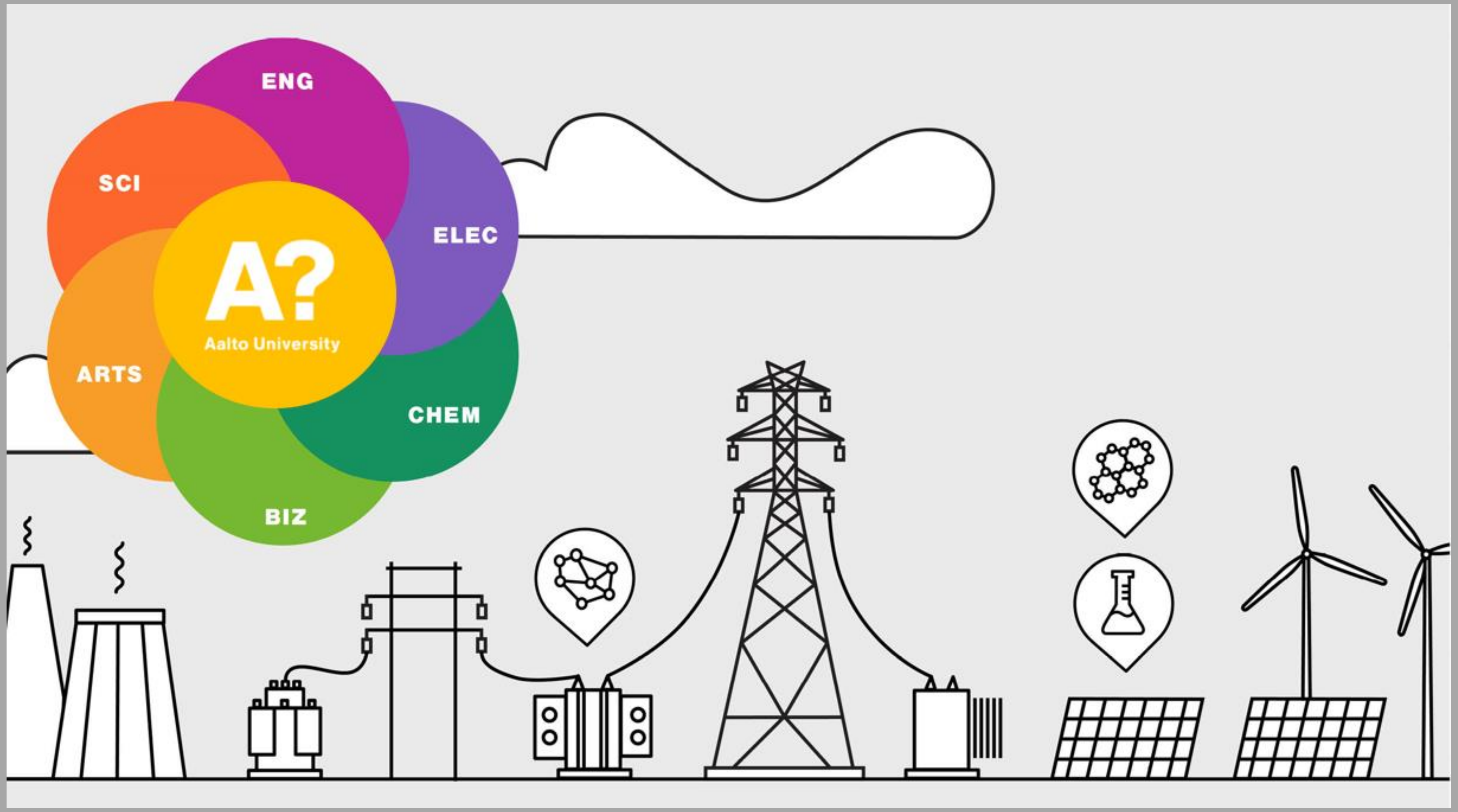
Hydrogen value chain – activities at Aalto



Mika Järvinen, Professor
Energy Conversion and Systems group
Department of Mechanical Engineering
Aalto University

Aalto University
School of Engineering

Contents

- Introduction to Energy @ Aalto
- Enabling green hydrogen economy – sufficient renewable and sustainable energy
- Production, storage and transportation of hydrogen.
- Utilization of hydrogen and its derivatives in energy field
- Summary

Introduction to Energy @ Aalto

Merger of three Finnish Universities

1849 Helsinki University of Technology

1871 University of Art and Design Helsinki

1911 Helsinki School of Economics

Aalto University 2010

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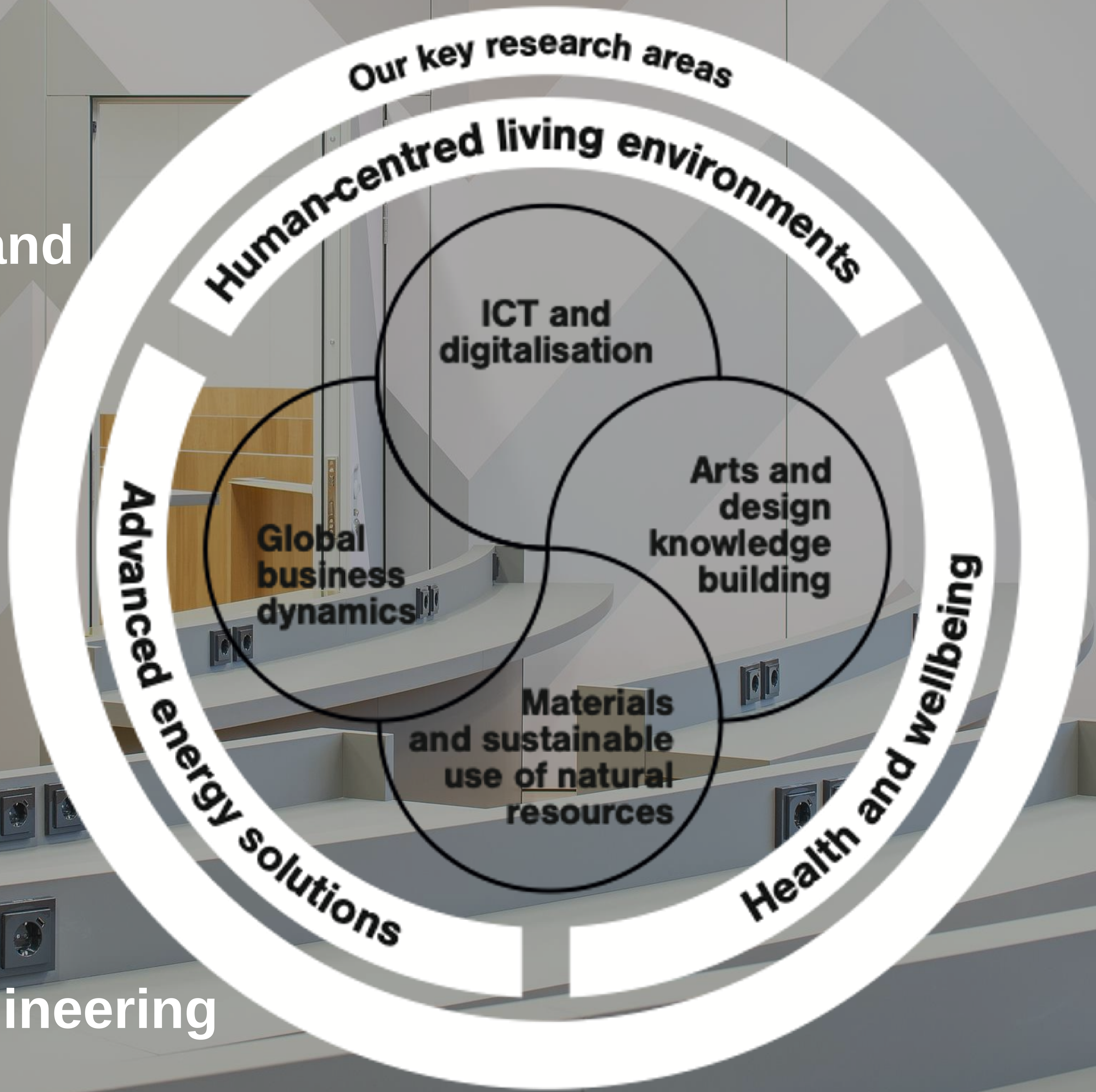
Aalto-universitetet
Aalto University

Six dynamic schools work across cross-cutting research areas…

School of Arts, Design and Architecture

School of Business

School of Chemical Engineering



School of Electrical Engineering

School of Engineering

School of Science

….Energy connects across all schools – over 70 professors in the field….

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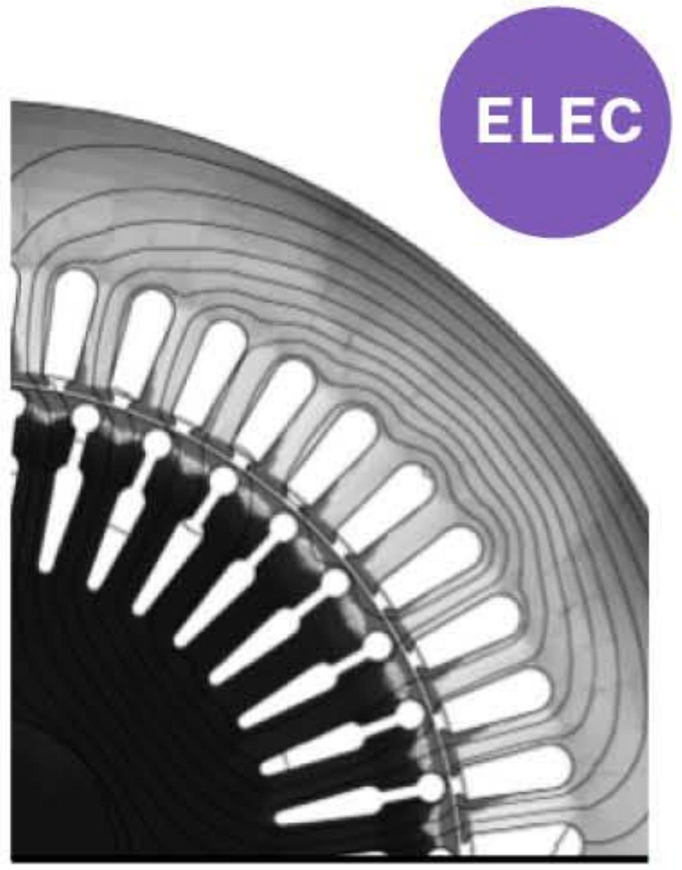
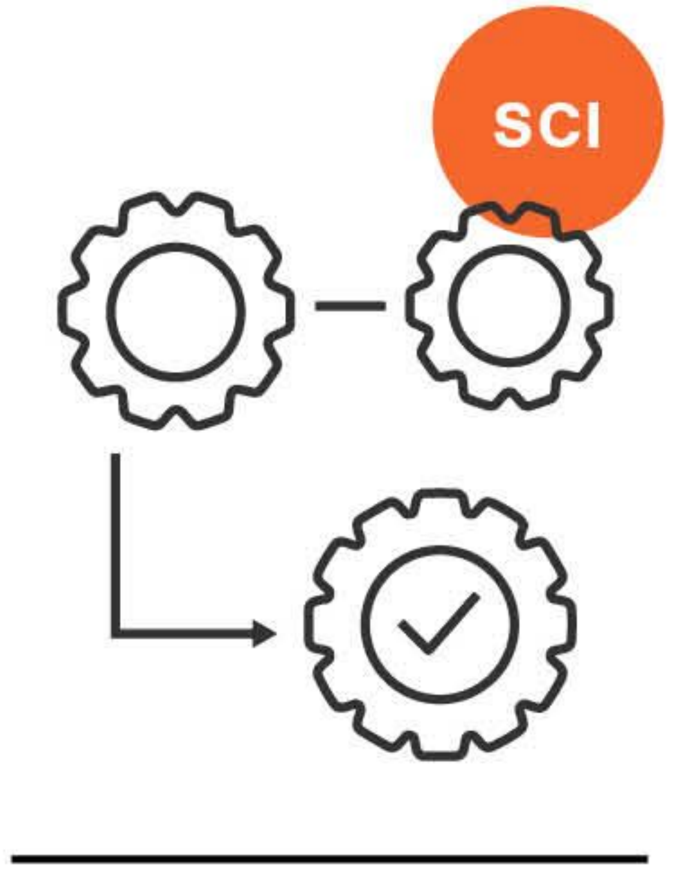
Aalto-universitetet
Aalto University

Every Aalto school works on Energy: Examples



Energy efficient electrical machines

Smarter regulation of electricity distribution networks



Improving systems with operations research

Advancing the circular economy of metals

Renewable energy materials

Co-creating poverty alleviating, sustainable innovations in complex global systems

