Fuels for the decarbonization of aviation, of shipping or for an entire economy?

Prof. Roberto Schaeffer

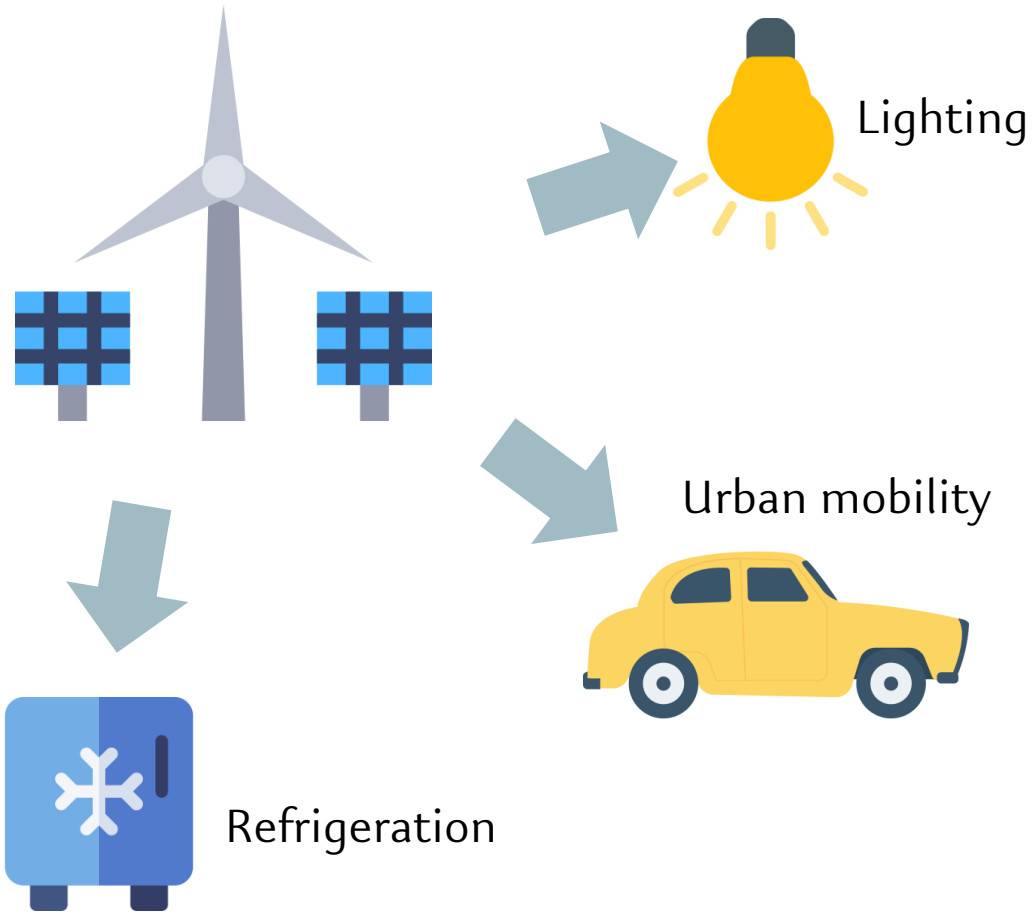
FAPESP, São Paulo, 16 May 2023

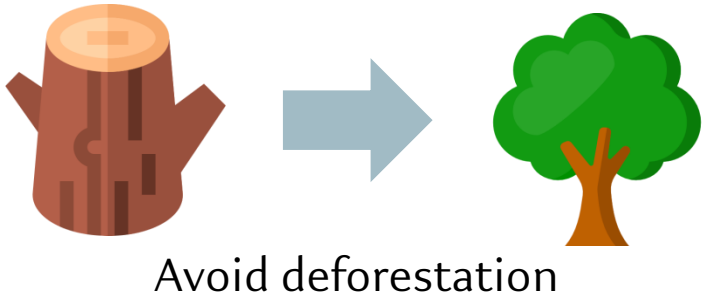
10th German-Brazilian Dialogue on Science, Research and Innovation

“Sustainable Energy Transition”

cenergia
COPPE
UFRJ

Low-hanging fruits for carbon abatement

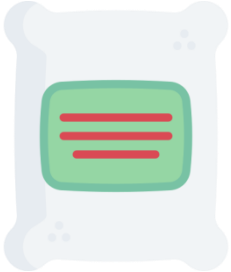




Crédito das figuras: flaticon/Freepik, flaticon/DinosoftLabs

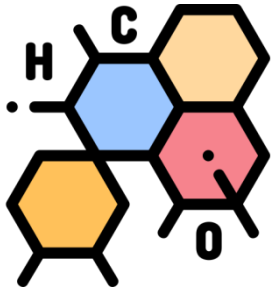
On the other hand, Hard-to-Abate

Iron and steel industry



Cement industry

Aluminum industry

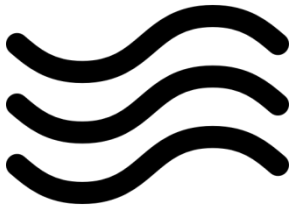


Chemical industry

Long-distance road transport

Air transport

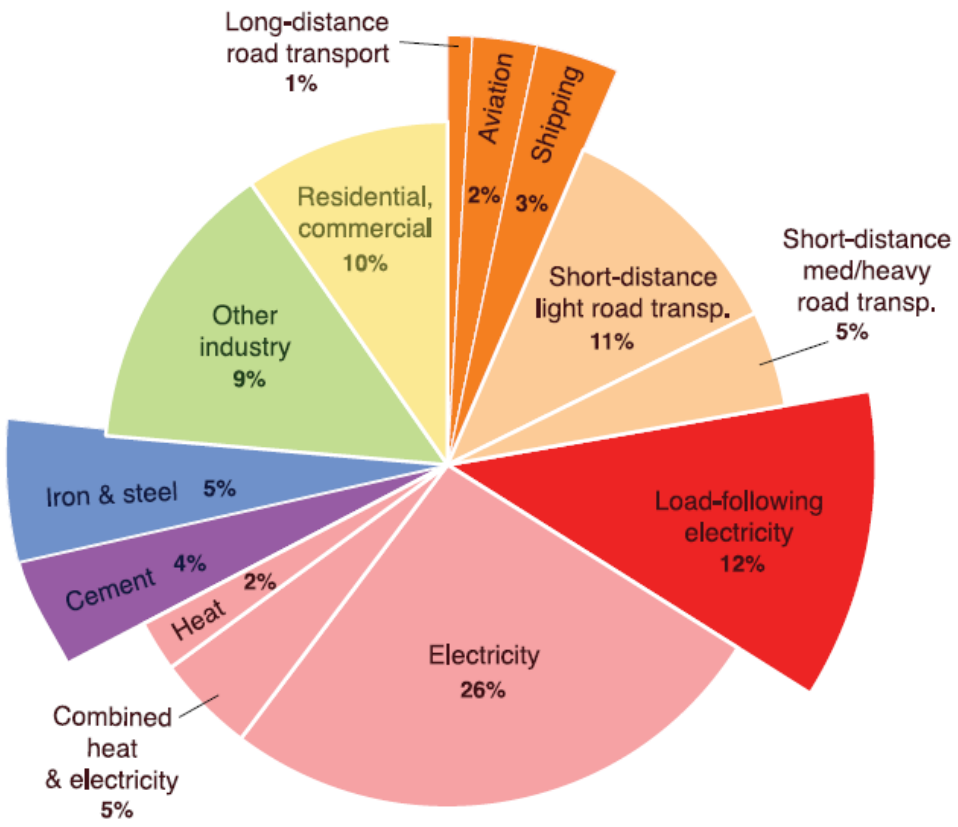
Maritime shipping



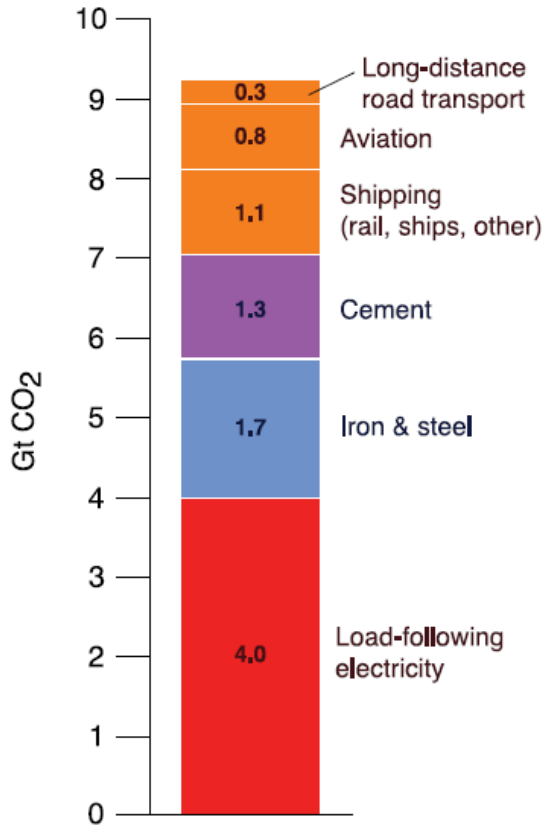
Load-following electricity

Icons: flaticon/Freepik, flaticon/DinosoftLabs, flaticon/Smashicons

Hard-to-Abate CO_2



A **Global fossil fuel & industry emissions, 2014 (33.9 Gt CO_2)**

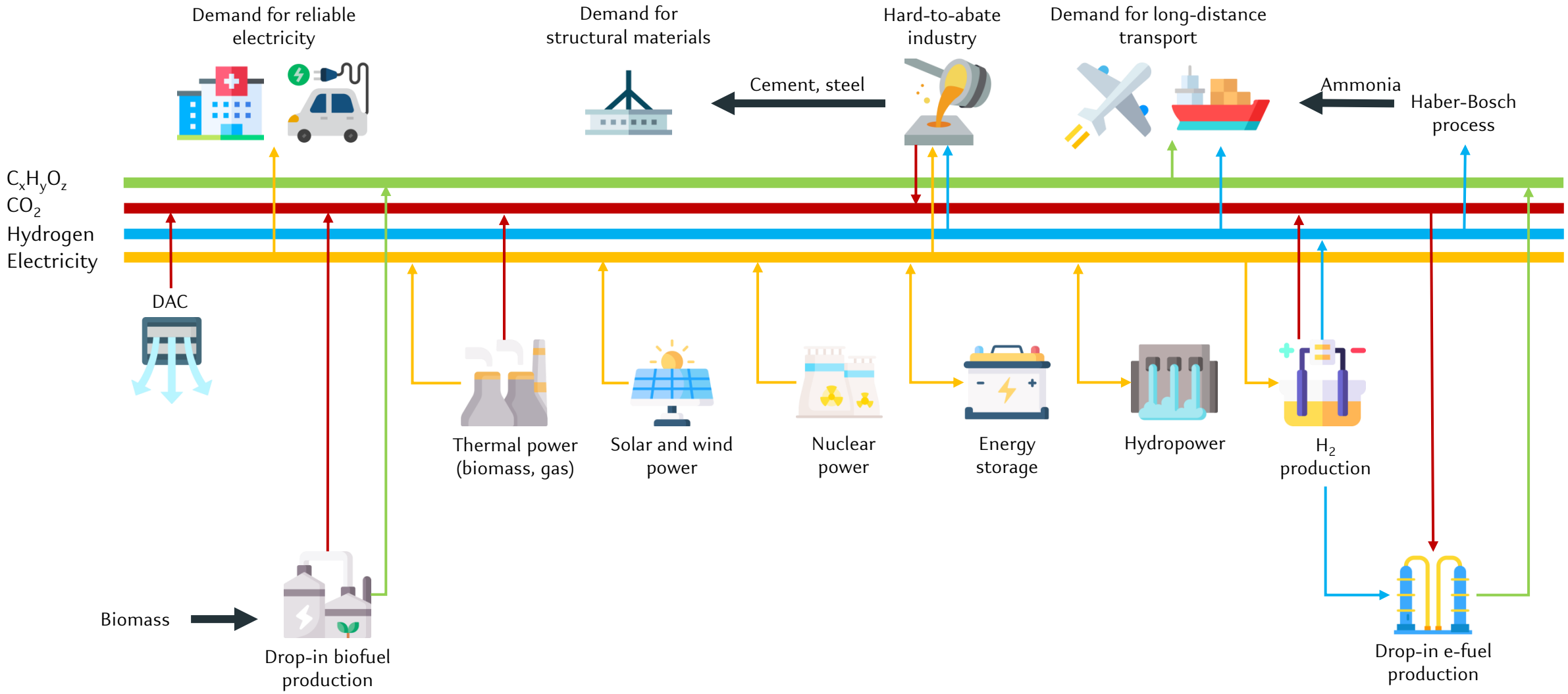


B **Difficult-to-eliminate emissions, 2014 (9.2 Gt CO_2)**

Bioenergy & hydrogen

Source: Davis et al. (2018) – Net-zero emissions energy systems

Hard-to-Abate and carbon neutrality



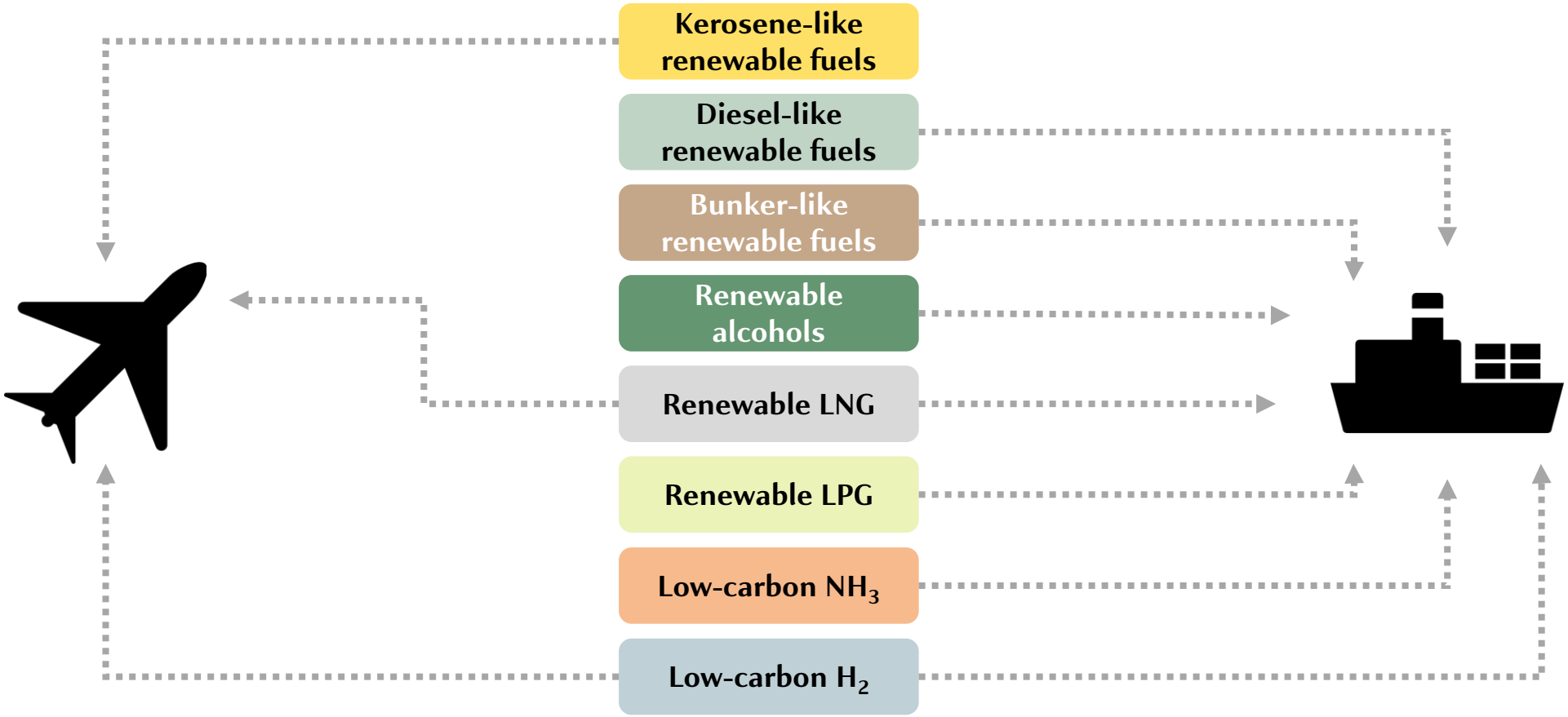
Source: own elaboration based on Davis et al. (2018). Icons: flaticon/Freepik, flaticon/DinosoftLabs, flaticon/Good Ware

