AURORA ENERGY RESEARCH

Unlocking the Potential of Hydrogen in the Nordics

Public Webinar

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Sources: Aurora Energy Research

The Nordics are well placed to secure their domestic and EU hydrogen demand thanks to their policy levers, compliant and cheap power system

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Category	Description	Denmark	Finland	Norway	Sweden
Policy	Efforts developing supply-side policies, demand-side policies and incentives				
Power system	Sourcing electricity from grid compliant with RED II				
LCOH	Competitiveness of the levelised cost of H_2				
Supply & demand	Projections for domestic and regional supply and demand				
Competition	Competition from European and international sources				
Transport & storage (T&S) infrastructure	Risk that infrastructure is delayed				

High risk Medium risk Low risk

Sources: Aurora Energy Research,

EU regulations offer investors regulatory certainty, and can be particularly beneficial for Nordic electrolysers

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EU regulation stipulates that H_2 produced from renewable must meet three criteria to be deemed *renewable hydrogen*:

- Additionality
- Geographical correlation
- Temporal correlation

But the Delegated Act also sets out four scenarios for when certain criteria may be exempt:

1. Electrolyser is directly connected to a RES[1] asset
2. Average RES share in the grid electricity mix >90%
3. Electrolyser uses otherwise curtailed power
4. Average carbon intensity in grid <64.8 gCO_2/kWh

Electrolysers in >90% RES zones, such as in the Nordics, can charge directly from the grid, which offers several benefits:

- Electrolyser can be located closer to demand
- Power is available whenever needed
- 90% Electrolyser can operate at a high load factor
- Operations can follow the offtake profile

1) Renewable.

Sources: Aurora Energy Research

Sourcing electricity from the grid in Denmark and some price zones in Norway & Sweden will give competitive RFNBO-compliant green hydrogen

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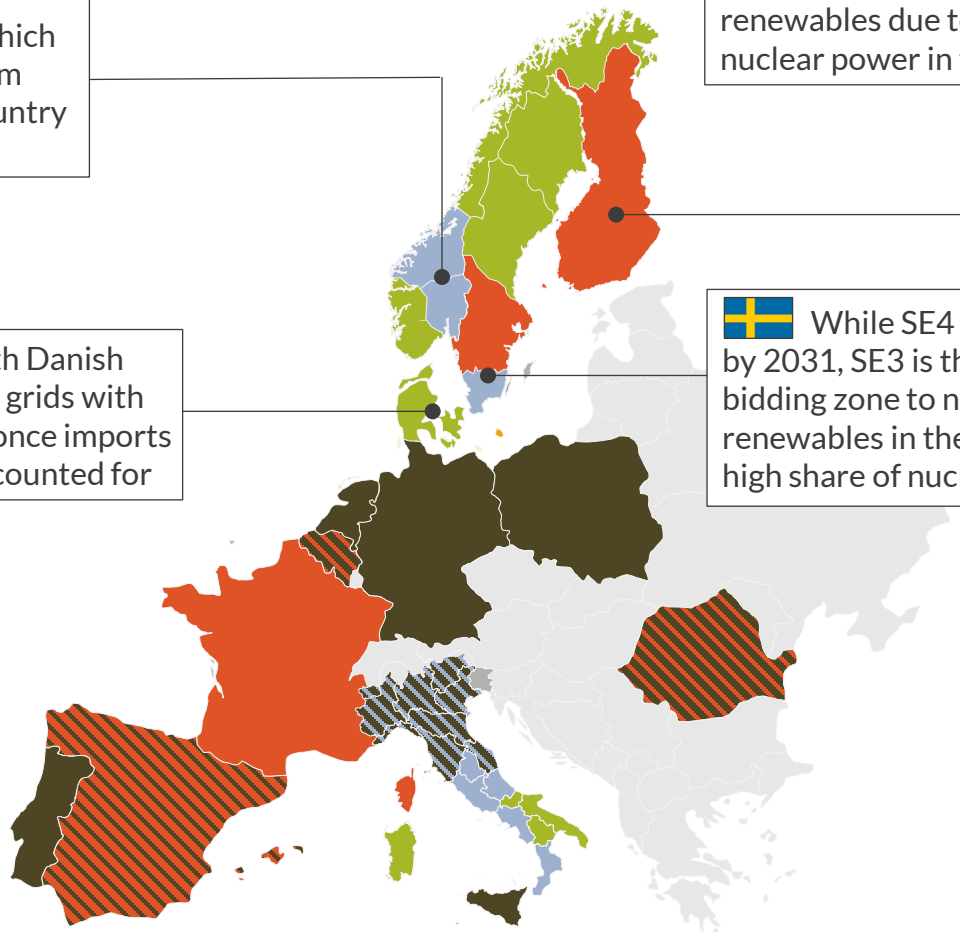
2030 snapshot of expected power system mix