Adaptive combustion research for high industrial impact

Research for safe and viable disposal of radioactive nuclear waste

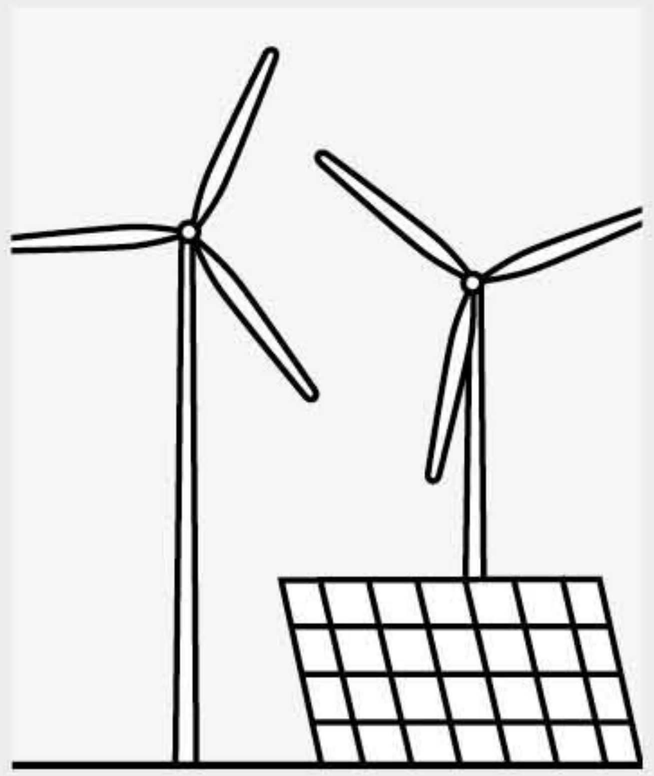
Design for society

Revolutionizing photonics with nanomaterials

Advanced energy solutions: nuclear power production & renewable energy technologies

MULTIDISCIPLINARY CASE STUDIES IN ENERGY

Smart Energy Transitions



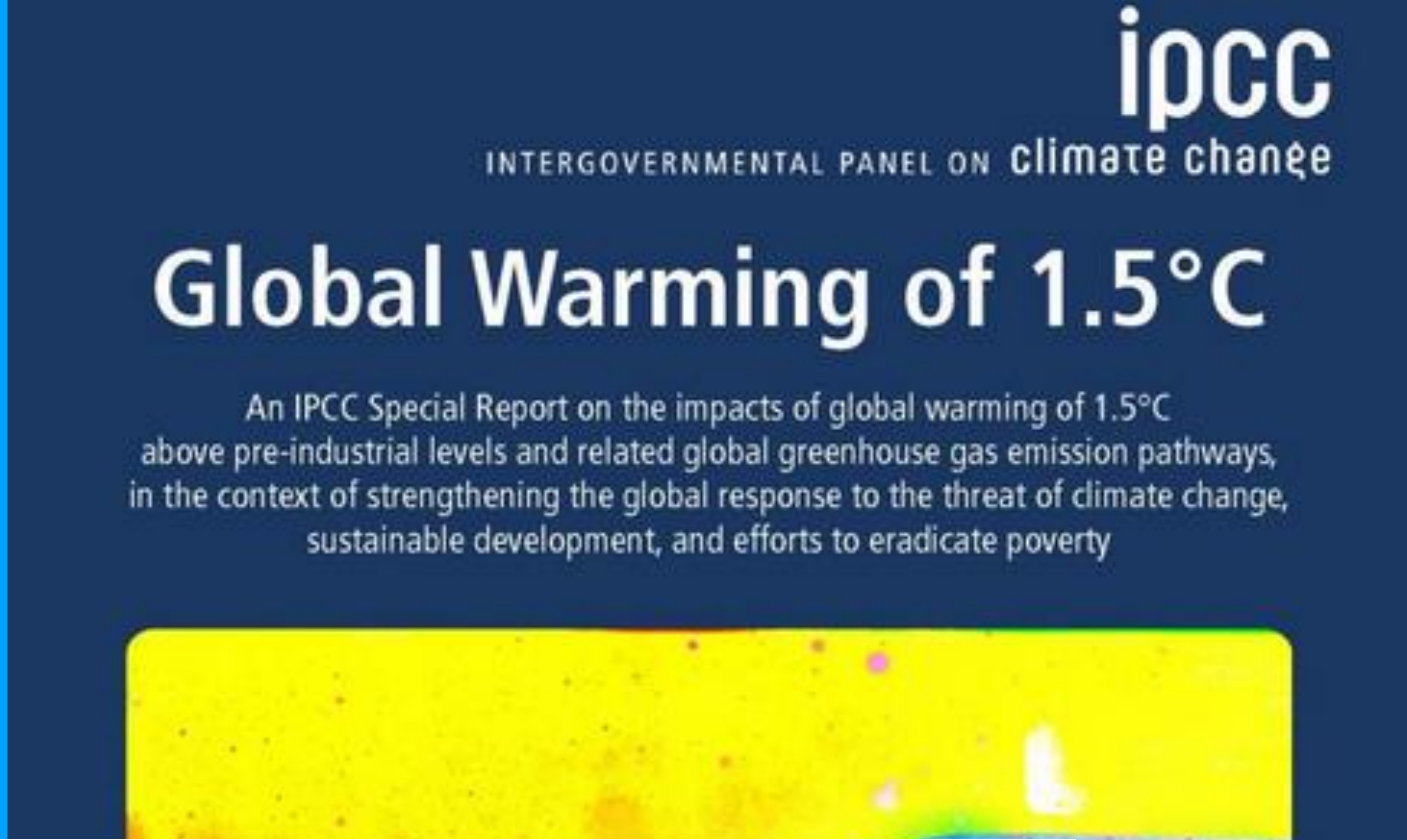
STEEM – Sustainable Transitions of European Energy Markets

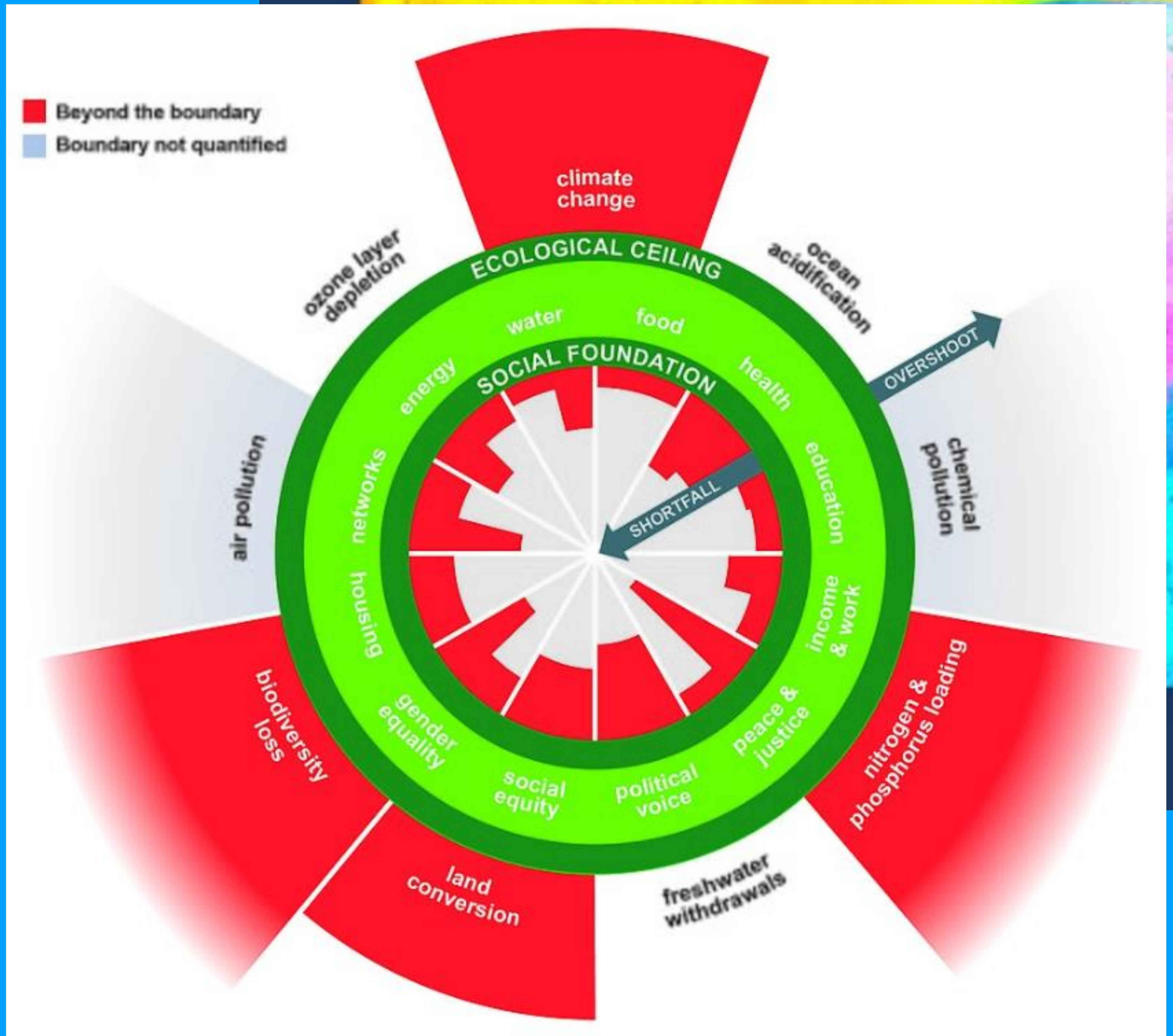
Wood Architecture

Aalto University
School of Engineering

Energy Conversion and Systems

Mika Järvinen, 8.8.2023





Personnel profile

- 9 + 3 new TT professors in the “pipeline”
- 3 Professors of practice (+ 1 PoP on Wind power)
- 3 Lecturers
- 2 Senior Scientists + 2 Staff Scientists
- 14 Post-docs
- 43 Doctoral students
- In-house Master’s thesis students
- In total 110-120

Mika Järvinen
Head of group

Thermal power plants, CCUS, wind power, P2X, circular economy, waste, plastics

Risto Kosonen
Vice head

HVAC, buildings and built environment

Panu Mustakallio

HVAC, buildings and built environment

Sanna Syri

Energy markets and systems

Ilkka Keppo

Energy markets and systems

Jaakko Jääskeläinen

Energy markets and systems

Risto Lahdelma

Energy systems optimization, district heating

Our research group covers the energy value chain, from sustainable energy production and conversion, storage and end use. We have strong focus on energy markets and optimization in dynamic environments.

Annukka Santasalo-Aarnio

Energy storage systems, P2X fuels, electrolysis circular economy, hydrogen storage

Olli Himanen

Hydrogen technologies

Hannele Holttinen

Wind power

Martti Larmi

Sustainable combustion, ICEs, hydrogen and X2P topics.

Ossi Kaario

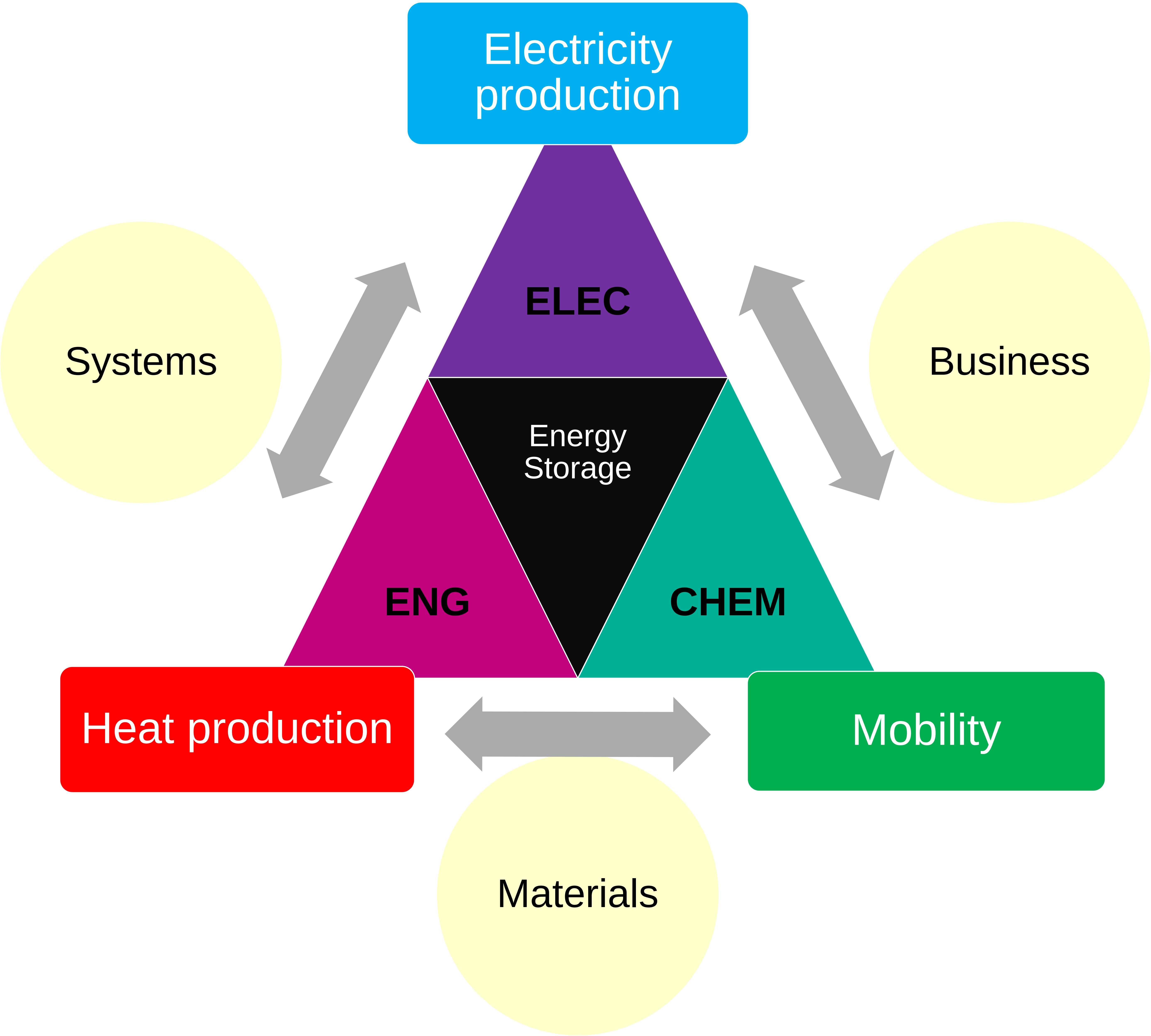
CFD modeling, sustainable combustion and flows in energy

