SYNTHETIC FUELS AND CHEMICALS:

OPTIONS AND SYSTEMIC IMPACT

Mahdi Fasihi and Christian Breyer

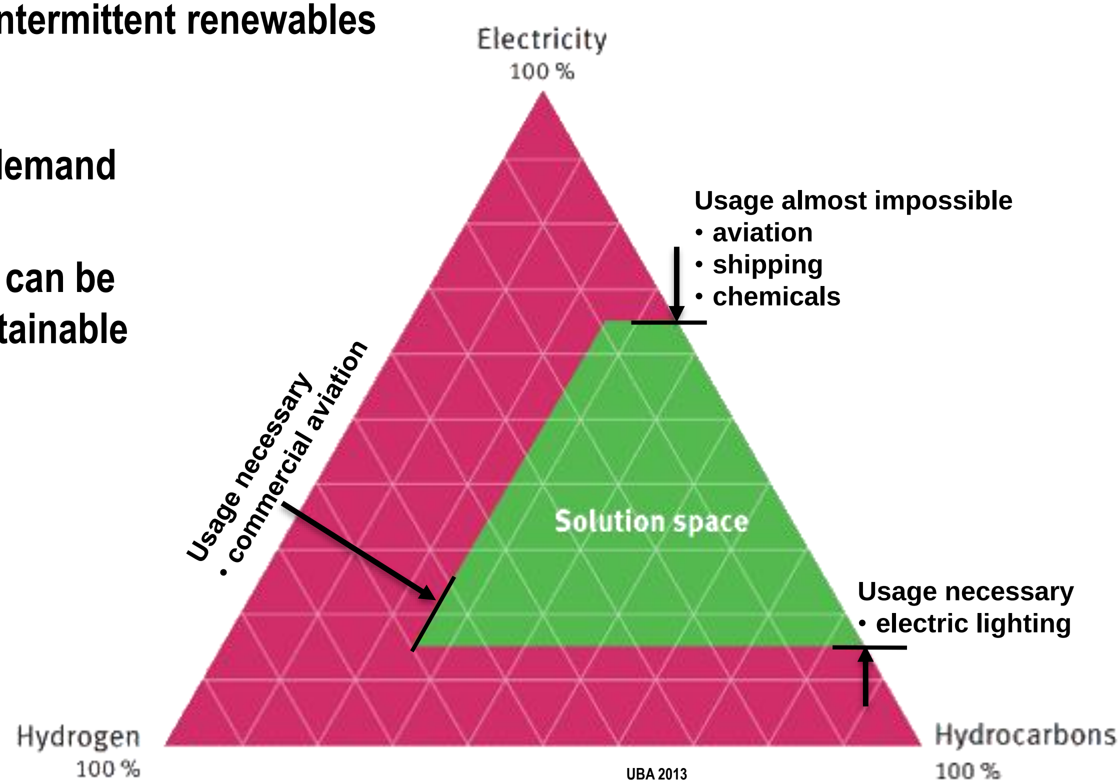
NEO CARBON ENERGY

Strommarkttreffen
Power-to-gas und power-to-fuel
Berlin, June 29, 2018

Motivation

- A globally net zero or negative emission energy system is needed to avoid drastic climate change
- RE available, but 100% direct electrification is impossible as hydrocarbons and their derivatives would be still partly needed for:
  - long-range aviation and marine transportation
  - non-energetic purposes, such as feedstock for chemical industry or fertiliser for food production
  - seasonal balancing solution for intermittent renewables

- Thus, defossilisation of hydrocarbon demand in these sectors is necessary
  - fossil-based fuels and chemicals can be generated synthetically from sustainable sources of carbon and electricity



UBA 2013

Synthetic fuels and chemicals: options and systemic impact
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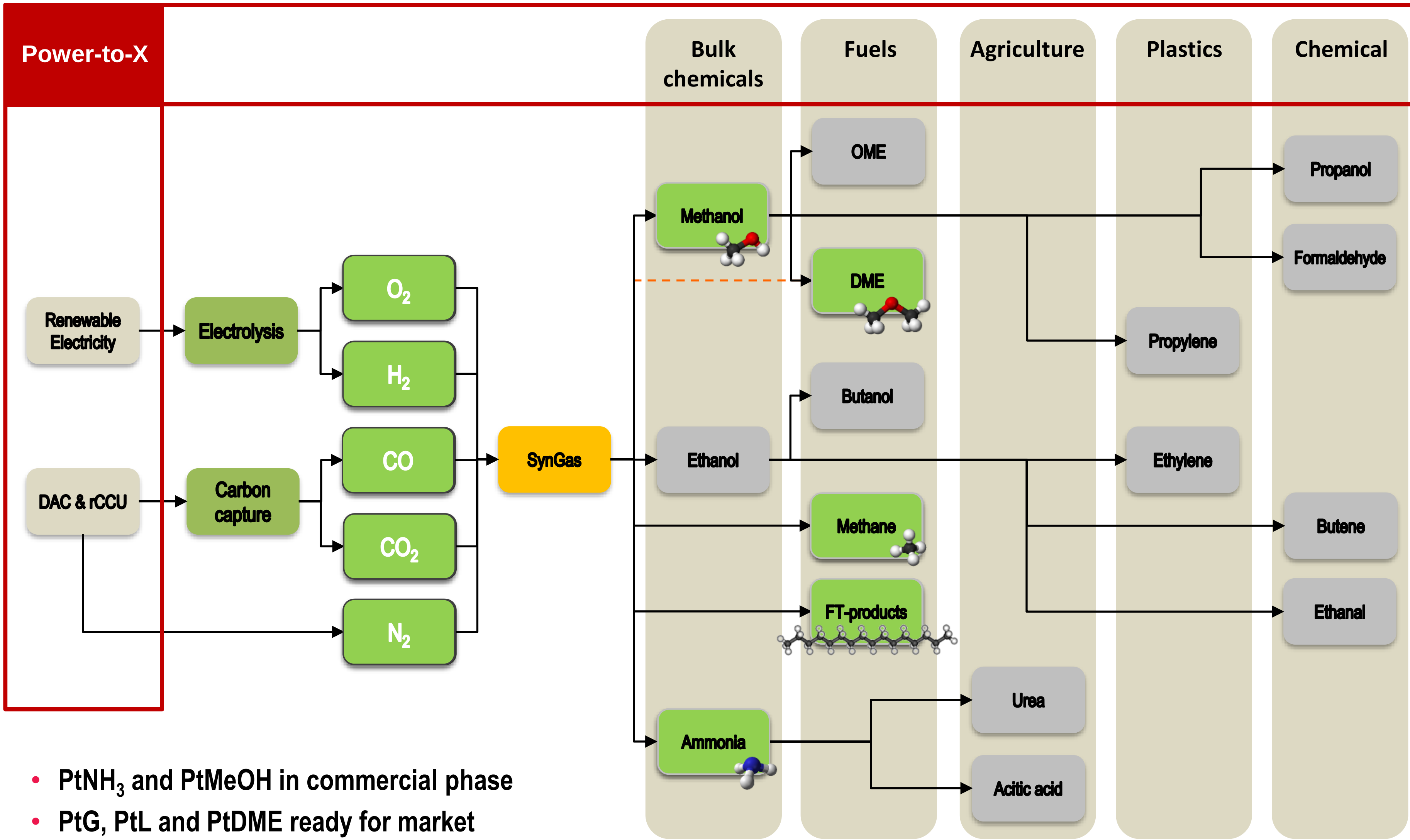
Motivation

Power-to-X options

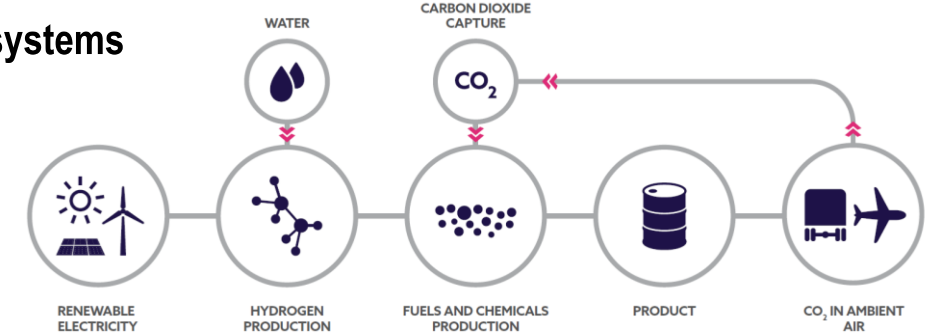


- $PtNH_3$ and PtMeOH in commercial phase
- PtG, PtL and PtDME ready for market

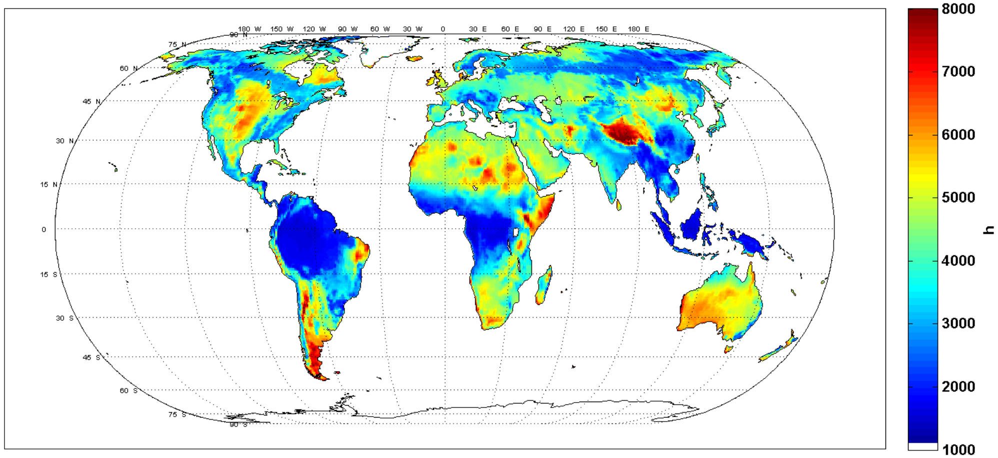
Diagram is based on: Stiessel S., et al., 2017. Techno-economic analysis of various Power2X concepts for the integration of CO_2-based synthesis, IRES, Düsseldorf, March

Motivation

- Solar and wind energy can be used to power PtX systems
- Air as the source of feedstock
- RE-fuels and chemicals
  - non-diminishing resources
  - costs stable or declining
  - no costs for harmful emissions (CO_2, etc.)
  - drop in fuels for available infrastructure
  - energy storage
  - a step towards fuel security



Hybrid PV1-Wind cumulative FLh in 2005



- Sites with excellent solar and wind energy potential promise cheaper synthetic products.
- The synthetic products could be transported globally
- Cost and generation potential in 2030 and beyond?

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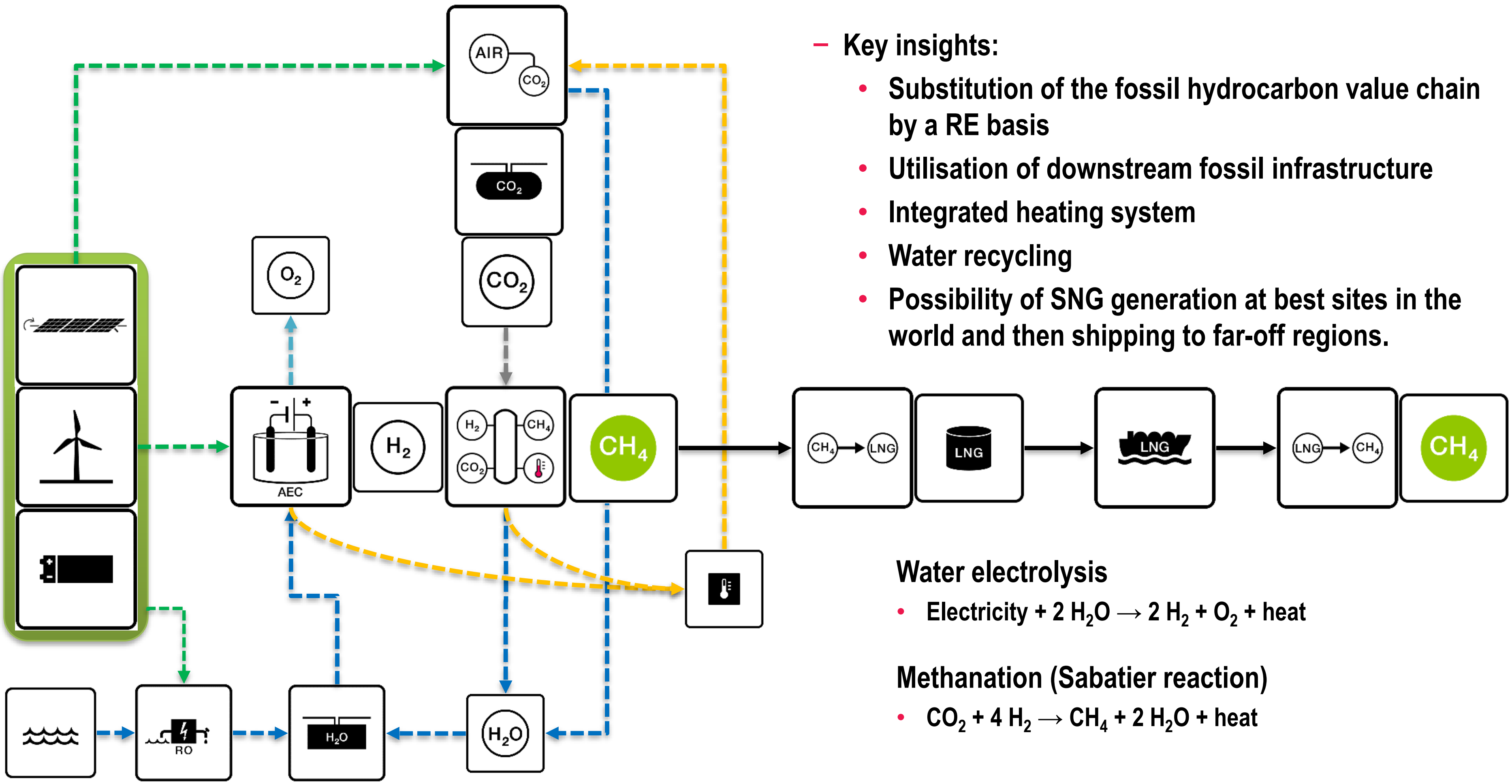
Methodology

RE-PtG-LNG Value Chain



- Key insights:
  - Substitution of the fossil hydrocarbon value chain by a RE basis
  - Utilisation of downstream fossil infrastructure
  - Integrated heating system
  - Water recycling
  - Possibility of SNG generation at best sites in the world and then shipping to far-off regions.

Water electrolysis

- Electricity + 2 $H_2O \longrightarrow 2\ H_2 + O_2$ + heat

Methanation (Sabatier reaction)

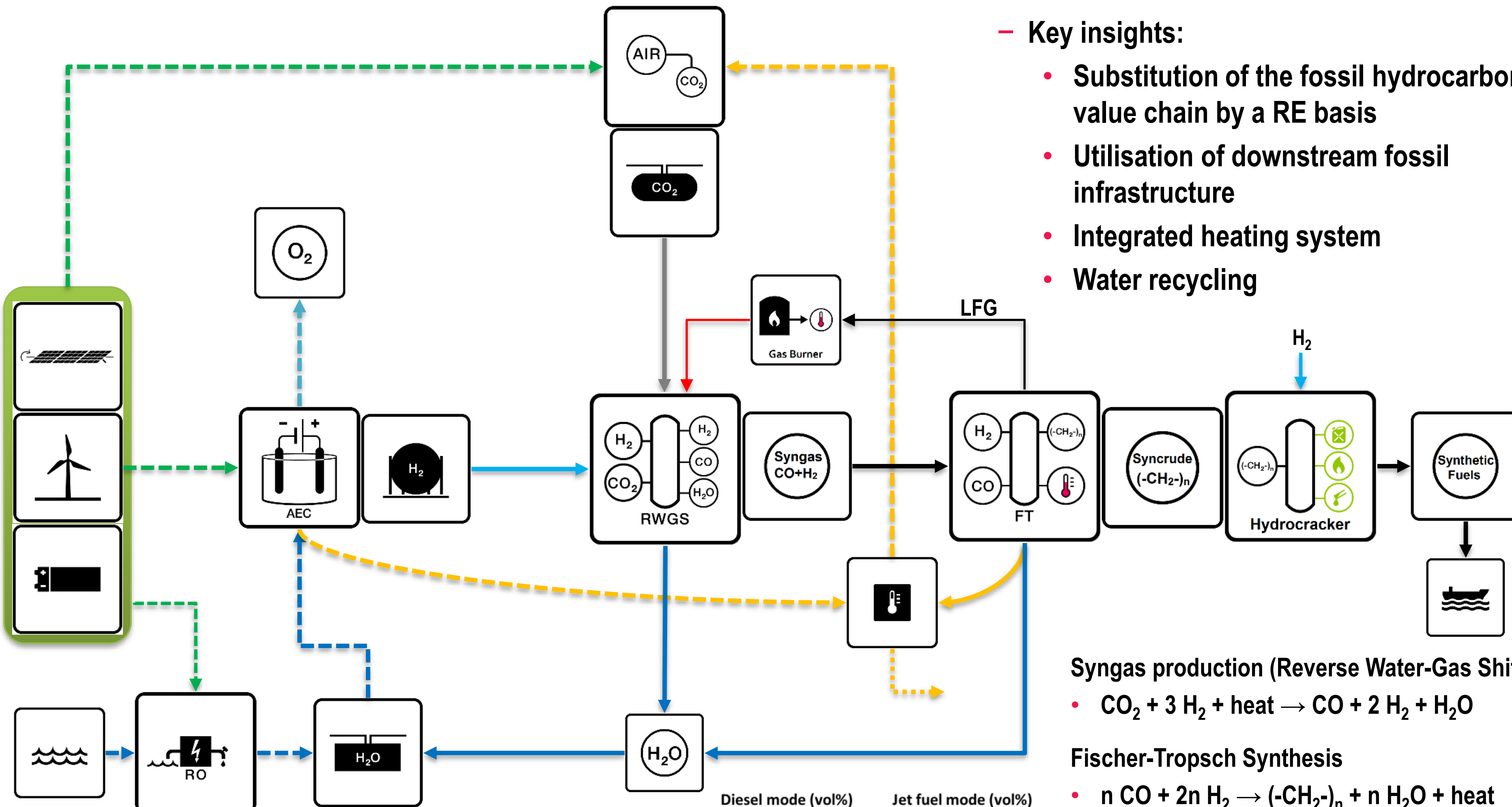
- $CO_2 + 4\ H_2 \longrightarrow CH_4 + 2\ H_2O$ + heat

