ELECTROLYSERS AND ELECTROFUELS IN SMART ENERGY SYSTEMS

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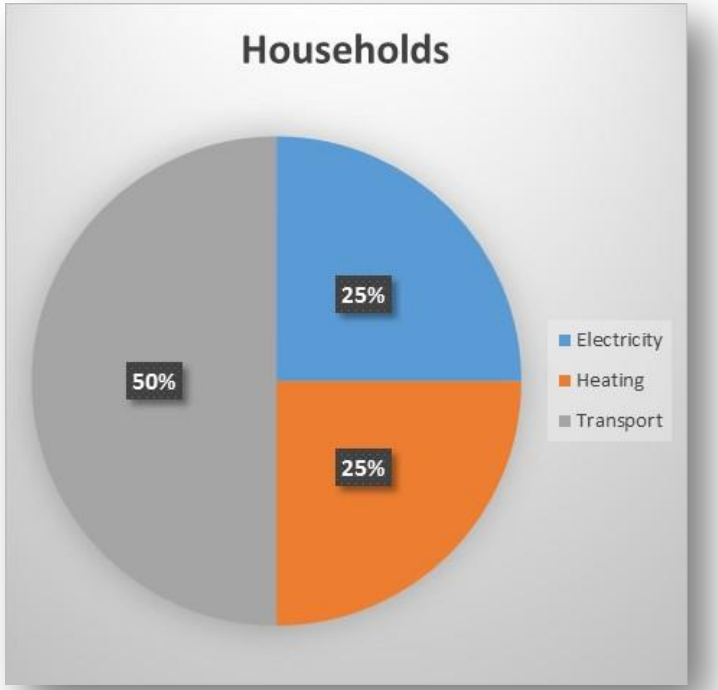
Solutions on the table

1. Interconnectors and trading
2. Flexible electricity demands and smart grids
3. Integrated efficient Smart Energy Systems



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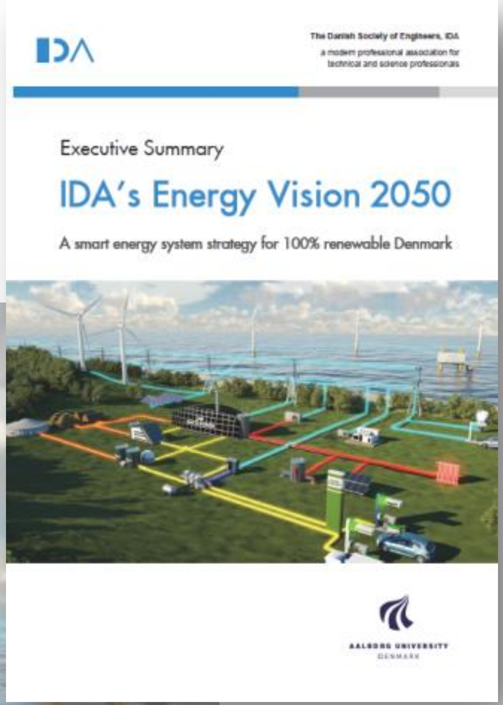
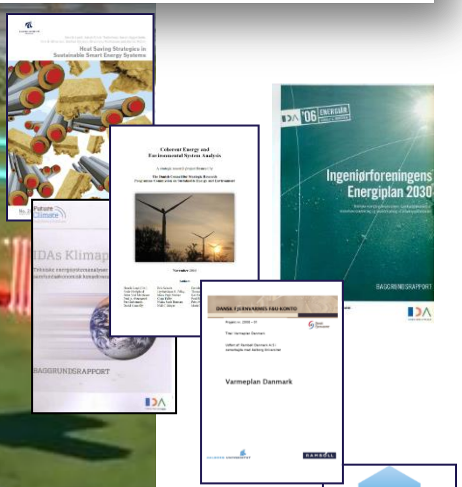
Smart Energy Systems





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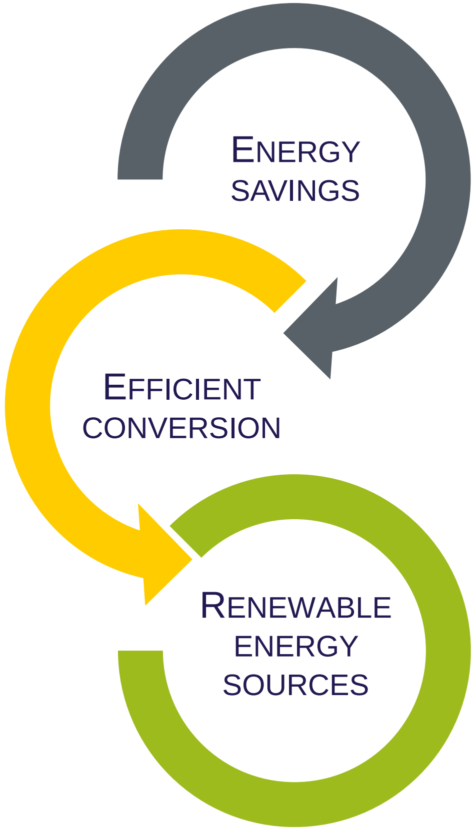
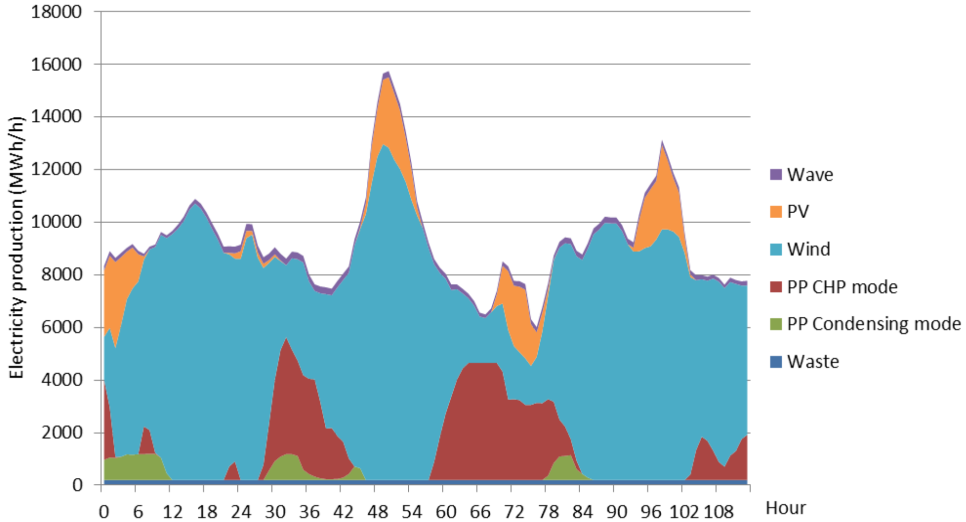
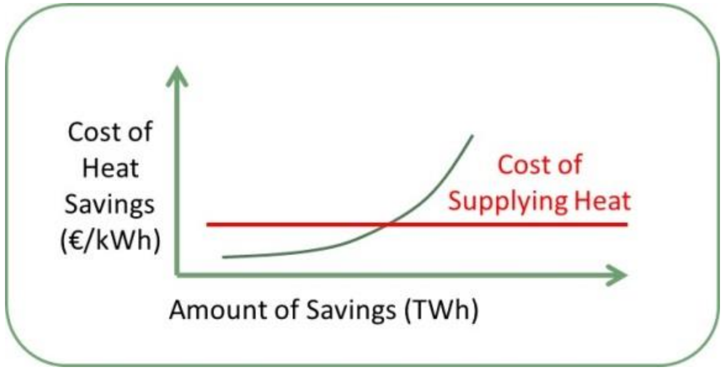
Key principles







FLEXIBLE TECHNOLOGIES

INTEGRATED ENERGY SYSTEMS

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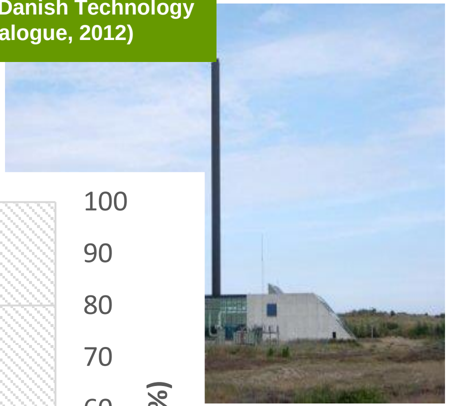
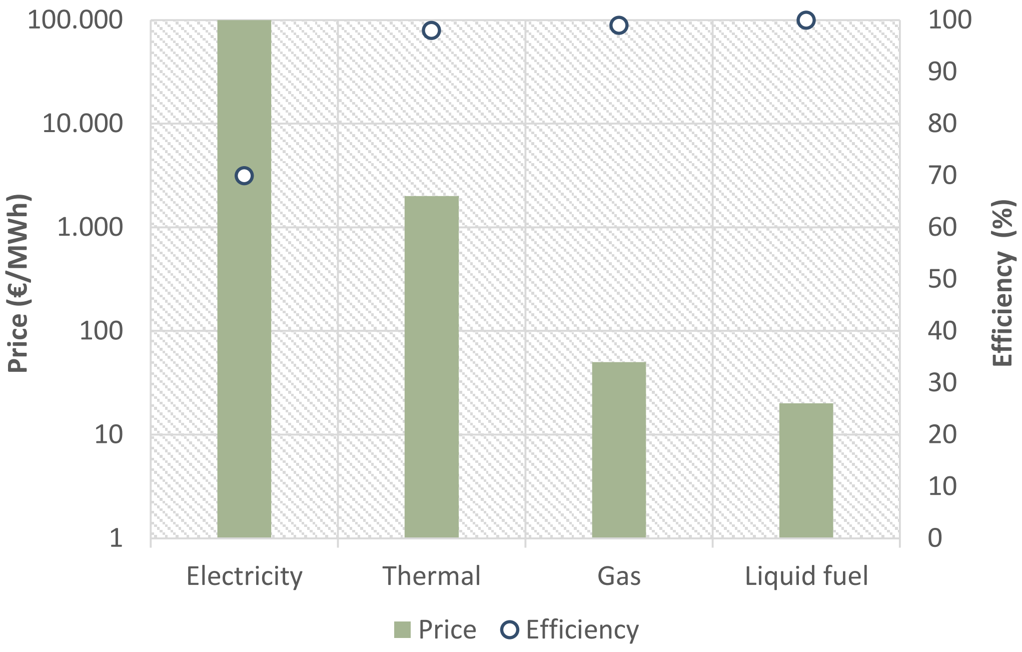
Storage Comparison

