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Distributed e-fuel hubs: Concept and case study

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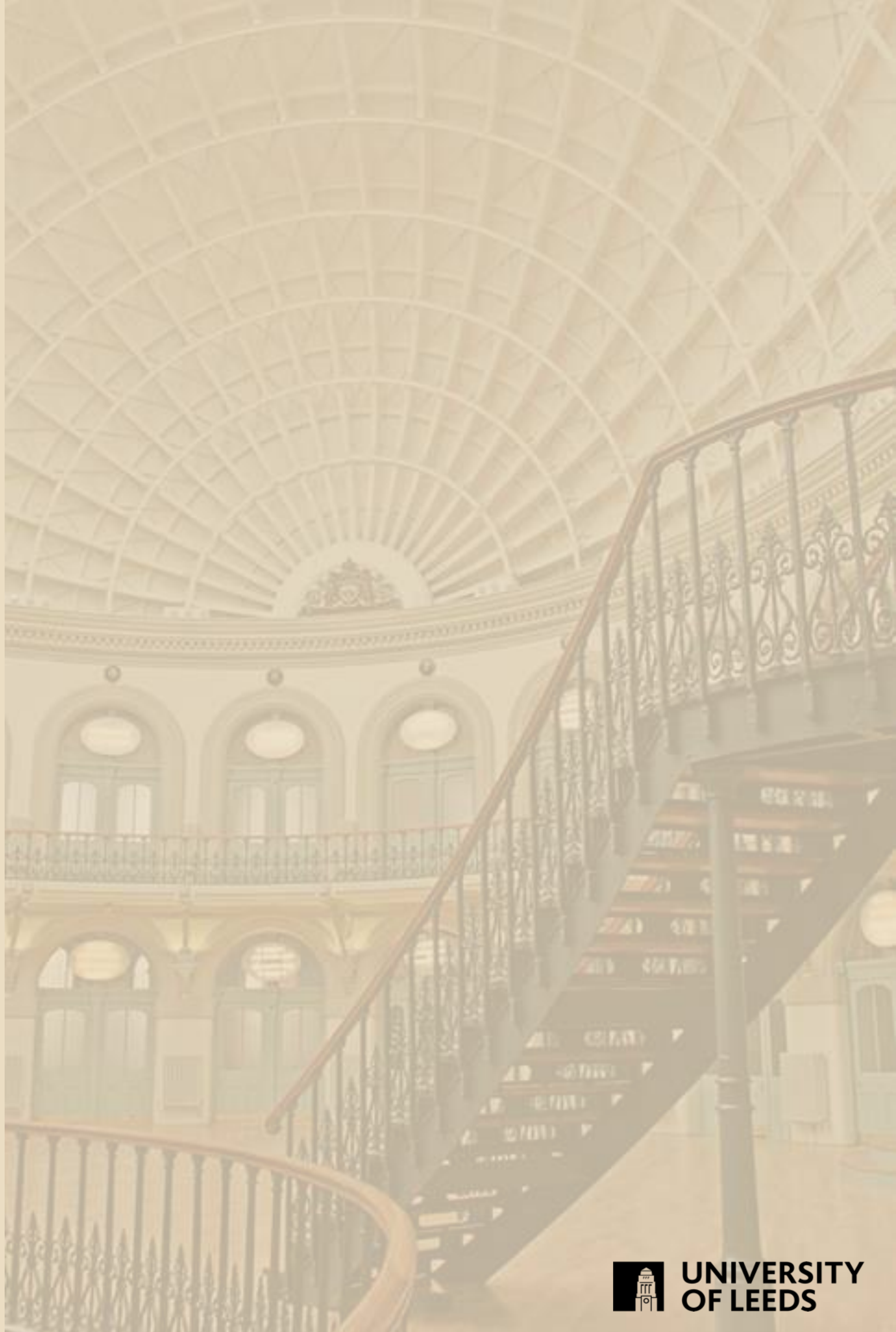
Samy Mokeddem, Bardhyl Miftari, Victor Dachet, Guillaume Derval, Damien Ernst

