

# Climate neutral refineries: Comparing Fischer Tropsch and Methanol-to- Hydrocarbons for production of e-fuels and e-high value chemicals in Germany

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# Contributors Speakers

## Speakers



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## Contributors



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### Feedstock transport

International pipeline imports (H<sub>2</sub>, CO<sub>2</sub>, MeOH, FT-crude, SAF)

### e-fuels production

Techno-economic assessment

### Refinery-specific analysis

German transmission infrastructure to refineries and petrochemical plants



# Climate neutral refineries: Comparing FT and MtH for e-fuels & HVC production in Germany

## Agenda

#	TOP	Speaker
	List of contributors	
1	<b>Motivation &amp; research questions</b>	Natalia Pieton (Fraunhofer IEG)
2	<b>Methodology</b>	
	<ul style="list-style-type: none"><li>• Model chain</li><li>• Scenario definition</li><li>• Import quantities</li></ul>	
3	<b>Results</b>	
	<ul style="list-style-type: none"><li>• Technical evaluation</li><li>• Economic evaluation</li><li>• Refinery-specific analysis</li></ul>	Ramy Essam (Fraunhofer ISE) Natalia Pieton (Fraunhofer IEG)
4	<b>Conclusions and recommendations for action</b>	Ramy Essam (Fraunhofer ISE)
5	<b>Q&amp;A</b>	



**Natalia Pieton**  
*Fraunhofer IEG*



**Ramy Essam**  
*Fraunhofer ISE*

Climate neutral refineries:

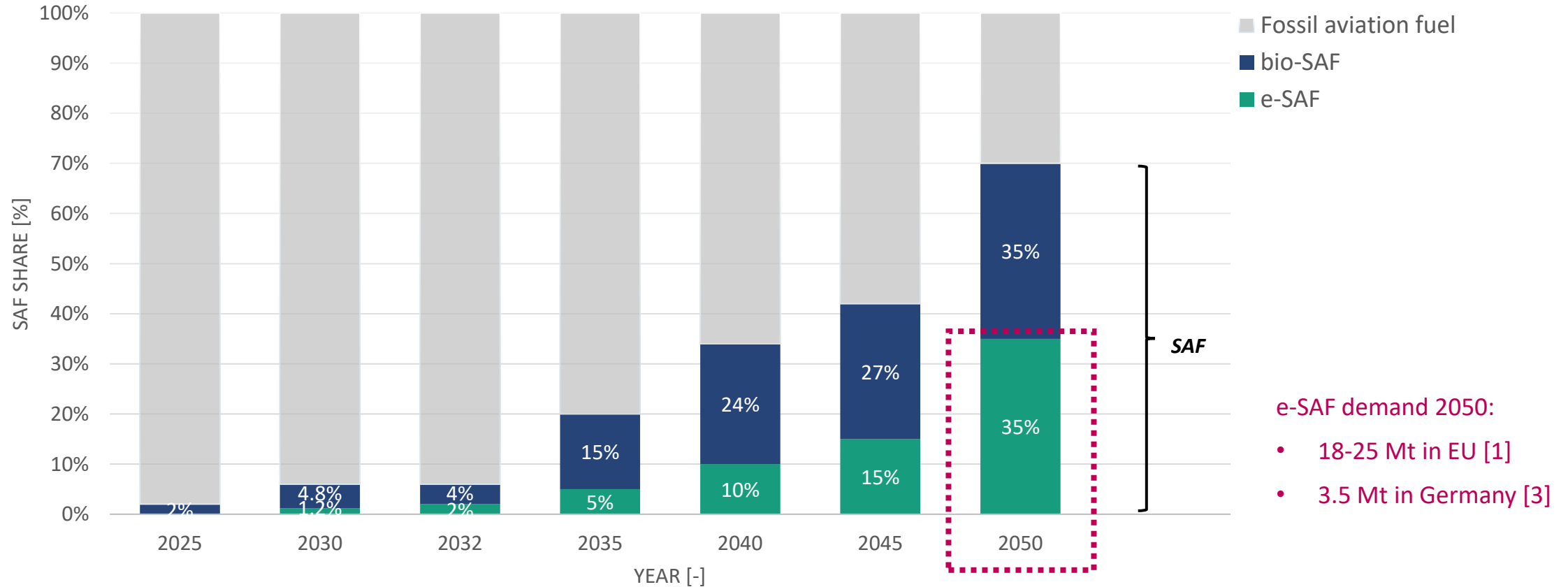
Comparing Fischer Tropsch and Methanol-to-Hydrocarbons for production of e-fuels and e-high value chemicals in Germany

# 1 Motivation

# e-SAF market in Germany reaches 3.5 Mt in 2050

## 1 Motivation

ReFuelEU Aviation (Regulation)<sup>[2]</sup>



[1]: Eurostat Database (2023)

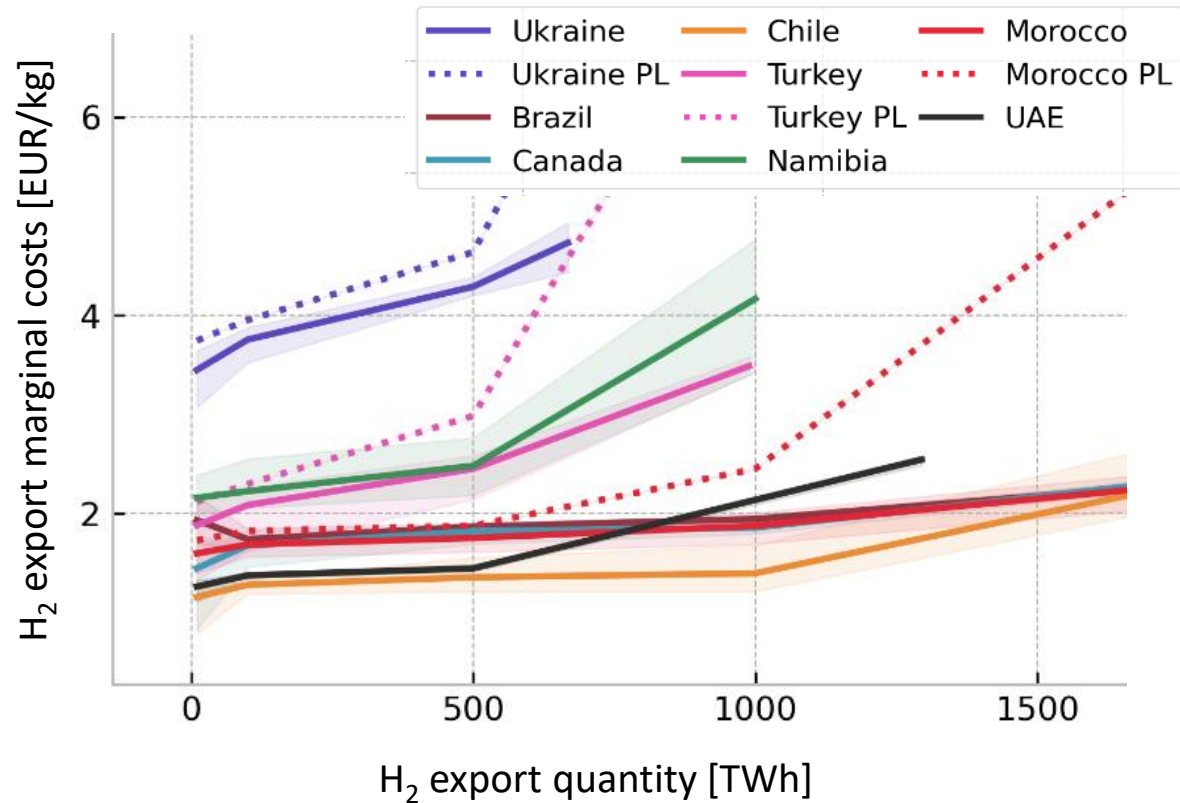
[2]: European Commission (2024)

[3]: BMWK long term scenarios (2024)

# H<sub>2</sub> costs in exporting countries: 2-4 EUR/kg in 2030 & 1-3 EUR/kg in 2050

## 1 Motivation

2050 | Medium WACC | Moderate emissions | No H<sub>2</sub> network



# Fischer Tropsch and Methanol-to-Hydrocarbons for future e-fuels production?

## 1 Research questions

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- (1) FT vs. MtH** – How do both pathways compare techno-economically for production of e-SAF?
- (2) e-SAF make own or import** – For pipeline imports from the **MENA** region, should Europe focus on green gases, liquid intermediates or e-SAF imports?
- (3) Integration of FT / MtH** – Which refineries are suitable for FT or MtH process integration? Why?

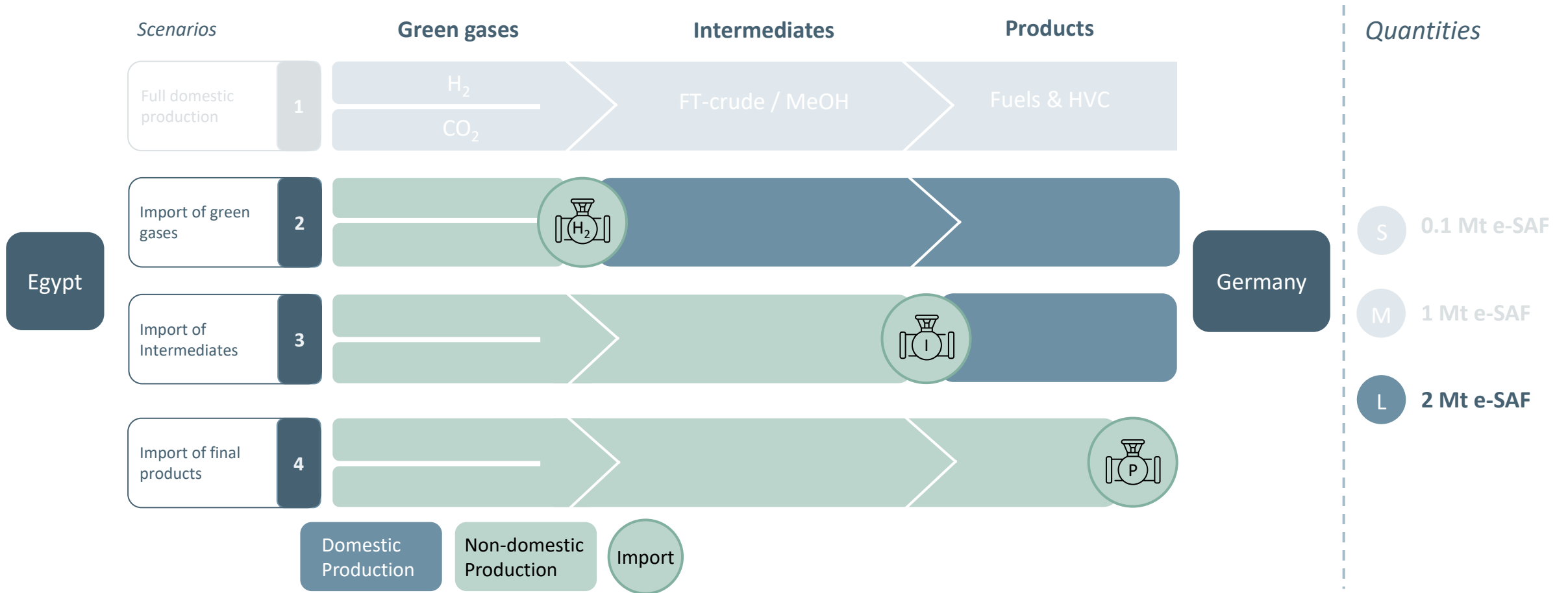
Climate neutral refineries:

Comparing Fischer Tropsch and Methanol-to-Hydrocarbons for production of e-fuels and e-high value chemicals in Germany