Ville Vuorinen

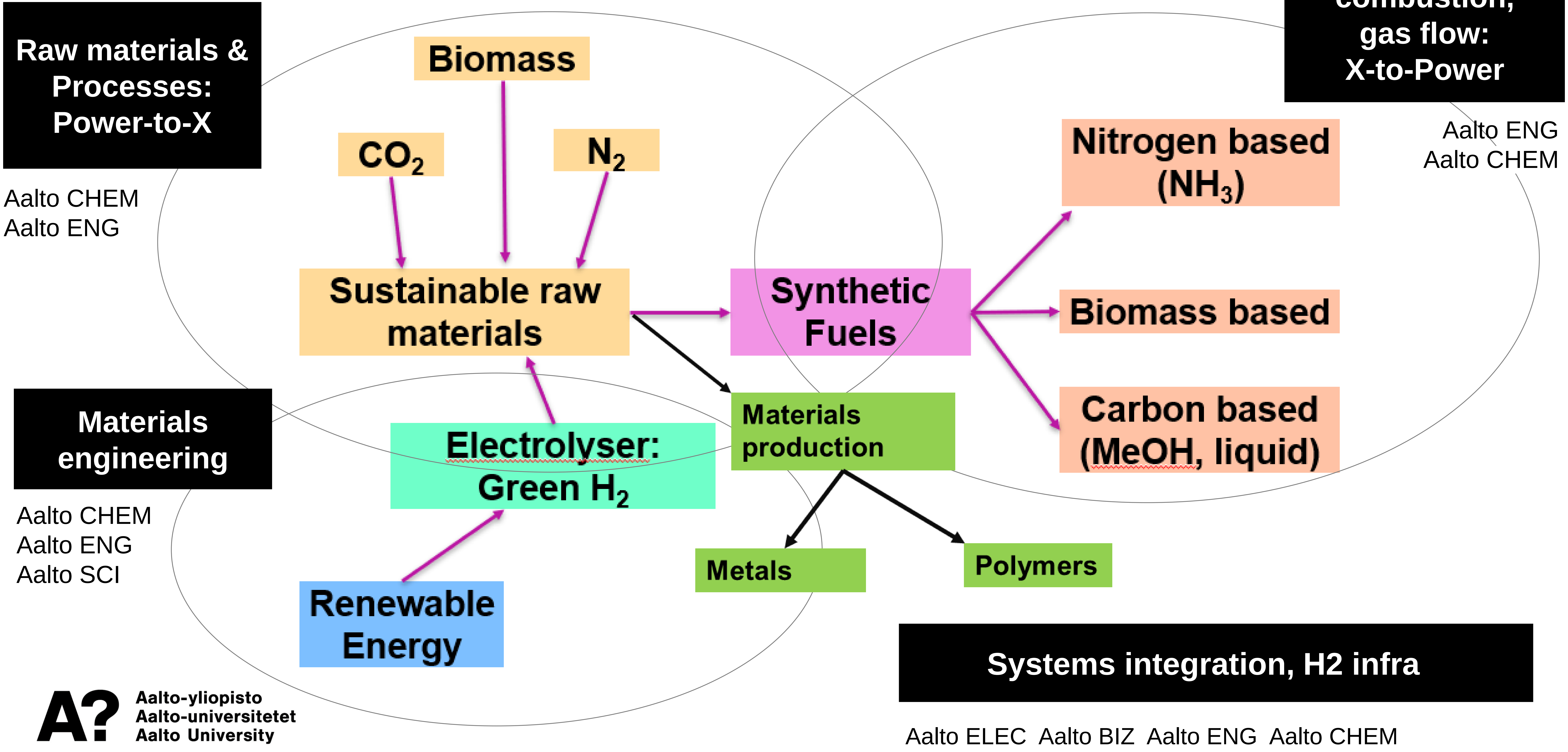
CFD modeling, sustainable combustion and flows in energy

PoP, Professor of practice

Key elements in energy transition



Power-to-X for replacing fossil raw materials



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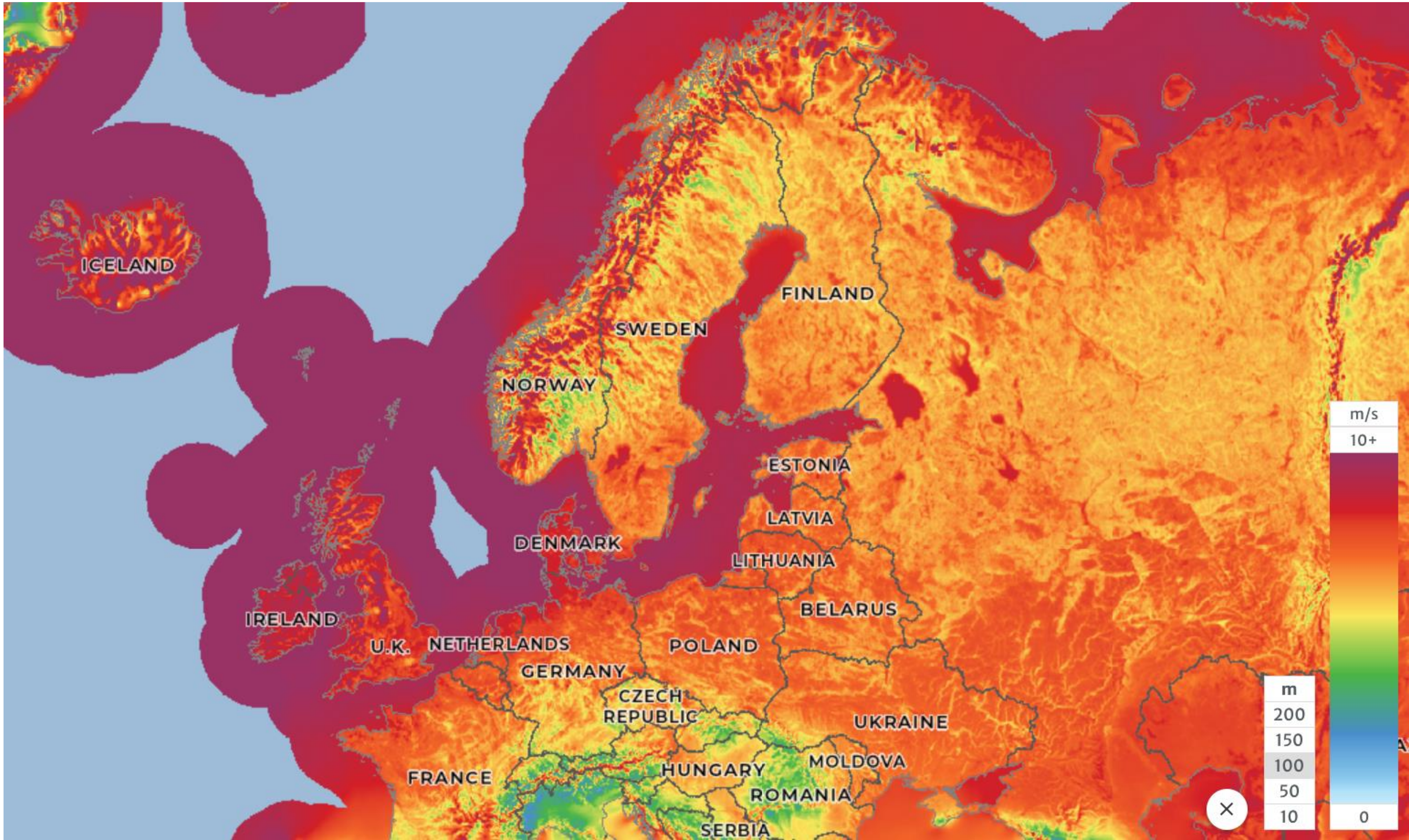
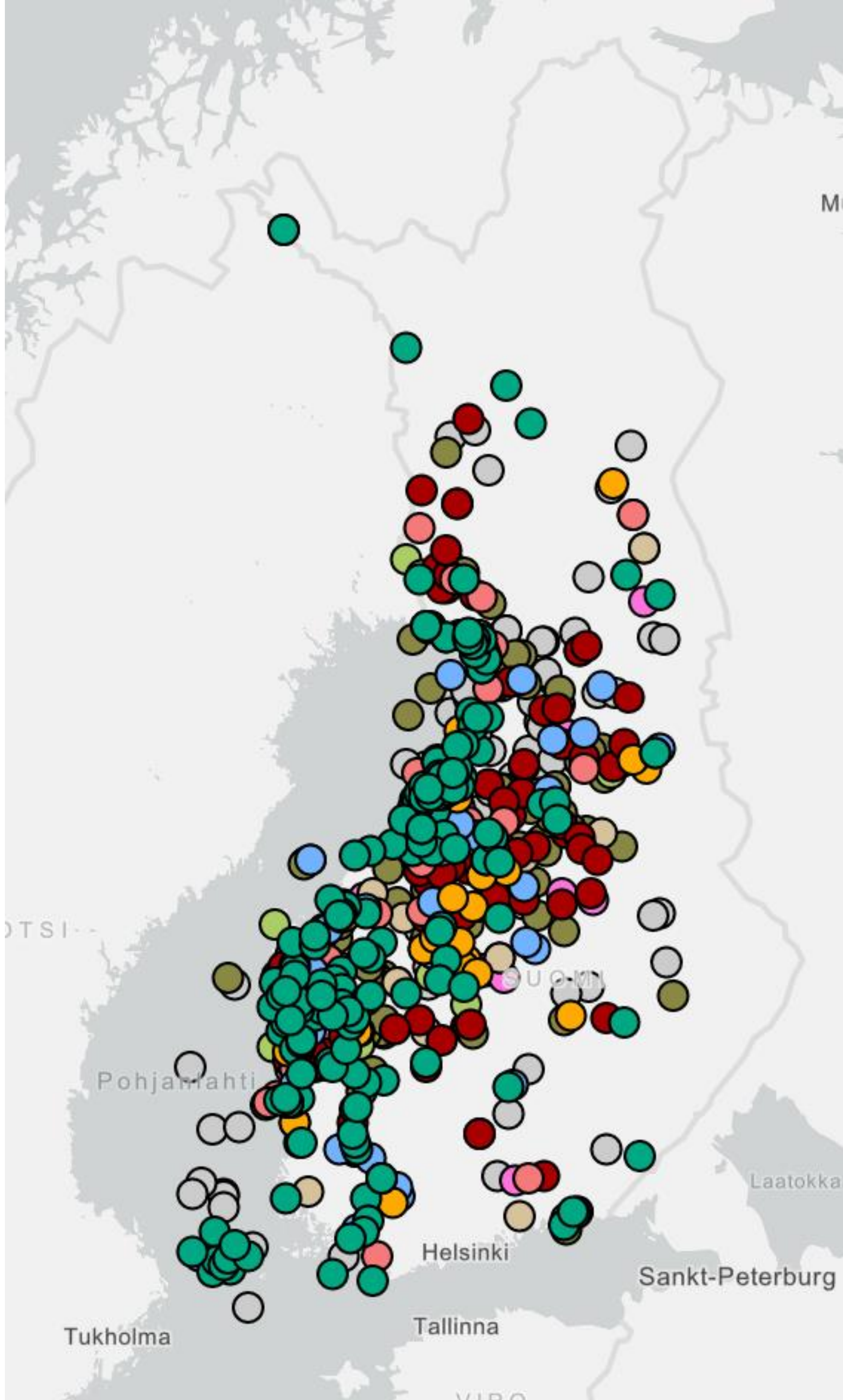
Enabling green hydrogen economy – sufficient renewable and sustainable energy

Wind resource in Finland



Status map of projects

Stage of development	Onshore MW	Offshore MW
Pre-screening	11 093	42 960
Land use plan started	16 489	1 400
Land use plan draft	2 581	0
EIA ongoing	18 938	10 792
Land use plan proposal	2 397	0
EIA done	2 271	900
Land use plan done	2 856	1 155
Permitted	3 069	400
Under construction	3 405	0
Totally new on the way	**63 100**	**57 607**
In production 2021	2 300	44
In production 2022	5 700	44
Predicted 31.12.2023	7 200	44