NO1 and NO3 are the demand centres in Norway which are heavily import-reliant from other bidding zones in the country with renewable surplus

Finland, though having a low grid emission intensity, is not expected to achieve >90% renewables due to a large share of nuclear power in the electricity mix

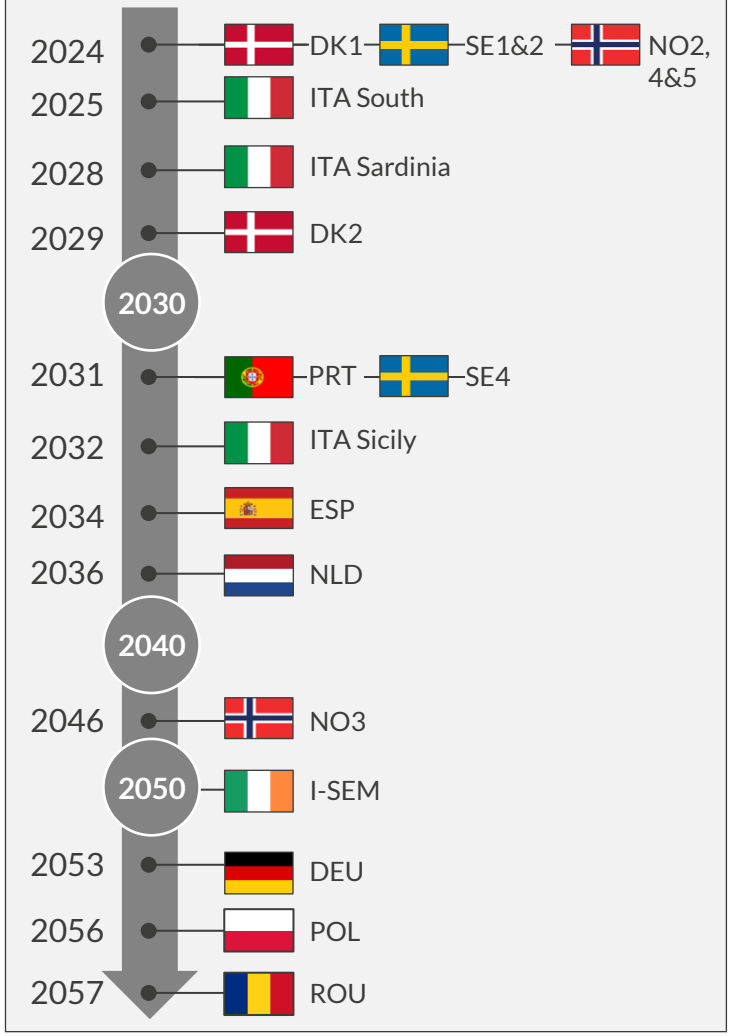
By 2030, both Danish bidding zones have grids with >90% renewables once imports and exports are accounted for

While SE4 will be compliant by 2031, SE3 is the only Swedish bidding zone to not achieve 90% renewables in the grid due to its high share of nuclear power



- 90% renewable
- Nuclear reliant
- Fossil fuel reliant
- Import reliant

Timeline of price zone RED II grid compliance[1]

