ICAO AVIATION AND SUSTAINABLE ALTERNATIVE FUELS WORKSHOP

ICAO Headquarters, Montréal, Canada

18 to 20 October 2011

Long-term Renewable Energy Perspectives in Aviation

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Christian Endres, Prof. Dr. Mirko Hornung

Bauhaus Luftfahrt

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The Bauhaus Luftfahrt

- founded in 2005 by
  - The Bavarian Ministry of Economic Affairs, Infrastructure, Transport and Technology
  - EADS (incl. subsidiaries)
  - Liebherr Aerospace
  - MTU Aero Engines
- A non-profit research institution with long-term time horizon
  - a holistic approach in science, economics, engineering and design
- Going „New Ways“ for the mobility of tomorrow

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Key elements of long-term renewable energy perspectives

- Global bio-energy potential
- Solar fuels
- All-electric aircraft

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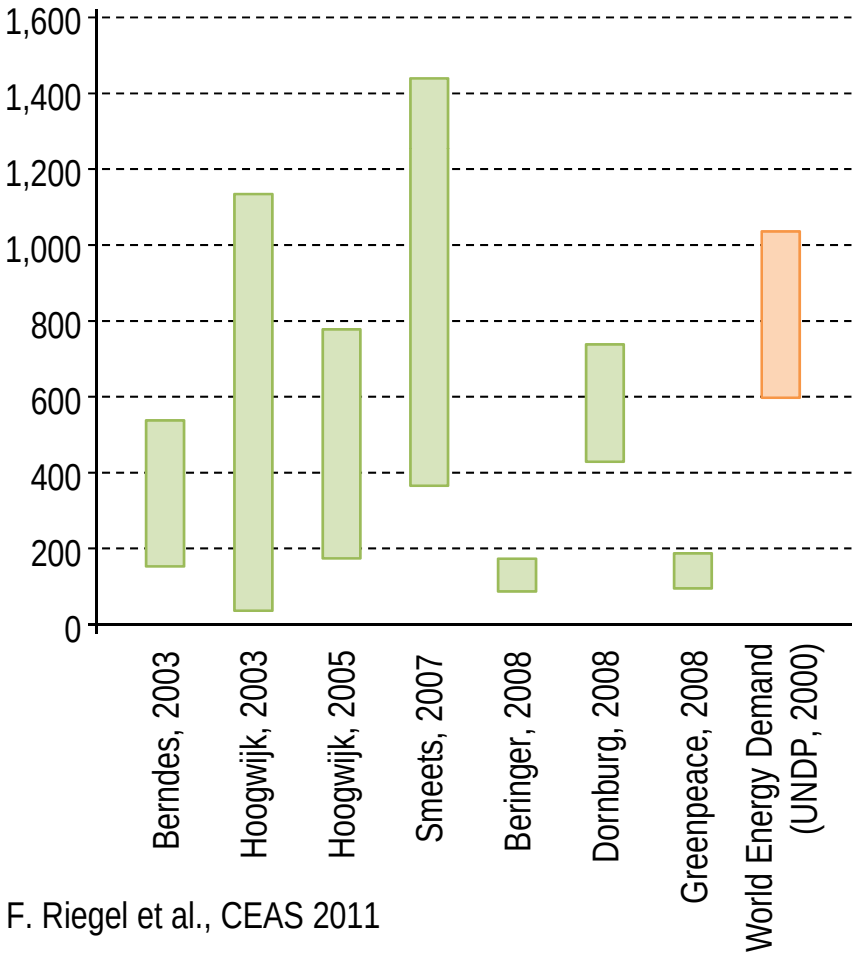
Global bio-energy potential

The long-term substitution of conventional kerosene by sustainable bio-fuel

- needs a well-performing biomass market,
- needs a sufficient biomass resource base

Global potentials for primary bioenergy in 2050 and the projected world energy demand, expressed in EJ yr^{-1}



F. Riegel et al., CEAS 2011

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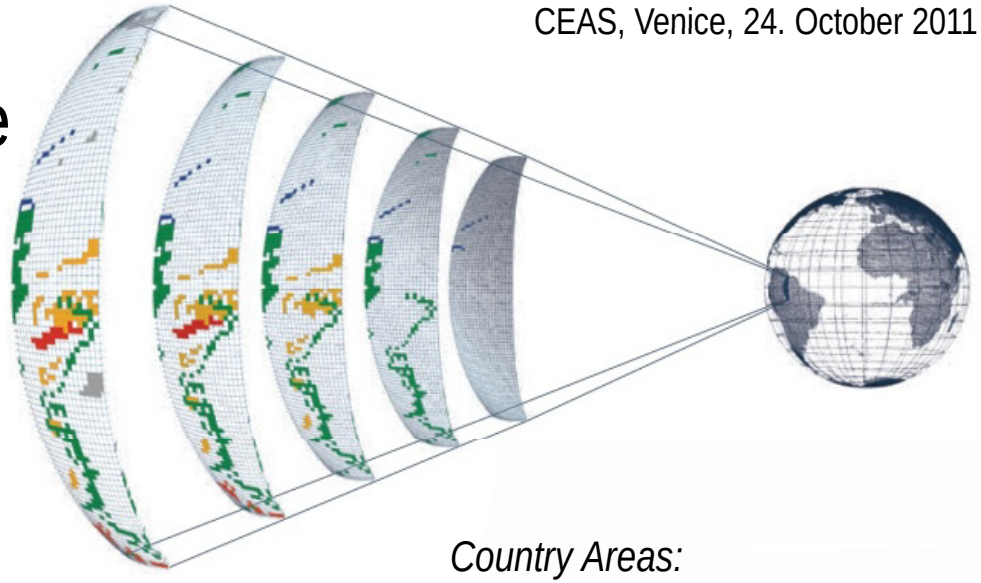
Global bio-energy potential