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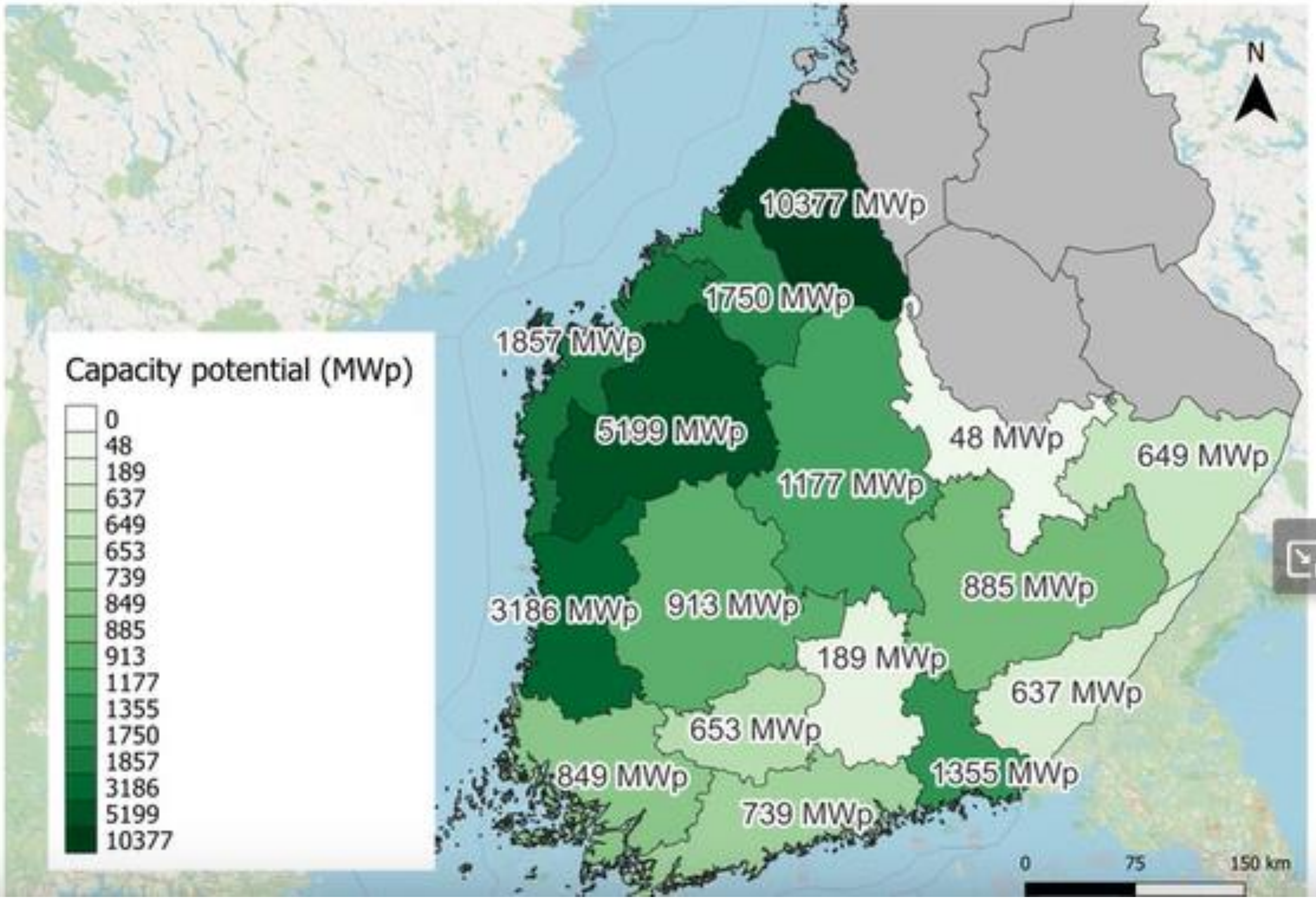
Suomen Tuulivoimayhdistys

SWECO

Solar PV potential

- 772 potential areas with a combined capacity potential up to 30 GWp
- Results concentrated on the west coast
- Average site area 60 ha, the areas are on average smaller in the south



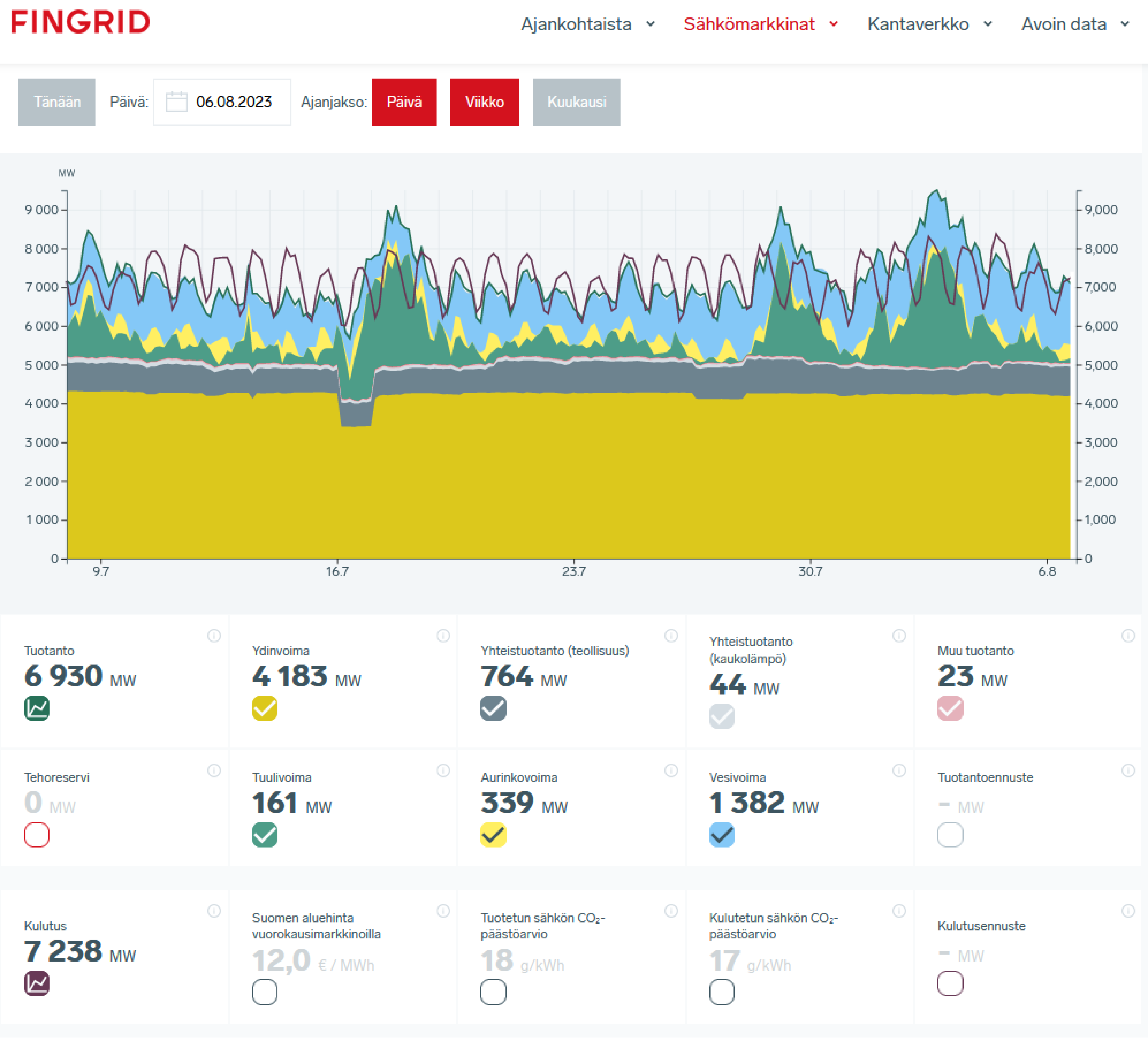
Eetu Laitila, 2023
Aalto, Valorem
Preliminary QGIS based modeling study including sustainability aspects

Comments

- Significant increase in the share of renewables, especially wind energy in Finland.
- There exists already 7.2 GW wind power by the end of 2023, and in overall there are 63 + 57 = 120 GW new wind power plants in the "pipeline". Not all of these will rationalize.
- 2022 power consumption was ~88 TWh. To give a perspective, with 50 GW, we would be able to generate 0.05 TW × 8760 h × 0.35 = 153 TWh.
- Decarbonization requires electrification that increase the power consumption by a factor of 2-3.

- **As comparison Germany/Finland:**
  - Population 85/5.6 millions
  - 64/7 GW wind power
  - Area 360000/340000 km²
  - We have great potential to make Finland a model country for the sustainable wind power development, very important for sustainability and biodiversity globally. This has direct link to climate aspects.
  - Based on IPBES and IPCC (2022), most climate actions have negative impacts on biodiversity but most biodiversity action have positive impacts on climate.

- **What if 50-60 GW wind production drops to ~zero suddenly for weeks?**
- **Renewable LCoH should be lower than fossil product ~1.5 €/kg, but still the RES projects should be paid back, are PPAs still going to work?**
- **Cannibalization?**
- **What will future’s energy system and markets look like?**



Production, storage and transportation of hydrogen.

Background

- Most, 95…98%, of the H_2 is today made from natural gas by steam reforming, releasing CO_2, $CH_4+2H_2O \leftrightarrow CO_2+4H_2$
- Green hydrogen requires cheap, renewable and sustainable electricity to compete with fossil H2
- Electrolysis is an extremely energy intensive process, and its efficiency is typically lower than 70%. If we then use a fuel cell (or combined GT cycle) to make electricity from H_2, with efficiency of 60%, we will waste 58% of the precious renewable electricity to heat, heat recovery should be used then.

→ Maximal use of power as power!

