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Solar Fuels – A Sustainable Drop-in Solution for the Future of Aviation

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Content

- The Bauhaus Luftfahrt approach
- Solar thermochemical fuels
- Solar resource and land use
- Solar fuel economics and impact

The Bauhaus Luftfahrt approach

- A non-profit research institution with long-term time horizon
  - Strengthening the cooperation between industry, science and politics
  - Developing new approaches for the future of aviation with a high level of technical creativity
  - Optimizing through a holistic approach in science, economics, engineering and design

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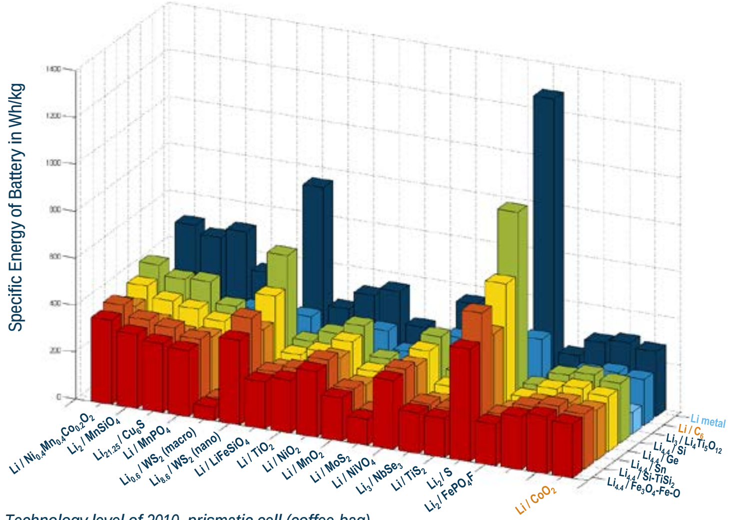
Renewable energy in aviation: Long-term view

- Basic energy options:
  - Lowest entry threshold: drop-in fuels
  - Adaption to novel fuels: non-drop-in fuels
  - Most radical approach: electric aviation



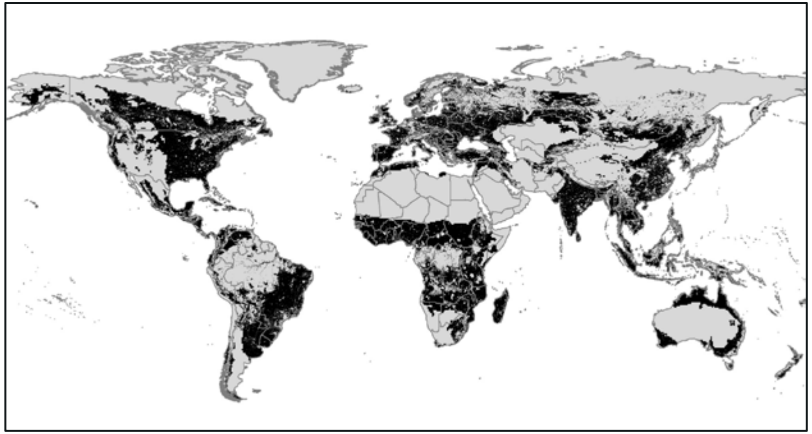
Technology level of 2010, prismatic cell (coffee-bag)

- Long-term strategy:
  - Sustainable feedstock availability:
    → Look beyond conventional biofuels
  - Limited efficiency of well-to-wake energy usage:
    → Look beyond conventional power systems: eAviation, hybrid systems

Renewable energy in aviation: Long-term focus

- Renewable energy focus:
  - eAviation innovation potential: key technologies, e.g. battery performance
  - Fuel-battery hybrid approaches: extend eAviation range

