Prefeasibility study for development of clean and stable energy production in the Pyhäjoki economic area

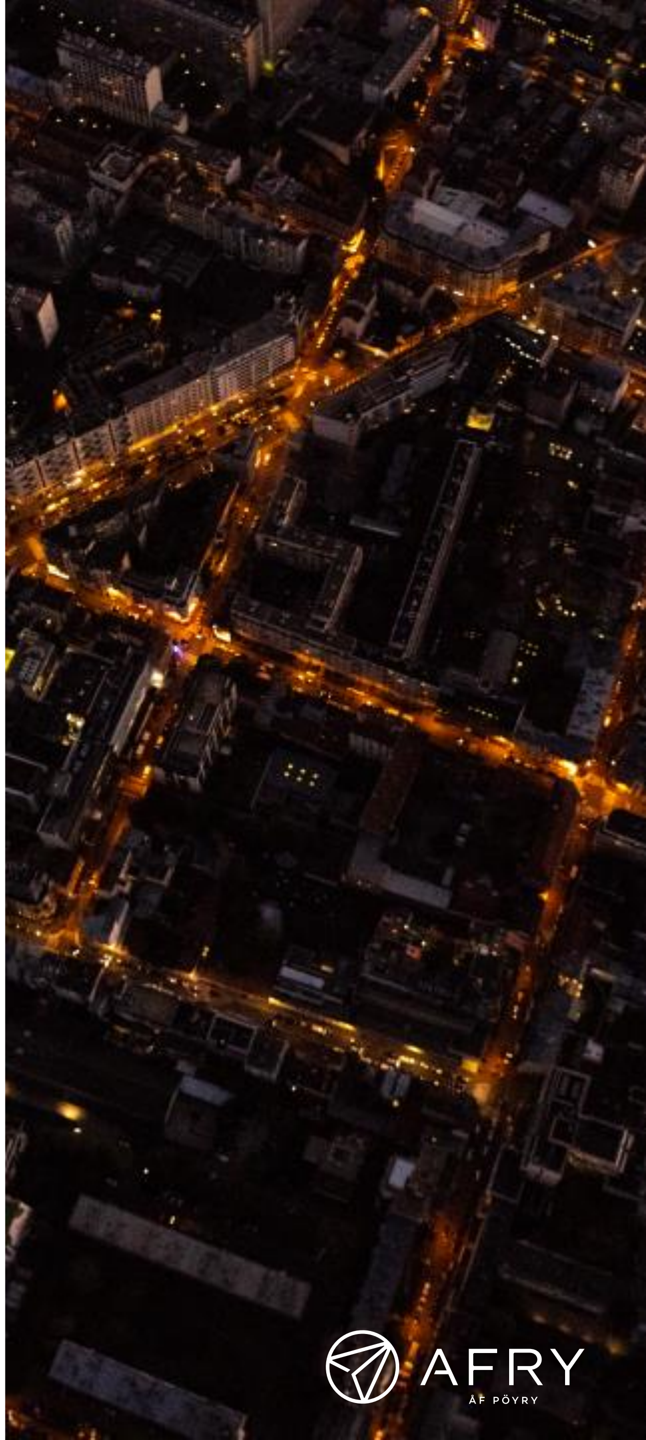
Final report

6.3.2024

DISCLAIMER AND RIGHTS

AFRY
ÅF PÖYRY

Content



Abbreviations used in the report (1/2)

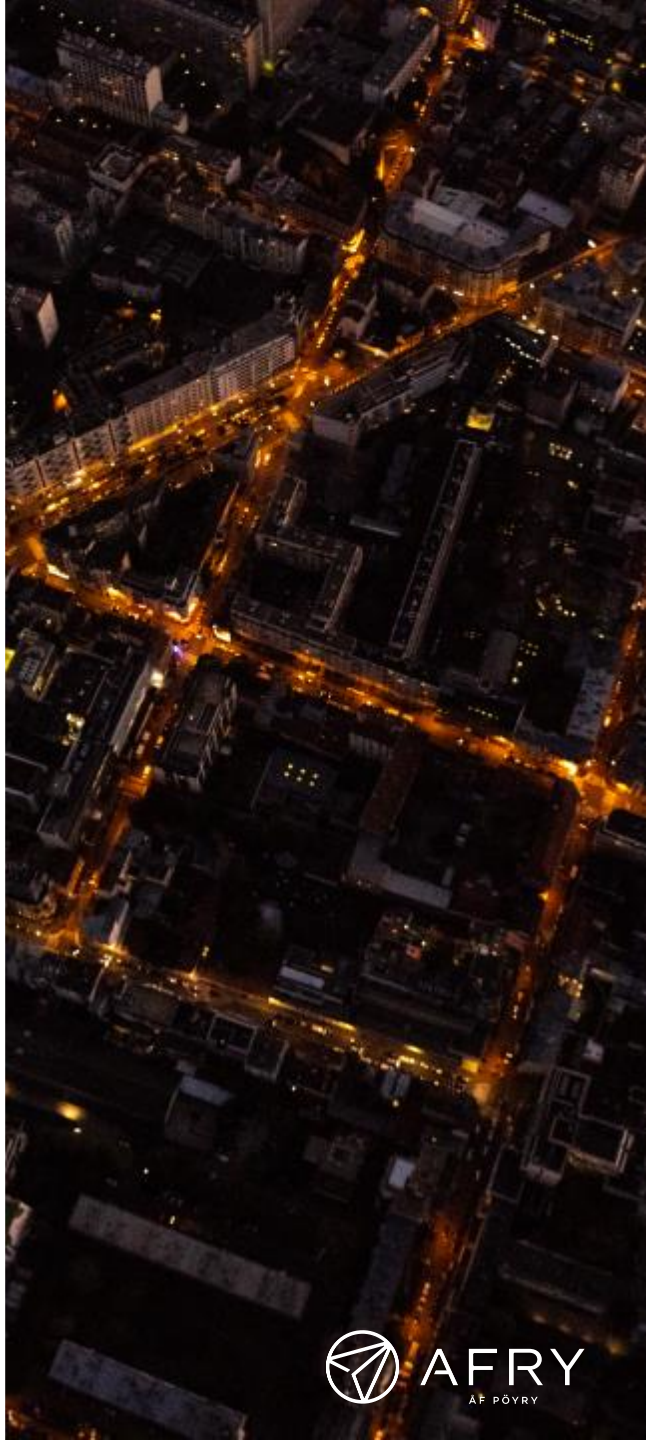
Abbreviation	Meaning
ALK	Alkaline electrolysis
ASU	Air Separation Unit for Nitrogen production
BOAK	Between-first-and-next-of-a-kind
BWR	Boiling Water Reactor
CAPEX	Capital Expenditures
CCU	Carbon Capture and Utilization
CfDs	Contract for Differences
COD	Commercial Operation Date
CRM	Capacity Remuneration Mechanism
DH	Direct Heat
DSR	Demand Side Response
e-fuels	electrofuels
EIA	Environmental Impact Assessment
EMR	Electricity market reform
EPR	Evolutionary Power Reactor
FEED	Front-End Engineering Design
FID	Final Investment Decision
FOAK	First-of-a-kind

Abbreviation	Meaning
GHG	Greenhouse gases
GO	Guarantees of Origin
IEA	International Energy Agency
LCOA	Levelized Cost of Ammonia
LCOE	Levelized Cost of Electricity
LCOH	Levelized Cost of Hydrogen
NOAK	Next-of-a-kind
NPP	Nuclear power plant
O&M	Operations and Maintenance
OPEX	Operating Expenses
PEM	Proton Exchange Membrane electrolyser
PPA	Power Purchase Agreement
PtX	Power to X
PWR	Pressurized Water Reactor
R&D	Research and Development
REMIT	Regulation on wholesale energy market integrity and transparency
RES	Renewable Energy Sources
RFNBO	Renewable Fuels of Non-Biological Origin

Abbreviations used in the report (2/2)

Abbreviation	Meaning
SMR	Small Modular Reactor
SOEC	Solid oxide electrolyser cell
STUK	Radiation and Nuclear Safety Authority
TRL	Technology Readiness Level
TSO	Transmission System Operator
VRH	Virtual regional hub

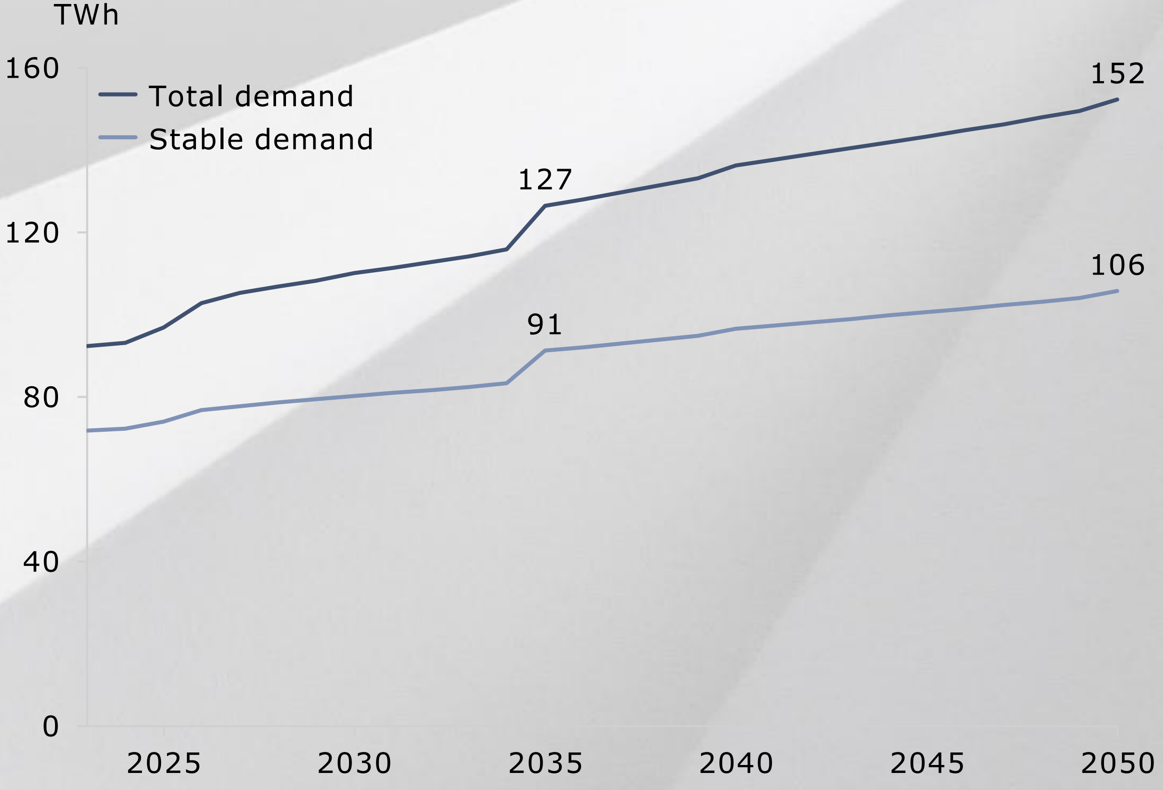
Content



Total electricity demand will grow in Finland and in Sweden significantly – stable demand can be reached by stable production capacity or higher flexibility on a system level

- Total electricity demand can grow by 65% until 2050 - demand is increased most through industrial demand for hydrogen production, forest and metal industries and transport sector. Inflexible demand under scenario assumptions would increase by ~34 TWh by 2050 compared to 2023.
- More stable supply is needed to bridge in the gap of future demand and supply. This can be achieved through more stable production capacity or higher flexibility on a system level. Besides nuclear power, measures to reach this are electrolysis, pumped storage, interconnection, demand side response, batteries, CHP and peak load power plants as well as strong internal grid.
- Price of electricity and security of supply have been in discussions lately. One solution mentioned in publicity is capacity mechanism.

FUTURE ELECTRICITY DEMAND IN FINLAND

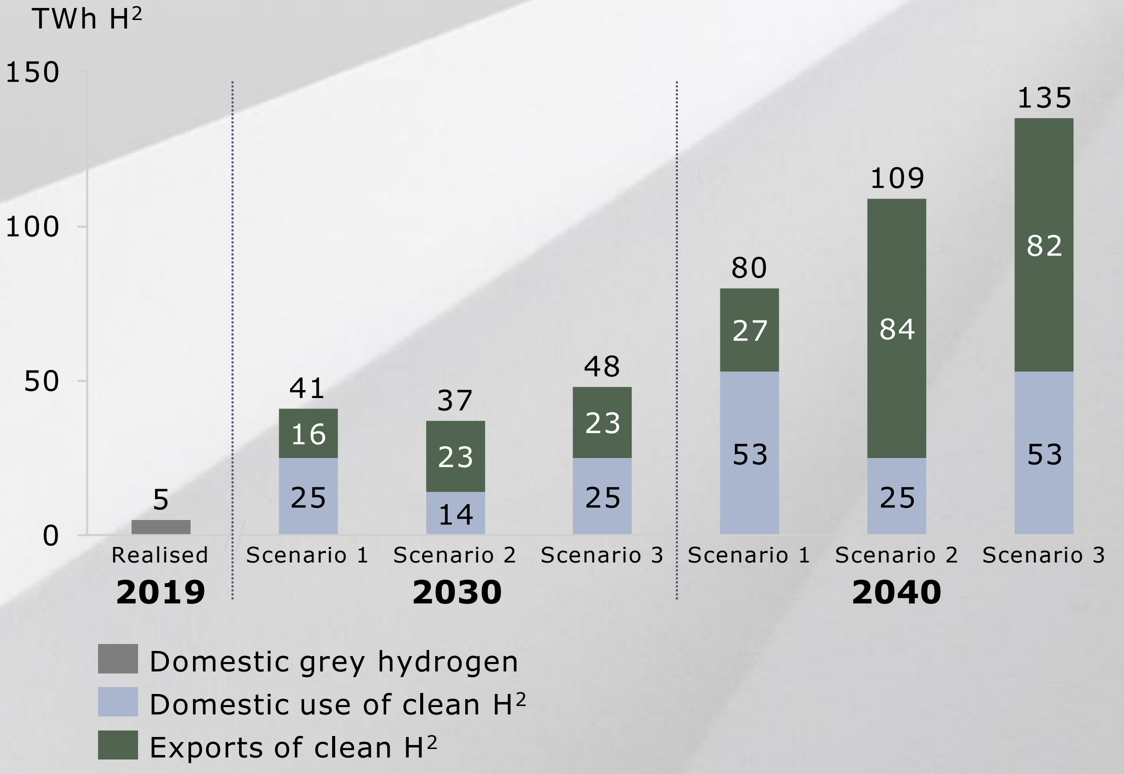


Source: AFRY analysis based on Elinkeinoelämän keskusliitto announced green investments ((https://ek.fi/tutkittua-tietoa/vihreat-investoinnit/))

Hydrogen demand will increase significantly in EU until 2050, offering new kind of possibilities for Finland through H2 production and industrial projects

- Hydrogen demand is forecast to grow across the EU to 2050, providing between 18-34% of total energy demand by 2050. European commission has set ambitious targets for H2 production.
- Finland is targeting 1 GW and Sweden 5 GW hydrogen production capacity by year 2030.
- RFNBO compatibility for nuclear produced hydrogen is still unclear but should receive clear guidelines in coming years.
- Finland has a major potential to become a PtX and hydrogen producer for both domestic end-use and for export.
- Publicly announced projects in Finland focus on industrial decarbonisation in steel and chemicals, and the production of ammonia, hydrogen, methane, and methanol. In the north of Sweden, hydrogen projects are clustered in Luleå-Boden region with a focus on green steel production.
- Fingrid and Gasgrid scenarios predicct that the electrolyser capacity is 10-15 times larger than the current national goal of 1GW by 2030. The rate of capacity increase naturally higher than national goals.

FINGRID AND GASGRID HYDROGEN PRODUCTION SCENARIOS



Source: www.consilium.europa.eu, Fingrid - Gasgrid hydrogen economy scenarios

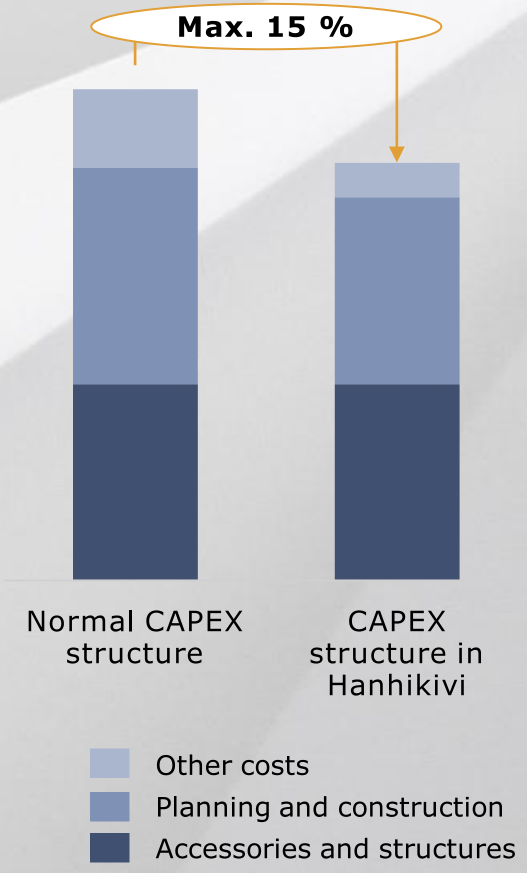
Hanhikivi area is perfectly suitable for nuclear power production and already completed work could bring significant cost savings for a nuclear project

HANHIKIVI AREA

- The existing permits cannot as such be utilized for new activity on Hanhikivi site but provide a good starting point for new projects.
- Preparation and construction works done at the site might provide even significant value for a new user of the site. Up to 15 % of the total CAPEX is evaluated to be included in the phases already performed in Hanhikivi.
- There is positive attitude towards nuclear power in Finland and in Pyhäjoki. Additionally, there is possibility for permanent disposal of the nuclear waste in Finland.

POSSIBLE PROJECT

- Essential in nuclear projects is well functioning risk management, financing solved, functioning technology, good relationships with authorities and decision makers and a good supply chain
- Cost of nuclear power (LCOE) is expected to decrease if we move to mass production, especially for SMR:s.
- With nuclear power you can produce a constant stream of hydrogen, contrary to hydrogen produced solely on renewables. There are, however, uncertainties regarding regulation on nuclear produced hydrogen.
- Possibility to locate hydrogen or ammonia on the same site needs to be examined more closely. Especially for SMR.s this could be possible, with active international discussions ongoing. Currently no decision has been made.



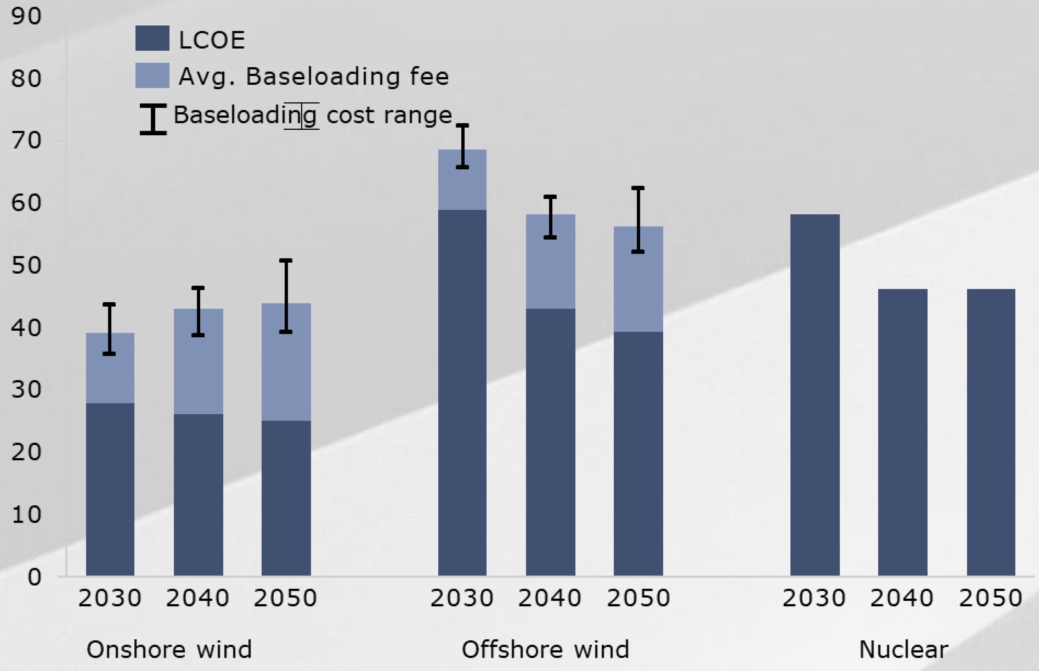
There was interest in the area in the stakeholder interviews

STAKEHOLDER INTERVIEWS

- In the stakeholder interviews, representatives of different companies from the following categories were interviewed: nuclear power owner-operators, plant suppliers and large electricity buyers.
- Plant suppliers were very interested in Hanhikivi area. Finding owner and licence holder are the key factors.
- Nuclear power is considered by large electricity buyers as an interesting option to mitigate price fluctuations. All companies interviewed stated that nuclear power is an attractive source of stable and CO2-free electricity – especially if it is approved as RFNBO compliant. The long duration of the nuclear power project was considered a risk.
- All the interviewed owner-operators were aware of the situation in Hanhikivi and are open to new opportunities to develop the area. Although many benefits were seen for the Hanhikivi area, the main focus of the companies interviewed at the moment is on their own projects. The possibility of SMR-investments were considered an interesting option.
- Mankala companies act as a platform for shareholders who can buy electricity at cost price. The Mankala model could also work for Hanhikivi.

Nuclear has the potential to be cost competitive when considering a case where a flat production profile brings economic benefits

COST OF BASELOAD PRODUCTION



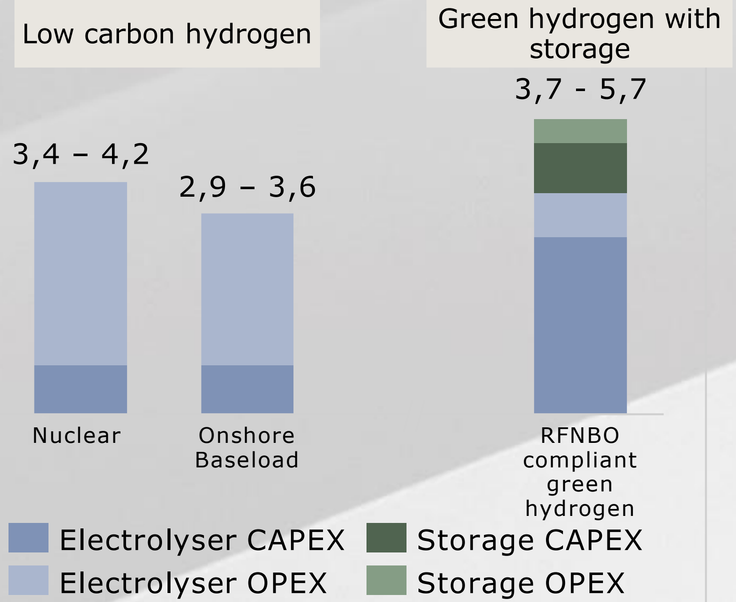
VALUE OF STABILITY IN POWER PRODUCTION

- Nuclear is not competitive against onshore wind on a pure basis of electricity production costs (LCOE). Offshore wind has similar or lower LCOE levels compared to nuclear.
- The benefit of nuclear power are especially the stable production throughout the year and predictability of production compared to wind power. This benefit can be examined by accounting for the need to buy electricity from the grid during hours of no wind (visualised with lighter blue in the graph).
- When considering the value of stability of nuclear production through baseloading logic, nuclear becomes potentially competitive in the future, especially against offshore wind
- Nuclear has uncertainties due to financing costs, realization of investment costs and project time schedule. The costs presented in the graph can be considered as optimistic for nuclear power.
- Moreover, possible capacity mechanism might also have an effect on the profitability comparison in the future. Nuclear could possibly benefit from separate capacity revenue, if Finland introduced some sort of capacity market.

LCOE levels are based on publicly available information (e.g. Idaho National Laboratory) and AFRYs database
Baseloading cost based on elecrtricity price predictions from AFRY report: Hiilineutraalisuustavoitteen vaikutukset sähköjärjestelmään - Valto (valtioneuvosto.fi))

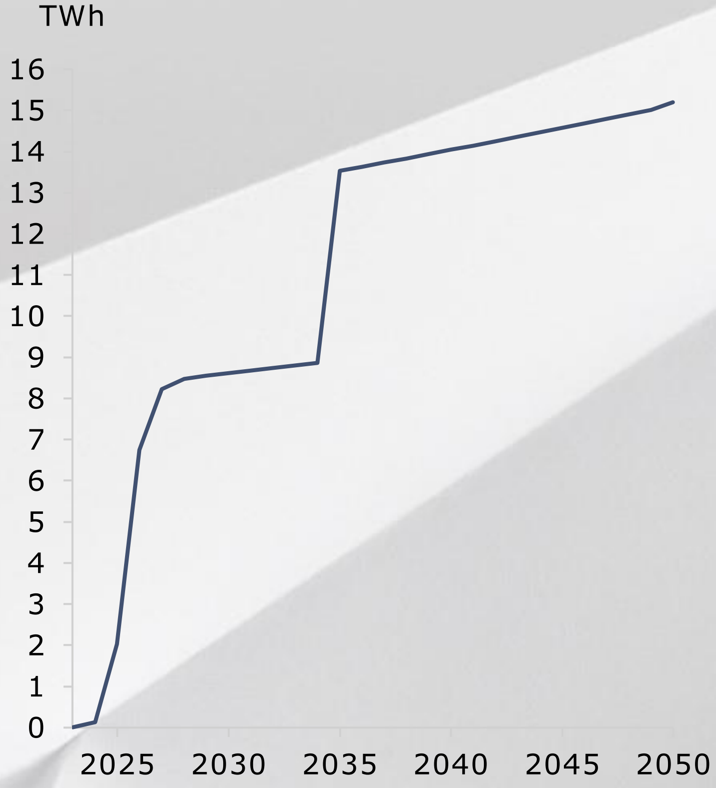
Nuclear-produced hydrogen may offer opportunities at Hanhikivi, especially if regulation categorises nuclear as green hydrogen under the RFNBO

LCOH COMPARISON (€/KG)



- Low carbon hydrogen is more competitive produced with renewables rather than nuclear
- If the electrolyser is oversized and complemented with storage, nuclear can acjhieve lower LCOH levels

ELECTRICITY DEMAND FOR GREEN HYDROGEN[1]



CONCLUSION

- EU legislation for nuclear-produced hydrogen is still developing but seems to be unfavourable for nuclear, as its more likely to be considered low carbon rather than green hydrogen
- The market for electricity supply that meets green hydrogen criteria can grow to 15TWh by 2050
- Otherwisee, nuclear can produce low carbon hydrogen which accounts for a smaller market
  - Nuclear will compete against other forms of low carbon hydrogen which can be produced at low cost

1) AFRY analysis based on Elinkeinoelämän keskusliitto announced green investments ((https://ek.fi/tutkittua-tietoa/vihreat-investoinnit/))

Placing nuclear power and H2 production on the same site is still uncertain, but conditions for building other functions nearby nuclear power are being improved

- At the moment it is still unclear whether industrial plants could be located in the vicinity of nuclear power plant. There is no clear limit to how close to a nuclear power plant a hydrogen plant could be located.
- Nuclear power plant includes a safety zone with considerable land use restrictions, for example a ban on significant employment areas that are not related to the NPP. The safety zone used to be 5km in the earlier legislation, but it was renewed in February 2024 so that the zone radius is defined case by case based on plant specifications. Factors affecting the zone radius include plant size and technological properties. The new legislation is targeted to enable placing NPPs closer to industry and human settlement. On the other hand, a hydrogen production plant could probably be located within the safety zone, because as an employment cluster it is probably not very large, and it also could be considered as related to the NPP.
- A hydrogen plant located close to a nuclear power plant must not have a negative impact on the safety of the nuclear power plant. External threats can be prepared for, and their effects reduced by design as well as technological solutions.
- The required distance between plants depends both on the defining of the NPP site area and possibly the safety zone, and on the required distance from the external threat posed by the hydrogen plant. The required distance must be considered from the perspective of both installations' characteristics.
- The topic is currently under discussion at many international forums. IAEA is updating their instructions to take future SMR plants better into consideration. As a part of this update also instructions regarding NPP licensing are renewed, including recommendations related to placing NPPs close to industrial activities. There are already some pilot plant examples.
- H2 production plant location, layout and design has to take into account the requirements of NPP, if H2 plant would be constructed first. Additionally, the electrical distribution line location has to be considered in layout and design of H2 plant. The same preconditions apply on ammonia production.

IAEA = International Atomic Energy Agency

There are at least four viable future solutions for utilization of Hanhikivi site

1

On-site production of hydrogen and ammonia

On-site production of hydrogen and ammonia based on baseload renewable PPAs from the grid or at-the-site connected renewable power production. The resulting ammonia would then be considered as RFNBO compliant ammonia.

2

Nuclear power production

Nuclear power production for grid-connected end-users with direct agreements or by Mankala model – or to be sold to the market. Possibility to help the stability of the electric system.

3

Nuclear power for on-site hydroden / ammonia

Nuclear power production for on-site hydrogen and ammonia production, provided that nuclear based H2 is accepted as low-carbon hydrogen in future EU regulation, and that the pricing of low-carbon H2 is competitive.

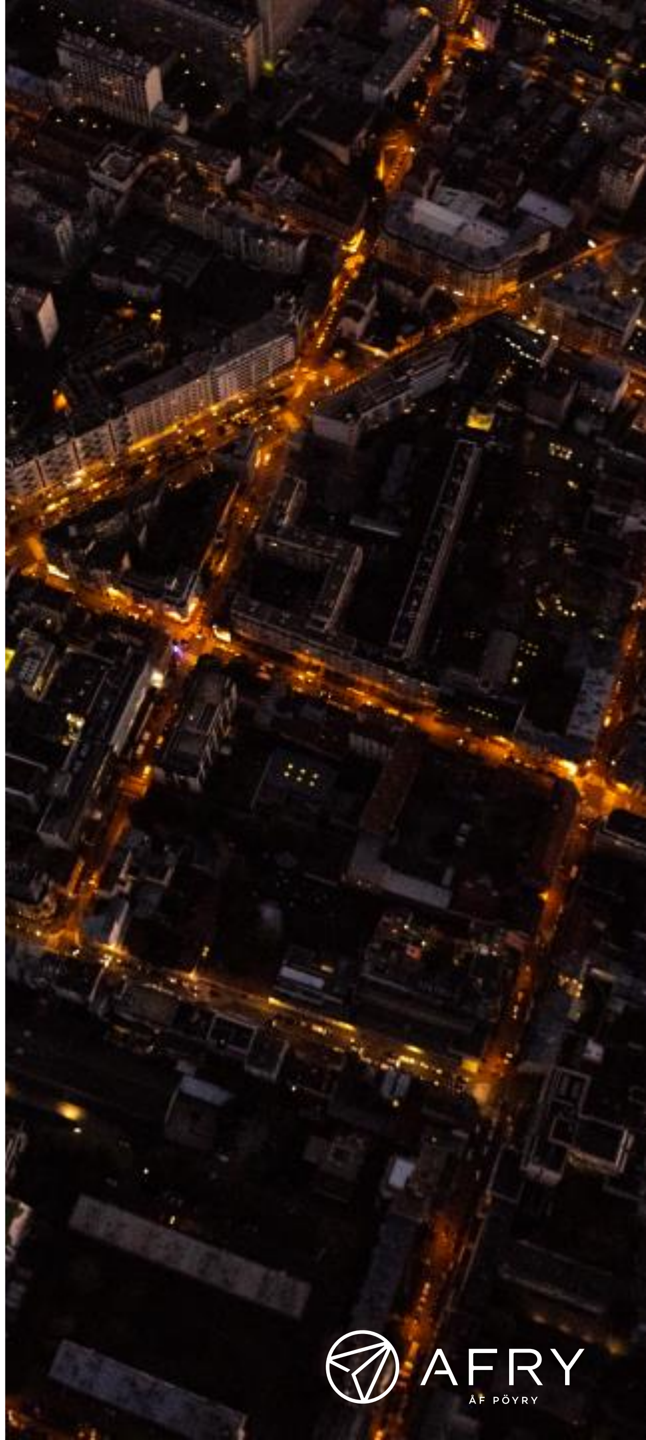
4

Nuclear power for on-site hydroden with pipeline

Nuclear power production for on-site hydrogen production connected with a H2 pipeline to H2 end-users provided that nuclear based H2 is accepted as low-carbon hydrogen in future EU regulation, and that the low-carbon H2 is competitive.

Time schedule
NPP project could be started before 2030 if financing and project structure would be settled and the project has been granted a construction permit. SMR project is viable later, in the 2030s. Hydrogen and/or ammonia production could start before 2030 if the project would be starting soon. Industrial activity in the same area needs to be examined more but discussions about locating SMR:s close to industry or residential areas are being held internationally.

Content



Introduction to the report

- The municipality of Pyhäjoki has launched the project "Development of Clean and Stable Energy Production in the Pyhäjoki Economic Area", which has been granted AKKE funding by the North Ostrobothnia Regional Council.

- AFRY Management Consulting has carried out a project for Pyhäjoki to explore possibilities for the production and further processing of clean and stable energy, focusing on nuclear power and hydrogen and hydrogen derivatives production. The project aims to describe suitable technological, economic and timely solutions to meet these needs, using the infrastructure already in place and the local environment. The project also identified and engaged potential national and international actors in the development of the energy sector in the region

- This report summarises the findings of the project including the following topics:
  1. Clean energy needs and energy market development: identifying the need for stable energy production with a focus on electricity and hydrogen
  2. Identifying the network of actors: the willingness and readiness of key actors to launch new projects using regional infrastructure
  3. Potential technologies and suppliers: Assessing the readiness of potential technologies and suppliers to implement projects that can be built already in this decade
  4. Economic viability of electricity, hydrogen and heat production: assessing the viability of different energy needs and appropriate technological solutions

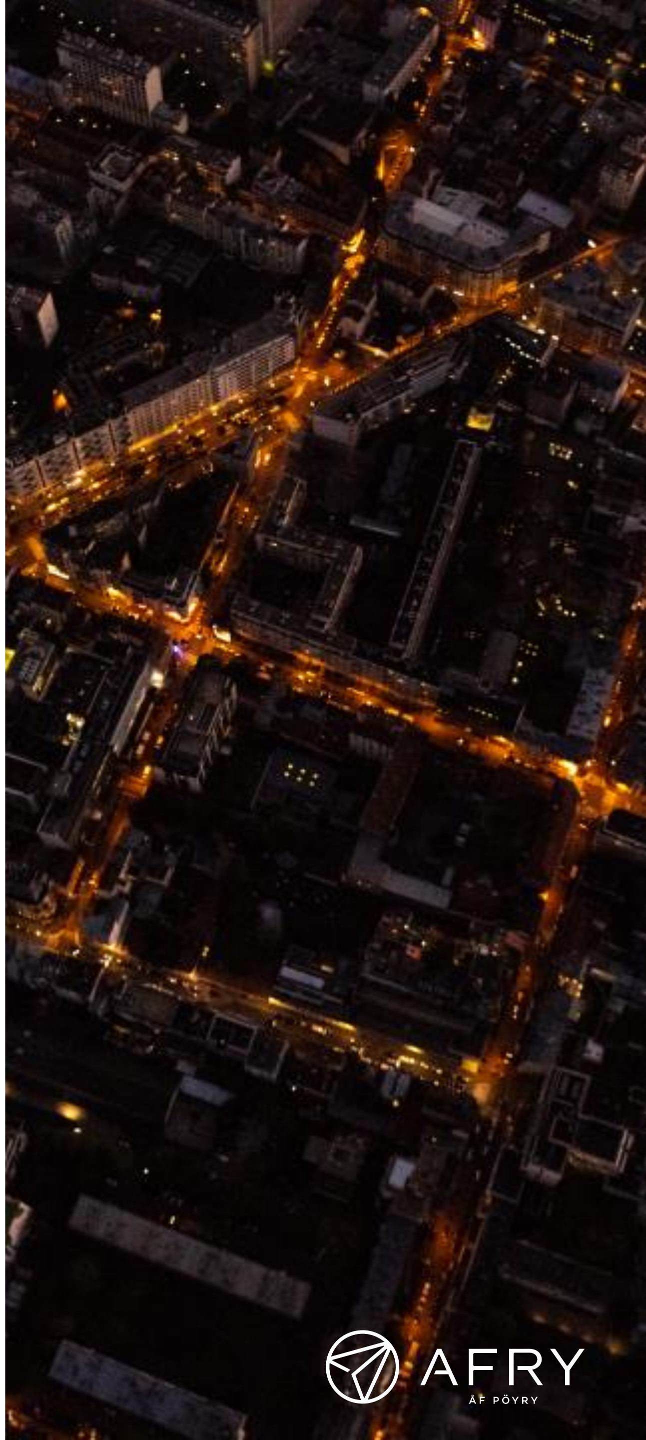
Introduction to the site

- Hanhikivi is located on the Hanhikivi peninsula in the municipality of Pyhäjoki. It is in the province of North Ostrobothnia. Hanhikivi is situated in the relatively remote location of Pyhäjoki. This remoteness can be advantageous for industrial activities, as it lowers the risk of public resistance. There is already good local acceptance for nuclear power.

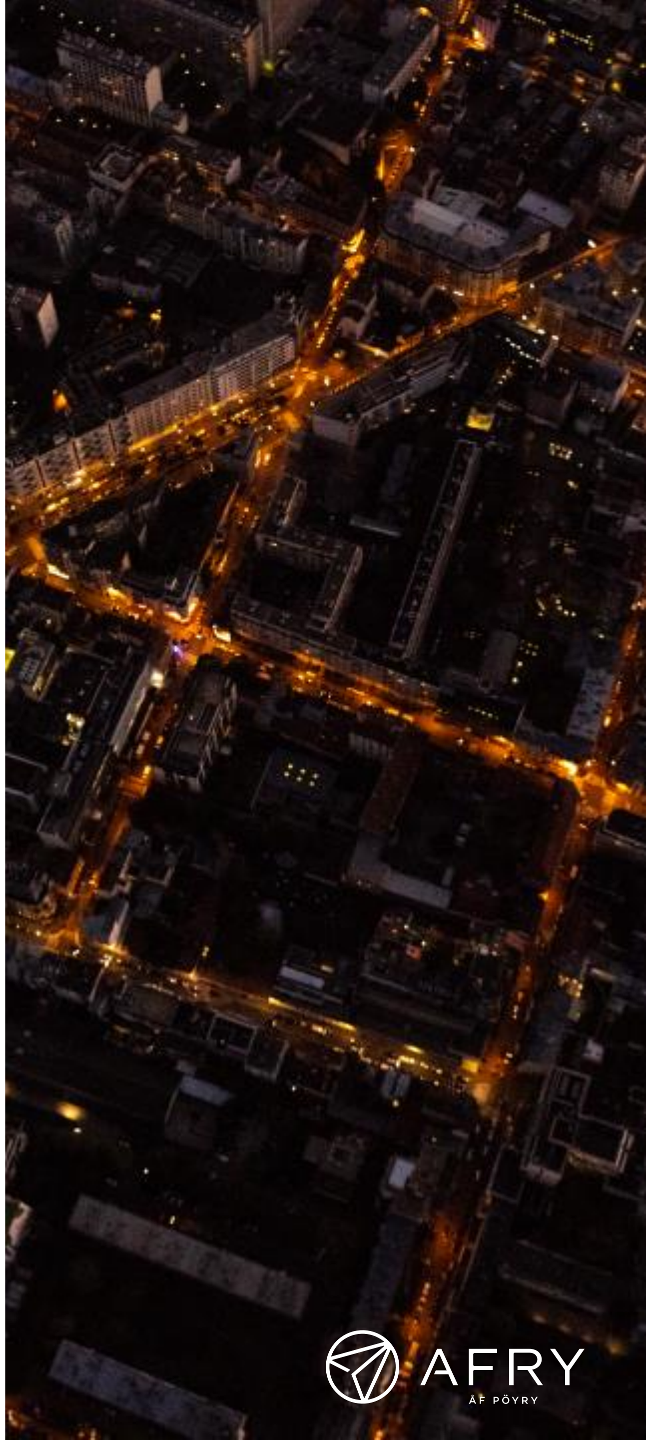
- The Hanhikivi location has been readied for the operation of a nuclear power facility. The total land and water area at the Hanhikivi site is 567 hectares. Civil works have been carried out, including the construction of roads and preparations for approximately 115 hectares. There are three permanent buildings: a training building of 1200 m2, a security gate building of 1200 m2, and an admin/office building of 10600 m2. The harbor's underwater works are complete, with a waterway depth of 8 m and a width of 80 m, but land constructions are pending. The water connection has a maximum capacity of 1200 tons per day for freshwater intake. The grid connection currently stands at 5 MW capacity, with a reserve of 2x5.5 MW. Basic design, zoning, and permitting are ready for 2x400 kV + 2x110 kV connections to the transmission grid. The zoning is designated for energy production use and supporting functions, specifically for a nuclear power plant. Permits include a water permit for a 3200 MW cooling heat load into the sea and harbor construction, an environmental permit for the nuclear power plant, and a chemical permit.

- Nuclear power plant project of Fennovoima ended in 2022. The municipality of Pyhäjoki is seeking for new business opportunities for the area.

Content

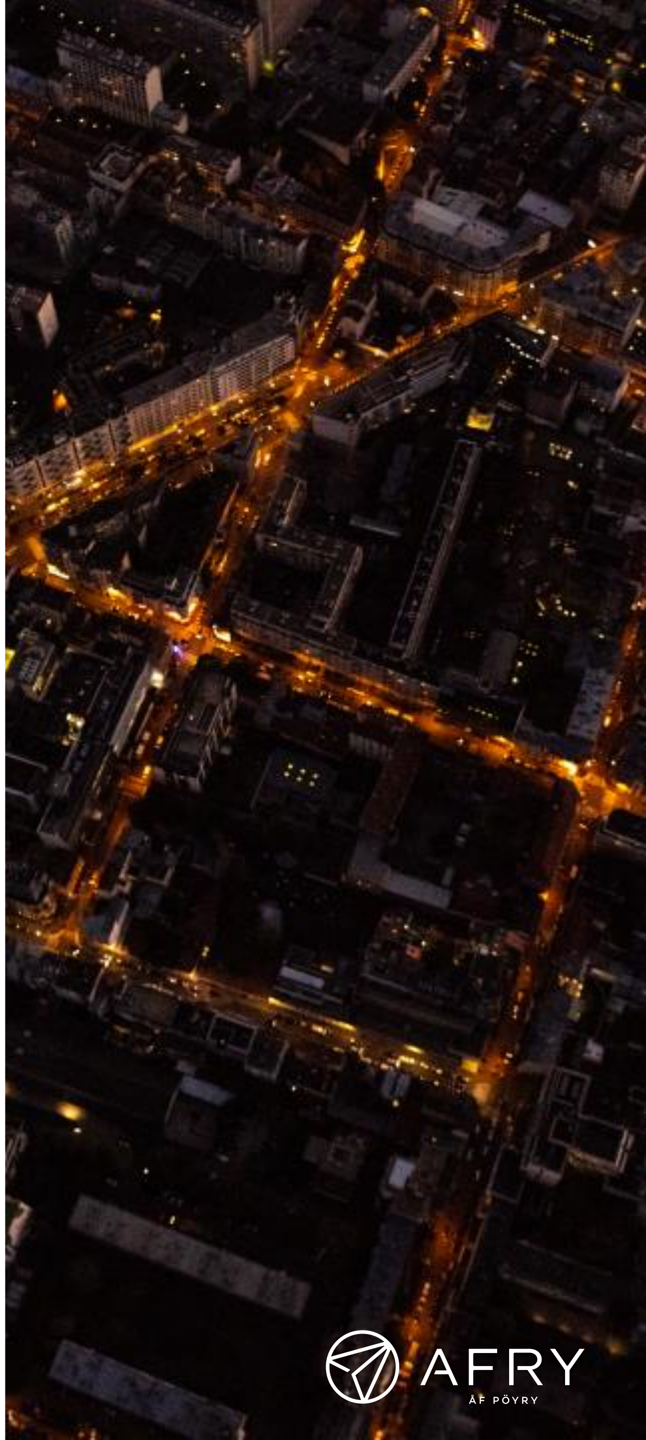


Content



AFRY ÅF PÖYRY

Content



INTRODUCTION

Increasing capacity of renewable energy production has created volatility in the energy market

- Renewable energy sources have increased the share of the Finnish electricity production rapidly during the last years. In year 2022, 54 % of the electricity produced in Finland was based on renewable sources and 31 % from the electricity production was based on onshore wind. *) The trend has continued and the renewable electricity production will be increasing in the future in Finland. There will be more onshore wind, solar power is starting to develop faster and offshore wind is also seeking for markets.
  - All this means that the electricity production will be volatile and there is a clear need for stable electricity supply in Finland.
  - This same development applies on Sweden, which is part of same Nordpool area and will be even more connected to Finnish electricity grid, when new Aurora line between the countries will be in use in 2025.
- Many industrial electricity users are putting extra value on stable electricity and this could be ensured by more baseload production from nuclear power plants, but also with other alternatives, which are described in this chapter.

*) Source: Production of electricity with wind power and nuclear power increased in 2022 - Statistics Finland

Need for stable energy supply in Finland

AFRY has developed a scenario for Finnish electricity demand based on public announcements of new investments and other growth sectors

Current situation

- Current level of electricity demand as shown in this report is based on *Statistics Finland´s* figures for year 2021
- Year 2021 is chosen as 2022 might hold anomalies with regards to electricity consumption due to the energy crisis

Growth outlook based on announced new investments

- Future increases in electricity demand are analysed based on publicly announced projects that will be significant consumers of electricity
- All the projects[1] are not assumed to be implemented in the end; Probabilities for the implementation are given based on the phase of the project and the possible future consumptions take these probabilities into account

Additional growth

- The publicly announced projects are not expected to be an exhaustive list of new future consumption
- Additional demand growth is therefore assumed on top of them

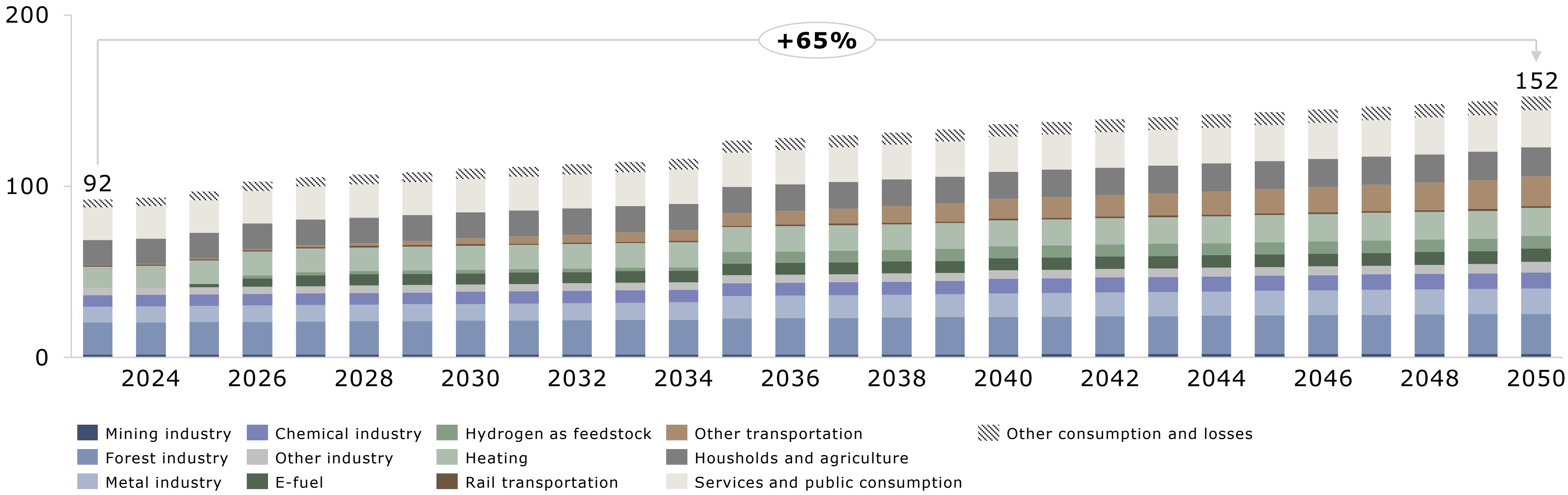
1 The projects assessed here are listed by *Elinkeinoelämän keskusliitto* as Finland´s green investments. The monitoring has started in 2021. https://ek.fi/tutkittua-tietoa/vihreat-investoinnit/

ELECTRICITY DEMAND DEVELOPMENT – FINLAND

Total electricity demand can grow by 65% by 2050 - demand is increased most through industrial demand for hydrogen production, forest and metal industries and transport sector

FUTURE ELECTRICITY DEMAND[1] IN FINLAND

TWh



1 The demand estimation is based on public announcements of future investments and other expected growth of the sectors. The estimation is indicative as it does not include large data centers or potential hydrogen exports. Assessment is based on probabilistic methodology

Different demand categories have varying levels of flexibility – Some have higher shares of inflexible, high uptime processes

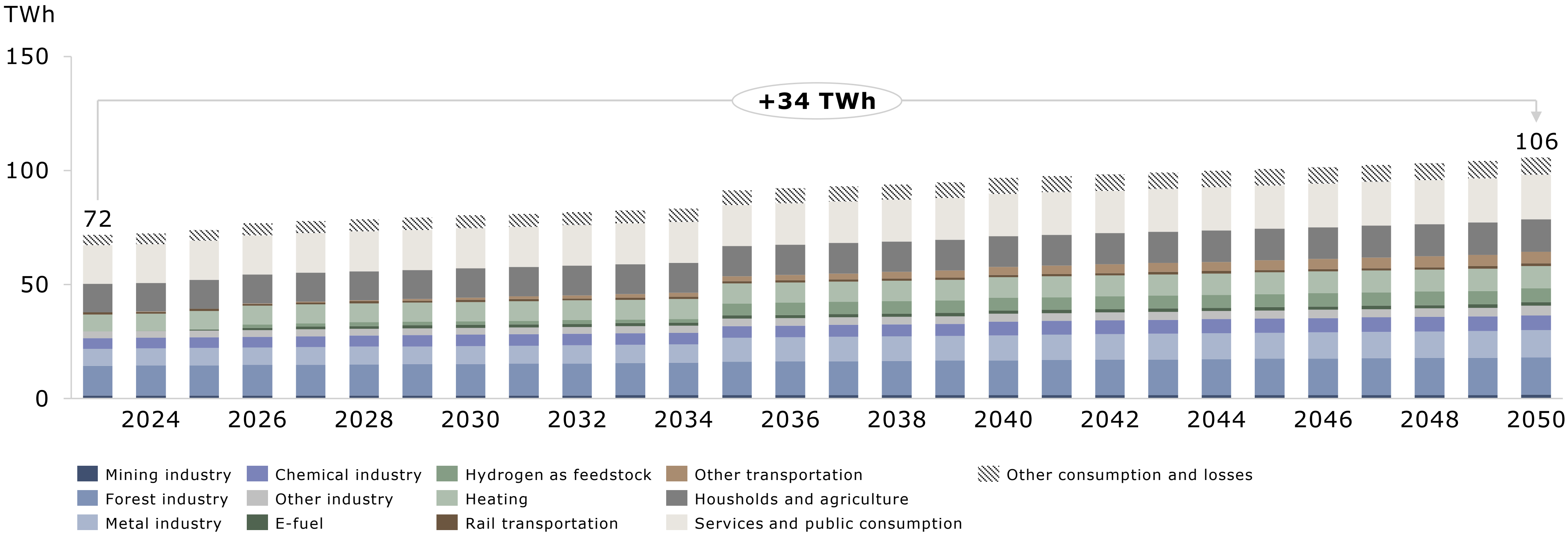
Demand category	Flexibility (Qualitative)	Stable demand (% of total)[1]	Flexible demand (% of total)[1]
Industry (excl. electrolysis)			
Mining industry	Low	80 %	20 %
Forest industry	Low to Moderate	70 %	30 %
Metal industry	Low to Moderate	80 %	20 %
Chemical industry	Low to moderate	70 %	30 %
Other industry	Low to Moderate	70 %	30 %
Electrolysis			
E-fuel	High	20 %	80 %
Hydrogen as feedstock	Low	80 %	20 %
Heating	Moderate	60 %	40 %
Rail transportation	Low	100 %	0 %
Other transportation	High	30 %	70 %
Households and agriculture		85 %	15 %
Services and public consumption	Low	90 %	10 %
Other consumption and losses	Low	95 %	5 %

1 The assumed percentages of stable and flexible demand are indicative estimates based on qualitative expert view. Assessing the level of flexibility in more detail was not in the scope of this study

ELECTRICITY DEMAND DEVELOPMENT – FINLAND

Inflexible demand under scenario assumptions would increase by ~34 TWh by 2050 compared to 2023

FUTURE STABLE ELECTRICITY DEMAND[1] IN FINLAND



1 The demand estimation is based on public announcements of future investments and other expected growth of the sectors. The estimation is indicative as it does not include large data centers or potential hydrogen exports.

AFRY ÅF PÖYRY

Development of supply is assessed through two scenarios that differ in future capacity of renewables and shutdown timelines of current NPPs

N.B.: Neither of the scenarios represent AFRY view as such. The scenarios are formed to assess hypothetical development if new stable production capacity was not built.

