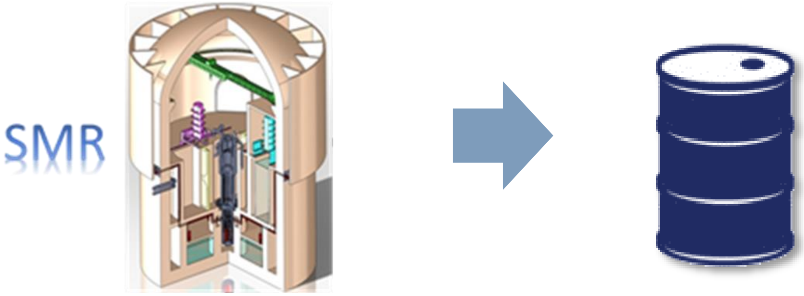
TANDEM
Workshop

E-fuel production with SMR

Non-electric applications of SMRs, hybrid energy systems and their components



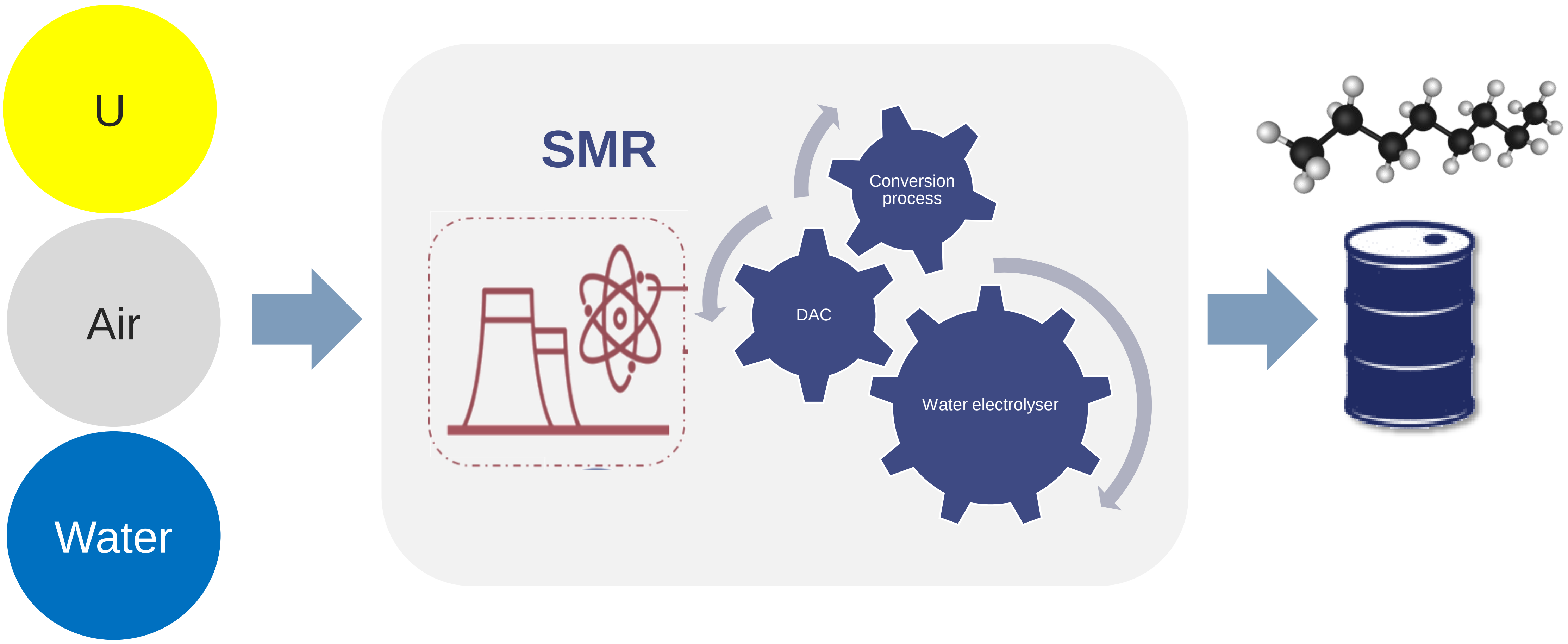
IRESNE/DER/SESI Philippe AMPHOUX

LITEN/DTCH/SSETI/LSET Luc BERTIER

19/09/2024

NUCLEAR to e-fuel

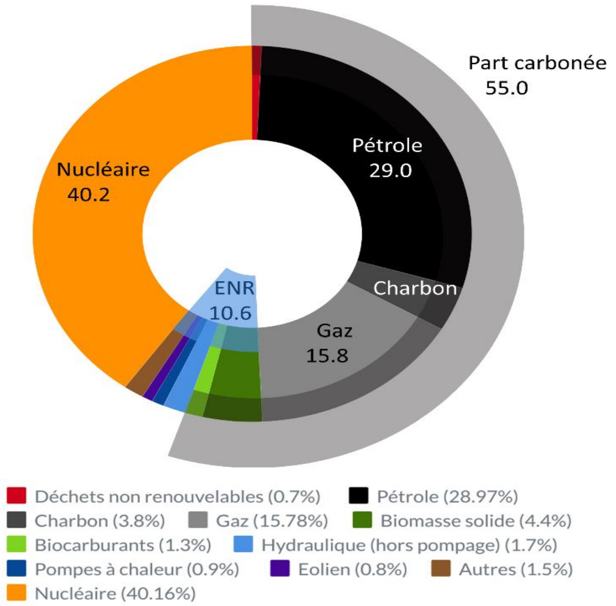
The way to produce synthetic fuel with air and water !



Why do we need synthetic molecules ?

55 %

Carbon content of the energy mix



Breakdown of primary energy consumption in France, for a total of 2900 TWh, in 2018. Data expressed in % (data not corrected for climatic variations); ENR = renewable energies; from “Chiffres clés de l'énergie - Edition 2018”, SDES data; Commissariat général au développement durable.

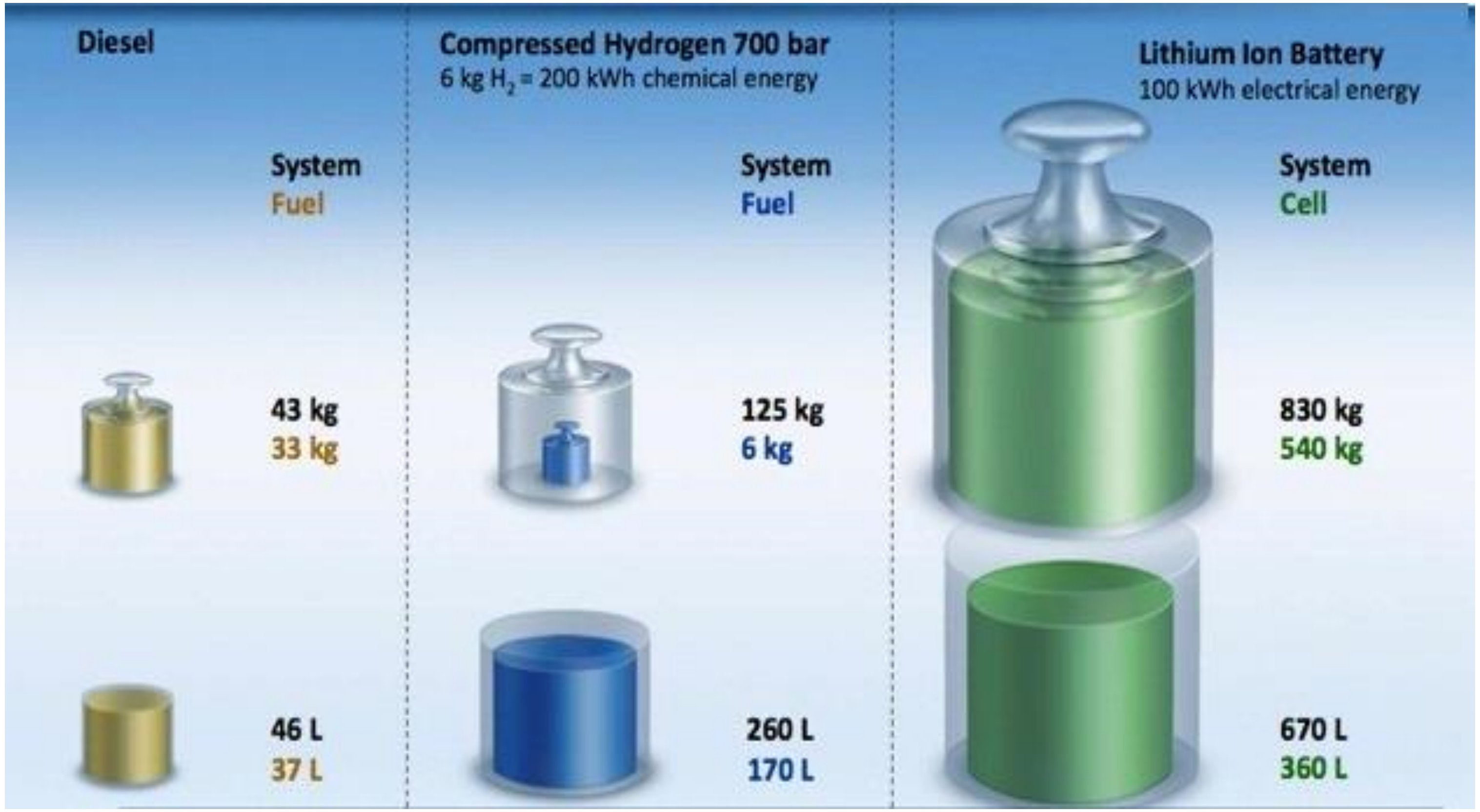
1/3

Share of uses that cannot be replaced by carbon-free alternatives

- **Liquid fuels for long distance transports**
- **Material production (steel, cast iron, cement)**
- **Production of chemical products (plastics, agrochemicals, solvents, etc.)**

