PUBLIC

Perspectives on renewable hydrogen

FutureGas Annual Meeting

Ørsted

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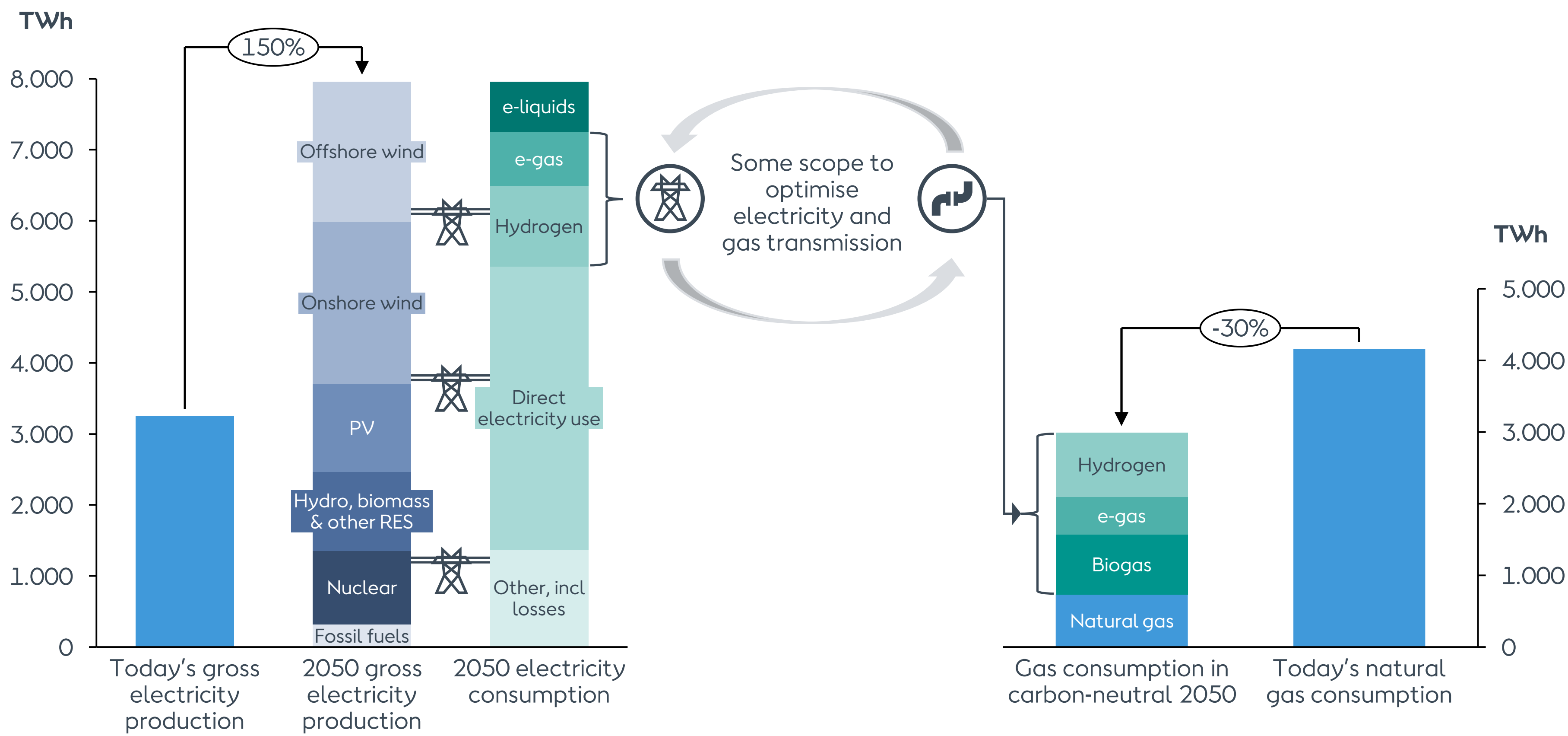
Offshore wind is a cornerstone of European decarbonisation; energy infrastructure will be key

