Nordic Energy Research

NORDIC POWER 2X FOR SUSTAINABLE ROAD TRANSPORT

Steering Group meeting 2020-09-02

Nordic P2X

Steering Group meeting #4

Project team

2020-09-02

Nordic P2X for Sustainable Road Transport

- Project scope
- Major results
  - Scenarios
  - Case studies
  - Site ranking analysis
- Conclusions & Policy insights
- Discussion – Feedback on report

Project scope

Identify and rank candidate locations for production of e-fuels for road transport from a Nordic perspective

Time frame: 2025 – 2035 – 2045

Ranking criteria:

- Production cost
- GHG emission reduction potential
- Infrastructure aspects
- Water availability

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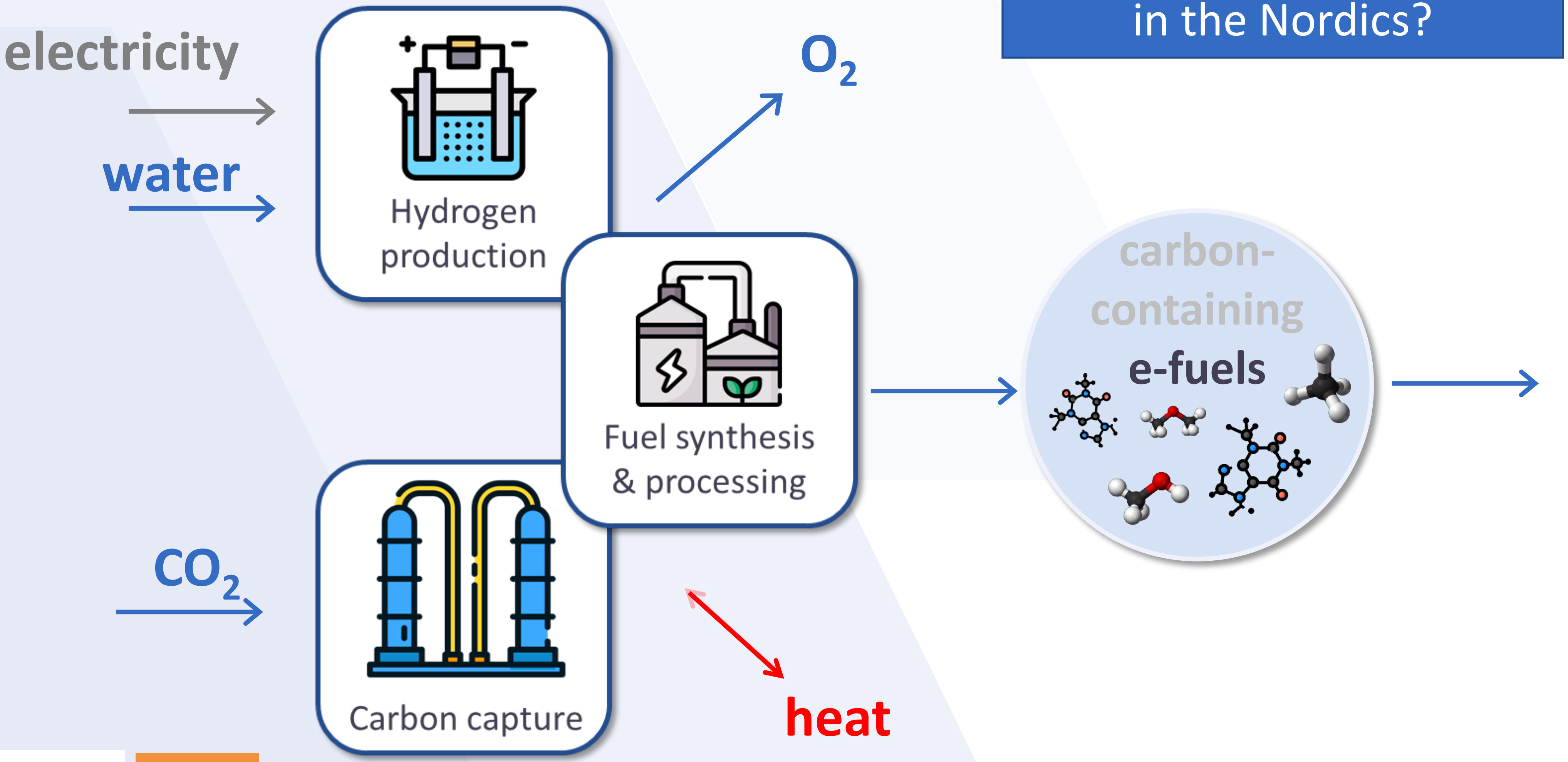
Project scope

Where are optimal locations for such plants in the Nordics?



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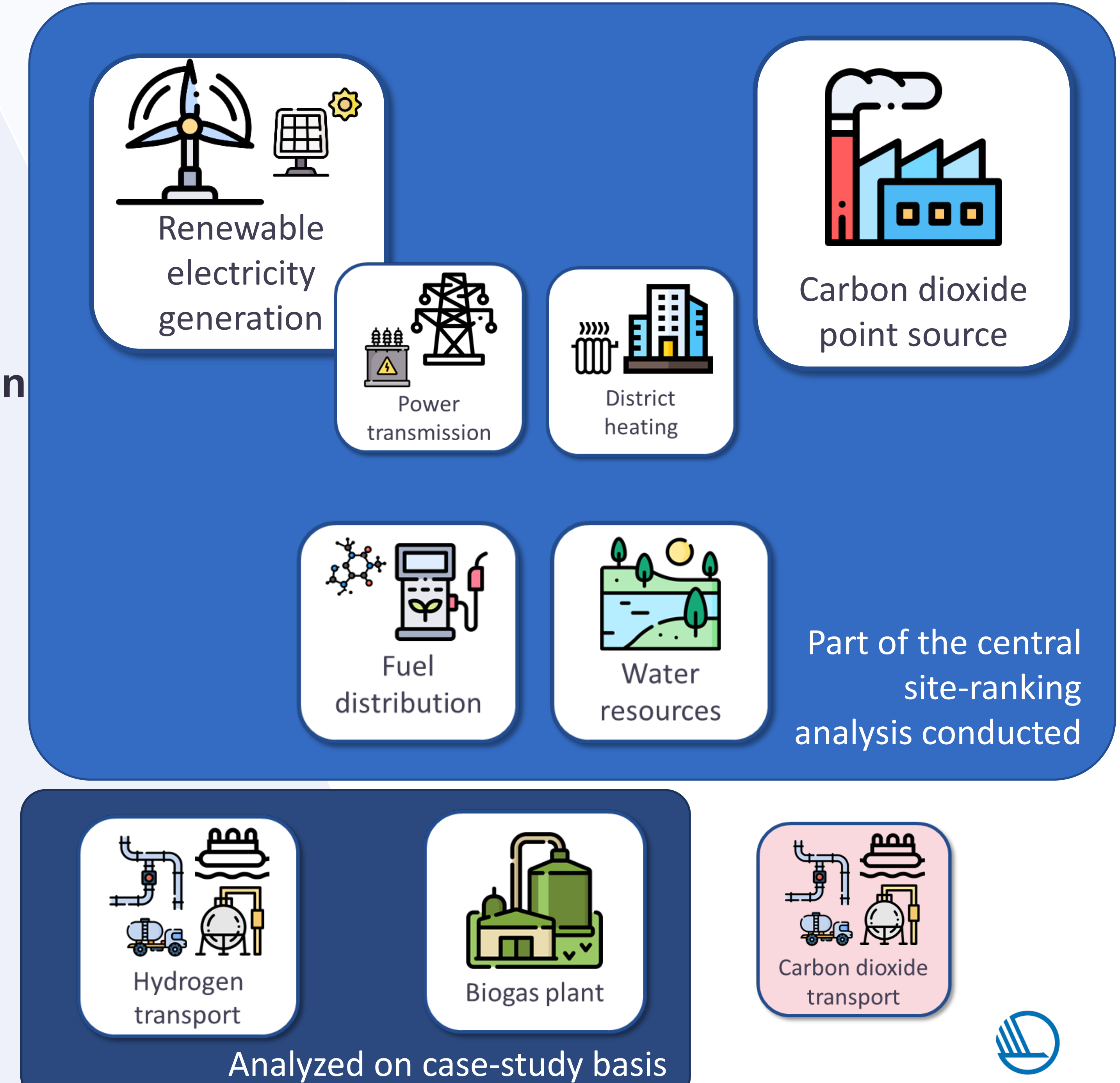
Project scope

What makes a good e-fuel production site?

