Power-to-X in energy transition

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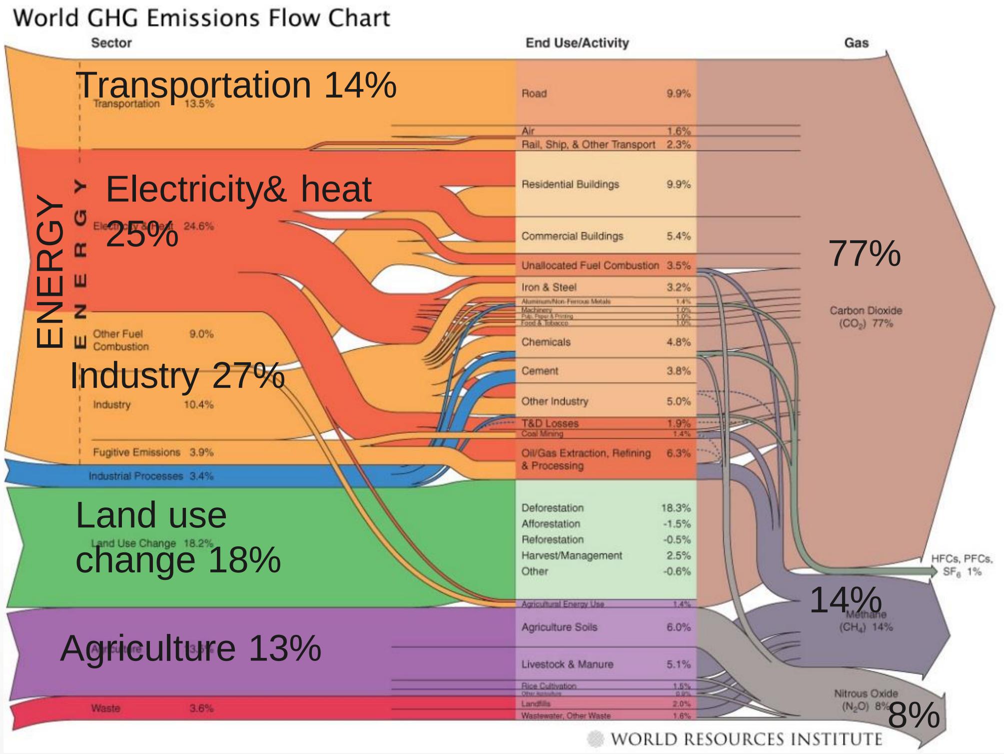
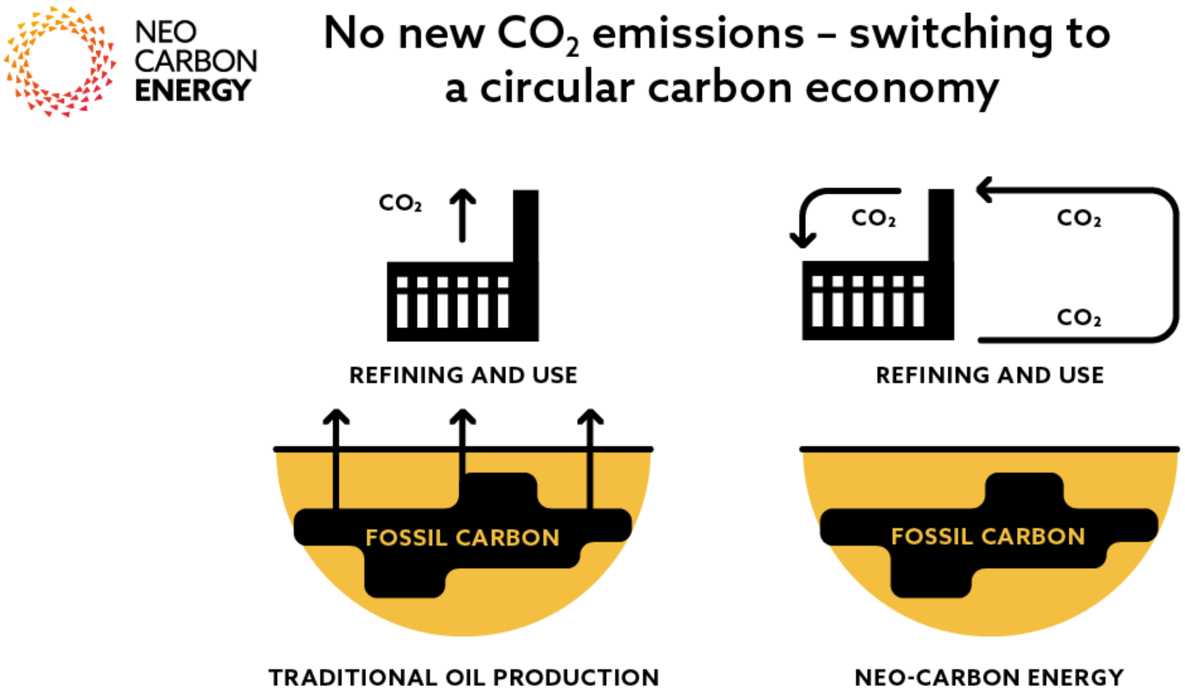
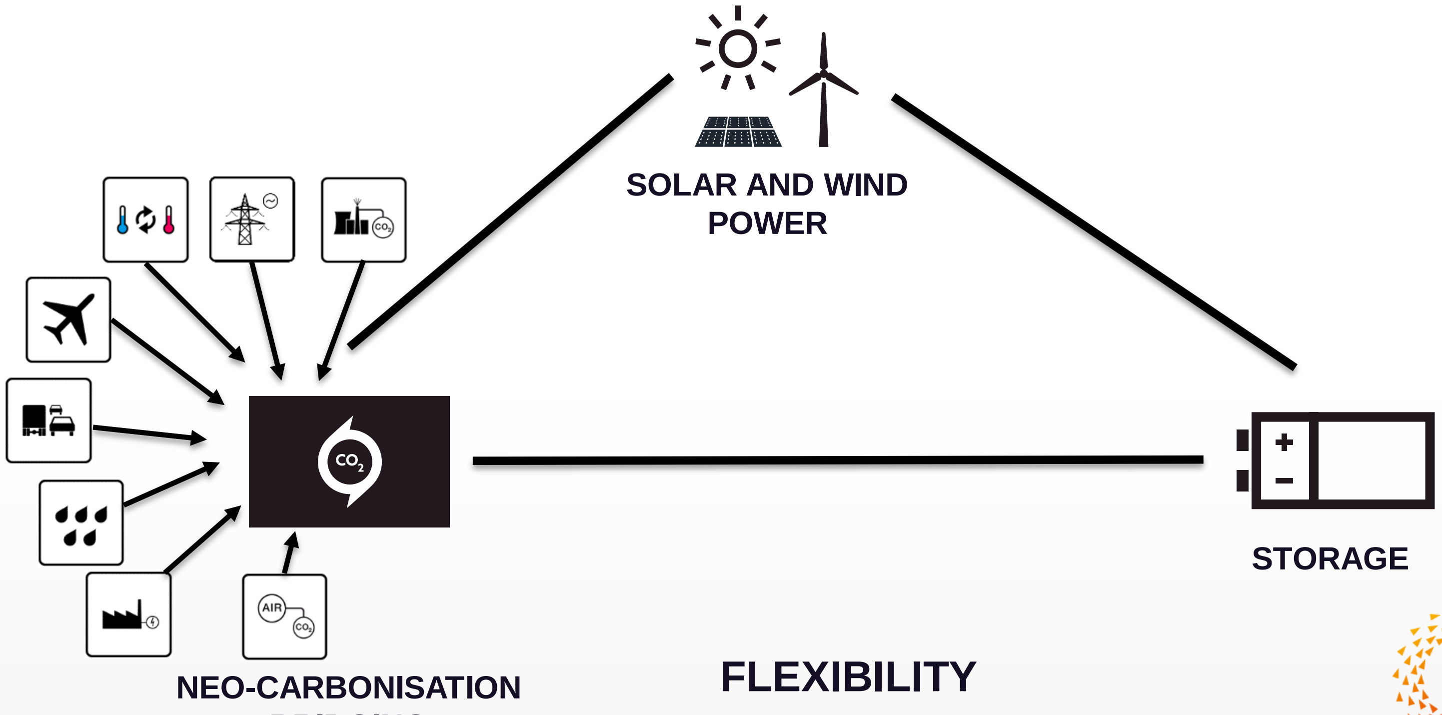
In order to achieve <2 °C target net-zero GHG emissions required by 2050



