SUNtoLIQUID II

FUELS FROM CONCENTRATED SUNLIGHT

Environmental and Economic Perspectives of Sustainable Aviation Fuel from Sunlight and Air

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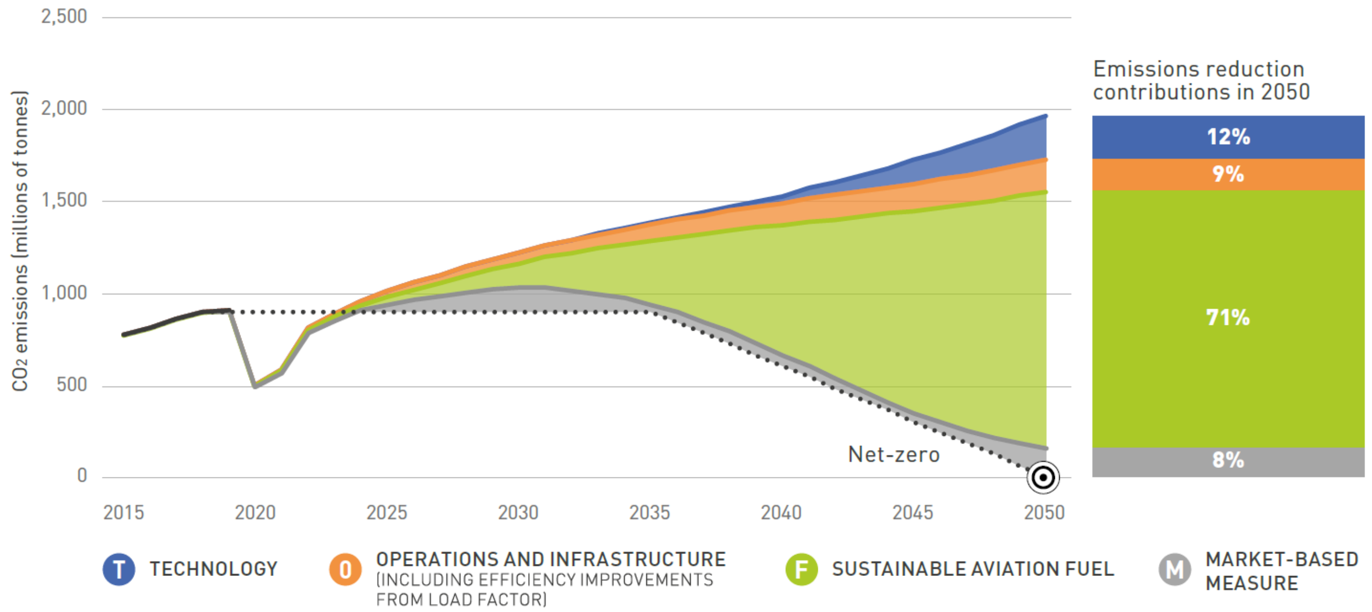
Bauhaus Luftfahrt
The Aviation Think Tank