1. Aviation and shipping

Hydrogen- and bio-based solutions for the international transport sector

cenergia

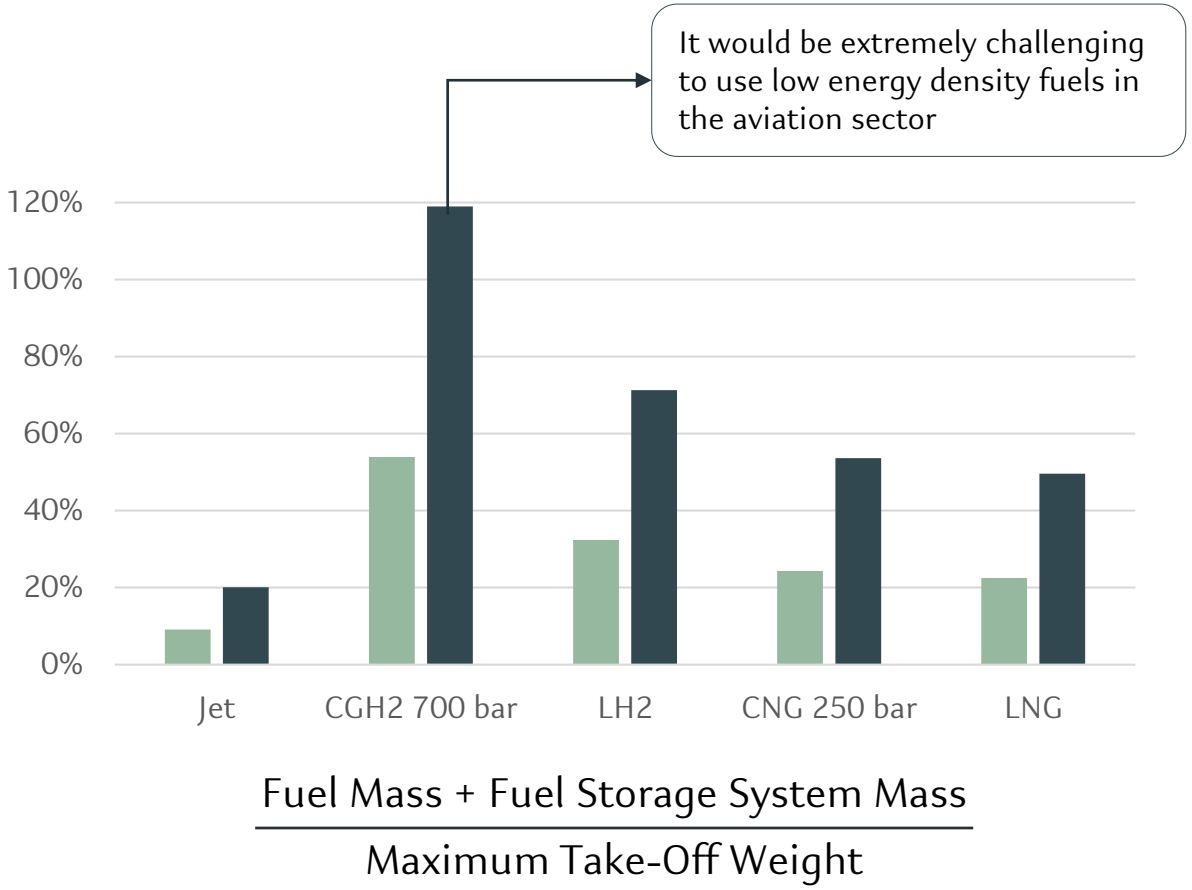
In principle main fuel options do exist …



Is it possible to use H_2 in airplanes?

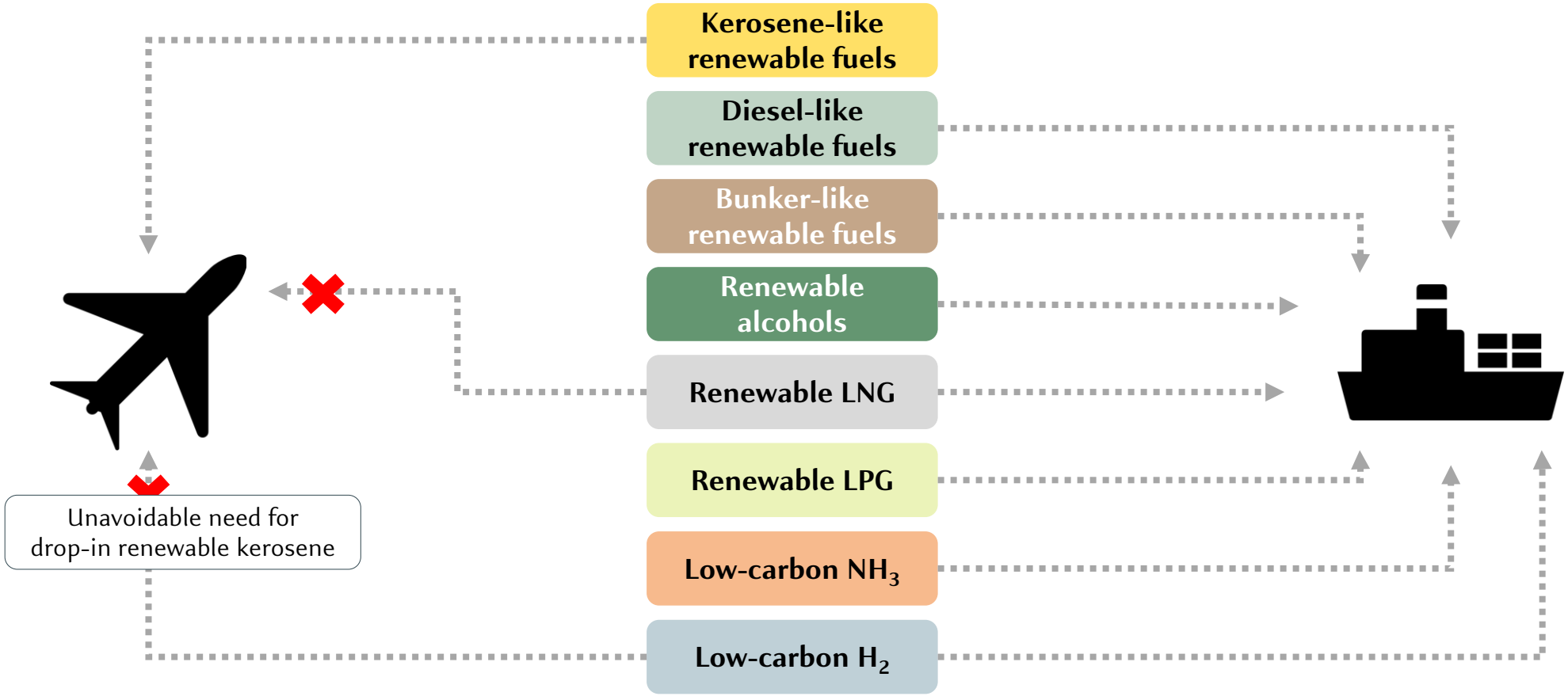
Short-haul
Dublin-Frankfurt (1,000 km)
Boeing 737-800
Total Fuel: 7,200 kg (jet fuel)
Max Take-Off Weight: 79,000 kg

Long-haul
London-Buenos Aires (11,000 km)
Airbus A380
Total Fuel: 112,500 kg (jet fuel)
Max Take-Off Weight: 560,000 kg

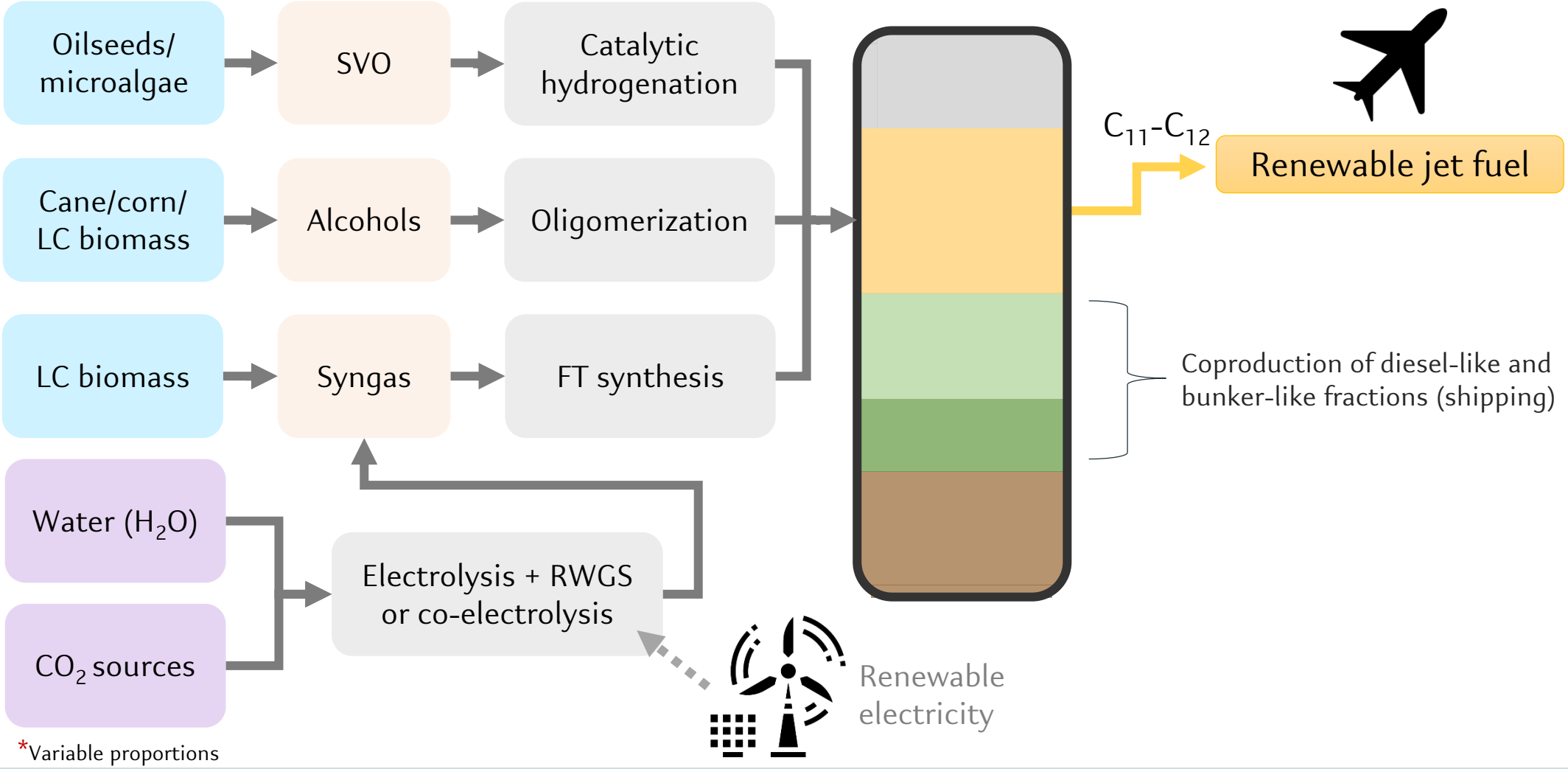


Source: Grey et al. 2021. Icons: freepik/flaticon

As such, less options…



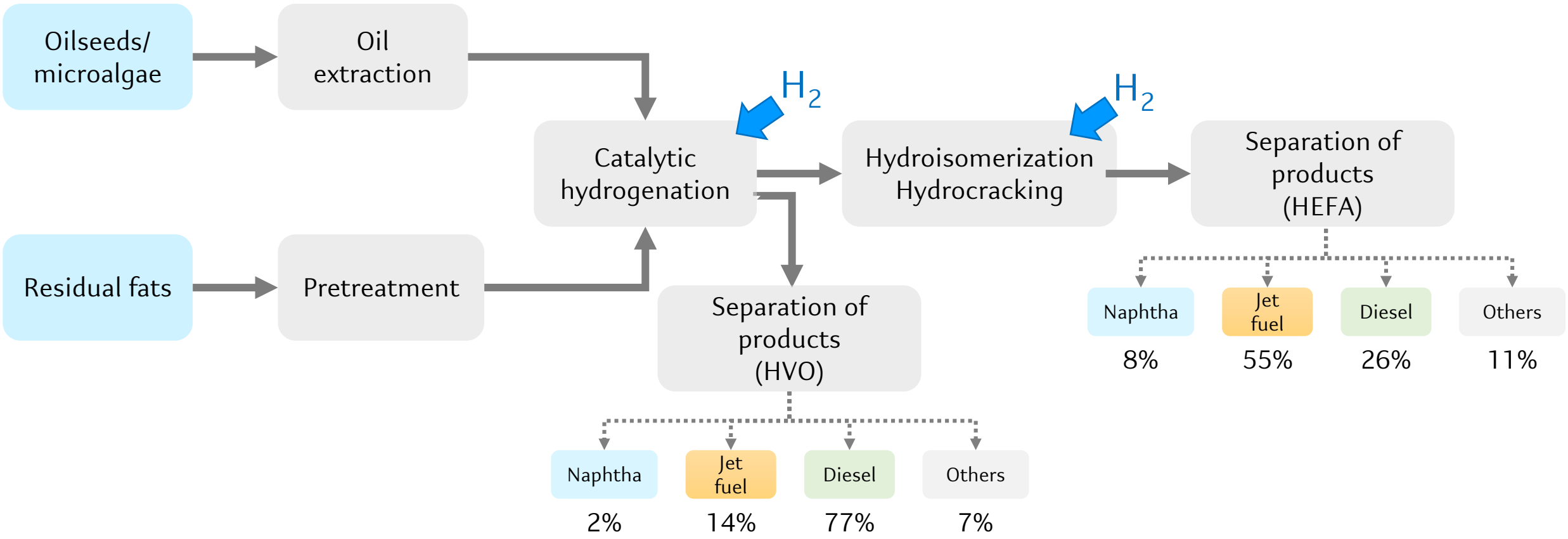
Renewable jet fuel: how?



