Techno-economic Assessment of the Integration of Direct Air Capture and the Production of Hydrogen and Solar Fuels

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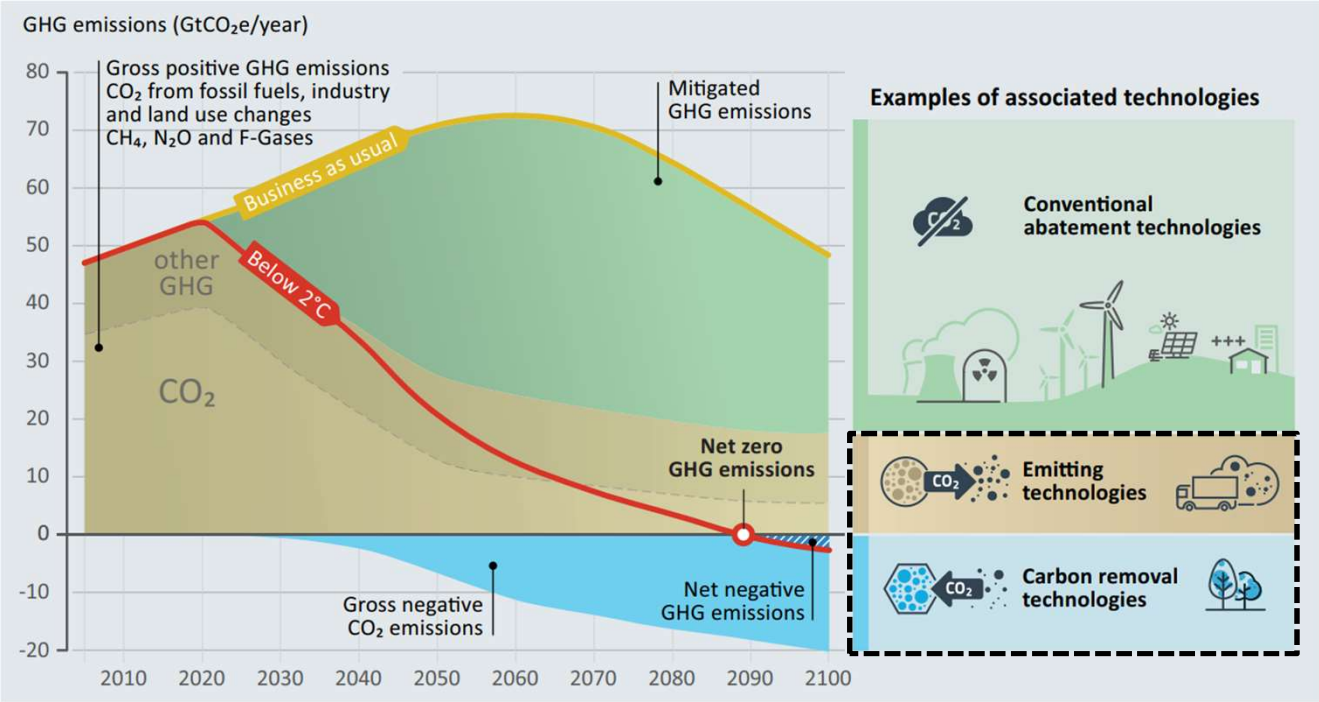
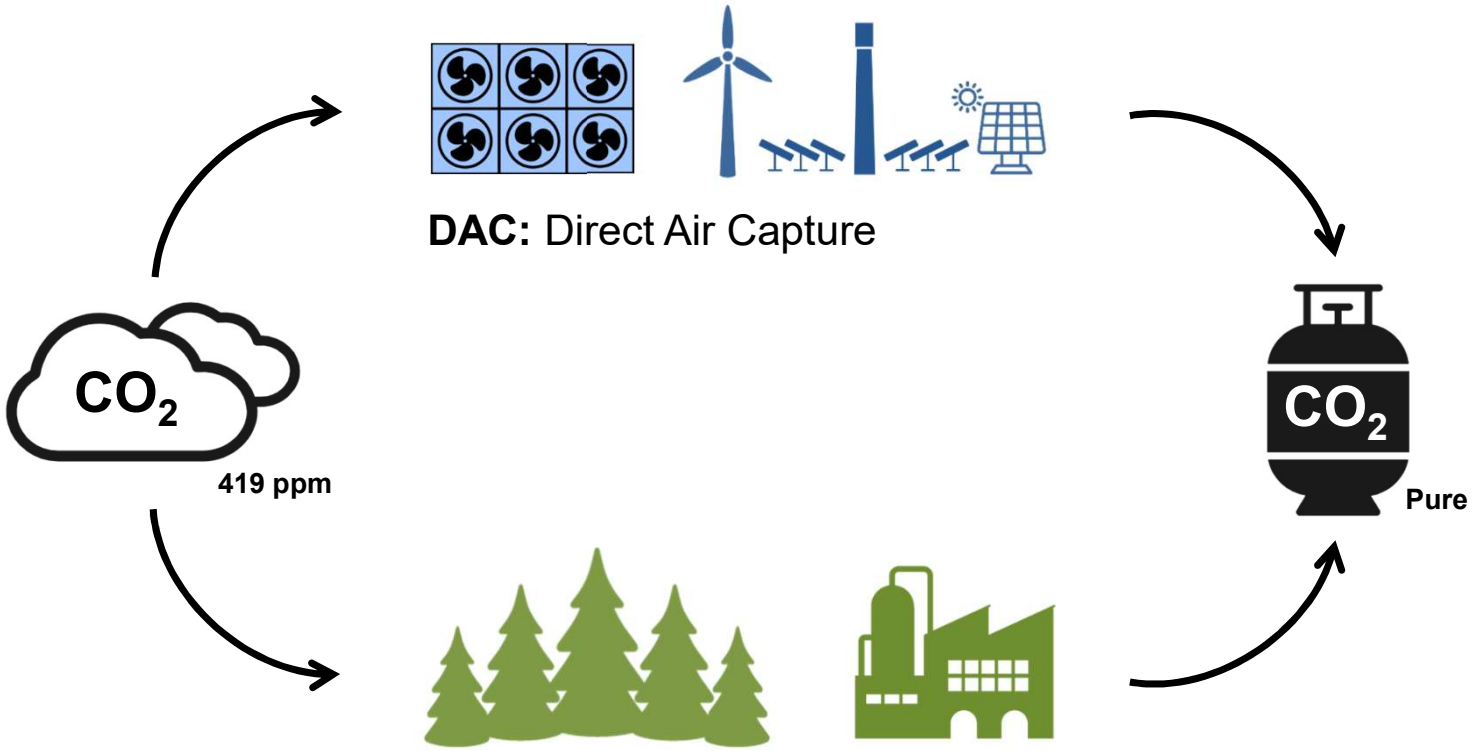
Introduction: Why do we need synthetic chemicals?



