Renewable hydrogen for Denmark

Ørsted

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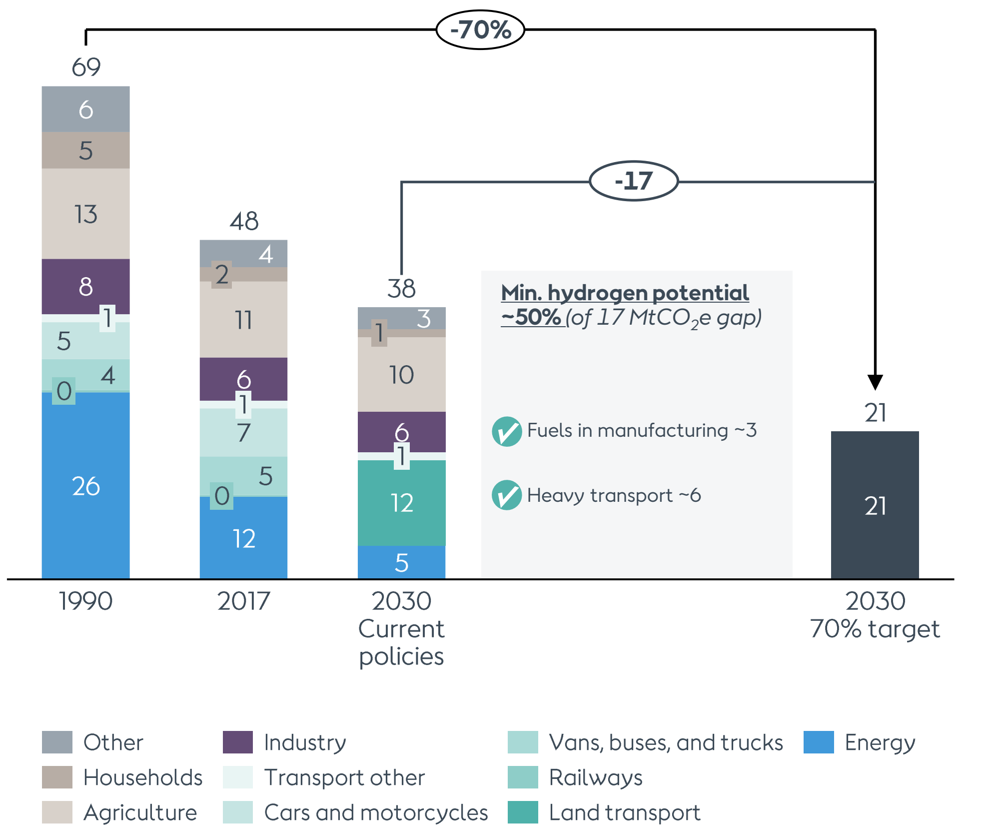
Why renewable hydrogen? Denmark's 70% decarbonisation target

- Current policies and trends are not sufficient to reach the 70% target
- Current policies and trends are not expected to lead to any improvement in the heavy transport sector
- Direct electrification, where possible, is most often the most efficient solution; in harder-to-abate sectors, however, indirect electrification will be needed
  - In those sectors, renewable hydrogen and its derivatives are the most cost-efficient solution for *at least* 9 $MtCO_2e$ by 2030[1], with additional potential applications towards 2050
  - This would all be new hydrogen consumption, as today Denmark's hydrogen demand is remarkably low