- Availability and price for renewable electricity
- Offset for by-products
- CO_2 availability
- Fuel infrastructure and market

Other impacting factors

- Transport of H_2/CO_2 vs electricity
- “free” CO_2



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Scope - delimitations

- E-fuels / P2X relates to all energy market segments
  - Materials
  - Fuels
  - Energy storage
- Industrial decarbonization/electrification
- Hydrogen economy/infrastructure
- CCU/CCS – CO_2 transport infrastructure
- National/EU policies

E-fuel uptake scenarios

Discussed & accounted for to the largest possible extent but not analyzed in detail

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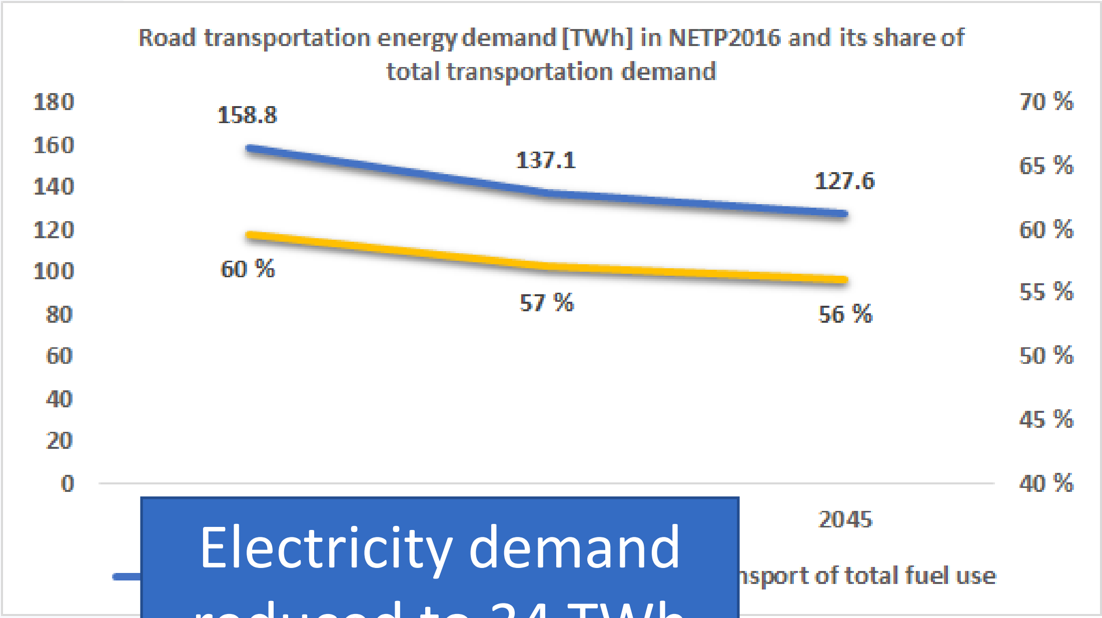
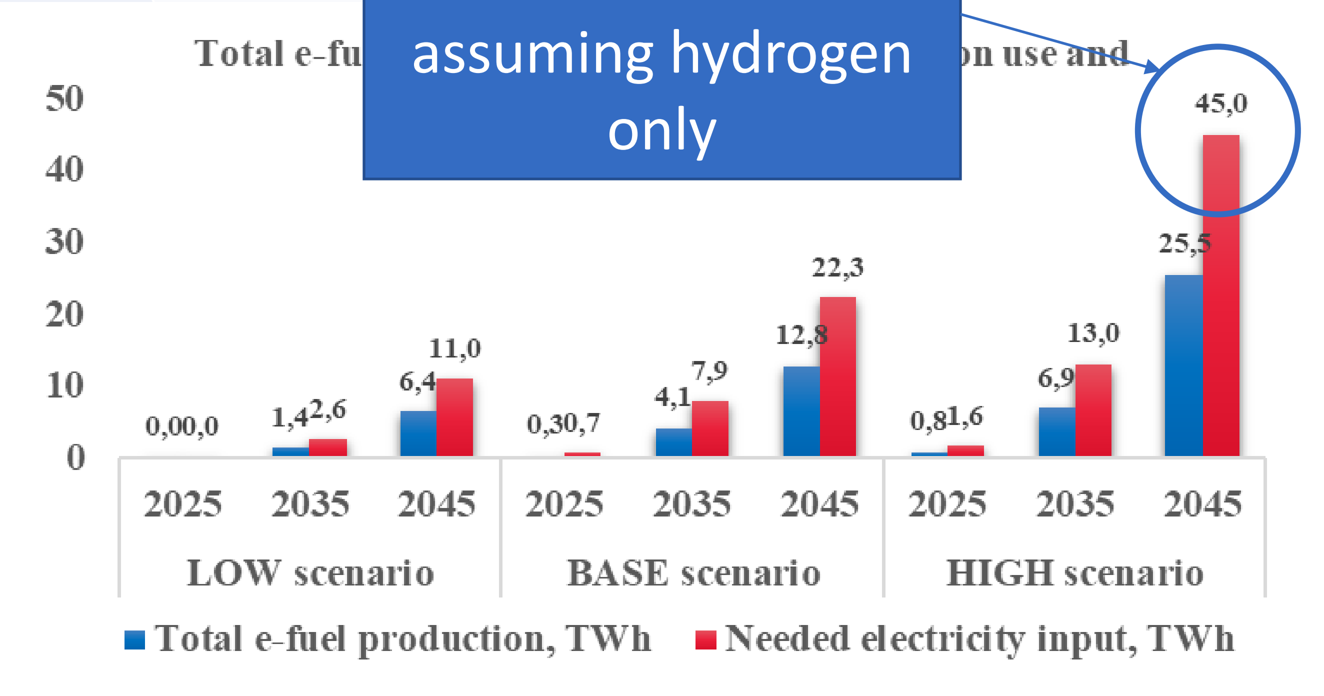
Results - Fuel uptake scenarios

- E-fuel production dependent on market uptake
- Three scenarios based on literature and national roadmaps
- 5 – 10 – 20 % of overall road energy transport (LOW – BASE – HIGH)
- Electricity demand matches predictions of P2X applications according to power market model (26 – 60 TWh_{el})
- Methanol, DME, methane, FT-liquids & hydrogen