The long-term substitution of conventional kerosene by sustainable bio-fuel

- needs a well-performing biomass market,
- needs a sufficient biomass resource base,
- needs a careful re-evaluation of the global bio-energy potential
- based on high-resolution geo-data

F. Riegel, J. Steinsdörfer, “Bio-energy in aviation”, CEAS, Venice, 24. October 2011



Country Areas:

>> Inland Water Bodies

>> Forest Areas

>> Constrained Habitats

>> Conservation Zones

>> Settlement Areas

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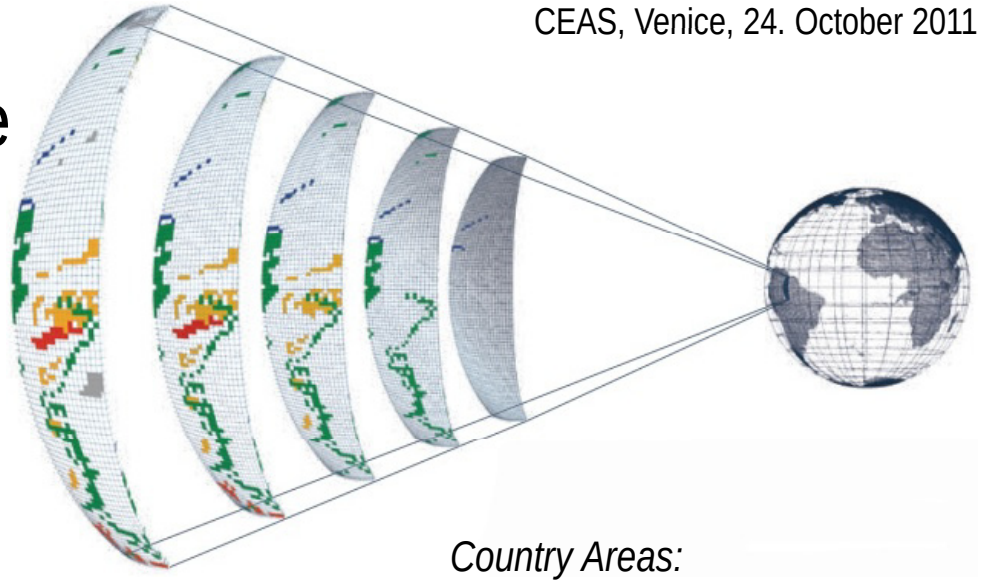
Global bio-energy potential

F. Riegel, J. Steinsdörfer, “Bio-energy in aviation”, CEAS, Venice, 24. October 2011

The long-term substitution of conventional kerosene by sustainable bio-fuel

- needs a well-performing biomass market,
- needs a sufficient biomass resource base,
- based on “net area”, food & cultivation patterns, energy crops yields
- Include non-agricultural biomass
- Other credible plan to produce feedstocks?



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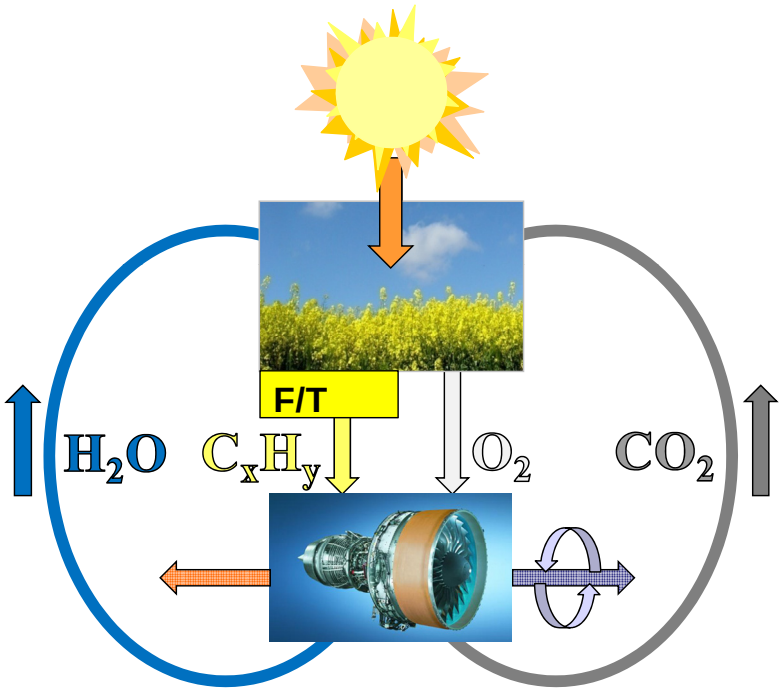
Basic considerations for long-term energy options

- Drop-in capable hydrocarbon fuels
  - Lowest system barrier
  - Very high exergy density
- Non-drop-in fuels
- Electric energy carriers



"Sunlight to liquid" (STL)

