

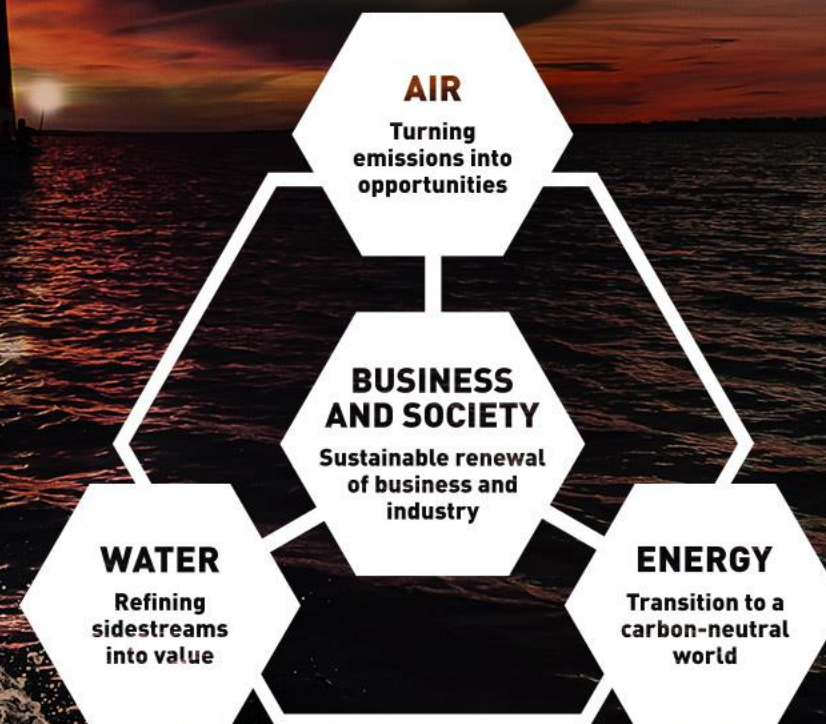
VETYÄ VIRTAA KAAKKOON

Vihreä siirtymä avaa ovia
Kaakkois-Suomelle

Petteri Laaksonen, D.Sc., Research Director

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SYSTEM EARTH





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15TH BEST SMALL UNIVERSITY



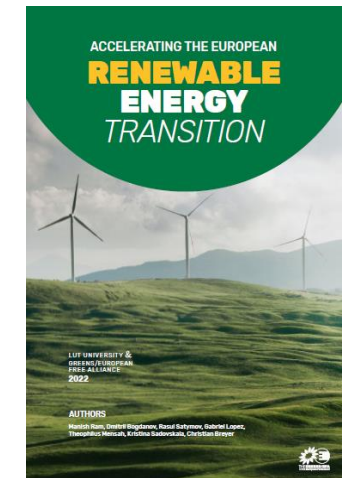
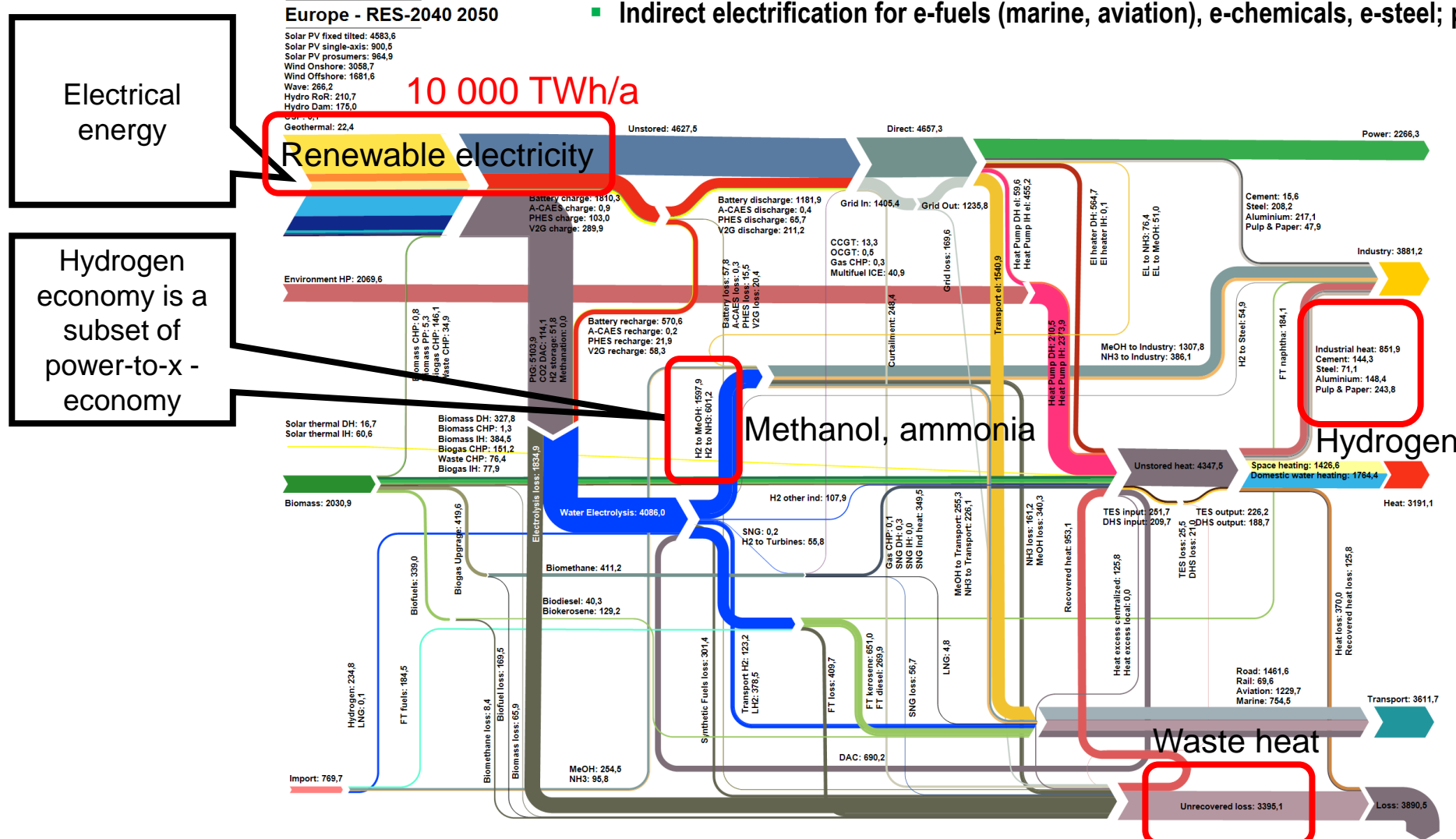