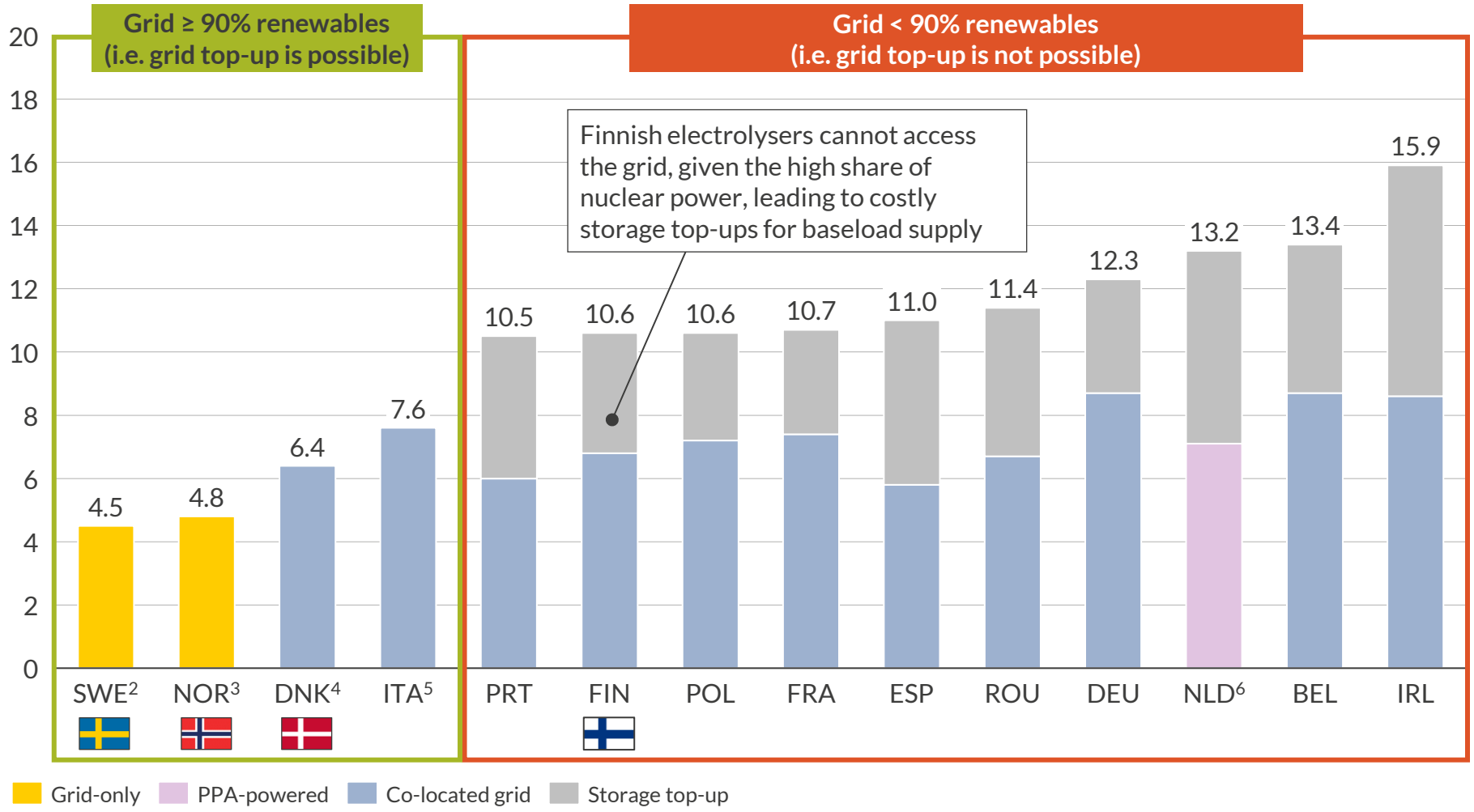


1) While the grid achieves a 90% renewable penetration in the stated year, imports from the grid are considered fully renewable only from the following year as per Article 4 of EU Directive 2023/1184.

Sources: Aurora Energy Research, European Commission

The cheapest European H_2 will stem from electrolysers in Sweden & Norway due to RFNBO-compliant grids and low electricity prices

Levelised cost of variable and baseload hydrogen supply with the cheapest business model (COD 2030, PEM electrolyser)[1]
€/kg H_2 (real 2023)



1) LCOHs are calculated with 10.5% WACC; 2) SE2 LCOHs reported; 3) NO4 LCOHs reported; 4) DK1 LCOHs reported; 5) Italy South LCOHs reported; 6) For the Netherlands and Ireland, offshore wind powering an electrolyser is assumed.
Sources: Aurora Energy Research

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Comments

- Electrolysers' production needs to time-match the renewable electricity input.
- However, renewable electricity is intermittent, while hydrogen off-takers expect a continuous supply.
- The RED II regulation allows grid top-ups in some regions to support continuous hydrogen supply, while others must invest in costly hydrogen storage.

