Role of CCU in fully renewable energy systems

Christian Breyer
LUT University, Finland

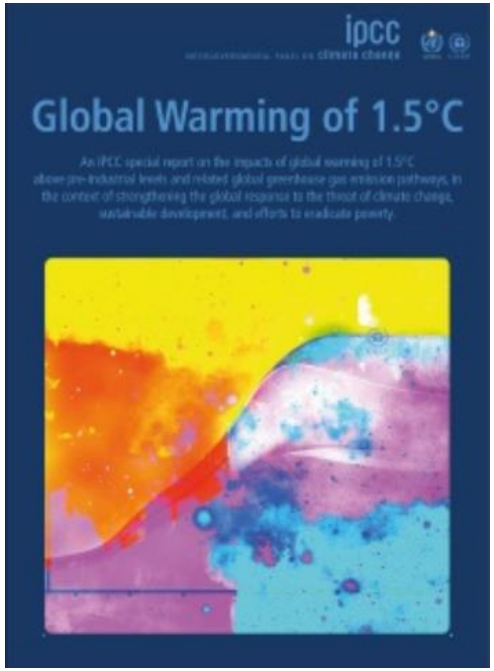
Renewable Energy and CCU
CO_2 Value Europe
Virtual Workshop, January 29, 2021

Background

European Green Deal

Paris Agreement

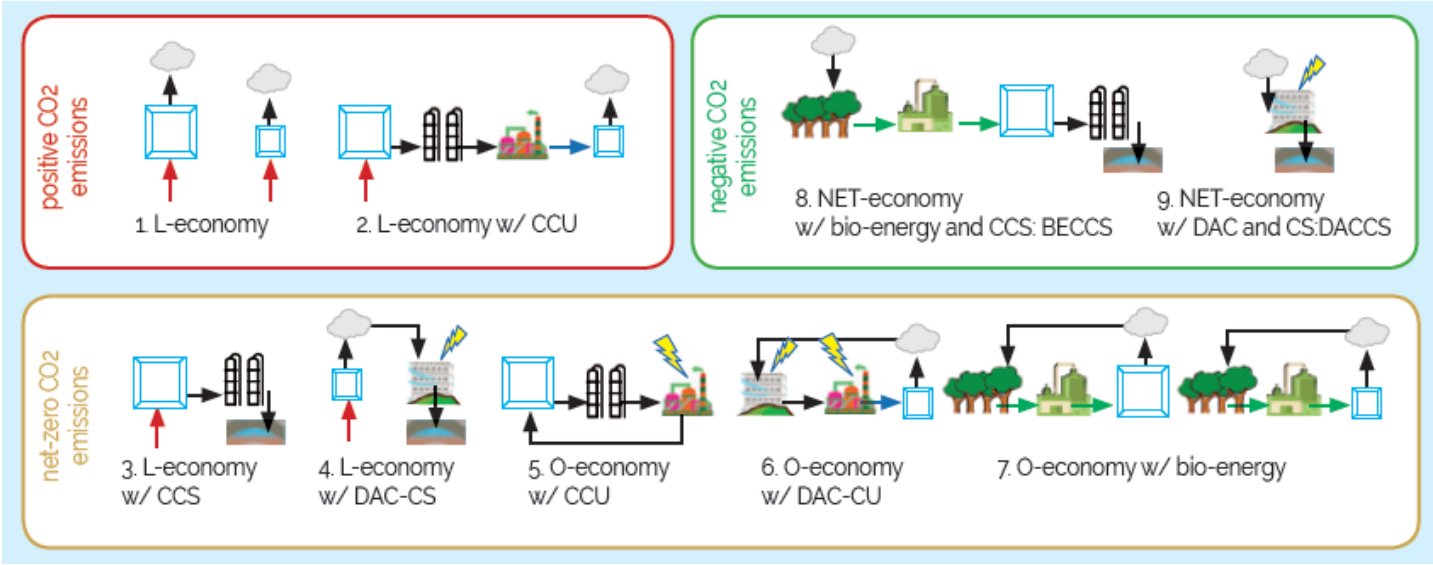
("well below 2ºC")

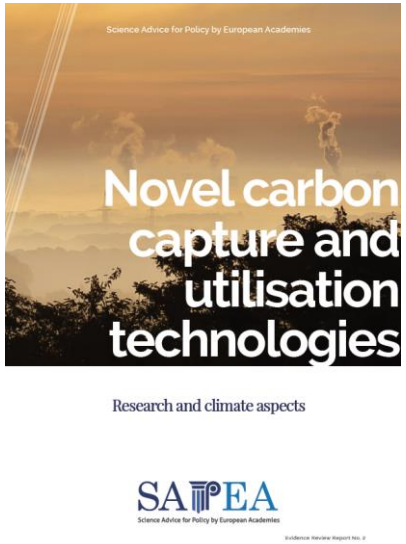


What does it mean?

- (net) zero greenhouse gas (GHG) emissions by 2050 are mandatory
- negative GHG emissions are costly, risky, with unclear responsibilities
- thus zero GHG emissions is the real target for the energy system

Carbon Capture and Utilisation



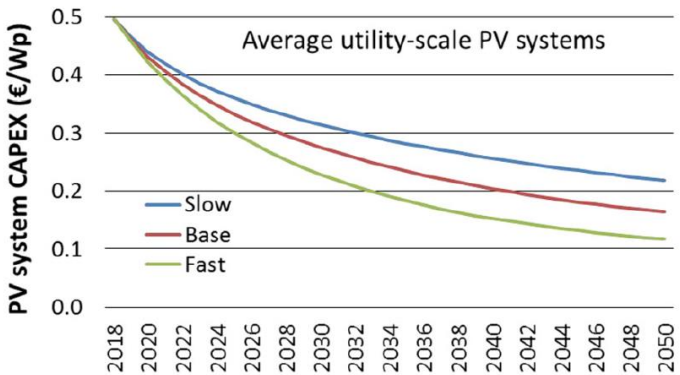


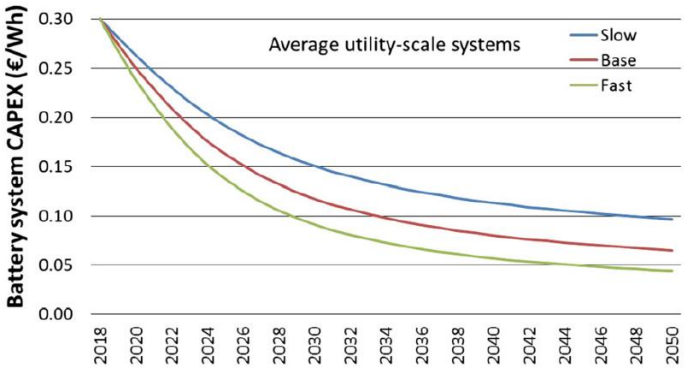
Valuable CCU routes

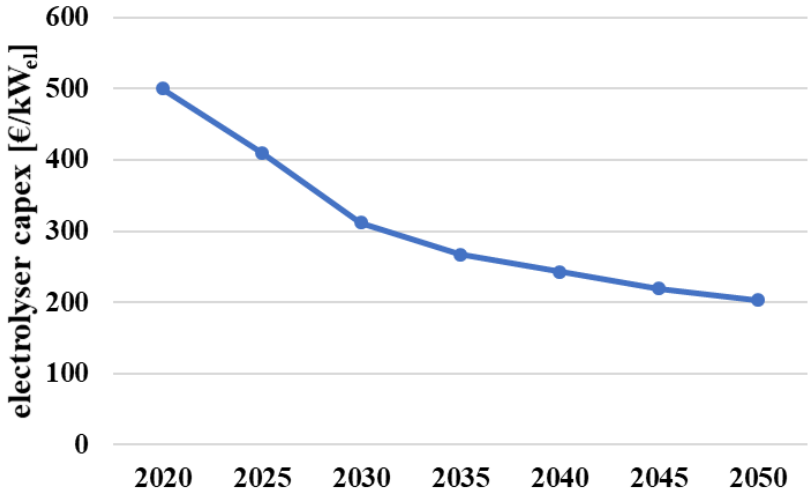
- (2): cement mills and CO_2 emissions related to limestone, as the only not avoidable fossil CO_2 route
- (5): in practice works only for waste incinerators: MSW-CC-U-Power-to-Methanol-Plastics-MSW route
- (6): CO_2 DAC enables the DACCU route, which is the only scalable CCU route
- (7): pulp and paper mills are attractive for bio-CO_2, while bioenergy is limited and expensive (energy crop)

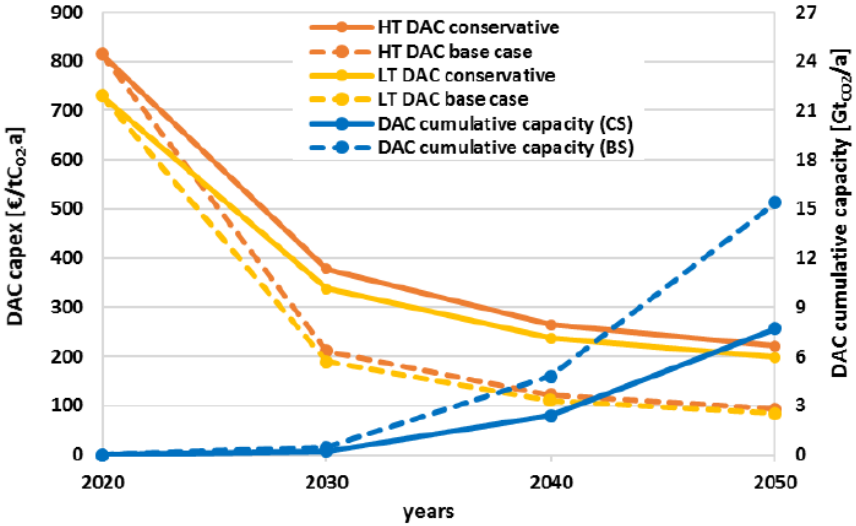
Routes (2) – cement, (5) waste incinerators, and (7) pulp and paper mills imply CO_2 point source capture
Route (5) requires CO_2 DAC, is scalable, more flexible in site locations, but higher in cost in the beginning