POINTIT

- » Vihreä sähkö on avain – sähkön tarve moninkertaistuu globaalista Suomella erityinen asema
 - » Sähkö tullaan tuottamaan tuuli- ja aurinko voimalla
 - » Edullinen sähkö on kilpailuetu – Euroopassa kolme aluetta Pohjoismaat, Pohjanmeri ja Iberian niemimaa
- » Sähköstä valmistettujen polttoaineiden ja kemikaalien vienti on nähtävissä olevista mahdollisuuksista suurin Suomen hyvinvoinnin ylläpitämiseksi ja kehittämiseksi
 - » Kaakkois-Suomen suuri mahdollisuus on biopohjainen hiilidioksidi
- » Olemassa oleva teollisuus sähköistyy ja kehittyy – poltosta pyritään eroon
- » Sähkö tuotanto, vedyn valmistus, polttoaineiden (metaani, metanoli, kerosiini) ja kemikaalit (ammoniakki) valmistus tulee sijaita lähellä toisiaan. Kaikki siirrot lisäävät kustannuksia ja vähentävät kilpailukykyä. Tuotannosta tulee siis paikallista.

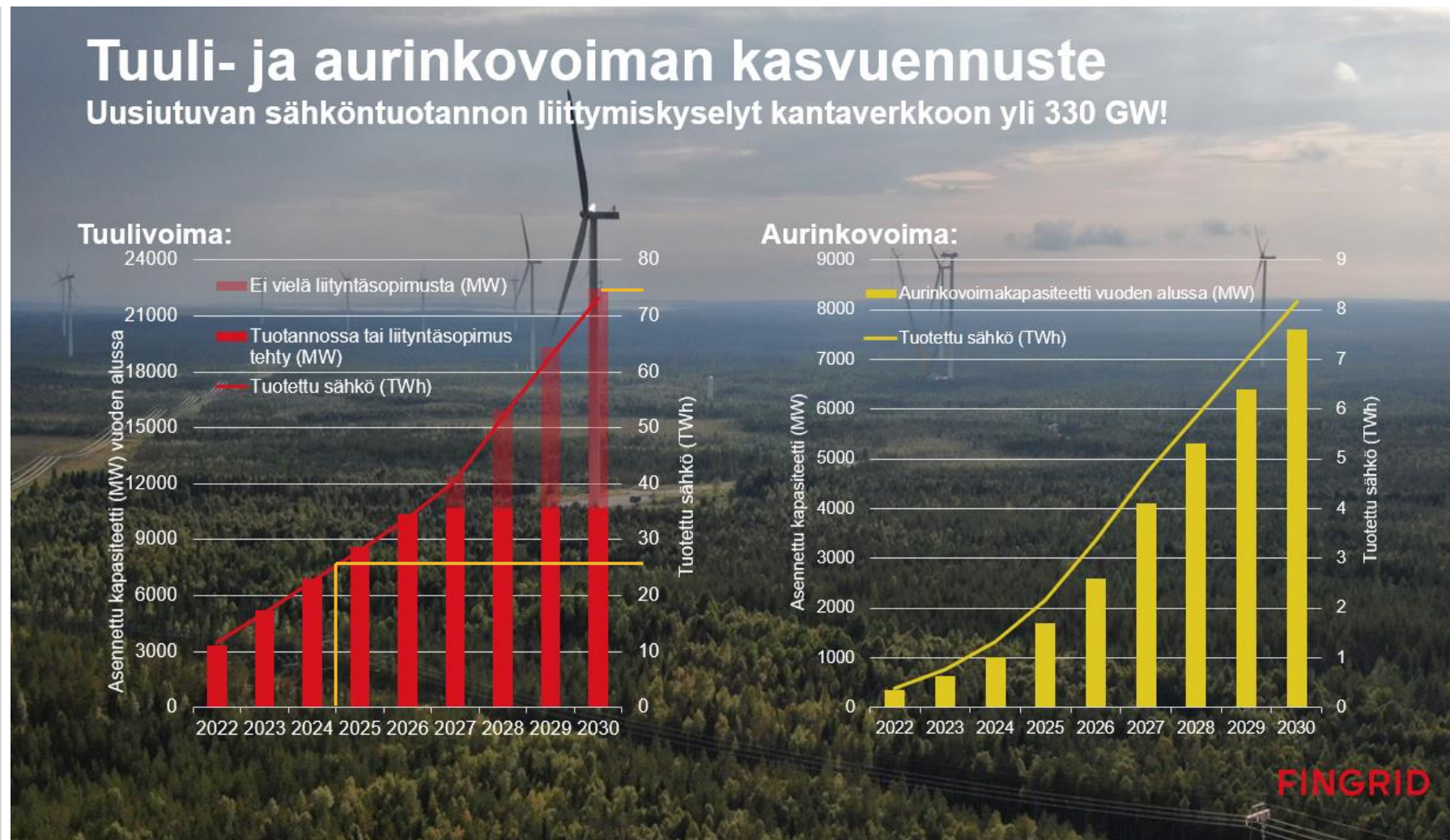
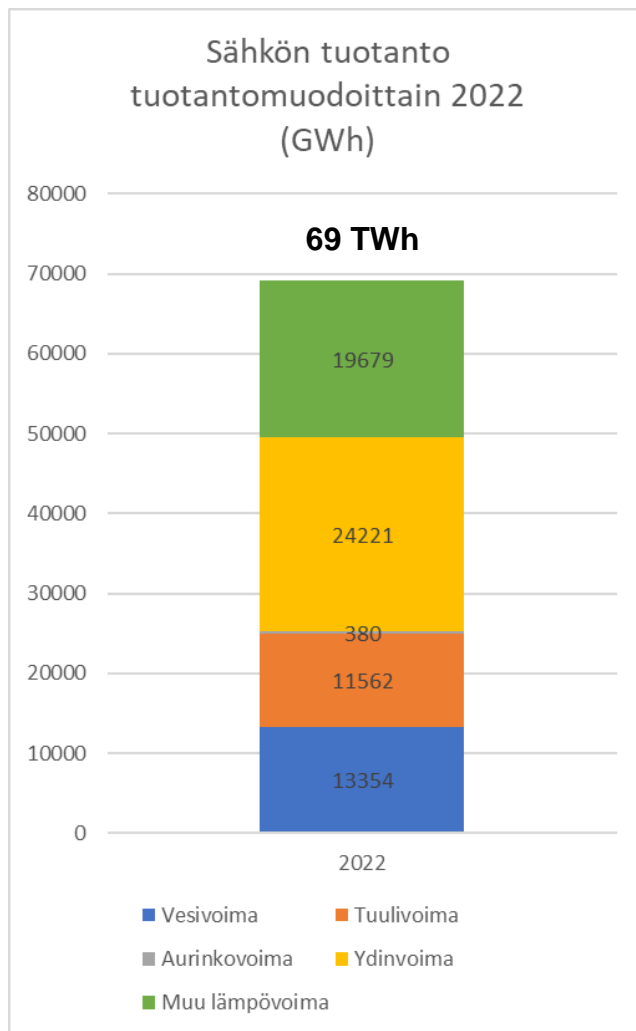
Energiajärjestelmän vihreä siirtymä