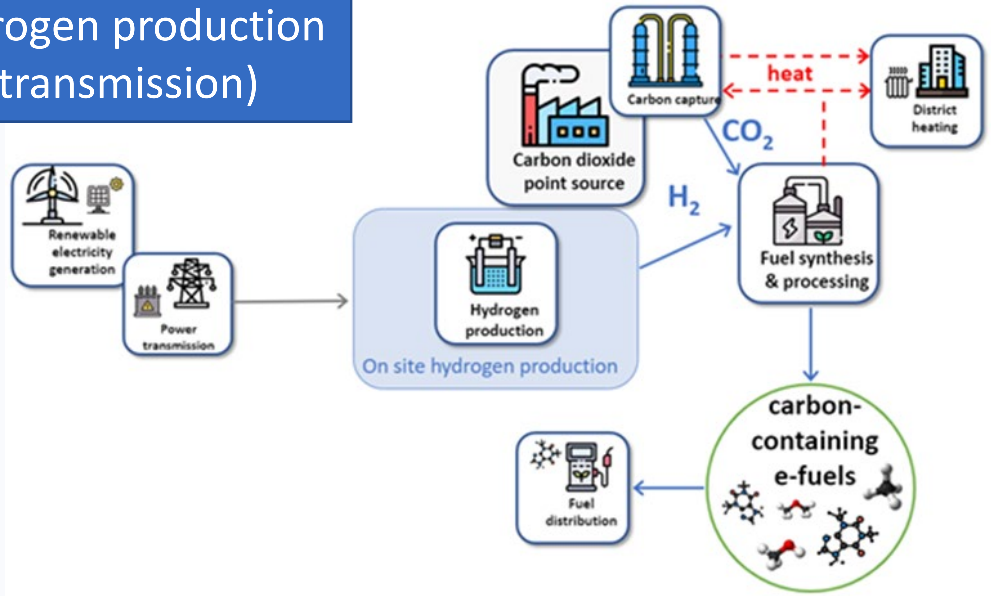


Electricity demand reduced to 34 TWh assuming hydrogen only

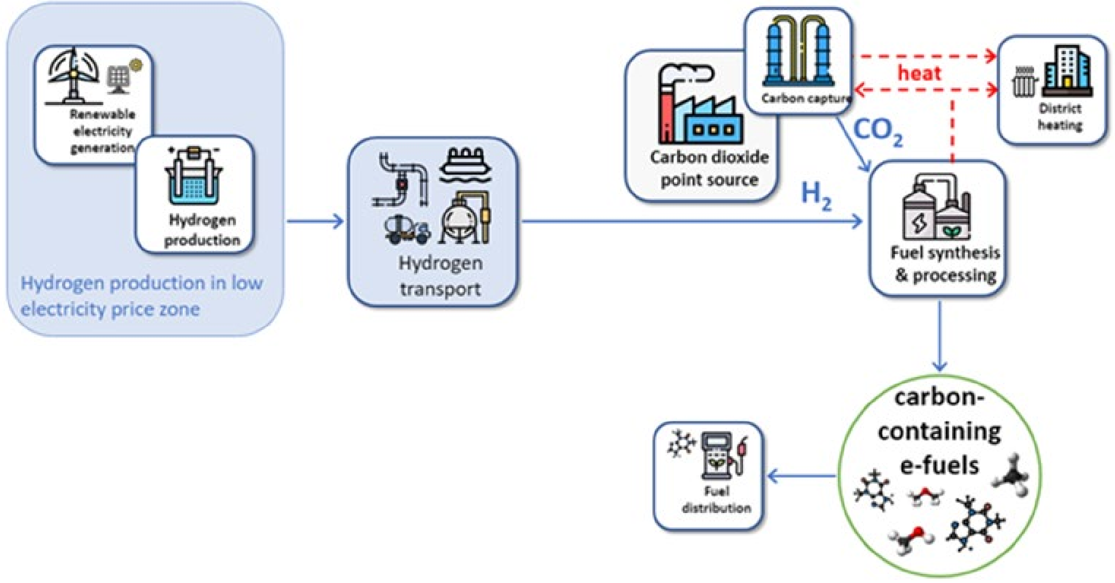
H_2 vs. power transport cost

- 6 case studies related to the location of hydrogen production
- More cost effective to
  - co-locate hydrogen and e-fuel production? *OR*
  - transport hydrogen from a location with low-cost power?

Onsite hydrogen production (power transmission)



Offsite hydrogen production & transport



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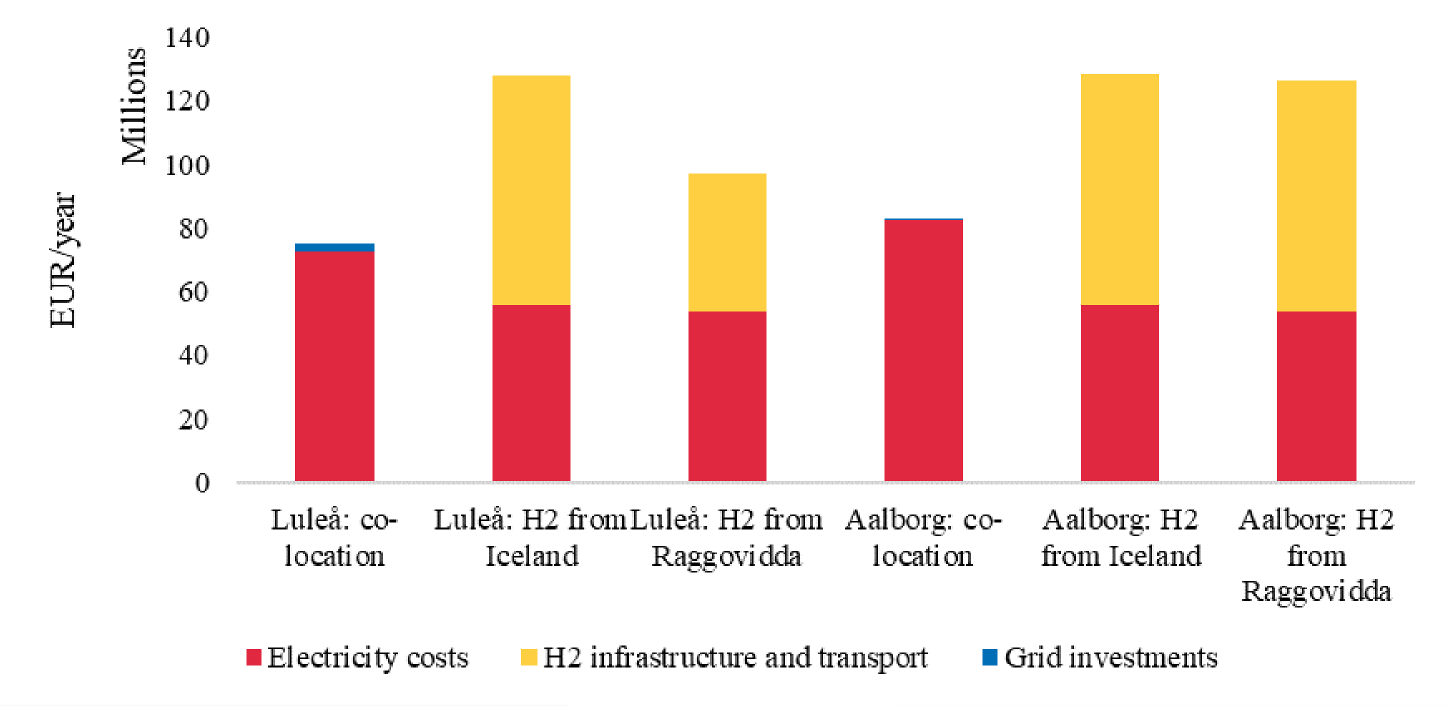
The results suggest that onsite electrolysis has a lower cost across all the cases examined

- Costs of power are not sufficient to justify the costs of constructing the hydrogen transportation infrastructure required for offsite electrolysis

- Future developments might change these conclusions
  - Hydrogen-transport related cost

- Assumes power generation in same price zone => limited investments in network infrastructure

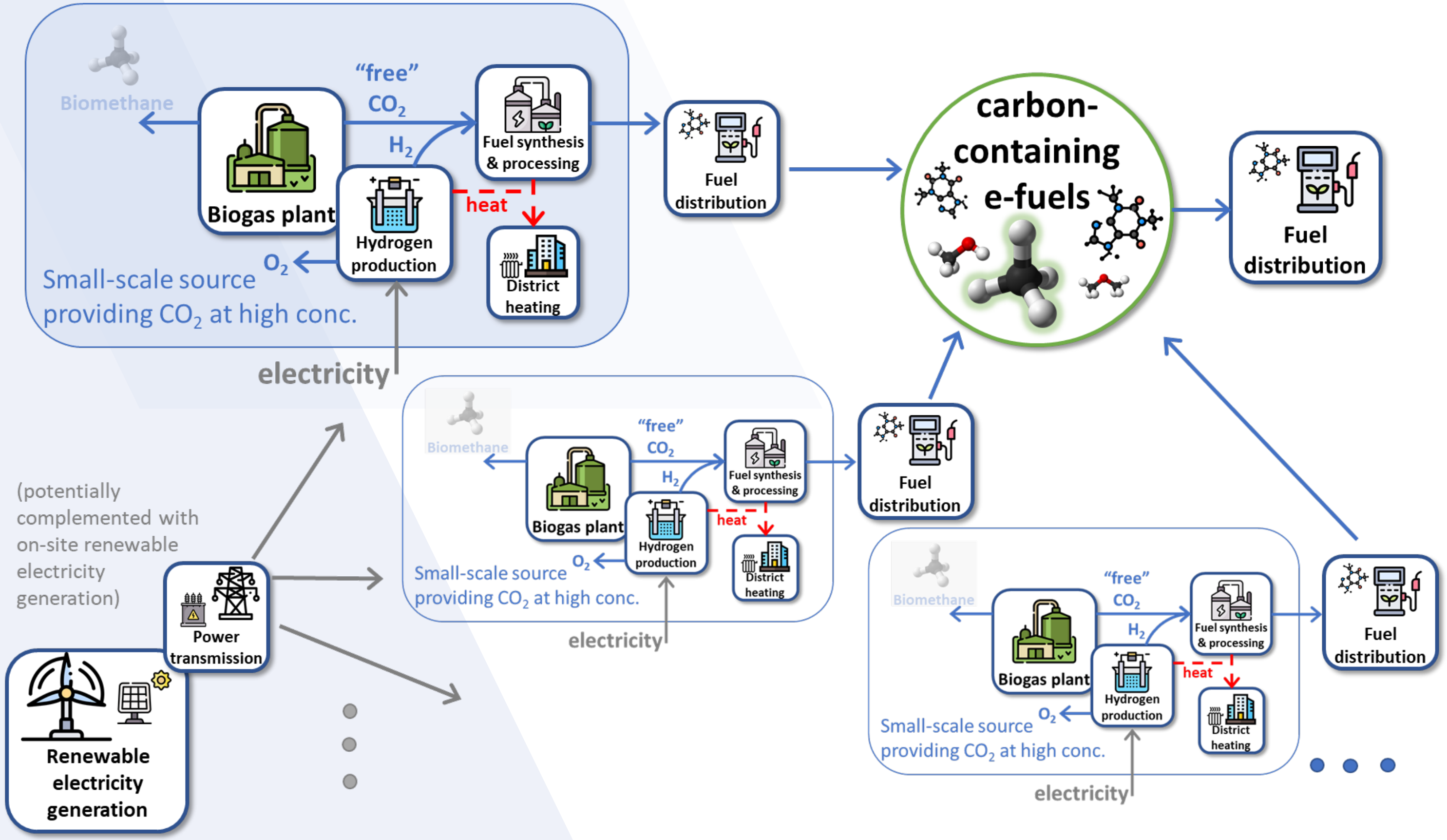
Cost of hydrogen production*



*Only hydrogen production costs illustrated as cost for e-fuel synthesis incl. CO_2 capture same for all cases