- Drop-in capable hydrocarbon fuels
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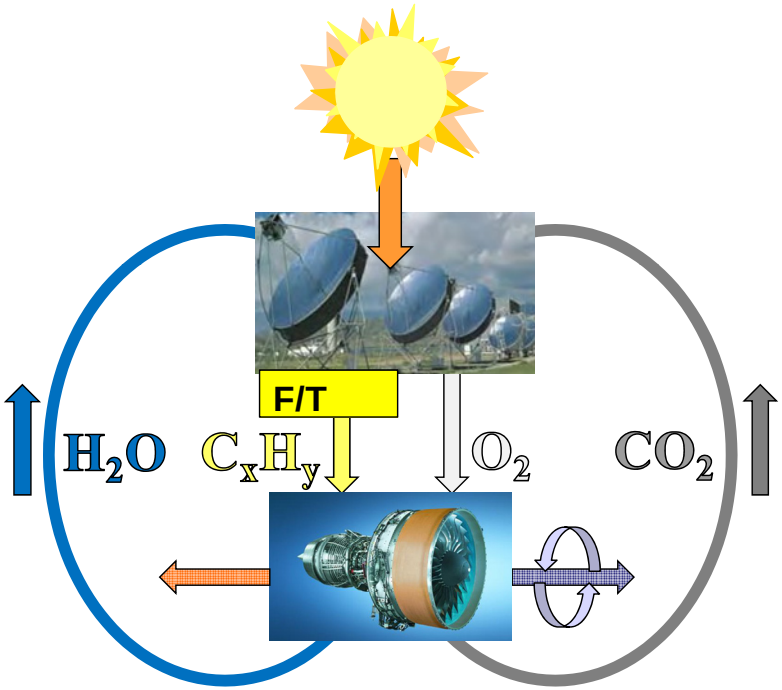
  - Very high exergy density
- Non-drop-in fuels
- Electric energy carriers



"Sunlight to liquid" (STL)

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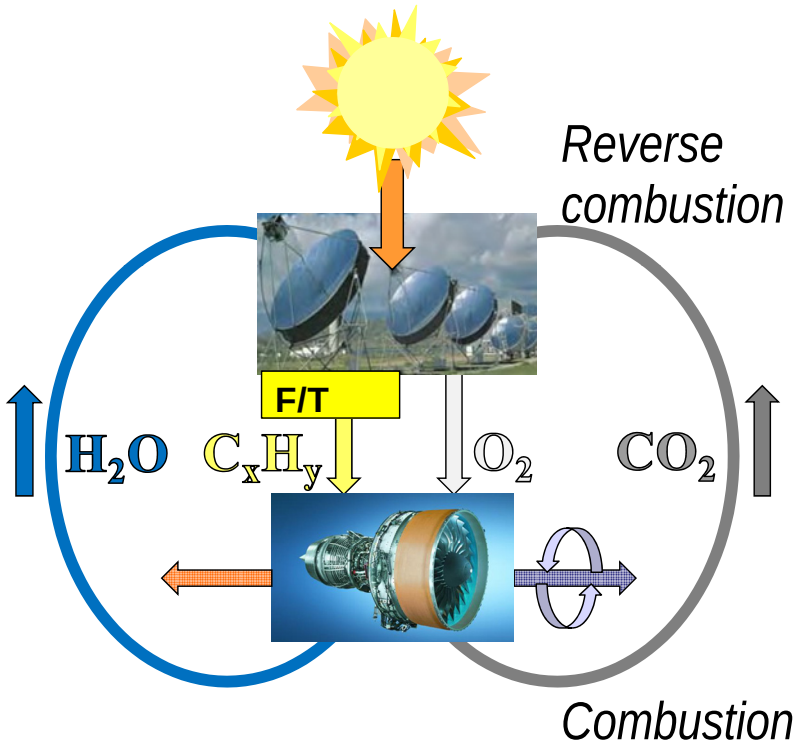
  - CO_2 becomes a resource!
- Non-drop-in fuels

- Electric energy carriers



Solar thermochemical reactor

- Drop-in capable hydrocarbon fuels
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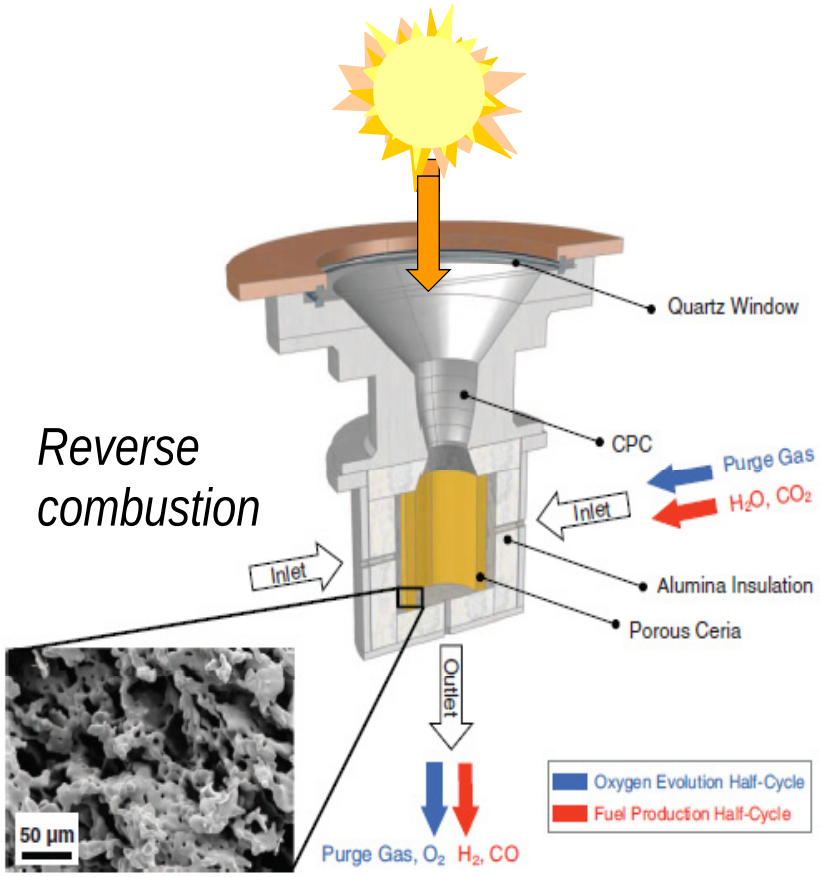
  - Very high exergy density
  - CO_2 becomes a resource!
- Non-drop-in fuels