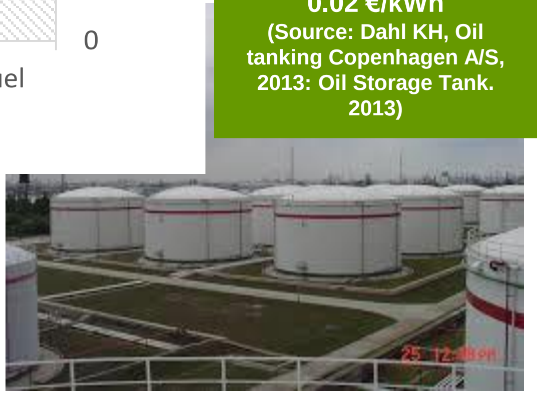
Pump Hydro Storage
175 €/kWh
(Source: Electricity Energy Storage Technology Options: A White Paper Primer on Applications, Costs, and Benefits. Electric Power Research Institute, 2010)

Thermal Storage
1-4 €/kWh
(Source: Danish Technology Catalogue, 2012)





Oil Tank
0.02 €/kWh
(Source: Dahl KH, Oil tanking Copenhagen A/S, 2013: Oil Storage Tank. 2013)



Natural Gas Underground Storage
0.05 €/kWh
(Source: Current State Of and Issues Concerning Underground Natural Gas Storage. Federal Energy Regulatory Commission, 2004)

We need much more electricity in the future

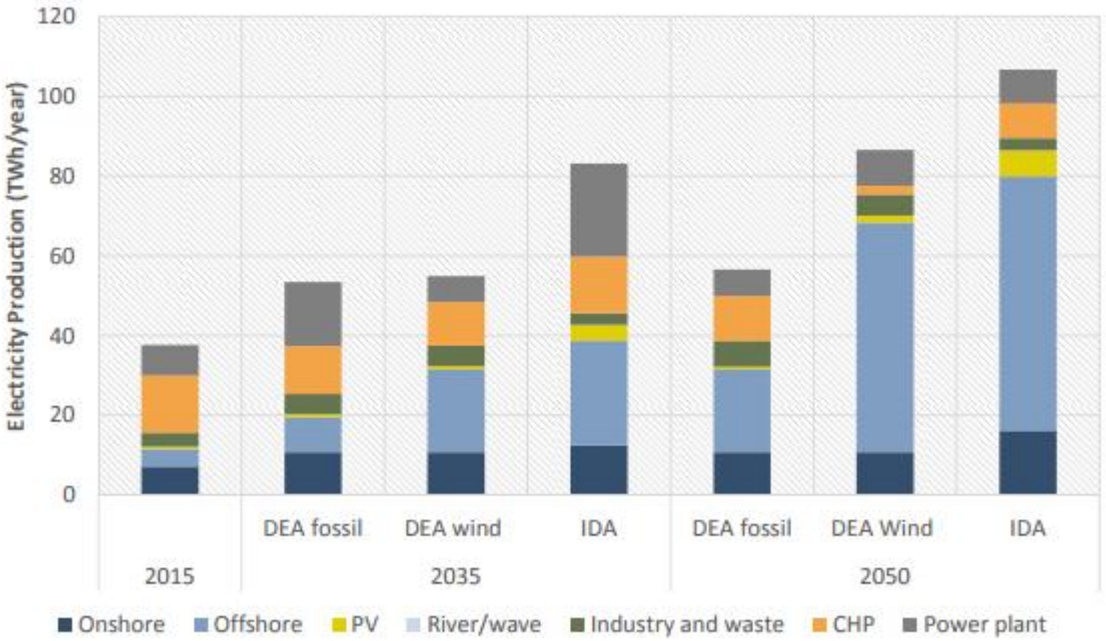
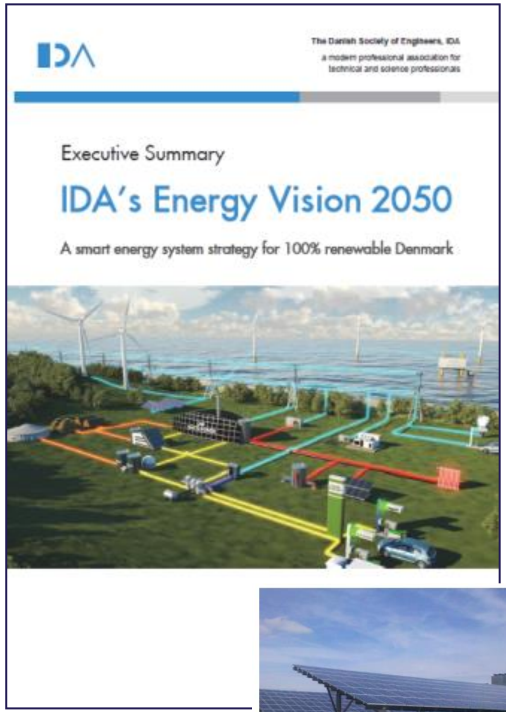
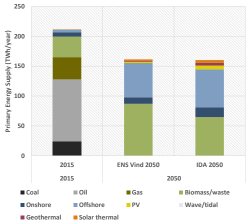
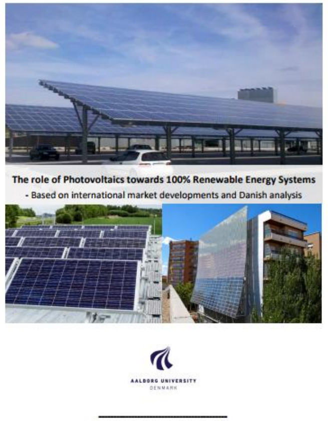


Figure 12: Electricity production for the 2015 reference, the 2035 and the 2050 DEA and IDA scenarios

Wind power should be prioritised, supplemented by PV and power plants







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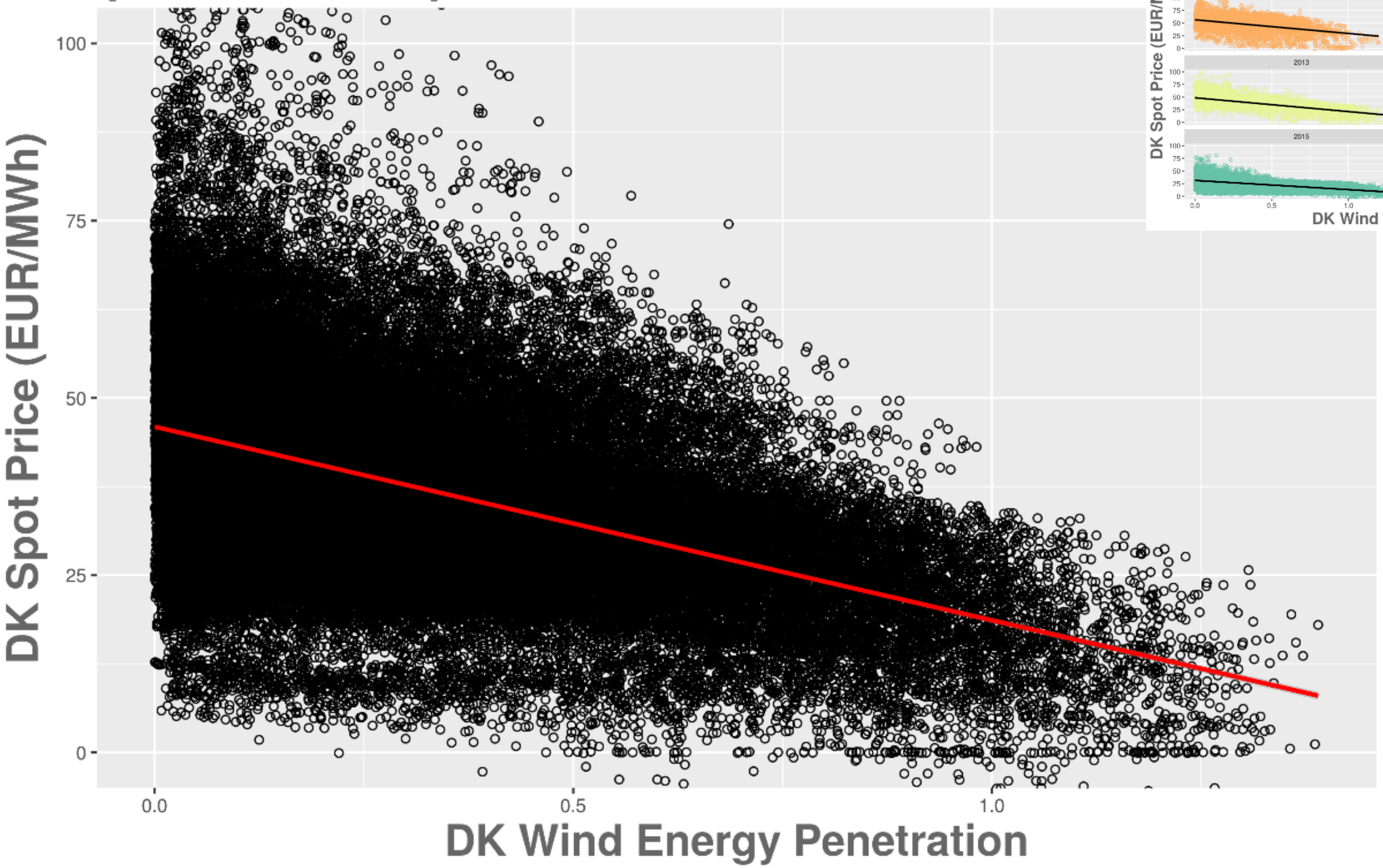
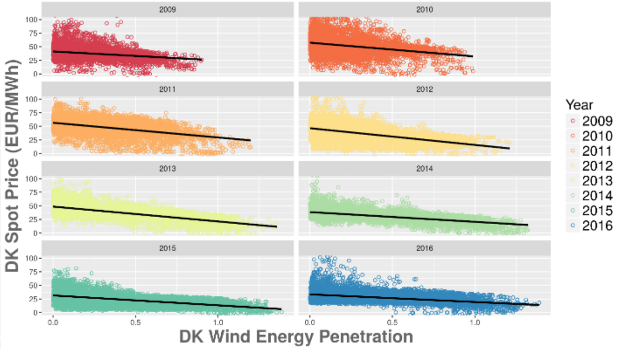
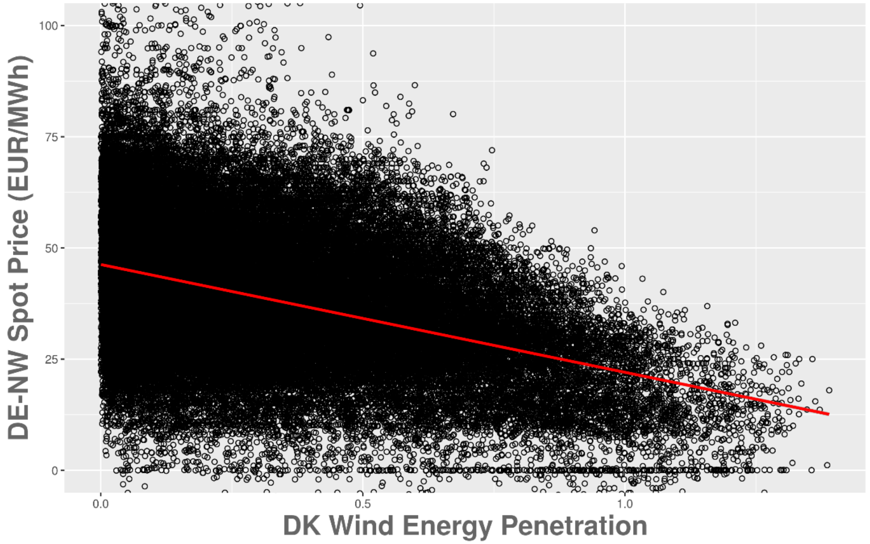
Danish Elspot Price by Danish Wind Power Penetration (2009-2016)