*Variable proportions

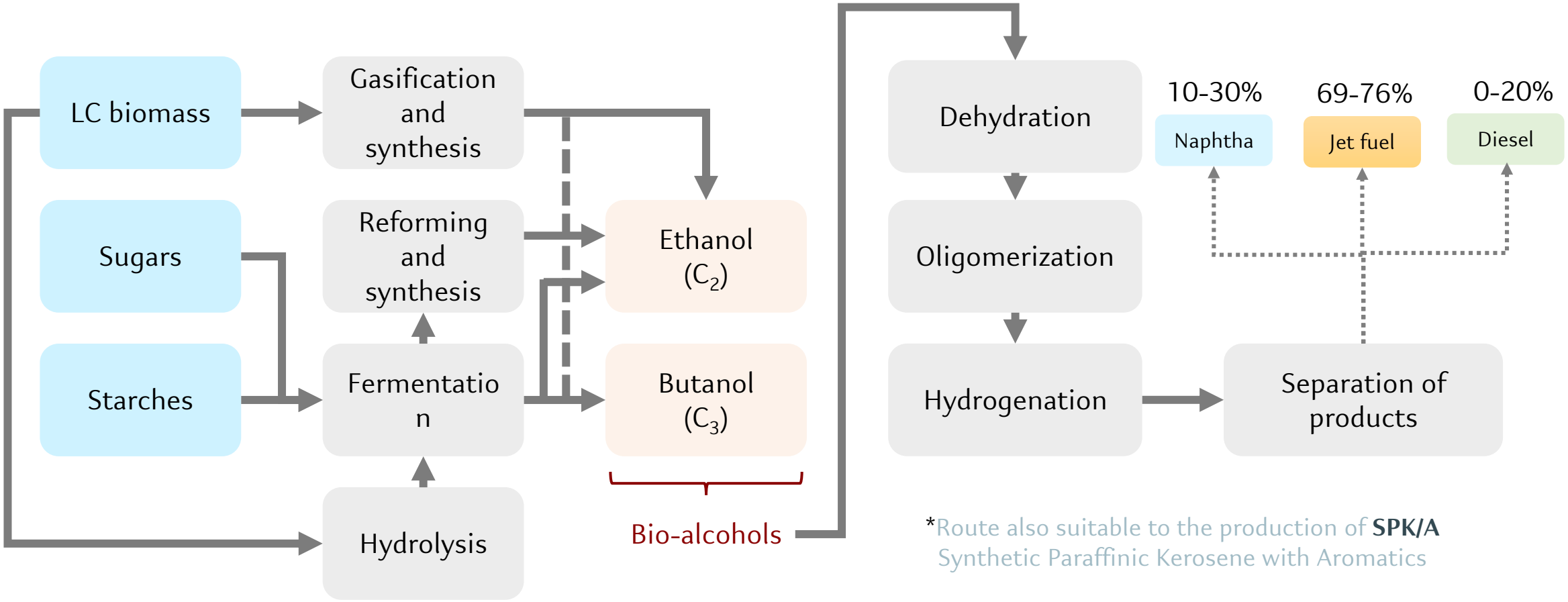
HEFA-SPK

Synthetic paraffinic kerosene from hydroprocessed fatty acids and esters



AtJ-SPK

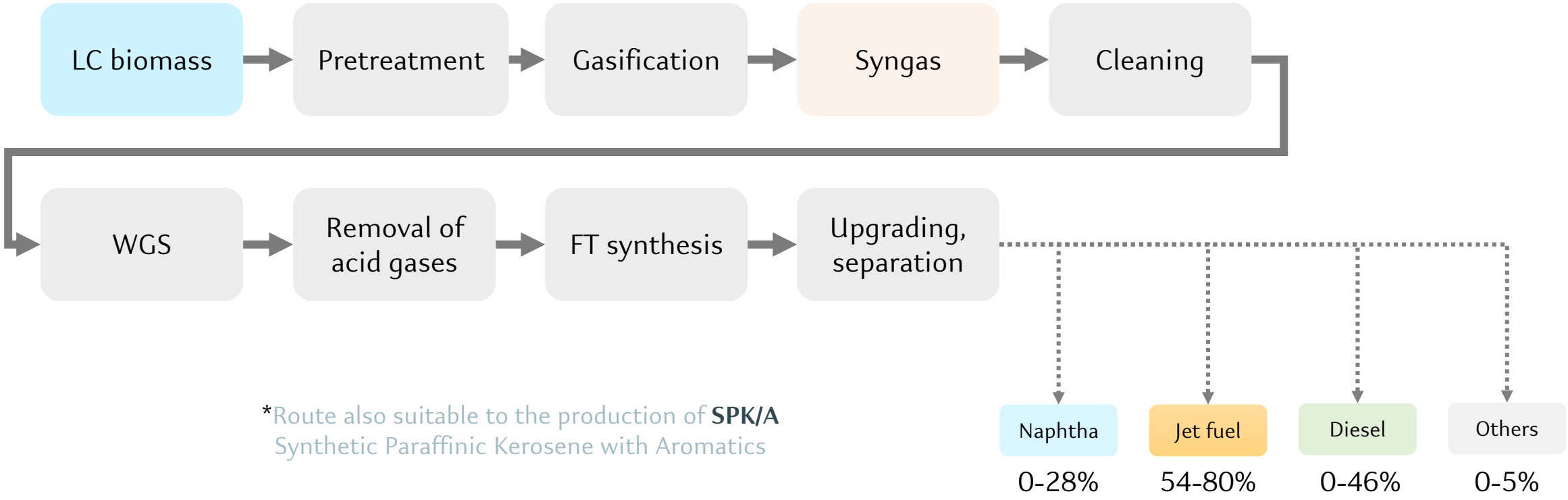
Synthetic paraffinic kerosene* from oligomerized alcohols



*Route also suitable to the production of **SPK/A** Synthetic Paraffinic Kerosene with Aromatics

FT-SPK (BtL)

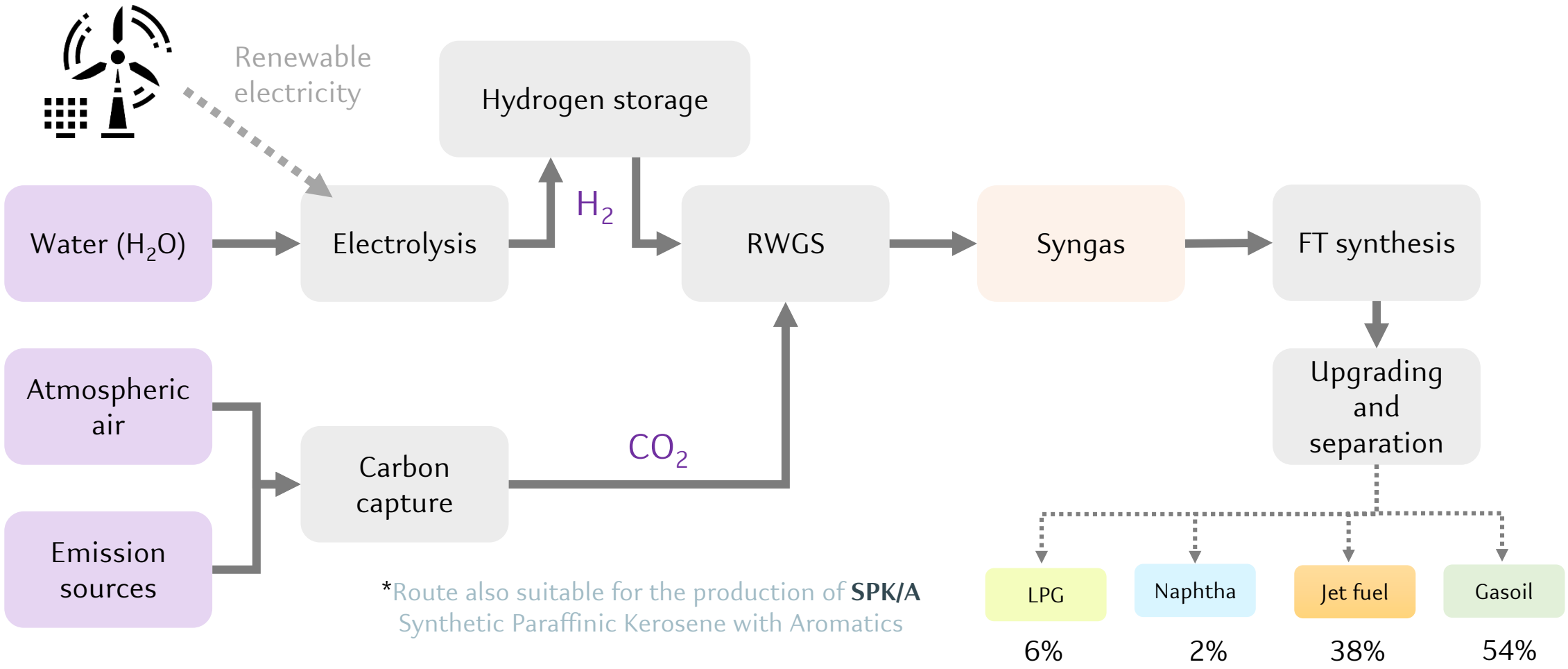
Synthetic paraffinic kerosene* from Fischer-Tropsch synthesis



*Route also suitable to the production of **SPK/A** Synthetic Paraffinic Kerosene with Aromatics

e-SPK

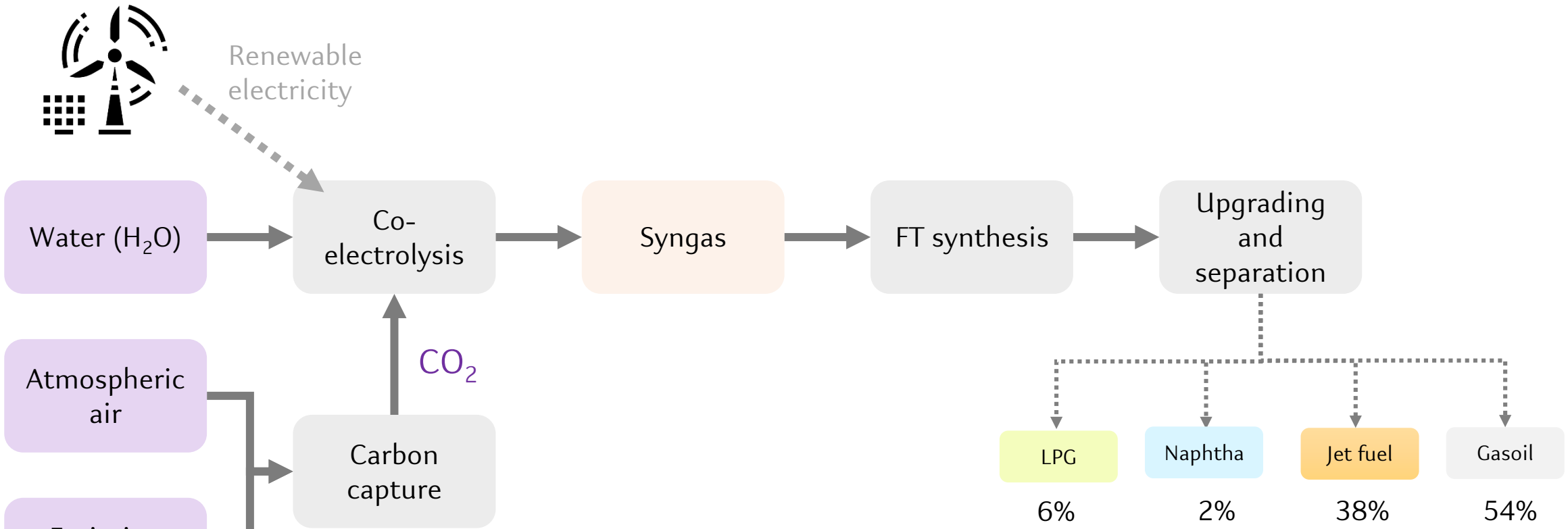
Synthetic paraffinic kerosene* from renewable hydrogen – route 1



*Route also suitable for the production of **SPK/A** Synthetic Paraffinic Kerosene with Aromatics

e-SPK

Synthetic paraffinic kerosene* from renewable hydrogen – route 2



*Route also suitable for the production of **SPK/A** Synthetic Paraffinic Kerosene with Aromatics

Renewable fuels for shipping

Group 1:
Distilled biofuels

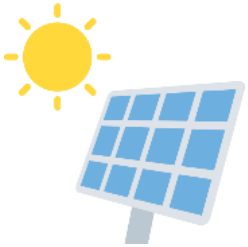
- SVO
- Biodiesel
- HVO
- HDPO
- FT-diesel

Group 2: Alcohols and liquefied gases

- Bio-LNG
- Biomethanol
- Bioethanol

Group 3:
Hydrogen-based fuels

- Green H_2
- Green NH_3
- e-diesel
- e-LNG
- e-methanol



Icons: freepik/flaticon

Criteria for Comparative Analysis

AVAILABILITY

Feedstock and production infrastructure

APPLICABILITY

Existing fleet and bunkering infrastructure

TECHNOLOGICAL MATURITY

Readiness level (production and use)