Key Diagrams for massive PV induced Change









Key insights:

- massive continued cost decline for solar PV, wind, battery, electrolysers, CO_2 DAC
- massive pressure to eliminate all fossil fuels
- massive direct and indirect electrification of all energy sectors and non-energetic fossil fuel demand

References:
PV, battery: Vartiainen et al., Progress in PV
Electrolyser: LUT model assumption, Nature
CO_2 DAC: Fasihi et al., J of Cleaner Prod

LUT Energy System Transition Model

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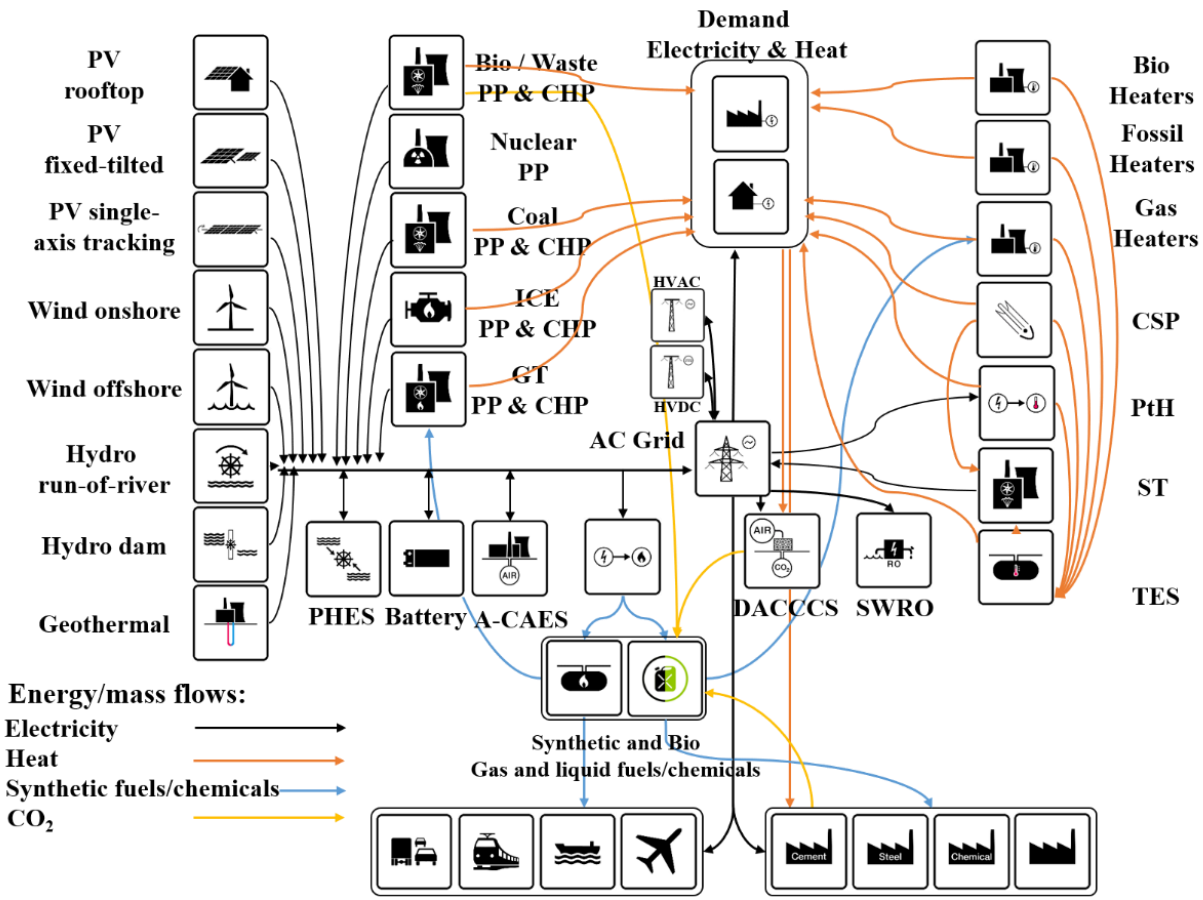
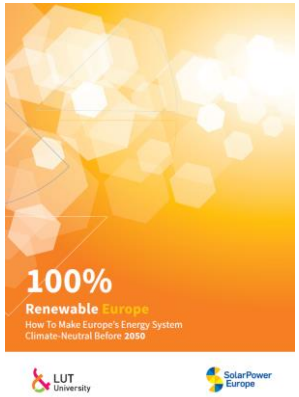


recent reports



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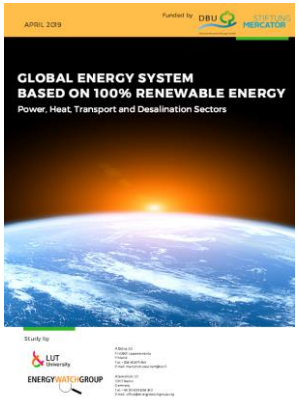

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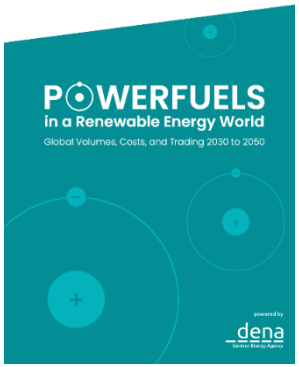

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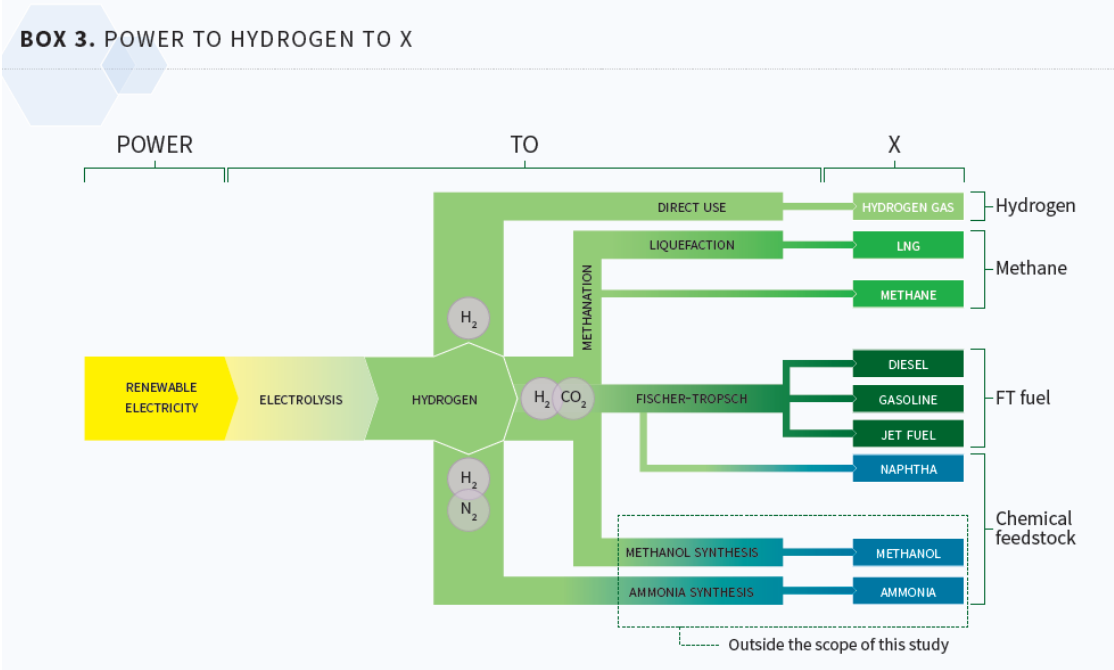
Key features:

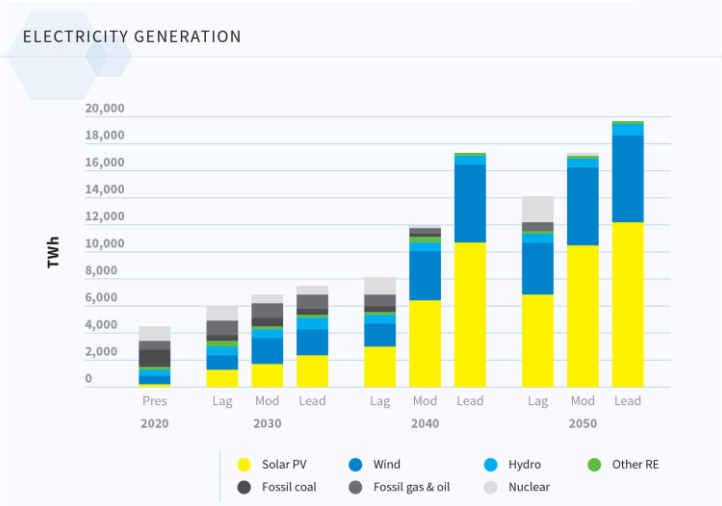
- full hourly resolution, applied in global-local studies, comprising about 120 technologies
- used for several major reports, in about 50 scientific studies, published on all levels, including Nature
- strong consideration on all kinds of Power-to-X (mobility, heat, fuels, chemicals, desalinated water, CO_2)

source: Bogdanov et al., 2021. Full energy sector transition towards 100% renewable energy supply: integrating power, heat, transport and industry sectors including desalination, Applied Energy, in press