- Zero CO₂ emission low-cost energy system is based on electricity
- Core characteristic of energy in future: **Power-to-X Economy**
 - Primary energy supply from renewable electricity: mainly solar PV and wind power
 - Direct electrification wherever possible: electric vehicles, heat pumps, desalination, etc.
 - Indirect electrification for e-fuels (marine, aviation), e-chemicals, e-steel; power-to-hydrogen-to-X



Greens/EFA, 2022
<https://extranet.greens-efa.eu/public/media/file/1/7862>

Sähkön tuotannon tulevaisuus Suomessa

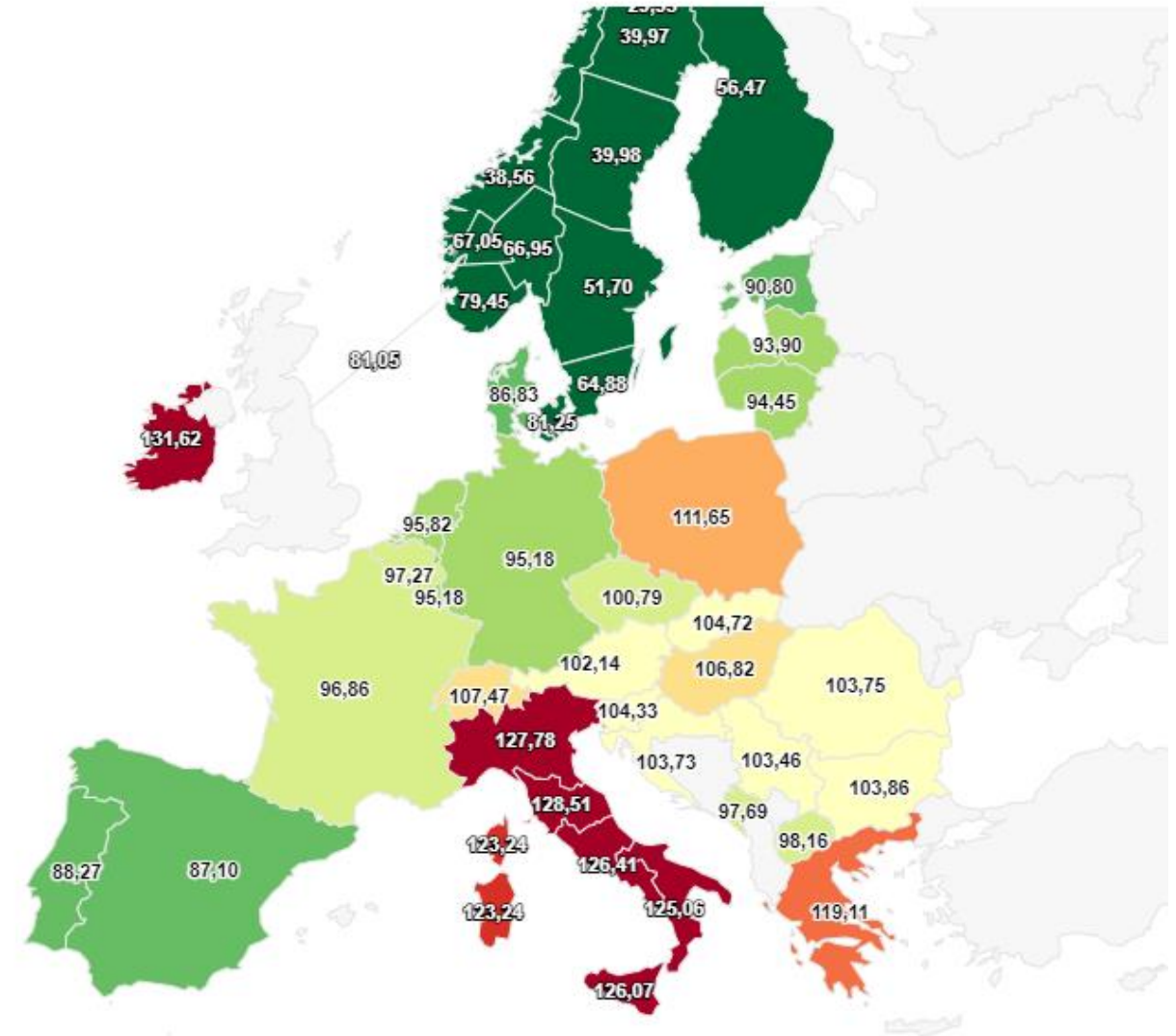


Average electricity spot market prices in 2023

in EUR/MWh

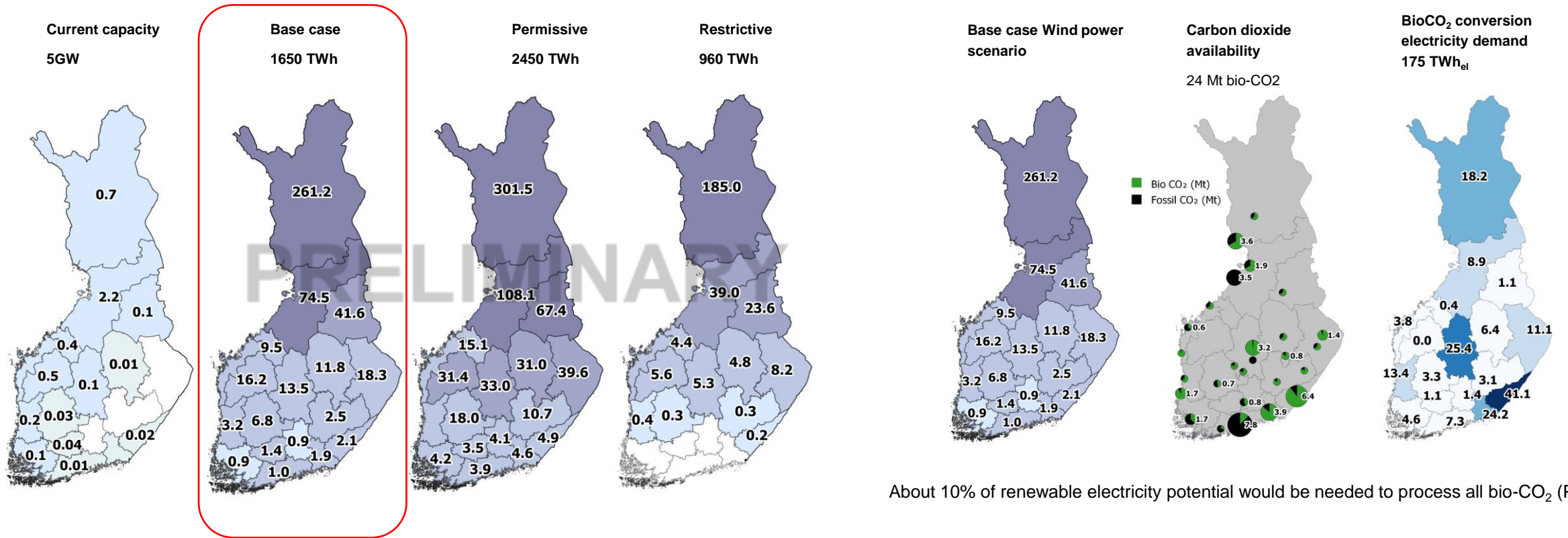
Sähkön hinnat Euroopassa 2023

Ruotsi ja Suomi halvimmat



LUT UNIVERSITY: P2X RESEARCH – On-shore wind power potential

USING GEOGRAPHIC INFORMATION SYSTEM (GIS)

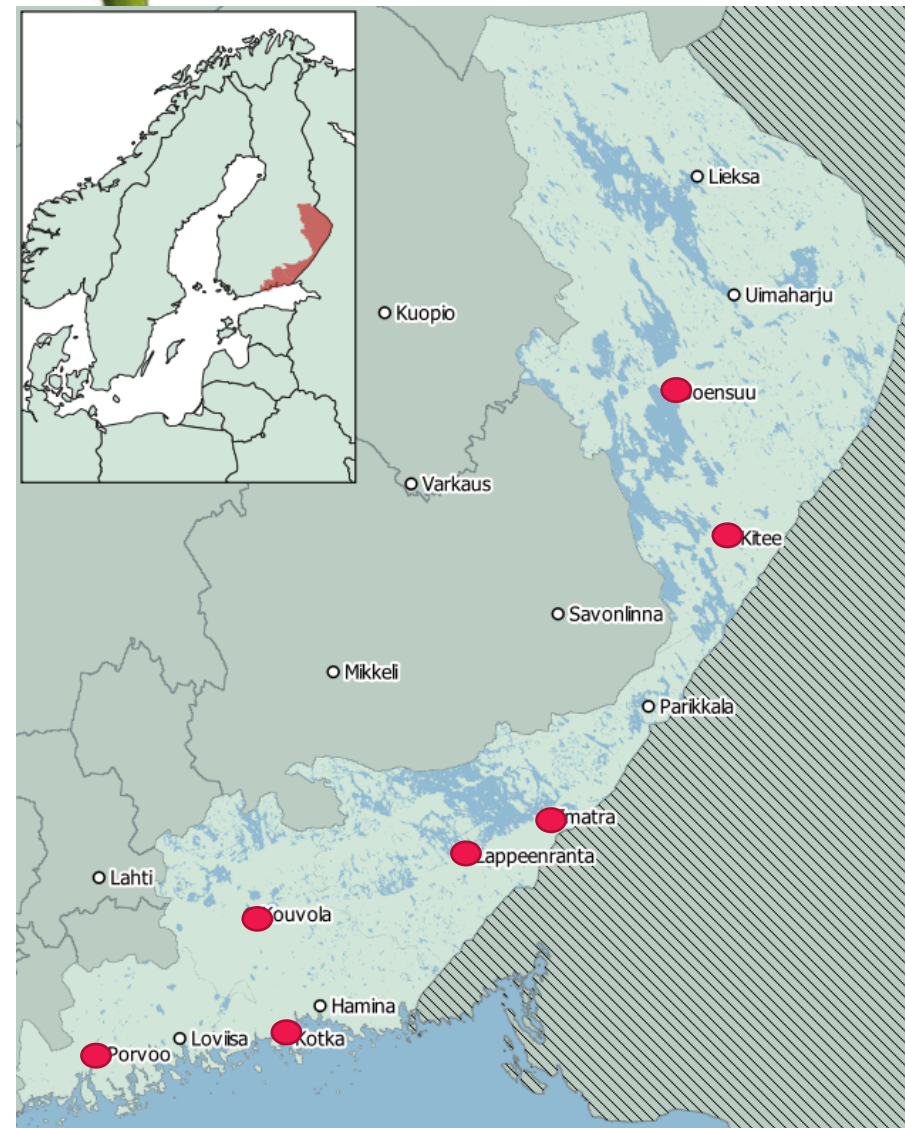