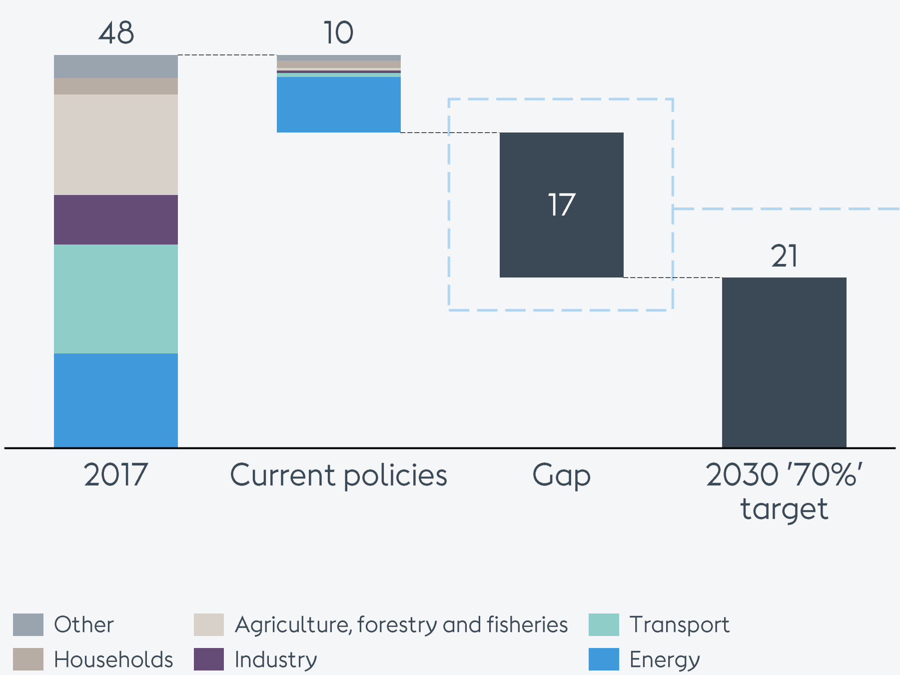


Source: 1.5Tech scenario from European Commission and own calculations
Note 1: Own calculation used to convert Mtoe e-liquids, e-gas and hydrogen into electricity consumption, assuming electrolyser with 70% efficiency and 3% losses converting hydrogen to e-gas and e-liquids.

Rationale for renewable hydrogen in Denmark

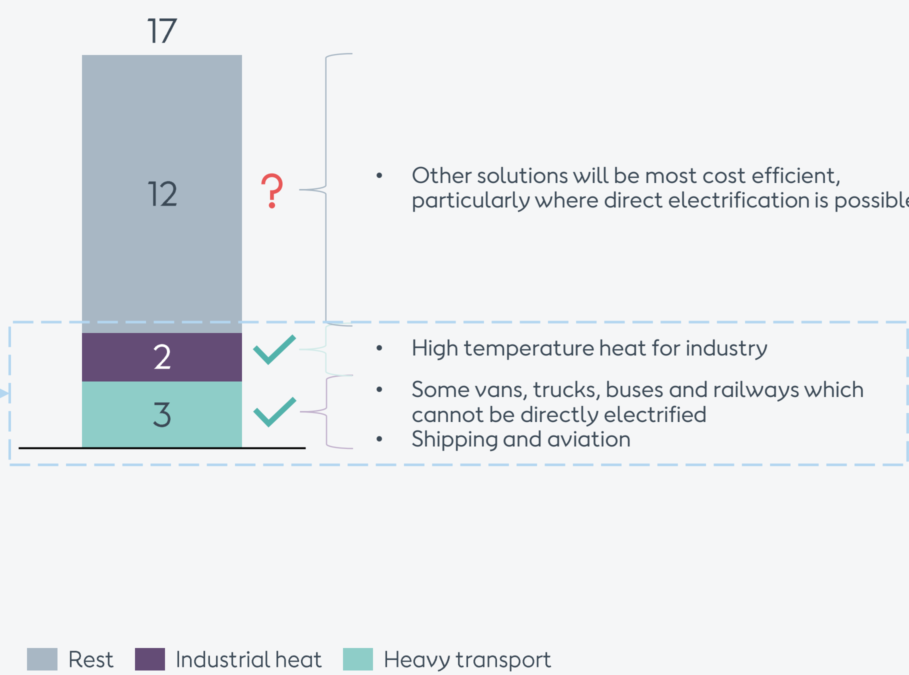
There is a gap towards 2030 targets of 17 $MtCO_2e$ that current policies do not address