Power-to-X: the Core of Sector Coupling



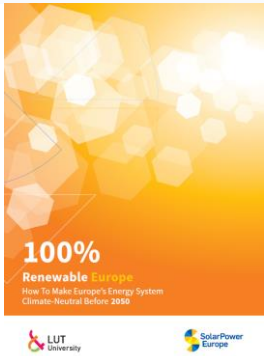
Case: Sustainable Europe



Source: SolarPower Europe. © SOLARPOWER EUROPE 2020

Key insights:

- Power-to-X comprises: Mobility, Fuels, Chemicals, Heat, Steel, Desalinated Water
- Hydrogen is ONLY required, where direct electrification fails, e.g. chemicals, fuels for aviation/ marine
- Power-to-X is an essential core element for least cost zero GHG emissions and a booster for solar PV demand



link to report

source: SolarPower Europe/ LUT, 2020. 100% Renewable Europe

Hourly Operation of the Energy System (Europe)

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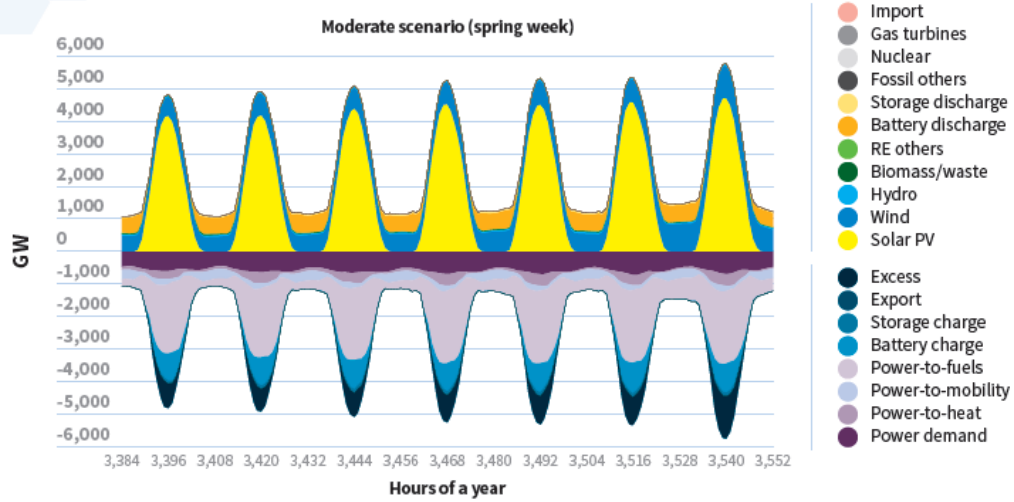
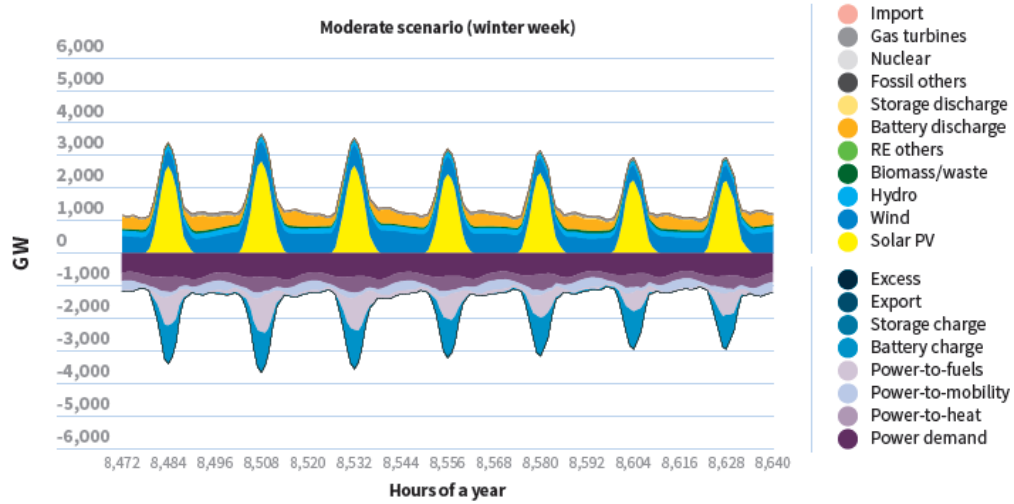
FIGURE 4.8 HOURLY OPERATION OF THE EUROPEAN ENERGY SYSTEM



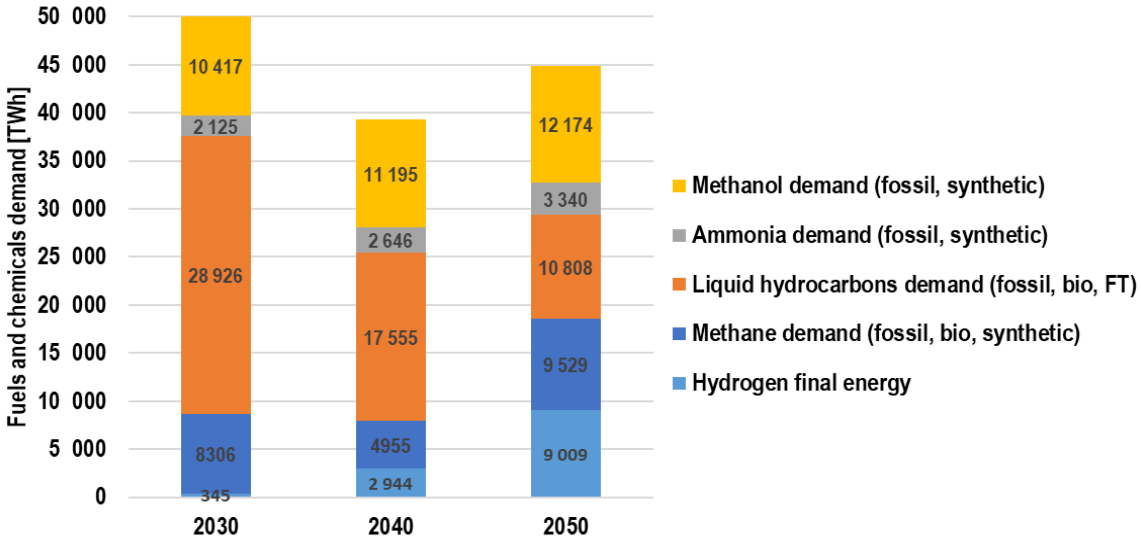


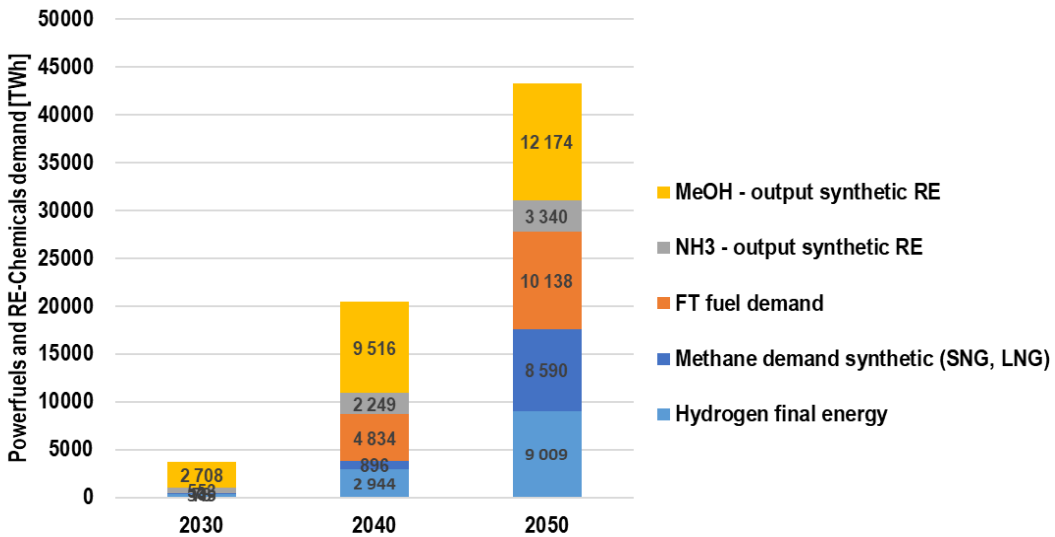
Key insights:

- Week of least renewables supply (winter) and most renewables supply (spring) is visualised
- A 100% renewables-based and fully integrated energy system in 2050 will function without fail every day of the year: Even in the dark winter days the region easily copes with energy demand
- Key balancing components are electrolysers (Power-to-fuels) which convert electricity to hydrogen, when electricity is available, but drastically reduce their utilisation in times of low electricity availability
- Massive ramp rates in the energy system have to be managed, as well as forecasting errors require balancing
- Collaboration with SolarPower Europe.