- Carbon Capture and Utilization (CCU):
  - Important role in **transition**
  - **Non-decarbonized** sectors
- Energy-intensive processes → Solar:
  - **Cheap** heat & electricity
  - **Low carbon intensity**

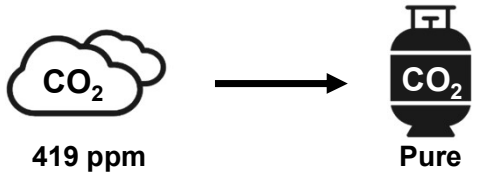
Source: UNEP Emissions Gap Report 2017

State of the art: Carbon capture

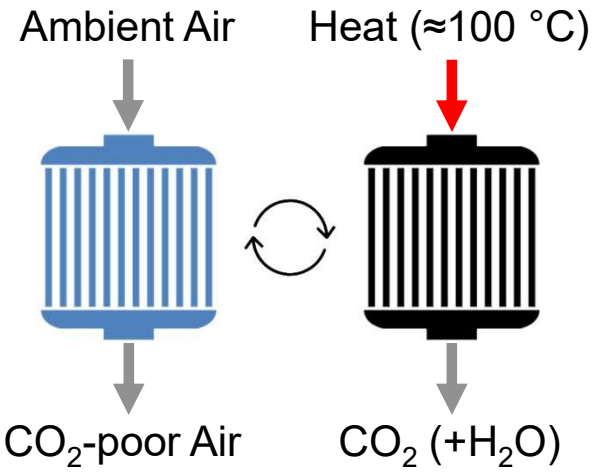


Source: Fasihi, 2019

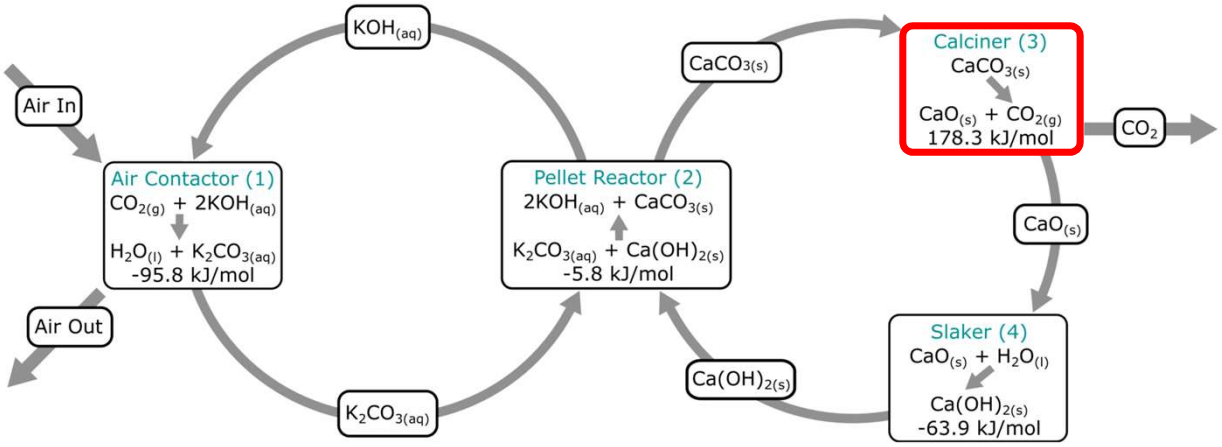
State of the art: Direct Air Capture Technologies



LT-DAC:



HT-DAC:

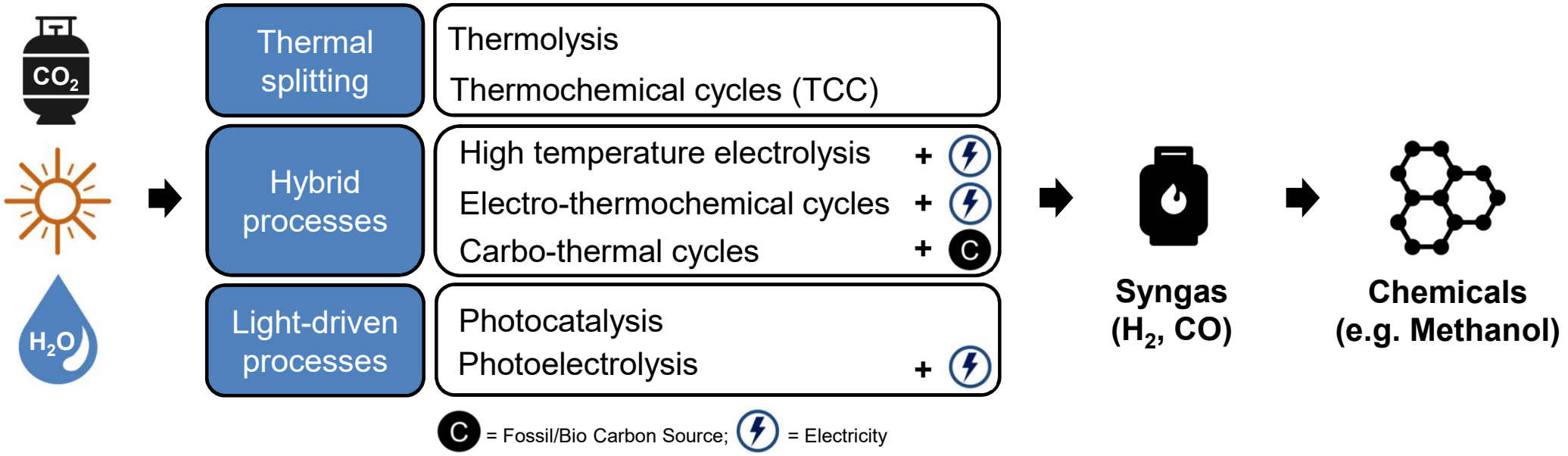


	LT-DAC	HT-DAC (NG)
Electricity* (kWh/t CO_2)	130	154
Thermal (kWh/t CO_2)	1750	1458

*Compression not included (≈120 kWh/t CO_2 for 150 bar)

Source: Fasihi, 2019

State of the art: Carbon utilization with concentrated solar energy



Source: Blanco and Ramirez, 2016

How does a Thermochemical Cycle work?

High T (T_{red})

Low T (T_{ox})

$$MO_{oxidized} \xrightarrow{\text{☀}} MO_{reduced} + \frac{1}{2}O_2 \qquad \Delta H_{red} > 0$$

$$MO_{reduced} + \frac{H_2O}{CO_2} \rightarrow MO_{oxidized} + \frac{H_2}{CO} \qquad \Delta H_{ox} < 0$$

☀ = process aided with solar energy

Source: Agrafiotis et al., 2018

How does a Thermochemical Cycle work?

High T (T_{red})

Low T (T_{ox})

$$ZnO \xrightarrow{\text{☀}} Zn + \frac{1}{2}O_2 \qquad \Delta H_{red} > 0$$

$$Zn + H_2O \rightarrow ZnO + H_2 \qquad \Delta H_{ox} < 0$$

☀ = process aided with solar energy

Source: Agrafiotis et al., 2018

How does a Thermochemical Cycle work?

Volatile Cycles

Zn/ZnO:

At T_R: $ZnO(s) \rightarrow Zn(g) + \frac{1}{2} O_2(g)$

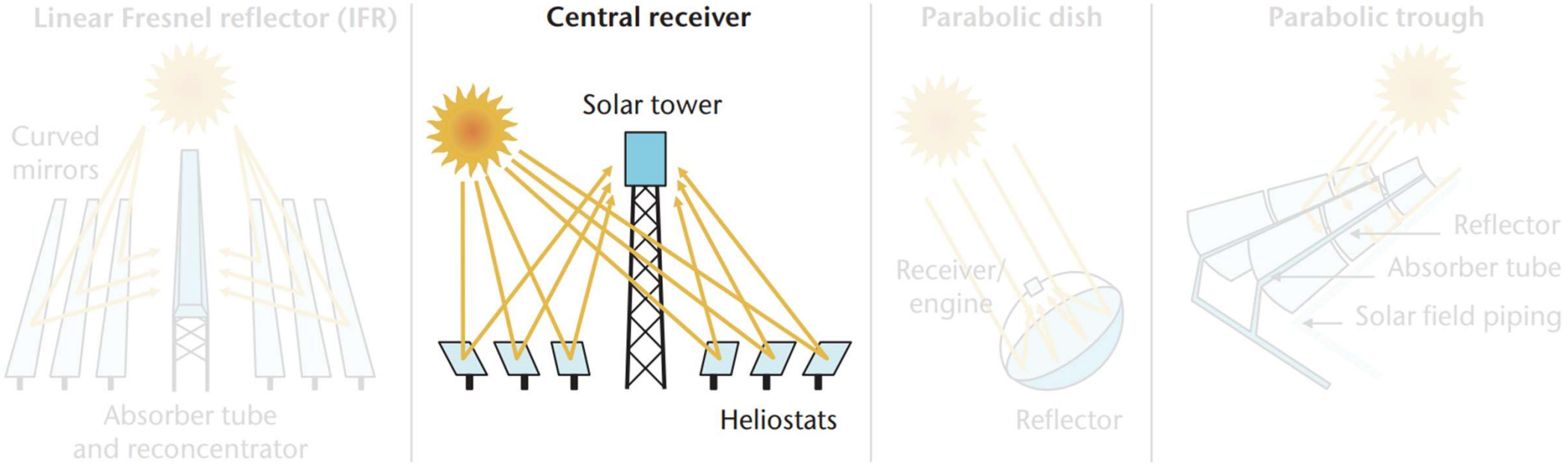
Non-volatile Cycles

- **Ferrites**
- **Ceria**
- **Perovskites**
- **Doped-hercynite**

T_R > 1300 °C
Vacuum / Inert Gas

Source: Agrafiotis et al., 2018

How is a Thermochemical Cycle powered?