$MtCO_2e$



From that gap, 5 $MtCO_2e$ are best addressed with renewable hydrogen

$MtCO_2e$ **Hydrogen application**



 Source: Energistyrelsen's Basisfremskrivning 2019

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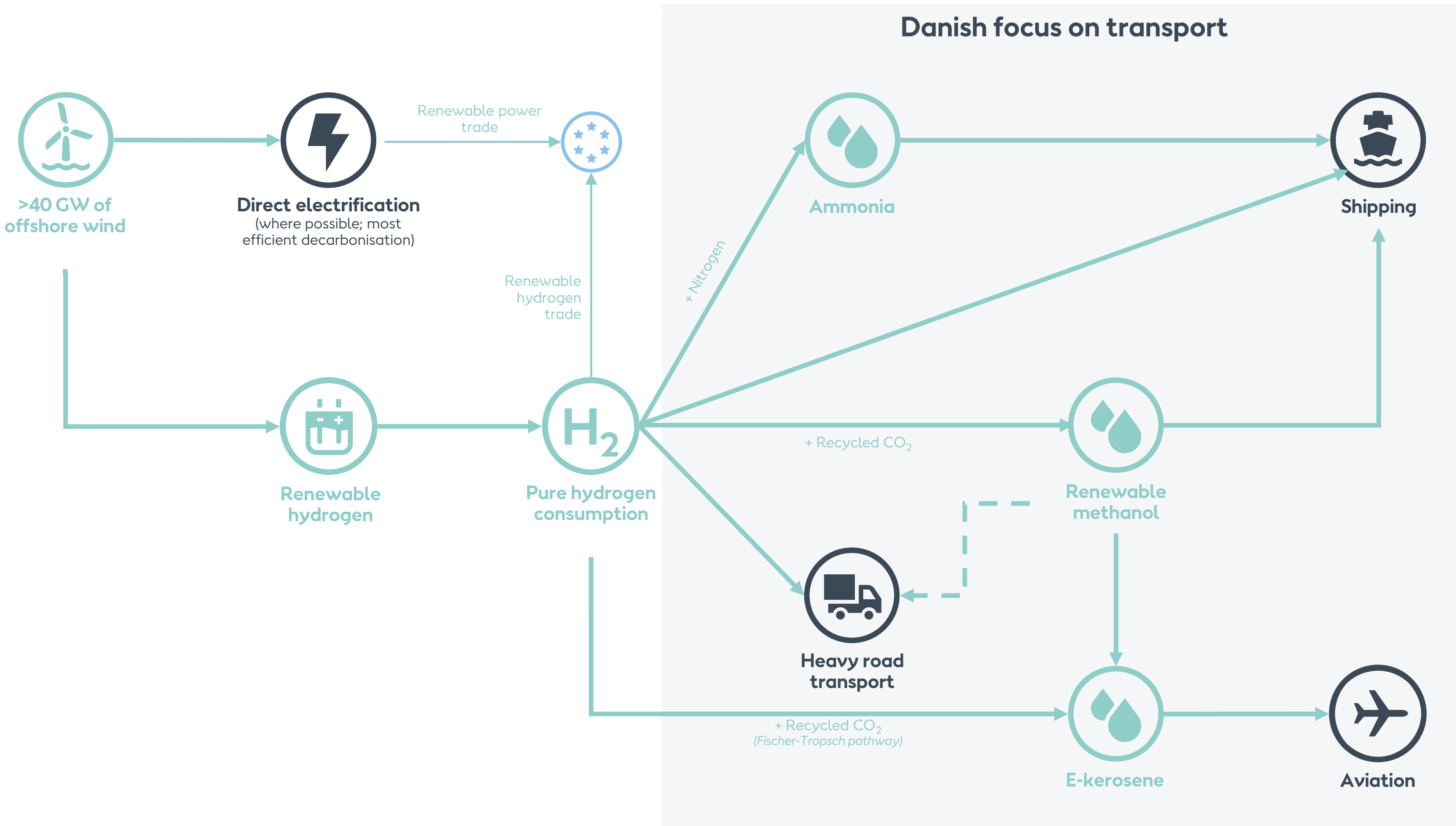
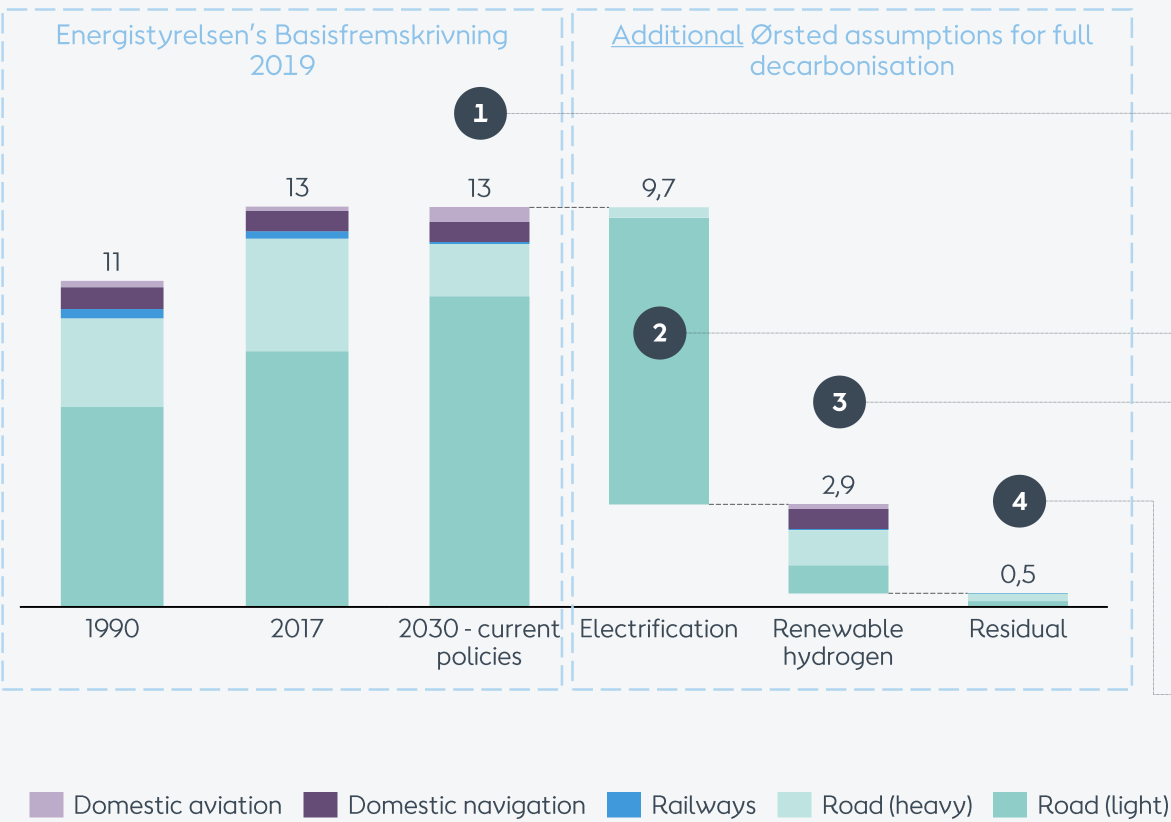
A Danish vision for decarbonisation



Decarbonising Danish transport through direct and indirect electrification

Transport emissions in Denmark, $MtCO_2e$



Achieving full decarbonisation

1.
- Already assumes some electrification of cars, vans, buses railways and navigation; and use of biofuels in cars, vans trucks and buses