Scalable Renewable Fuels for Aviation Decarbonization

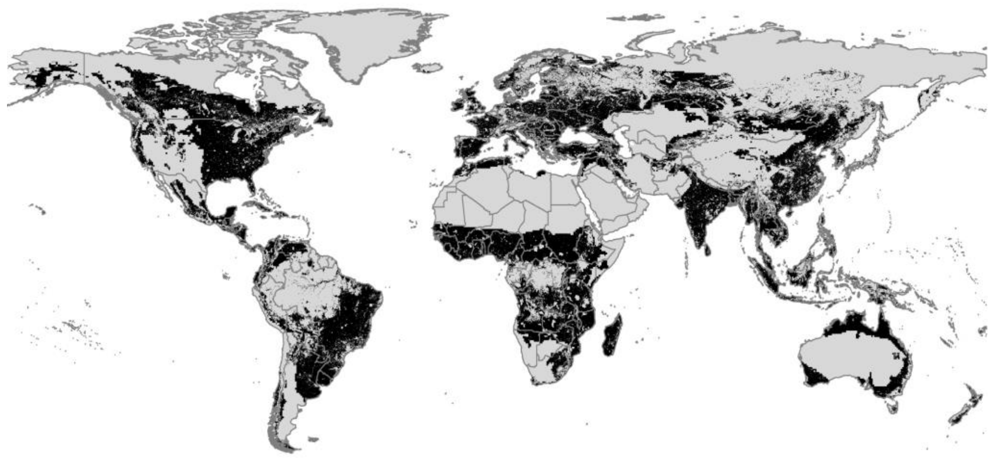


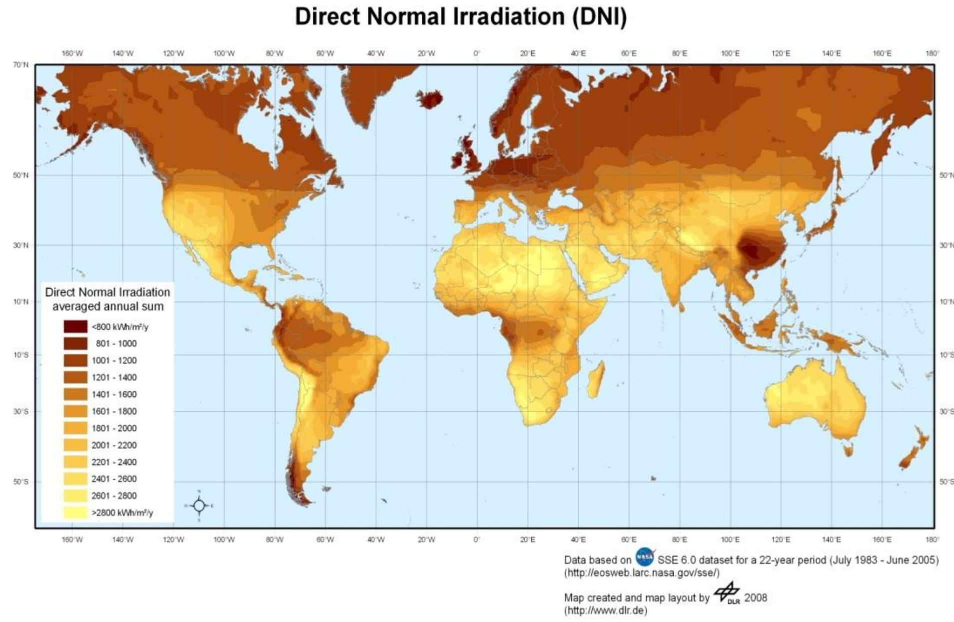
ATAG – Air Transport Action Group, Waypoint 2050
https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050

- Aviation's urgent decarbonization challenge:
  - IATA commitment for net zero flight in 2050
  - Translates into 500 Mt/a SAF at net zero carbon emission
- Longterm target demands scalable solution beyond biomass-potential
- Synthetic fuels (non-bio origin):
  - Power to Liquid
  - Sunlight to Liquid

Solar Fuel Potential

- Attractive locations: Annual DNI > 2000 kWh/m^2
  - High direct normal irradiation (DNI) requires low level of humidity
  - Little overlap with arable land, high population density and rich biodiversity
- Solar fuel potential surpasses global demand around 50 times