Circular carbon economy as an objective



The electricity system as the primary energy system



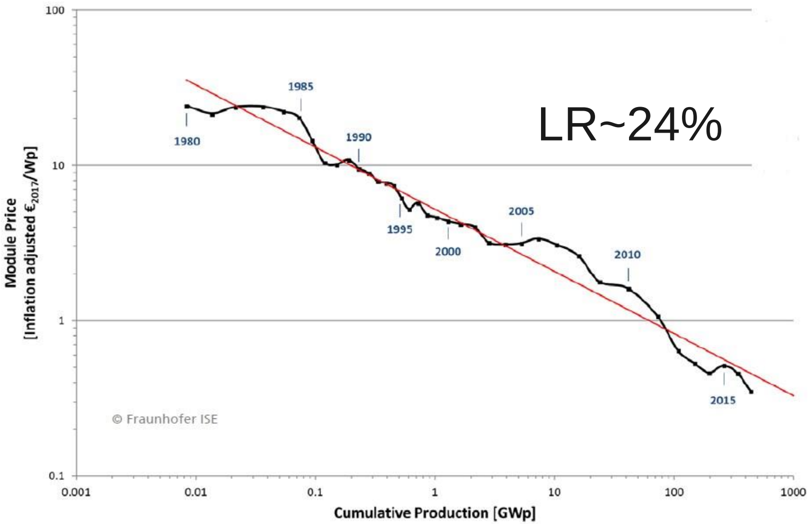
http://www.neocarbonenergy.fi/library/reports/

Solar and wind electricity

Learning curves in mass produced energy technologies

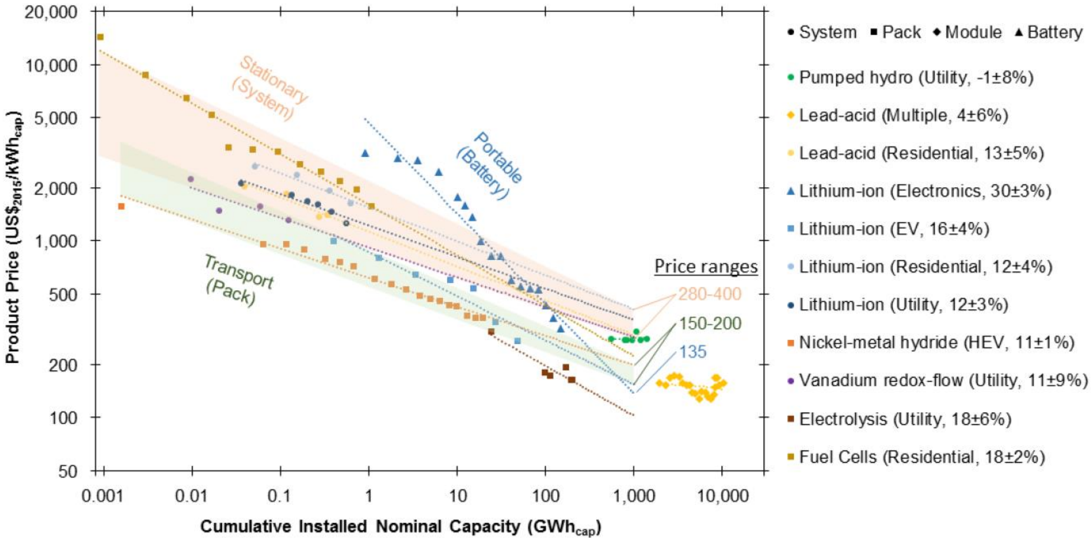
LUT University

Solar PV module learning curve



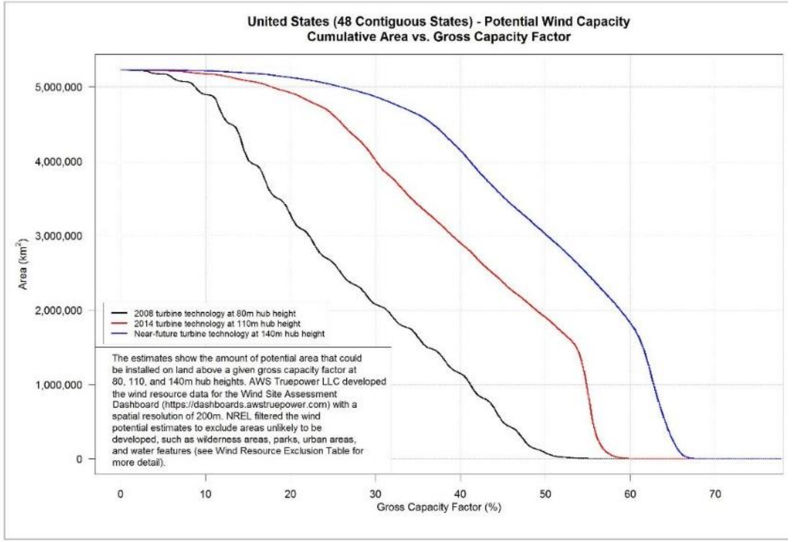
Photovoltaics Report, Fraunhofer-ISE, Germany, 27.8.2018