ENERGY DENSITY

Requirement of space for fuel storage

ECONOMIC

LCOE - fuel, bunkering and ship modifications

SAFETY

Safety in operation and toxicity

STANDARDS

Existence of standards and certifications

LOCAL SUSTAINABILITY

Air pollutant emissions, impacts on water

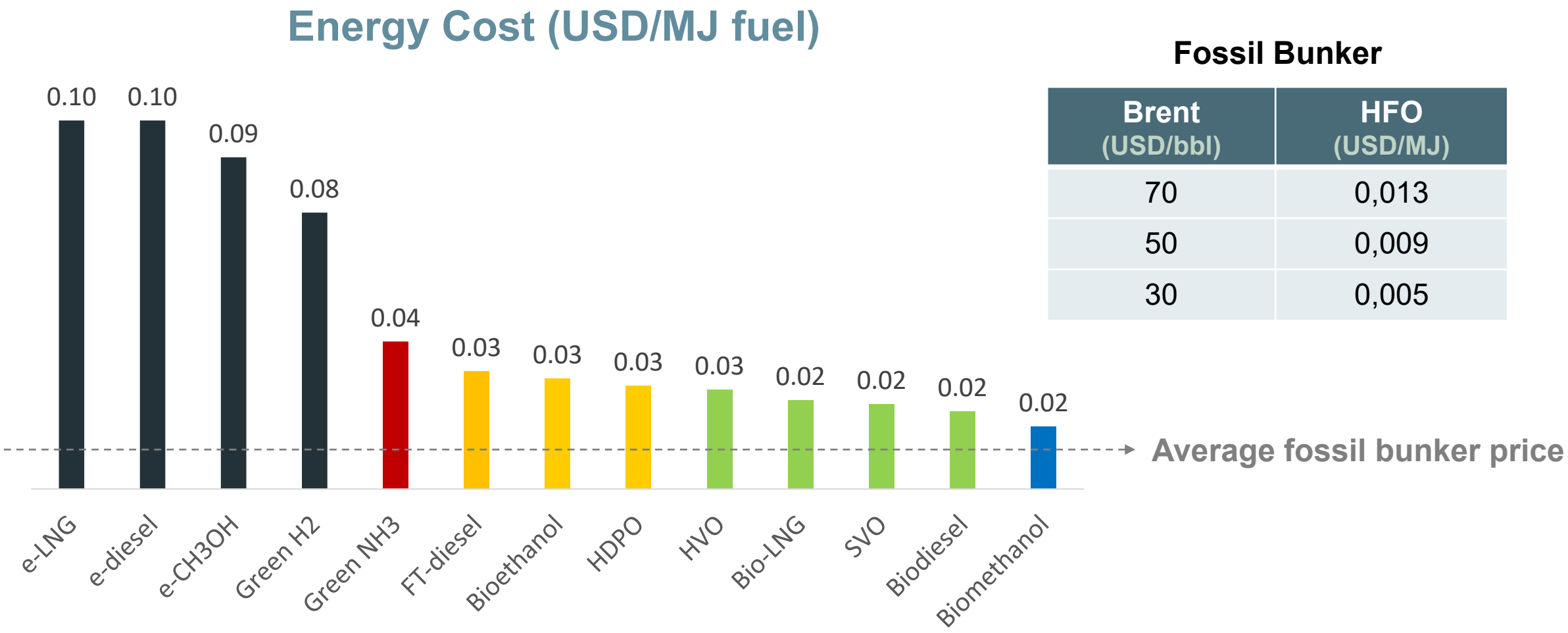
GLOBAL SUSTAINABILITY

Direct and indirect GHG emissions

- Technical
- Economic
- Environmental

Icons: freepik/flaticon

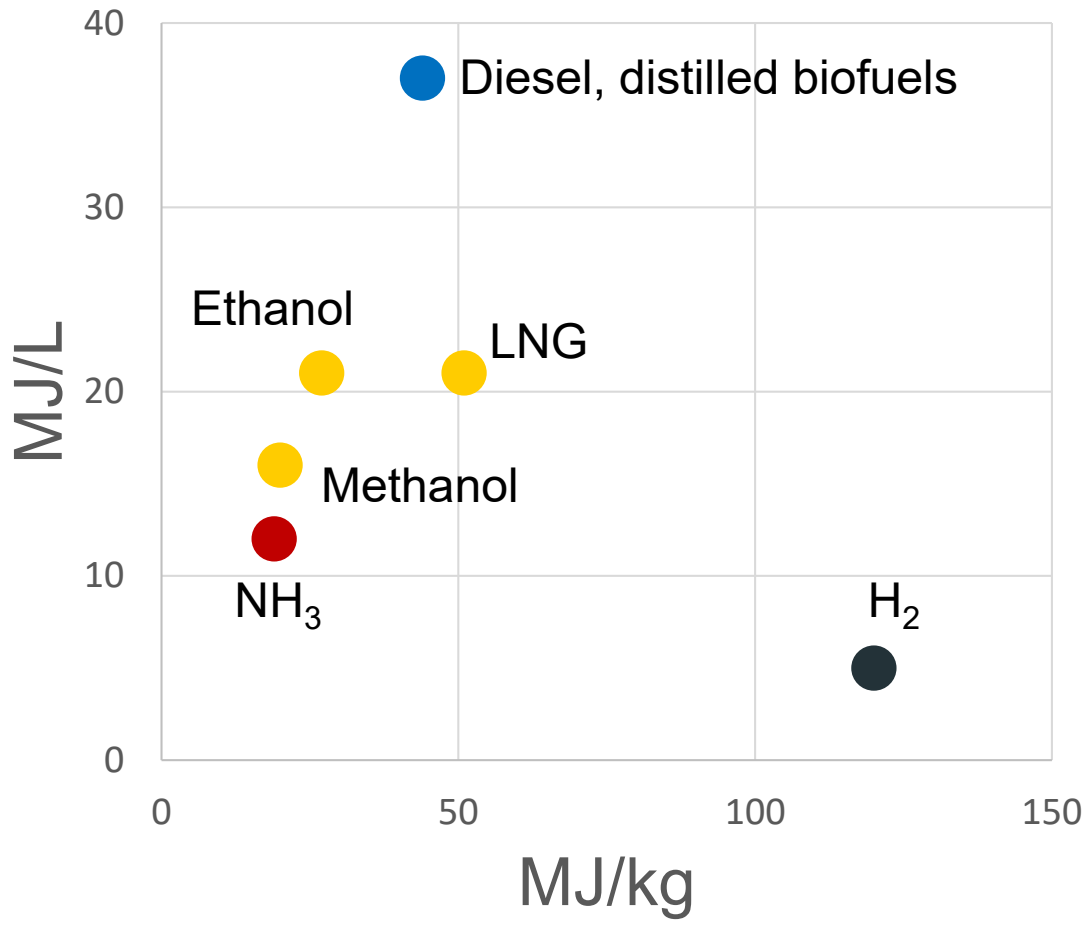
Economic Criterion



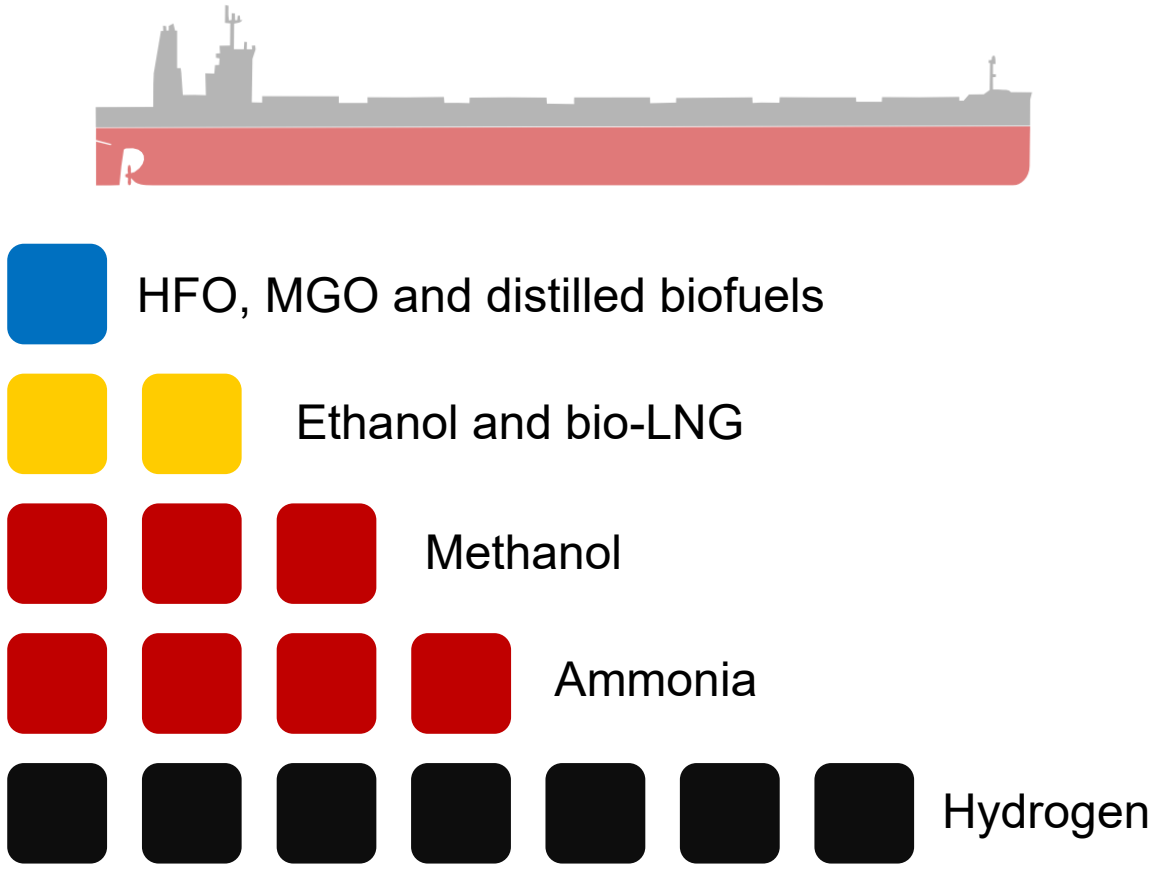
Fossil Bunker

Brent (USD/bbl)	HFO (USD/MJ)
70	0,013
50	0,009
30	0,005

Energy Density Criterion



Space required for fuel storage



Operational Safety

MGO

- Flammable liquid and vapour
- Toxic to aquatic life
- Aspiration hazards

LNG

- Highly flammable gas
- Cryogenic gas risks

Hydrogen

- Highly flammable gas
- Cryogenic gas risks

Biomethanol

- Highly flammable liquid and vapour
- Toxic if swallowed or in contact with skin

Ammonia

- Flammable gas
- Gas under pressure
- Toxic, skin burns
- Toxic to aquatic life

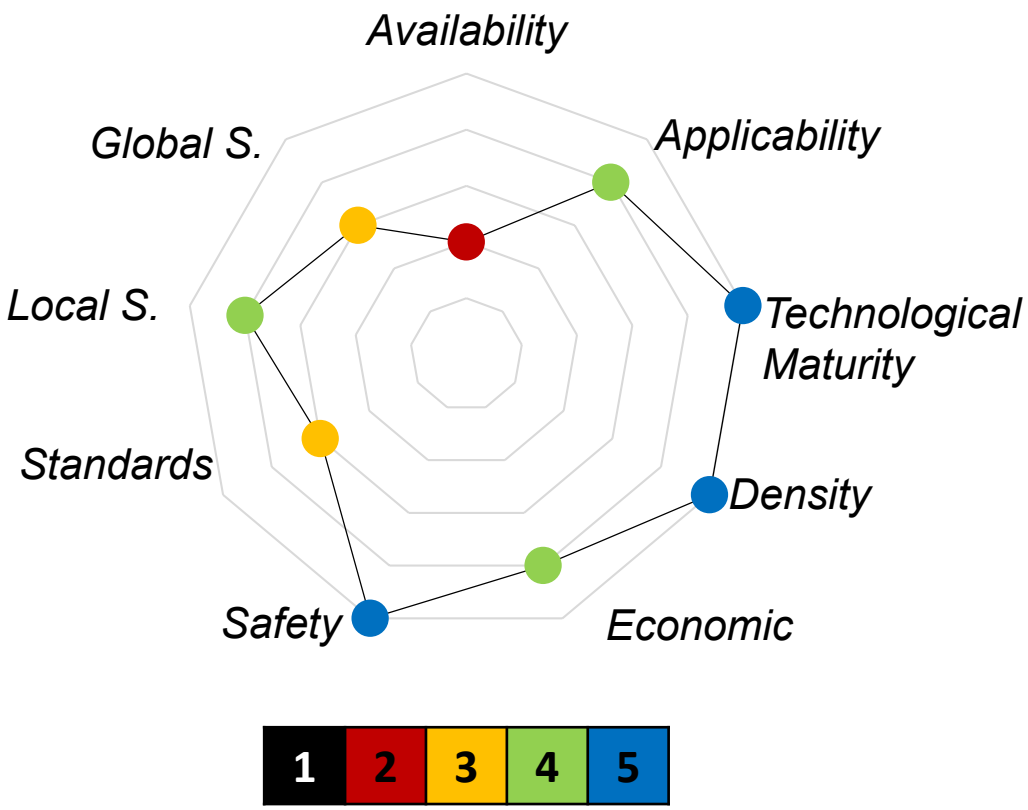
SVO (Straight Vegetable Oil)

STRENGHTS

Drop-in biofuel

Mature production technology

Good energy density



WEAKNESSES

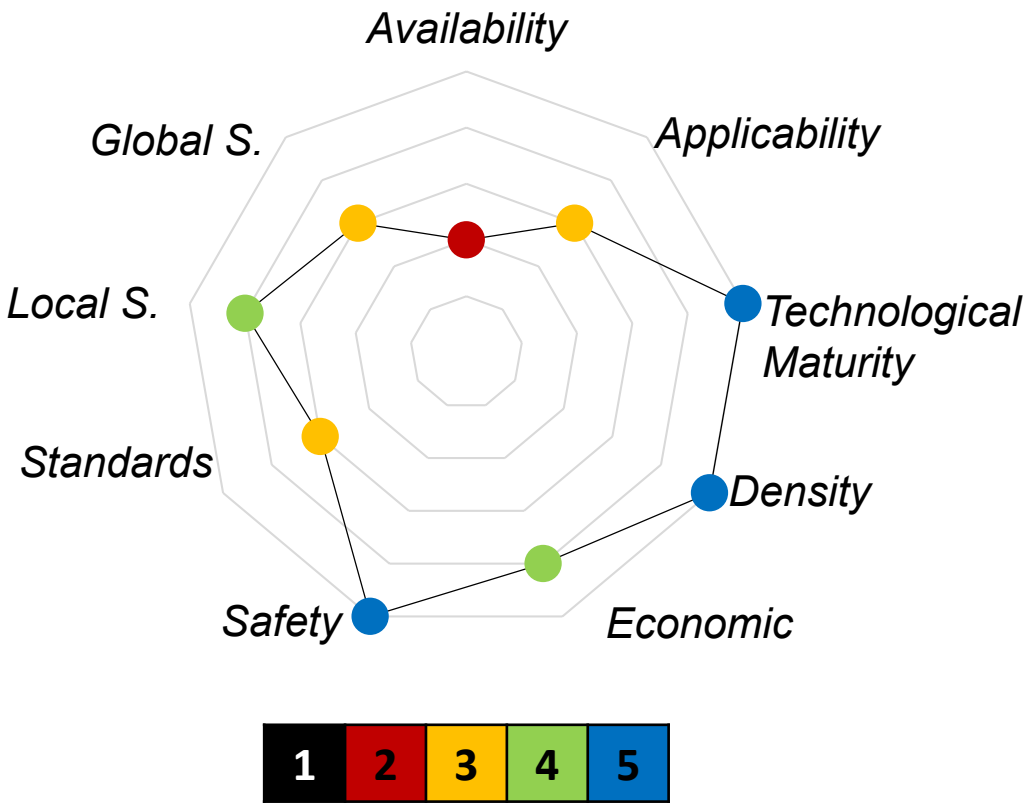
Competition with other uses

Land use change threats

Biodiesel (FAME/FAEE)

STRENGHTS

- Drop-in biofuel
- Mature production technology
- Good energy density



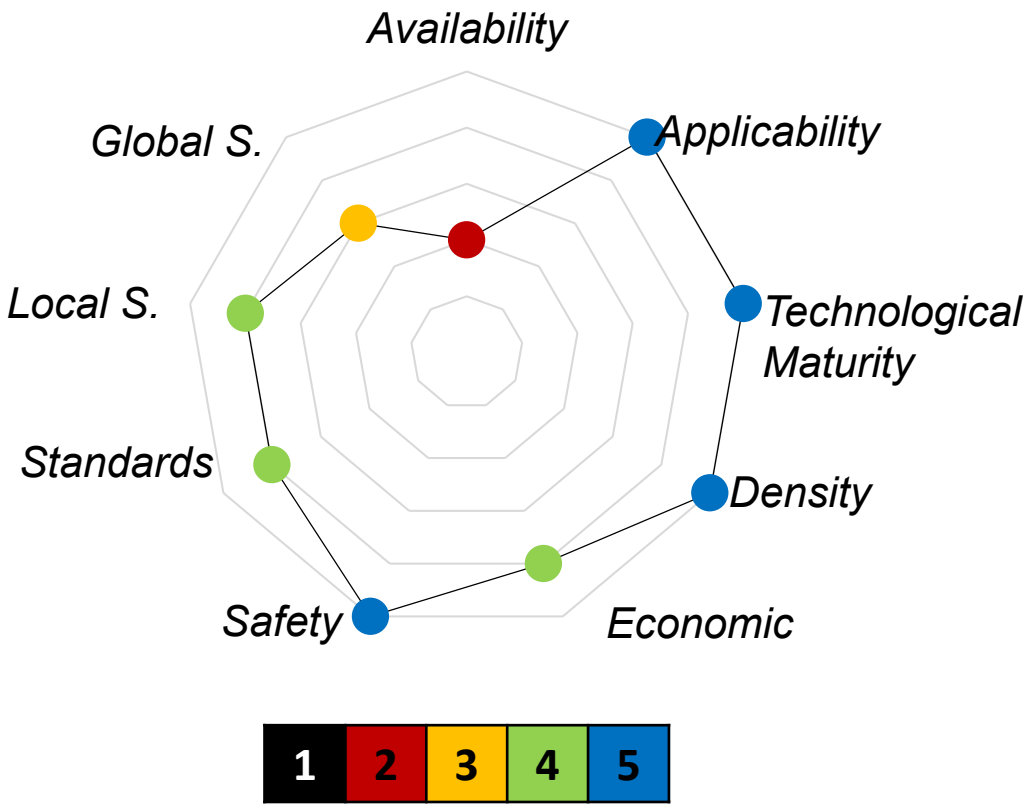
WEAKNESSES

- Competition with other uses
- Land use change threats
- Low quality compared to HVO

HVO (Hydrotreated Vegetable Oil)

STRENGHTS

- Drop-in biofuel
- Mature production technology
- Good energy density
- High quality



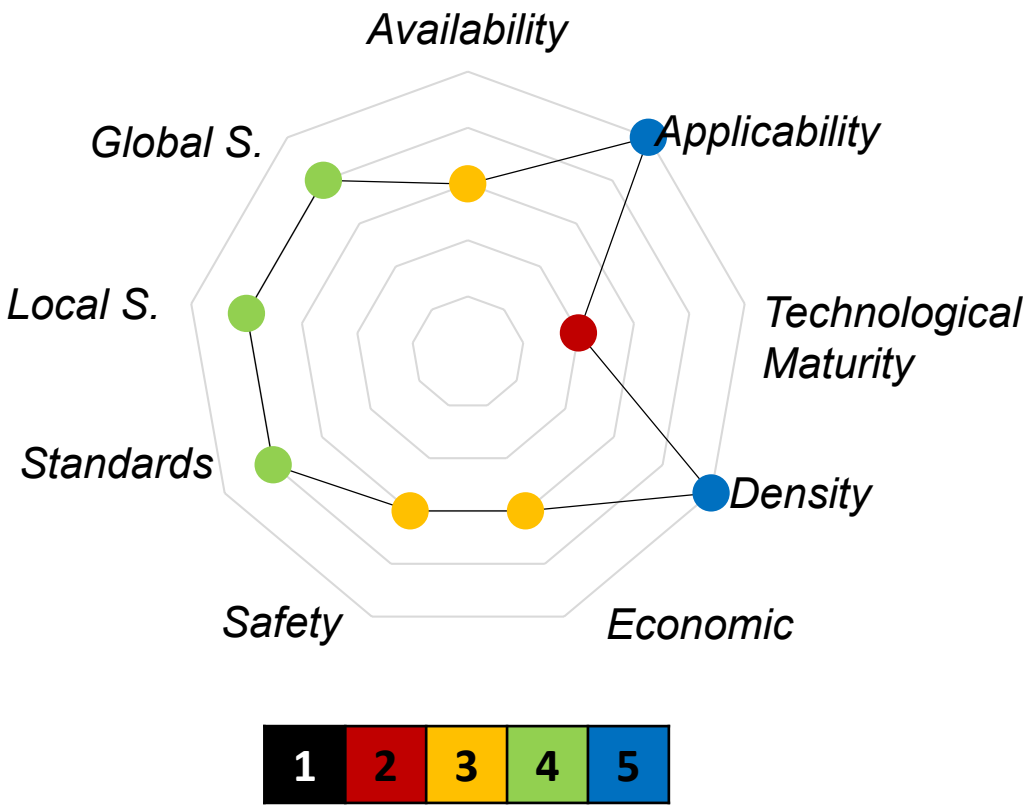
WEAKNESSES

- Competition with other uses
- Land use change threats

HDPO (Hydrotreated Pyrolysis Oil)

STRENGHTS

- Drop-in biofuel
- Better feedstock availability
- Good energy density
- High quality