source: SolarPower Europe/ LUT, 2020. 100% Renewable Europe

Results for global Powerfuel demand





Fuels and Chemicals in general:

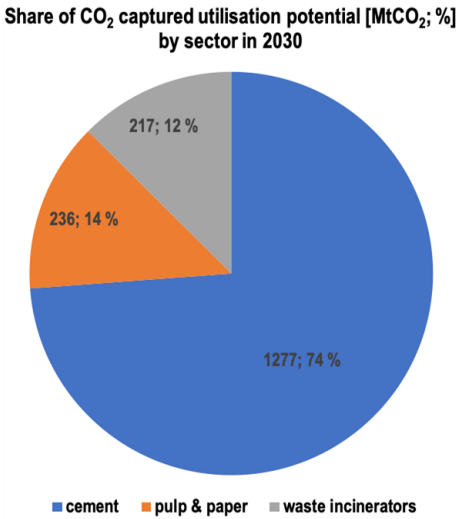
- steady growth of chemicals, whereas Methanol represents non-Ammonia chemicals feedstock equivalent
- liquid hydrocarbons are in steady decline, mainly due to electrification of road transportation
- Methane demand in decline until 2040 with increase towards 2050, with some uncertainty for substitution of Methane by Hydrogen

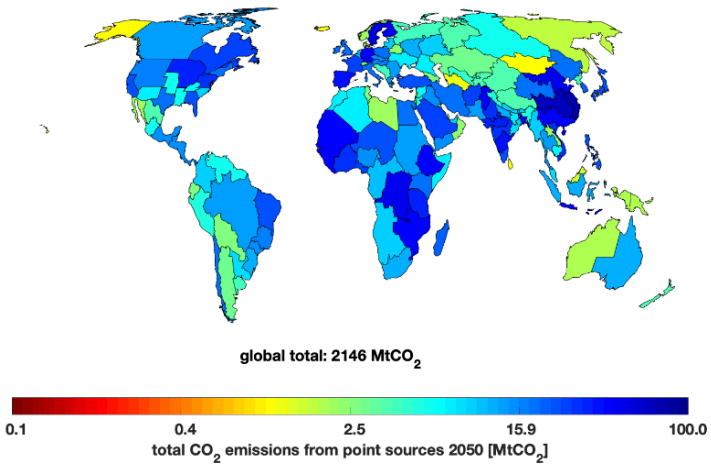
Powerfules:

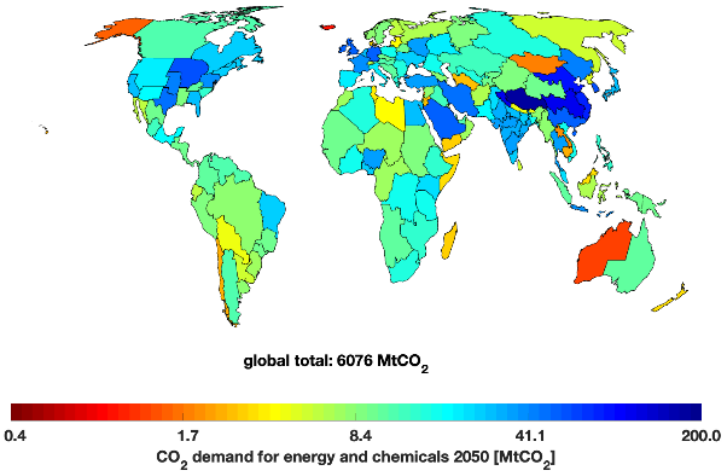
- first markets in 2030
- strong growth until 2040, continued until 2050
- less uncertainty for synthetic Chemicals
- highest uncertainty for Methane demand due to substitution by Hydrogen (heat) and Ammonia/Methanol (marine)
- sustainable bioenergy is limited

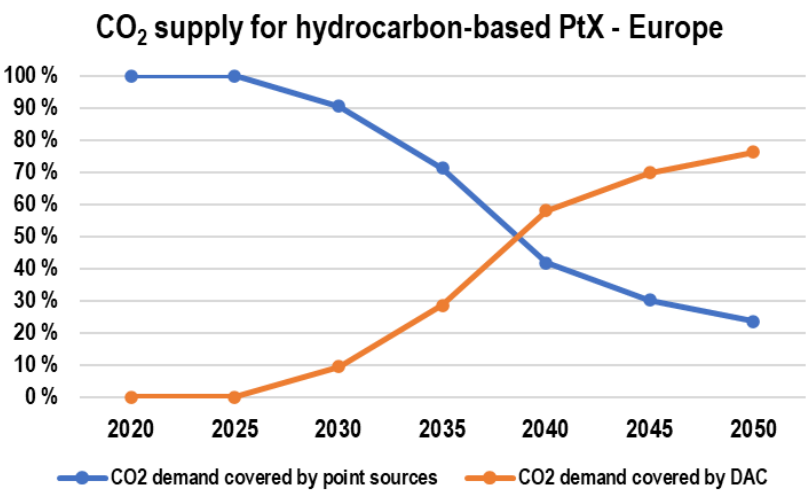
source: dena/LUT, 2020. Powerfuels in a Renewable Energy World

CO_2 as raw material: supply and demand





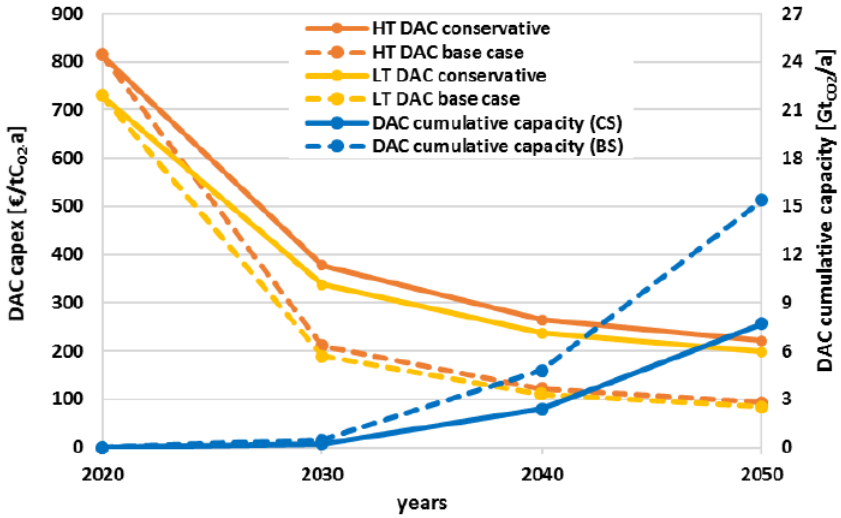


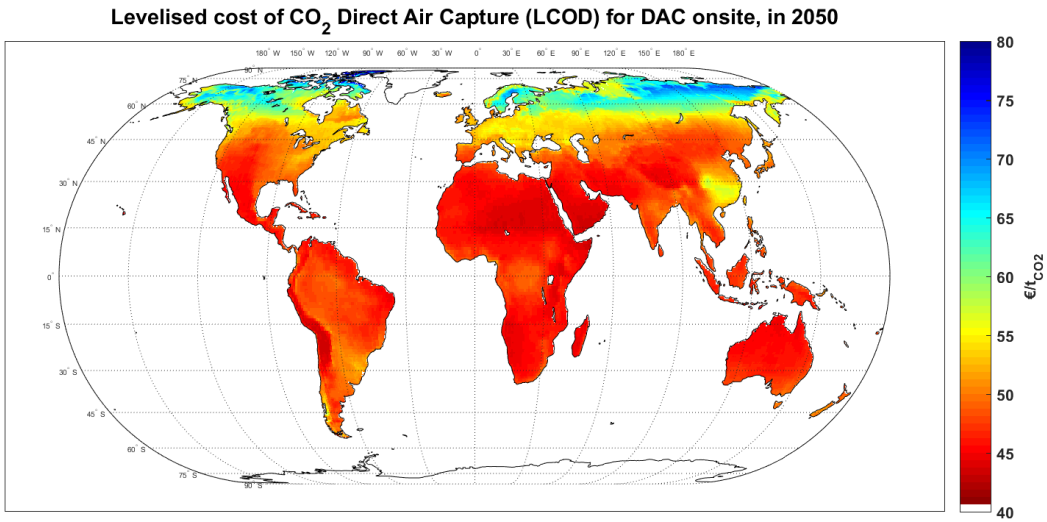


- cement mills are the major CO_2 point source, with more than 70% of supply in 2030s and 2040s, whereas waste incinerators and pulp&paper industries' contribution is ~13-15% each
- 80% of global CO_2 raw material demand needs to be covered by DAC, while the DAC demand in Europe is slightly lower at 76%
- Industrial phase-in of DAC is critical in 2020s, as point sources are available, while DAC requires a first market ramp-up for massive scaling in 2030s and 2040s

source: dena/LUT, 2020. Powerfuels in a Renewable Energy World

Cost of CO_2 DAC





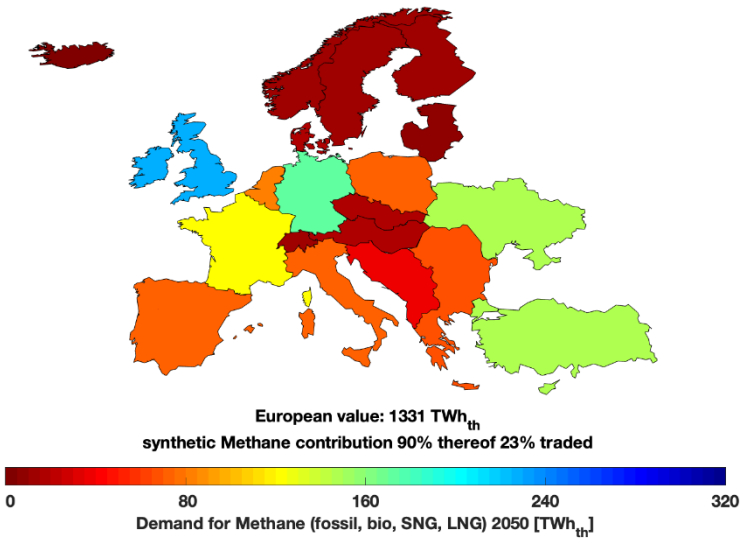
Key insights:

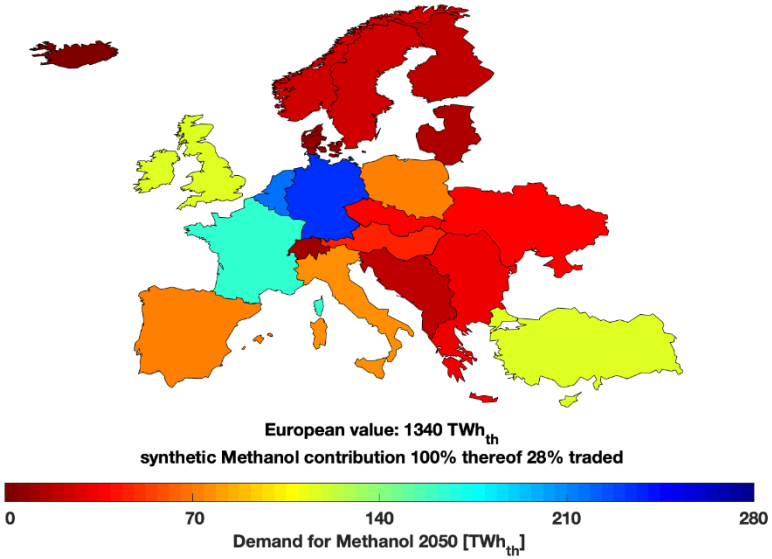
- DAC capex decline is driven by learning rate (10-15%) and capacity demand
- half of DAC capacity demand can be expected from energy and chemicals demand as the DACCU application
- half of DAC capacity demand can be expected from carobn dioxide removal (CDR) in the from of DACCS
- DAC business will become most likely a triple digit billion industry by 2050

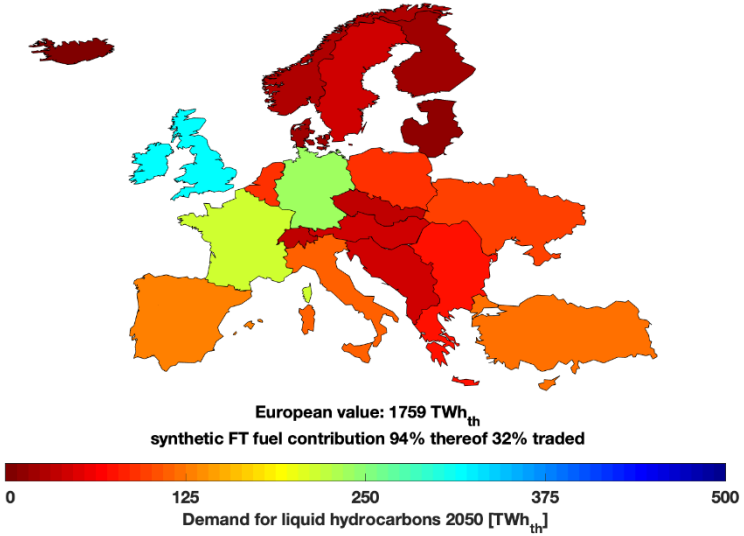
Role of CCU in fully renewable energy systems
Christian Breyer ► christian.breyer@lut.fi

source: Fasihi M., et al., 2019. Journal of Cleaner Production, 224, 957-980; Breyer et al., 2019. Mitigation and Adaptation Strategies for Global Change, online ; Breyer et al., 2019. Joule, 3, 2053-2057

Powerfuels demand in Europe







- Assumption for a fully sustainable and renewable energy system and chemicals for Europe in 2050, without imports
- Remaining hydrocarbons demand is mainly covered by powerfuels, as sustainable biofuels are very limited
- Total powerfuel demand:
  - synthetic methane: ~1200 TWh$_{th}$
  - synthetic FT fuels: ~1650 TWh$_{th}$
  - synthetic methanol: ~1340 TWh$_{th}$

source: dena/LUT, 2020. Powerfuels in a Renewable Energy World

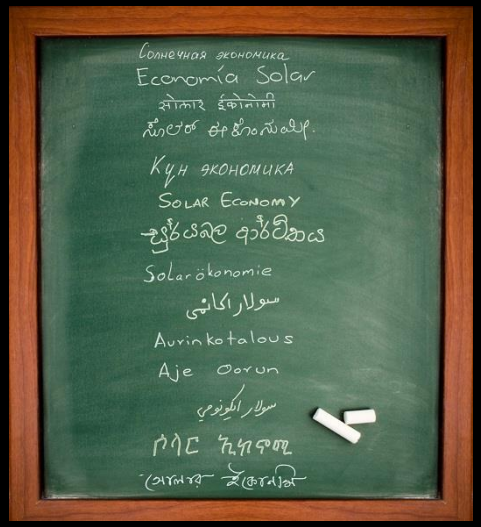
Is enough renewable electricity available?

- no bottleneck to be expected from industrial availability, as PV and wind industry output can grow faster than the demand rise is projected
- no bottleneck to be expected from economic viability, as long as there is a positive business case for powerfuels, which would be already achieved TODAY, if the real GHG emission cost and air pollution cost were fully factored in
- no bottleneck to be expected, if powerfuels would be imported, but this may be in conflict with high levels of energy supply security and energetic sovereignty
- thus, testing the limits would be a full European energetic self-supply, which may lead to area limitation
  - 20,510 TWh_{el} total electricity demand for energy and chemicals (high electrification and 100% RE)
  - thereof about 35% for CCU-based hydrocarbons (methane, Fischer-Tropsch, methanol)
  - 0.46% for PV of total area of Europe based on 25% efficient modules expected for 2035 as average
  - 1.33% for wind onshore of total area of Europe (on arable land and in forests)
  - societal discourse required to conclude whether the area demand would be a challenge
- all renewable electricity could be supplied in Europe, given the societal will

Summary

- Zero GHG emissions by 2050 is the target of the European Green Deal
- Highly renewable energy systems emerge as the least cost solution
- Hydrocarbon demand will not disappear
- CCU will deliver the CO_2 from point sources and DAC
- Europe has to decide what share of powerfuels to be produced in Europe
- Full European powerfuel supply is possible, economically and with area
- Societal discourse on pros and cons is required
- CCU and powerfuels represent a HUGE business opportunity ahead

Thank you for your attention …
… and to the team!



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Major Milestones on 100% RE Research

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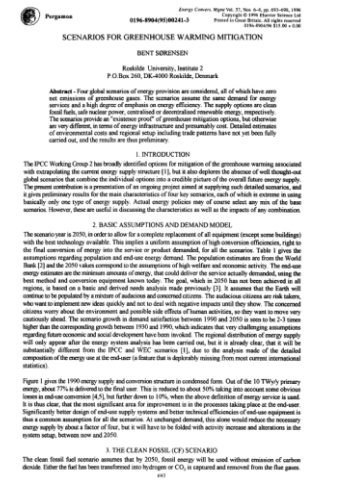
SCIENCE

Energy and Resources

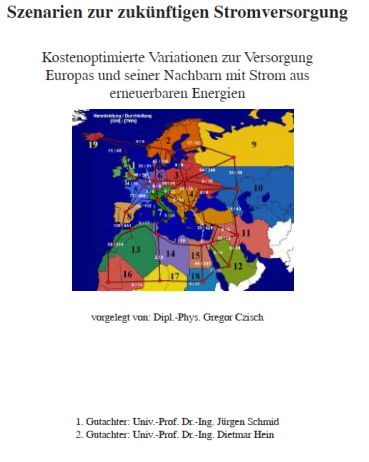
A plan is outlined according to which solar and wind energy would supply Denmark's needs by the year 2050.