Nuclear shutdowns Scenario

- No new nuclear builds are assumed
- No lengthening of current nuclear permissions are assumed
- Wind and solar being built to match yearly energy balance
- Hydro power production staying stable
- Thermal power (other than nuclear) decreasing a bit into the future

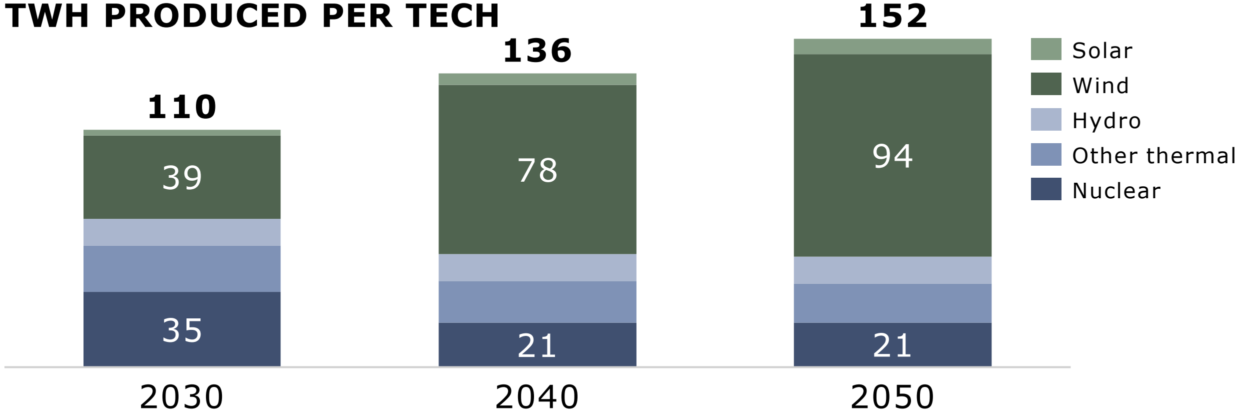
Nuclear extensions Scenario

- No new nuclear being built
- Current nuclear permissions lengthened until 2050
- Wind and solar being built to match yearly energy balance
- Assumptions on hydro and other thermal power as in High Renewables Scenario

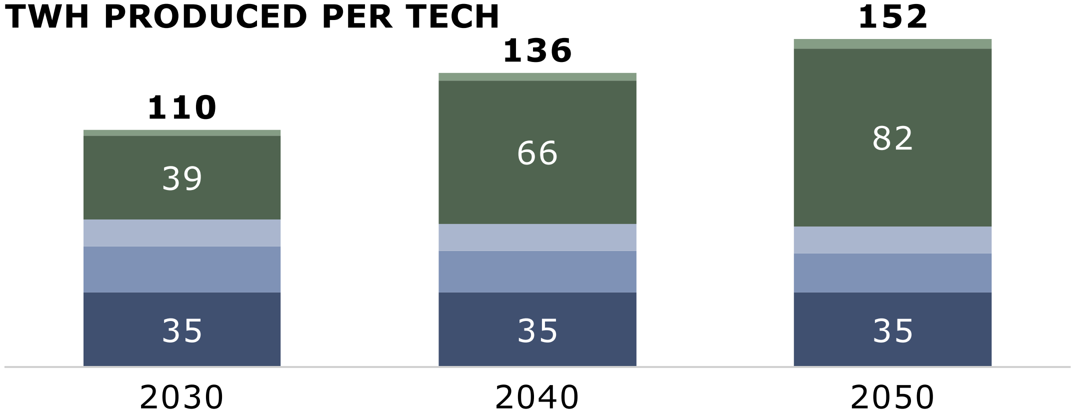
ELECTRICITY PRODUCTION DEVELOPMENT – FINLAND

The largest difference in the scenarios is the split between wind and nuclear production

NUCLEAR SHUTDOWNS SCENARIO – TWH PRODUCED PER TECH



NUCLEAR EXTENSIONS SCENARIO – TWH PRODUCED PER TECH



Nuclear shutdowns

- Energy produced through wind increases with a factor of almost 2.5 from 2030 to 2050
- The stable energy production is decreased through nuclear power plants being decommissioned
- Stable production from Nuclear, Other thermal and Hydro lowers to ~51 TWh/a in 2050

Nuclear extensions

- Energy produced through wind increases significantly, but still notably less than in the other scenario
- The stable production lowers to ~65 TWh/a in 2050
- The slight decrease is caused by reduction in other thermal power production

Flexibility provided by several technologies can augment intermittent power production to provide stable power supply – strong grid supports balancing

Electrolysis

- Grid electrolysis can store energy into, *e.g*, hydrogen during hours of excess production
- The energy can then be injected back to the grid during later hours
- Round-trip efficiency of grid electrolysis is somewhat low, only ~40%

Pumped storage

- In pumped storage plants energy can be stored for long periods by pumping water to higher reservoirs for later power production
- As a technology it is limited by suitable locations and capex heavy profile

Interconnection

- Finnish and Swedish grids are especially well-connected
- Sweden is further connected to the rest of Europe making also Finland connected via Sweden
- Imports and exports support the systems to be balanced as needed

DSR

- Demand side response cannot store energy, but it can increase system level flexibility through balancing
- During low production DSR can provide upregulation by lowering demand, and vice versa during times of high production

Batteries

- Batteries are an agile technology to store energy with a capability to very short response time
- At present, batteries in Finland and Sweden are targeted to ancillary services - technology is expected to develop to longer duration storage

CHP + peakers

- Thermal power production in CHP-plants and peakers is well adjustable and CHPs currently provide strong system support – *e.g.* capacity during hours of peak demand
- Using biomass, biofuels or hydrogen minimises emissions[1]

Grid (Internal)

- Strong transmission grid supports grid stability, which gets emphasized in long countries such as Finland and Sweden
- Finnish grid is currently strong whereas the Swedish grid is already congested because of bottlenecks

1 If production is fired by e.g. biomass or biofuels or hydrogen the emissions can be considered as low

COMPARISON OF FUTURE DEMAND AND SUPPLY OF STABLE POWER

Maximising RES production leads to an additional need for flexibility to ensure stable supply

QUALITATIVE IMPACT FOR FLEXIBILITY OF SCENARIOS

Need in system

+++ **High need**
+ **Less need**

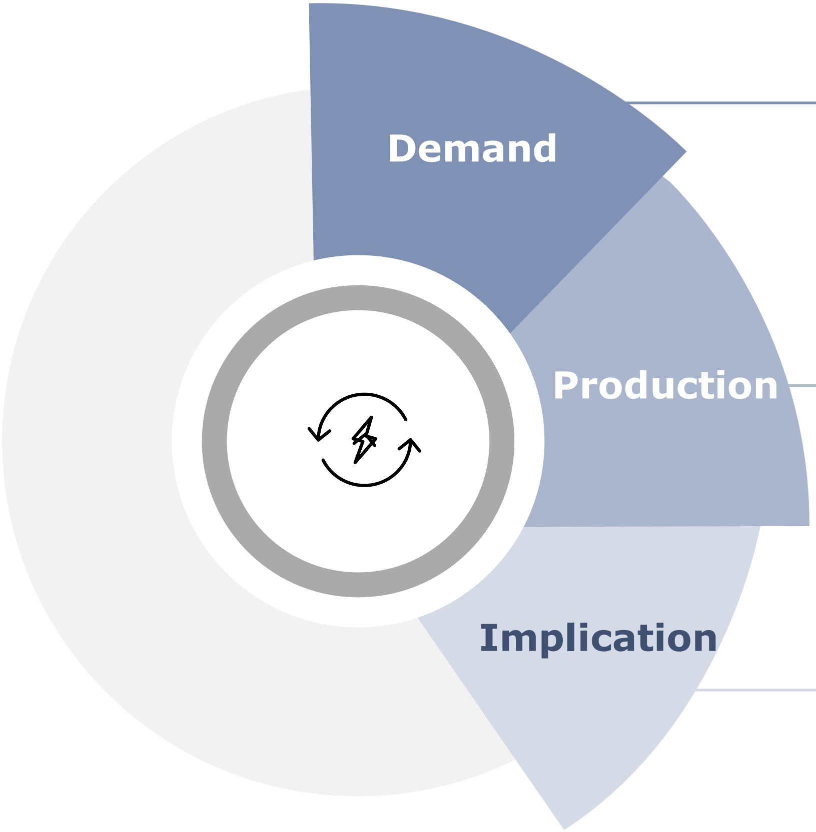
	Nuclear phase out	Nuclear extension
RES	+++	++
Electrolysis	+++	++
Pumped storage	+++	++
Interconnection	+++	++
DSR	+++	++
Batteries	+++	++
Peakers	+++	++
Grid (Internal)	+++	++

COMMENTS

- In both scenarios, increasing RES generation means that the need for flexibility grows with increasing demand
- Assumed lengthening of current nuclear operating lifetime would not be enough to satisfy the expected stable demand of future
- An even larger gap is shown in stable production in the scenario where nuclear permissions are not extended
- Slightly less RES is required when nuclear plants are kept open
- In addition, slightly less flexibility is required (from all sources) due to more stable supply from nuclear

AFRY ÅF PÖYRY

New stable supply is needed in Finland to satisfy the increasing future demand – this can be achieved by increasing stable production or flexibility



Demand
- Through announced future investments the electricity demand in Finland can grow to a level of ~150 TWh/a by 2050
- Over 100 TWh/a of the total demand is estimated to be inflexible (i.e. baseload)

Production
- In the assessed scenarios ~50-70 TWh/a out of 150 TWh of electricity production can be classified as adjustable production[1] in 2050

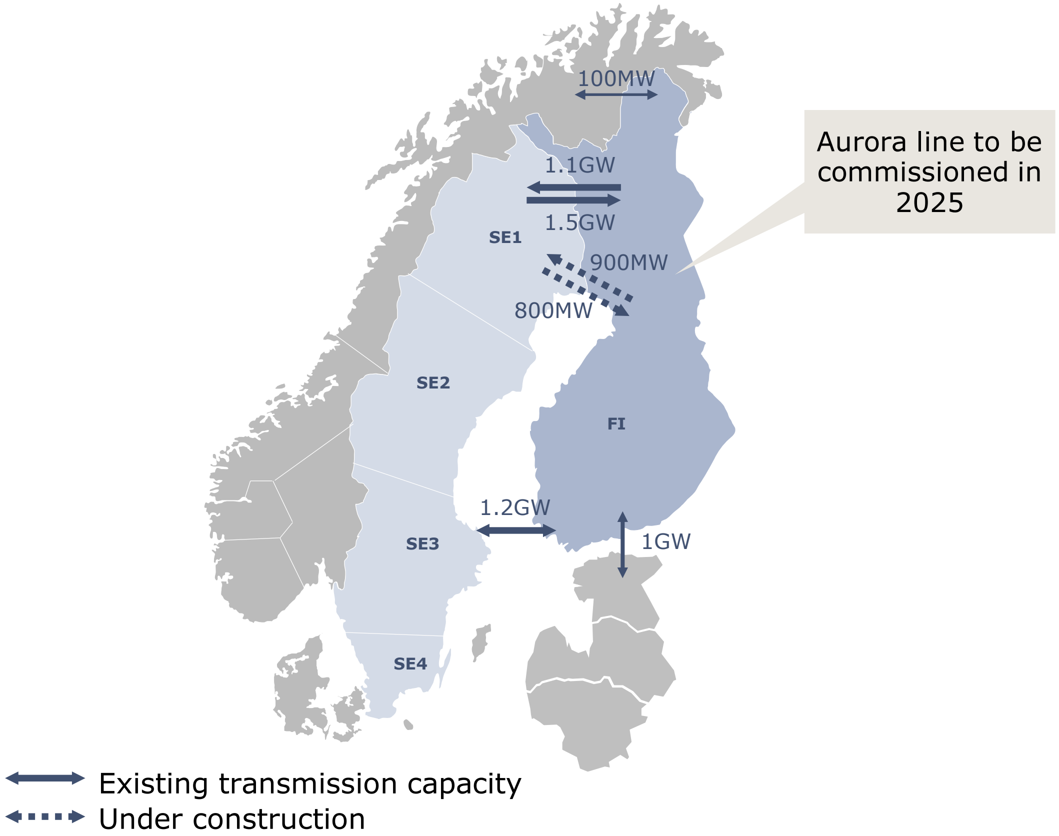
Implication
- More stable supply is needed to bridge in the gap of future demand and supply
- This can be achieved through more stable production capacity or higher flexibility on a system level

1 Adjustable production here means a production technology that can be adjusted according to market conditions, and not requiring flexibility for stable supply.

Needs for stable energy supply in Sweden

Significant capacity of transmission lines to Sweden makes future demand of Sweden also relevant to Finnish power production

TRANSMISSION LINES CONNECTING FINLAND TO NEIGHBOURING COUNTRIES



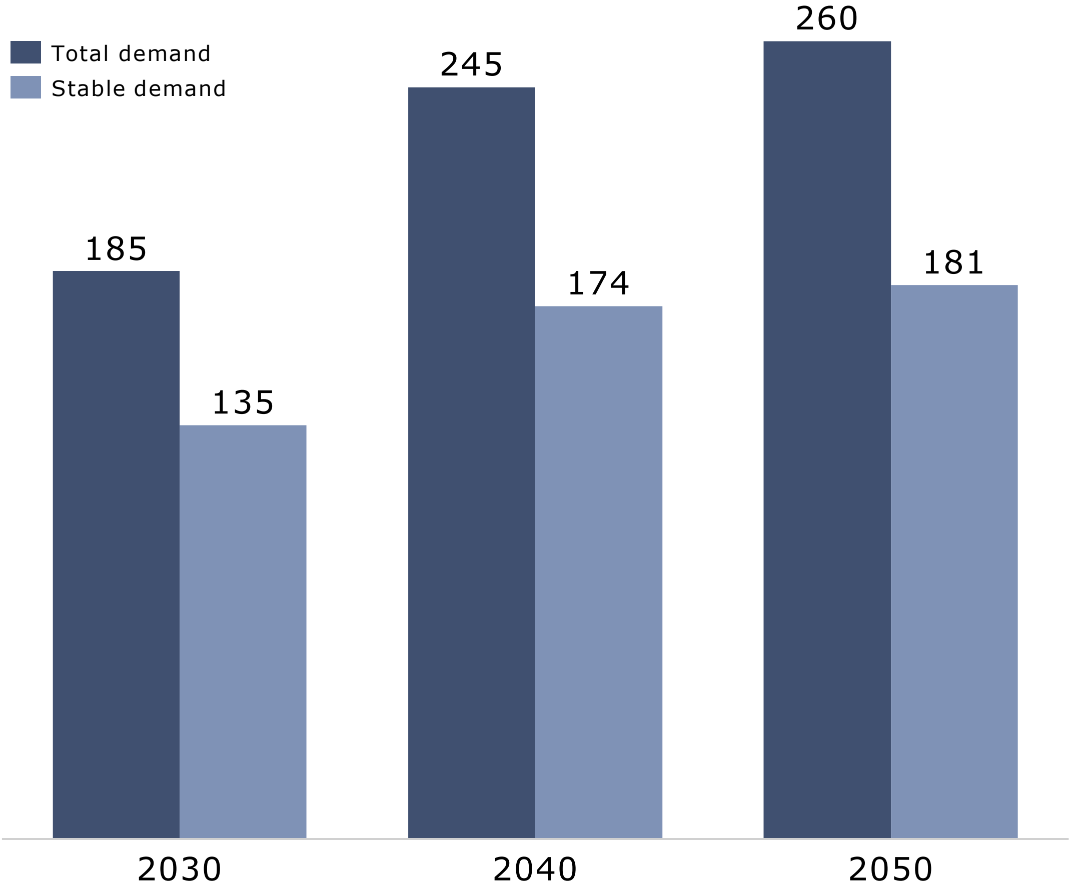
COMMENTS

- Finland has working transmission lines connecting to Sweden, Estonia and Norway
- Fenno-Skan 1 and 2 connect price zones FI and SE3 in the south with a combined capacity of 1.2GW
- In the north, there exists 1.1GW capacity from FI to SE1 and 1.5GW to the other direction
- Soon Aurora line will be adding transmission capacity from FI to SE1 by 900MW and from SE1 to FI by 800MW
- Aurora line has been announced to be commissioned in 2025
- All of the nominal capacity expressed here is not available for energy trading purposes as some of it is reserved for system protection purposes
- However, the existing and future transmission capacity makes Finland especially well connected to northern Sweden where electricity demand is expected to grow in the future[1]

1 There are several energy intensive projects being planned to northern Sweden, e.g. battery, steel and hydrogen production

According to *Energimyndigheten* the total electricity demand in Sweden can grow to ~260TWh/a by 2050 – Stable demand could grow to ~180TWh/a

TOTAL DEMAND VS. STABLE DEMAND - TWH



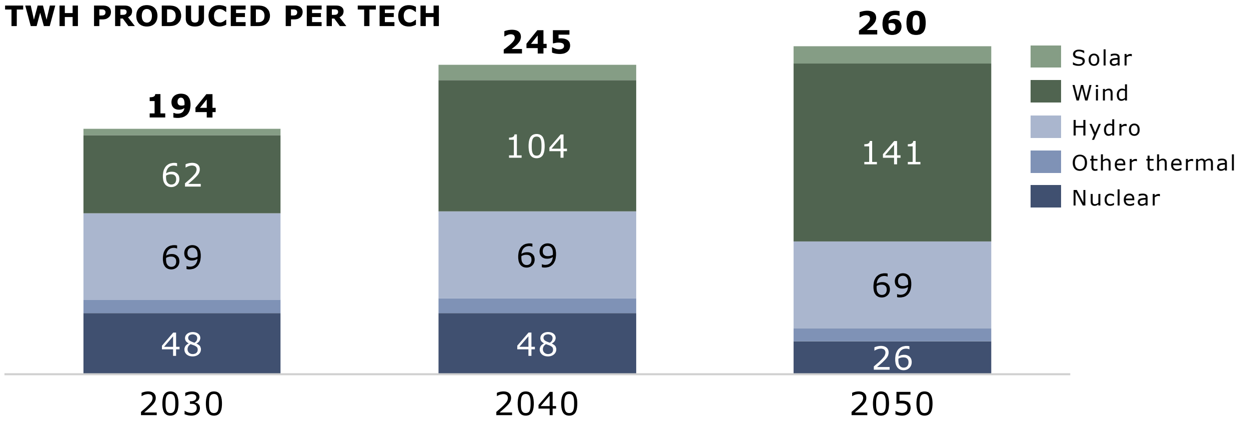
COMMENTS

- A projection[1] of the *Swedish energy agency* is used as a possible outlook for future electricity demand in Sweden
  - Out of the three scenarios formed by Energimyndigheten the scenario of *lower electrification* is assessed here
- The total demand could grow to ~260TWh by 2050
- Similar proportions of the total demand are assumed to be flexible as in the Finnish system. That is,
  - ~20% of flexible demand in 2030 growing to
  - ~30% of flexible demand in 2050
- Through these assumption the need for stable electricity could grow to ~180 TWh by 2050 in Sweden

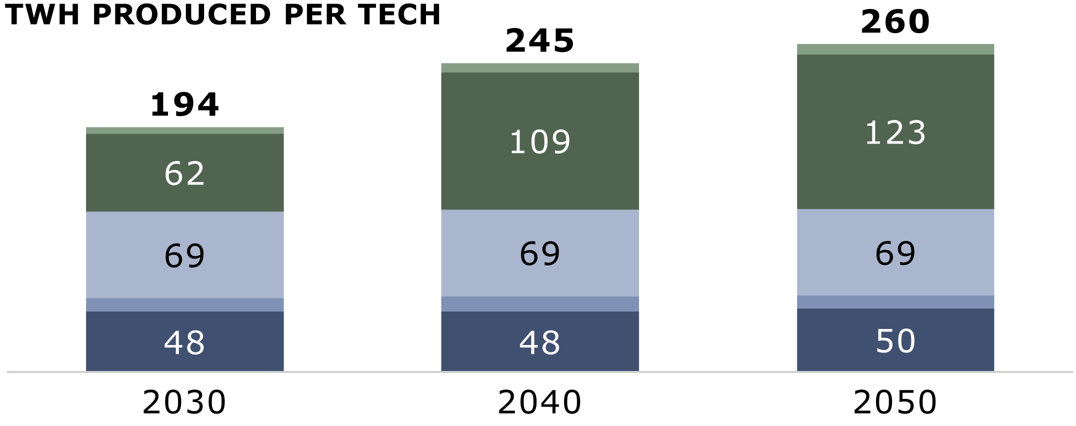
1 https://www.energimyndigheten.se/49428c/globalassets/statistik/prognoser-och-scenarier/langsiktiga-scenarier/langsiktiga-scenarier-over-sveriges-energisystem-2023.pdf

Sweden has a large proportion of hydro power in the system – otherwise the scenarios are similar to the Finnish cases

NUCLEAR SHUTDOWNS SCENARIO – TWH PRODUCED PER TECH



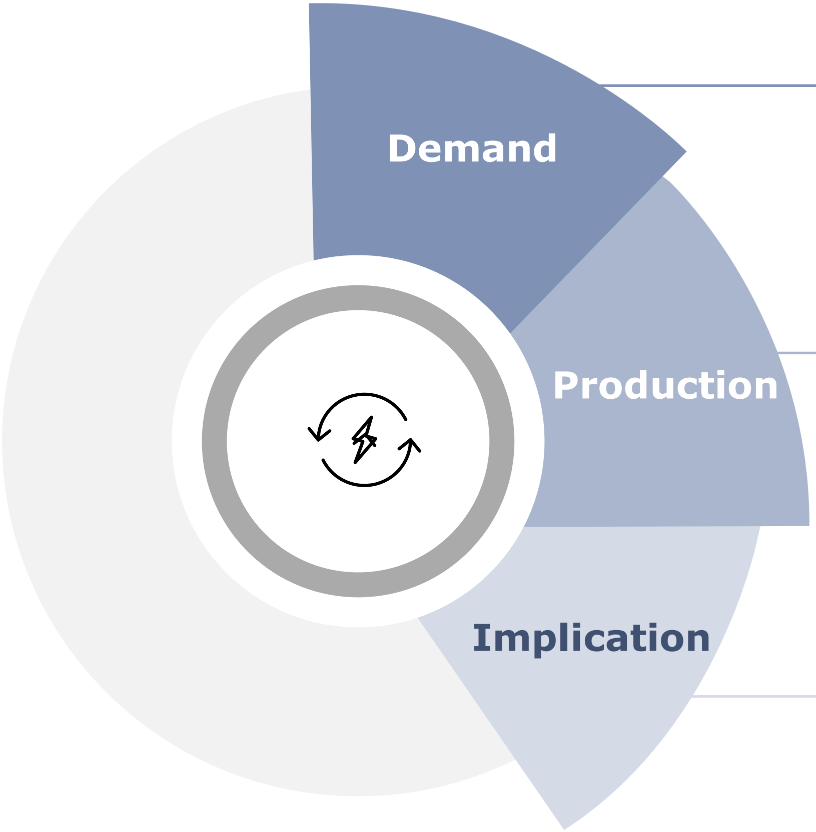
NUCLEAR EXTENSIONS SCENARIO – TWH PRODUCED PER TECH



COMMENTS

- Sweden has a large amount of hydro power in its portfolio compared to Finland
  - This raises the proportion of adjustable production
- Otherwise, the scenarios are similarly formed as for Finland:
  - Aging nuclear production is either shutdown or extended until 2050
  - Energy balance is met with new renewable capacity
- Wind power production grows substantially in both scenarios
- Nuclear shutdowns would lead to a decrease in the adjustable production to 105 TWh/a by 2050 (Top graph)
- Nuclear extensions would keep the adjustable production at a constant level of ~129 TWh/a (Bottom graph)

Similar development can be expected in Sweden as in Finland - new stable supply will be needed in the future

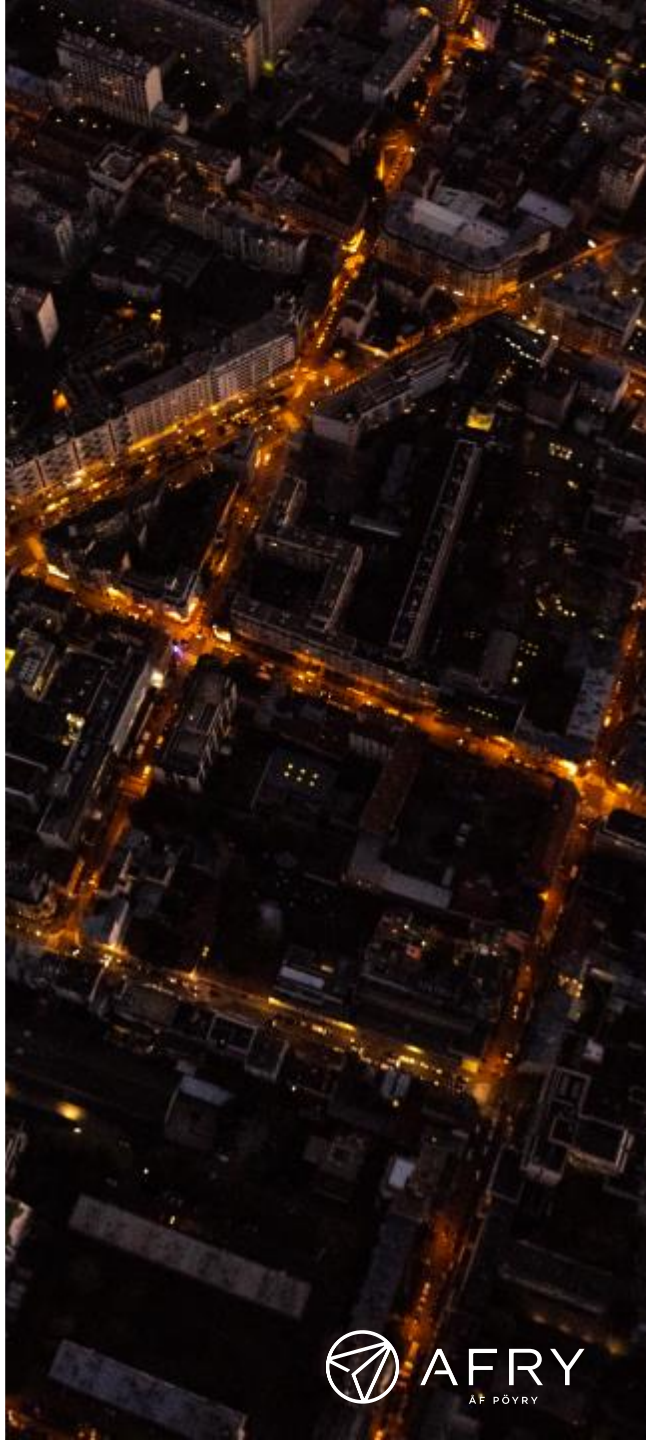


- Electricity demand will grow. It can be expected to grow to ~260 TWh/a by 2050
- Inflexible demand (baseload) can be expected to cover ~180 TWh/a by the same time

- In the assessed scenarios about 110 or 130 TWh/a of production can be described as adjustable production in 2050

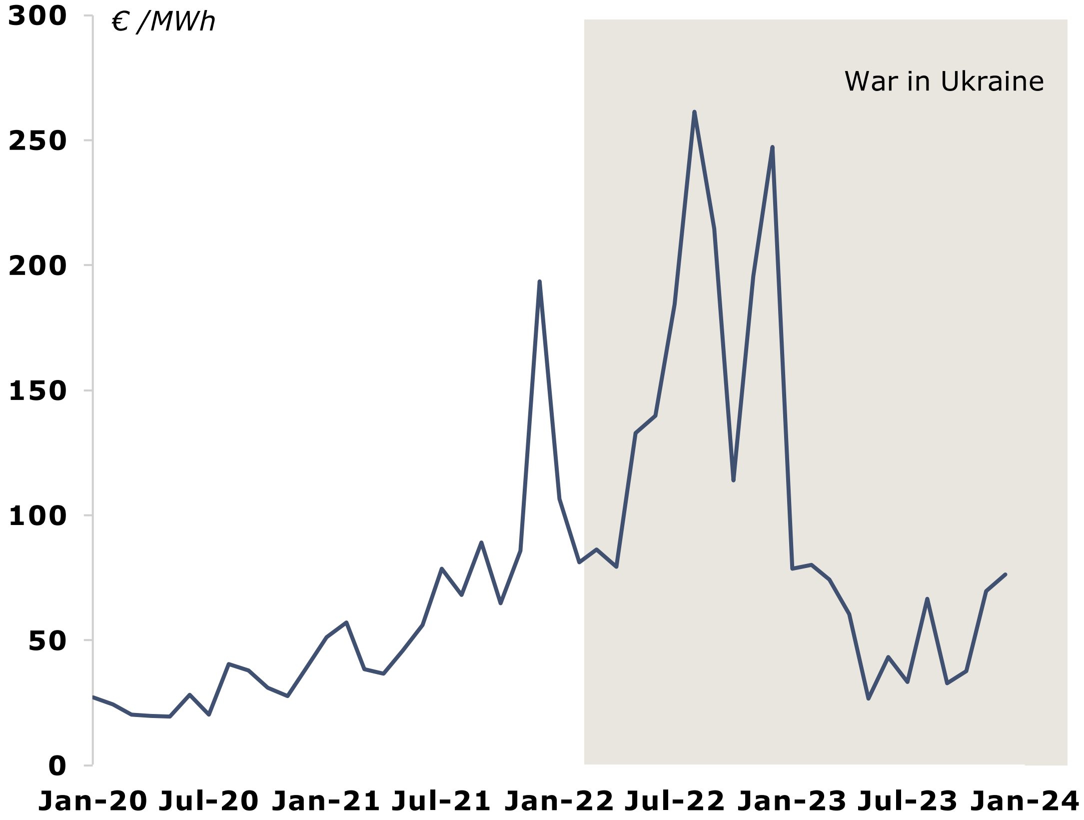
- As in Finland, more stable supply is needed – either in form of stable production or higher flexibility (See pages 21 and 22)

Content



The Ukraine war resulted in spiking electricity prices resulting in a political debate on affordability

FINNISH ELECTRICITY PRICE ROSE SHARPLY IN 2022-2023…



…RESULTING IN PUBLIC DEBATE AROUND AFFORDABILITY

Poll: More than half of Finns worry about electricity bills

Finland preparing new measures to help consumers meet rising energy costs

Government survives confidence vote over electricity prices, Fortum

Energy Authority: Electricity prices rose 142% in 2022

Save electricity on Friday – spot prices are up to 20 times higher than normal

Sources: Left: Nordpool; Right: YLE, TEM

In addition, security of supply has been sharply in focus

RECENT SITUATION IN ELECTRICITY MARKET

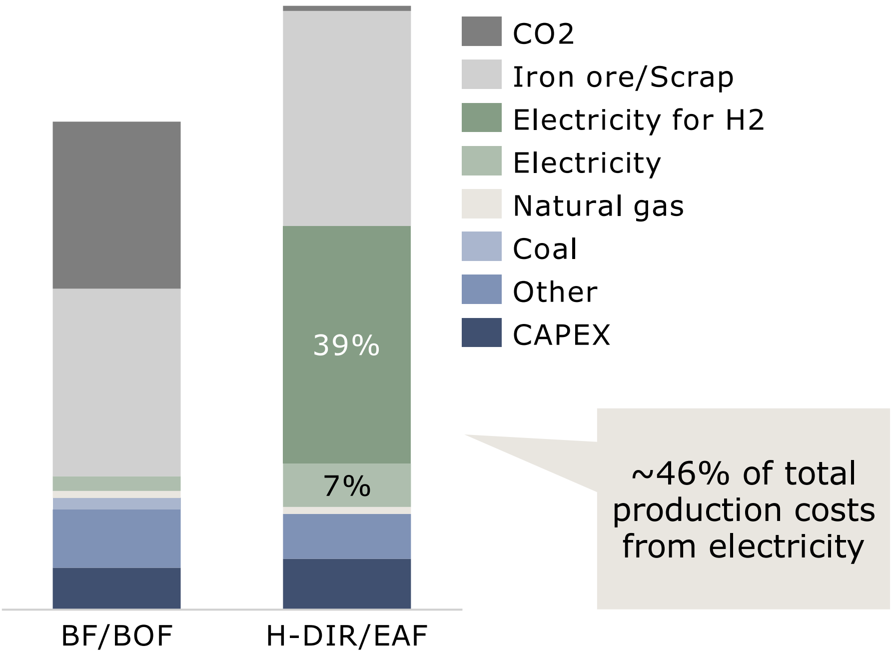
- Security of supply and high electricity prices have been in focus recently.
- In general, the situation during this winter (2023-2024) has been good. According to the Fingrid, the adequacy of electricity could be weakened during consumption peaks if simultaneous disturbances arise in important production plants or electricity transmission connections.
- 5th of January 2024, the price of electricity in Finland was record high, even more than 2 €/kWh between 19:00-20:00 EET.
- Previous day (4th of Jan 2024) Fingrid called for electricity flexibility in very cold weather and Fingrid announced to increase readiness due to tightening electricity power balance situation. Due to flexible consumption, the situation was not as strained as anticipated.

FUTURE

- Finland's electricity production is changing considerably in next few years.
- Fingrid's adequacy analysis highlights potential challenges with electricity adequacy, especially during longer periods (days to weeks) of cold weather and low wind production or a disruption in the availability of production plants or cross-border connections
- Huoltovarmuuskeskus has reserved the Meri-Pori coal condensing power plant to be in reserve in case of severe disturbances or crisis. The agreement with Fortum is signed for the period of 1.3.2024-31.12.2026
- The Programme of Prime Minister Petteri Orpo's Government (20th of June 2023) states that the Government will implement cost-effective capacity mechanism to support system adequacy. Ministry of Economic Affairs and Employment (TEM) has the lead in the matter
- In public, there has been discussions to involve nuclear power plants, gas fired peak power plants and pumped hydro power plants into the possible upcoming capacity mechanism

New industry based on the green transition requires low-cost carbon free electricity to be competitive (*e.g.* Case green steel[1])

STEEL PRODUCTION COST BREAKDOWN (EUR/T) 2030



COMMENTS

- Currently ~60% of steel produced in EU is based on *Blast Furnace/Basic Oxygen Furnace* (BF/BOF) route defined by a study from European Parliament[2]
- The same steel is suitable for *Hydrogen direct reduction of iron* (H-DRI) route which is low-emission
- The primary route of future combining H-DIR and *Electric Arc Furnaces* (EAF) is much more electricity intense than the BF/BOF route
- ~46% of the total costs of a ton of steel in the low-emission H-DIR/EAF route are estimated to be electricity cost
- To enable the transition to green steel production in large scale, the industry needs access to low-cost carbon free electricity

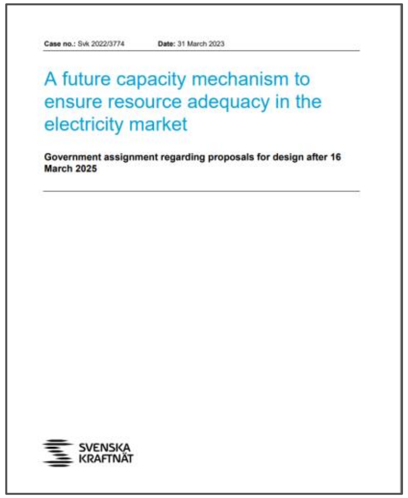
1 Green steel is only one example of electricity intensive sectors – Other relevant sectors include, for example, e-fuel
2 Source: *Carbon-free steel production,* Study by European Parlamentary Research Service, April 2021

Capacity mechanisms for the electricity market are now openly discussed in Finland and Sweden

FINLAND

- AFRY paper in 2023 June (at request of Fingrid)
- Paper defined capacity adequacy issue in Finland and presented CRM alternatives to be considered
- As well as enduring CRM, interim solution is required before 2027 when an enduring solution is needed
- Now on TEM desk for next steps

SWEDEN


Case no.: Svk 2022/3774 Date: 31 March 2023

A future capacity mechanism to ensure resource adequacy in the electricity market

Government assignment regarding proposals for design after 16 March 2025

SVENSKA KRAFTNÄT

- SvK (Svenska Kräftnät, Swedish transmission system operator) paper in March 2023
- SvK instructed by Swedish government to propose CRMs to replace Swedish power reserve
- SvK proposed market wide CRM to be introduced by 2025
- SvK noted market wide CRM unlikely to be in place by time the current power reserve expires – interim solution also required

Energy system reforms are being prepared also on the EU-level to protect consumers, to increase competitiveness and to support green transition

§

- The **Electricity Market Reform (EMR)** is a collection of proposals from the European Commission, published on March 14th 2023
- It envisages changes to existing regulations like the **Electricity Regulation, the Electricity Directive, and the REMIT Regulation**

PROTECT EU CONSUMERS

- The energy crisis revealed how exposed consumers are to spot market prices and the short-term cost of fossil fuels
- The intention is for consumers to be better protected against volatile (and high) electricity prices

INCREASE INDUSTRY COMPETITIVENESS

- Ensure access to clean and affordable energy for the European industry, including electrification where possible

MORE ENERGY FROM RENEWABLE SOURCES

- This is expected to be achieved with more RES[1], and contracts that both protect RES from low prices and price volatility and at the same act as a hedge for demand
- However, there are no proposed changes to the marginal pricing philosophy in spot markets and no interference with short-term price formation

Sources: European Commission (EC); Electricity Market Design revision: Proposal to amend the Electricity Market Design rules & Proposal to amend the Wholesale Energy Market Integrity and Transparency (REMIT) Regulation as well as all related staff working documents and recommendations 1 RES – Renewable energy sources

Finland and Sweden are both updating their nuclear regulations to ease the implementation of new capacity

- Nuclear regulation often follows the social acceptance of nuclear power. After accidents regulatory updates are often made regarding current and upcoming nuclear power production. Historically the effect of regulatory changes to Finnish nuclear production capacity development have been minor.

- Finland and Sweden are both in the process of updating their national nuclear regulations. The coming updates aim to easen implementation and market entry of SMRs[1] and conventional large scale nuclear power in the future. The national regulation can affect this especially through licensing.

- Governmental sentiments in Finland and Sweden towards extending existing nuclear licences are positive. Also new nuclear licenses will be granted, if the requirements will be fulfilled, and governments might be willing to guarantee loans for new builds

- Lately the European Union has also tried to give guidance on standardization, strengthening of supplier networks and financing regarding nuclear power production. More work is, however, needed if the aim is to effectively unify the national legislation that differ between member countries.

1 Small Modular Reactor

Nuclear is viewed as sustainable and thus a part of EU taxonomy, for now, with strict conditions that are fulfilled by Finland

The EU taxonomy harmonizes what can be considered as sustainable, guiding new investments

Debated inclusion of nuclear power

- EU Joint research commission and other independent expert groups deemed nuclear sustainable on the same grounds as other sustainable solutions.
- European commission is being sued by environmental campaigners (18 April 2023) for inclusion of nuclear in taxonomy as "green" investment

There are restrictions on the inclusion of nuclear power

- R&D and the introduction of advanced technology are included without restrictions
- Modifications and upgrades to extend the service life of existing nuclear installations shall be recognized until 2040
- New nuclear construction projects shall be based on best available techniques until **2045 (date of approval of the building permit)**

A new nuclear power plant to be built at Pyhäjoki site needs to obtain the approval **before 2045**

This timetable is the reason why nuclear energy is considered a **transitional** solution

The inclusion of nuclear power is subject to strict conditions that are met by Finland

- Lifecycle greenhouse gas emissions shall be less than 100g CO2e/kWh
- From 2025, existing and new construction projects will have to use accident-tolerant fuel, certified and approved by the national regulatory authority
- There must be funds available for waste management and decommissioning
- Operational capacities shall be in place for the disposal of low and intermediate-level waste streams

The conditions are met only in **Finland**, France and Sweden, mainly due to the readiness of the final disposal facilities for high-level nuclear waste

Finland holds a strong position within the European Union in terms of Nuclear taxonomy, owing to its early investment in a final waste disposal site. It is among the select few countries in the EU that can boast this achievement.

https://www.world-nuclear-news.org/Articles/Nuclear-and-gas-criteria-set-for-inclusion-in-EU-t
https://world-nuclear-news.org/Articles/European-Commission-presents-text-of-taxonomy-CDA

Only SMRs and advanced nuclear technologies can benefit from Net Zero Act framework so far

- 13.03.2023 the Commission proposed the Net-Zero Industry Act to scale up manufacturing of clean technologies in the EU. Current draft legislation could still be amended by the European Parliament
- The proposed legislation defined the technologies contributing to decarbonization, and among those are the advanced technologies to produce energy from nuclear processes with minimal waste from the fuel cycle, small modular reactors, and related best-in-class fuels. These eligible technologies benefit from Net zero act framework that has 3 axis:

Simplifying the regulatory framework for net-zero technologies

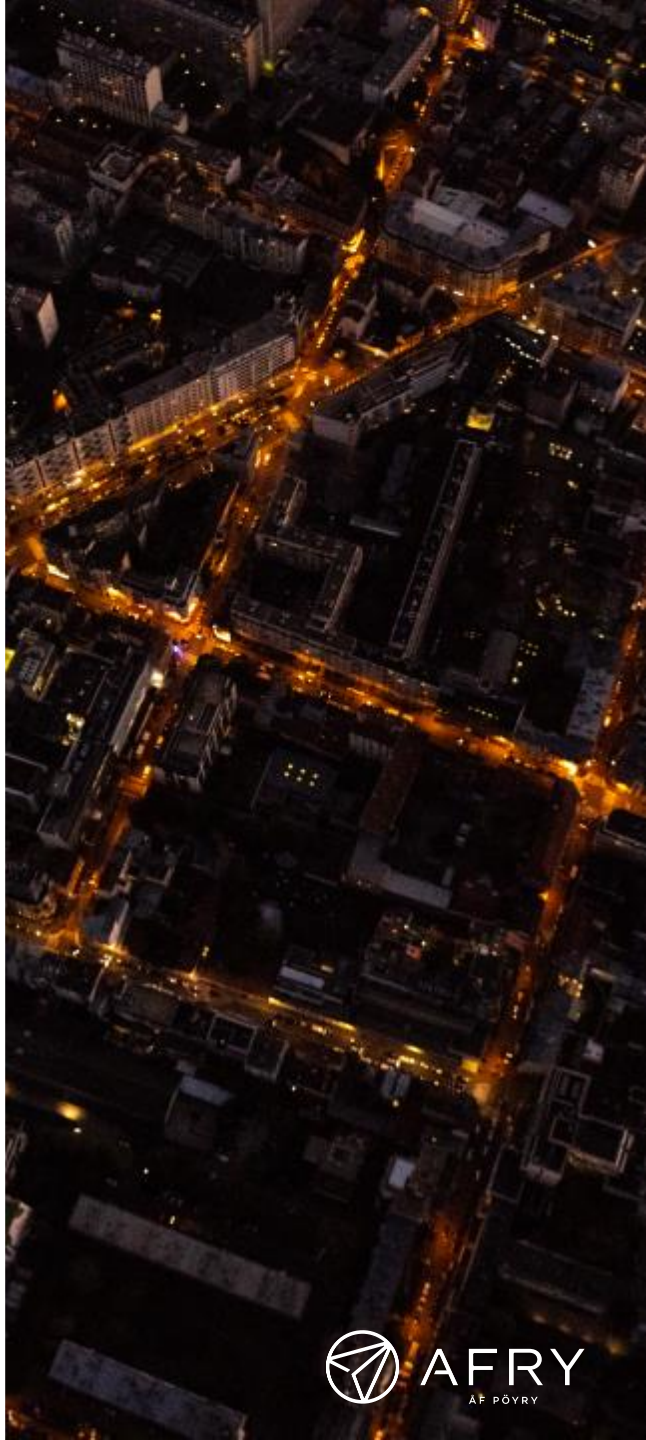
Scaling up manufacturing of net-zero technologies

Fostering competitive and resilient european net-zero industry

- There is a need for more forward-looking analysis of standardization, as well as analysis that charts different future scenarios. For example, the following topics should be examined: a supranational actor that could promote standardization, the risks of EU-driven standardization, the impact of standardization on technology suppliers, the effects of SMR, new supplier networks outside the EU and the EU's attitude towards non-EU actors
- The French government is pushing for the inclusion of all nuclear technologies beyond emerging technologies within this new industry plan since advanced technologies are not market ready yet

Sources : Net Zero Industry Act proposal

Content



EU and national objectives for hydrogen

Demand and use cases for hydrogen

The European Commission has set ambitious targets for European hydrogen production in its Hydrogen Strategy and RePowerEU initiative

- According to the "**hydrogen strategy for a climate-neutral Europe**" published by European Commission in 2020**,** EU considers hydrogen as the most compatible option with the EU's climate neutrality and therefore the priority for the EU is to develop renewable hydrogen, produced using renewable energy. In the first phase, from 2020 up to 2024, the strategic objective is to install at least 6 GW of renewable hydrogen electrolysers and the production of up to 1 million tonnes of renewable hydrogen to decarbonize existing hydrogen production in EU
- Based on AFRY estimates, the 1 million tonnes H2 target would require 11 GW of offshore wind capacity
- In a second phase, from 2025 to 2030, the EU's "**hydrogen strategy for a climate-neutral Europe"** sees hydrogen becoming an intrinsic part of an integrated energy system with a strategic objective to install at least 40 GW of renewable hydrogen electrolysers by 2030 and the production of up to 10 million tonnes of renewable hydrogen in the EU. REPowerEU, sets a target of producing 10 million tonnes of domestic renewable hydrogen and importing 10 million tonnes of renewable hydrogen by 2030
- By 2030, all Member States would have hydrogen included in their National Energy and Climate Plans

By 2025

+11 GW **offshore wind**[1,2]

+6 GW **Electrolyser capacity**

+1 Million tonnes **H_2**

By 2030

+115 GW **offshore wind**[1,2]

+ 80 GW additional wind and solar

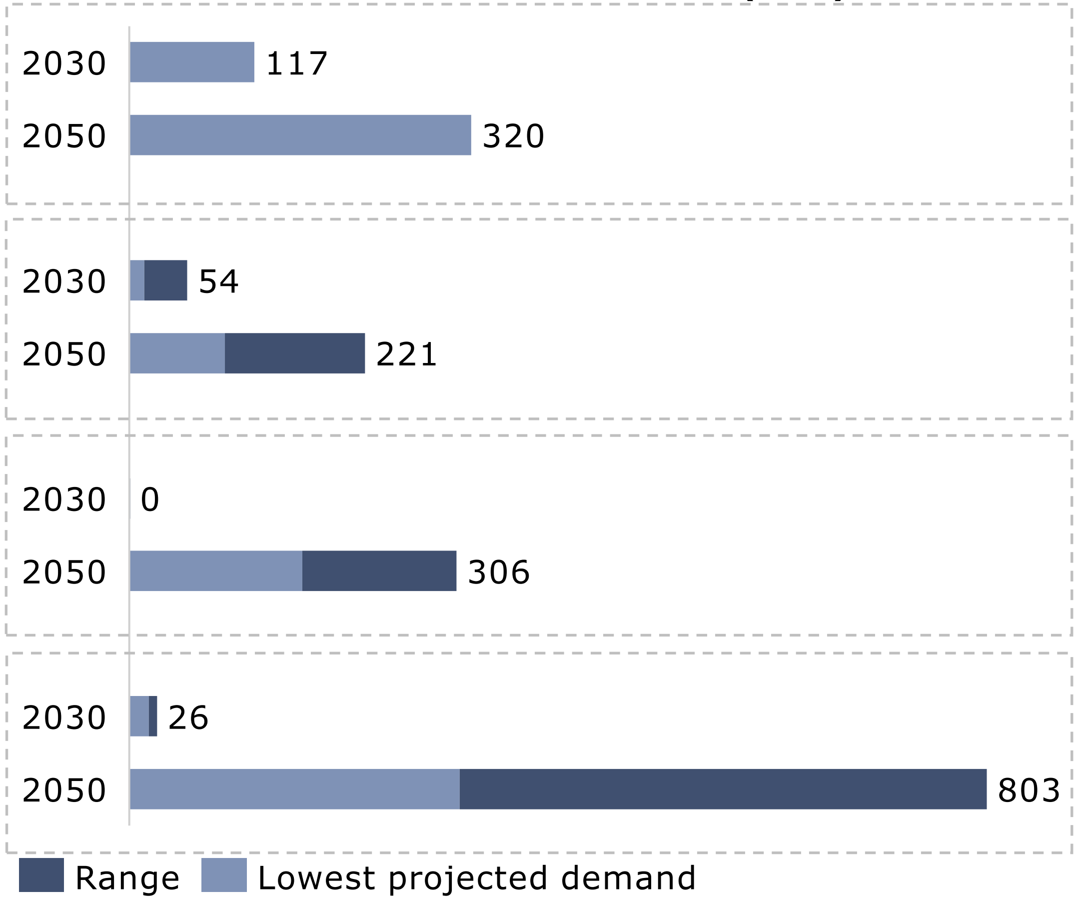
+40 GW **Electrolyser capacity**

+20 Million tonnes of **H_2**

Sources: REPowerEU, 2022; Hydrogen strategy, 2020. Notes: 1. Based on AFRY estimates. 2. Requires grid balancing and/or battery storage to achieve load factors based on electrolyser capacity and production targets

Hydrogen demand is forecast to grow across the EU to 2050, providing between 18-34% of total energy demand by 2050[1]

HYDROGEN DEMAND BY SECTOR IN EUROPE (TWH)



KEY DRIVERS

Industrial sector

- Replacement of 117TWh of grey hydrogen by 2030
- Replacement of fossil fuels for some industries using high temperature heat
- New process uses in steel and chemical industries

Transport sector

- Heavy trucks and long-haul freight, buses and trains
- Maritime and shipping (ammonia, methanol, methane)
- Aviation (synthetic fuels)

Power sector

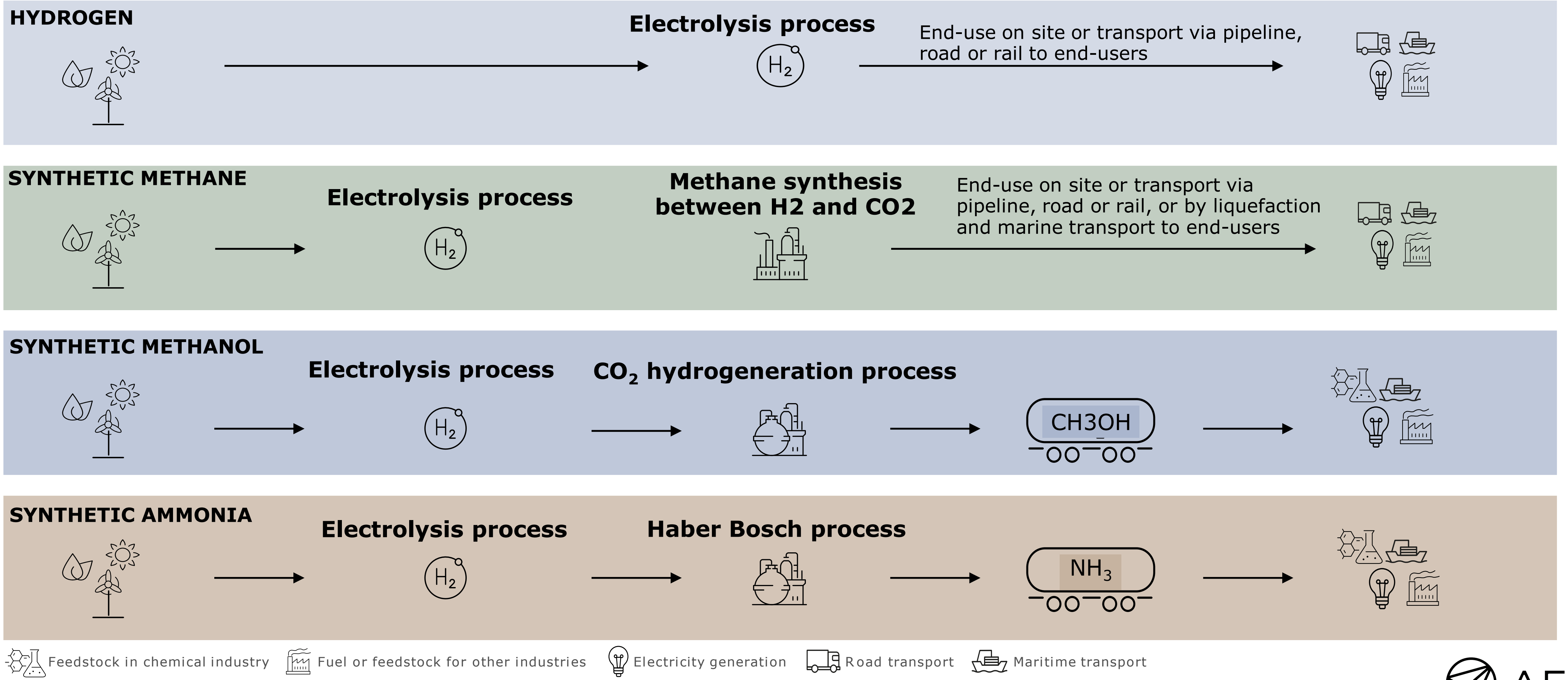
- A strategic role providing flexibility and security to power systems with long- and short-term storage
- Utilization of 'excess' renewable generation
- Direct H_2 use in power generation is not a foreseen market in the Nordics

Heating sector

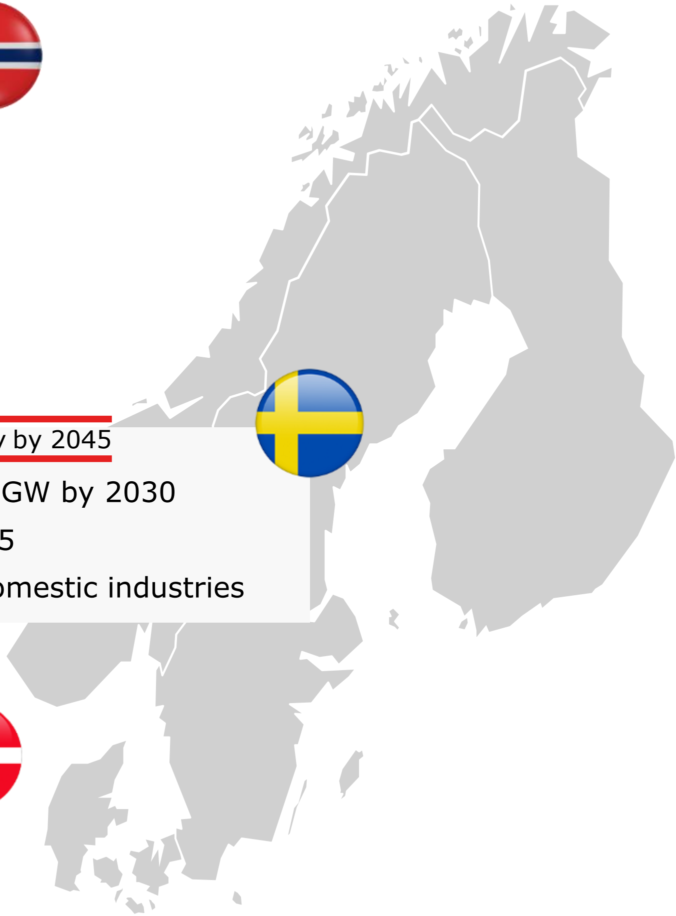
- Space heating with hydrogen boilers or hybrid heat pumps to replace gas and other fossil fuels
- Use in space heating is a key uncertainty and not foreseen in the Nordics

1) EU level scenarios by IEA

Hydrogen can be used directly in industrial processes (steelmaking, oil refining, high-temperature heating) or as processed into multiple chemicals or fuels (so-called PtX)



National hydrogen strategies differ from each other in the Nordics



Norway Carbon-neutrality by 2030

- No definitive electrolyser capacity targets
- RDI support for maritime and heavy road transport projects
- Collaboration with other countries

Sweden Carbon-neutrality by 2045

- Electrolyser capacity 5 GW by 2030
- Another 10 GW by 2045
- Weight on supplying domestic industries