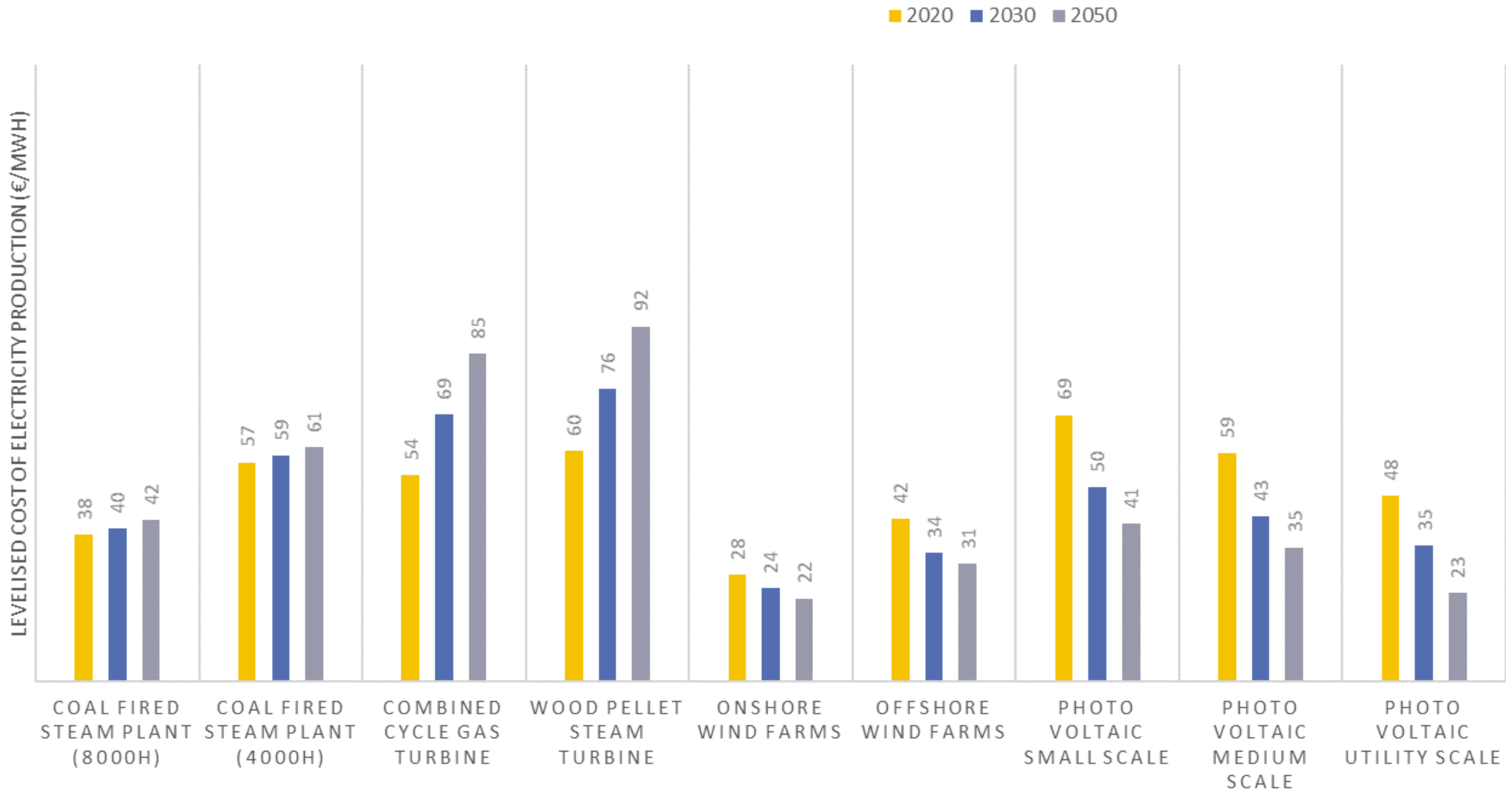
Danish Elspot Price by Danish Wind Power Penetration (2009-2016)



North-western Germany Elspot Price by Danish Wind Power Penetration (2009-2016)



RES LCoE are dropping



ELECTRICITY PRICE DROP IS A MAIN DRIVER FOR PTX INSTALLATIONS

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We have to use much more electricity in the future (flexibly)!

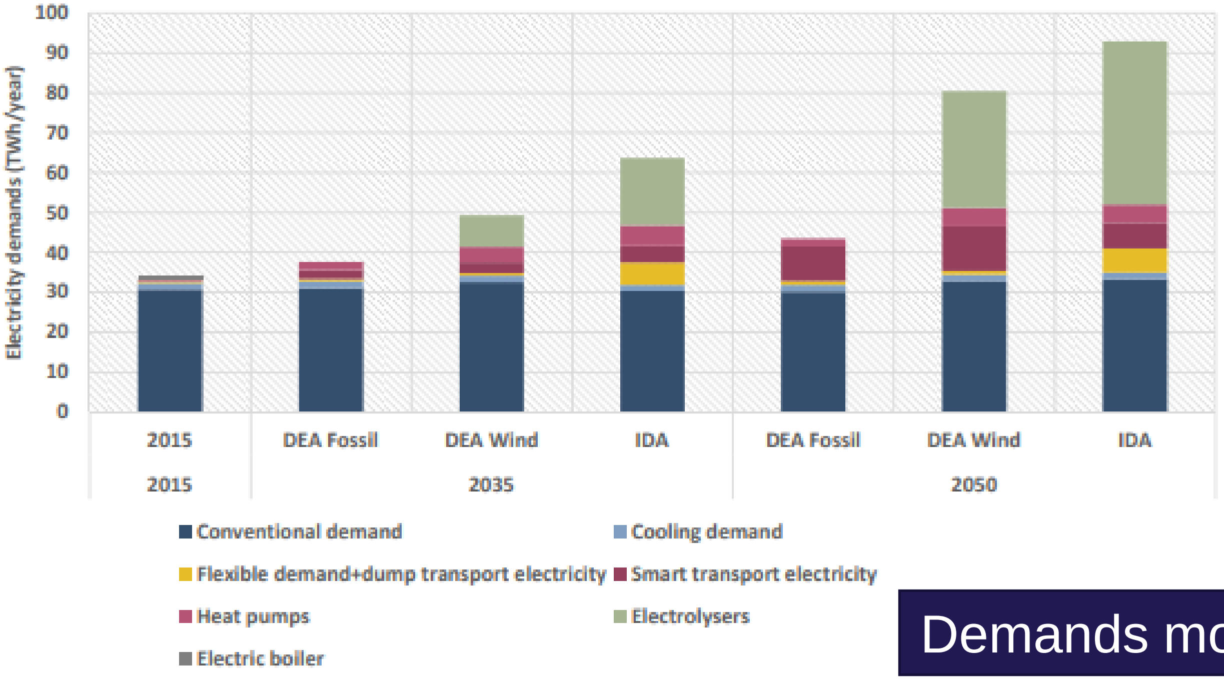
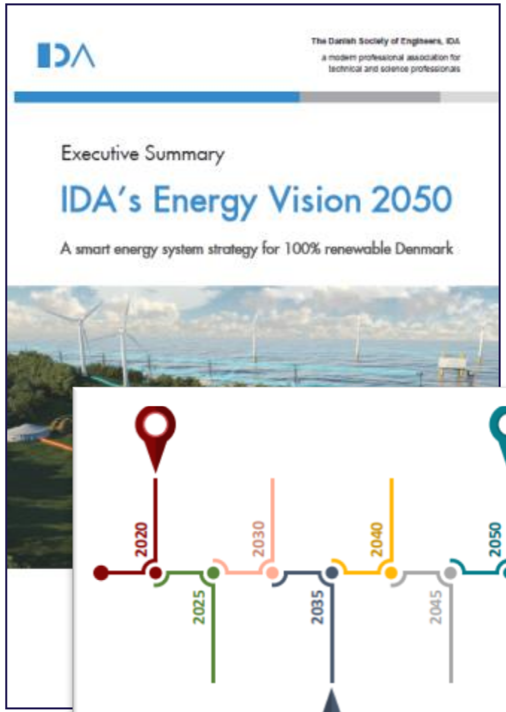
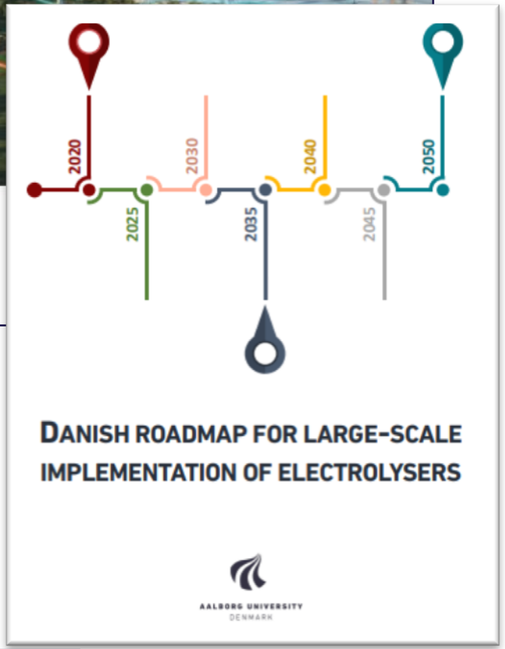


Figure 31: Electricity demands in the 2015, 2035 and 2050 scenarios





Demands more than doubles

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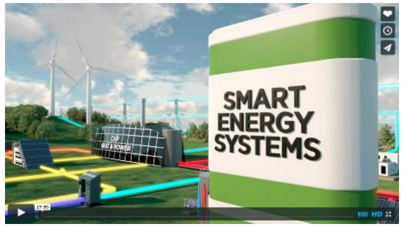
Smart energy systems

- The key to cost-effective renewable energy systems

- Heat storage, district heating, CHP and large heat pumps
- New electricity needs from large / small heat pumps and electric cars (with electricity storage)
- Electrolysis and liquid fuels for transport sector with storages
- Integration of gas system and gas storage

More El = Sustainable biomass consumption

Power-to-Heat Power-to-Transport	Power-to-Gas Power-to-liquids



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The top 10 technologies that require additional investment in the 100% renewable energy system in 2050

- From Electricity markets to Smart Energy System Markets?