## 2 Methodology

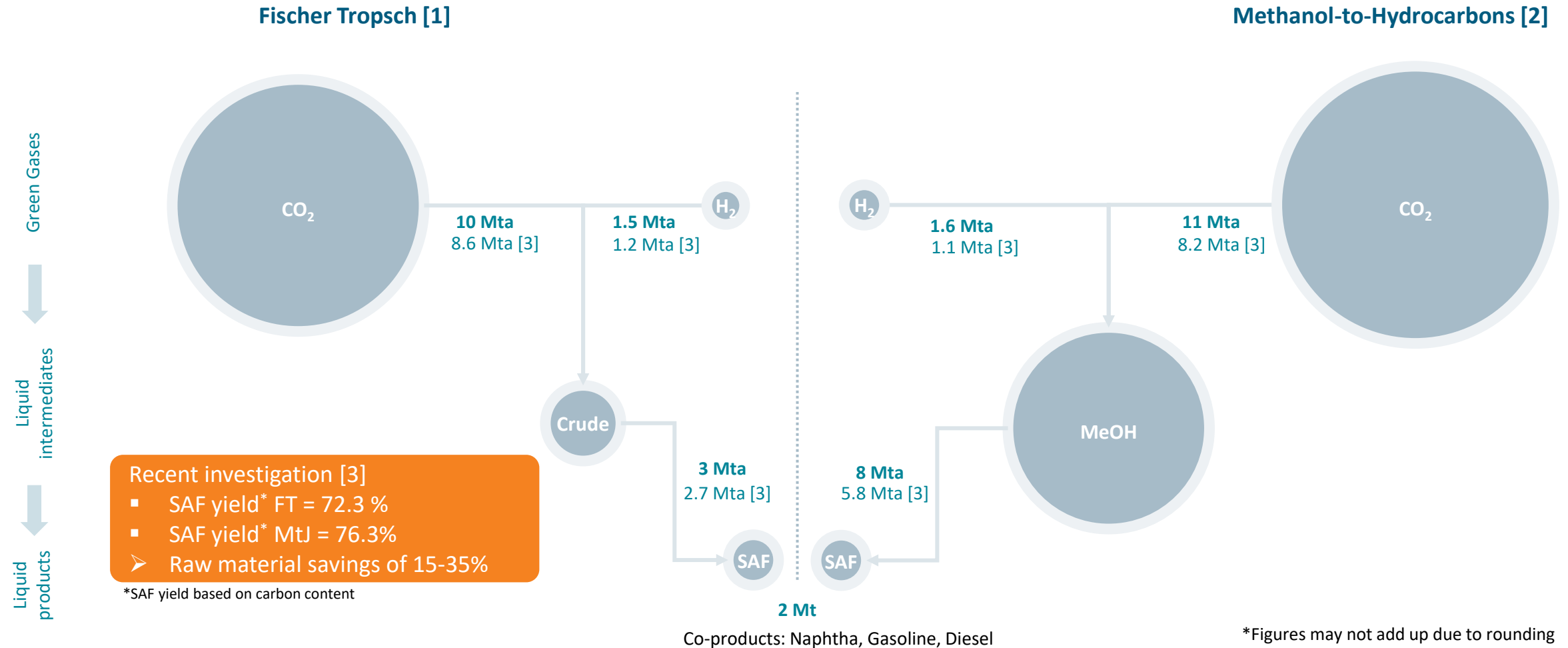
# Different import options have different value creation potential

## 2 Methodology: Scenario overview



# Higher value chain - lower quantities for transport

## 2 Methodology: Import quantities for e-SAF (production) per year



Climate neutral refineries:

Comparing Fischer Tropsch and Methanol-to-Hydrocarbons for production of e-fuels and e-high value chemicals in Germany

## 3 Results

Climate neutral refineries:

Comparing Fischer Tropsch and Methanol-to-Hydrocarbons for production of e-fuels and e-high value chemicals in Germany

# 3.1 Technical evaluation

## 3 Results & discussion

# Methanol-to-Hydrocarbons (Mth) enables a flexible product portfolio

3 Results – Synthesis steps and operation conditions of a Methanol-to-Jet fuel (MtJ) process

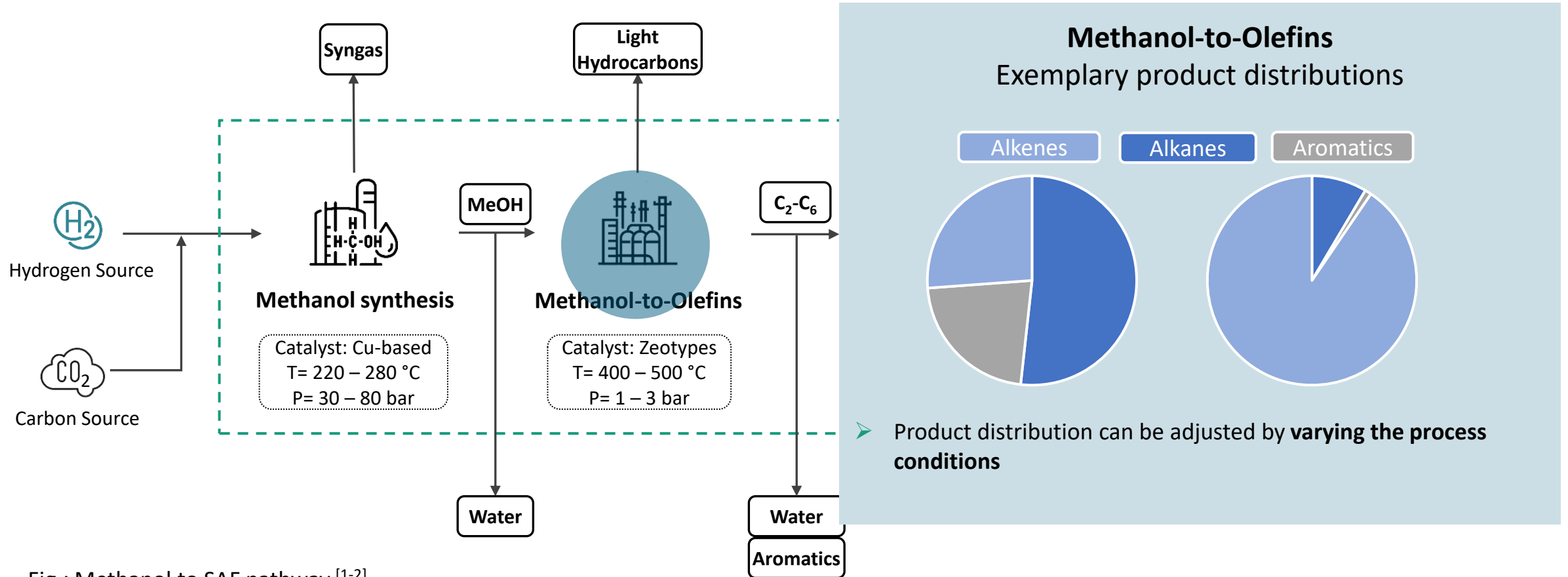


Fig.: Methanol to SAF pathway.<sup>[1-2]</sup>

[1]: A. Elwalily et al. (2024). Sustainable Aviation Fuel Production via the Methanol Pathway: A Technical Review. [Manuscript submitted for publication]. CONFIDENTIAL

[2]: J. Lopez et al. (2019).

# Methanol-to-Hydrocarbons (Mth) enables a flexible product portfolio

3 Results – Synthesis steps and operation conditions of a Methanol-to-Jet fuel (MtJ) process

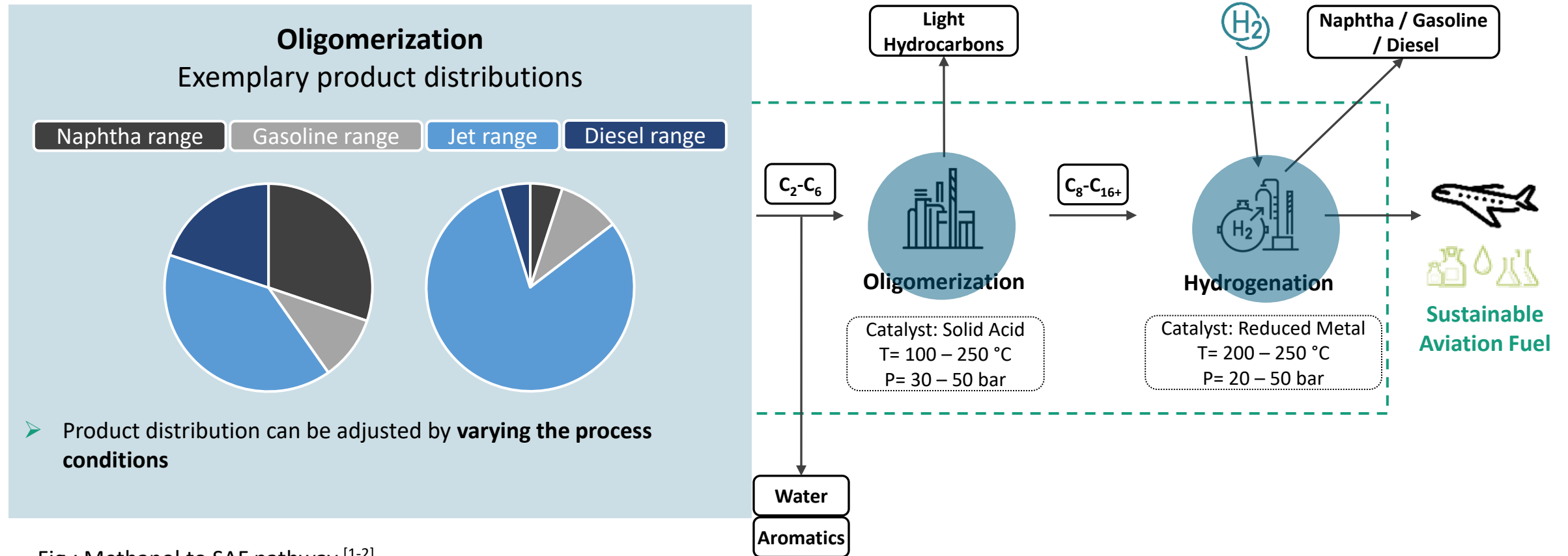


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[1]: A. Elwalily et al. (2024). Sustainable Aviation Fuel Production via the Methanol Pathway: A Technical Review. [Manuscript submitted for publication]. **CONFIDENTIAL**

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# Fischer Tropsch Synthesis enables a flexible product portfolio

## 3 Results – Synthesis steps and operation conditions of Fischer Tropsch process

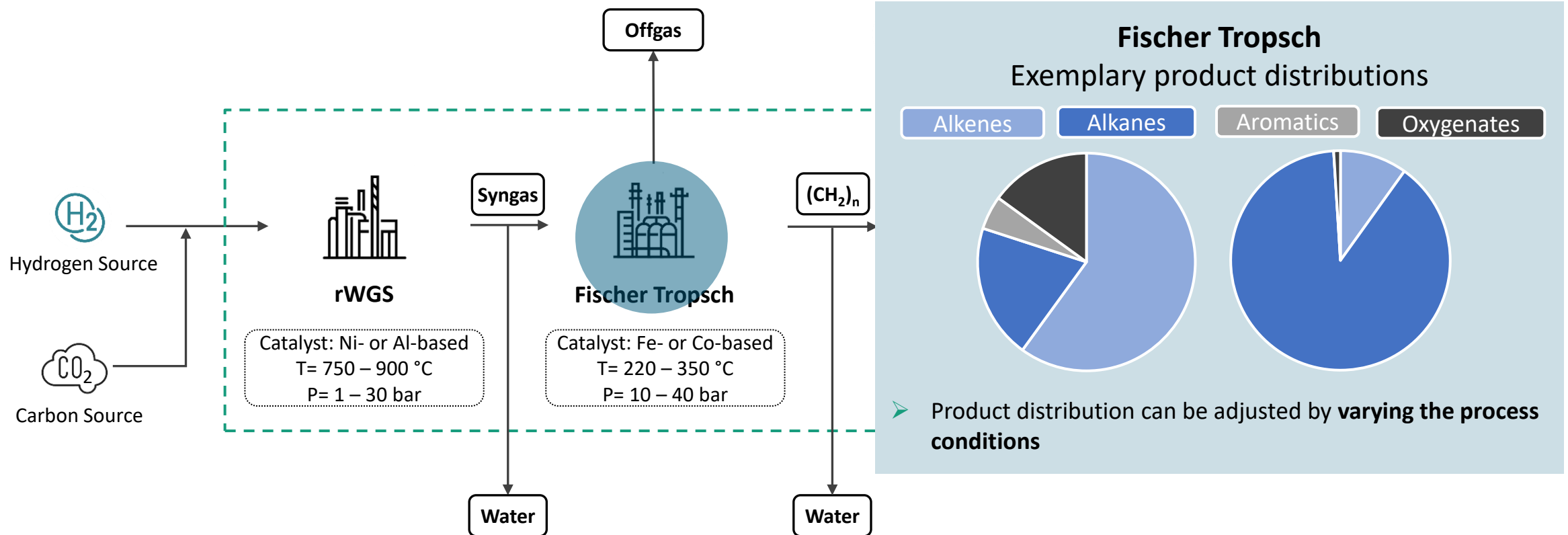


Fig.: Fischer Tropsch to SAF pathway.<sup>[1-2]</sup>

[1]: König at al. (2016).

[2]: Moodley at al. (2022).