Smart Grids Lab, University of Liège, Belgium



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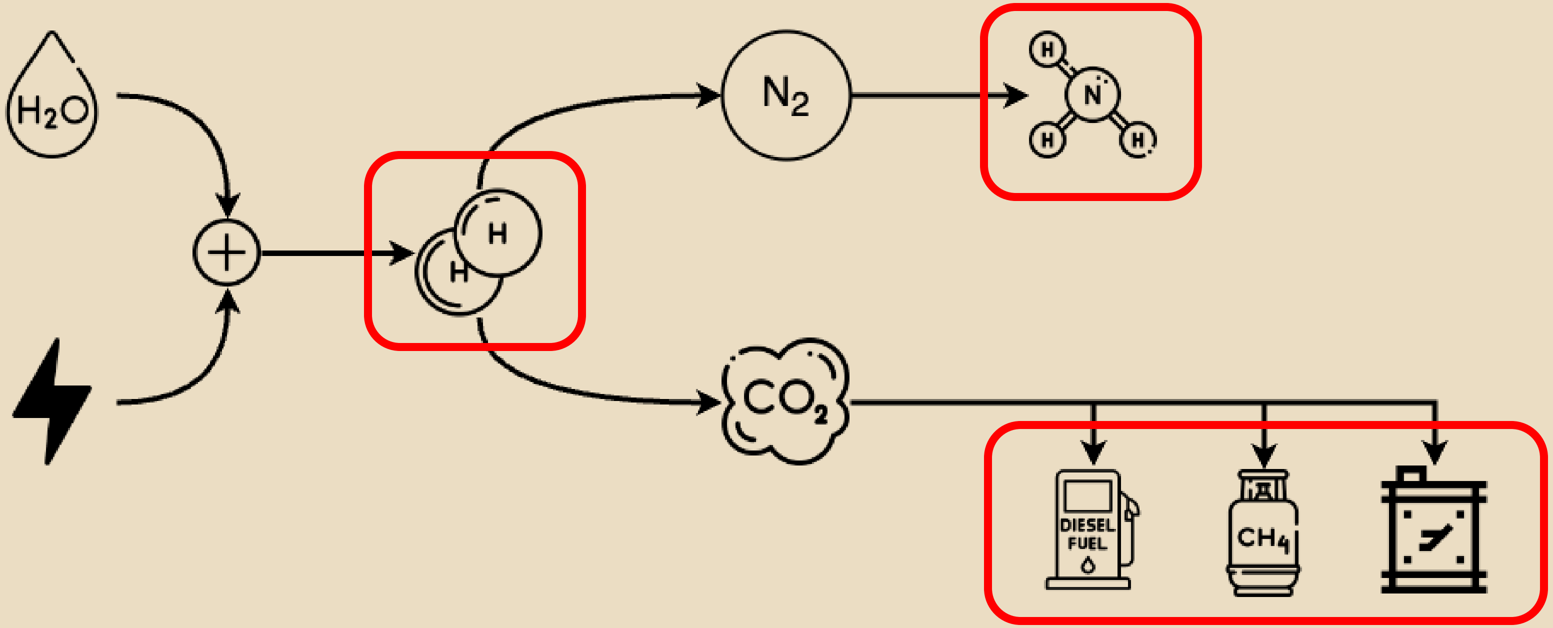
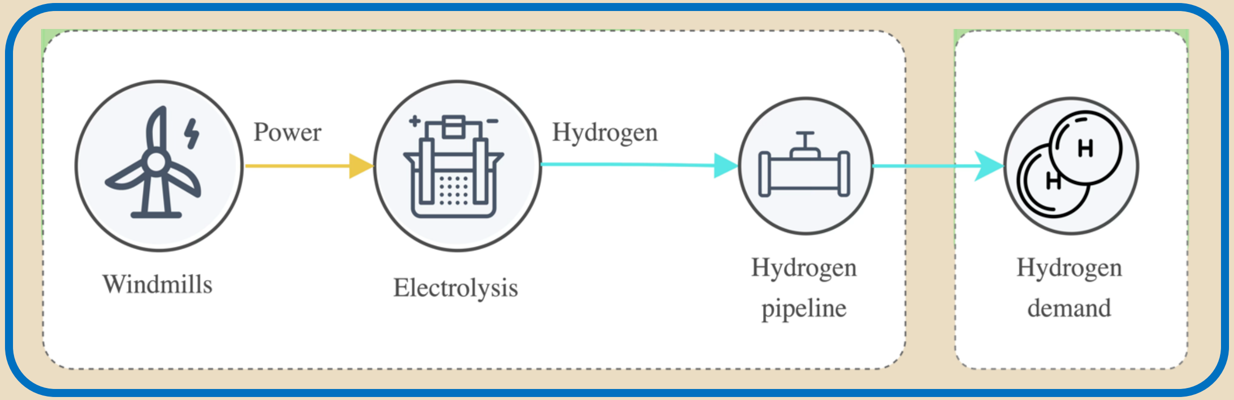
What is an e-fuel Hub?





Why we want to produce e-fuels?

There are challenges to decarbonizing all sectors

Many industrial processes need high-temperature heat.

High-temperature heat is difficult to obtain without combustion of fossil fuels.

E-fuels can be a solution

E-fuels can replace fossil fuels in these processes.

Why e-fuels?

There are challenges to decarbonizing all sectors

Some production processes release CO2 as by-products (e.g. cement production).

Planes, long-haul trucks, and ships need fuels for their high density energy storage requirement.

E-fuels can be a solution

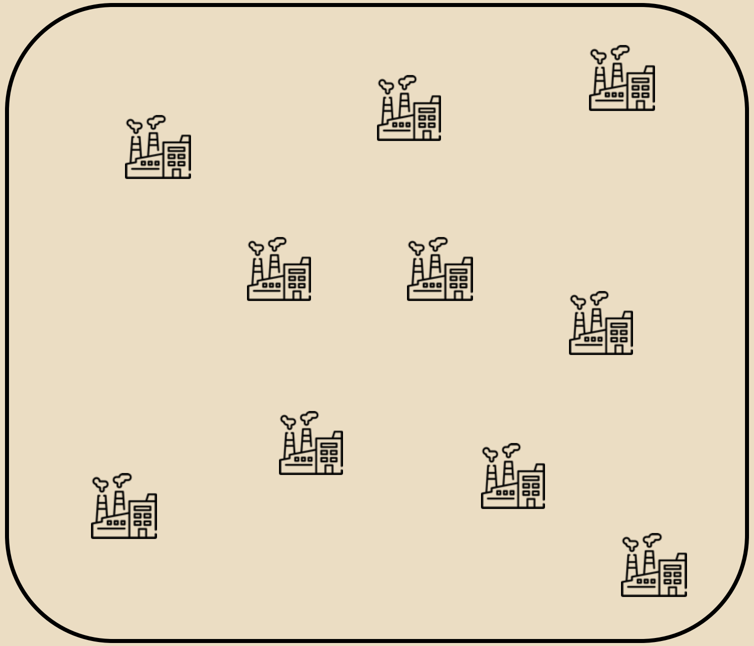
One simple solution is to convert the CO2-rich flue gases emitted by the industries that inevitably produce it as a by-product into e-fuels.

These e-fuels can then be used by sectors that require high-density energy storage.

What do we mean by distributed?

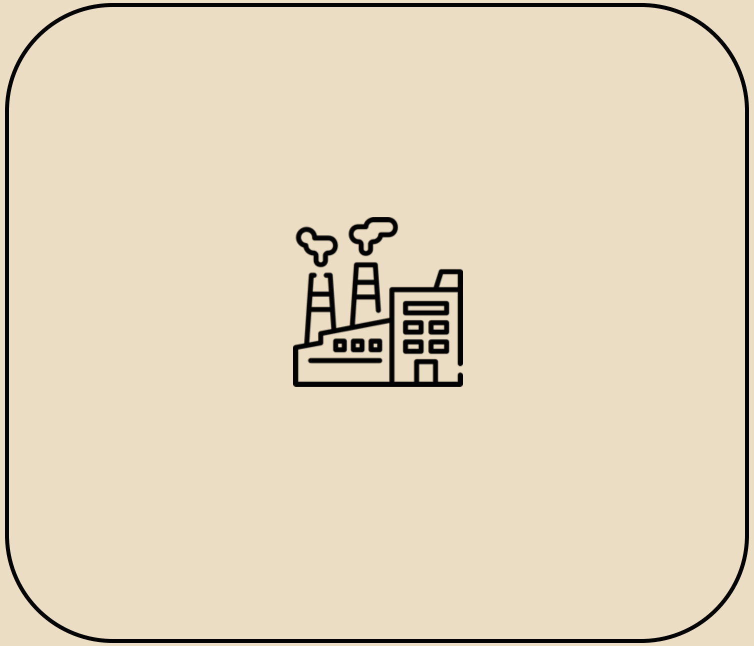
Distributed hubs

Small units scattered across an area.