E-fuel production based on biogas plants

- Using CO_2 from biogas production -> no cost for CO_2 separation
- Considerably smaller scale than industrial point sources, still large scale biogas (> 50 GWh/yr)
- e-Methane production in Denmark and southern Sweden



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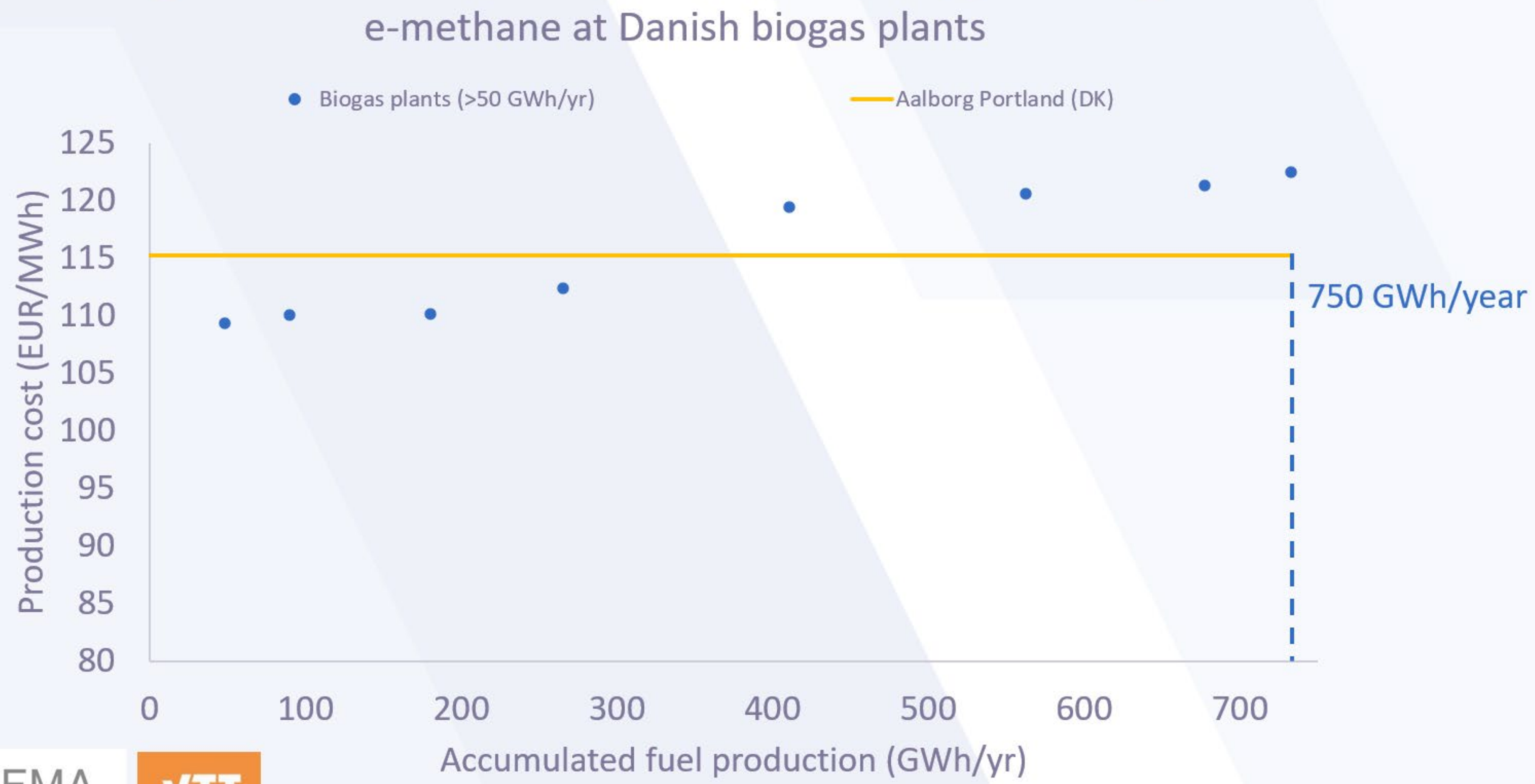
E-fuel production at biogas plants



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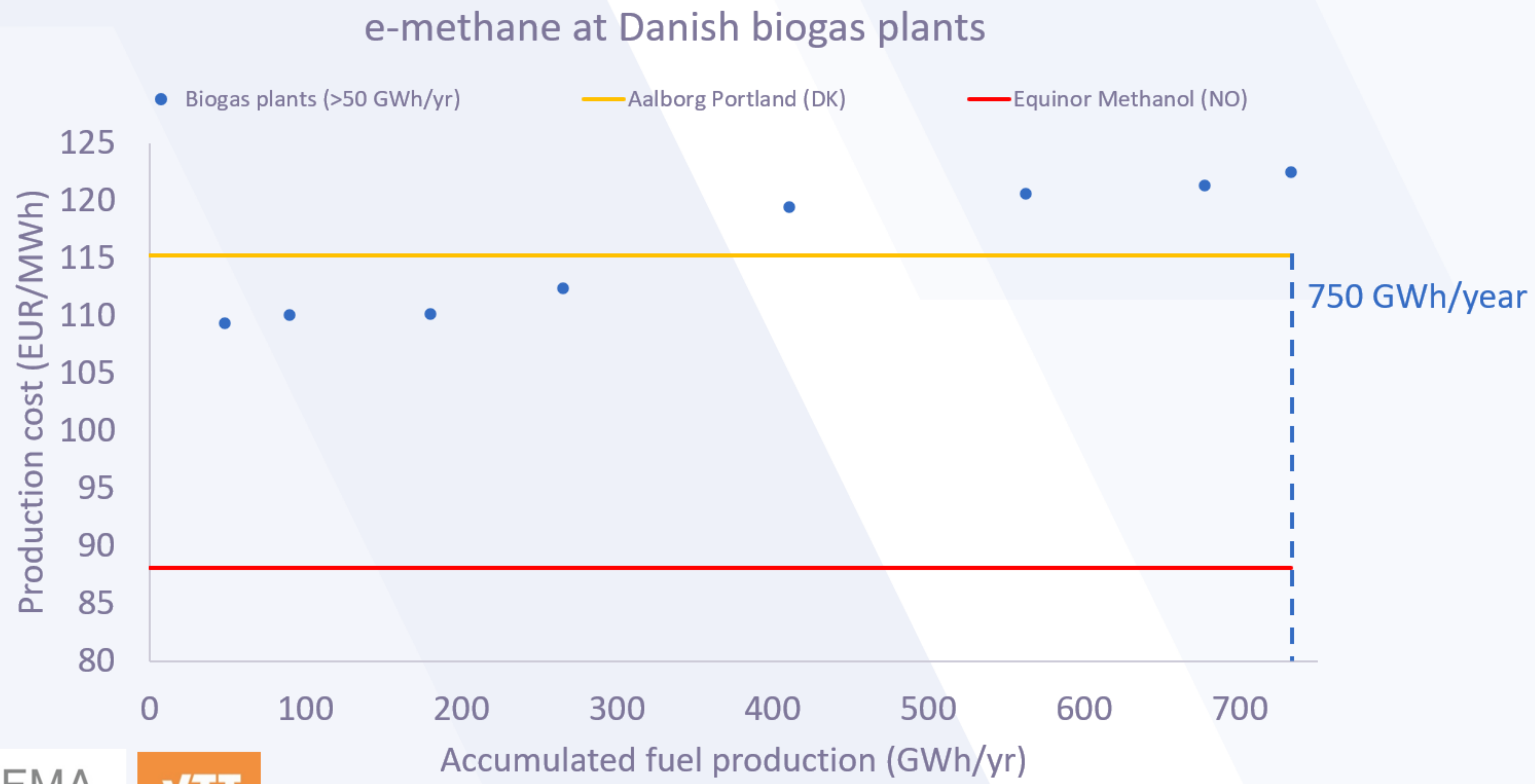