Bent Sørensen


SCENARIOS FOR GREENHOUSE WARMING MITIGATION

BENT SØRENSEN

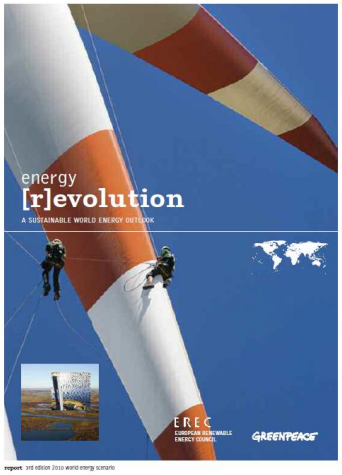
Roskilde University, Institute 2
P.O.Box 260, DK-4000 Roskilde, Denmark


Szenarien zur zukünftigen Stromversorgung

Kostenoptimierte Variationen zur Versorgung Europas und seiner Nachbarn mit Strom aus erneuerbaren Energien

vorgelegt von: Dipl.-Phys. Gregor Czisch

1. Gutachter: Univ.-Prof. Dr.-Ing. Jürgen Schmid
2. Gutachter: Univ.-Prof. Dr.-Ing. Dietmar Hein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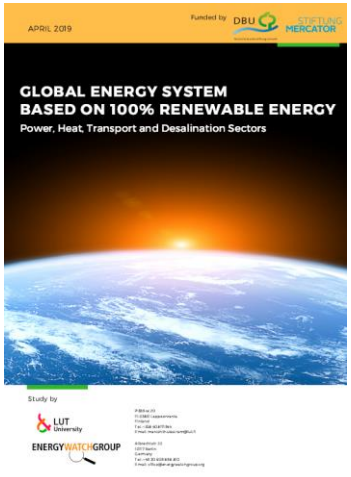
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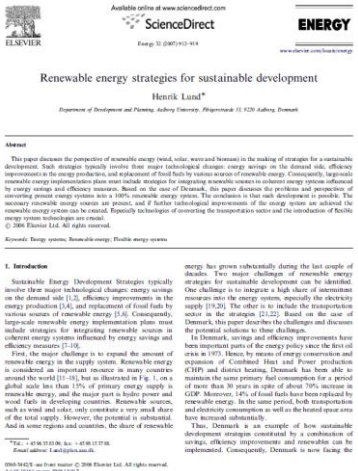
GLOBAL ENERGY SYSTEM BASED ON 100% RENEWABLE ENERGY
Power, Heat, Transport and Desalination Sectors
Study by
LUT University
ENERGYWATCHGROUP

Sørensen, 1975 | Sørensen, 1996 | Czisch, 2005 | Greenpeace, 2010 | LUT/EWG, 2019

Lovins, 1976 | Lund, 2007 | Sterner, 2009 | Jacobson, 2011 | Bogdanov et al., 2019

Energy Strategy: The Road Not Taken?
By Amory B. Lovins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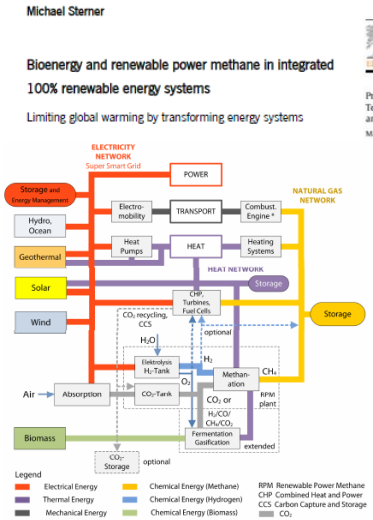
Renewable energy strategies for sustainable development
Henrik Lund


Michael Sterner
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POWER
Storage and Energy Management
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Heat Pumps
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Heating Systems
Geothermal
HEAT NETWORK
Storage
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Wind
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optional
Legend
Electrical Energy
Thermal Energy
Mechanical Energy
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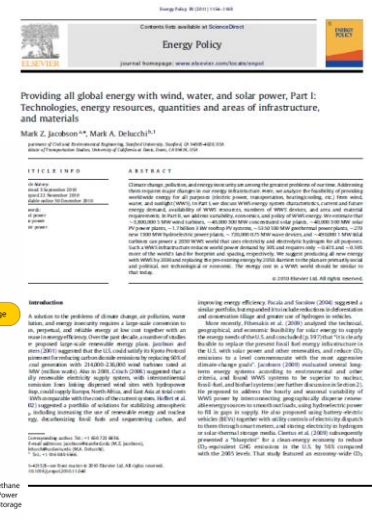
Chemical Energy (Hydrogen)
Chemical Energy (Biomass)
RPM Renewable Power Methane
CHP Combined Heat and Power
CCS Carbon Capture and Storage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Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials
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nature COMMUNICATIONS
ARTICLE
Radical transformation pathway towards sustainable electricity via evolutionary steps

Role of CCU in fully renewable energy systems
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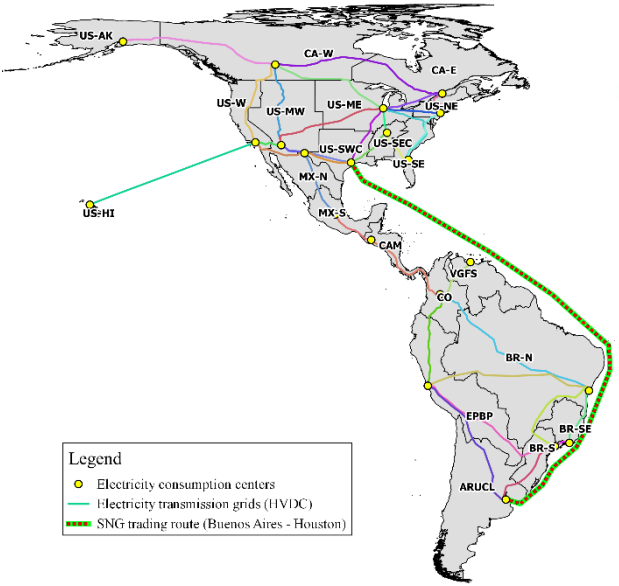
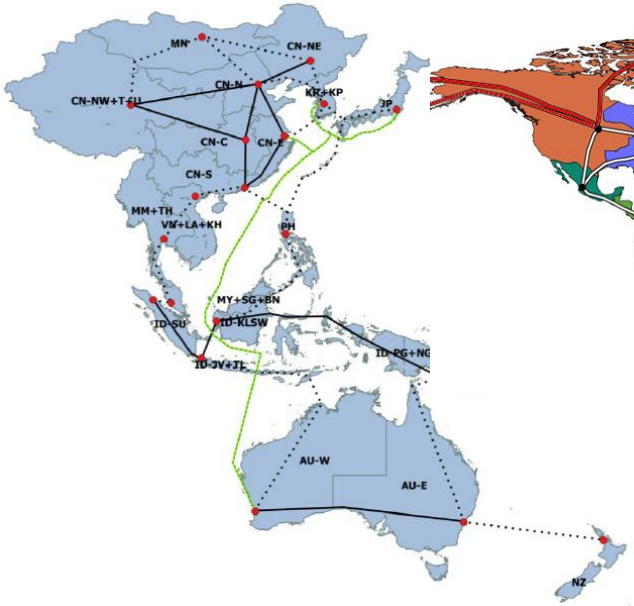
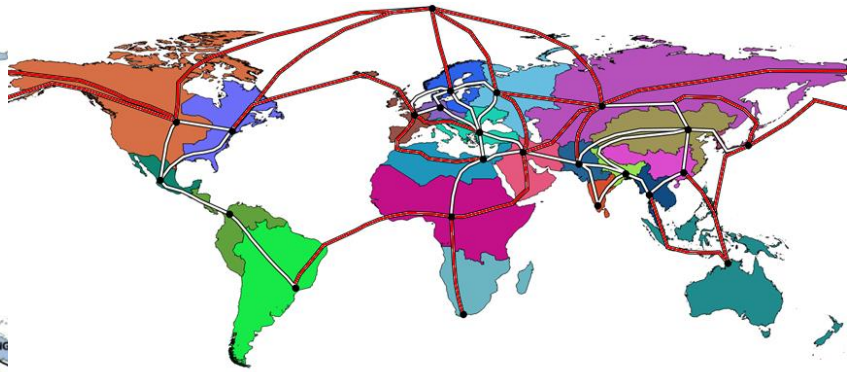
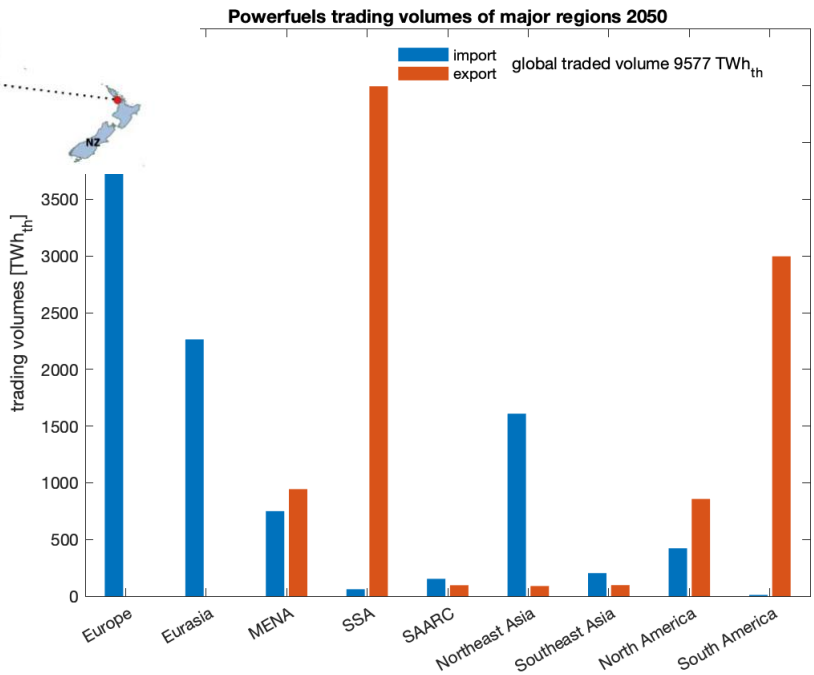
Regional and Global Super Grids