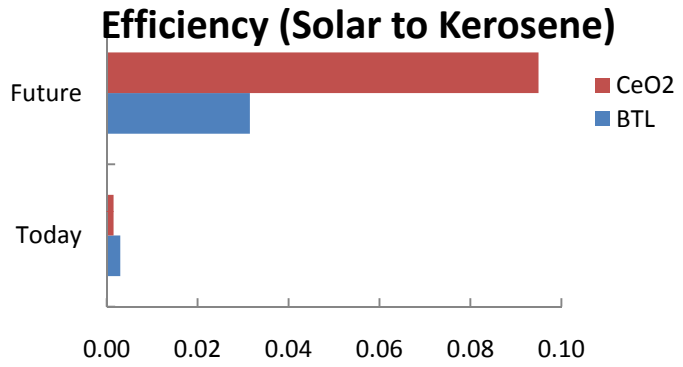
- Electric energy carriers



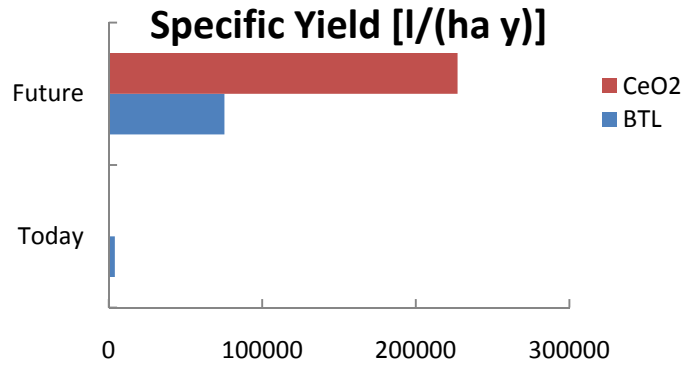
From: „High-Flux Solar-Driven Thermochemical Dissociation of CO2 and H2O Using Nonstoichiometric Ceria“, Chueh et al., Science 330, 1797 (2010)

Theoretical potential of STL versus BTL

- Drop-in capable hydrocarbon fuels
  - Lowest system barrier
  - Very high exergy density
  - CO_2 becomes a resource!
- Non-drop-in fuels



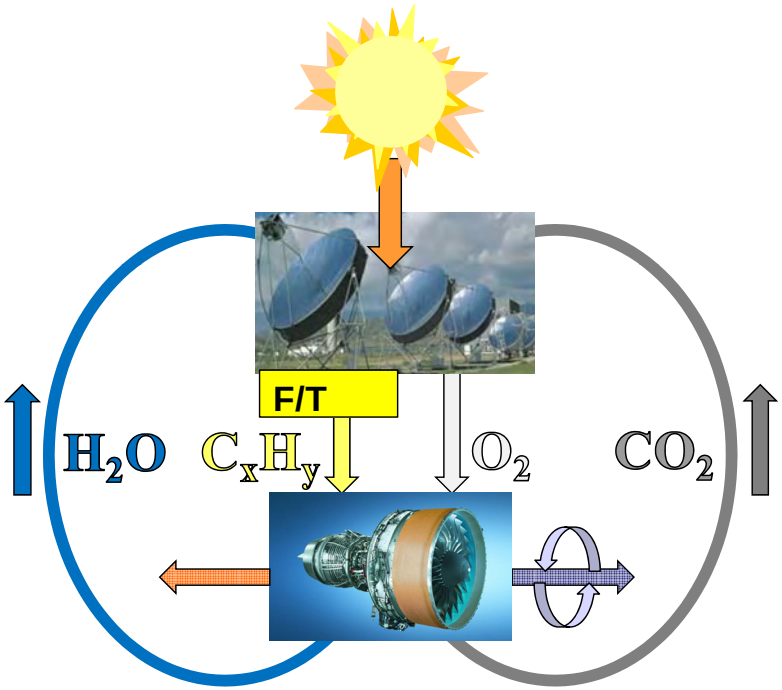
- Electric energy carriers



Solar non-drop in fuels?

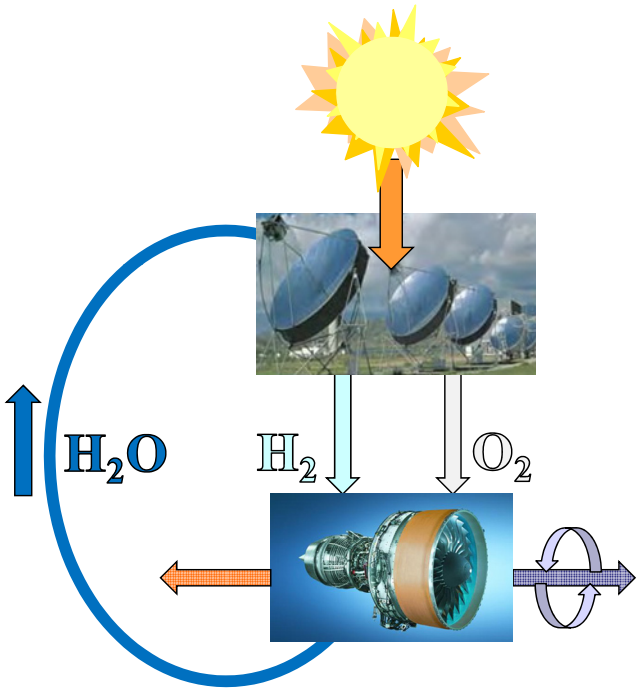
- Drop-in capable hydrocarbon fuels
  - Lowest system barrier
  - Very high exergy density
  - CO_2 becomes a resource!
- Non-drop-in fuels
  - High system barriers