Research highlights

Energy Conversion and Management 271 (2022) 116200

Contents lists available at ScienceDirect

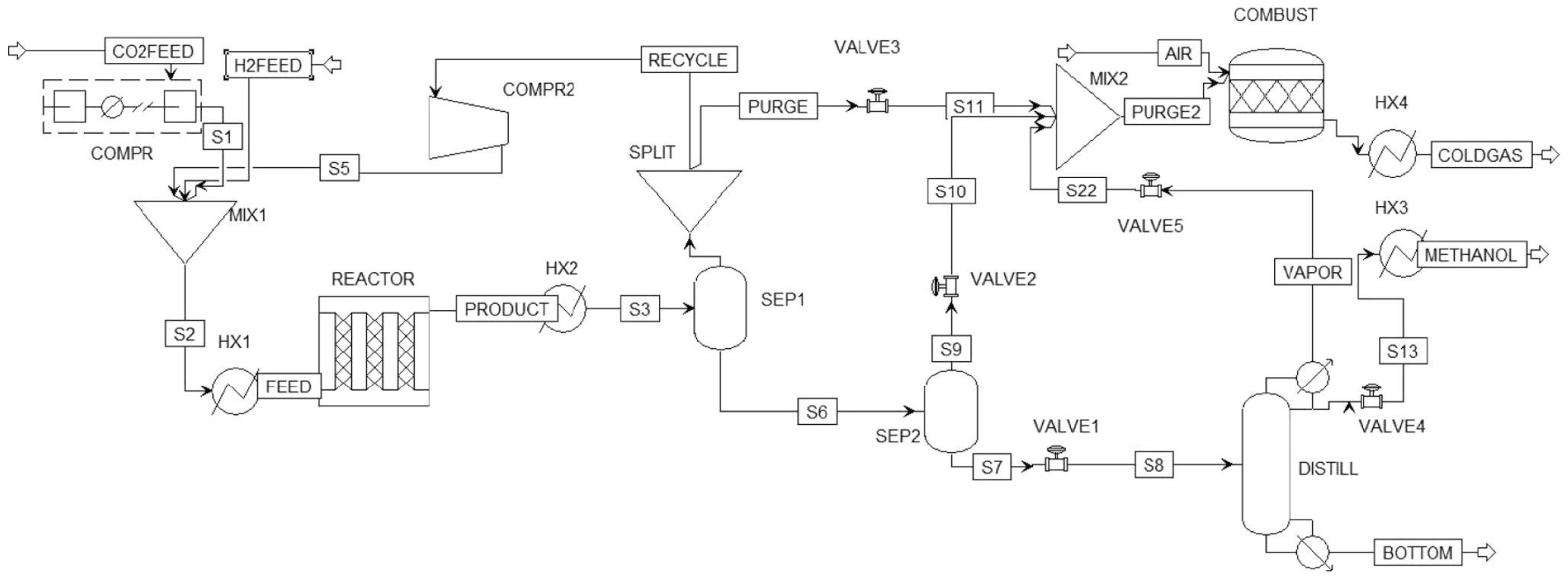
Energy Conversion and Management

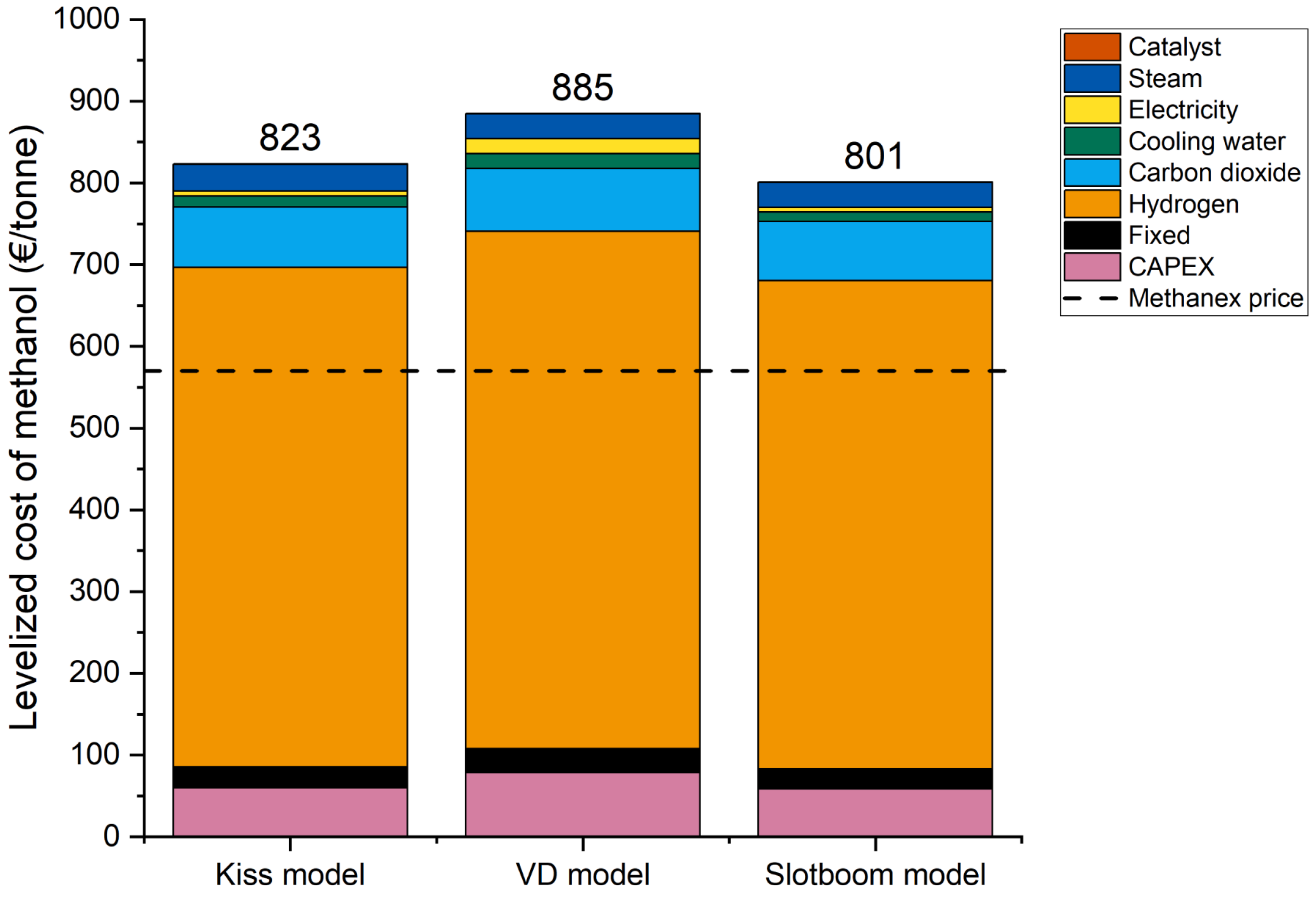
journal homepage: www.elsevier.com/locate/enconman

Choice of the kinetic model significantly affects the outcome of techno-economic assessments of CO_2-based methanol synthesis

Judit Nyári *, Daulet Izbassarov, Árpád I. Toldy, Ville Vuorinen, Annukka Santasalo-Aarnio

Research Group of Energy Conversion, Department of Mechanical Engineering, Aalto University, FI-00076 Espoo, Finland





Kinetic model selected for the basis of modelling has significant impact on Levelized cost of Methanol

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Research highlights

Applied Energy 348 (2023) 121536

Contents lists available at ScienceDirect

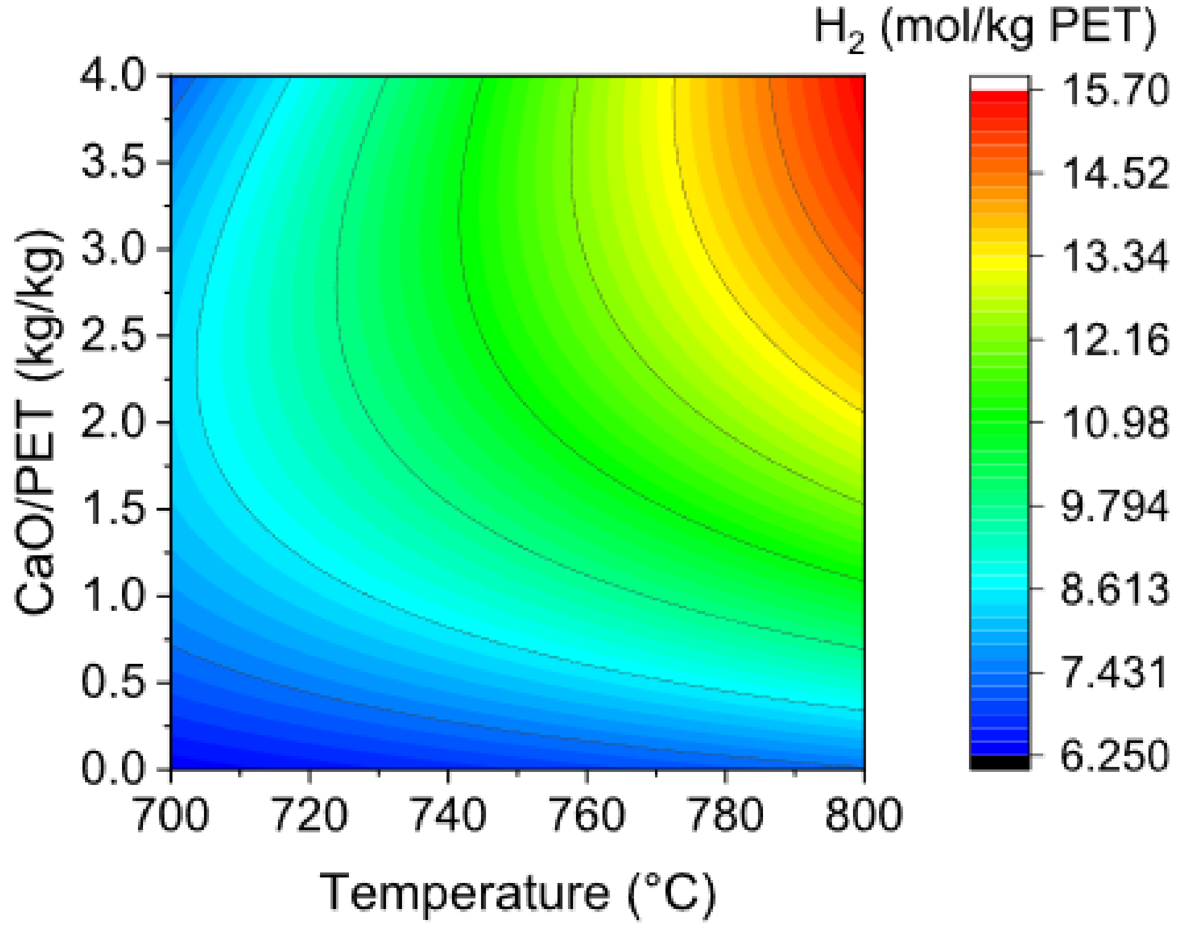
Applied Energy

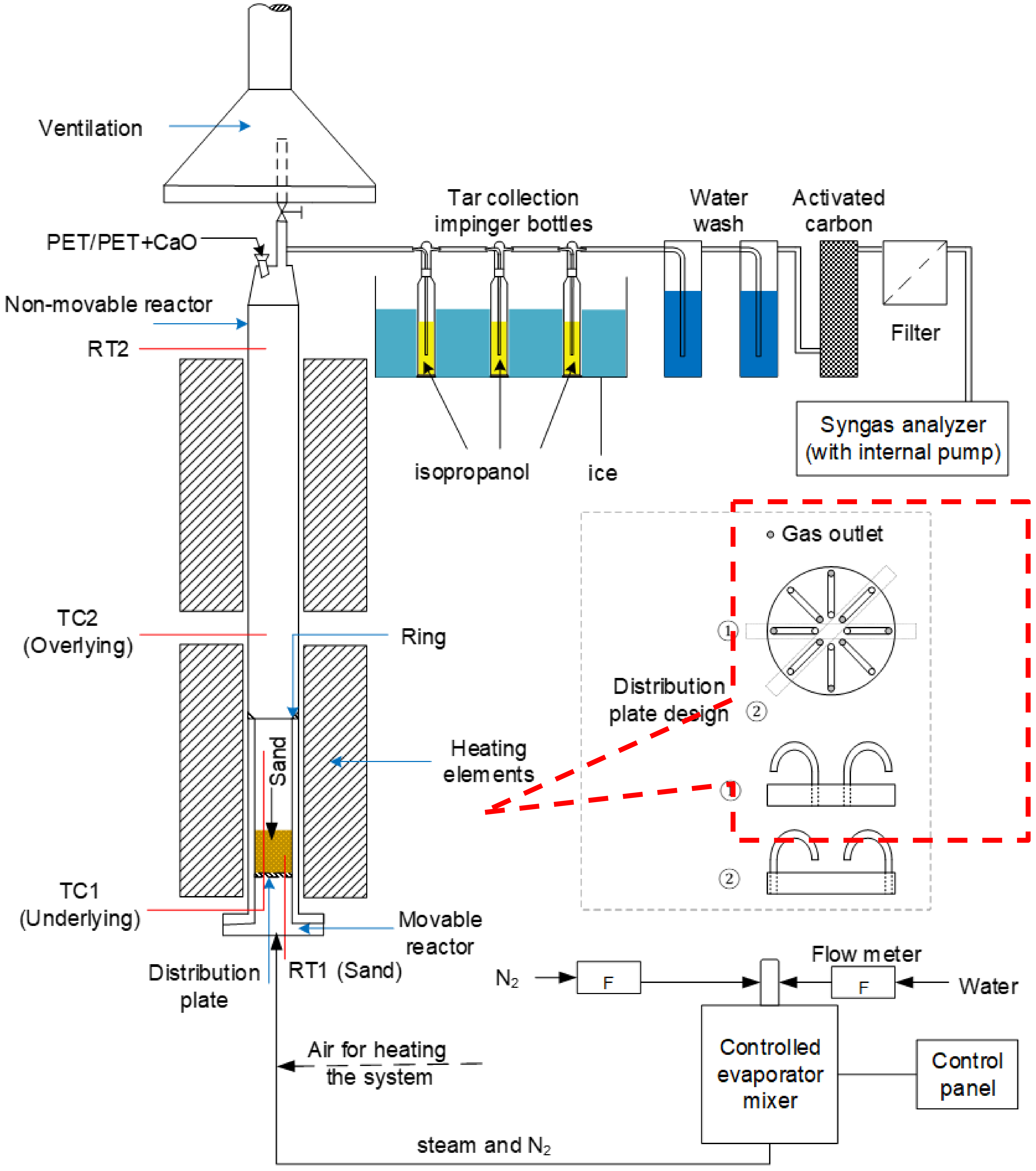
journal homepage: www.elsevier.com/locate/apenergy

Steam gasification of polyethylene terephthalate (PET) with CaO in a bubbling fluidized bed gasifier for enriching H_2 in syngas with Response Surface Methodology (RSM)

Shouzhuang Li *, Muddasser Inayat, Mika Järvinen

Energy Conversion and Systems Research Group, Department of Mechanical Engineering, School of Engineering, Aalto University, Sähkömiehentie 4J, 02150 Espoo, Finland