About 10% of renewable electricity potential would be needed to process all bio-CO₂ (PTX)

South-East Finland Hydrogen Valley project

SUUNNITELTUJA VEDYN KÄYTTÖÖN

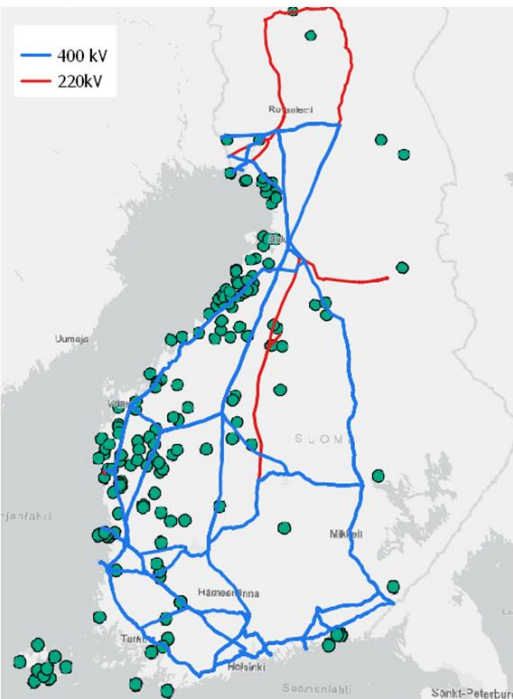
- » P2G-laitos Joensuuhun, P2xsolutions, Savon Voima
- » Puhoksen vety/metanolitalous Kiteellä, Bakelite
- » Lappeenrannan sähkömetanolilaitos, ST1, Finnsementti
- » Joutseno-Imatra vetyputkisuunnitelma, Ovako, Kemira, Gasgrid Finland
- » Sähkövarasto Lappeenrannassa, Neoen
- » Sähkön varastoinnista alustavia suunnitelmia (Joensuu)
- » P2G-laitos Kotkaan, Kotkan energia, Ren-Gas
- » Vihreään vetyyn siirtyminen Kouvolassa, Solvay Chemicals
- » Vihreään vetyyn siirtyminen Kaukaan tehtaalla, UPM Kaukas
- » Vihreän ja sinisen vedyn tuotanto Porvoossa, Neste
- » Akkumateriaalitehdasta suunniteltu Kotka/Hamina
- » Lämpövarastosuunnitelmia useilla
- » Useita suuren kokoluokan aurinkovoimahankkeita