2.
- Electrification of 95% cars (rest continue using biofuels) and 100% motorcycles
- Electrification of 50% of vans, and 10% of trucks

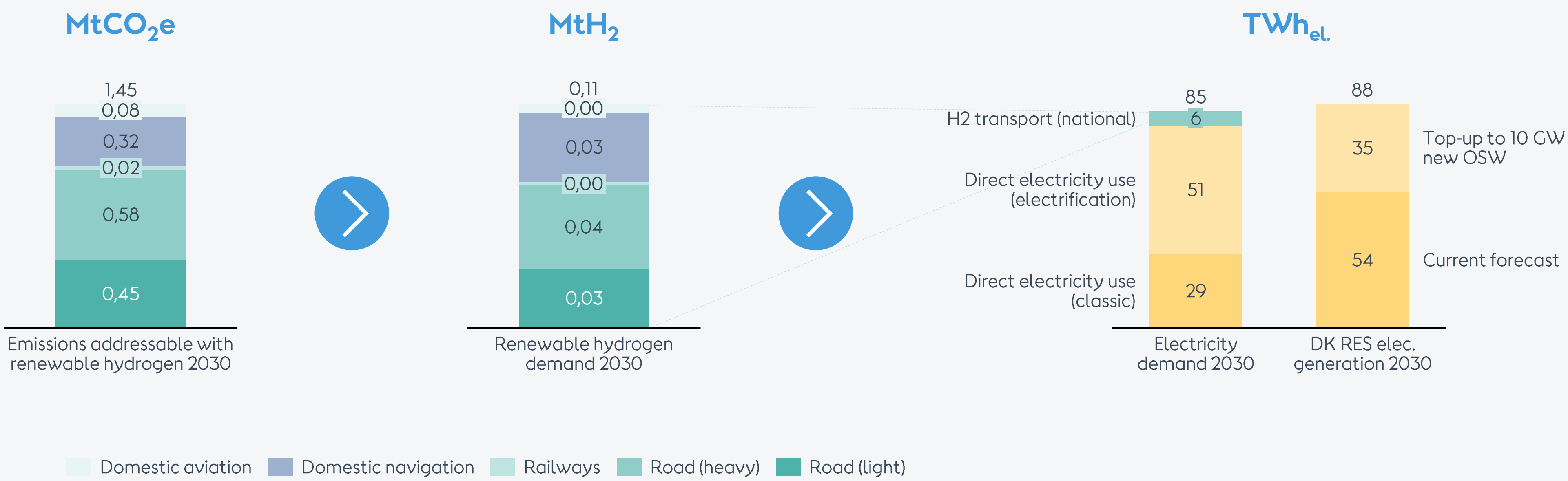
3.
- Hard-to-decarbonise segments switch to renewable hydrogen and derivatives

4.
- Residual emissions from cross-border transport of trucks and trains that need to maintain diesel fuelling

Detailed fuel use rates in Appendix; Source: Basisfremskrivning 2019 plus Ørsted assumptions on additional potential for decarbonisation.

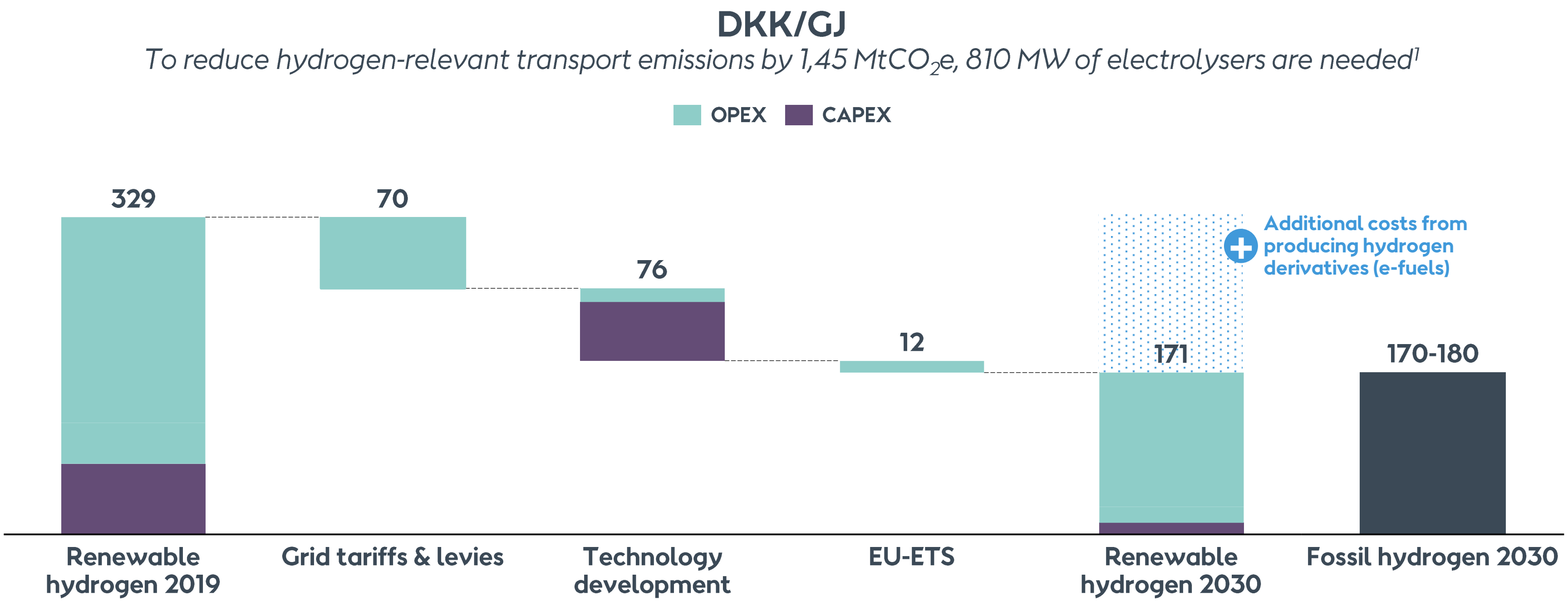
Decarbonisation challenge: Hydrogen and electricity demand