Denmark Carbon-neutrality by 2050

- Electrolyser capacity 4-6 GW by 2030
- Emphasis on exports

Finland Carbon-neutrality by 2035

- Electrolyser capacity 1 GW by 2030
- Blending obligations for e-fuels starting from 2023 and raised to 3% by 2030
- Weight on supplying domestic industries first, exports secondary
- The new Government of Finland will propose an updated national hydrogen strategy for the Finnish Parliament in spring 2024

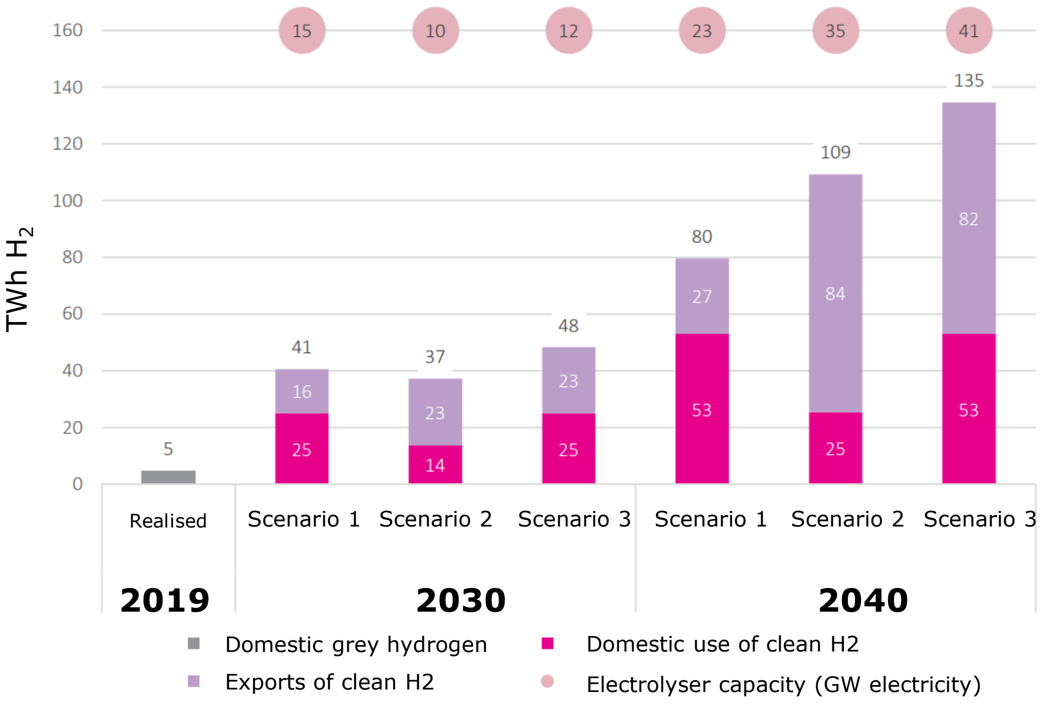
Finland has potential to cover the country's domestic demand of hydrogen plus 10% of the European PtX market over the long term

BACKGROUND FOR FINGRID-GASGRID SCENARIOS

- Fingrid and Gasgrid published scenarios in May 2023 on Finland's future energy infrastructure where investments in electrification and hydrogen economy are both included
- In all the three published scenarios, the following assumptions apply:
  - Renewable hydrogen replaces fully the grey hydrogen used in Finland and there is new use of hydrogen in the steel industry
  - Aurora line, i.e. electricity transmission line between Sweden and Finland, is in use
  - A hydrogen transmission pipeline, the so-called Nordic Hydrogen Route, is commissioned between Finland and Northern Sweden, as well as several domestic hydrogen pipelines and hydrogen storage facilities
- In addition to the above, the following assumptions apply per scenario:
  - Scenario 1. Finland also produces H2 and PtX for export to Sweden
  - Scenario 2. Finland also exports H2 to Sweden and Central Europe
  - Scenario 3. Finland also produces and exports H2 and PtX to Sweden and Central Europe
- All the scenarios forecast an electrolyser capacity of **10-15 times the existing national target of 1 GW by 2030.** Hence the assumed speed of change is dramatically more rapid than what is assumed in the current energy and climate strategy of Finland

Sources: Fingrid, Gasgrid Finland, 2023 (link)

FINGRID AND GASGRID SCENARIOS TO 2040



Conclusions

- Finland has a major potential to become a PtX and hydrogen producer for both domestic end-use and for export.
- Fingrid and Gasgrid scenarios are based on the assumption that Finland could reach 10% of the European hydrogen and PtX market. Reaching this level is yet uncertain since investment decisions on industrial scale hydrogen projects have not yet been made (except 20 MW project by P2X Solutions in Harjavalta) and it is unclear how much of the proposed wind power capacity can be permitted
- Even though there is uncertainty over the scale of future hydrogen production in Finland, Finland is very well positioned in the international competition for hydrogen projects thanks to its carbon neutrality target, the commitment of transmission system operators to construct further infrastructure as needed, and the vast potential for growth in carbon neutral electricity production
- The proposed large increase of intermittent power production induces a need for discussion on the balancing of the future electricity system and the role of stable electricity production in this

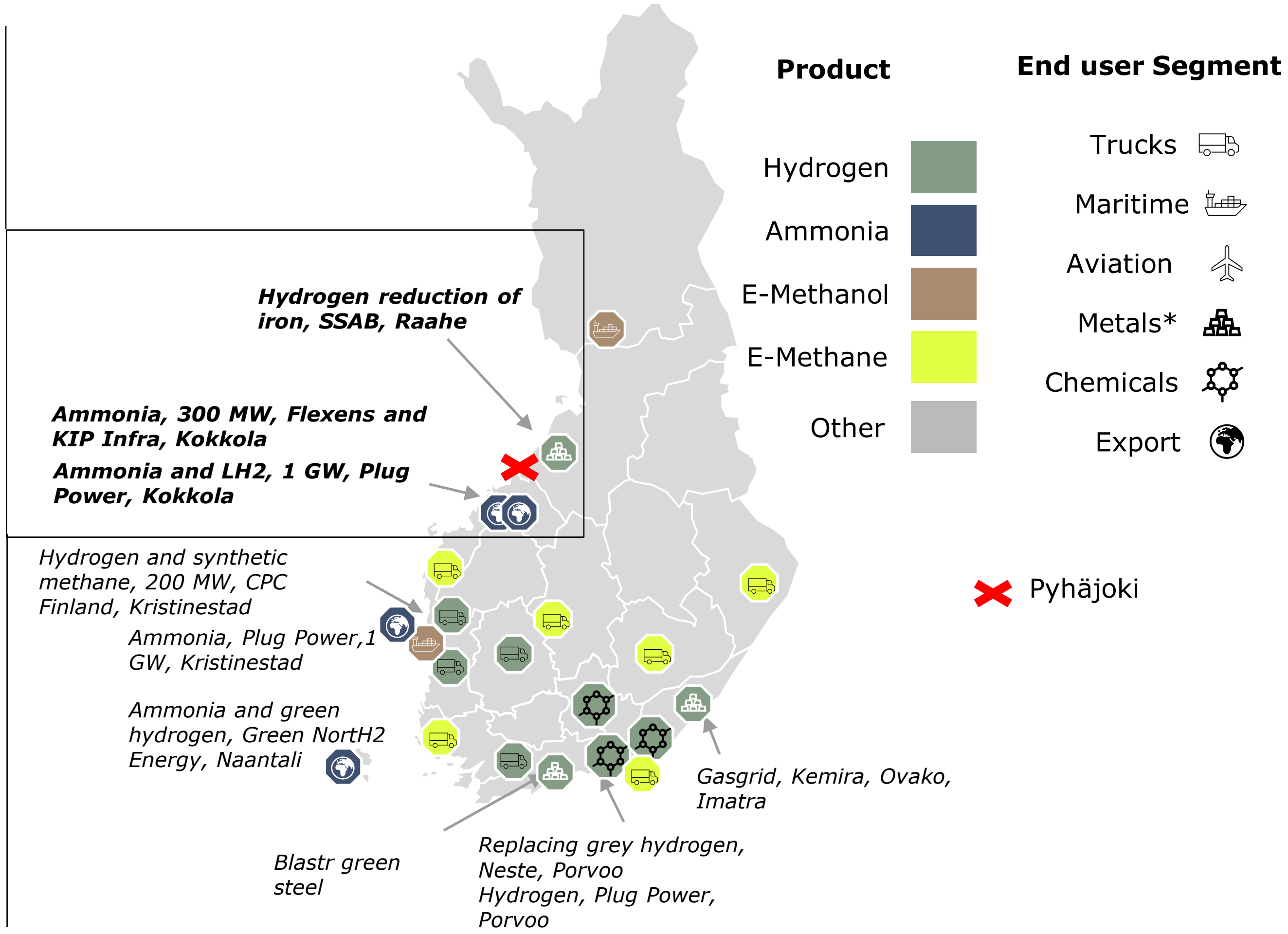
Hydrogen and PtX project status in Finland and Northern Sweden

Demand and use cases for hydrogen

Publicly announced projects in Finland focus on industrial decarbonisation in steel and chemicals, and the production of ammonia, hydrogen, methane, and methanol

Projects in the vicinity of Pyhäjoki

- SSAB announced on 5.06.2023 to launch FEED study exploring building hydrogen plant at Raahe to use hydrogen locally for its iron reduction purposes
- Kokkola chemical industry ecosystem has dozens of chemical and metal processing plants
- The readiness of Kokkola port, infrastructure and presence of heavy chemistry cluster made Kokkola an attractive hub for production of hydrogen and ammonia for local use and export
    - Flexens (Finnish start up) project for green hydrogen and **ammonia** production in Kokkola, announced start of operation by 2027 with a plant capacity of 300 MW which is the largest hydrogen project in Finland. Part of the hydrogen produced would be transported via a hydrogen transmission network to **Nordic Hydrogen Route** to which consumers would be connected. Flexens and Gasgrid plan to develop the needed local hydrogen infrastructure at Kokkola
    - Plug Power (US based) announced on 30.5.2023 a 1 GW electrolyser project at Kokkola to produce liquid hydrogen and **ammonia** for **export** via **Kokkola port** and for potential local industrial use

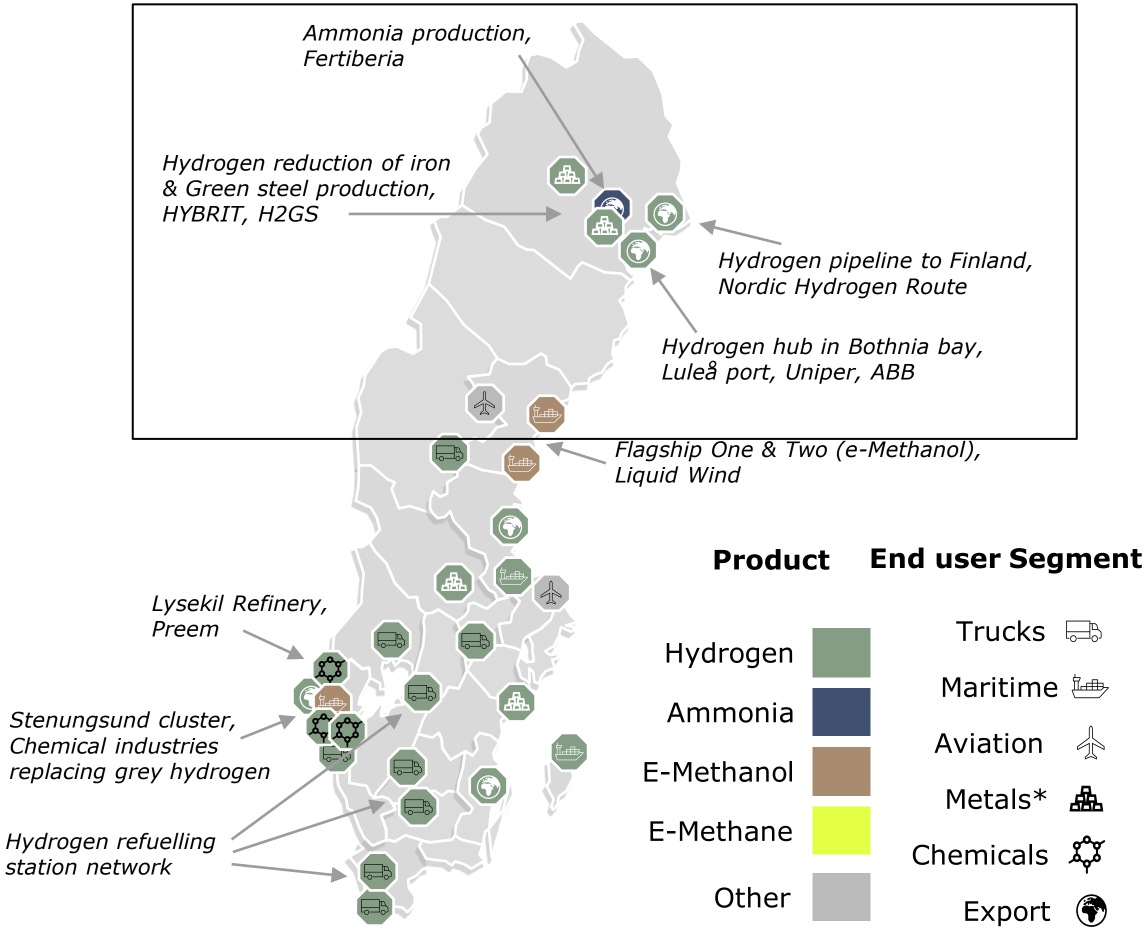


Source: Company announcements in public
FEED : Front-End Engineering Design

In the north of Sweden, hydrogen projects are clustered in Luleå-Boden region with a focus on green steel production

Projects in the north of Sweden

- The Swedish hydrogen production market in the north is focused on the green steel industry as well as ammonia and methanol production in Luleå-Boden region where renewable electricity is available. Luleå-Boden region would be connected to the Nordic Hydrogen Route
- HYBRIT initiative have pushed the international technology development regarding hydrogen reduction of iron and green steel production. **LKAB** plans to produce hydrogen needed for sponge iron manufacturing, a product that is then processed into green steel by SSAB. H2GS plans to produce hydrogen using **1GW** electrolyser and produce onsite both green iron and green steel.
- Green Wolverine project for ammonia production plant using 600 MW electrolyser is planned to be operational by 2026 and would process ammonia into fertilisers and other industrial products
- There is also large plans for build-out of hydrogen refuelling station networks in multiple municipalities including Trelleborg in the north
- Multiple e-methanol plants, are already under construction
- Some small-scale pilot projects for hydrogen production that will be **directly connected to RES** are under development.



Selected hydrogen projects and prospects in Sweden per March 2023

Gasgrid Finland is actively developing domestic and international hydrogen pipeline projects

PRE-FEASIBILITY STUDIES ON-GOING

- Gasgrid Finland and Nordion Energi, the main gas grid operators in Finland and Sweden launched the **Nordic Hydrogen Route project** in spring 2022 to build a cross-border hydrogen infrastructure around 1000 km in Bothnian Bay region to transport and store hydrogen
  - NHR would in its current layout be located along the coast of Bothnian Bay in Finland and Sweden and reaching to the Kiruna in Swedish Lapland
  - Final investment decision is planned in 2024 and commissioning by 2030
- Six European TSOs signed cooperation agreement in winter 2022 to develop the **Nordic-Baltic Hydrogen Corridor**
  - This hydrogen pipeline network would connect Southern Finland with Baltic, Polish and German gas networks
- In winter 2022, Finnish and Swedish TSOs, and industry companies OX2 AB and Copenhagen Infrastructure Partners initiated the **Baltic Sea Hydrogen Collector**
  - This marine pipeline 1000 km would connect hydrogen production in offshore and onshore facilities with the mainland in Finland, Sweden, and Germany

Source: Gasgrid Finland, 2023

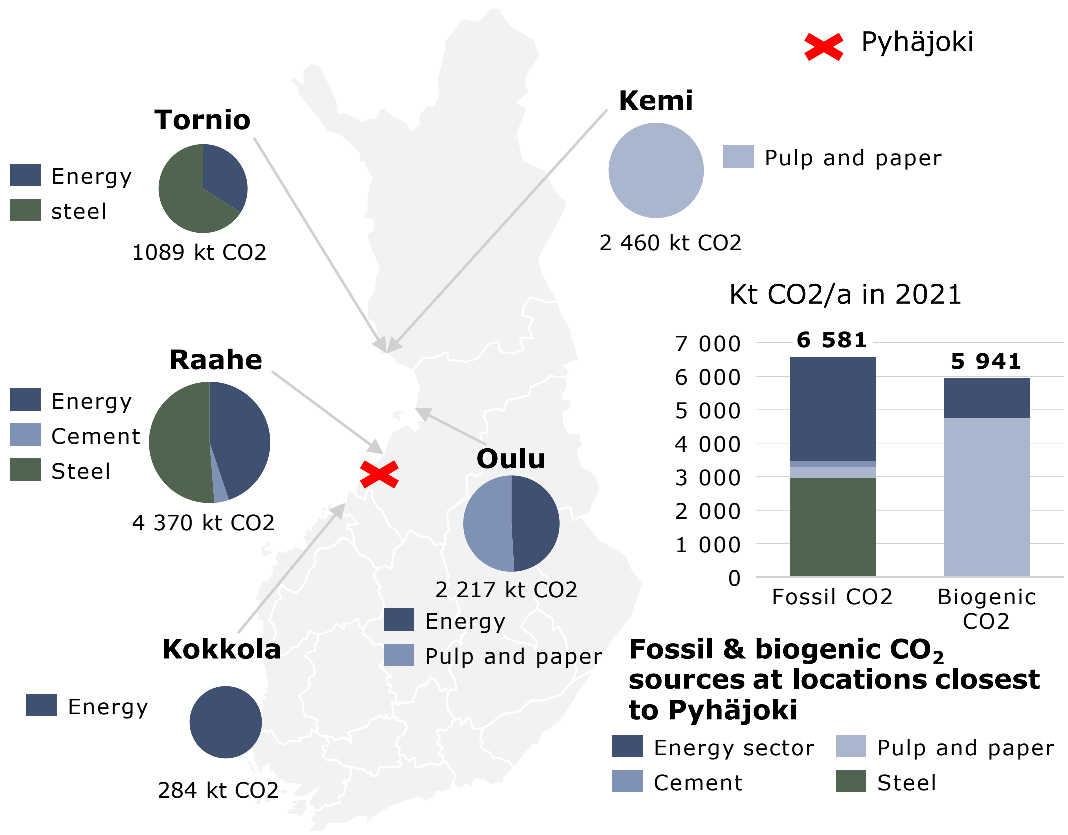
GAGRID FINLAND'S HYDROGEN PIPELINE PROJECTS IN 2023

AFRY ÅF PÖYRY

CO_2 availability becomes important factor for E-fuel production - largest CO_2 sources are currently in Raahe and Oulu

- The availability of CO_2 streams at high concentration is an important parameter when choosing the most promising location for PtX production since direct carbon capture from the air technologies are still in infancy and are more costly than CCU from a source
- The largest point source CO_2 emitters in the region are:
  - SSAB Europe Oy steel factory in Raahe
  - Energy producer Raahen Voima Oy
  - Stora Enso Oyj's pulp and paper mill at Oulu
  - Energy production plants of Oulun Energia Oy
  - Outokumpu Stainless Oy at Tornio
- Synthetic hydrocarbon fuels could be produced at the exact sites where high CO_2 concentration are emitted in Raahe, Oulu and Tornio
- Pyhäjoki is not a large CO_2 emitter. CO_2 would need to be transported via pipeline or trucks from the emitting sites (Raahe, Oulu and Tornio) to Hanhikivi site, but CO_2 transport is not yet an adopted technology
- **CO2 emissions are expected to progressively decrease:**
  - Energy production is still the sector with highest CO_2 emissions (mostly fossil). However, the path to decarbonization is not reliant on CCU but on lowering emissions by using fossil free fuels. Before 2030, the CO_2 from energy production would decrease
  - Steel production in Raahe and Tornio plan to phase out fossil fuels used as feedstocks and fuel and replace them with hydrogen and biogas

CO2 sources at locations closest to Pyhäjoki



Sources : AFRY analysis based **2021** CO2 emissions data from E-PRTR database, CCU : Carbon Capture and Utilisation

Conclusions

- There are announced hydrogen or PtX projects by SSAB in Raahe and Flexens and Plug Power in Kokkola in a near proximity in Finland
- Further projects are found along the planned hydrogen pipeline Nordic Hydrogen Route:
  - Oulu, Kemi, Tornio (projects not announced, but could be, since the CO2 emissions as feedstock is available)
  - Luleå (project BotnialänkenH2 for hydrogen production using wind power, Project Green Wolverine for the production of ammonia and green fertilizer, H2 Green Steel producing green hydrogen and green steel)
  - Skellefteå (Flagship Four producing hydrogen for the aviation sector)
  - Kiruna (LKAB plans to produce hydrogen used in the reduction of iron)
- It is not yet clear how the above projects are going to produce or procure the electricity and hydrogen they need.

Source: Company announcements in public

EU regulations on renewable and nuclear energy for PtX

Demand and use cases for hydrogen

EU regulation on hydrogen is to be finalized

HYDROGEN REGULATION

- EU regulation on hydrogen is not finalised yet although the EU Commission has presented their proposals on these. This concerns the following aspects:
  - What constitutes “clean hydrogen”, in that the relevant guidance documents are yet under preparation, and the delegated act for “low carbon hydrogen” is yet to be published
  - EU targets for the use of synthetic fuels and hydrogen in transport and industry
  - Regulation on hydrogen pipeline transport and hydrogen markets (legislative package on gas and hydrogen to be finalised soon)
  - Standard for Guarantees of Origin for hydrogen

NUCLEAR REGULATION IN HYDROGEN RELATED REGULATION

- EU regulations surrounding nuclear have been mostly focusing on safety aspects
- Nuclear has not been a focal point in hydrogen related regulation
  - Nuclear energy was not included in the REPowerEU plan, despite the plan’s aim to reduce dependence on gas by electrifying systems
  - A move towards including nuclear specific mentions is on-going
    - The first move was putting officially sustainability label on nuclear energy

Summary of key hydrogen related legislation in the EU (1/2)

Legislation	Status	Purpose	Implications for hydrogen and RFNBOS
Renewable Energy Directive (currently known as RED II)	in effect since 2021	– 32% RES by 2030, sub-target of 14% in transport – GOs mandatory for energy – GHG emissions savings from the use of renewable liquid and gaseous transport fuels **RFNBO** shall be at least 70 % from 2020	– Member States shall set an obligation on fuel suppliers that RES within final energy consumption in transport is at least 14% – Member States create their own policy to meet the RED II targets and have the freedom to set higher targets

RED III	Final version published in Official Journal 31 Oct 2023	Share of renewable energy in the EU's overall energy consumption to 45%.
		– **Transport sector**
		– Member states can choose between:
		  – A binding target of least 13% reduction of greenhouse gas intensity in transport from the use of renewables by 2030, OR
		  – A binding target of at least 29% share of renewables within the final consumption of energy in the transport sector by 2030
		– Sets **a minimum requirement of 1% of RFNBOs** in the share of renewable energies supplied to the transport sector in 2030
		– **Industry sector**
		    – Industry would increase their use of renewable energy annually by 1.6%. They agreed that **42% of the hydrogen used in industry** should come from **renewable fuels of non-biological origin by 2030 and 60% by 2035**.
			– **Hydrogen trade** hydrogen trade between member states is critical for member state to reach their renewable energy target achievement
			– Centralization of GOs for renewable fuels including **hydrogen** in a "Union Wide" database
			– Ambitious targets for industry and transport drive demand for renewable fuels

Provisional agreement FuelEU Maritime Initiative	Provisional deal reached on 23.03.2023,
	Parts relevant for EU ETS already final
		–GHG emission reduction targets apply to shipping companies:
		    –50% of the energy used by ships in voyages departing from EU port to a non-EU port and vice versa
		    –100% of the energy used by ships in voyages between EU ports
		– **2 %** RFNBO usage target would take effect from 2034 if in 2031 RFNBO amount to less than 1 % in the fuel mix
			– Increased use of **RFNBOS** in European marine fleet
			– With the tight targets after 2035, RFNBOs are being promoted in FuelEU maritime. There is a large potential for demand growth in the maritime sector especially with ammonia and methanol powered engines that are actively being developed

GO Guarantees of Origin, RFNBO : Renewable Fuels of Non-Biological Origin (e.g. synthetic fuels or PtX); EU ETS = European Emissions Trading Scheme
Source : www.consilium.europa.eu

Summary of key hydrogen related legislation in the EU (2/2)

Legislation	Status	Purpose	Implications for hydrogen and RFNBOS
ReFuelEU Aviation initiative	Trilogues negotiations started on July 2022	– Ensuring a level playing field across the EU air transport market, when it comes to the use of aviation fuel – Setting out the objective to boost the uptake of sustainable aviation fuels : sustainable aviation fuels should account for at least 5% of aviation fuels by 2030 and 63% by 2050 – ReFuelEU Aviation therefore specifically targets the drop-in liquid sustainable aviation fuels	– Introduction to commercial use aircrafts powered by hydrogen and RFNBO – European Parliament supports the creation of a **Sustainable Aviation Fund** from 2023 to 2050 to support investment in sustainable aviation fuels or innovative aircraft propulsion technologies
REPowerEU	Provisional agreement reached **2023**	– Diversifying gas supplies, from non-Russian suppliers, and higher levels of **hydrogen** production and deployment – RePowerEU also acknowledged that other forms of fossil-free **hydrogen**, notably **nuclear**-based, play a role in substituting natural gas	– Boost **hydrogen** production to 35bcm by 2030 (Doubling the objective of Fit for 55). This is a non-binding target. – Funding channeled to **hydrogen** produced
H_2 and decarbonised gas market package	Pending approval	– EU has established regulatory frameworks to support the development of the **hydrogen** market. These regulations cover areas such as market design, infrastructure development, safety standards, and certification requirements	– Facilitating **hydrogen** market harmonization by harmonizing standards – Established regulations for safe handling of hydrogen throughout **promoting safety and consumer confidence**

Source : www.consilium.europa.eu

Hydrogen production has to fulfill the below criteria to be eligible as Renewable Fuels of Non-Biological Origin

ADDITIONALITY REQUIREMENTS

Unsubsidized RES installation came into operation not earlier than **36 months** before the RFNBO plant

Transition Period

Does not apply until 1 Jan 2038 for grid-connected operating assets prior to 1 Jan 2028

TEMPORAL CORRELATION

RFNBO production in the **same calendar hour** as the generation of renewable electricity under the **PPA** (**monthly basis** until 31st Dec 2029)

OR

RFNBO is produced during the one-hour period where the bidding zone price is ≤ 20 Eur/MWh or < 0.36 times the price of 1 tonne of CO_2 allowance

GEOGRAPHIC CORRELATION

Electrolyser and RES installation under **PPA** are located in same bidding zone

OR

Interconnected bidding zones but electricity price should be ≥ than the bidding zone where the RFNBO is produced

OR

RES under PPA located in an offshore bidding zone interconnected with RFNBO facility

Dedicated RES

PPA as source of electricity

	Additionality requirements	Temporal correlation	Geographic correlation
Directly connected installations[1]	Applies – no transition period	Does not apply	Does not apply
Directly connected to grid: **90 % RES in bidding zone in previous calendar year**[2]	Does not apply - hours of hydrogen production limited by the percentage of RES-E e.g., 90% * 8760	Does not apply	Does not apply
Emission intensity of grid[1] **< $18gCO_2/MJ$**[2]	Does not apply	Applies	Applies
RES dispatched down or reduced need for redispatch	Does not apply	Does not apply	Does not apply
All other grid connections	Applies with transition period	Applies	Applies

Notes: 1. In case of having grid connection, a SMART Meter is required to demonstrate that no power from the grid is used to produce hydrogen
2. Applies for subsequent 5 calendar years

Direct grid connection without adding new RES and direct connection to RES are two viable electricity sourcing concepts for renewable hydrogen production in Finland

In Finland :

- Renewable hydrogen production can source electricity from an **unsubsidized** RES installation that comes into operation not earlier than **36 months** before the hydrogen plant and in this case the production no longer need to prove temporal nor geographical correlation with the RES
- Renewable hydrogen production can source electricity from the grid since Finland's electricity grid is fulfilling the emission intensity criteria of **<18 gCO2/MJ** with Olkiluoto 3 nuclear power plant becoming fully operational
  - The production still needs to use renewable PPA and correlates temporally as well as geographically with the RES

Dedicated RES

PPA as source of electricity

	ADDITIONALITY REQUIREMENTS	TEMPORAL CORRELATION	GEOGRAPHIC CORRELATION
	Unsubsidized RES installation came into operation not earlier than **36 months** before the RFNBO plant	RFNBO production in the **same calendar hour** as the generation of renewable electricity under the **PPA** (**monthly basis** until 31st Dec 2029)	Electrolyser and RES installation under **PPA** are located in same bidding zone
Directly connected installations[1]	Applies – no transition period	Does not apply	Does not apply
Grid connection Emission intensity of grid[1] < 18gCO_2/MJ[2]	Does not apply	Applies	Applies

Source : Delegated act on RFNBO

Electricity from nuclear is not clearly recognized in EU regulation especially when it comes to hydrogen produced from nuclear electricity

Nuclear as a low carbon energy source has not been a focus point in the EU legislation. However, there is ongoing effort to address this shortcoming

- Currently there is work within European commission to assess the nuclear ecosystem. European Commission study in 2023 “the European nuclear energy ecosystem: is it fit for EU's climate objectives?”
- The 16 European countries participating in the “nuclear alliance” are preparing a roadmap to develop an integrated European nuclear industry reaching **150 GW** of nuclear power capacity in the EU’s electricity mix by 2050 (100 GW is the current installed capacity)
- The dispute between countries over nuclear-based hydrogen has been one of the reasons behind the delay in the negotiations on the new renewable energy targets in EU

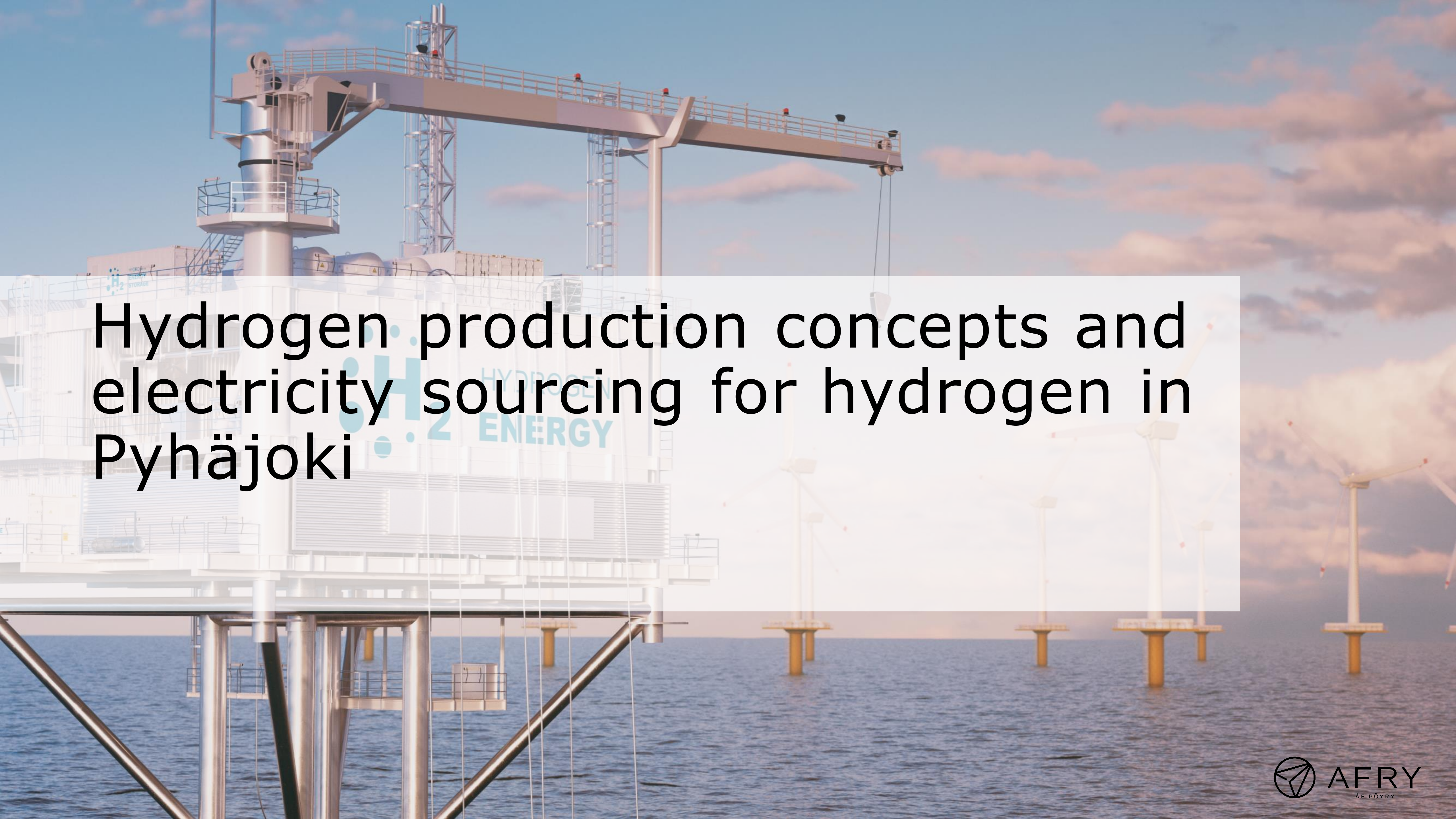
Hydrogen made from direct connection to nuclear is considered low carbon and so are the fuels or products such as steel or chemicals produced from this low carbon hydrogen

- According to European Commission answers on delegated act on RFNBO “nuclear is not listed among the renewable energy sources……the Commission put forward a definition of **low-carbon hydrogen**, that is when it is derived from non-renewable sources producing at least 70% less greenhouse gas emissions than fossil”
- Status of nuclear in all new EU legislation is not defined and is under heavy debate. The tension is between France and other European countries (Germany and Belgium in the lead), as they favour importing renewable hydrogen rather than producing low-carbon hydrogen in Europe
- Czech EU Presidency proposed an amendment, that is now being discussed, to the Gas and Hydrogen directive. The amendment gives the option for member states to consider low carbon hydrogen to fulfill the binding hydrogen target in industry, and to consider low carbon hydrogen and its derivatives to fulfill binding hydrogen target in transport (both set in the upcoming REDIII legislation)

Sources : https://ec.europa.eu/commission/presscorner/detail/en/qanda_23_595

Conclusions

- Hydrogen regulation will be defined for the first time in the EU in 2023-2024. While the negotiations over the legislative proposals have already taken more time than expected, we may expect future revisions over time.
- One reason for the debate is that renewable electricity and hydrogen production are difficult to combine because industrial processes require a steady supply of resources to suffice a high rate of operating hours.
  - For directly connected facilities, this means a significant oversizing of the production concept added with an intermediate hydrogen storage to enable a steady supply of hydrogen for the end-users
  - In part of grid connected sites, the RFNBO Act requires that renewable electricity supply must be in balance with the electricity consumed for hydrogen production on a monthly or hourly basis with similar implications as for the directly connected sites.
- Another item currently under debate is the role of low carbon hydrogen and nuclear power in this. The steady supply profile of nuclear power would be ideally suited to service hydrogen production without a need for over-sizing the electricity supply nor equipment. The main drawback of nuclear power vs. renewable power is the cost of electricity, but this factor may be overcome by other factors depending on the concept. For large industrial facilities running 24/7, the security of supply is very important.



Hydrogen production concepts and electricity sourcing for hydrogen in Pyhäjoki

AFRY

A fully grid connected renewable hydrogen concept is bound to a RES PPA agreement to ensure renewable hydrogen production

STRENGTHS

- Hanhikivi has plans and permits in place for 400 kv connection. The location is on the north side of cut P1, which can be beneficial for the hydrogen production site from the transmission system perspective. It is also beneficial for an industrial site that consumes hydrogen as feedstock such as ammonia, methanol or iron & steel site
- Availability of water and land area allows for the build of an industrial site that consumes hydrogen.
- The entire hydrogen production could fulfil RFNBO requirements and qualify as RFNBO
- Without a large nuclear plant on-site, there would be a large area available for building an industrial site, for example, to process hydrogen into synthetic fuels or to utilize the hydrogen on-site, such as in a chemical or metal processing facility

WEAKNESSES

- The production is bound by the conditions defined in the RES PPA agreement
- The electricity end use for hydrogen production need to be balanced on monthly basis up to 2029 and on hourly basis afterwards

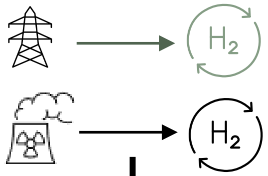
OPPORTUNITIES

- Hydrogen produced at Hanhikivi site can be sold via pipeline to a specific industrial off taker such as SSAB Raahe or Kokkola ammonia plant
- Hydrogen produced can be sold via the Nordic Hydrogen Route which is hydrogen pipeline running along the Bothnian bay
- Hydrogen can be used as feedstock and fuel onsite
- Start of production with grid power early on and later directly connecting to nuclear/RES one site or nearby when the for nuclear/new RES can be commissioned

THREATS

- The hydrogen production site is limited by the available types and prices of PPA

Hydrogen production constructed partially on grid power and partially on on-site nuclear power has multiple strengths but is bound to a RES PPA to ensure the share of renewable hydrogen production



STRENGTHS

- Hanhikivi has plans and permits in place for 400 kv connection. The location is on the north side of cut P1, which can be beneficial for the hydrogen production site from the transmission system perspective[2]. It is also beneficial for an industrial site that consumes hydrogen as feedstock such as ammonia, methanol or iron & steel site
- Availability of water and land area allows for the build of an industrial site that consumes hydrogen
- The support for nuclear power in the region is high and a new operator on site could benefit from that
- There is flexibility with dimensioning nuclear for **low carbon hydrogen** production while the rest of electricity is sourced from PPA to produce the RFNBO

WEAKNESSES

- The part of hydrogen produced with nuclear power would be **low carbon hydrogen** and EU regulation on low carbon hydrogen are not yet defined

S W O T

OPPORTUNITIES

- Hydrogen produced at Hanhikivi site can be sold via pipeline to a specific industrial off taker such as SSAB Raahe or Kokkola ammonia plant
- Hydrogen produced can be sold via the Nordic Hydrogen Route which is hydrogen pipeline running along the Bothnian bay
- Hydrogen can be used as feedstock and fuel onsite
- Excess power can be sold to the grid
- Local acceptance for nuclear could indicate potential for local acceptance of other industrial activities

THREATS

- The renewable hydrogen production onsite is limited by the available type and price of PPA but the exposure to the market's uncertainties is smaller since the needed electricity from PPA is smaller

PPA: Power Purchase Agreement

Hydrogen production with a direct connection to a renewable energy source qualifies the hydrogen as fully renewable

STRENGTHS

- Hydrogen produced complies with the delegated act on RFNBO and therefore would be qualified as **RFNBO**
- Hanhikivi site is in an area with the potential for to offshore and onshore wind power where many projects are ongoing. Puskakorpi wind farm and Siikajoki wind project is under construction and Pyhäjoki's Polusjärvi wind farm is recently completed
- Potentially new wind power could be directly connected to Hanhikivi site

WEAKNESSES

- Additional capex is needed to develop enough capacity to overcome the intermittency of wind power through excess wind power capacity, excess electrolyser capacity, and/or hydrogen storage

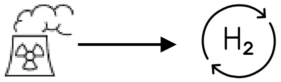
OPPORTUNITIES

- Excess power not used for hydrogen production can be sold to the grid
- Hydrogen produced at Hanhikivi site can be sold via pipeline to a specific industrial off taker such as SSAB Raahe or Kokkola ammonia plant
- Hydrogen produced can be sold via the Nordic Hydrogen Route network between Finland and Sweden
- Hydrogen can be used onsite as a feedstock or a fuel by an industrial plant

THREATS

- Halla offshore wind site h (12 TWh annual production) has already planned to connect to SSAB. Hanhikivi would need develop its own RES

Hydrogen production constructed on on-site nuclear power has multiple strengths but with a major drawback of producing low carbon hydrogen instead of renewable



STRENGTHS

- Nuclear power delivers a large capacity of steady flow **low carbon** electricity
- The support for nuclear power in the region is high and a new operator on site could benefit from that
- Using a localized generation source, local industrial user can reduce or eliminate transmission costs associated with relying on the main grid and grid connection fees

WEAKNESSES

- The hydrogen produced would be **low carbon hydrogen** and EU regulation on low bon hydrogen are not yet defined
- The excess heat produced from nuclear cannot be sold as district heat since municipalities are far from

OPPORTUNITIES

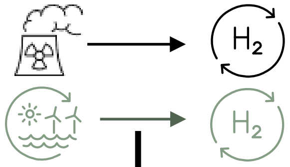
- Excess power not used for hydrogen production can be sold to the grid
- Hydrogen produced at Hanhikivi site can be sold via a pipeline to any connected industrial off taker such as SSAB Raahe or Kokkola ammonia plant
- Hydrogen can be used onsite if there would be a new industrial off taker
- The infrastructure has been built for nuclear with a 400 KV grid connection planned for Hanhikivi
- Nuclear capacity can be dimensioned larger than the capacity of electrolyzer to be able to benefit from sales of excess power

THREATS

- Regulation on SMR (if this would be the concept of choice) is not yet finalized in the Finnish legislation. The nuclear energy act in Finland is undergoing a comprehensive legislative reform to better account for new technologies incl. SMR

AFRY ÅF PÖYRY

Hydrogen production constructed partially on on-site nuclear power and partially on direct connection to RES produces both low carbon and renewable hydrogen



STRENGTHS

– Nuclear power delivers a large capacity of steady flow low carbon electricity
– The support for nuclear power in the region is high and a new operator on site could benefit from that
– Using a localized generation source, local industrial user can reduce or eliminate transmission costs associated with relying on the main grid and grid connection fees
– Allows for continuous flow of hydrogen to a local industrial off taker on site or via a pipeline without the need for intermediate storage
– This option allows for the electrolyser capacity to be sized according for a steady supply of electricity throughout the year. This combination has the potential to **produce large volumes of hydrogen**
– The variability of electricity supplied from RES can be managed via the electricity supplied by baseload nuclear

WEAKNESSES

– Hydrogen is **partially RFNBO and partially low carbon**. The production from RES likely needs to be distinguished
– The flow of RFNBO is less steady than the flow of low carbon hydrogen
– The excess heat produced from nuclear cannot be sold as district heat since municipalities are far from

S W O T

OPPORTUNITIES

– Excess power not used for hydrogen production can be sold to the grid
– Hydrogen produced at Hanhikivi site can be sold via pipeline to a specific industrial off taker such as SSAB Raahe or Kokkola ammonia plant
– Hydrogen produced can be sold via the Nordic Hydrogen Route network between Finland and Sweden
– Hydrogen can be used onsite
– Heat produced by nuclear can be used by a local industrial site
– The infrastructure has been built for nuclear with a 400 KV grid connection planned for Hanhikivi
– Nuclear capacity can be dimensioned larger than the capacity of electrolyzer to be able to benefit from sales of excess power
– The requirements from off takers regarding RFNBO and low carbon hydrogen can be met

THREATS

– Regulation on SMR (if this is the concept of choice) is not yet finalized in the Finnish legislation. The nuclear energy act in Finland is undergoing a comprehensive legislative reform to better account for new technologies incl. SMR

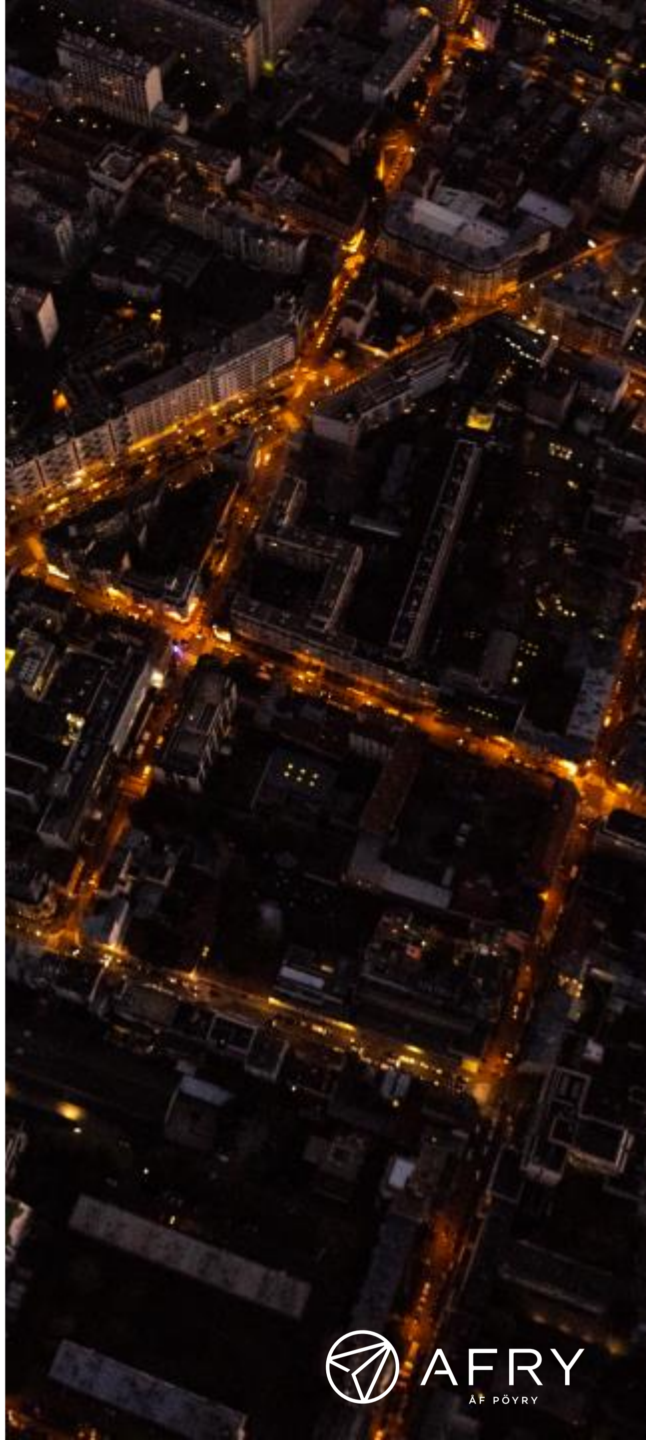
RES : Renewable Energy Source

Conclusions

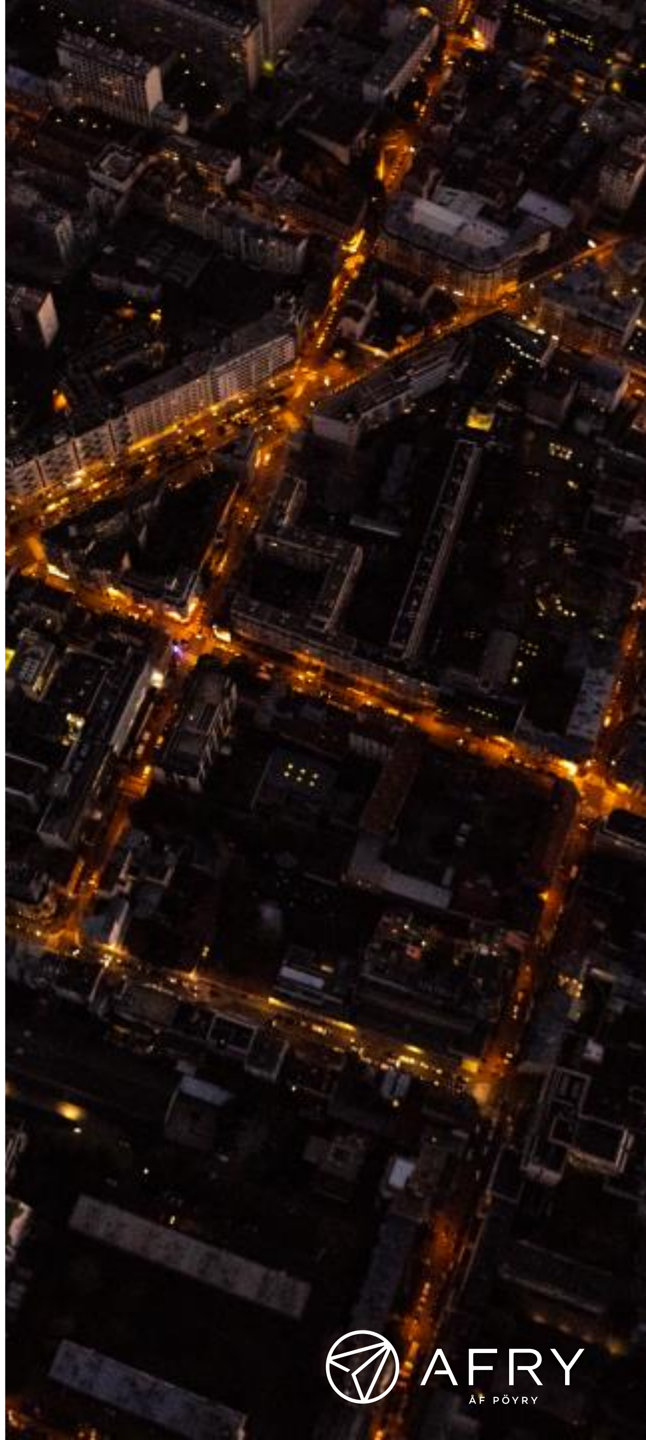
- Hanhikivi site is well-suited for nuclear power production. The electricity could be sold via PPA or other type of contracts to any electricity offtaker, including those active in the PtX business
- Hydrogen could also be produced on-site with a direct connection to a nuclear power plant. The benefits of this would be a low carbon source of electricity without having to pay for electricity transmission, a steady supply of electricity without having to invest in hydrogen storage and in oversizing the on-site electrolyser capacity, and ability to sell excess electricity to the grid.
  - The lack of possibilities for heat integration does not significantly affect Hanhikivi project since heat demand for district heat would be seasonal in any case and the majority of the Finnish district heating networks are already fossil-free
- Hanhikivi site would enable, for example, an evolutionary concept, where in the first phase renewable hydrogen is produced from a direct connection (with PPA agreement as required by the delegated act on RFNBO) to the grid (before nuclear is commissioned) and at the second phase additional hydrogen production is done via direct connection to nuclear power onsite. This second stage could then yield two distinct types of hydrogen: low-carbon hydrogen generated from nuclear electricity, and renewable hydrogen derived from the grid connection. The benefit of this concept would be to enable a quick commissioning of hydrogen production at site and its future capacity increase based on low carbon hydrogen as soon as the nuclear capacity is commissioned
- Due to the lack of on-site CO2 emitters, the production of hydrocarbons such as e-methane, e-methanol, and e-kerosene are not likely to be the most competitive solutions for Hanhikivi site in comparison to sites where one could utilize the CO2 available on site such as the sites in Raahe and Oulu
- On-site low carbon and/or renewable ammonia production could be a viable option since the required nitrogen is captured from air. This would require investments in the harbor operations of Hanhikivi site for ammonia shipping.

PPA : Power Purchase Agreement

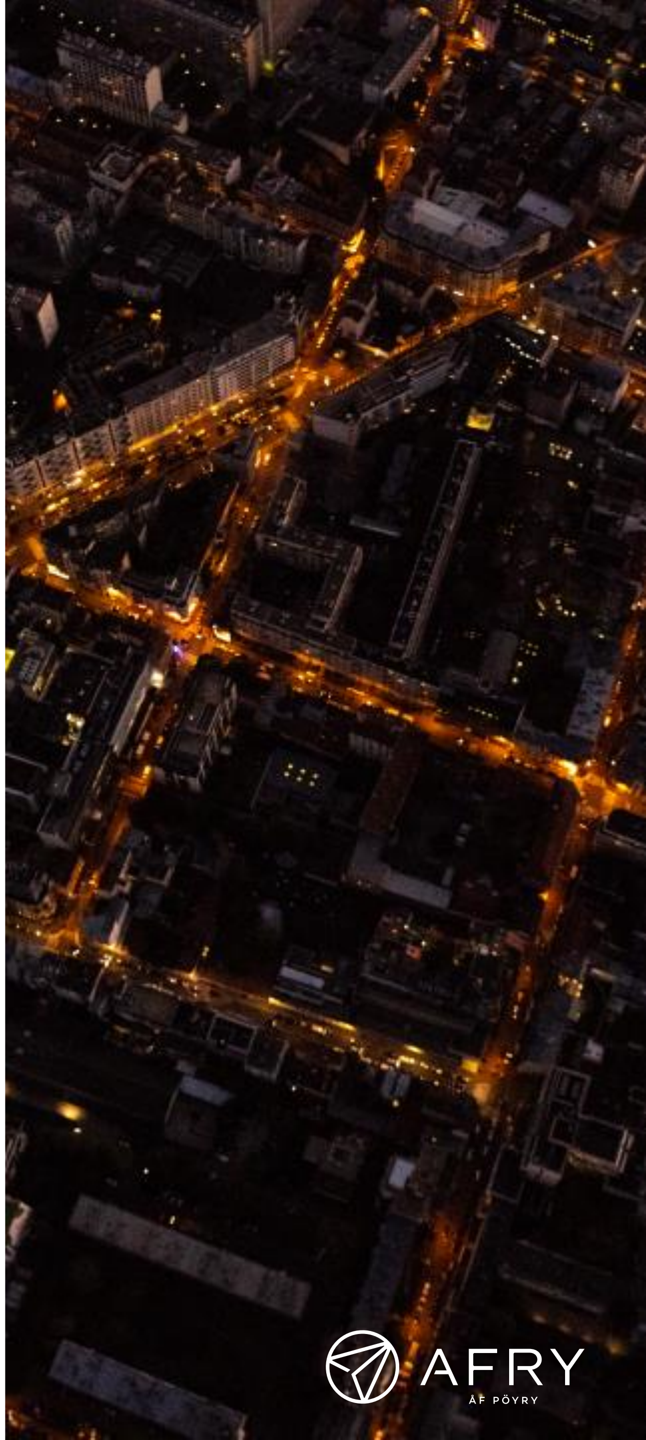
Content



Content



Content



Four phase approach for technology review provides backbone for further analysis in later parts of the report

CHAPTER	CONTENT
4.1 Mapping of relevant technologies	• Technology maturity and prevalence • Cost levels • Market potential • Project timeline • Risks, advantages and disadvantages regarding the technology in general
4.2 Evaluation of regional infrastructure	• Site infrastructure • General suitability of the site location • Ability to combine different options at the site • Risks / Advantages / Disadvantages regarding the site compared to other technologies in consideration
4.3 Evaluation of technology feasibility and potential	• Evaluation for technology feasibility and potential at Hanhikivi site by combining the techno-economical suitability and site related suitability
4.4 Mapping of potential suppliers and assessment of delivery readiness	• Mapping of potential suppliers with main focus on nuclear power

Mapping of relevant technologies is assessed with chosen comparable aspects for each relevant technology

- AFRY has prepared technology mapping for relevant energy technologies based on the earlier analysis of the report and general site suitability
- Chosen technologies for further analysis are large scale nuclear, SMRs, green ammonia, hydrogen liquefication, gaseous hydrogen compression and hydrogen production with ALK, PEM & SOEC electrolysers
- Similar evaluation with key perspectives has been performed for each technology, including:
  - Technology maturity and prevalence
  - Cost levels
  - Market potential
  - Project timeline
  - Risks, advantages and disadvantages regarding the technology in general
- Based on the analysis, technologies have been ranked by their techno-economical suitability

Mapping of relevant nuclear technologies for electricity production by their techno-economical potential

Rating	
++	Very positive
+	Positive
+/-	Neutral
-	Negative

	Technology maturity and prevalence	Cost levels	Project timeline	Risks / Advantages / Disadvantages
Large scale nuclear power plant	++	-	-	Mature technology. Increasing electricity demand in the market. Cost competitiveness is uncertain and cost overruns have been substantial in recent projects Project timeline is long and delays substantial
Small modular reactors	-	-	-	Future technology with high market potential in general. Uncertain technology maturity, cost levels and project timeline

Mapping of relevant hydrogen electrolysers by their techno-economical potential

Rating	
++	Very positive
+	Positive
+/-	Neutral
-	Negative

	Technology maturity and prevalence	Cost levels	Project timeline	Risks / Advantages / Disadvantages
Alkaline electrolysis	++	+/-	+	Mature technology and available in large scale. However, requires an additional hydrogen purification before further use
Proton Exchange Membrane	+	-	+/-	High operational flexibility and small footprint. Also high purity but more expensive than Alkaline electrolysis
Solid Oxide Electrolysis	-	+	-	Immature technology still in R&D-phases. High efficiency and output purity but only available in small scale

Mapping of relevant technologies for hydrogen transportation by their techno-economical potential

Rating
++ Very positive
+ Positive
+/- Neutral
- Negative

	Technology maturity and prevalence	Cost levels	Market potential[1]	Project timeline	Risks / Advantages / Disadvantages
Green ammonia	++	+	++	++	Large international market for ammonia although willingness to pay for green ammonia is uncertain. Technology for ammonia production and transport is already mature.
Marine transportation of hydrogen in liquified state	+/-	-	+	+	Costly alternative for transportation because liquefied hydrogen requires very low temperatures.
Transportation of gaseous hydrogen via pipeline	+/-	+	++	+/-	Nordic hydrogen route is a major advantage if it realizes at least from Pyhäjoki to some major end users close by.