Hybrid PV-Wind & Battery | Power-to-Gas | SNG Liquefaction | LNG Shipping | LNG Regasification

- Dashed lines represent fluctuating flows
- Continuous lines represent steady flows

Methodology

RE-PtL Value Chain



- Key insights:
  - Substitution of the fossil hydrocarbon value chain by a RE basis
  - Utilisation of downstream fossil infrastructure
  - Integrated heating system
  - Water recycling

Syngas production (Reverse Water-Gas Shift)

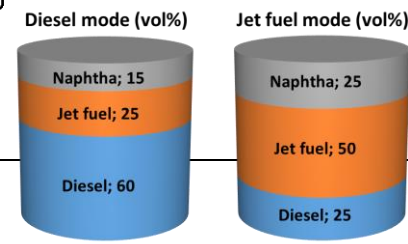
- $CO_2 + 3\ H_2 + \text{heat} \rightarrow CO + 2\ H_2 + H_2O$

Fischer-Tropsch Synthesis

- $n\ CO + 2n\ H_2 \rightarrow (-CH_2-)_n + n\ H_2O + \text{heat}$

Products upgrading (Hydrocracker)

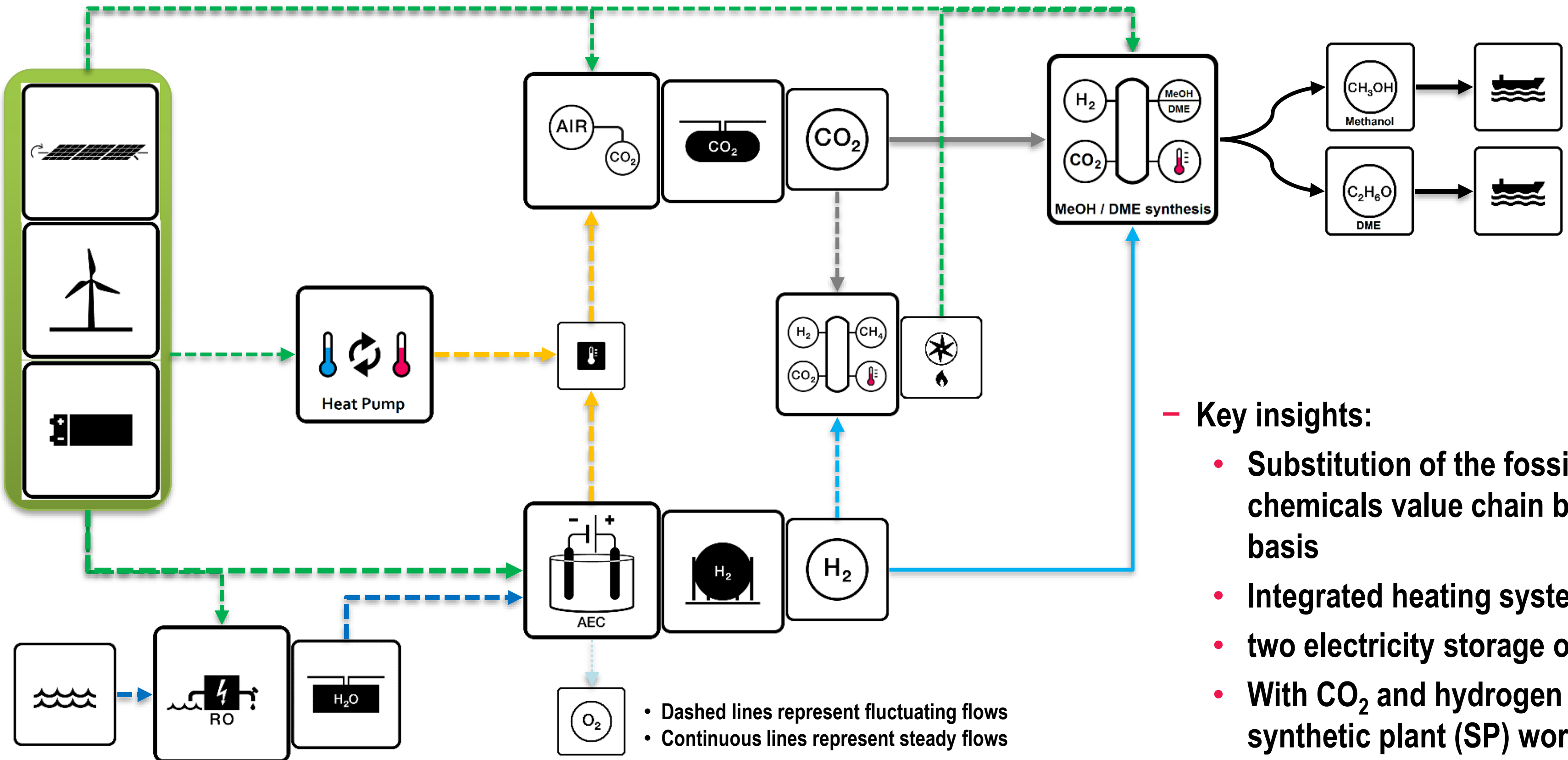
- $(-CH_2-)_n + H_2 \rightarrow C_nH_{2n+2}$



- Dashed lines represent fluctuating flows
- Continuous lines represent steady flows

Methodology

RE-PtMeOH/DME Value Chain



- Dashed lines represent fluctuating flows
- Continuous lines represent steady flows

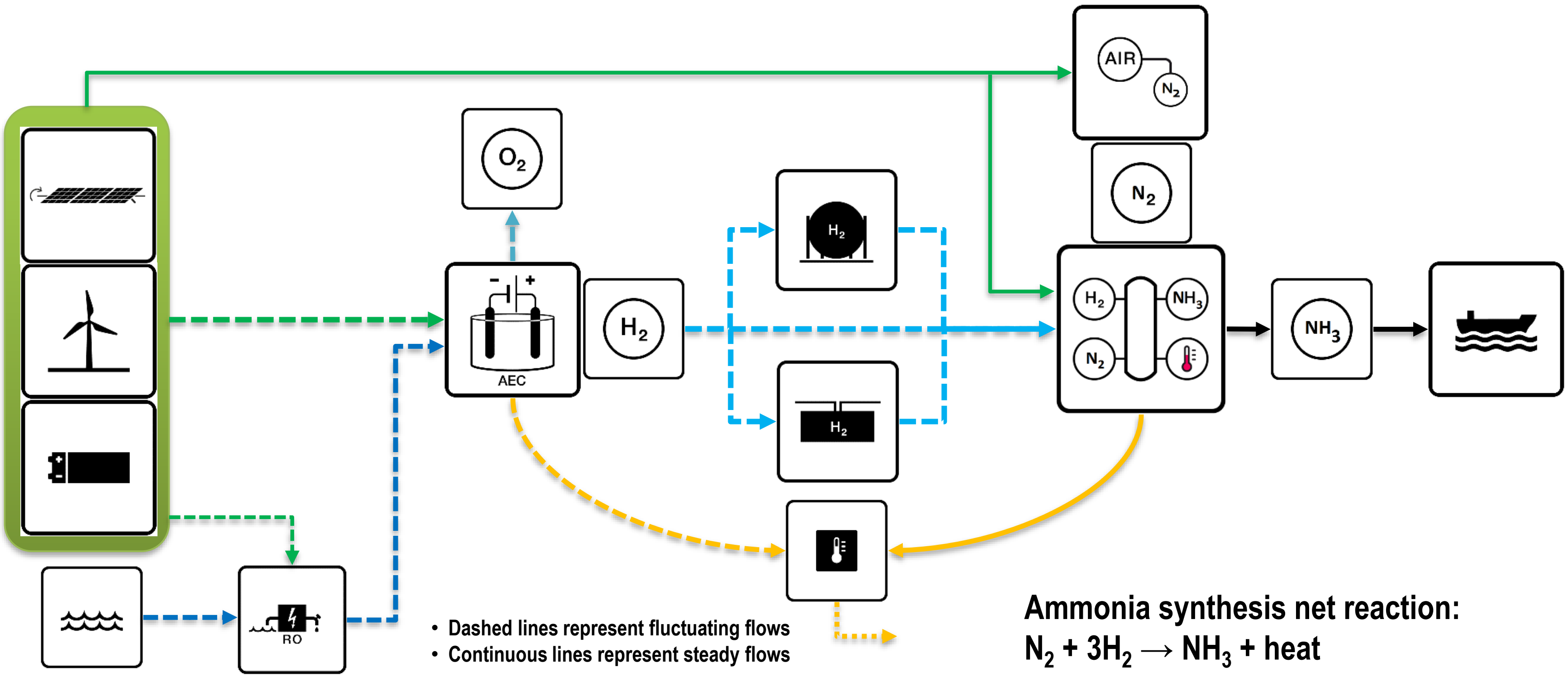
– Key insights:
  - Substitution of the fossil-based chemicals value chain by a RE basis
  - Integrated heating system
  - two electricity storage options
  - With CO_2 and hydrogen storage, synthetic plant (SP) works on baseload

– Methanol is one of the most widely used chemicals in industry with a growing potential as a fuel

– With no carbon-carbon bonde and high ecetane number, RE-DME could be a potential carbon neutral soot-free substitution for diesel

Methodology

RE-PtNH_3 Value Chain



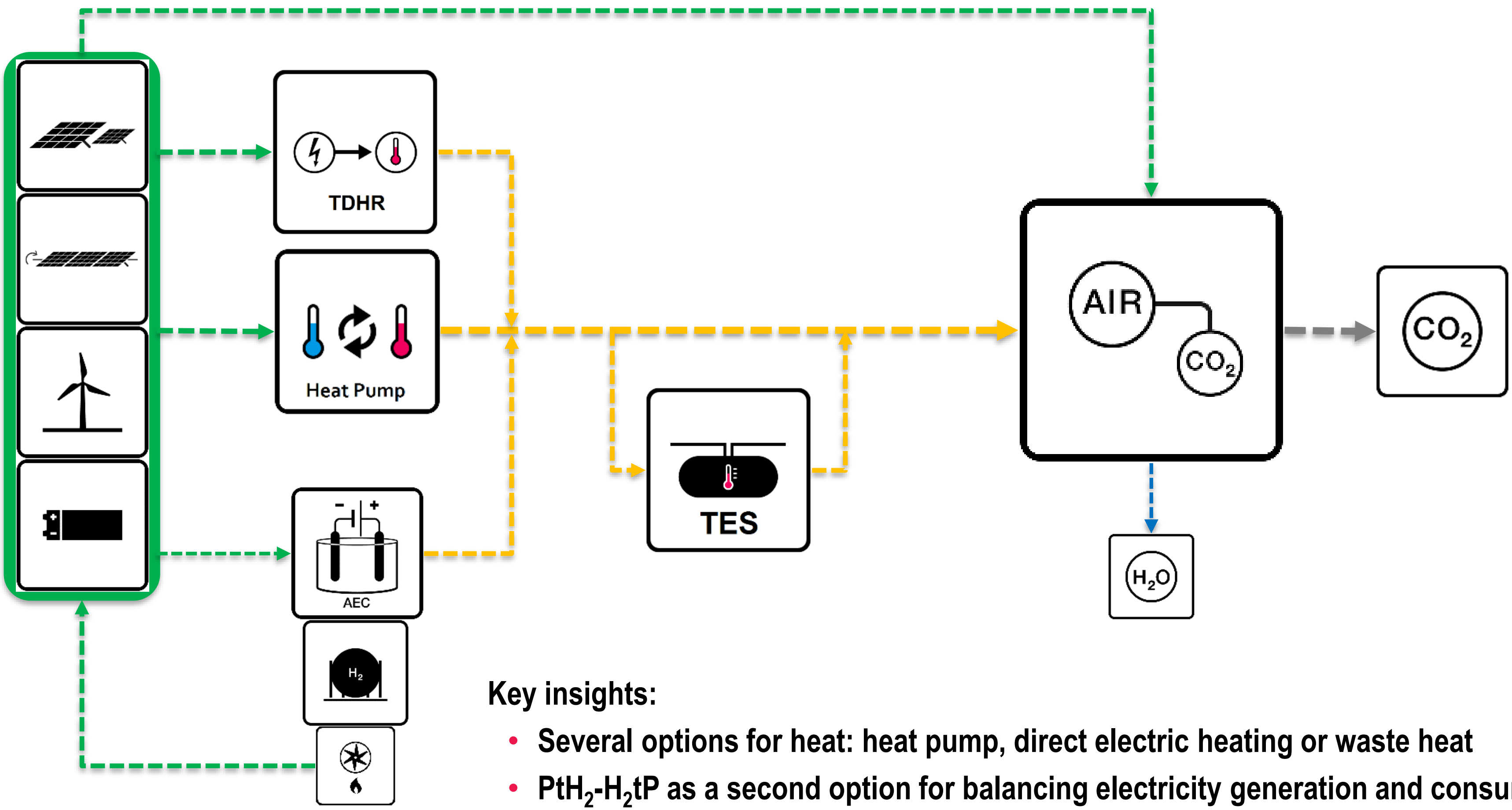
Ammonia synthesis net reaction:
$N_2 + 3H_2 \longrightarrow NH_3 + \text{heat}$

Key insights:

- Substitution of fossil-based ammonia value chain by a RE basis
- ASU and ammonia synthesis plants are coupled and run on a baseload
- Two storage options for hydrogen (cavern & buffer)
- PtG-GtP as a second option for maintaining partial baseload electricity demand (not in the figure)

Methodology

RE-PtCO$_2$ Value Chain



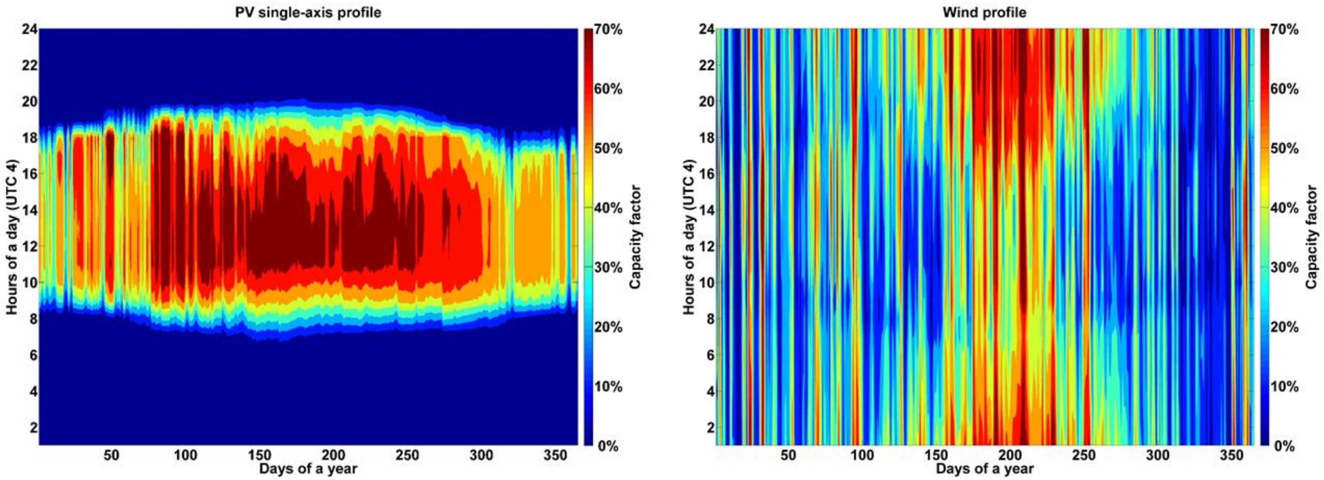
Key insights:

- Several options for heat: heat pump, direct electric heating or waste heat
- PtH$_2$-H$_2$tP as a second option for balancing electricity generation and consumption

- Dashed lines represent fluctuating flows
- Continuous lines represent steady flows

Weather Data

- Hourly potential of solar and wind in a 0.45° × 0.45° spatial resolution
- The datasets for solar irradiation components and wind speed are taken from NASA databases.
- Feed-in time series of wind power plants are calculated for standard 3 MW wind turbines (E-101) with hub height conditions of 150 meters.