Electricity storage learning curves



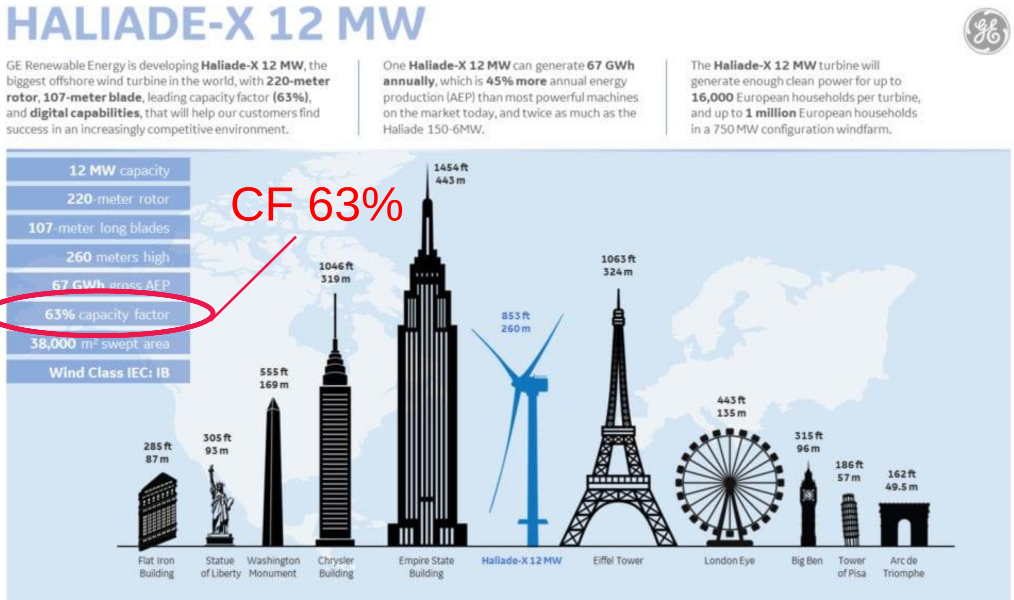
O. Schmidt, A. Hawkes, A. Gambhir & I. Staffell, The future cost of electrical energy storage based on experience rates, Nature Energy volume 2, Article number: 17110 (2017)

Capacity factor still increasing in wind power



AWS Truepower®

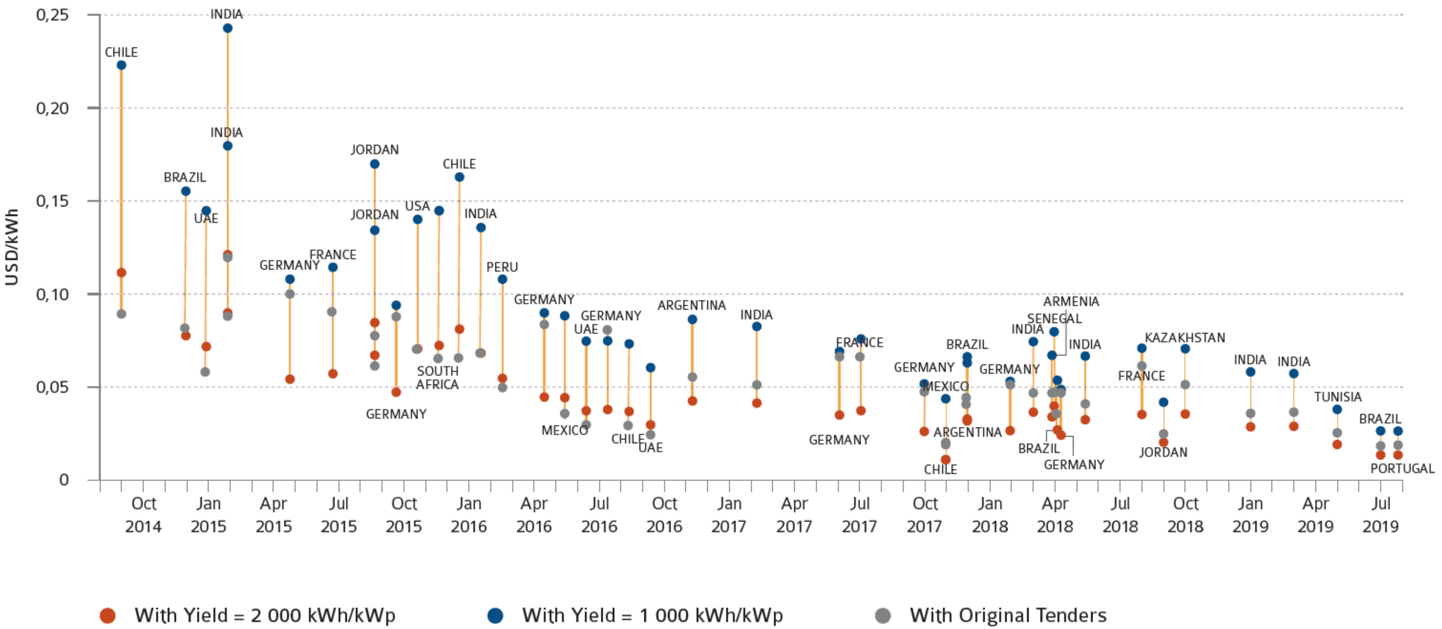
NREL
NATIONAL RENEWABLE ENERGY LABORATORY