1) Market potential of the end product, hydrogen or ammonia

Large scale nuclear power is proven technology for electricity production, but timeline for new projects and cost levels cause high uncertainties

LARGE SCALE NUCLEAR POWER

- Nuclear energy provides about 10% of the world's electricity from about 440 power reactors. There are about 100 operational Nuclear Power Plants in Western Europe
- Majority of current reactors rely on PWR technology, with BWR reactors being the second commonly utilised reactor type
- Nuclear power capacity worldwide is increasing steadily, with about 55 reactors under construction. Most reactors on order or planned are in the Asian region, though there are major plans for new units in Russia. Few NPPs are under construction in Europe
- The general emission targets, war in Ukraine and recent update of European taxonomy may turn the European political view more in favour of nuclear power as efforts must be made to increase energy self-sufficiency and to lower the CO_2 emissions

KEY PERSPECTIVES

Technology prevalence, technology maturity & market potential +

- Technology widely used for power production over decades in Finland and globally.

Advantages ++

- Feasible technology with proven commissioned plants worldwide. Western technology suppliers available. Secure electricity producer when commercial operation achieved

Disadvantages +/-

- Cost levels are high and budget overruns have been remarkable in recent projects in Finland and many other Western countries

Project timeline, risks & uncertainties -

- Earlier large scale projects have shown the timeline and cost risks related to large scale NPPs. The timeline for new project is estimated to be at least 10 years. Funding for a new project will be challenging and the majority of owners should be Finnish

KEY NUMBERS

Item	Value
CAPEX	High (From ~5000 €/kWe up to ~8000 €/kWe*)[1]
OPEX	Medium/High
LCOE ESTIMATE	~50-100 €/MWh[1,2,**]
PROJECT TIMELINE	10+ years

EXAMPLES OF TECHNOLOGY SUPPLIERS

KEPCO, framatome, Westinghouse

1. World Nuclear Association - Economics of nuclear power 2. IEA *based on Olkiluoto 3 and Flamanville 3 capital cost estimates **With capacity factor of >80%

Small modular reactors can provide an agile and stable power production alternative in the future

OVERVIEW OF SMR

- Small modular reactors are emerging technologies that aim to make nuclear energy easier to access and implement. The strengths of SMRs are decentralization and agility compared to traditional larger scale nuclear production
- There are currently a few noteworthy Western developers with planned commercial targets for their first reactors even still during this decade
- In the Nordics SMRs are expected to become commercially viable earliest around 2030-2035

TECHNOLOGICAL DETAILS

- There are several reactor types in development which can be categorized according to the cooling material used
- The first wave technologies use water for cooling and utilise similar fuels as conventional nuclear power. Hence, the sourcing or waste management of the fuel are considered similar to traditional NPPs
- SMRs enable separate electricity production as well as co-generation of heat and power
- The temperatures reached by water cooled reactors are not applicable as process heat in e.g. steel manufacturing or other high temperature industrial solutions
- The so called second wave SMRs (advanced reactors) will utilise different fuels and coolants than conventional NPPs. They will generate also higher temperature and pressure levels, which would enable the utilisation of second wave SMRs also in high temperature industrial processes

OPPORTUNITIES AND CHALLENGES

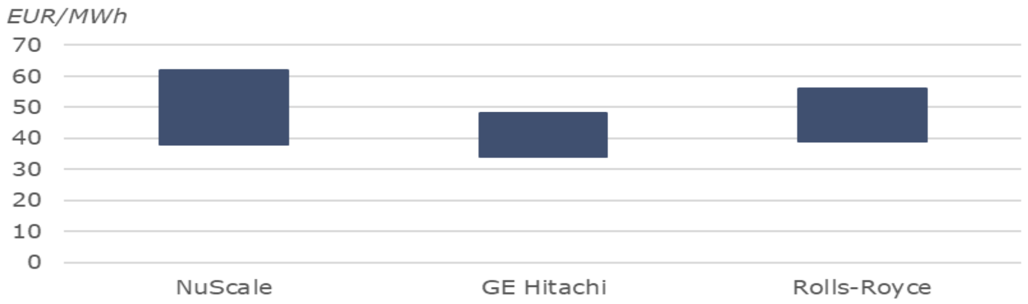
SMRs are a sustainable source involving only scope 3 greenhouse gas emissions. However, nuclear waste needs to be managed

SMRs can provide a stable power supply similarly to large scale NPPs but can also be operated more flexibly if needed.

It is hard to predict the costs and the technological readiness of the technology as there is very little operational experience

Obstacles regarding policy and licensing need to be overcome for the agility of SMRs to actually materialize

PRESENTED TARGET LCOE[1] OF SMR, THREE DEVELOPERS



1. The presented values are estimates by the developers themselves. The analysis behind the estimates have not been provided

SMRs are not yet commercial, but they could provide scalable solutions for energy production in the future

SMALL MODULAR REACTORS

- Traditionally nuclear reactors generate electricity, however SMRs are suitable also for co-generation of heat and power, heat only and other non-electric applications
- There are over 70 SMR designs and concepts globally[1]. Most of them are in various developmental stages and some are claimed as being near-term deployable
- There are currently SMRs in advanced stages of construction in Argentina, China and Russia, and several existing and newcomer nuclear energy countries are conducting SMR research and development
- In the 2030s there could very well be many SMRs in operation but in this decade not necessarily in a commercial sense yet

KEY PERSPECTIVES

Technology prevalence, technology maturity & market potential +

- Scalable solution with potential to be an industrial scale energy provider. Technology is under development phase for commercialisation. Market potential expected to be good after first plants have been proven to be commercially viable

Advantages ++

- Scalability provides opportunities for different solutions (electricity generation, district heating, desalination, commercial-scale hydrogen production and other process heat applications).

Disadvantages -

- Not commercial solution yet and therefore no certainty for e.g. cost levels for project phase and operational phase

Project timeline, risks & uncertainties +/-

- Uncertainties in the project timelines due to no benchmark plants available. However, construction times between 2 to 5 years have been evaluated for SMRs, which is shorter construction period than for large scale NPPs[2,3]. The total project timeline expected to be much shorter than for large scale NPPs when regulative challenges for first plants have been solved

KEY NUMBERS

Item	Value
CAPEX	High (estimates vary between 3300-5500 €/kWe for first projects and 1900-4900 €/kWe for later commercial phase projects)
OPEX	Medium/High
Target LCOE	~35-65 €/MWh*
PROJECT TIMELINE	Total 5+ years (construction time 2-5 years)

EXAMPLES OF TECHNOLOGY SUPPLIERS

NuScale, Rolls-Royce SMR, Westinghouse, GE Hitachi, EDF

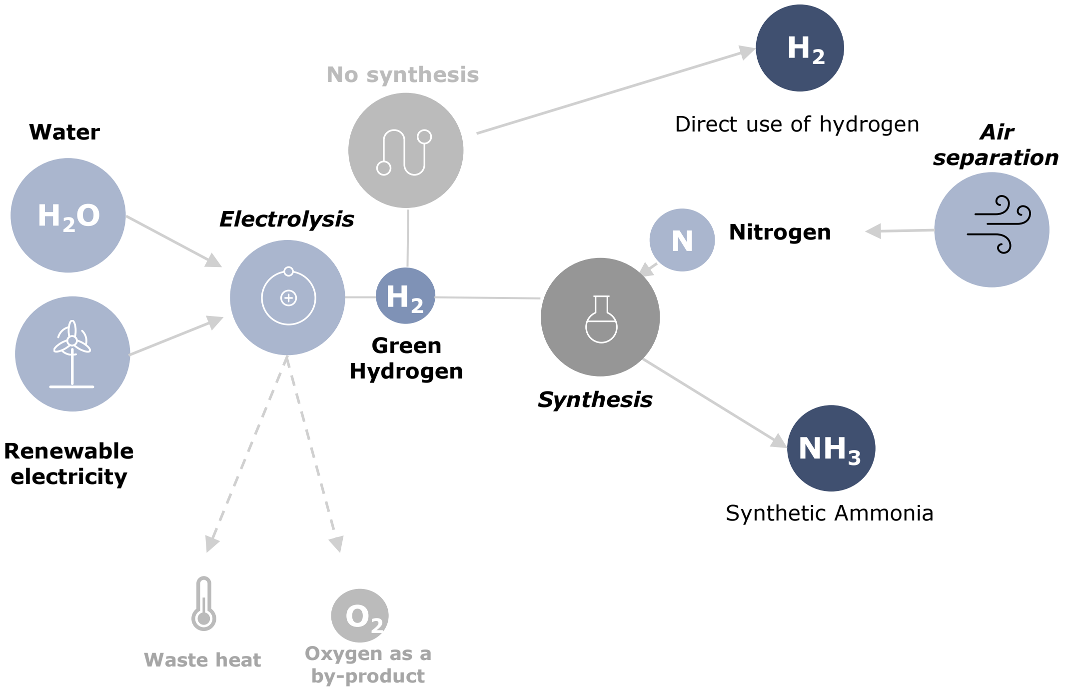
1. IAEA 2. Idtech 3. ansto.gov.au *Based on estimates by the developers themselves. The analysis behind the estimates have not been provided

AFRY ÅF PÖYRY

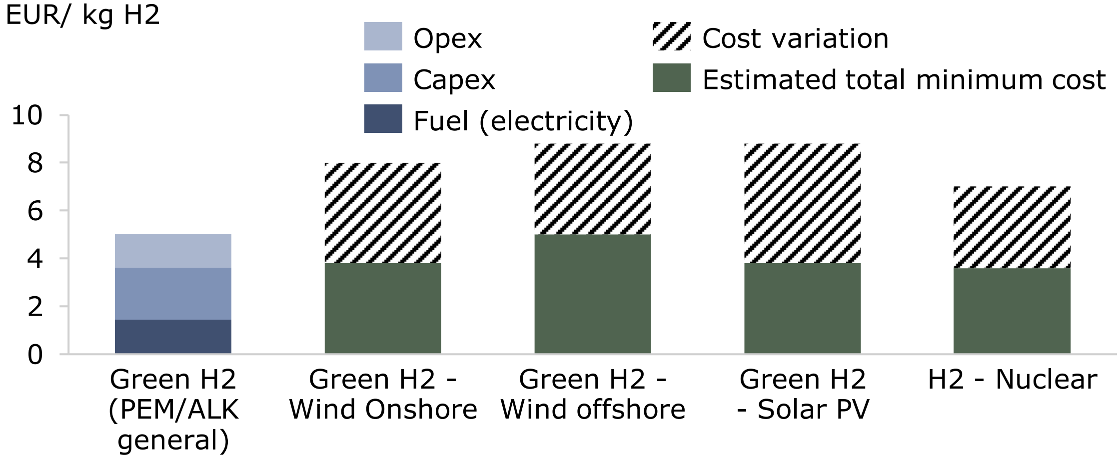
Green hydrogen and ammonia are produced with electrolysis and synthesis process – Hydrogen production is responsible for majority of total costs

HYDROGEN AND SYNTHETIC AMMONIA PRODUCTION PROCESS

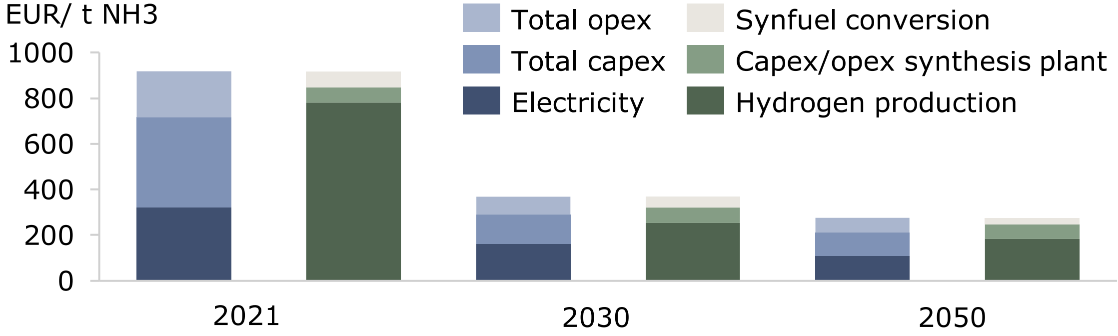
Green hydrogen is produced with electrolysis using water and renewable electricity. The hydrogen can be utilized as such, or combined with nitrogen to produce synthetic ammonia.



HIGH LEVEL ESTIMATES FOR LCOH (YEAR 2021)[1]



HIGH LEVEL ESTIMATES FOR LCOA DEVELOPMENT (2021, 2030, 2050)[1*]



LCOH : Levelised Cost of Hydrogen LCOA : Levelised Cost of Ammonia 1. IEA – Global Hydrogen Review 2022 *Numbers include the electrolysis process and ammonia synthesis process

There are three different main electrolysis technologies with differing strengths and weaknesses

	Alkaline Electrolysis (ALK)	Proton Exchange Membrane (PEM)	Solid Oxide Electrolysis (SOEC)
+	• Most mature • No noble metals needed • Available on large scale • Longest proven stack lifetime	• Highest operational flexibility → well suitable for intermittent power sources • Available on large scale • Smallest footprint • High hydrogen output purity • Potential for significant CAPEX reductions if replacing noble metals	• Can operate reversely as a fuel cell • High hydrogen output purity • Flexible fuel operation (H_2, CH_4) • Possibility to integrate CO_2 in the input and syngas in the output • High efficiency • Potential for sector-coupling
−	• Not suited for intermitted power sources • Lye circulation requires more balance of plant equipment • Alkaline operating environment is corrosive • Requires additional hydrogen purification for further use	• Expensive catalyst materials → expensive	• Still only available on small scale • Require a heat source • High operational temperature → material lifetime challenges • Long start-up • Pre-commercial demonstration • Significant heat waste if not utilized

AFRY ÅF PÖYRY

Alkaline electrolyser (ALK) technology is most mature and available in large scale

SUMMARY OF THE TECHNOLOGY

- Alkaline electrolysers uses a liquid alkaline solution of sodium or potassium hydroxide and operates via transport of hydroxide ions (OH-) through the electrolyte from the cathode to the anode with hydrogen being generated on the cathode side
- ALK electrolyser are usually operated at baseload
- ALK with lifetime of 12y is the most popular in large scale applications today. Once full stack is replaced due to cells degradation, ALK electrolysers' lifetime extends to 20 years

KEY PERSPECTIVES

Technology prevalence, technology maturity & market potential ++

- ALK have been commercially available for many years. Its TRL is 8 and there are multiple European technology suppliers such as Nel Hydrogen, Green Hydrogen Systems and Enapter

Advantages ++

- New ALK designs are quickly catching up in flexibility
- ALK does not contain noble materials. Hence it is the cheapest electrolyser type and is less exposed to materials supply risk
- ALK is the most mature electrolyser technology, has long stack lifetime and lowest CAPEX among electrolyser types

Disadvantages +

- ALK is less flexible than other electrolysers and is the least efficient
- Lead time is close to 3 years from order

KEY COST CHARACTERISTICS

Item	Value
CAPEX	~ 500 EUR/KW
OPEX	Medium (electricity is the highest operational cost)
LCOH[1]	3.2 – 4.6 EUR/kg
PROJECT TIMELINE	Depending on scale can be ordered with a lead time from 12[2] to 36 months

EXAMPLES OF TECHNOLOGY SUPPLIERS

GREEN HYDROGEN SYSTEMS

LONGi

John Cockerill

NEL HYDROGEN

Sources: IRENA 2020, Hydrogen tech world
TRL : Technological Readiness Level a systematic metric used to assess the maturity and readiness of a technology with 1 being the lowest and 9 being the highest level for a technology that has been successfully deployed 1) Levelized cost of hydrogen, values represent the LCOH values determined at electricity prices of 30 and 60 EUR/MWh, respectively 2) One supplier: Stargate hydrogen

Proton Exchange Membrane (PEM) electrolysers are also available on large scale but they are pricier due to expensive catalyst materials

SUMMARY OF THE TECHNOLOGY

- In a PEM electrolyser, the electrolyte is a solid specialty plastic material. Water reacts at the anode to form oxygen and positively charged hydrogen ions at the cathode; hydrogen ions combine with electrons from the external circuit to form hydrogen gas. The operating temperature of PEM is 70-90°C
- Commercial MW-scale PEM electrolysers have been introduced to the market by several suppliers for its flexibility

KEY PERSPECTIVES

Technology prevalence, technology maturity & market potential +

- PEM is a relatively new technology that is commercially available but less mature than ALK type (TRL is 7). There are European technology suppliers available, such as Nel Hydrogen, McPhy Energy Systems and Enapter

Advantages ++

- PEM has the highest operational flexibility and is well suitable for intermittent power sources
- PEM has small footprint, and its CAPEX is continuously decreasing

Disadvantages +/-

- Expensive technology because of the materials it contains, and it has been used in industries less than ALK
- Some of the materials used in PEM (iridium, scandium and yttrium and moderately titanium) might be under significant future supply risk, whereas materials in alkaline electrolysis are not

KEY COST CHARACTERISTICS

Item	Value
CAPEX	~ 750 EUR/kW (higher than ALK CAPEX)
OPEX	Medium (electricity is the highest operational cost)
LCOH[1]	3.9-5.4 EUR/kg (Higher than ALK with all electricity prices)
PROJECT TIMELINE	Same kind of lead time as with ALK can be expected

EXAMPLES OF TECHNOLOGY SUPPLIERS

ITM POWER
NEL HYDROGEN
H-TEC SYSTEMS
Cummins

Sources: IRENA 2020, Hydrogen tech world 1) Levelised cost of hydrogen, values represent the LCOH values determined at electricity prices of 30 and 60 EUR/MWh, respectively

Solid oxide electrolysis (SOEC) has high efficiency but is still available only on small scale

SUMMARY OF THE TECHNOLOGY

- SOECs typically use a solid ceramic material as the electrolyte that selectively conducts negatively charged oxygen ions (O^{2-}) at elevated temperatures (700-800 °C)
- SOEC is the least mature out of the three electrolyser technologies presented

KEY PERSPECTIVES

Technology prevalence, technology maturity & market potential -

- SOEC is the least mature out of the three electrolyser technologies presented. SOEC technology is primarily at R&D stage, and commercialisation is only on its way

Advantages +

- SOEC can produce hydrogen with a high purity
- SOEC operates at a high efficiency

Disadvantages +/-

- SOEC is still available only in small scale
- Because of the very high operating temperatures, SOEC requires a heat source and significant heat waste is produced

KEY COST CHARACTERISTICS

Item	Value
CAPEX	~ 800 EUR/kW (higher than both ALK and PEM)
OPEX	Medium (electricity is the highest operational cost)
LCOH[1]	3.19-4.3 EUR/kg (Cheaper than ALK with all electricity prices)
PROJECT TIMELINE	When matured, same kind of lead time as with ALK can be expected

EXAMPLES OF TECHNOLOGY SUPPLIERS

Bloomenergy®

HALDOR TOPSØE

Sources: IRENA 2020, Hydrogen tech world 1) Levelised cost of hydrogen, values represent the LCOH values determined at electricity prices of 30 and 60 EUR/MWh, respectively

Ammonia is a global commodity with multiple potential future uses

1 **Ammonia is an essential global commodity**

– Ammonia is a global chemical commodity, primarily used to produce **fertilisers**. Ammonia exists in a liquid state below -33.3°C at atmospheric pressure. No boil-off occurs during the storage of liquid ammonia

2 **Ammonia accounts for a large share of hydrogen consumption**

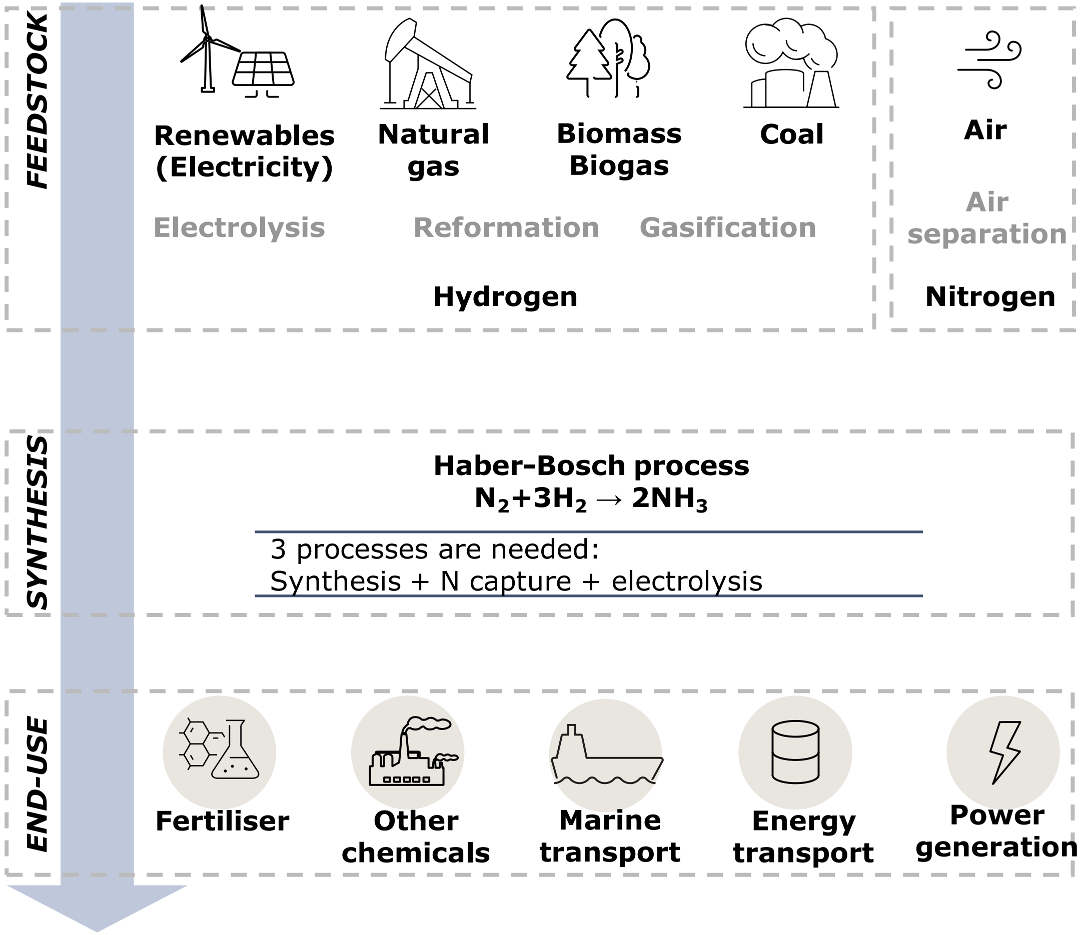
– Global consumption is at ~183Mt. Ammonia is derived from hydrogen accounting for ~34% of global hydrogen consumption today. Ammonia is formed spontaneously under high temperatures (400 to 500°C) and pressure (100 to 250 bar) in the presence of a catalyst (typically iron)

3 **Synthetic ammonia**

– Ammonia has potential as a clean fuel in maritime transport and as a hydrogen carrier & for stationary power generation

4 **Safe handling is a key challenge for ammonia**

– While renewable ammonia is expected to be the most economic & energy-dense clean fuel, ammonia faces safety and regulatory challenges before reaching commercial feasibility



Green ammonia production using Haber-Bosch process is a commercial technology with relatively low capex requirements

SUMMARY OF THE TECHNOLOGY

- Ammonia is synthesized by reacting hydrogen and nitrogen at high pressure and temperature over a catalyst (‘the Haber-Bosch process’)
- Renewable ammonia synthesis is a mature technology based on the same process as the current fossil Haber-Bosch process that uses fossil hydrogen produced via reforming of natural gas. In case of renewable ammonia, fossil hydrogen is replaced by green hydrogen
- Nitrogen is required for the process, and it is produced by Air separation Unit (ASU)

KEY PERSPECTIVES

Technology prevalence, technology maturity & market potential

- Haber-Bosch process is an established commercial technology with TRL 9. Multiple European technology suppliers available. Green ammonia production market potential is seen rather high due to the increase in demand for renewable energy ++

Advantages

- Ammonia is the most cost-effective technology route for a synthetic fuel due to high efficiency, 97% conversion efficiency is typically reached. Ammonia is produced in a condensed liquid state, there is no extra cost for converting the ammonia into a transport-ready state ++

Disadvantages

- Haber-Bosch process requires a significant amount of energy to operate. Technology is designed for large scale production and scaling it down based on availability of renewable electricity and renewable hydrogen might be challenging. Ammonia becomes toxic when it leaks or undergoes combustion +

Project timeline, risks & uncertainties +

- Expected project timelines vary between 3-4 years for ammonia production facilities*

KEY COST CHARACTERISTICS

Item	Value
CAPEX	Low (~100 € per ton of ammonia when taking to account only the Haber-Bosch facility, ~400 € per ton of ammonia for whole process, including electrolysis and synthesis plant)[1]
OPEX	Medium
LCOA	~1000 € per ton of ammonia, including electrolysis and synthesis plant (Haber-Bosch process expected to be responsible for ~15% of total costs)[1]
PROJECT TIMELINE	~3-4 years*

EXAMPLES OF TECHNOLOGY SUPPLIERS FOR AMMONIA PRODUCTION

TOPSOE YARA OCI Global

TRL : Technological Readiness Level; a systematic metric used to assess the maturity and readiness of a technology with 1 being the lowest and 9 being the highest level for a technology that has been successfully deployed LCOA: Levelised Cost of Ammonia 1. EIA – Global Hydrogen Review 2022 *Based on publicly announced estimates for industrial scale by e.g. Yara, Saipem, Flexens

Hydrogen liquefaction for maritime transportation is costly because its requirements for very low temperatures

SUMMARY OF THE TECHNOLOGY

- Hydrogen liquefaction is the process of condensing hydrogen gas into a liquid state by reducing its temperature to below -253ºC. In this liquid form, hydrogen has a much higher energy density, making it more practical for storage, transport over long distances by ships carriers or trucks
- Hydrogen liquefaction technology is supplied by the largest gas processing technology companies. The cost effectiveness is low due to extreme process conditions the process is highly energy intensive
- Liquefied form through cryogenic tube trailers a novel method of transportation that have yet to reach commercial maturity due to the lack of appropriate infrastructure

KEY PERSPECTIVES

Technology prevalence, technology maturity & market potential

- TRL of hydrogen liquefaction is 7 but commercial availability of ships transporting liquid hydrogen is currently limited due to challenges involved in handling and storing this cryogenic substance and the costs related +

Advantages

- Liquid hydrogen can be transported on longer distances and stored for extended periods, enabling greater flexibility in meeting fluctuating demand or bridging supply gaps +

Disadvantages -

- Large vessel capacities required because of the low volumetric density of hydrogen
- Energy for cooling consumes 30% of the initial quantity of hydrogen affecting the costs and the practicality of liquefaction
- Regasification equipment is required at the end use of hydrogen
- Hydrogen Boil-off during delivery in the order of 0.2-1% hydrogen per day and hydrogen is flammable

KEY COST CHARACTERISTICS

Item	Value
CAPEX (only the liquefaction plant excluding the hydrogen production facility)	High €1,000 to €5,000 per ton of liquified hydrogen production capacity
OPEX	High €100 to €500 per ton per year

EXAMPLES OF TECHNOLOGY SUPPLIERS

Linde

CHART

CAPEX and OPEX figures for hydrogen liquefaction can vary depending on project scale, technology, location, and other factors. TRL : Technological Readiness Level a systematic metric used to assess the maturity and readiness of a technology with 1 being the lowest and 9 being the highest level for a technology that has been successfully deployed

Gaseous hydrogen compression for transport via pipeline is more viable but dependent on a pipeline implementation

SUMMARY OF THE TECHNOLOGY

- Gaseous hydrogen is kept under pressure in tanks or pipelines . Compression requires less equipment and energy than liquefaction, but uses large compressors due to the relatively low energy density:
  - Truck transport: 200-500 bar
  - Pipeline: majority <100 bar
- Hydrogen pipelines enable the delivery of large volumes of compressed hydrogen over long-distances and compressed hydrogen can be transported by trucks.

KEY PERSPECTIVES

Technology prevalence, technology maturity & market potential ++

- Feasible technology with proven commissioned plants and European technology suppliers such as Linde and Siemens Energy

Advantages +

- A commercially available option that is appealing if a pipeline is implemented and an end user for the hydrogen is known

Disadvantages +/-

- Pipelines require extensive structural testing. Hydrogen can cause embrittlement of steel pipelines and lead to an increased risk of leakage
- Transported hydrogen quantity by trucks is usually limited due to road regulations and also the hydrogen storage requires large vessel capacities
- Compressor reliability is challenging and increased safety risks as hydrogen burns much faster than natural gas and increases the risks of flames spreading

KEY COST CHARACTERISTICS

Item	Value
CAPEX	Medium around €500 to €2000 per ton of hydrogen compression capacity
OPEX	Medium €50 to €150 per ton of hydrogen produced annually (lower than liquefaction since compression does not require changing hydrogen phase to liquid)

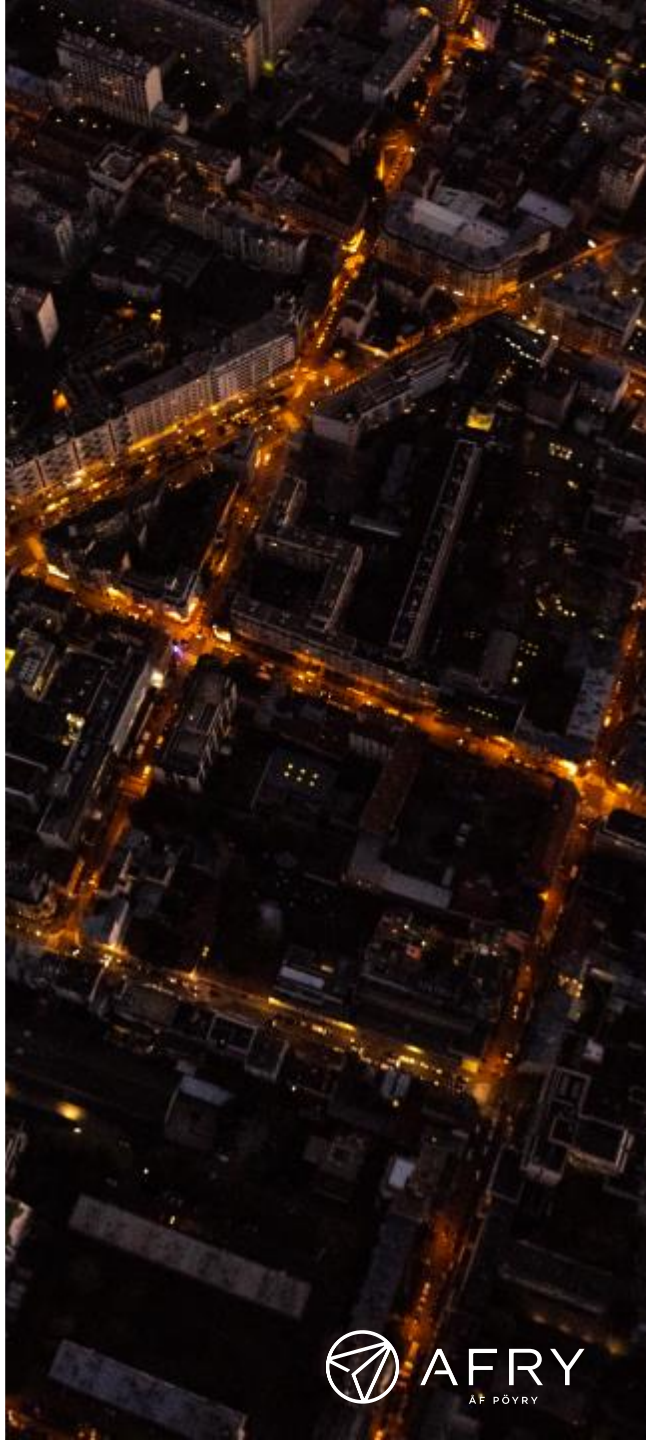
EXAMPLES OF TECHNOLOGY SUPPLIERS

PDC MACHINES

NEUMAN & ESSER

AFRY ÅF PÖYRY

Content



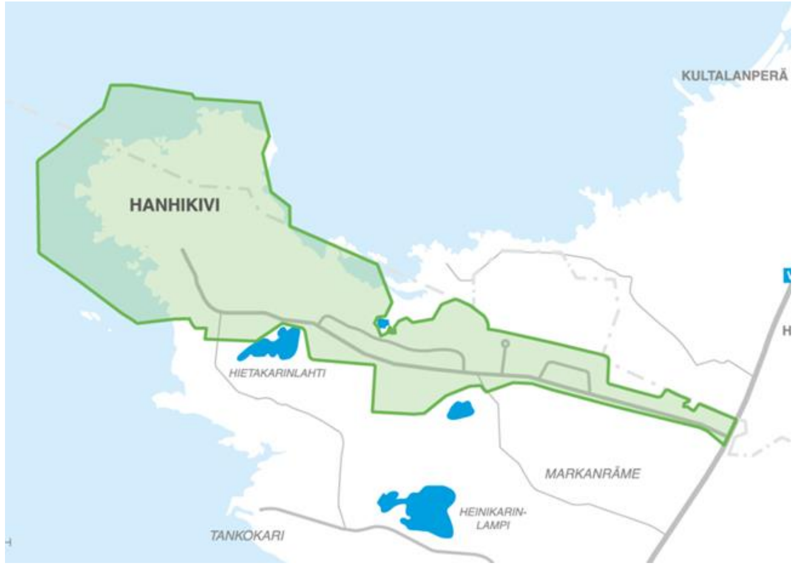
Site infrastructure, location and ability to combine different technologies at the site are seen as the key value providers for different technologies

- Evaluation for the regional site infrastructure was performed by choosing a few key elements and investigating their relevance for the technologies in question
- Four main features were taken under evaluation with each having their own sub-categories
  - **Site infrastructure;** Land area, civil works, buildings, harbour, water connection, grid connection, zoning and permits
  - **General suitability of the site location;** Site location in general (e.g. proximity of coast, nearby industries, rather rural location)
  - **Ability to combine different options at the site;** Could the technology in question be combined with other technologies at the same site
  - **Risks / Advantages / Disadvantages regarding the site compared to other technologies in consideration**

Hanhikivi is a large site with preparations for nuclear power plant use

The Hanhikivi site has been prepared for use by a nuclear power plant. Significant works that have taken place include:

- Major earth works, roads and preparations
- Buildings
- Harbour (mainly underwater works)
- Electricity grid connection preparations
- Zoning and Permitting



Physical

Area: Land and water area owned by Fennovoima 557 ha in total.

Civil works: Roads constructed, earth works and preparations done for ~115 ha.

Buildings: In total 3 permanent buildings: training building 1167 m^2, security gate building 1147 m^2 and admin/office building 9665 m^2.

Harbour: Underwater works completed for harbour, constructions on land not done. Waterway depth is 8 m, width 80 m.

Connections

Water connection: Current freshwater intake capacity max 1200 t/day.

Grid connection: Distribution network connection currently at 5 MW capacity, 2x5,5 MW in reserve. Basic design, zoning and permitting ready for 2x400 kV + 2x110 kV connections to transmission grid.

Other

Zoning: Zoning is for energy production use and supporting functions, specified for nuclear power plant.

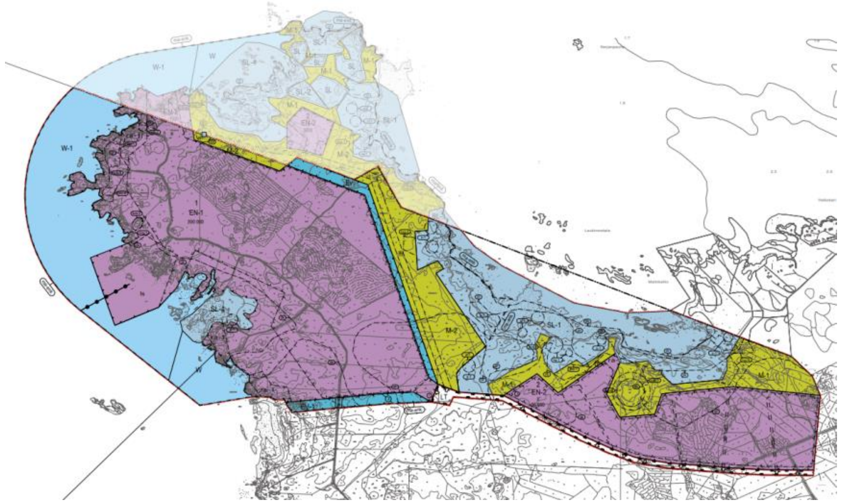
Permits: Water permit for 3200 MW cooling heat load into the sea and harbour construction. Environmental permit for nuclear power plant. Chemical permit.

BACKGROUND

The existing permits cannot as such be utilized for new activity on Hanhikivi site, but provide a good starting point for new projects

Zoning at Hanhikivi

- The main area of the Hanhikivi site is currently zoned as an area for energy production use, with a specification for nuclear power plant use.
  - Practically any other activity would require a zoning change.
  - Change in the zoning is not likely to be difficult but will take normal time. Risk for complaints or nature preservation findings is lower compared to green field but exists.
- The grid connection plans are in the regional land use plan and do not require land use plan change.



Environmental permits at Hanhikivi

- There is currently an environmental permit for the NPP, a water permit for the harbour and cooling water and a chemical permit in place.
- The existing permits cannot as such be utilized for new activity on the site. New permits and a new EIA is needed (if EIA required for new activity).
  - The fact that these existing permits have been granted can give some reassurance to a new developer, especially if the environmental impacts caused by the new activity are similar to those of the NPP.
  - However, permits are assessed at a given time, and for example the state of the environment might have changed after the existing permits have been granted.

*EIA = Environmental Impact Assessment

Physical works might provide value for a new user of the site

	Description	Potential for new user
Land area	Land acquisition.	Land needed for any activity, though Hanhikivi is large area compared to many uses. Cost overall is small.
Civil works	Earth works, roads, foundations etc.	All industrial activity requires site preparations, but only for needed area. Area prepared in Hanhikivi is very large compared to many uses.
Buildings	Significant amount of personnel needed in construction and operation of an NPP. Buildings needed accordingly.	Many potential other uses for the site require significantly less personnel at site, reducing the need for building facilities.
Harbour	Underwater works done. Harbour constructions, support functions etc. still needed.	Roughly half of costs incurred, significant investment still needed for a ready harbour.
Water connection	Costs included in ‘Civil works’. Freshwater max intake capacity 1200 t/day.	Freshwater intake capacity could limit very water-intensive industries.
Grid connection	Connection to TSO grid prepared well, construction not started.	TSO connection needed for many potential uses, either for production or consumption. Planned capacity in Hanhikivi very large compared to most other uses. Small share of costs incurred.
Zoning & Permits	Zoning for energy production use. Environmental permits, major impact is cooling water use.	Practically all permits will need to be re-applied for a new activity. Environmental impacts lesser than already permitted are on the safer side, although changes might have occurred e.g. in state of the environment.

Site infrastructure, location and ability to combine different technologies at the site are seen as the key value providers for different technologies

Rating
- ++ Very positive
- + Positive
- +/- Neutral
- - Negative

	Site infrastructure	General suitability of the site location	Ability to combine different options at the site	Risks / Advantages / Disadvantages
Nuclear – Large scale	++	++	+/-	The site is preliminarily prepared for large scale nuclear power plant.
Nuclear – SMR	+	+	+	Site could provide facilities for several SMRs or SMR combined with other technologies.
Green hydrogen production – All electrolysis technologies	++	++	++	The site is well suited for all three electrolysis technologies; They do not differ meaningfully from the site requirement perspective.
Green ammonia	+	+	++	Haber-Bosch facility could be combined with green hydrogen production facility at same site. Requires a harbor.
Hydrogen liquefaction	+	+	+	Requires a harbour.
Hydrogen compression	+	+	+	Requires a hydrogen pipeline.

AFRY ÅF PÖYRY

Hanhikivi site is suitable for large nuclear power plants as well as one or several SMRs

GENERAL SITE REQUIREMENTS FOR NPP	HANHIKIVI SITE SUITABILITY FOR NUCLEAR POWER
Availability of water Enough water to be used as reactor coolant and other process water	Freshwater connection available for 1200 m³ daily use. The process water production plant and other supporting facilities to be constructed according to the power plant needs.
Availability of ultimate heat sink Ultimate heat sink to transfer the generated heat from power plant (usually large water intake and discharge arrangement)	Location at Finnish coast provides sea water as ultimate heat sink. Permit for 3200 MWth heat load (45 m³/s) available.
Distance from a populated area Due to safety reasons (e.g. rescue planning & local zoning planning) a protection zone of 5 km and contingency area of 20 km shall be evaluated for large scale NPP	In site location planning, the rather rural area of Hanhikivenniemi takes into account the distances. Around 500 people live inside protection zone and some 11-12 thousand people inside contingency area.
Transportation and accessibility Especially the construction phase requires heavy duty transportation, later the nuclear fuel to be delivered safely to the site	The site is located in the immediate vicinity of Finnish national road 8 and the site has its own harbour with 8-meter-deep waterway to the sea. The harbour structures are not fully constructed.
Electrical grid connection Powerplant needs grid connection for transporting the electricity and to have electricity for own purposes	The site does not have the required 400 kV connections yet, but the environmental impact assessment, pre-design and regional land use plan take into account the future 400 kV connection.
Land area Enough space for the plant itself and to arrange all auxiliary facilities for the plant	Preliminary design of land area use has been performed for 1200 MWe nuclear power plant's needs. The land area can be seen suitable for NPP.
External threats taken into account General geological location to be assessed as safe regarding environmental hazards and possibility to arrange safety measures for the plant	External threats, such as environmental phenomena have been taken into account during the site planning for Fennovoima and during Fennovoima construction license application. Finland in general can be seen as safe location for nuclear power plant.

SMR : Small Modular Reactors
Source : AFRY analysis based on Fennovoima construction permit

Large scale nuclear reactors would be the optimal solution for site utilisation

\+ Value of the item o Not applicable/no value ✘ Deal breaker

VALUE OF THE SITE

Infrastructure		
Cooling water	++	Permit and preliminary structure for large scale NPP cooling purposes (~3200 MWth cooling permit)
Harbour	+	The harbour could be mostly utilised during the construction phase a NPP project, later there is very little use for it
400 kV plan	++	Large scale NPP requires the 400 kV Grid connection
Civil works	++	The constructed civil works on site are planned for NPP use and readiness in Hanhikivi is much better than in other sites
Buildings	++	The already constructed buildings could provide facilities at least for the site owner's personnel
Zoning & Permits	++	Zoning plan and environmental permits prepared for large scale NPP

OTHER FACTORS

Location	++	Plant location is planned for large scale nuclear power plant
Area	++	According to preliminary plans, the area is suitable and large enough for NPP use
Potential to combine options		
Area	o	-
Grid connection	o	-

Summary

The Hanhikivi site is perfectly suitable for large scale NPP, as it is originally designed for that. Site readiness (ground works, etc.) is offering savings for a new NPP construction.

NPP = Nuclear Power Plant

AFRY ÅF PÖYRY

Hanhikivi site is suitable for SMR as well as for large scale plants

+ Value of the item   o Not applicable/no value   ✘ Deal breaker

VALUE OF THE SITE

Infrastructure		
Cooling water	++	Enough cooling water for possibly several SMRs
Harbour	+	The harbour could be mostly utilized during the construction phase a NPP project, later there is very little use for it
400 kV plan	++	The planned grid connection can be seen valuable especially if the scale of SMRs to be built is hundreds of megawatts
Civil works	+	Civil works could support generally a larger industrial project like SMR project
Buildings	+	Buildings could support the SMR project as any other larger project especially during project phase
Zoning & Permits	+	SMR could benefit from the zoning and permits prepared for large scale NPP

OTHER FACTORS

Location	+	Generally good location as cooling for SMR is ensured on site. For DH use, the municipalities are quite far from the site
Area	+	Most probably suitable for several SMR units on the site
Potential to combine options		
Area	+	In the future, the power and/or heat generated by SMRs could be utilised in an industrial energy user at the same site
Grid connection	o	-

Summary

The basic needs for SMRs (especially cooling) can be provided on the site

Availability of electricity as well as logistics for end-products are main requirements for a green hydrogen or green ammonia site

GENERAL SITE REQUIREMENTS FOR HYDROGEN AND SYNTHETIC AMMONIA PRODUCTION

H_2

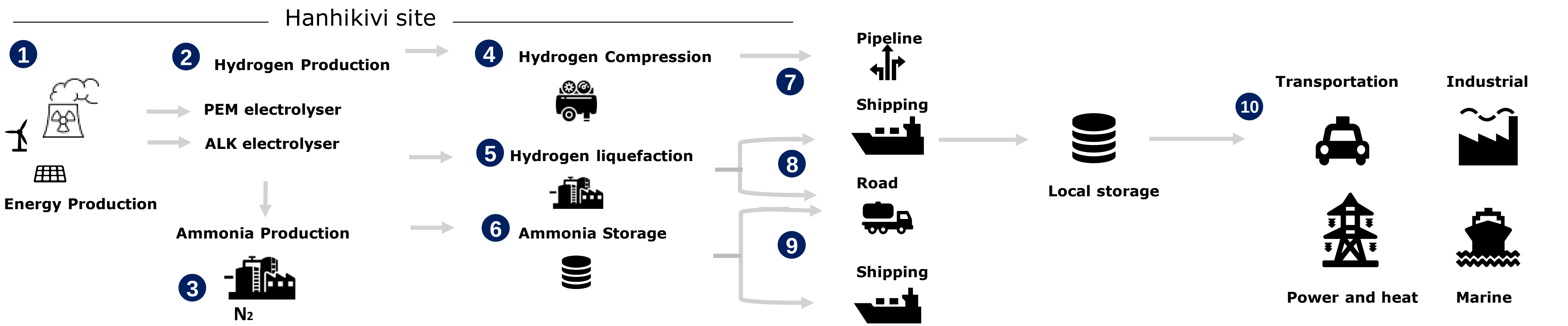
Green hydrogen production
- High-capacity electricity supply
- High-capacity freshwater supply
- Cooling water or other solution for waste heat
  - DH network or other heat demand would be able to utilize waste heat
- Logistics for produced hydrogen
- Wastewater treatment

NH_3

Synthetic ammonia production
- Nitrogen gas sourced from the air
- The process involves high temperatures and high pressures and thus requires a significant amount of energy
- Logistics for liquid ammonia, with trucks or through port

General
- Suitable industrial site, relatively high area requirement
- Dangerous Chemicals permit
- Strict safety measures due to toxic nature of ammonia and flammable nature of hydrogen

Multiple steps on PtX value chain could be done on Hanhikivi site to produce and transport various green hydrogen and ammonia



Production

1 Energy production

Renewable electricity generated from solar PV or wind. Low carbon electricity produced from nuclear power plant

2 Green hydrogen production

Hydrogen produced by Alkaline electrolyser or PEM electrolyser

3 Green Ammonia production

Green Ammonia produced by Haber Bosch Process using green H_2 and N_2 separated from air

Conditioning

4 Hydrogen Compression

Hydrogen is compressed to high pressures (e.g., 350-700 bar) for storage in high-pressure cylinders and transport purposes

5 Hydrogen liquefaction

Hydrogen is compressed then cooled to cryogenic temperatures (around -253°C) to reach liquid state

6 Ammonia storage

Ammonia will be stored in a storage tank physically as liquid at -33°C under atmospheric pressure

Transportation

7 Compressed hydrogen transportation

Through pipelines is an efficient way to move large volumes of hydrogen over long distances

8 Liquid hydrogen transportation

Liquid hydrogen is transported in specialized cryogenic tankers double-walled with vacuum insulation to prevent leaks and ensure the hydrogen remains in its liquid state

9 Ammonia transportation

Depending on the location of the end-user, the transportation can be done via shipping or trucks

Downstream application

10 Depending upon the ammonia carrier and end application; deconversion/re-cracking infrastructure may be required Ammonia Ammonia has multiple applications:

Existing uses for hydrogen and ammonia

Industrial sectors, including chemicals, textile fiber manufacturing, glass, electronics and metallurgy

Expanded uses

Transport fuel, including direct combustion engine/turbine

Energy Storage to electricity generation

AFRY
ÅF PÖYRY

Hanhikivi is a suitable site for green hydrogen production – proximity of a planned hydrogen pipeline is a major advantage

+ Value of the item   o Not applicable/no value   ✘ Deal breaker

SUITABILITY OF THE SITE

Infrastructure		
Cooling water	+	Electrolysis needs cooling water, though significantly less than a nuclear power plant
Harbour	+	Harbour could be used for shipping of liquid hydrogen
400 kV plan	++	Large scale electrolysis requires high-capacity electricity supply
Civil works	+	Electrolysis and supporting functions at site require relatively large area, but Hanhikivi site area has abundant space for this need
Buildings	+	Large scale hydrogen or synthetic fuel production would require staff at site, needing buildings for multiple uses

OTHER FACTORS

Location	++	• Proximity to a planned hydrogen pipeline (Nordic Hydrogen Route) is a major advantage for hydrogen production • Offshore wind sites planned nearby, with possible synergies • No DH network to utilize waste heat from electrolysis
Freshwater intake capacity	o	Current fresh water intake capacity from the municipality at site is 1200 t/day which limits the size of electrolyser to around 100 MW that produces **15 000 tons/year of hydrogen**[1] · However, this issue can be technically solved.
Potential to combine options		
Area	+	Green hydrogen production would leave a lot of area available for other uses.
Grid connection	+	Electrolysis requires high inbound capacity. Capacity available for generation, e.g. offshore wind.

Summary

Green hydrogen production is a very potential site user, due to advantages from proximity to a planned pipeline. If hydrogen is transported by pipeline it would be in compressed form.
Freshwater intake capacity limits the annual hydrogen production to around **15 000 tons/year of hydrogen.**

1 : assuming 8000h of operation in the year and 70% efficiency

Hanhikivi is a suitable site for green ammonia production, the harbour presents an opportunity for shipping the produced ammonia

\+ Value of the item o Not applicable/no value ✘ Deal breaker

SUITABILITY OF THE SITE

Infrastructure		
Cooling water	+	Electrolysis, Haber-Bosch and Air separation processes need cooling water, though significantly less than a nuclear power plant
Harbour	+	Harbour could be used for shipping of ammonia. The harbour depth of 8m could allow shallow draft LNG-type carrier vessels, but this would have to be explored with a future transport partner
400 kV plan	++	Large scale Haber-Bosch process requires high-capacity electricity supply
Civil works	+	Electrolysis, Air separation unit and Haber Bosch processes at site require relatively large area, but Hanhikivi site area has abundant space for this need
Buildings	+	Hydrogen and ammonia production would require staff at site, needing buildings for multiple uses

OTHER FACTORS

Location	+	Proximity to a planned hydrogen pipeline is advantageous for ammonia production allowing usage of hydrogen from the pipeline. Potential ammonia offtakers nearby: Yara International at Kokkola, Kemira industrial sites at Oulu, green fertiliser production site by Fertiberia in Luleå-Boden (Sweden)
Freshwater intake capacity	o	Current fresh water intake capacity limits the quantity of hydrogen produced onsite to **15 000 t/year and as result 85 000 tons of ammonia produced annually** Haber-Bosch and Air Separation unit don't consume directly freshwater
Potential to combine options		
Area	+	Hydrogen and ammonia production would leave area available for other uses such as electricity production and industrial site
Grid connection	+	Electrolysis, Air Separation and Haber Bosch requires high inbound capacity. Capacity available for generation, e.g. offshore wind.

