D4.4 Final report on common research needs & key results

WP4: Networked hydrogen activities

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Summary

- Project results and research questions from research partners
  - Main findings of the work packages collected, as well as research questions for future work identified
- Hydrogen economy SWOT analysis for Finland
  - Main strengths for Finland were identified to be low-cost electricity from a reliable power grid, and Finnish society as a whole (public, private, governance). Main weaknesses were seen in distant location, limitations in funding and approval processes, and competences in electrolysis and hydrogen transport. Power-to-X was identified as a major opportunity for Finland.
- Hydrogen value chains in FinH_2 and literature
  - Collection of hydrogen value chains from literature and presenting the value chain for electrolytic hydrogen developed in the project
- Company survey to find out Finnish companies in hydrogen business
  - Results from the company survey: Finnish strenghts, gaps, actors and research questions identified
- Lessons learnt from hydrogen piloting projects
  - Valuable lessons from European hydrogen projects collected. Unfavorable regulatory environment and higher then expected costs have been identified as reasons for cancellations of projects, whereas there are many good practices to learn from.
- Support and financing mechanisms in Finland for hydrogen projects
  - Hydrogen networks listed and main financing options collected for hydrogen projects in Finland, divided by the technology readiness level of the project

Contents

Objectives & actions of the work package

Objective	Actions
To create a networked research infrastructure	➢ Finnish value chain for electrolytic H_2 defined ➢ H_2 research and innovation activities and infrastructure updated for VTT, LUT, Aalto University ➢ Could Hydrogen Research Forum Finland create and update a database of Finnish hydrogen research and infrastructure?
To understand the common research needs for different electrolyser applications	➢ Company surveys ➢ Lessons learnt from European piloting projects
To have an active role in European network and future projects	➢ Active reporting of events and possible project opportunities for project members
To help Finnish companies and research partners get involved in different EU-funded research and demonstration projects with more than 10 M€ funding for Finnish partners.	➢ Gathering information about funding opportunities

Project results and research questions from research partners (Aalto, VTT, LUT)

$FinH_2$: Inventory of project results

Aalto University
School of Chemical Engineering

Result/innovation (shortly)	Novelty	IPR status	Potential customers	Open research questions
Nobel metal free electrocatalyst for oxygen evolution reaction (OER) in proton exchange membrane electrolysers (PEMEL).	The material shows stable cycling for OER without the usage of precious metals (Ir or Ru) at 25°C and in a lab-scale PEM electrolyser for ~100 h at 50°C.	An innovation disclosure has been submitted to Aalto University. The inventors of the innovation are Moritz Karl Rosenthal and Tanja Kallio.	Potential customers are electrocatalysts manufactures, companies fabricating electrolysers with an OER anode.	1. What is the reason for the relatively high activity and durability? 2. How to enhance the stability of the material at elevated temperatures. 3. How can the intrinsic activity of the material be increased to be more competitive (onset, current).

FinH$_2$: inventory of project results
- 50 kW PEM

VTT

Result/innovation (shortly)	IPR status	Potential customers	Open research questions
PEM electrolysis system, structure, control, safety, interfaces	Invention disclosures	Hydrogen producers	Stack lifetime, optimal ways of operating, problems during operation
Integration of heat pump to PEM electrolysis system	No invention disclosures yet	Electrolyser manufacturers, end users	Efficiency, operating together with PEM system
Stacks connected in series in PEM electrolysis system	No invention disclosures yet	System manufacturers	The effect of high voltage to insulation

FinH2

$FinH_2$: inventory of project results

Result/innovation (shortly)	Novelty	Potential customers	Open research questions
Developed lab scale test rig for pressurized PEM electrolysis stack characterization	Capabilities for pressurized PEM electolysis operations and stack characterization	PEM electrolysis stack manufacturers, Companies that are interested in hydrogen production	How does electrolysis operating point affect on stack (short and long term) performance. How does operating pressure affect on: stack performance, crossover leakages. Differences in stack performance between dynamic and static operation. How does reactant water purity affect on long term performance.
Know how on pressurized low temperature electrolysis system engineering	Gained knowledge	PEM electrolysis stack manufacturers, Companies that are interested in hydrogen production	
Know how on safety protocols and regulations	Gained knowledge	PEM electrolysis stack manufacturers, Companies that are interested in hydrogen production	
Know how on high pressure hydrogen applications	Gained knowledge	PEM electrolysis stack manufacturers, Companies that are interested in hydrogen production	

FinH$_2$: inventory of project results - WP3

VTT

Result/innovation (shortly)	Novelty	Potential customers	Open research questions
Mapping of hydrogen-related regulation within the EU	Thorough inspection of H2 connected regulation crucial for industry and investments	Industry partners, jointly funded projects	How do regulations contribute to the formation of a hydrogen economy? What kind of barriers do regulations impose on hydrogen economy?
Regulation-based future RFNBO + CO2 market analysis	Market analysis of H2 and CO2 need for future e-fuels based on latest regulation	Industry partners, jointly funded projects	How do regulations affect the renewable fuel markets in Europe?

FinH2

$FinH_2$: inventory of project results

LUT University

Result/innovation (shortly)	Novelty	IPR status	Potential customers	Open research questions
Effect of process conditions on the energy efficiency and control of a megawatt-scale alkaline water electrolyzer (AWE).	Energy savings potential achievable by process control.		Green hydrogen plants, electrolyzer manufacturers, hydrogen end users, decision makers.	Experimental verification for results of modeling different electrolyte flow rates?
Stray currents are a significant energy loss in pressurized AWEs.	Understanding of the importance of stray currents. Publication of the real energy consumption of a typical pressurized megawatt-scale system.		Green hydrogen plants, electrolyzer manufacturers, hydrogen end users, decision makers.	Stray currents in state-of-the-art pressurized systems?
The effect of pressurization in the design of AWEs.	Pressurization and - stray currents - stack cooling - gas impurities and safe control range.		Green hydrogen plants, electrolyzer manufacturers, hydrogen end users, decision makers.	Limiting stray currents in pressurized AWE systems.
AWE substacking	Stray current reduction in high voltage systems	Patent application	Stack manufacturers	Optimal cell number in substacks

Publications:
[1] *Sensitivity analysis of the process conditions affecting the shunt currents and the SEC in an industrial-scale alkaline water electrolyzer plant*
[2] *Influence of shunt currents in industrial-scale alkaline water electrolyzer plants*
[3] *Dynamic Mass- and Energy-Balance Simulation Model of an Industrial-Scale Atmospheric Alkaline Water Electrolyzer* (under review in Applied Energy)

$FinH_2$

Hydrogen economy SWOT analysis for Finland

SWOT analysis of Finnish H_2 possibilities

VTT

The information has been gathered from:

- Hydrogen Cluster Finland, 2021. White paper – A systemic view to the Finnish Hydrogen economy
- Sivill et al., AFRY Management Consulting Oy, 2022. Vetytalous – mahdollisuudet ja rajoitteet and
- Discussions with experts in the field.