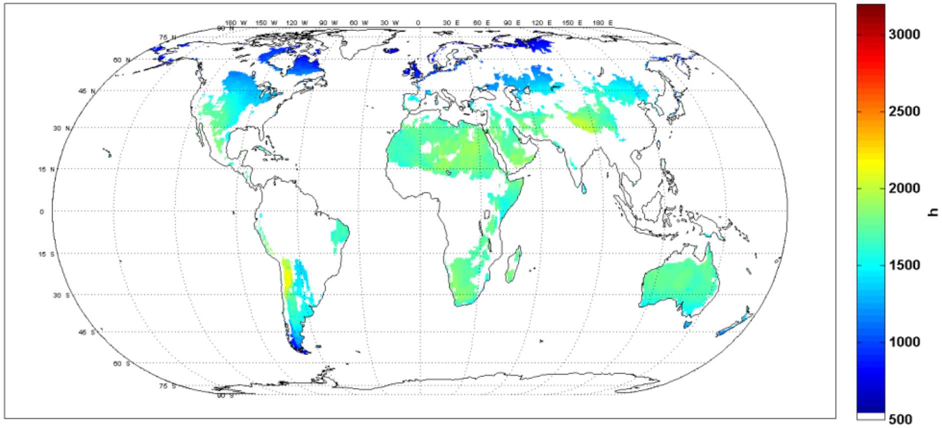


weighed average PV and Wind hourly generation profile for Iran

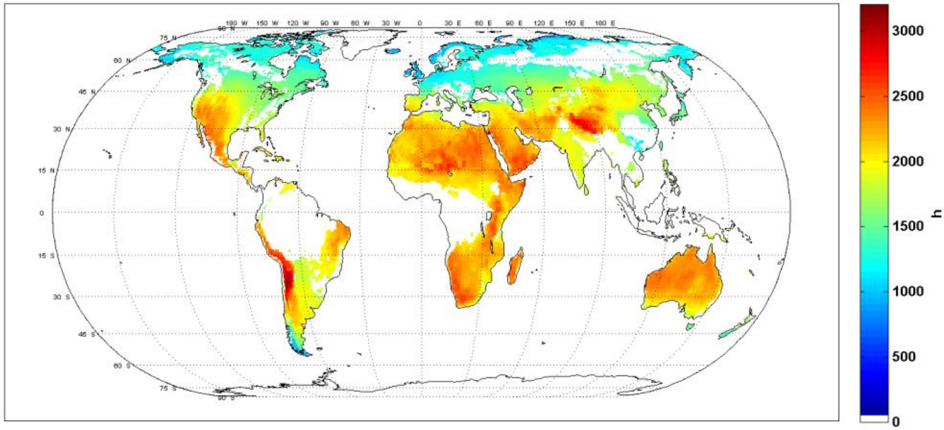
Results

Full load hours

PV (fixed tilted) FLh for cost year 2030

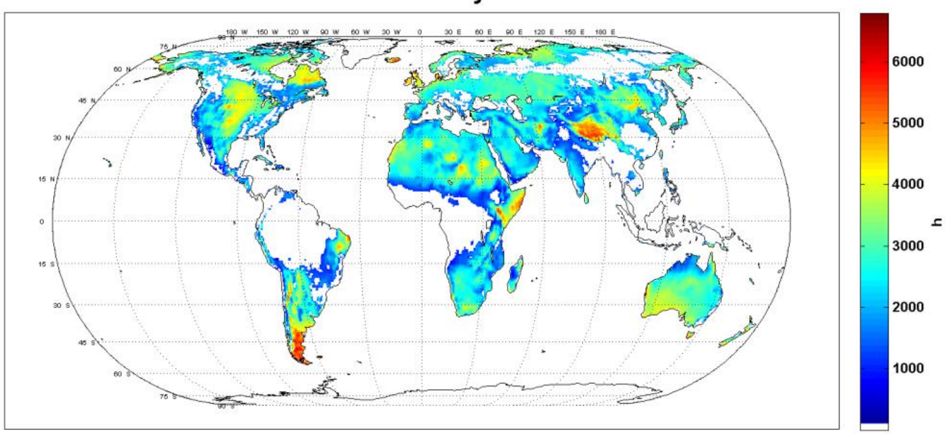


PV (1-axis tracking) FLh for cost year 2030



- sites with cumulative FLh higher than 3000 have been taken into account as they have the lowest LCOE
- PV single-axis tracking provides 200-600 higher FLh than PV fixed-tilted
- wind FLh are much higher than PV FLh due to 24h harvesting
- Patagonia, Somalia and Tibet have the highest cumulative FLh globally

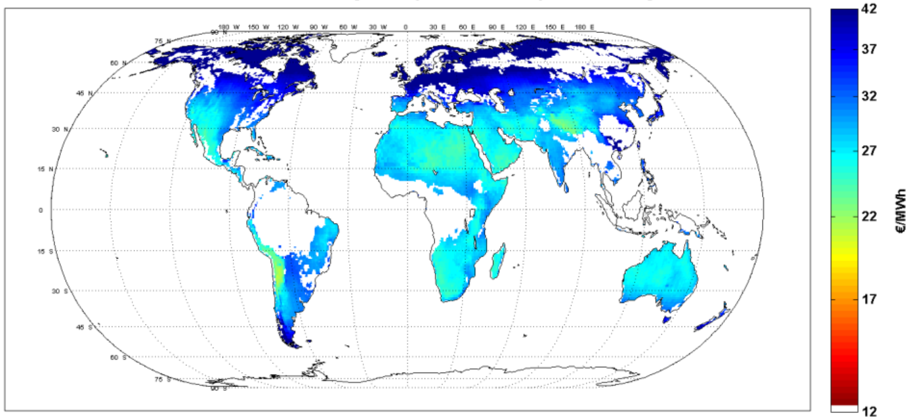
Wind FLh for cost year 2030



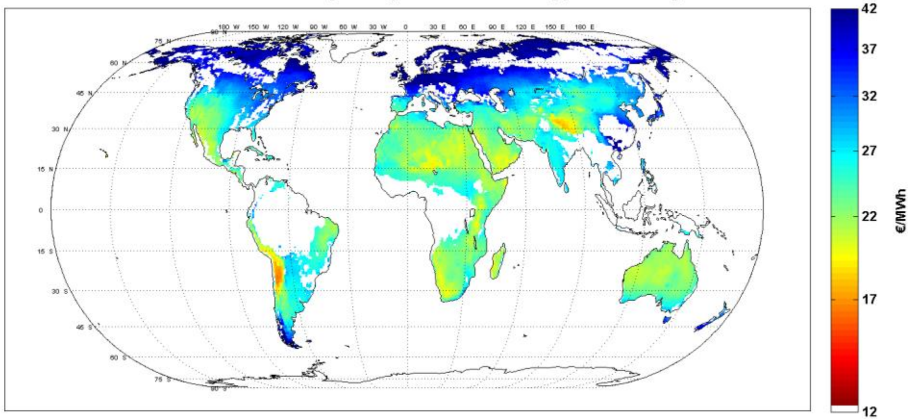
Results

Levelised Cost of Electricity (LCOE)

Levelized cost of electricity PV (fixed tilted) for cost year 2030

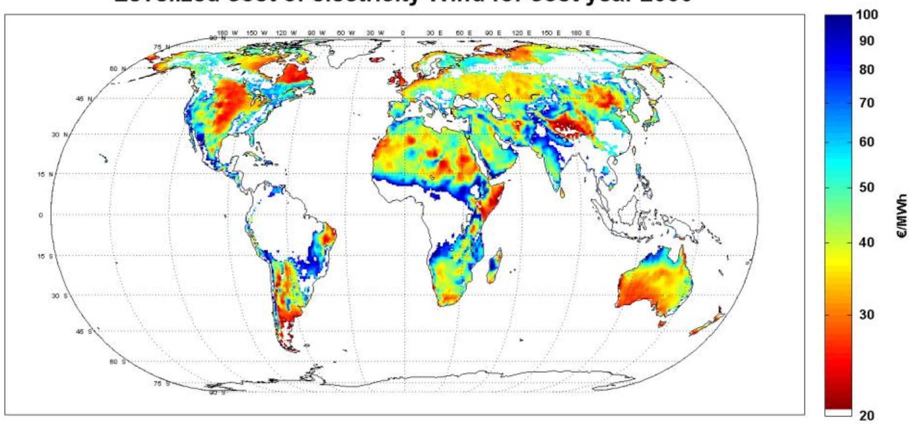


Levelized cost of electricity PV (1-axis tracking) for cost year 2030



- sites of high FLh of PV or Wind plants have the lowest LCOE
- LCOE of PV single-axis tracking is about 4-5 €/MWh cheaper than LCOE of PV fixed tilted, and even more relevant more FLh (20-30%) on a least cost basis
- Atacama Desert reaches PV LCOE of close to 15-17 €/MWh
- Patagonia reaches wind LCOE of close to 19-20 €/MWh

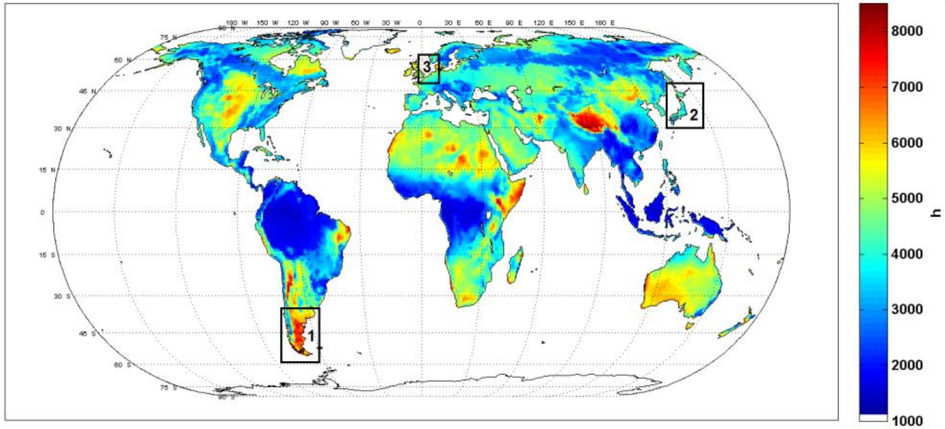
Levelized cost of electricity Wind for cost year 2030



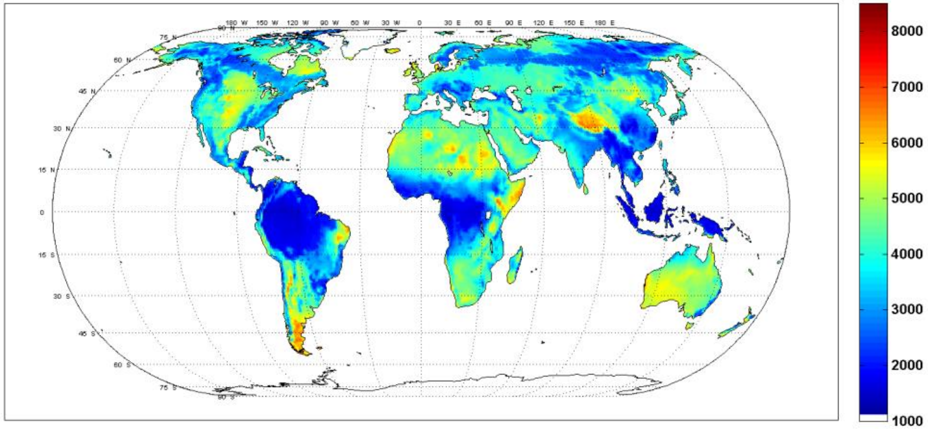
Results

Annual Basis Model (case study)

Hybrid PV1-Wind cumulative FLh in 2005



Hybrid PV1-Wind FLh adjusted by critical overlap in 2005



1) Patagonia as the case study

- Equal installed capacities of PV single-axis tracking and Wind
- 7200 annual cumulative FLh with 10% critical overlap: 6480 net FLh
- All PtX plants at coast
- No storage option or transmission line cost included
- Synthesis units (except PtG) run on baseload

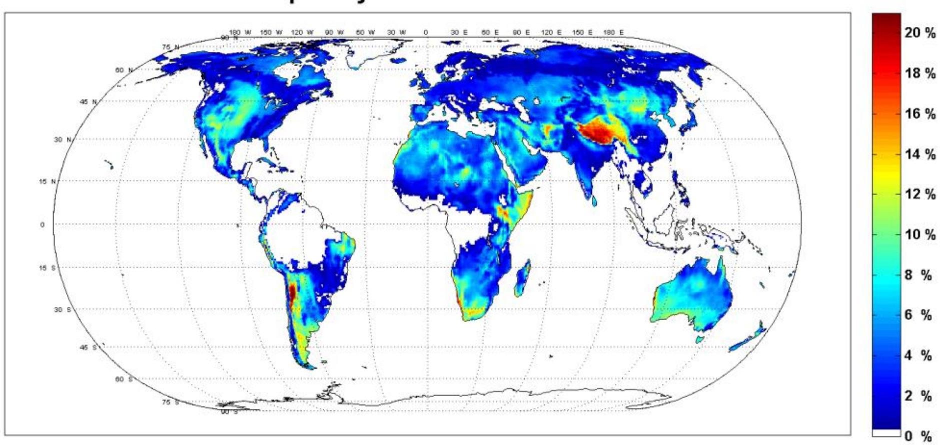
2) Japan as the target market for RE-LNG

- Regasification Plant
- Patagonia – Japan marine distance: 17,500 km

3) EU as the target market for RE-diesel and RE-chemicals

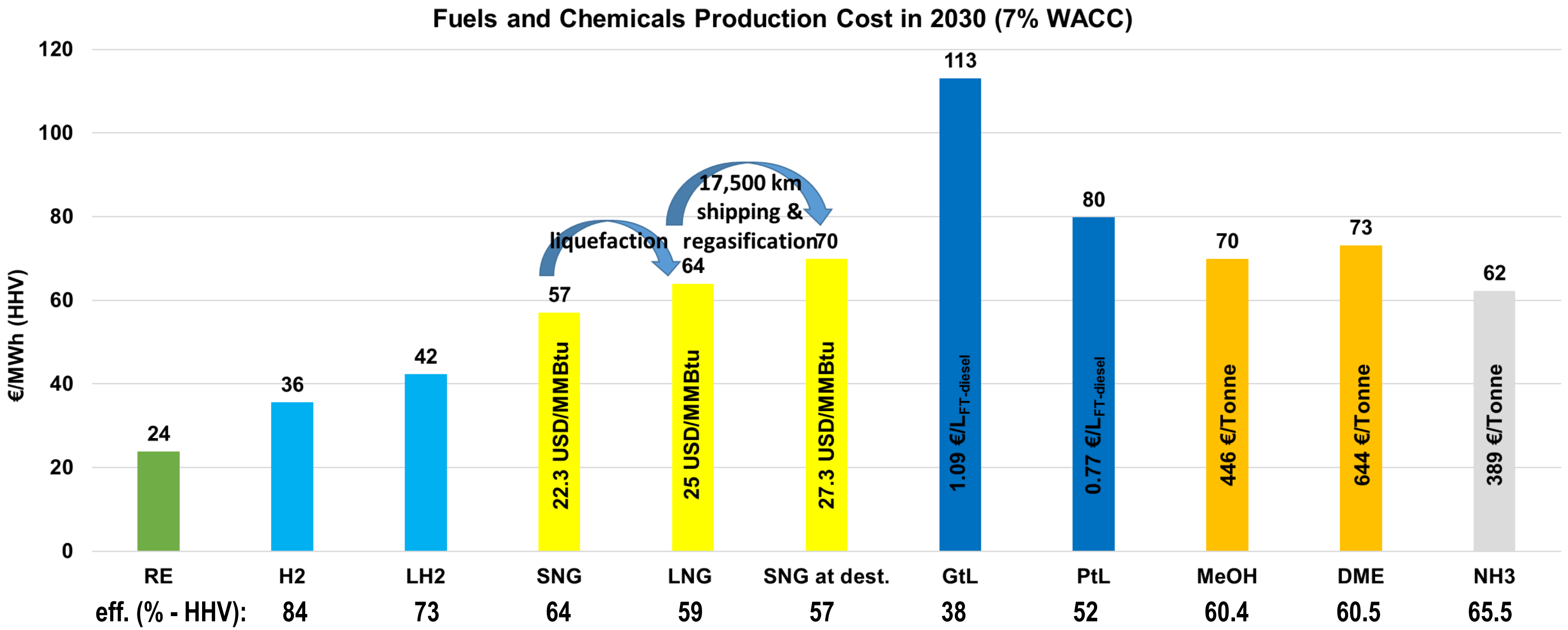
- Patagonia – Rotterdam marine distance: 13,500 km

Ratio of critical overlap to hybrid PV1-Wind cumulative FLh in 2005



Results

Cost of Power-to-Fuel/Chemical Options (Annual Basis Model)



- SNG and PtG-GtL are the cheapest and the most expensive synthetic fuel, respectively.
- the production cost of RE-diesel, RE-methanol and RE-DME are close to each other, however the fuel-parity (cost competitiveness) depends on their respective market price and CO_2 emission cost.