Summary

The site is well suited for ammonia production which would greatly benefit from the harbour. However, the harbour depth could impose limitations on the size of carrier vessels and the required conditioning of the harbour has to be analysed

AFRY ÅF PÖYRY

Hanhikivi is a suitable site for compression of locally produced hydrogen – Liquefaction is also possible if found feasible

+ Value of the item o Not applicable/no value ✘ Deal breaker

SUITABILITY OF THE SITE

Infrastructure		
Cooling water	+	Liquefaction and compression processes need cooling water
Harbour	+	Harbour could be used for long distance shipping of liquified hydrogen however compressed hydrogen is commonly transported through pipelines
400 kV plan	++	Liquefaction and compression processes requires high-capacity electricity supply
Civil works	+	Liquefaction plant or compression at site require relatively large area, but Hanhikivi site area has abundant space for this need
Buildings	+	Liquefaction plant or compression would require staff at site, needing buildings for multiple uses

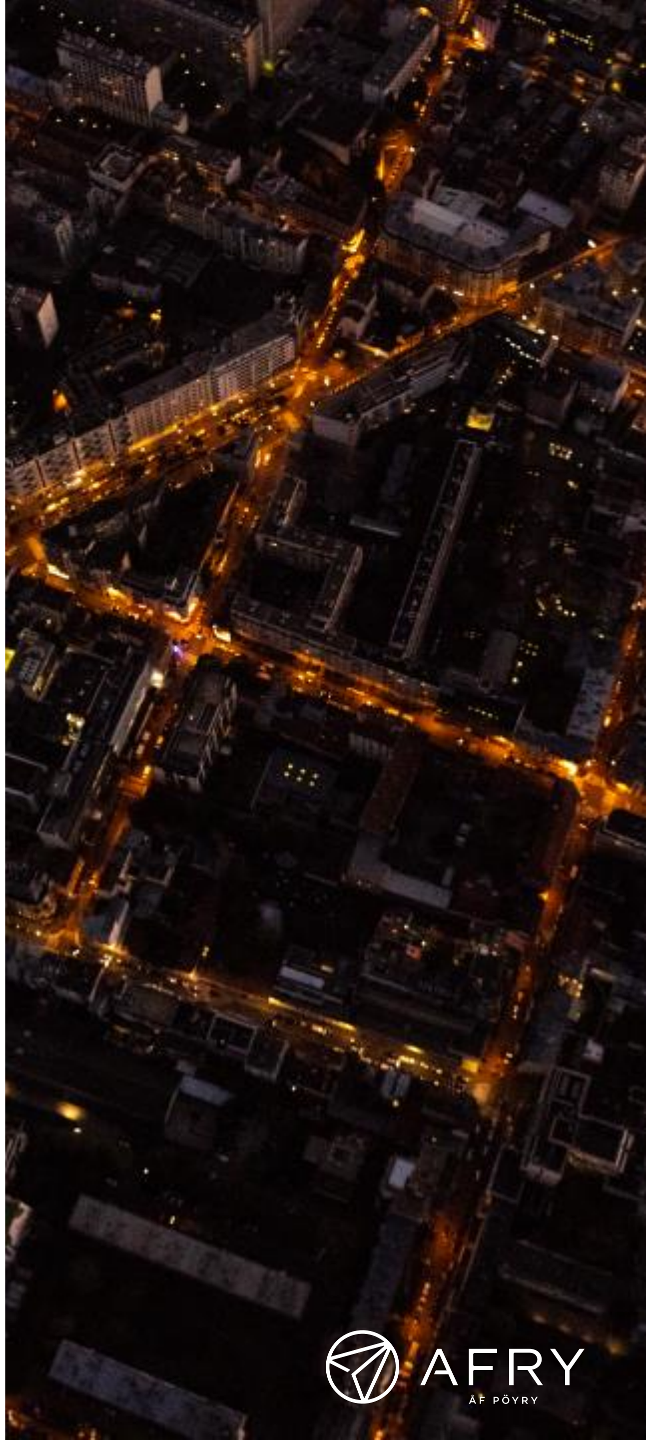
OTHER FACTORS

Location	++	Proximity to a planned hydrogen pipeline (Nordic Hydrogen Route) is a major advantage for compressed hydrogen but not as advantageous for liquified hydrogen
Road	+	Access to roads is crucial for truck transport of compressed or liquefied hydrogen. Hanhikivi has good logistics opportunities, due to proximity of the Finnish national road 8
Potential to combine options		
Area	++	Compression or liquefaction plant would leave a lot of area available for other users
Grid connection	+	Liquefaction and compression both need high inbound capacity

Summary

Hydrogen compression plant would suit well for the site, with hydrogen pipeline as major advantage. Liquefaction plant would benefit from the harbour for shipping for hydrogen overseas to hydrogen intensive industries located outside Finland.
However, at the moment, commercial capability of liquid hydrogen transport via ships is limited and costly. Transport by truck over larger distances (compressed or liquefied hydrogen) is also costly

Content



Evaluation of technology feasibility and potential

- The full evaluation for technology feasibility and potential at the Hanhikivi site is evaluated by combining the techno-economical suitability and site related suitability
- Different technologies are ranked by their techno economical features;
  - **Technology maturity & cost levels**
  - **Market potential**
  - **Project timeline**
- And their site related potential
  - **Ability to utilise infra at site**
  - **General suitability of the site location**
  - **Ability to combine different options**
- The main risks / advantages and disadvantages are also evaluated technology by technology which affect to the total potential of the technology in concern

Assessment of the technology potential is a combination of site and area specific topics together with technological and market suitability

- The total technology potential for different technologies and technology combinations at Hanhikivi site is estimated with the chosen key aspects taking into account both techno-economical and site related potential

Techno-economical potential ← → Site related potential

Technology maturity & cost levels

The maturity of the technology in question

and

Opex & Capex level evaluation of the technology

Market potential

The market potential evaluation in general for the industry in question

Project timeline

The timeline aspect is evaluated by the general project and commissioning timelines for each technology

Risks & limitations

Risks and limitations regarding the technology itself or technology combined with the site

Ability to utilise infra at site

Potential to utilise preparations made at the site

In general, how much of the already constructed infra can be utilised by the industry in question and does it provide value compared to starting from e.g. greenfield

General suitability of the site location

Suitability of the site regarding e.g., location

For example, does the location at coast provide value for the industry or is the site large enough for the site developer

Ability to combine different options

The potential to combine the industry in question with other industries at the same site

For example, could the energy generated by the energy production facility in question be utilized by an industrial process located at same site

Nuclear power plant could be built in the Hanhikivi site if a new large scale project would start in Finland

TECHNOLOGY MATURITY AND COST LEVELS, MARKET POTENTIAL & PROJECT TIMELINE

Technology maturity & cost levels

Large scale nuclear power is a proven technology with hundreds of operable plants worldwide. PWR technology has been lately the most favourable reactor type, BWRs holding second largest share of the total capacity. The cost levels with recently built large scale nuclear units have been very high.

Market growth potential

Nuclear power capacity shows increasing trend worldwide. Fighting the climate change provides a good backbone for new nuclear capacity in general.

General project timeline for the technology

Large scale nuclear power has the longest construction & commissioning period among the discussed technologies. The already performed site preparations help the construction phase of a large scale nuclear power plant project.

SITE VALUE, LOCATION & POTENTIAL TO COMBINE OPTIONS

Ability to utilise infra at site

Hanhikivi site is designed for nuclear power plant. Of compared technologies, large scale nuclear power would find most value from the site infrastructure as the site is prepared for NPP.

General suitability of the site

The location near coast and in the immediate vicinity of Finnish national road 8 provide good connections for logistics. Yet the site is in relatively remote location and therefore suitable for large scale NPP.

Potential to combine options

There would be land area left for other activities, although more area needed during construction of an NPP. A nuclear plant would fully occupy current cooling water and grid connection capacity.

Risks & Limitations

Current limitation for the thermal load of the plant is around 3200 MW as the sea water intake permit is for 3200 MWth (~45 m^3/s). Nevertheless, applying for higher thermal load is possible in case of need. High uncertainties for new large scale NPP project in general in Finland and the cost levels for constructing the plant could be very high.

Summary

The site has been planned for nuclear power plant use and if new nuclear power is considered to be built in Finland in large scale, Hanhikivi site could be attractive location for the project. Uncertainties regarding nuclear power projects in general and relatively high-cost levels have to be taken into account.

AFRY
ÅF PÖYRY

SMR alone could not benefit from the site infra like large NPP, unless several reactors were built on the site

TECHNOLOGY MATURITY AND COST LEVELS, MARKET POTENTIAL & PROJECT TIMELINE

Technology maturity & cost levels

SMRs are developing technology and due to that only estimates are available for the technology maturity. Cost level evaluations face similar challenges because there are no reference plants built for commercial use.

Market growth potential

Fighting the climate change and promises for scalability, wide utilisation possibilities and lower costs than large scale NPPs seem promising for SMR market growth. Nevertheless, some guarantees for technology feasibility and cost levels should be achieved before wider commercialisation.

General project timeline for the technology

SMR construction time and overall project timeline is expected to be shorter than for large scale NPPs. First SMR projects probably have longer project timelines.

SITE VALUE, LOCATION & POTENTIAL TO COMBINE OPTIONS

Ability to utilise infra at site

Hanhikivi site is designed for nuclear power plant. SMRs could utilise some of the infra that has been prepared for large scale nuclear, but no to full extent.

General suitability of the site

The location near coast and in the immediate vicinity of Finnish national road 8 provide good connections for logistics. The location is rather remote and therefore SMRs would be utilised for electricity production only unless industrial activity with heat demand is built on the same site.

Potential to combine options

SMR and industrial energy user could find beneficial opportunities utilising the site to full extent together.

Risks & Limitations

The risks with SMR are related to the general commercialisation uncertainties (technology maturity, legislation, cost levels). It is still unclear when and how the SMRs become commercial in Finland and where their total costs levels would settle. Rather remote location of the site is seen as the only clear site related limitation regarding SMRs, leaving district heat generation with SMR out of question.

Summary

The uncertainty regarding SMRs is the main topic of consideration. If the technology and Finnish legislation are developed effectively and reasonable cost levels can be achieved, SMRs could be very potential site utilisers. The potential to combine SMRs with other technology on same site could provide profitable opportunities.

Ammonia production on site would be a clear short-term solution for site utilisation. Technology combinations provide further options in future

TECHNOLOGY MATURITY AND COST LEVELS, MARKET POTENTIAL & PROJECT TIMELINE

Technology maturity & cost levels

Ammonia production itself with Haber-Bosch technology is fully mature. Cost level for ammonia production alone are rather low. Combined with green hydrogen production, the total cost levels still expected to be competitive.

Market growth potential

Generally good market potential, especially due to the increase in demand for renewable energy.

General project timeline for the technology

Of the technologies in consideration, ammonia production is the fastest solution for finding utiliser for the site. After investment decision, an operable ammonia production facility could be on site after a couple of years.

SITE VALUE, LOCATION & POTENTIAL TO COMBINE OPTIONS

Ability to utilise infra at site

Site infrastructure could be utilised to some extent, but not in full scale as for nuclear power, especially for only ammonia production. Harbour, office buildings, water connection and grid connection plans can be found useful.

General suitability of the site

Coastal location could be beneficial for shipping ammonia. Nearby offtakers could utilise produced ammonia.

Potential to combine options

Good potential for combining different technologies on site. The hydrogen for ammonia production could be produced on site or sourced e.g. via PPA contract. Supportive facilities and e.g. SMR could be built on same site in the future.

Risks & Limitations

The harbour depth could impose limitations on the size of carrier vessels and the required conditioning of the harbour has to be analysed

Summary

Ammonia production would be the fastest solution for site utilisation. Other technologies supporting the ammonia production could be built on same site and there is potentially good connection for transportation via harbour. The harbour depth and general suitability could impose limitations for ammonia transportation.

Hydrogen production is viable solution for the site and could itself be implemented relatively quickly – Transportation capacity is an uncertainty

TECHNOLOGY MATURITY AND COST LEVELS, MARKET POTENTIAL & PROJECT TIMELINE

Technology maturity & cost levels

Maturity of different electrolysers vary, but hydrogen production in general is nothing new. Costs associated to different types of electrolysers also differ. Large part of the costs in hydrogen production come from electricity procurement.

Market growth potential

Market potential through the end product hydrogen. See next page.

General project timeline for the technology

Hydrogen electrolysers come in different types of configuration and scales. A containerised "plug-and-play" solution might be delivered to the site in a year from order while a larger implementation could take a few years.

SITE VALUE, LOCATION & POTENTIAL TO COMBINE OPTIONS

Ability to utilise infra at site

Site infrastructure could be utilised to some extent, but not in full scale as for nuclear power, especially for only ammonia production. Harbour, office buildings, water connection and grid connection plans can be found useful.

General suitability of the site

Site is very well prepared for implementation of any of the three electrolyser technologies

Potential to combine options

Good potential for combining different technologies on site as the footprints of electrolysers are not large. Electricity produced with nuclear technology could be utilised in hydrogen production. Hydrogen compression would also be needed for transporting the produced hydrogen off the site.

Risks & Limitations

Electricity price is one main driver of green hydrogen production costs. Hence, the future of electricity prices is a big factor in the future profitability. On top of electricity, green hydrogen production requires significant fresh water intake which might become a limiting factor on the site depending on the production capacity.

Summary

Hydrogen production is a viable solution from both techno-economical and site perspectives – electrolyser technologies in general are mature. The hydrogen, however, needs to be further processed before transportation off the site, and this is limited by a hydrogen pipeline implementation. (See next page.)

AFRY ÅF PÖYRY

Hydrogen compression is a potential option for transporting hydrogen off the site – It is, however, completely dependent on a pipeline implementation

TECHNOLOGY MATURITY AND COST LEVELS, MARKET POTENTIAL & PROJECT TIMELINE

Technology maturity & cost levels

Hydrogen compression and liquefaction technologies are mature. Liquefaction is clearly the costlier option because of its requirement for extremely low temperatures.

Market growth potential

Good market potential for gaseous hydrogen, especially due to the increase in demand for renewable energy.

General project timeline for the technology

For hydrogen compression to be a viable option, a pipeline to the site is needed. This effectively sets the timeline. Liquefaction could be implemented faster relying on maritime transportation through the harbour, but this is a costly option.

SITE VALUE, LOCATION & POTENTIAL TO COMBINE OPTIONS

Ability to utilise infra at site

Site infrastructure could be utilised to some extent, but not in full scale as for nuclear power. Harbour, office buildings, and grid connection plans can be found useful.

General suitability of the site

Suitability of the site relies heavily on a future hydrogen pipeline.

Potential to combine options

Good potential for combining different technologies on site. Should be implemented alongside of hydrogen production on site.

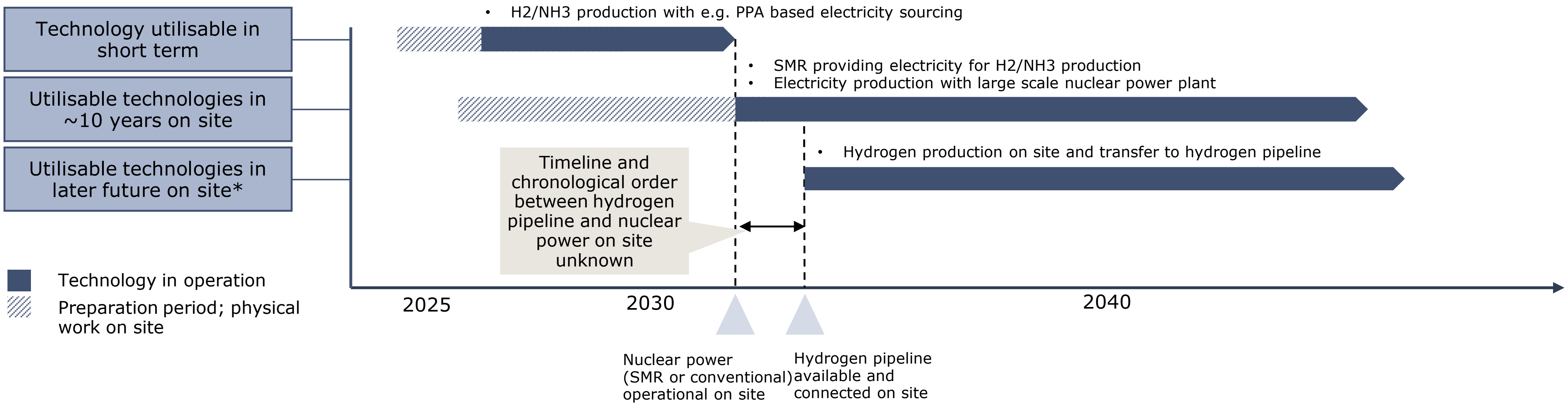
Risks & Limitations

The implementation timeline of Nordic Hydrogen route, or some other hydrogen pipeline, is the main limiting factor.

Summary

If hydrogen were to be produced at the site and transported off the site as hydrogen, it needs to be either compressed to pipeline transportation or liquefied for maritime transportation. Liquefaction is not a viable solution due to its cost level. Compression to a pipeline is a potential option but completely dependent on a future pipeline.

Ammonia production seems to be a good option for site utilisation in short term. In the future H2-pipeline and nuclear power provide further options



- Taking the technology feasibility timelines in consideration, ammonia production with renewable energy sourcing and hydrogen produced for the process on site seem to be a clear option if short-term solution is favoured. The produced ammonia could be transported to markets by shipping
- Hydrogen/ammonia production combined with SMR-based electricity sourcing or sole electricity production by large scale nuclear power plant become considerable options when the timeframe for site utilisation is around 10 years from now
- Depending on the hydrogen pipeline development, large scale hydrogen production shows as viable option for site utilisation in the future also. The produced hydrogen can be transferred straight to the connected hydrogen pipeline. Similar timeline constraints and uncertainties apply to hydrogen pipeline than for nuclear power

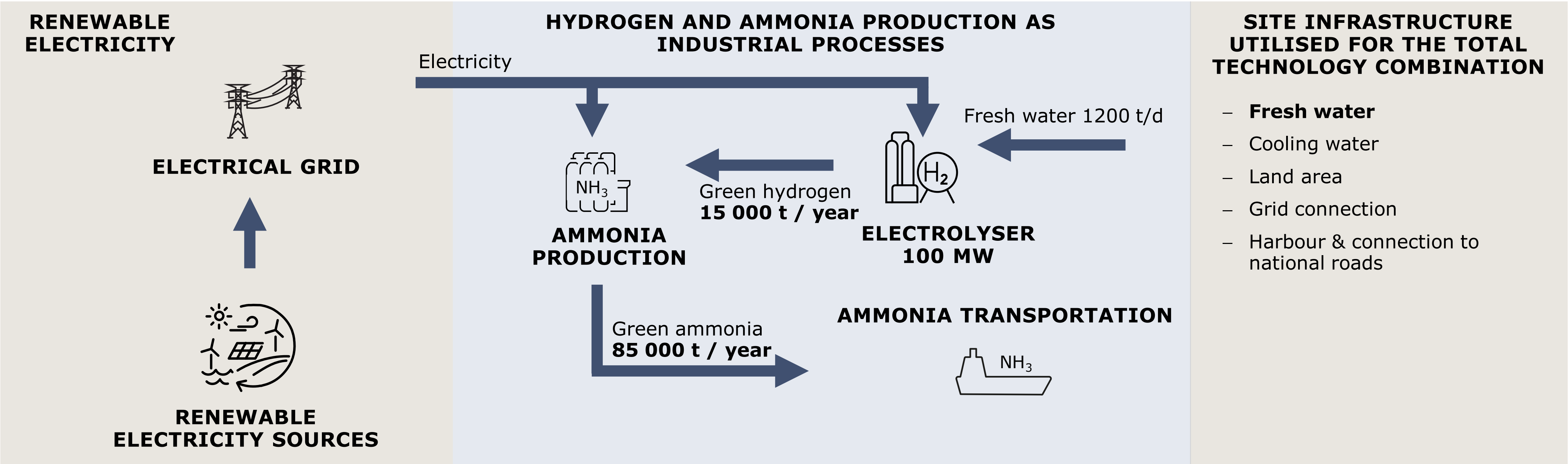
*Potentiality for e.g. hydrogen pipeline to be earlier available than nuclear power on site

Evaluated technology combinations are expected to bring synergies and to utilise the site infrastructure better than only one technology at the site

- Based on earlier total technology potential evaluation, promising technology combinations are provided for utilising the Hanhikivi site:

  - **Green ammonia production with green hydrogen production at the same site**
  - **Low carbon ammonia production with low carbon hydrogen produced by the electricity generated with nuclear at the same site**
  - **Large scale hydrogen production with connection to hydrogen pipeline. Electricity produced by nuclear and/or renewable energy**

Annual green ammonia production could be around 85 000 t based on produced green hydrogen at same site



Renewable electricity procurement by

-PPA

-GoOs

Electrolyser utilised for hydrogen production

Haber-Bosch synthesis plant for ammonia production

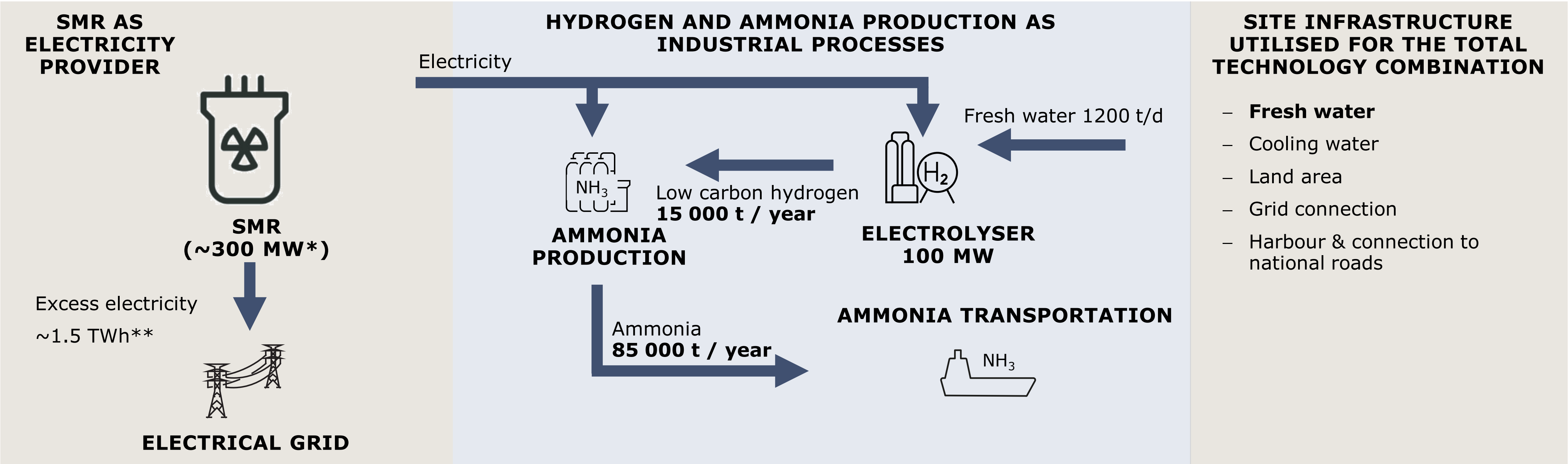
Produced ammonia for transportation by

-Shipping from harbour

Site infrastructure utilised for H2 and NH3 production. Fresh water connection of 1200 t/d as limiting factor

Hydrogen production capacity is based on assumption that 1 kg of hydrogen requires roughly 20 kg of fresh water. The electrolyser capacity of 100MW is estimated by hydrogen production of 150 t/MW annually (with 8000h operating hours and 75% efficiency). Ammonia production is calculated based on 180kg hydrogen needed for 1 t ammonia production.

Almost self-sustainable site could be achieved with SMR producing electricity for hydrogen and ammonia production



SMR provides the required electricity for electrolyser that produces hydrogen

Excess electricity is sold to the electrical grid

Electrolyser utilised for hydrogen production

Haber-Bosch synthesis plant for ammonia production

Produced ammonia for transportation by

-National roads

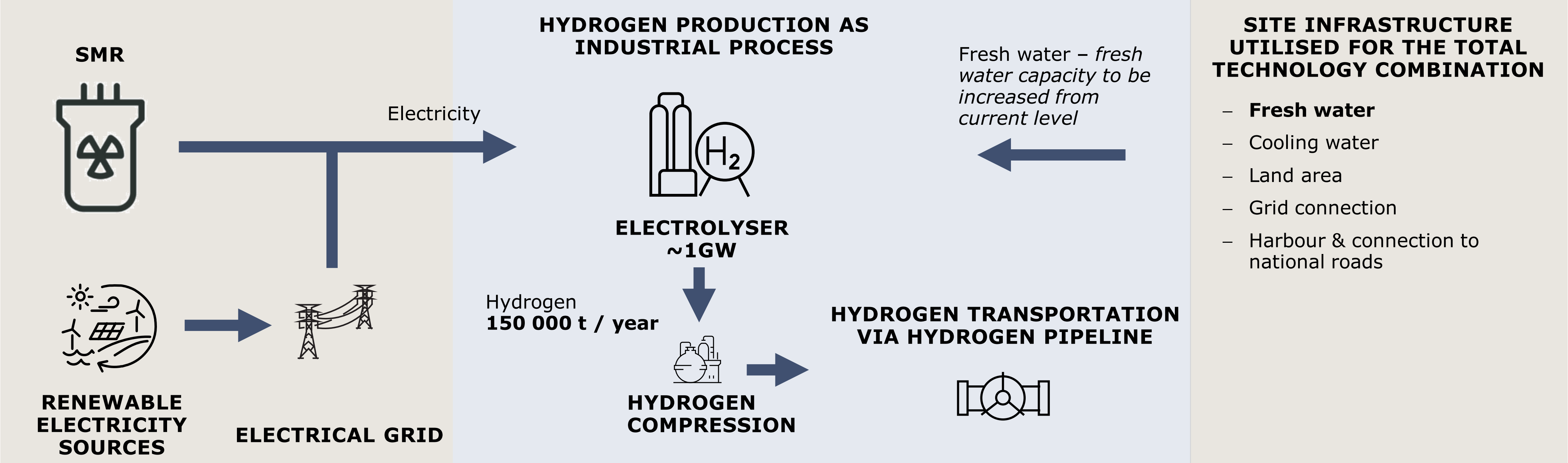
-Shipping from harbour

Site infrastructure utilised for H2 and NH3 production. Fresh water connection of 1200 t/d as limiting factor

Hydrogen production capacity is based on assumption that 1 kg of hydrogen requires roughly 20 kg of fresh water. The electrolyser capacity of 100MW is estimated by hydrogen production of 150 t/MW annually (with 8000h operating hours and 75% efficiency). Ammonia production is calculated based on 180kg hydrogen needed for 1 t ammonia production.

*Depends on the chosen SMR implementation **Assuming 200 MW of excess electricity produced 8000h/a

In the future, hydrogen could be produced in large scale for H2-pipeline transportation with SMRs and/or renewable energy based electricity



SMRs and/or renewable energy from grid as electricity source for large scale hydrogen production

Electrolyser utilised for hydrogen production. Hydrogen compressed for transportation on site

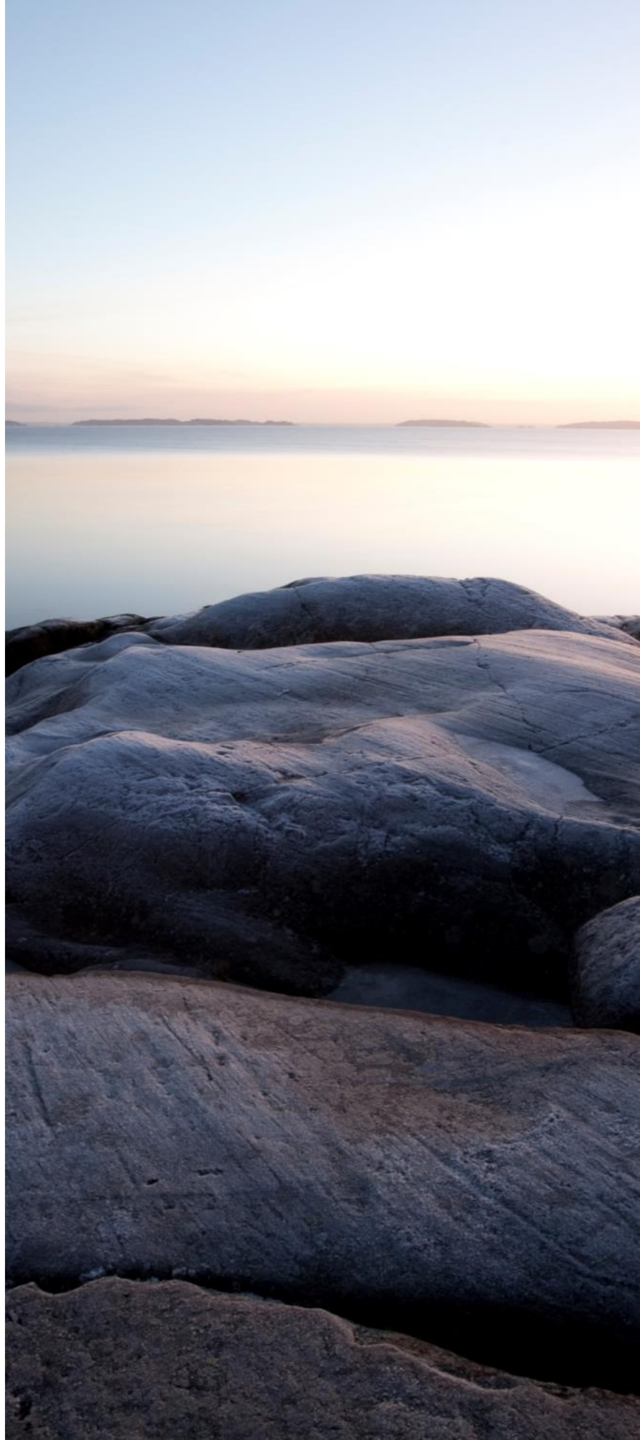
Produced hydrogen for transportation by

-Connection to hydrogen pipeline

Site infrastructure utilised for H2 production (& potentially SMR). Current fresh water connection to be increased to large scale hydrogen production requirements

Placing industry nearby a nuclear power plant is under investigation in international forums

- Nuclear can be used to generate clean and stable electricity for hydrogen production. However, a few important considerations are related to placing nuclear power and hydrogen production on the same site.
- Nuclear power plant (NPP) comes with requirements regarding to the site and the safety zone. Safety, security and safeguards need to be taken into account.
- During the nuclear power plant location assessment, among other things, also site-related external threats need to be evaluated. These threats include rare weather conditions, seismic phenomena, **impacts of possible accidents happening in the vicinity of the plant** and other factors caused by the environment or human activity.
- Earlier nuclear power plants tend to have been placed to rather rural areas, and also away from other industrial activities. However, lately there has been increasing interest to locate NPPs closer to human settlement and industry, which would enable e.g. district heat and process steam generated by nuclear power. This would also enable locating hydrogen production closer to nuclear power plant and utilizing nuclear-based electricity for hydrogen production at the same site.
- The topic is currently under discussion at many international forums, e.g. IAEA (International Atomic Energy Agency) and NEA (Nuclear Energy Agency). IAEA is updating their instructions to take future SMR plants better into consideration. As a part of this update also instructions regarding NPP licensing are renewed, including recommendations related to placing NPPs close to industrial activities.



Site area, protection zone and the contingency area have to be defined for of a nuclear power plant

- The borders of an NPP need to be defined. They have to based on safety, security, and safeguards, and not e.g. on factors related to energy production. This is expected to be the requirement in the future new instructions by IAEA when talking about locating NPPs close to other industrial activities.

- Nuclear power plant includes a safety zone with considerable land use restrictions, for example a ban on significant employment areas that are not related to the NPP. The safety zone used to be 5km in the earlier legislation, but it was renewed in February 2024 so that the zone radius is defined case by case based on plant specifications. Factors affecting the zone radius include plant size and technological properties. The new legislation is targeted to enable placing NPPs closer to industry and human settlement. On the other hand, a hydrogen production plant could probably be located within the safety zone, because as an employment cluster it is probably not very large, and it also could be considered as related to the NPP.

- However, the safety zone only concerns the threat caused by the NPP to its environment. Defining the zone is based on a potential accident happening at the NPP. It does not define how close a hydrogen production plant can be built to the NPP from the perspective of the threat caused by the hydrogen plant.

The external threat posed by the hydrogen plant is evaluated case by case

THE EXTERNAL THREAT POSED BY THE HYDROGEN PLANT

- The hydrogen plant must be considered as a potential external threat to the NPP (e.g. explosions, hydrogen leaks and potentially ignitable/explosive hydrogen clouds related to hydrogen production, storage and transport, etc.). The external threat must be assessed on a case-by-case basis.
- The external threat posed by a hydrogen plant is influenced, for example, by the size of the hydrogen plant and the amount of hydrogen or other hazardous substances stored on site, the pressure level, etc. The potential threat is posed both by the hydrogen production itself and by the storage and transport of hydrogen. For example, if hydrogen were to be transported from the site by sea, the threat of that to the NPP should also be considered.
- The external threat posed by a hydrogen plant can be addressed by technical solutions at the hydrogen plant, for example by reducing the amount of hydrogen stored on site or by moving storage facilities further away.

EXAMINING AND ADDRESSING AN EXTERNAL THREAT

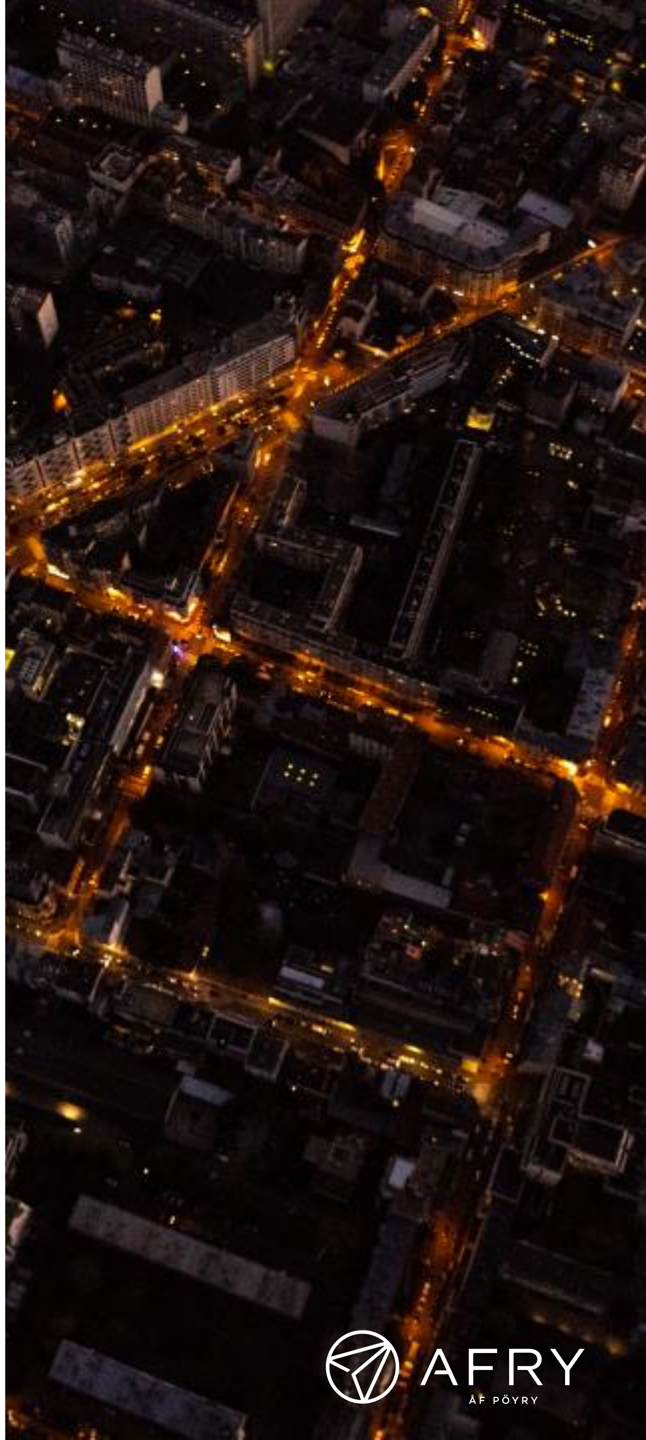
- The IAEA guidance on external threats identifies that a hydrogen plant could be located on the same site as an NPP. However, the guidance only states that the external threat posed by such a plant should be considered in the same way as off-site threats. However, it should be noted that in the case of on-site threats, the NPP may have greater potential to influence the course of events.
- According to the information available on the upcoming IAEA guidelines, the guidelines state that a hydrogen production plant on the same site must not negatively affect the safety of the NPP. This should be demonstrated in the context of the external threats analysis.
- The systems, structures and equipment of the NPP and access routes must be designed, located and protected in such a way that the impact of possible external events on the safety of the NPP is minimized. The operability of systems, structures and equipment must be demonstrated under the external environmental conditions of the plant for which they are designed.
- The location of the hydrogen plant must also consider the electricity transmission lines. According to TUKES, the hydrogen plant must not be placed under overhead power lines and the lateral distance is considered based on the consequences of a potential accident. This not only protects the power transmission but also prevents ignition of the leaked hydrogen from sparking the overhead lines.
- External threats can be addressed through a variety of solutions, both at the site and in the design and siting of the facility itself. For example, protection against explosions can be provided by earth barriers, where the distance from the possible explosion could be smaller than without a barrier.

The nuclear power sector has a desire to enable usability of nuclear power for industrial needs

- There is no clear limit to how close to a nuclear power plant a hydrogen plant could be located.
- When considering the location of a nuclear power plant, the external threat posed by a hydrogen plant planned on the same site or in the vicinity must also be taken into account.
- A hydrogen plant located close to a nuclear power plant must not have a negative impact on the safety of the nuclear power plant.
- External threats can be prepared for, and their effects reduced by plant and site design as well as technological solutions.
- The required distance between plants depends both on the defining of the NPP site area and possibly the safety zone, and on the required distance from the external threat posed by the hydrogen plant. The required distance must be considered from the perspective of both installations' characteristics.
- In the future, it is possible that for example a hydrogen production plant and SMR units or nuclear power plant can be located at the same site. There are already some international pilot examples:
  - Hydrogen electrolysis container at Nine Mile Point
  - Hydrogen production at the planning stage in Davis-Besse
  - Fortum plans a hydrogen production pilot plant nearby Loviisa NPP
- Same preconditions and needs for investigations apply on ammonia production.

Sources: Nine Mile Point Begins Clean Hydrogen Production | Department of Energy
3 Nuclear Power Plants Gearing Up for Clean Hydrogen Production | Department of Energy
Fortum plans to pilot hydrogen production in Finland | Fortum

Content



Mapping of potential suppliers and assessment of delivery readiness

- Both large scale nuclear and SMRs could be potential site utilisers as well as ammonia and hydrogen production. A further supplier specific mapping has been performed especially for the nuclear technologies
- For large scale nuclear, three different reactor types with respective technology suppliers have been tracked as promising technology suppliers
  - **EPR from Framatome**
  - **AP1000 from Westinghouse**
  - **APR1400 from KEPCO**
- Most promising SMR suppliers with their specific concepts have been mapped based on their technology readiness, cost levels and by their advantages or disadvantages compared to other suppliers
- Five different SMR concepts have been tracked as potential future commercial SMRs
  - **Nuscale VOYGR**
  - **Rolls-Royce SMR**
  - **EDF Nuward**
  - **GE Hitachi BWRX-300**
  - **Westinghouse AP300**
- Green ammonia and hydrogen production based technology cards with relevant reference projects, cost levels and high level evaluation have been prepared for comparison and for further evaluation of potential site utilisers

Three large scale reactors and five SMRs have been mapped as promising nuclear energy production options in the future

	Large scale			SMR				
								
	EPR	**AP1000**	**APR1400**	**NuScale**	**Rolls-Royce**	**Nuward**	**BWRX-300**	**AP300**
Country of Origin	**France**	**USA**	**South Korea**	**USA**	**UK**	**France**	**USA/ Japan**	**USA**
Capacity per Unit (MWe)	**1600**	**1100**	**1400**	**300**	**470**	**340**	**300**	**300**
Estimated CAPEX (kEUR/MW)	**Up to 8000+**	**High**	**High**	**5525* (2450**)**	**<4900**	**-**	**3300-3700* (1900**)**	**-**
Target LCOE estimates by suppliers (€/MWh)	**50-100**	**50-100**	**50-100**	**38-65**	**40-55**	**-**	**35-48**	**-**
Implementation Readiness	**Commercial**	**Commercial**	**Commercial**	**Equipment Manufacturing in Progress**	**Detailed Design Phase**	**Conceptual Design Phase**	**Detailed Design Phase**	**-**
Land Area Requirement (m^2/MW) ***	**500-600[4]**	**-**	**-**	**~140[1]**	**~85[2]**	**-**	**~150[3]**	**-**

CAPEX and LCOE estimates presented above are not comparable with each other, as they are figures presented by the suppliers. Especially for SMRs the LCOE can be seen in many cases seen as the targeted level. Also in large scale nuclear projects recent realised cost levels may have been even significantly higher.

*Estimates by the developer for fist reactors **Expected capex level by the developer after wider commercialisation *** Total land area with all the facilities, yet the developers have not provided accurately which site infra is included in the area - uncertainties expected 1. nuscalepower.com 2. Power-technology.com 3. fermi.ee 4. physical footprint comparison

There are few western main suppliers for large scale nuclear power plants

- In the field of nuclear power plant provision, three technologies notably stand out: the AP1000 from Westinghouse, the EPR from Framatome, and the APR1400 from KEPCO. Recently, these technologies have successfully deployed units in various countries and have further units presently under construction
- In a noteworthy recent development, these three entities were contenders for a significant contract in Poland, which entailed a considerable commitment to the supply of nuclear energy
- Ultimately, Westinghouse's AP1000 clinched the contract for the initial three units. Despite being the most affordable choice, KEPCO's APR1400 faced intellectual property-related challenges. Nevertheless, it managed to secure a Memorandum of Understanding for the potential supply of the next three units. On the other hand, although Framatome's EPR packs a substantial power output, it tendered the highest bid and was consequently not selected

EPR is a large scale solution with proven commercialisation and ongoing projects. Project timeline and cost levels have caused challenges

SUMMARY OF THE TECHNOLOGY

- The EPR from Framatome is a four-loop PWR, designed to produce around 1,650 MWe
- The design includes both active and passive safety systems. While the EPR provides more power output, the design has been criticized for construction delays and cost overruns in various projects
- However, a EPR has already been granted operation license in Finland which would facilitate the acquisition of a second one

KEY PERSPECTIVES

Advantages ++

- Feasible technology with proven commissioned plants. European technology supplier and licensed in Finland

Disadvantages -

- Large reactor size can present a challenge for the grid. In Olkiluoto Fingrid provided up to 1300MWe grid protection, an owner for a EPR 1600 needed to provide the remaining 300MWe which represent a significant cost

Risks -

- Earlier projects have shown the timeline and cost risks related to EPR in Europe

KEY COST CHARACTERISTICS

Item	Value
CAPEX	High (even 8000 €/kWe)*
OPEX	Medium/High
LCOE	~50-100 €/MWh*** (Hinkley P. higher)

EXISTING FACILITIES OR ONGOING PROJECTS

Project	Construction time	Project owner
Olkiluoto 3	17y	TVO
Taishan 1 & 2	9y, 9y	Taishan Nuclear Power
Flamanville	**	EDF
Hinkley Point C 1 & 2	**	EDF

*Based on Flamanville & Olkiluoto 3 cost estimates **Project ongoing ***Based on general estimates for large scale NPP

AP1000 is an attempt to reconsolidate US as a large plant supplier

SUMMARY OF THE TECHNOLOGY

- The AP1000 from Westinghouse is a two-loop pressurized water reactor (PWR) that generates around 1,100 MWe
- The AP1000 has passive safety systems to improve safety. The design reduces the number of components, resulting in higher reliability and safety, less piping, less penetration and less safety classified components.
- It aims to be economically competitive by reducing construction which have been around 8-10y from the first nuclear safety concrete

KEY PERSPECTIVES

Advantages

- Westinghouse aims to reconsolidate as a competitive plant supplier with a simplified and proven design. Construction of 3 units in Poland may establish stable European supply chain ++

Disadvantages

- Large scale reactor and therefore not a solution for only industrial electricity sourcing in Finland. To this date no AP1000 have been connected to the grid in Europe +

Risks

- While Westinghouse is a reputable supplier, licensing in Finland could require some design modifications which would increase cost and construction time +/-

KEY COST CHARACTERISTICS

Item	Value
CAPEX	Medium/High
OPEX	Medium
LCOE	~50-100 €/MWh**

EXISTING FACILITIES OR ONGOING PROJECTS

Project	Construction time	Project owner
Vogtle-3 & 4	10y, *	Georgia Power
Sanmen-1 & 2	9y, 9y	Sanmen Nuclear Power
Haiyang-1 & 2	9y, 8y	China Power Inv.

*Project ongoing **Based on general estimates for large scale NPP

APR1400 could provide high capacity with similar risks as other large scale nuclear plants

SUMMARY OF THE TECHNOLOGY

- The APR1400 from KEPCO is an evolution of the earlier AP1000 design. It is a two-loop PWR, producing around 1,400 MWe.
- Like the AP1000, it features both active and passive safety systems but leans more towards the active side. The design has been well received, with successful implementations in the United Arab Emirates. There is an ongoing dispute between KEPCO and Westinghouse over Intellectual Property of the design which might cause challenges to its implementation.

KEY PERSPECTIVES

Advantages

- The design has been well received and offered the lower cost during the bidding process in Poland **++**

Disadvantages

- Large scale reactor and therefore not a solution for only industrial electricity sourcing in Finland. To this date no AP1400 have been connected to the grid in Europe **+**

Risks

- While KEPCO have been demonstrating to be a capable supplier, licensing in Finland could require some design modifications which would increase cost and construction time **+/-**

KEY COST CHARACTERISTICS

Item	Value
CAPEX	Medium/High
OPEX	Medium
LCOE	~50-100 €/MWh**

EXISTING FACILITIES OR ONGOING PROJECTS

Project	Construction time	Project owner
Barakah 1-4	8y, 8y, 8y, *	Emirates Nuclear Energy
Shin Hanul 1 & 2	10y, *	Korea Hydro And Nuclear Power
SAEUL 1-4	8y, 10y, *, *	Korea Hydro And Nuclear Power

*Project ongoing **Based on general estimates for large scale NPP

AFRY
ÅF PÖYRY

Five promising SMR suppliers show high potential in bringing early stage commercial SMR to markets

- According to IAEA, there are currently over 70 different SMR concepts under development with varied outputs and different applications, such as electricity, hybrid energy systems, heating, hydrogen production, water desalinisation and steam for industrial applications
- Taking into account the commercialisation potential in general and the current status of the design, few SMRs stand up as promising solutions for energy production in near future
- Nuscale VOYGR, Rolls-Royce SMR, EDF Nuward, GE Hitachi BWRX-300 and Westinghouse AP300 all seem potential candidates for bringing their SMR design commercial in early stages of the general SMR commercialisation

1. IAEA

Scalable Nuscale VOYGR had ambitious plans but project in the US was terminated likely meaning other projects will not be continued either

NUSCALE VOYGR, USA

- Offers different configurations of several 77MWe PWR modules: VOYGR-4 (308 MWe), VOYGR-6 (462 MWe) and VOYGR-12 (924 MWe)
- First commercially operating project in USA have been terminated and won't continue toward deployment
- Foreign interest expressed from Romania, Bulgaria, Poland, Czech Republic, Estonia and Jordan, however, are unlike to progress due to USA project termination.

KEY PERSPECTIVES

Technology prevalence as industrial energy sourcing alternative ++

- Scalable for industrial sized energy sourcing

Advantages

- Scalability provides opportunities for different solutions (electricity generation, district heating, desalination, commercial-scale hydrogen production and other process heat applications). According to public information, closest to commercialisation/construction phase of among the discussed SMR solutions ++
- Its development is ahead of most SMR projects +

Disadvantages

- Not commercial yet and therefore no project references and user experience available -
- Termination of USA project most likely will slow down or cancel other deployments

KEY COST CHARACTERISTICS

Item	Commentary
CAPEX	CAPEX for the first project estimated to be ~5525€/kWe, and targeted to lower to ~2450€/kWe in the future by the developer
OPEX	Medium/High
Target LCOE	38-65 €/MWh

EXISTING FACILITIES OR ONGOING PROJECTS

Project	Project characteristics	Project owner
The Carbon Free Power Project (CFPP)	- Spearheaded by Utah Associated Municipal Power Systems (UAMPS), will be the first VOYGR SMR power plant to begin operation in the U.S. The six-module plant will be built at the Idaho National Laboratory (INL) in Idaho Falls, and will generate 462 megawatts of carbon-free electricity - Note: The project is terminated (11/2023)	Utah Municipal Power Systems

AFRY ÅF PÖYRY

Rolls-Royce provides a 470 MWe PWR as their SMR design without more accurate information about scaling possibilities

ROLLS-ROYCE SMR, UK

- Rolls-Royce offers a 470MWe pressurized water reactor as their SMR design
- Target for the first commercially operating module in 2029 in UK. Additionally, a target to build 10 reactors by 2035
- Foreign interest expressed from Estonia, Czech Republic, Turkey, Jordan and Netherlands
- Design status: Detailed Design phase ongoing

KEY PERSPECTIVES

Technology prevalence as industrial energy sourcing alternative +

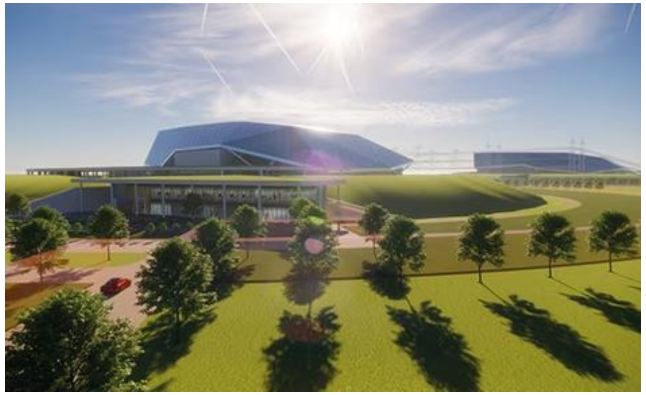
- The 470 MWe capacity requires a very large scale industrial energy consumer to provide electricity only for their process

Advantages ++

- RR SMR has the nuclear knowhow from the military submarine program, its design is similar to a conventional power plant but scaled down with modularized parts. It offers less risk for licensing as its design characteristics and fuel type are mostly well known.
- The design aims to have even the larger parts able to be transported on conventional roads, increasing the constructability on remote locations.

Disadvantages -

- Only one design with 470 MW electrical capacity planned



KEY COST CHARACTERISTICS

Item	Commentary
CAPEX	CAPEX targeted to settle under 4894€/kWe in the future
OPEX	Medium/High
Target LCOE	40-55 €/MWh

EXISTING FACILITIES OR ONGOING PROJECTS

Project	Project characteristics	Project owner
-	-	-

EDF Nuward provides a scalable solution, but the concept is still under development

EDF NUWARD, FRANCE

- Offers a 340MWe concept that consists of two 170MWe PWRs
- Target to commence the constructions of first project in 2030 in France and siting studies ongoing in Poland
- Aims to become a shared SMR concept for the EU area. Early joint review of the design will be performed by ASN (France), SUJB (Czech Republic) and STUK (Finland) in order to consider regulation of different countries
- Design status: Basic Design ongoing

KEY PERSPECTIVES

Technology prevalence as industrial energy sourcing alternative +++

- Nuward is aiming European market buy designing a reactor with early engaging of European regulators and reducing licensing risks

Advantages ++

- Nuward rely mostly in a European supply chain which have been active with EDF and contribute for a significant less risk on project implementation
- EDF owns 18 licenced nuclear sites in France that could be utilized for a FOAK and has strong commitment from French government to fund its development

Disadvantages -

- Compared to other design it seams that Nuward still have large parts which could not be transported easily, limiting its implementation on remote locations. It remains to be seen if the design will take full advantage of the economy modularization

KEY COST CHARACTERISTICS

Item	Commentary
CAPEX	Cost estimates not published by the developer
OPEX	Medium/High
Target LCOE	-

EXISTING FACILITIES OR ONGOING PROJECTS

Project	Project characteristics	Project owner
-	-	-

GE Hitachi BWRX-300 is an advanced stage SMR solution with high potential to be deployed in early stage when SMRs become commercial

GE HITACHI BWRX-300, USA/JAPAN

- Offers a 300MWe boiling water reactor (BWR)
- Target for the first commercially operating module in 2028 in Canada
- Foreign interest expressed from; Poland, Czech Republic and Sweden
- Selected design by Fermi Energia to be implemented in Estonia
- Design status: Detailed Design phase ongoing

KEY PERSPECTIVES

Technology prevalence as industrial energy sourcing alternative ++

- Well known and accepted technology with good engagement in the market

Advantages ++

- BWRX-300 is a well know technology and its development is in an advanced state if compared to other SMRs. Most likely will be among the firsts to deploy a unit.

Disadvantages -

- BWR adoption on Large Scale plants have been declining in favour of PWR which raises questions about long term supply chain availability if the pattern continue to their SMRs versions.
- GE Hitachi have not built reactors for a long time which raises concern about supply chain and implementation readiness

KEY COST CHARACTERISTICS

Item	Commentary
CAPEX	CAPEX for the first projects in Europe ~3300-3700€/kWe, and targeted to lower to ~1900€/kWe in the future
OPEX	Medium/High
Target LCOE	35-48 €/MWh

EXISTING FACILITIES OR ONGOING PROJECTS

Project	Project characteristics	Project owner
Fermi Energia's SMR project in Estonia	- BWRX-300 chosen as the reactor type for Fermi Energia's SMR project. Estimated commissioning date early 2030's	Fermi Energia

AFRY ÅF PÖYRY

Westinghouse AP300 relies on the same licensed technology that is utilised in AP1000 reactor

WESTINGHOUSE AP300, USA

- Offers a 300MWe pressurized water reactor (PWR)
- The design is based on the licensed and operating AP1000 pressurized light water technology that has proven reliability

KEY PERSPECTIVES

Technology prevalence as industrial energy sourcing alternative ++

- Scaled down version of a well known and proven design

Advantages ++

- It is based on the proven design of the AP1000 which should simplify licensing process as Westinghouse claims that every safety component have already being licensed.

Disadvantages +

- Westinghouse have revealed this design just recently in 2023, there is little information about potential sites and state of its design.