Strenghts

- Availability of reliable, low-cost, clean electricity (especially wind power)
- Resilient power distribution and transmission infrastructure and modern power grid
- High-tech society with good expertise and educated talent pool
- Public-private collaboration
- Abundant clean fresh water resources
- Existing fuel production
- Finnish industry committed to climate actions
- Geographic location of Finland and good governance

Weaknesses

- Lack of key competences, e.g. electrolysis
- Lack of shared vision on society's role in hydrogen economy and its implementation
- Distant location (need to develop high value-added solutions and P2X products that are more cost-efficient to export)
- Small country with limited public funding
- Approval processes and resources
- Not enough experience of hydrogen use in transport or of hydrogen production upscaling
- Renewable power production might face interference with defense surveillance radar systems (possible issue in Eastern Finland)

Opportunities

- Investments in monitoring and control → measuring renewability and emissions
- Sector coupling enables integration of industries (e.g., grid balancing, waste heat utilization especially as district heat) and creates flexibility & energy storages
- Abundant sources of condensed, biogenic CO_2 (e.g., from flue gases) that can be coupled with hydrogen to produce carbon-neutral products
- Combining different parts of H_2 value chain, e.g. IT or AI based optimization or project management skills
- Power-to-X for higher value products (also for export)

Threats

- Not fully optimizing the value of H_2 by-products and job creation
- Low price of fossil fuels and carbon dioxide
- The price of hydrogen technology too high
- Slow upscaling of electrolyser technologies
- Not making Finland attractive location for (foreign) private investments
- Not incorporating H_2 opportunities into long-term development plans of national and local energy transmission and distribution grids
- Lack of regulations (e.g., city planning, feed-in tariffs) and monitoring for negative impacts
- Long-term sufficiency & durability of materials

Hydrogen value chains in FinH$_2$ and literature

Finnish value chain for electrolytic H_2 defined in FinH_2 project

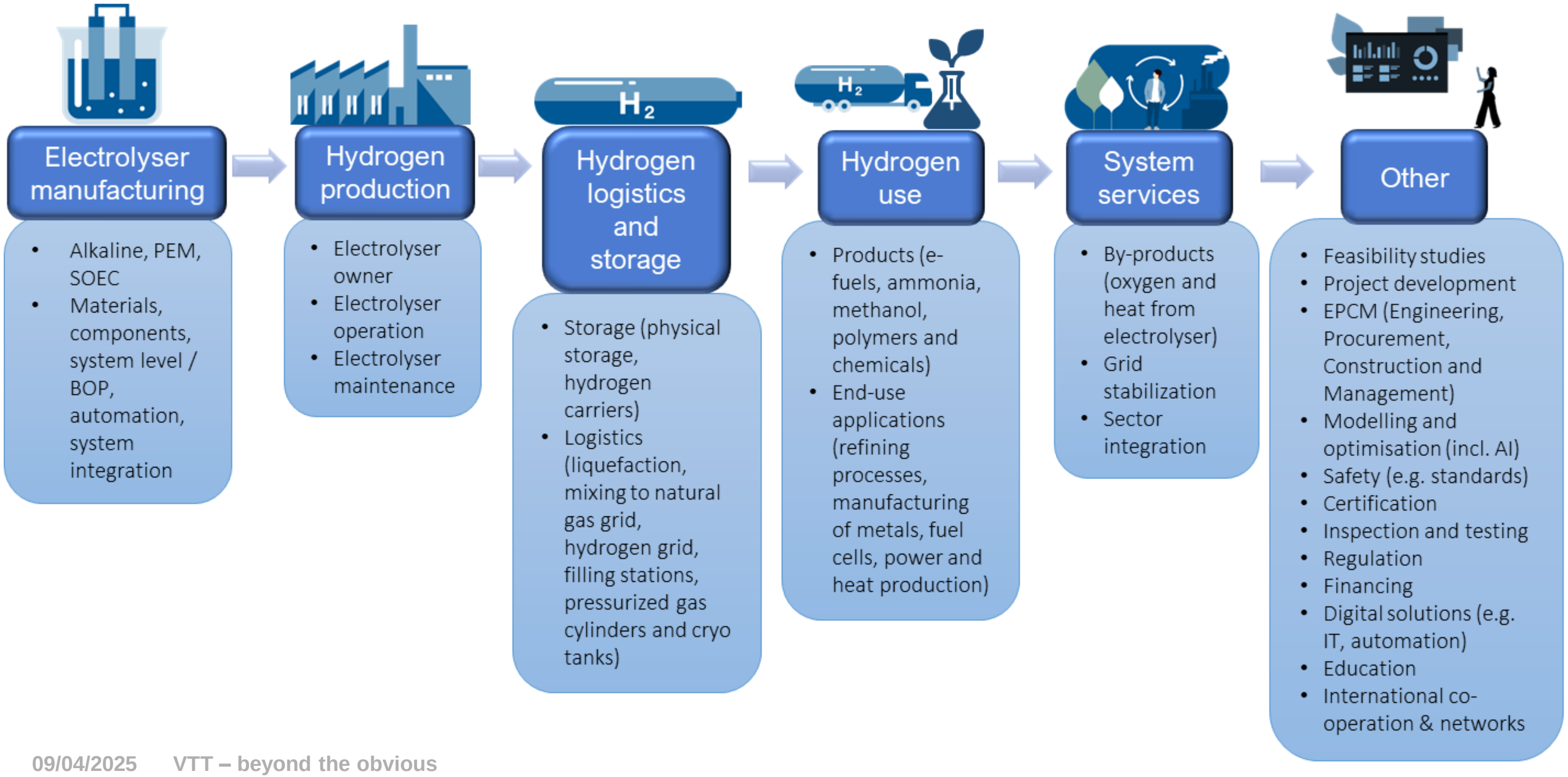
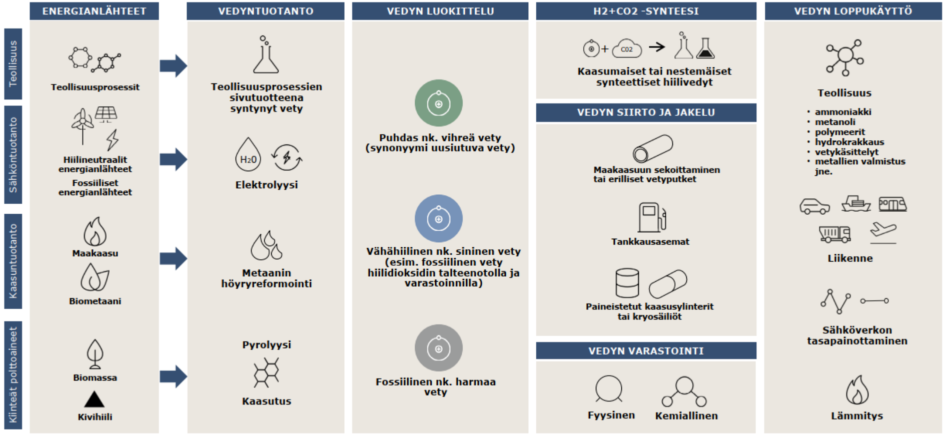