	Technology	Required additional investment from today to 2050 (Billion €)
1	Energy renovations of the existing building stock	29.9
2	Offshore wind	28.4
3	Individual heat pumps	14.7
4	District heating grid expansion	5.5
5	Electrofuel production (PtX)	4.4
6	Photovoltaic	2.6
7	Individual solar thermal	2.6
8	Biogas plants	2.6
9	Charging stations	2.2
10	Large-scale heat pumps	2.0

What are electrofuels?

ELECTROFUELS

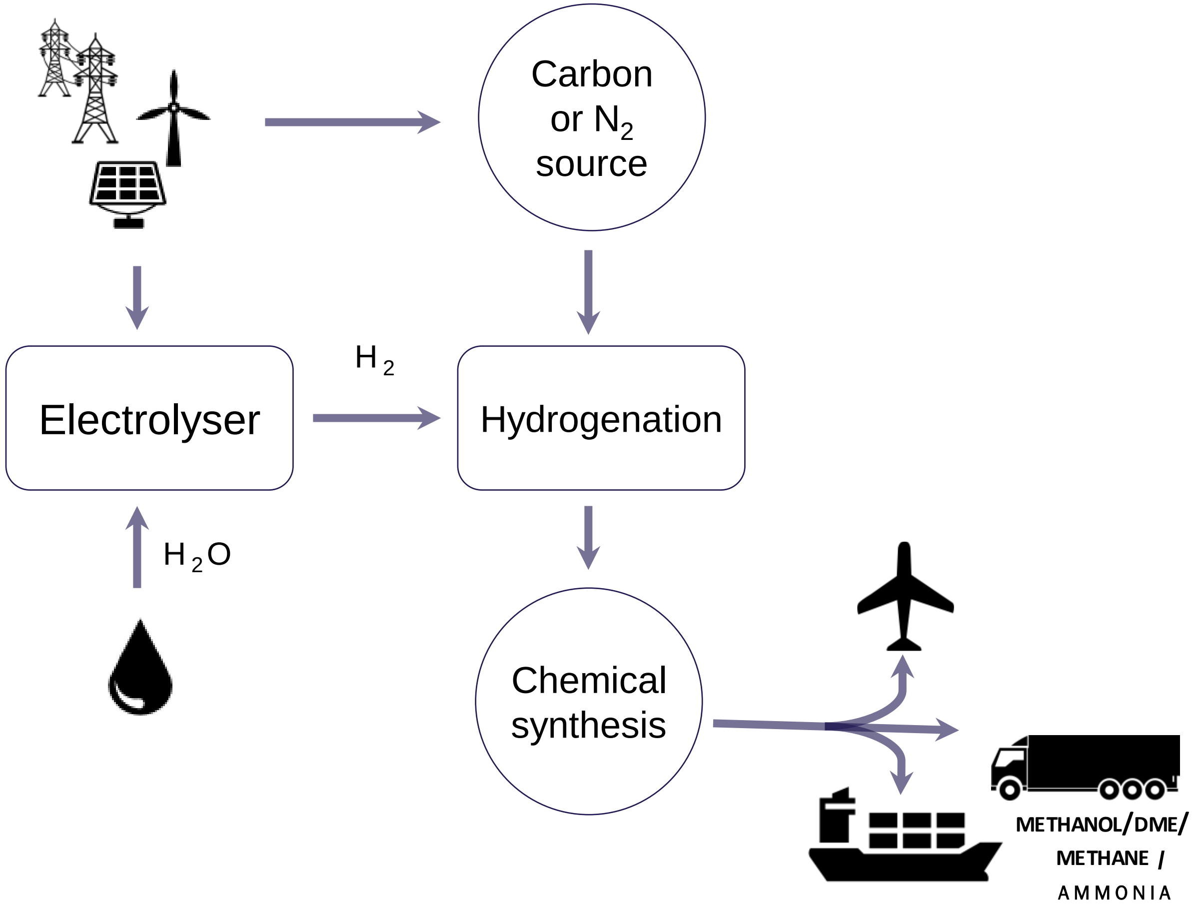
- High share of electricity in production process
- New way of producing hydrocarbons/ammonia
- Merging hydrogen with carbon or nitrogen
- Redirecting electricity to transport sector
- Open a door to fuel storage
- Flexible end-fuel choice

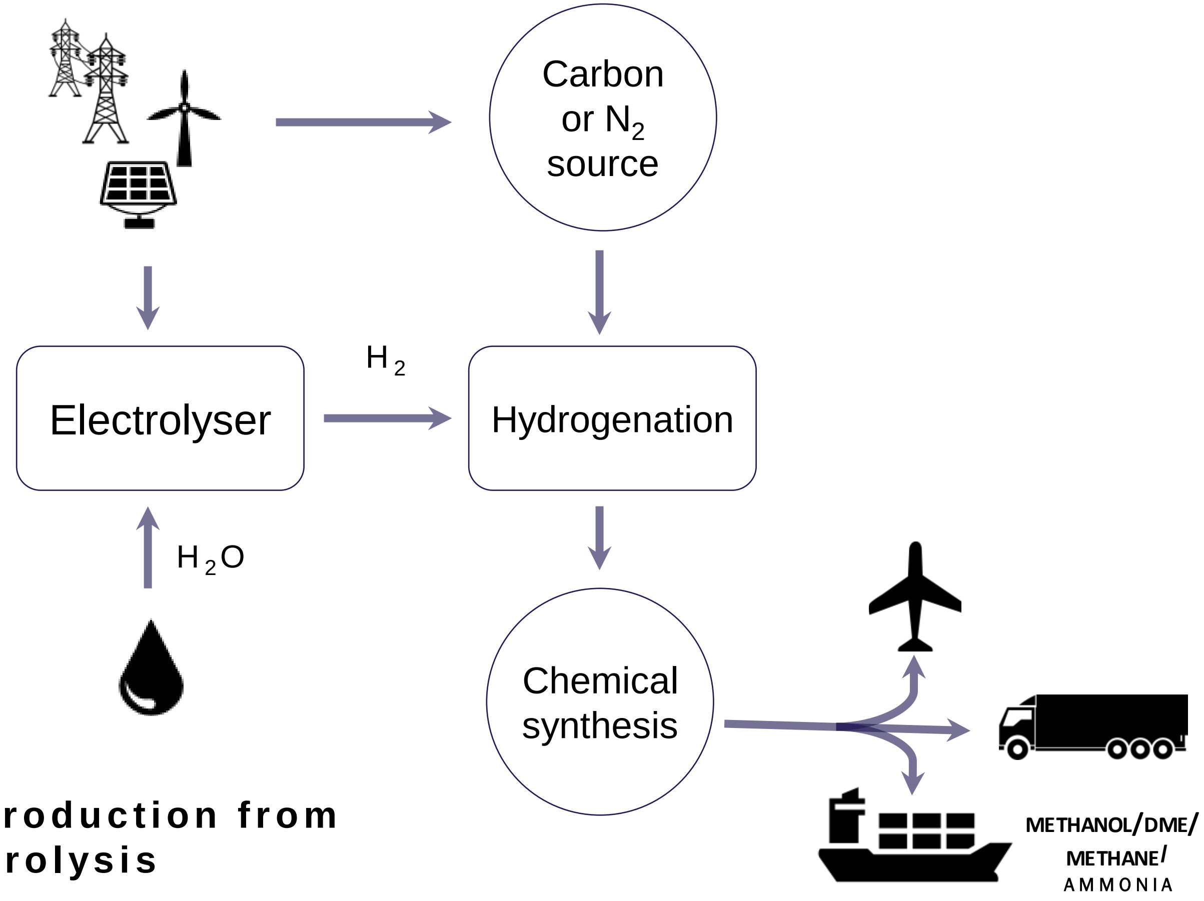
ELSEVIER
Journal of Cleaner Production
Volume 112, Part 5, 20 January 2016, Pages 3709-3720

Review

Terminology used for renewable liquid and gaseous fuels based on the conversion of electricity: a review

Iva Ridjan, Brian Vad Mathiesen [1], David Connolly [2]

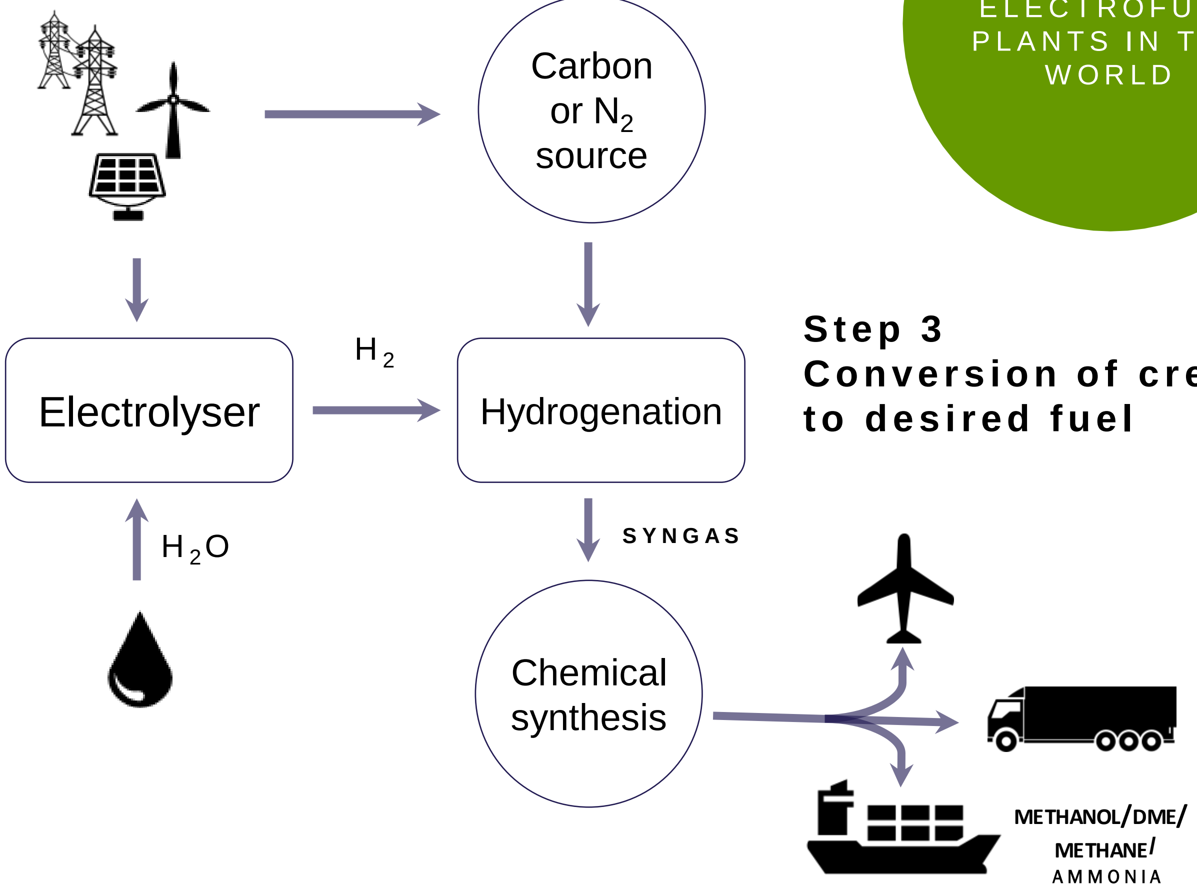

Carbon
or N_2
source
Electrolyser
H_2
Hydrogenation
H_2O
Chemical
synthesis
METHANOL/DME/
METHANE /
AMMONIA