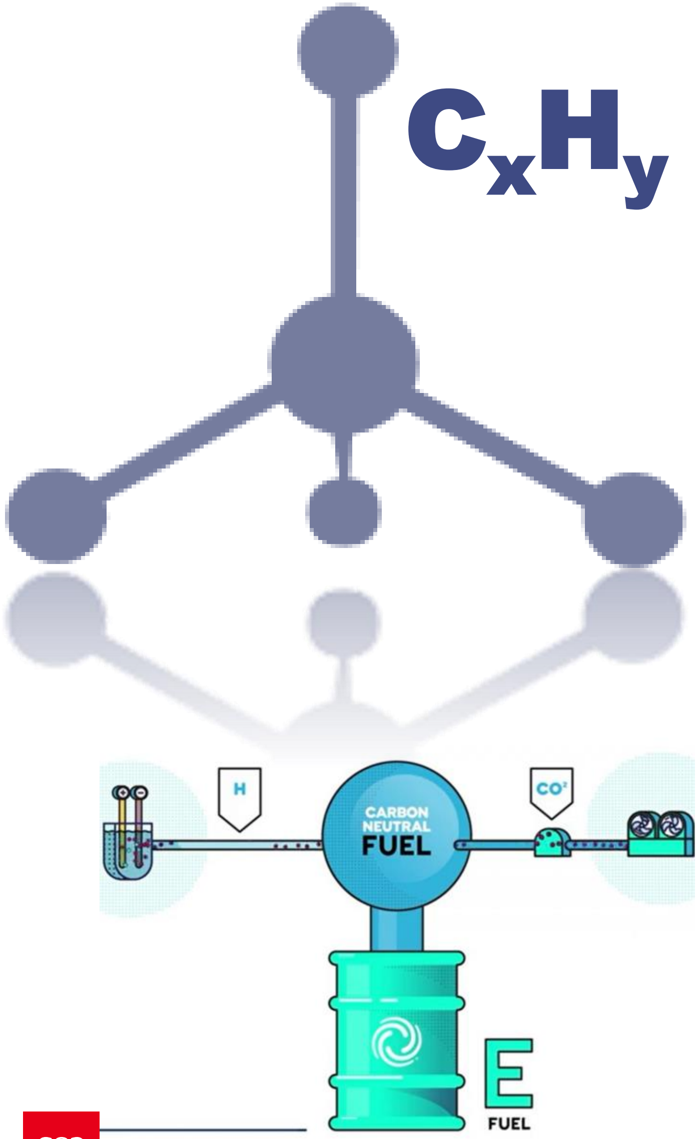
Example for mobility : a question of energetic density

The chemical storage of energy (in atomic bonds) remains the most compact solution, the easiest to store and transport



Example : Mass and volume energy densities for a ~ 600 km drive

What are synthetic fuels and how are they produced ?