- Electric energy carriers



Solar hydrogen

- Drop-in capable hydrocarbon fuels
  - Lowest system barrier
  - Very high exergy density
  - CO_2 becomes a resource!
- Non-drop-in fuels
  - High system barriers
  - Require great primary benefits to offset cost of implementation
- Electric energy carriers



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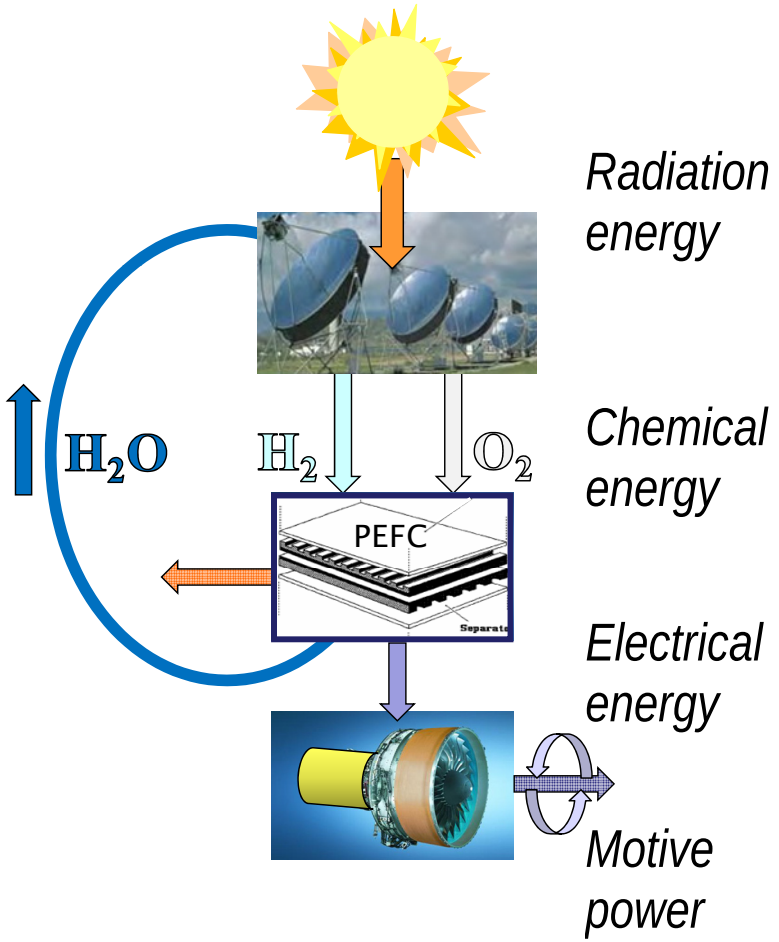
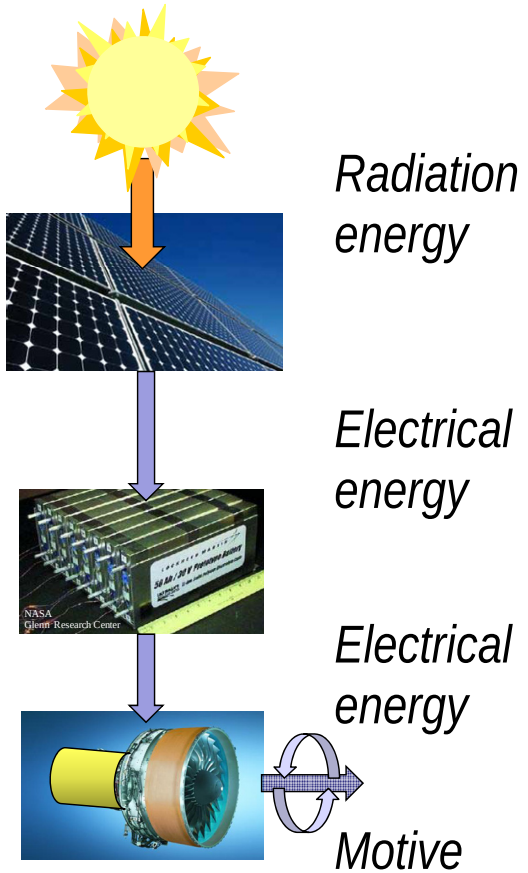


All-electrical power system

- Drop-in capable hydrocarbon fuels
  - Lowest system barrier
  - Very high exergy density
  - CO_2 becomes a resource!
- Non-drop-in fuels
  - High system barriers
  - Require great primary benefits to offset cost of implementation
- Electric energy carriers
  - Radical redesign of power systems and aircraft architectures
  - Low exergy density (but rapid progress)
  - Zero emission, flexibility in choice of primary energy