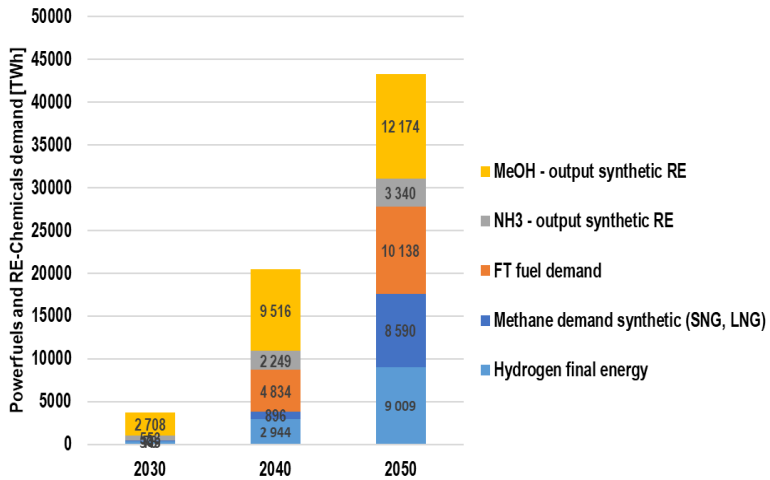


Key insights:

- What's the value add of very large Super Grids?
- Grids on a major region level (SAARC, Europe, etc.) reduce the system cost by about 10% by resource balancing, compared to state/ country level optimisation.
- The higher the solar PV share, the lower the balancing value.
- Integration beyond major region level, e.g. Americas North & South, Europe & Eurasia & MENA, Asia Northeast & Southeast, leads to negligible further cost reductions of about 1%.
- PtX powerfuels/ chemicals trade will generate substantial value.

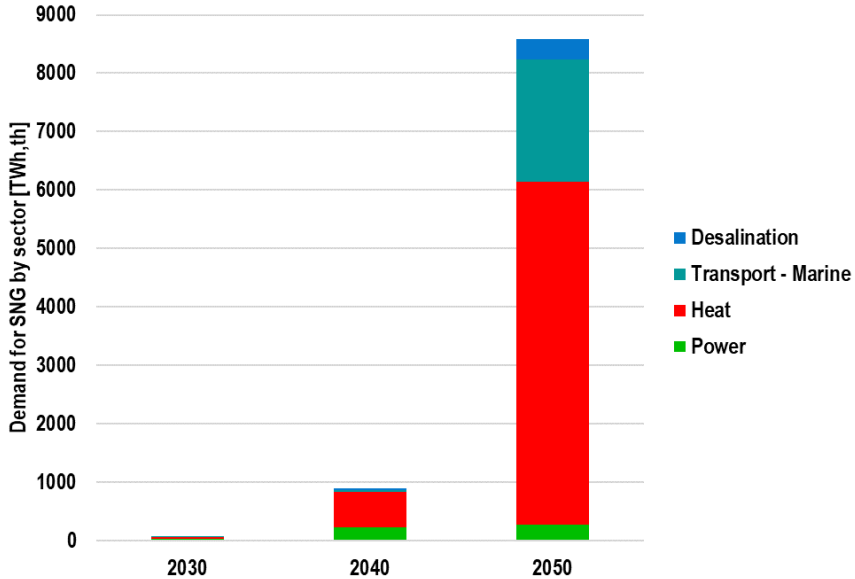
source: Aghahosseini et al., 2019. Renew Sustain Energy Rev 105, 187-205; Gulagi et al., 2017. Energies 10, 583; Breyer et al., 2020. EEEP 9, 83-102

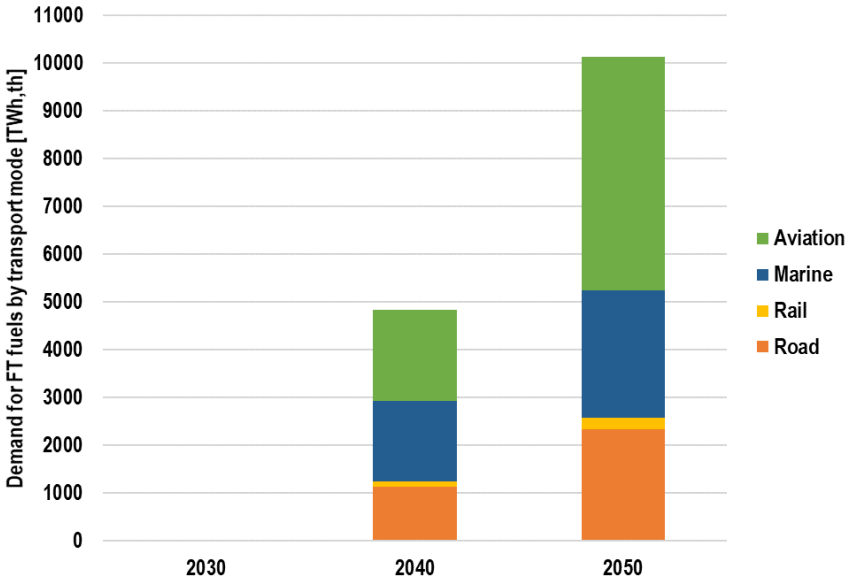
Details for Methane and FT fuels markets



Methane (SNG) and Fischer Tropsch markets:

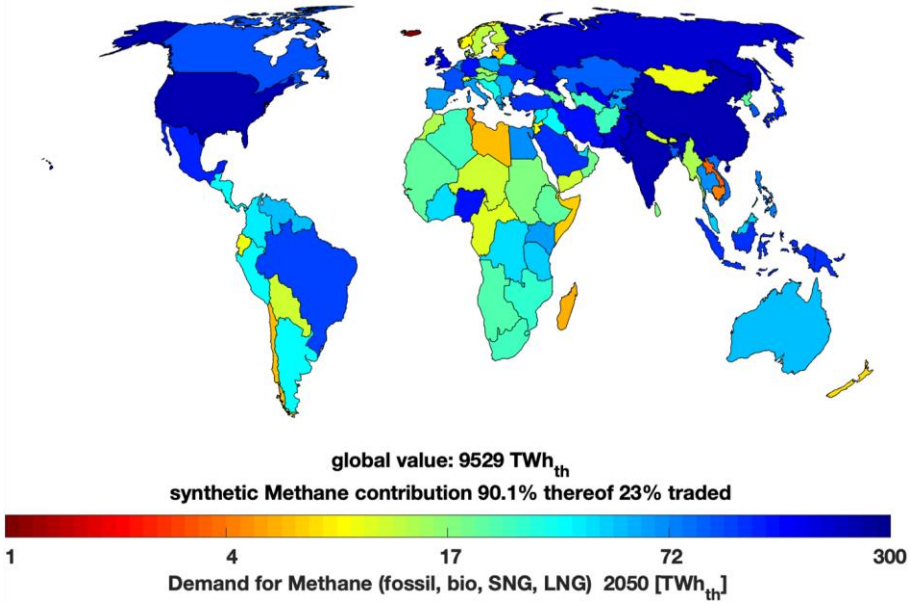
- **Phase-out of fossil gas does not necessarily lead to SNG phase-in, in particular not in the power sector**
- **High temperature heat demand requires SNG**
- **Marine fuel may require SNG/LNG, while ammonia and methanol may gain high shares**
- **Aviation requires highest share of FT fuels**
- **Marine and Road demand for FT fuels is more uncertain**
- **Green Hydrogen is the basis for these synthetic fuels**