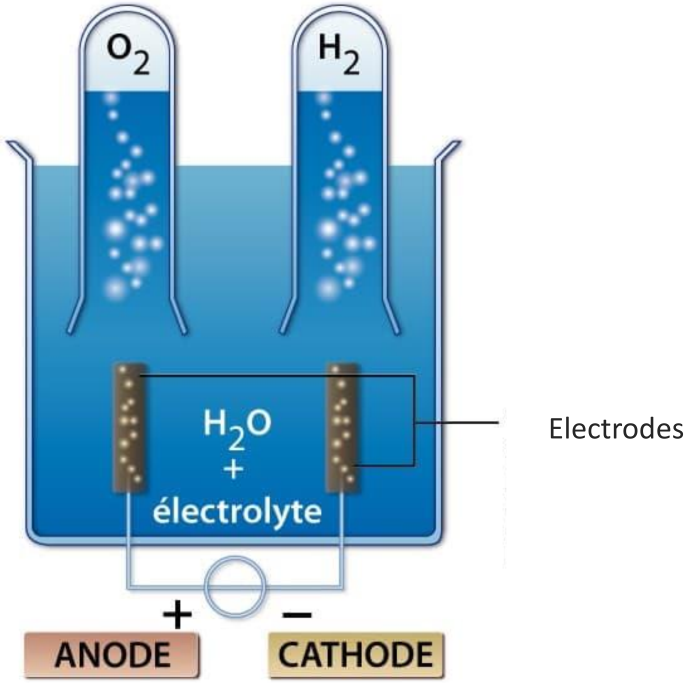
Biofuels from biomass

E-fuel from power

E bio fuels from biomass and power

Basic ingredients:
1. Water for hydrogen

Water



$$H_2O \rightarrow H_2 + ½\ O_2$$

Power

Technology
High Temperature Steam Electrolysis

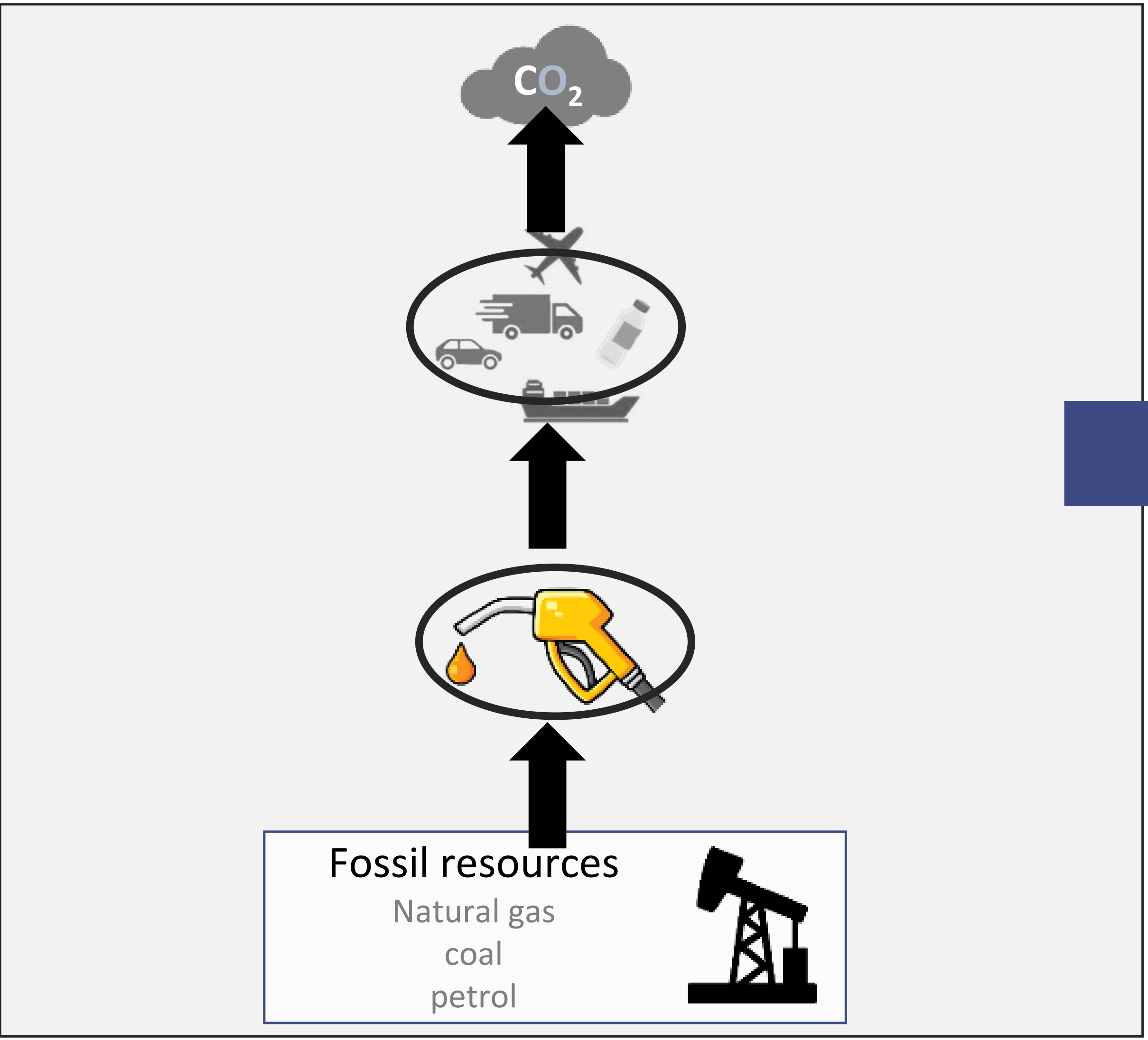
Heat

$$H_2O \rightarrow H_2 + ½\ O_2$$

Power

Basic ingredients
2. Carbon

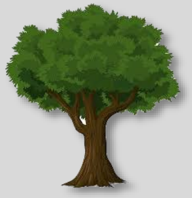
Carbon linear economy



Carbon circular economy

Basic ingredients
2. Carbon

CO_2 from fossils



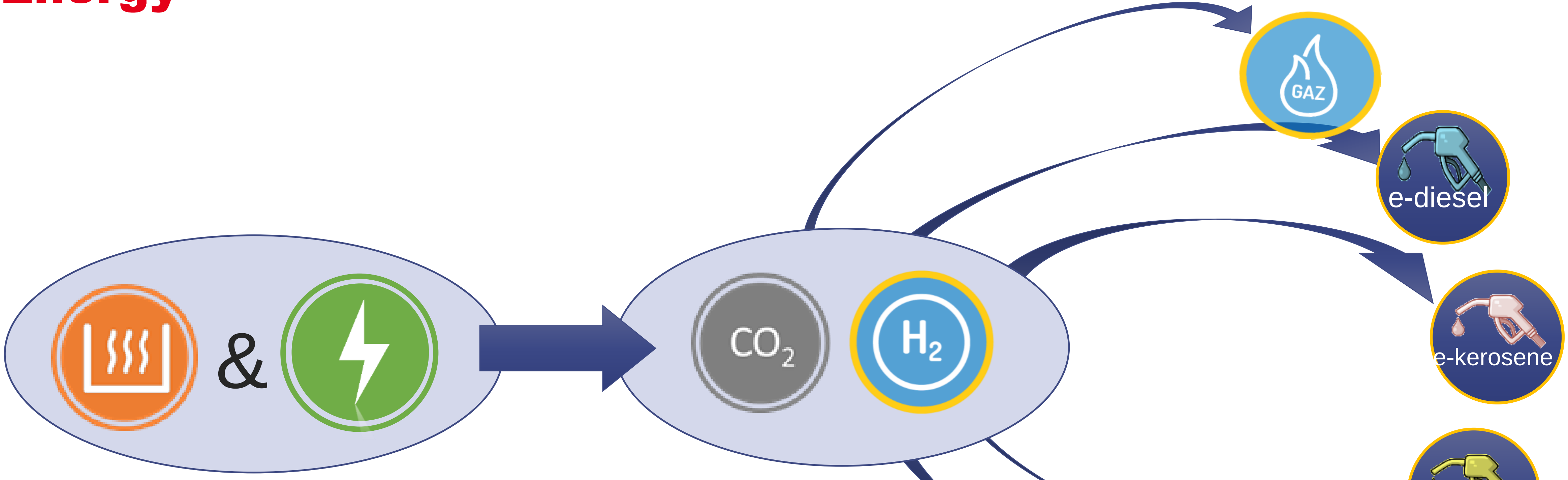
Carbon from biomass

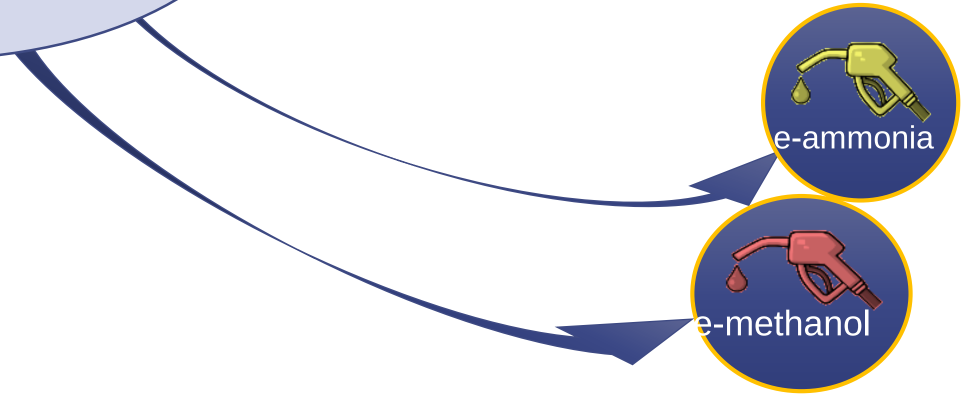
Climeworks' direct air capture plant in Hinwil, Switzerland

Atmospheric CO_2 :
DAC (Direct Air capture)

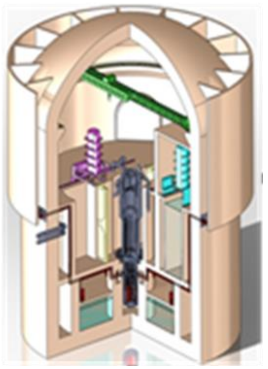
Basic ingredient

3. Energy





SMR



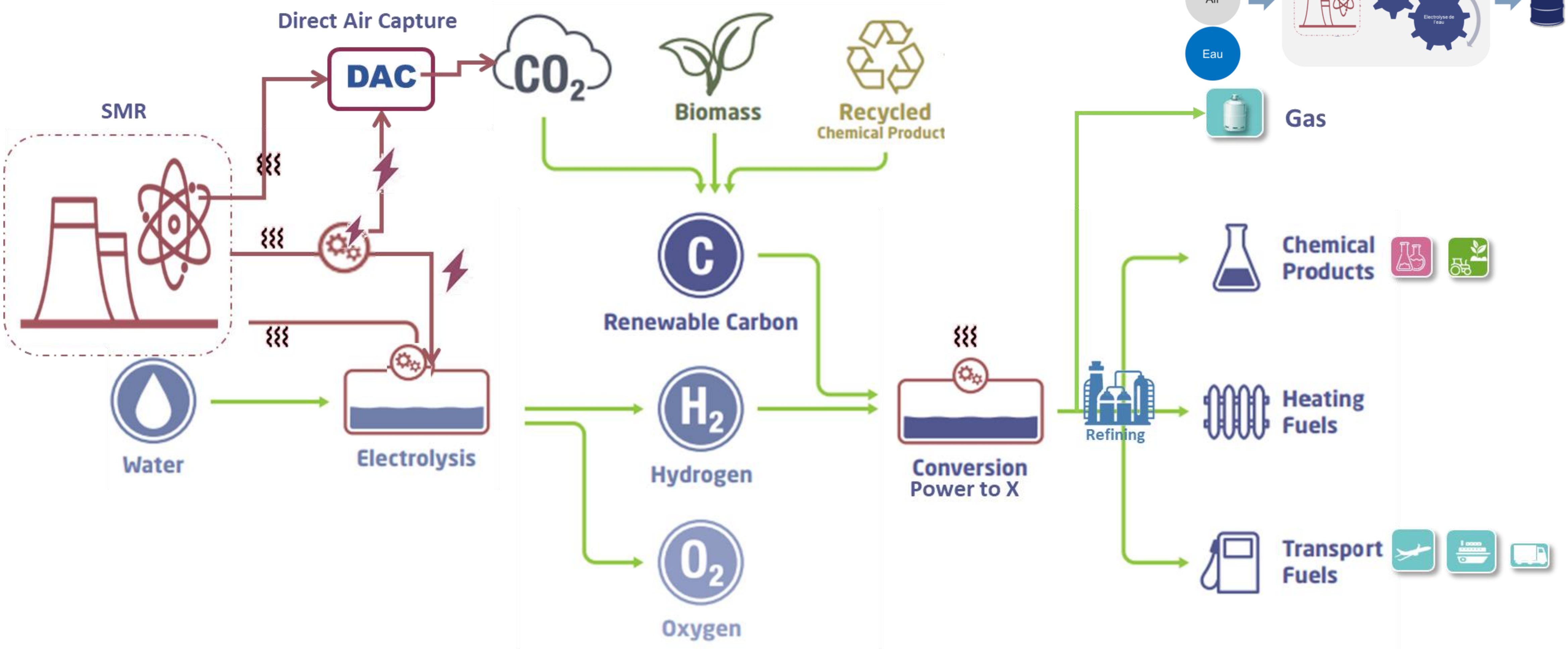
massive

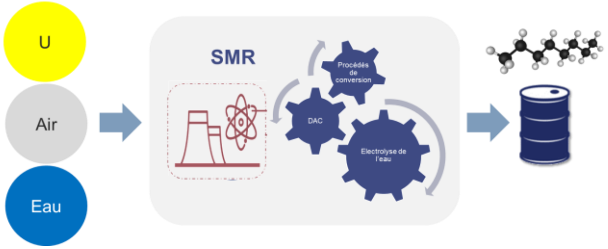
continuous

Low-carbon

affordable

Integrated energetic system from neutron to molecule

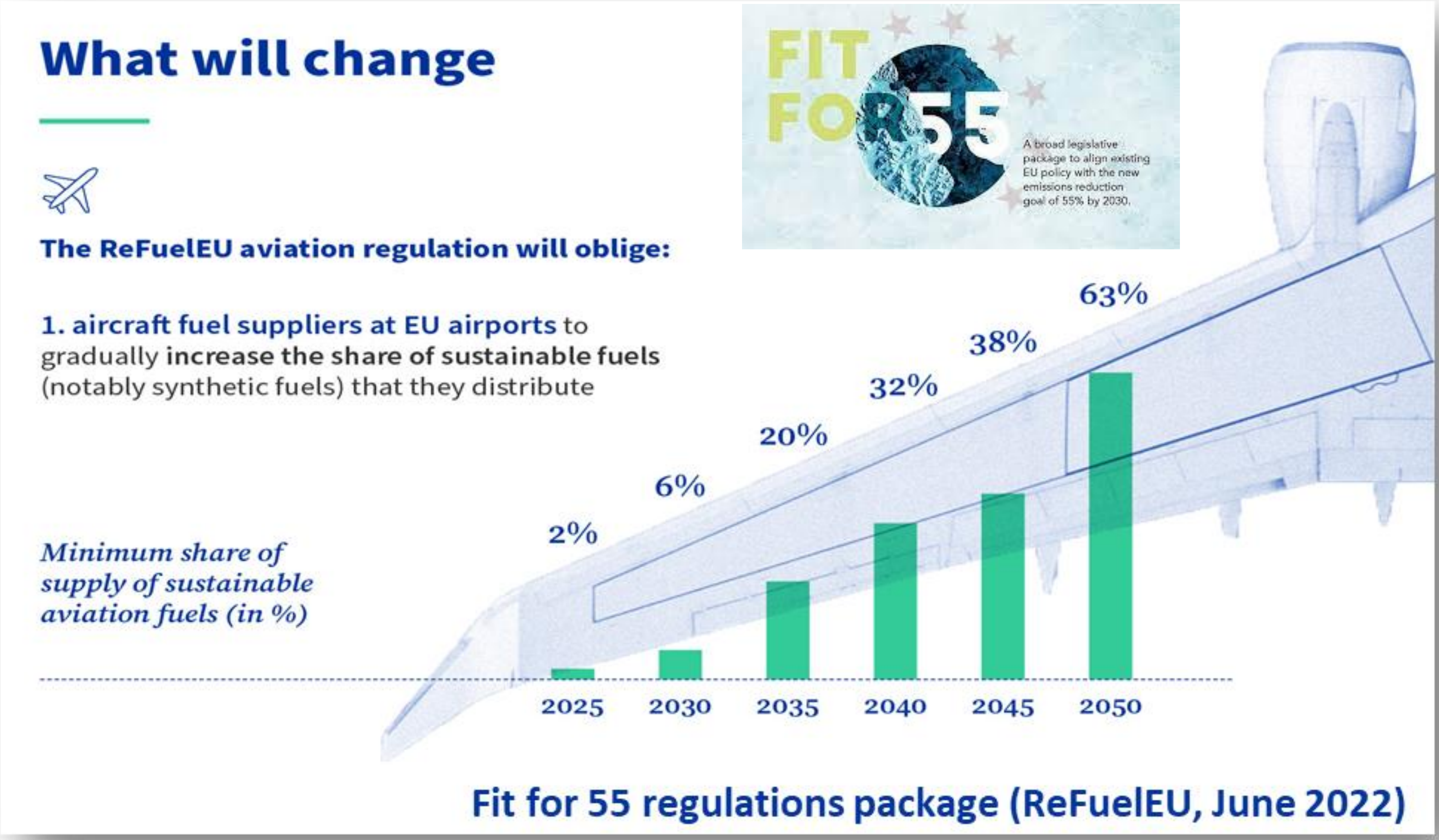




Main goal : evaluate the relevance of the coupling system in terms of energetic efficiency