Source: IEA, 2014

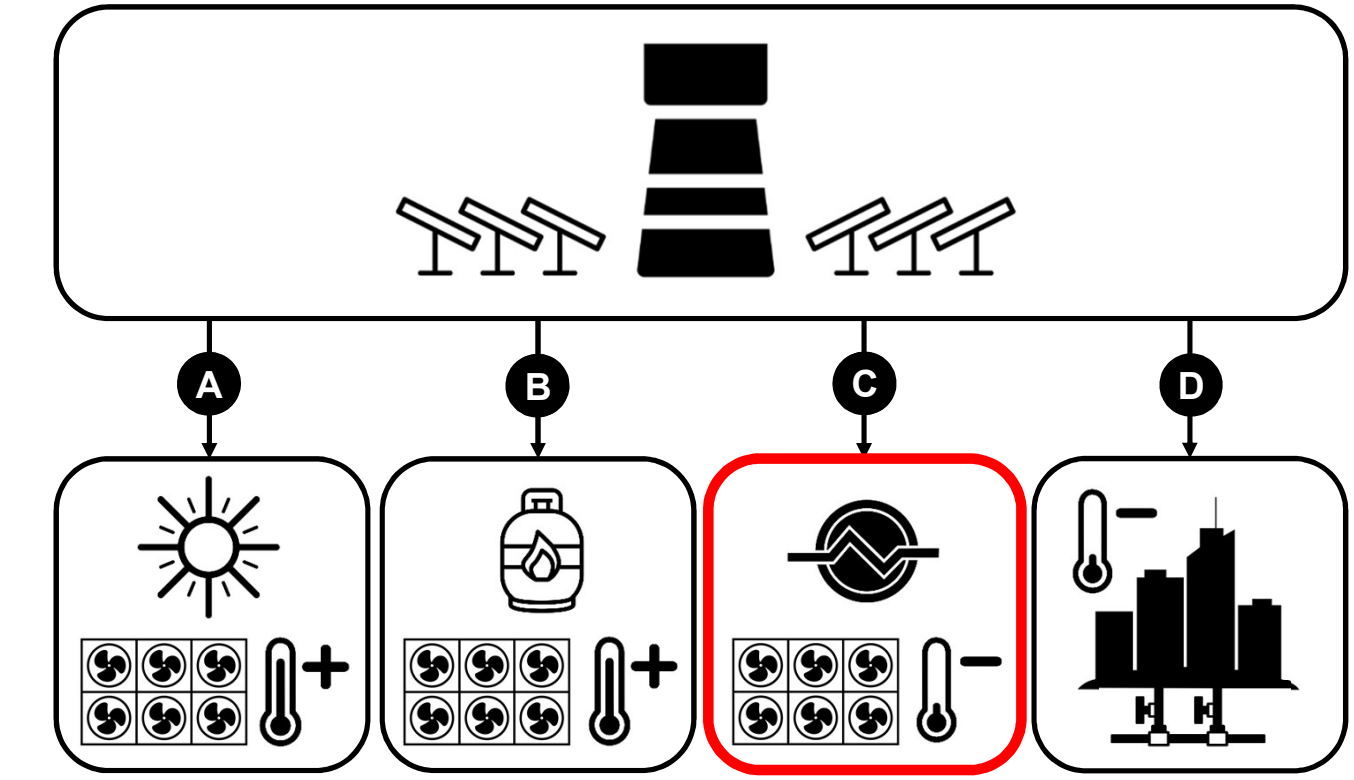
How is a Thermochemical Cycle powered?