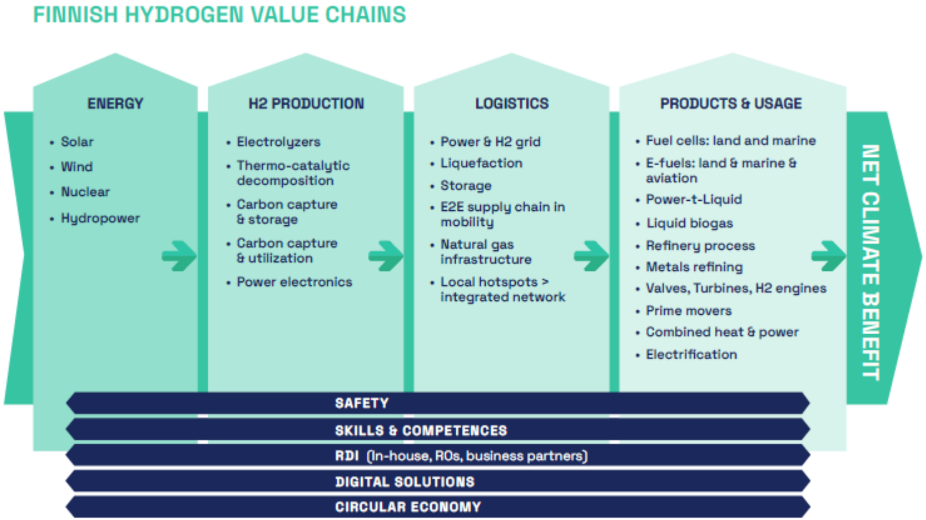
Figure: VTT

Finnish value chain for electrolytic H_2 in literature



[Sivill et al., 2022. Vetytalous – mahdollisuudet ja rajoitteet]

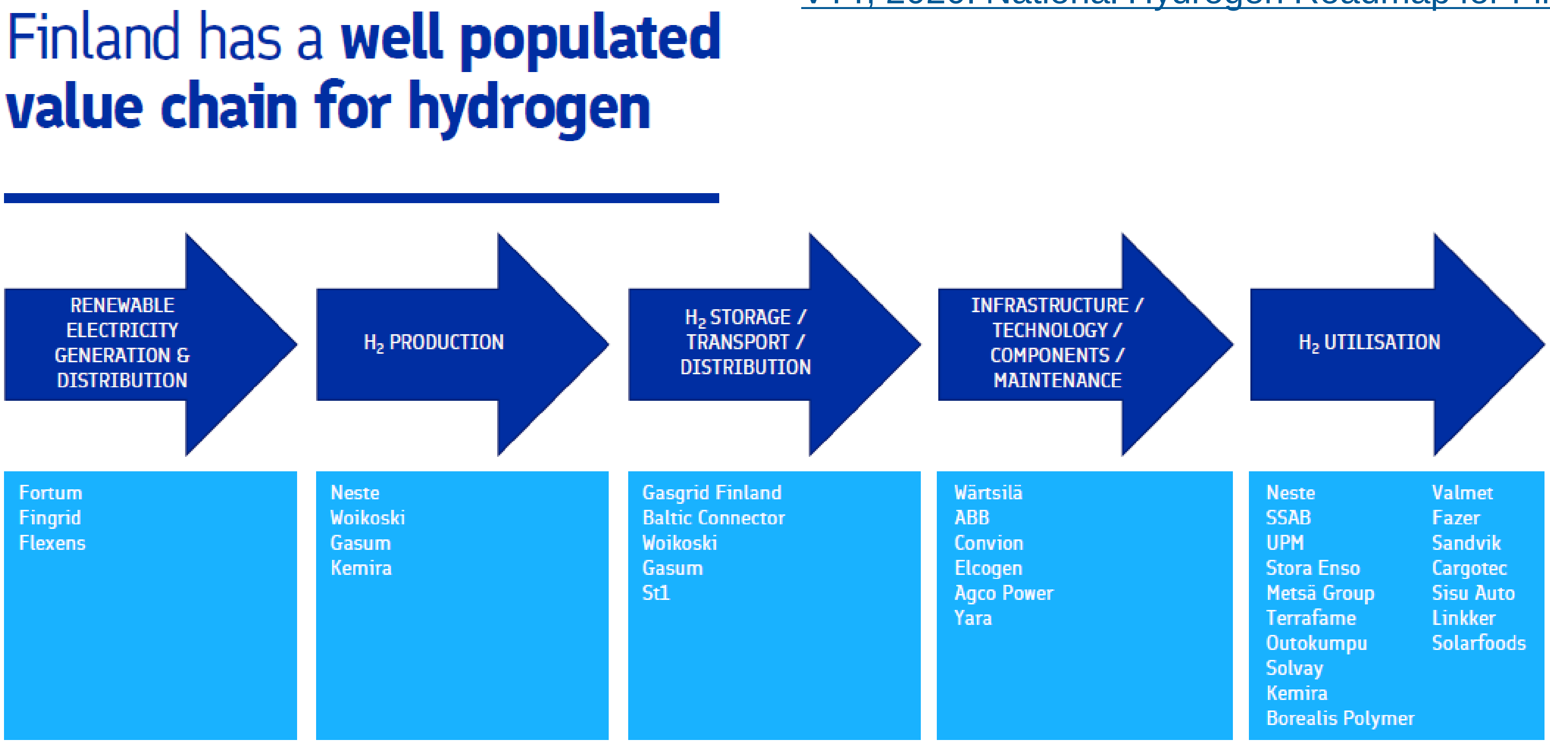
[Hydrogen Cluster Finland, 2021. A systemic view on the Finnish hydrogen economy today and in 2030 – Our common playbook for the way forward]