# Fischer Tropsch Synthesis enables a flexible product portfolio

## 3 Results – Synthesis steps and operation conditions of Fischer Tropsch process

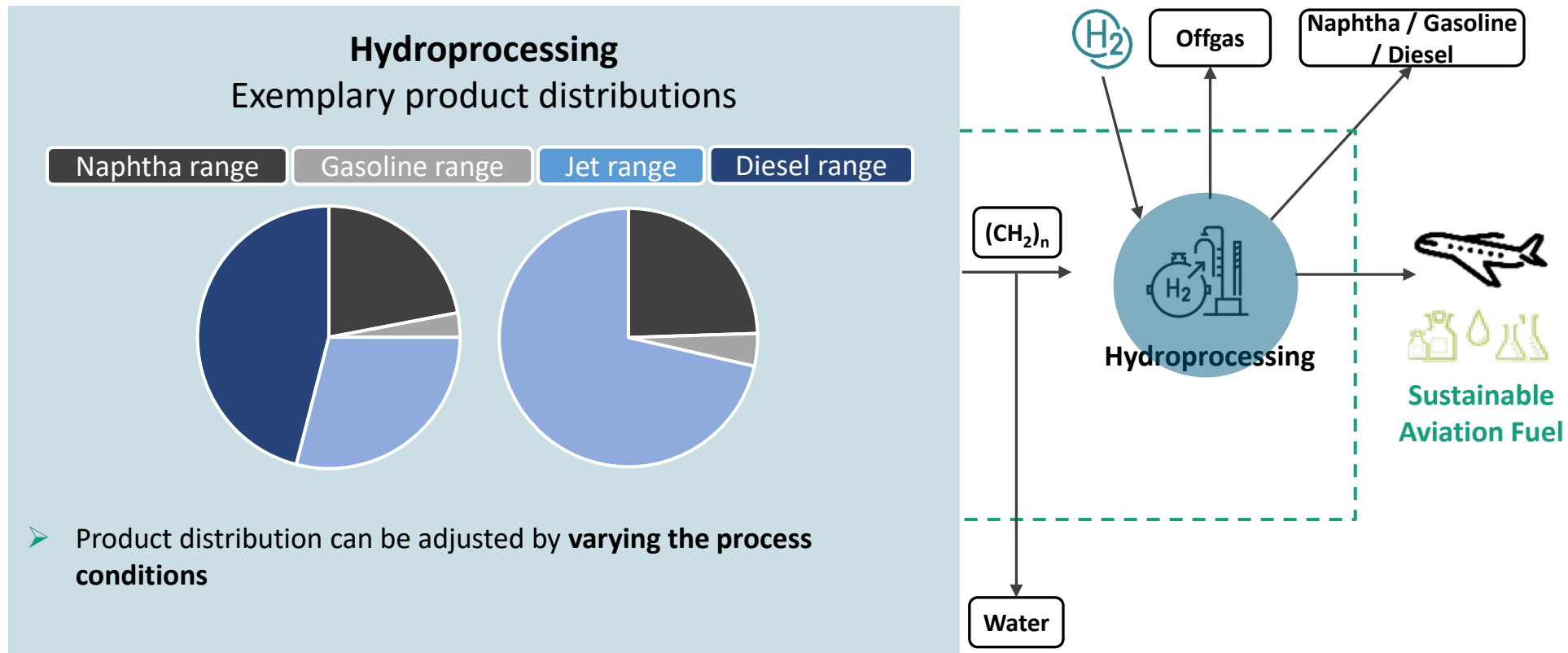


Fig.: Fischer Tropsch to SAF pathway.<sup>[1-2]</sup>

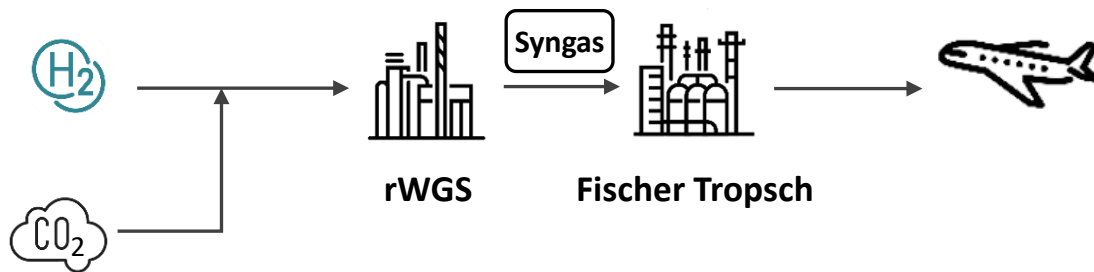
[1]: König at al. (2016).

[2]: Moodley at al. (2022).

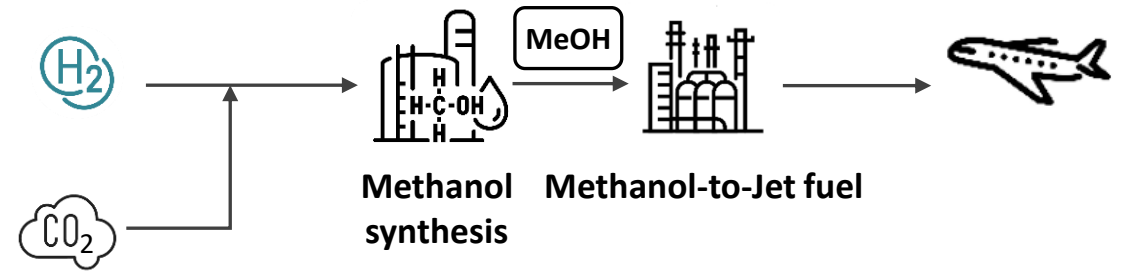
# Existing pilot plants demonstrate technical feasibility for FT and MtJ

## 3 Results – e-SAF from CO<sub>2</sub> and H<sub>2</sub>

### Fischer Tropsch Synthesis



### Methanol-to-Jet fuel



- + FT-based SAF is approved for commercial use in blends up to 50% with conventional fossil aviation fuel
- + FT-crude similar to crude oil. Simple integration into existing refinery infrastructures
- Dynamic operation at low TRL < 3 (fluctuating renewable energy)
- rWGS must be demonstrated at relevant scale

- + MeOH production can be operated dynamically
- + High SAF yield and high H<sub>2</sub>-efficiency
- + Each process step has TRL of 9 and is commercially available
- Overall process integration for optimization on SAF yield still under investigation and demonstration
- ASTM approval in process

# SAFari project for ASTM approval and demonstration of MtJ

## Sustainable Aviation Fuels based on Advanced Reactions and Process Intensification

### SAFari

- 2022-2028
- 15 Mio. € funding
- MtJ pilot plant
- ASTM approval
- Refinery integration

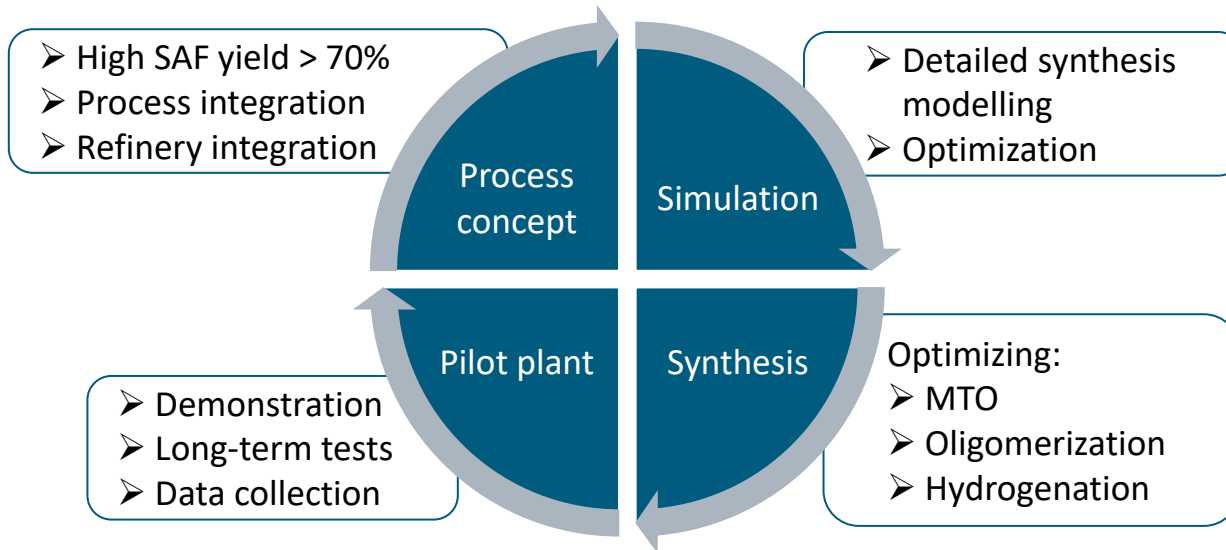
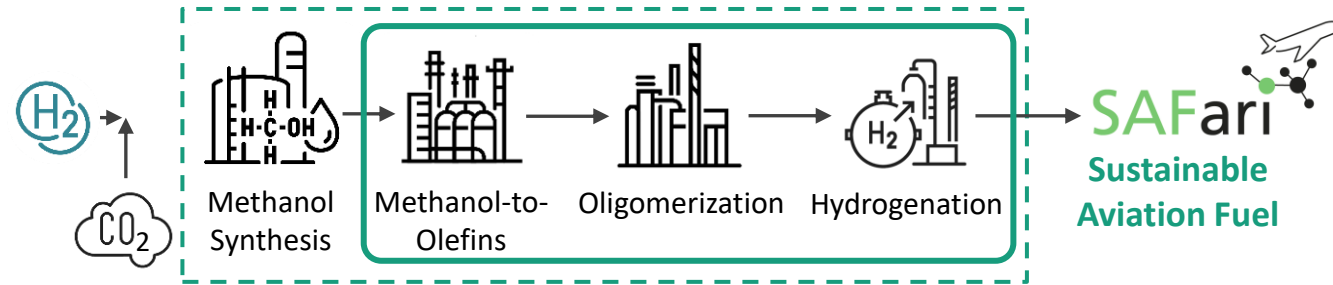


Fig.: Distillation column at ISE

Climate neutral refineries:

Comparing Fischer Tropsch and Methanol-to-Hydrocarbons for production of e-fuels and e-high value chemicals in Germany

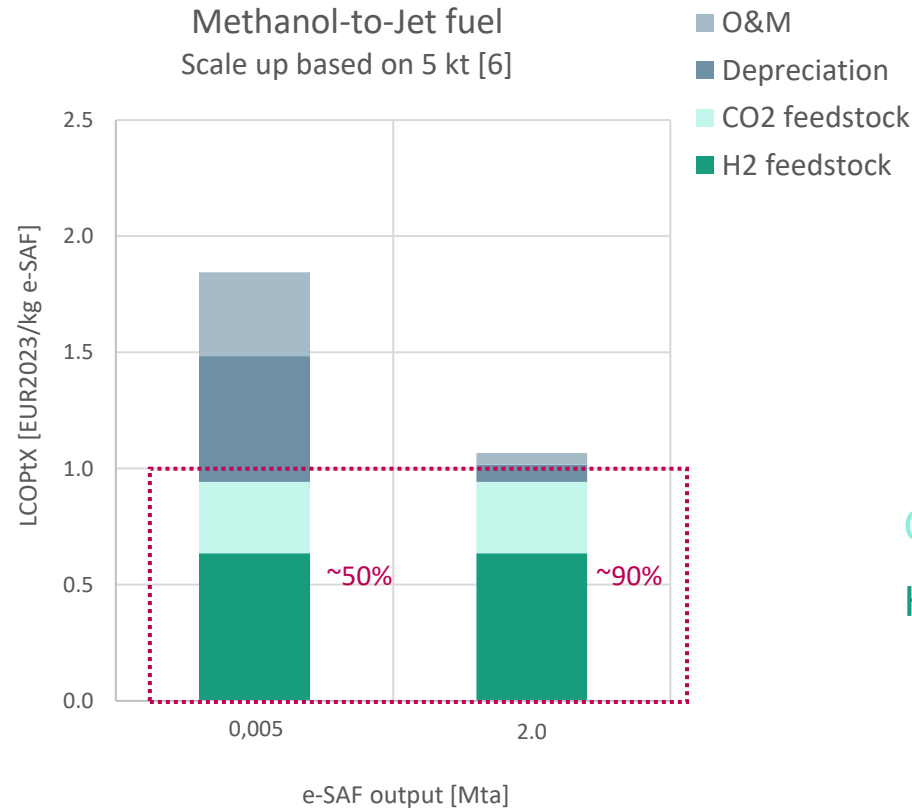
## 3.2 Economic evaluation

### 3 Results

# H<sub>2</sub> & CO<sub>2</sub> drive production costs

## 3 Preliminary results – Levelized cost of e-SAF production

DISCLAIMER: The results do not display the most recent raw material efficiencies. New model runs will be conducted.