Step 2
Hydrogen production from steam electrolysis

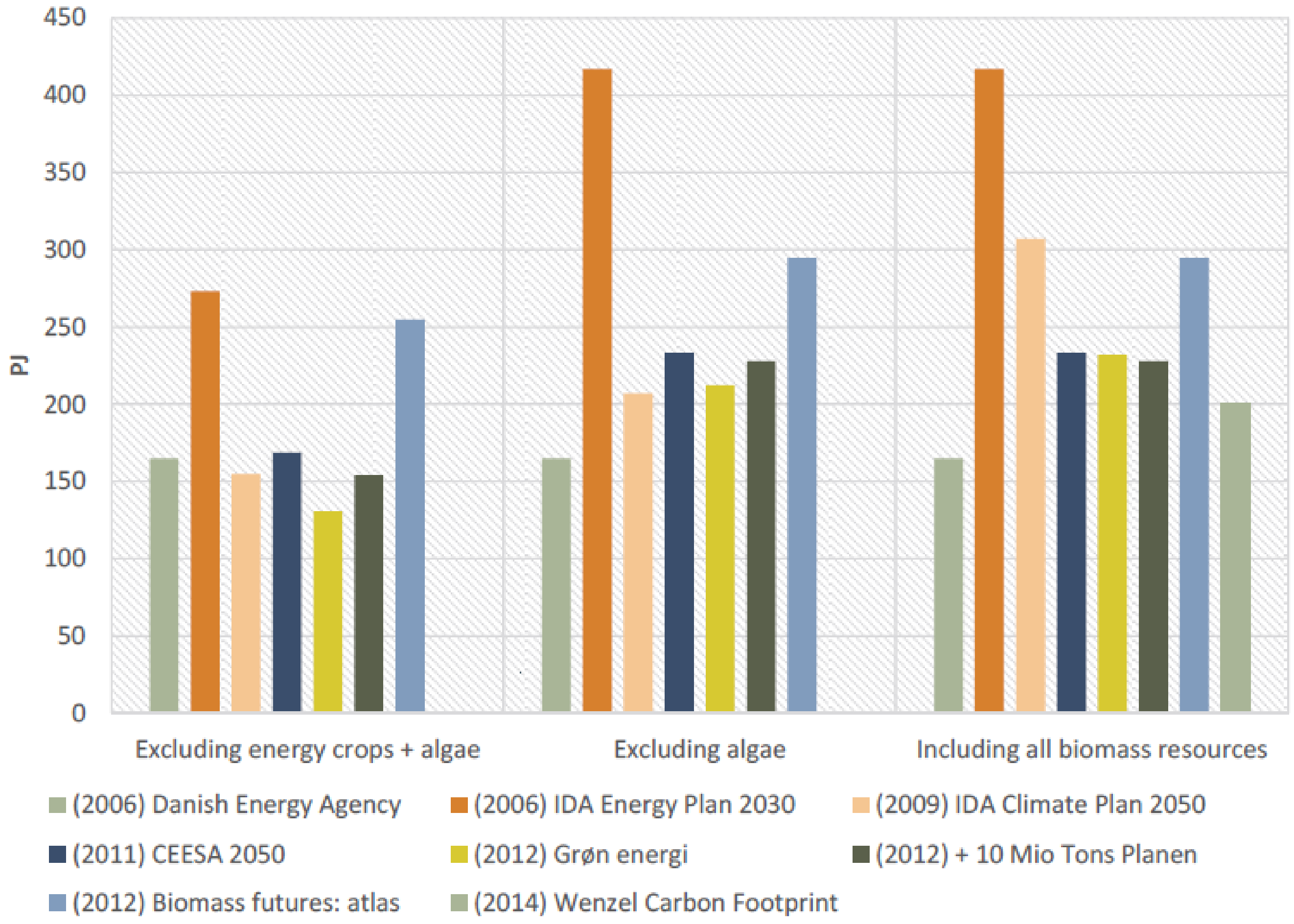
TWO LIQUID ELECTROFUEL PLANTS IN THE WORLD

NUMERUS POWER-TO-GAS INSTALLATIONS



Step 3
Conversion of created syngas to desired fuel

Biomass potential



BIOMASS POTENTIAL

OPTIMISTIC: CA. 300 PJ
PESIMISTIC: 165 PJ
REALISTIC: 200 PJ

40 GJ BIO PR. CAPITA HIGH GLOBALLY

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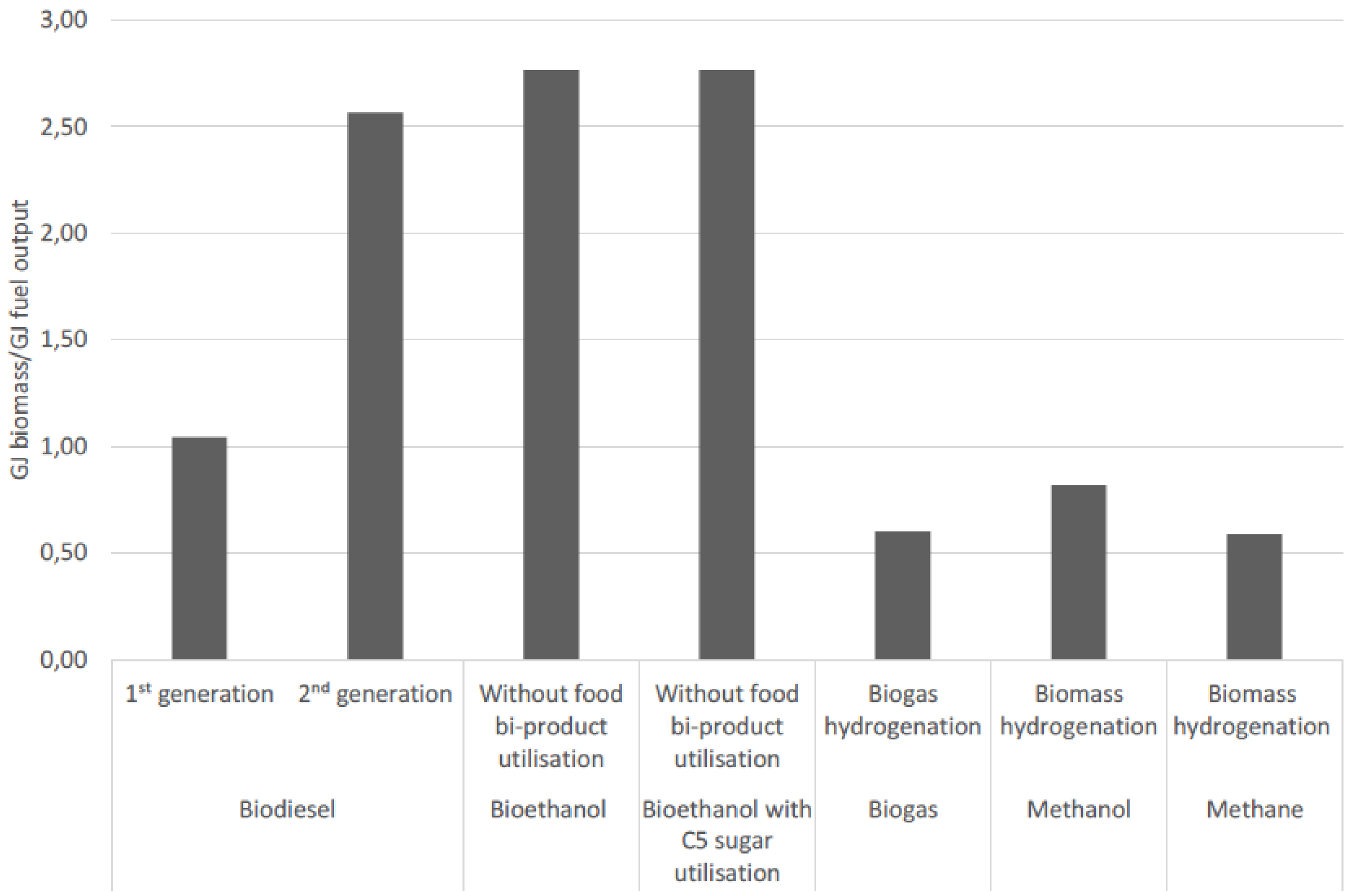
Biomass consumption