Finnish value chain for electrolytic H_2 in literature

VTT

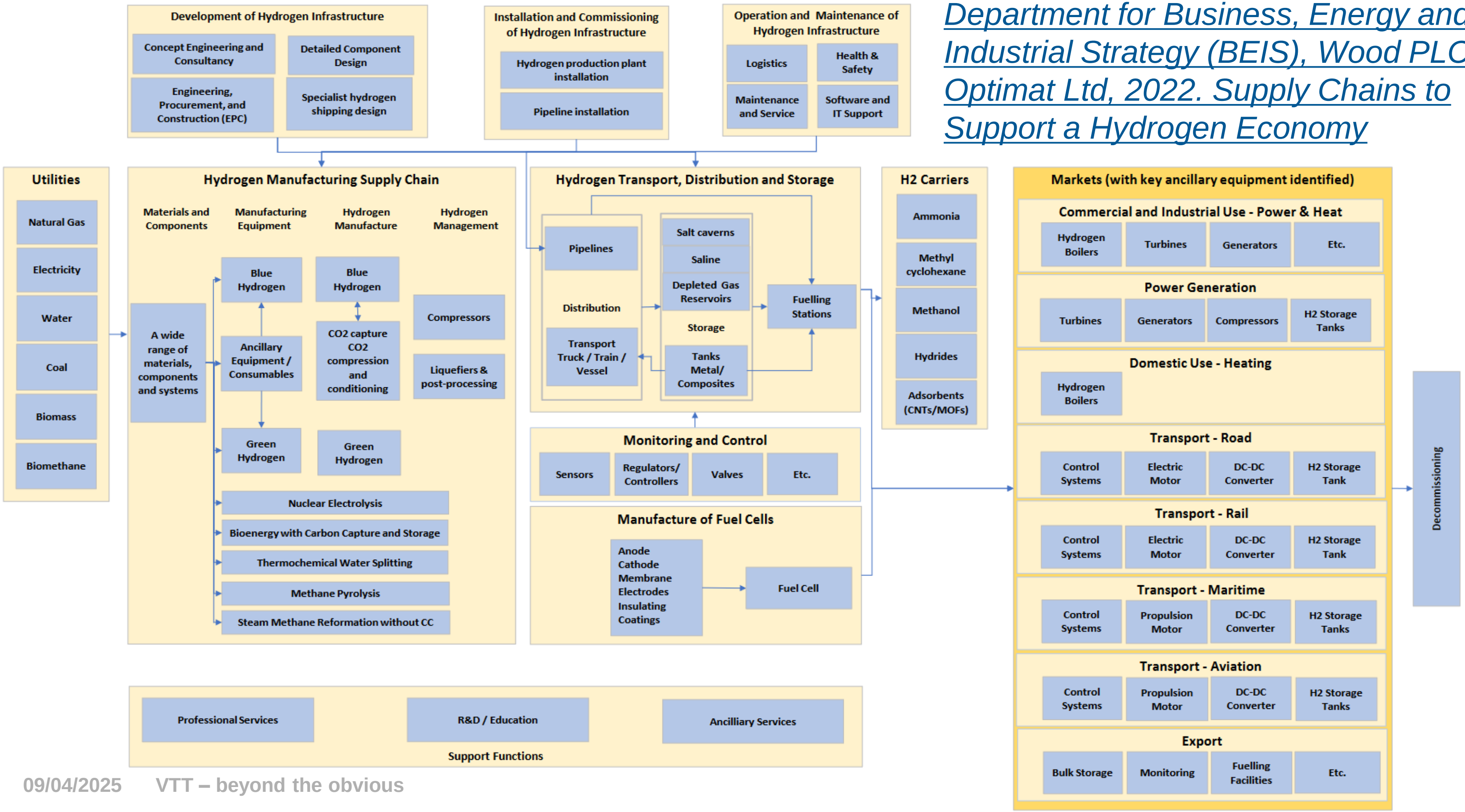
[VTT, 2020. National Hydrogen Roadmap for Finland]



Supply chain framework of H_2 economy

VTT

[Department for Business, Energy and Industrial Strategy (BEIS), Wood PLC & Optimat Ltd, 2022. Supply Chains to Support a Hydrogen Economy]



Company survey to find out Finnish companies in hydrogen business

Company survey to map the Finnish value chain for electrolytic H_2

- Survey was conducted between November 2022 - March 2023
- The objective was to create a picture of the Finnish value chain for electrolyser technology
- 35 answers from 32 companies were received


FinH2 - Company survey

Welcome to answer the survey of FinH2 project!

Choose Next on the bottom of this page to begin answering the questions. Answering the survey takes less than 10 minutes.

FinH2 project significantly improves Finland's know-how and competitiveness in electrolysis and hydrogen technology and creates a networked research infrastructure. The website for the project can be found here: www.finh2.fi

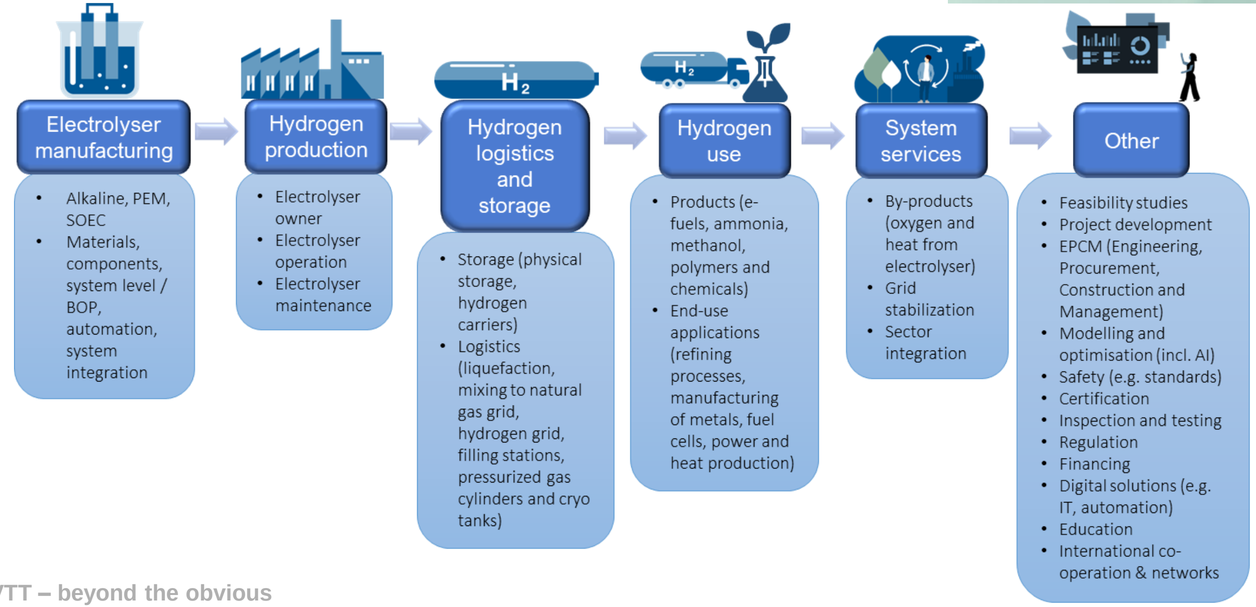


Figure: VTT

Electrolyser components listed & illustrated with the help of other work packages

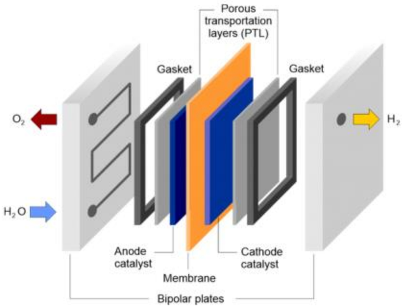
https://www.finh2.fi/electrolyser-technologies/

PEM electrolysis

PEM electrolysis has become commercial in the recent years, with the benefit of producing high purity hydrogen with rapid power ramp rates and wide power range. Furthermore, it has a compact design. The challenges of the technology are currently the higher cost compared to alkaline electrolysis and the need for noble metal catalysts. FinH$_2$ project increases know-how and experience on PEM electrolyser technology by designing, building, and demonstrating a PEM electrolyser system optimised for sector coupling. Furthermore, an iridium-free catalyst will be developed to overcome the barrier of shortage of suitable catalyst materials.