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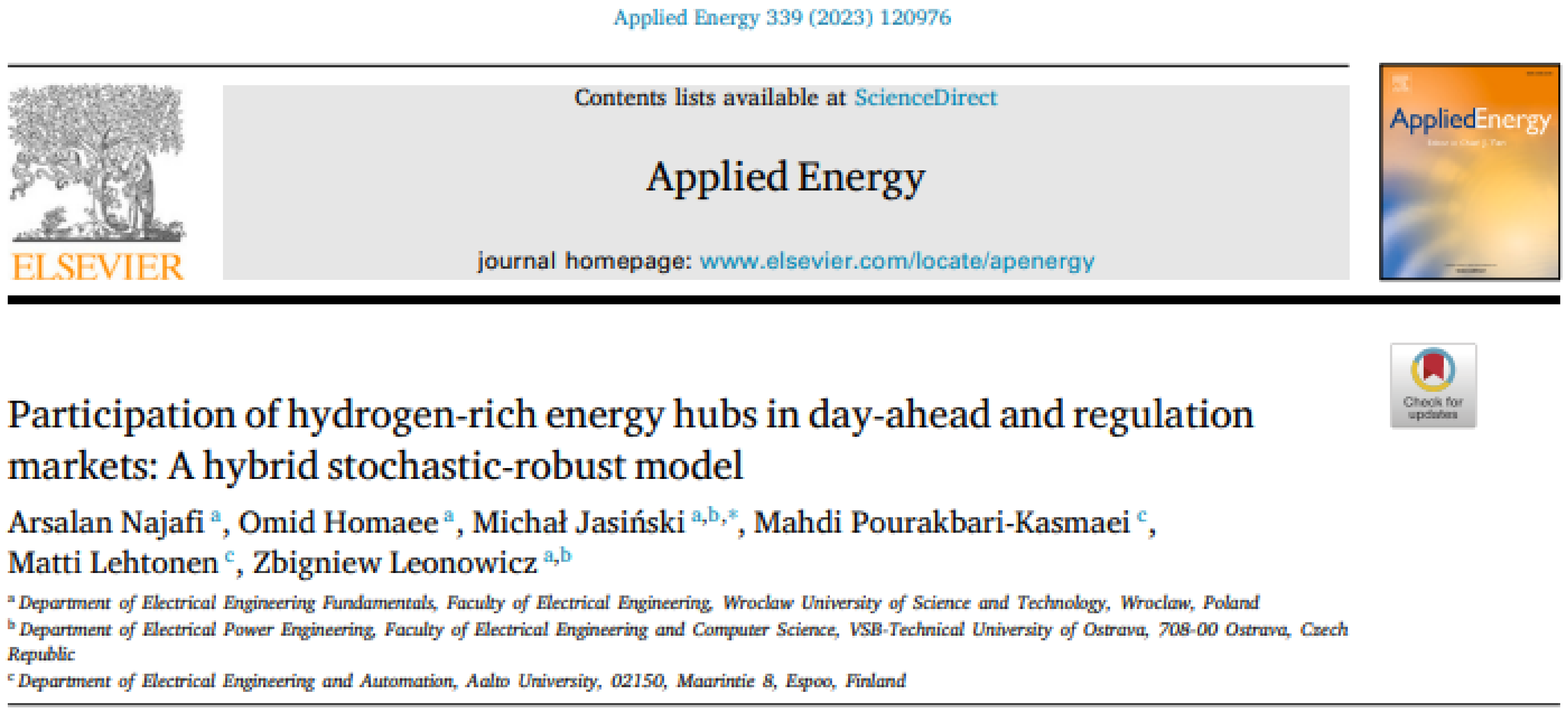
Research highlights


Applied Energy 339 (2023) 120976

Contents lists available at ScienceDirect

Applied Energy

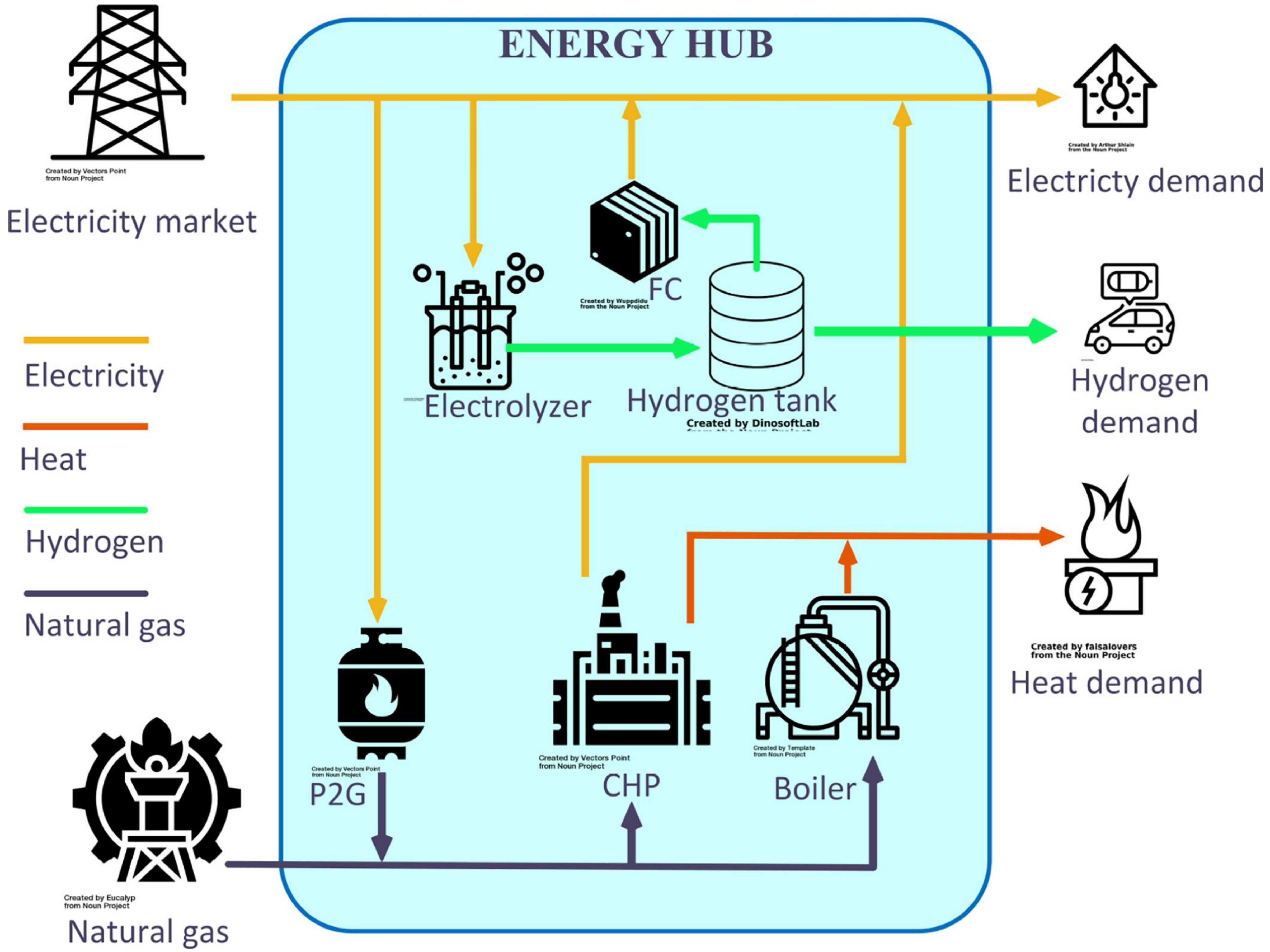
journal homepage: www.elsevier.com/locate/apenergy

Participation of hydrogen-rich energy hubs in day-ahead and regulation markets: A hybrid stochastic-robust model

Arsalan Najafi [a], Omid Homaee [a], Michał Jasiński [a,b,*], Mahdi Pourakbari-Kasmaei [c], Matti Lehtonen [c], Zbigniew Leonowicz [a,b]

[a] Department of Electrical Engineering Fundamentals, Faculty of Electrical Engineering, Wroclaw University of Science and Technology, Wroclaw, Poland
[b] Department of Electrical Power Engineering, Faculty of Electrical Engineering and Computer Science, VSB-Technical University of Ostrava, 708-00 Ostrava, Czech Republic
[c] Department of Electrical Engineering and Automation, Aalto University, 02150, Maarintie 8, Espoo, Finland

- The decisions in the DA market change in RM by regulation up/down actions to compensate for the forecasting error of the DA electricity loads.
- The HT is charged using the hydrogen released by the electrolyzer to refuel the HVs. The HT charges mostly during reasonable pricing hours.
- The existence of the HT resulted in proper refueling of the HVs in DA and compensating for the errors in the RT horizon.
- Due to the increase in the FC production to compensate for the RT demands error, the RT discharge of the HT is always higher than or equal to the DA values.
- The P2G is fed by electricity, when the electricity prices are lower than gas prices, while the decisions may change, paying attention to the difference of the RM and DA prices.



CHP: Combined heat and power.
DA: Day-ahead market.
EH: Energy hub.
FC: Fuel cell.
HT: Hydrogen Tank
HRS: Hydrogen refueling station.

HV: Hydrogen Vehicle.
P2G: Power-to-gas.
RM: Regulation market.
RT: Real Time

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Research highlights

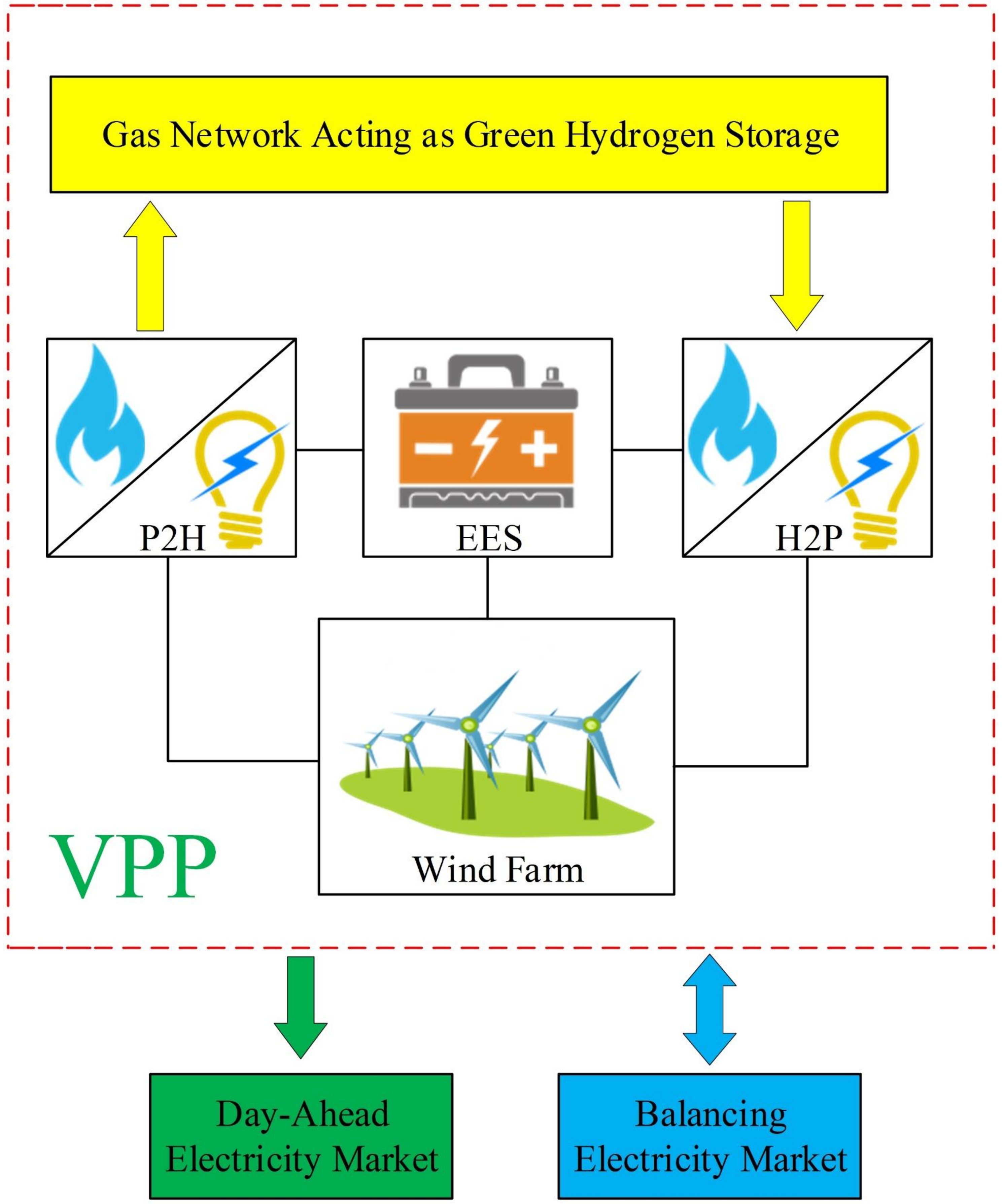
Wind Farm-based Green Hydrogen: A Virtual Power Plant Case Study

09/EEM54602.2022.9921061

Ramin Ahmadi Kordkheili, Mahdi Pourakbari-Kasmaei, Matti Lehtonen
Dept. Electrical Engineering and Automation
Aalto University
Espoo, Finland
ramin.ahmadikordkheili@aalto.fi, Mahdi.Pourakbari@aalto.fi, Matti.Lehtonen@aalto.fi

Reza Ahmadi Kordkheili
Dept. Systems and Maintenance Engineering
Vattenfall vindkraft A/S
Kolding, Denmark
reza.ahmadikordkheili@vattenfall.com

- The paper studied the planning-operation actions of a real wind farm (Capacity: 700 MW).
- Considering **Gas/H2 network as Virtual Clean-H2 storage** resulted in increasing the profit of Wind Farm by about 2,3 M€/year.