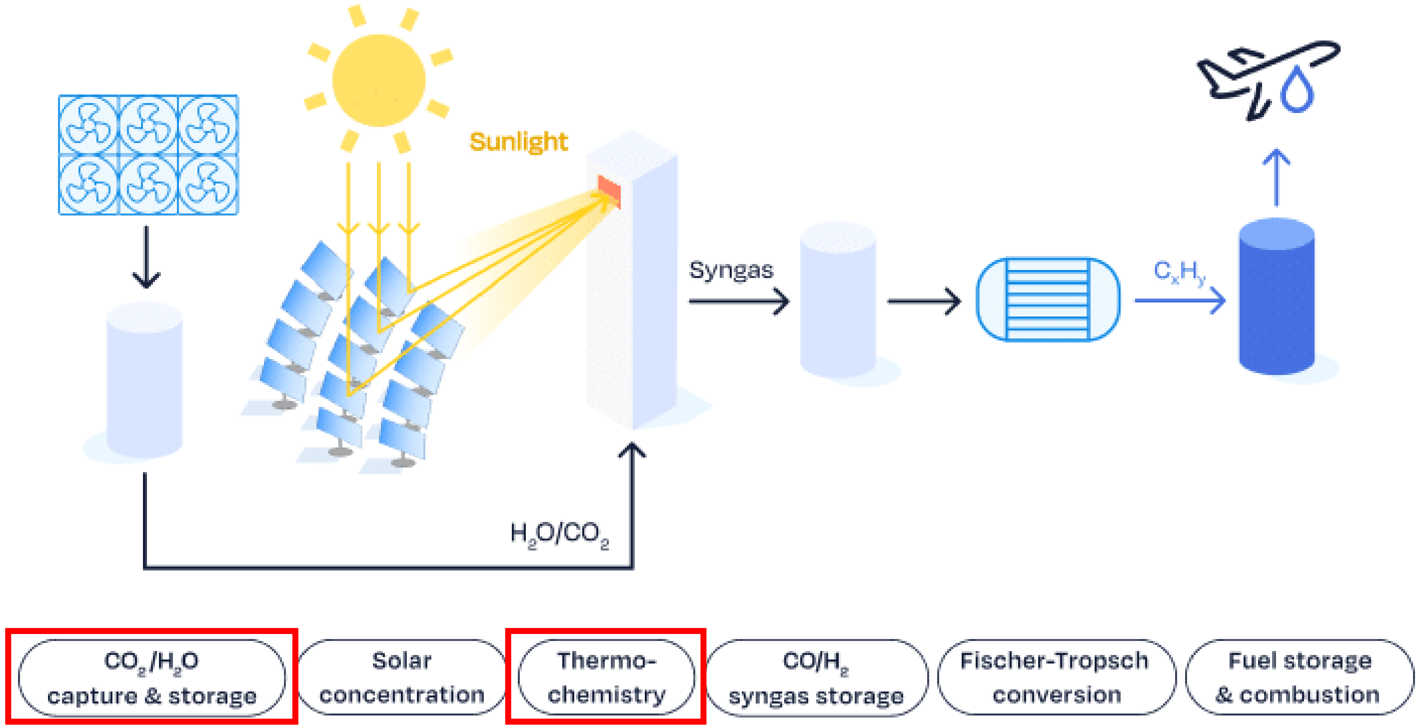
C. Falter, N. Scharfenberg, A. Habersetzer, "Geographical Potential of Solar Thermochemical Jet Fuel Production", Energies 2020, 13, 802

Energy Options and Multiple-Criteria Solutions

Energy carrier	Suitability	Sustainability	Scalability
GTL, CTL	Drop-in capable blend	Fossil carbon release	Commercial scale implementation
BTL		Potentially low carbon emission	Feedstock development, logistics and competition for bio-mass
HEFA			
New bio-fuels			
STL, PTL			Large-scale production less restrictive than for biofuels
LNG	Non-drop-in solution	Fossil carbon release	Existing infrastructure
LH_2		Potentially zero carbon emission	Distribution and storage
Electric power	Low specific energy in storage		Scalable through diversity and large-scale plants