Noor III (150 MW), Morocco

Jülich Solar Tower (1.5 MW), Germany

Source: SolarPACES, DLR Images

TEA: Scenarios Overview



A. Central sHT-DAC

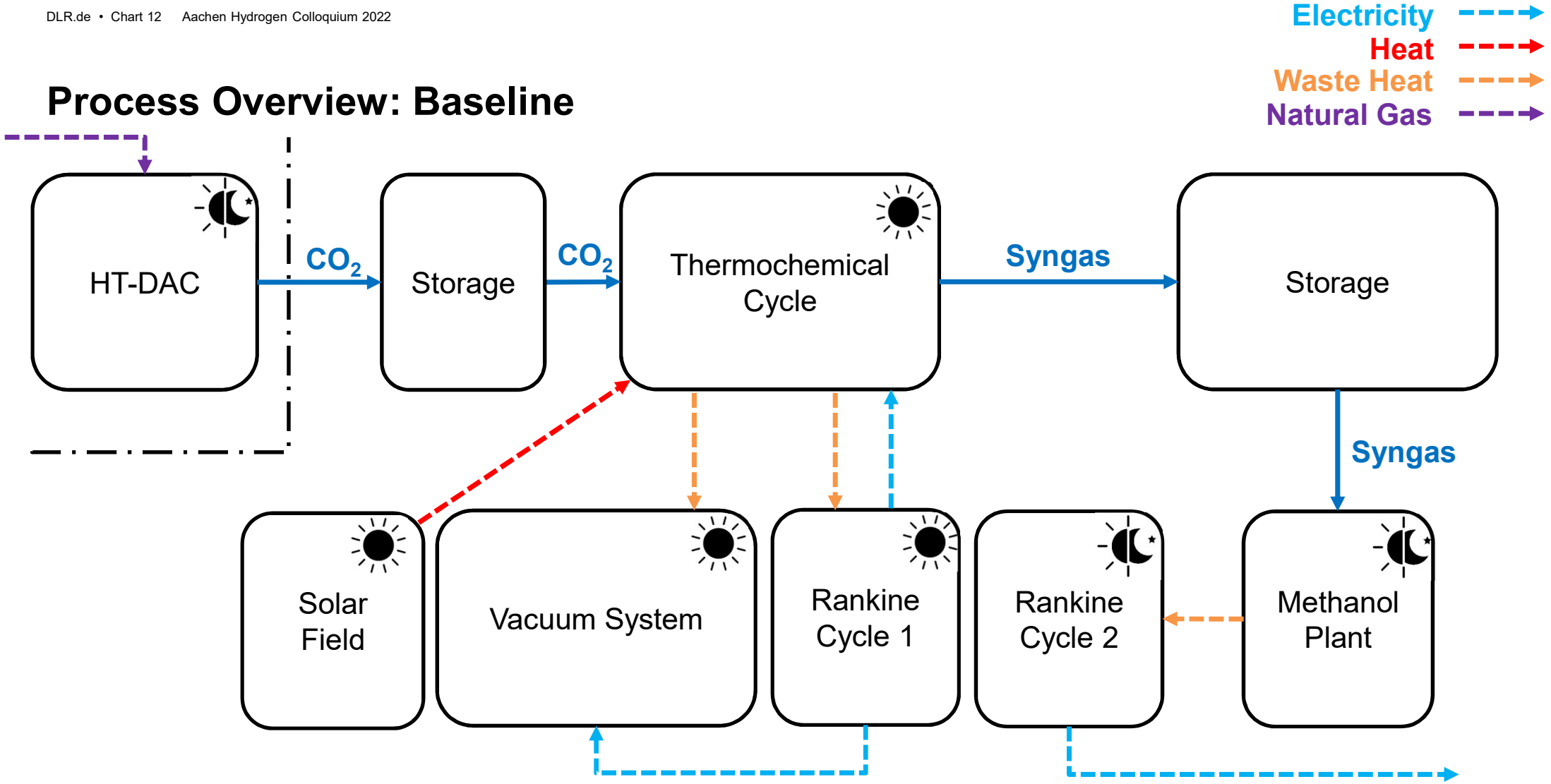
B. Central HT-DAC

C. Central LT-DAC