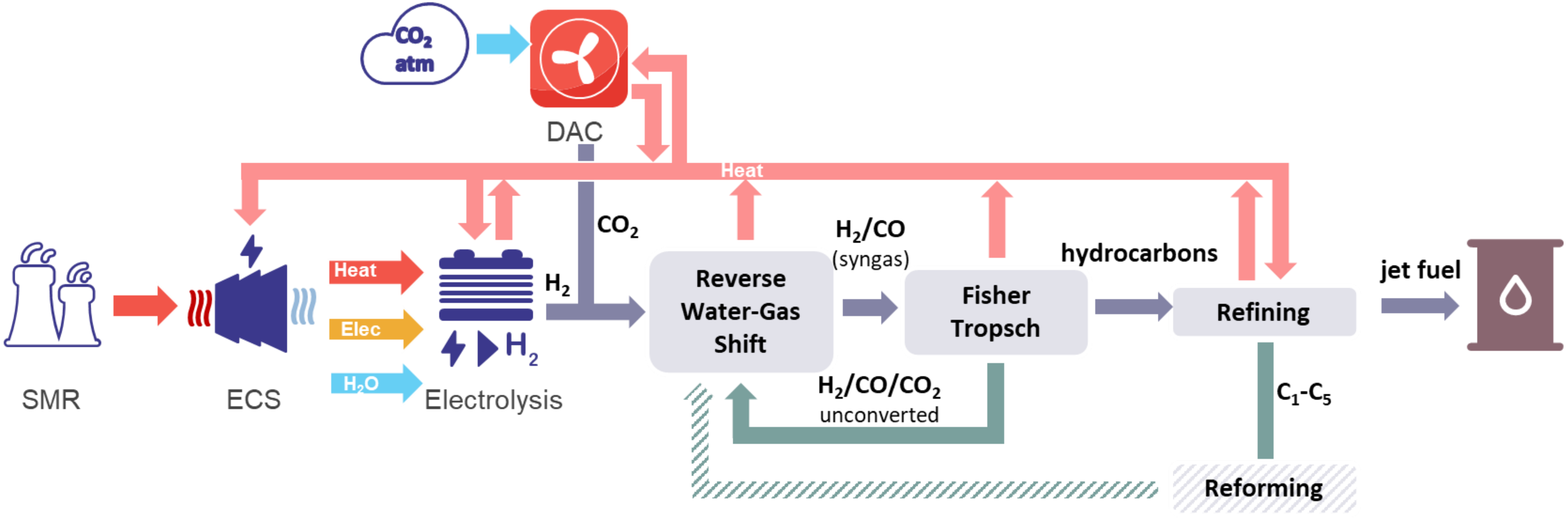
Focus on SAF (Sustainable Aviation Fuel)

Air transport : one of the most difficult to decarbonize

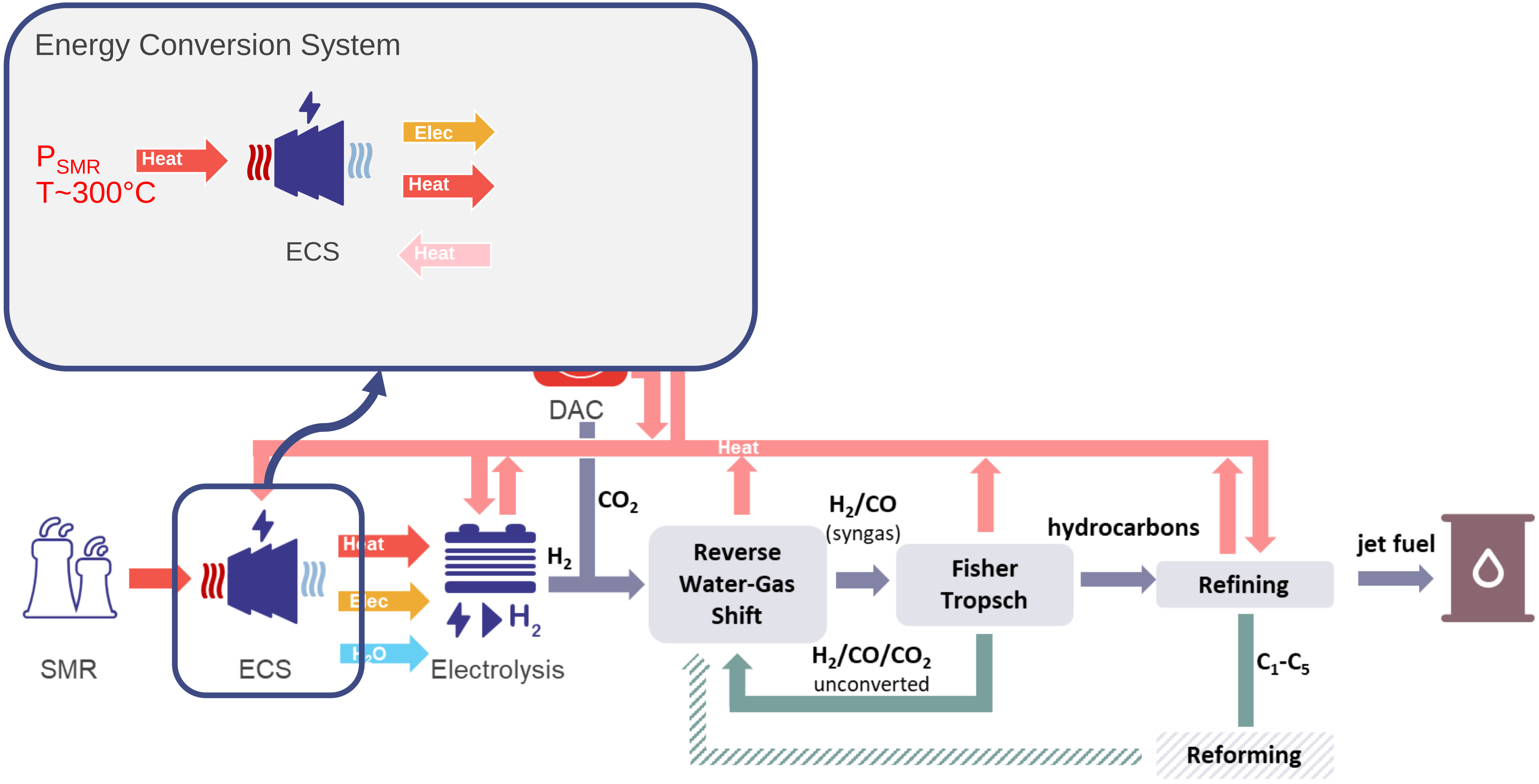


Global configuration for e-fuel production

- Identified reference chain
- Technological bricks : SMR, SCE, DAC, EHT, RWGS, FT,
- Recycles of unconverted reagents (H_2, CO_2, CO)
- Reform of unwanted product (C_1-C_5)