P2H: Power-to-hydrogen
H2P: Hydrogen-to-power
EES: Electrical energy storage

Research highlights

Optimal Sizing of a Wind-PV Grid-Connected Hybrid System for Base Load– Helsinki Case

Amin Moghimy Fam, Matti Lehtonen, Mahdi Pourakbari-Kasmaei
Dept. Electrical Engineering and Automation
Aalto University
Espoo, Finland
amin.moghimyfam@aalto.fi, matti.lehtonen@aalto.fi, Mahdi.Pourakbari@aalto.fi

Mahmud Fotuhi-Firuzabad
Dept. Electrical Engineering
Sharif University of Technology
Tehran, Iran
fotuhi@sharif.edu

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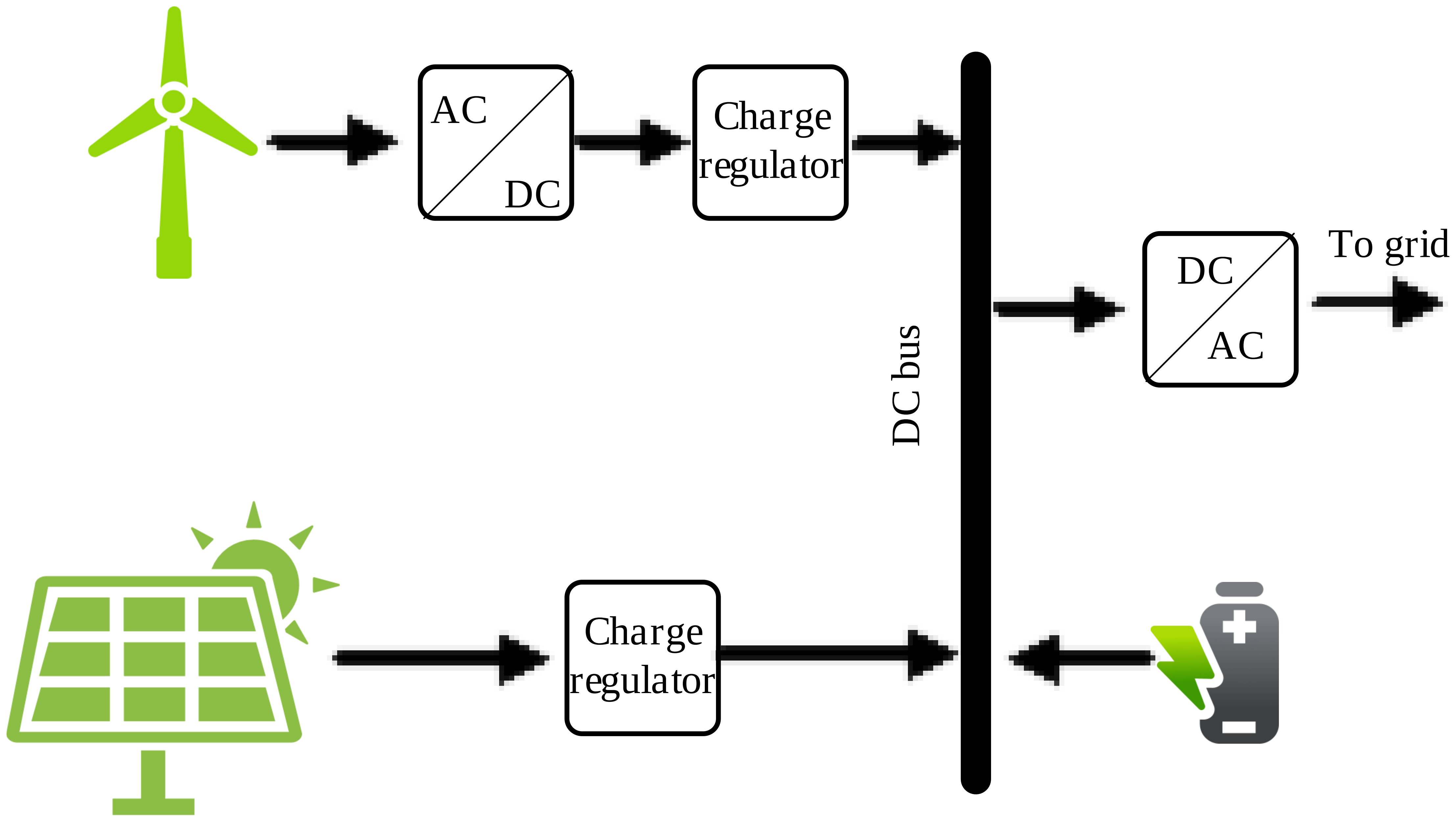


- This paper mainly studied the feasibility of using Hybrid Renewable Energy Systems consisting of both PV panels and wind turbines in Finland.
- Results show that even in Finland with a small amount of solar irradiation, considering **PV decreases the investment cost required to supply the base load by roughly 91% than considering wind power alone**!
- Furthermore, the size of the storage shows that clean H2 is one of the few options to make carbon neutrality possible. (to be studied in more detail)

Research highlights

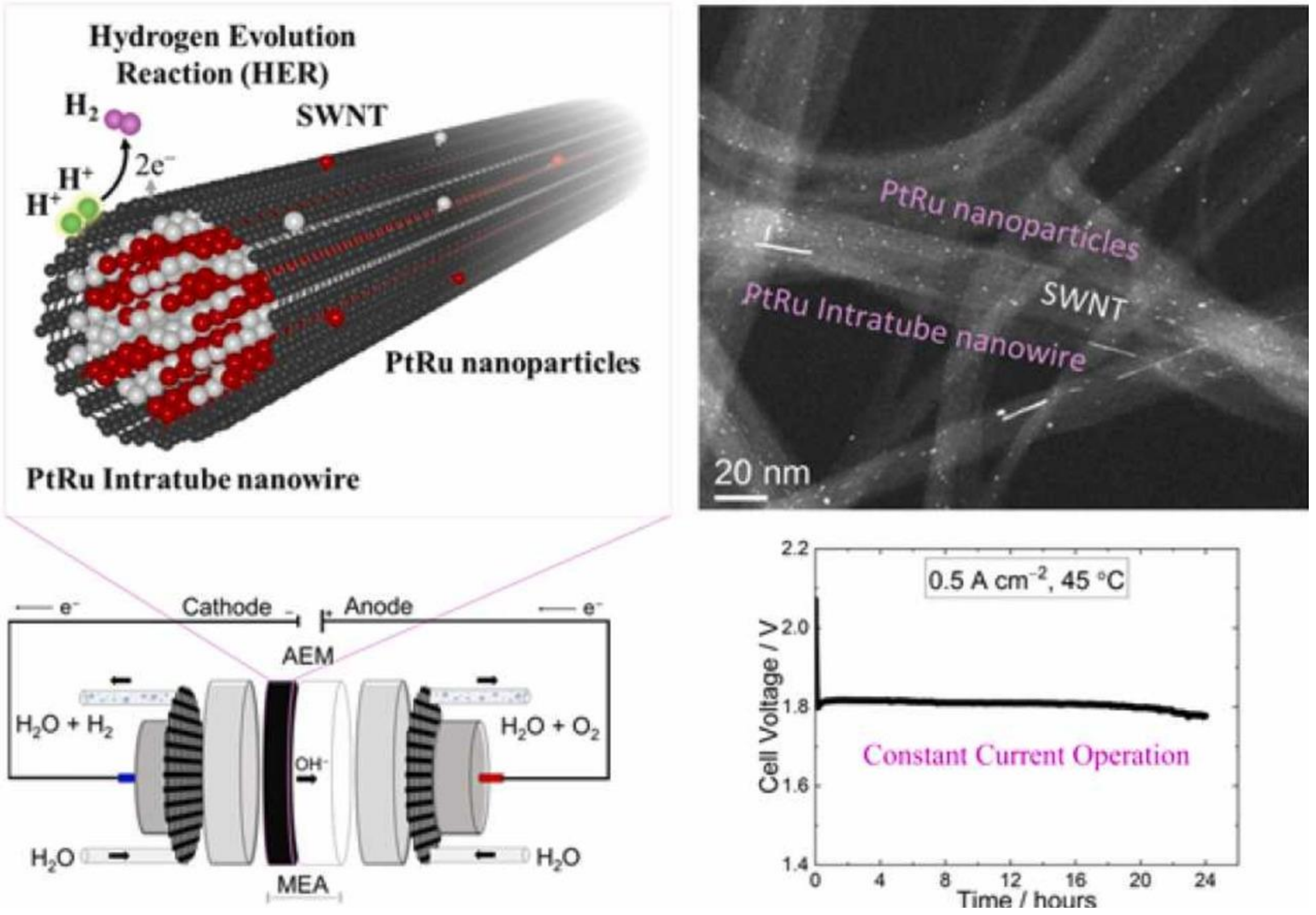
ELSEVIER

Applied Catalysis B: Environmental

Volume 315, 15 October 2022, 121541

Hydrogen evolution in alkaline medium on intratube and surface decorated PtRu catalyst

Farhan S.M. Ali [a], Ryan Lacdao Arevalo [b], Matthias Vandichel [b], Florian Speck [c], Eeva-Leena Rautama [a], Hua Jiang [d], Olli Sorsa [a], Kimmo Mustonen [e], Serhiy Cherevko [c], Tanja Kallio [a]



Abstract

For anion exchange membrane (AEM) electrolysis, challenges include finding an optimal catalyst for hydrogen evolution reaction (HER), as the noble metals are scarce while non-noble metals are inferior. Here, the noble metal amount is reduced in a straightforward solution synthesis which produces Pt-Ru surface nanoparticles and unique intratube nanowires decorated on single walled carbon nanotubes (SWNT). In half-cell tests, 5 wt_{PtRu}-% Pt-Ru SWNT demonstrates stable 10 mA cm^{-2} HER current at 46 mV overpotential and outperforms commercial electrocatalysts. When integrated in an AEM electrolyser, a high current density of 500 mA cm^{-2} at a low voltage of 1.72 V is achieved with 34 µg cm^{-2} metal loading. First-principles calculations reveal that both the Pt-Ru alloy nanoparticle and intratube nanowires promote near optimal H* binding energy, thereby releasing the H_2 faster. Thus, our approach yields an active low metal loading alkaline HER catalyst without sacrificing the performance in an AEM electrolyser.

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Utilization of hydrogen and its derivatives in energy field.

Background

- We should first prioritize use of H_2 in sectors that are not possible to decarbonize in any other way, such as metallurgy, chemical industry, aviation.
- In energy sector we can use H_2 as energy storage medium as such or convert it to methane, methanol, ammonia… to reduce volume and then use these with heat engines based on combustion or by fuel cell.
- Even $H_2 + 0.5\ O_2 = H_2O$, the actual reaction mechanism is very complex, and if air is used, there can be significant thermal nitrogen oxides formation issues.

Comment | Published: 05 October 2022

Using ammonia as a shipping fuel could disturb the nitrogen cycle

Paul Wolfram, Page Kyle, Xin Zhang, Savvas Gkantonas & Steven Smith

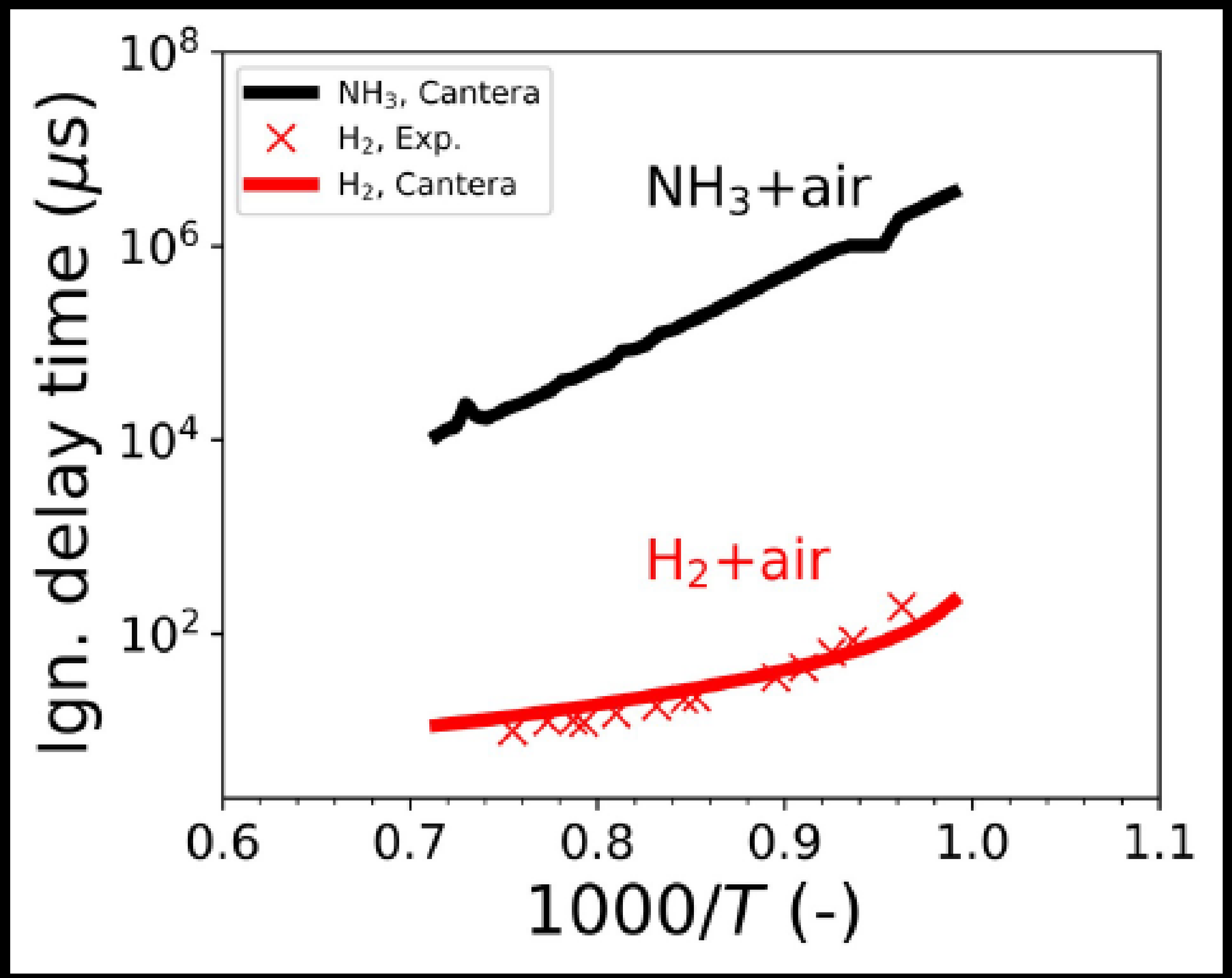
Nature Energy **7**, 1112–1114 (2022) | Cite this article