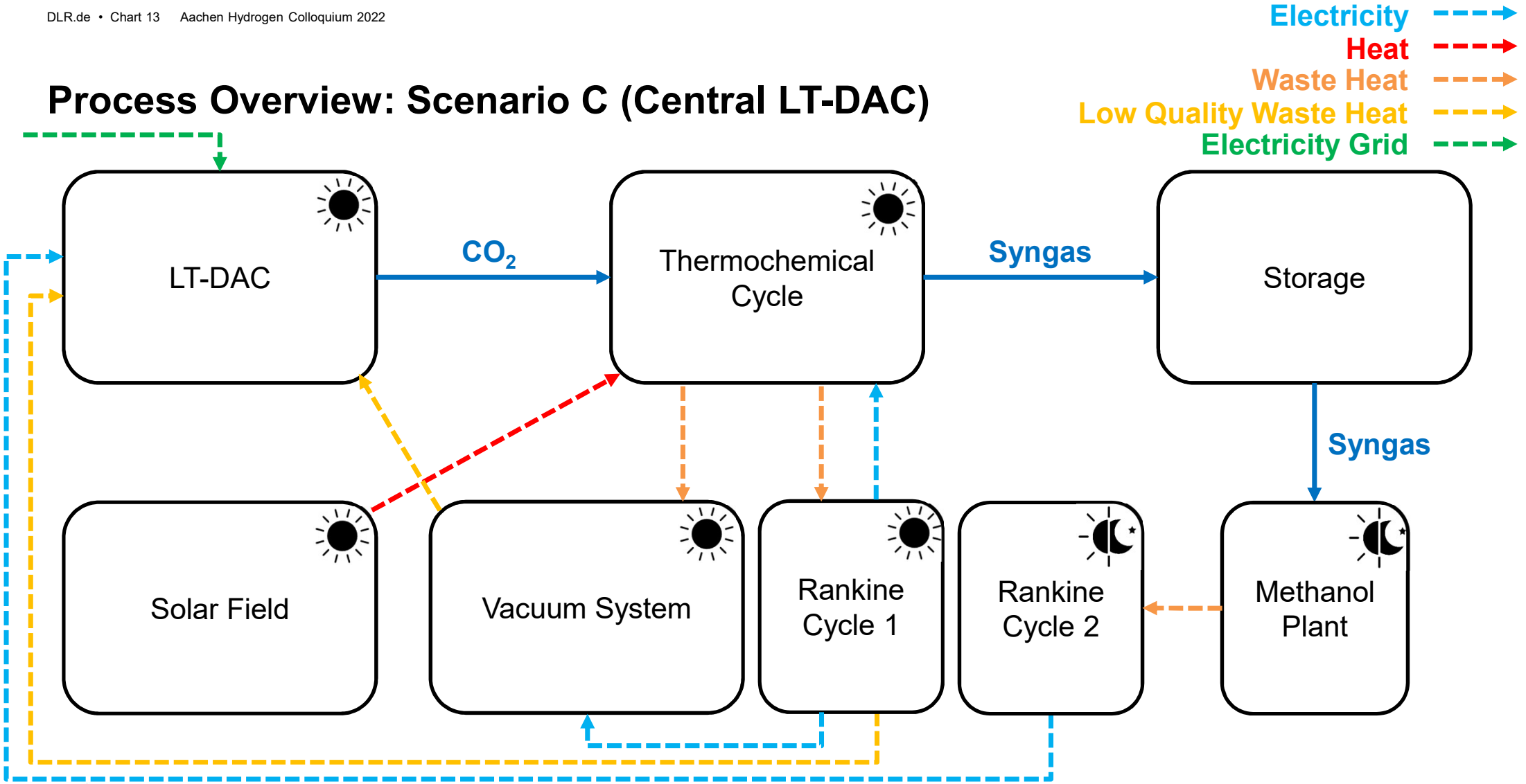
D. Hybrid LT-DAC

Source: Prats-Salvadó, 2021

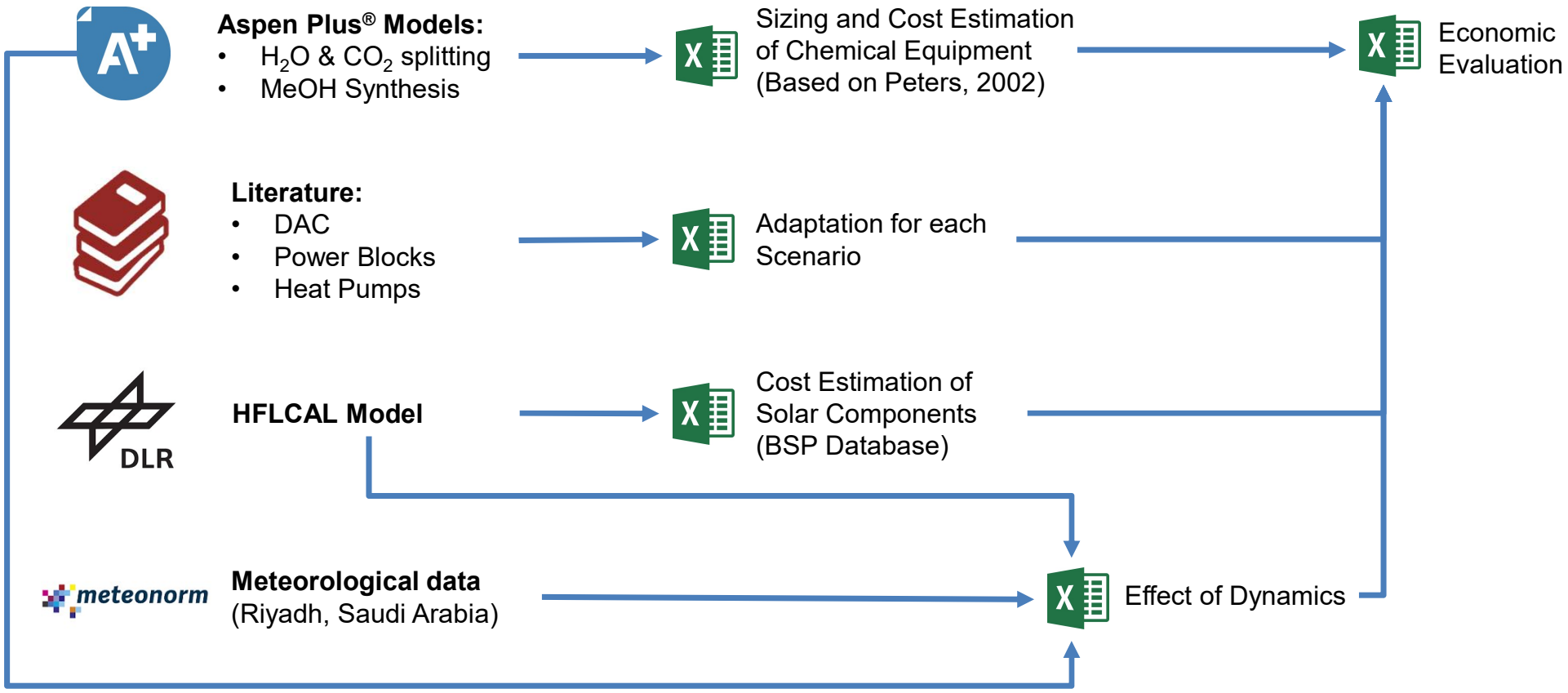
Process Overview: Baseline



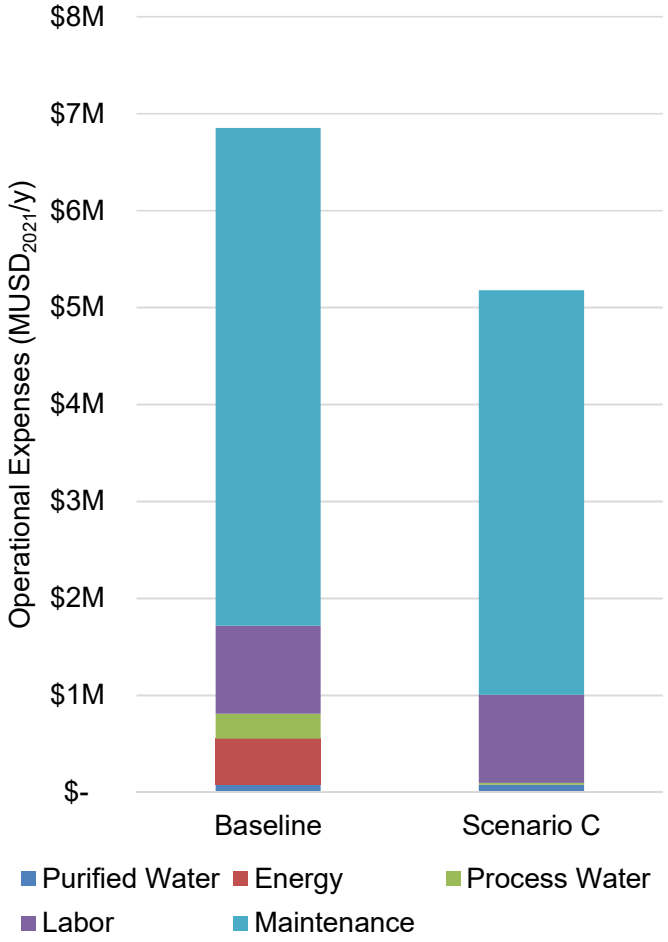
Process Overview: Scenario C (Central LT-DAC)