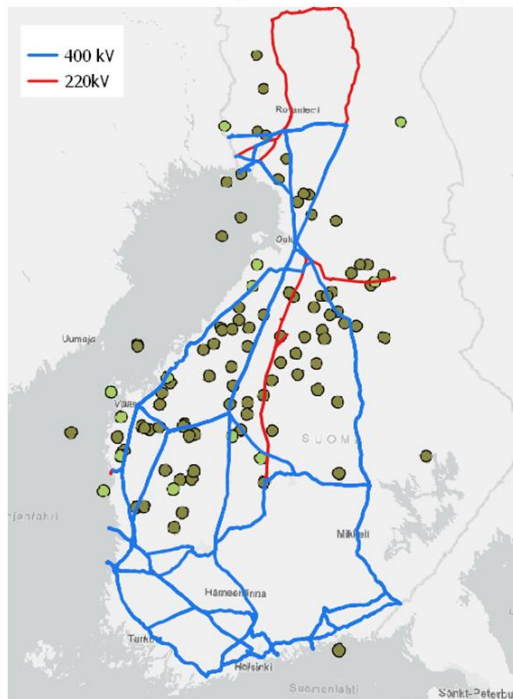
Itätuuli -hanke

Tuulivoimapotentiaali ja verkkoinfrastruktuuri Itä-Suomessa

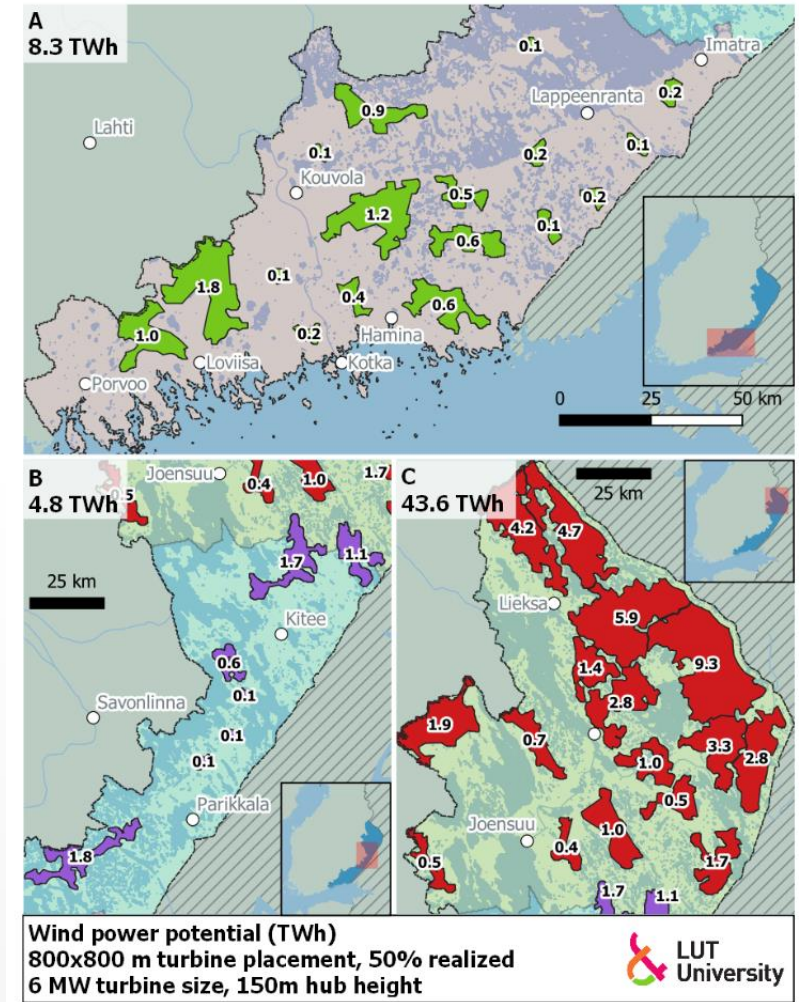
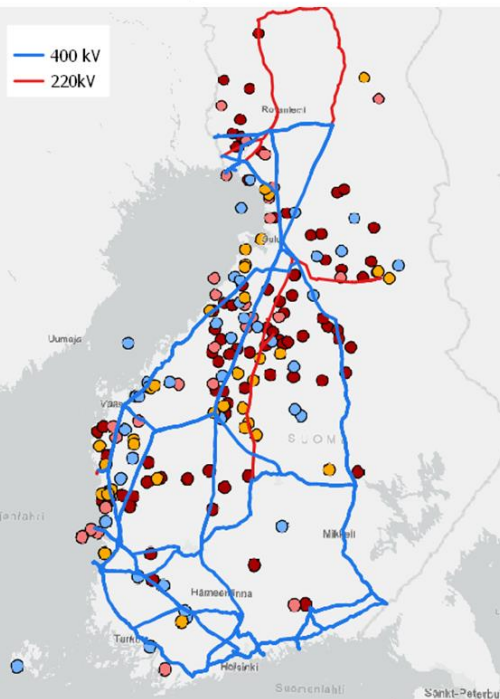
In operation



Environmental impact assessment (YVA)