- Renewable hydrogen could address a minimum of **2,9 $MtCO_2e$ emissions from heavy transport** (in addition to around 2,1 $MtCO_2e$ from high temperature heat industrial processes)
- Going forward, we assume that towards 2030, realistically **half of the decarbonisation in transport via renewable hydrogen is achieved**, meaning 1,45 $MtCO_2e$ emissions are addressed



Assumptions: $MtCO_2e$ to MtH_2e: transport factor = 9,57-19,39 depending on transport and fuel type; industry factor = 10; Electrolyser efficiency = 65%.
Direct electricity use figure from Basisfremskrivning – 105.1 PJ of "classic" demand + 31.4 PJ of electricity for heat (process and residential) + 25.3 PJ for data centres + Ørsted's assumption of electricity in transport with additional policies totalling 125.4 PJ.

The first step to decarbonising Danish transport: Making renewable hydrogen competitive to cut 1,45 MtCO_2e emissions



Cost-reflective grid tariffs based on location and time of use

Support from IF[2] and national budget, combined with mandated offtake, to support development of electrolyser scale and efficiency

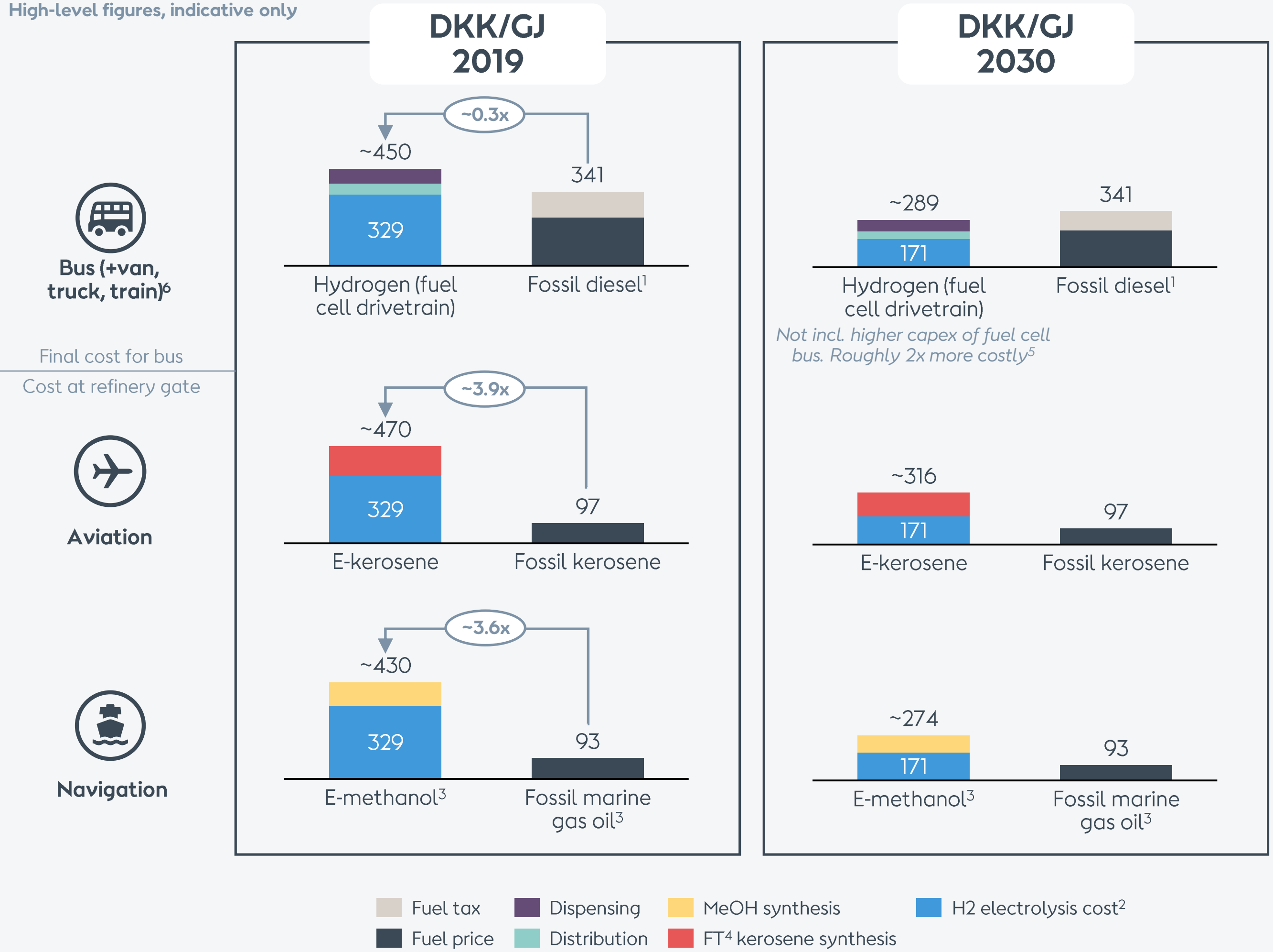
Need to address perverse incentive of free allowances exclusively for fossil hydrogen to fully reflect the socio-economic value of renewable hydrogen