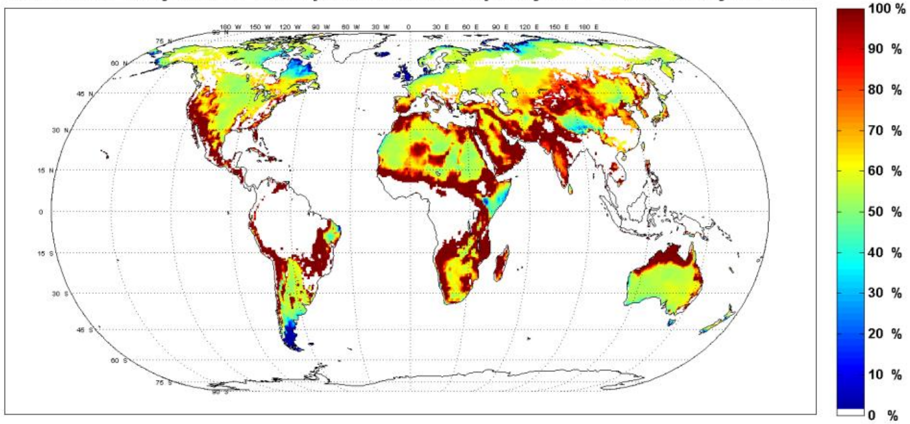
Results

Hourly Basis Model

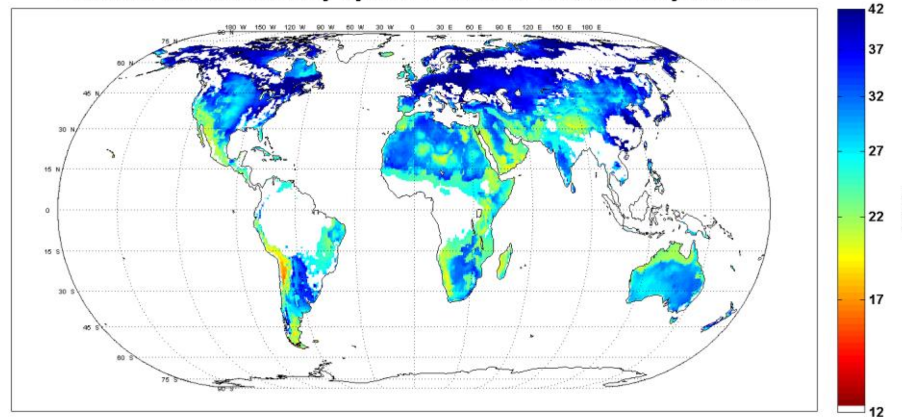
- Optimised configuration of PV (fixed tilted and single-axis tracking), wind power, storage options (battery, PtG-GtP), electricity transmission lines and PtX plants facilities (electrolyser, CO_2 DAC, desalination and synthesis plants), based on an hourly potential of solar and wind in a 0.45° × 0.45° spatial resolution for the least cost fuel production.

Results
LCOE for Cost-optimised PtX Systems

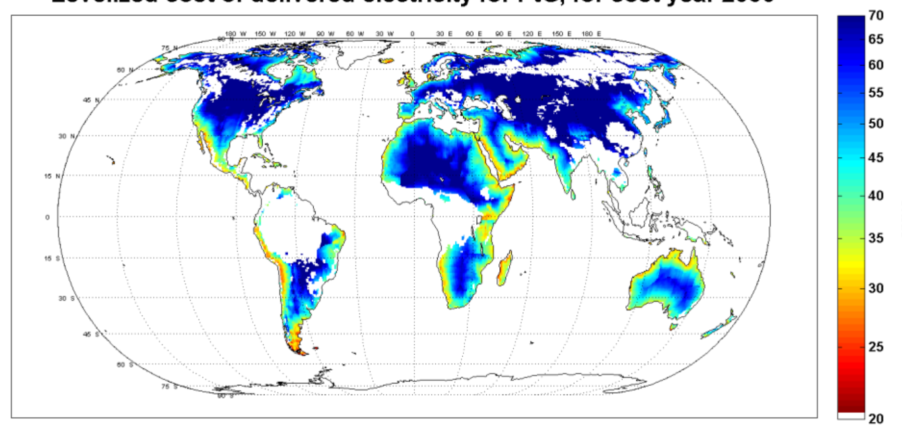
Ratio of PV to hybrid PV-Wind plant installed capacity for PtG, for cost year 2030



Levelized cost of electricity Hybrid PV-Wind for PtG, for cost year 2030



Levelized cost of delivered electricity for PtG, for cost year 2030

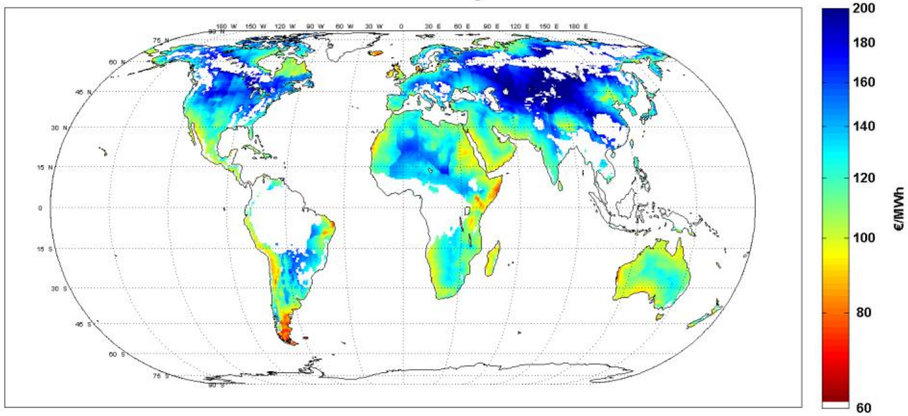


- **optimal combination of PV and Wind for hybrid PV-Wind plants to achieve an optimal combination of LCOE and FLh for downstream PtX plants**
- **top sites in the world may reach hybrid PV-Wind LCOE of 17-20 €/MWh**
- **top sites in the world are usually located at coast and can deliver electricity to PtX plants at costs of about 25-30 €/MWh**
- **additional costs consist of transmission lines, batteries and curtailed electricity**
- **long distance power lines may be too expensive for harvesting electricity far away from the coast**

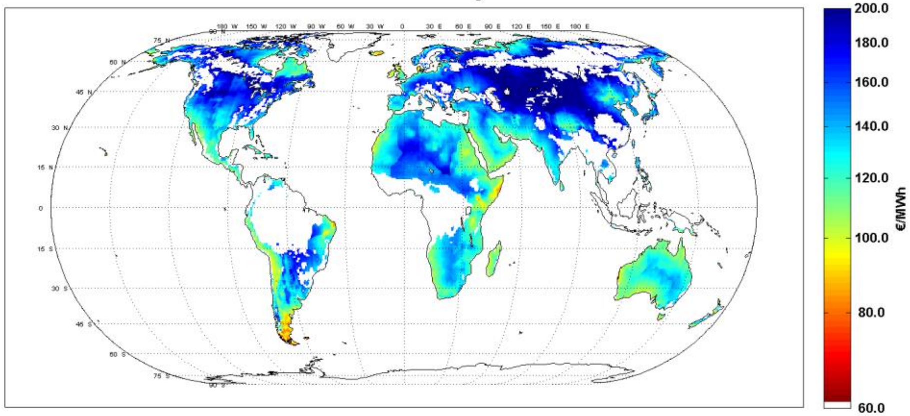
Results

Levelised Cost of Fuels (LCOF) at Coast

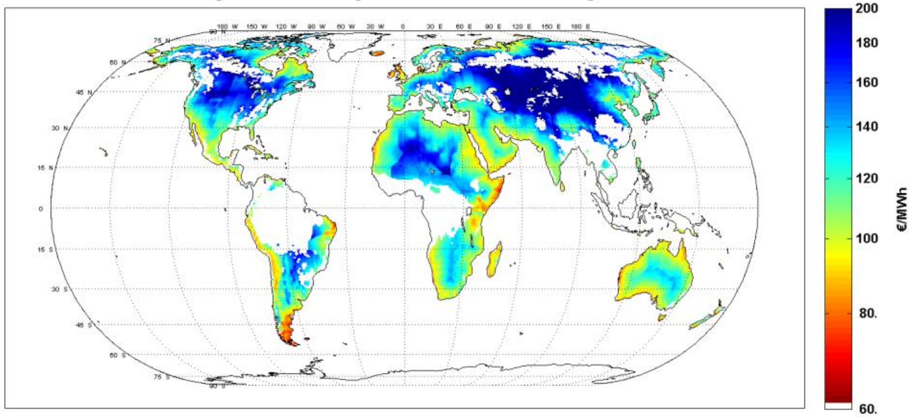
Cost of SNG for cost year 2030



Cost of LNG for cost year 2030



Cost of Synthetic Liquid Fuels for cost year 2030

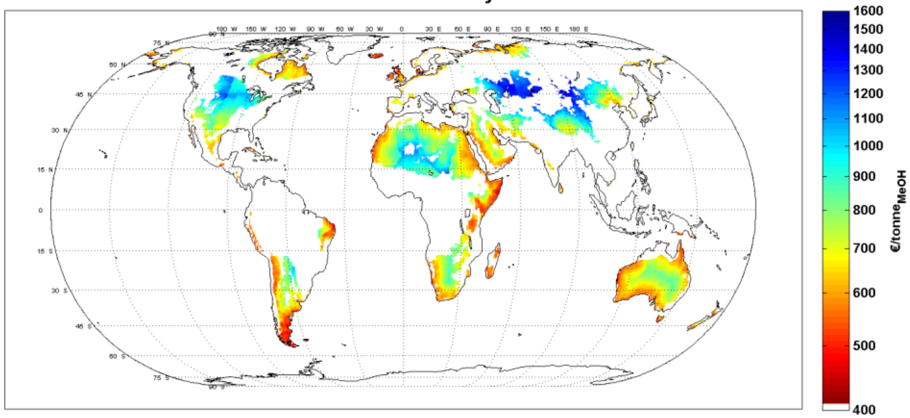


- LCOF as a function of LCOE and FLh of plants' components
- in 2030, top sites in the world reach LCOF of 70 – 80 €/MWh (0.68 - 0.77 €/l for diesel and 27.4 - 31.3 USD/MMBtu for SNG)
- LNG value chain adds 15-20 €/MWh to delivered SNG cost
- regions not so far from coast are generally a better place due to lower electricity transmission cost

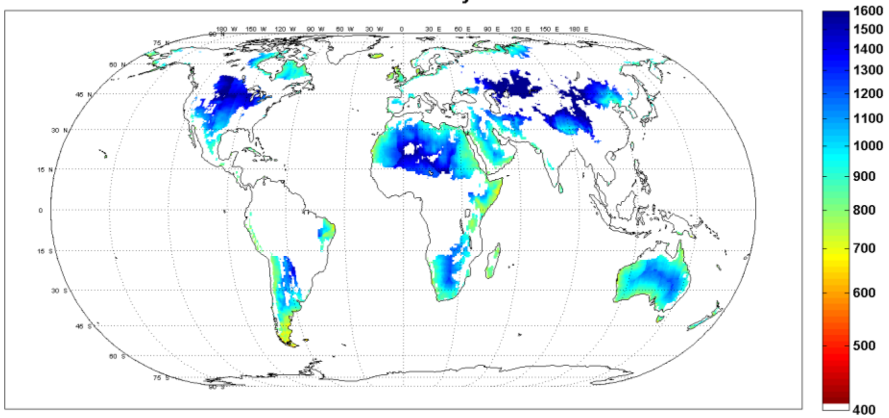
Results

Levelised Cost of Fuels (LCOF) at Coast

Cost of Methanol for cost year 2030

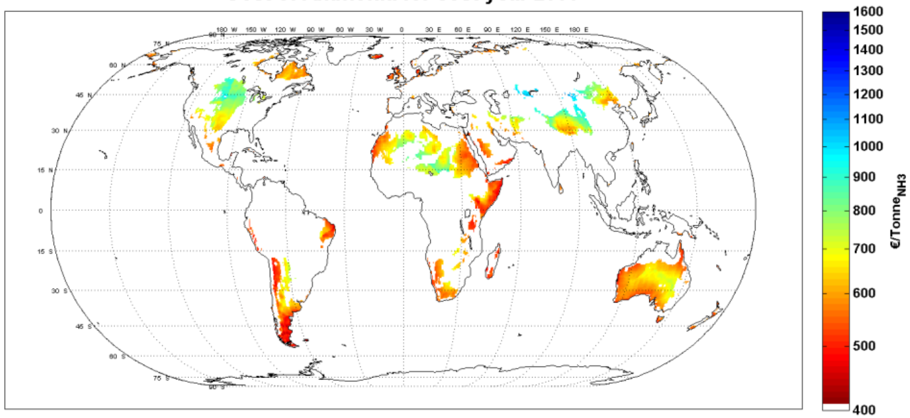


Cost of DME for cost year 2030



- Patagonia, Somalia, Western Sahara and the coasts of Australia and Brazil produce the cheapest methanol within the range of 400-600 €/tonne.
- DME production cost is about 200-300 €/tonne more expensive for each site, depending on the corresponding LCOE.
- The difference in ammonia production cost at coast and remote areas is smaller than the methanol case, due to lower transmission line cost assumption

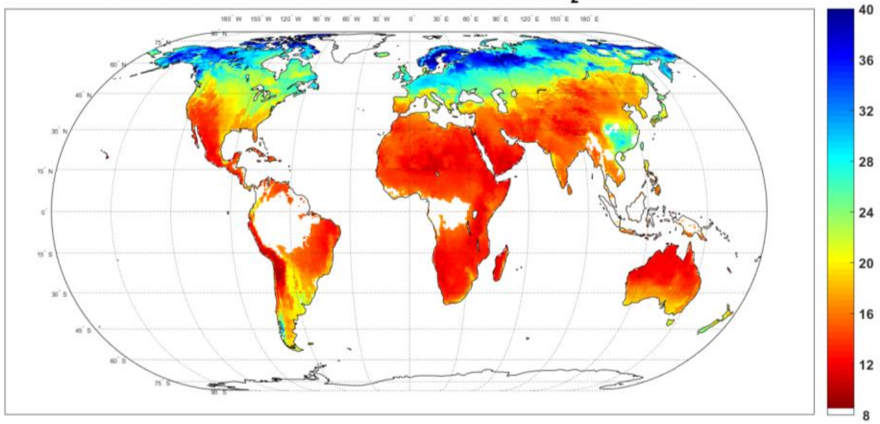
Cost of Ammonia for cost year 2030



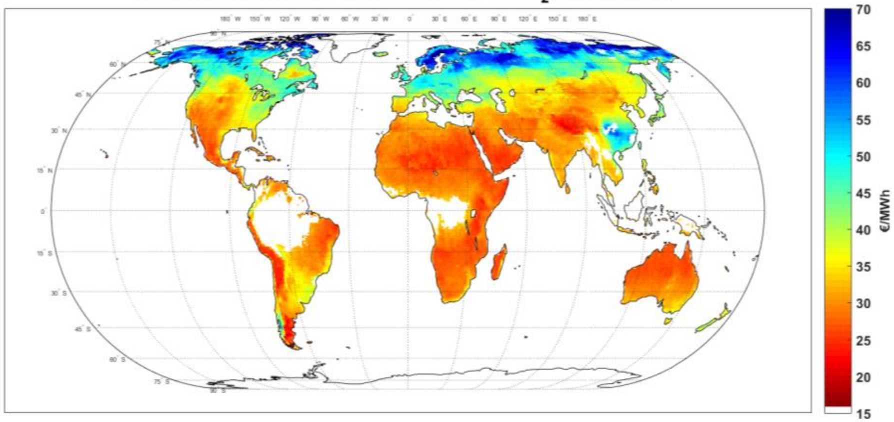
Results

Levelised Cost of Electricity and CO_2 DAC Onsite in 2050

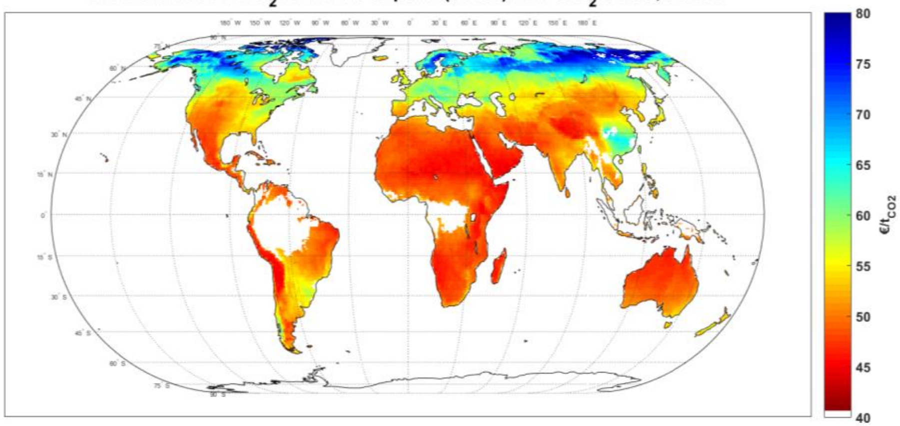
Levelised cost of electricity hybrid PV-Wind for $PtCO_2$ onsite, in 2050



Levelised cost of delivered electricity for $PtCO_2$ onsite, in 2050



Levelised cost of CO_2 Direct Air Capture (LCOD) for $PtCO_2$ onsite, in 2050



- **Best sites would reach a PV-based LCOE of 9-15 €/MWh.**
- **Levelised cost of delivered electricity to the DAC system includes batteries, PtH_2tP and curtailment, which would reach 20-30 €/MWh at best sites**
- **Least-cost DAC would be accessible in most parts of the world at costs below 50 €/t_{CO2}**
- **Access to free waste heat could decrease the costs by about 40%, which is the case for PtG and PtL.**

Summary

- The idea is to use hybrid PV-Wind electricity to produce synthetic fuels in the best sites in the world for export.
- RE-fuels are a non-diminishing fossil CO_2 free fuels, which will insure both fuel security and environmental issues.
- LNG downstream value chain is needed for delivering RE-SNG to far-off regions.
- With PtL, refinery products downstream value chain can be used.
- The by-products of the synthetic plants (O_2 & heat) can play a significant role in some regional cases to reach fuel parity
- RE-NH_3 is a non-diminishing carbon-free chemical and fuel, which could insure both fuel security and environmental issues. In Patagonia, ammonia could be produced with a cost of 400 €/tonne in 2030
- In the best scenario, for a Brent crude oil price more than 109 USD/bbl in 2030 and CO_2 emission cost of 61 €/t_{CO2}, and O_2 benefit of 20 €/t_{O2} RE-diesel is competitive to fossil diesel prices in EU.
- This would be an upper limit for the fossil diesel price in the long-term and a business opportunity whenever crude oil price is higher than mentioned level.
- DAC could be implemented as a negative emission technology in 2050 for costs below 50€/t_{CO2}.