Authorization, under construction



South-East Finland Hydrogen Valley project

TUULIVOIMAN INVESTOINTIKUSTANNUKSET

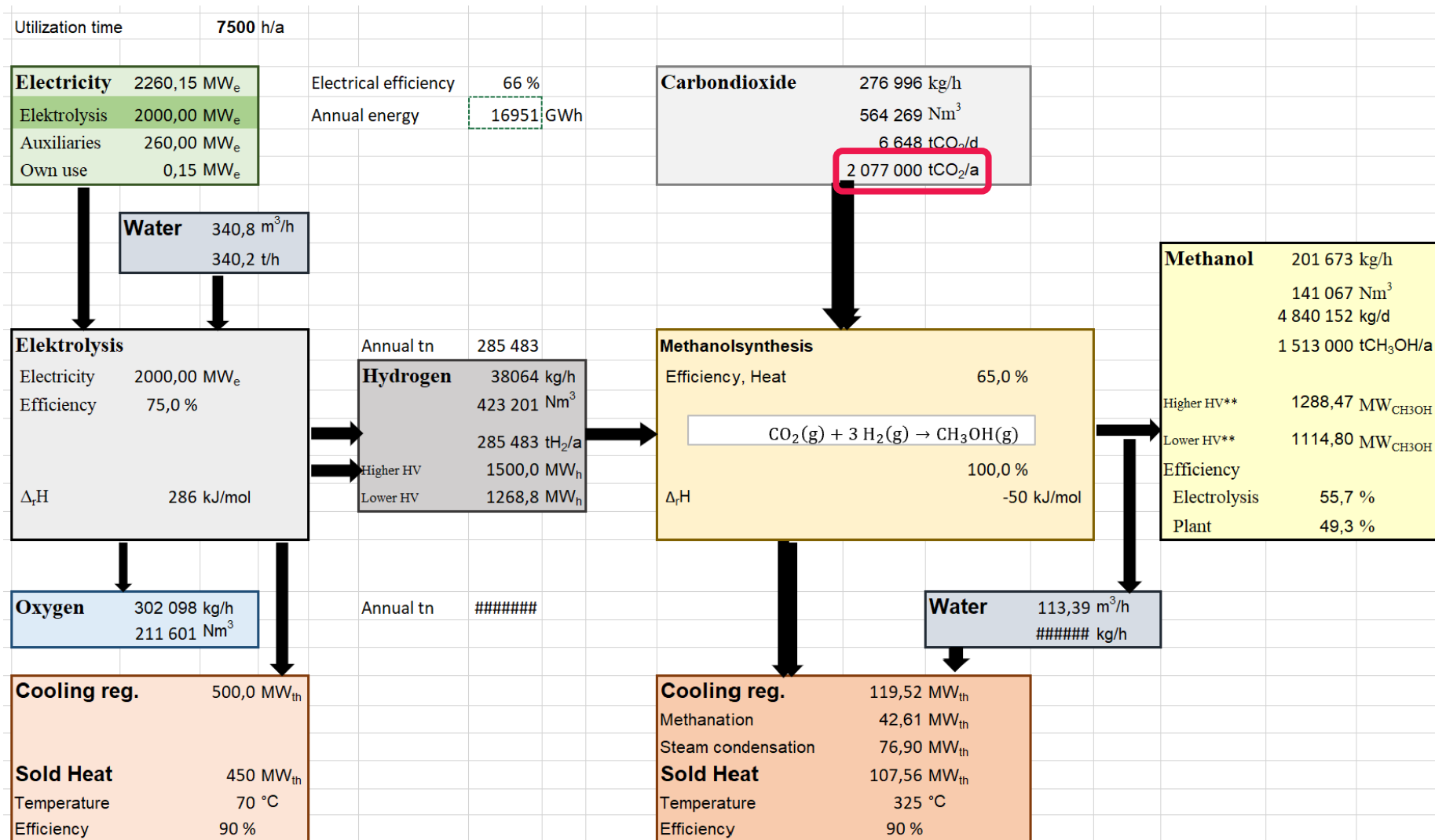
- Tuuliturbiini-investoinnit perusskenaariossa (poislukien sähköverkkoratkaisut) yhteensä 20,4 Mrd EUR
- Vuosittaiset kiinteistöverotulot n. 40 MEUR/a
- Vuosittaiset maanvuokratulot n. 40 MEUR/a
- Tuulivoimainvestointeihin liittyvät suorat ja välilliset työpaikat yli 400 000 henkilötyövuotta 30 vuoden aikana



Perusskenaario							Kansantaloudelliset vaikutukset alueelle		
		TWh	MW	kpl	Investointi EUR	MEUR	Verotulot/a		Työpaikat (30 vuoden yli)
					1 200 000	MEUR/MW	Kiinteistö	Maanvuokra	HT vuodet
							14 000	14 000	
Etelä	A	8.30	2 300	383	2 760 000 000	2 760	5 366 667	5 366 667	58 321
Väli	B	4.80	1 400	233	1 680 000 000	1 680	3 266 667	3 266 667	35 500
Pohjoinen	C	43.60	13 300	2217	15 960 000 000	15 960	31 033 333	31 033 333	337 250
		56.7	17 000	2 833	20 400 000 000	20 400	39 666 667	39 666 667	431 071