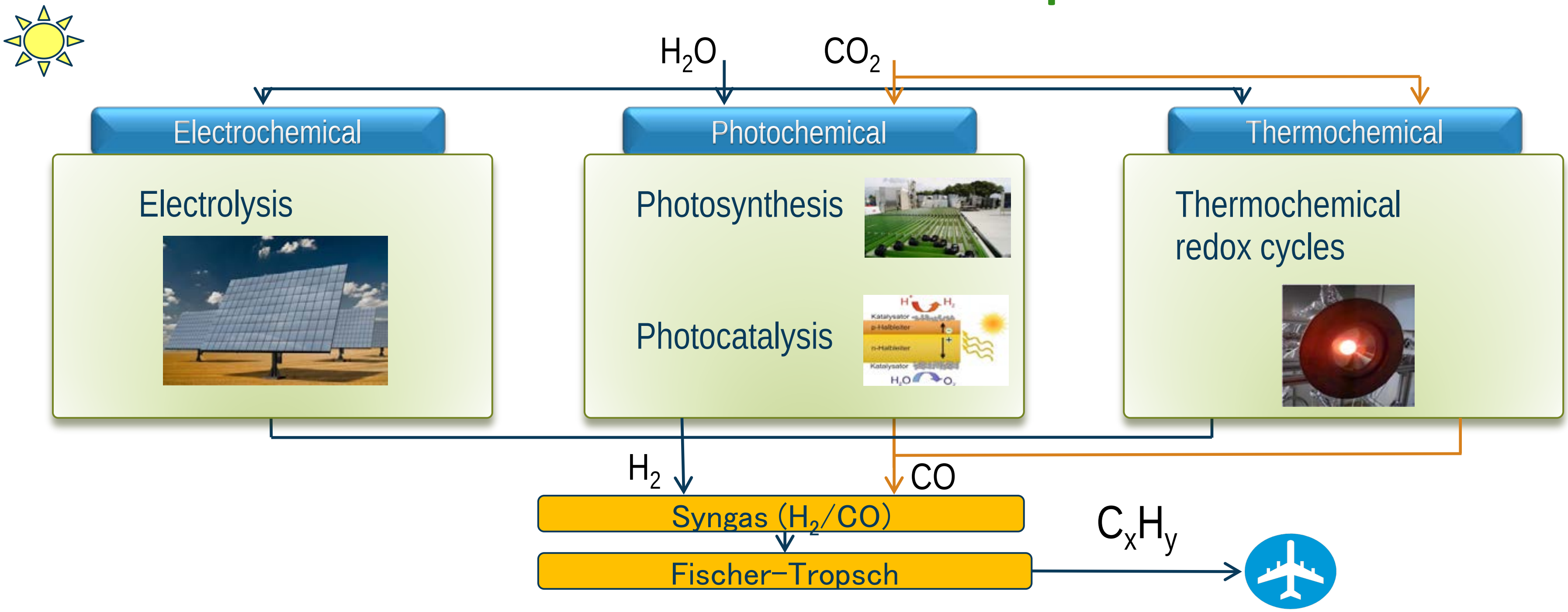
- Renewable drop-in fuels:
  - Global bio-energy potential
  - Novel fuel production paths: e.g. solar fuels



Jet fuel alternatives– long-term perspectives

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			
SOLAR-JET (STL)			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	Non-fuel energy carrier, low specific energy		Potentially scalable through diversity and large-scale plants