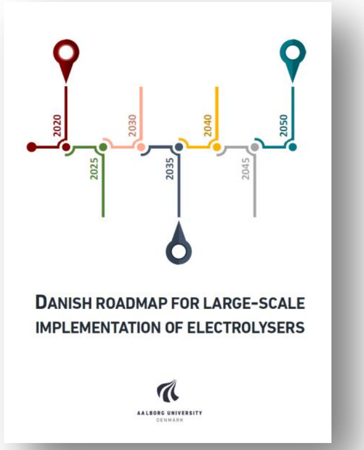


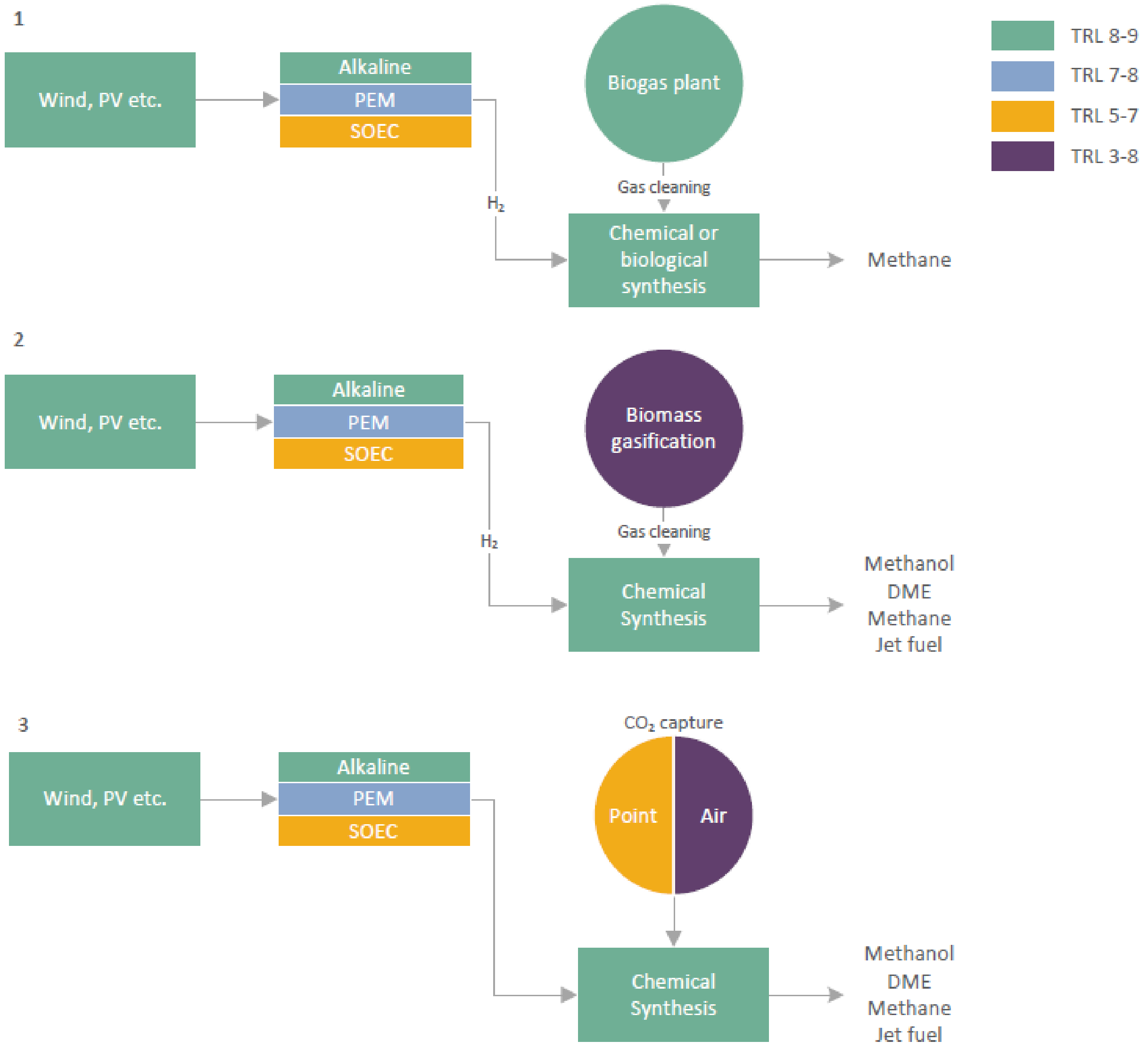
ADDITION OF HYDROGEN REDUCES SIGNIFICANTLY BIOMASS CONSUMPTION

Ridjan (2015), Integrated electrofuels and renewable energy systems

Technology readiness level

- The individual technologies more advanced than generally presumed
- The concept as an integrated production system remains to be proven on a larger scale.





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What is the role of electrolysis in the future?

	kW to few MW scale	MW scale	GW scale
Niche markets	Specialized gas markets (H_2, CO)	Unlikely to emerge on larger scales	
Energy storage	Demonstration of Power-to-methane for grid injection and transport	Demonstration and commercialization of Power-to-Liquid for transport	Cross-sectorial integration and seasonal storage
Hydrogen	Hydrogen refuelling stations Hydrogen for ancillary service		No further expansion of hydrogen refuelling station is expected
	2017-2020	2020-2030	Beyond 2030

Growth of PtX installations?

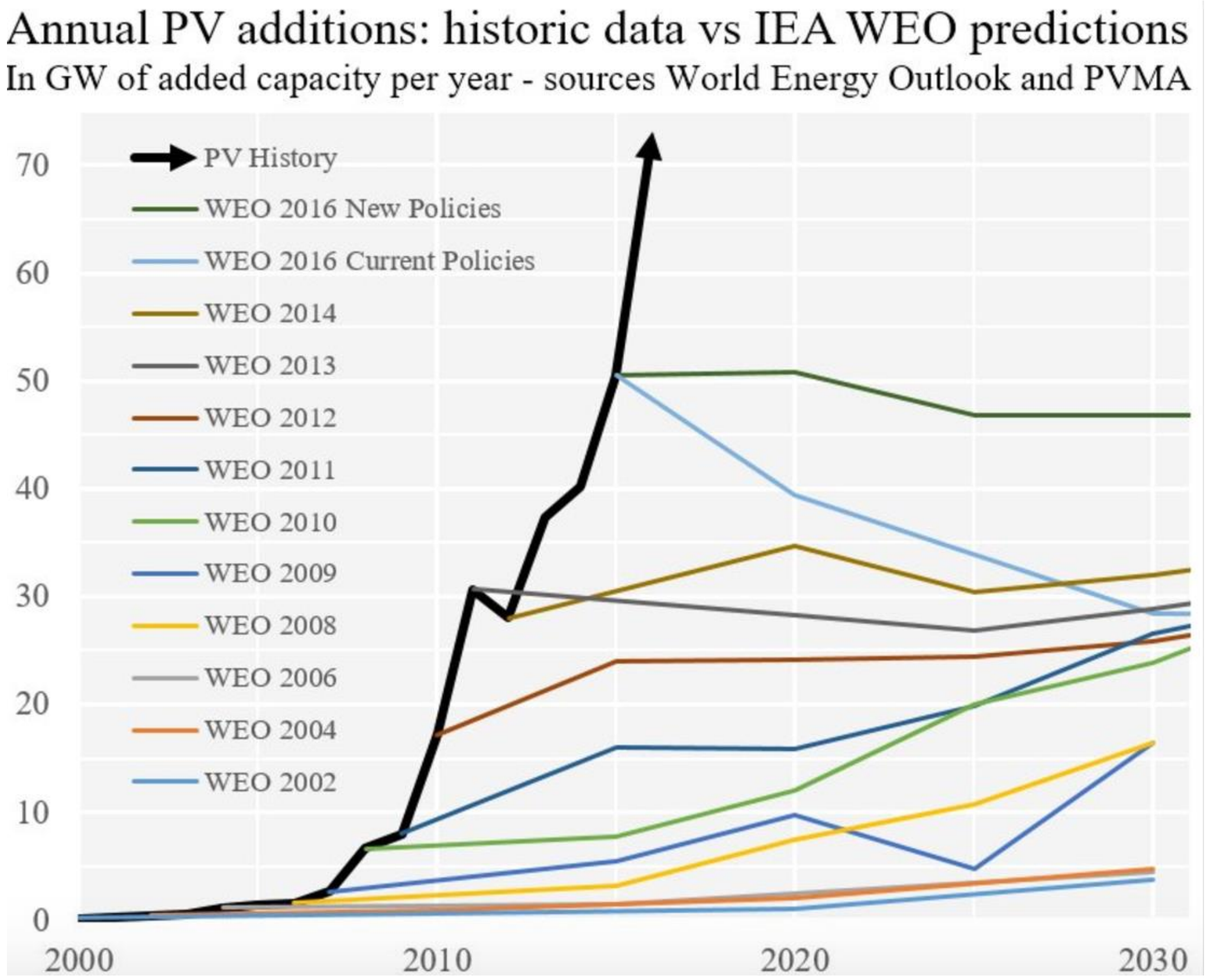
- Electrolysis installations are growing:

  2018: 1 MW (typical big demo project)

  2020: 10 MW (Shell refinery in Germany)

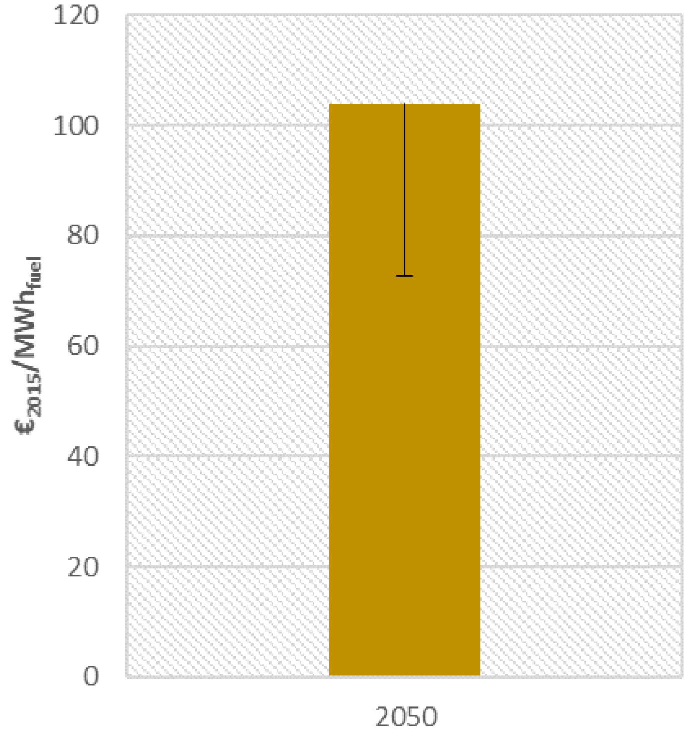
  2022-2023: 100 MW

SAME DEVELOPMENT FOR ELECTROLYSIS?



Source: Auke Hoekstra Twitter

Costs?

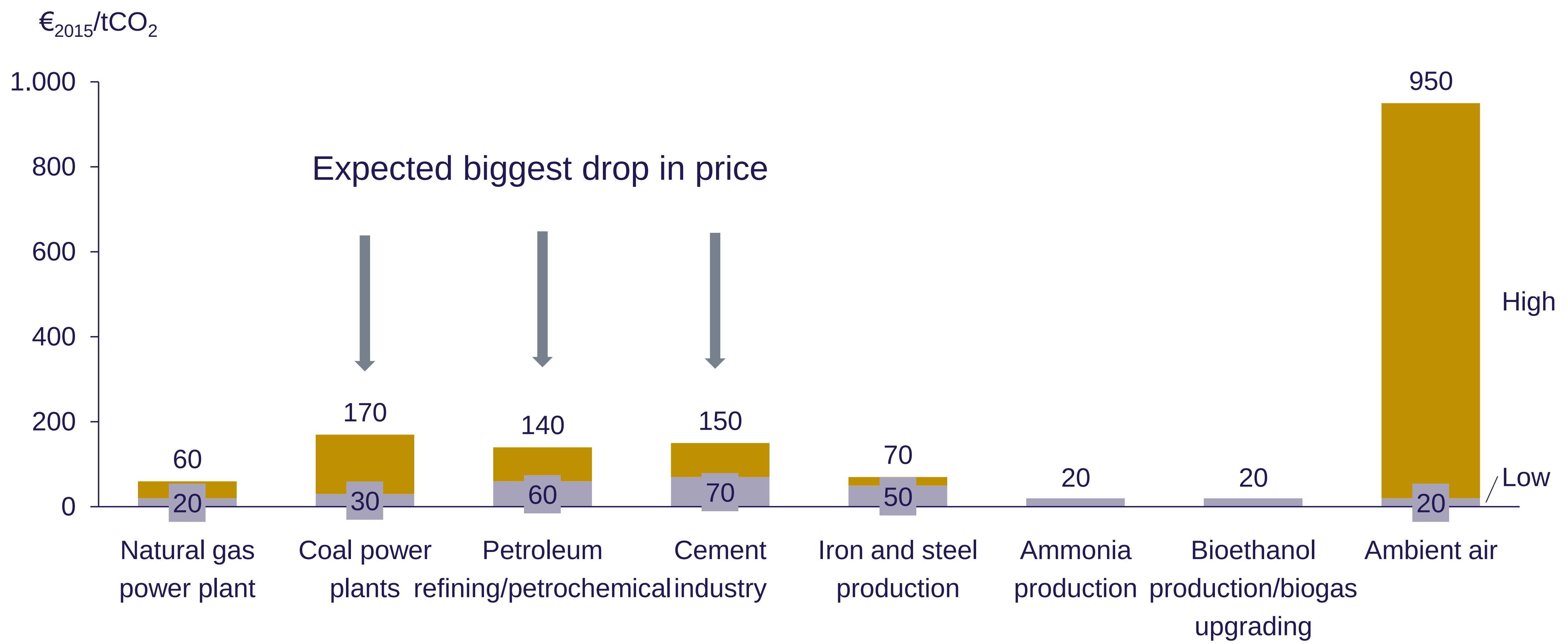


Ridjan (2015), Integrated electrofuels and renewable energy systems

Brynolf et al (2018) Electrofuels for the transport sector: A review of production costs