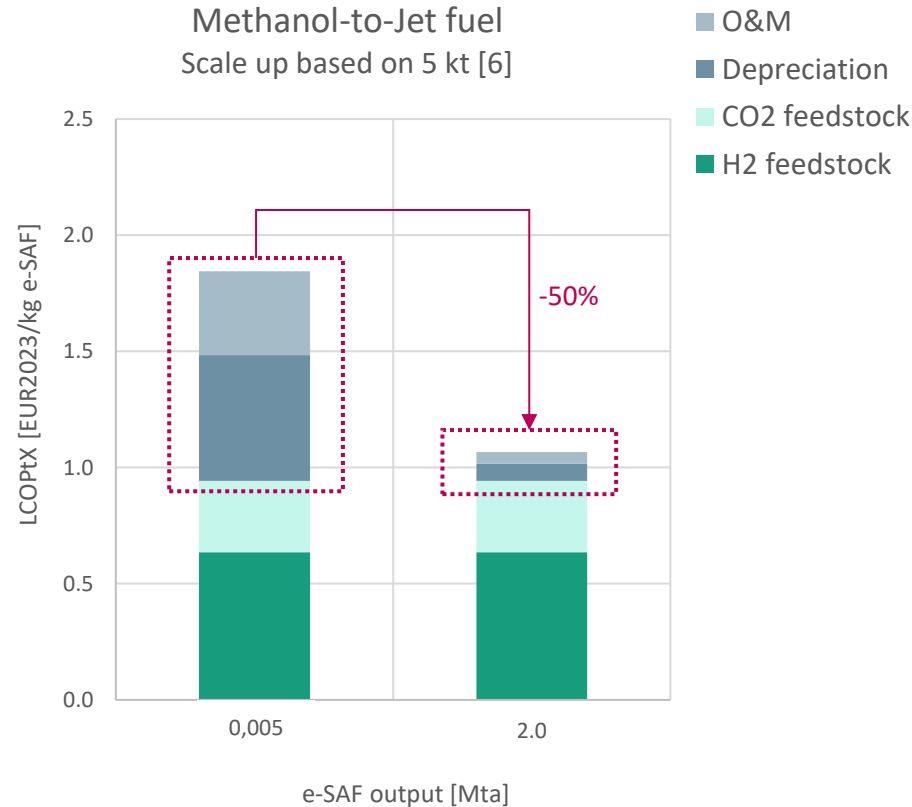
CO<sub>2</sub> (DAC) @ 0.1 EUR/kg, MENA [1]  
H<sub>2</sub> @ 1.5 EUR/kg, MENA [1]

Remarks: Labor costs, taxes, insurance, plant over head costs and general expenses (administration, R&D) are not included in this stage!; Depreciation (Total capital invest) might deviate by jet fuel share & cost estimations are not standardized – this is subject to further research. ; H<sub>2</sub>: 1.5 EUR/kg [1]; CO<sub>2</sub> (DAC): 0.1 EUR/kg [1]; WACC: 7%, Lifetime: 20 a [8]; Degression exponent: 0.67; e-SAF share: ~ 75 m% [9]; Cost allocation: By mass.

# Economies of scale reduce production costs by 50%

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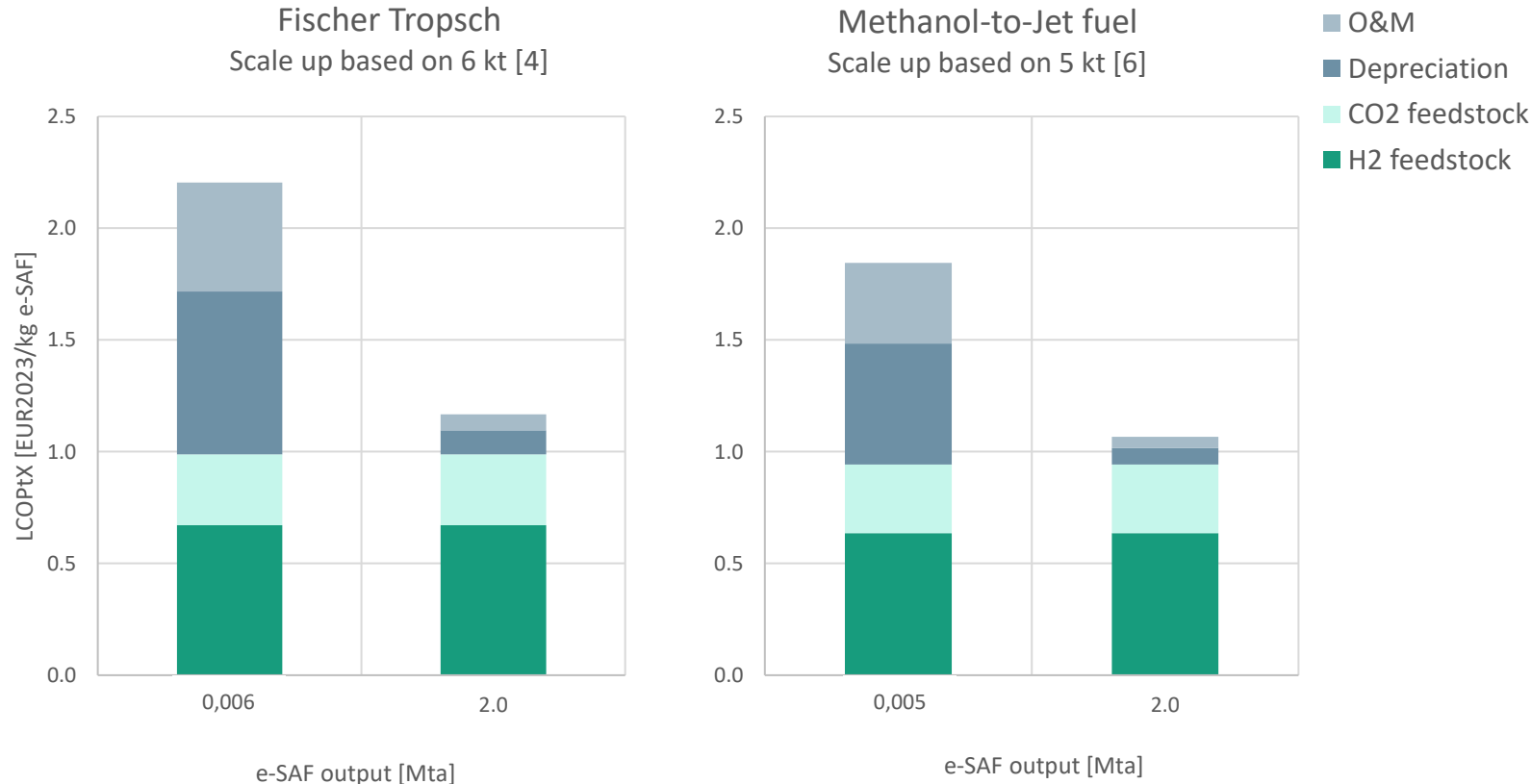
[1] Pieton et al 2024  
[2] Genge et al 2023  
[3] German Environment Agency 2016  
[4] Arndt et al 2021

[5] Ruokonen et al 2021  
[6] Niziolek et al 2015  
[7] IEA 2020  
[8] Schemme et al 2020  
[9] Bube et al 2024

# FT and MtH have similar costs for e-SAF production

## 3 Preliminary results – Levelized cost of e-SAF production

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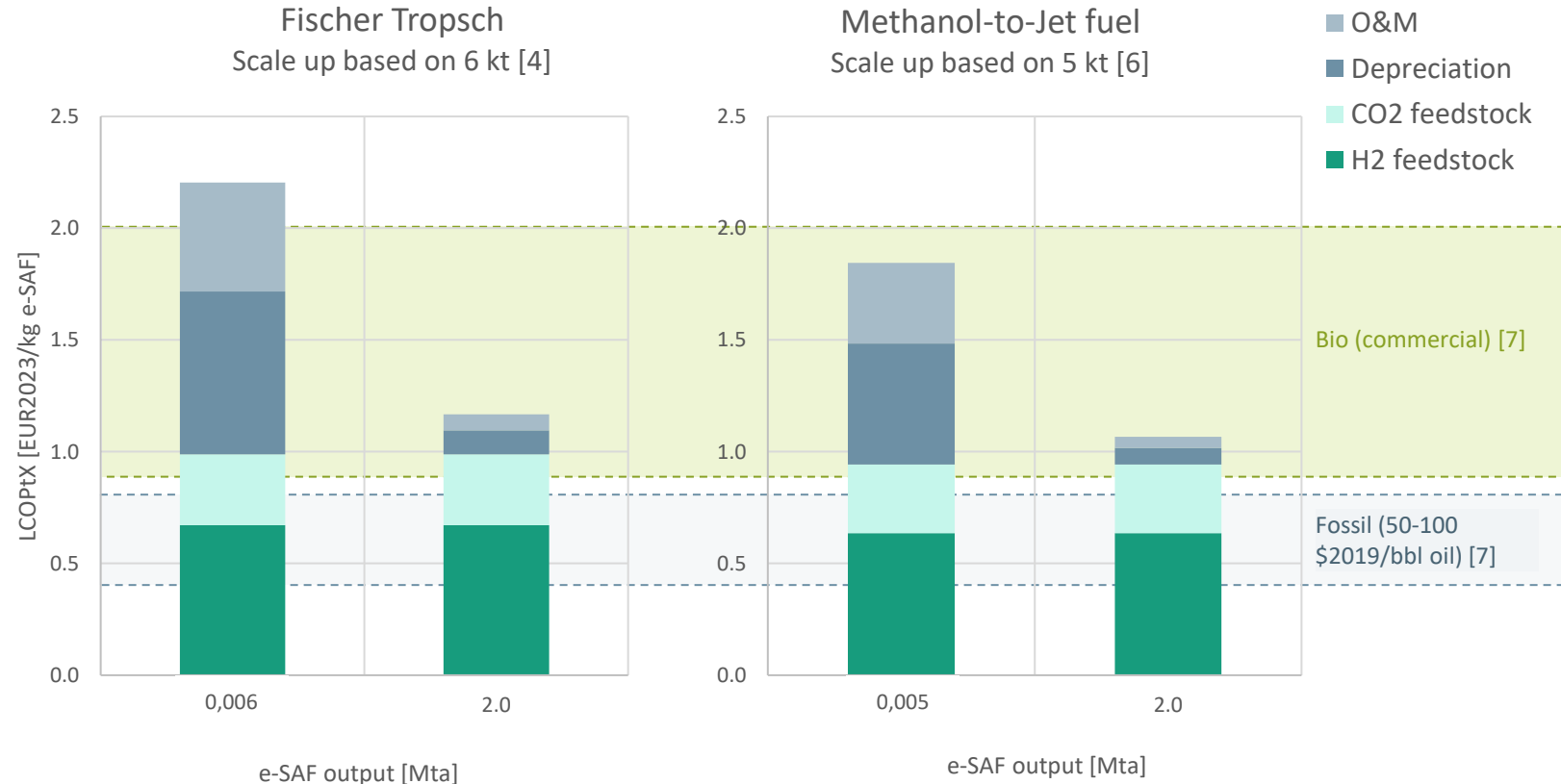
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 [9] Bube et al 2024

# Cost parity between fossil and sustainable aviation fuels?

## 3 Preliminary results – Levelized cost of e-SAF production

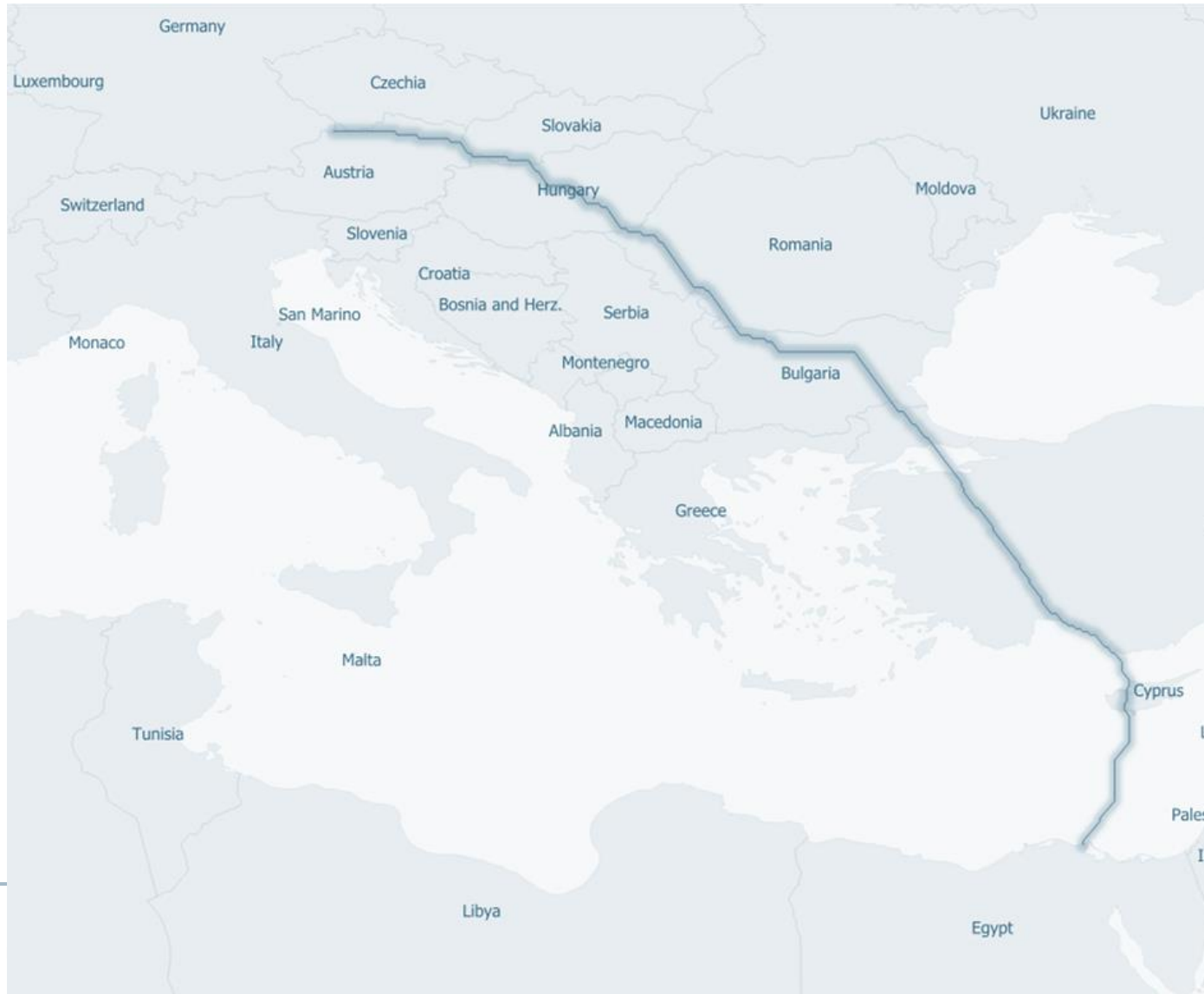


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# Pipeline avoids areas of land use, high population density and nature reservoirs