Paths to solar Fischer-Tropsch fuels



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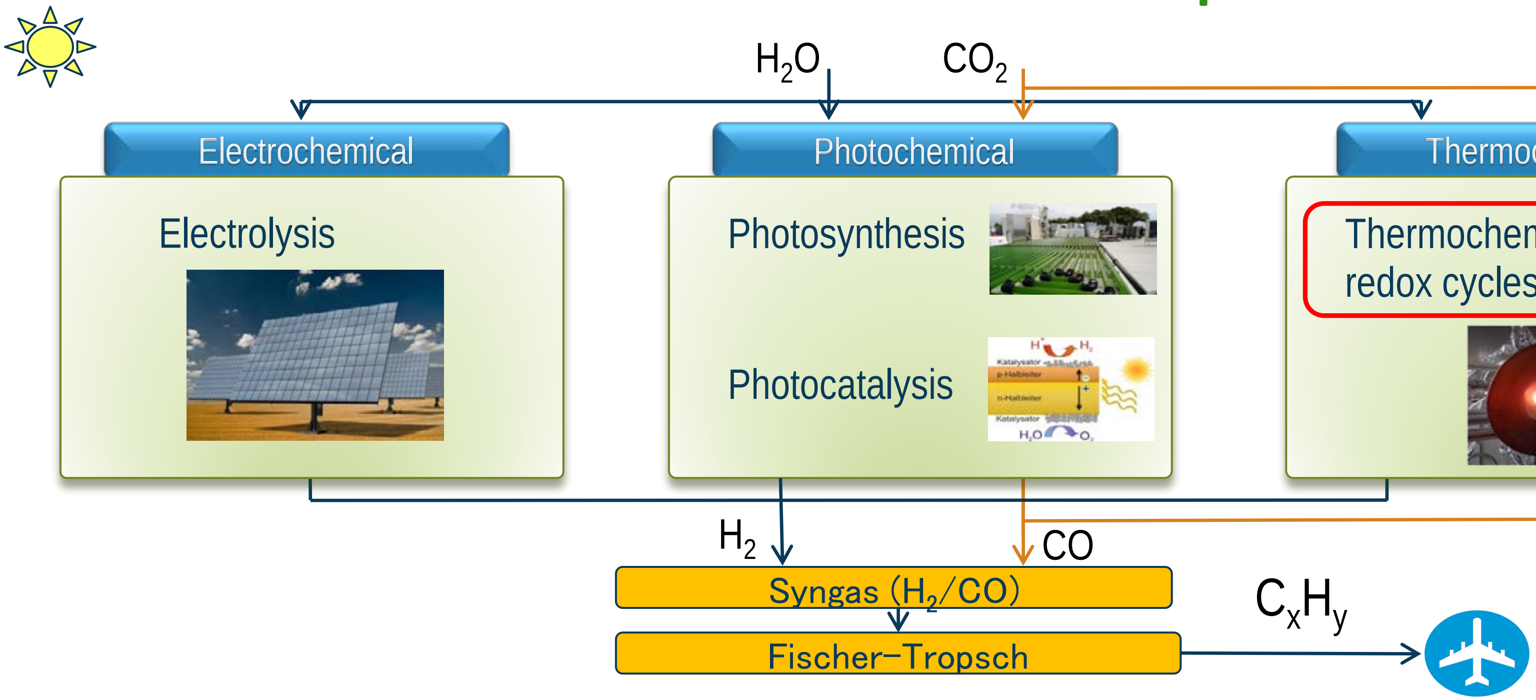
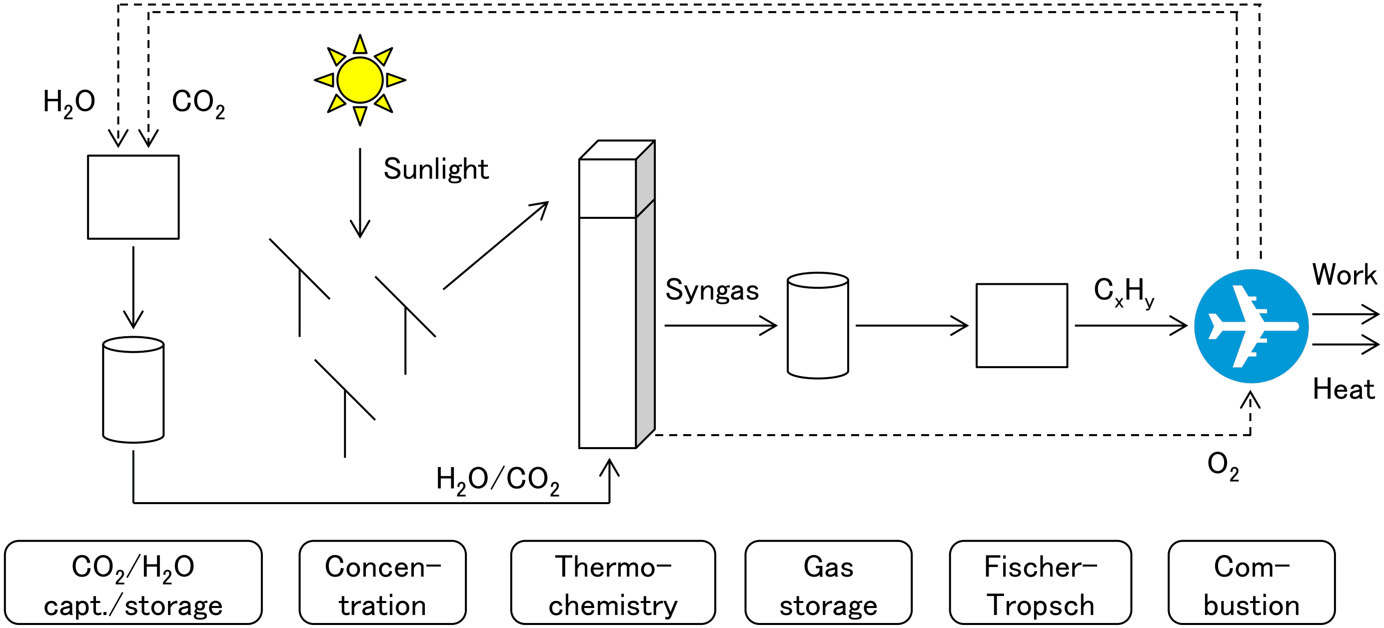