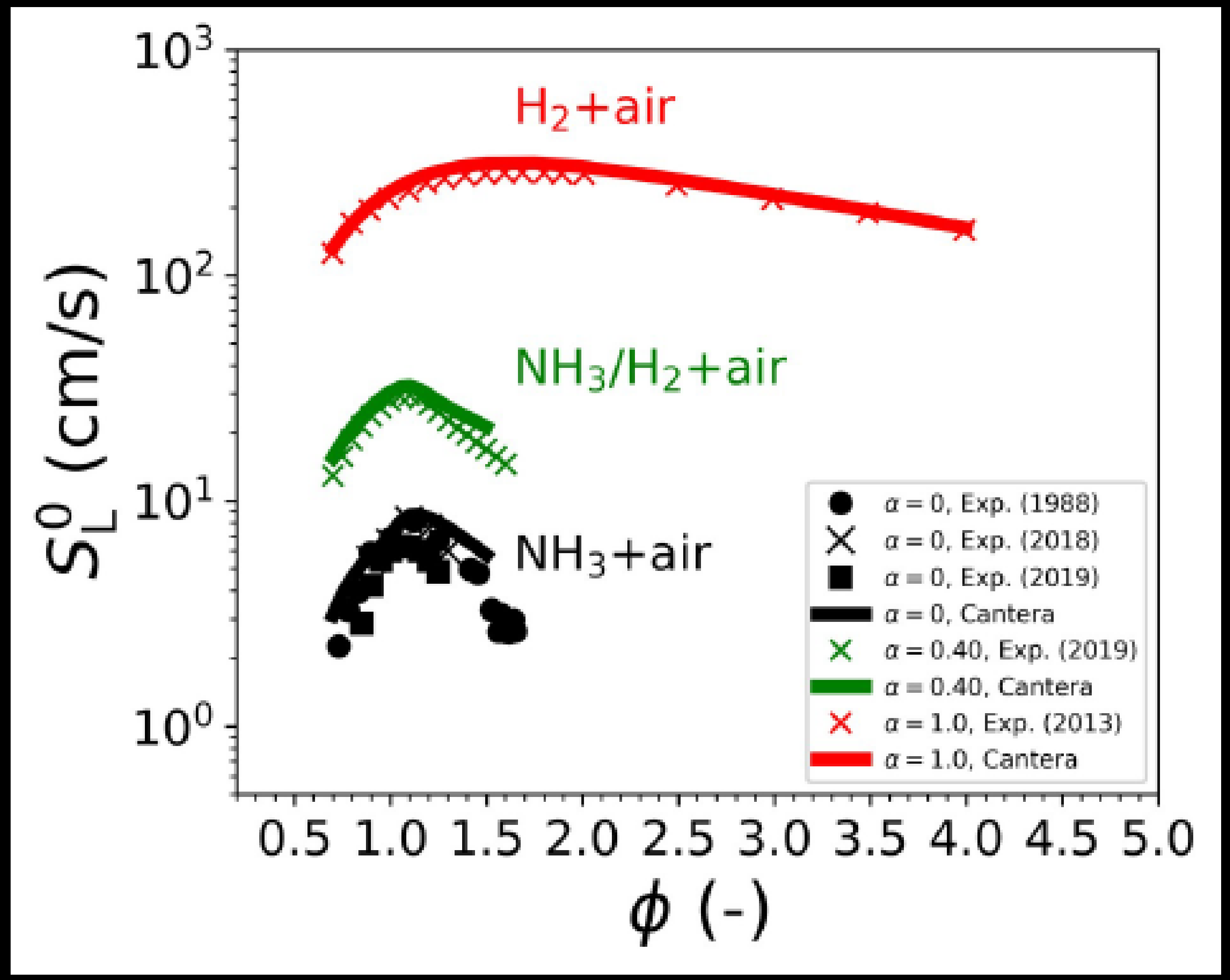
[just 0.4% of ammonia converting into N_2O (GWP_{N2O}=273) may negate climate benefits of green ammonia ...]

- **Another problem is the slip of gases due to incomplete combustion, CH_4, H_2 are much worse GHGs than CO_2!**
- **Research and development for these new sustainable combustion technologies is in the core of our research.**

Research highlights

Different fuels – including green fuels – may have very different burning characteristics (ignition time and flame speed) affecting combustion dynamics strongly. Hydrogen is a very different fuel than what we are used to. Retrofitting, optimization, combustion research needed!





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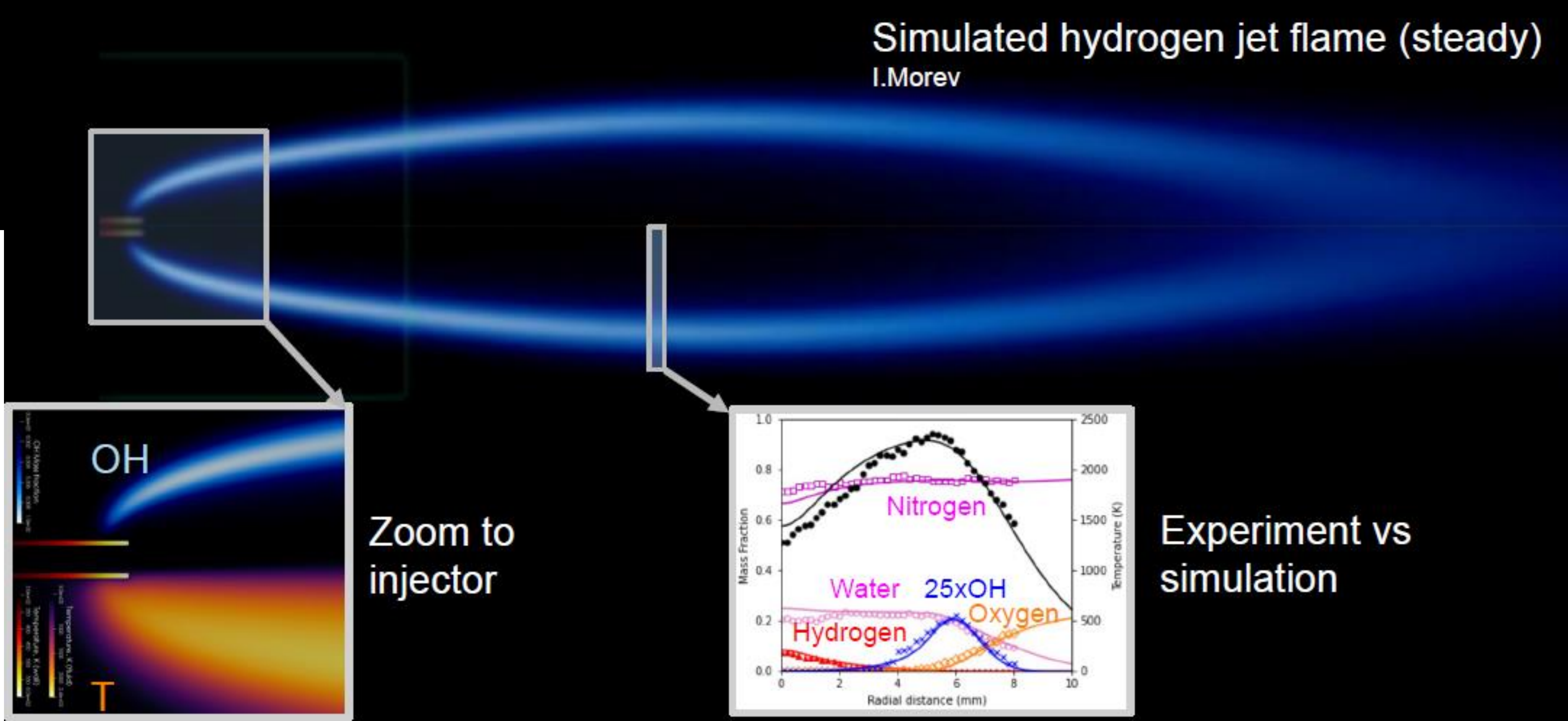
Courtesy: P.Tamadonfar

Results from prof. Ville Vuorinen's group

3D flame structure essential (e.g. flame stability)



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Education highlights

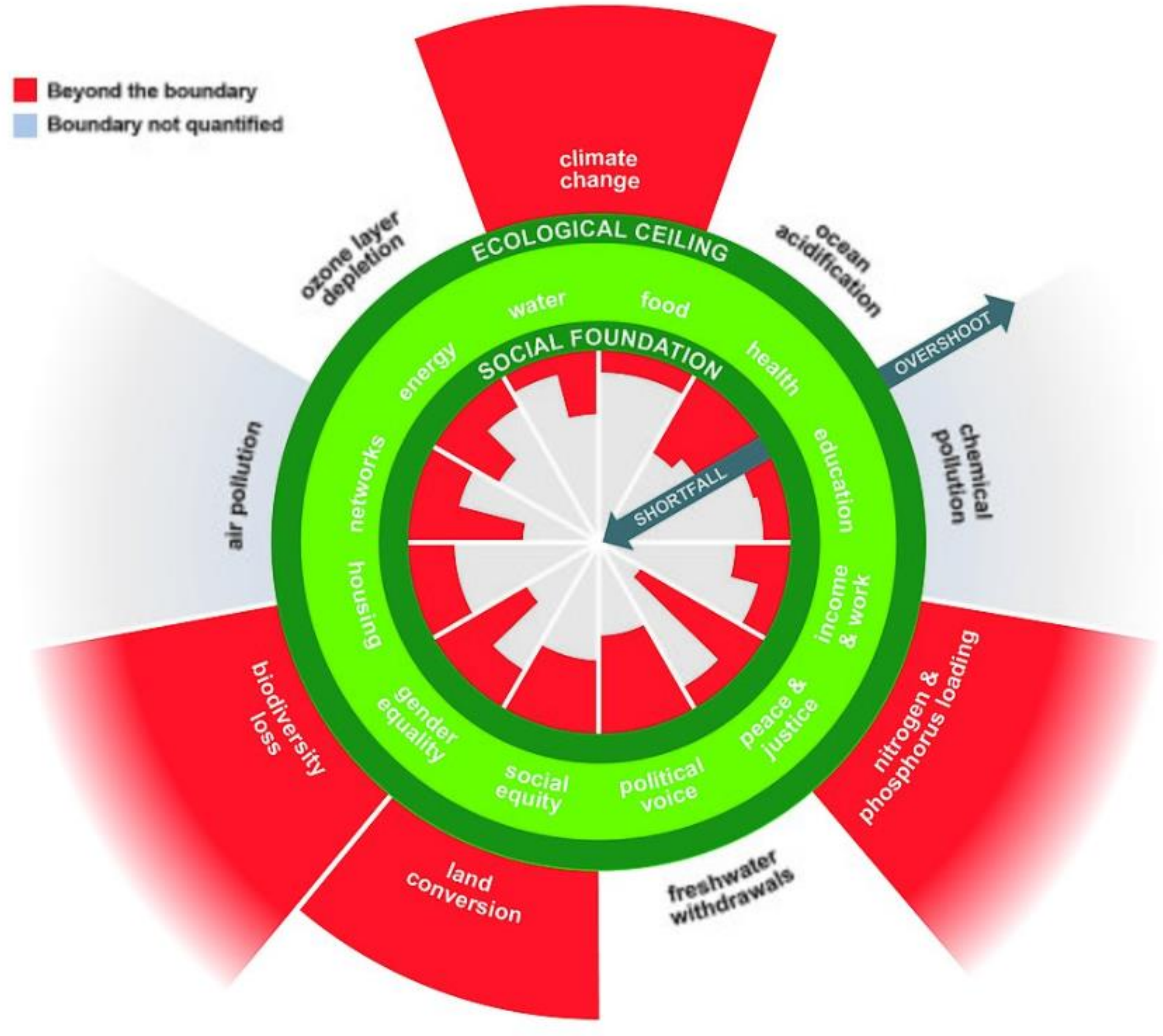
Designing energy systems within planetary boundaries - New textbook for game changers of energy transition

SPRINGER NATURE

A! Aalto University School of Engineering

TAH TIINA AND ANTTI HERLIN FOUNDATION

Mika Järvinen and Hanna Paulomäki



Mika Järvinen
mika.jarvinen@aalto.fi
+358 50 414 2593