KEY COST CHARACTERISTICS

Item	Commentary
CAPEX	Cost estimates not published by the developer
OPEX	Medium/High
Target LCOE	-

EXISTING FACILITIES OR ONGOING PROJECTS

Project	Project characteristics	Project owner
-	-	-

AFRY ÅF PÖYRY

Green ammonia production using Haber Bosch process

SUMMARY OF THE TECHNOLOGY

- Ammonia is synthesized by reacting hydrogen and nitrogen at high pressure and temperature over a catalyst ('the Haber-Bosch process')
- Renewable ammonia synthesis is a mature technology based on the same process as the current fossil Haber-Bosch process that uses fossil hydrogen produced via reforming of natural gas. In case of renewable ammonia, fossil hydrogen is replaced by green hydrogen
- Nitrogen is needed and is produced by Air separation Unit (ASU)

KEY PERSPECTIVES

Technology prevalence

- Haber-Bosch process is an established commercial technology with TRL 9. Multiple European technology suppliers exist such as Haldor Topsoe (Denmark) ++

Advantages

- Ammonia is the most cost-effective technology route for a synthetic fuel due to high efficiency, 97% conversion efficiency is typically reached. ++
- Ammonia is produced in a condensed liquid state, there is no extra cost for converting the ammonia into a transport-ready state

Disadvantages

- Haber-Bosch process requires a significant amount of energy to operate +
- Technology is designed for large scale production and scaling it down based on availability of renewable electricity and renewable hydrogen might be challenging
- Ammonia becomes toxic when it leaks or undergoes combustion

KEY COST CHARACTERISTICS

Item	Value
CAPEX	Low (~100 € per ton of ammonia production when taking to account only the Haber-Bosch facility, ~400 € per ton of ammonia for whole process, including electrolysis and synthesis plant)[1]
OPEX	Medium
LCOA	~1000 € per ton of ammonia, including electrolysis and synthesis plant (Haber-Bosch process expected to be responsible for ~15% of total costs)[1]

EXISTING FACILITIES OR ONGOING PROJECTS

Project	Project characteristics	Project owner
Yara Pilbara Renewable Ammonia Plant in Australia	- Production capacity of 30 000 tons of ammonia per year	Yara international
HØST PtX Esbjerg in Denmark, project under development	- Largest green ammonia plant in Europe producing 600 000 tons of ammonia for use in fertilizers and in fuels	Copenhagen Infrastructure Partners (CIP)

TRL : Technological Readiness Level a systematic metric used to assess the maturity and readiness of a technology with 1 being the lowest and 9 being the highest level for a technology that has been successfully deployed

Hydrogen liquefaction for maritime transportation is costly because its requirements for very low temperatures

SUMMARY OF THE TECHNOLOGY

- Hydrogen liquefaction is the process of condensing hydrogen gas into a liquid state by reducing its temperature to below -253ºC. In this liquid form, hydrogen has a much higher energy density, making it more practical for storage, transport over long distances by ships carriers or trucks
- Hydrogen liquefaction technology is supplied by the largest gas processing technology companies. The cost effectiveness is low due to extreme process conditions the process is highly energy intensive
- Liquefied form through cryogenic tube trailers a novel method of transportation that have yet to reach commercial maturity due to the lack of appropriate infrastructure.

KEY PERSPECTIVES

Technology prevalence

- TRL of hydrogen liquefaction is 7 but commercial availability of ships transporting liquid hydrogen is currently limited due to challenges involved in handling and storing this cryogenic substance and the costs related +

Advantages

- Liquid hydrogen can be transported on longer distances and stored for extended periods, enabling greater flexibility in meeting fluctuating demand or bridging supply gaps +

Disadvantages -

- Large vessel capacities required because of the low volumetric density of hydrogen
- Energy for cooling consumes 30% of the initial quantity of hydrogen affecting the costs and the practicality of liquefaction
- Regasification equipment is required at the end use of hydrogen
- Hydrogen Boil-off during delivery in the order of 0.2-1% hydrogen per day and hydrogen is flammable

KEY COST CHARACTERISTICS

Item	Value
CAPEX (only the liquefaction plant excluding the hydrogen production facility)	High €1,000 to €5,000 per ton of liquified hydrogen production capacity
OPEX	High €100 to €500 per ton per year

EXISTING FACILITIES OR ONGOING PROJECTS

Project	Project characteristics	Project owner
HyNet is a hydrogen production and liquefaction project in UK	- The project focuses on utilizing renewable and low-carbon energy sources	Progressive Energy, Cadent
Shell's Rhineland hydrogen liquefaction plant in Germany	- Liquefaction of fossil and green hydrogen	Shell Rhineland

CAPEX and OPEX figures for hydrogen liquefaction can vary depending on project scale, technology, location, and other factors. TRL : Technological Readiness Level a systematic metric used to assess the maturity and readiness of a technology with 1 being the lowest and 9 being the highest level for a technology that has been successfully deployed

AFRY ÅF PÖYRY

Gaseous hydrogen compression for transport via pipeline is more viable but dependent on a pipeline implementation

SUMMARY OF THE TECHNOLOGY

- Gaseous hydrogen is kept under pressure in tanks or pipelines . Compression requires less equipment and energy than liquefaction, but uses large compressors due to the relatively low energy density:
  - Truck transport: 200-500 bar
  - Pipeline: majority <100 bar
- Hydrogen pipelines enable the delivery of large volumes of compressed hydrogen over long-distances and compressed hydrogen can be transported by trucks.

KEY PERSPECTIVES

Technology prevalence ++

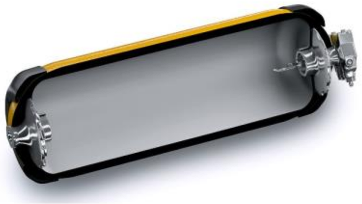
- Feasible technology with proven commissioned plants and European technology suppliers such as Linde and Siemens Energy

Advantages +

- A commercially available option that is appealing if a pipeline is implemented and an end user for the hydrogen is known

Disadvantages +/-

- Pipelines require extensive structural testing. Hydrogen can cause embrittlement of steel pipelines and lead to an increased risk of leakage
- Transported hydrogen quantity by trucks is usually limited due to road regulations and also the hydrogen storage requires large vessel capacities
- Compressor reliability is challenging and increased safety risks as hydrogen burns much faster than natural gas and increases the risks of flames spreading



KEY COST CHARACTERISTICS

Item	Value
CAPEX	Medium around €500 to €2000 per ton of hydrogen compression capacity
OPEX	Medium €50 to €150 per ton of hydrogen produced annually (lower than liquefaction since compression does not require changing hydrogen phase to liquid)

EXISTING FACILITIES OR ONGOING PROJECTS

Project	Project characteristics	Project owner
Energiepark Bad Lauchstädt in Germany	- Hydrogen compression facilities to support the refueling of hydrogen-powered vehicles	H2 MOBILITY Deutschland, TOTAL, and Linde:
H2FUTURE in Austria	- Hydrogen compression facilities to enable the use of hydrogen in various sectors, particularly in steel production	voestalpine AG

AFRY ÅF PÖYRY

Alkaline electrolyser (ALK) technology is most mature and available in large scale

SUMMARY OF THE TECHNOLOGY

- Alkaline electrolysers uses a liquid alkaline solution of sodium or potassium hydroxide and operates via transport of hydroxide ions (OH-) through the electrolyte from the cathode to the anode with hydrogen being generated on the cathode side
- ALK electrolyser are usually operated at baseload
- ALK with lifetime of 12y is the most popular in large scale applications today. Once full stack is replaced due to cells degradation, ALK electrolysers' lifetime extends to 20 years

KEY PERSPECTIVES

Technology prevalence, technology maturity & market potential ++

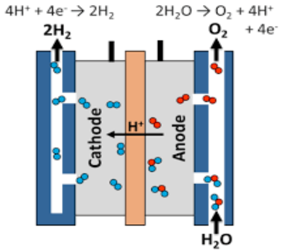
- ALK have been commercially available for many years. Its TRL is 8 and there are multiple European technology suppliers such as Nel Hydrogen, Green Hydrogen Systems and Enapter

Advantages ++

- New ALK designs are quickly catching up in flexibility
- ALK does not contain noble materials. Hence it is the cheapest electrolyser type and is less exposed to materials supply risk
- ALK is the most mature electrolyser technology, has long stack lifetime and lowest CAPEX among electrolyser types

Disadvantages +

- ALK is less flexible than other electrolysers and is the least efficient
- Lead time is close to 3 years from order



KEY COST CHARACTERISTICS

Item	Value
CAPEX	~ 500 EUR/KW
OPEX	Medium (electricity is the highest operational cost)
LCOH[1]	3.2 – 4.6 EUR/kg

EXISTING FACILITIES OR ONGOING PROJECTS

Project	Project characteristics	Project owner
NorthH2 in the Netherlands	- Development of green hydrogen value chain, with a target of producing 4 GW of wind-powered alkaline electrolysis capacity	Shell, Gasunie, Groningen Seaports, RWE, and Equinor
H2Future in Austria	- Construction of a 6 MW alkaline electrolysis plant to produce hydrogen for industrial use, mobility, and energy storage	Voestalpine, Siemens, Verbund

Sources: IRENA 2020, Hydrogen tech world
TRL : Technological Readiness Level a systematic metric used to assess the maturity and readiness of a technology with 1 being the lowest and 9 being the highest level for a technology that has been successfully deployed 1) Levelized cost of hydrogen, values represent the LCOH values determined at electricity prices of 30 and 60 EUR/MWh, respectively 2) One supplier: Stargate hydrogen

Proton Exchange Membrane (PEM) electrolysers are also available on large scale but they are pricier due to expensive catalyst materials

SUMMARY OF THE TECHNOLOGY

- In a PEM electrolyser, the electrolyte is a solid specialty plastic material. Water reacts at the anode to form oxygen and positively charged hydrogen ions at the cathode; hydrogen ions combine with electrons from the external circuit to form hydrogen gas. The operating temperature of PEM is 70-90°C.
- Commercial MW-scale PEM electrolysers have been introduced to the market by several suppliers for its flexibility

KEY PERSPECTIVES

Technology prevalence, technology maturity & market potential +

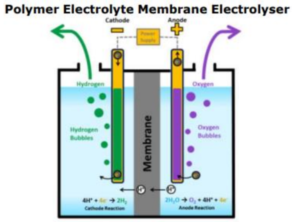
- PEM is a relatively new technology that is commercially available but less mature than ALK type (TRL is 7). There are European technology suppliers available, such as Nel Hydrogen, McPhy Energy Systems and Enapter

Advantages ++

- PEM has the highest operational flexibility and is well suitable for intermittent power sources
- PEM has small footprint, and its CAPEX is continuously decreasing

Disadvantages +/-

- Expensive technology because of the materials it contains, and it has been used in industries less than ALK
- Some of the materials used in PEM (iridium, scandium and yttrium and moderately titanium) might be under significant future supply risk, whereas materials in alkaline electrolysis are not



KEY COST CHARACTERISTICS

Item	Value
CAPEX	~ 750 EUR/kW (higher than ALK CAPEX)
OPEX	Medium (electricity is the highest operational cost)
LCOH[1]	3.9-5.4 EUR/kg (Higher than ALK with all electricity prices)

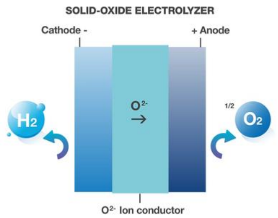
EXISTING FACILITIES OR ONGOING PROJECTS

Project	Project characteristics	Project owner
REFHYNE II	- PEM electrolyzer capacity 100 MW at the Rheinland refinery in Germany	Shell, ITM Power, and Linde

Sources: IRENA 2020, Hydrogen tech world 1) Levelised cost of hydrogen, values represent the LCOH values determined at electricity prices of 30 and 60 EUR/MWh, respectively

AFRY
ÅF PÖYRY

Solid oxide electrolysis (SOEC) has high efficiency but is still available only on small scale



SUMMARY OF THE TECHNOLOGY

- SOECs typically use a solid ceramic material as the electrolyte that selectively conducts negatively charged oxygen ions (O^{2-}) at elevated temperatures (700-800 °C)
- SOEC is the least mature out of the three electrolyser technologies presented

KEY PERSPECTIVES

Technology prevalence -

- SOEC is the least mature out of the three electrolyser technologies presented. SOEC technology is primarily at R&D stage, and commercialisation is only on its way.

Advantages +

- SOEC can produce hydrogen with a high purity
- SOEC operates at a high efficiency

Disadvantages +/-

- SOEC is still available only in small scale
- Because of the very high operating temperatures, SOEC requires a heat source and significant heat waste is produced

KEY COST CHARACTERISTICS

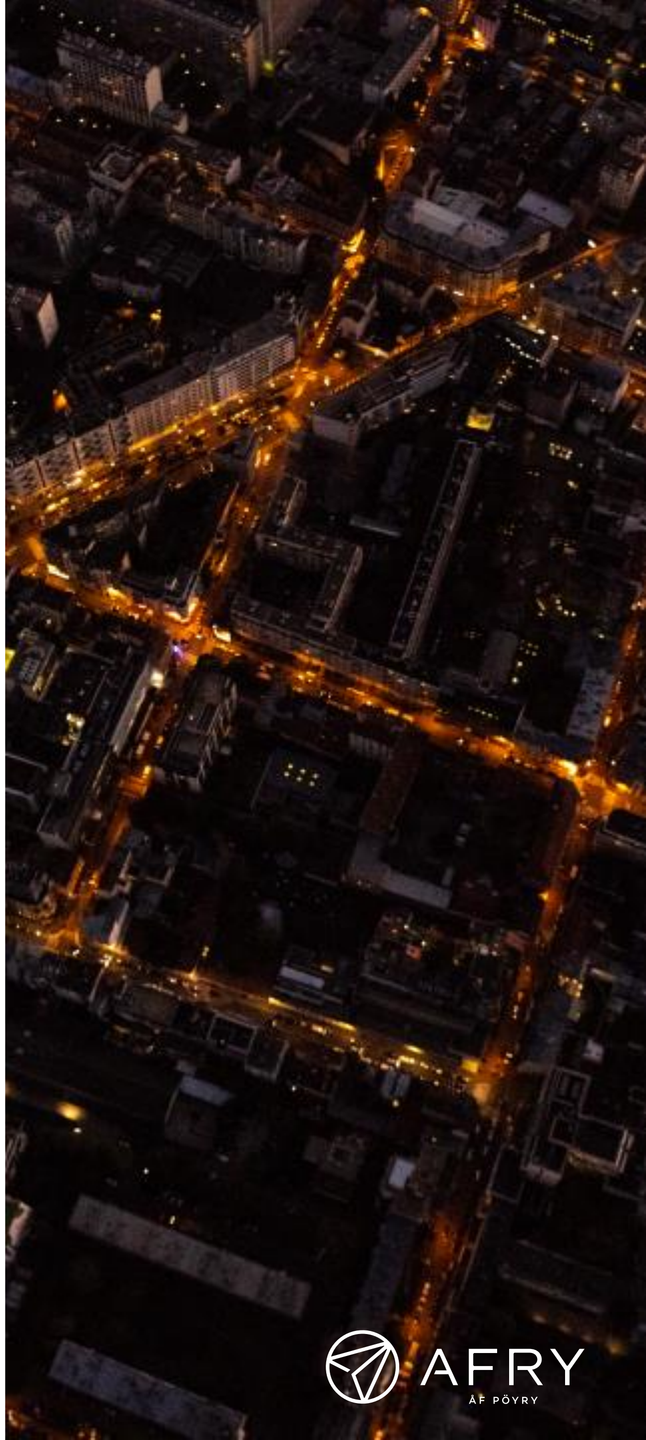
Item	Value
CAPEX	~ 800 EUR/kW (higher than both ALK and PEM)
OPEX	Medium (electricity is the highest operational cost)
LCOH[1]	3.19-4.3 EUR/kg (Cheaper than ALK with all electricity prices)
PROJECT TIMELINE	When matured, same kind of lead time as with ALK can be expected

EXISTING FACILITIES OR ONGOING PROJECTS

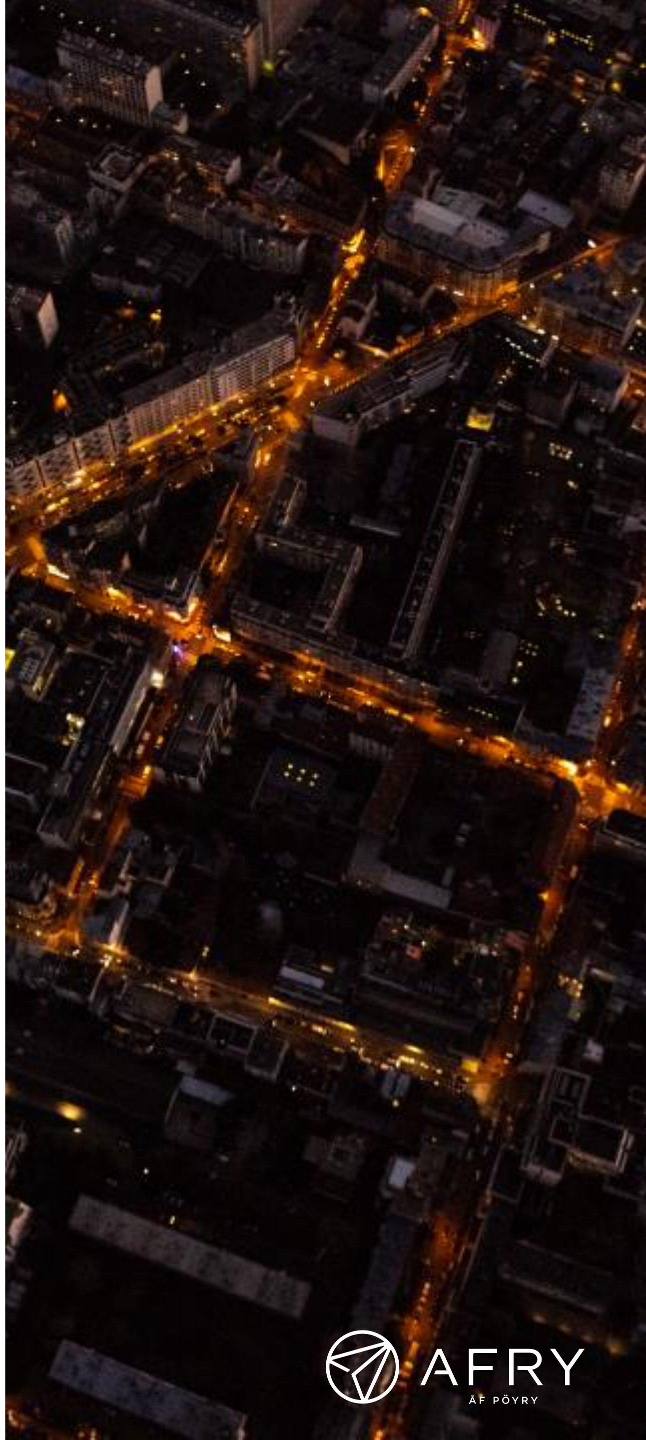
Project	Project characteristics	Project owner
GrInHy2.0	- World's largest SOEC electrolyser, at 720 kW, utilizing waste heat from a co-located steel production process. Project reported an efficiency of 84% in 2022.	Salzgitter AG

Sources: IRENA 2020, Hydrogen tech world 1) Levelised cost of hydrogen, values represent the LCOH values determined at electricity prices of 30 and 60 EUR/MWh, respectively

Content



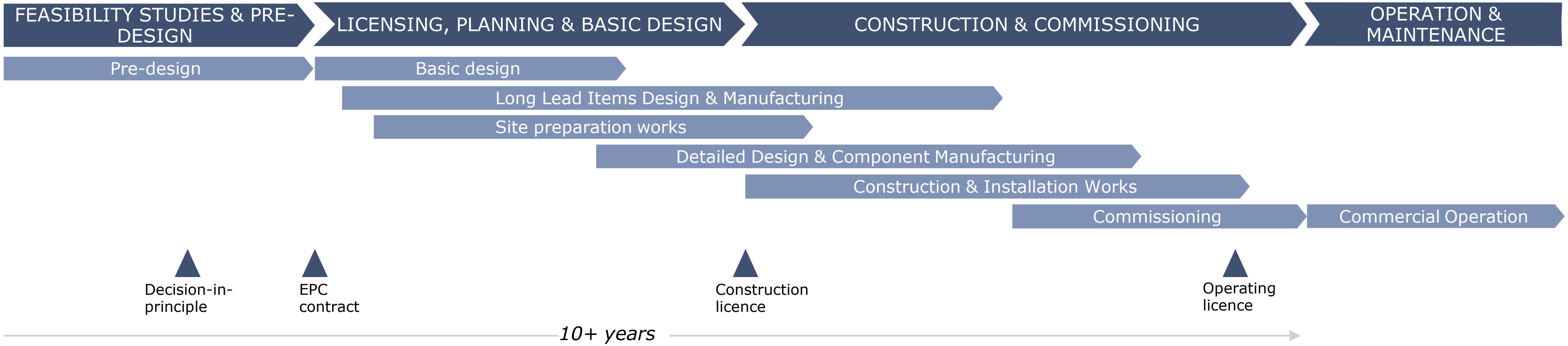
Content



Stakeholder network mapping has been performed for each relevant technology by their specific project development phase and stakeholders taking part into the process

- This section of the report describes **typical stages of project development processes and related key stakeholders for the relevant technology and project types**. Assessment focus on traditional nuclear power, SMR, hydrogen production and refining into synthetic fuels or other end-products (P2X)
- The stakeholders have been mapped by technology and stakeholder group, taking into account both national and international players
    - Stakeholder groups and key actors may include, for example, investors, project developers/energy companies (e.g. Fortum, Vattenfall, TVO), suppliers (e.g. GE Hitachi, Rolls Royce) and energy end-users (e.g. Outokumpu, SSAB)

Nuclear power plant project requires constant co-operation between the license holder, plant supplier and regulatory authority (STUK)



KEY STAKEHOLDERS FOR DIFFERENT PHASES OF A NUCLEAR POWER PLANT PROJECT

- Investors, energy companies and potentially some current NPP license holders build up a company to act as project owner for new NPP
- Regulatory co-operation and connection with local authorities for e.g. suitable location and preliminary environmental impact analysis
- Parliament approval for decision in principle
- Negotiations with potential plant suppliers

- Plant supplier engaged with EPC contract
- Subcontractors for system level and main component design and manufacturing
- Civil works companies for e.g. earthworks on site which do not require construction license for the power plant
- Plant supplier engaged on design and manufacture of long lead items
- STUK provides a statement on the application for a construction licence, accompanied by the safety assessment

- Plant supplier enforces local participation to the project. Commissioning phase organisation is being built
- High participation of contractors for engineering, manufacturing and site works. Several companies on site for different parts of buildings and power plant systems
- Project owner develops its own organisation, targeting for commercial operation in the future
- STUK surveillance for design, manufacturing, construction/installation & commissioning. The operating licence for a nuclear facility is applied for from the Government. STUK provides a statement on the application for an operating licence

- Reliable operation secured with appropriate licence holder's own organisation following STUK guidelines
- Support for operation and maintenance guaranteed by e.g. Long term Service Agreements with plant supplier, OEM contracts and contracts with local service providers
- Produced energy supplied to offtakers and/or sold to electricity markets

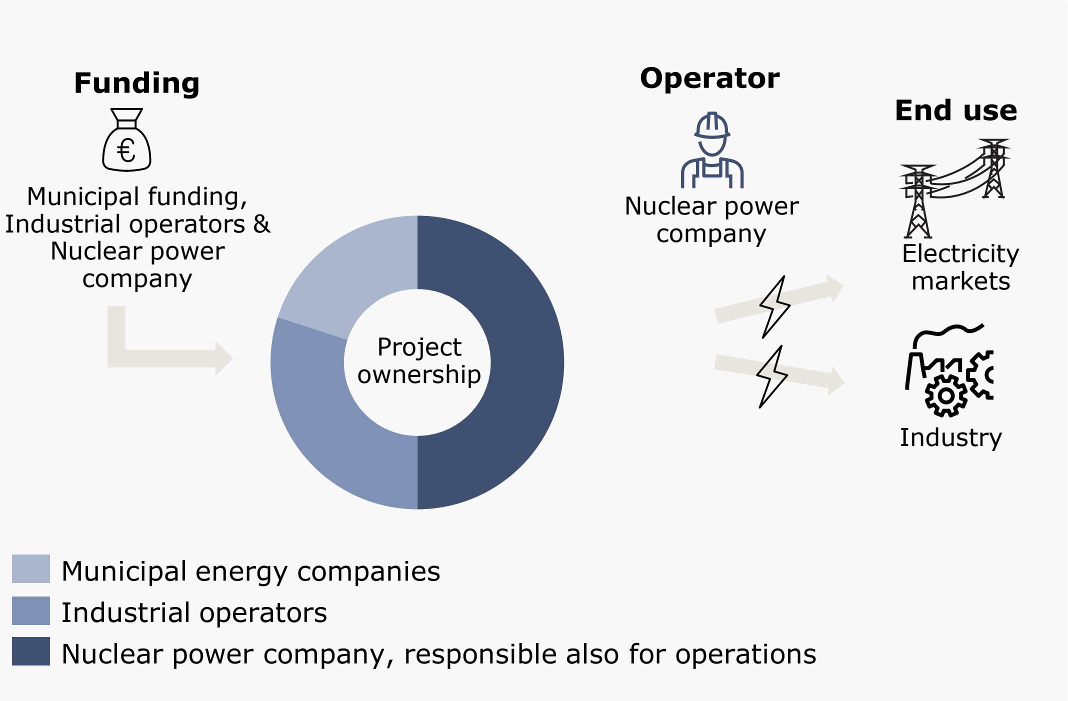
NPP = Nuclear Power Plant, OEM = Original Equipment Manufacturer

AFRY ÅF PÖYRY

OPERATING MODEL OF A NEW NUCLEAR POWER COMPANY

Key element for starting a new nuclear power plant project is to find a way to establish a company that is responsible for the project

EXAMPLE OF THE OWNERSHIP MODEL OF A NEW NUCLEAR POWER PLANT COMPANY



ESTABLISHING A COLLABORATIVE OWNERSHIP MODEL FOR NEW NUCLEAR POWER PLANT PROJECTS

- To start a new nuclear power plant project, an owner company has to be established to be responsible for the whole project and act as the license holder or partner with a project developer that will be responsible for certain phases of the nuclear power plant project
- The company could be built up by gathering together energy companies, energy users and investors. The ownership of the company could be shared for example between
  - Municipal energy companies
  - Industrial operators
  - Already existing nuclear company that has the competency to operate a nuclear power plant
- Mankala model (presented in Chapter 5.21) is a common model combining energy production and industrial users. In Mankala model the shareholders can purchase energy at cost price.
- The operating model could be structured in a way that the nuclear company could be responsible for the plant operations and the other shareholders could take profit from the sold electricity or utilise the produced electricity for their own use (industrial operators)

Project ownership between different parties is given as an indicative example. The assumption is that the shareholders have to establish a joint venture to act as the licence holder, and the licence holder company should be based on Finnish/EU ownership.

Potential stakeholders and their capabilities regarding new NPP (1/2)

	Description	Motivation/drivers towards new nuclear projects	Capabilities	Pros/Cons
Fortum	Large energy producer, with competencies in nuclear power	Targeting towards new nuclear power production in the future, especially SMRs	Licence holder at Loviisa Nuclear power plants in Finland. Know-how in owning large scale energy production facilities	Potential service provider by the long term knowledge in operating and building nuclear power plants. Could be interested on both large new built and SMRs. Existing site can accommodate a new built, interest on expanding to Pyhäjoki can be limited
Vattenfall	Large energy producer, with competencies in nuclear power	Targeting towards new nuclear power production in the future, especially SMRs	License holder of 2 nuclear plant in Sweden. Know-how in owning large scale energy production facilities	Could be interested on both large new built and SMRs. Potential service provider by the long term knowledge in operating. Focused on Swedish market, interest in expanding to Finland can be limited
TVO	Largest nuclear power producer in Finland	Interest towards opportunities provided by SMR & hydrogen development; Utilising current production capacity, constructing new capacity, and seizing new business opportunities[1]	Licence holder at Olkiluoto Nuclear power plants in Finland	Potential service provider by the long term knowledge in operating and building nuclear power plants. Existing site can accommodate a new built, interest on expanding to Pyhäjoki can be limited since they have Olkiluoto site as an option
EDF	Large energy producer, largest nuclear power producer in Europe	Targeting world leading excellence in nuclear construction, operation and decommissioning. Shareholder	Licence holder of several nuclear power plants in France and UK as well as shares in the USA, Belgium and China	With one EPR in operation in Finland, the construction of a similar might be attractive. With several projects ongoing and planned the interest of new large investments could be limited

1. TVO sustainability report 2022

Potential stakeholders and their capabilities regarding new NPP (2/2)

	Description	Motivation/drivers towards new SMR projects	Capabilities	Pros/Cons
Kärnfull	Nuclear SMR project developer	Targeting Small Modular Reactors project development	Have secured initial funding and have competence on stablishing a project (licensing, owner, operator, finance, suppliers etc.)	Focus and knowhow on SMR project development. Interest to expand to Finland is unknown
Municipal energy companies	Power and district heating distributors	Stable electricity production for the portfolio and decarbonization target	No competency in nuclear field expected, only ownership and utilisation of the produced energy	Based on the experience from Fennovoima, interest towards a new large project could be limited
SSAB, Outokumpu, UPM, Blastr	Large energy consumers	Stable energy production for the industrial process, reduce exposure of price fluctuation and decarbonization targets	No competency in nuclear field expected, only ownership and utilisation of the produced energy	Based on the experience from Fennovoima, interest towards a new large project could be limited

PRE-DESIGN PHASE

Project owner is responsible for co-operation with authorities

Project owner

- Feasibility studies & pre-design for bidding phase
- Preliminary permits and zoning plan preparations including environmental impact assessment
- Tendering material and plant specification. Contacting of potential suppliers with the tendering documentation
- Decision-in-principle application. The application for a decision-in-principle concerning a nuclear facility includes a description of the facility's safety systems in principle. At this stage, the facility's technology and safety is not yet subject to a detailed assessment

Authorities

- Local authorities support with zoning & permitting
- STUK
  - STUK provides the Ministry of Economic Affairs and Employment with its own statement concerning both the EIA programs and EIA reports
  - STUK's statement on planning of land use
  - Preliminary safety assessment on the application for decision-in-principle
- Parliament approval for decision-in-principle

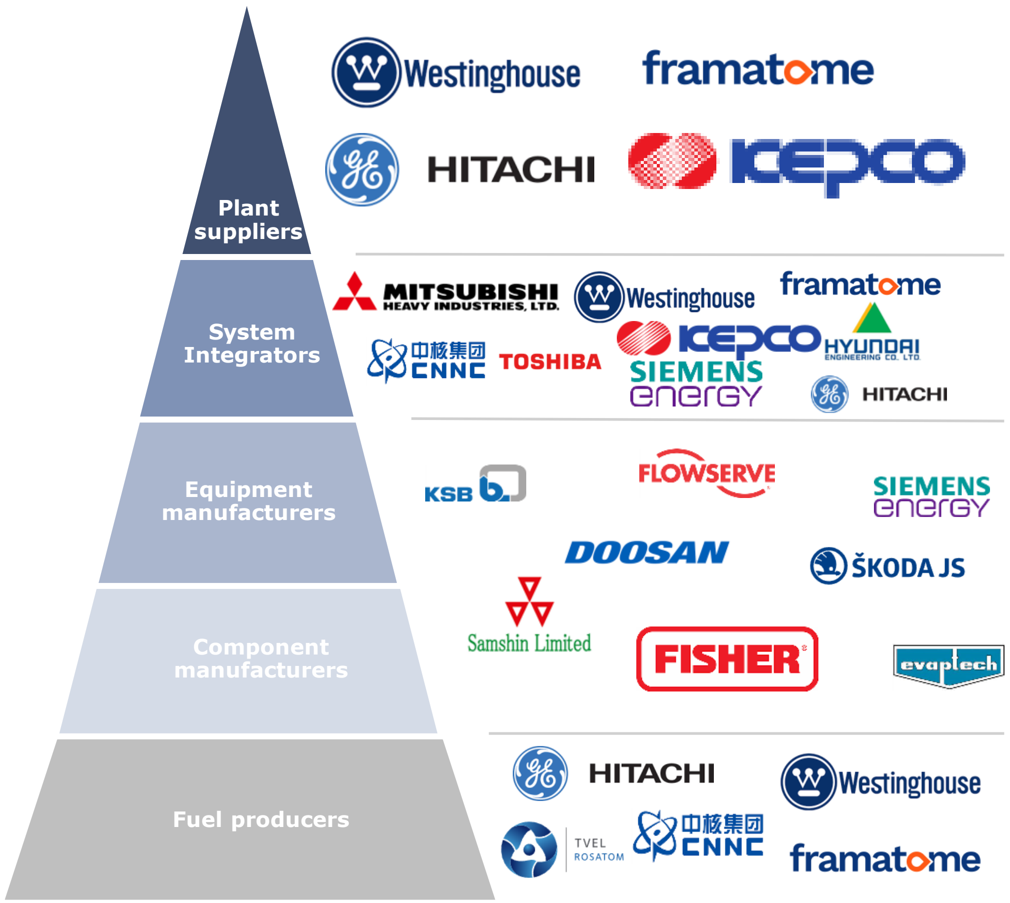
Potential plant suppliers

Supplier	Global Activities	Drivers for interest towards supplying newbuild NPP in Pyhäjoki
Framatome	Largest plant supplier in Europe -2 units under construction in UK -Perspective of 2 new units in UK and 6 units in France	-Increase market share in Europe and have long term supply of nuclear fuel and service -Existing EPR reactor at Olkiluoto site can be of a significant mitigation factor for project risks and can benefit Framatome in terms of available skilled workforce and authorities familiar with the reactor design
Westinghouse	-1 unit under construction in US –Perspective of 4 new units in China and 3 in Poland	-Increase participation in Europe and have long term supply of nuclear fuel and services
KEPCO	-2 units under construction in South Korea and one unit in UEA -Perspective of 6 units in Poland	-Increase participation in Europe and have long term supply of nuclear fuel and services

EIA = Environmental Impact Assessment

PROJECT EXECUTION & OPERATION PHASE

NPP project involves large supply chain during the actual project execution phase and after the project



*TVEL is not foreseen as an option for fuel producer at the moment

- Supply chains for new nuclear power plants are built up around the plant supplier during project execution and how it has constructed its supply chain containing trusted partners
- Plant supplier is responsible for the whole plant delivery including suppliers from different level of the supply chain in the process:
  - System integrators; responsible for larger entities
  - Equipment manufacturers; responsible for equipment entities
  - Component manufacturers; responsible for components as part of equipment or power plant systems
- For operating power plants, the plant owner often builds up also straight relationships with equipment manufacturers
- Nuclear fuel as a key element for the whole power plant operation is a major part of the supply chain and a more separate component in the entity. Nuclear fuel production is a controlled process and often the same companies operating as plant suppliers are also the fuel producers/suppliers for nuclear power plant

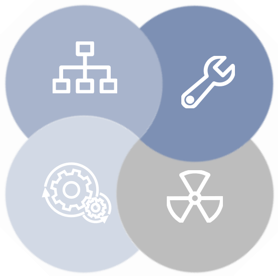
Supply chain under the plant supplier can be divided in four different main categories, each having their own important tasks

SYSTEM INTEGRATORS

- System integrators are responsible for complex system entities in nuclear power plants. The systems may include I&C systems, safety systems and different level of process systems in the power plant. System integrators integrate their systems into the whole plant level operation
- System integrators are in crucial role for delivering nuclear power plant. They connect single equipment and component manufacturers to their system level delivery and eventually to power plant entity

EQUIPMENT MANUFACTURERS

- Equipment manufacturers build their equipment as part of different power plant systems. The equipment itself are structured based on components from component manufacturers
- E.g. pumping units are good examples of equipment for the power plant. The units require several different components and they are connected to the power plant as part of different power plant systems



COMPONENT MANUFACTURERS

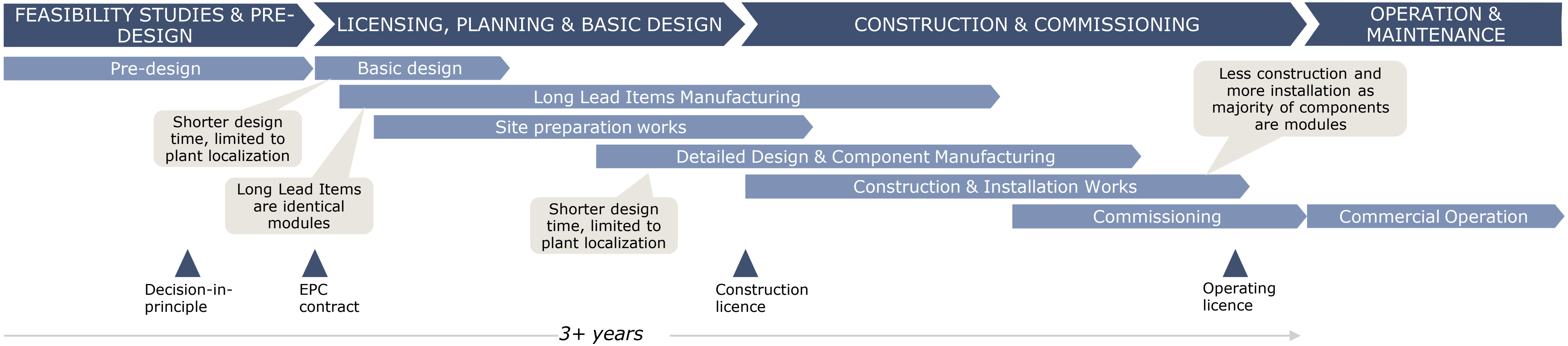
- Component manufacturers deliver single components as part of equipment for the power plant
- Sensors, impellers and e.g. valve bodies forming pumping units are examples of components
- Component manufacturers could often be companies that are not specialised for nuclear projects, but can meet the requirements for nuclear component delivery based on what has been characterised in the delivery requirements

FUEL PRODUCERS

- At the moment, fuel element manufacturing is settled for five large companies: Framatome, GE Hitachi, Westinghouse, China National Nuclear Corporation and Rosatom
- The manufacturing of fuel rods is a highly regulated process with strict safety and quality control requirements. As a result, companies involved in this part of the nuclear fuel supply chain must meet strict regulatory standards and undergo regular audits to ensure compliance
- Established companies with extensive experience dominate this market. As a result, it can be difficult for new entrants to successfully enter the fuel manufacturing business, especially given the high capital costs and regulatory hurdles associated with processing nuclear materials
- Framatome and Westinghouse take over Rosatom's fuel customers in the EU as a result of sanctions against Russia

Sources: Eileen M. Supko (2021), "The Front End of the Nuclear Fuel Cycle" & FCWMD Nuclear Fuel Cycle, NEA 7634

The differences between SMR project compared to large scale are the expected shorter timeline and more centralised manufacturing of equipment



KEY STAKEHOLDERS FOR DIFFERENT PHASES OF A NUCLEAR POWER PLANT PROJECT

- Investors, energy companies and potentially some current NPP license holders build up a company to act as project owner for new NPP
- Regulatory co-operation and connection with local authorities for e.g. suitable location and preliminary environmental impact analysis
- Parliament approval for decision in principle
- Negotiations with potential plant suppliers

- **License to be divided in two part, one concerning technology and other concerning the site. Technology should be granted only once and re-utilized for multiple sites**
- **Subcontractors for system level are limited to plant localization adapting the plant to specific site, typical components are to be factory built by plant supplier**
- **Plant supplier engaged on manufacture of long lead items**
- STUK provides a statement on the application for a construction licence, accompanied by the safety assessment

- Plant supplier enforces local participation to the project. Commissioning phase organisation is being built
- **Limited participation of contractors for engineering, manufacturing and site works. Modularized components are delivered from the factory and assembled at the site**
- Project owner develops its own organisation, targeting for commercial operation in the future
- STUK surveillance for design, manufacturing, construction/installation & commissioning. The operating licence for a nuclear facility is applied for from the Government. STUK provides a statement on the application for an operating licence

- Reliable operation secured with appropriate licence holder's own organisation following STUK guidelines
- Support for operation and maintenance guaranteed by e.g. Long Term Service Agreements with plant supplier, OEM contracts and contracts with local service providers
- Produced energy supplied to offtakers and/or sold to electricity markets

NPP = Nuclear Power Plant, OEM = Original Equipment Manufacturer

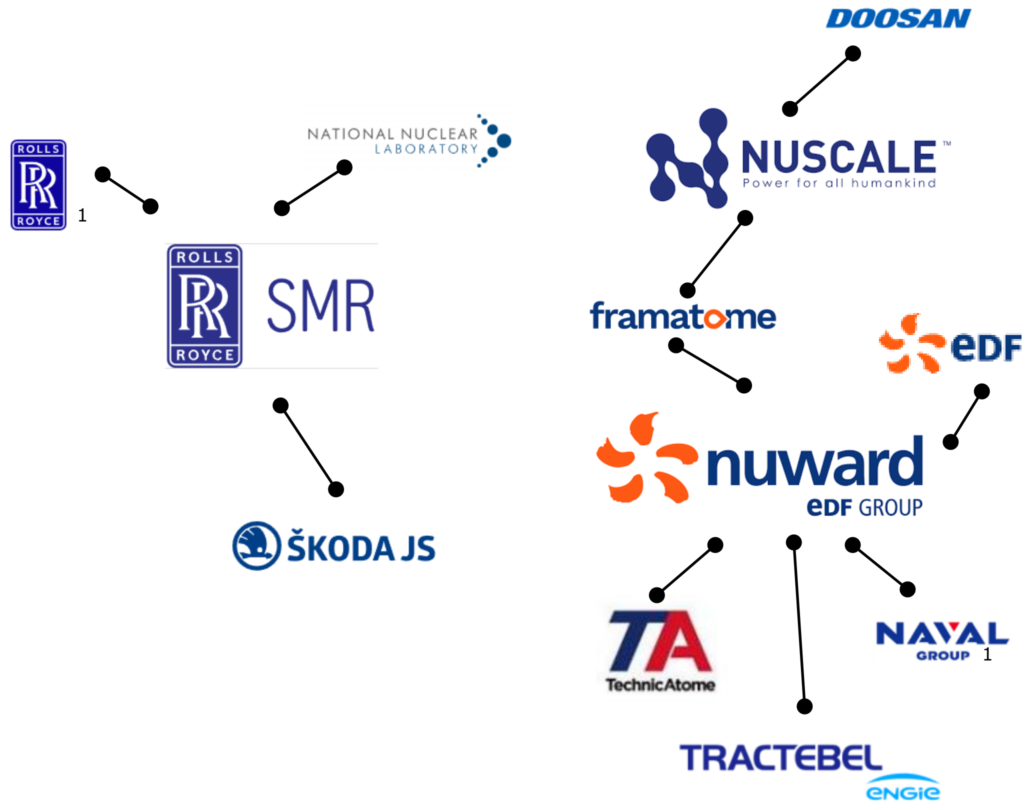
Established technology suppliers develop their own SMR models and actively cooperate with new SMR players

PLANT SUPPLIERS

Focus on design and development of technologies integrated into the entire nuclear system, such as, fuel technologies, and control systems

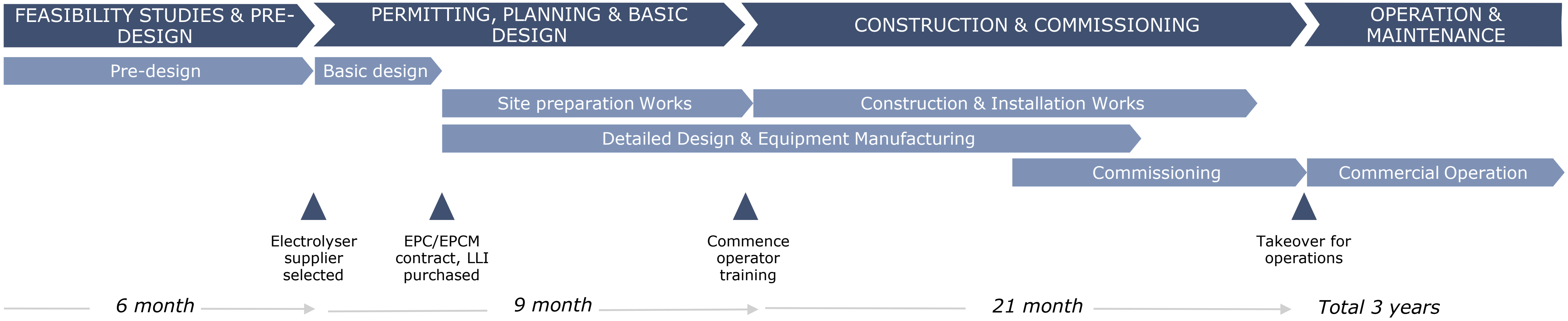
- There are currently several different SMR models under development. Most of the actors involved in this design have neither the capacity nor the interest to participate in all phases of the project to implement a commercially viable plant
- New SMR operators have not gone through the licensing process in several countries and have not yet submitted their first SMR project. As with traditional plant projects, delays and project cost overruns can be expected in the successful implementation of new SMR plant projects
- To be successful, new companies are planning to collaborate with large players who can be responsible for design and project management, including supply chain establishment, licensing and construction phases.
- Nevertheless, the supply chain of SMR is expected to be more centralized for the technology supplier than in large scale plants as the plan is to deliver factory manufactured modules with short assembly times to plant location

SMR DEVELOPERS COOPERATE WITH ESTABLISHED OPERATORS



1) Part of the design concept comes from the expertise of the military maritime industry

Basic structure & timeline for building a hydrogen production (electrolysis) facility follows the same steps as nuclear plant, but timeline is shorter



KEY STAKEHOLDERS FOR DIFFERENT PHASES OF A HYDROGEN PRODUCTION PLANT PROJECT

- Investors, energy companies and hydrogen off-takers build up a company to act as project owner for new hydrogen plant
- Regulatory co-operation and connection with local authorities for e.g. suitable location and preliminary environmental impact analysis. Including hydrogen transport impact
- Negotiations with potential OEM suppliers
- Operator of hydrogen plant agreed

- Plant supplier engaged with EPC/EPCM contract
- Subcontractors for system level and main component design and manufacturing
- Early contract award for LLI long lead items (electrolyser manufacturing capacity can be limited)
- Civil works companies for e.g. earthworks on site
- Off-taker agreement signed
- Environmental permit approved by AVI and chemical permit approved by Tukes
- Landowner approval to build
- Municipality approval to build (including updated land use plan)

- High participation of key OEM's for engineering, manufacturing and site works. Several companies on site for different systems
- Hydrogen plant operator develops its own organisation and safety management system (to be trained during FAT and onsite commissioning)
- Municipality approval to commission and operate

- Support for operation and maintenance guaranteed by e.g. Long Term Service Agreements with plant supplier, OEM contracts and contracts with local service providers
- Produced hydrogen supplied to off-takers and/or kept for own use

OEM= Original equipment manufacturer, FAT= Factory Acceptance Testing, LLI= long lead items

Hydrogen production plant offers opportunities for project suppliers, investors, energy companies and hydrogen utilisers

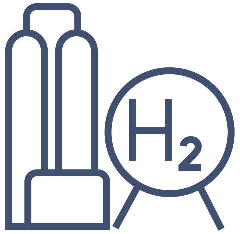
PROJECT DELIVERY

EPC contractor

Electrolyser supplier | Integrators

Sub-supplier network

- Project delivery is performed most probably under an EPC contractor
- Electrolyser supplier could limit its own risk by not taking the whole project delivery under its responsibility
- System integrators provide the required systems for building whole production facility together with the EPC contractor and electrolyser supplier
- Sub-supplier network is utilised based on each major project participant’s supply network



PRODUCTION FACILITY

ENERGY SUPPLY & HYDROGEN UTILISATION

Renewable energy supplier

- Companies providing renewable energy, such as wind power companies

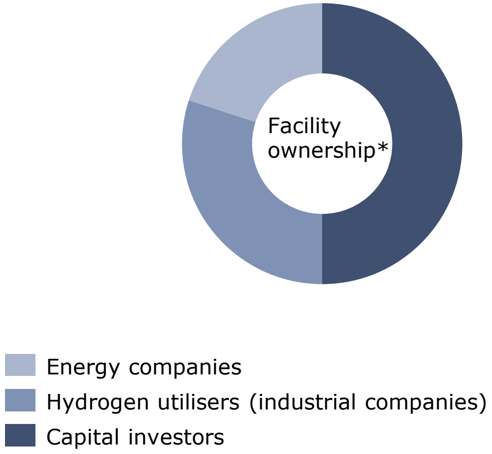
Hydrogen off-takers

- Industrial hydrogen utilisers utilise the produced hydrogen

NEW HYDROGEN PRODUCTION COMPANY

Owner(s)

- Owner base can be structured in several different ways, depending on different companies interests for hydrogen in the area. Generally energy producers, hydrogen utilisers and capital investors could build a joint venture for a new hydrogen production facility



*Indicative shares

AFRY ÅF PÖYRY

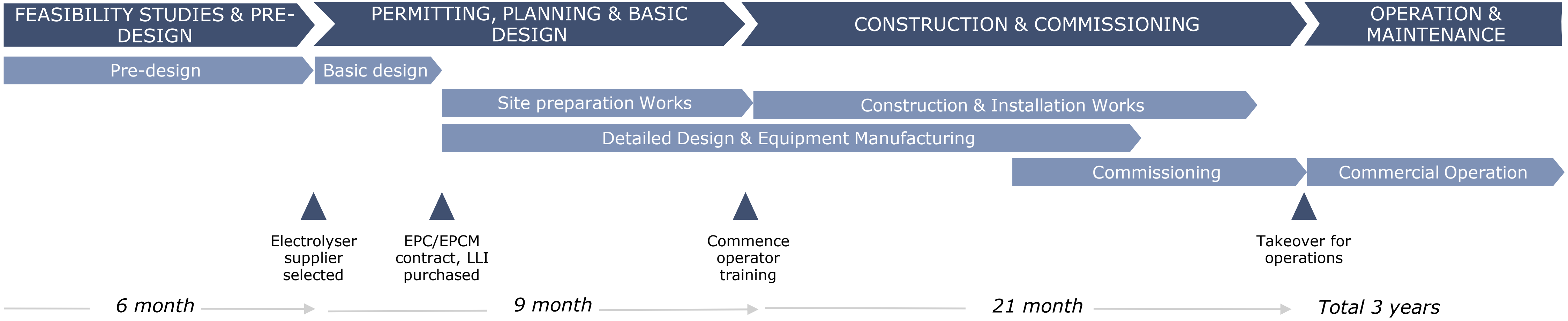
Separate operator for the electrolyser plant (not the owner potentially)

Potential stakeholders and their capabilities regarding hydrogen

	Motivation/drivers towards new hydrogen projects	Capabilities	Pros/Cons
Electricity suppliers -Fortum, Ilmatar, EPV energia	Creates an off-taker for electricity, minimizes the need for grid upgrade Utilize their electricity in good price	Electricity supply, project and operations expertise, potential investors for the project	Potentially high electricity cost for hydrogen production, may not invest in hydrogen due to economics
Electrolyser suppliers -Nel, Green hydrogen systems, Sunfire, Thyssenkrupp, Elogen	Want to sell their equipment and services	Provides electrolysers, Potentially feed and EPC services	Mature technology available, but lead times could be long for bigger orders
Electrolyser operators -Fortum, SSAB, Helen, EPV energia	Flexible hydrogen production when electricity prices are low, can get revenue when acting as grid stabilizer	Project and operations expertise, potential investors for the project	No company has long expertise on flexible production of hydrogen from renewables, no need for hydrogen off-taker to operate the hydrogen plant, these companies have O&M experience
Hydrogen off-takers -SSAB, Neste, St1, Ren-Gas, Flexens, Blastr	Want to replace fossil-based hydrogen with green, utilized new technology which needs hydrogen, producing synthetic fuels from hydrogen	Utilisers (also potential investors)	No need for refining hydrogen further
Investors -Government investment funds (ilmastorahasto), Venture Capital (Prime Capital)	Promoting the green transition, profit from successful investment	Financing the project	Some investors conservative until full value chain is demonstrated
Carbon emitters -Westenergy, Oulun energia, Metsä group, UPM, Stora Enso	Potentially want to capture the carbon coming from their process and utilise it with hydrogen	No or little competency related to hydrogen production	Potential for heat integration, requires carbon capture and hydrogen plant to be available at the same time

AFRY
ÅF PÖYRY

Basic structure & timeline for building a ammonia production facility is very similar to the hydrogen production facility project



KEY STAKEHOLDERS FOR DIFFERENT PHASES OF AMMONIA PRODUCTION PLANT PROJECT

- Investors, energy companies and ammonia off-takers build up a company to act as project owner for new hydrogen plant
- Regulatory co-operation and connection with local authorities for e.g. suitable location and preliminary environmental impact analysis. Including hydrogen transport impact
- Negotiations with potential OEM suppliers
- Operator of hydrogen plant agreed

- Plant supplier engaged with EPC/EPCM contract
- Subcontractors for system level and main component design and manufacturing
- Early contract award for LLI long lead items
- Civil works companies for e.g. earthworks on site
- Off-taker agreement signed
- Environmental permit approved by AVI and chemical permit approved by Tukes
- Landowner approval to build
- Municipality approval to build (including updated land use plan)

- High participation of key OEM's for engineering, manufacturing and site works. Several companies on site for different systems
- Ammonia plant operator develops its own organisation and safety management system (to be trained during FAT and onsite commissioning)
- Municipality approval to commission and operate

- Support for operation and maintenance guaranteed by e.g. Long Term Service Agreements with plant supplier, OEM contracts and contracts with local service providers
- Produced hydrogen supplied to off-takers and/or kept for own use

OEM= Original equipment manufacturer, FAT= Factory Acceptance Testing, LLI= long lead items