Fuel production cycle - overview

- Most process steps already proven on an industrial scale
- Lowest technology readiness level for thermo-chemical conversion and CO_2 capture



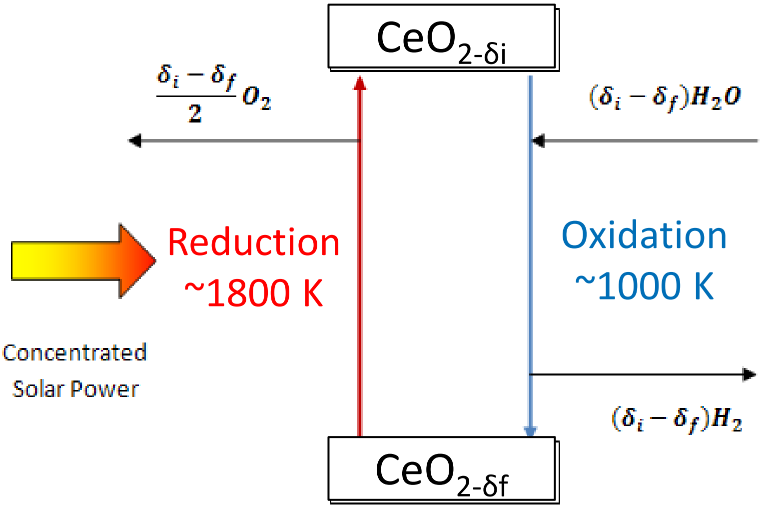
Solar thermochemical syngas production

- Two-step solar thermochemical process to produce syngas
- Reduction with oxygen depleted purge gas at high temperatures (~1800 K):

  $CeO_2 \rightarrow CeO_{2-x} + x/2 \cdot O_2$
- Reoxidation with steam and/or carbon dioxide at lower temperatures (~1000 K):

  $CeO_{2-x} + x \cdot H_2O \rightarrow CeO_2 + x \cdot H_2$

  $CeO_{2-x} + x \cdot CO2 \rightarrow CeO_2 + x \cdot CO$
- Syngas is a precursor for solar kerosene