CF 63%

Development of solar PV PPA prices

FIGURE 3.3: NORMALIZED LCOE FOR SOLAR PV BASED ON RECENT PPA PRICES DURING 2014 - Q3 2019

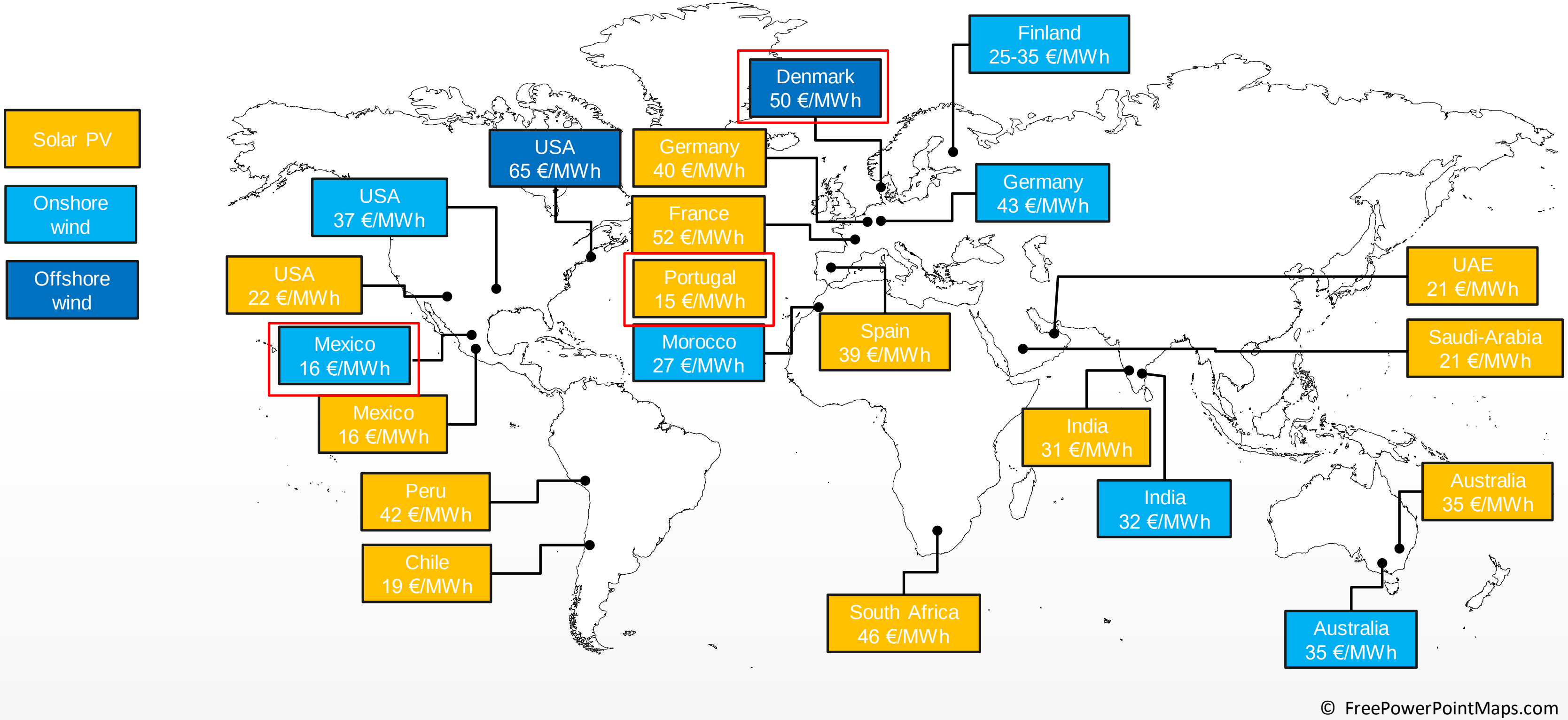


SOURCE IEA PVPS, BECQUEREL INSTITUTE.

Trends 2019 in Photovoltaic Power Applications, IEA PVPS, www.iea-pvps.org

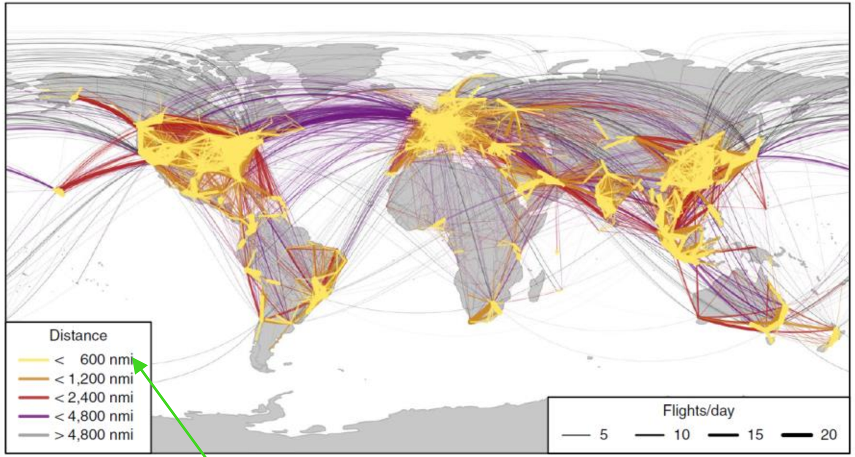
Recent PPA auction prices of wind & solar

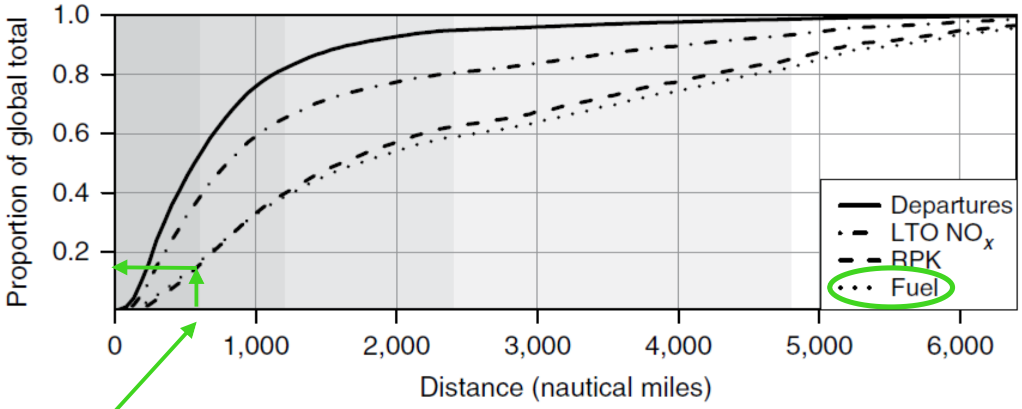
LUT University



Power-to-X fuels, chemicals and food

Intercontinental flights will not be realistic in medium term without chemical fuels