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The Nordics has the potential to export its surplus hydrogen to industrial demand centres in Europe

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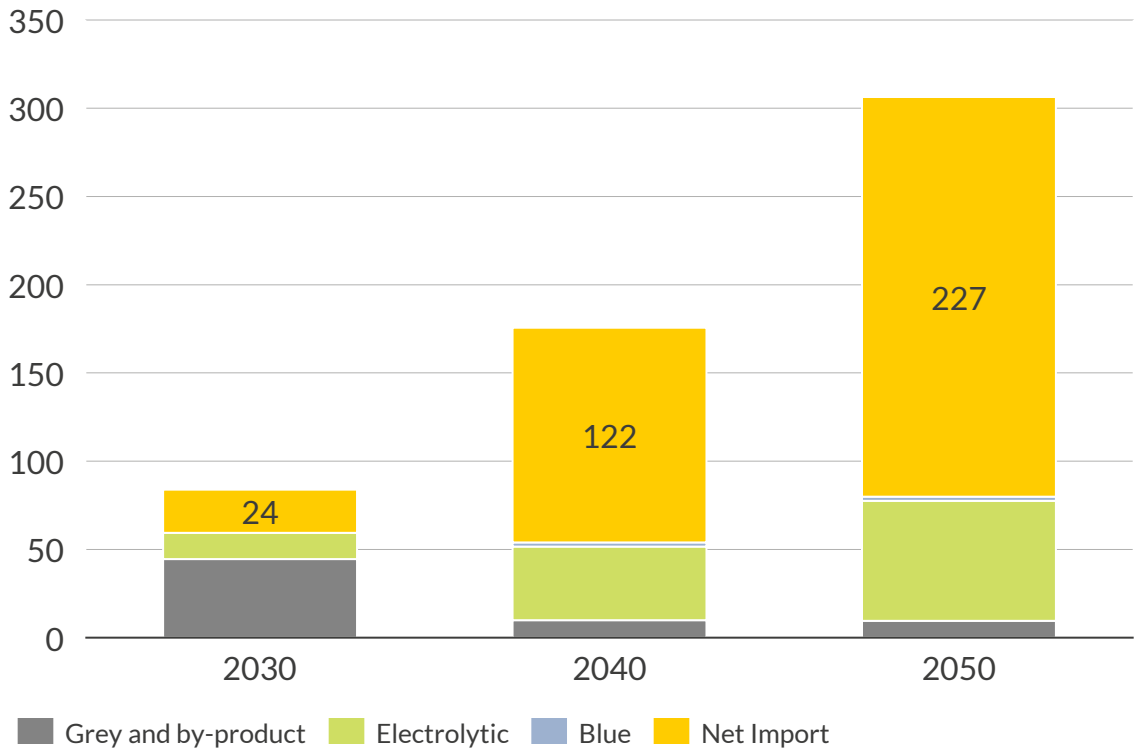
We can identify mainly two types of supply and demand patterns across European countries: net importers and net exporters