PEM electrolysis stack (most common) materials

- Proton exchange membrane: Nafion®
- Electrode catalysts:
  - Anode catalyst: iridium oxide (IrO_2)
  - Cathode catalyst: platinum (Pt)
- PTL, porous transportation layers:
  - Anode: titanium (Ti)
  - Cathode: carbon paper (C), titanium (Ti)
- Bipolar plates:
  - Anode: titanium (+ platinum coating)
  - Cathode: titanium (+ gold coating)



PEM electrolyser system components

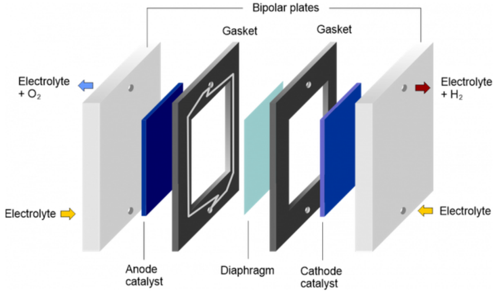
- Stack
- Anode side: water purification unit, water circulation pump, ion exchange filters, heat exchanger, O_2/H_2O separation unit
- Cathode side: H_2/H_2O separation unit, O_2 removal unit from product hydrogen, drying unit
- Power electronics (grid electricity à DC)
- Automation system

Alkaline electrolysis

Alkaline electrolysis is a well-known and mature technology for green hydrogen production. It requires less scarce raw materials with a relatively simple construction. Cost reductions and technology development can be achieved by e.g., increasing the operating temperature of the electrolyser to 130-150 ºC.

Alkaline electrolysis stack (most common) materials

- Diaphragm: ZIRFON
- Electrolyte: potassium hydroxide (KOH)
- Electrode catalysts: nickel mesh
- Bipolar plates: nickel-coated stainless steel



Alkaline electrolyser system components

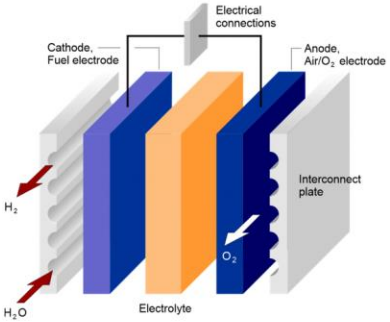
- Stack
- O_2-liquid separator
- H_2-liquid separator
- Electrolyte pumps + heat exchangers
- H_2 purification system
- Water treatment system
- Power electronics + automation system

SOEC electrolysis

SOEC electrolysis has potential to have the highest electrical efficiency compared to other electrolyser technologies. However, the technology needs to be developed further, especially regarding lifetime and costs, to reach commercialisation.

SOEC electrolysis stack (most common) materials

- Electrolyte: YSZ
- Fuel electrode: Ni + YSZ
- Air/O_2 electrode: LSC, LSM, LSCF
- Interconnect plate: Crofer and other high-temperature ferritic stainless steels with protective coating
- Seals: glass, glass-ceramic, mica



SOEC electrolyser system components

- Stack
- Steam generator
- Air blower
- Fuel recycling pump
- Heat exchangers + condensers
- Supporting structures + piping (gas and stack max. temperature 700-800 °C)
- High temperature insulation materials
- Power electronics + automation system

Electrolyser BoP (Balance of Plant) in general:

- Power electronics (power source, converter AC-DC, rectifier) + automation system
- Water purification (ion-exchange, reverse osmosis, water-gas separator)
- Cooling system
- Pipes and mechanical structures
- Gas analysis equipment (gas chromatography, GC) is needed to monitor the quality and safety of the product gas. Oxygen removal unit and hydrogen dryer might be needed, depending on the application, and required hydrogen purity.
- Compressor (often needed to reach desired pressure)

Key conclusions from the company survey

Electrolyser manufacturing

Component providers available, but specific product requirements needed to develop the products.

Room for domestic stack/stack module manufacturers and system integrators.

Hydrogen production

Not many hydrogen producers yet.

Energy companies interested, but application and business model not yet defined.

H_2 logistics and storage

Limited experience from hydrogen grids and storing – but high interest, especially towards large-scale storage.

Hydrogen use

Many potential end-users identified.

Experience mainly from refining and chemical industry.

Interest in further processing of hydrogen into products and derivatives / P-t-X.

System services

Experience (optimization, data management, smart solutions) in e.g., balancing energy markets, heat recovery, and sector coupling can be expanded to hydrogen applications.

Other

Good base of EPCM companies, consultants and project developers.

Room for companies in safety issues, certification, testing, regulation, and financing.

Research needs raised in the questionnaire

”What research needs do you see related to hydrogen value chains?
In your opinion, what do we not know enough about?”

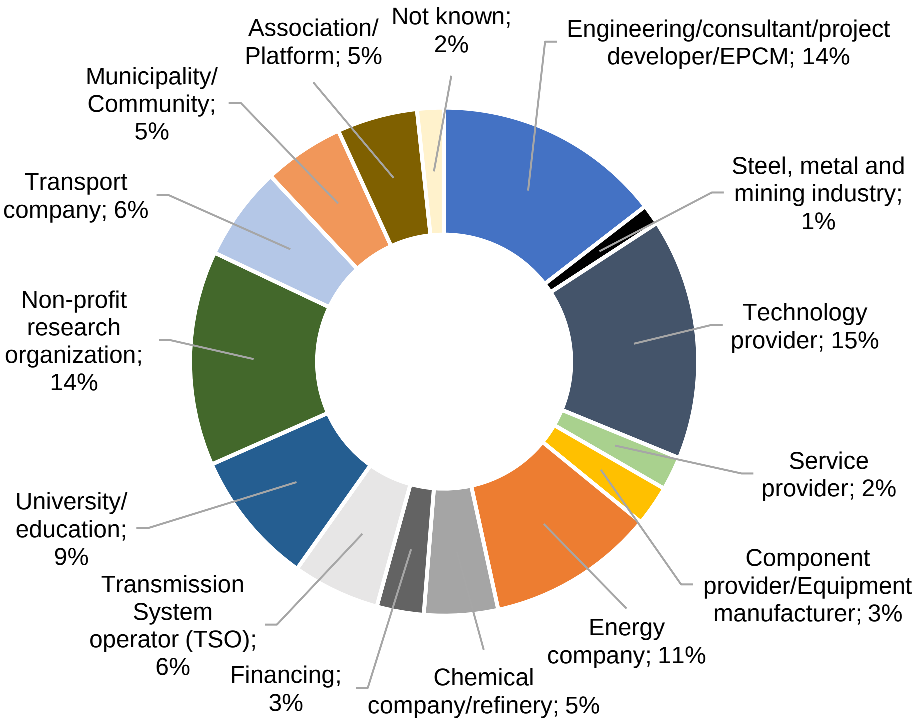
Lessons learnt from hydrogen piloting projects