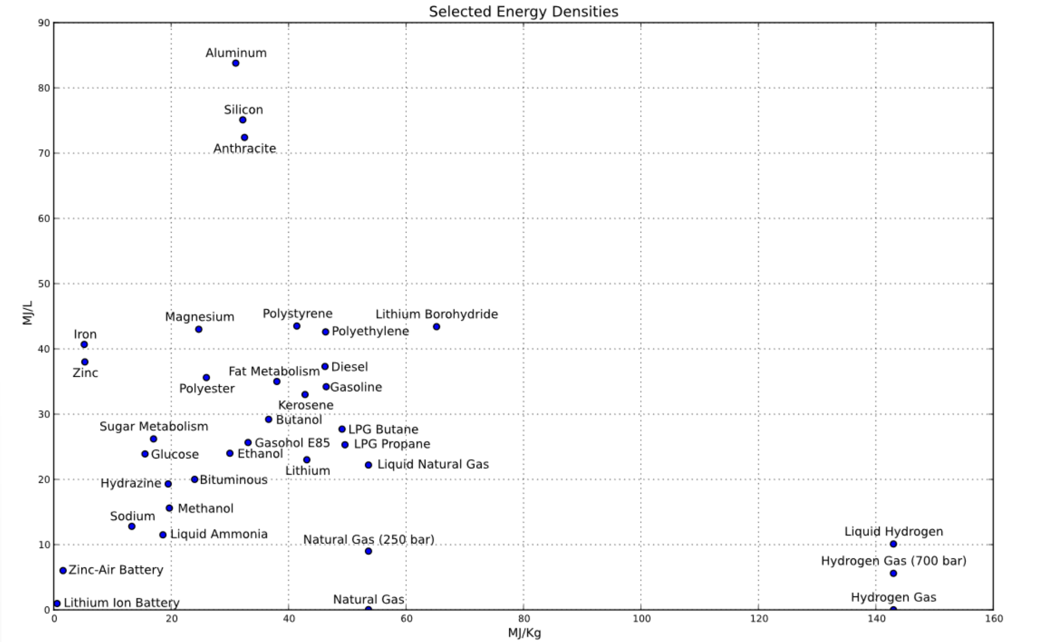




Electric flights at distances < 600 nmil (1100 km) ~15 % of total fuel consumption of battery energy density 800 Wh/kg will be reached

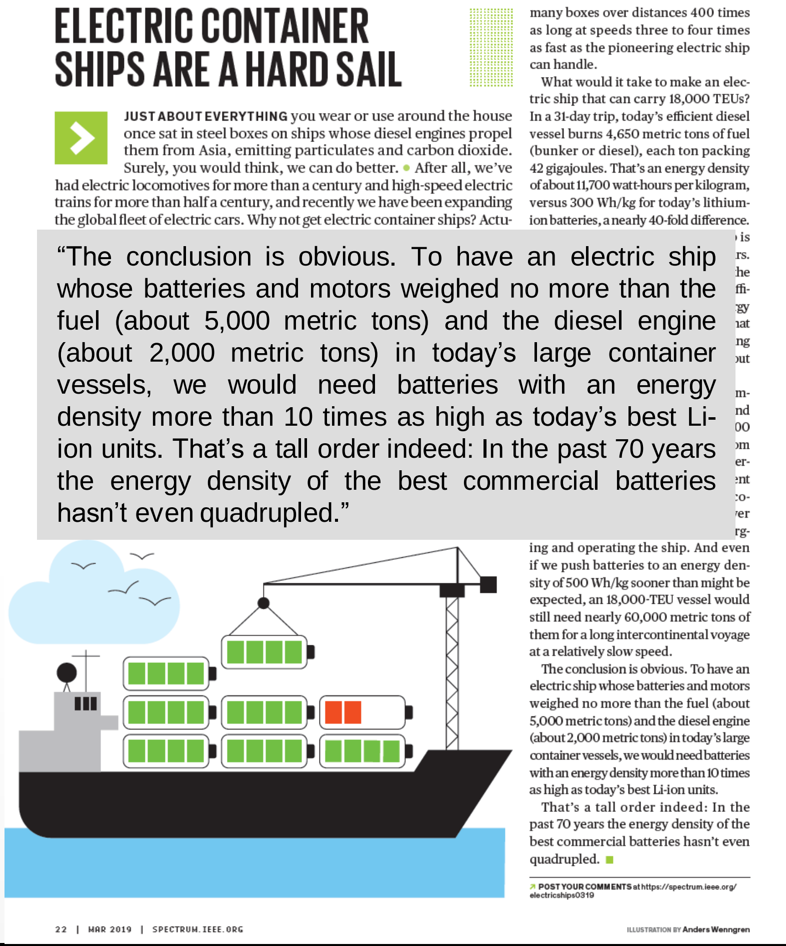
Source: Andreas W. Schäfer, et. Al., Technological, economic and environmental prospects of all electric aircraft, Nature Energy, Vol. 4, February 2019, pp. 160-166.

Chemical fuels will be needed also in marine transportation



Source: Vaclav Smil, Electric container ships are a hard sail, IEEE Spectrum, 27th February, 2019.

"The conclusion is obvious. To have an electric ship whose batteries and motors weighed no more than the fuel (about 5,000 metric tons) and the diesel engine (about 2,000 metric tons) in today's large container vessels, we would need batteries with an energy density more than 10 times as high as today's best Li-ion units. That's a tall order indeed: In the past 70 years the energy density of the best commercial batteries hasn't even quadrupled."



ELECTRIC CONTAINER SHIPS ARE A HARD SAIL

JUST ABOUT EVERYTHING you wear or use around the house once sat in steel boxes on ships whose diesel engines propel them from Asia, emitting particulates and carbon dioxide. Surely, you would think, we can do better. After all, we've had electric locomotives for more than a century and high-speed electric trains for more than half a century, and recently we have been expanding the global fleet of electric cars. Why not get electric container ships? Actu-

many boxes over distances 400 times as long at speeds three to four times as fast as the pioneering electric ship can handle.

What would it take to make an electric ship that can carry 18,000 TEUs? In a 31-day trip, today's efficient diesel vessel burns 4,650 metric tons of fuel (bunker or diesel), each ton packing 42 gigajoules. That's an energy density of about 11,700 watt-hours per kilogram, versus 300 Wh/kg for today's lithium-ion batteries, a nearly 40-fold difference.

ing and operating the ship. And even if we push batteries to an energy density of 500 Wh/kg sooner than might be expected, an 18,000-TEU vessel would still need nearly 60,000 metric tons of them for a long intercontinental voyage at a relatively slow speed.

The conclusion is obvious. To have an electric ship whose batteries and motors weighed no more than the fuel (about 5,000 metric tons) and the diesel engine (about 2,000 metric tons) in today's large container vessels, we would need batteries with an energy density more than 10 times as high as today's best Li-ion units.

That's a tall order indeed: In the past 70 years the energy density of the best commercial batteries hasn't even quadrupled.