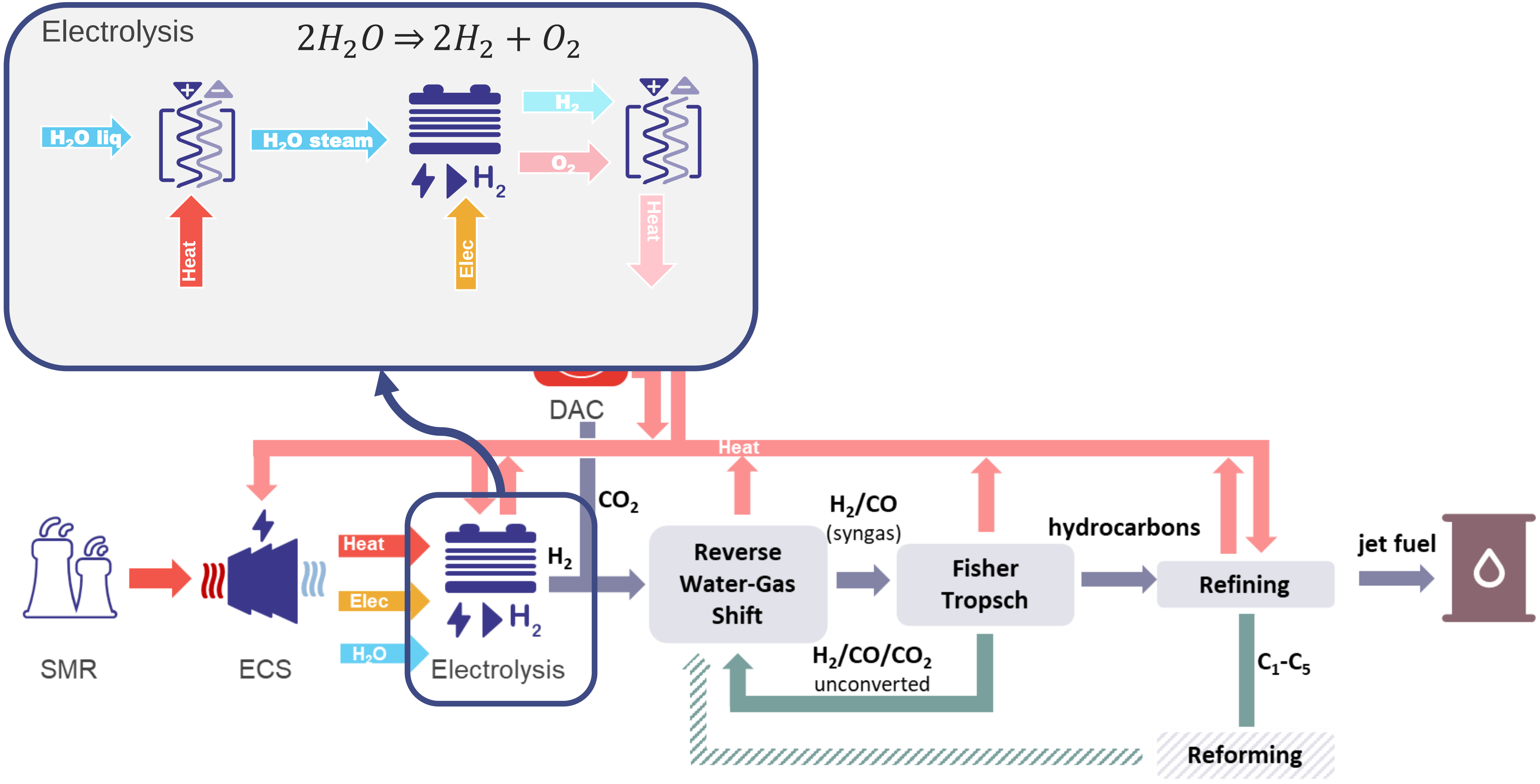


Global configuration for e-fuel production



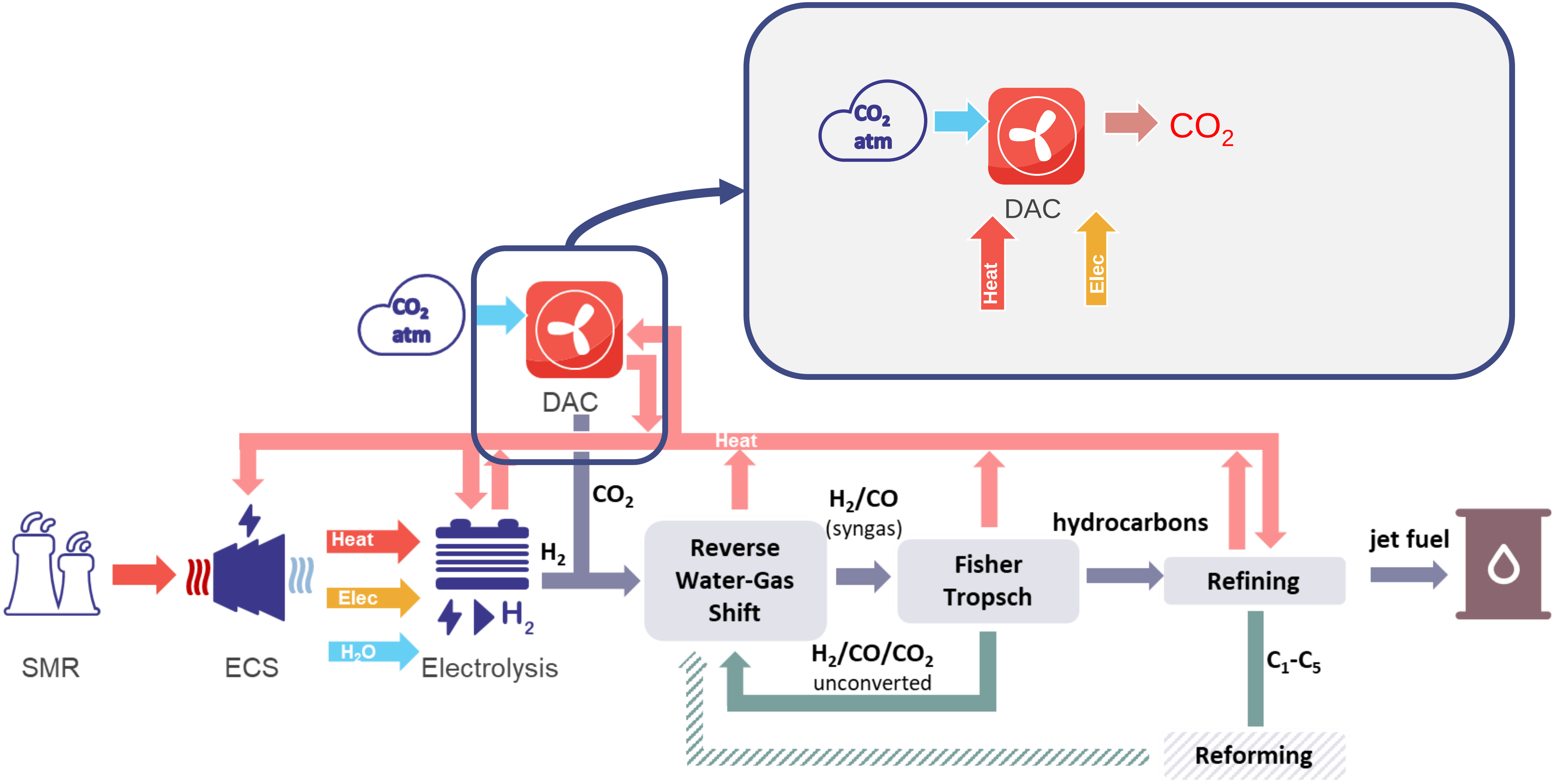
**Values are order of magnitude, they are moving depending of configuration and technologies assumptions*

Global configuration for e-fuel production



**Values are order of magnitude, they are moving depending of configuration and technologies assumptions*

Global configuration for e-fuel production



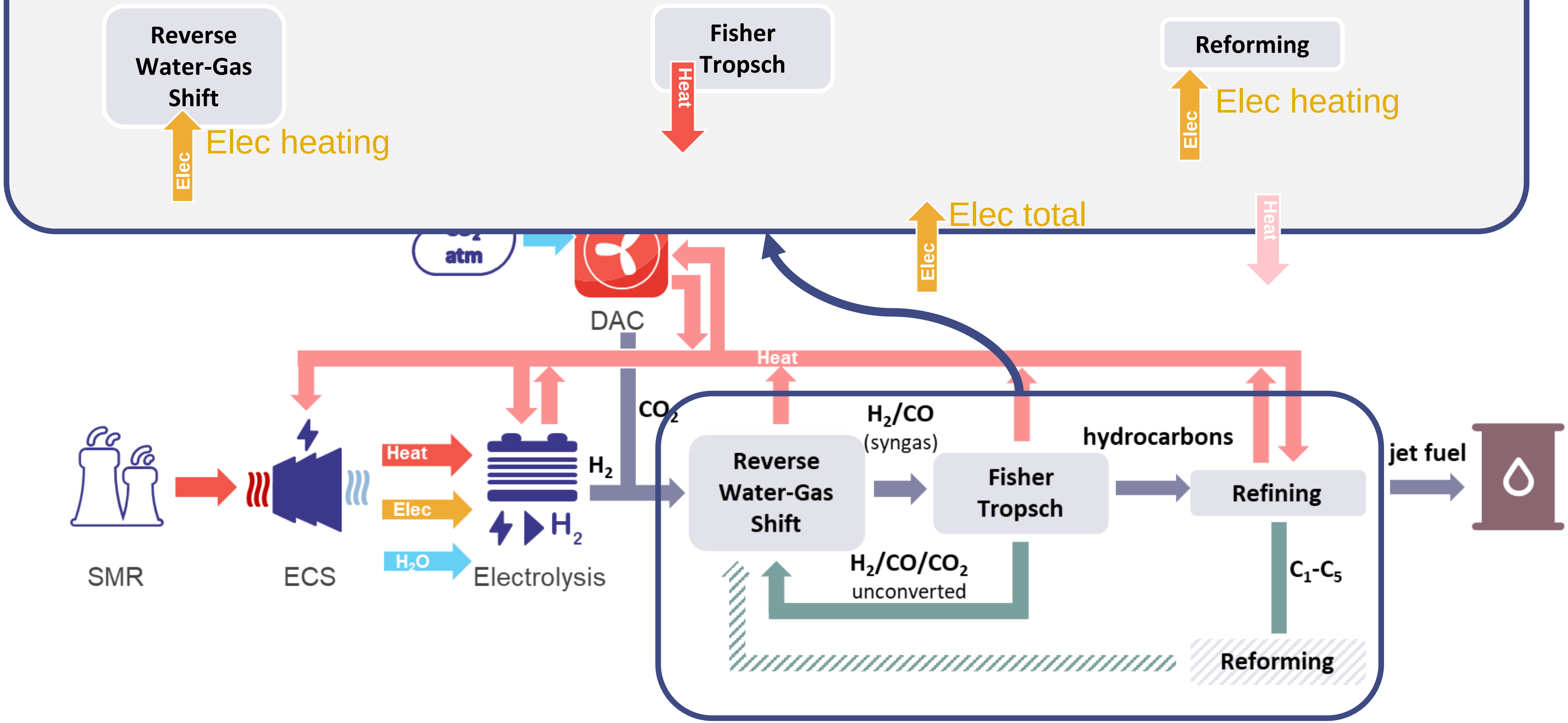
**Values are order of magnitude, they are moving depending of configuration and technologies assumptions*

Global configuration for e-fuel production

$H_2 + CO_2 \Rightarrow CO + H_2O$

$(2n+1)H_2 + nCO \Rightarrow C_nH_{2n+2} + nH_2O$

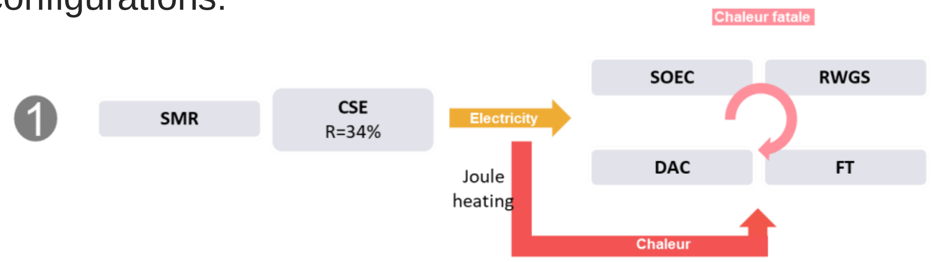
$CH_4 + H_2O \Rightarrow CO + 3H_2$

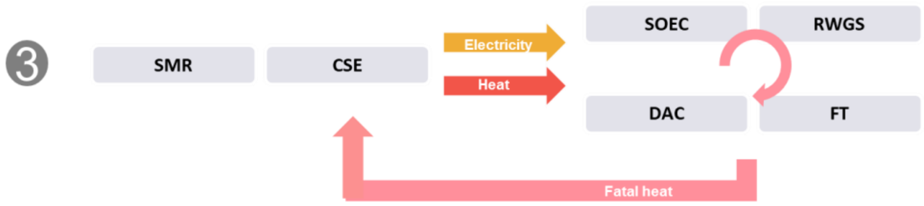


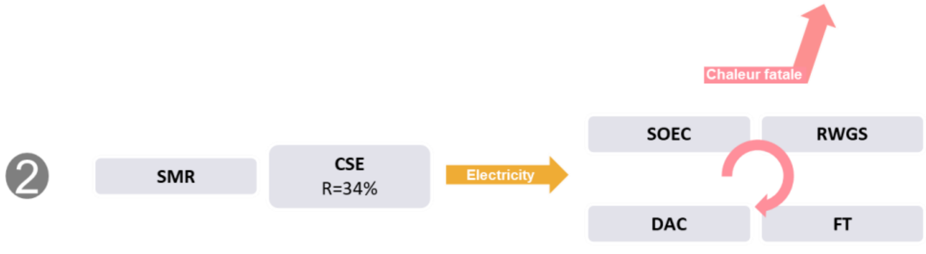
**Values are order of magnitude, they are moving depending of configuration and technologies assumptions*