Efficient Integrated Process Chain

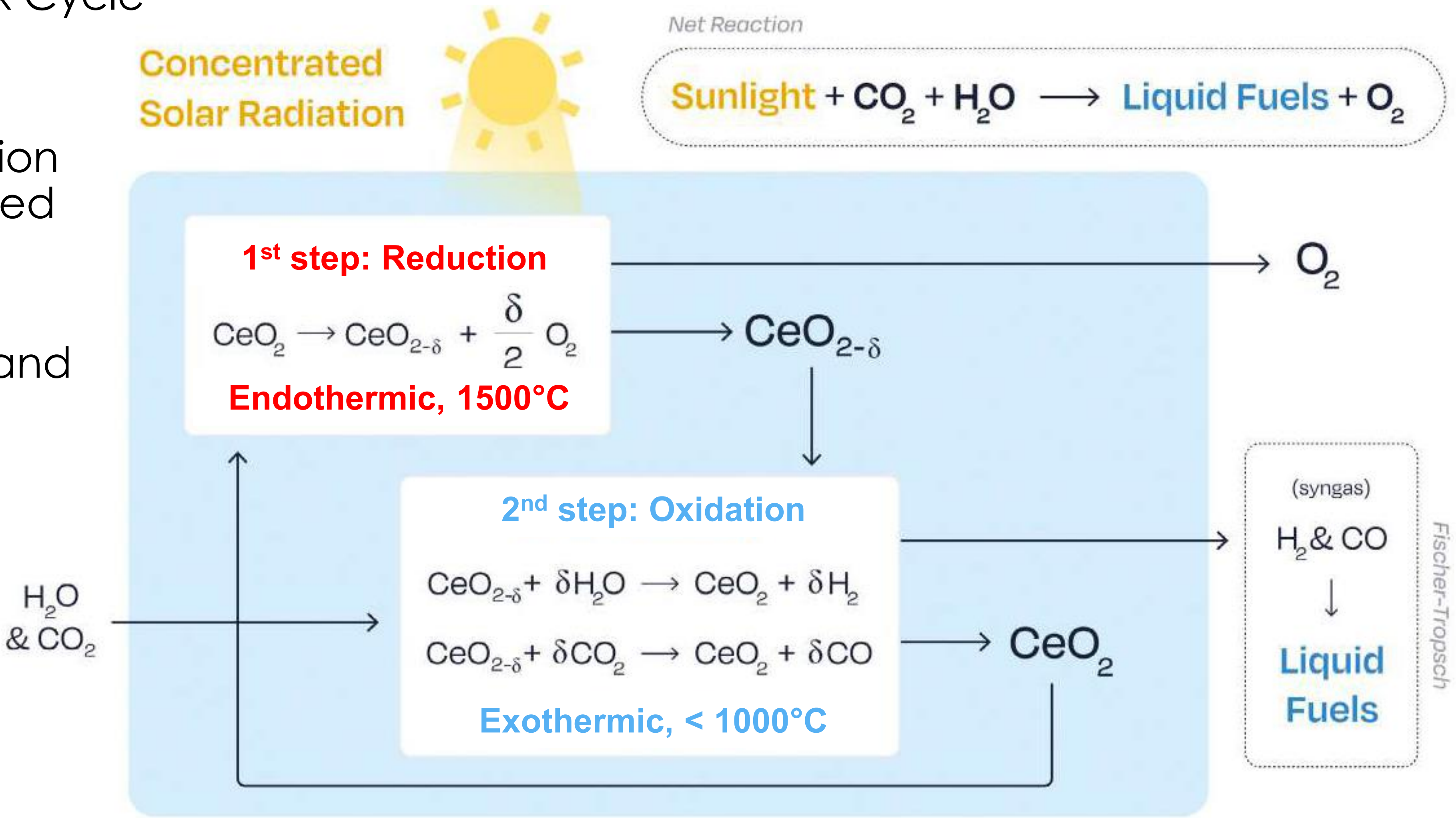
- Building on RIA projects
- Direct path from H_2O + CO_2 and sunlight to drop-in fuels
- Carbon-neutral ‘closed’ cycle
- Wide availability of most components
- Low TRL for DAC and the thermochemical reactor



Efficient Integrated Process Chain

Thermochemical Redox Cycle

- Simultaneous production of H_2 and CO in required ratio
- Two-step reaction separates O_2 from H_2 and CO