POST YOUR COMMENTS at https://spectrum.ieee.org/electricships0319

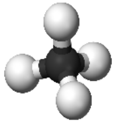
22 | MAR 2019 | SPECTRUM.IEEE.ORG

ILLUSTRATION BY Anders Wenngren

Different PtX fuel and chemical options

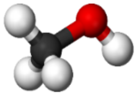
Hydrogen (H_2)

- Can be used in fuel cells or as a mixture with methane in combustion engines
- Energy efficient to make, just water electrolysis needed
- Non-toxic, not greenhouse gas, storage may be problematic (e.g. pressurized, liquefied, etc.)



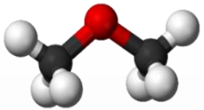
Methane (CH_4)

- Can be used as a transport fuel and seasonal storage (gaseous form or liquefied)
- Simplicity - the synthesis process can produce pure methane
- **Strong greenhouse gas, non-toxic**



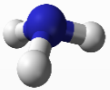
Methanol (CH_3OH)

- Liquid fuel at standard conditions, easy to store and can be used as drop-in fuel
- Important role as feedstock in chemical industry, e.g. route to plastics with methanol-to-olefins (MTO) synthesis
- Toxic and corrosive



Dimethyl ether (C_2H_6O)

- Synthesis from methanol with e.g. silica alumina catalyst
- Direct replacement to diesel, high cetane number ~60 (diesel ~50), non-toxic, not greenhouse gas
- Gaseous at standard conditions, can be stored as liquid form at 0.5 MPa, (@20 C, ρ=0.67 kg/l, LHV = 28.5 MJ/kg)



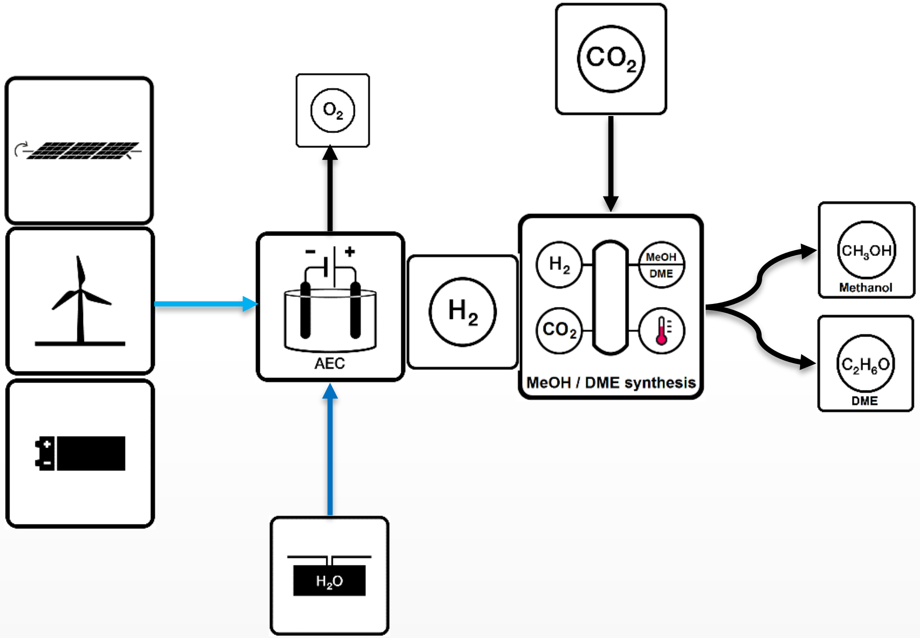
Ammonia (NH_3)

- Fertilizer and feedstock for chemical industry, toxic, flammable gas
- Can be used also as energy storage and fuel (energy denisity ~11.5 MJ/l)
- Air as a source of nitrogen (78 % of N_2) available everywhere

Fischer-Tropsch products (C_nH_{2n+2})

- Produces different hydrocarbon chains (C_nH_{2n+2}) where n is typically 10-20.
- With hydrocracking these can be further refined to direct replacements of fossil fuels
- Starting point is syngas, it has to be first produced with reverse-water-shift-gas reactor from H_2 and CO_2

The diagram of power-to-methanol



Hybrid PV-Wind & Battery **Power-to-Methanol/DME** **Methanol/DME**

Summary:

- Water electrolysis: $\eta_{el} \approx 80$ % (HHV)
  - Waste heat at temperature level 70-80°C
- Methanol synthesis: $CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$
  - Copper and zinc-based catalyst, 150-200°C, 50-100 bar
  - Distillation needed to separate methanol from water, the steam produced by the synthesis can be used for this purpose
- Methanol-DME synthesis:
  - Silica-alumina catalyst
- Power-to-Methanol/DME efficiency ≈ 50-55 %

Power-to-H_2 in Kokkola, Finland

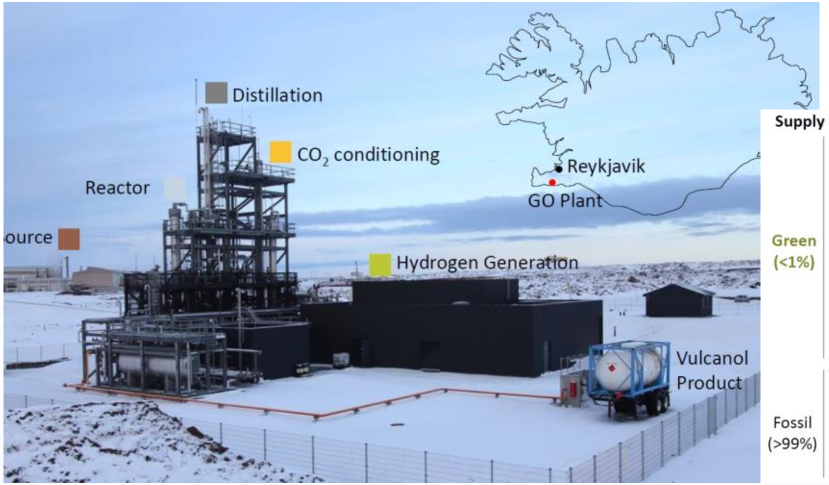
LUT University

Summary:

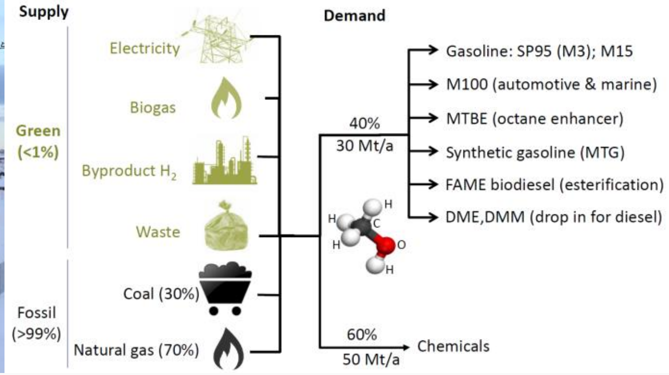
- Located in Kokkola, Finland
- Power-to-Hydrogen: 1800 Nm^3/h (H_2)
- 3x3 MW pressurized alkaline water electrolyzers, 3x600 Nm^3/h, 16 bar (H_2)
- The main use of H_2 plant is at nearby Cobal plant, delivery with a pipeline
- The rest of H_2 compressed to 200-300 bar and stored in bottles for delivery with trucks

How to improve significantly the energy efficiency of water electrolysis -> Koponen, J., Ruuskanen, V., Ahola, J., et. al., Effect of Converter Topology on the Specific Energy Consumption of Alkaline Water Electrolyzers, *IEEE Trans. Power Electron.*, 34, pp. 6171-6182.