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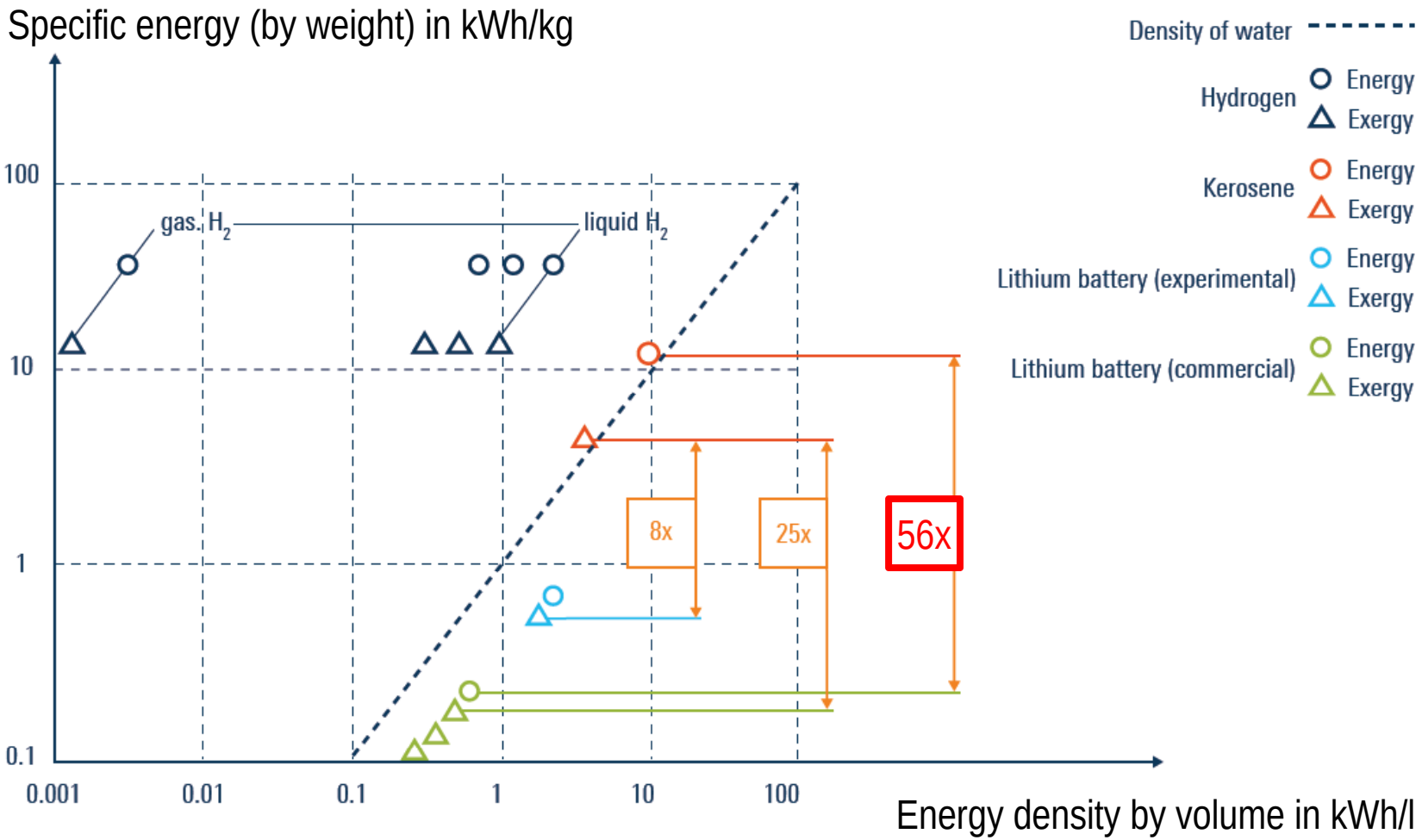
The energy gap of kerosene vs. battery: a factor of 56



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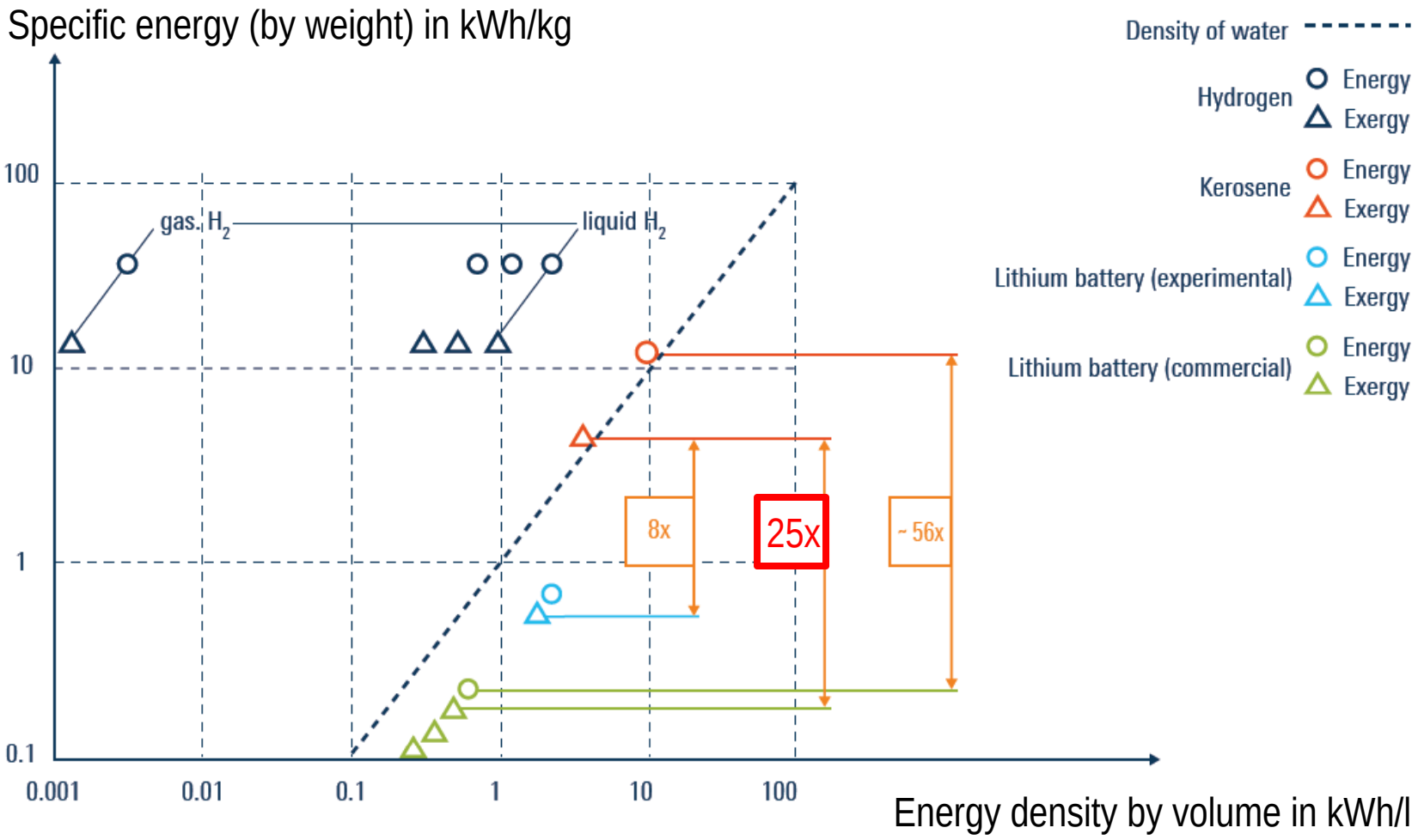
The exergy gap of kerosene vs. battery: a factor of 25