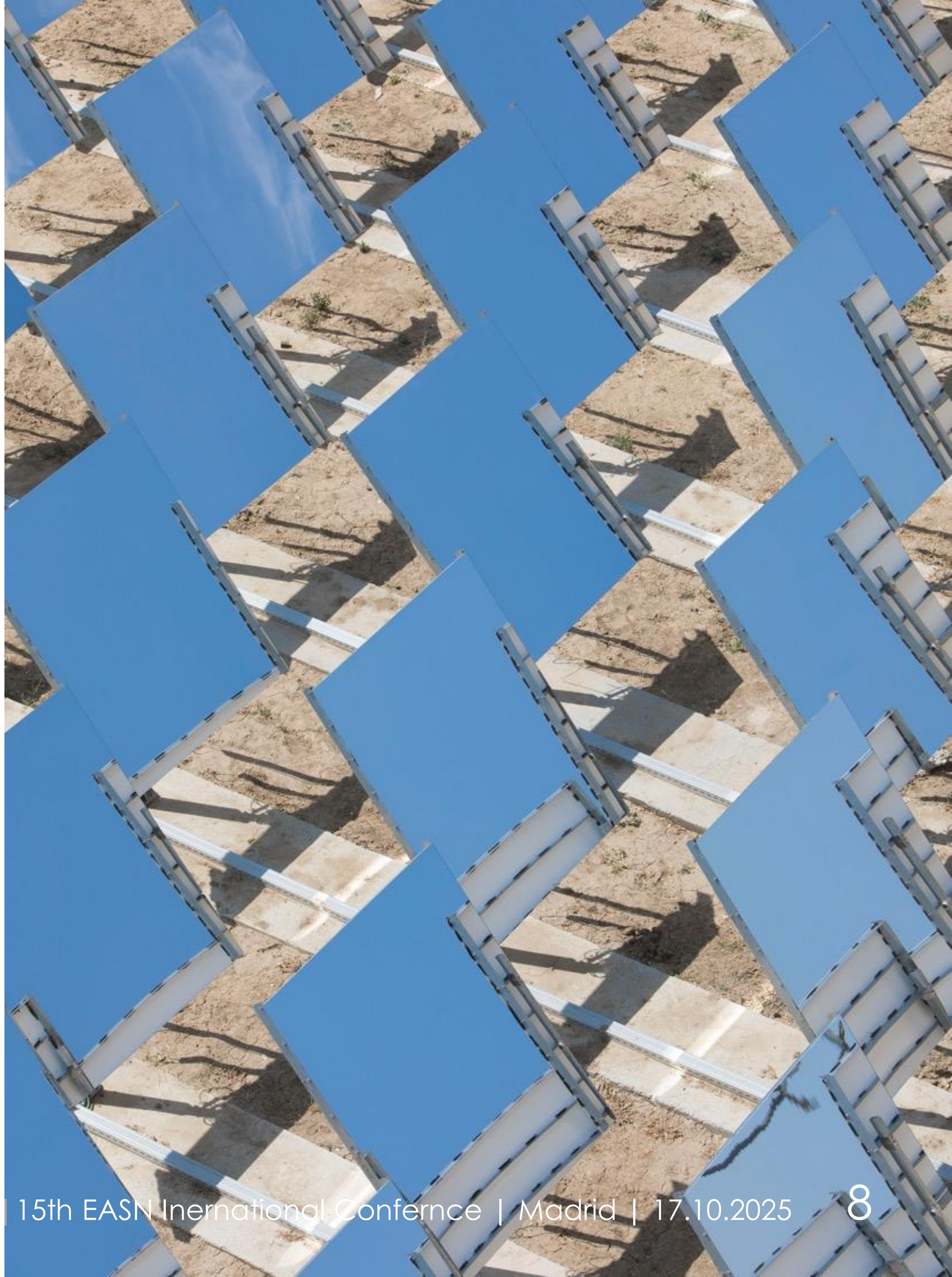
StL as Alternative to PtL — Why Diversity Matters

- Direct utilization of the full solar spectrum
- Bypasses endothermic RWGS which requires substantial excess H_2
- Ability to co-split CO_2 and H_2O simultaneously or separately

→ Thermodynamically interesting pathway to syngas production

→ Technology diversity reduces supply chain risks of critical materials and technologies

Zoller et al., 2022, A solar tower fuel plant for the thermochemical production of kerosene from H2O and CO2. Joule. 6. 1606-1616