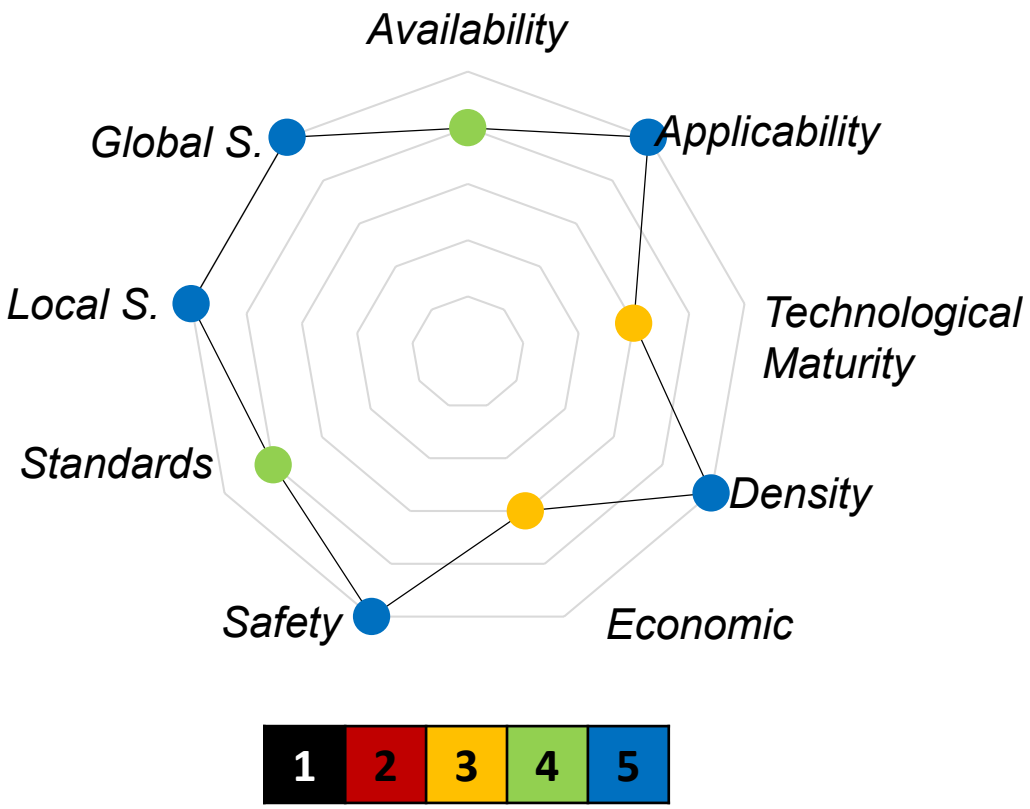
WEAKNESSES

- Technology not well developed yet
- Higher cost

FT-diesel (Biomass-derived Diesel)

STRENGHTS

- Drop-in and high quality
- Fischer-Tropsch coproducts
- Very high global sustainability
- Feedstock availability



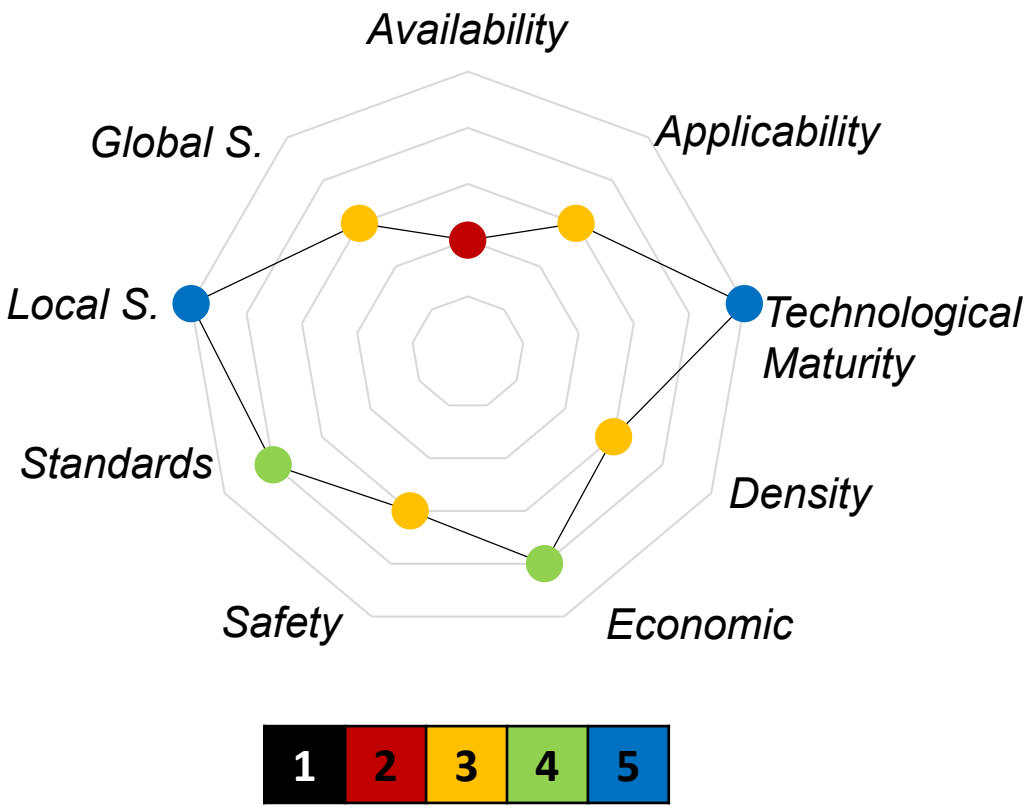
WEAKNESSES

- Not yet in commercial stage
- Costs higher than SVO/HVO

Bio-LNG (Liquefied Biomethane)

STRENGHTS

- Mature production and liquefaction
- Interesting cost
- Very low air pollutant emissions



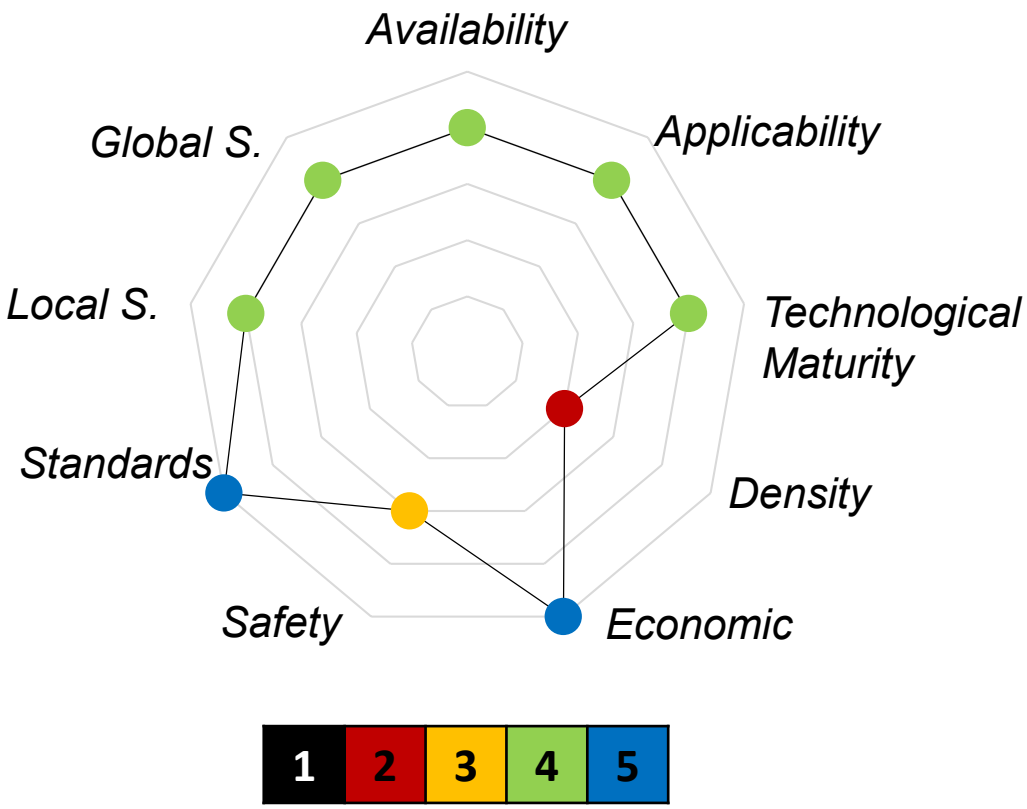
WEAKNESSES

- Geographically dispersed resources
- Heterogeneous feedstock
- Requires dual-fuel engine
- Methane slip

Bio-CH_3OH (Biomethanol)

STRENGHTS

- Good feedstock availability
- Existing infrastructure
- Competitive costs
- Easier to storage than LNG



WEAKNESSES

- Requires dual-fuel engine
- Intermediate energy density
- Flammability

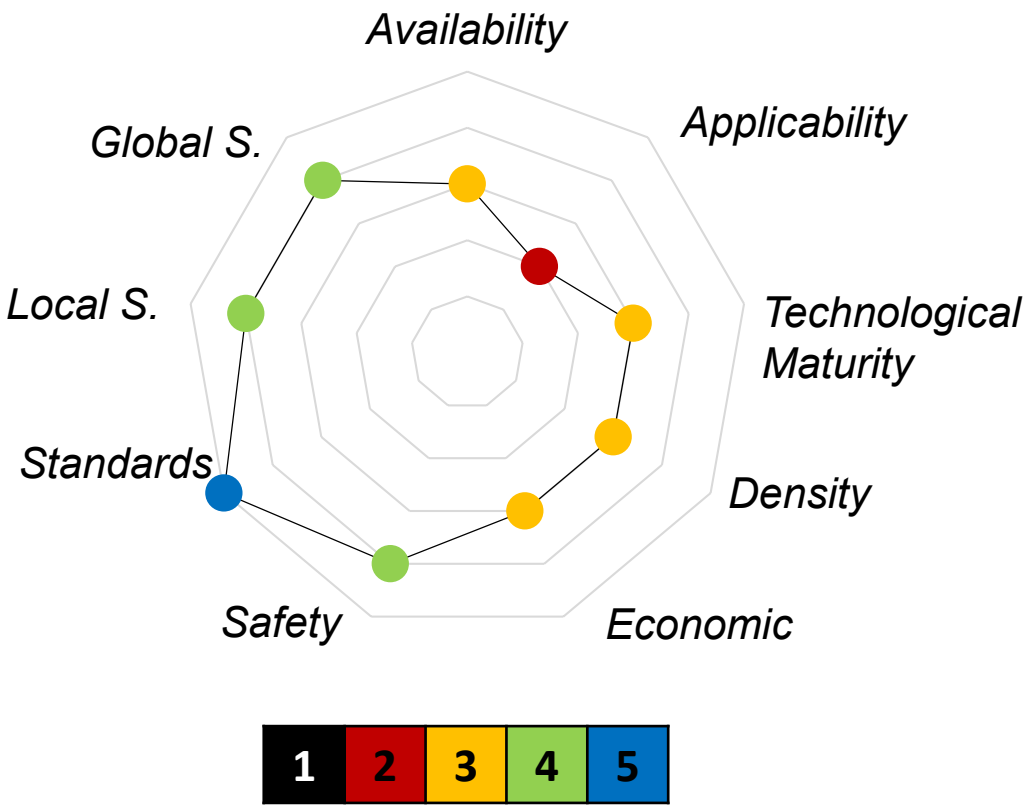
Bio-C_2H_5OH (Bioethanol)

STRENGHTS

Mature production process

Safe biofuel

Standards available



WEAKNESSES

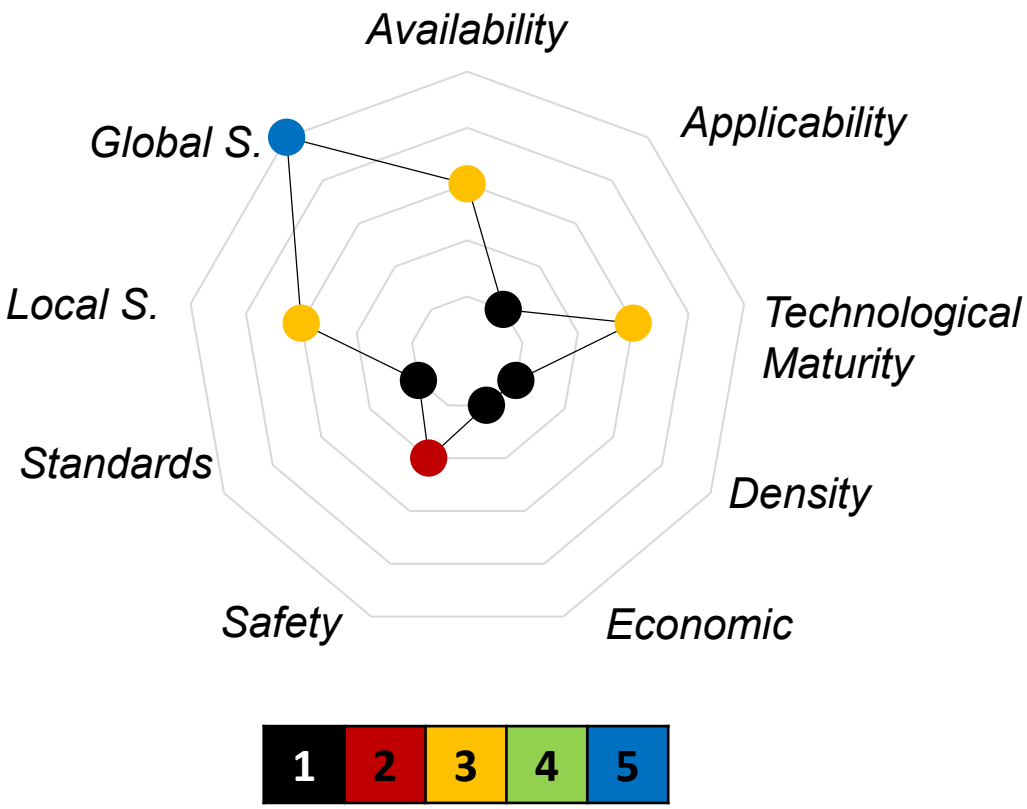
Use in diesel engine requires booster

Intermediate energy density

Green H_2 (Renewable-based Hydrogen)

STRENGHTS

- Very high global sustainability
- No air pollutant emissions



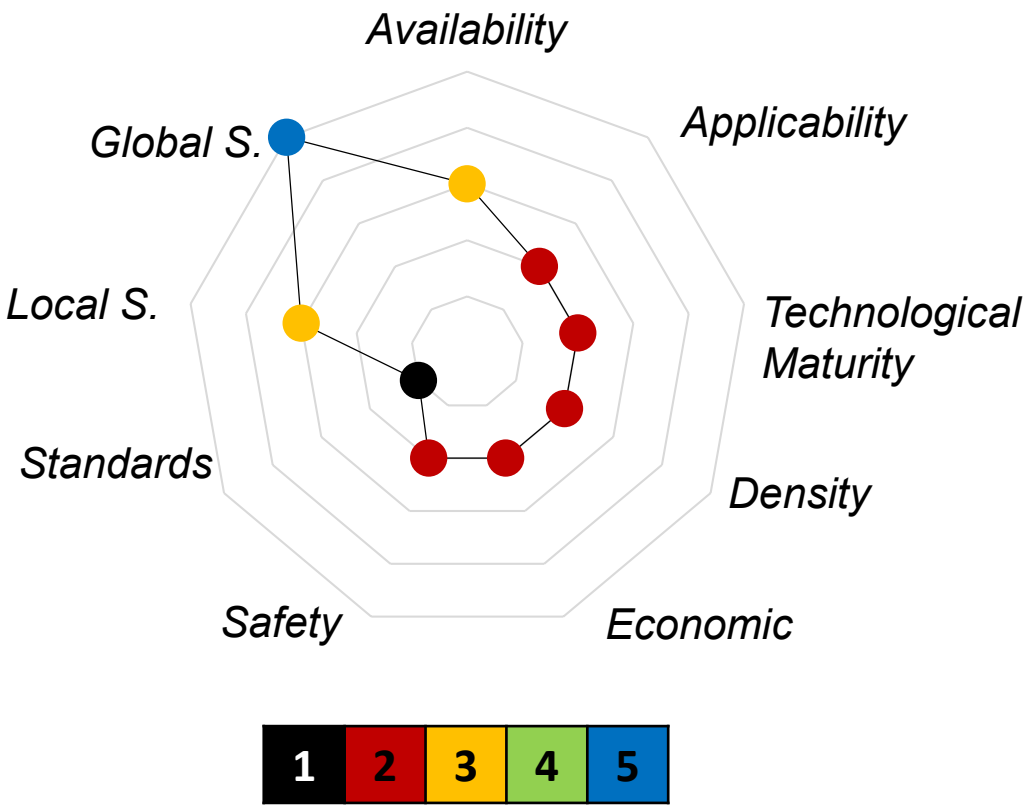
WEAKNESSES

- Low TRL and applicability
- Safety concerns
- Cost of electrolysis
- Poor energy density