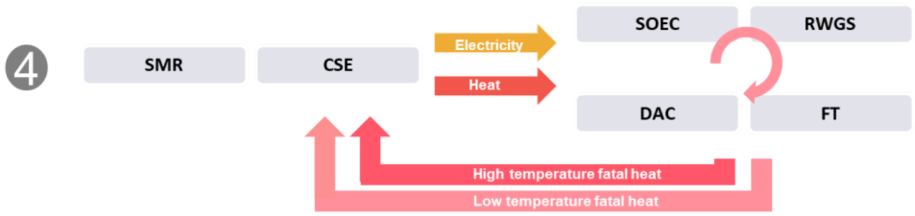
Coupling SMR process efficiency evaluation

- 4 configurations:





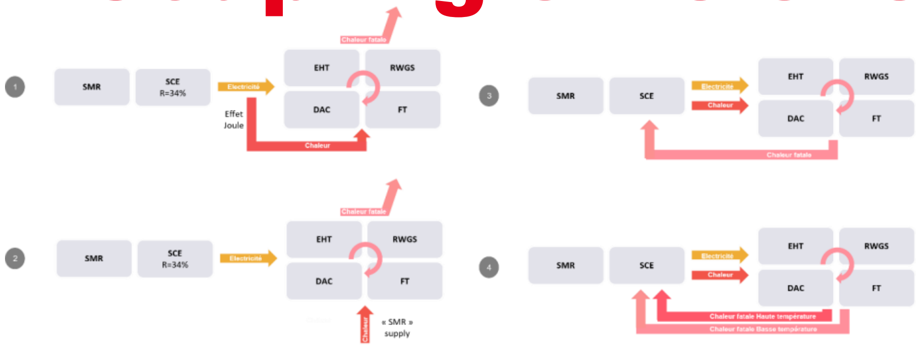




- Some selected KPIs
  - C_{5+} LHV / thermal core Power $_{SMR}$
  - € / $MWh_{valuable}$ C_1-C_{30}
  - tCO_2eq / $MWh_{valuable}$ C_1-C_{30}

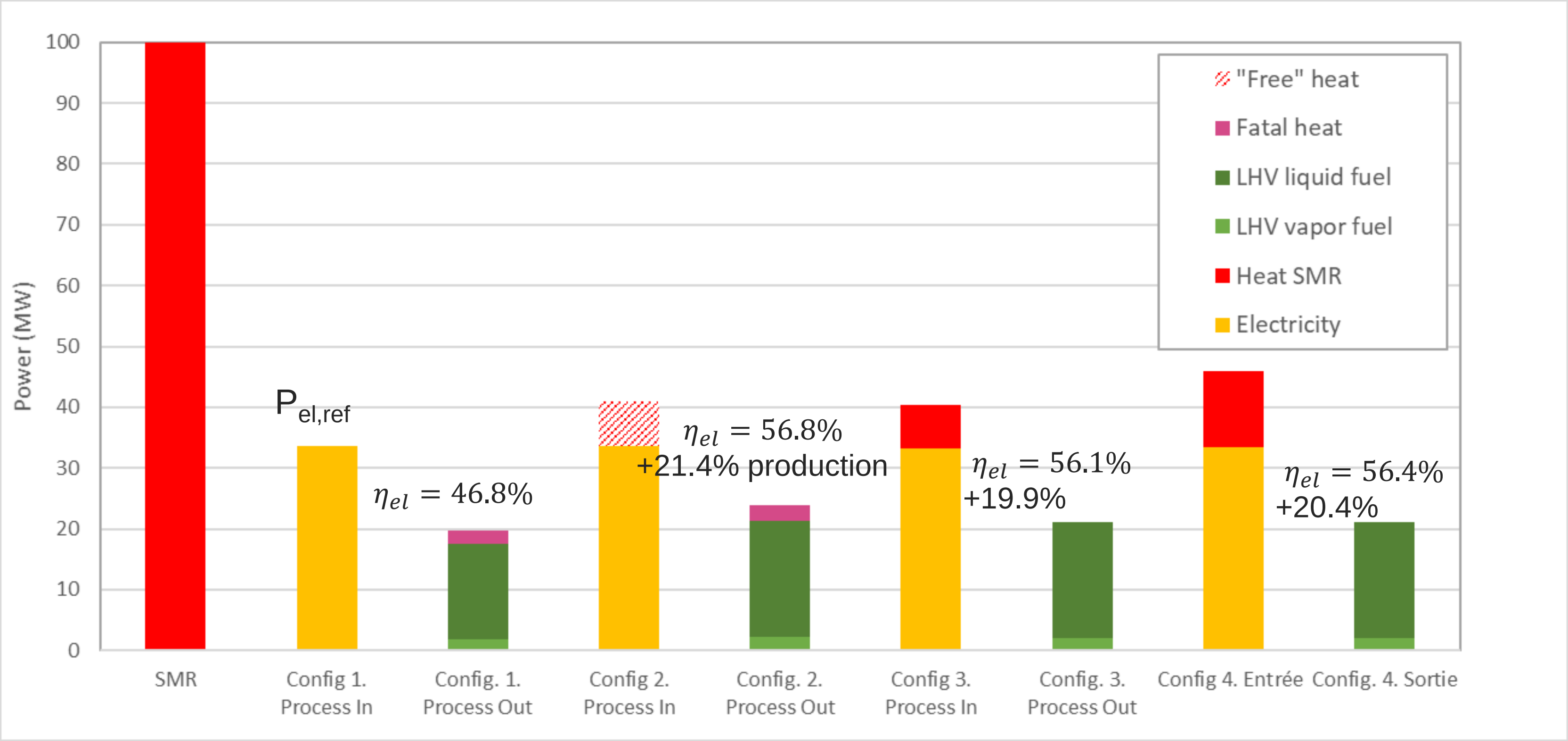
1. Decoupling. The SMR supplies electrical power only. Unused low-temperature waste heat is lost.
2. External heat. The SMR supplies electrical power only. If heat is required, an “external” input is considered.
3. Simple coupling. The SMR supplies electrical and thermal power. Unused low-temperature waste heat is returned to the SCE.
4. Double coupling. The SMR supplies electrical and thermal power. Unused low-temperature waste heat and high-temperature waste heat are returned to the SCE

Coupling efficiency



Kerosene efficiency reported to electrogen electric power:

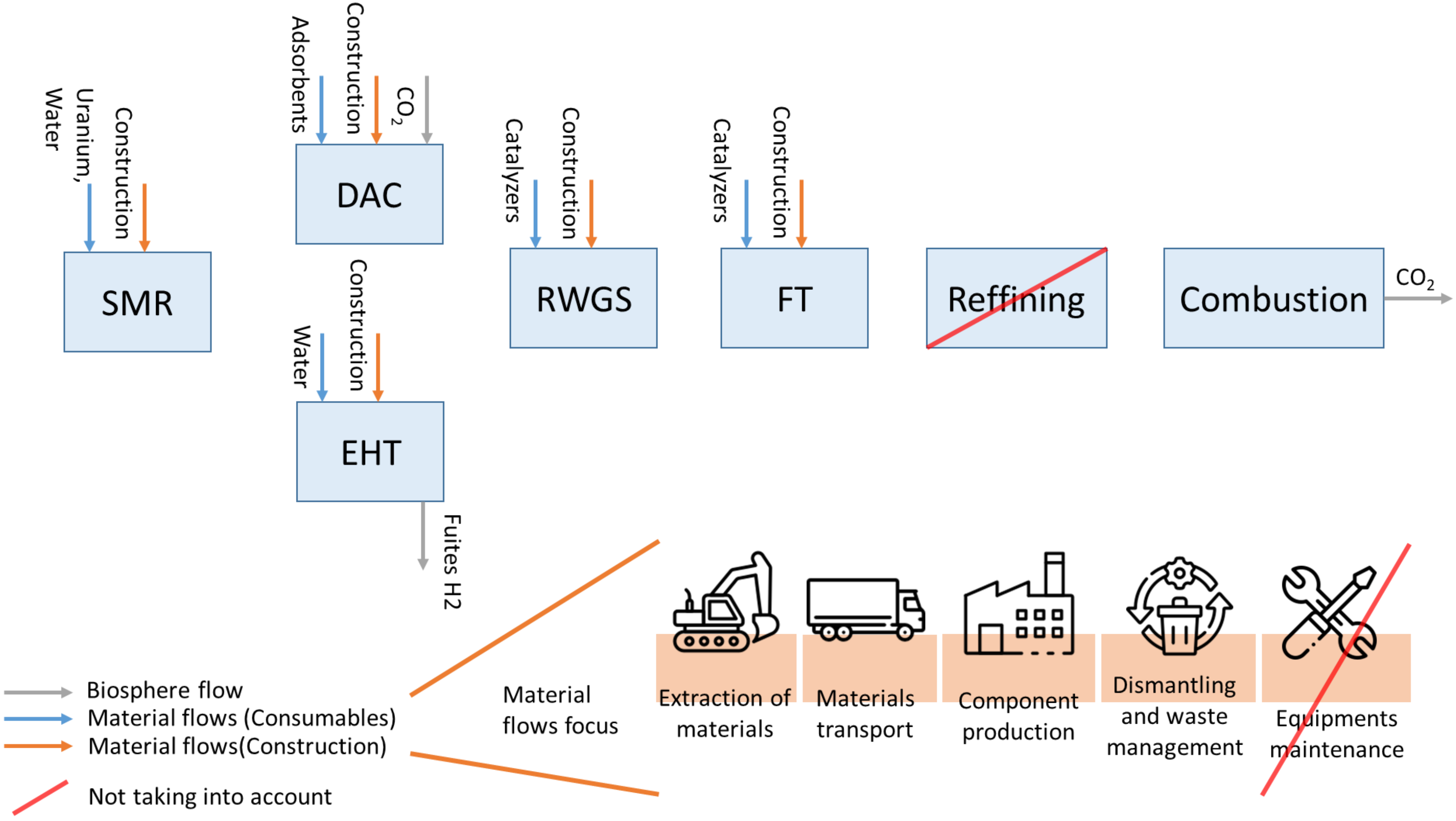
$$\eta_{el} = \frac{LHV_{kero}}{P_{el,ref}}$$



Coupling enable:
+ 20% kerosene production
Very close from free heat case.

