes) or as feedstock in other sectors

Challenges:

- Long-term high electricty needs (for electrolysis)
- Energy efficiency losses
- Requires enabling framework and breakthroughs for economic feasibility

Political perspectives

Technology openness for sustainable H2 provision at least during transistion period

Improvement of framework conditions for cost-efficient deployment of renewable energy sources

- H2 depends on low-cost electricity (e.g. max. 4 Cent/KWh)

Early development of energy partnerships with other countries whilst maintaining national value chains

Building H2 grid infrastructures

Public acceptance of costs and infrastructures

Supporting introduction of new climate-neutral technologies