Green NH_3 (Renewable-based Ammonia)

STRENGHTS

- Very high global sustainability
- No air pollutant emissions
- Haber-Bosch, mature process



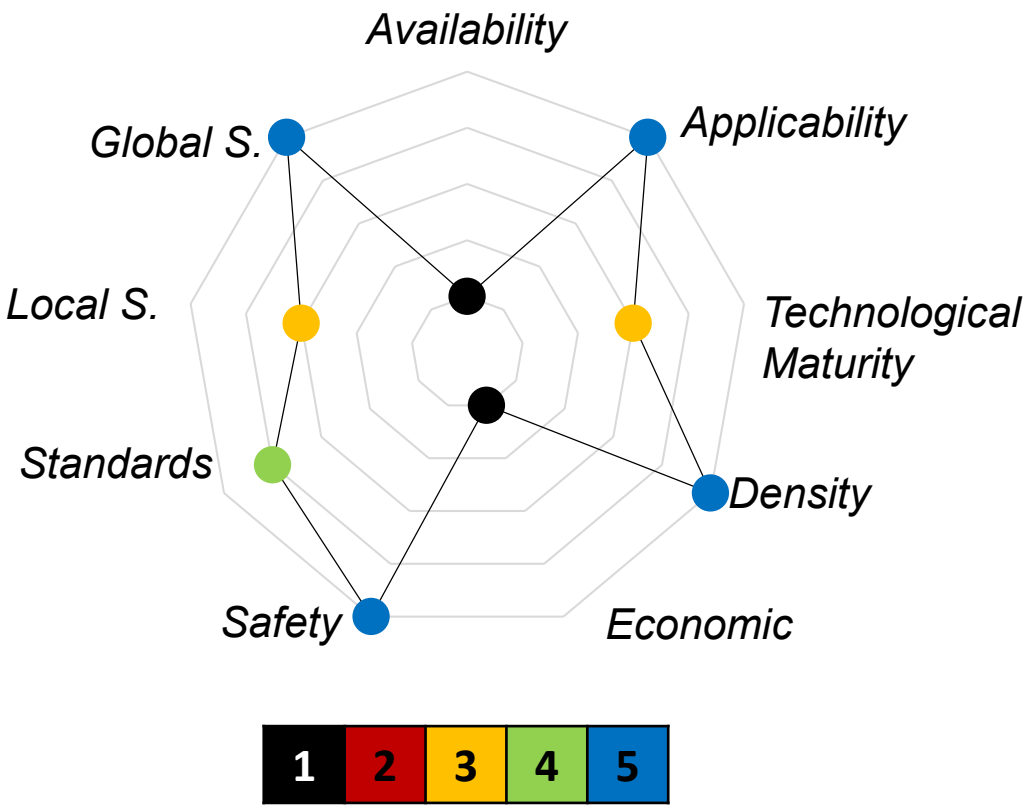
WEAKNESSES

- Low TRL and applicability
- Safety concerns
- Cost of electrolysis
- Poor energy density (but > H_2)

e-diesel (Green H_2-based Diesel)

STRENGHTS

- Drop-in and high quality
- Fischer-Tropsch coproducts
- Very high global sustainability
- Good energy density



WEAKNESSES

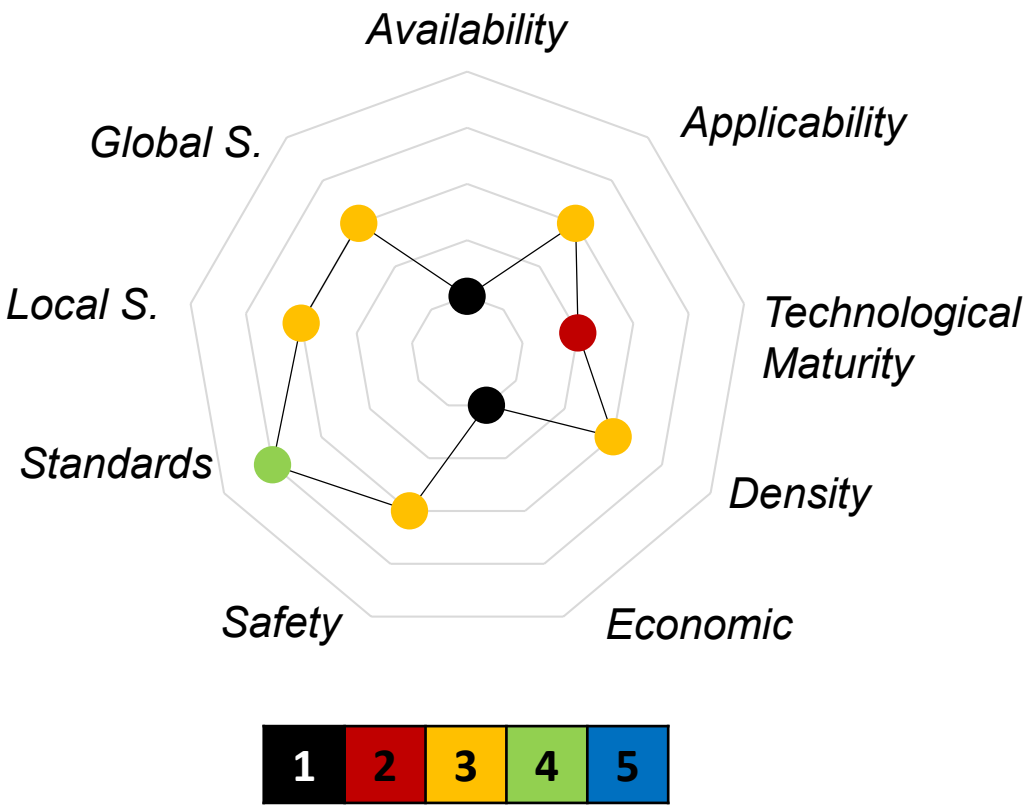
- Not available in the near-term
- High costs
- Water consumption

e-LNG (Green H_2-based LNG)

STRENGHTS

Mature CH_4 production and liquefaction

CO2 recycling



WEAKNESSES

High costs

CO_2 unavailable (DAC/CCS)

Only dual-fuel engines

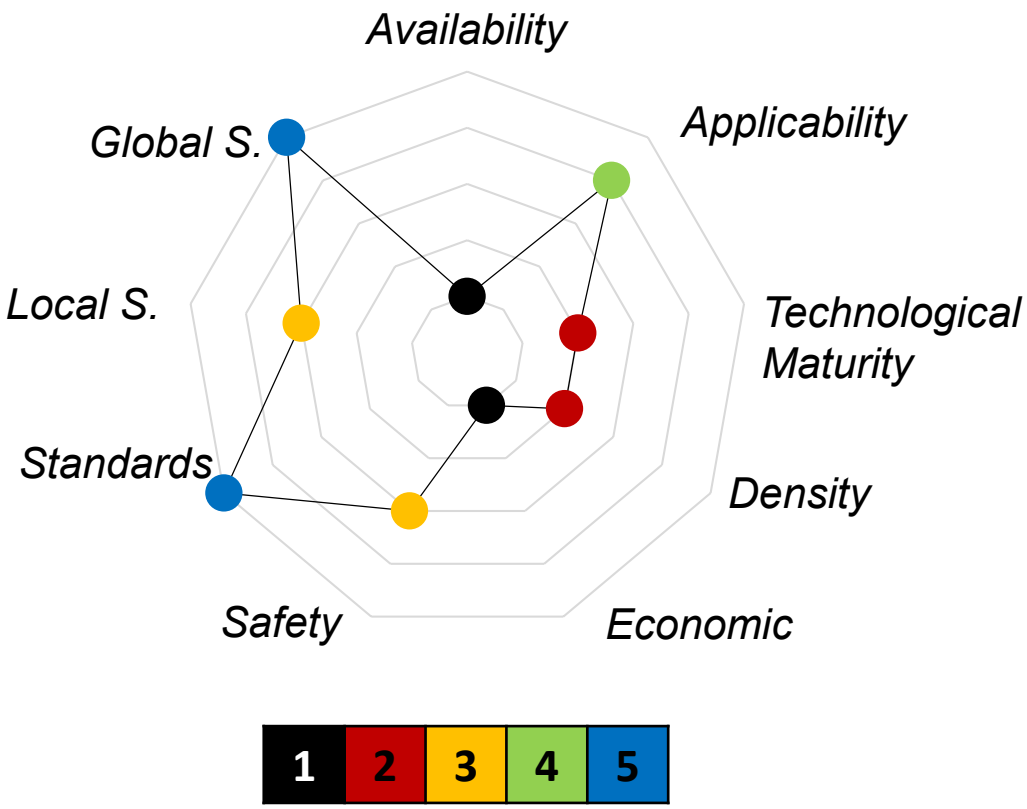
Methane slip

e-CH_3OH (Green H_2-based Methanol)

STRENGHTS

Storage advantages (bio-LNG or e-LNG)