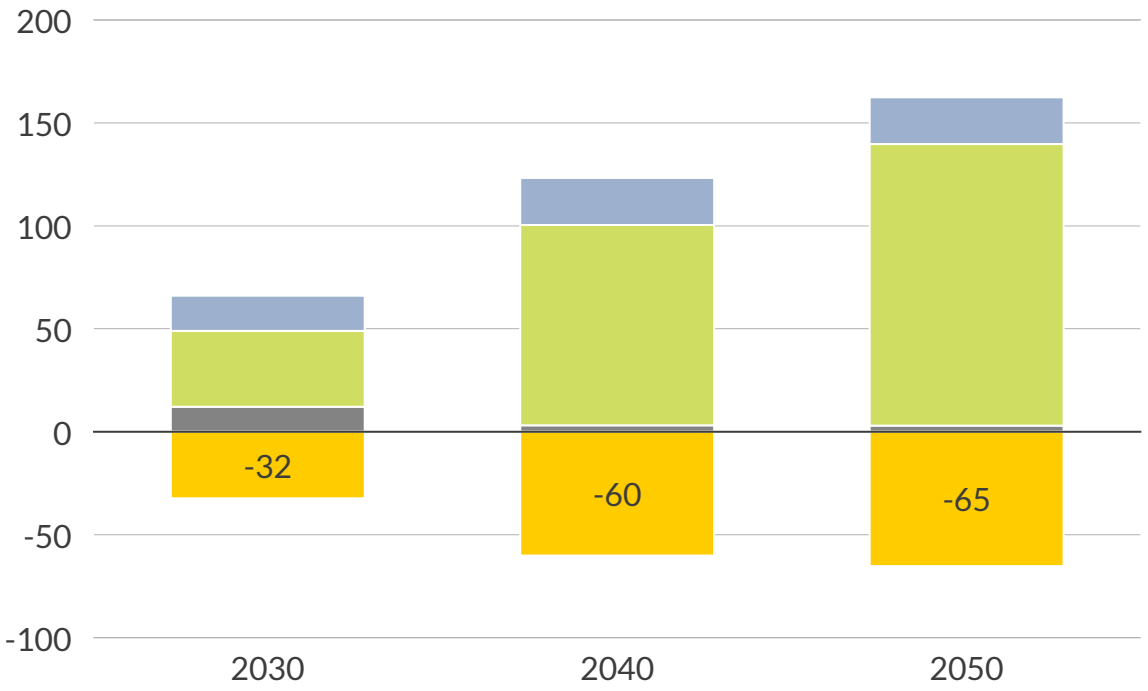
1 Net importers

Hydrogen supply by source, Germany
TWh_{HHV}, final energy consumption



2 Net exporters

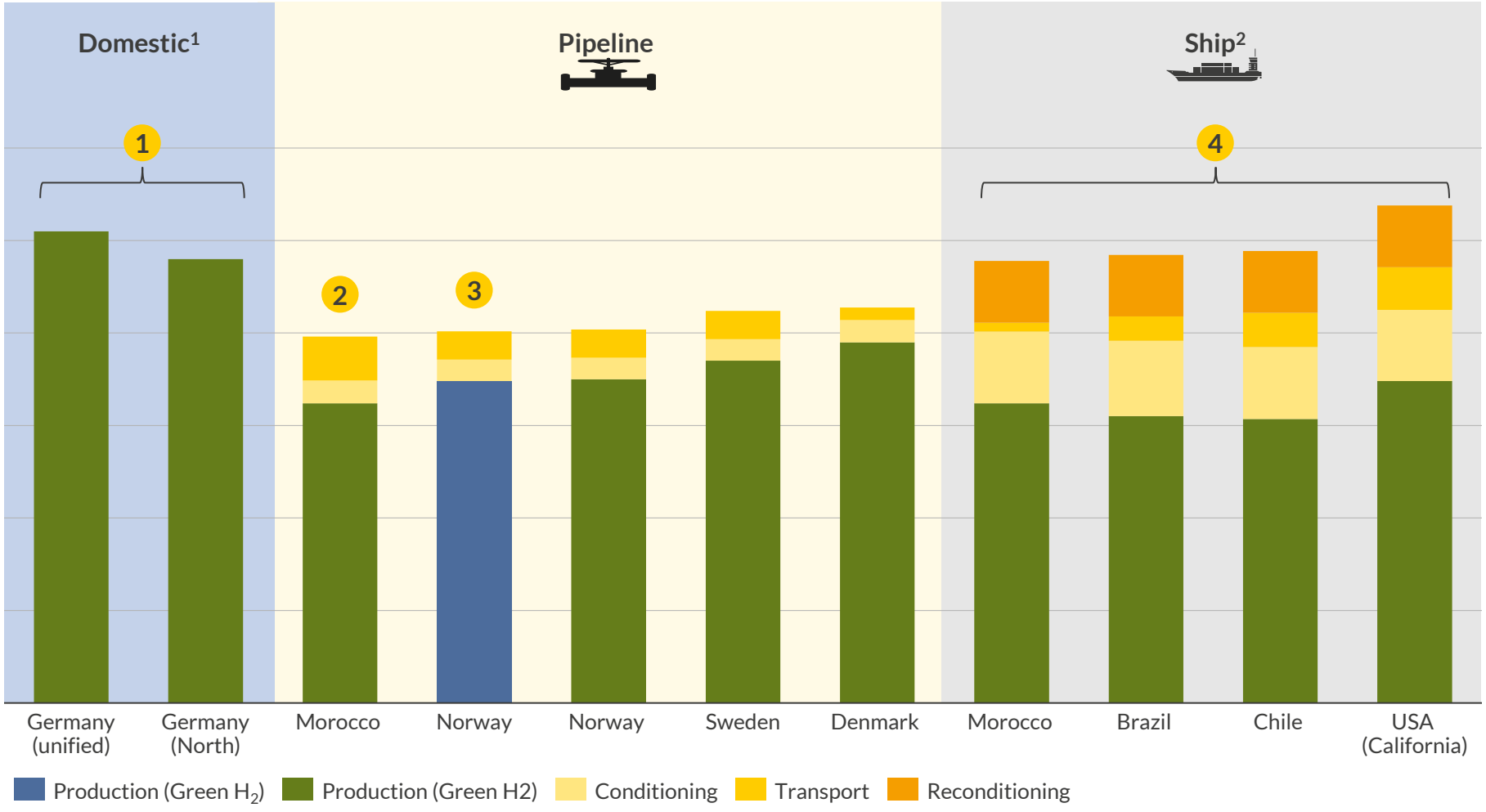
Hydrogen supply by source, Nordics
TWh_{HHV}, final energy consumption