CASE A PULP MILL – METHANOL PRODUCTION

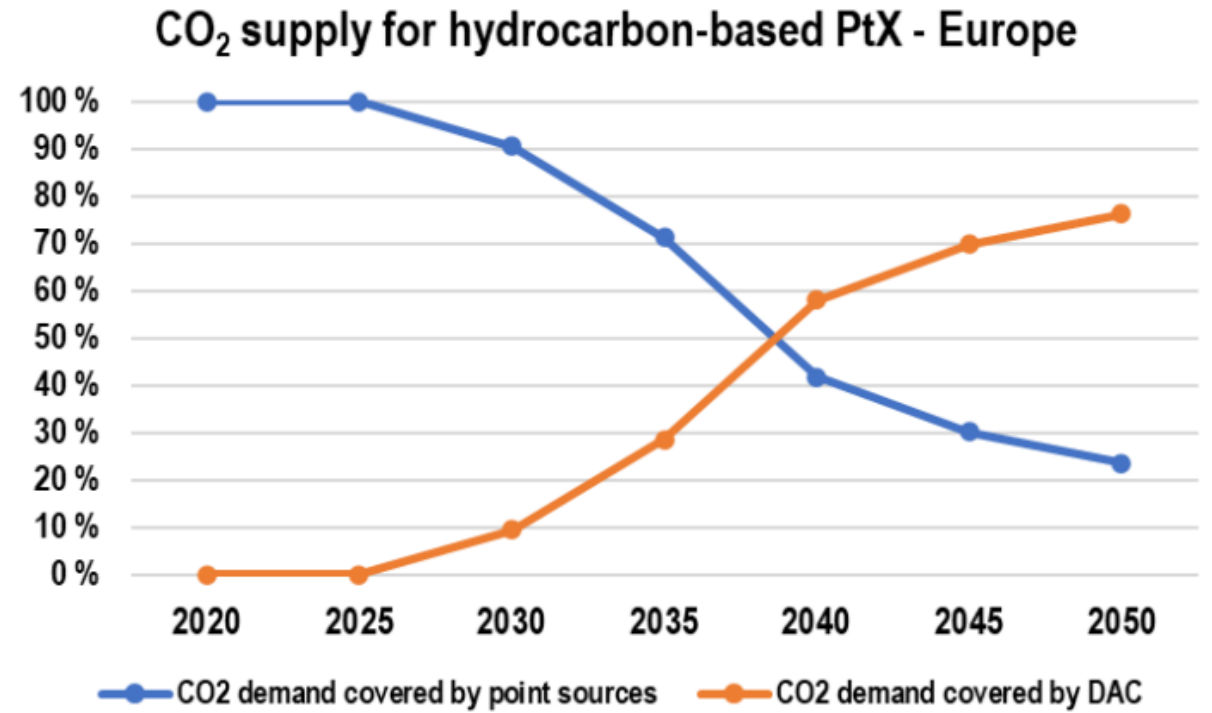
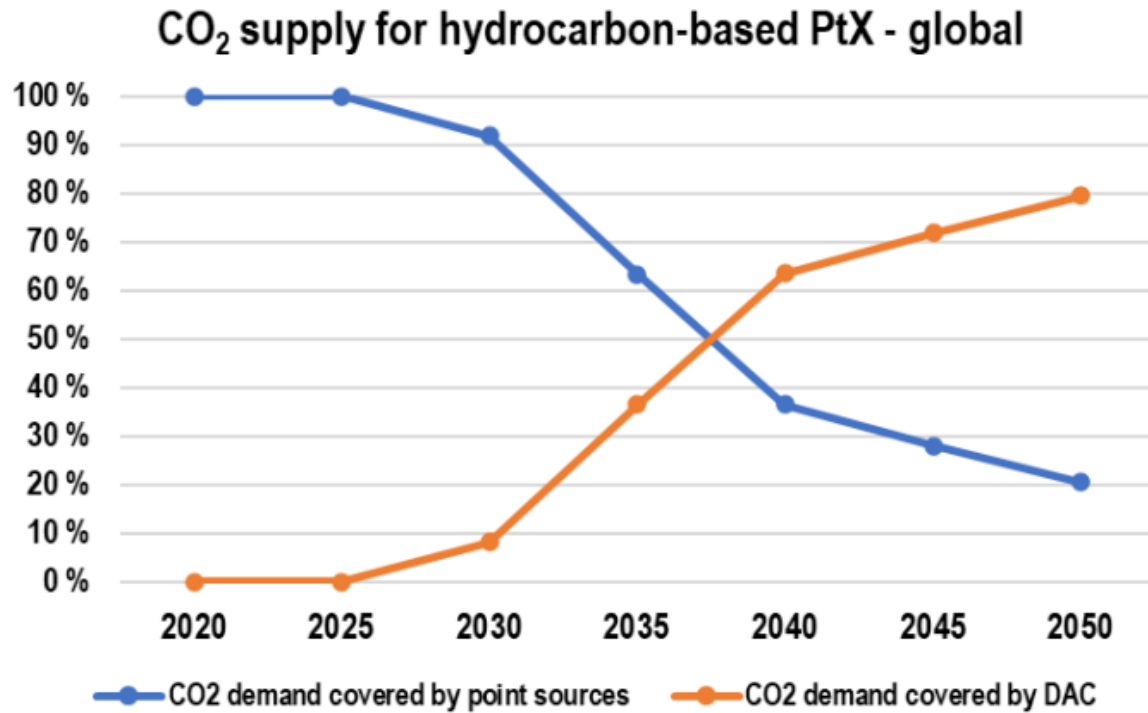
- Annual biobased CO2 emissions 2,1 Mt (2017)
- Chemical scrubbing (amine, 40 - 140 C)
 - CO2 capture efficiency 98%
 - CO2 capture purity
- Electrolyser 2 GW
- Annual electricity 17 TWh
- Green Methanol production 1,5 Mt/a
- Value á 1000 EUR/tn
- 1,5 Mrd EUR/a



Thank you!

Petteri Laaksonen, D.Sc., Research Director

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In 2030, the total potential of captured CO₂ from point sources that could be utilised is 2112 Mt annually (T. Galimova et al.(2022))

P2X in Finland – some LUT research



- Carbon Negative Åland: Strategic Roadmap
<https://lutpub.lut.fi/handle/10024/163456>
- Bothnian Bay Hydrogen Valley – Research report
<https://lutpub.lut.fi/handle/10024/163667>
- South-East Finland Hydrogen Valley – Research report
<https://lutpub.lut.fi/handle/10024/164642>
- Feasibility Study for Industrial Pilot of Carbon-Neutral Fuel Production – P2X
<https://lutpub.lut.fi/handle/10024/162597>

P2X TECHNOLOGIES

- » Commercially available
- » Technology Readiness Level 9



Technology	Supplier	Technology type	Reference	
Electrolysis	Cummins	Alkaline, PEM	[21]	
	Green Hydrogen Systems	Alkaline	[22]	
	Hydrogen Pro	Alkaline	[23]	
	ITM Power	PEM	[24]	
	McPhy	Alkaline	[25]	
	NEL Hydrogen	Alkaline, PEM	[26]	
	Siemens	PEM	[27]	
	Sunfire	Alkaline, SOEC	[28]	
	CO ₂ capture	Air Liquide Engineering & Construction	Cryogenic	[29]
		Aker Carbon Capture	Amine	[30]
Carbon ReUse		Water	[31]	
GE Power		Amine, oxy-combustion	[32]	
Mitsubishi Heavy Industries		Amine	[33]	
Shell		Amine	[34]	
Toshiba Energy Systems & Solutions Corporation		Amine	[35]	
MeOH synthesis		Air Liquide Engineering & Construction	Syngas/CO ₂ to MeOH	[29]
	BSE Engineering	n.a. ¹⁵	[36]	
	Carbon Recycle International	CO ₂ to MeOH	[37]	
	Johnson Matthey	Syngas to MeOH	[38]	
	Mitsubishi Gas Chemical	Syngas to MeOH	[39]	
	Fuel synthesis	Chemieanlagenbau Chemnitz	MTG	[40]
ExxonMobil		MTG	[41]	
Haldor Topsøe		MTG, syngas to gasoline	[42]	
Sunfire		Fischer-Tropsch	[28]	

P2X & Carbon Dioxide

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Tutkimusjulkaisut - Research Reports 123

Petteri Laaksonen, Hannu Karjunen, Jenna Ruokonen, Arto Laari, Maria Zhuravova, Sini-Kaisa Kinnunen, Antti Kosonen, Timo Kilri, Tina Sirinkkonen, Tommi Rissanen, Antero Tervonen, Juha Varis

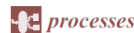
Feasibility Study for Industrial Pilot of Carbon-Neutral Fuel Production – P2X

Final report

LAPPEENRANTA-LAHTI UNIVERSITY OF TECHNOLOGY LUT
LUT School of Energy Systems
Energy Technology

Joonas Hyvärinen

TECHNO-ECONOMIC EVALUATION OF CARBON CAPTURE TECHNOLOGIES INTEGRATED TO FLEXIBLE RENEWABLE ENERGY SYSTEM



Modelling and Cost Estimation for Conversion of Green Methanol to Renewable Liquid Transport Fuels via Olefin Oligomerisation

Jenna Ruokonen ^{1,*}, Harri Nieminen ¹, Ahmed Rafiq Dahiru ^{2,3}, Arto Laari ¹, Tuomas Koironen ¹, Petteri Laaksonen ¹, An Vuokila ¹ and Mika Huuhimäki ^{2,3}

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Abstract: The ambitious CO₂ emission reduction targets for the transport sector set in the Paris Climate Agreement require low-carbon energy solutions that can be commissioned rapidly. The production of gasoline, kerosene, and diesel from renewable methanol using methanol-to-olefins (MTO) and Mobil's Olefins to Gasoline and Distillate (MOGD) synthesis was investigated in the study via process simulation and economic analysis. The current work presents a process simulation model comprising liquid fuel production and heat integration. According to the economic analysis, the total cost of production was found to be 3420 €/t_{DM} (271 €/MWh_{DM}), corresponding to a renewable methanol price of 963 €/t (124 €/MWh_{DM}). The calculated fuel price is considerably higher than the current cost of fossil fuels and biofuel blending components. The price of renewable methanol, which is largely dictated by the cost of electrolytic hydrogen and renewable electricity, was found to be the most significant factor affecting the profitability of the MTO-MOGD plant. To reduce the price of renewable fuels and make them economically viable, it is recommended that the EU's sustainable transport policies are enacted to allow flexible and practical solutions to reduce transport-related emissions within the member states.