CO2 recycling



WEAKNESSES

High costs

CO_2 unavailable

H_2O consumption

MJ/L ≈ bunker ÷ 2,5

Criteria Weights

AVAILABILITY

APPLICABILITY

TECHNOLOGICAL MATURITY

ENERGY DENSITY

ECONOMIC

SAFETY

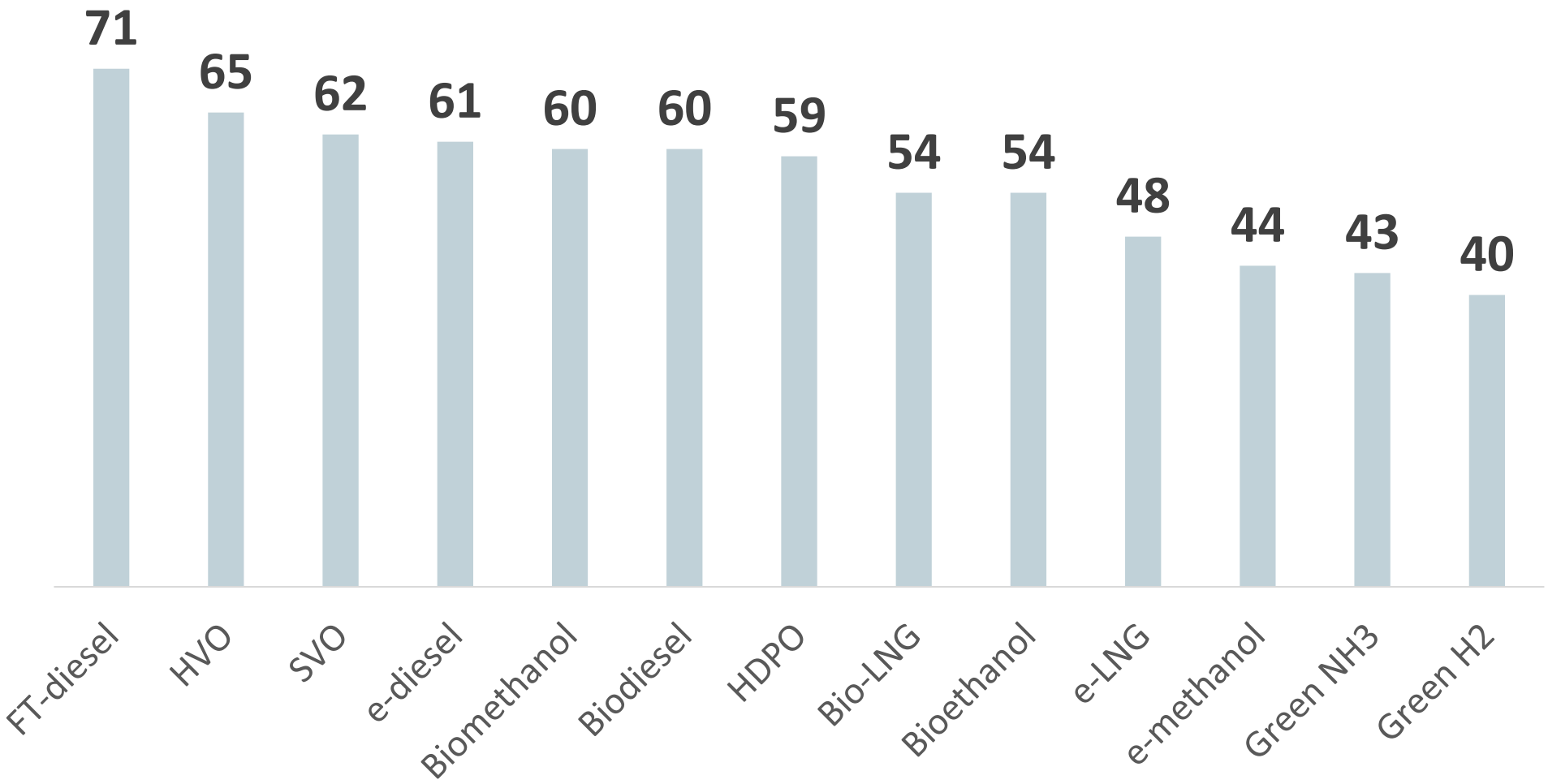
STANDARDS

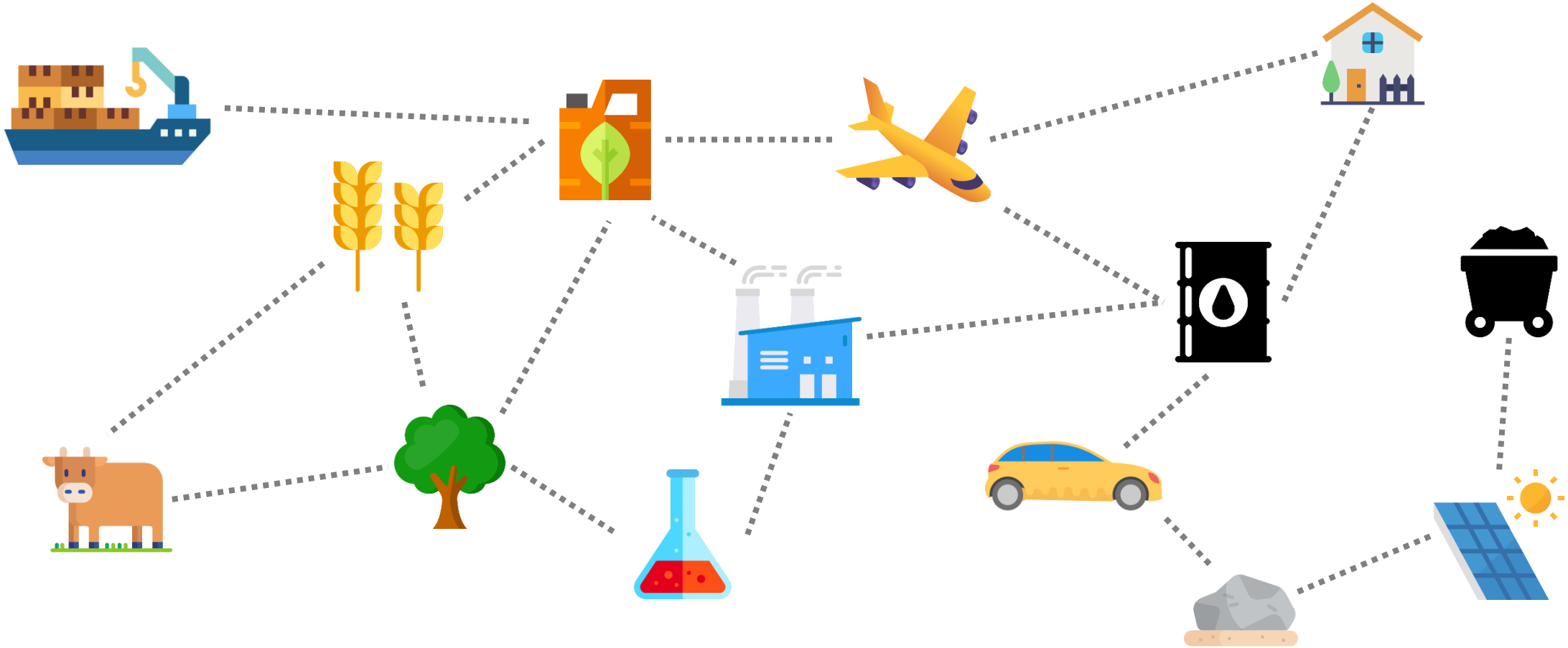
LOCAL SUSTAINABILITY

GLOBAL SUSTAINABILITY

Icons: freepik/flaticon

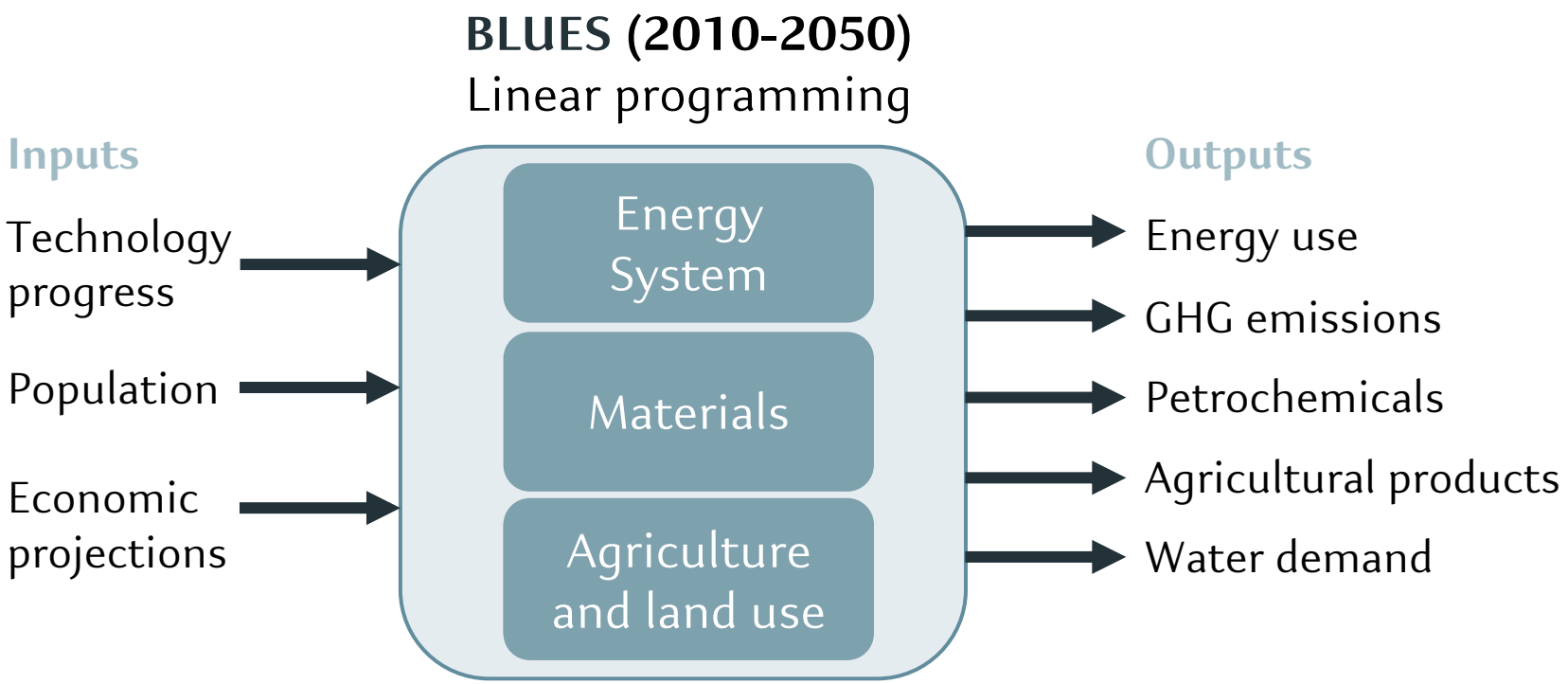
Score and Ranking





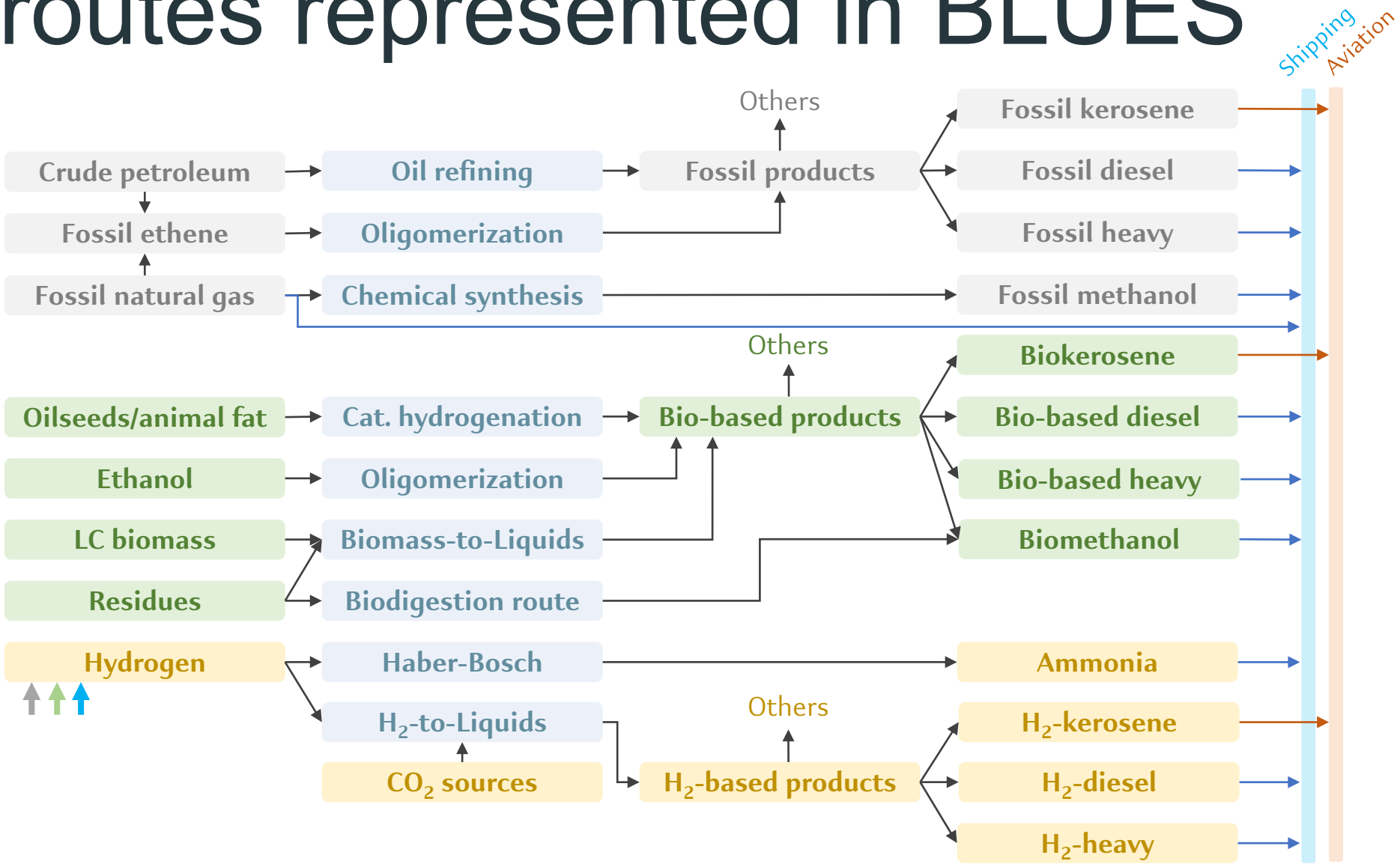
What is an integrated assessment perspective on these matters with a special focus on aviation and shipping?

The BLUES model

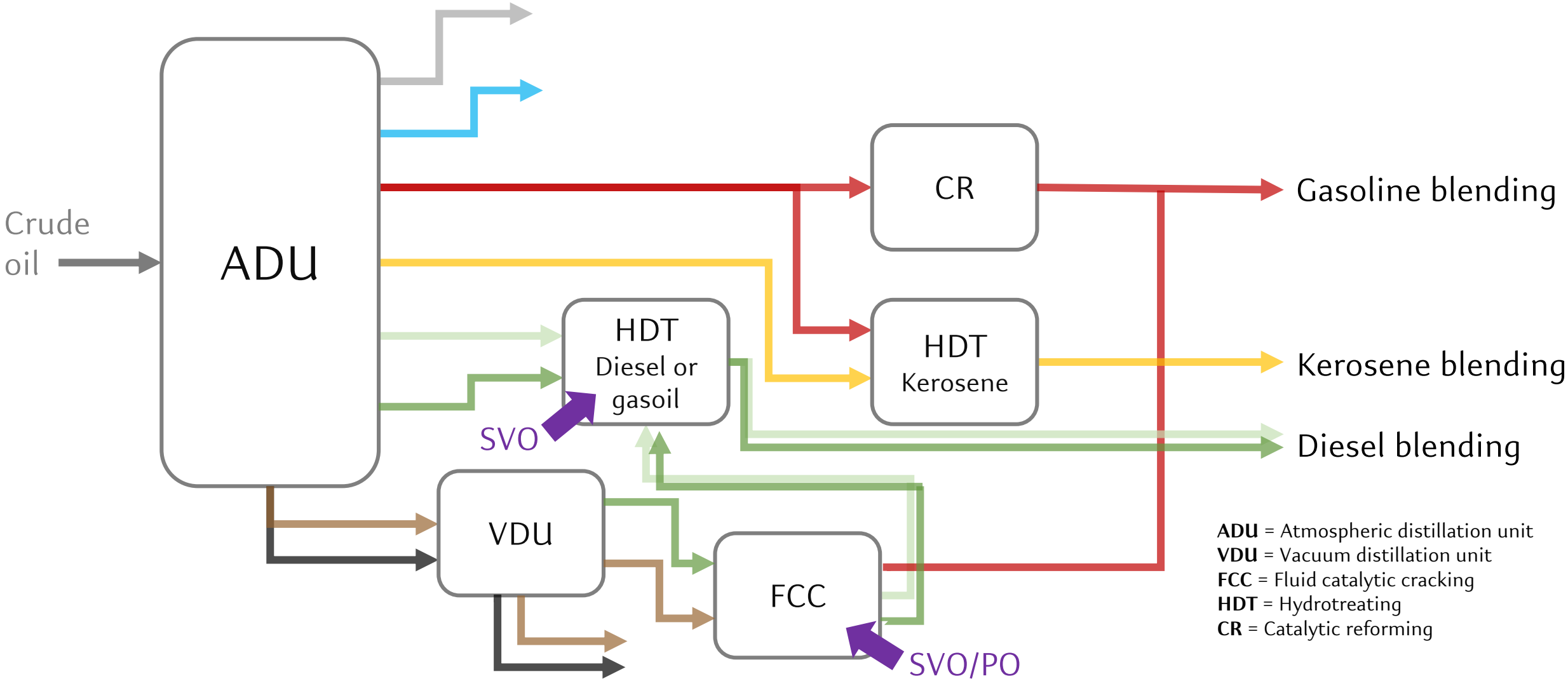


5 regions

Fuel routes represented in BLUES



Additionally, coprocessing…



Design of scenarios: our choice

Originally, four scenarios:

Carbon budget:
Global IAM, Brazil as a region in a World below 2ºC

CO_2

IATA

Current policy view
IATA2050 as a restriction

IMO

Current policy view
IMO2050 as a restriction

IATA IMO

Combination of the first two scenarios

B2C

Climate policy scenario:
Brazil **well-below 2ºC**

In a second moment, sensitivity analyses:

IATA IMO (KeroExp)

IATA_IMO with Brazil becoming a major aviation biofuel exporter

IATA IMO (Sml BtL)

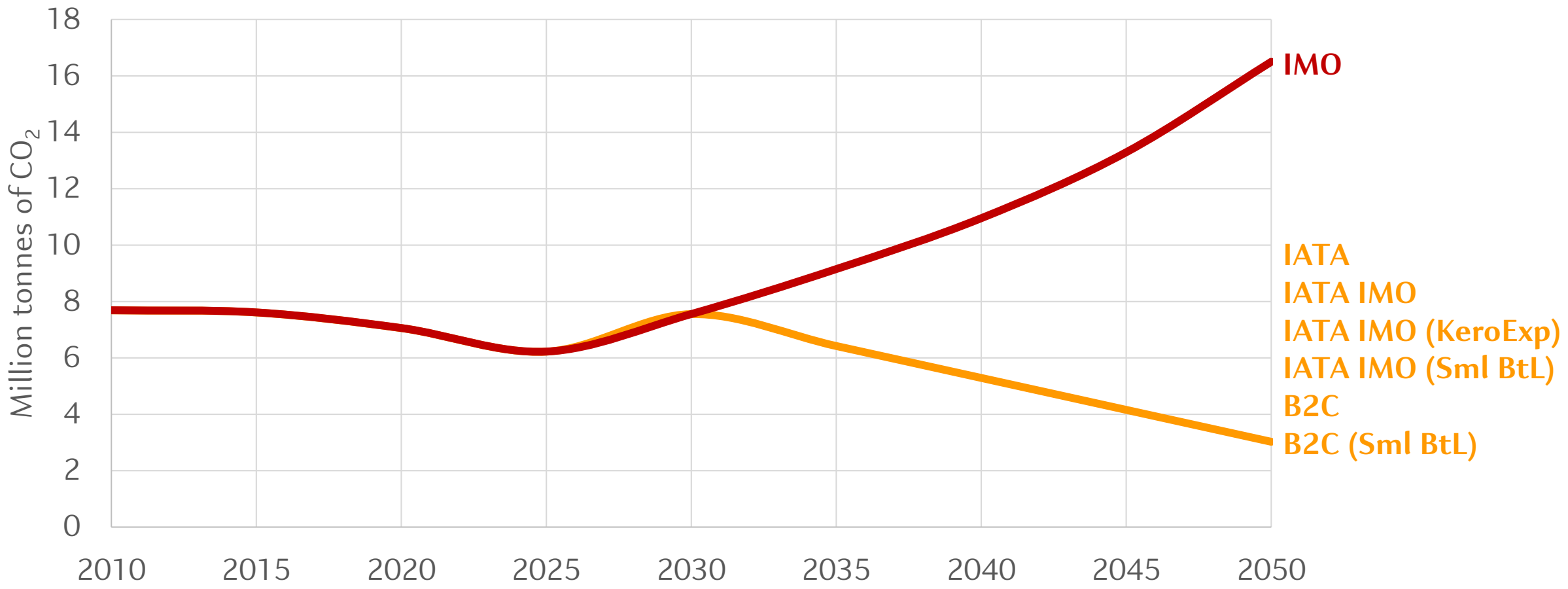
IATA_IMO considering smaller BtL plants

B2C (Sml BtL)

B2C considering smaller BtL plants

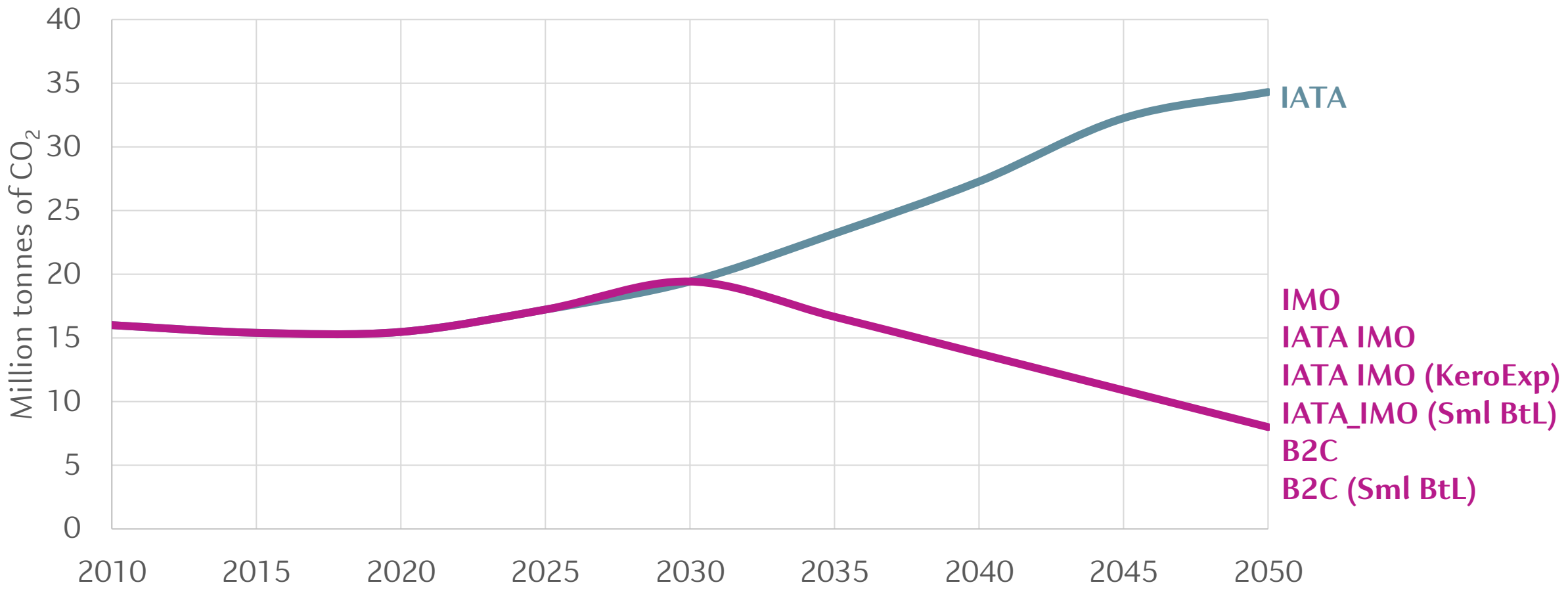
For simplicity,
IATA/ICAO scenarios
are referred to as IATA