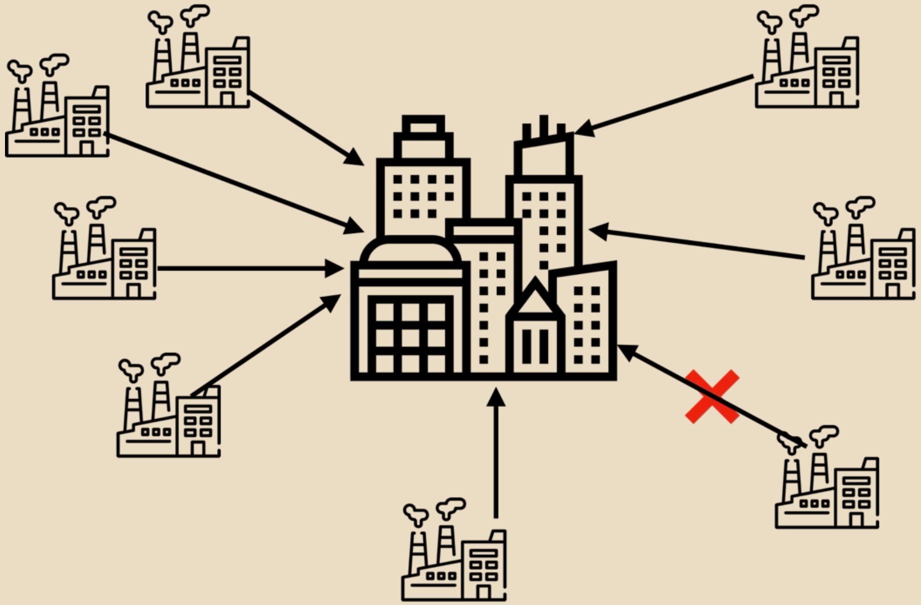
Centralized hub

One big unit that centralized the production for an area.

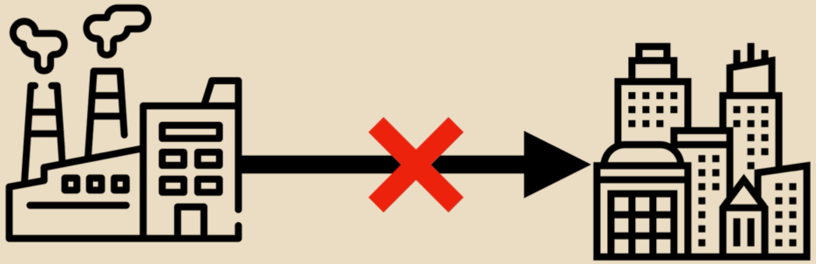


Why Distributed?

Distributed hubs



Centralized hub



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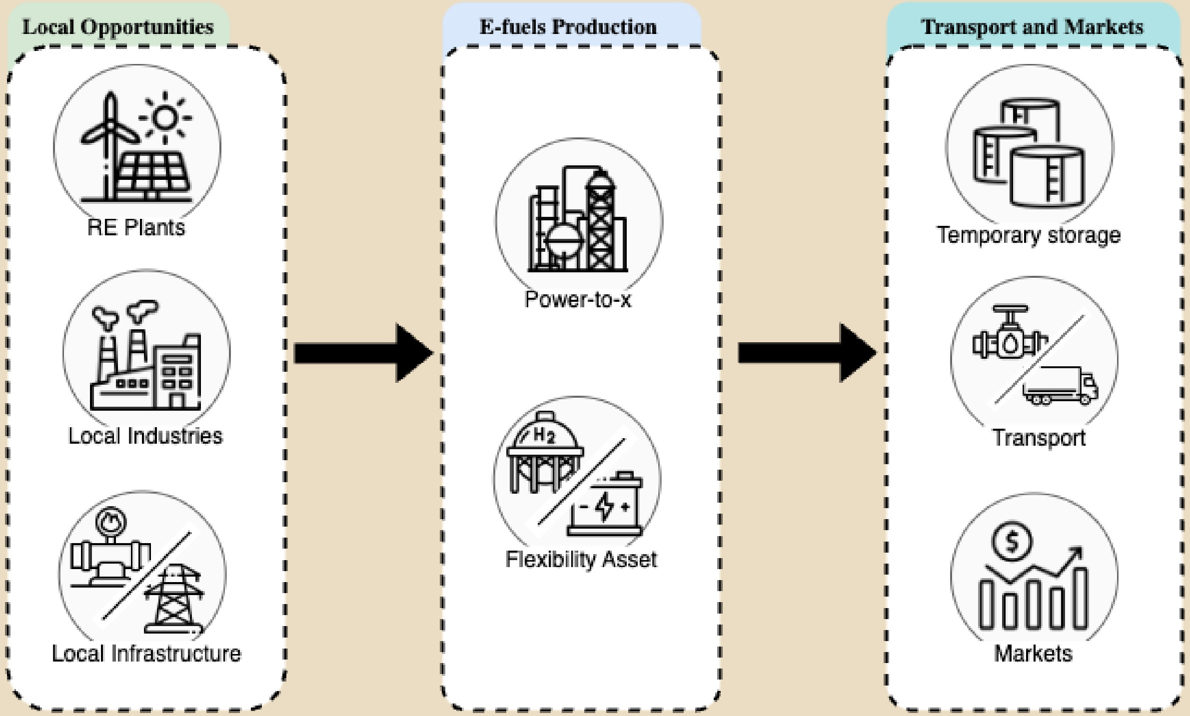
DEFH concept

DEFHs are small, distributed units designed for local e-fuel production.

To minimize production costs, DEFHs aims to take full advantage of local opportunities (e.g. industrial waste heat), valorize synthesis by-products (e.g. waste heat for district heating), and be located close to Energy Demand Centers (EDCs).



How DEFH can be viable?