Power-to-Methanol, Carbon Recycling International - George Olah plant



George Olah's P2Methanol plant



Usage routes of Methanol

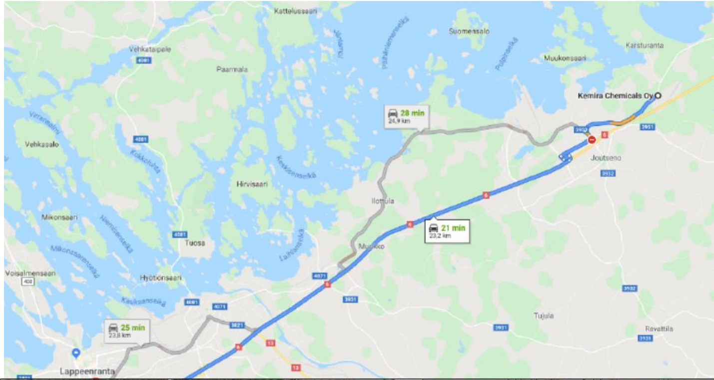
Summary:

- Located in Svartsengi, Iceland
- Power-to-methanol: 4000 t/a (CH_3OH)
- Pressurized alkaline water electrolyzers, 1200 Nm^3/h (H_2)
- Methanol synthesis: solid copper and zinc oxide catalyst, 250°C, 100 bar
- The methanol is blended with gasoline and sold e.g. in Iceland

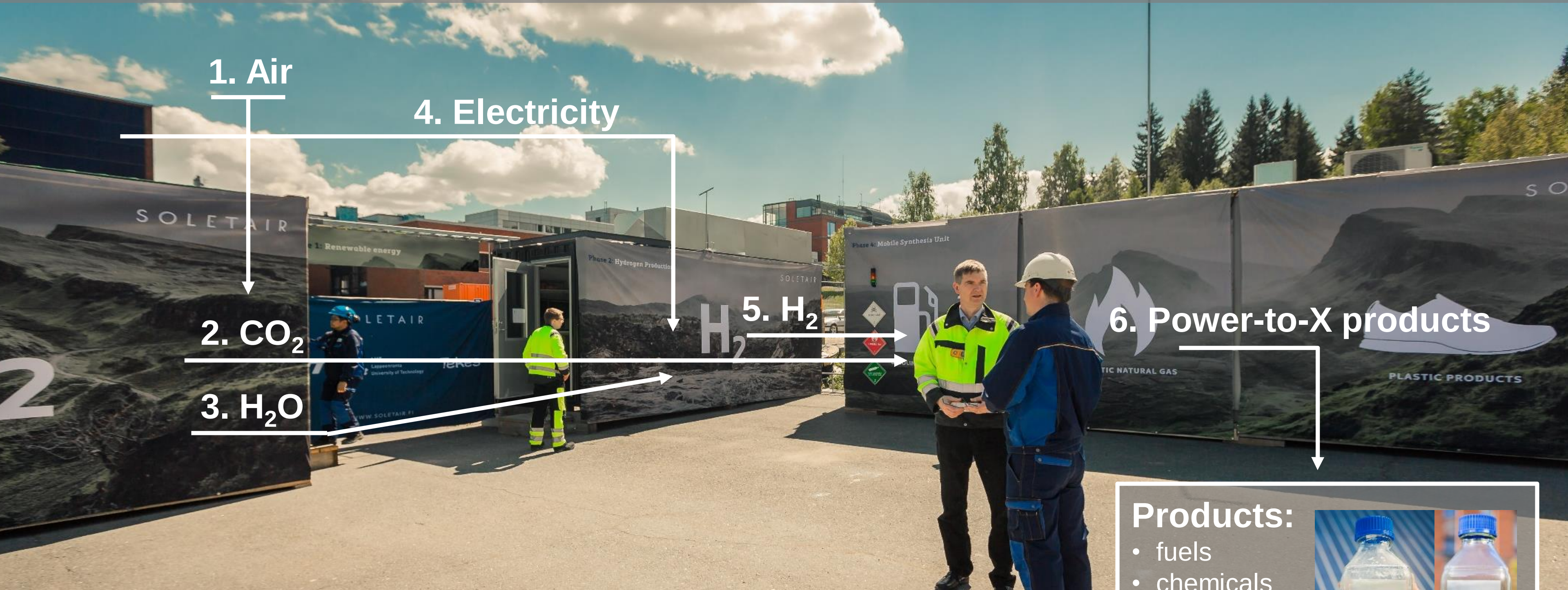
Source: CRI Presentation, CO2-to-Methanol: Nordic technology with global application, available at: https://www.iea.org/media/workshops/2017/cop23/presentations/171115NordicCRI.pdf

Project P2X Joutseno, 10/2019->: Industrial-scale PtMeOH demo plant – Feasibility study and development

- Industrial scale pilot plant in Joutseno, Lappeenranta
  - CAPEX: 40-50 M€
- Raw materials:
  - Hydrogen (H_2) 5 000 t/a, (Chlor-Alkali electrolysis), Kemira Chemicals
  - Carbon dioxide (CO_2) 36 667 t/a from Finnsementti
- End products:
  - Methanol 26 667 t/a (appr. 1 000 truck loads)
  - Can be further processed to e.g. gasoline, kerosene (aviation), diesel (to be studied)
- Partners with LUT:
  - St1 Oy, Kemira Oy, Wärtsilä, Finnsementti Oy, etc.
  - City of Lappeenranta
  - Local SME engineering workshops



SOLETAIR – Fuel from the air



Vidal Vázquez, F., Koponen, J., Ruuskanen, V., Bajamundi, C., Kosonen, A., Simell, P., Ahola, J., Frilund, C., Elfving, J., Reinikainen, M., Heikkinen, N., Kauppinen, J., Piermartini, P. (2018). Power-to-X technology using renewable electricity and carbon dioxide from ambient air: SOLETAIR proof-of-concept and improved process concept. Journal of CO2 Utilization, Vol 28, p. 235-246.