Key References

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Thank you for your attention!

NEO-CARBON Energy project is one of the Tekes strategy research openings and the project is carried out in cooperation with Technical Research Centre of Finland VTT Ltd, Lappeenranta University of Technology (LUT) and University of Turku, Finland Futures Research Centre.

Backup

100% RE Scenarios: Country to Global

Open your mind. LUT.
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Breyer et al., 100% RE articles in journals

Plessmann et al.	2014	J	Global, ON
Moeller et al.	2014	J	Berlin-Brandenburg, ON
Bogdanov & Breyer	2015	J	Northeast Asia, ON
Bogdanov & Breyer	2016	J	Northeast Asia, improved, ON
Child & Breyer	2016	J	Finland, ON
Barbosa et al.	2016	J	Brazil, ON
Gulagi et al.	2017	J	Southeast Asia, ON
Barbosa et al.	2017	J	South America, ON
Breyer et al.	2017	J	Global, ON
Gulagi et al.	2017	J	East Asia, ON
Aghahosseini et al.	2017	J	North America, ON
Gulagi et al.	2017	J	India/ SAARC, ON
Caldera et al.	2017	J	Saudi Arabia, ET
Ghorbani et al.	2017	J	Iran, ET
Child et al.	2017	J	Ukraine, ET
Gulagi et al.	2017	J	India, ET
Child et al.	2017	J	Åland, ON
Gulagi et al.	2017	J	India, monsoon, ET
Caldera et al.	2018	J	Saudi Arabia, water, ET
Kilickaplan et al.	2017	J	Turkey, ET
Breyer et al.	2017	J	Global, ET
Barasa et al.	2018	J	Sub-Saharan Africa, ON
Aghahosseini et al.	2018	J	Iran, ON
Sadiqa et al.	2018	J	Pakistan, ET
Meschede et al.	2018	J	La Gomera, ON
Caldera & Breyer	2018	J	Saudi Arabia, desalination, ET
Bogdanov et al.	2018	J	Northeast Asia, ET, accepted
Oyewo et al.	2018	J	Sub-Saharan Africa, Grand Inga, ON
Solomon et al.	2018	J	Israel, ET

Breyer et al., related topics, articles in journals

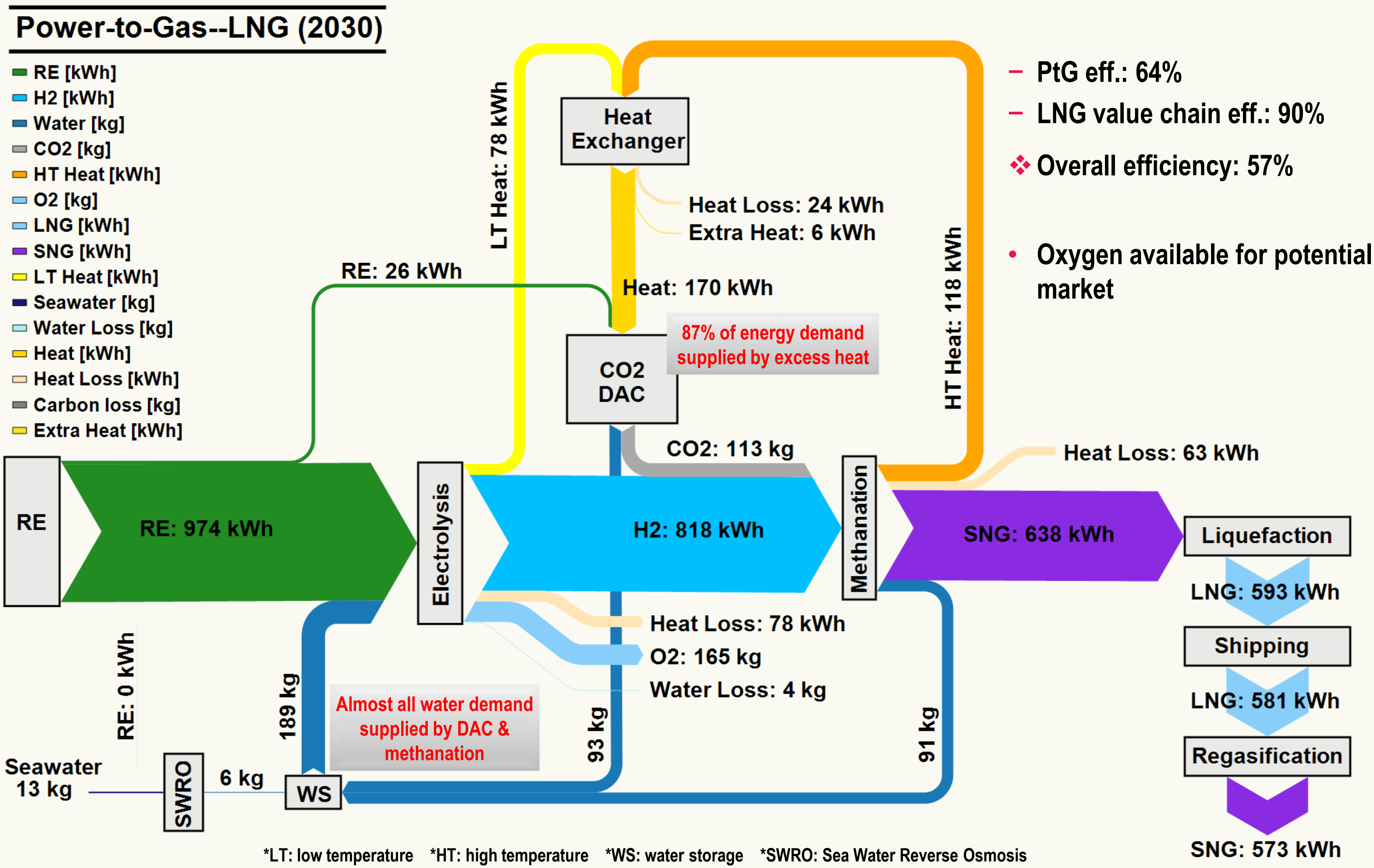
Blechinger et al.	2014	J	Islands
Breyer et al.	2015	J	PtX: PtG value chains
Breyer et al.	2015	J	CO_2 reduction benefits
Cader et al.	2016	J	off-grid: PV-battery-diesel
Caldera et al.	2016	J	PtX: RE-based desalination
Görig & Breyer	2016	J	Energetic learning curves of PV
Blechinger et al.	2016	J	Islands
Koskinen & Breyer	2016	J	Storage in global scenarios
Fasihi et al.	2016	J	PtX: power-to-liquids
Afanasyeva et al.	2016	J	Battery and hybrid PV plants
Breyer et al.	2017	J	Rebalancing within limits of Earth
Farfan & Breyer	2017	J	Global power plant databasis
Raugei et al.	2017	J	EROI of PV systems
Fasihi et al.	2017	J	PtX: Hydrocarbons from Maghreb
Child & Breyer	2017	J	Transition and Transformation
Breyer et al.	2017	J	CSP vs hybrid PV-battery plants
Solomon et al.	2017	J	Storage demand
Bertheau et al.	2017	J	Electrification in Sub-Saharan Africa
Caldera & Breyer	2017	J	PtX: RO desalination learning curve
Horvath et al.	2018	J	Defossiliated marine sector
Azzuni & Breyer	2018	J	Energy security
Child et al.	2018	J	Sustainability guardrails in scenarios
Brown et al.	2018	J	Review on feasibility of 100% RE
Aghahosseini et al.	2018	J	CAES resource potential

Please send me documents on 100% RE, in case you think it could be not well know (journal, reports, conference papers, dissertations)

Abbreviations: OverNight scenario (ON), Energy Transition scenario (ET), peer-reviewed journal publication (J)

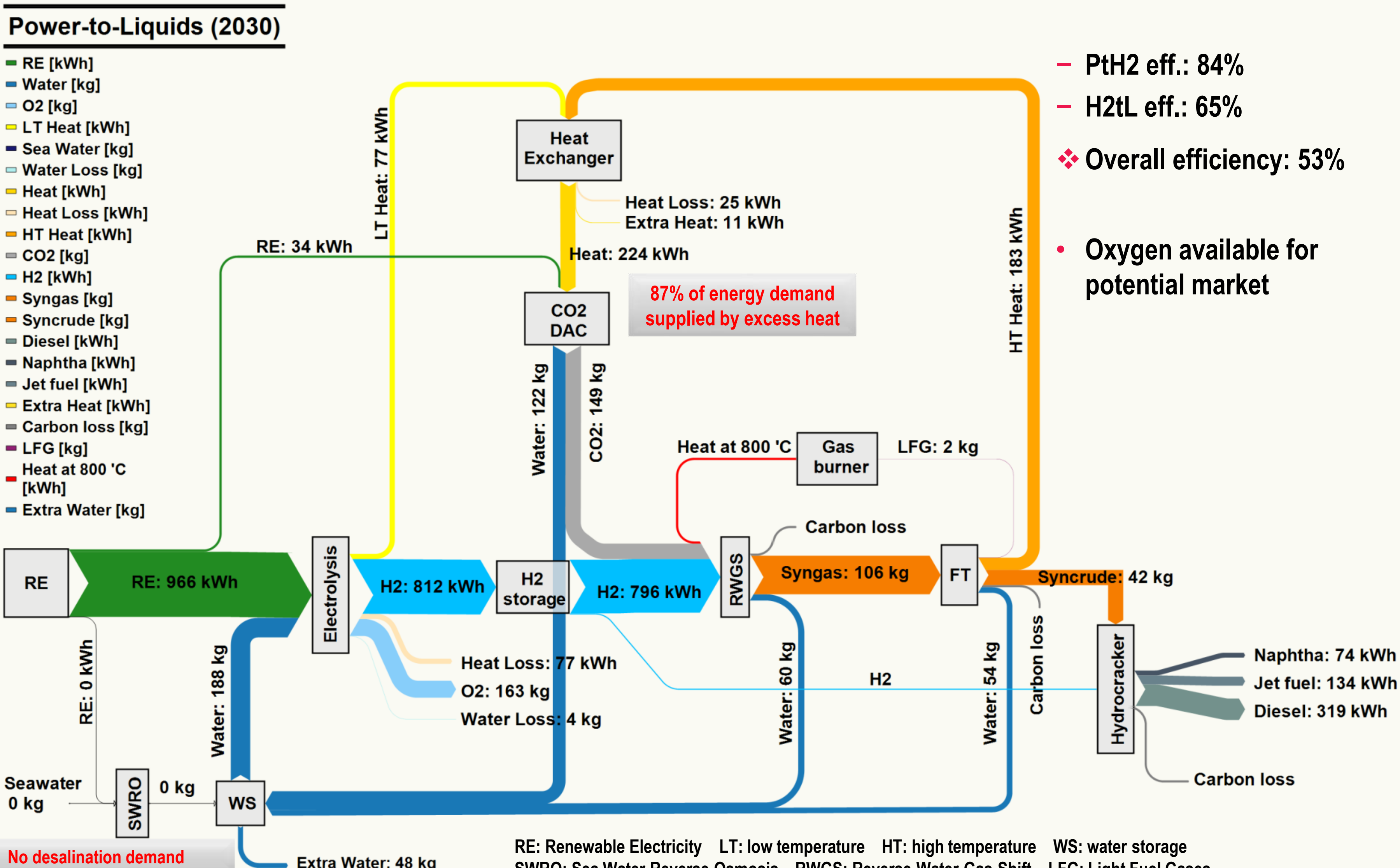
Methodology

PtG-LNG Value Chain Energy Flow & Mass Balance



Methodology

PtL Energy Flow & Mass Balance



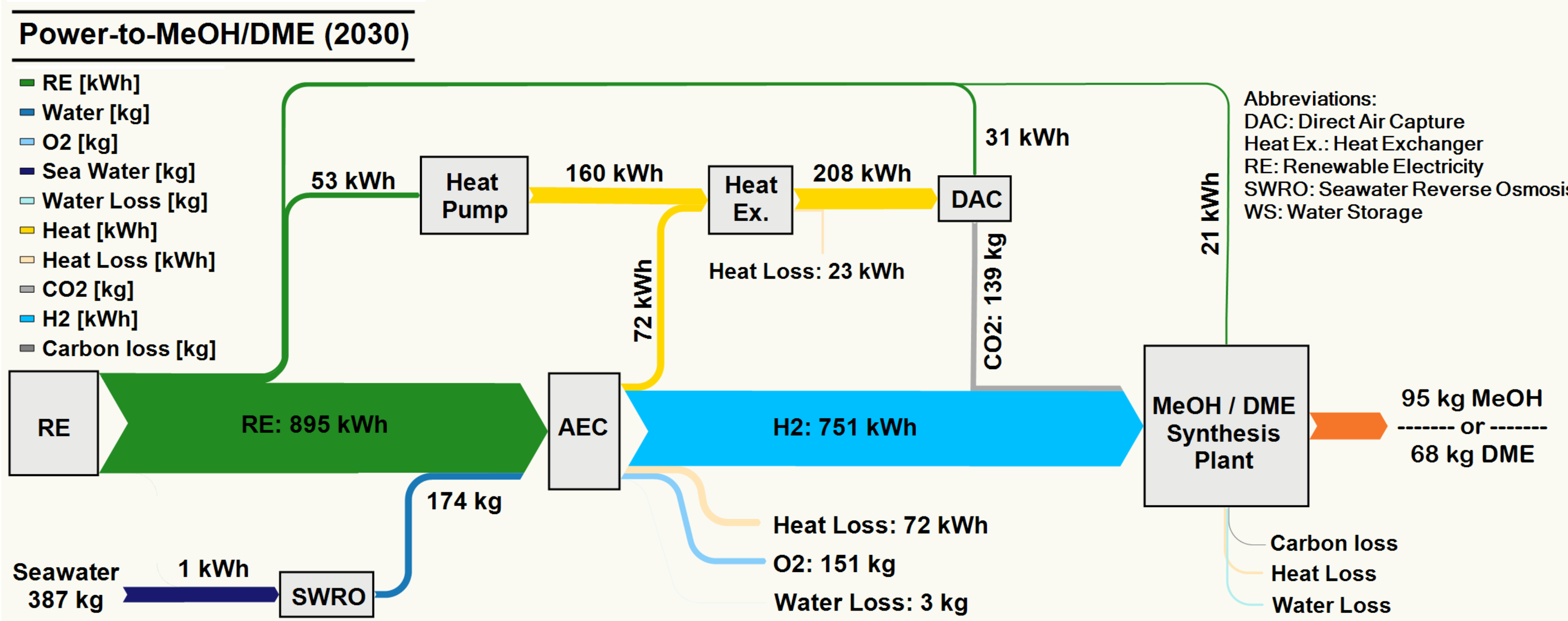
- PtH2 eff.: 84%
- H2tL eff.: 65%
- Overall efficiency: 53%

- Oxygen available for potential market

RE: Renewable Electricity LT: low temperature HT: high temperature WS: water storage
SWRO: Sea Water Reverse Osmosis RWGS: Reverse Water-Gas Shift LFG: Light Fuel Gases

Methodology

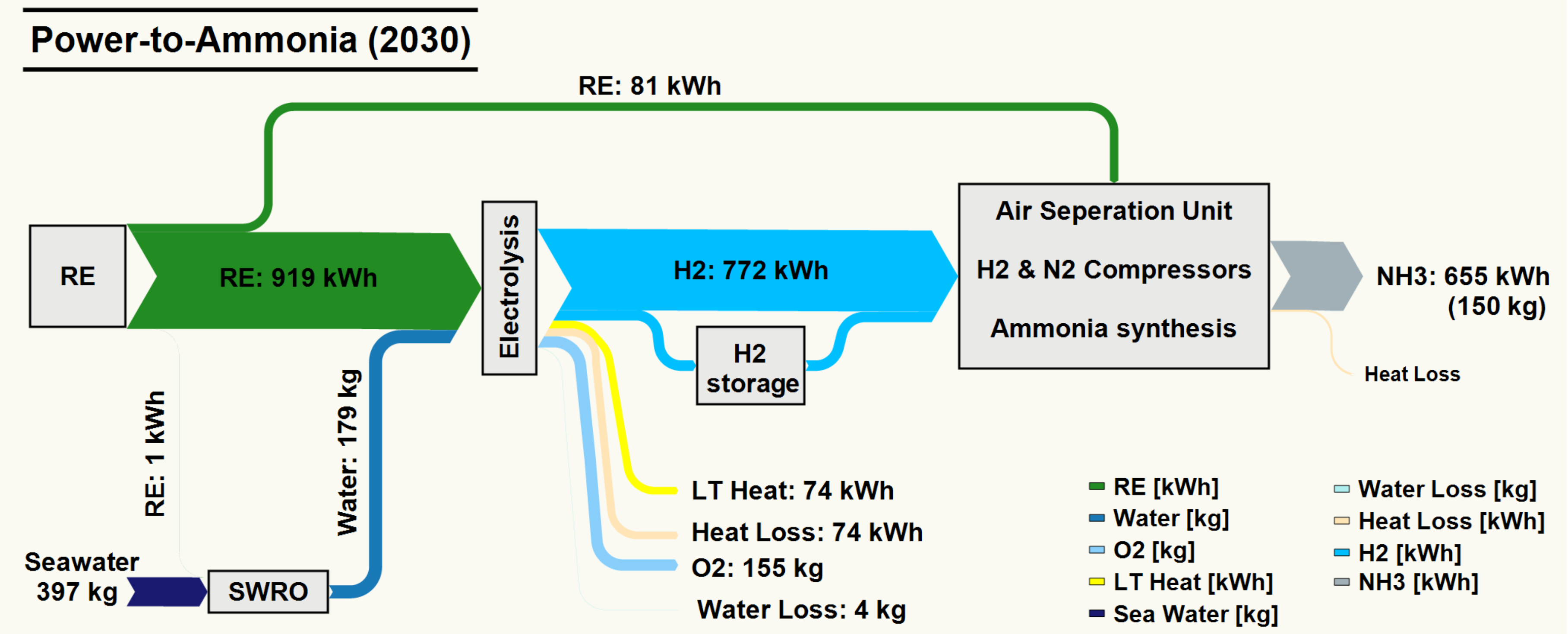
PtMeOH/DME Energy Flow & Mass Balance



- Electrolyser is the main electricity consumer
- PtH_2 eff.: 84%
- PtMeOH overall efficiency eff.: 60.4%
- PtDME overall efficiency eff.: 60.5%
- Oxygen available for sale on respective O_2 markets
- Heat pump decreases direct electricity consumption