International Energy Agency (IEA) database used to find piloting projects

Countries	EU countries
Date online	2018 → 2023
Status	Operational
Technology	ALK, PEM, SOEC
Electricity	Renewable
Capacity	>0.1 MW_{el}
Count of projects	58

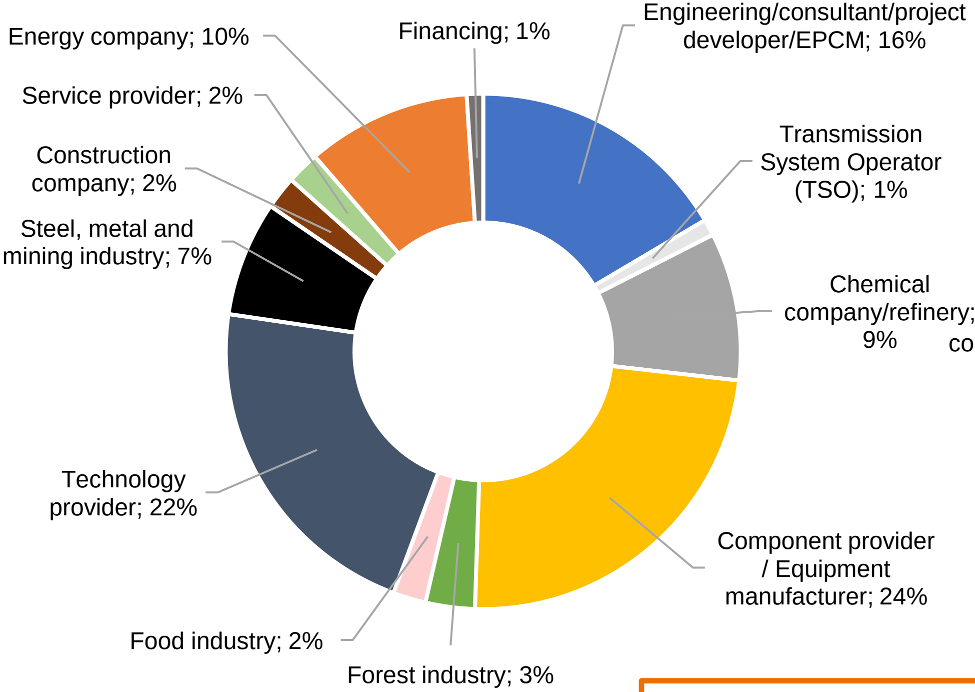
[Link to IEA database]

Hydrogen actors identified from IEA database's hydrogen projects with capacity >0.1 MW_{el}

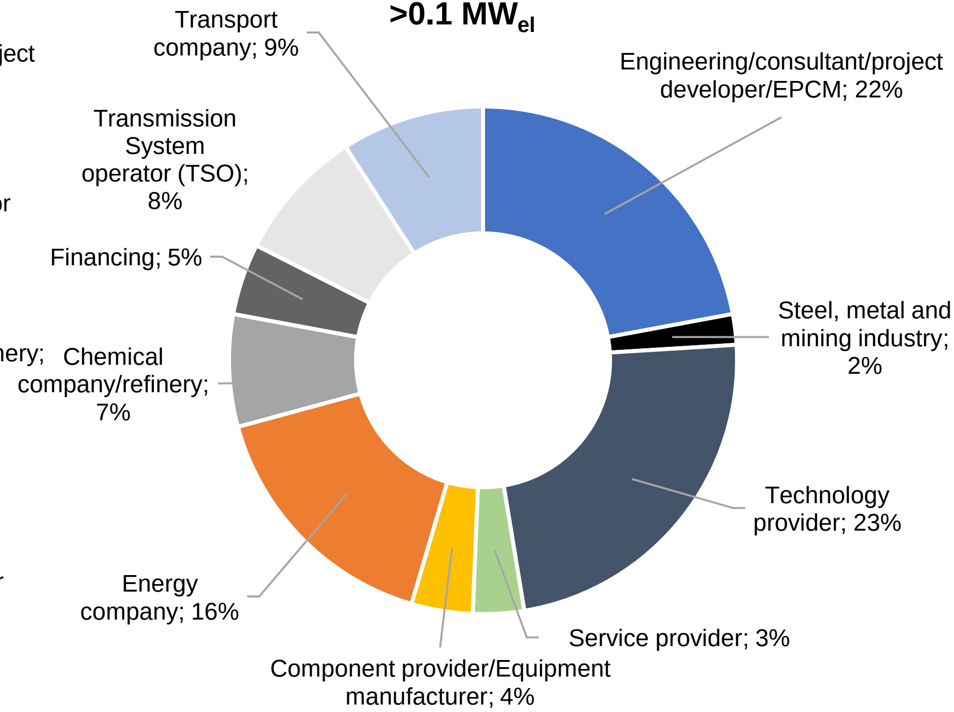


Companies in hydrogen business

Existing and potential Finnish hydrogen companies (FinH_2 company survey and public references)