Potential stakeholders and their capabilities regarding ammonia

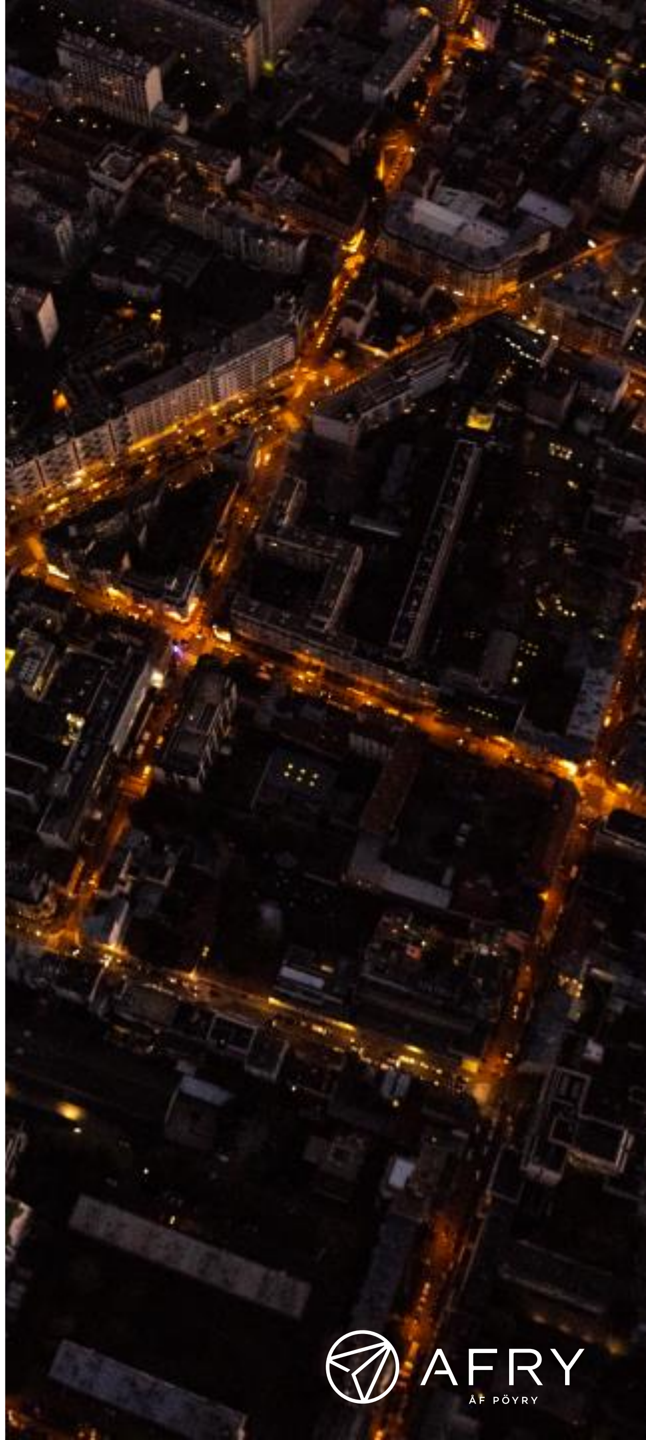
	Motivation/drivers towards new hydrogen projects	Capabilities	Pros/Cons
Equipment suppliers -Thyssenkrupp, Linde, Haldor Topsoe, Cryostar	Want to sell their equipment and services	Provides equipment, potentially feed and EPC services	Mature technology can be found
Ammonia plant operators -Fortum, Helen, EPV energia,	Flexible hydrogen production when electricity prices are low Can get revenue when acting as grid stabilizer	Project and operations expertise, potential investors also	General O&M experience
Ammonia off-takers -Yara, Shipping companies	Want to replace fossil-based ammonia with green ammonia, transition to clean fuels	Utilisers (potential investors)	Don’t have to refine ammonia further, get fixed price for ammonia, their demand for hydrogen can change in the future
Investors -Government investment funds (ilmastorahasto), Venture Capital (Prime Capital), Individual investors	Promoting the green transition, profit from successful investment	Financing the project	Some investors conservative until full value chain is demonstrated

AFRY
ÅF PÖYRY

Supply chain

- Renewable energy supplier (Fortum, Ilmatar, EPV energia)
- Suppliers for air separation unit (Linde, Cryostar, Messer group)
- Suppliers for ammonia synthesis reactor (Thyssenkrupp, Linde, Haldor Topsoe)
- Integrators (AFRY, Sweco, Ramboll, Rejlers)
- EPC companies (Åker solutions, Rejlers)
- Owner/Operator (Fortum, Helen EPV energia, Stora Enso, JV)

Content



Stakeholder groups

Stakeholder interviews for their interest in new projects

Variety of stakeholders have been interviewed from different groups

	Main responsibilities	Example companies
Nuclear owner-operators	• Operating, financing, feasibility study, technology selection • Owner holds the licenses	fortum, uniper, EDF, tvo, POHJOLAN VOIMA, VATTENFALL
Plant vendors	• Plant delivery, procurement, engineering, construction	EDF, GE, HITACHI, Westinghouse, Rolls Royce
Large power purchaser	• Purchasing electricity from the power plant with e.g. long-term agreements	SSAB, BLASTR Green Steel, NESTE, outokumpu

Some of the companies described above have been interviewed

One large company as the sole owner-operatorship – Loviisa 1 & 2 case example

Loviisa 1 & 2 owner
% of total

fortum

100%

Key insights of operations

- Loviisa power plant was deployed in 1980
- Originally the plant was owned by Imatran Voima and the company was renamed as Fortum in 1998, when Imatran Voima and Neste merged. Neste was re-established later and the ownership of Loviisa remained with Fortum

- The site has required active investments for modernification
- In 2014-2018 Fortum invested 0,5 mrd EUR to improve site's safety and efficiency

- Fortum has 500 employees working at Loviisa nuclear plant

- In 2009 Fortum applied for a decision in principle to build a third reactor to the Loviisa site
- Application was rejected in 2010

A large company such as Fortum can act as the sole owner-operator

Mankala companies have a unique feature, acting as a platform for shareholders who can purchase electricity at cost price

	Comments
Overview	• In a Mankala principle multiple companies collectively establish a non-profit corporation for a common purpose • Each participating company owns a share of the project proportionate to its investment • In Mankala power plants, electricity is produced at cost
Advantages	• Mankala enables construction of large power plants which would often be too large projects for individual companies • Additionally, Mankala allows sharing of expertise and risk sharing, as well as economies of scale
Operating model	• Shareholders drive projects - if they need new production, Mankala company arranges the project for them • Mankala company issues new project shares which each company can purchase up to their needs • All members must approve the project, but participation is not a requirement

Indications for new projects

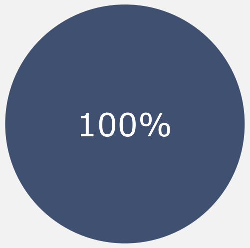
- Mankala company acts as a platform for the shareholders
- Mankala company will not alone drive new development projects
- Therefore, when assessing Mankala companies' interest to start new projects, the shareholder interest must be assessed separately
- Shareholders usually consist of industrial players and energy companies
- The need of new projects depend on development of shareholders' power demand

AFRY ÅF PÖYRY

Mankala nuclear project owner-operatorship – Fennovoima Hanhikivi case example

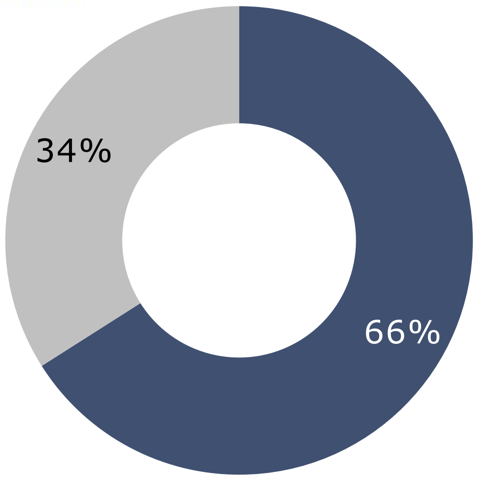
Hanhikivi owner
% of total

FENNOVOIMA



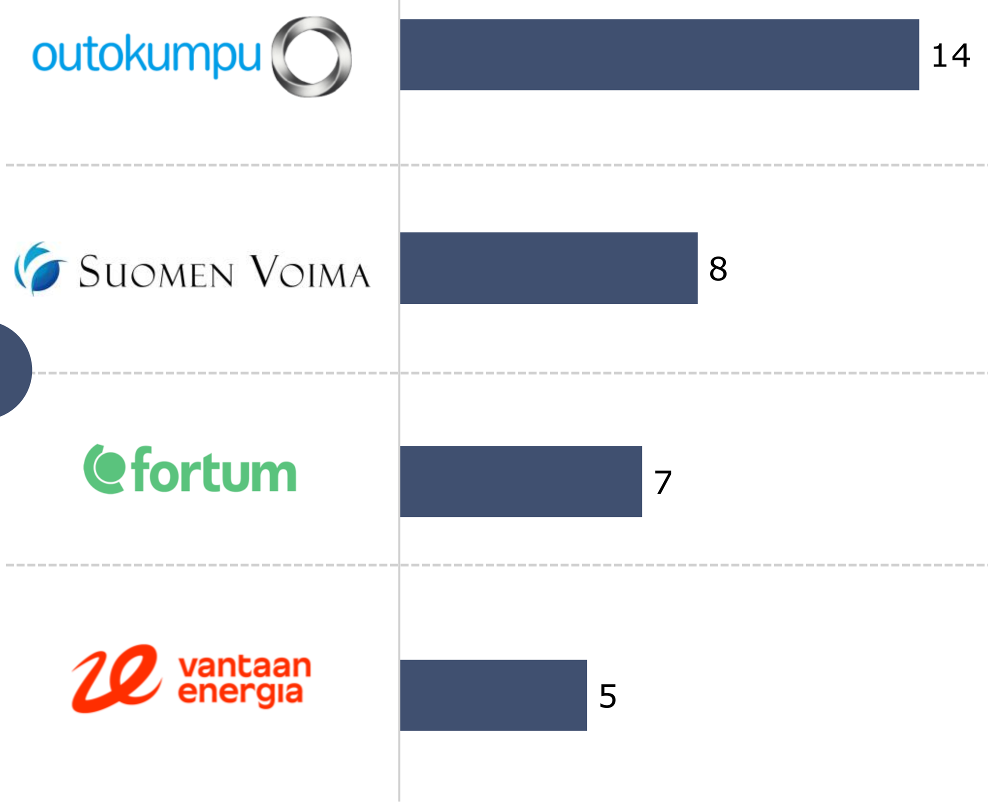
Fennovoima shareholders in 2015
% of total

RAOS VOIMA
ROSATOM



VSF

VSF main shareholders
% of total

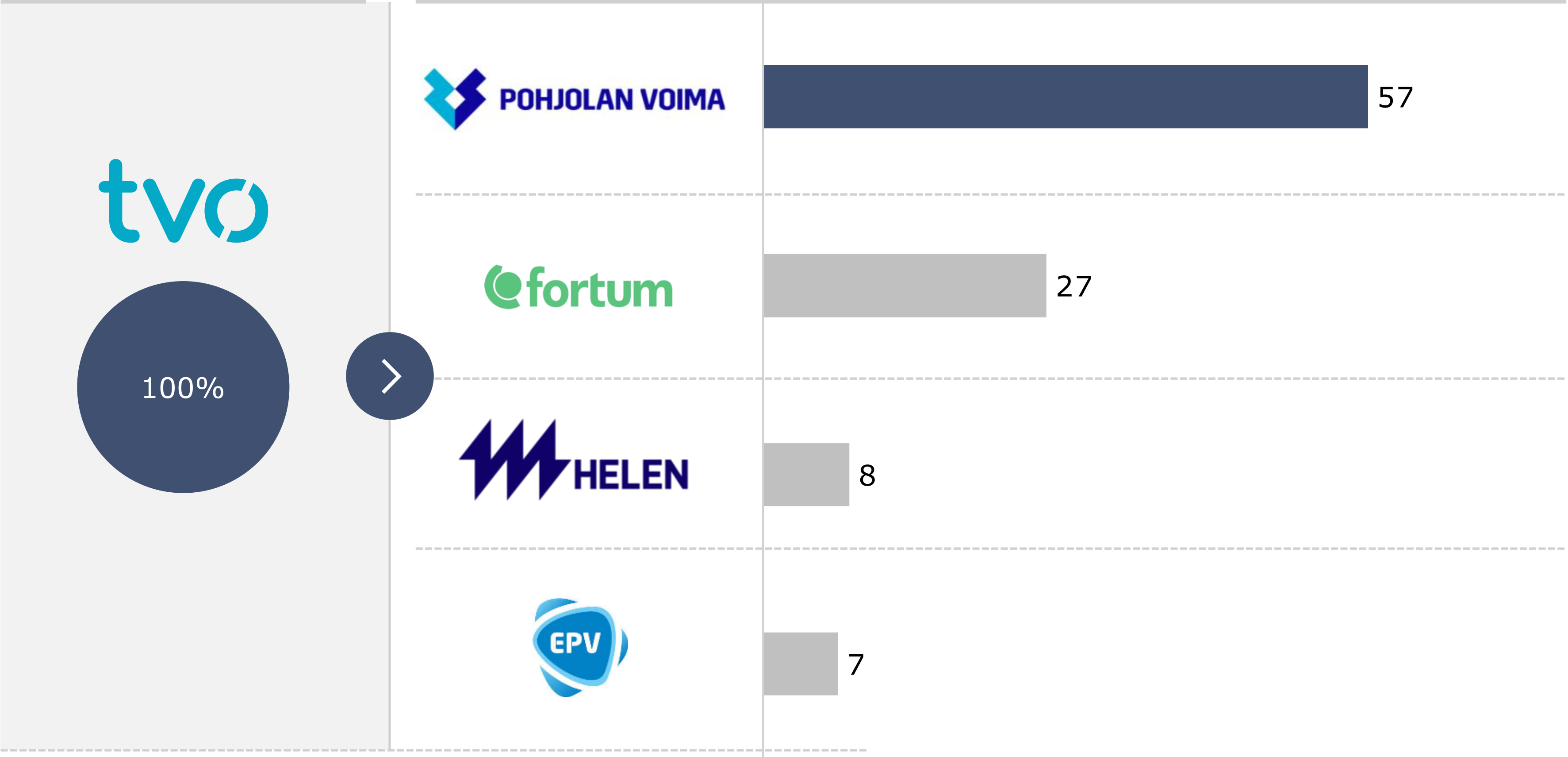


AFRY
ÅF PÖYRY

Mankala nuclear project owner-operatorship – Olkiluoto 3 case example

Olkiluoto 3 owner
% of total

TVO shareholders
% of total



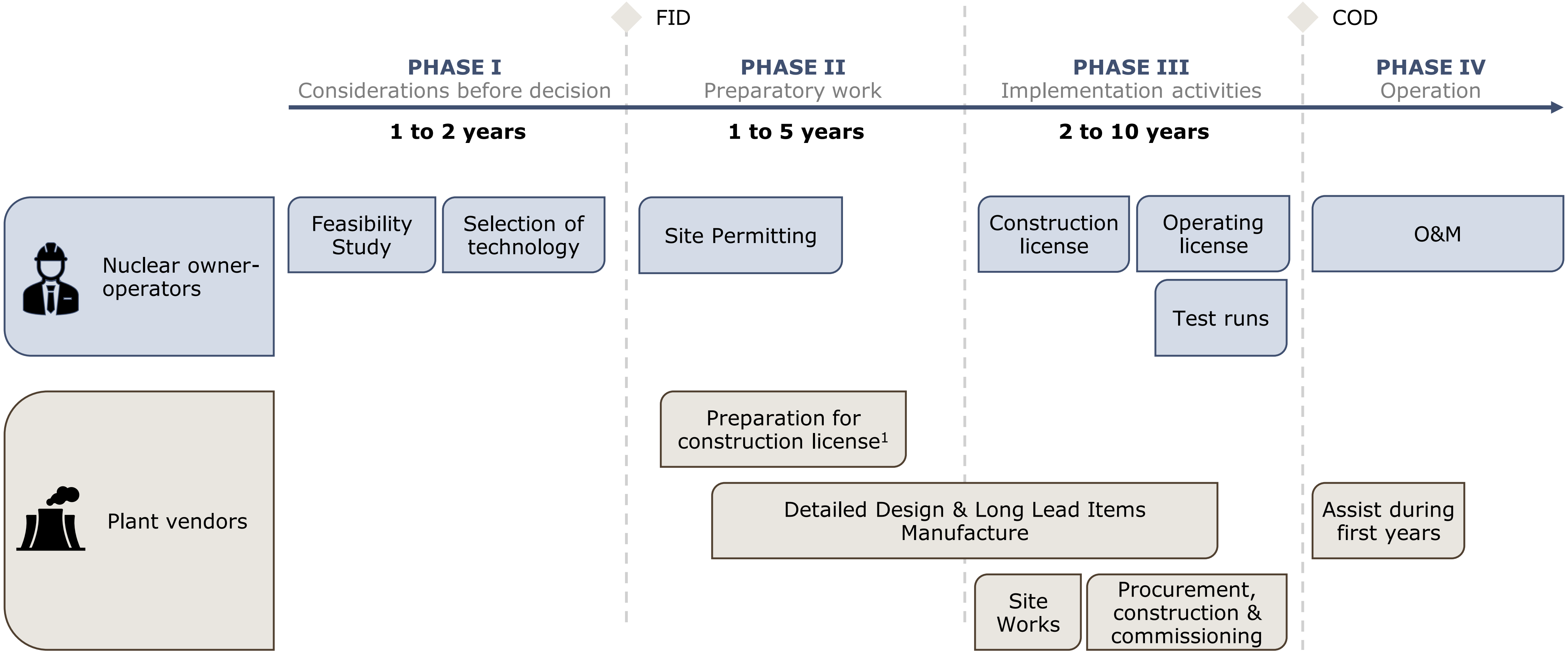
Pohjolan Voima is owned by industrial players and energy companies

Pulp and paper companies UPM (48%) and Stora Enso (16%) hold a significant share

AFRY
ÅF PÖYRY

SCOPE BETWEEN OPERATOR AND PLANT VENDOR

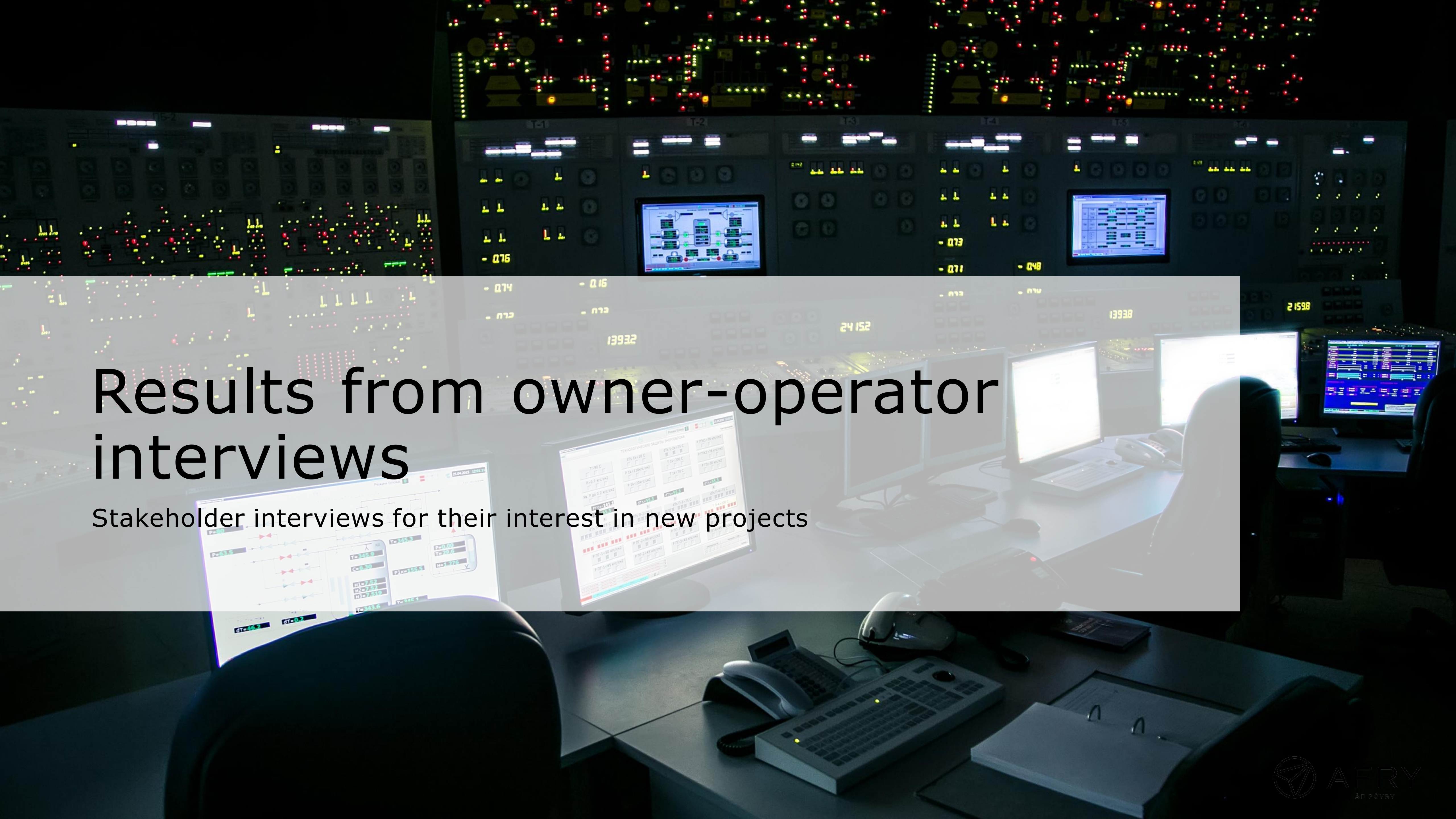
Responsibilities between owner-operators and plant vendors



1. SMR projects may need regulatory guide assessment prior to license application

Relevant stakeholders' interest towards new projects was mapped in the interviews

	Main question for companies
Nuclear owner-operators	• Would they be interested to start a nuclear project at Hanhikivi site
Plant vendors	• What is their readiness to deliver a project by the end of this decade • Would they be interested to start a project at Hanhikivi
Large scale power consumers	• Would they be interested to use nuclear power from Hanhikivi



Results from owner-operator interviews

Stakeholder interviews for their interest in new projects

Nuclear owner-operators are cautiously positive about the possibility of a new project at Hanhikivi, while the main focus is on their current projects

	Owner-operators opinion of topics
Location	• For nuclear plant owner and/or operator, Finland is at the top of the ranking list. • Existing infrastructure in Hanhikivi provides a big advantage. However, ongoing disputes at the site reduce its appeal. • The main considerations for new project locations are site availability, public opinion, conflicts in the area, local demand, and how attractive the area is for workforce.
Project pipeline	• Potential nuclear owner-operators currently focus on either ongoing projects or development plans in their local countries or existing sites • There are actively ongoing studies related to SMR in the Nordic region and there is an active SMR R&D project on-going. SMR investment options in Hanhikivi are seen as interesting option. • Among the companies, there are many collaborations with European and local companies in the SMR topic. • All interviewed owner-operators were aware of the situation of Hanhikivi and remain open to new opportunities to develop site.

AFRY ÅF PÖYRY

Owner-operators see nuclear energy as essential to addressing climate change – outside their primary market, they are willing to take a smaller role in the project

Owner-operators opinion of topics

Nuclear power's role	• All interviewed companies stated that nuclear power will have a crucial role in addressing climate change by providing a low-emission method for electricity generation to meet the increasing needs from industries. Need for new nuclear investments is subject to demand growth pace, which all respondents assessed very uncertain. • Both in Finland and Sweden, acceptance of nuclear energy is very high, directing generally the interest of nuclear plant operators to the area.
Role in the projects	• The role that the owner-operator would assume depends on many factors, such as the involvement of the end customer, local acceptance, the developer's previous track record, location, and potential other shareholders' interests (especially in the Mankala principle). • When owner-operators are operating outside their primary market, they strongly prefer partnership with an experienced local developer and presence of an end customer. • In this case, international operators prefer a smaller role in the project, ranging from 10-30%.

AFRY
ÅF PÖYRY

Results from large power purchaser interviews

Stakeholder interviews for their interest in new projects

Large scale power users see high value in stable power and nuclear power specifically, but some concerns were raised about regulatory aspects

Large scale power customers opinion of topics

Green transition	• All companies interviewed stated that their main target as regards of sustainability is to reduce CO2 emissions. Nuclear is considered as a solution to meet CO2 emission targets • For example for steel producers, shifting to green steel requires large quantities of hydrogen. Although the RFNBO regulation applies to certain fuel production, it is crucial to closely follow the RFNBO regulations and be prepared to meet the requirements of customers. Currently nuclear is not eligible for RFNBO directly.
Electricity profile	• If nuclear is allowed and accepted by the customers, it is a highly interesting source of electricity. • Nuclear power is seen as an interesting option to mitigate price fluctuations. All interviewed companies stated that nuclear is an attractive source of stable and CO2 emission-free electricity. • One company stated that nuclear could be a solution, but the long project schedule is a concern due to the proximity of the company's electrification targets.
Power price level	• The willingness to pay for nuclear power is for large electricity users tied to the average price paid in competitor countries or by competitors in Europe. On the other hand, electricity users see value in predictable electricity prices and lower risks, but the overall cost has to be competitive.

RFNBO = Renewable fuels of non-biological origin

Among the large scale power users, there could be some interest in being investors in nuclear projects, especially SMR seen as interesting option

Large scale power customers opinion of topics

Location	• Hanhikivi site was considered generally as an interesting site, and there are many large electricity users in the proximity. • Hanhikivi site preparations would help start the new project faster and easier.
Interest in nuclear projects	• Among the interviewed companies, there are ongoing capital-heavy projects that reduce interest in nuclear investments and commitments. • Also, concerns were related to SMR costs, which remain uncertain and increase risks. This affects the willingness to invest/participate in the project.
Price predictability	• All companies stated that price predictability was an important factor for both production costs and project financing. • There was a rising interest in nuclear energy with PPAs spanning 7-10 years for baseloads. Some energy users expressed a willingness to cover a maximum of ~30% of demand with nuclear energy to mitigate risks and ensure flexibility.

Results from plant vendor interviews

Stakeholder interviews for their interest in new projects

SMR Plant vendors are highly interested in providing technology to new sites, and the Hanhikivi location is particularly intriguing

	Plant vendors opinion of topics
Location	• Site work at Hanhikivi is considered a high advantage due to the time and money it could save, but it is not on the critical path for a project and mostly on the owner scope. • Finding an owner and licensee are crucial factors that need to be addressed. • Hanhikivi site is seen suitable location for SMR project and for plant vendors technology. • Interviewed plant vendors see Finland generally as a priority market.
Plant vendors advantages	• Plant vendors are tightly following European regulators, including STUK, which could support with decreasing licensing risk in Finland if regulation is updated. • Plant vendors have advantages in their environmental operation: one's modules are produced in their own factories and transported to the site for assembly, and the other has a large supply chain network that allows seamless transportation and manufacturing processes.

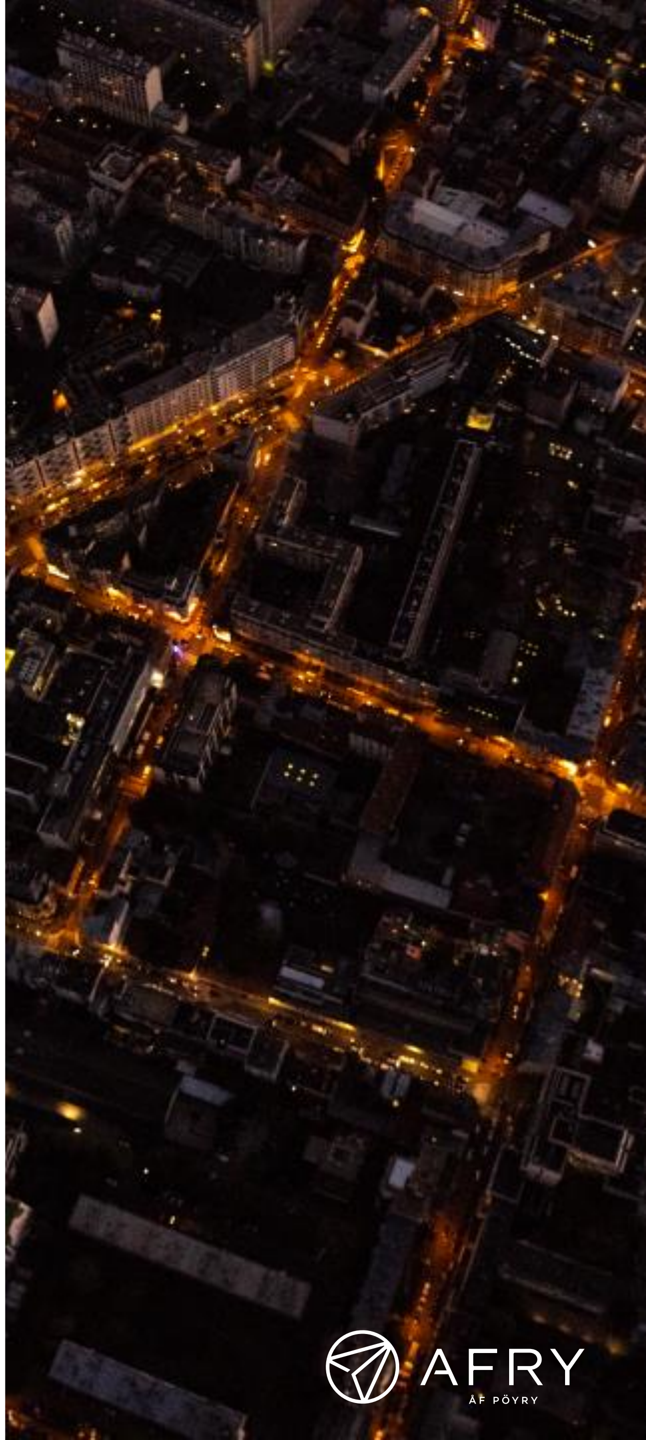
STUK = Radiation and Nuclear Safety Authority

AFRY
ÅF PÖYRY

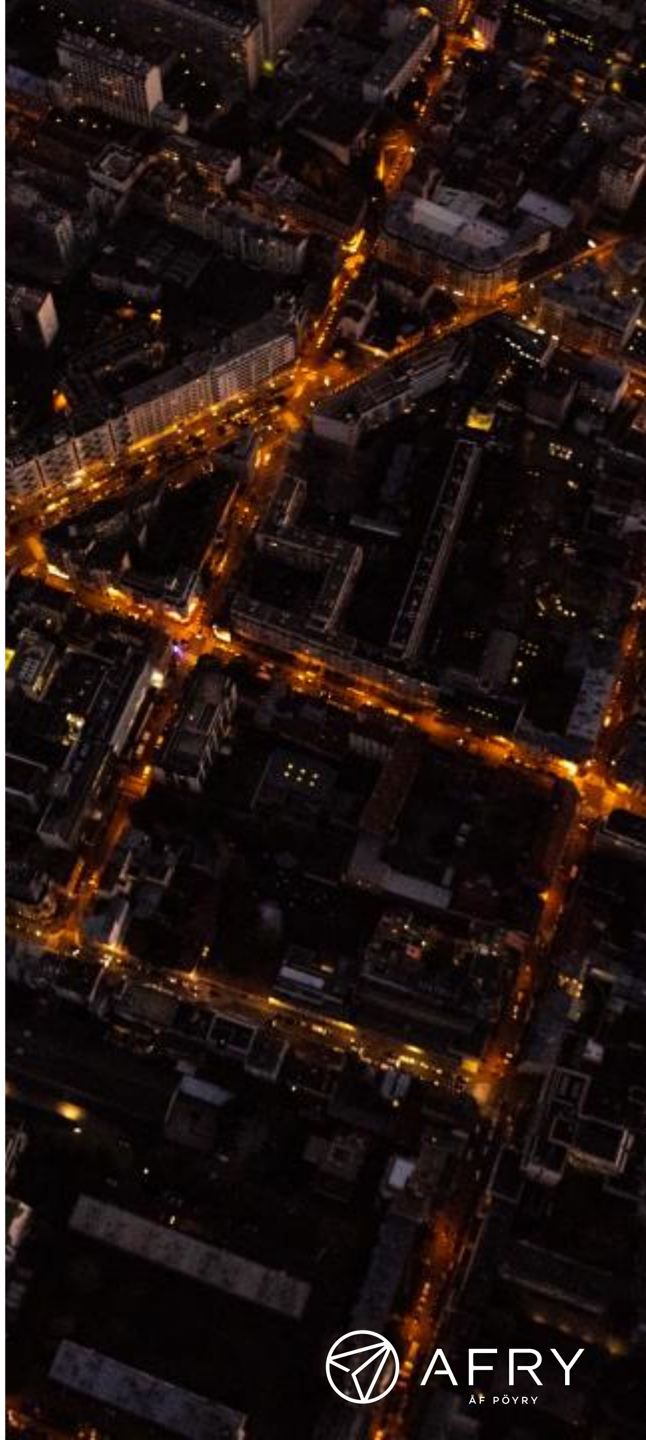
Both SMR technologies have similar delivery times

	Plant vendors opinion of topics
Technology	• Plant vendors have well-known PWR technology designed in a way to improve project delivery. • One SMR plant vendor is designing a single control room for two reactors which will reduce operation cost. Other vendor is designing one control room per reactor unity which are proven to be licensable in European countries.
Cost	• Plant vendors are reluctant on providing cost estimates as the design are developing, and changes might still occur. One vendor mentioned that the cost range would be in the mid to lower range compared to main competitors. • On the other hand, another plant vendor estimated that current CAPEX could be around 5100 (EUR/kW), and the LCOE could range from 50-70 (EUR/MWh). There are naturally question marks around LCOE and CAPEX levels at the moment.
Schedule	• Both interviewed plant vendors could construct the plant in a 40-41 month time period from the first concrete pouring. This assumes that all investment decisions and manufacturing processes have been started before obtaining the construction license. By 2035, up to two units could be operating in theory. • Both plant vendors have reference plants projects ongoing. Also, regulations can affect the timetable, but companies are well aware of that.

Content



Content



Competitiveness and feasibility of nuclear power investments

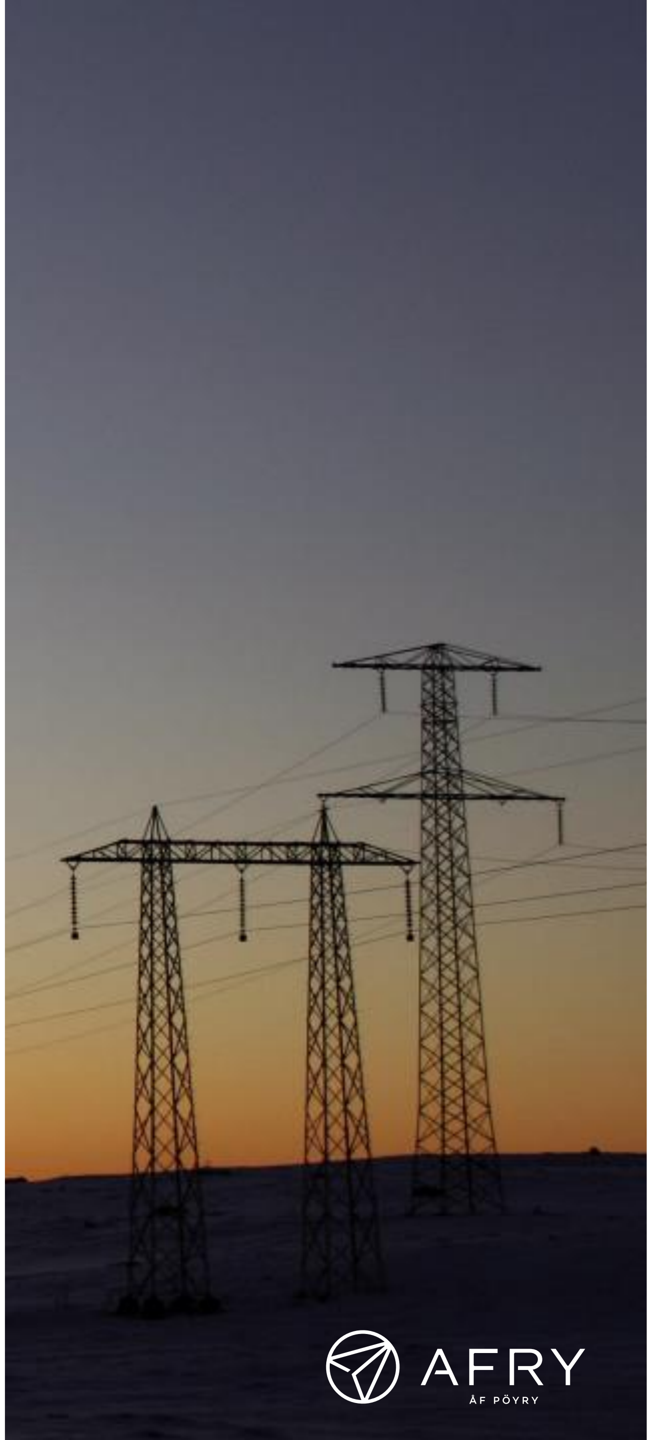
Attractivity of nuclear power generation and hydrogen production at Hanhikivi site are assessed

NUCLEAR POWER GENERATION

- Feasibility and relative competitiveness of nuclear power investment in the Finish market is assessed for both conventional nuclear and SMRs
- The assessment is based on the levelized cost of electricity (LCOE), which is calculated from CAPEX and OPEX structures
- Specific benefits of nuclear power in the future market of higher renewable electricity (RES) generation and quickly growing electricity demand are considered in the analysis
- Nuclear LCOE levels are compared to RES LCOE, historical power prices and AFRYs power price predictions *)

HYDROGEN DEVELOPMENT

- Besides nuclear electricity production investments only, we have also assessed the competitiveness of nuclear-produced hydrogen and its derivatives, mainly ammonia
- Feasibility is determined in terms of levelized cost of hydrogen (LCOH) compared to renewables, considering the same demand profile resulting in electrolyser oversizing and storage capacity for renewables
- Additionally we have considered the technical benefits of nuclear compared to renewables, especially when considering growing hydrogen demand and possible industrial use cases
- Main drivers of LCOH is electrolyser CAPEX and price of electricity



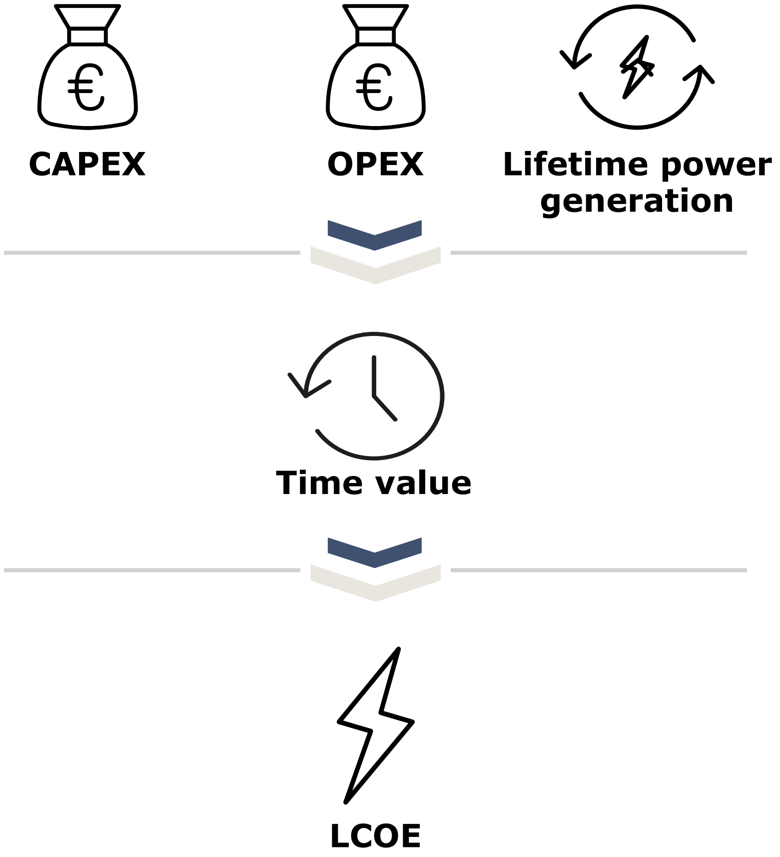
*) AFRY report: Impact of carbon neutrality target to the power system (Hiilineutraalisuustavoitteen vaikutukset sähköjärjestelmään - Valto (valtioneuvosto.fi))

AFRY ÅF PÖYRY

LCOE is calculated from lifetime CAPEX, OPEX and electricity generation for comparing reasons and is essential in investment decisions

LCOE LEVELS CRITICAL FOR INVESTMENT DECISIONS

- Levelized cost of electricity gives an average cost of each produced MWh for the lifetime of the plant
- LCOE is used for comparing lifetime costs of generating electricity with different technologies. Also feed into bidding in price setting of sold electricity.
- Lifetime costs are discounted to present valuer together with produced electricity to get the total cost of lifetime produced electricity in and €/MWh in today's values.
- All costs are accounted for including both CAPEX and OPEX in present value.
- By calculating the LCOE for both conventional nuclear and SMR, we'll be able to compare the options from a purely financial point of view



Lifetime costs and generation accounted for

Future costs and generation discounted to present value

Dividing lifetime costs with generation gives LCOE level

To assess the overall LCOE for nuclear investments, we have assessed the current and potential future level of CAPEX and OPEX

DIVISION OF CAPEX (CAPITAL EXPENDITURE) STRUCTURE OF A NUCLEAR POWER PLANT

Other costs

- Includes i.a. preconstruction, land area preparation, infrastructure, electricity work, project management, licenses etc.

Planning and construction

- *Planning work:* includes planning, simulation and license documentation fees
- *Construction:* Covers temporary facilities, site safety, electricity, water, and employee costs etc.
- *Construction supervision:* Supervision of construction processes, salaries, quality control and coordinating work

Accessories and structures

- *Reactor:* Steam supply systems, processing of nuclear waste, safety and control systems
- *Structures:* containment building, turbine halls, control building, diesel generator building, tunnels
- *Energy conversion:* Turbine generator, condensation system, instrumentation, control system

CAPEX is typically higher than in conventional power plant, mostly due to high safety demands in design and construction

DIVISION OF OPEX (OPERATIONAL EXPENDITURE) STRUCTURE OF A NUCLEAR POWER PLANT

Fixed costs

- *Personnel:* Salaries for operational and service personnel and management
- *External service:* Outsourced service, support and expert services
- *Administrative and other*: Admin, tax, insurance and other

Variable costs

- *Fuel:* Lifecycle costs include procurement, loading and disposal
- *Accessories:* Electricity, water, chemicals and other costs

OPEX is typically lower than in conventional power plant, mostly due to low fuel costs

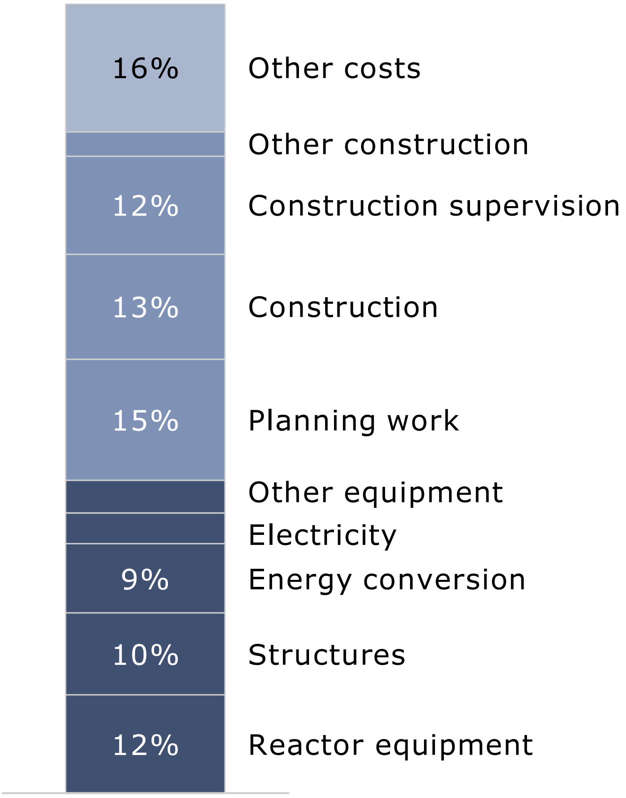
Competitiveness of conventional nuclear power and SMR at Hanhikivi site

AFRY

Nuclear power plant CAPEX is estimated to range between 4-7 EURm/MW, SMRs having higher relative CAPEX compared to conventional plants

REFERENCE CAPEX STRUCTURE

%- share of total CAPEX



- Based on different sources, the total CAPEX for a nuclear plant can be expected to range between 4–7 EURm/MW
- CAPEX structure is very similar for large-scale modular reactors and SMRs, with conventional nuclear having a slightly lower specific CAPEX requirement, due to economies of scale
- CAPEX estimates vary between different producers
- Division of CAPEX depend on the location, site, costs of equipment and construction works
- Nuclear power plant has relatively high cost of planning and construction when compared to coal or biomass power plants, where main equipment create a larger portion of the costs
- Safety is very essential in nuclear power and therefore planning work and construction take more time, material and resources than in other power plants
- Relative CAPEX for SMRs is generally slightly higher due to economies of scale

MAIN CAPEX STRUCTURE

Other costs

Planning and construction

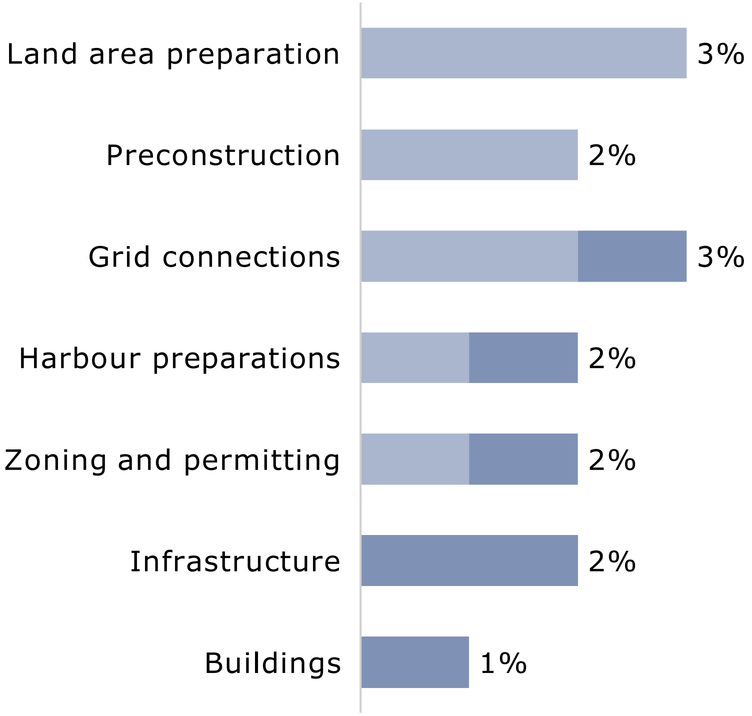
Accessories and structures

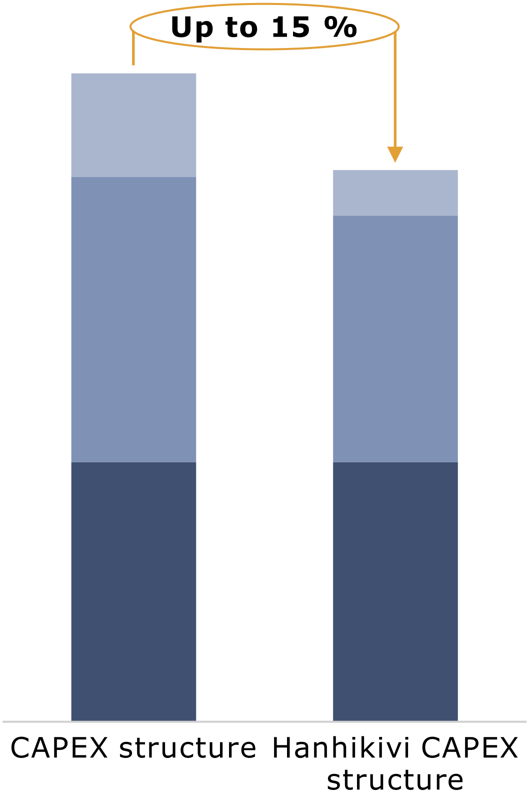
Sources: Idaho Nuclear laboratory and World Nuclear Association

Thanks to preparatory and construction works already done, Hanhikivi site can offer up to 15% CAPEX saving potential

POTENTIAL SAVINGS CATEGORIES FOR HANHIKIVI

%- savings from total CAPEX (estimations, needs a more detailed study for more accurate numbers)





Other costs | Planning and construction | Accessories and structures

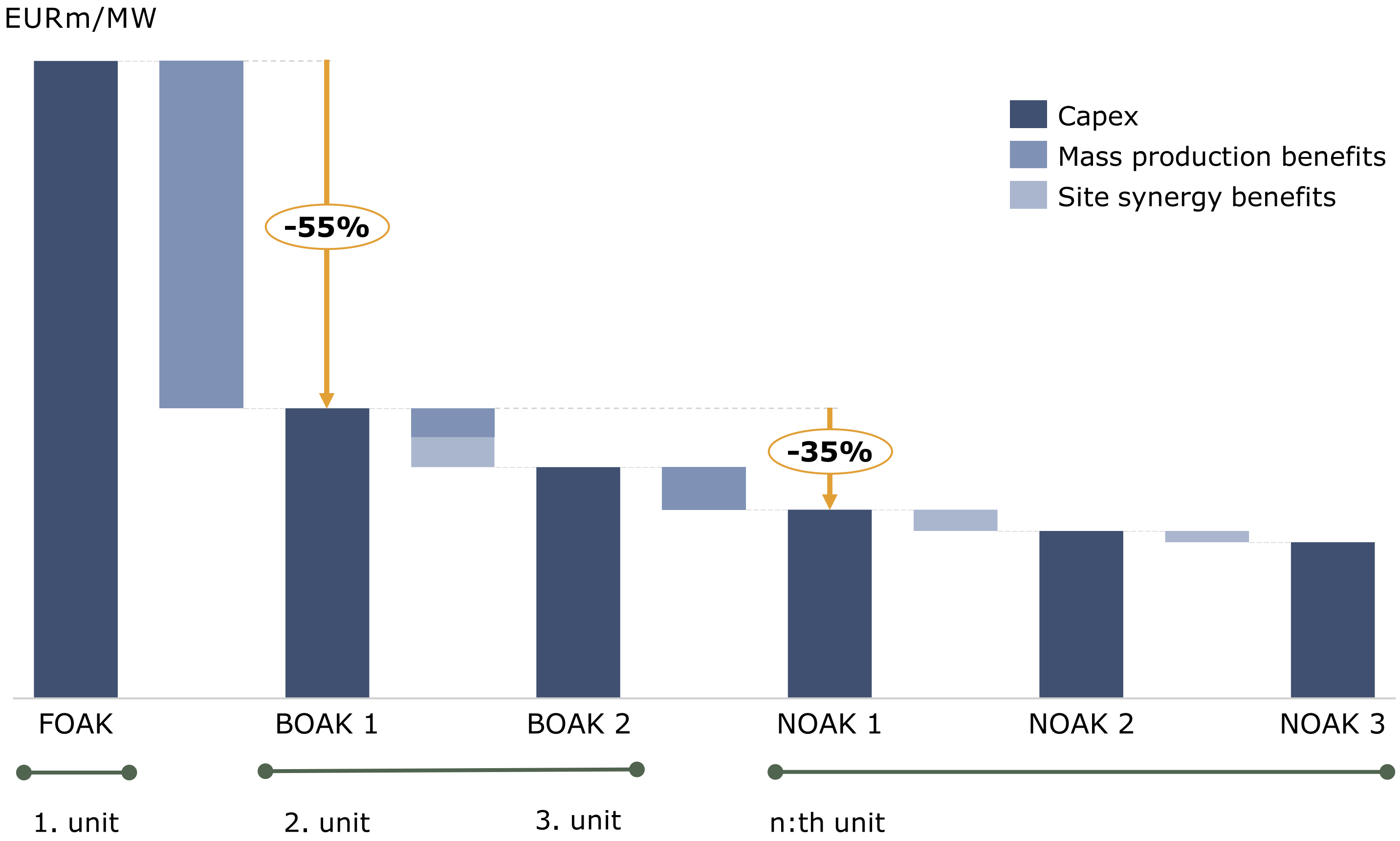
COMPLETED WORKS AT HANHIKIVI SITE

- **Civil works:** Roads constructed, earth works and preparations done for ~115 ha.
- **Buildings:** In total 3 permanent buildings: training building 1200 m^2, security gate building 1200 m^2 and admin/office building 10600 m^2.
- **Electrical work:** Distribution network connection currently at 5 MW capacity. Zoning and permitting ready for 2x400 kV + 2x110 kV connections to transmission grid.
- **Harbour:** Underwater works completed for the harbour, constructions on land not done.
- **Zoning and permitting:** Zoning is for energy production use and supporting functions, specified for nuclear power plant Zoning and permitting ready for 2x400 kV + 2x110 kV connections to transmission grid.

AFRY ÅF PÖYRY

SMR CAPEX for the first plants is high, but the potential for mass production and multi-reactor site synergies can create significant CAPEX benefits

EXAMPLE OF ESTIMATED CAPEX DEVELOPMENT OF SMR



Sources: AFRY estimate based on Idaho Nuclear laboratory (2023)

DEFINITIONS

FOAK*:* First-of-a-kind, High planning costs

BOAK*:* Between FOAK and NOAK, first installed units, first Finnish SMRs

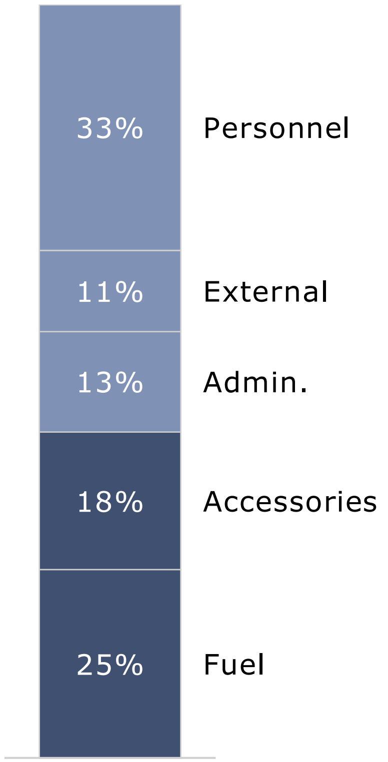
NOAK*:* Next-of-a-kind, benefits of mass-production

- Site synergy benefits result from sharing infrastructure, administrative functions, centralised control building etc.
- In the NOAK phase all learning-based cost benefits are achieved, with synergy benefits still achievable by expanding sites
- Estimated learning pace for CAPEX reduction is **5 – 10 % per new reactor** starting from BOAK 1

OPEX structure is similar for both SMRs and conventional nuclear, with biggest uncertainties and cost-saving potential in personnel-related costs

OPEX STRUCTURE FOR MODULAR NUCLEAR

%- share of total OPEX (EUR/MWh)



*According to Idaho National Laboratory, OPEX numbers vary between **14 and 33 EUR/MWh***

- Generally, SMR OPEX structure is assumed to be similar with conventional nuclear
- Nuclear power has relatively low OPEX when compared to conventional power plant, mostly due to low fuel costs
- The biggest uncertainty and cost reduction potential is personnel
  - SMR manufacturers have estimated lower operational personnel requirements than traditional large-scale nuclear. However, this hasn't been confirmed yet. Safety standards still need to be fulfilled.
- No assumed differences in variable costs for SMRs and large-scale
- US multiunit sites have shown a **38 % reduction in OPEX** compared to sites with one reactor, indicating potential in site synergies rather than size of the reactor in terms of OPEX savings

DEFINITIONS OF OPEX STRUCTURE

- **Fixed costs**
- **Variable costs**

Sources: AFRY estimate based on INL and (Ingersoll et al., 2020).

The role of nuclear in the future power markets – the need for stable electricity generation increases with increasing demand

NUCLEAR BENEFITS IN POWER MARKET

The value of stable and constant electricity supply increases when inflexible demand increases – this requires either more stable generation and / or flexibility to integrate variable electricity generation

Nuclear power offers CO2-neutral power generation. EU regulation and country- and company-specific emissions targets increase nuclear attractiveness.