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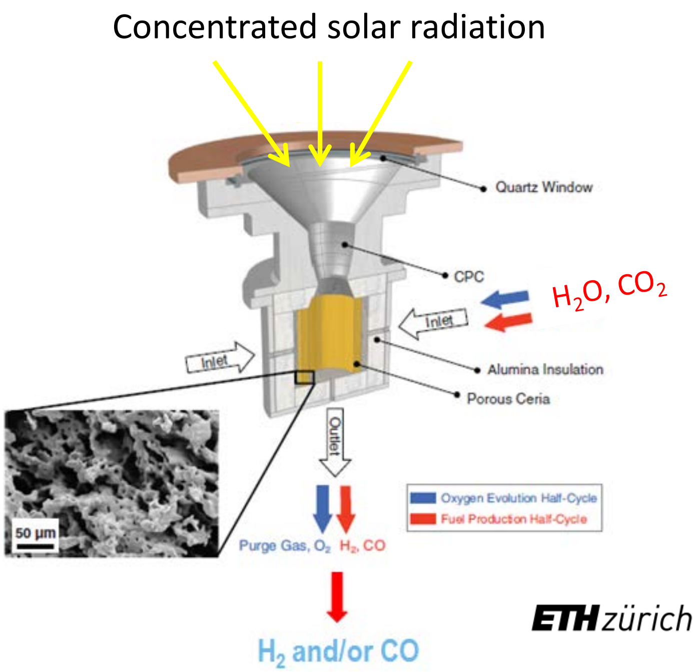


ETH zürich

First-ever solar kerosene

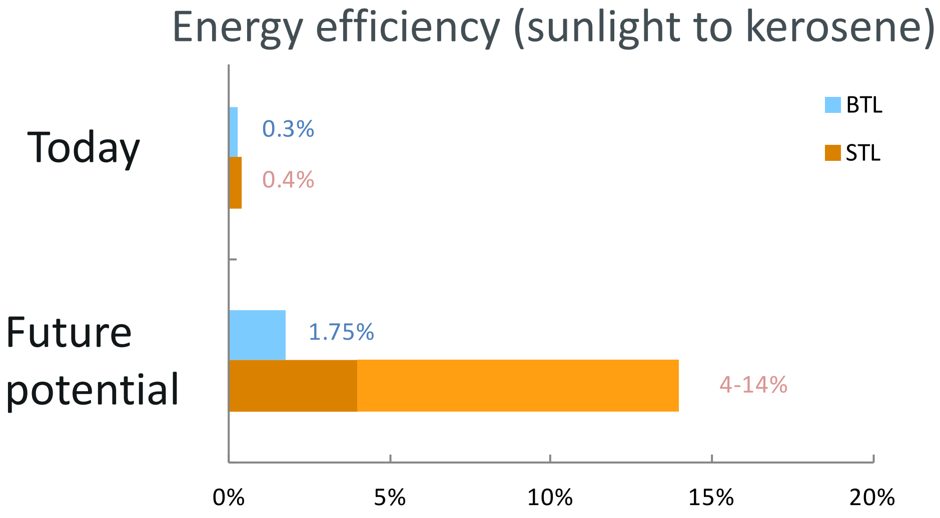
Fischer-Tropsch products synthesized at Shell

Energy efficiency – STL vs. BTL

Future potential	
Sunlight-to-liquid (STL)	
Concentration	50-85%
Thermochemistry	20-30%
Fischer-Tropsch	50%
Total:	**≈4-14%**

Biomass-to-liquid (BTL)	
Photosynthesis	5%
Gasification	70%
Fischer-Tropsch	50%
Total	**≈1.75%**