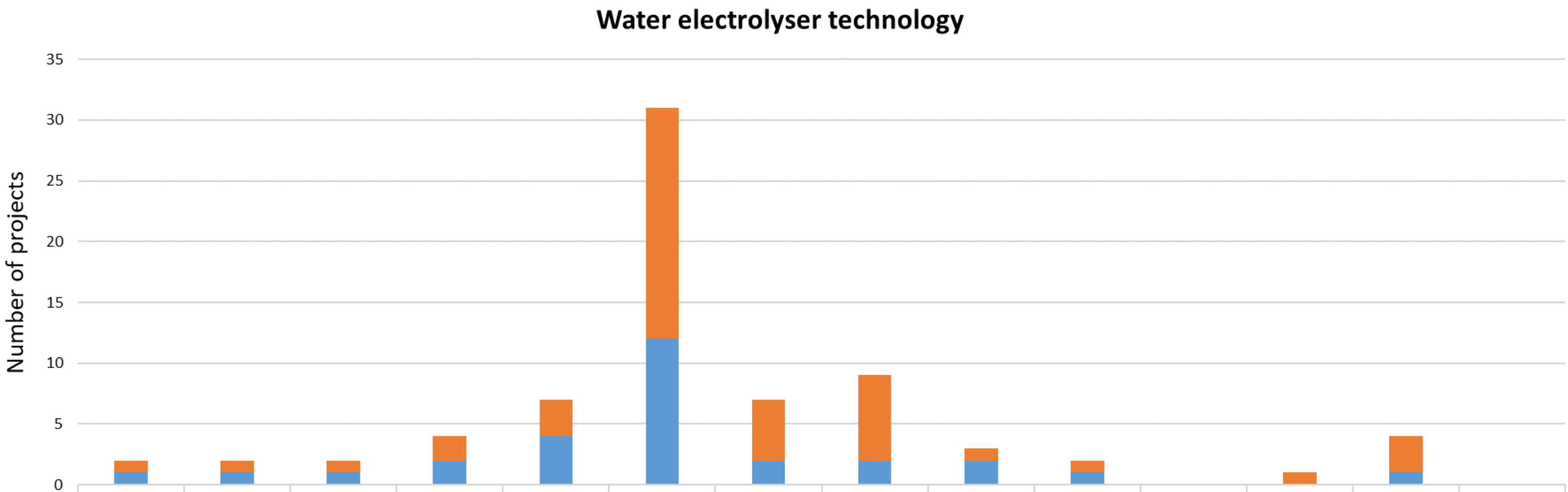


Hydrogen companies identified from IEA database's hydrogen projects with capacity >0.1 MW_{el}



- Identified Finnish companies include forest and food industry, with a higher percentage of equipment manufacturers (the questionnaire was targeted to them)
- European perspective includes transport companies

Electrolyser technology choice in different end-use applications

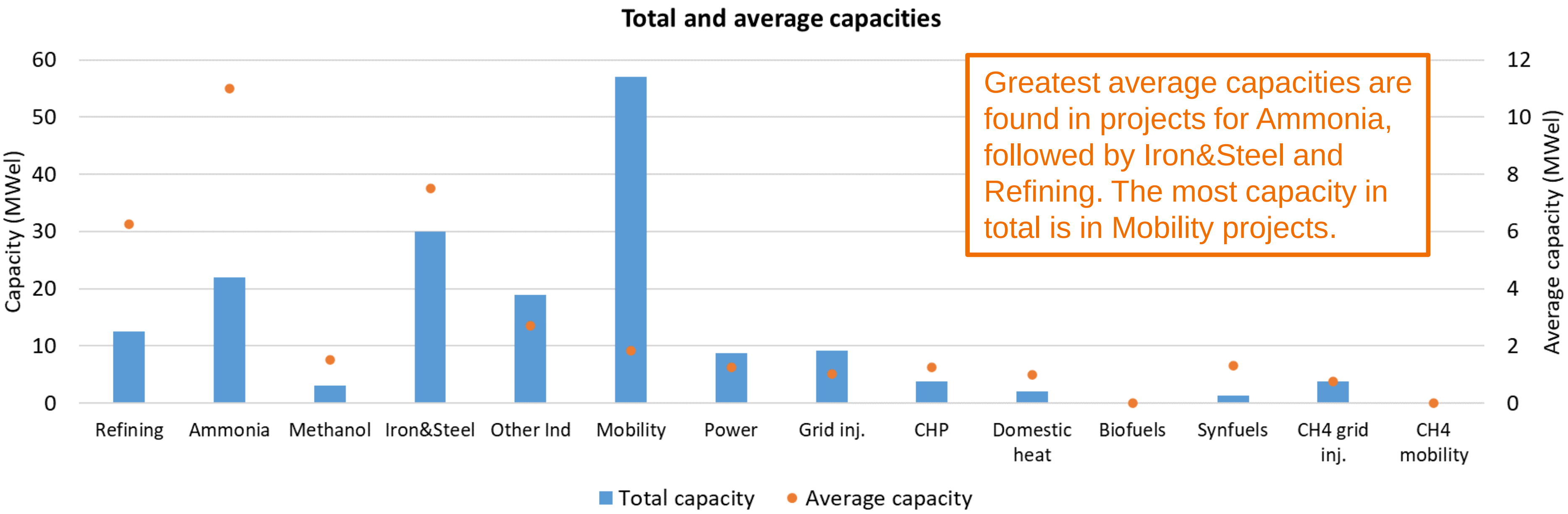


	Refining	Ammonia	Methanol	Iron&Steel	Other Ind	Mobility	Power	Grid inj.	CHP	Domestic heat	Biofuels	Synfuels	CH4 grid inj.	CH4 mobility
PEM	1	1	1	2	3	19	5	7	1	1	0	1	3	0
AEL	1	1	1	2	4	12	2	2	2	1	0	0	1	0

AEL PEM

Other Ind = Use of hydrogen in high-temperature heat (excluding oil refining, ammonia production, methanol production and steelmaking).
Grid inj. = Injection of hydrogen in the natural gas grid.
CH4 grid inj. = Injection of synthetic methane in the natural gas grid.

Electrolyser capacities for different end-use applications

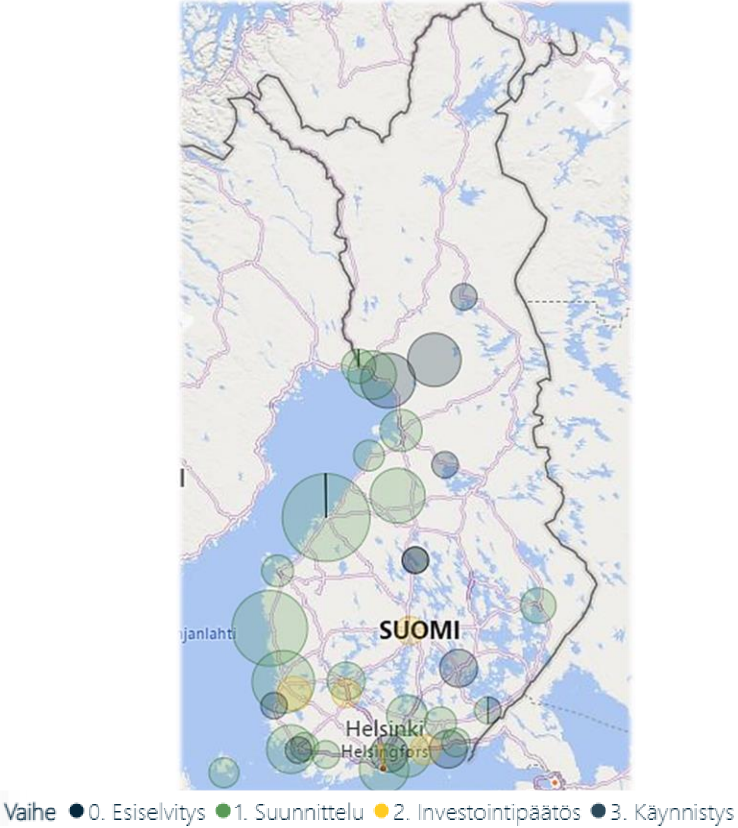


Greatest average capacities are found in projects for Ammonia, followed by Iron&Steel and Refining. The most capacity in total is in Mobility projects.