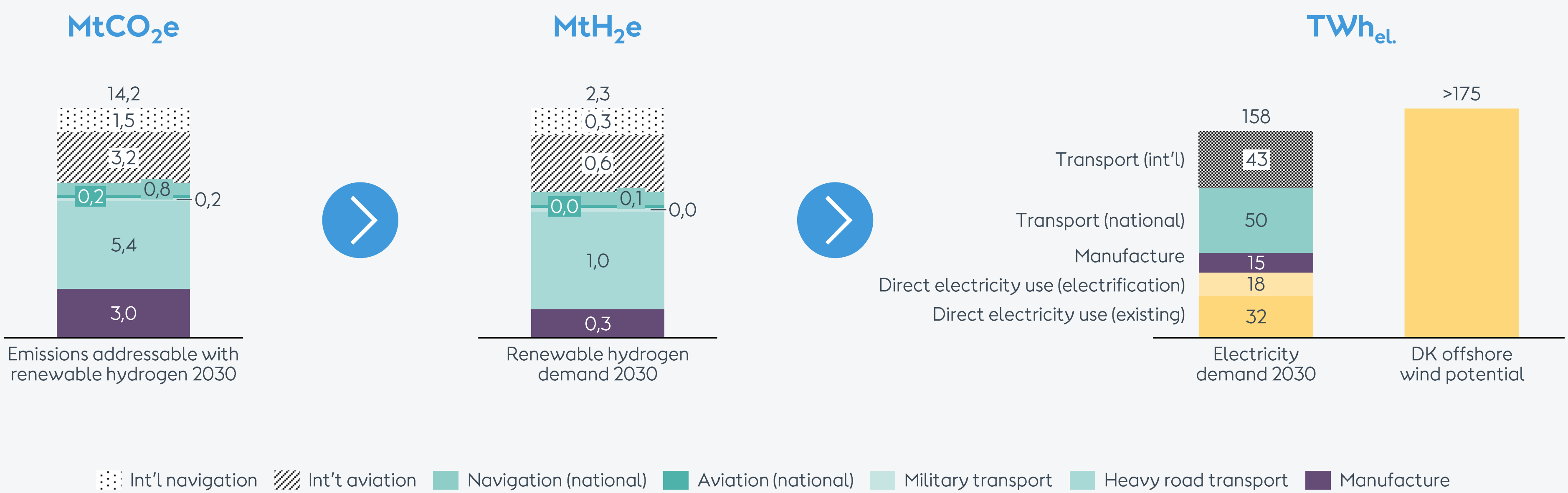
Emissions in Denmark[2], $MtCO_2e$



1. Assuming that light transport will be addressed through direct electrification, rather than hydrogen (although hydrogen could technically also tackle those emissions); additional potential in industry possible but not calculated, i.e. regard the 8 $MtCO_2e$ as a conservative estimate.
2. Source: Energistyrelsen's Basisfremskrivning 2019; and transport modes breakdown from EEA.

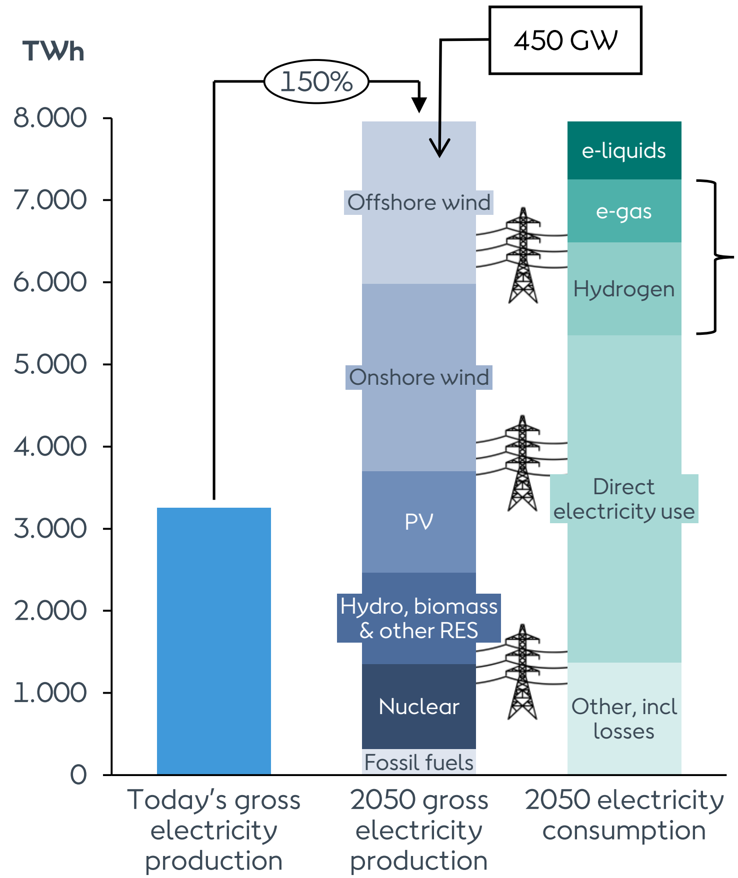
Why renewable hydrogen? Denmark's potential in an international context