TEA: Model Architecture



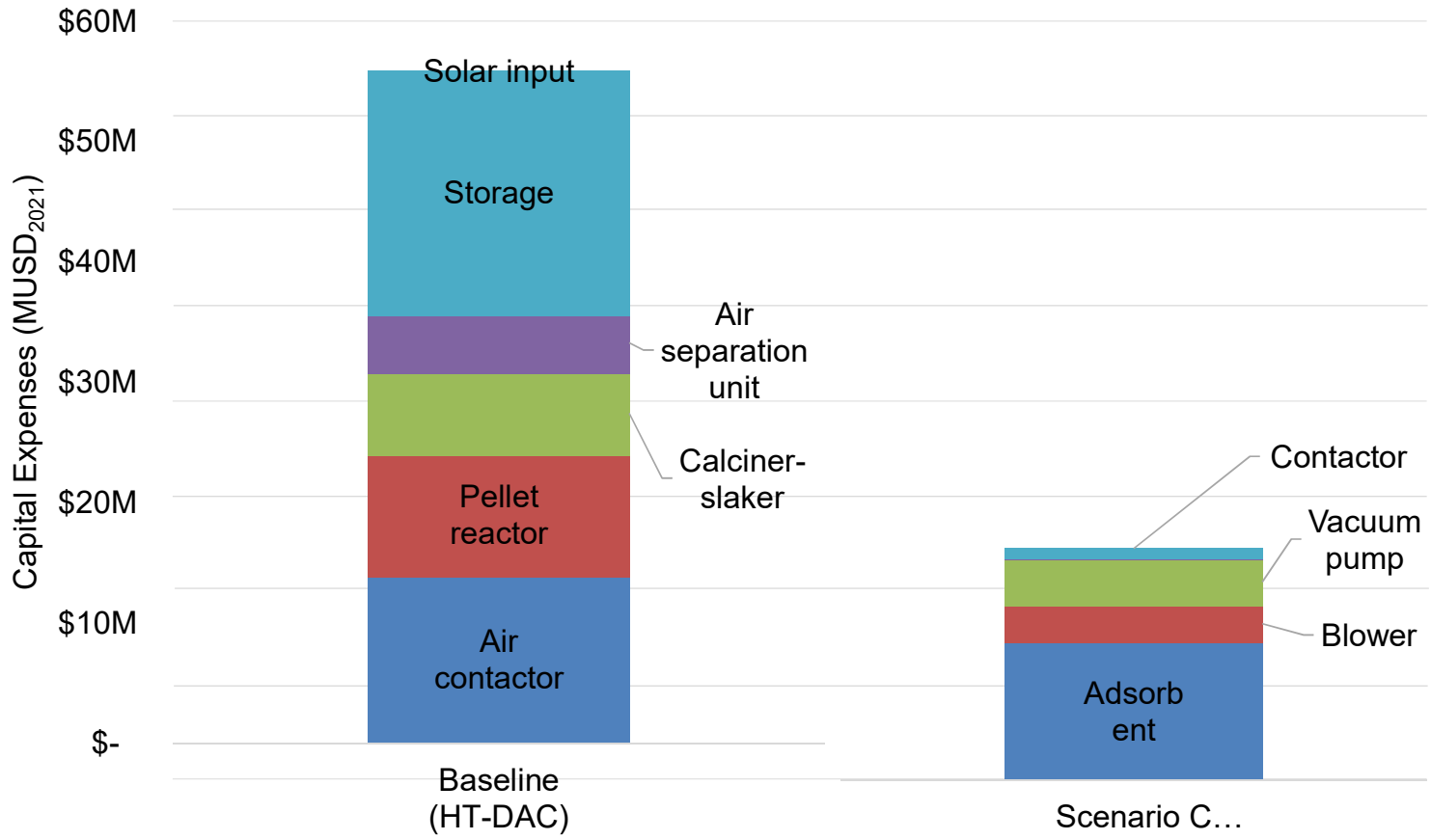
TEA: Total CAPEX and OPEX



Optimal Design Size	
Solar Field (MW)	280
Peak CO_2 processed (t/h)	6.00
Annual CO_2 processed (kt/y)	16.55
Annual MeOH produced (kt/y)	11.36