Methodology

$PtNH_3$ Energy Flow & Mass Balance

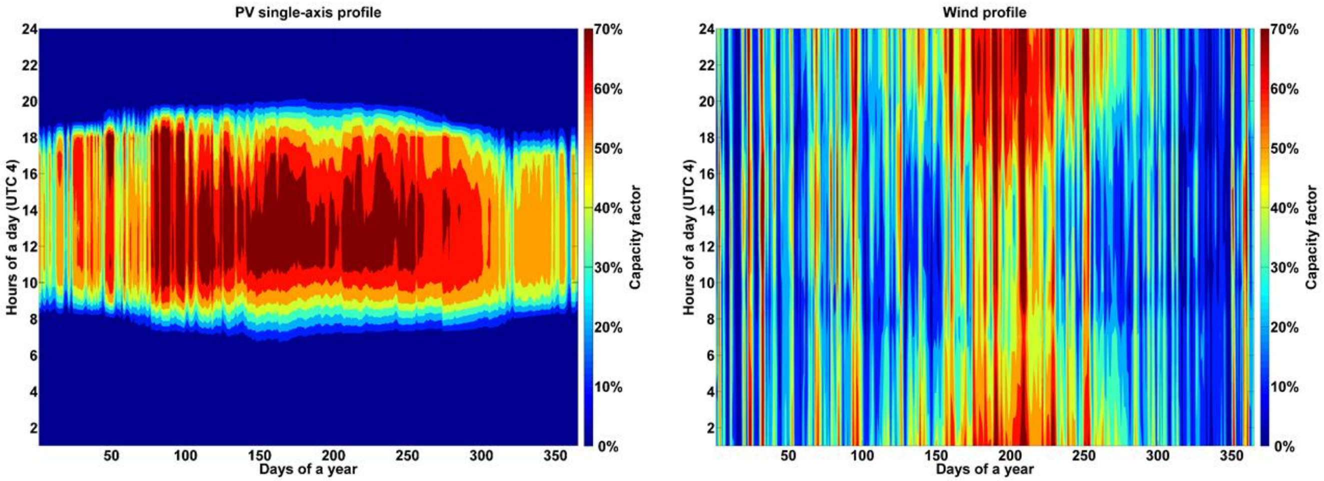


RE: Renewable Electricity LT: low temperature SWRO: Sea Water Reverse Osmosis

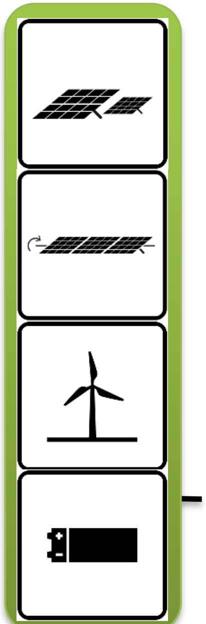
- Electrolyser is the main electricity consumer
- PtH_2 eff.: 84%
- $PtNH_3$ overall eff.: 65.5%
- Oxygen available for sale on respective O_2 markets
- Excess utilisable heat available from electrolyser and synthesis plant

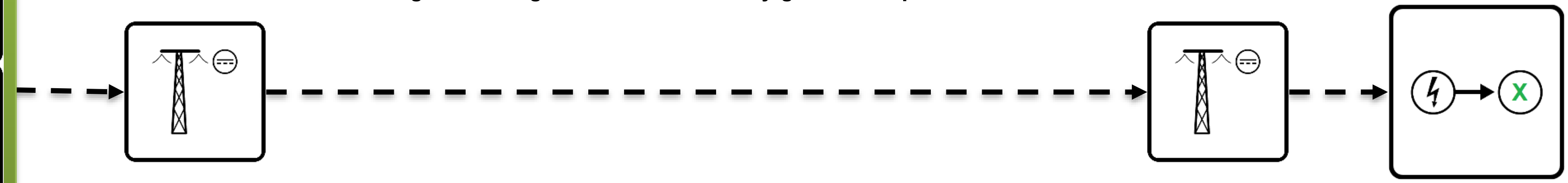
Results
Hourly Basis Model

- Optimised configuration of PV (fixed tilted and single-axis tracking), wind power, storage options (battery, PtG-GtP), electricity transmission lines and PtX plants facilities (electrolyser, CO_2 DAC, desalination and synthesis plants), based on an hourly potential of solar and wind in a 0.45° × 0.45° spatial resolution for the least cost fuel production.
  - The datasets for solar irradiation components and wind speed are taken from NASA databases. Feed-in time series of wind power plants are calculated for standard 3 MW wind turbines (E-101) with hub height conditions of 150 meters.



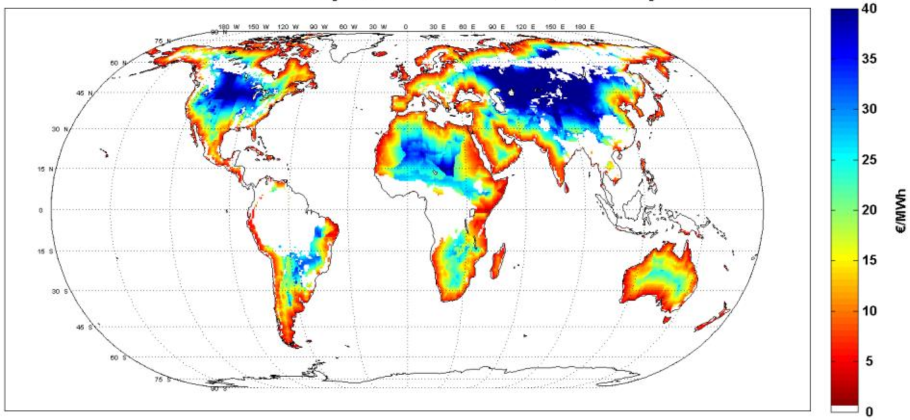
weighed average PV and Wind hourly generation profile for Iran



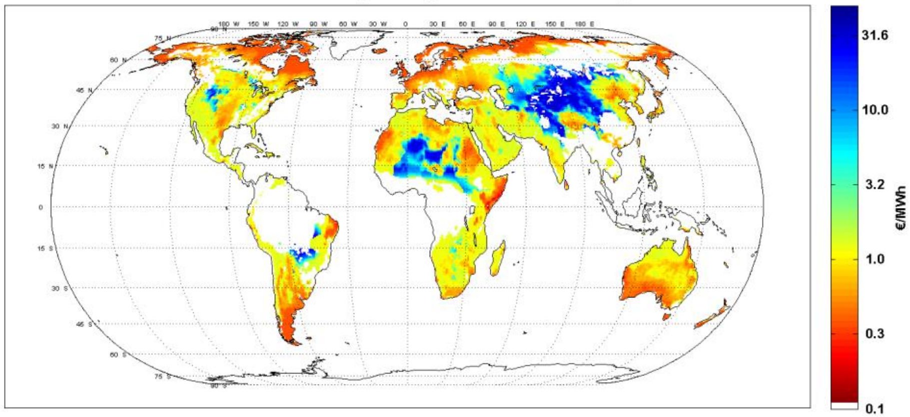


Results
Sources of Additional LCOE

Levelized cost of electricity transmission for PtL, for cost year 2030

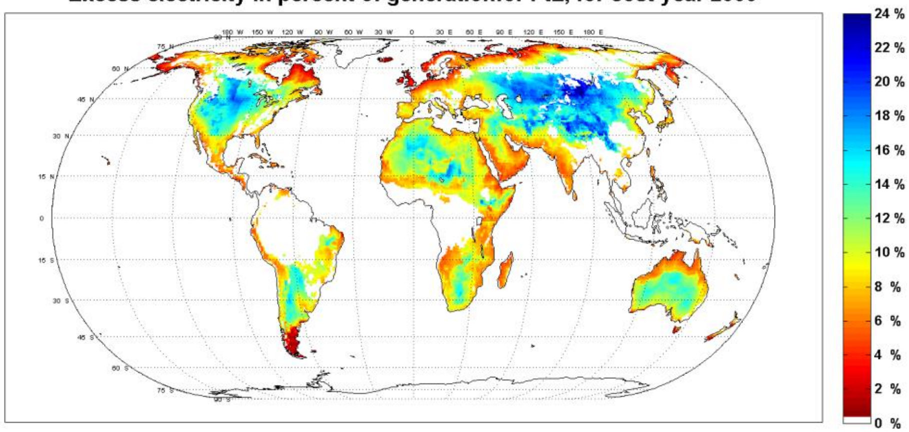


Levelized cost of electricity storage for PtL, for cost year 2030



- distance to coast and consequently electricity transmission cost are determinative factors which can block a fuel export case
- for long distances to the coast with a high share of PV, such as Tibet, more battery installations, balance the system for a lower electricity transmission cost
- excess electricity due to overlap and curtailments (to optimise the capacity of transmission lines and PtX plants)

Excess electricity in percent of generationfor PtL, for cost year 2030



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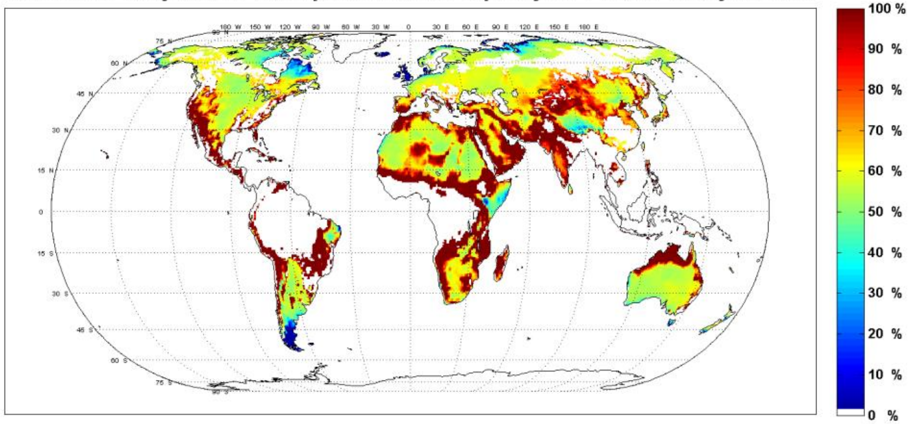
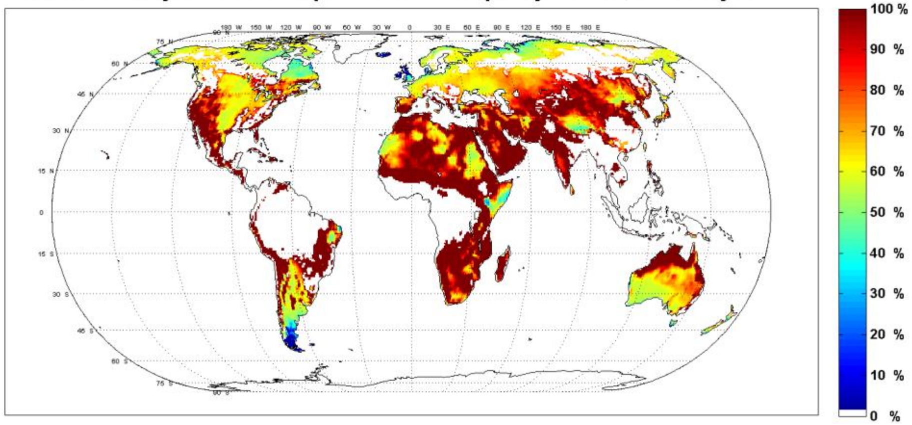
Results

The share of PV and batteries from 2030 to 2040

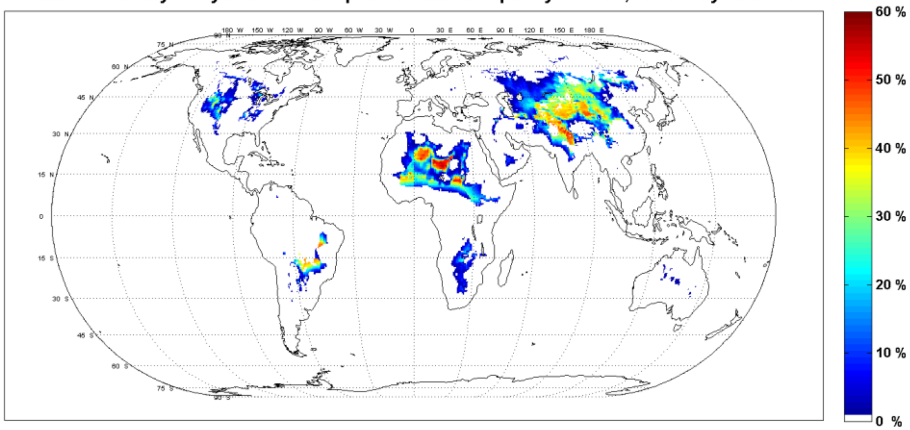
Ratio of PV to hybrid PV-Wind plant installed capacity for PtG, for cost year 2030



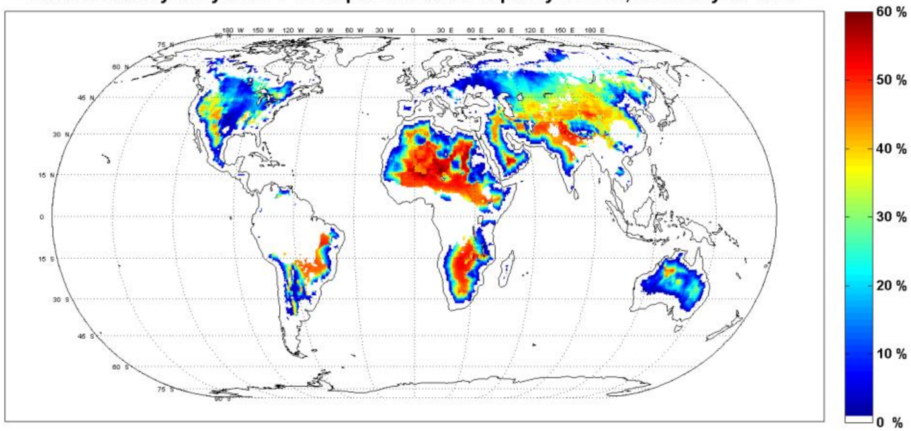
Ratio of PV to hybrid PV-Wind plant installed capacity for PtG, for cost year 2040



Ratio of battery to hybrid PV-Wind plant installed capacity for PtG, for cost year 2030



Ratio of battery to hybrid PV-Wind plant installed capacity for PtG, for cost year 2040

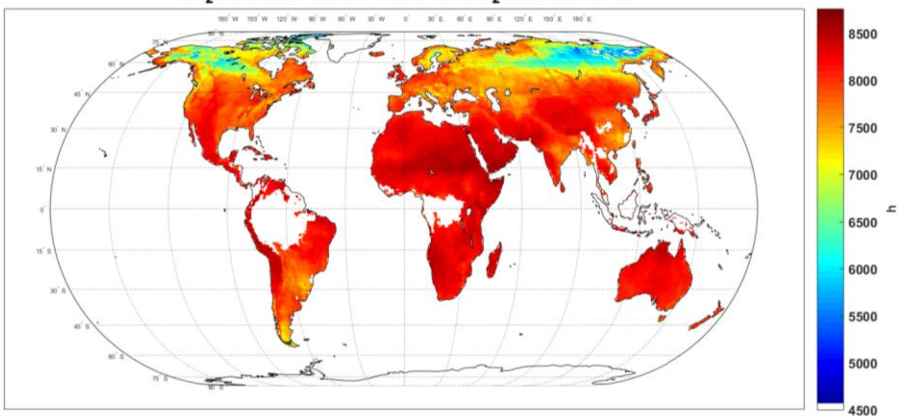


- in Africa, the installed capacity of batteries would be up to 60% of installed capacity of hybrid PV-wind plant by 2040.
- strong increasing relevance of battery technology from 2030 to 2040