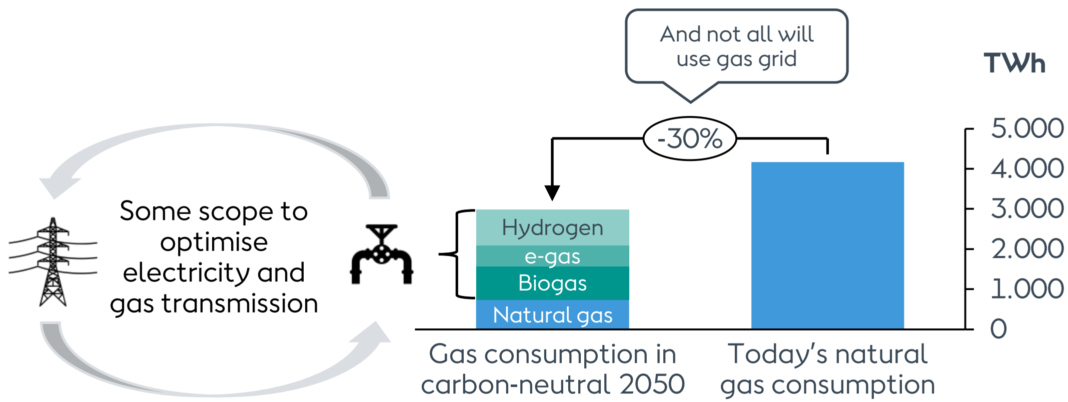
- Towards 2030, renewable hydrogen can address a minimum of 9 $MtCO_2e$ emissions from heavy transport and manufacturing in Denmark
- Additionally, it can address almost 5 $MtCO_2e$ of "exported" emissions from fuelling in Denmark of international aviation and navigation
- This still leaves a significant share of Denmark's offshore wind potential "free" for renewable direct electrification nationally and electricity exports to Europe



Assumptions:
$MtCO_2e$ to MtH_2e: transport factor = 5.55; industry factor = 10.64 (MtH_2e to illustrate hydrogen equivalent; some of it would be on the basis of recycled carbon use)
Electrolyser efficiency = 65%
Direct electricity use figure is a proxy from Energinet's "Systemperspektiv 2035"

Need for PtX in the European energy system: 'direct electrification first'





- EU Roadmap estimates 150% increase in electricity consumption
- Electricity transmission must expand to handle 150% more electricity, including offshore grid for 450 GW offshore wind
- Rethinking needed to reduce additional need for electricity transmission to less than 150% and to bring down cost:
  - ➢ Optimise location and flexibility of new power use
  - ➢ Optimise use of different infrastructure modes (gas vs electricity)
  - ➢ Optimise offshore grid planning with hybrids that combines offshore wind and interconnectors

Source: 1.5Tech scenario from European Commission and own calculations; Own calculation used to convert Mtoe e-liquids, e-gas and hydrogen into electricity consumption, assuming electrolyser with 70% efficiency and 3% losses converting hydrogen to e-gas and e-liquids.

Cost-efficient path: electrification and the case for renewable hydrogen

Direct electrification

The preferred solution where possible:
- Light transport, some heavy duty transport, heating (buildings), industrial heat, etc.