Additional revenue from sale of excess heat and oxygen could reduce cost further

1. 811.26 MW; depends on conversion factors for each transport mode; see accompanying spreadsheet.
2. IF = Innovation Fund (from EU-ETS).

The second step to decarbonising Danish transport: From renewable hydrogen to renewable fuels

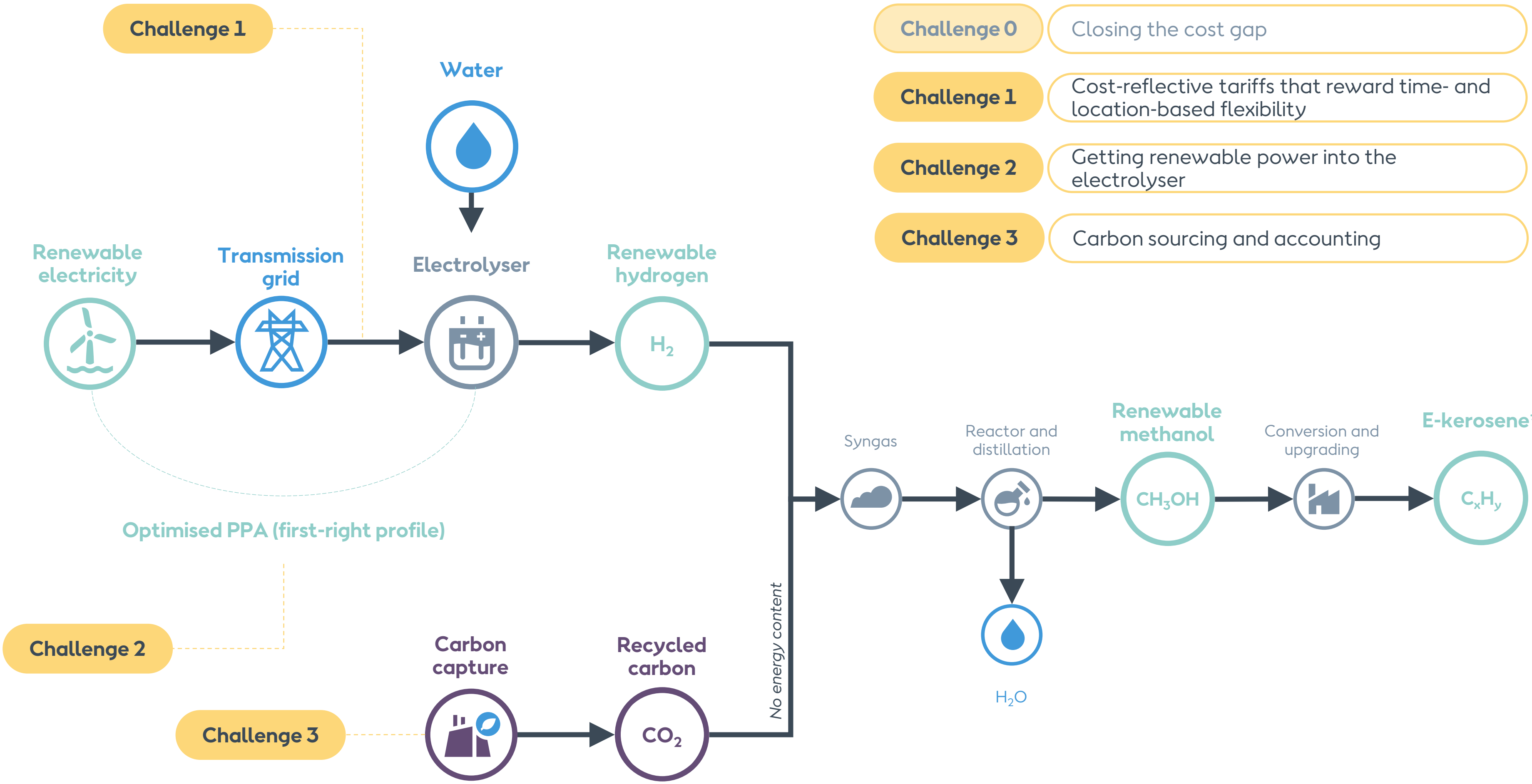
High-level figures, indicative only



	Current fuel consumption *(national)* PJ/year	Assumed substitution *(2030)* PJ/year	Electrolyser capacity required MW	CO_2e reduction Mt
Bus (+van, truck, train)	66.5	15	597	1.05
Aviation	1.3	0.7	38	0.08
Navigation	6.2	3	162	0.32

Source: shipandbunker.com, effship.com, h2tools.org, IATA, OK.dk, Bus & Tram In-depth focus (2017), Chalmers University – Electrofuels for the transport sector: A review of production cost (2018), Ørsted analysis 1. B2B prices for delivery of 1,000 litres of diesel. Diesel numbers adjusted upwards to account for 33.7% poorer drive-train efficiency than fuel cell busses 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 resulting IRR of 6%. And H2 price of 5.3 EUR/kg 3. Fuels have similar thermal efficiency when combusted in marine diesel engine. 4. Fischer-Tropsch process. 5. Current cost of 12m FC bus EUR ~400k. A comparable diesel bus costs EUR ~200k. 6. Empirical data on cost only available for bus, but assumed to be similar for vans, trucks and trains.