Sources: Aurora Energy Research; European Hydrogen Observatory

Cheap international H_2 and future regulatory changes could lead to an increase in competition for the Nordics' export opportunities

Cheapest available delivered variable LCOH imports to Germany, electrolyser entry year 2040 (illustrative)
€/kg H_2



1) Calculated based on ALK electrolysers; 2) Through Wilhelmshaven.

Sources: Aurora Energy Research

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Cost analysis from 2023

1 Domestic hydrogen production

- A change in bidding zones in Germany **could lead to lower domestic production costs**, reducing the need for imports.

2 Non-EU pipeline imports

- By 2040, **H_2 exports from North African countries** such as Morocco presents the **most competitive option** to Nordic countries' export possibilities.

3 Blue hydrogen

- The EU is **currently promoting green H_2 over blue H_2.** Due to the cheap price of blue H_2, should large volumes of H_2 be needed, a change in regulation could push blue H_2 production over green H_2

4 Non-EU ship imports

- Non-EU sources **remain cost competitive** but other end demand users, such as the transport sector which requires **higher purity requirement**, would result in higher cost after factoring in the purification process needed onsite.

High infrastructure costs, along with recent pipeline delays and cancellations, present risks to the Nordics' capacity to export hydrogen

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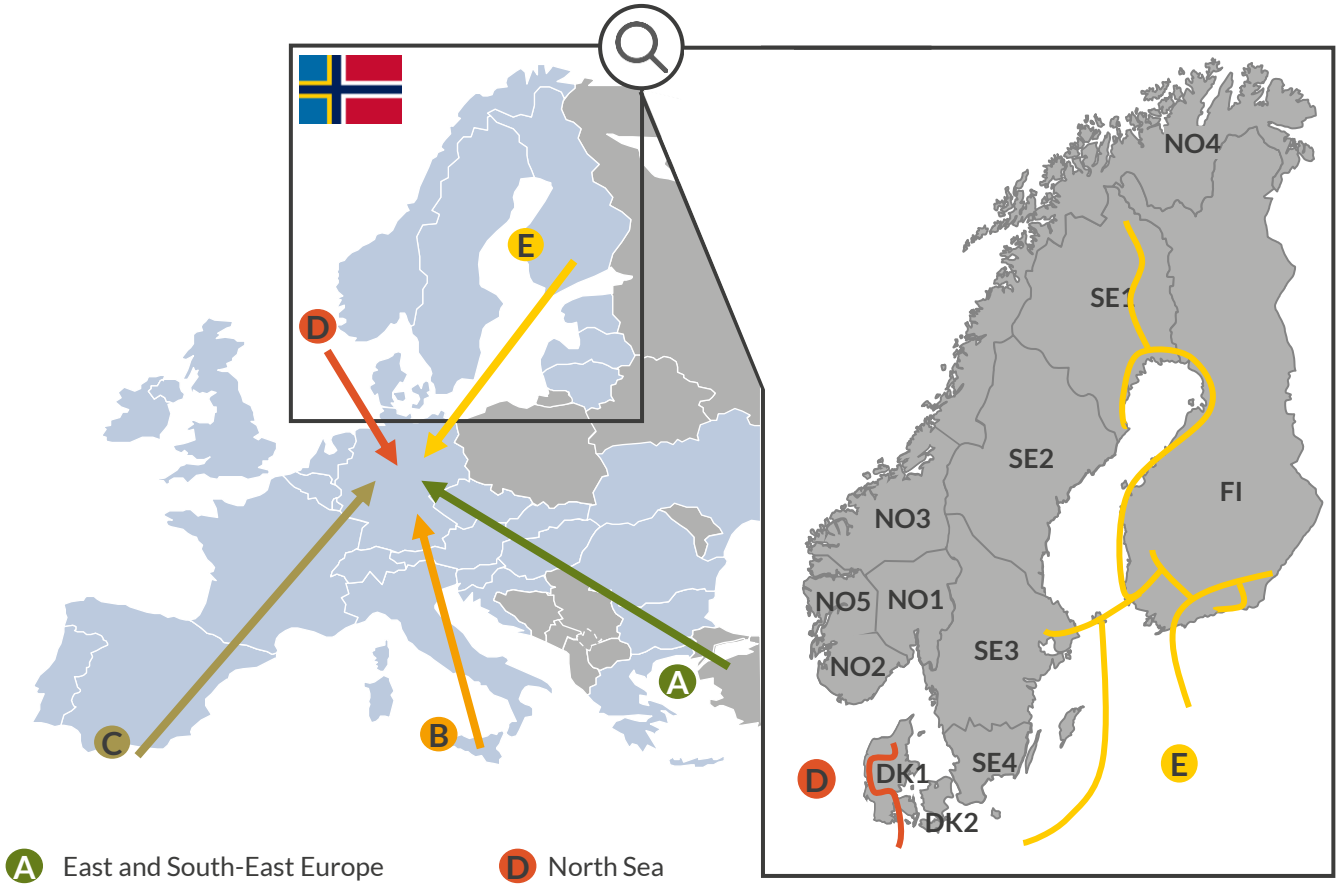
Five supply corridors proposed by the European Hydrogen Backbone



A East and South-East Europe
B North Africa & South Europe
C Southwest Europe & North Africa
D North Sea
E Nordic and Baltic regions

D North Sea supply corridor

- ✚ Close to key demand regions in Northern Europe
  - **November 2024:** Denmark-Netherlands pipeline announced
- ▬ Corridor focuses on blue hydrogen, which has less policy support
- ▬ Pipelines to Germany have recently been cancelled/postponed
  - **September 2024**: Norway-Germany pipeline cancelled