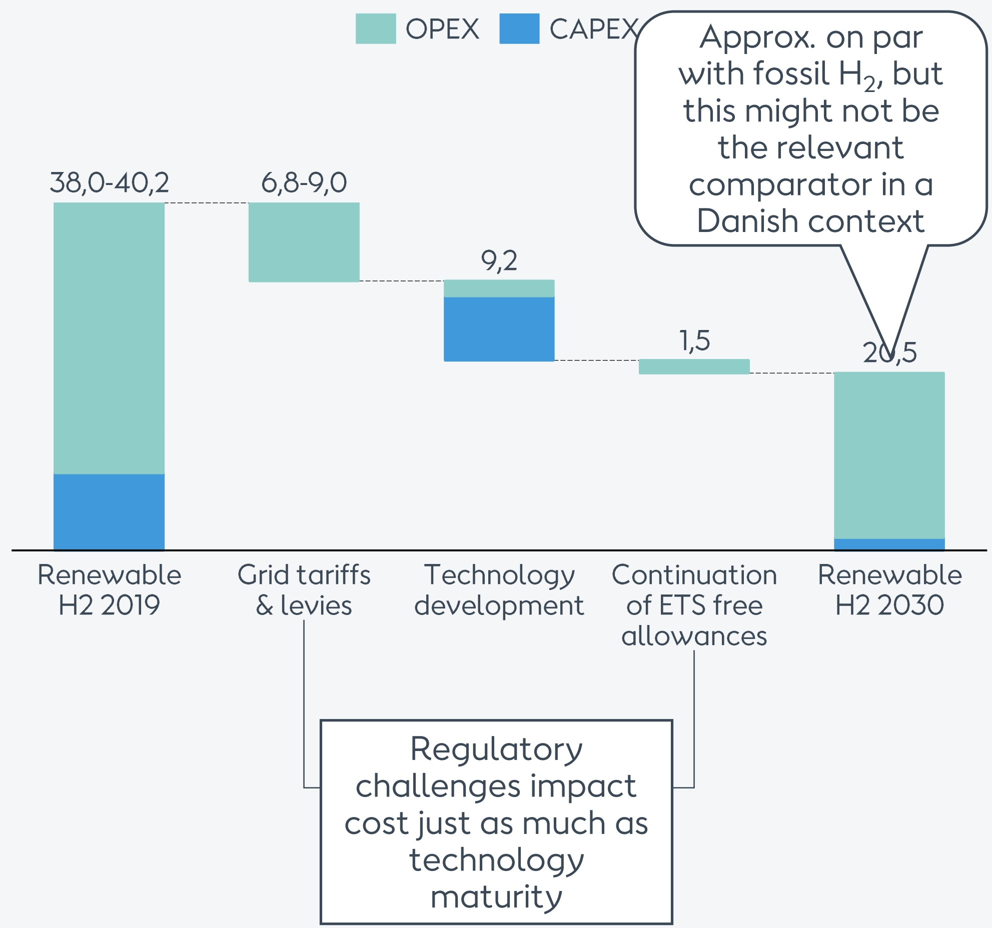
Renewable hydrogen

The solution to replace current fossil hydrogen use and decarbonize some transport applications:
- Process industry (fertilizers, chemicals, refining)
- Heavy transport (busses, local trains, trucks,...)