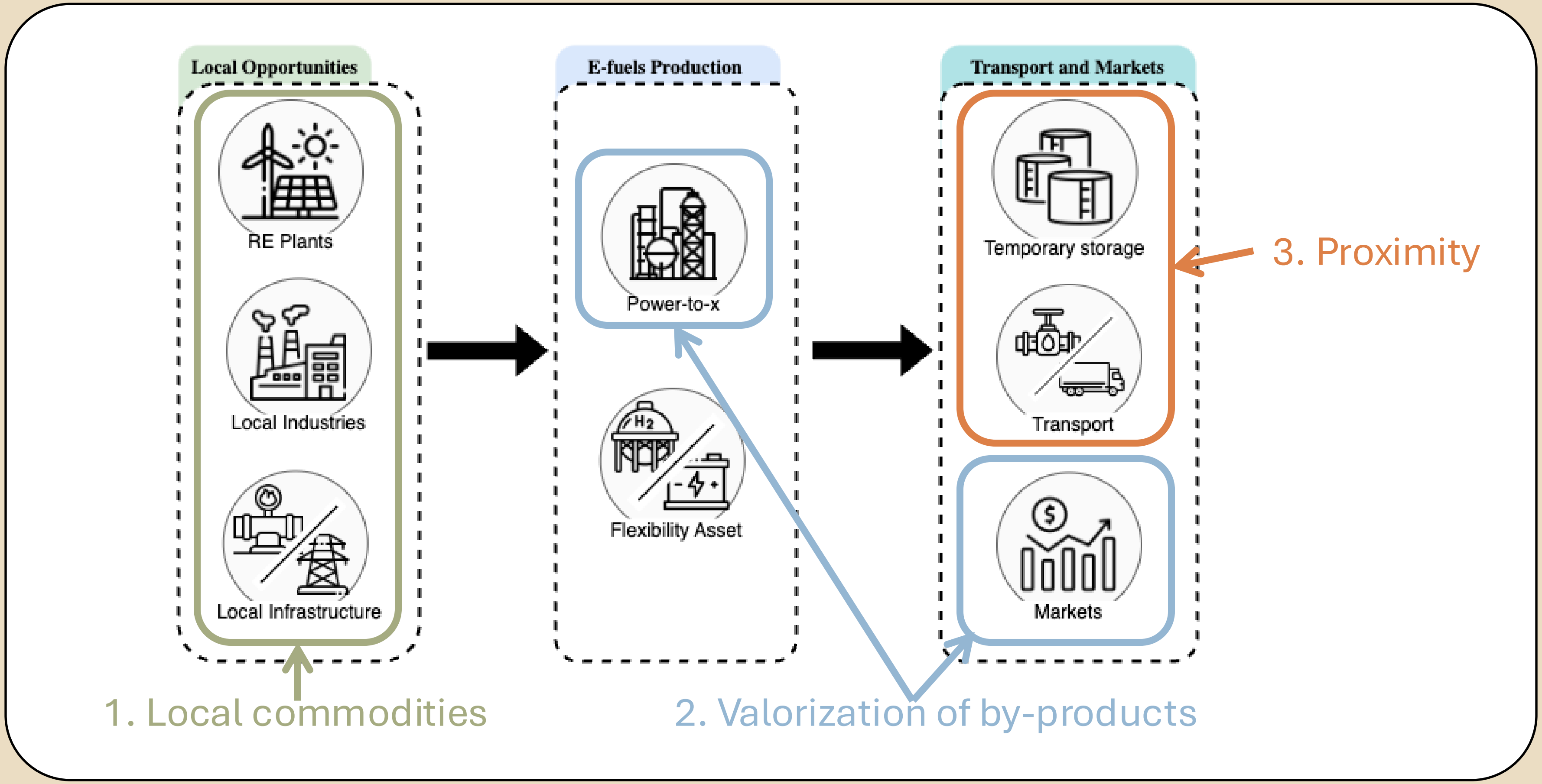
There are barriers to the deployment of DEFHs

DEFH installed in some European countries can lead to higher e-fuel production costs due, the low quality of renewable resources.

Additionally, DEFHs cannot benefit from economies of scale like larger centralized units, limiting their ability to optimize costs.

How DEFH can be viable?

To mitigate these two cost-related barriers, DEFHs are strategically located and sized to take full advantage of three key factors: i) access to local commodities, ii) valorization of by-products, and iii) proximity to demand.



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Problem statement: what is the minimal production cost of DEFH?

$$\min \sum_{i=0}^{N_a} K_x^i \cdot (\Psi_i + \psi_i) + \sum_{i=0}^{N_a} \sum_{j=0}^{N_{in}} \mathbf{q}_j^i * \phi_j - \sum_{i=0}^{N_a} \sum_{h=0}^{N_{out}} \mathbf{q}_h^i * \phi_j$$