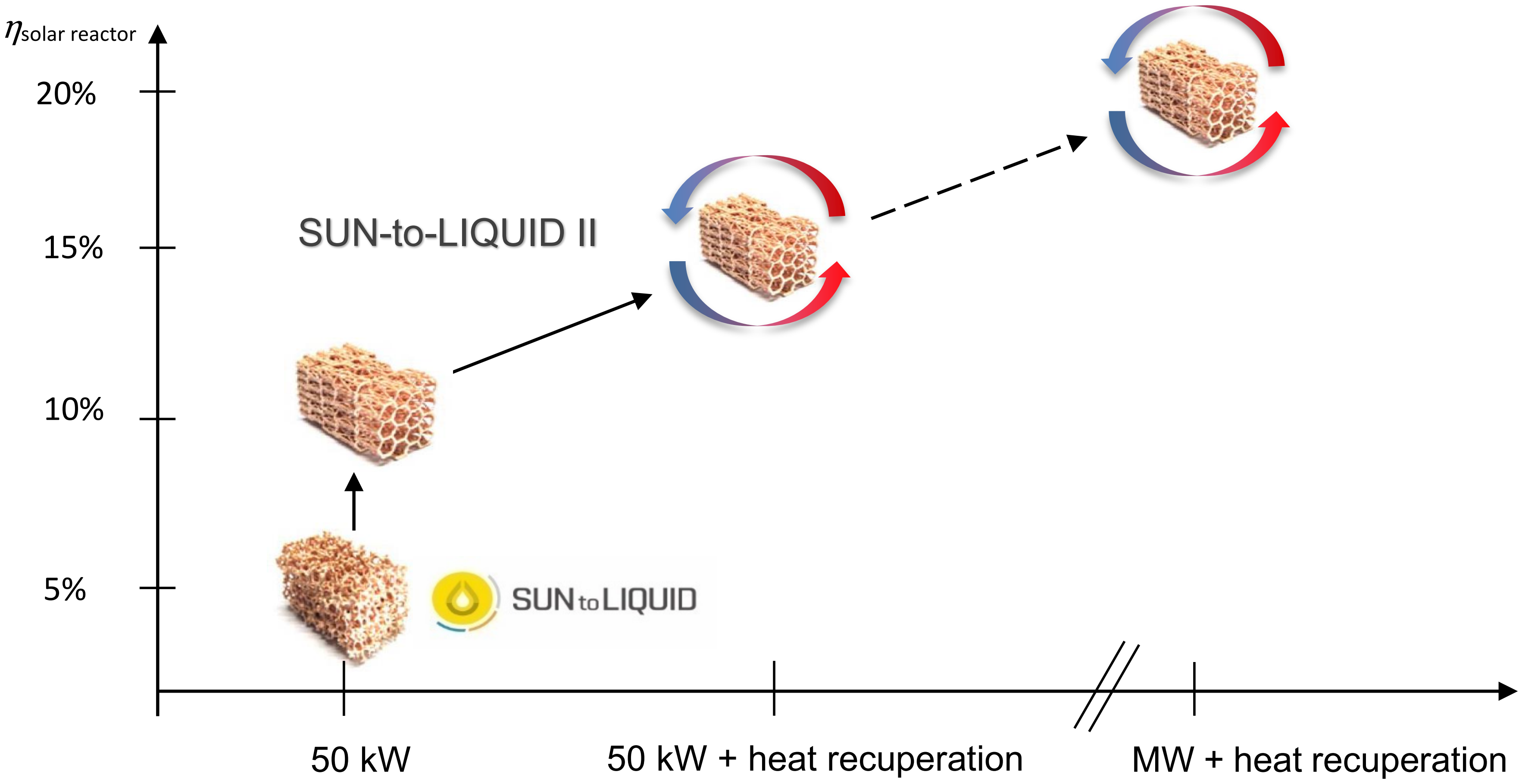


Proven Technological Feasibility

https://synhelion.com/news/worlds-first-motorcycle-ride-powered-by-synhelions-solar-gasoline
https://newsroom.swiss.com/pionierleistung-swiss-integriert-erstmals-solartreibstoff-von-synhelion-in-flugbetrieb/#