Producing renewable hydrogen and its derivatives: Process and challenges



* According to REDII, all of a refinery's outputs will be considered to have the same renewable content
If a refinery produces e-kerosene (100% renewable) and other conventional fuels, in the following proportions: (A) E-kerosene = 10% of total output; and (B) Conventional fuels = 90% of total output; then it will be assumed that 10% of each of the refinery's outputs is renewable (i.e. e-kerosene is 10% renewable; conventional fuels are 10% renewable).

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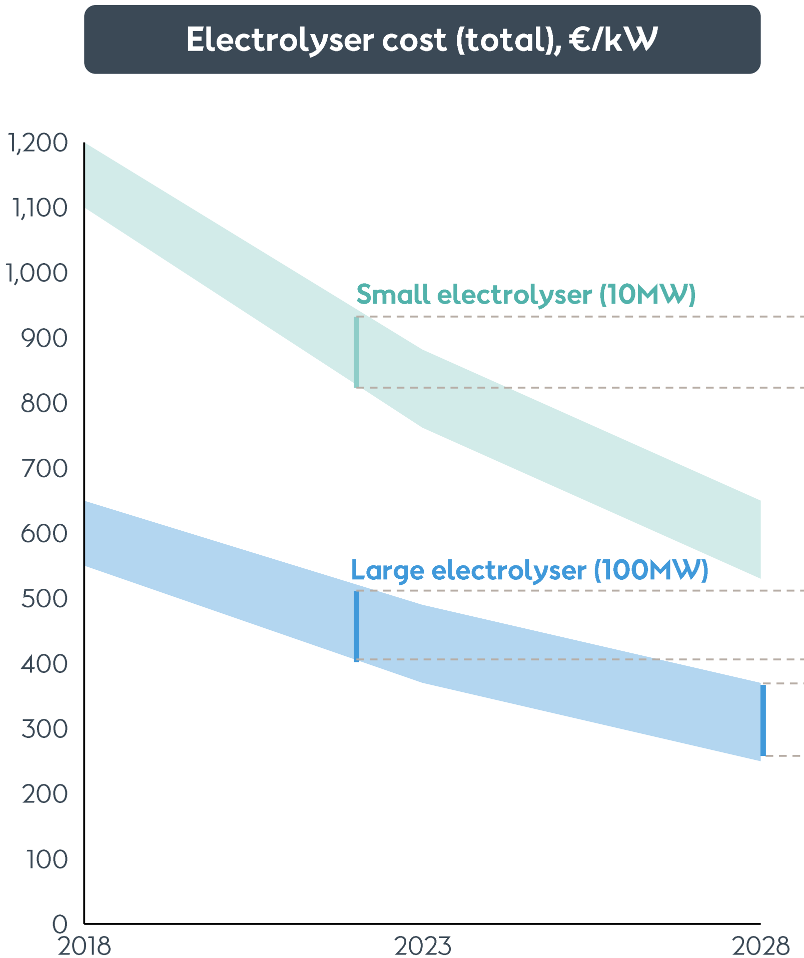
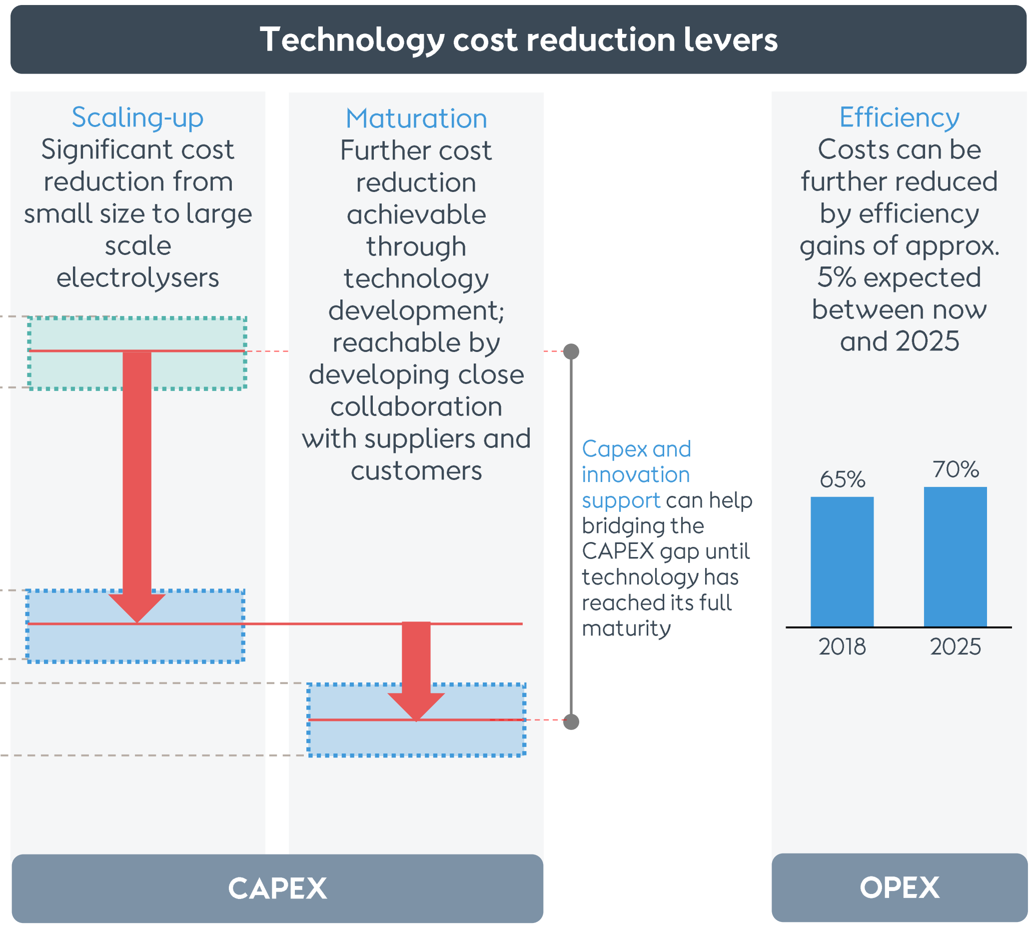
Cost-out of electrolyser CAPEX