Today	
BTL, STL:	**≤ 0.3%**

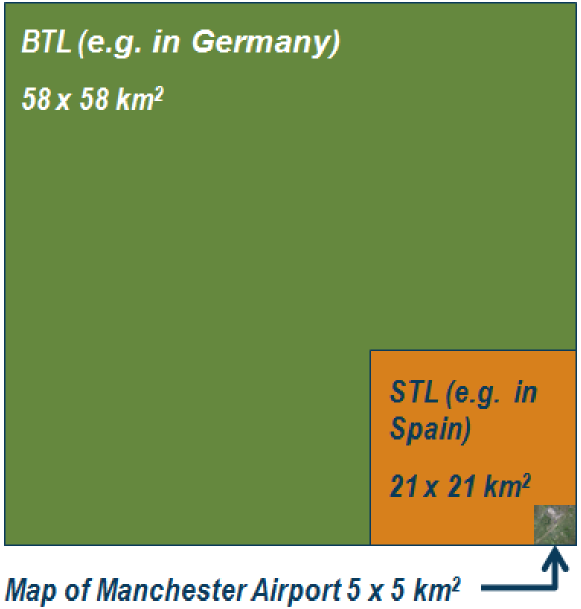


Land requirement, example Manchester Airport

- Fuel demand:
  - 3 Mio. liters per day

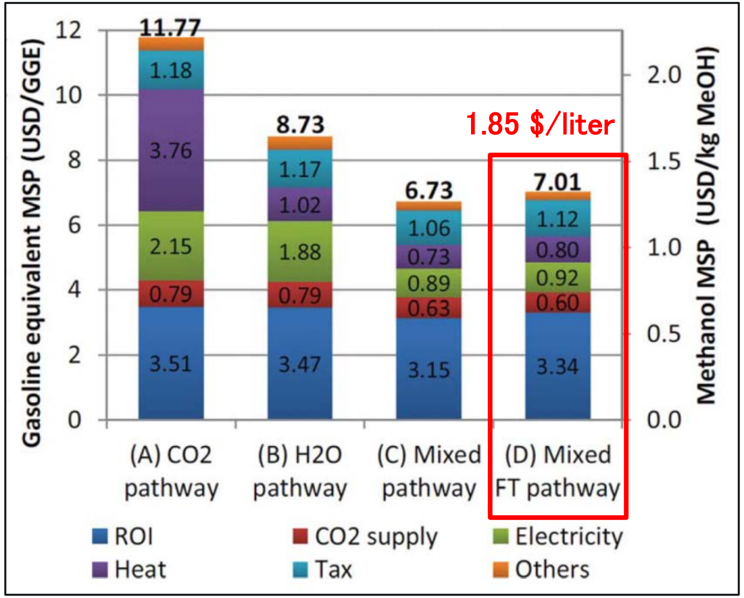
- Assumptions for productivity
  - Short rotation woody crops, BTL
    - (unconcentrated) solar-to-jet fuel conversion efficiency of 0.55 %
  - Solar thermochemical conversion, STL
    - (unconcentrated) solar-to-jet fuel conversion efficiency of 4.33%

- Required total ground area:
  - BTL: 3380 km^2 (58 x 58 km^2)
  - STL: 433 km^2 (21 x 21 km^2)



STL - Economics

- Economics dominated by large investment cost and cost of capital
  - Mainly due to collection of solar energy and interest
    =>Thermochemical efficiency decisive
- A path efficiency of ~10% is assumed to be required for economic viability
- Own calculations: Production costs of 1.3-2.9 $/l (publicly owned facility)



Source: Kim et al., Energy and Environmental Science, 2012

Conclusions

- **Solar thermochemical fuels**
  - Solar fuels could provide suitability, scalability and sustainability
- **Solar resource and land use**
  - Smaller and complementary land use wrt biofuels
- **Solar fuel economics**
  - 1.3-2.9 $/l production costs estimated for publicly owned future facility

Contact and acknowledgement

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SOLAR-JET
Zero-carbon jet fuel from sunlight

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Neue Wege.

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