HUGE COST DIFFERENCES DUE TO DIFFERENT ASSUMPTIONS

CO_2 capture costs (short term)



Brynolf et al (2018) Electrofuels for the transport sector: A review of production costs

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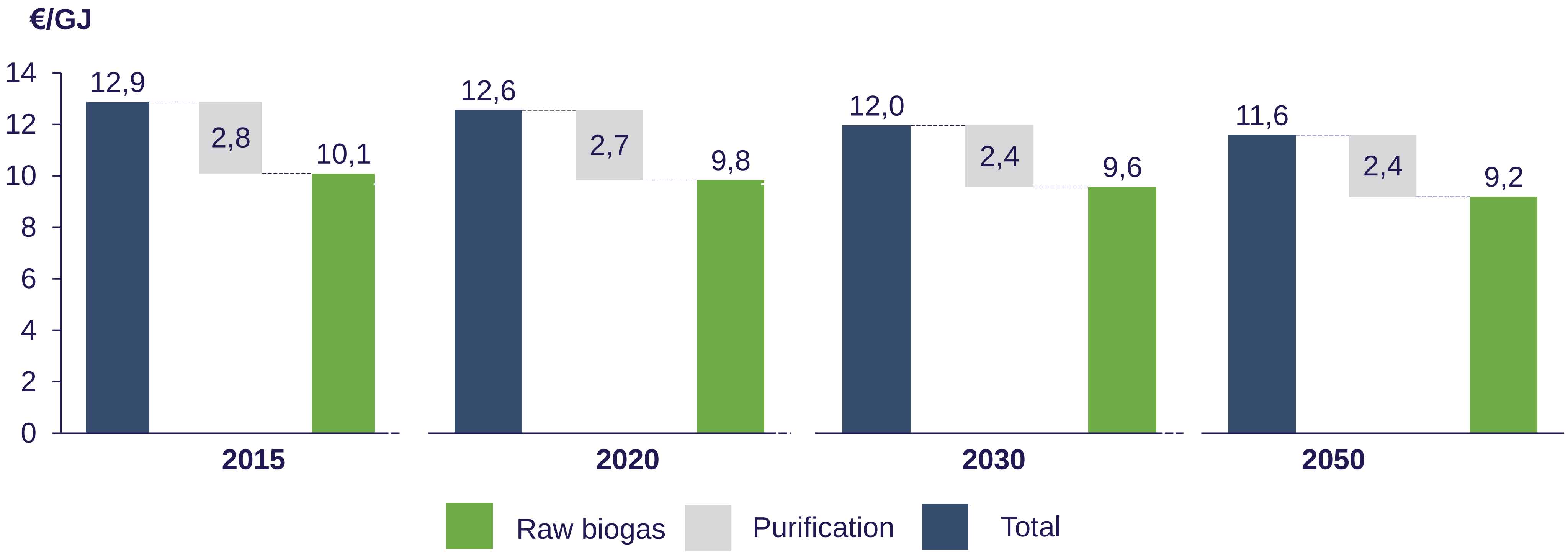
Biogas purification



**Assumed free manure for biogas production*

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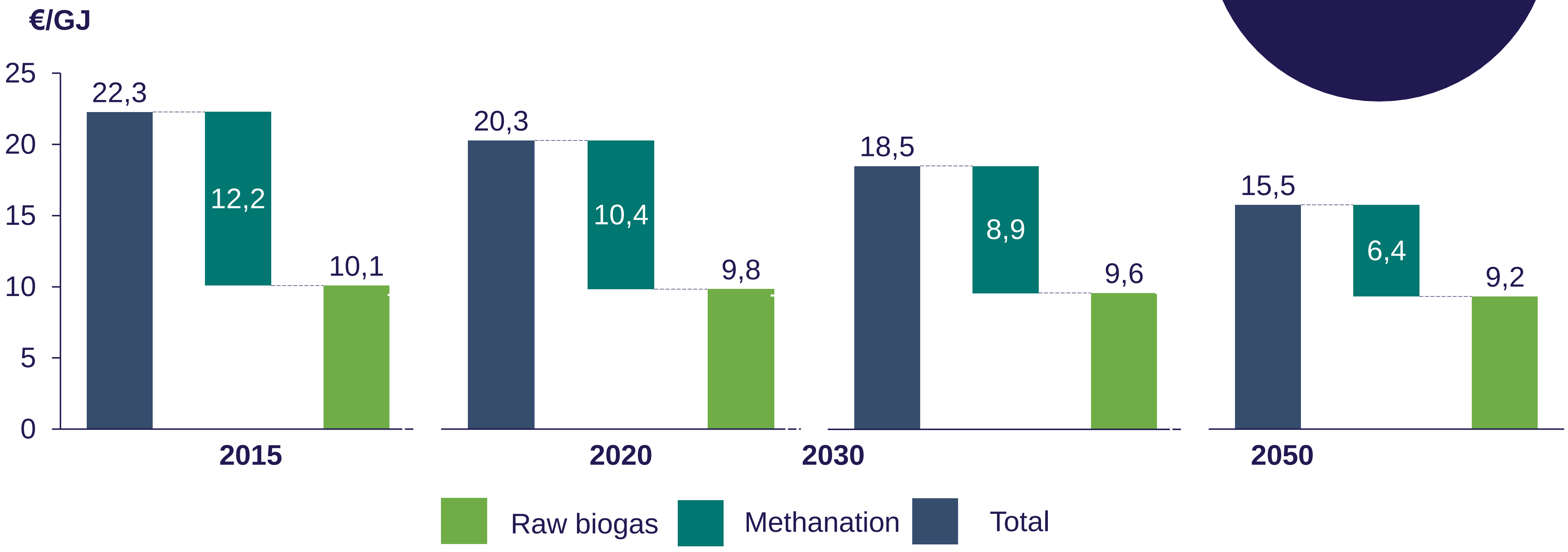
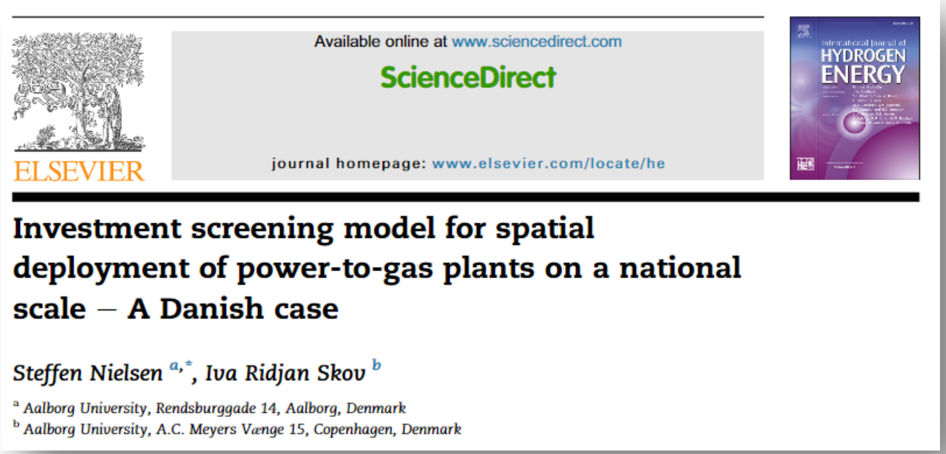
Biogas methanation

FINAL CONSUMER NG PRICE EU28 (2017): HOUSEHOLDS 16.2 €/GJ INDUSTRY 7 €/GJ



**Assumed free manure for biogas production, and 96% technical availability of the methanation plant. Electricity cost for hydrogen production via alkaline electrolysis 63.6% efficiency included with price for onshore wind.*

Locations for P2Methane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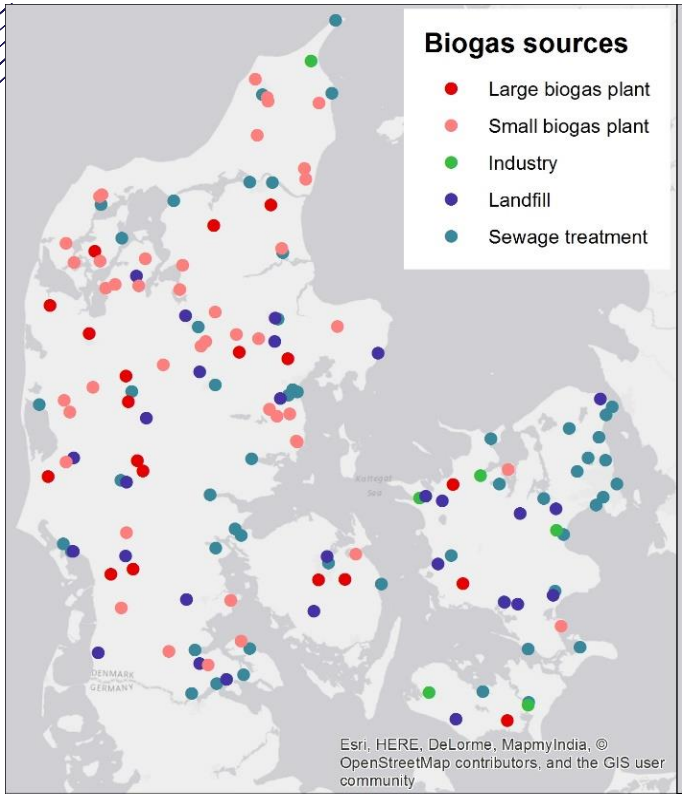
International Journal of HYDROGEN ENERGY