Capacity install

Number of Assets

Operational cost

Number of inputs

Number of outputs

Commodity price

Installation cost

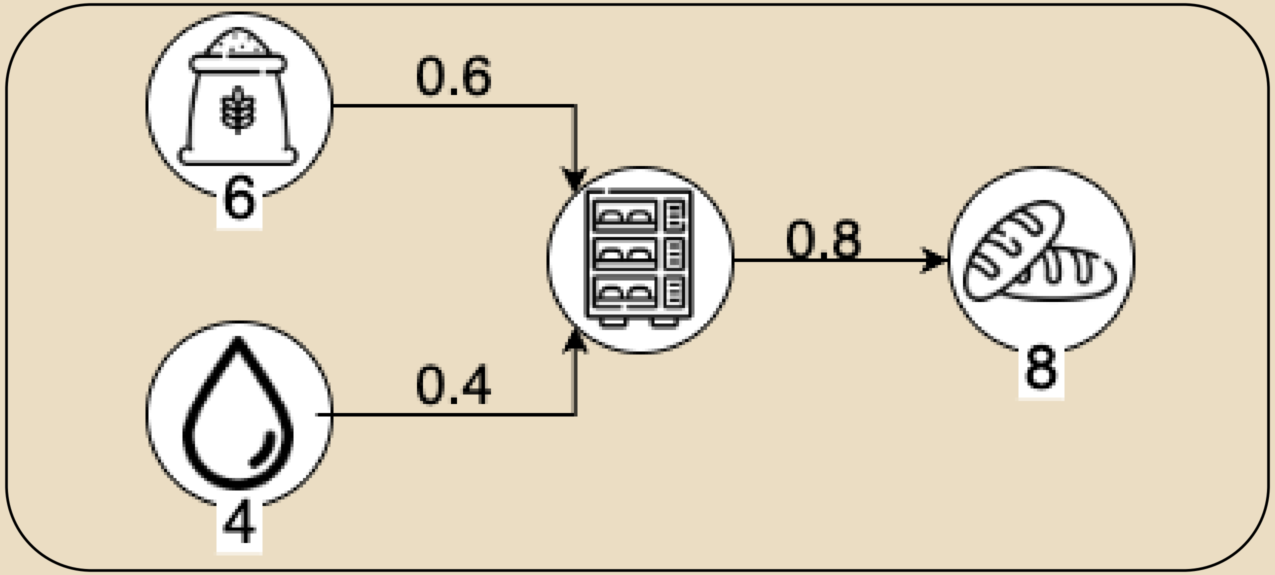
Commodity quantity

Modeling: generic node

I. Assets are modeled as conversion nodes.

II. Conversions are represented by constraints: $\mathbf{q}_x^n \alpha_x^n \leq \mathbf{q}_x^n \beta_x^n$

1. $\mathbf{q}_x^n$ is a time-indexed vector of size T representing the flow of the commodity x at each time step $t \in [0, T-1]$ in node n.
2. α_x^n is the conversion factor of the commodity x in node n.
3. β_x^n is the conversion efficiency of the commodity x in node n.



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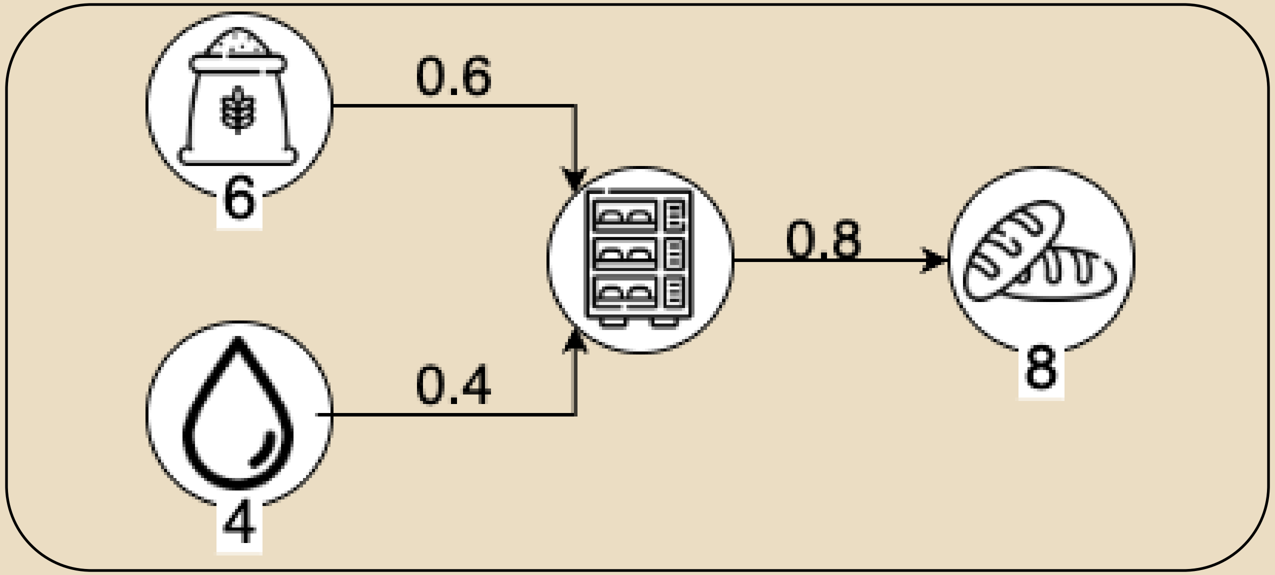
Modeling: generic node

i. Each node has a reference commodity and its flow through the node is constrained: $\mathbf{q}_x^n \leq K_x^n$

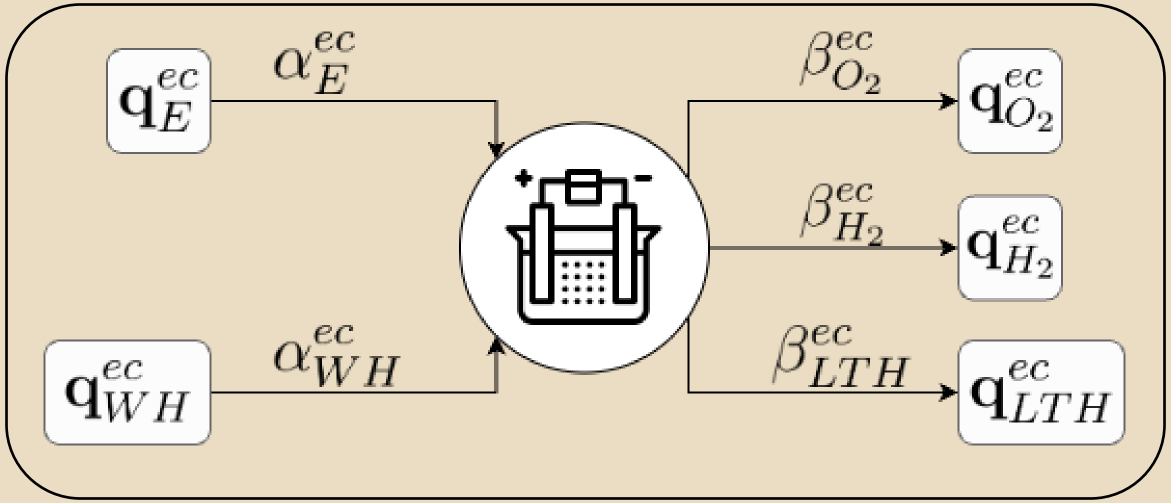
   1. K_x^n is the capacity installed

ii. Minimum load constraints are also considered: $K_x^n \kappa_x^n \leq \mathbf{q}_x^n$