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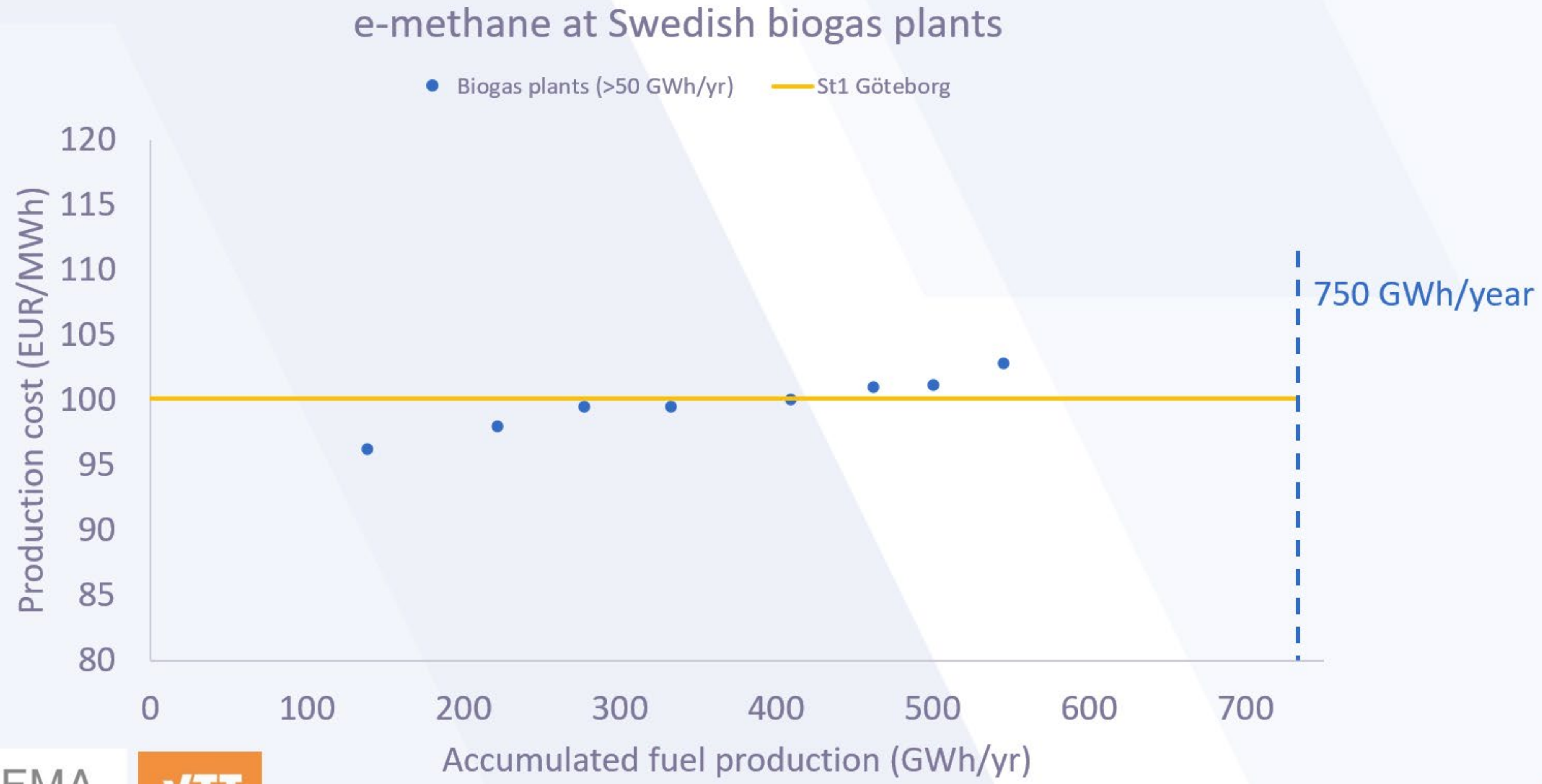

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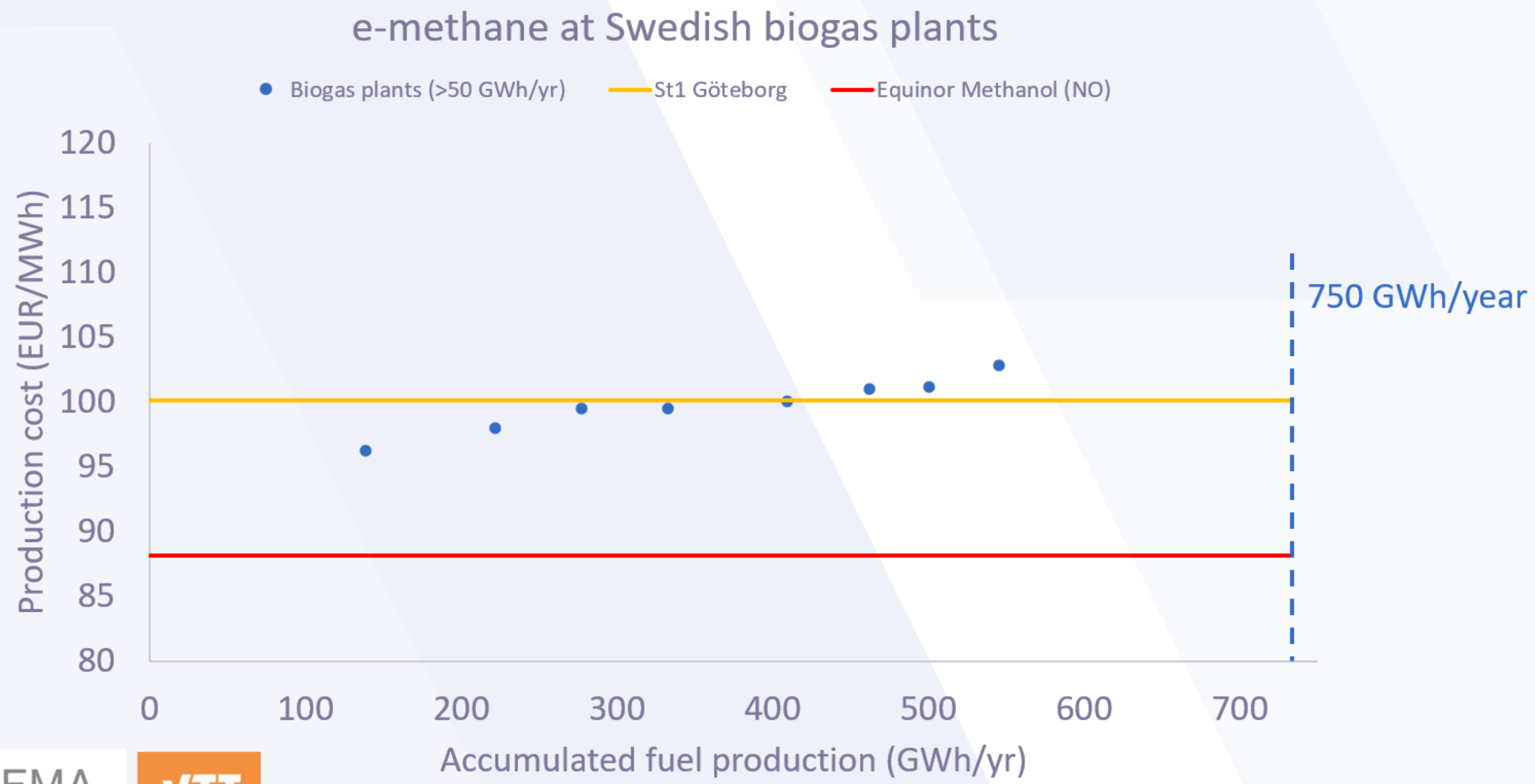


E-fuel production at biogas plants

- Large biogas plants can be cost competitive with industrial point sources in the same power price area