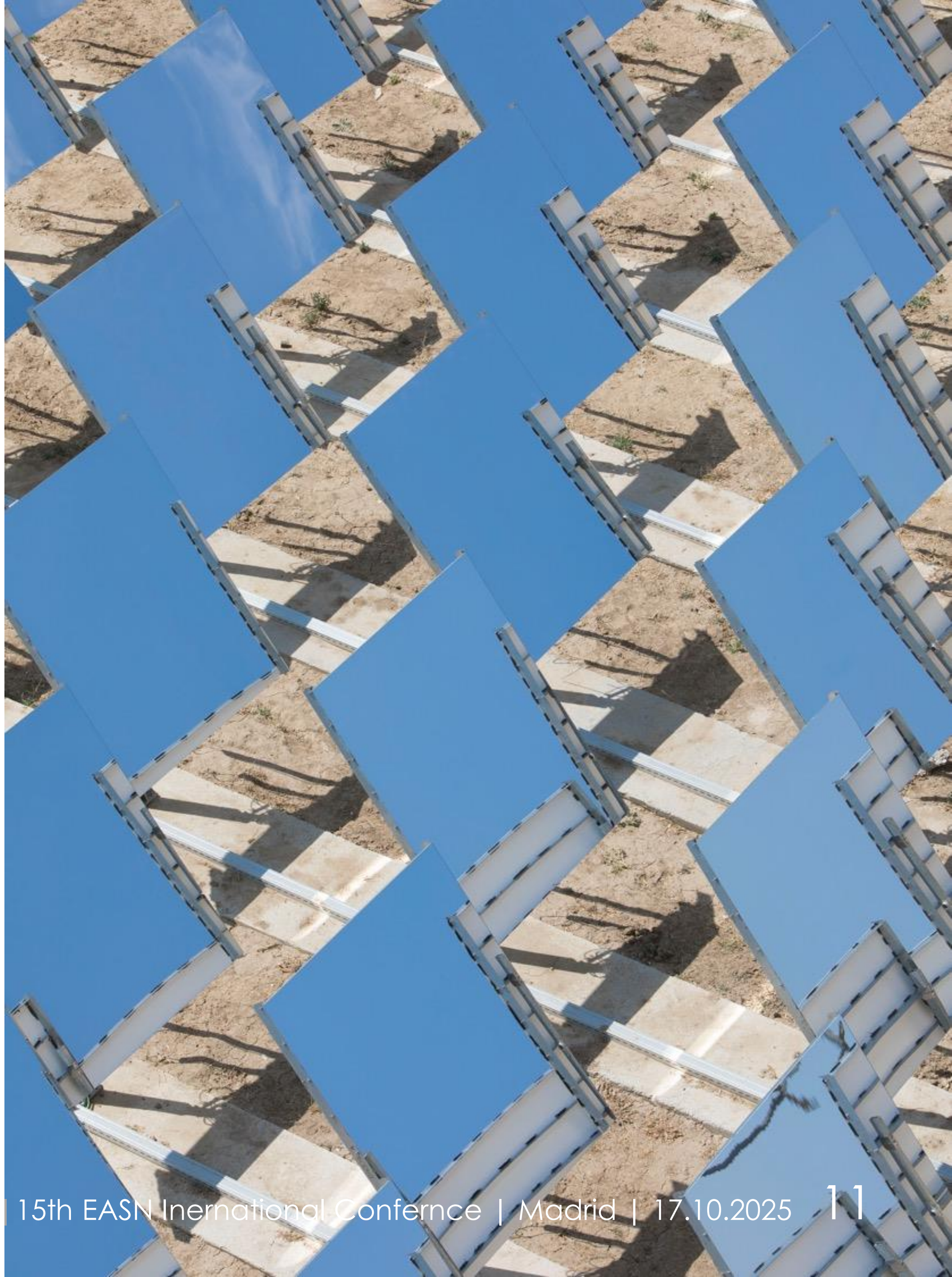
Project Ambition

Solar reactor efficiency:



Project Objectives

- Construction of a 50-kW demonstration plant
- Improve effective radiative absorption using 3D-printed redox materials
- Improvement of reactor efficiency to ~15 % by using heat recovery and sophisticated reactant structures
- Implementation of a catalyst recycling strategy
- Integrated system analysis of a future commercial-scale plant



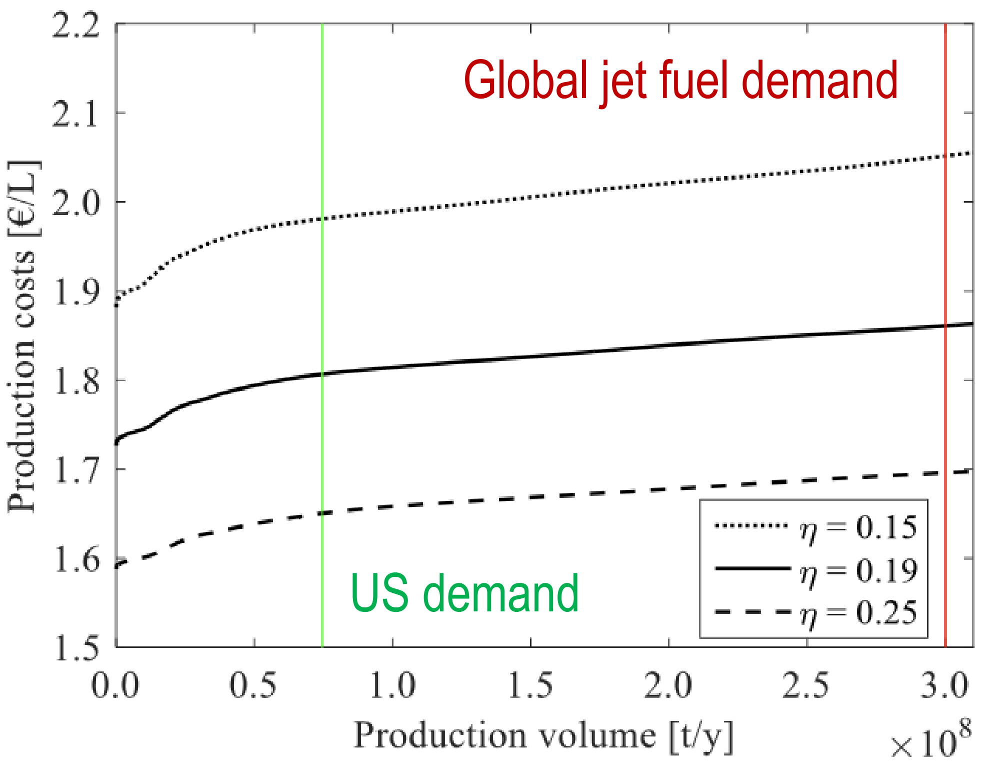
Technoeconomic Analysis

Cost-supply relation of production potential in the USA

- Costs between 1.74 and 1.88 €/L
- Reactor efficiency has a strong influence on fuel costs (1.6 €/L possible for 25% efficiency)