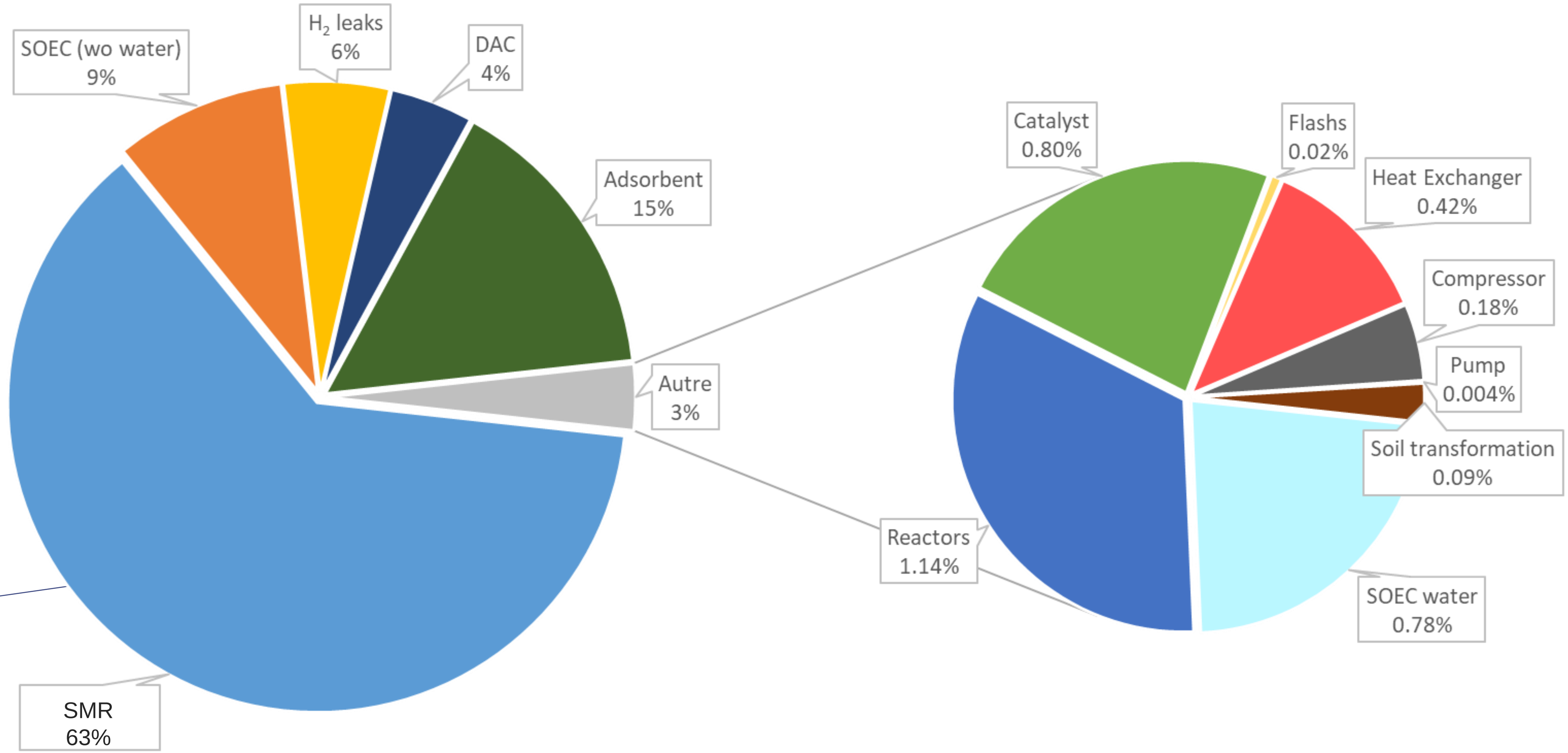
Method Evaluation on 16 impacts indicators recommended by European commission (method EF v3.1)