3 Preliminary results – Total supply chain costs incl pipeline imports

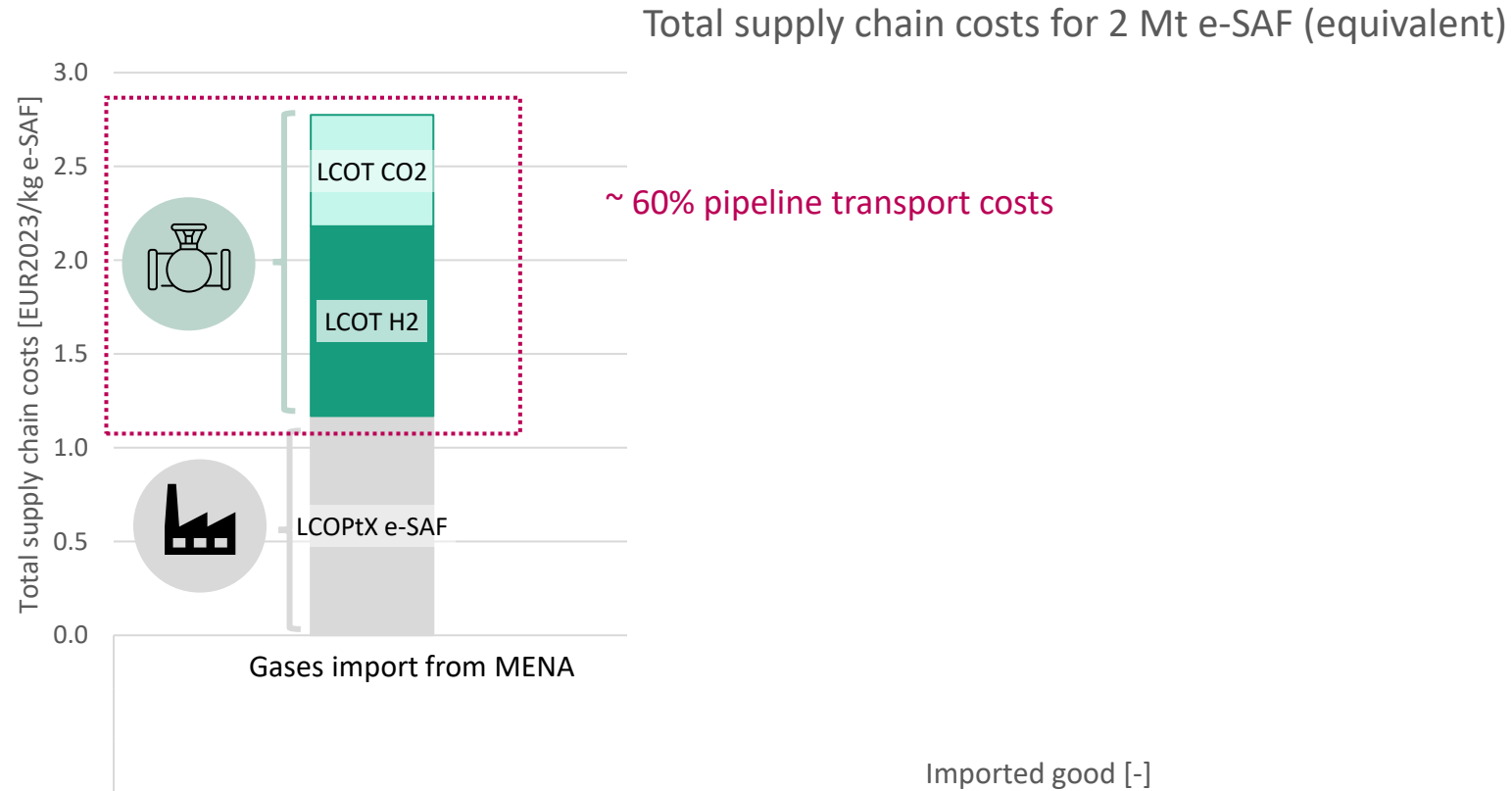


- New pipeline construction
- H<sub>2</sub> & CO<sub>2</sub> pipeline: No synergies assumed

# High import costs for H<sub>2</sub> & CO<sub>2</sub> result in high total supply chain cost

## 3 Preliminary results – Total supply chain costs incl pipeline imports

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Remarks: Labor costs, taxes, insurance, plant over head costs and general expenses (administration, R&D) are not included in this stage!; Assumptions: New pipeline construction; Green gases pipelines: No synergies assumed; Cost structure: OPEX (pumping/ compression energy, O&M), CAPEX (depreciation pipe/pump); WACC: Country-specific

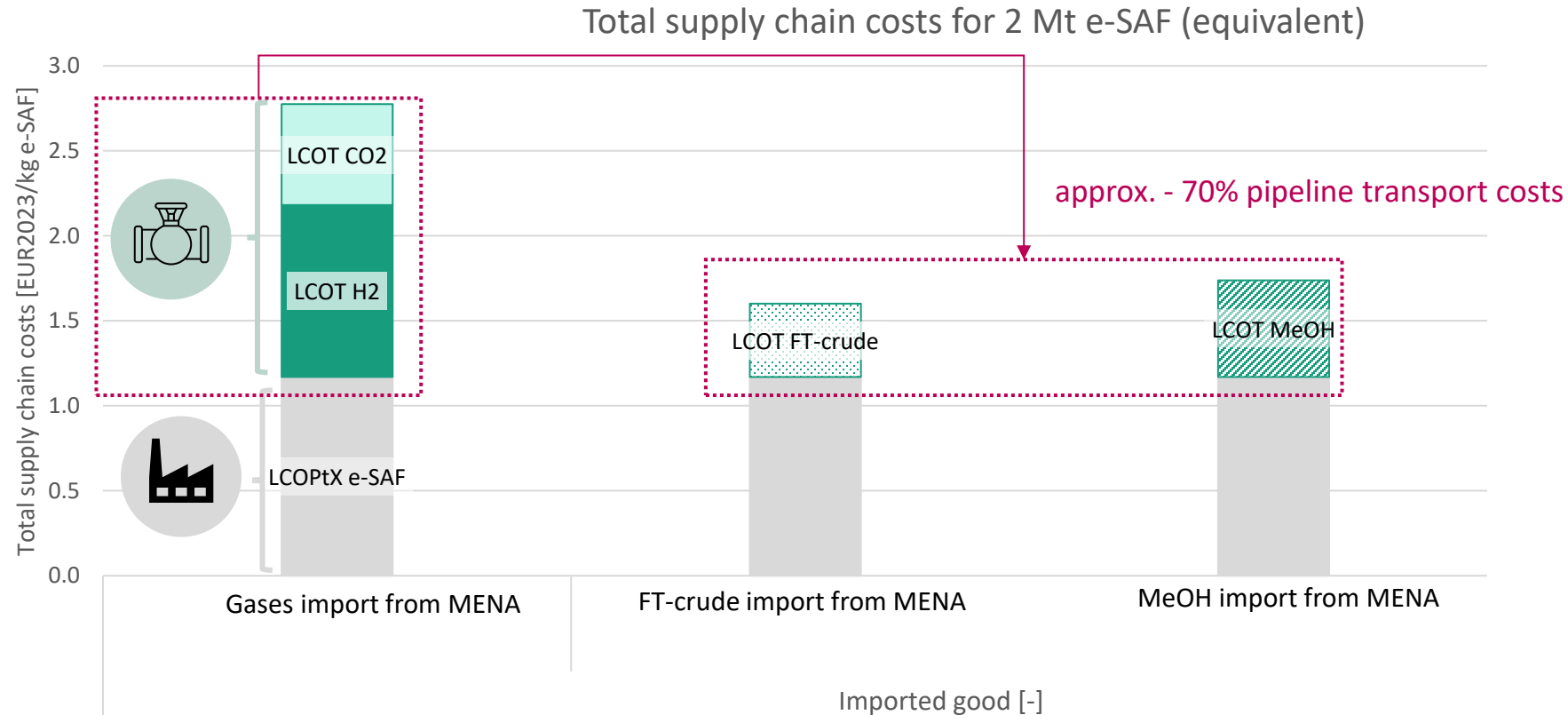
LCOT = levelized costs of transport

LCOPTx = levelized costs of PtX production

# Liquids have smaller pipeline import costs than gases

## 3 Preliminary results – Total supply chain costs incl pipeline imports

DISCLAIMER: The results do not display the most recent raw material efficiencies. New model runs will be conducted.



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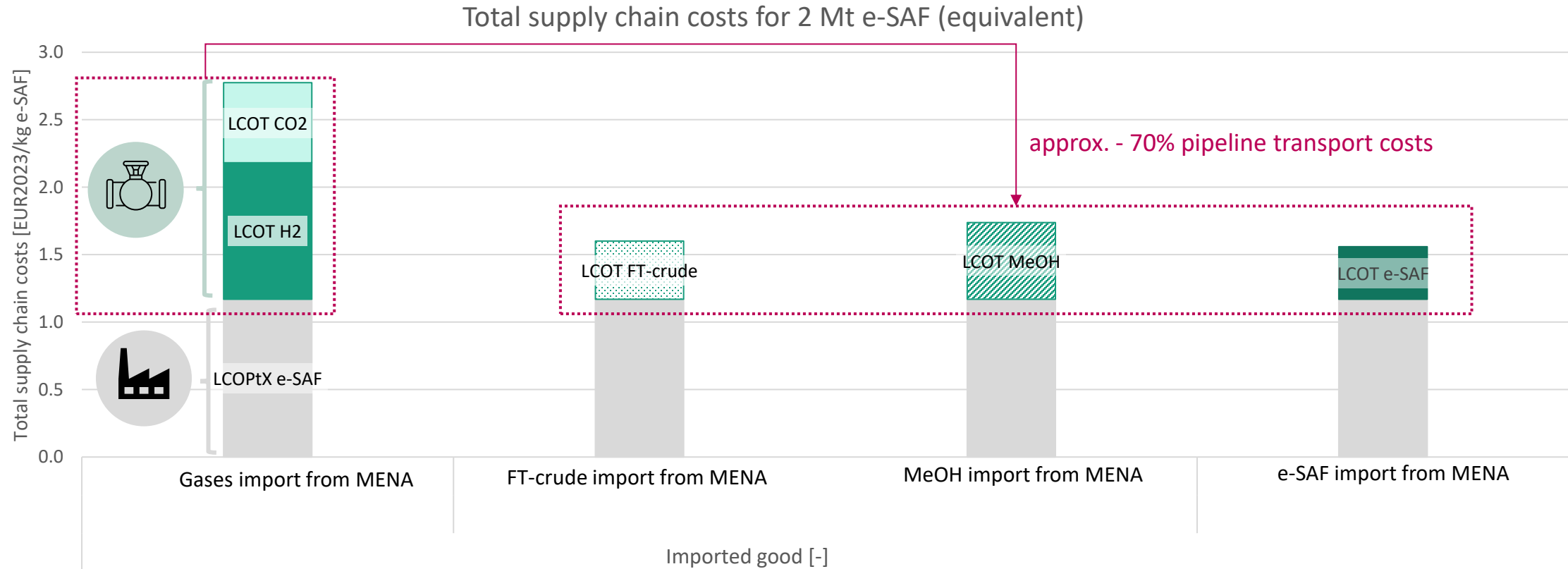
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Climate neutral refineries:

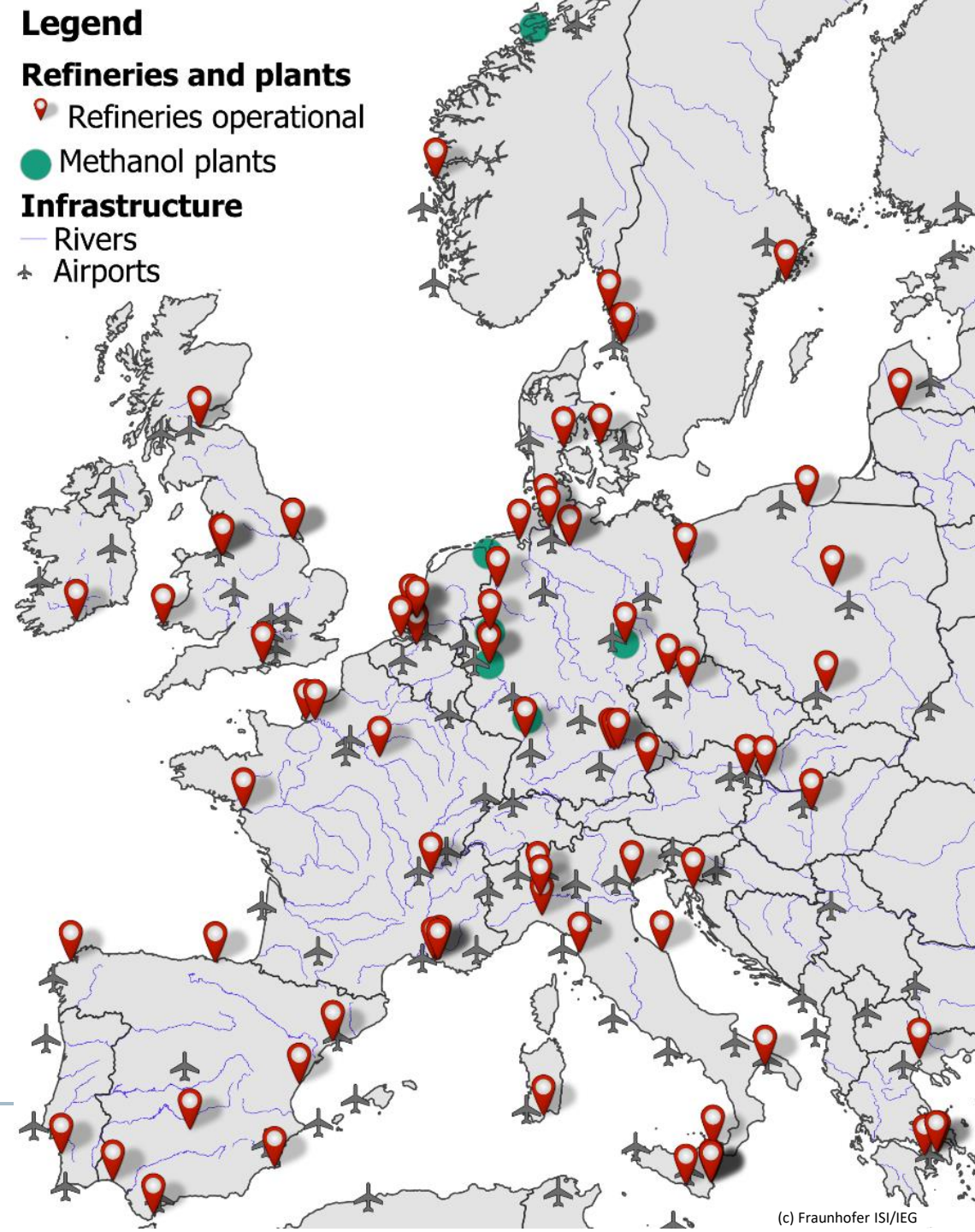
Comparing Fischer Tropsch and Methanol-to-Hydrocarbons for production of e-fuels and e-high value chemicals in Germany

## 3.3 Refinery-specific analysis

### 3 Results

# 86 fossil refineries are operational in EU 27 + 3

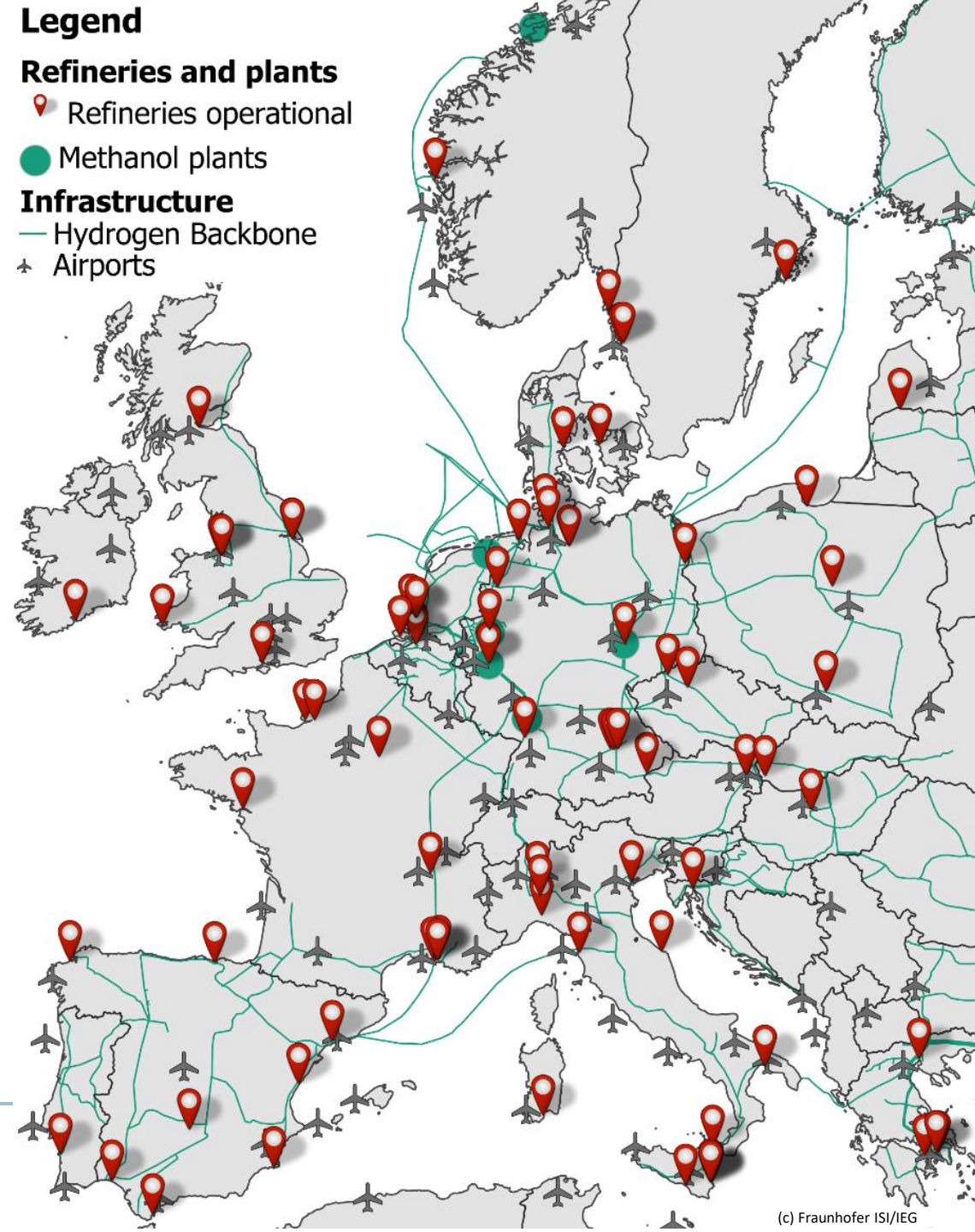
## 3 Results – Domestic feedstock transmission



[1]: [Global Energy Monitor](#) Oil Pipelines (2024)  
[2]: [European Hydrogen Backbone](#) H2 Pipelines (2024)  
[3]: [Concawe](#) Refineries (2024)  
[4]: [OpenStreetMap](#) contributors: Airports (2024)  
[5]: Plant information: Own research (2024)

# All refineries are connected to the EHB by 2030

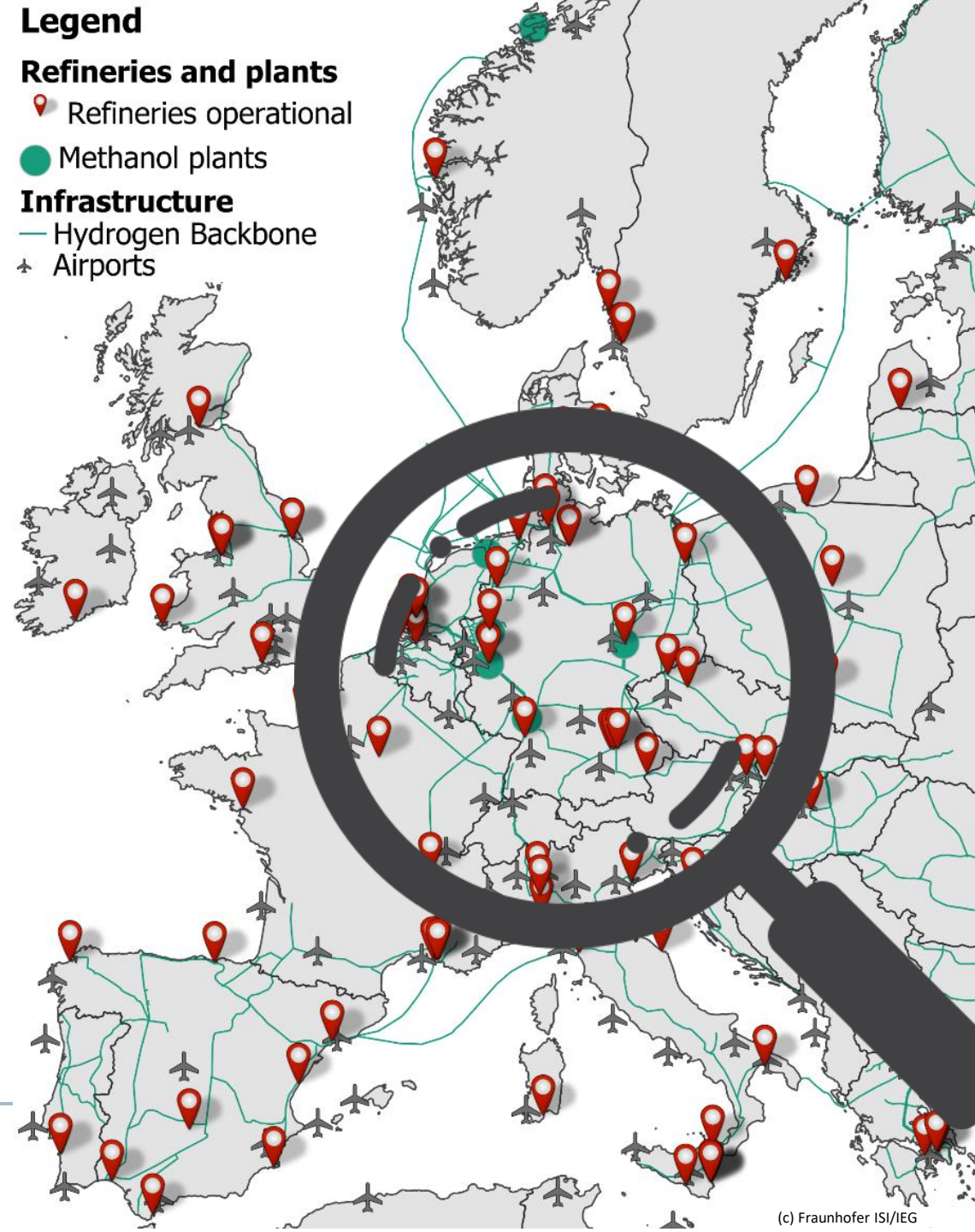
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# 4 of 6 European MeOH plants are in Germany