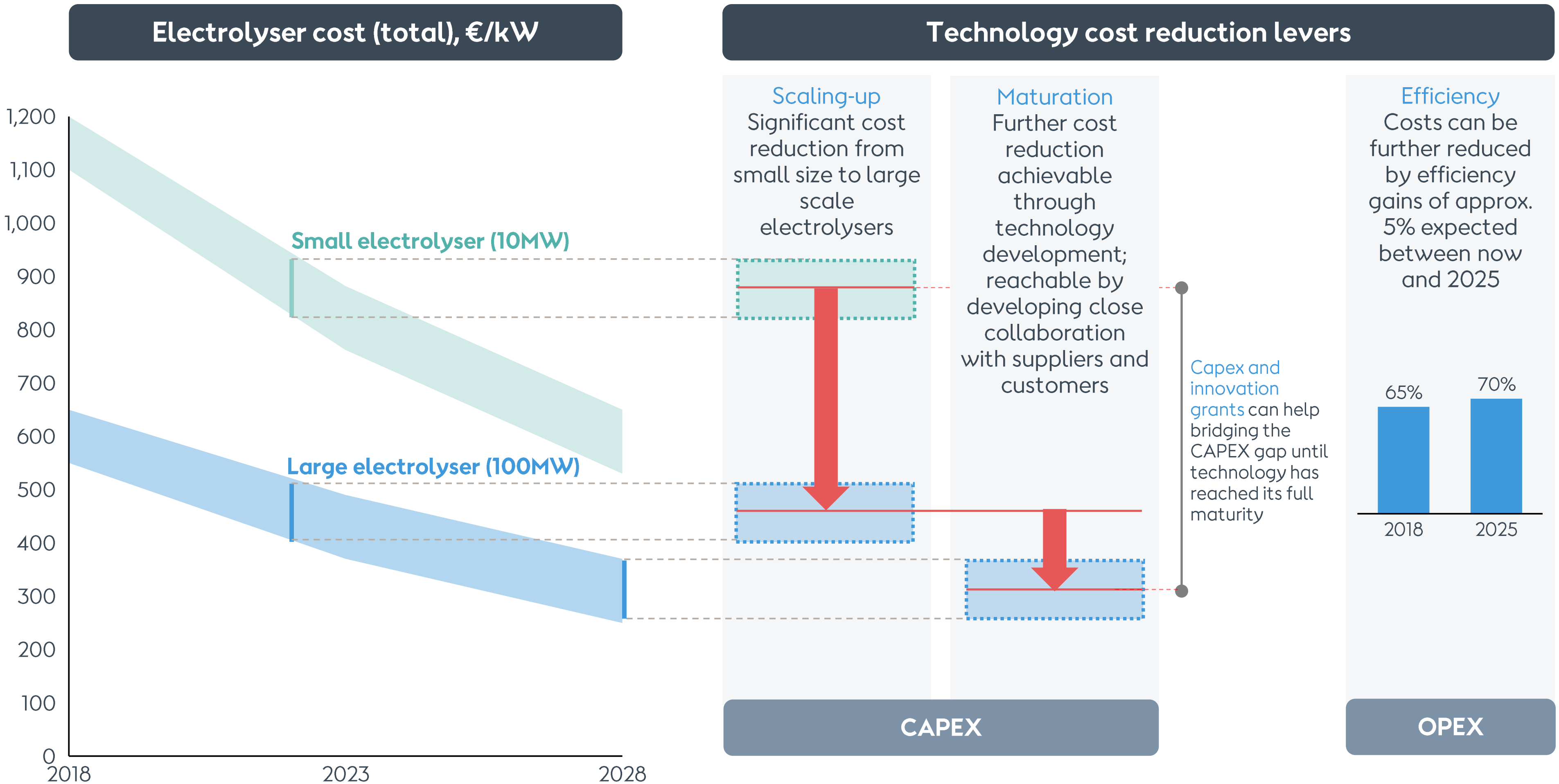
Other zero- or low-carbon fuels

The solution where direct electrification and green hydrogen is difficult:
- E-kerosene for aviation from renewable hydrogen, biogas/biomethane and hydrogen from natural gas with CCS
- Green bunker for shipping (ammonia, methanol etc. from renewable hydrogen)
- Flexible electricity generation, last-mile industrial heat applications, etc.

Renewable H_2 cost development (DKK/kg)