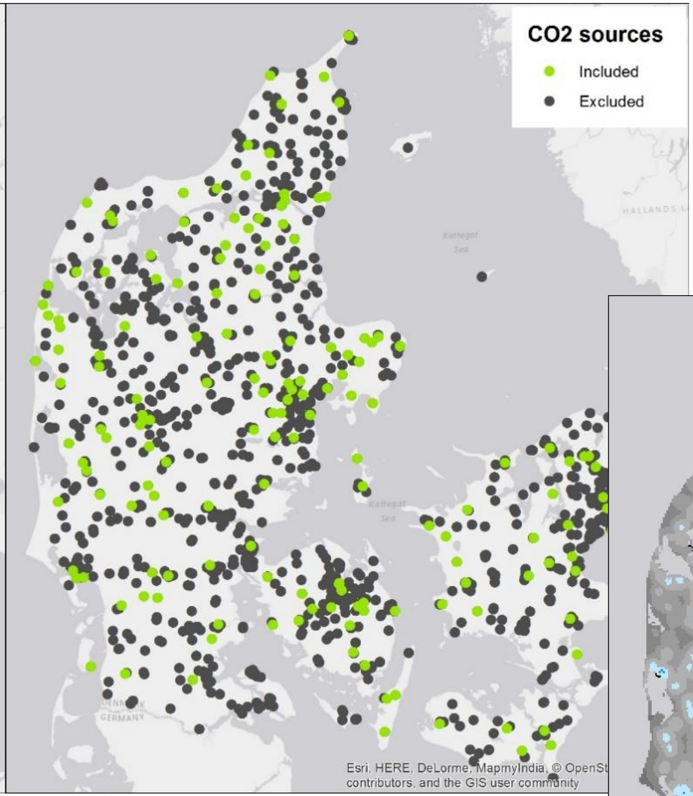
Investment screening model for spatial deployment of power-to-gas plants on a national scale — A Danish case

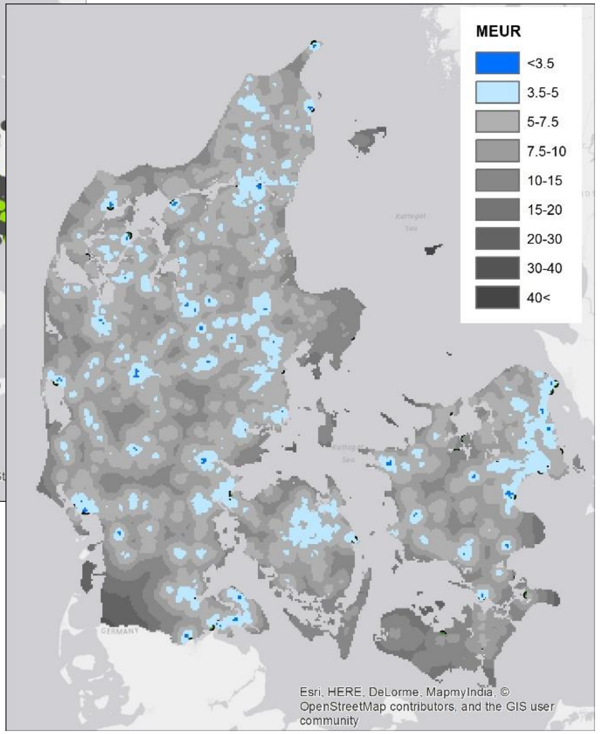
Steffen Nielsen [a,*], *Iva Ridjan Skov* [b]

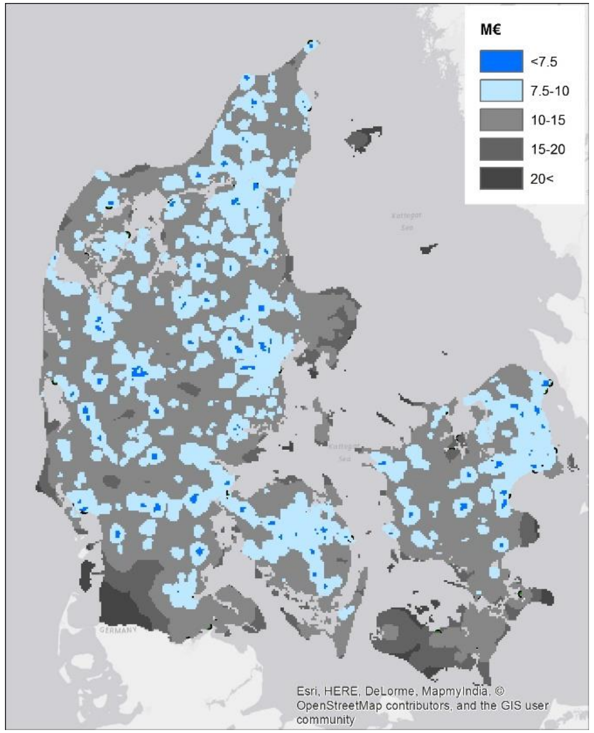
[a] Aalborg University, Rendsburggade 14, Aalborg, Denmark

[b] Aalborg University, A.C. Meyers Vænge 15, Copenhagen, Denmark









Both biogas methanation and CO_2 methanation

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The role of future gas grids

- Existing natural gas networks can handle max 20% of H_2 in the pipeline
  - What the carbon steel natural gas pipes can handle due to the material properties.
- Very few modification necessary if the hydrogen concentration is below 15%

The role of future gas grids

Danish grid tests

- In case the grid is connected to either filling stations, gas turbines or any gas engines, the percentage of hydrogen that can be tolerated drops to 2%.
- **Previous conclusion:**
  - maximum of 2% can be injected into natural gas grids if connected to CNG filling stations;
  - maximum of 5% if the grid is not connected to CNG filling stations, gas turbines and most gas engines;
  - maximum of 10% if the grid is not connected to filling stations, gas turbines and or gas engines.

Advantages of electrofuels

- Improved flexibility of the system
- Cross-sector integration
- Flexibility of fuel choice
- Conversion of electricity into form of liquid or gaseous fuels
- Reduction of CO_2 emissions in case of CO_2 recycling pathways
- Reduction of biomass usage for fuel production in case of biomass hydrogenation
- No big infrastructure adaptations

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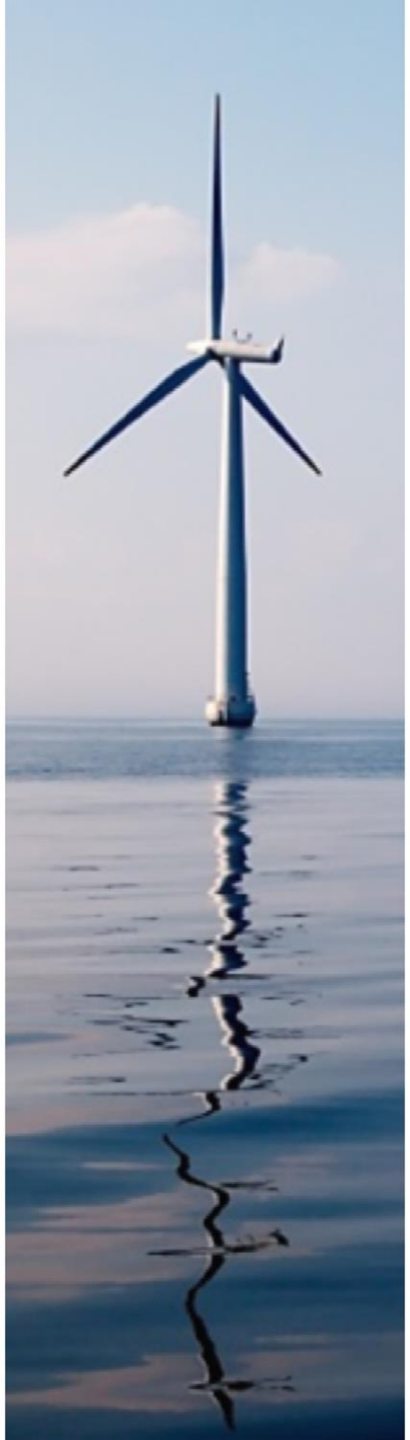

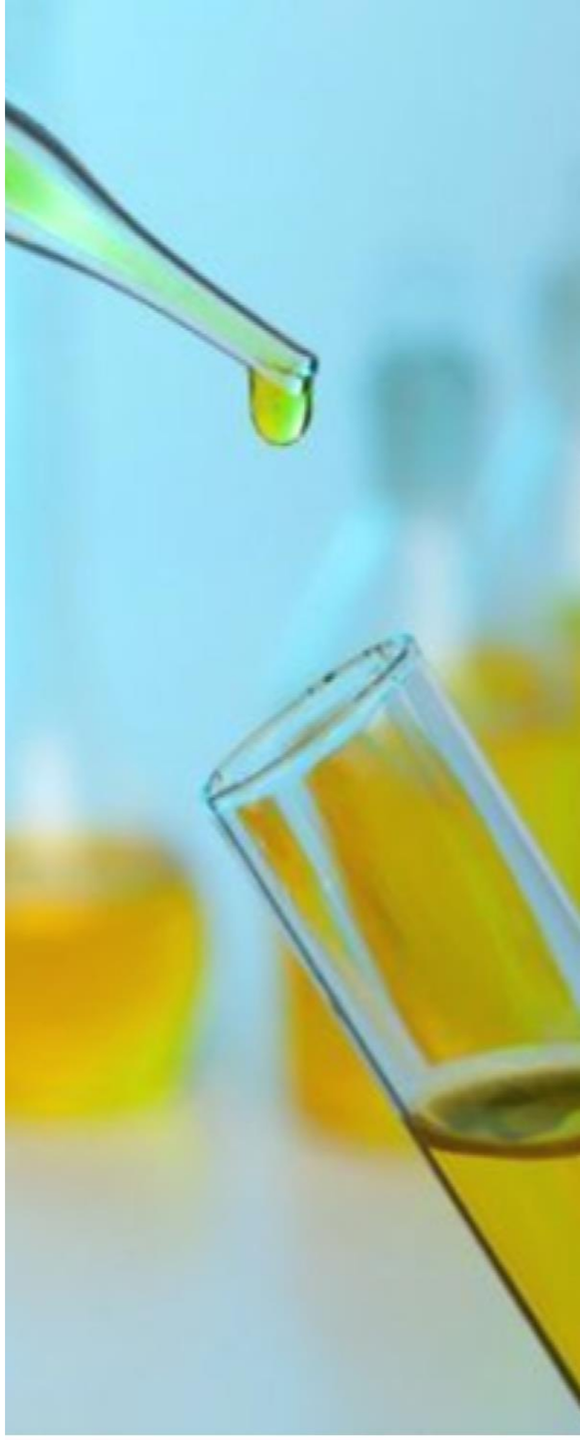

Any questions?

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