Perimeter



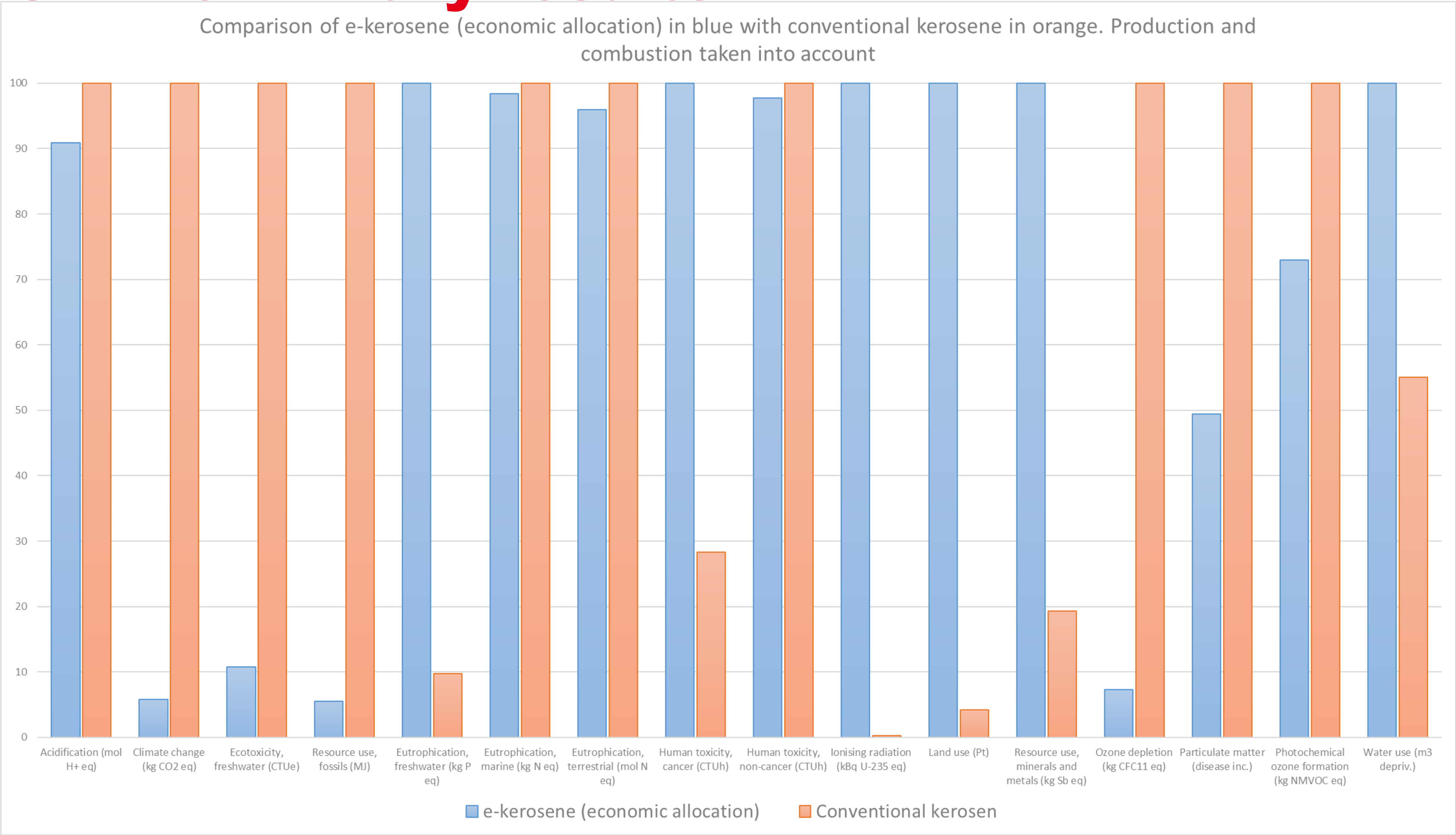
LCA Preliminary results

Total CO_{2e} emissions over 20 years: **304 000 tCO2e**

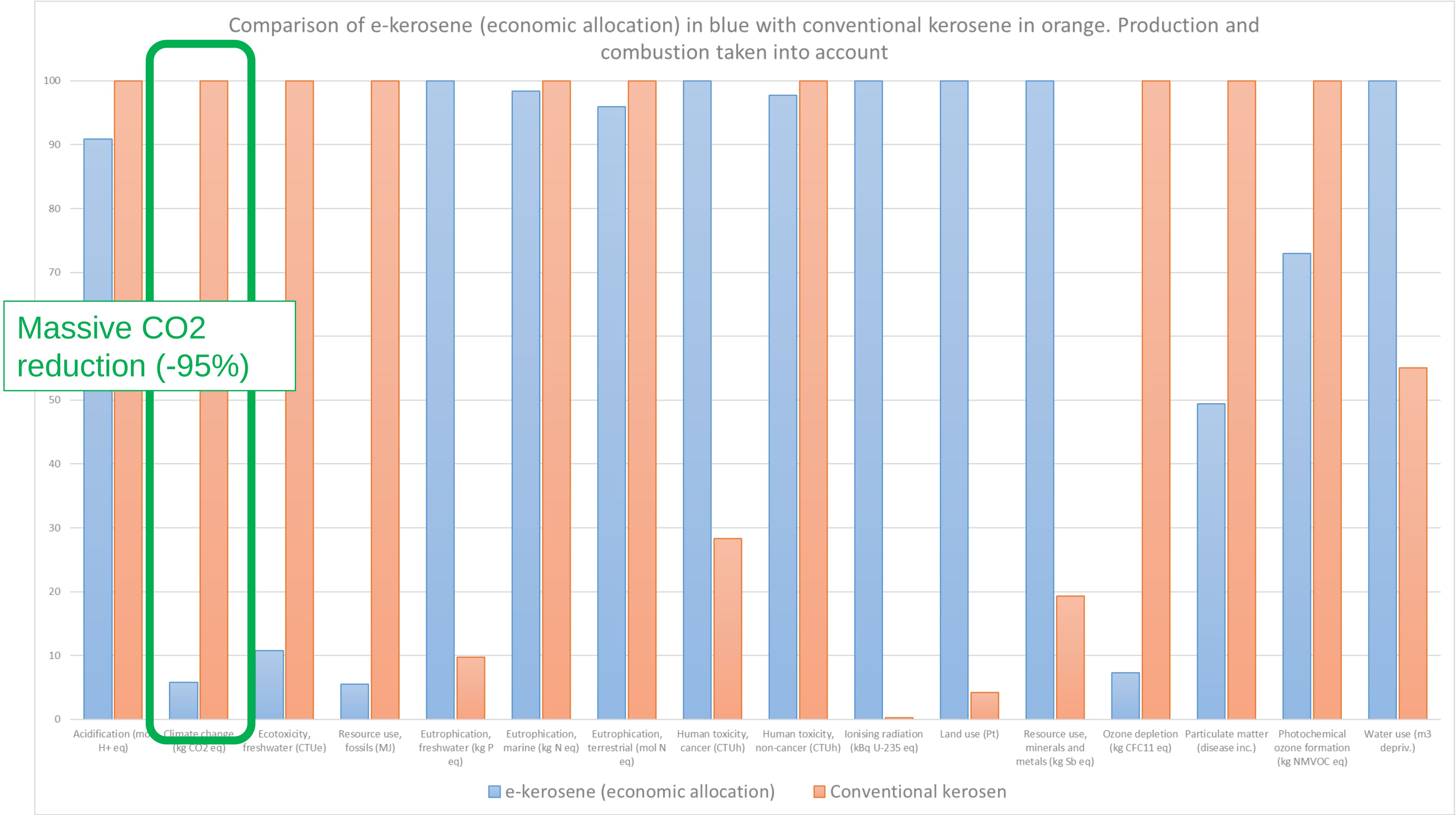


Emission factor:
4,89 gCO2e / kWhel

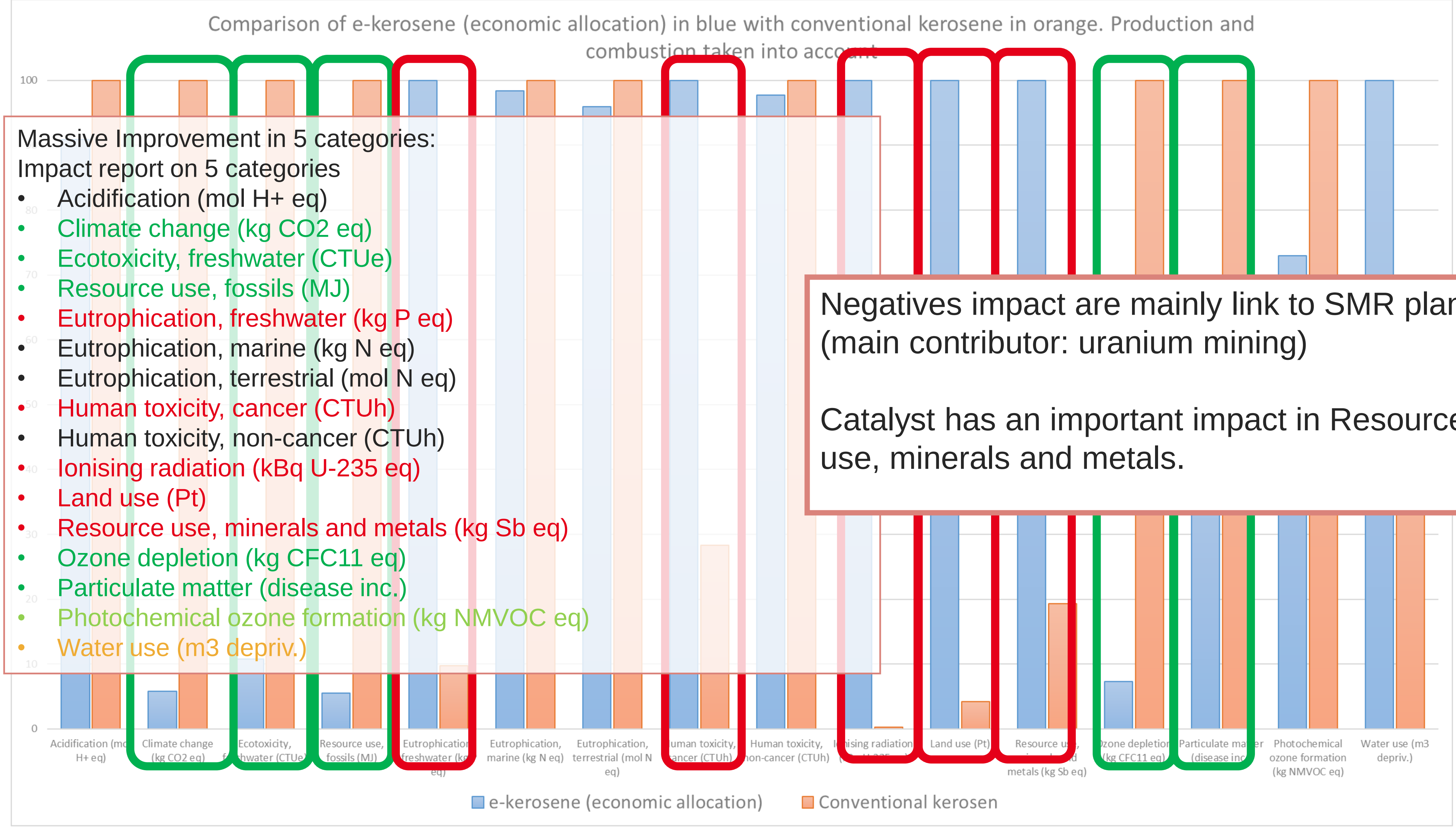
LCA Preliminary results



LCA preliminary Results



LCA Preliminary Results



Massive Improvement in 5 categories:
Impact report on 5 categories

- Acidification (mol H+ eq)
- Climate change (kg CO2 eq)
- Ecotoxicity, freshwater (CTUe)
- Resource use, fossils (MJ)
- Eutrophication, freshwater (kg P eq)
- Eutrophication, marine (kg N eq)
- Eutrophication, terrestrial (mol N eq)
- Human toxicity, cancer (CTUh)
- Human toxicity, non-cancer (CTUh)
- Ionising radiation (kBq U-235 eq)
- Land use (Pt)
- Resource use, minerals and metals (kg Sb eq)
- Ozone depletion (kg CFC11 eq)
- Particulate matter (disease inc.)
- Photochemical ozone formation (kg NMVOC eq)
- Water use (m3 depriv.)

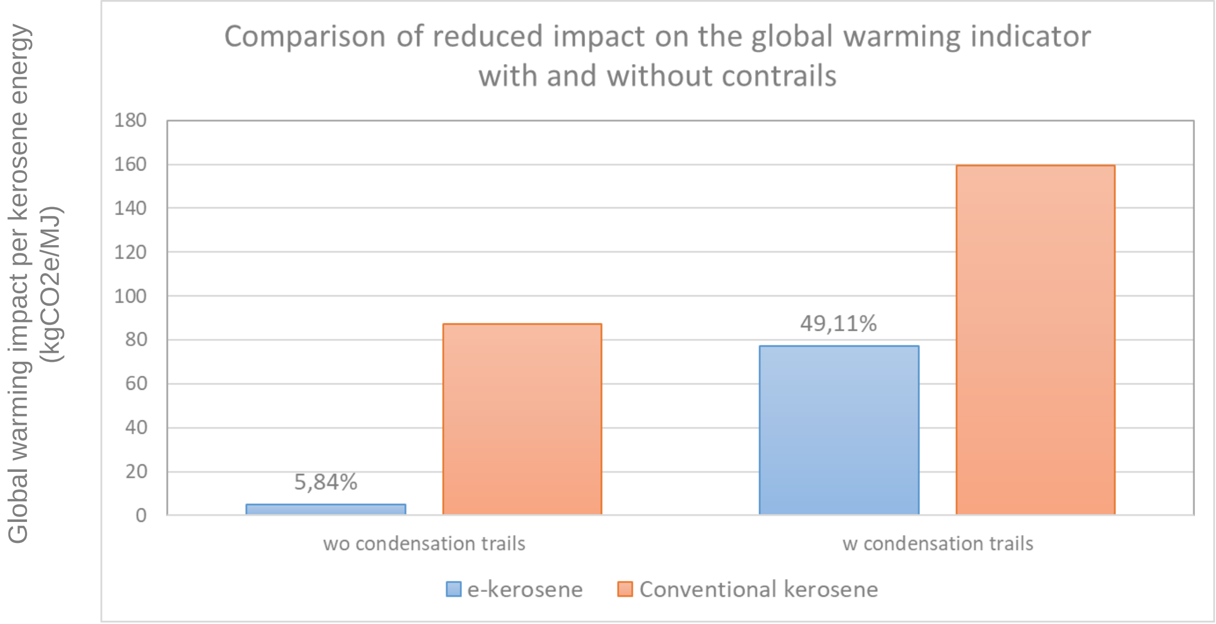
Negatives impact are mainly link to SMR plant (main contributor: uranium mining)

Catalyst has an important impact in Resource use, minerals and metals.

Limits and interpretations

Condensation trails:

E-kero can reduce 95% of production and combustion impact
But doesn't enable to reduce Condensation trails (around 50% of global impact of conventional kerosene)



Order of magnitude kerosene use

Assumption only **C8-C16 in kerosene**: **72 800 L/day** :

Approx. 4 Paris-Ankara / day (A320, 180 seats)
Approx. 1 Paris-Singapore / 3 days (A380, 800 seats)

Assuming all C5+ kerosene is used: 243,500 L/day :

Approx. 12 Paris-Ankara / day (A320, 180 seats)
Approx. 1 Paris-Singapore / day (A380, 800 seats)