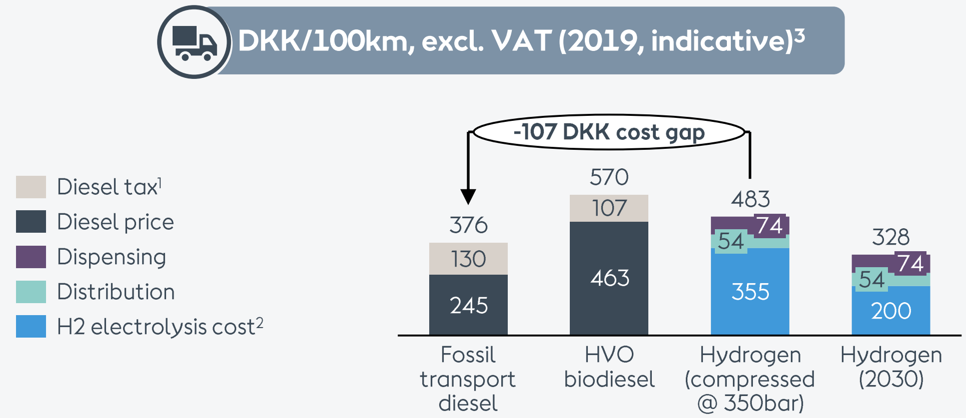
Status of electrolysis: technology cost reductions

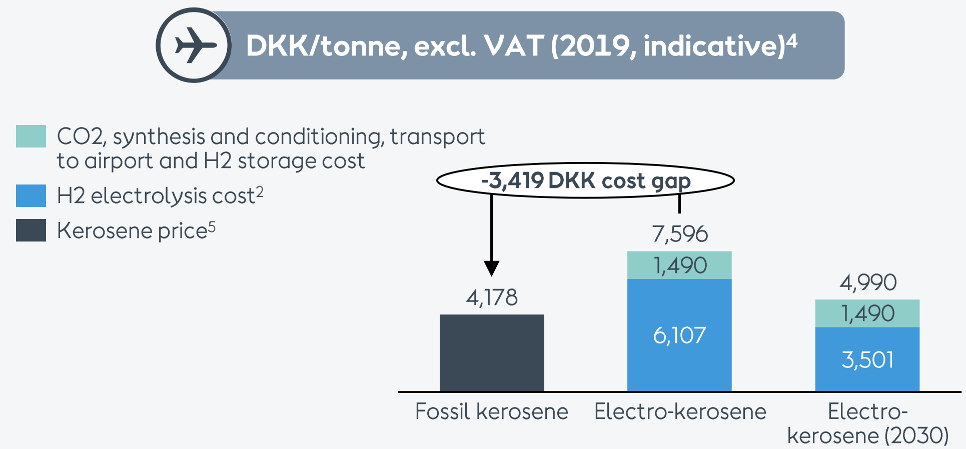


Note: Polymer electrolyte membrane electrolysis technology assumed
Source: IEA, IRENA, FVV, DLR/LBST/Fraunhofer/KBB, Schmidt et al. 2017, Ferrero et al. 2016, Gätz et al. 2016, company presentations, expert interviews BCG analysis

Status of electrolysis: support for deployment and regulatory challenges

1. Support mechanisms should focus on consumption (rather than production) to close the cost gap and ensure offtake
   - Minimal fossil hydrogen production in Denmark today, so it is not about substitution but about new demand
2. Resolve regulatory challenges
   - Cost-reflective tariff structure that creates incentives to locate near renewable electricity generation, to optimise use of offshore wind potential and ensure electrolysers connect to the grid
   - REDII implementation at both national and EU level (delegated acts)
   - Continuation of free EU-ETS allowances, and clarify treatment of recycled carbon (CCU; currently double-counted) under ETS Directive





Source: OK, SKAT, CHIC project, NEL, Morningstar, IBST, IATA, Ørsted analysis 1. Energy tax and CO_2 tax 2. 2MW alkaline electrolyser with 75% HHV efficiency co-located with offshore wind turbines in DK in the year 2019. Capex of EUR 2.3m, expected lifetime of 12 years. And H2 price of 5.3 EUR/kg in 2019 (expected to decrease to 3 EUR/kg in 2030). 3. Direct fuel cost only. Calculation based on bus drivetrain using 9kg H_2/100 km vs. 40.9 l/100km diesel. This is consistent with findings in the CHIC project 4. Cost of CO_2, kerosene synthesis and conditioning, transport to airport and storage cost based on IBST Power-to-liquids report from 2016 with projection for 2050. For the purpose of this analysis it is assumed the price of this will remain relatively unchanged from today 5. Price average for Europe & CIS

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