Keywords: methanol; MTO-MOGD; hydrocarbon fuels; renewable energy; sustainable transport; process simulation; techno-economic analysis

1. Introduction
The legal framework set by the Paris Climate Agreement [1] calls for practical technological solutions to realise emission reduction targets at both the European Union (EU) and the national levels. The ultimate target of the EU is to gradually achieve carbon neutrality by 2050 [2]. The realisation of considerable emission reductions requires marked reconfiguration of the energy sector. The role of hydrogen in the energy transition has gained significant interest, and the question of whether to use renewable electricity directly as a source of power or to convert electricity to hydrogen via the electrolysis of water remains unresolved. The direct use of electricity in battery electric vehicles is the most energy efficient option, and this can be readily observed by comparing the overall well-to-wheels efficiencies of fully electric vehicles and internal combustion engine vehicles. After taking fuel production, distribution, retail, and vehicle losses into account, the well-to-wheels efficiency of fossil fuel-powered internal combustion engine vehicles is only 25–29%, while the corresponding figure for battery electric vehicles charged with renewable electricity is

ANALYSIS AND DESIGN OF CARBON DIOXIDE UTILIZATION SYSTEMS AND INFRASTRUCTURES

Hannu Karjunen



Short Communication The role of electricity-based hydrogen in the emerging power-to-X economy

Christian Breyer ¹, Gabriel Lopez, Dmitrii Bogdanov, Petteri Laaksonen
LUT University, Yöpyöintiekuja 34, 53850 Lappeenranta, Finland

Highlights:
• The term "Hydrogen Economy" insufficiently describes future energy systems.
• "Power-to-X Economy" better highlights the essential role of renewable electricity.
• The highest reported demand for e-hydrogen is presented at over 40 PW_{th,DM}.

Abstract:
An energy system research into high shares of renewables has developed, so have the perspectives of the fundamental nature of a highly renewable economy. Early energy system transition research suggested that current fossil fuel energy systems would transition to a "Hydrogen Economy", whereas more recent insights suggest that a "Power-to-X Economy" may be a more appropriate term, as renewable electricity will become both the most important primary and final energy carrier through various Power-to-X conversion routes across the energy system. This paper provides a detailed overview on research insights of recent years on the core elements of the Power-to-X Economy and the role of hydrogen based on latest research results. These results suggest that, by 2050, upwards of 42 TWh_{DM} of hydrogen will be required to fully decarbonise the global energy industry system. Hydrogen, therefore, emerges as a central intermediate energy carrier and its relevance is driven by significant cost reductions in renewable electricity, especially of solar photovoltaics and wind power. Efficiency and cost drivers position direct electrification as the primary solution for decarbonisation of the global energy industry system; however, electro-to-molecule routes are essential for the large subset of remaining energy-related demands including chemical production, marine and aviation fuels, and steelmaking.

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<https://doi.org/10.1016/j.hydrox.2023.08.001>
ISSN 1540-4834 (The Author(s)). Published by Elsevier Ltd on behalf of Hydrogen Energy Publications LLC. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).



Global demand analysis for carbon dioxide as raw material for key industrial sources and direct air capture to produce renewable electricity-based fuels and chemicals

Taru Gallimore ¹, Manish Ram, Dmitrii Bogdanov, Mahdi Fathi, Sarah Khalili, Ashish Gulagi, Hannu Karjunen, Theophilus Nii Odoi Mensah, Christian Breyer
LUT University, Yöpyöintiekuja 34, Lappeenranta, Finland

Abstract:
Defossilification of the current fossil fuels dominated global energy systems is one of the key goals in the coming decades to mitigate climate change. Sharp reductions in the costs of solar photovoltaics, wind power, and battery technologies enable a rapid transition of the power and some segments of the transport sectors to sustainable energy resources. However, renewable electricity-based fuels and chemicals are required for the defossilification of hard-to-abate segments of transport and industry. The global demand for carbon dioxide as raw material for the production of e-fuels and e-chemicals during a global energy transition to 100% renewable energy is analyzed in this research. Carbon dioxide capture and utilization potentials from key industrial point sources, including cement mills, pulp and paper mills, and waste incinerators, are evaluated. According to this study's estimates, the demand for carbon dioxide increases from 0.4 to 2000 to 0.1 gtpa in 2050. Key industrial point sources can potentially supply 2.1 gtpa of carbon dioxide and thus cover the majority of the demand in the 2050s. By 2050, however, direct air capture is expected to supply the majority of the demand, contributing 3.8 gtpa of carbon dioxide annually. Sustainable and scalable industrial point sources and direct air capture are vital technologies which may help the world to achieve ambitious climate goals.

Renewable energy capacities for power generation have been steadily growing across the world with China, the European Union, and the United States making the largest investments into renewables in 2019 (REN21, 2020). Globally added capacity of solar photovoltaic (PV) systems grew at an average rate of 21% per year between 2010 and 2020 (Igor-Walden, 2021). Similarly, wind power grew at a compound annual growth rate of 21% during the same period (REN21, 2021). The power sector is leading the transition to sustainable energy, with rapid ramping of solar PV and wind power capacities. Rapidly growing capacities are driven by declining costs of these technologies as more of them were reported to be even cheaper than continuing running existing fossil fuel-based power plants (Hirata, 2020). Renewable energy sources increasingly replace fossil fuels and cover growing electricity demand. Moreover, many industrial processes and transport modes are adopting electrification for increased efficiency levels as well as complementing renewables. Electrification could be direct, as in adoption of electric vehicles (EV) or indirect such as the production of green hydrogen that is utilized in many applications. On the contrary, other energy sectors face challenges in shifting from fossil fuels to direct electrification via

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<https://doi.org/10.1016/j.jclepro.2023.139030>
Received 21 February 2023; Received in revised form 16 August 2023; Accepted 20 August 2023
Available online 1 September 2023
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