Maximum US potential ca. 780 Mt/a

- Corresponds to 2.6 x current world demand of jet fuel of 300 Mt/a.
- Available and preferred US locations mainly in the SW at high solar irradiation levels



Falter, Scharfenberg, Habersetzer, *Geographical potential of solar thermochemical jet fuel production*, Energies, Vol 13(4), 2020 www.mdpi.com/1996-1073/13/4/802

Life-cycle Emission Reduction Potential

Renewable CO_2 decisive for environmental performance

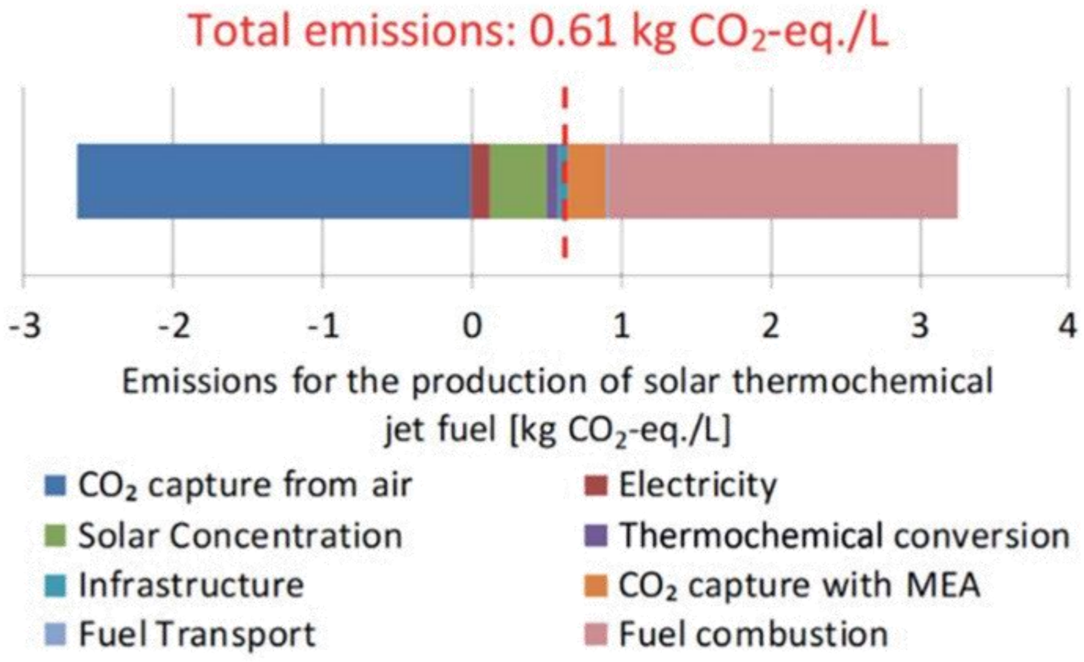
Drivers of emissions:

- Combustion of product
- Solar concentration infrastructure
- Thermochemical efficiency

Further leverage

- Higher optical efficiency or less material requirements
- Higher solar irradiation

→ **Reduction of GHG by 80%**
Conventional jet fuel: 3.0 kg/L



Falter et al., Sustainable Energy and Fuels, 4, 2020

Current Status

Key developments in progress:

1. Advanced reactor-recuperator design
2. Innovative 3D-structured reactant
3. Ultra-stable high flux solar concentrating facility
4. Fischer-Tropsch facility

To be integrated in one plant in 2026

Key Messages

1. Not competing with agricultural land use
   Global potential largely surpasses demand.
2. Simple Process Handling
   Key development lies in reactor efficiency.
3. Alternative to PtL
   Technological diversity is maintained while being competitive in terms of cost and GHG reduction.

Consortium:

Bauhaus Luftfahrt The Aviation Think Tank
institute IMDEA energy
DLR
HYGEAR THE GLOBAL HYDROGEN SOURCE
UPL
Synhelion

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