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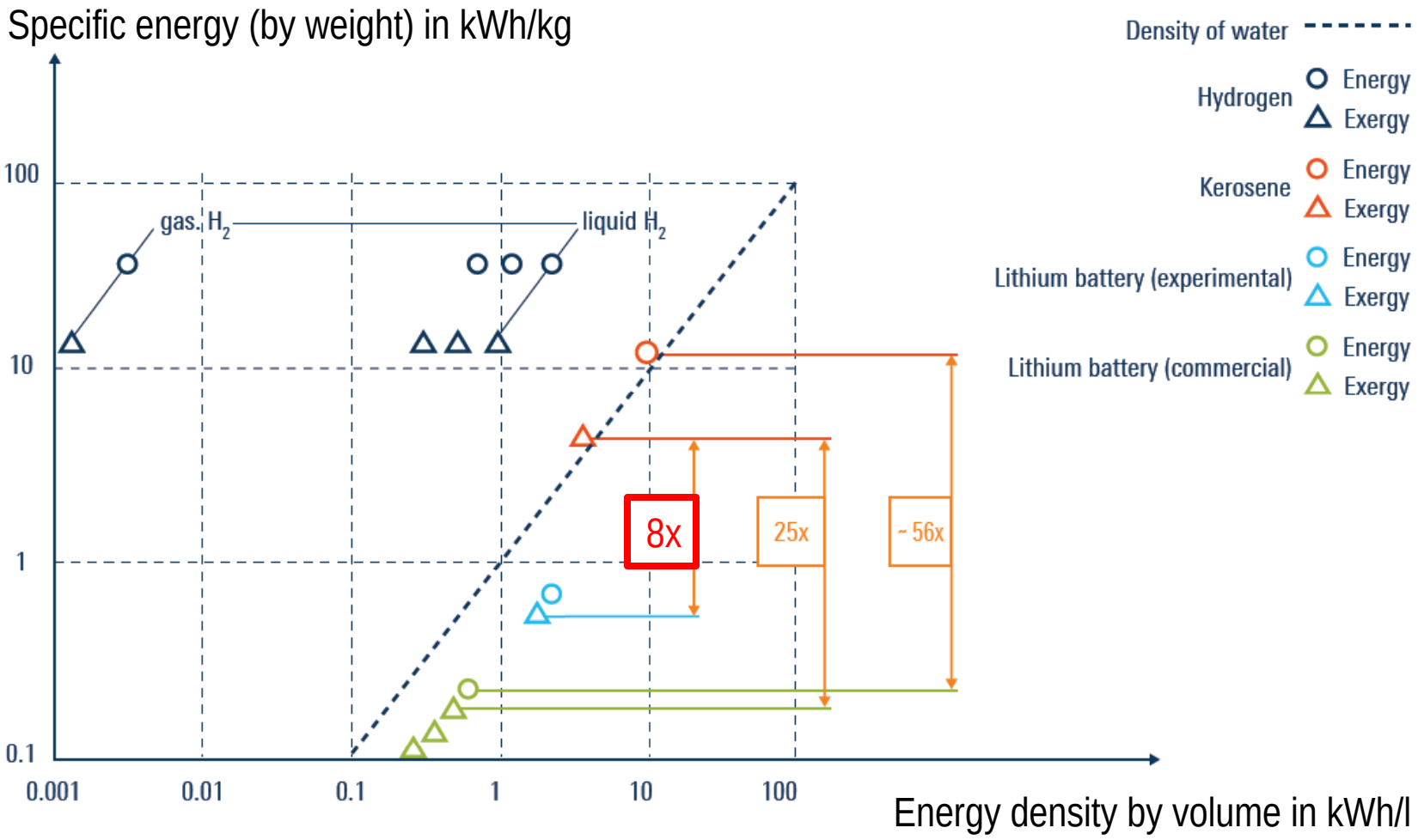
The potential exergy gap of kerosene vs. battery: a factor of 8