International aviation CO_2 emissions*



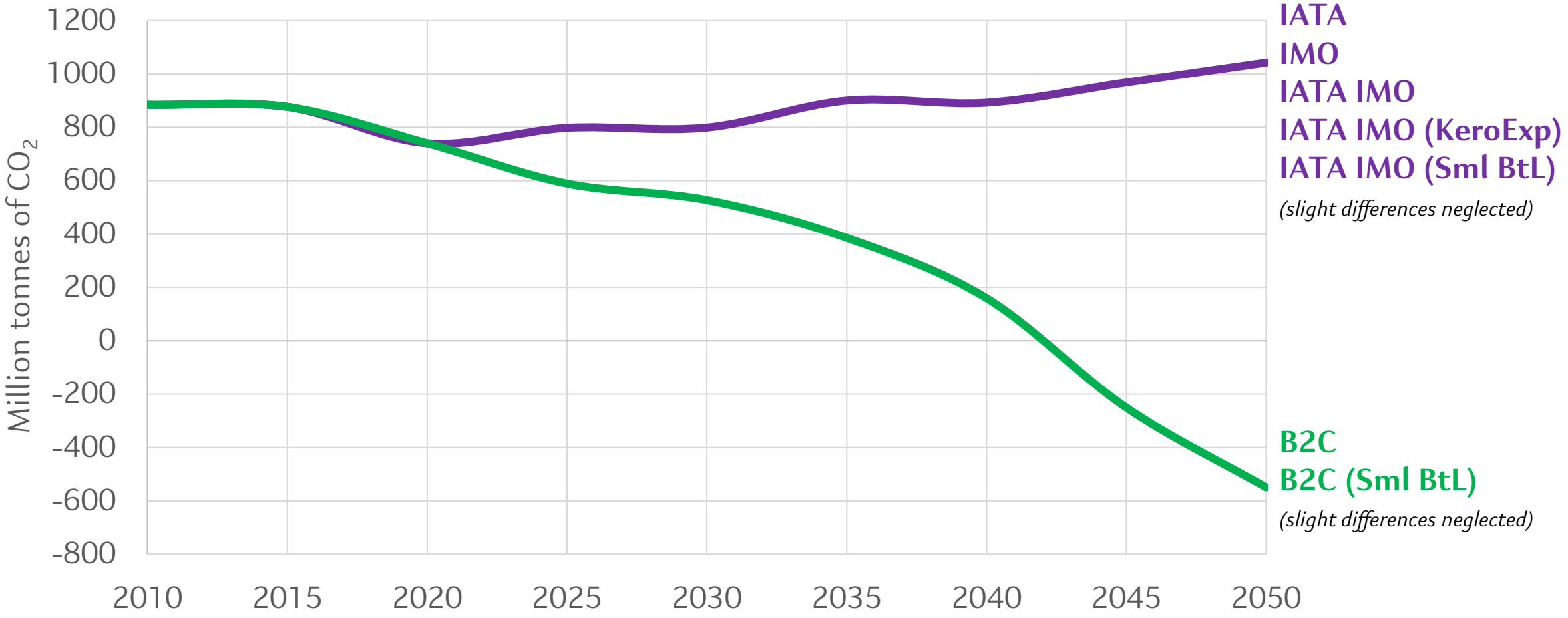
* International emissions associated with the Brazilian fuel supply (not total international aviation emissions)

International shipping CO_2 emissions*



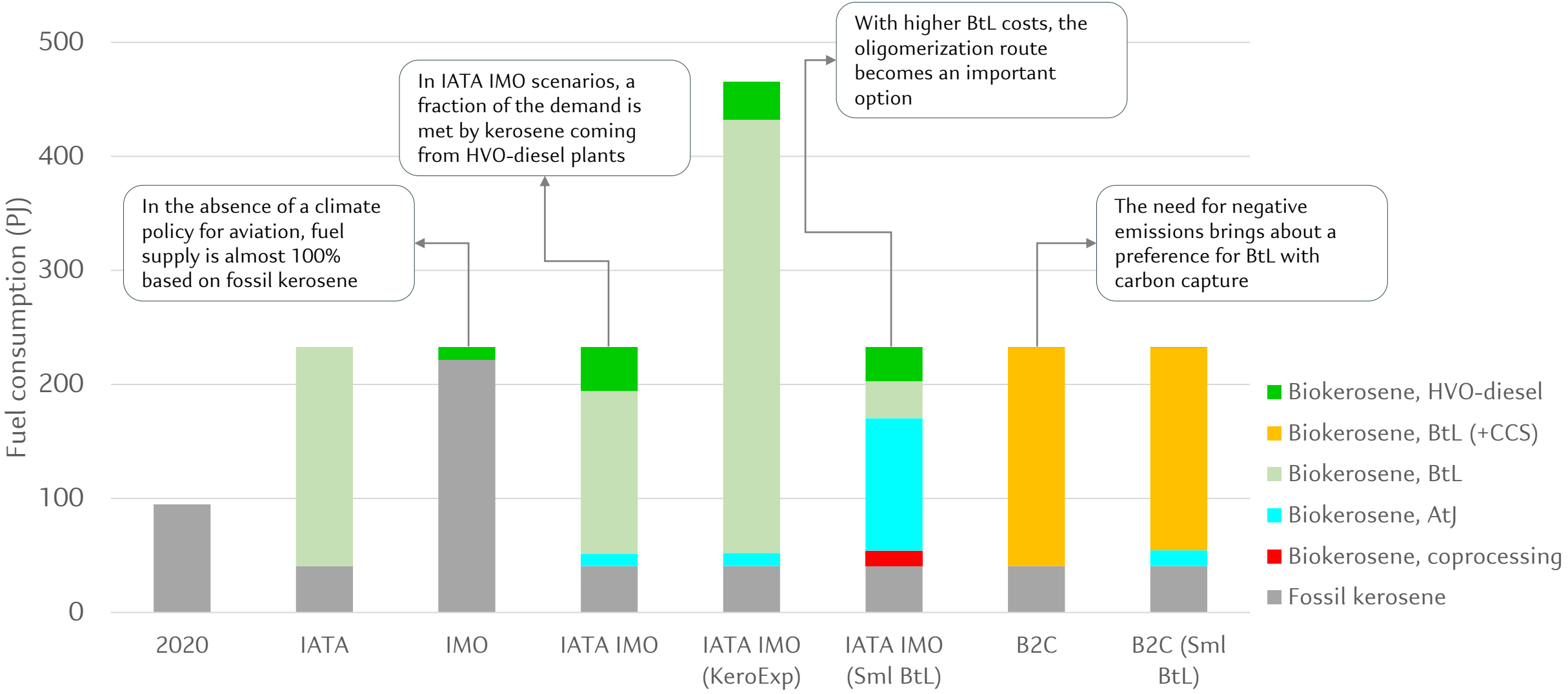
* International emissions associated with the Brazilian fuel supply (not total international shipping emissions)

Brazilian CO_2 emissions*

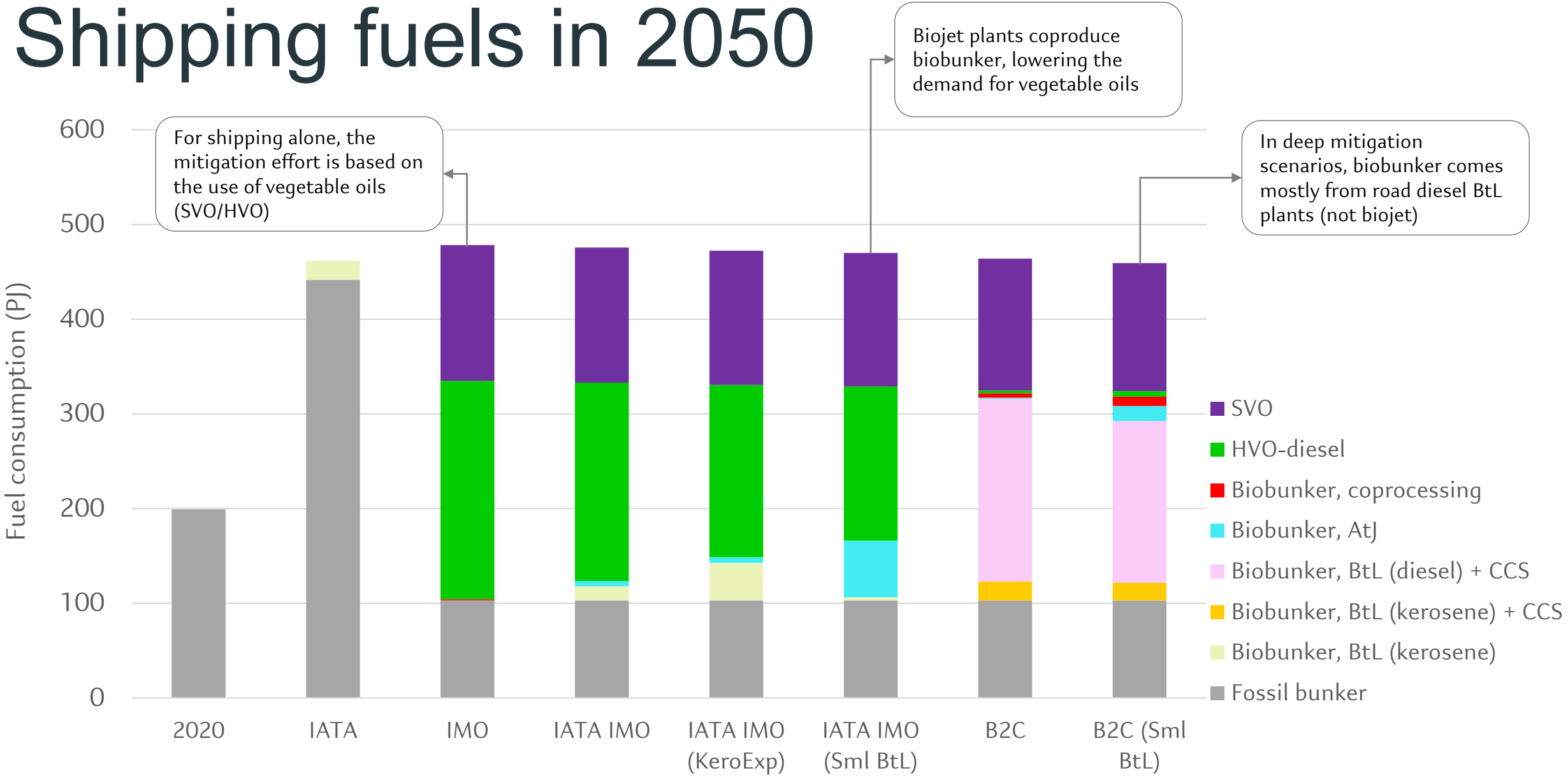


* Does not include the emissions shown in the two previous graphs (which are international)

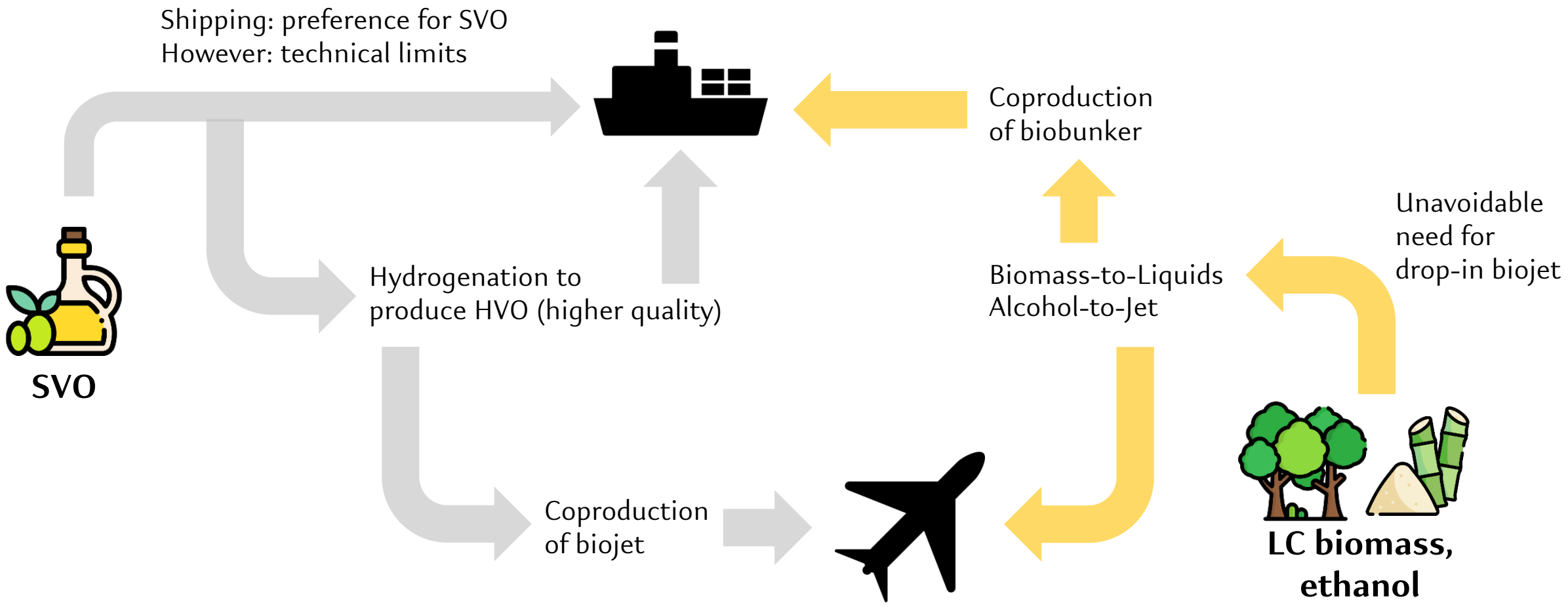
Aviation fuels in 2050



Shipping fuels in 2050



Is there a synergy between sectors?



However, the difference in the size of the two sectors does not allow a full-scale synergy → B2C scenarios: shipping fuels mostly associated with road diesel plants

Icons: Freepik/flaticon

Concluding remarks (1/2)

- **Fuel switch** is key to mitigate GHG emissions in aviation and shipping
- From an IAM perspective, **drop-in biofuels** are the most promising alternatives for both aviation an shipping
- Brazil: shipping >> aviation (in 2020: 200 PJ versus 100 PJ)
- As such a **synergy** between these two sectors is **somehow limited**
- This synergy would probably be greater **if the opposite were true** (premium fuel demand >> residual fuel demand)
- Still a **certain degree of synergy** can be observed

Concluding remarks (2/2)

- **BtL** and **AtJ** kerosene plants produce significant amounts of bunker fuels
- **HVO-diesel** plants built to fuel the marine sector coproduce kerosene
- National climate policy → need for **negative emissions**
- Thus, large amounts of **BECCS** – biojet plants, but especially **bio-based road diesel** plants
- In all these scenarios biobunker stands out as a **major byproduct**
- In sum, **there is no silver bullet for HtA sectors** in the short to medium term
- **Different** niche markets do exist for different geographies, sectors and realities, and as such **only a truly integrated approach can provide the best response for each case**

Thanks!

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