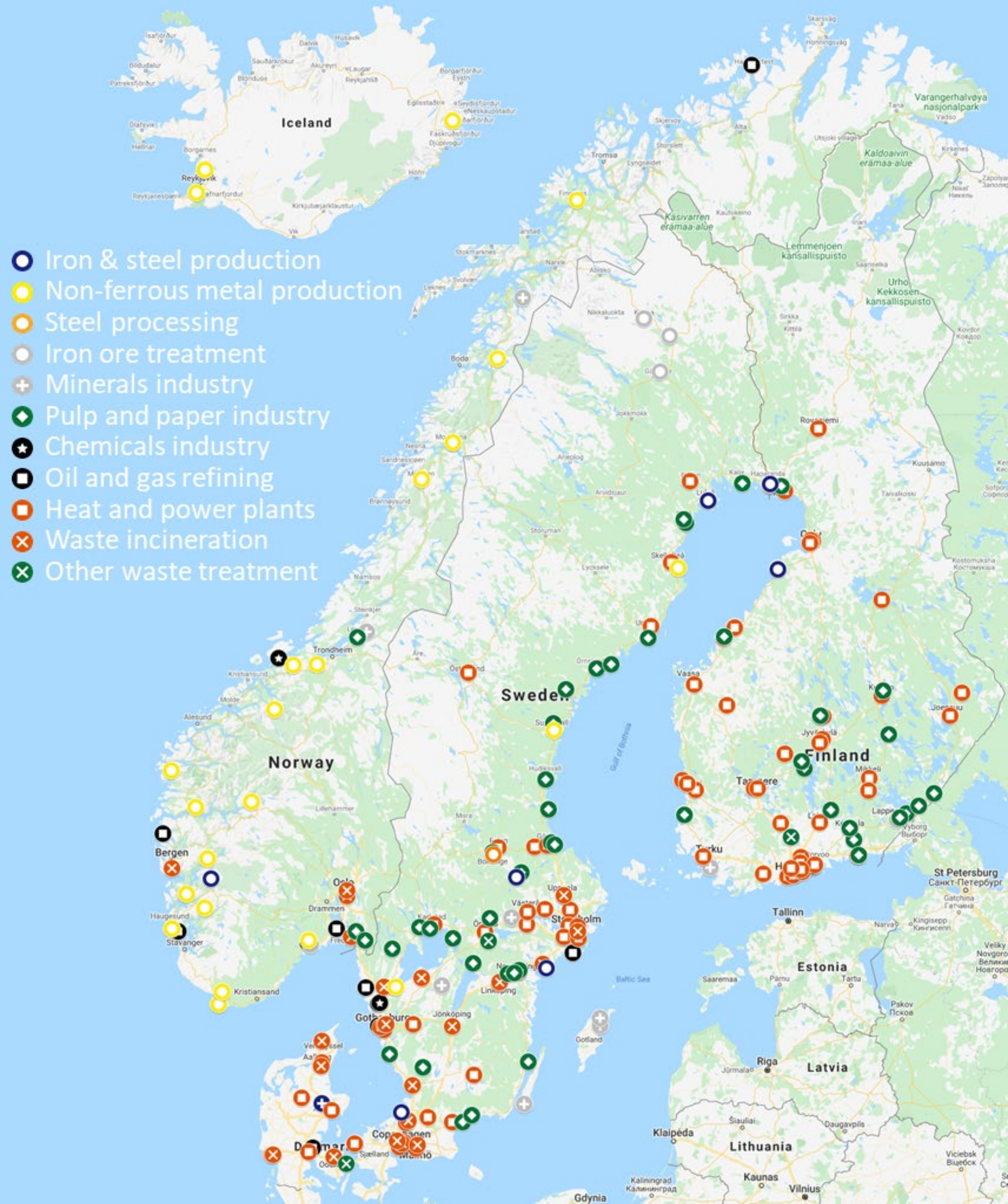
  => makes sense from a national perspective

- But...
  - The volumes that can be produced at low cost are relatively small
  - From a Nordic perspective considerably larger volumes can be produced at lower cost in other regions with lower power price (most biogas plants are in Denmark or southern Sweden)

Site ranking

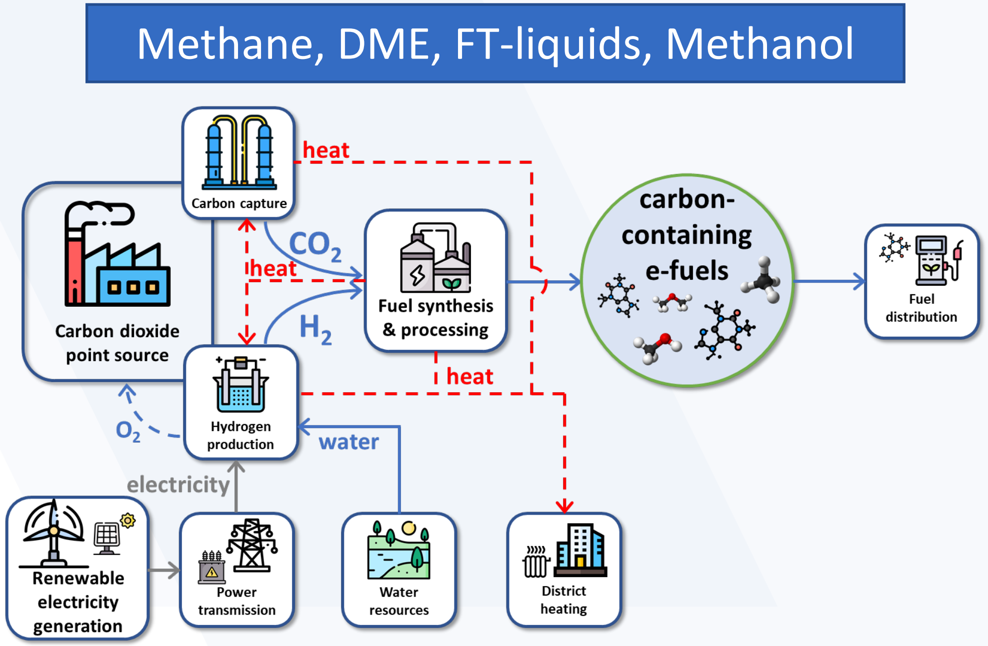
Ranking of sites considering three perspectives

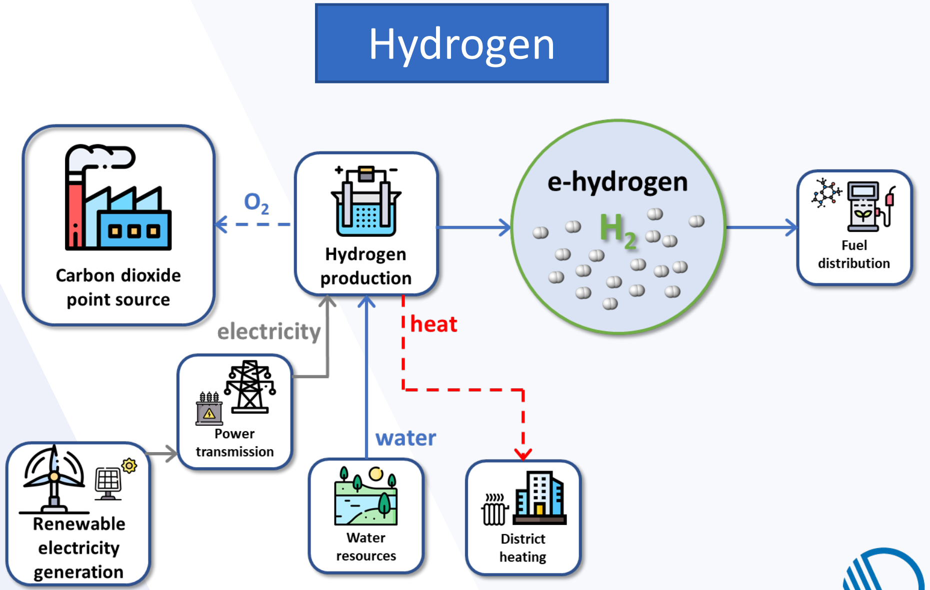
A. Fuel costs
B. Carbon emission reduction
C. Fuel specific infrastructure



Site ranking: production costs

- Fuels: Methane, DME, FT-liquids, Methanol, Hydrogen
- Covers 232 sites emitting more than 100 ktonne CO_2 per year
- Assumptions
  - 80% P2X plant availability
  - P2X plant size limit: 200 MW_{el}
  - **Power supply under PPA-contract**
  - Operation at annual average power price
  - **Increasing electrolyser efficiency: 65 – 70 – 75 %**
- Cost aspects covered
  - CAPEX of electrolyser, carbon capture unit and fuel synthesis plant
  - OPEX: power cost, steam cost for carbon capture, cost of water, O&M
  - Oxygen revenue – limited by on-site demand
  - Heat revenue – limited by district heating demand





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Top 15 – Carbon based fuels

- Based on average production cost using power prices of years 2025/2035/2045
- Site ranking mainly influenced by
  - Power cost (price zone)
  - By-product revenue
  - Plant size (size of CO_2 source)
- Norwegian sites: very low power costs
- Iron and steel, metals
  - Low power costs
  - Large plants
  - Oxygen demand
- Oil refineries
  - Gothenburg – Large potential heat revenue
- Waste incineration
  - Close to DH grids – heat revenue

Site (country)	Industry/activity
Equinor Tjeldbergodden (Norway)	Chemicals (Methanol)
SSAB EMEA AB i Luleå (Sweden)	Iron and steel
Fortum Oslo Varme (Norway)	Waste incineration
Norcem Kjøpsvik (Norway)	Minerals industry (cement)
Elkem Rana AS (Norway)	Non-ferrous metals (FeSi)
Sävenäsverket (Sweden)	Waste incineration
Rönnskärsverken (Sweden)	Non-ferrous metals (Cu (Pb, Zn))
Högdalenverket (Sweden)	Waste incineration
Finnfjord (Norway)	Non-ferrous metals (FeSi)
Hammerfest LNG (Norway)	Natural gas processing
Preemraff Göteborg (Sweden)	Oil and gas refining
St1 Göteborg (Sweden)	Oil and gas refining
Ferroglobe Mangan Norge AS (Norway)	Non-ferrous metals (FeMn)
Haraldrud energigjenvinningsanlegg (Norway)	Waste incineration
Sysavs avfallsförbränningsanläggning (Sweden)	Waste incineration

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N	t)
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R	Pb, Zn))
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St1 Göteborg (Sweden)	Oil and gas refining
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E-fuel production from Top 15 sites
10-11.5 TWh/year
(depending on fuel)

Uptake Scenario BASE (10%) indicates a demand of 12.8 TWh/year in 2045

!!Produced volumes limited by upper size of electrolyzer (200 MW_{el})
CO_2 amounts allow for significantly larger volumes!!