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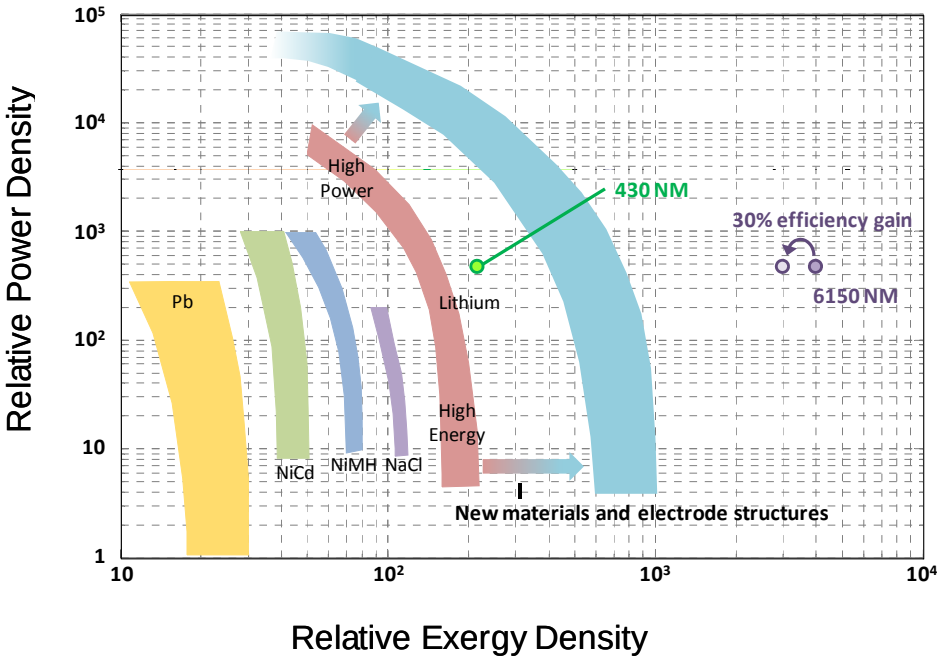
Zero emission feasibility assessment



- Exergy (useable energy): the energy density is an insufficient criterion for assessing the feasibility of electric flight
- Ragone metrics: Exergy and power densities are the key indicators for electric aircraft feasibility in the comparison of alternative power sources

[1] A. Sizmann, Fuelling the Climate 2010, Hamburg, 18. June 2010

[2] H. Kuhn et al., "Renewable energy perspectives for aviation", CEAS, Venice, 24. October 2011

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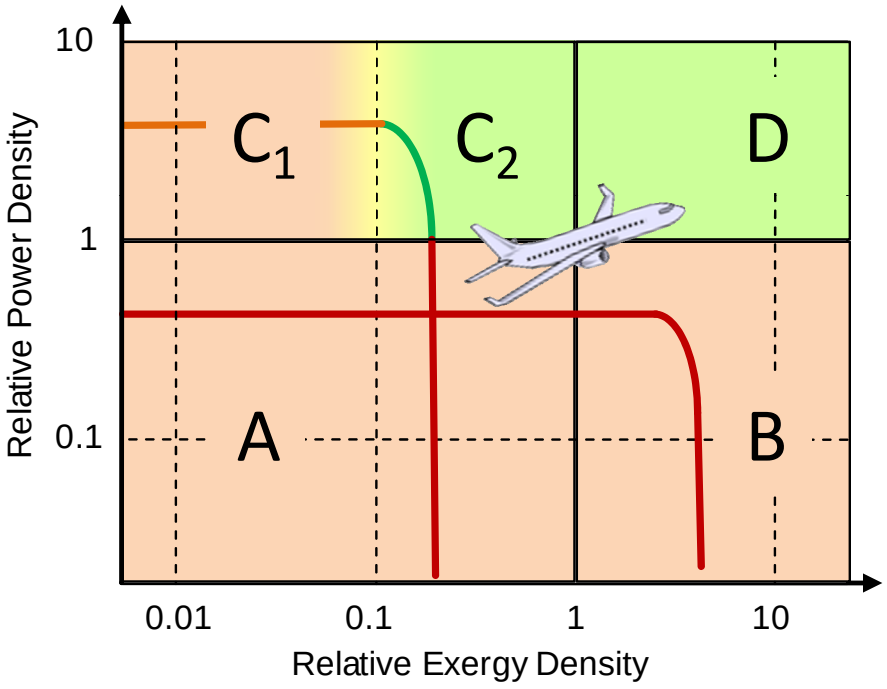
Zero emission feasibility assessment



- Exergy (useable energy): the energy density is an insufficient criterion for assessing the feasibility of electric flight
- Ragone metrics: Exergy and power densities are the key indicators for electric aircraft feasibility in the comparison of alternative power sources
- Hybridization degree of freedom: energy storage devices each inadequate may be an enabling energy system in combination

[1] A. Sizmann, Fuelling the Climate 2010, Hamburg, 18. June 2010

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Conclusions of long-term renewable energy perspectives

- Global bio-energy potential
  - High-resolution assessment in progress
  - BTL efficiency now 0.3%, later 3%
- Solar fuels
  - Potential high-yield pathway
  - CO_2 becomes a resource
- All-electric aircraft
  - Ragone metrics based feasibility assessment
  - Potential zero-emission aircraft