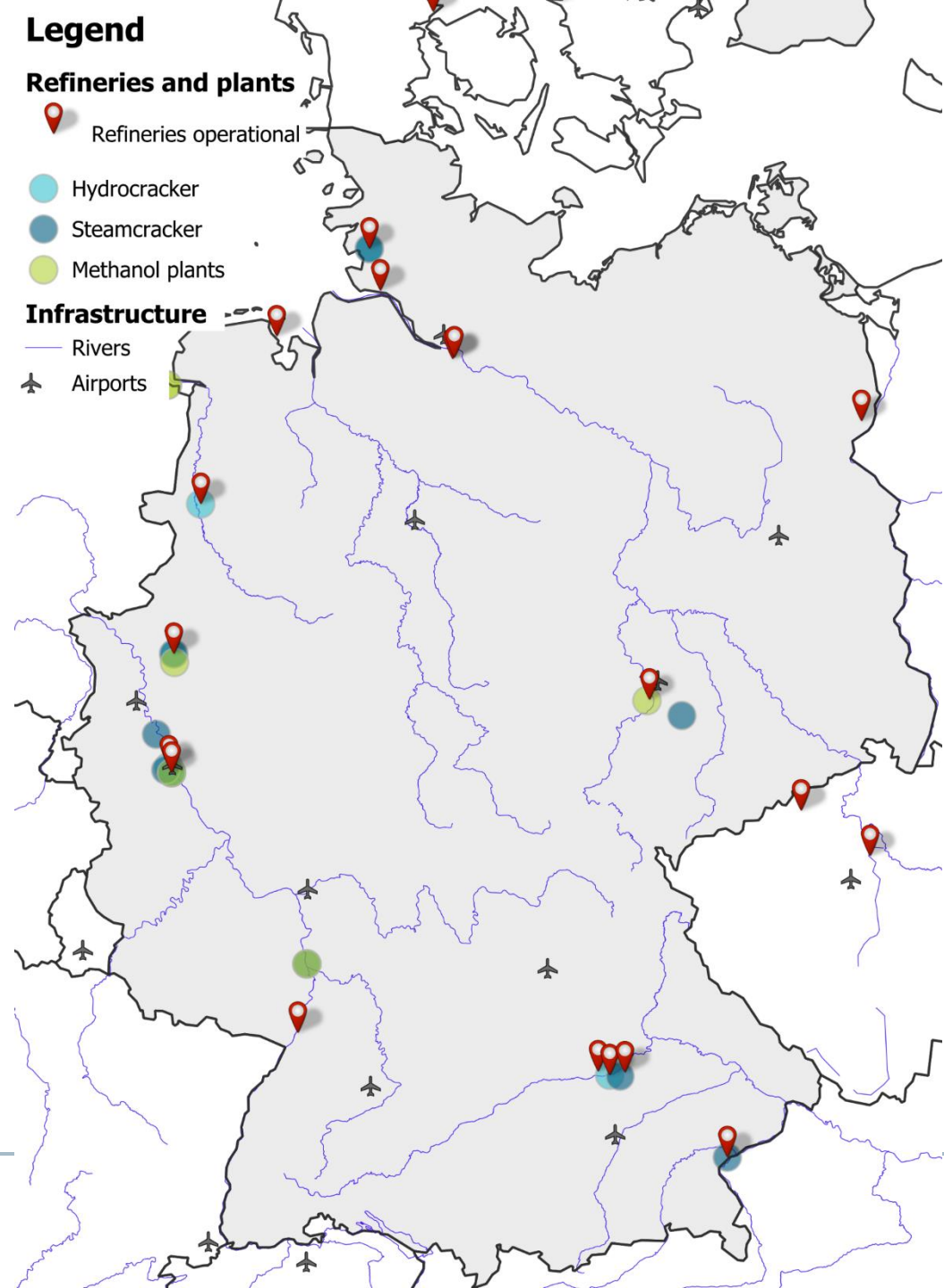
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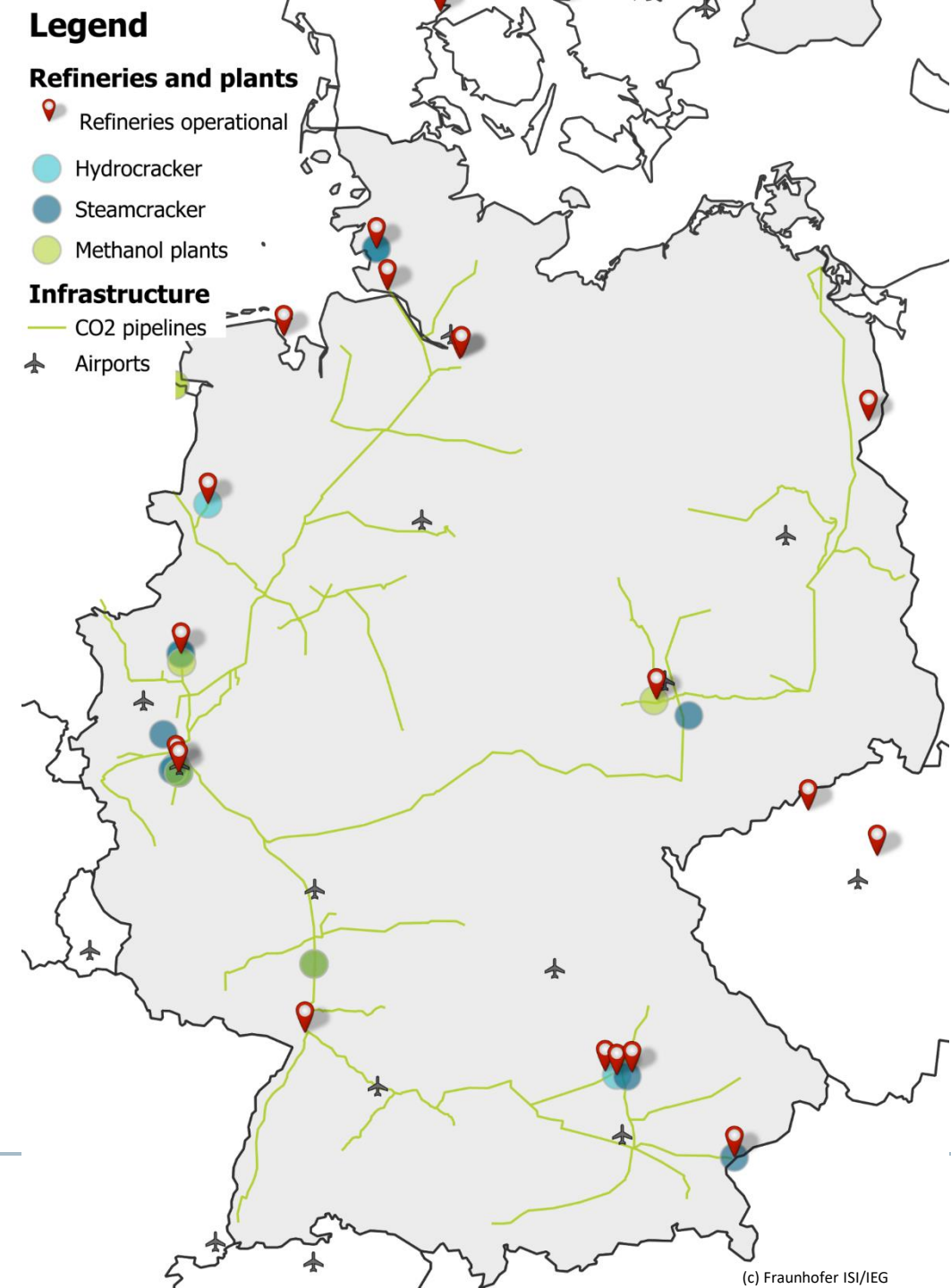
# 15 operational refineries in Germany

## 3 Results – Domestic feedstock transmission



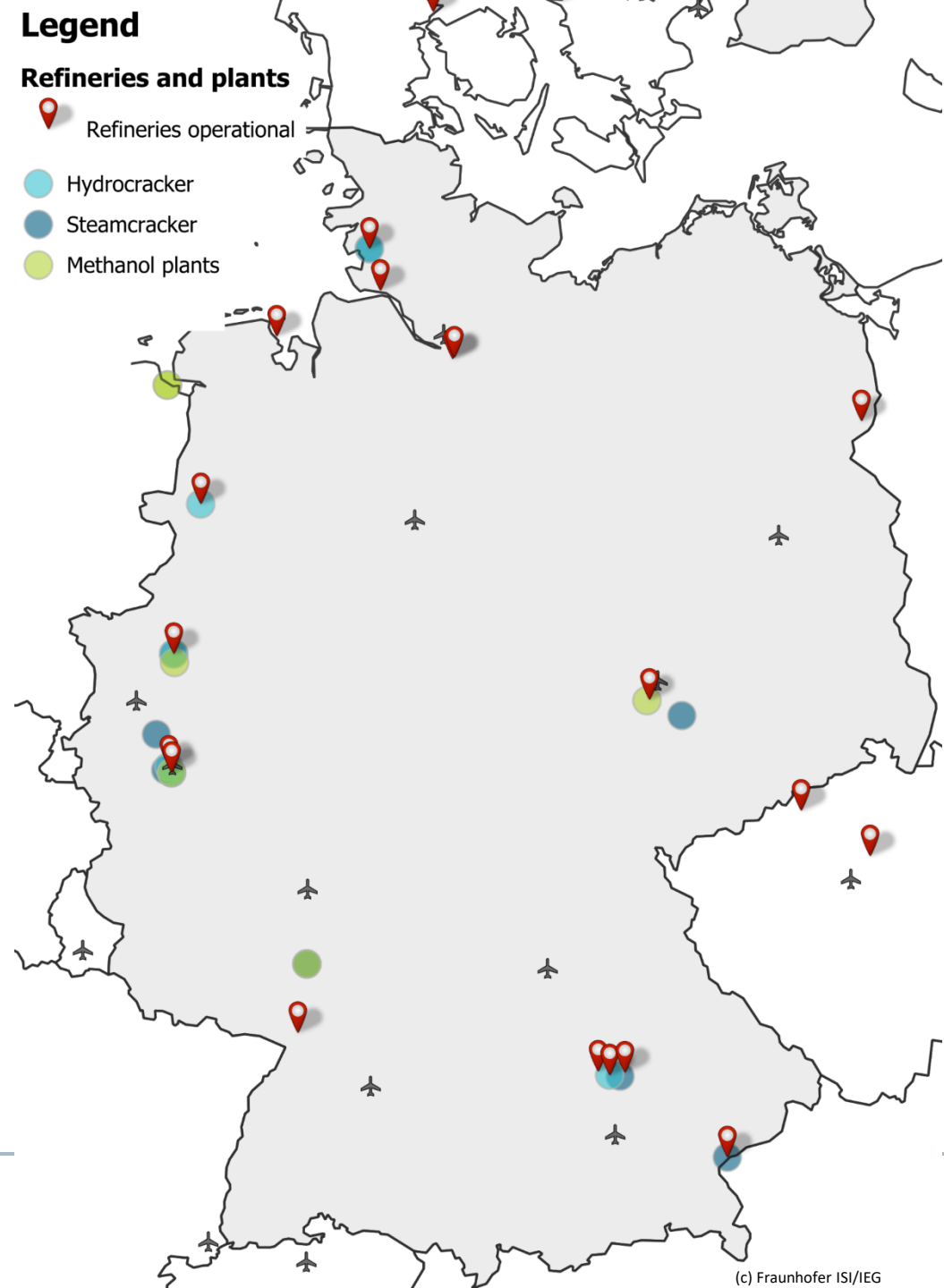
# Refineries have excellent infrastructures

## 3 Results – Domestic feedstock transmission



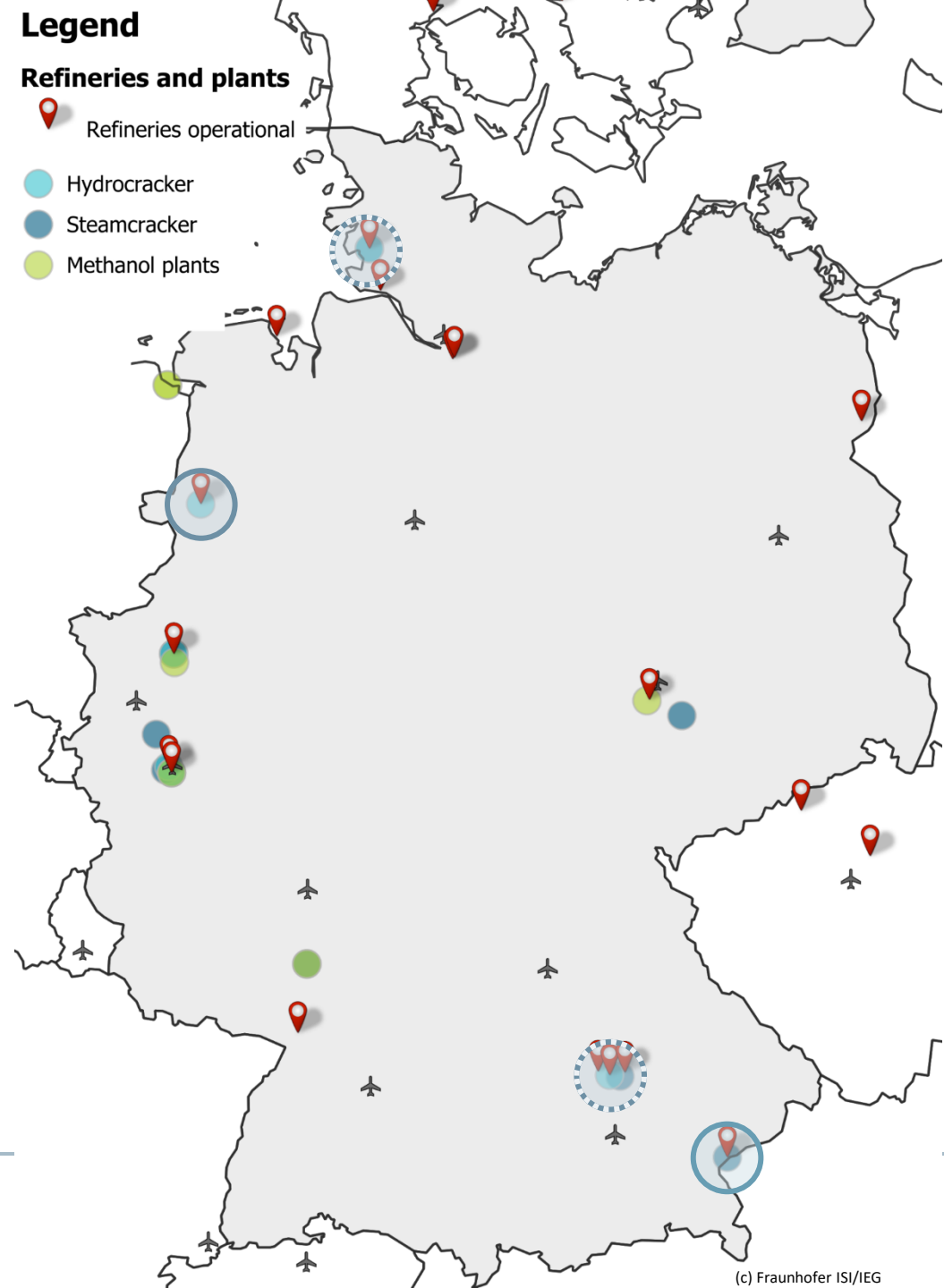
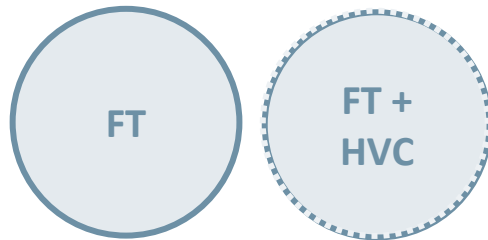
# FT or MtH?