New nuclear has the potential to provide predictable and stable pricing for offtakers. Cost competitiveness can be approached through multiple identical plants

Nuclear power generation responds to industry requirements on stability, emissions and predictability as **baseload generation**

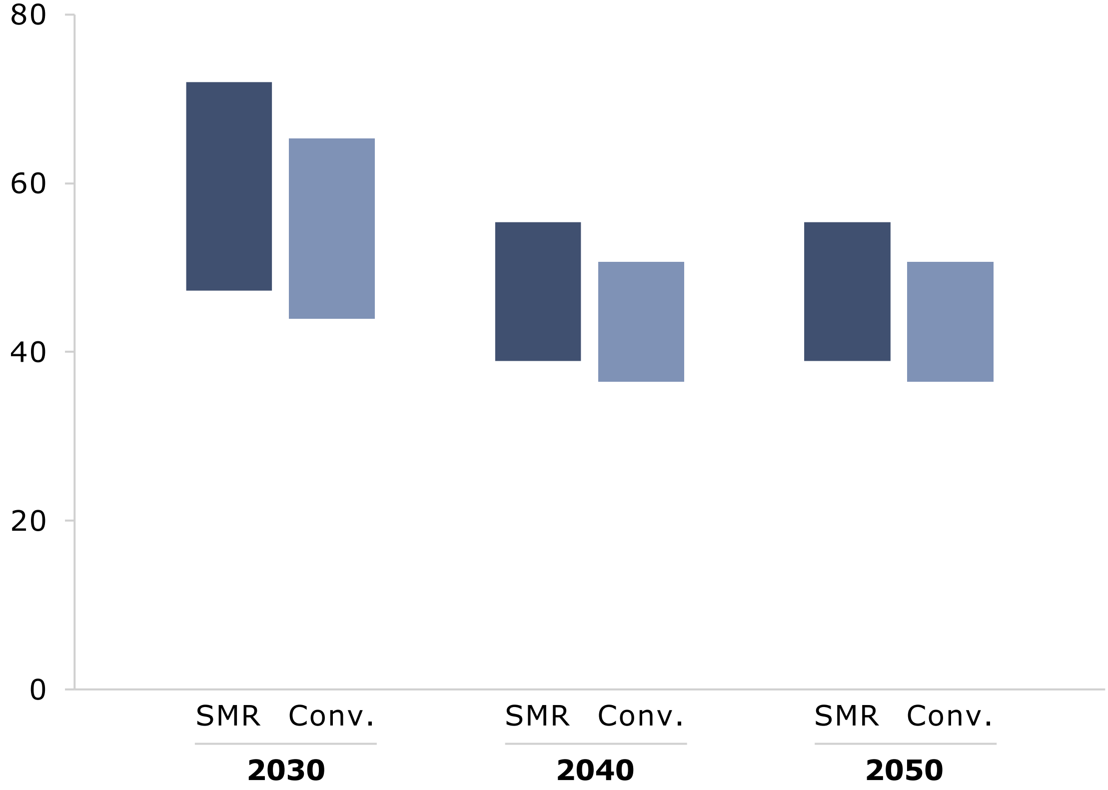
Source: AFRY power market analysis, industry interviews

AFRY ÅF PÖYRY

Plant suppliers are aiming to drop nuclear LCOE levels when moving towards mass production for both SMRs and conventional nuclear

ESTIMATE OF SMR AND CONVENTIONAL LCOE RANGE

EUR/MWh



LCOE source: plant suppliers

CONCLUSION

- Plant suppliers see LCOE levels for conventional nuclear and SMR are generally very similar
- SMRs can be more flexible, which offers higher capture prices, but evidence still lacking for this
- SMRs can be located closer to populated areas due to size and are easier to connect to the grid. Neither applies as a clear benefit at the Hanhikivi site.
- Decreasing LCOE levels, due to learning in construction and multiunit site synergy benefits.
- Unlocking declining LCOE path requires large scale adoption of new nuclear at global scale

Note: The estimations are based on nuclear power and SMR commonly, not specifically for Hanhikivi

LCOE-potential calculations

- Used estimated CAPEX and OPEX ranges to calculate potential lifetime costs
- Typical capacities for conventional and SMR used to calculate lifetime generation

N.B. The presented ranges for LCOE-potential can differ when using differing assumptions. A different assumption on WACC, for example, could have a significant effect on LCOE-potential of these CAPEX-heavy production technologies

To be able to compare stable nuclear project investments to weather-dependant RES investments, we have assessed the so called baseload power cost for both nuclear and RES investments

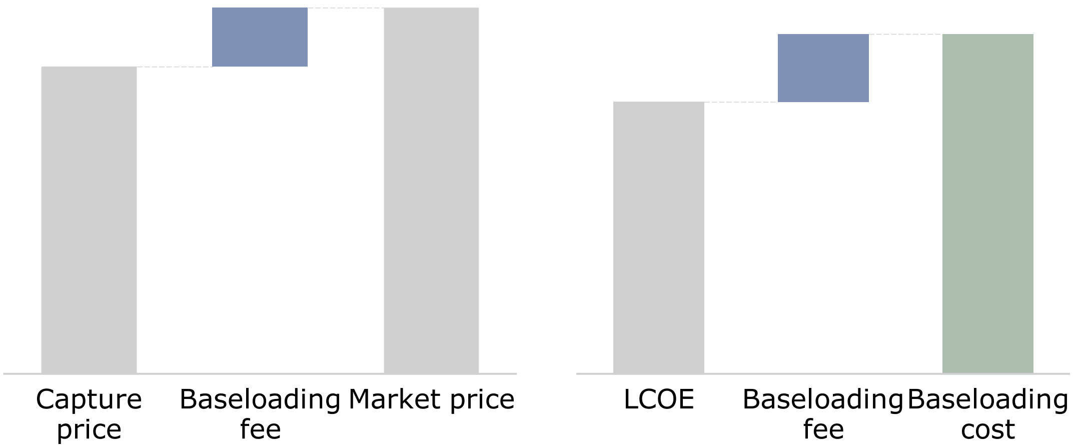
BASELOAD POWER

- Baseload power is the minimum constant level of electricity demand required at all times
- It ensures a stable and continuous supply to meet essential energy needs, that can’t be fixed with demand side flexibility
- Traditionally baseload power is provided by coal, nuclear, and certain hydroelectric plants
- Baseload power produced with renewables comes with additional costs due to generation profile

- **With increasing market penetration of renewables, the capture rate will decrease hence increasing the baseloading cost of weather dependent generation**

- ***Baseloading-cost*** = Technology-specific price, which reflects the total price achieved by offering a constant profile of power generation, by complementing intermittent generation with grid electricity
- ***Baseloading-fee*** = Fee, which represents the difference between the average market price of electricity and the capture price

FORMATION OF BASELOADING COST



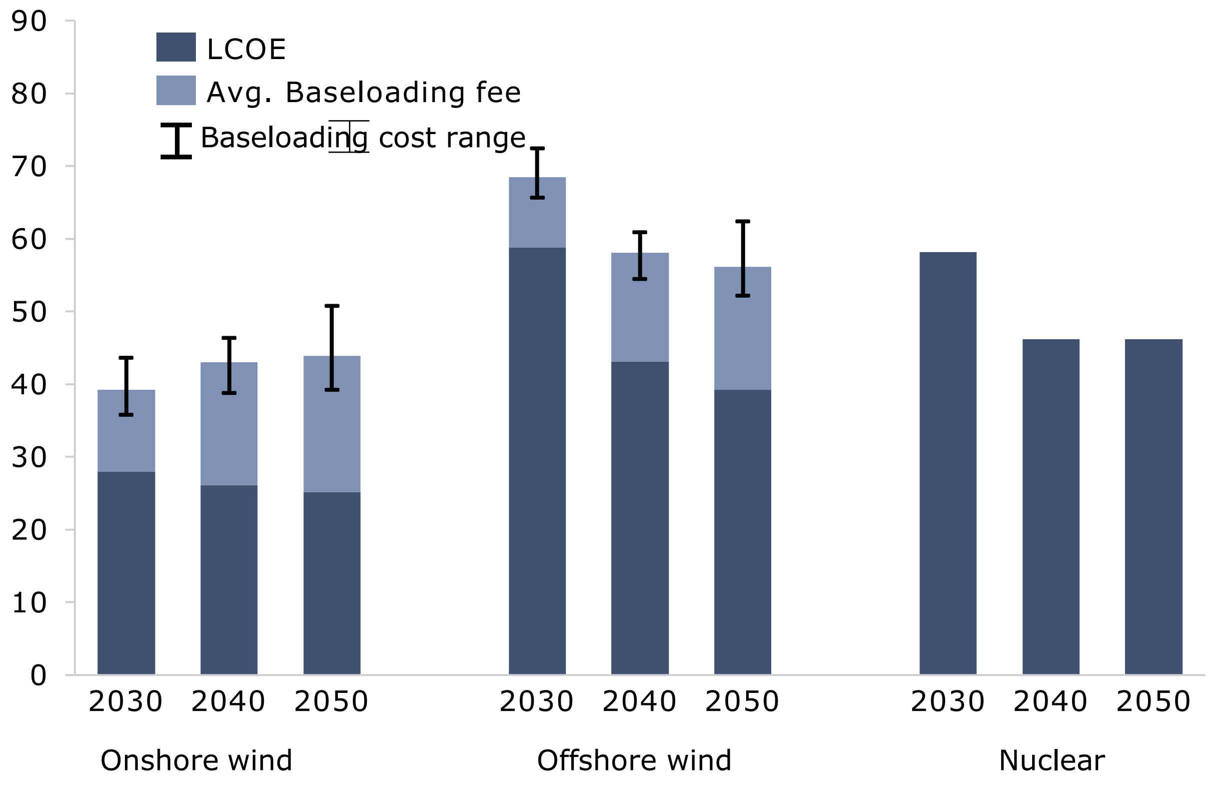
Baseloading fee = Avg. Market price × (100%-capture rate%)

Baseloading cost = LCOE + **Baseloading fee**

AFRY ÅF PÖYRY

Baseloading costs for renewables increase the relative competitiveness of nuclear, with otherwise higher LCOE levels

COST OF BASELOAD PRODUCTION



CONCLUSION

- Baseloading accounts for the fact that variable RES doesn't generate electricity constantly and needs to compensate with grid electricity
- Baseloading cost is highly relevant for users that depend on a constant flow of electricity and set prices. Such users are industry and other large electricity consumers
- Increased RES in the power system tends to increase price volatility and drive up baseloading cost
- With improvements in LCOE through multiple projects and learning effects, nuclear could be competitive providing stable power as baseload electricity

Baseloading calculations

- Baseloading cost is calculated from the difference in capture price (average price captured by the given technology) and average market electricity price.
- The baseload cost range is given by different electricity price projections.
- Three Electricity price projection scenarios from AFRYs study for the Prime Minister's office *)

*) AFRY report: Impact of carbon neutrality target to the power system (Hiilineutraalisuustavoitteen vaikutukset sähköjärjestelmään - Valto (valtioneuvosto.fi))

Capacity markets could partly support nuclear investment case, if new nuclear would be included in the potential capacity mechanism

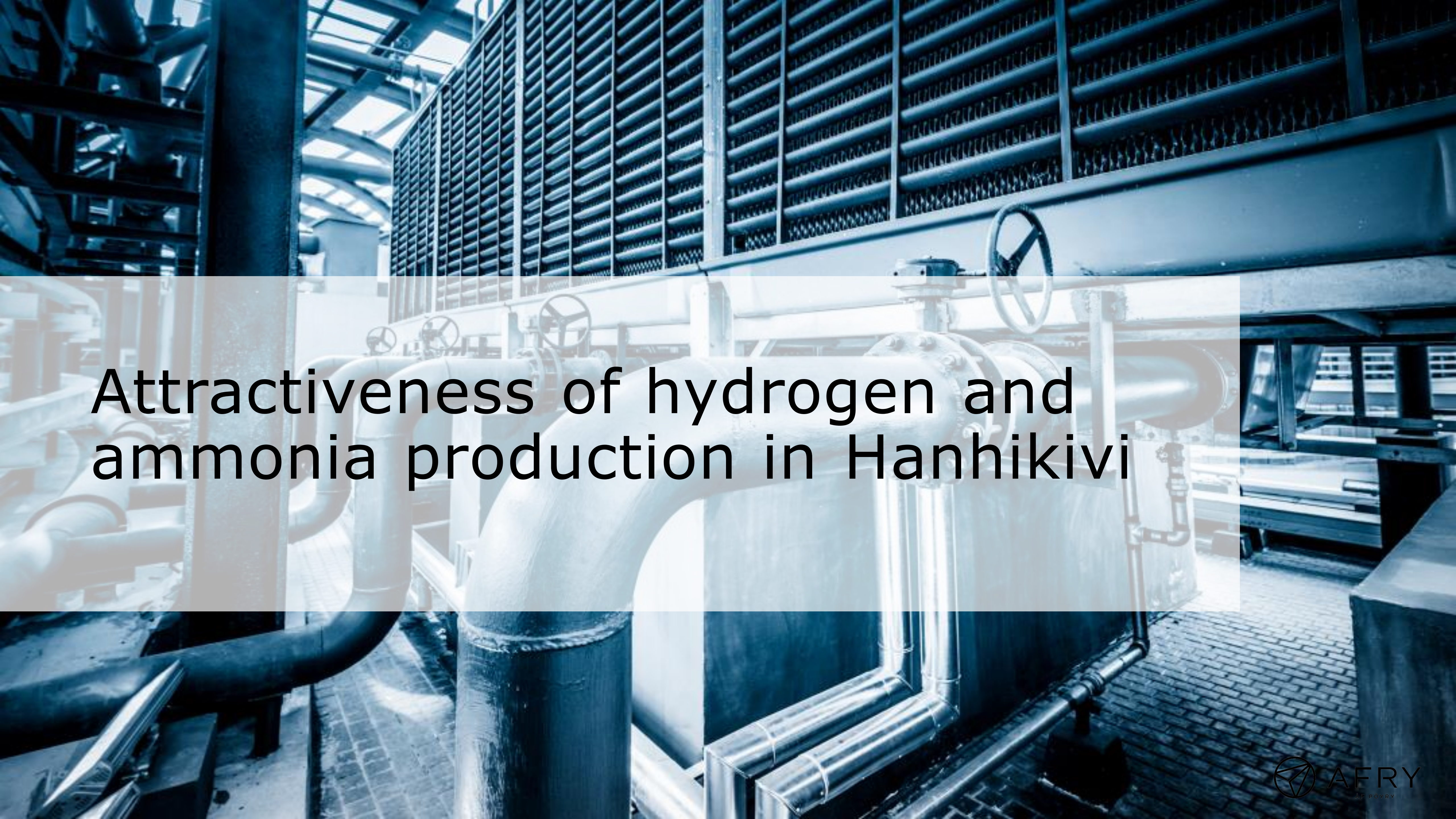
A CAPACITY MARKET COULD OFFER REVENUE NUCLEAR

- A capacity market increases reliability and decreases volatility in the power system by compensating offered capacity in addition to generation
- The need for a capacity market may come with the intermittency of increased RES in the power market, if energy only market alone is not able to induce investments into flexibility or firm capacity
- The capacity market would compensate at least peaking generation, but in a market wide format may also compensate generation via derating factors which reflect firm availability. If this were to happen, nuclear could gain additional revenue

CONCLUSION

- A capacity market could offer additional revenue, making nuclear more appealing in the power market already earlier than the LCOE indicates
- Demand-side flexibility will likely be important for price optimisation, but also for grid reliance in the future. With a capacity market and higher share of baseload power, dependency on demand flexibility for grid reliance decreases

Attractiveness of hydrogen and ammonia production in Hanhikivi



Nuclear-produced hydrogen offers technical benefits but is not currently classified as producing green hydrogen under the RFNBO

BENEFITS OF NUCLEAR GENERATED HYDROGEN

Constant stream of electricity	Contrary to renewables nuclear offers constant power generation that isn't dependant on weather or other conditions. Major benefit for some industries
Less electrolyser capacity required	Due to the constant stream of hydrogen, the annual production of hydrogen is larger than with variable power generation
Smaller hydrogen storages required	Without oversizing the electrolyser, you can use the hydrogen directly instead of having to store large parts of the hydrogen for later use
High full load hours	With constant power generation, you can better utilise your electrolyser, producing more H2 with a smaller electrolyser. Less fluctuation also prolongs the lifetime of the electrolyser

REGULATORY HURDLES REMAIN

- At the moment nuclear cannot produce green hydrogen under the RFNBO (according to the current RFNBO delegated act).
- Nuclear-produced hydrogen could be considered low-carbon hydrogen if it produces 70% less lifetime GHG emissions than traditional hydrogen from natural gas.
- The definition of nuclear produced hydrogen may or may not change - a delegated act on low carbon hydrogen is currently under preparation in the EU
- Until the above happens, nuclear derived hydrogen competes against other low carbon hydrogen, not green hydrogen under the RFNBO

AFRY LCOH and LCOA modelling assumptions used for feasibility calculations based on nuclear power

Assumption	Value	Explanation
Discount rate / WACC	8 %	Real values, money baser of 2022
Electrolyser CAPEX	741 €/kW	AFRY technology cost team report q3 – 2023, lack of real-life data increases uncertainty around CAPEX
Storage CAPEX	0,6 – 19 €/kWh H2	AFRY technology cost team report q3 – 2023, lack of real-life data increases uncertainty around CAPEX
Electricity price	40 – 60 €/MWh	Electricity price projections combined with nuclear LCOE estimate. Used for nuclear modelling Adjusted for flexibility analysis
Renewables OPEX	25 €/ kW_h2 / year	Modelled with wind capture rates
Electrolyser efficiency	72 %	AFRY benchmarks
H2 heating value	39,39 kWh / kgH2	Higher heating value (HHV) used

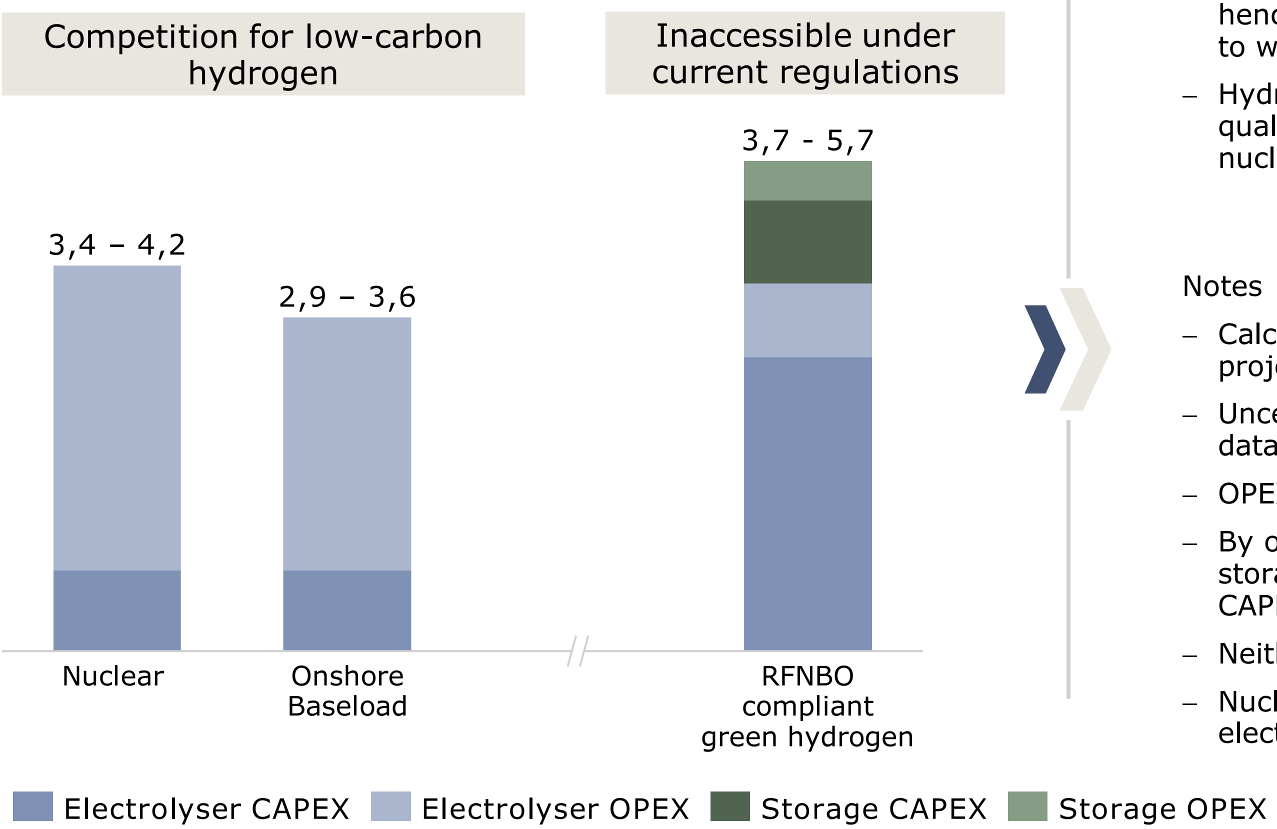
COMMENTS

- Renewable modelling done via optimizing the combination of oversized electrolyser and storage capacity
- Cost of producing ammonia from hydrogen considered equal add-on cost for both nuclear and RES
- For the high-level analysis we don’t consider degradation of components, minimum load factors of electrolyser, efficiency variations based on load factor

Under current regulations nuclear produced hydrogen needs to compete with other low-carbon hydrogen

NUCLEAR LCOH

€/kg H2



COMMENTS

- Current regulation prefers RFNBO-compliant green hydrogen and hence restricting the market potential for low-carbon hydrogen, to which nuclear is likely to be included
- Hydrogen produced with grid electricity in Finland does not qualify as RFNBO compliant green hydrogen and competes with nuclear-produced hydrogen.
  - Nuclear is less competitive against grid derived low carbon hydrogen

Notes

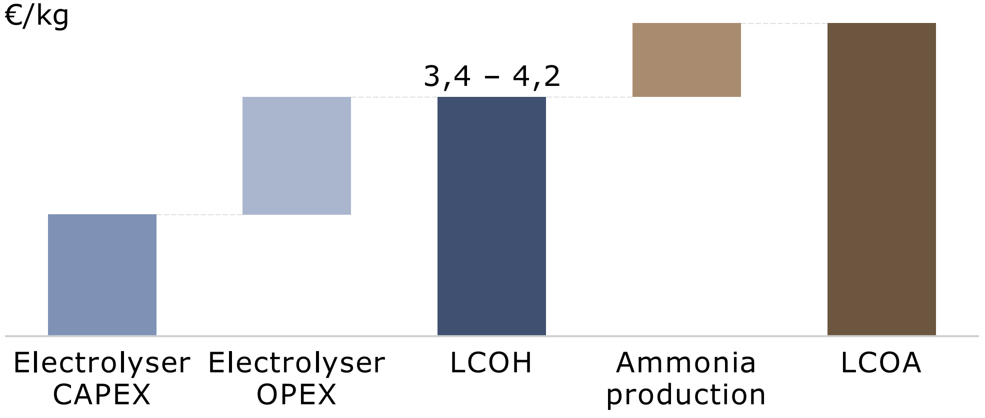
- Calculations are indicative and a more granular analysis on a project basis would be required for any investment decisions.
- Uncertainties around electrolyser CAPEX development as real-life data is scarce
- OPEX mainly consists of electricity costs
- By oversizing the electrolyser for RES and complementing it with storage, lower capture prices are achievable. Explaining higher CAPEX and lower OPEX
- Neither case accounts for hydrogen grid fees
- Nuclear case does not account for possible faults in the electrolyser, which would call for a small storage capacity

Ammonia is the most likely possibility for P2X technologies at Hanhikivi site, lack of biogenic CO2 in the proximity of the site limits other alternatives

POWER TO X POSSIBILITIES AT HANHIKIVI SITE

- No large sources of biogenic CO_2, which is necessary for carbon-based synthetic fuels, in the proximity of the Hanhikivi site.
- Lack of biogenic CO2 limits options of power-to-X to ammonia unless liquefied CO2 transport to the site by ship can be considered as a future option.
- A possibly large demand for ammonia is found throughout Europe in fertilizers, chemicals and as a fuel for maritime sector (see the next page for more details)
- The main building blocks for green ammonia are hydrogen and nitrogen, resulting in the cost of hydrogen being crucial for the cost of ammonia
- Ammonia production is dependent on a constant stream of hydrogen, which is suitable for nuclear or RES with large hydrogen storage and oversized electrolyser

AMMONIA COST ASSUMED AS ADD-ON



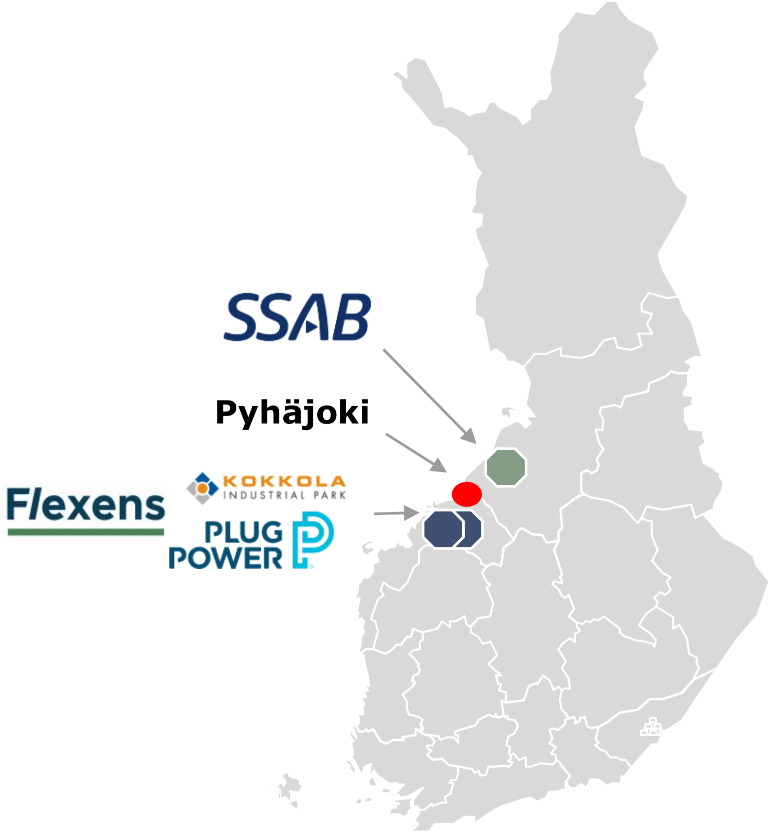
- Cost of ammonia production is considered an add-on cost to LCOH in the above, meaning that the comparison between nuclear and renewables stays the same as for LCOH
- We know that ammonia production requires a constant hydrogen stream giving a technological edge to nuclear-produced ammonia
- RFNBO regulation applies for ammonia too, meaning that nuclear ammonia needs to compete against other low-carbon, and not RFNBO compliant ammonia

The Nordic hydrogen economy is developing, with Hanhikivi being in a promising location for some players

DEVELOPMENT OF HYDROGEN ECONOMY

- The Nordic hydrogen economy is rapidly developing with multitude of projects announced
- PtX projects by SSAB in Raahe Flexens and Plug Power in Kokkola in a near proximity to Pyhäjoki
- Further projects are found along the planned hydrogen pipeline Nordic Hydrogen Route:
  - Oulu, Kemi, Tornio (projects not announced, but could be, since the CO2 emissions as feedstock is available)
  - Luleå (project BotnialänkenH2 for hydrogen production using wind power, Project Green Wolverine for the production of ammonia and green fertilizer, H2 Green Steel producing green hydrogen and green steel)
  - Skellefteå (Flagship Four producing hydrogen for the aviation sector)
  - Kiruna (LKAB plans to produce hydrogen used in the reduction of iron)
- Additionally, the planned hydrogen pipeline to Sweden, might increase the attractiveness of hydrogen investments
- What the hydrogen is used for also determines the technical requirements of production, however, the financial feasibility is still important

CLOSE BY PROJECTS DEPENDANT ON HYDROGEN



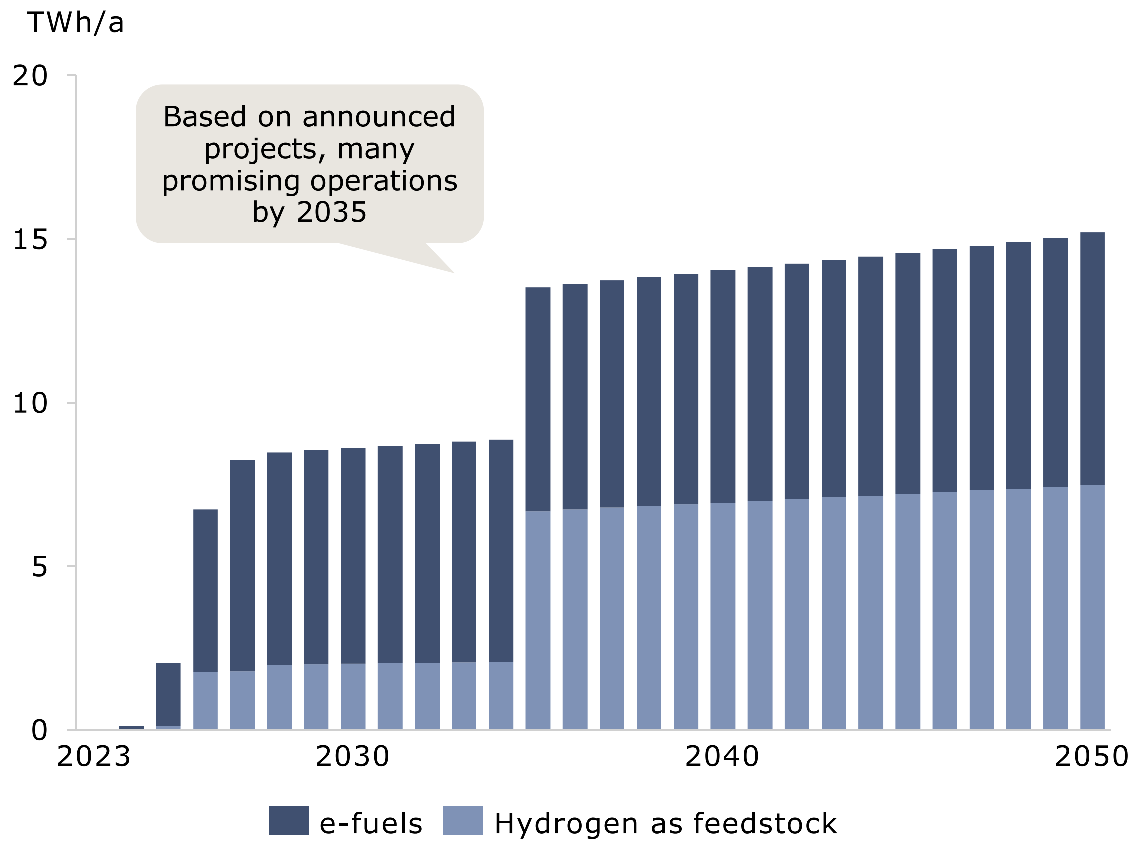
The energy transition creates new end-use applications for ammonia as a fuel and H2 carrier

	EXISTING APPLICATIONS	EMERGING APPLICATIONS		
	Industry feedstock	**Power**	**Transport**	**Hydrogen carrier**
MAIN APPLICATIONS	• **Fertiliser** • **Industrial chemicals**	• **Power generation**	• **Maritime fuel**	• **H2 carrier (means of H2 transport to be cracked back to H2)**
PROS/CONS FOR MARKET GROWTH	✓ Low-carbon ammonia substituting grey ammonia, preventing associated CO_2 emissions ✓ Drive amongst policymakers to reduce emissions in fertilizer production and application ✓ Potential to improve food security in countries with RES potential and high fertiliser / food imports ✗ Sensitivity of farmers to fertiliser costs	✓ Potential to reduce CO2 emissions in existing coal- and gas-fired power plants ✗ There is still research required to allow 100% ammonia-fired power generation in either conventional boilers or gas turbines ✗ NOx resulting from combustion and safety issues (e.g. high toxicity) need to be resolved	– Ship OEMs are currently developing direct combustion engines and fuel cell propulsion technology, but still at testing stage ✓ Existing global ammonia transport infrastructure ✗ NOx resulting from combustion and safety issues (e.g. high toxicity) need to be resolved ✗ Lack of safety and handling regulations and standards	✓ Green H_2 produced in regions with favorable RES conditions can be synthesised to NH_3 via Haber-Bosch process, then shipped to regions with less favorable RES conditions ✓ Existing global ammonia transport infrastructure ✗ Potential for medium term bottlenecks s infrastructure expands

AFRY
ÅF PÖYRY

Finland has an impressive published hydrogen project pipeline, part of this new demand may be addressable market for nuclear H2

ELECTRICITY DEMAND DEVELOPMENT FOR HYDROGEN (FIN)

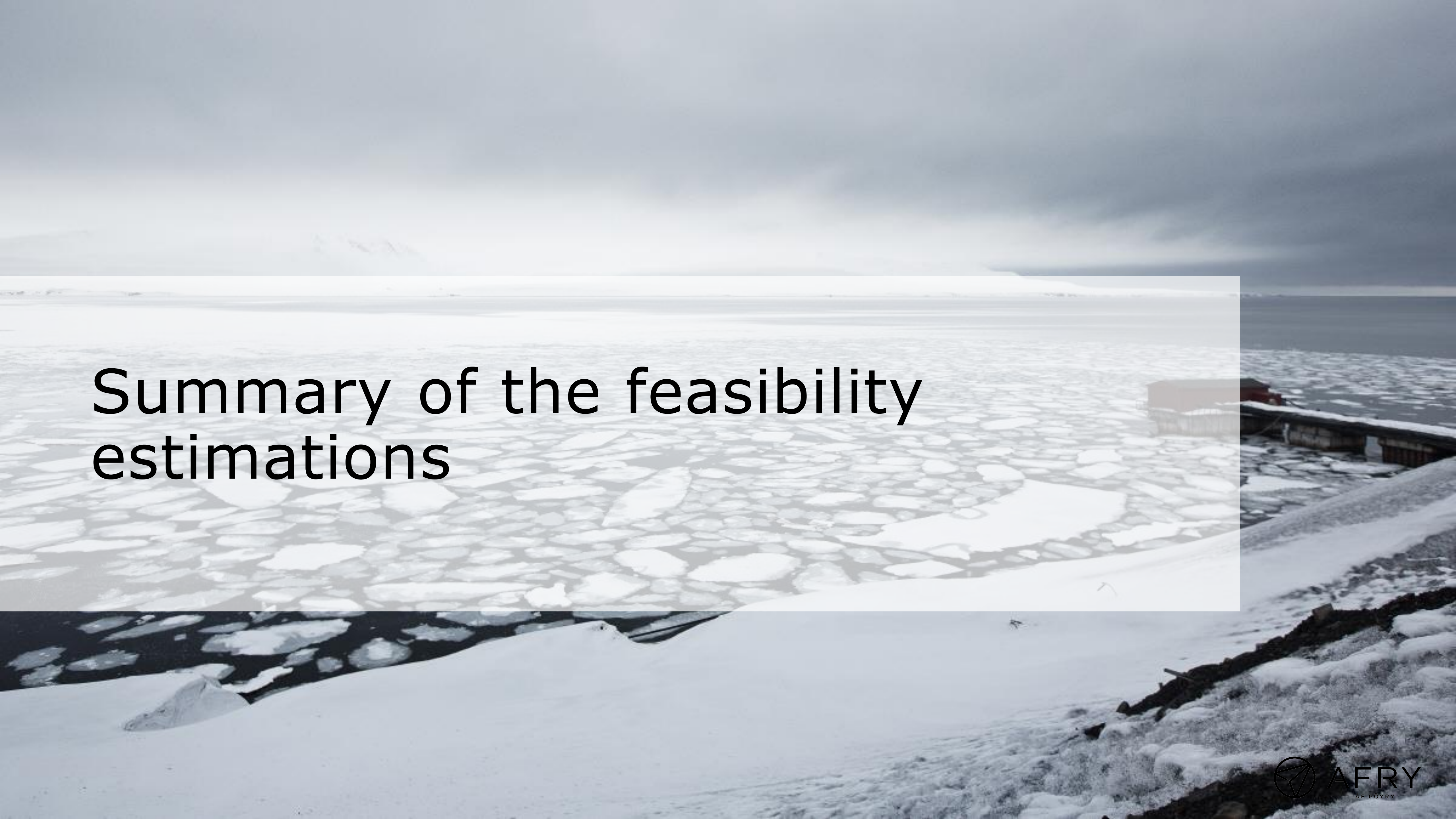


COMMENTARY

- According to published projects, Finland has a large hydrogen project pipeline. Many of the projects are looking for export opportunities of hydrogen and PtX products.
- The future Delegated Act on low carbon hydrogen may finally clarify the position of nuclear power in hydrogen production. As a result, we expect the willingness-to-pay for low-carbon hydrogen to be lower than for renewable hydrogen.
- The future demand growth for hydrogen and e-fuels in Europe might be difficult to match with only RES, especially when the total electricity demand is growing simultaneously. Regulation would have to be amended however to allow a role for nuclear
- We may expect the project status in Finland to change over time – some projects will be cancelled or postponed while some appear as new to the project pipeline. Hanhikivi site's potential should therefore be promoted to both existing and potential new developers.

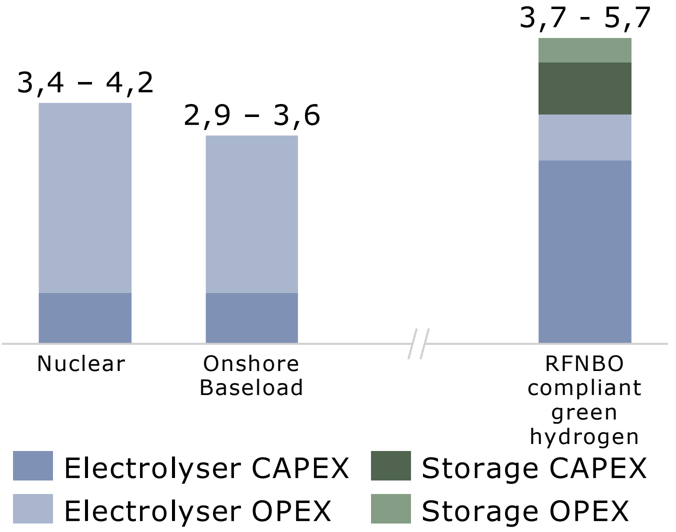
AFRY ÅF PÖYRY

Summary of the feasibility estimations



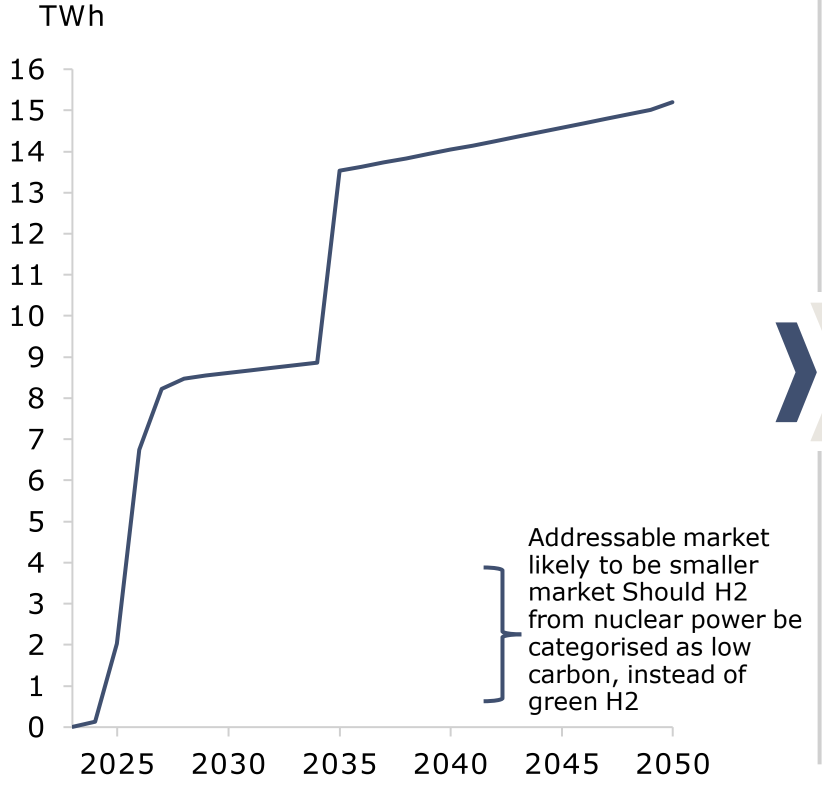
Nuclear-produced hydrogen may offer opportunities at Hanhikivi, especially if regulation categorises nuclear as green hydrogen under the RFNBO

LCOH COMPARISON (€/KG)



- Oversizing of the electrolyser and optimizing with storage allows lower capture prices, explaining a higher share of CAPEX and a lower OPEX
- Ammonia production is considered equal add-on cost, not affecting nuclear vs. RES relation

ELECTRICITY DEMAND FOR GREEN HYDROGEN



CONCLUSION

- EU legislation for nuclear-produced hydrogen is still developing but seems to be unfavourable for nuclear, as clear seems likely to be classified as low-carbon than as renewable
- If nuclear were classified as able to produce green hydrogen, then the addressable market for electricity supply that meets green hydrogen criteria can grow to 15TWh by 2050
- Otherwise nuclear can produce low carbon hydrogen which accounts for a smaller market
  - Nuclear will compete against other forms of low carbon hydrogen which can be produced at low cost

Nuclear power generation could play an important role in the future power market as baseload, with increasing demand for stable power from industry

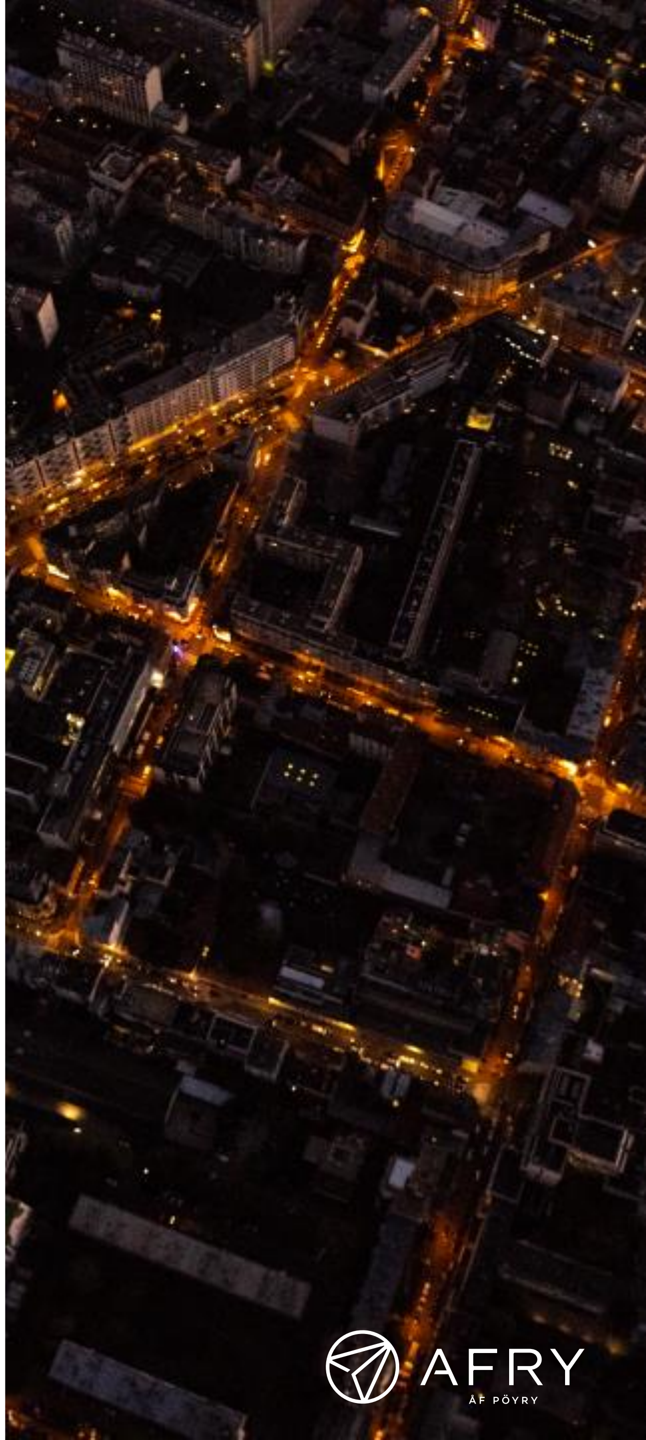
PROS AND CONS OF NUCLEAR AT HANHIKIVI SITE

Pros	Cons
Stable baseload production	EU legislation regarding nuclear-produced hydrogen
Benefiting from the site readiness	Long project lead time
Technical benefits for industrial use cases and the future hydrogen industry	

CONCLUSION

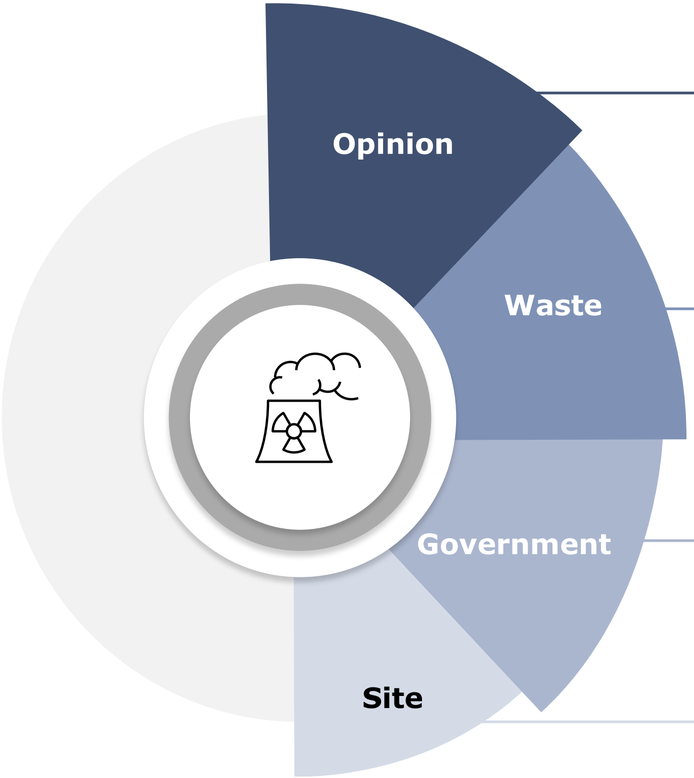
- Nuclear power generation could be a competitive option to meet the needs of projected increasing demand from new industries, valuing stability in production and predictable prices. LCOE levels at Hanhikivi could also benefit from cost savings due to preparatory work at the site
- A potential capacity market could make nuclear power generation more appealing
- Projected large increase in electricity demand, with large shares coming from the hydrogen industry requiring a stable flow of electricity, makes a baseload nuclear power plant ideal.
- However, nuclear construction comes with a long lead time. Uncertainty of the demand development in the market and power prices create significant risks from an investor's perspective
- The high-level case study for hydrogen and ammonia sees slightly lower annualised costs for nuclear than for RES based hydrogen production combined with storage
- The classification of nuclear-based hydrogen is expected to be clarified soon in EU regulation. This will ease the decision-making of potential industrial end-users who are reviewing nuclear power as a potential future resource.

Content



Conclusions

Finland has favorable environment for new nuclear and Hanhikivi is one of the best locations



FAVORABLE PUBLIC OPINION

Even 68 % of Finns were supporting nuclear power in 2023 and only 6 % were against it.*) Finland has solid tradition of nuclear power plants from 1970s.

WASTE HANDLING POSSIBILITY

Posiva's Onkalo permanent disposal of nuclear waste will start operation in Olkiluoto in 2025 if the project will be finalized according to the time schedule.

POSITIVE GOVERNMENT PERSPECTIVE

Current Finnish government is favourable to nuclear power and is prepared to receive application(s) for new nuclear or SMR during its reign.

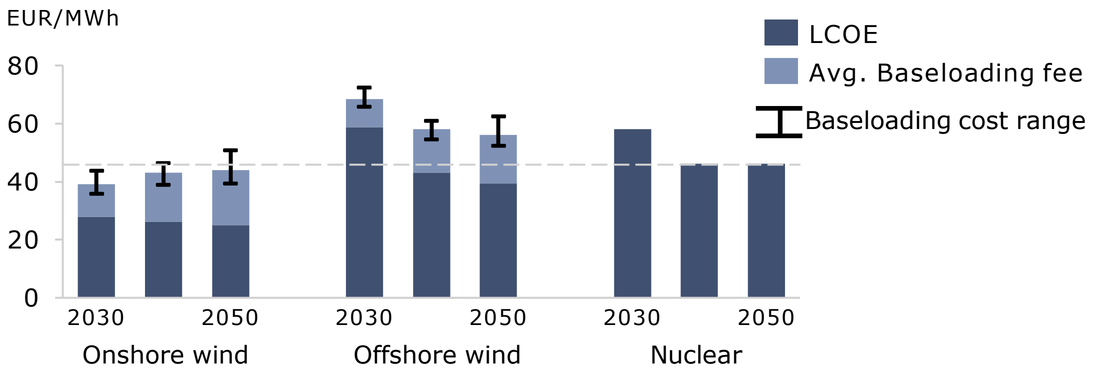
HANHIKIVI SITE HAS STRUCTURAL ADVANTAGES TO SUPPORT NUCLEAR BUILD

Well-proceeded ground works and site preparations give Hanhikivi site a clear advantage when comparing feasibility of new nuclear power plant sites.

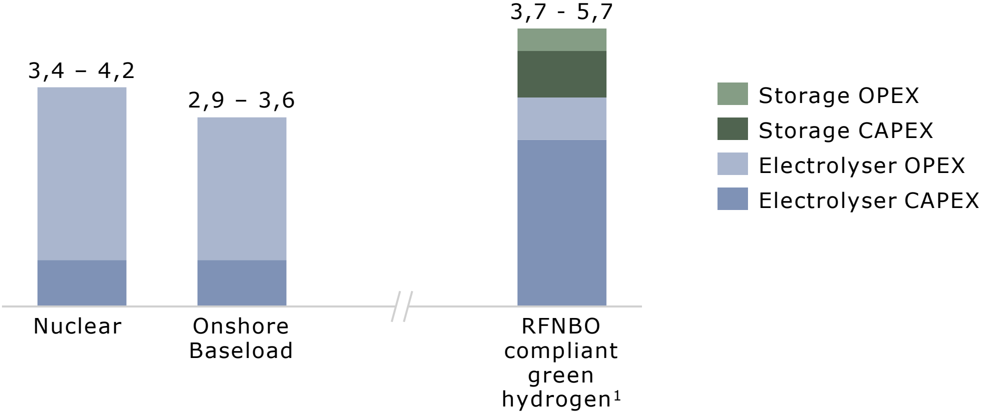
*) Popularity of nuclear power reaches a new record in Finland - Energiateollisuus

Nuclear at Hanhikivi has the potential to be cost competitive when considering a case where a flat production profile brings economic benefits

COST OF POWER PRODUCTION WITH BASELOADING EFFECT



LCOH COMPARISON (€/KG) OF NUCLEAR VS. DEDICATED-RES[1] PRODUCED HYDROGEN



VALUE OF STABILITY IN POWER PRODUCTION

- Nuclear is not competitive against onshore wind on a pure LCOE basis
- While considering the value of stability of nuclear production through baseloading logic, nuclear becomes potentially competitive in the future, especially against offshore wind
- Moreover, possible capacity mechanism might also have an effect on the profitability comparison in the future – Not on the cost side but through revenue potential

VALUE OF STABILITY IN HYDROGEN PRODUCTION

- With stable electricity input hydrogen production can potentially achieve lower cost levels compared to RES-produced hydrogen, if storages for RES-based production are considered
- However, hydrogen and ammonia derived from nuclear power would likely not be considered RFNBO, decreasing the potential market and willingness to pay by customers
- With stable electricity the electrolyzer capacity does not need to be overdimensioned and the CAPEXs are hence lower
- Nor is there need for storaging and the costs associated to it

1 In RFNBO compliant case a PPA with restricted usage hours and a dedicated connection to renewable production is assumed. Hence, storage is needed if end-usage of produced hydrogen happens on the site, *e.g.*, further processing to ammonia. With a hydrogen transmission pipeline connection, the hydrogen could possibly be injected to it without intermediate storage

Nuclear developers will need to successfully manage risks to realise nuclear at Hanhikivi

RISKS

A nuclear power plant project is a risky investment due to high CAPEX and long time schedule.

Major risks and cost drivers must be managed effectively, especially if tied to industrial projects

- CAPEX, time schedule, permitting, procurement, etc.
- Site related benefits and risks have to be studied thoroughly before the investment decision

FINANCING

Financing costs must be minimized due to high CAPEX

- Options including Mankala model and other innovative solutions should be considered

TECHNOLOGY

Well-proven technology and experienced suppliers with willingness to adapt to Finnish circumstances are in key role to tackle the risk portfolio.

Supplier's references and track record of the similar kind of projects are important

STAFF AND SUPPLIERS

Operational staff has to be hired and trained in good time during the implementation project

Good sub-supplier network has to be established and maintained

RELATIONS

Management and maintaining the local public and political support is essential to a successful project

Open dialogue with STUK and other authorities are important issues in all phases of the project

Nuclear electricity production at Hanhikivi site is a future opportunity for electricity end-users who value stable electricity supply. The site is also suitable for on-site hydrogen and ammonia production based on renewable or nuclear power.

In summary, Hanhikivi site has four interesting options depending on investment timeline and future EU regulation:

1. On-site production of hydrogen and ammonia based on baseload renewable power purchase agreements from the grid or directly connected renewable power production. The resulting ammonia would then be considered as RFNBO compliant ammonia.
2. Nuclear power production for grid-connected industrial end-users who value stable supply of electricity provided a competitive electricity production cost in comparison to other types of baseload power purchase agreements in the future.
3. Nuclear power production for on-site hydrogen and ammonia production provided that nuclear based H2 is accepted as low-carbon hydrogen in future EU regulation and that the pricing of low-carbon hydrogen is competitive at market. Industrial production at the site needs with nuclear power to be studied more in detail, but at least connection with SMR would probably be possible.
4. Nuclear power production for on-site hydrogen production connected with a hydrogen pipeline to one or more hydrogen end-users provided that nuclear based H2 is accepted as low-carbon hydrogen in future EU regulation and that the pricing of low-carbon hydrogen is competitive at market. Industrial production at the site needs with nuclear power to be studied more in detail, but at least connection with SMR would probably be possible.

PPA : Power Purchase Agreement


Making Future
06/03/2024
AFRY
ÅF PÖYRY