   1. κ_x^n is the minimal load factor



Modeling: electrolyser example



i. Conversion constraints

$$\mathbf{q}_E^{ec}\alpha_E^{ec} \leq \mathbf{q}_{H2}^{ec}\beta_{H_2}^{ec}$$

$$\vdots$$

$$\mathbf{q}_{WH}^{ec}\alpha_{WH}^{ec} \leq \mathbf{q}_{LTH}^{ec}\beta_{LTH}^{ec}$$

ii. Capacity constraint

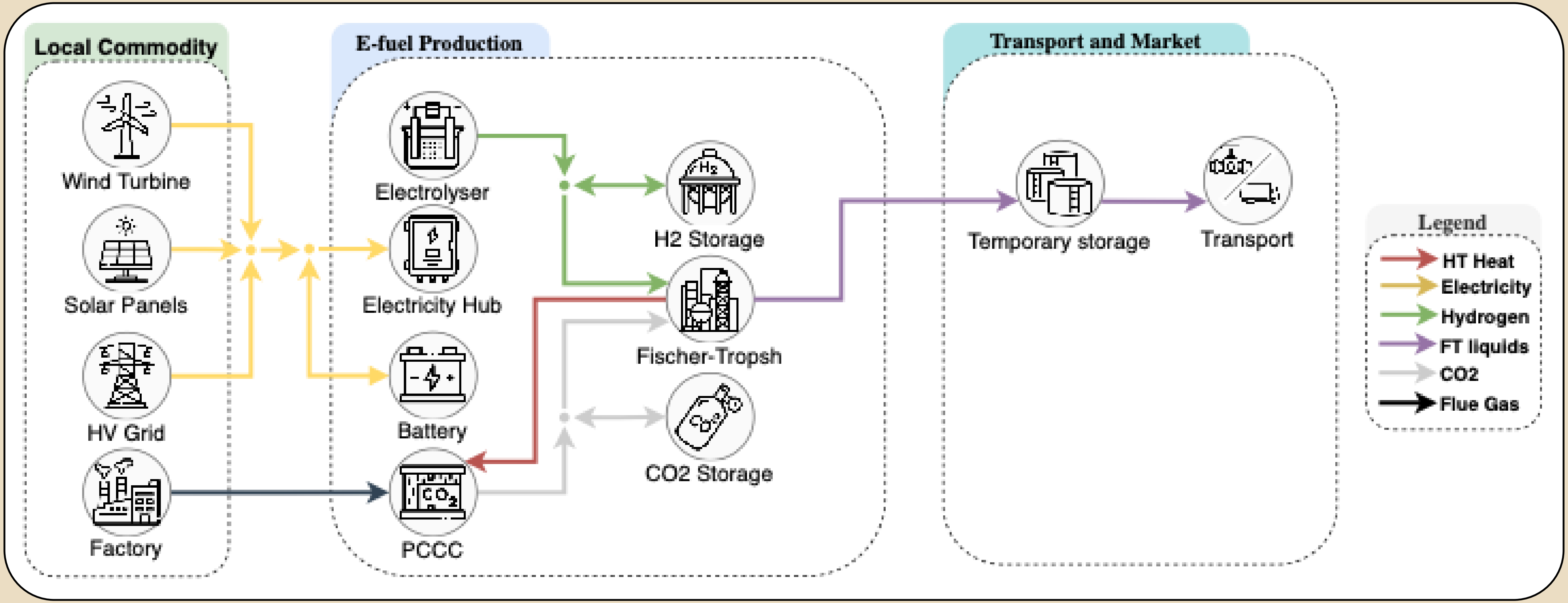
$$\mathbf{q}_E^{ec} \leq K_E^{ec}$$

iii. Load constraint

$$K_E^{ec}\kappa_E^{ec} \leq \mathbf{q}_E^{ec}$$

Case study: Belgian Fischer-Tropsch Liquids Hub

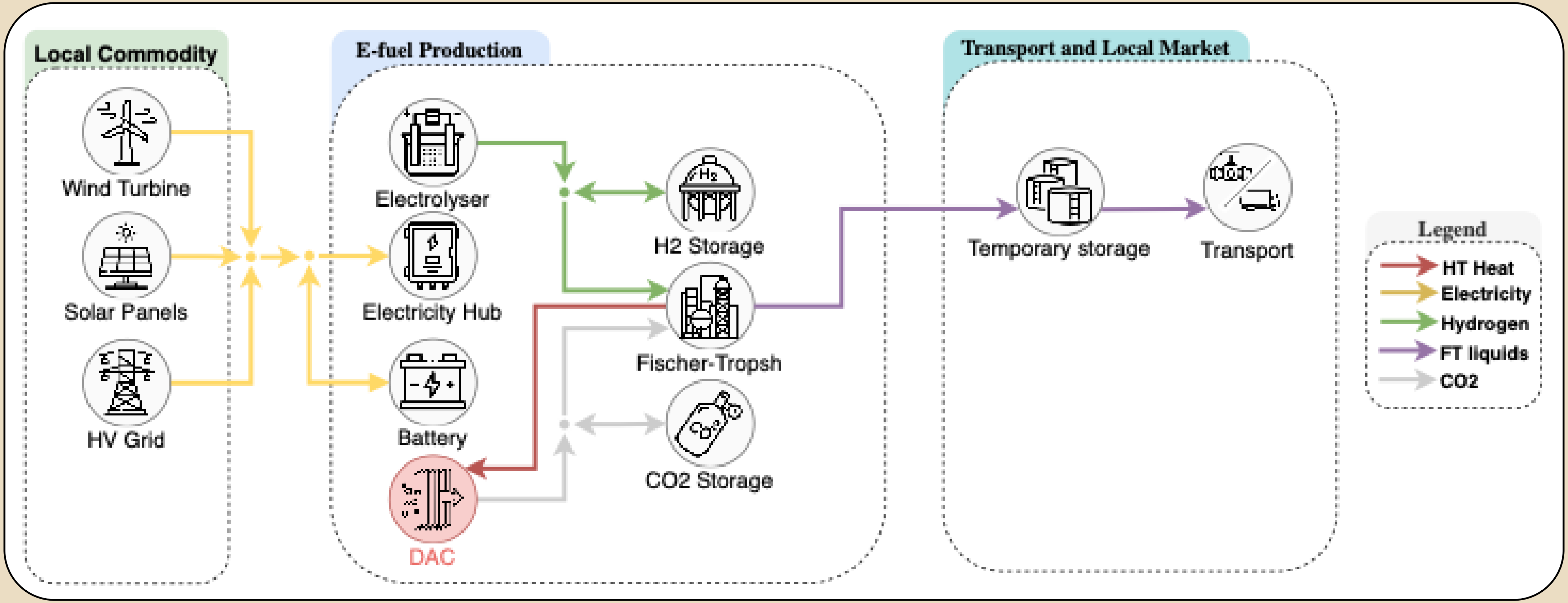
Scenario 1: PCCC



We are considering an industrial site located next to a lime plant that emits a constant flow of CO_2-rich flue gases equivalent to a capture rate of 9 tCO_2/hour.