## 3 Results – Domestic feedstock transmission



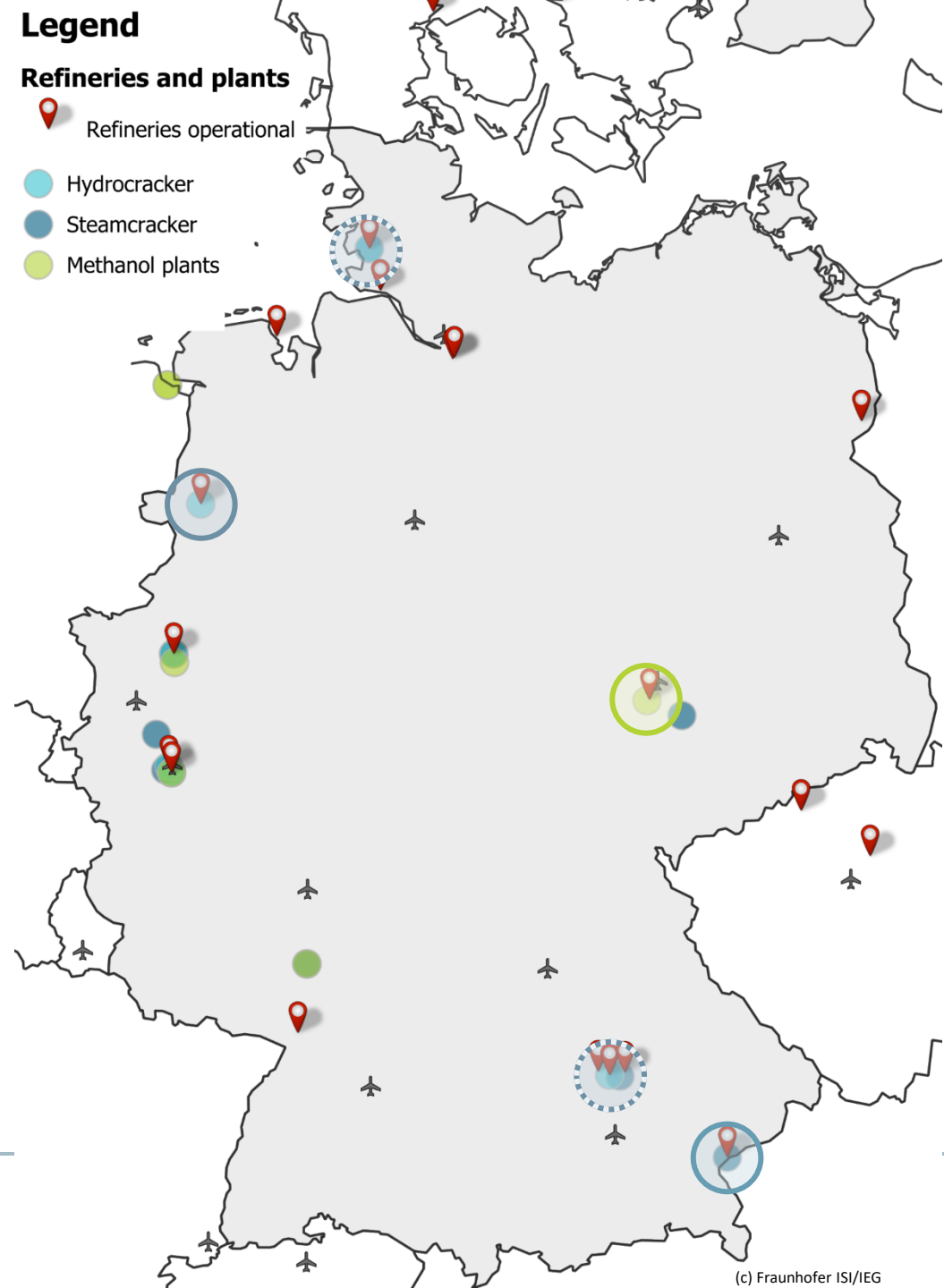
# FT - Requires hydro (+ steam) crackers

## 3 Results – Domestic feedstock transmission



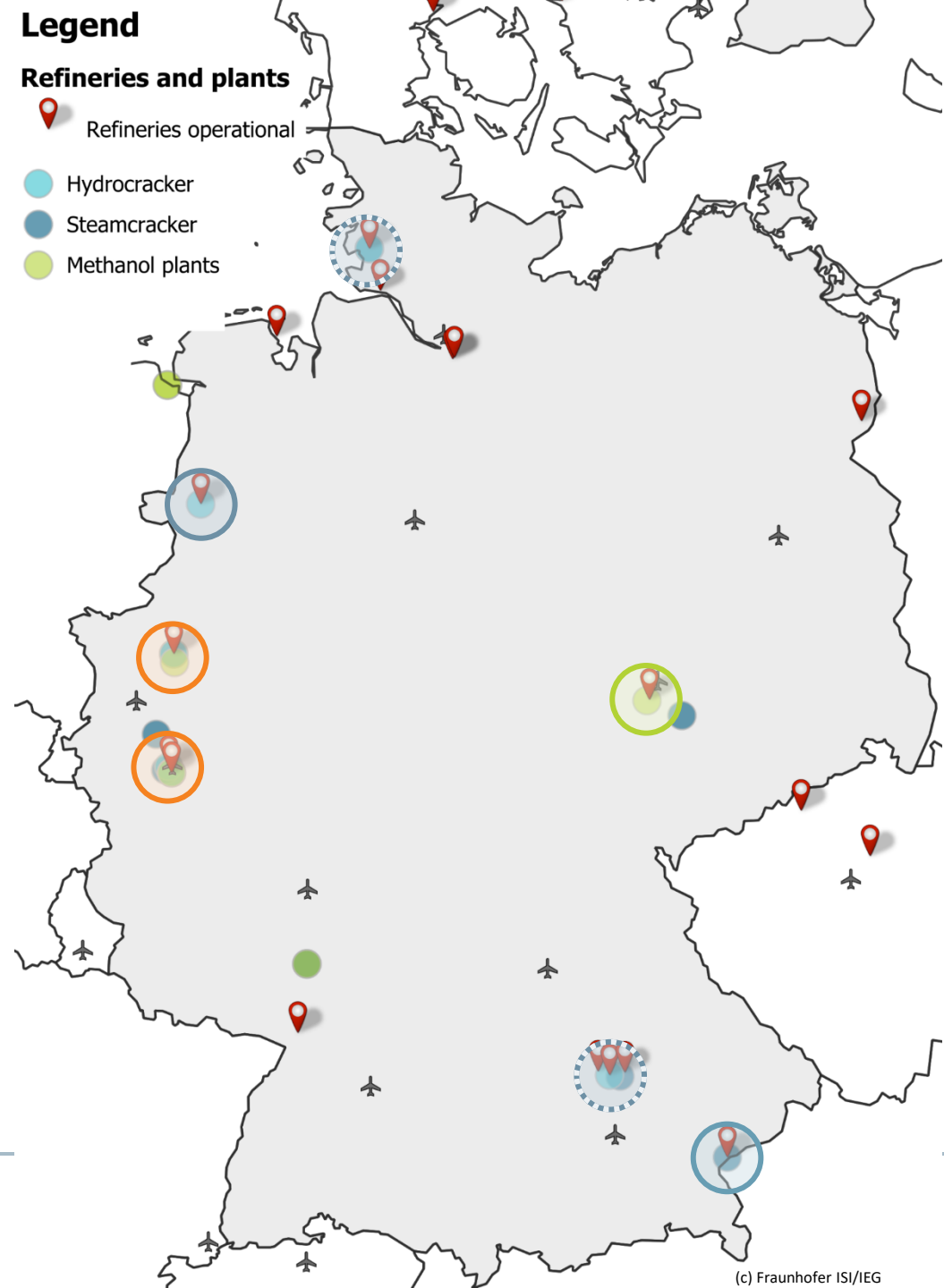
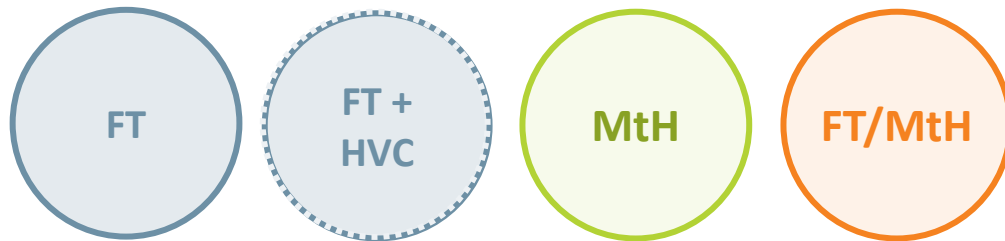
# MtH - Existing MeOH plants as starting points

## 3 Results – Domestic feedstock transmission



# Some refineries could integrate both – FT and MtH

## 3 Results – Domestic feedstock transmission



Climate neutral refineries:

Comparing Fischer Tropsch and Methanol-to-Hydrocarbons for production of e-fuels and e-high value chemicals in Germany

## 4 Conclusions and recommendations for action

# e-SAF from FT or MtH has high techno-economic potentials & more research is needed

## 4. Conclusions

1

### FT vs. MtH

How do both pathways compare techno-economically for production of e-SAF?

- Pilot plants have demonstrated high jet fuel yields and flexible product distribution
- Large-scale production costs of about 1.2 EUR/kg<sub>SAF</sub> - H<sub>2</sub> & CO<sub>2</sub> are the cost driver. **NEVERTHELESS most recent raw material efficiencies are not considered**
- Consider carbon taxes to assess cost competitiveness between e-SAF and fossil fuel

2

### e-SAF make own or import

For pipeline imports from the MENA region, should Europe focus on green gases, liquid intermediates or e-SAF imports?

The most cost-effective imports under this boundary conditions:

- Import large-scale liquid intermediates (~0.5 EUR/kg<sub>SAF</sub>) and further processing to e-SAF **NEVERTHELESS most recent raw material efficiencies are not considered**
- Or direct imports of e-SAF are

3

### Integration of FT / MtH

Which refineries are suitable for FT or MtH process integration? Why?

- FT: Refineries with hydro (+steam) crackers potentially suitable for fuels (+HVC) production
- MtH: Make use of existing MeOH plants as a starting point
- The desired product portfolio (fuels or HVC) can be a decision driver too

# Fraunhofer has the tools, data, and expertise to assess refinery transformation

## 4. Recommendations for action



H<sub>2</sub> should be produced where renewable electricity is abundant at low cost:

Thus, focus on starting the domestic value chain in Germany with *either imported Methanol or FT-crude* for e-fuels and e-HVC production.



The *ultimate scenario* will most likely be a *mix of multiple technologies*, possibly integrated in ways we have yet to fully envision.



The decarbonization journey is a challenge, and this challenge is best tackled with *partnerships & collaborations between industry & research*.



**Fraunhofer has the tools, data, and expertise** to evaluate costs and technical feasibility for refinery transformation.

We need your industrial feedback on our scientific results, to reflect it with politicians regarding **policies and regulatory frameworks**.

# Thank you for your attention

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For more information please visit



Pieton N.; Neuwirth M.; Jahn, M.; Ragwitz, M. (2022):  
Policy Paper zur Sicherstellung einer mittel- bis  
langfristigen klimaneutralen Rohstoffversorgung der  
Raffinerie Schwedt.



SAFARI: Sustainable Aviation Fuels based on Advanced  
Reactions and Process Intensification



Neuwirth M.; Fleiter T.; Hofmann R. (2024): Modelling  
the market diffusion of hydrogen-based steel and  
basic chemical production in Europe – A site-specific  
approach

# Kontakt

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# 5 Q&A

# ANNEX

# List of references

## A - H

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# SAFari project for ASTM approval and demonstration of MtJ Sustainable Aviation Fuels based on Advanced Reactions and Process Intensification



- MtJ Pilot plant for process demonstration and production
- **Full MtJ ASTM approval** with potentially **> 50% SAF**

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