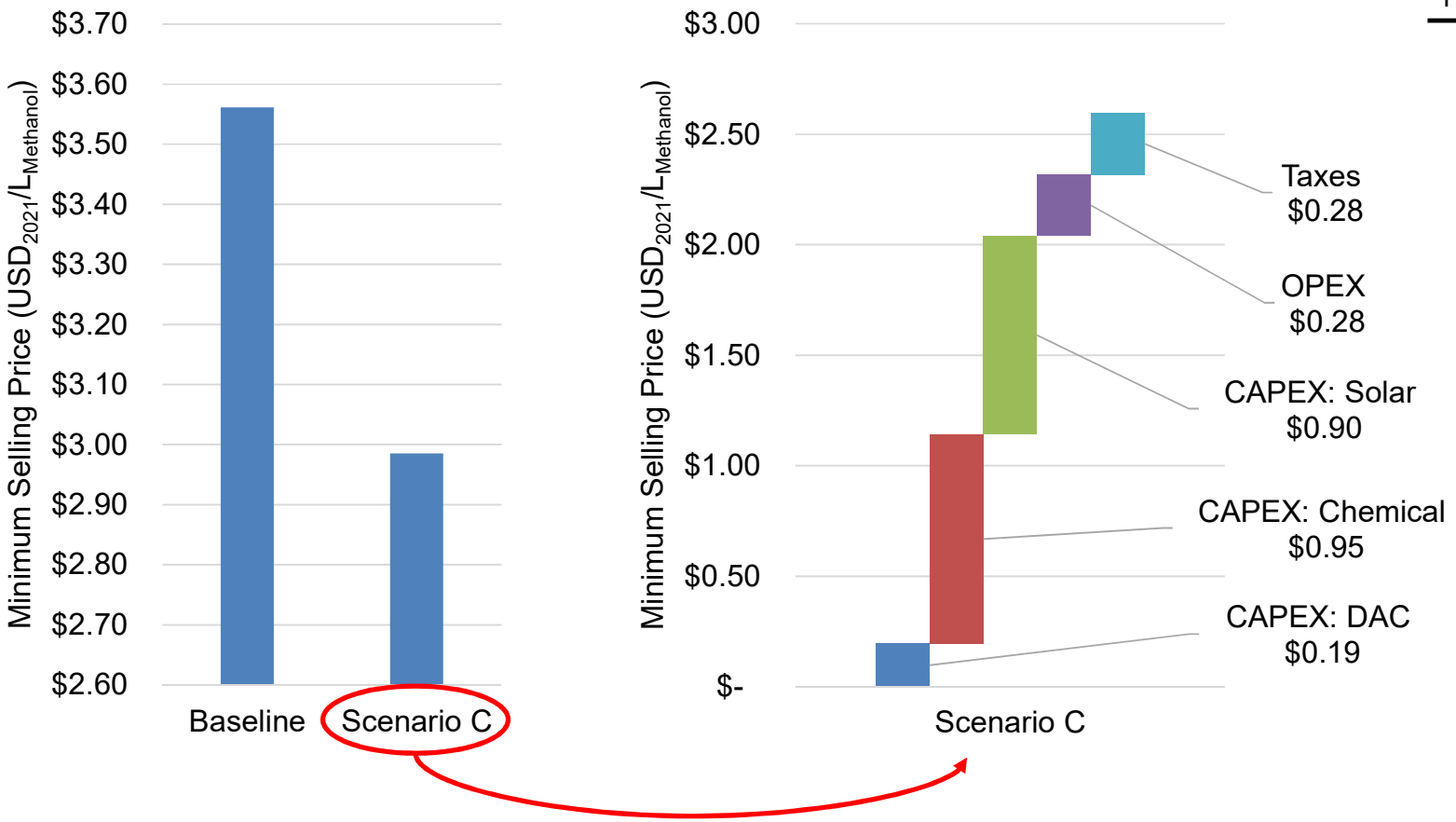
Operational Costs	
Raw Material Water (USD_{2021}/t)	8.20
DAC & Mirrors Water (USD_{2021}/t)	1.64
Grid Electricity (USD_{2021}/MWh)	159.0
Natural Gas (USD_{2021}/GJ)	3.8
Labour (USD_{2021}/h)	39.1
Mirror annual replacement (%)	0.2
Maintenance (% of FCI)	2

TEA: CAPEX of the DAC Technologies



TEA: Minimum Selling Price of Methanol

Economic Conditions	
Discount rate (%)	10
Taxes (%)	20
Linear Depreciation (y)	20
Plant Lifetime (y)	25



Conclusions

- Solar thermochemical cycles are a **competitive alternative** to produce synthetic fuels
- Comprehensive process integration is critical to **reduce the MSP**
- There are remarkable **synergies between DAC and synthetic fuels** production processes
- The **carbon-neutrality** must be assessed with an LCA

Thank you for your attention

Q & A

References

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