  - **October 2024**: Denmark-Germany pipeline postponed three years (from 2028 to 2031)

E Nordic and Baltic corridor

- ✚ Enables connection to Poland with high potential demand
- ▬ Requires a large number of new hydrogen pipelines, rather than repurposed, which increases costs

✚ Positive factor
▬ Potential uncertainty/risk

Sources: Aurora Energy Research, Montel

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Hydrogen Subscription Services in Europe & APAC

Hydrogen Market Report

Comprehensive and in-depth analysis of evolving hydrogen market dynamics, the demand outlook, policy and regulatory environment, and impact on electrolyser investment economics

Global Electrolyser Database

Regularly updated database, profiling over 1,300 GW of planned electrolyser capacity

Electrolyser business case modelling

Hydrogen production economics (LCOH) under a range of business models, fundamentals-based benchmarking for bilateral hydrogen purchase agreements & offtaker willingness to pay, and long-term hydrogen prices

Policy updates

Regular updates on European Hydrogen policy developments and incentive schemes

Group meetings

Round table discussions with developers, investors and policymakers, with presentations of the latest Aurora analysis

Consulting Project Themes

Transaction support and lenders market advisory due diligence

Market reports, reviews of vendor materials, tailored analysis and Q&A support throughout your transaction or financing

Power sourcing strategy and electrolyser dispatch analysis

Assessments of power sourcing strategies and compliance with regulatory requirements, PPA costs, and impact on costs and volumes of hydrogen produced

Asset analysis: Hydrogen to power

Modelling of CCGT, peaker & H2 LDES operations and gross margins, reflecting hydrogen costs and subsidies, across power market scenarios

Transport & storage requirements and assessments

Assessment of demand, prospective tariffs, and competition for planned pipelines; sizing of storage requirements

Strategy development

Assessments of market size, growth, competition and economics for your target geography and value chain position