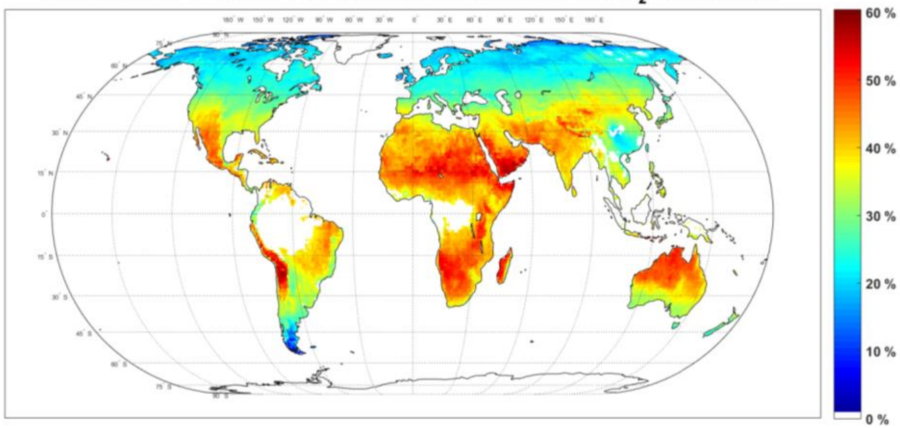
Results

CO_2 Direct Air Capture in 2050

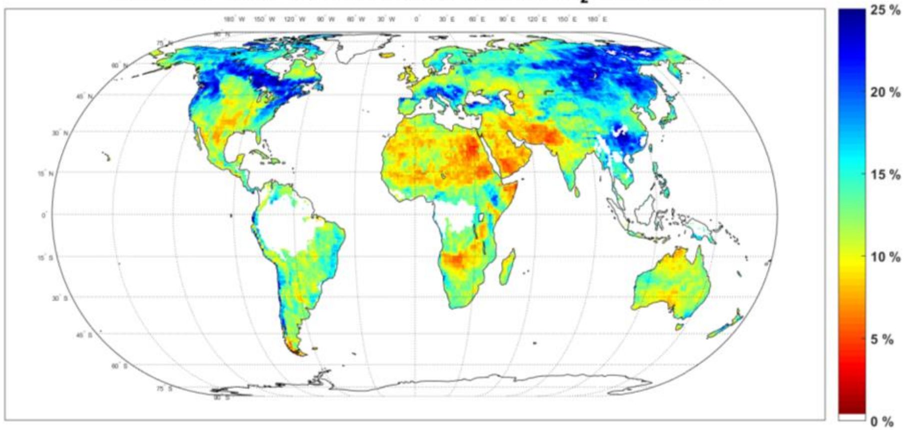
CO_2 Direct Air Capture FLh for $PtCO_2$ onsite, in 2050



Ratio of battery to hybrid PV-Wind plant installed capacity for $PtCO_2$ onsite, in 2050



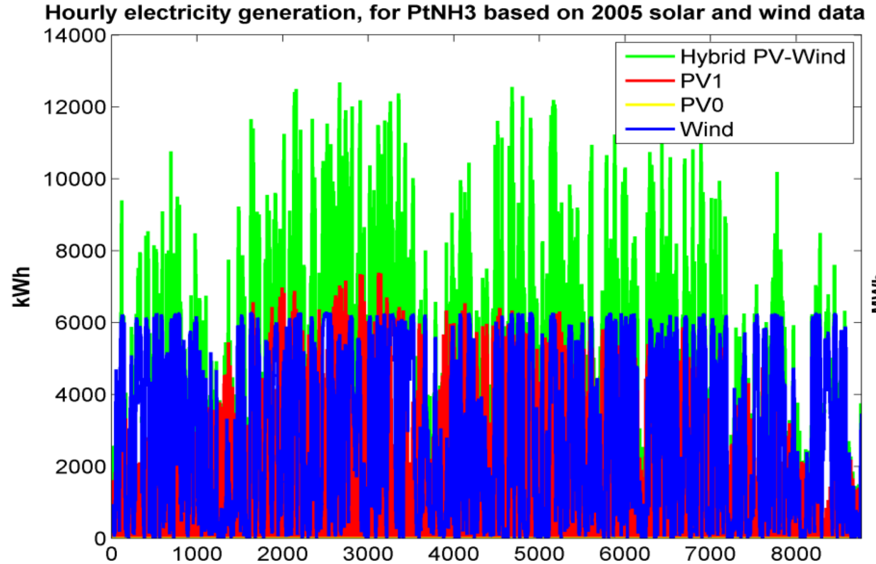
Curtailed electricity in percent of generation for $PtCO_2$ onsite, in 2050

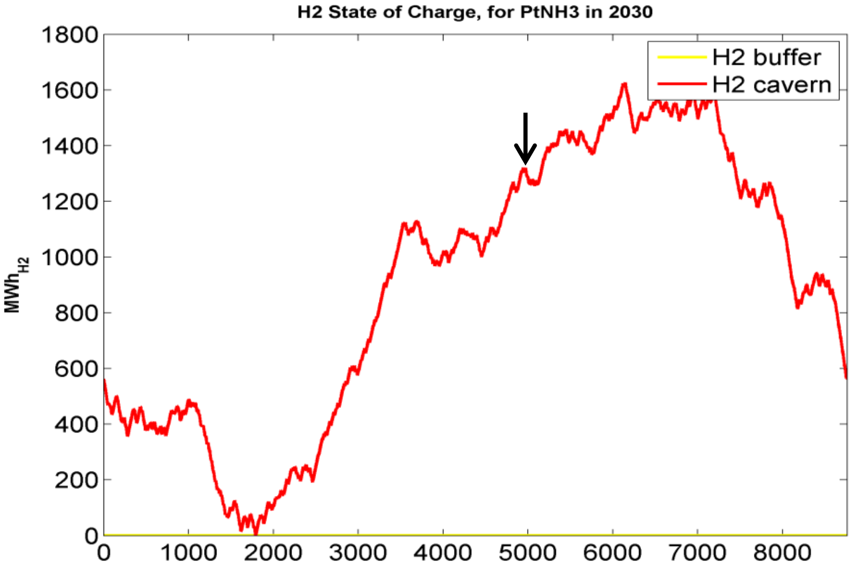


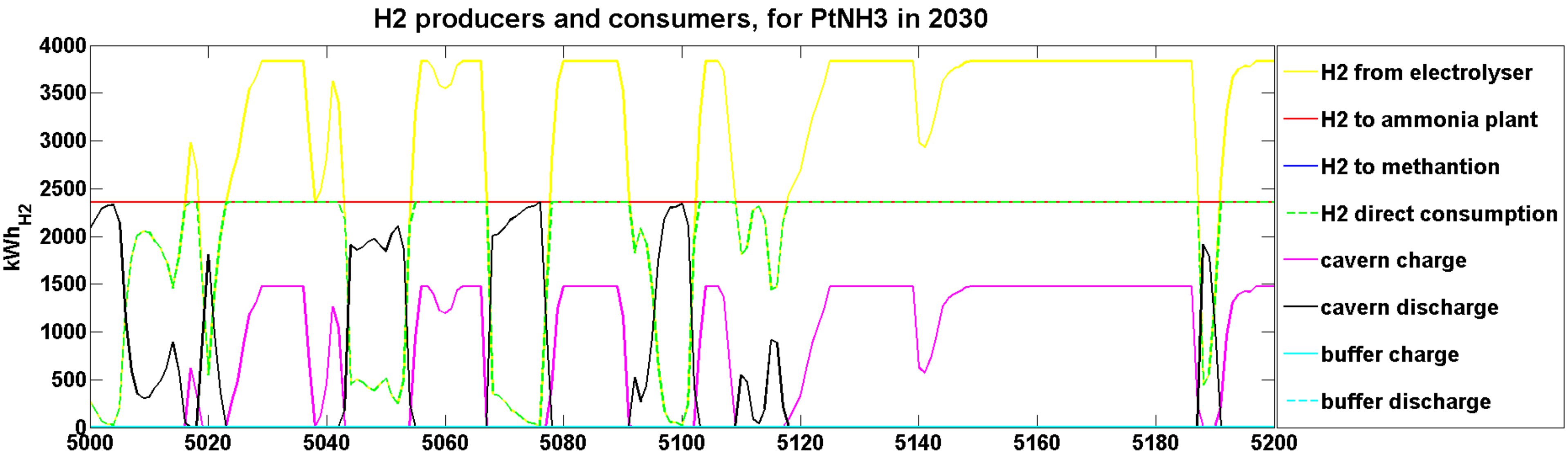
- **Cost-optimised CO_2 direct air capture tends to run on baseload due to high capital expenditures.**
- **Batteries would play a significant role in achieving high FLh for DAC systems in 2050**
- **Up to 25% electricity curtailment is a part of cost-optimised solution some regions in the North.**

Results

Hourly electricity & H_2 generation and consumption for $PtNH_3$ in a sample node

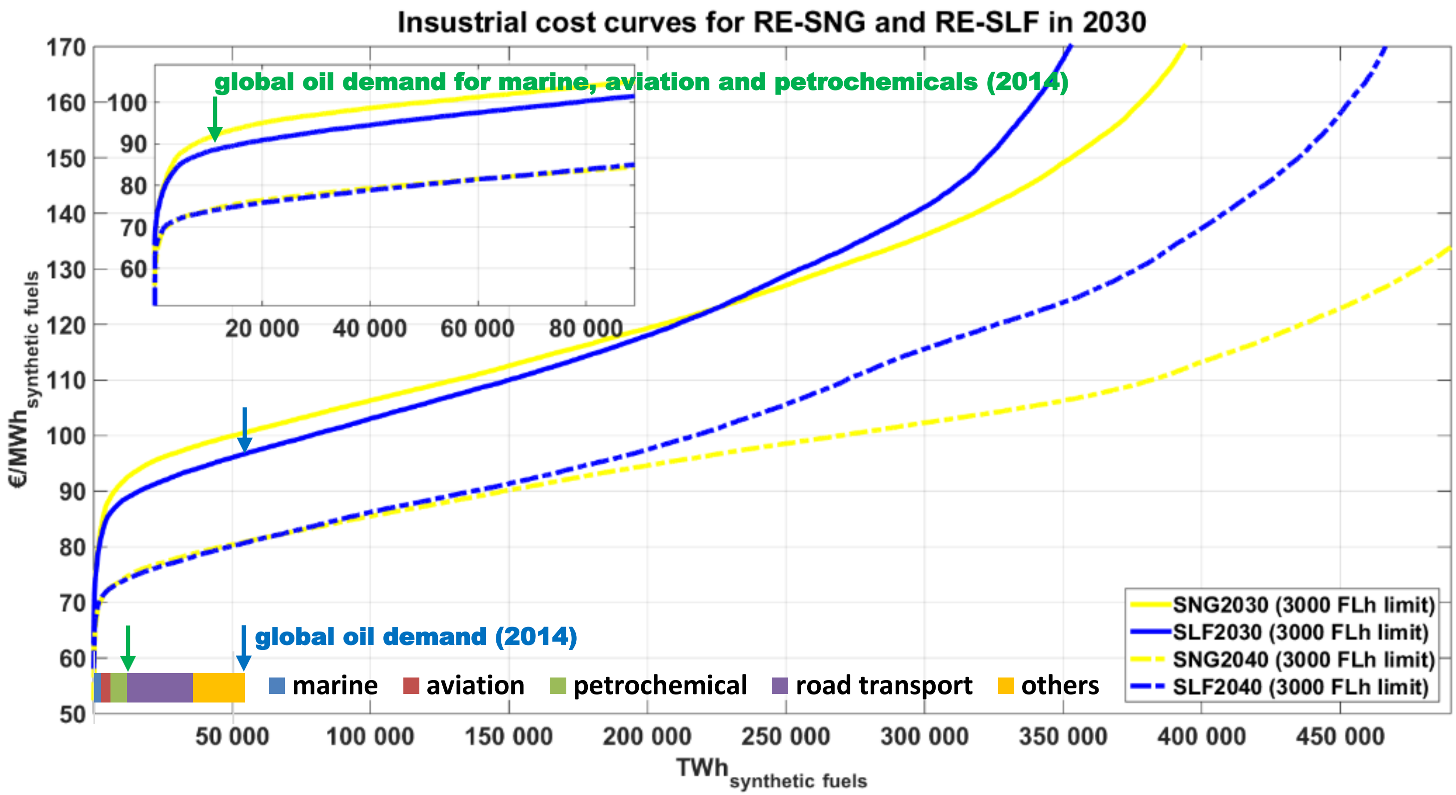






Results

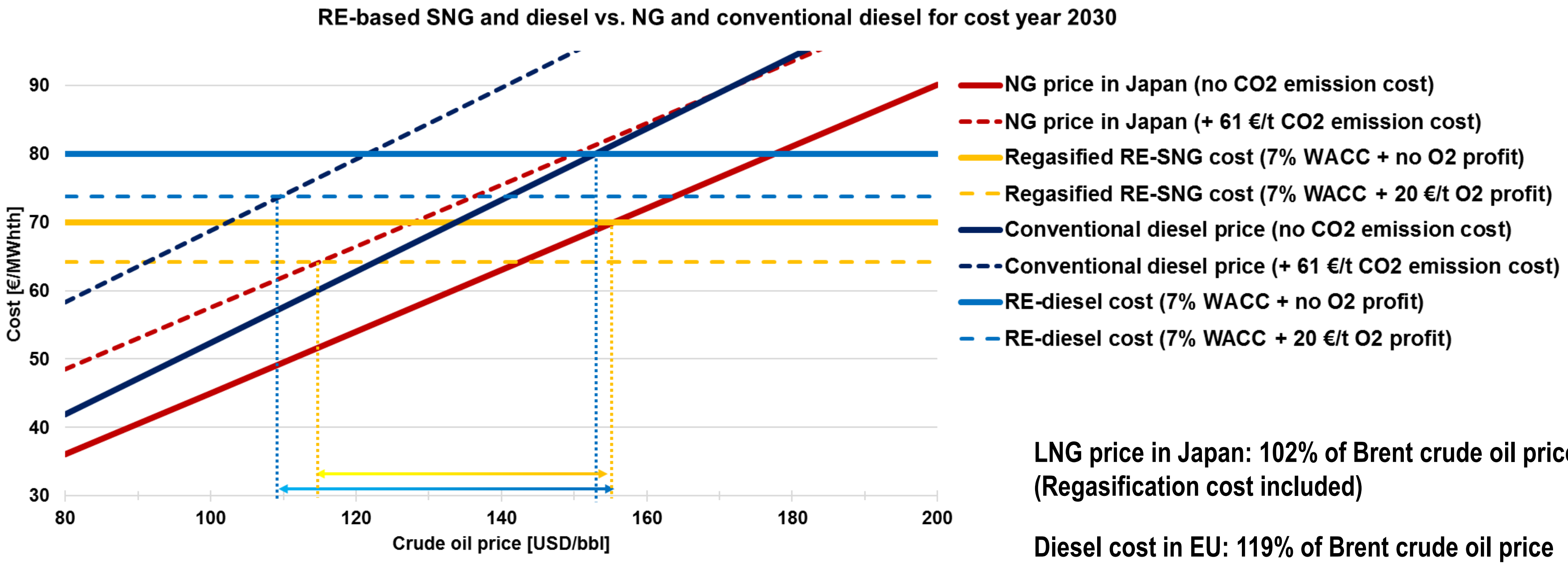
Optimised PtX Production Potential (PtX overview)



- maximum 10% of the land allowed to be used for PV and Wind each, in regions with minimum 3000 cumulative PV-Wind FLh
- global oil demand for marine, aviation and petrochemicals in 2014 was about 12,000 TWh, which could be met at costs less than 90 €/MWh$_{SLF}$ (0.84 €/l$_{SLF}$)
- potential of about 50,000 TWh$_{SNG}$ for cost less than 100 €/MWh$_{fuel}$ (39.1 USD/MMBtu) in 2030
- the production cost of synthetic fuels decreases about 15% from 2030 to 2040

Results

Final Cost and Breakeven in 2030



LNG price in Japan: 102% of Brent crude oil price. (Regasification cost included)

Diesel cost in EU: 119% of Brent crude oil price

CO_2 emission cost:

- 0-61 €/t_{CO2}
- NG CO_2 emission: 56 t_{CO2}/TJ
- Diesel CO_2 emission: 74 t_{CO2}/TJ

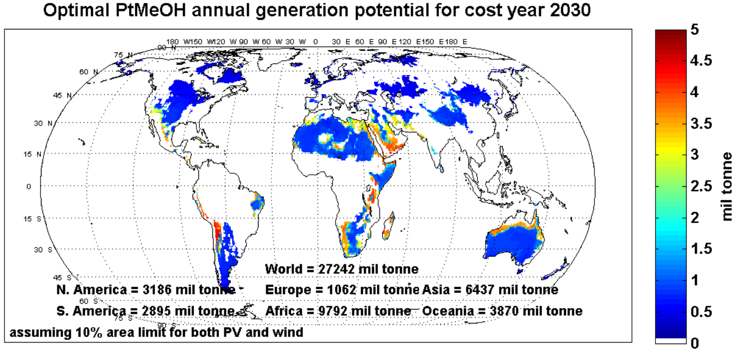
O_2 profit:

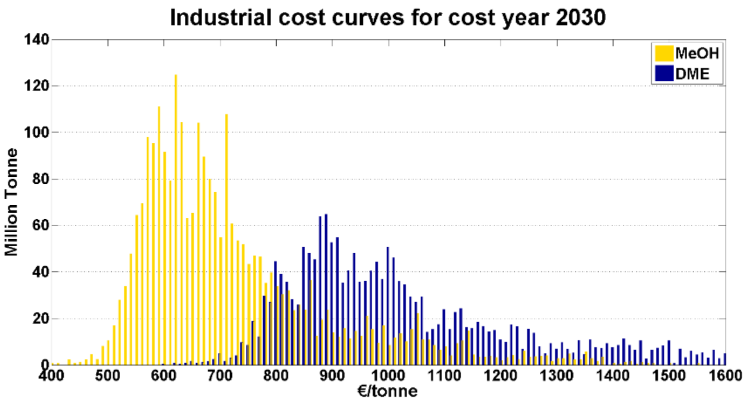
- O_2 market price: up to 80 €/t_{O2}
- Our most optimistic scenario: 20 €/t_{O2}

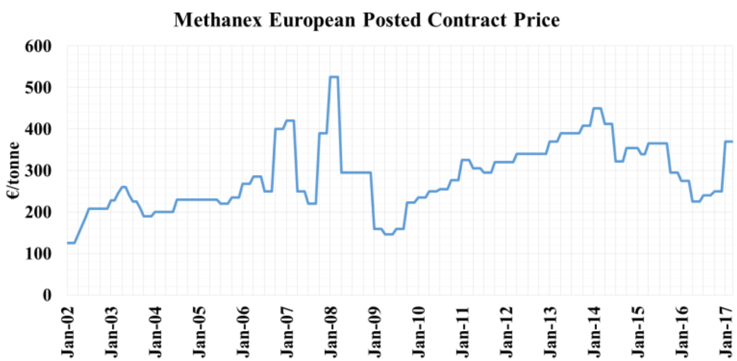
- RE-diesel reach the fuel parity sooner than RE-SNG, even with higher production cost
- The first breakeven can be expected for a produced RE-diesel with a WACC of 5% and an O_2 benefit of 20 €/t_{O2} and a conventional diesel price with CO_2 emission cost of 61 €/t_{CO2} and a crude oil price of 109 USD/bbl in 2030.
- A realistic breakeven is expected for the crude oil prices between 120-140 USD/bbl in 2030.
- A business case with a WACC of 5% could decrease the cost by about 15% and make the synthetic fuels cost competitive for lower crude oil prices.
- With today's prices, large scale production of SNG or SLF would not be cost competitive with conventional fuels even in the best scenario, in 2030. However, it would be still in an aceptable range.
- The technology advances and reduction of LCOE would decrease the costs even further.