Case study: Belgian Fischer-Tropsch Liquids Hub

Scenario 2: DAC



For the sake of comparison with the previous scenario, we will consider a maximum capture rate equivalent to 9 tCO_2/hour.

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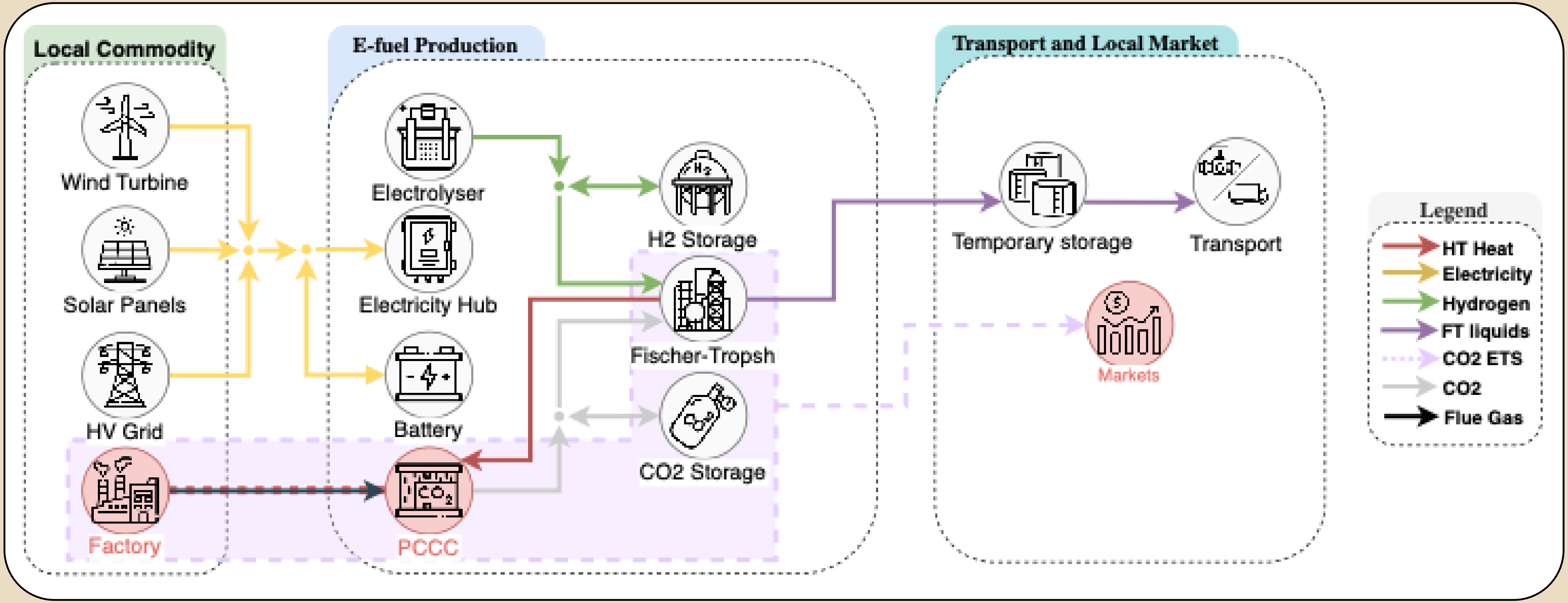
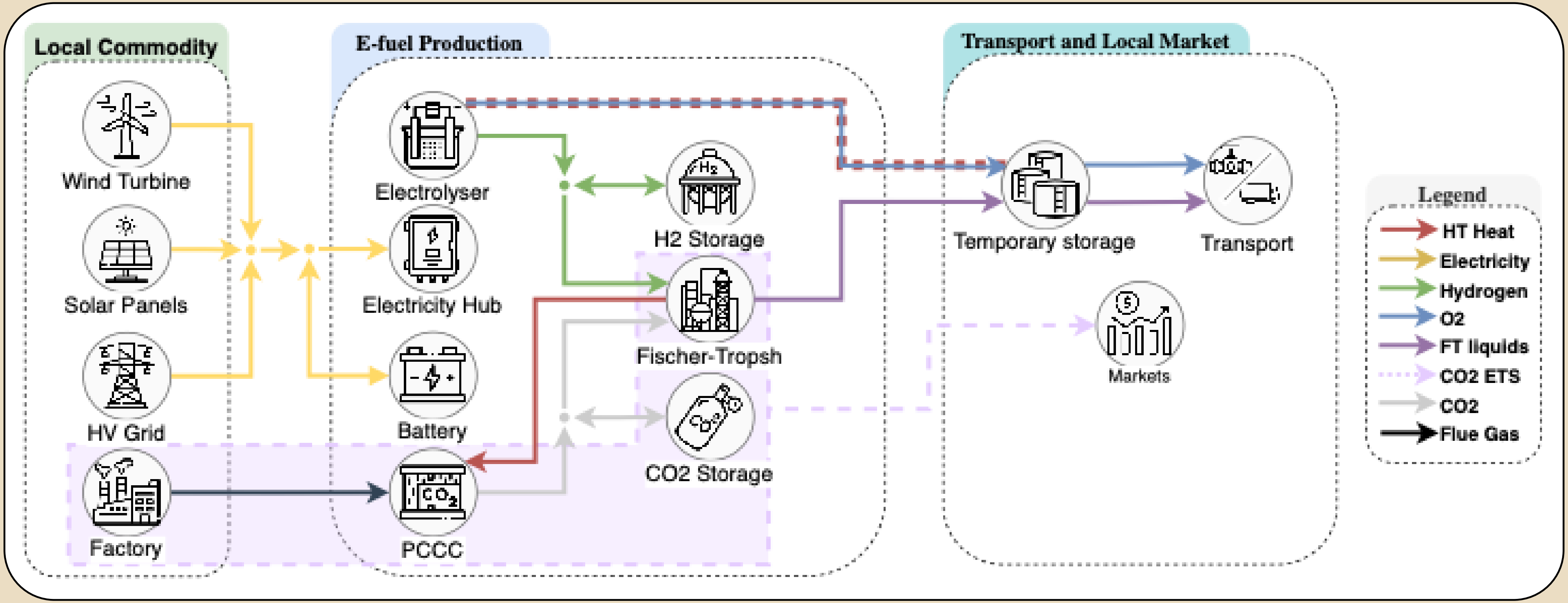
Scenario 3: PCCC with ETS