Other Ind = Use of hydrogen in high-temperature heat (excluding oil refining, ammonia production, methanol production and steelmaking).
Grid inj. = Injection of hydrogen in the natural gas grid.
CH4 grid inj. = Injection of synthetic methane in the natural gas grid.

Finnish perspective: hydrogen production investments

- Based on [Green investments in Finland](https://ek.fi/tutkittua-tietoa/vihreat-investoinnit/) data by Confederation of Finnish Industries (EK)
  - There are 47 on-going hydrogen projects in different phases (planning, feasibility study, investment decision, start of operation)
    - Total planned capacity 8200 MW
  - Four significant projects have been discontinued
    - Fortum & SSAB, 700 MW, Raahe
    - St1, 40 MW, Lappeenranta
    - Vantaan Energia, 70 MW, Vantaa
    - Neste, 120 MW, Porvoo

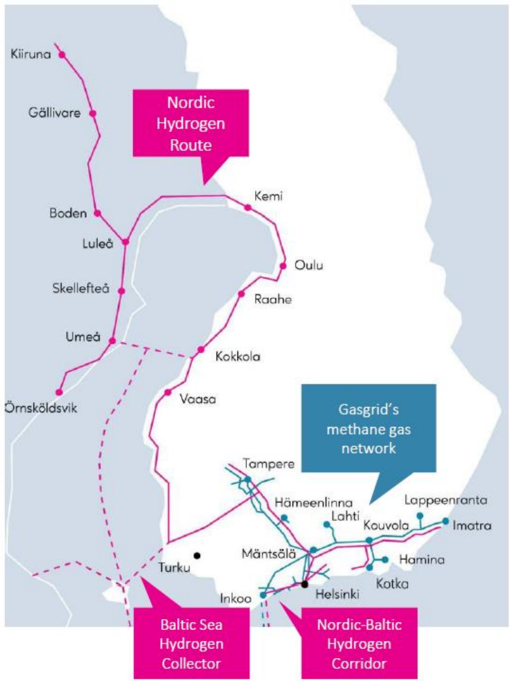


https://ek.fi/tutkittua-tietoa/vihreat-investoinnit/

Hydrogen backbone in Finland

- Gasgrid has a task to promote
  - The development of the national hydrogen infrastructure
  - International infrastructure co-operation
  - Hydrogen market in Baltic Sea Region
- The goal of the task is to
  - Attract new investments and create job opportunities
  - Support energy security
- H_2 infrastructure also facilitates
  - Market growth and export opportunities
  - Flexibility for different process operation through hydrogen storage

Baltic Sea Region - Hydrogen market network



Most recent national H_2 network plan

https://oulu.com/wp-content/uploads/2024/02/7_heli-virkki-gasgrid.pdf

https://gasgrid.fi/

Project challenges and lessons learnt

Why are some projects facing delays or cancellations?

- **Unfavorable regulatory environment** (e.g. about distribution obligations for e-fuels or reduction mandates for marine transport) creates uncertainty for long-term investments
- **Higher than expected cost** of building and operating renewable hydrogen projects. Cost estimation for electrolyser projects is challenging due to lack of reliable data, as much is kept confidential to maintain a competitive edge.

Lessons learnt (working practices, experiences)

- Use of **pre-approved subcontractors** and **combining approaches of mature organizations and SME culture**
- Learning from past incidents and **implementing safety measures** to address the unique challenges associated with handling hydrogen
- Managing a large, multidiscipline team with **"one project = one team" attitude**
- **Sharing experiences and lessons learnt** is essential for overcoming challenges

1) **Refhyne project**: Lessons learnt
2) **GreenHy scale**: Experiences from hydrogen projects
3) **IEA:** H_2 project database

Support and financing mechanisms in Finland for hydrogen projects

Financing for H_2 projects in Finland

VTT

Laboratory, R&D TRL 1-4

EU Research and Innovation Action

Business Finland Deep Tech Accelerator (DTA)

European Innovation Council (EIC): Pathfinder

Business Finland Co-Research calls (e.g. Veturi)

European Innovation Council (EIC): Transition (TRL3-5)

~ 1 M€

Demo TRL 5-6

Innovation Action (Horizon Europe)

BF Co-Innovation (not for investments)

Euroopan aluekehitys-rahasto (EAKR)

Just Transition Fund (JTF)

~ tens M€

Pilot or industrial scale TRL 7-9

European Innovation Council (EIC): Accelerator (TRL 5-9)

Governmental venture capital, note! loans: Business Finland loan, Finnish Industry investment (Teollisuussijoitus (Tesi), Finvera

Energy aid (Recovery and Resilience Facility (RRF), RePowerEU)

Business Finland investment aid

Innovation fund – project financing support, e.g. European Hydrogen Bank (EHB)

~ tens-hundreds M€

In addition:

- Tax expenditures to corporate tax (planned, could be applied in 2025)
- EU-taxonomy (affects the price of the loan)
- IPCEI – Important Project of Common European Interest (helps to provide financing with lighter notification procedures)

Image: VTT

Hydrogen networks in Finland or related to Finland

- Hydrogen Cluster Finland (H_2 Cluster)
- Hydrogen Research Forum Finland
- BotH2nia
- Finnish Hydrogen Valley Association (Suomen Vetylaakso ry)
- IEA Hydrogen TCP
- European Clean Hydrogen Alliance
- Hydrogen Initiative by Clean Energy Ministerial (CEM)
- Mission Innovation: Clean Hydrogen
- Mission Innovation: Hydrogen Valley Platform
- International Partnership for Hydrogen and Fuel Cells in the Economy
- Hydrogen Council
- UNIDO: Global Programme for Green Hydrogen in Industry
- Hydrogen Valleys S3 Partnership

Conclusions and recommendations

Conclusions and recommendations

More Finnish electrolyser stack & stack module manufacturers, as well as system integrators are needed

More national collaboration between Finnish universities and research organizations is needed

Finland has many strengths and good potential for realizing Power-to-X projects. However, there are also weaknesses and threats which should be addressed and minimized

A variety of financing mechanisms and options exist for technologies with different readiness levels

Funded by the European Union
NextGenerationEU

Euroopan unionin rahoittama
NextGenerationEU