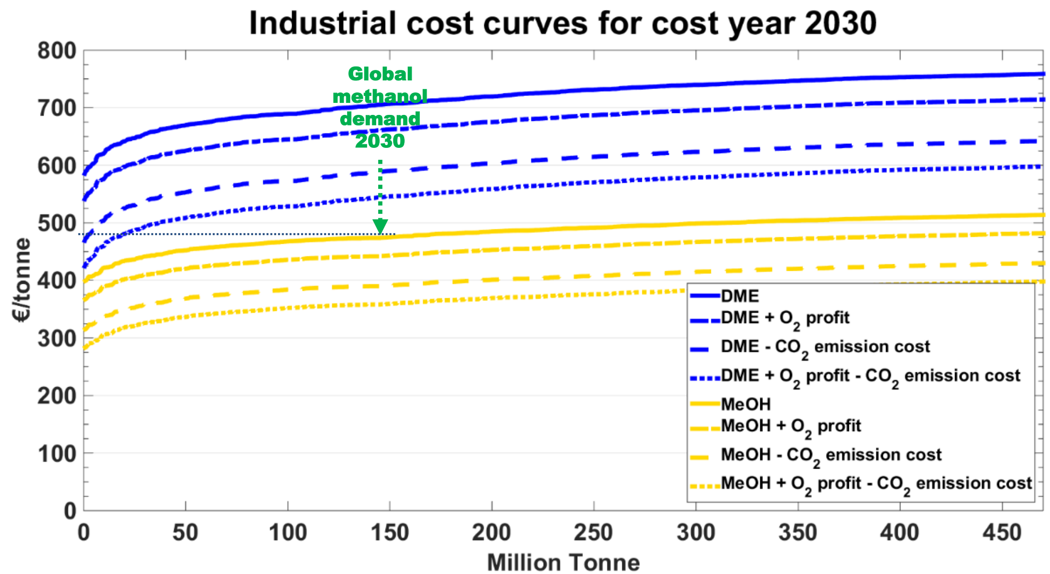
Results

Optimised Methanol and DME Production Potential





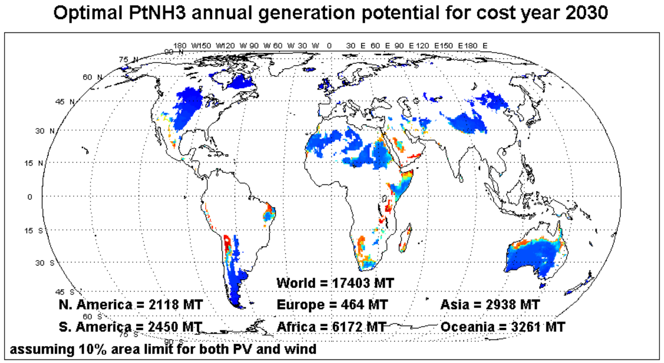


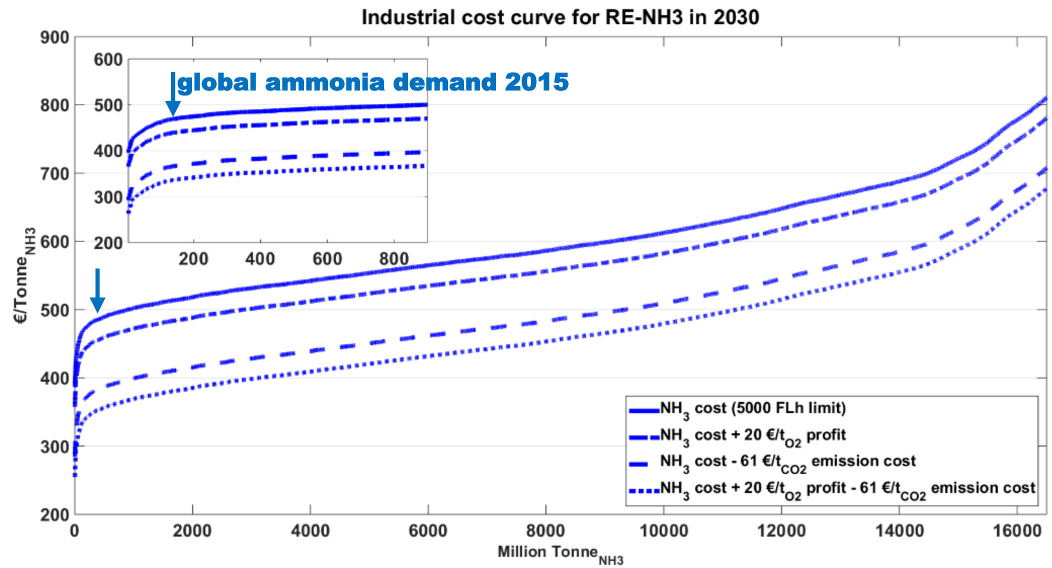


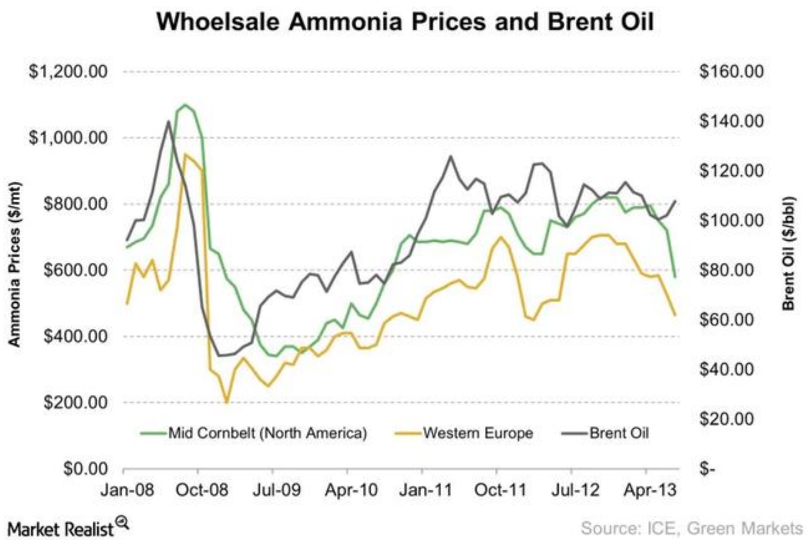
- maximum 10% of the land allowed to be used for PV and Wind each
- DME generation potential in each area would be about 18% less of methanol generation potential in that area
- methanol demand in 2030 could be met at production costs less than 480 €/tonne
- 20 €/tonne$_{O2}$ profite and 61 €/tonne$_{CO2}$ emission cost would improve the attractivness of RE-methanol and RE-DME
- European methanol wholesale market has experienced prices higher than 300 €/tonne in the last decade
- shipping costs and market competitiveness to be studied in the next phase of this research

Results

Optimised Ammonia Production Potential and Global Market







- maximum 10% of the land allowed to be used for PV and Wind each, in regions with minimum 5000 FLh
- Ammonia demand in 2030 could be met at production costs less than 480 €/tonne. However, up to 40 €/tonne additional shipping cost might be needed
- NG-based ammonia CO_2 emission: 1.694 t_{CO2}/t_{NH3}
- 20 €/t_{O2} profit and 61 €/t_{CO2} emission cost would improve the attractiveness of RE-ammonia by 30 and 103 €/t_{NH3}, respectively
- European ammonia wholesale market has experienced prices higher than 400 €/tonne in the last decade

Results
Case studies

sustainability

MDPI

Article

Long-Term Hydrocarbon Trade Options for the Maghreb Region and Europe—Renewable Energy Based Synthetic Fuels for a Net Zero Emissions World

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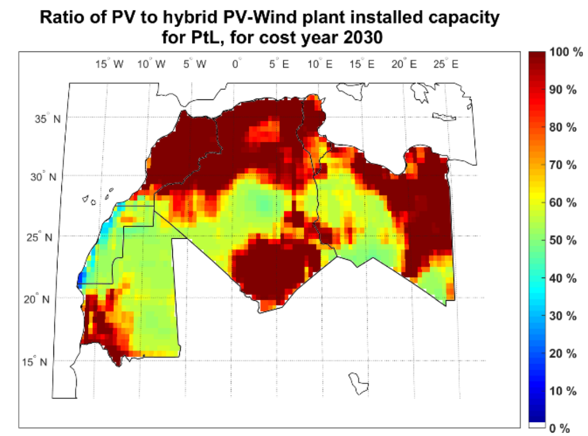

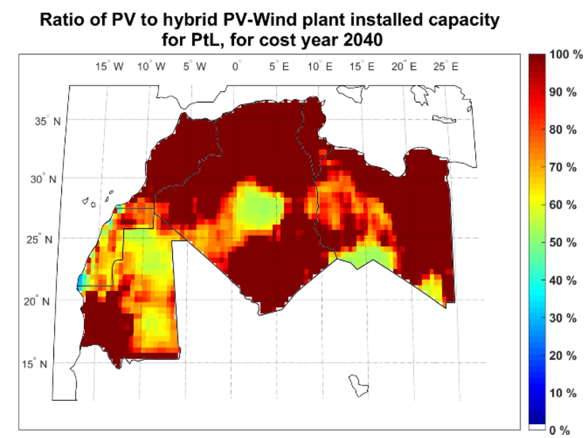

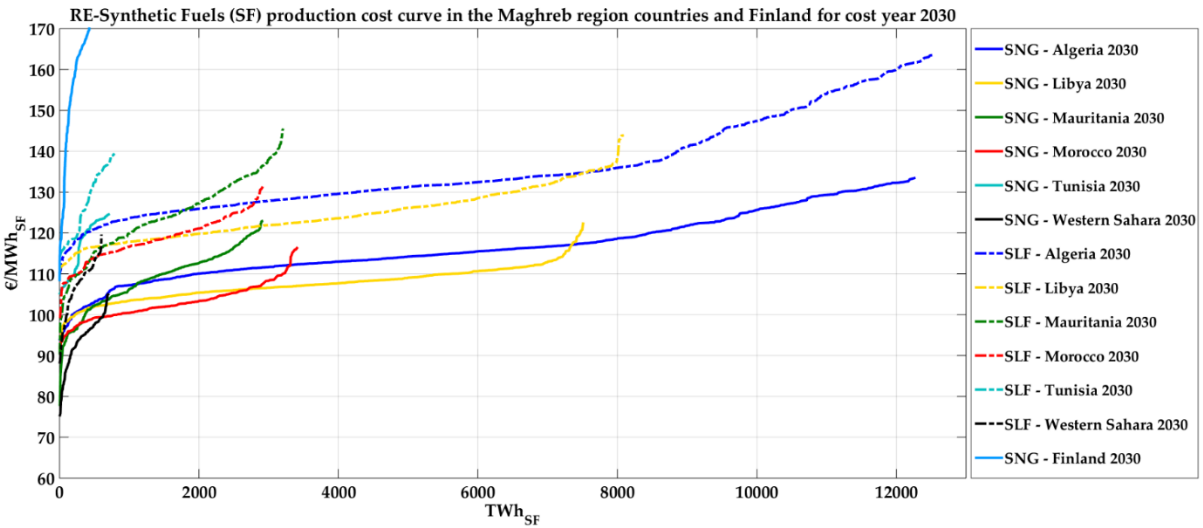

Results
Case studies

sustainability

MDPI

Article

Can Australia Power the Energy-Hungry Asia with Renewable Energy?

Ashish Gulagi *, Dmitrii Bogdanov, Mahdi Fasihi and Christian Breyer

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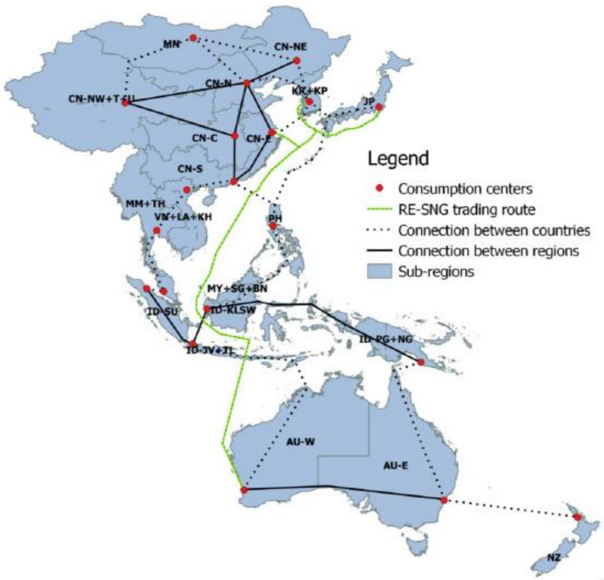
Abstract: The Paris Agreement points out that countries need to shift away from the existing fossil-fuel-based energy system to limit the average temperature rise to 1.5 or 2 °C. A cost-optimal 100% renewable energy based system is simulated for East Asia for the year 2030, covering demand by power, desalination, and industrial gas sectors on an hourly basis for an entire year. East Asia was divided into 20 sub-regions and four different scenarios were set up based on the level of high voltage grid connection, and additional demand sectors: power, desalination, industrial gas, and a renewable-energy-based synthetic natural gas (RE-SNG) trading between regions. The integrated RE-SNG scenario gives the lowest cost of electricity (€52/MWh) and the lowest total annual cost of the system. Results contradict the notion that long-distance power lines could be beneficial to utilize the abundant solar and wind resources in Australia for East Asia. However, Australia could become a liquefaction hub for exporting RE-SNG to Asia and a 100% renewable energy system could be a reality in East Asia with the cost assumptions used. This may also be more cost-competitive than nuclear and fossil fuel carbon capture and storage alternatives.



http://bit.ly/2pclaOs

Results
Case studies

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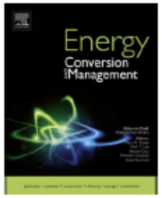

Techno-economic analysis of a decarbonized shipping sector: Technology suggestions for a fleet in 2030 and 2040

Check for updates

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A R T I C L E I N F O

Keywords:
Synfuel
Marine propulsion
Carbon-neutral
Emission reduction
Marine transportation

A B S T R A C T

Growing concerns about anthropogenic climate change and its effects on the environment have encouraged significant recent developments towards decarbonizing the energy system. Developments in transportation technology, such as vehicle electrification, can result in significant CO_2, particulate matter, and SO_x reductions over the lifetime of a vehicle. The shipping industry alone accounted for 2.1% of global greenhouse gas emissions in 2012, however, due to energy requirements and weight restrictions, batteries and direct electrification cannot be used to mitigate emissions. Synthetic fuels, as an indirect electrification option, are a viable solution to achieve emission reduction goals. The purpose of this study is to determine the most cost effective combination of synthetic fuels and fuel cells or internal combustion engines to replace fossil oil as the main propulsion fuel in the shipping industry in 2030 and 2040. The fuels, namely RE-FT-Diesel, RE-LNG, RE-LH_2 and RE-MeOH, are analysed for both an internal combustion engine and a fuel cell. The scenarios were analysed by comparing the levelised cost of mobility (LCOM). The LCOM was composed of 5 different facets including the capex of the engines/fuel cells and the tanks, the opex of the engines/fuel cells, the cost of lost cargo space, fuel cost and the CO_2 cost. The final unit of comparison was €/1000DWT-km. It was determined that hydrogen fuel cells were the most likely to replace fossil internal combustion engines if the fuel cells follow their expected development. Significant gains in fuel cell average efficiency and decreases in production cost between today and 2030 and 2040 are factors contributing to the competitiveness. A CO_2 cost was set to 61 €/tCO_2 in 2030 and 75 €/tCO_2 in 2040. Most of the other technology combinations are close to competing with fossil diesel with a CO_2 price in 2040; however, hydrogen fuel cells are close to competing with fossil fuel without a CO_2 cost in 2040.

https://bit.ly/2HlVnpv