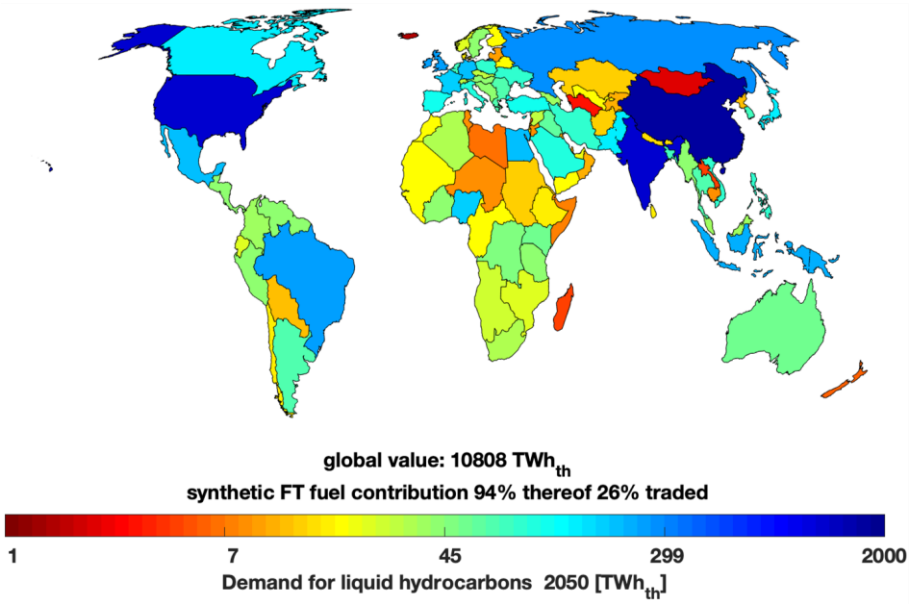




source: dena/LUT, 2020. Powerfuels in a Renewable Energy World

Global demand distribution: SNG/FT fuels



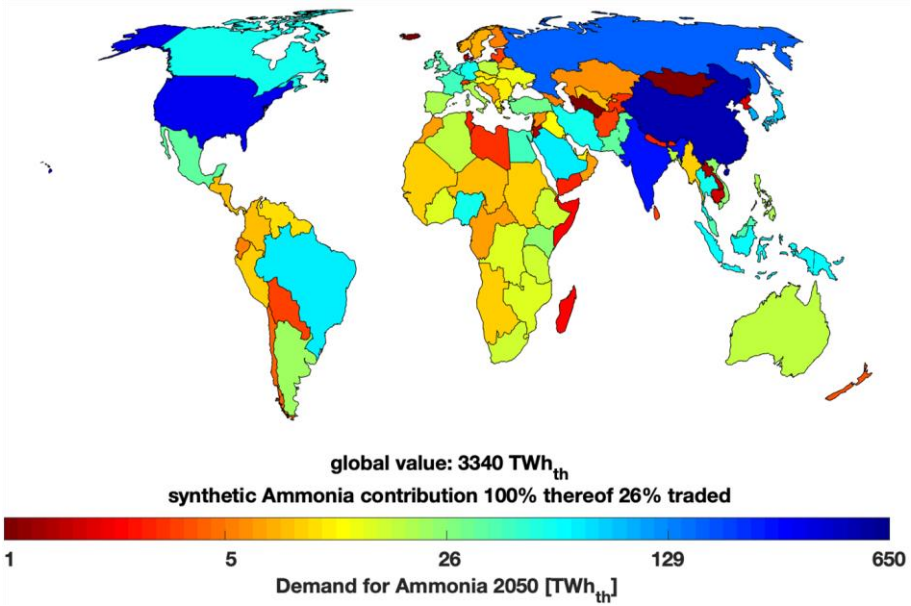


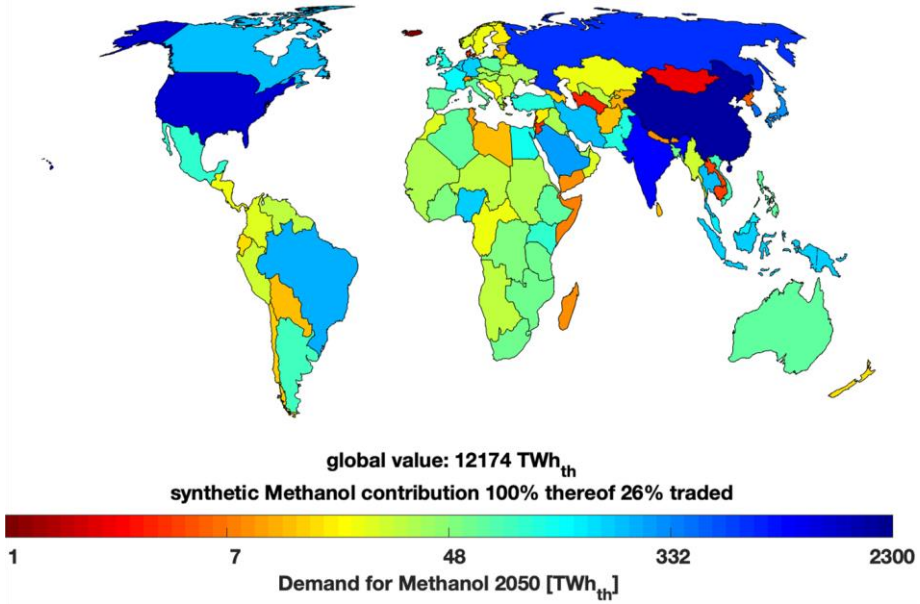
Key insights:

- Dominant share (90%) of methane demand based on green hydrogen, thereof 23% traded, rest local
- Large green hydrogen based methane markets in North America, Europe, South and Northeast Asia
- FT fuels dominate the sustainable liquid fuels market (94% share), as biofuels are strongly limited
- Large green hydrogen based FT fuels markets similar to SNG
- Green hydrogen is the basis for these synthetic fuels

source: dena/LUT, 2020. Powerfuels in a Renewable Energy World

Global demand distribution: Ammonia, MeOH



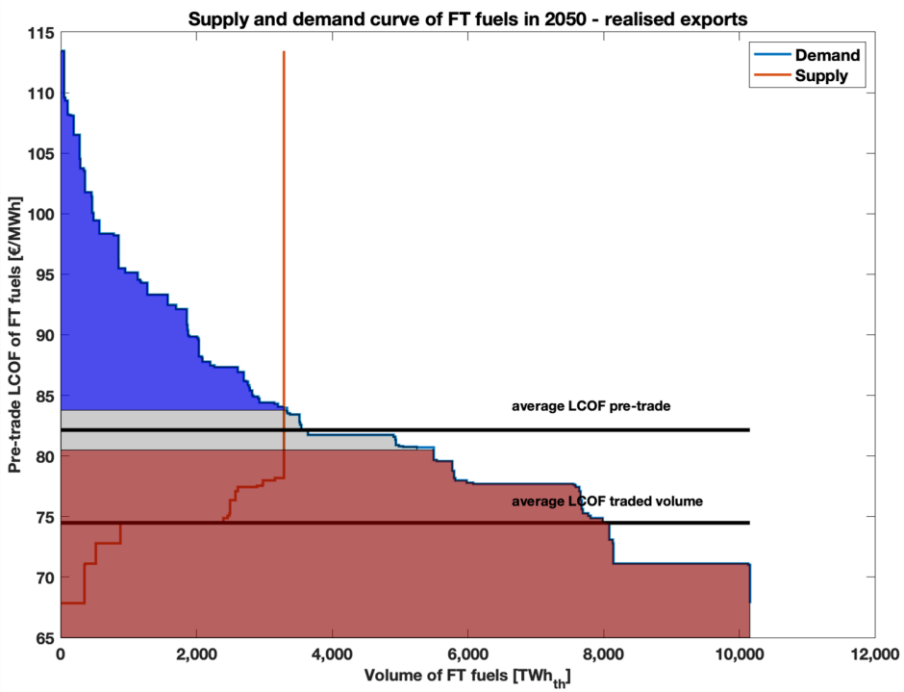


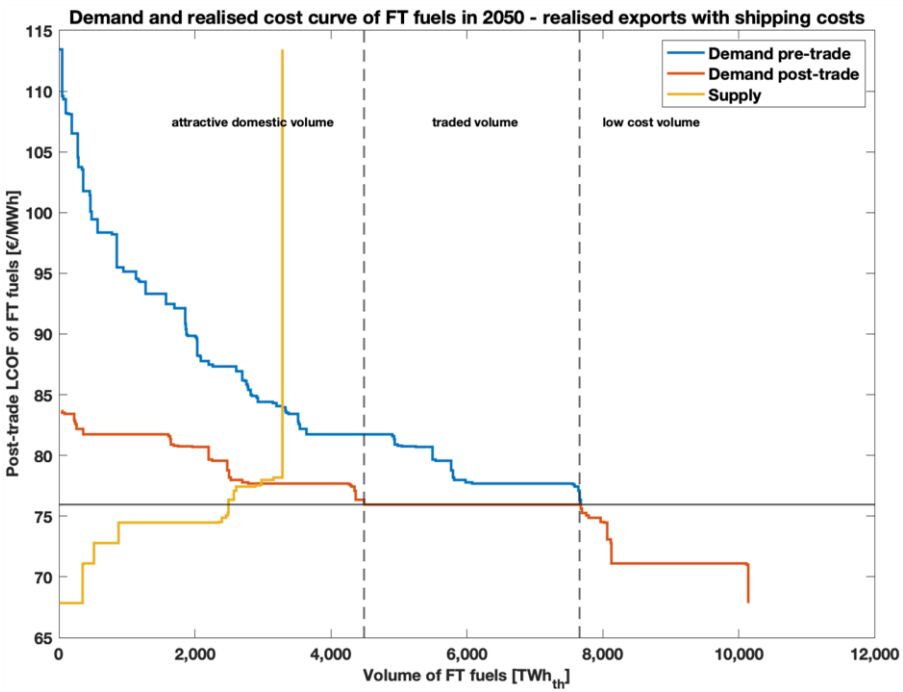
Key insights:

- **Ammonia is the basis for fertilisers, but can be also used as fuel, in particular for marine transport**
- **Methanol is expected to become the dominant new bulk chemical for multi-use, e.g. plastics, however, methanol could be also used as fuel, in particular for marine transport**
- **Similar to SNG/FT, about a quarter may be traded, thus most demand could be domestically supplied**
- **Demand distribution similar to SNG and FT fuels: North America, Europe, South and Northeast Asia**
- **Green hydrogen is the basis for these synthetic fuels**

source: dena/LUT, 2020. Powerfuels in a Renewable Energy World

Global trading of synthetic fuels: case FT





Key insights:

- Global trading model has been established, based on 145 regions, aggregated to 92 countries/regions
- Global average levelised cost of fuels has been defined as separator for imports and exports
- Exporter attractiveness has been introduced: cost, volume, political stability
- About a quarter of the global demand may be traded
    - Key importers: Europe, Japan, Russia, but even countries of the Sun Belt
    - Key exporters: South America, sub-Saharan Africa
- Most countries in the world can opt for domestic self-supply
- Green hydrogen is the basis for Fischer-Tropsch fuels