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Top 15 – Hydrogen

- Differs to some extent from carbon-containing fuels
  - Lower by-product generation (heat and O_2) due to higher conversion efficiency from electricity to final fuel, no excess heat from carbon capture

  ⇒ Low power price even more important

  ⇒ Norway (& Northern Sweden) dominant in highly ranked sites

- Given electrolyser size constraint of 200 MW_{el}, the top 15 sites produce roughly 15 TWh/year, exceeding the estimates from the BASE scenario in 2045

Site	Branch	Price area	H2 rank
Equinor Tjeldbergodden	Chemicals (Methanol)	NO3	1
SSAB EMEA AB i Luleå	Iron and steel	SE1	2
Rönnskärsverken	Non-ferrous metals (Cu (Pb, Zn))	SE1	3
NORETYL AS	Chemicals (olefins and VCM)	NO2	4
Ferroglobe Mangan Norge AS	Non-ferrous metals (FeMn)	NO4	5
Alcoa Mosjøen	Non-ferrous metals (Al)	NO4	6
Norcem Kjøpsvik	Minerals industry (cement)	NO4	7
Elkem Rana AS	Non-ferrous metals (FeSi)	NO4	7
Elkem Salten	Non-ferrous metals (Si)	NO4	7
Finnfjord	Non-ferrous metals (FeSi)	NO4	7
Hammerfest LNG	Natural gas processing	NO4	7
Fortum Oslo Varme	Waste incineration	NO1	12
Haraldrud energigjenvinningsanlegg	Waste inceneration	NO1	12
Hydro Aluminium, Sunndal	Non-ferrous metals (Al)	NO3	14
NorFraKalk	Minerals industry (lime)	NO3	15
Norske Skog Skogn	Pulp and paper industry	NO3	15

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Cost breakdown - example

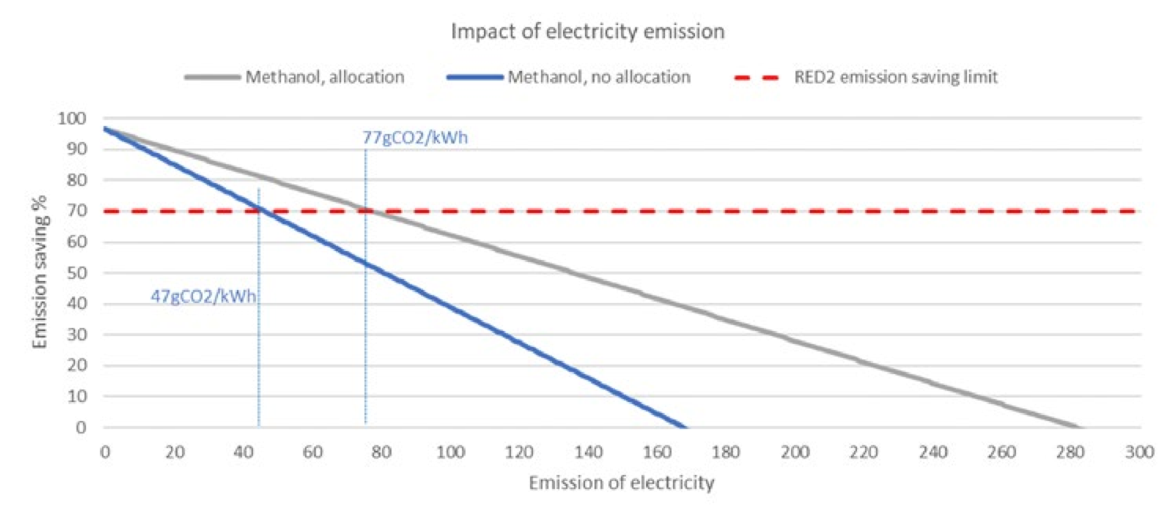
- Methanol production in 2035
  - Cost range 96-147 EUR/MWh
- Most important costs
  - Power
  - Electrolyser CAPEX
- Cost difference breakdown
  - **Total**: 36 EUR/MWh
  - Power: 26 EUR/MWh
  - By-product revenue: 5.4 EUR/MWh
  - Carbon capture: -4.5 EUR/MWh
  - Economy of scale: 7.0 EUR/MWh

National cost rankings

- Available in the report appendix
- Finland: Iron and steel, pulp and paper:
  - Oxygen demand, large scale
- Denmark: waste incineration close to larger cities, Aalborg Portland Cement
  - Potential heat exports, large scale
  - E-fuels from large biogas plants cost-competitive (=> case study!)
- Iceland: only three plants included – aluminum producers

Site-ranking: Greenhouse gas emissions

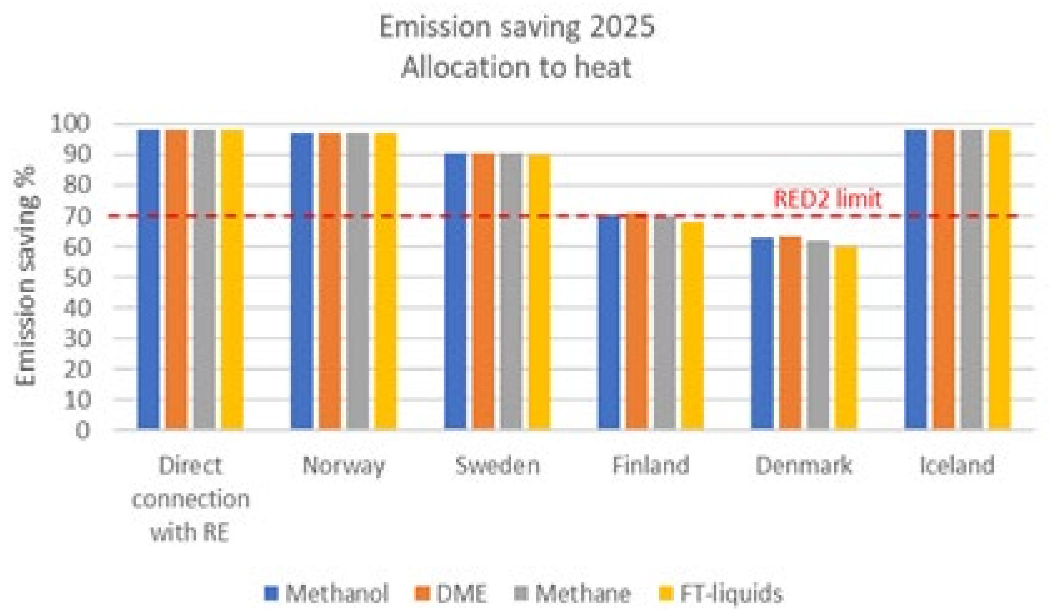
- A delegated act to supplement RED II and to specify the methodology for assessing greenhouse gas emission savings for e- fuels shall be given by 31 December 2021.
- Here GHG emission calculations are based on the current RED II methodology for transport biofuels.
- CO_2 used in the process is assumed to have zero emissions.
- Site ranking mainly influenced by:
  - The emission intensity of the electricity in the country
  - The ability to allocate emission to the co- product heat produced in the e-fuel production (need for heat in the region?)