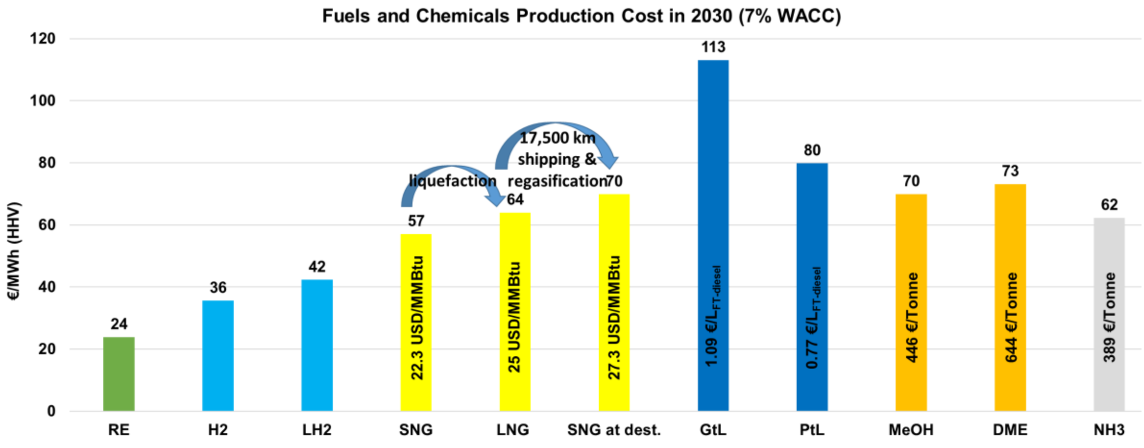
Products:

- fuels
- chemicals

replacing the ones currently refined from fossil oil & gas

SOLETAIR – Power-to-X site at LUT Lappeenranta campus in 2017 – www.soletair.fi

PtX fuels are scalable, will be probably cheaper than biofuels, and do not need arable land



Source: http://www.neocarbonenergy.fi/wp-content/uploads/2016/02/13_Fasihi.pdf

How Bill Gates aims to clean up the planet

▲ An artists impression of what Carbon Engineering's ambitious direct air capture project would look like when completed. Photograph: Carbon Engineering

It's a simple idea: strip CO2 from the air and use it to produce carbon-neutral fuel. But can it work on an industrial scale?

It's nothing much to look at, but the tangle of pipes, pumps, tanks, reactors, chimneys and ducts on a messy industrial estate outside the logging town of Squamish in western Canada could just provide the fix to stop the world tipping into runaway climate change and substitute dwindling supplies of conventional fuel.

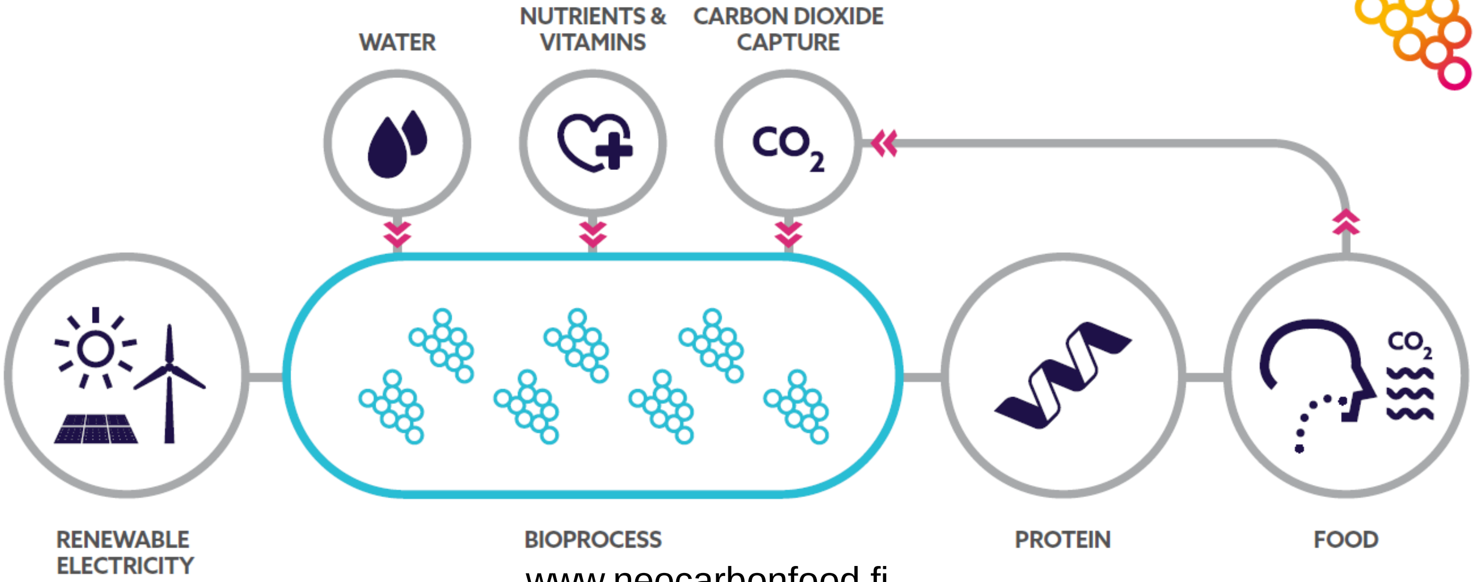
https://www.theguardian.com/environment/2018/feb/04/carbon-emissions-negative-emissions-technologies-capture-storage-bill-gates

Jani Sillman, Lauri Nygren, Helena Kahiluoto, Vesa Ruuskanen, Anu Tamminen, Cyril Bajamundi, Marja Nappa Mikko Wuokko, Tuomo Lindh, Pasi Vainikka, Juha-Pekka Pitkänen, Jero Ahola, “Bacterial protein for food and feed generated via renewable energy and direct air capture of CO_2: Can it reduce land and water use?”, *Global Food Security*, Vol. 22, Sep. 2019, pp. 25-32.

Food from electricity

THE PRINCIPLE

Neo-Carbon Food is a microbial process. Protein production takes place in a reactor suitable for microorganisms to grow and divide. The energy of the process is electricity, and carbon dioxide is the carbon source.



www.neocarbonfood.fi

Neo-Carbon Food – Food from electricity pilot
at LUT Lappeenranta campus in 2019
https://www.youtube.com/watch?v=KTEEmRcShBw

Photo taken on 19.6.2019 at 11 pm from International PtX Workshop in Lappeenranta, Finland. Co-arranged with EERA JP ES.