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.

Producing renewable hydrogen: The challenges in detail

1

There is potential to cut renewable hydrogen production cost by 50%, but half of that cost reduction potential consists of regulatory barriers

- Grid tariffs and levies based on location and time of use would be the most cost-reflective
- Renewable hydrogen at competitive disadvantage as fossil hydrogen receives free ETS allowances that are lost when switching to renewable (as electrolysis is not part of Annex I of EU-ETS Directive)
  - Short-term solution: unilateral allocation of free allowances to renewable hydrogen production (by Member State, under Art. 24)
  - Long-term solution: Annex I to include substitute products/process in cases where free allowances apply

2

Timing of REDII[1] implementation could delay renewable hydrogen roll-out until the mid-2020s

- **Will we be forced to produce advanced biofuels?**
  - Deadline for national implementation of REDII is 30/06/2021; until then renewable hydrogen producers in each Member State will not know if they will be forced to also produce advanced biofuels (Article 25 of REDII), which would be extremely burdensome particularly for parties dedicated exclusively to electrolyser ownership and operation
- **Will the PPA setup be sufficient proof of 'greenness'?**
  - Deadline for Delegated Act under Article 27 of REDII is 31/12/2021; until then renewable hydrogen producers will not know to what extent hydrogen produced from grid-connected electrolysers contributes to REDII transport target

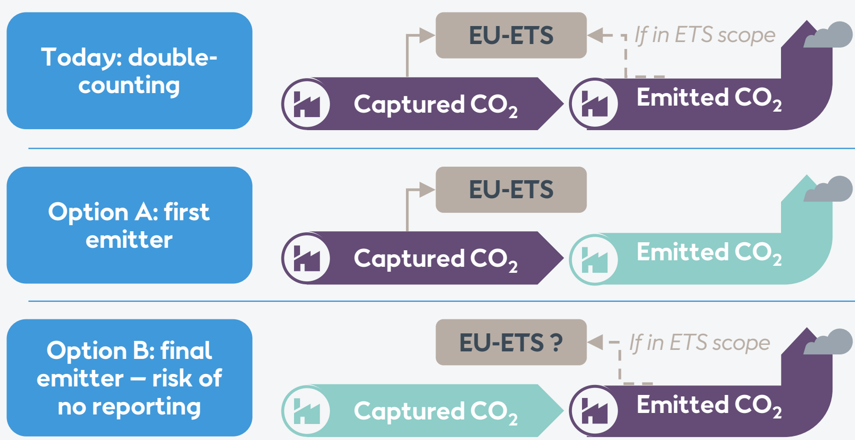
1. REDII: recast Renewable Energy Directive

Producing renewable methanol: The challenges in detail

3

Regulation for Carbon Capture and Utilisation (CCU) is underdeveloped

- Current EU-ETS Directive only exempts CCS (permanent storage) from surrendering allowances, but new recital 14 opens door to CCU: *'allowances will not need to be surrendered for CO_2 emissions which are avoided or permanently stored'*
- To ensure consistency with REDII requirements, first emitter should surrender allowances



4

Clarity around how recycled carbon contributes towards the REDII transport target needed

- Member States may take into account recycled carbon fuels towards REDII transport target (Article 25 of REDII); renewable hydrogen and recycled carbon fuel producers will benefit from clarity as to Denmark's plans in this regard
- European Commission to adopt Delegated Act by 01/01/2021 in relation to methodology for calculating greenhouse gas emissions savings from recycled carbon fuels – to qualify as "renewable" they must save at least 70% emissions

Final user (methanol producer) does not have carbon emissions (already declared by first emitter), so the methanol produced with recycled carbon and renewable hydrogen meets 70% savings requirement

Final user (methanol producer) has to surrender emissions as the first emitter did not, and thus it cannot meet the 70% savings requirement