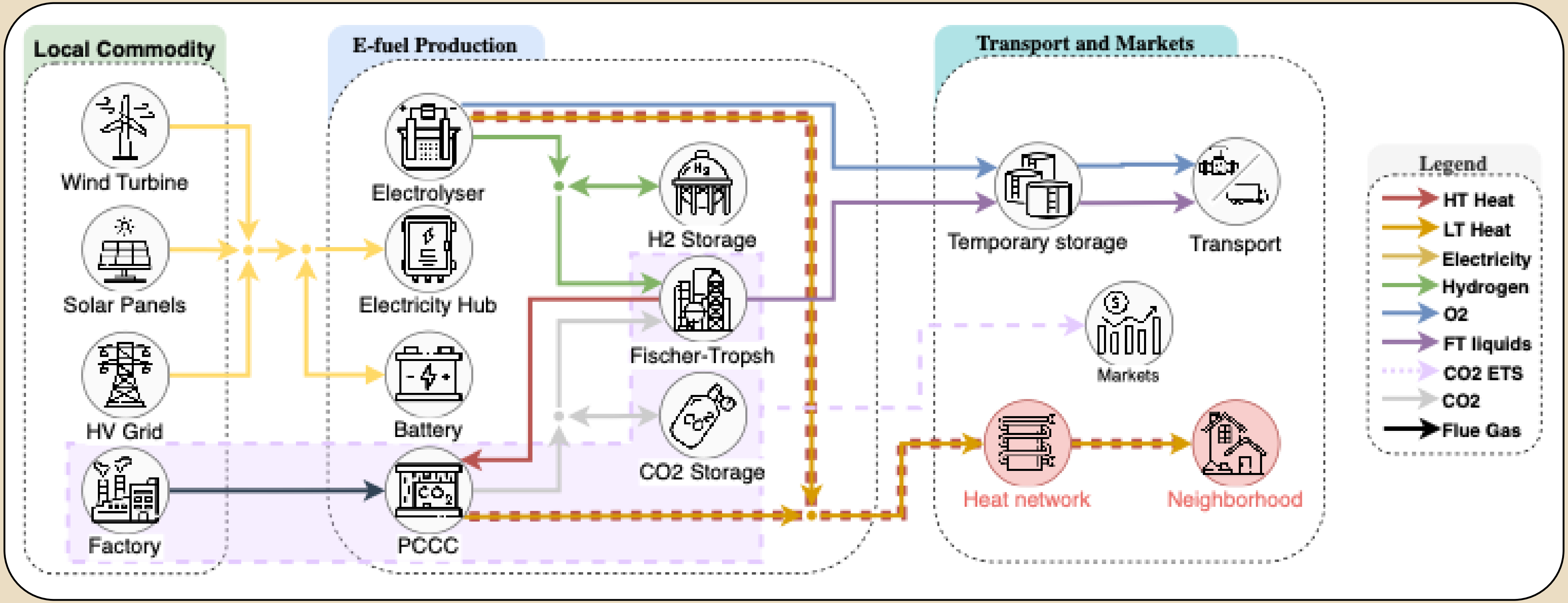
Case study: Belgian Fischer-Tropsch Liquids Hub

Scenario 4: PCCC with ETS and valorization of O2



Case study: Belgian Fischer-Tropsch Liquids Hub

Scenario 5: PCCC with ETS, valorization of O2, and district heating



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Case study: Belgian Fischer-Tropsch Liquids Hub Modeling assumptions

i. Formulated as a linear programming (LP) problem;

ii. Investment and operational planning over one year;

iii. 2023 weather and market data used (renewable load factor & electricity price);

iv. Perfect foresight;

v. The grid can only be used to buy electricity, not sell it;

vi. CO_2 capture limited to 9 tCO_2/hour;

vii. No constraint on land surface usage;

viii. We don’t modelize the transport part;

Case study: Belgian Fischer-Tropsch Liquids Hub

Scenario	S1	S2	S3	S4	S5
CO2 sourcing	PCCC	DAC	PCCC	PCCC	PCCC
CO2 emission allowance	✗	✗	✓	✓	✓
Oxygen valorization	✗	✗	✗	✓	✓
Waste heat valorization	✗	✗	✗	✗	✓

Case study: Belgian Fischer-Tropsch Liquids Hub

Results under the following assumptions:

i. CO_2 emission allowance is valued at €80 per ton CO_2 converted into e-fuel,

ii. O_2 is valued at €40 per ton

iii. Waste heat is valued at €40 per MWh.

Scenario	**S1**	**S2**	**S3**	**S4**	**S5**
CO2 sourcing	PCCC	DAC	PCCC	PCCC	PCCC
CO2 emission allowance	✗	✗	✓	✓	✓
Oxygen valorization	✗	✗	✗	✓	✓
Waste heat valorization	✗	✗	✗	✗	✓
Minimum e-fuel price [€/MWh]	211 (-11.0%)	237 (0%)	192 (-18.9%)	178 (-24.9%)	131 (-44.7%)

It is estimated that the e-fuel mix costs 66 €/MWh for its fossil fuel equivalent.

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Conclusion

This work introduces the concept of **Distributed E-Fuel Hubs (DEFHs),** a decentralized approach to increase local fuel production and reduce reliance on imports.

Our simulations demonstrate that, when well integrated into their environment, DEFHs can significantly reduce production costs.

This cost reduction relies on 3 key factors: i) leveraging local commodities, ii) capitalizing on by-product valorization opportunities (e.g. waste heat resale), and iii) proximity to energy demand centers.

Thank you for your attention

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