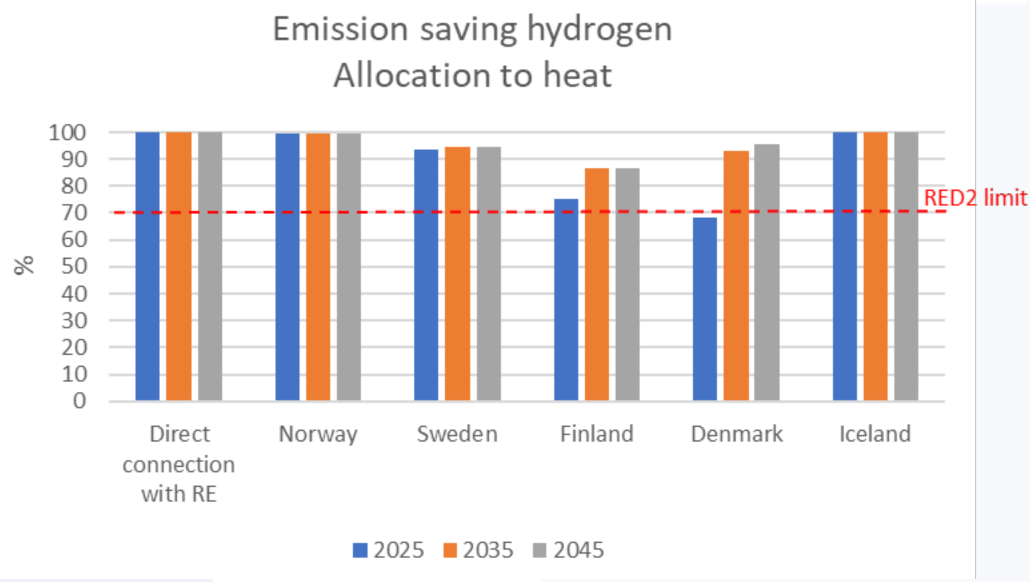


Greenhouse gas emissions ranking

- With **country average emission intensity for electricity**:
  - E-fuels from sites in Iceland, Norway and Sweden pass the 70% emission saving limit of the RED II
  - In 2025, e-fuels from sites in Finland and Denmark rarely pass 70% emission saving, even if emission could be allocated to co-product heat
  - In 2035 and 2045 it is more probable to pass the emission saving limit also in Finland and Denmark
  - H_2 achieves higher GHG emission reductions due to higher WTT efficiency
- With the **PPA scenario**, basically all sites pass the emission saving limit

- More careful LCA studies needed to compare sites in detail





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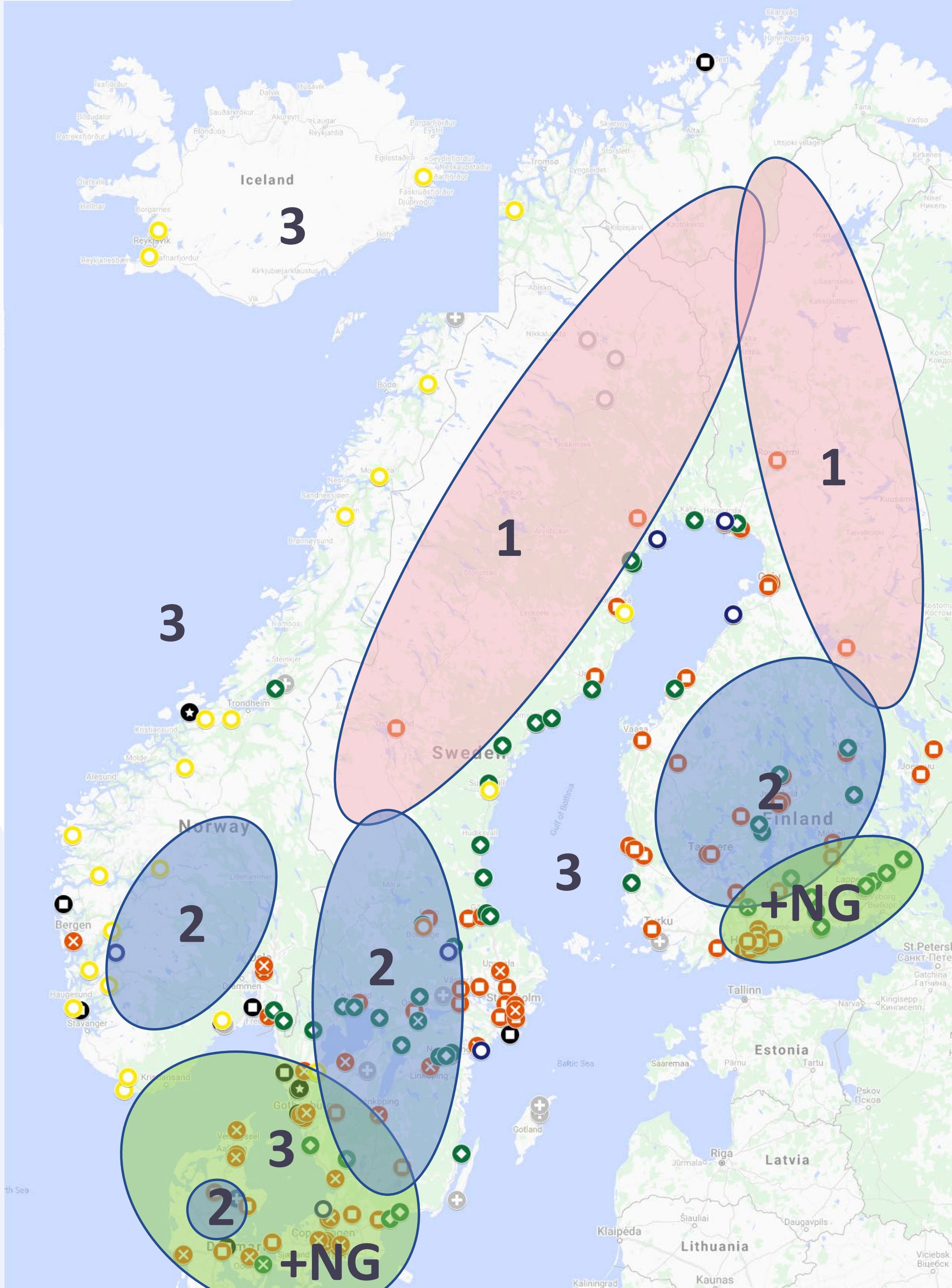
Site-ranking: Infrastructure – fuel distribution infrastructure

Location

- Remote location without harbour – 1
- Central location without harbour – 2
- North/central location with harbour - 3
- Region with distributed natural gas grid +NG

Fuel

- FT-liquids
- Methanol/DME
- Methane
- H2



Results - infrastructure

Type of e-fuel produced / Site location	E-diesel and e-gasoline	Methanol, DME	Methane	Hydrogen
Northern, inland areas (primarily in north Sweden and Finland)				
Central inland areas, close to fuel demand centers (Denmark, south Norway, Sweden and Finland)				
All coastal locations with a harbour (north and central, all countries)				
Areas with a distributed natural gas/bio-methane grid (primarily Denmark and southwest of Sweden)				

Infrastructure for specific high ranked sites (cost)

- Most sites have a harbour (third row)
- But not all (waste incineration, non-ferrous metal) => placed in top or second row
- Sites in Denmark/south Sweden NOT on list – favourable from infrastructure perspective

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Conclusions & policy insights

- Factors for low e-fuel production cost:
  - Low power price – even more important for H2
  - Potential by-product revenues
  - Larger plant size
  - Co-location with large biogas plants interesting at national level

=> Co-location at ***large-scale CO_2 sites*** in ***low power cost regions*** is deemed to be the ***best near term choice*** to allow ***rapid ramp-up of e-fuel production in the Nordics***

Conclusions & policy insights

- Factors for low GHG emissions from e-fuels (based on current REDII/EU regulation)
  - Renewable electricity production
  - Heat as co-product
  - Source of CO_2 not impacting calculations

=> E-fuels produced in the Nordics (using PPA) **reach RED II requirements of 70% GHG emission** reductions (and more!)

- Bio-based CO_2 sources more relevant/stable in long-term, since fossil energy to be phased out (?)
- Real climate impact of e-fuels – require complete LCA

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Conclusions & policy insights

- Factors for infrastructural advantageous e-fuel distribution
  - Availability of harbour (NG-grid)
  - Drop-in fuel

⇒Possibility to utilize **existing distribution infrastructure** benefits near-term development of e-fuel production

- Build-up of new infrastructure systems need to be analysed from a broader perspective – not only e-fuel for road transport

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Conclusions & policy insights

- Interaction e-fuels ↔ P2X in other sectors ↔ Energy system
  - A more holistic approach is necessary and the results from the present study can feed into such a study
- Infrastructure developments
  - Our assessment is based on the current energy system infrastructure and known near to medium term developments, drastic changes (e.g. H_2/CO_2 infrastructure) might change the conclusions

Conclusions & policy insights

- E-fuel production volumes in line with uptake scenarios
  - 15 top sites produce e-fuel volumes in the range of 10-15 TWh/year (BASE scenario)
  - Volumes function of electrolyzer size (200 MW_{el}), CO_2 available for considerably larger volumes => no dedicated estimation of production volume potential

- E-fuels development at large scale requires
  - Vast investments
  - Large amounts of renewable electricity
  - Parallel evaluation of other measures for low-carbon transport that may be more cost- and resource-efficient

Thanks for today!

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