

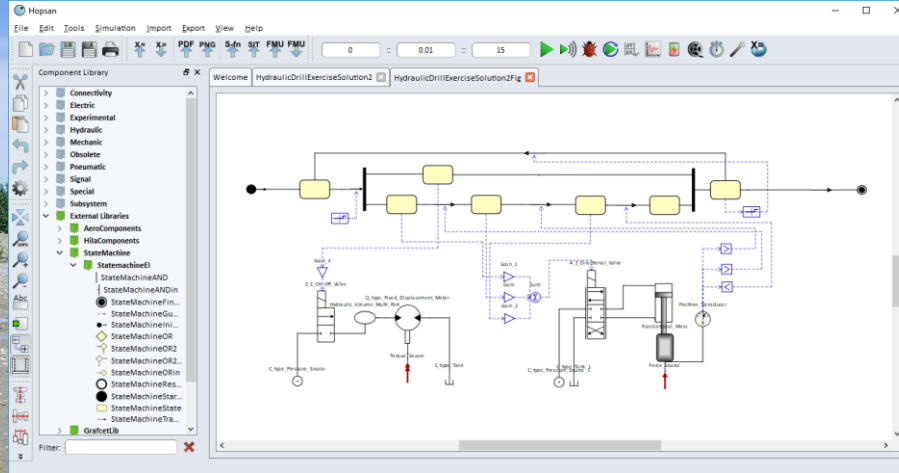
Petter Krus, LiU

# POWER FOR AVIATION AND RELATED AREAS



# LiU/Fluid and Mechatronic Systems

- Research in fluid power (hydraulics), mobile applications
- Aircraft system design

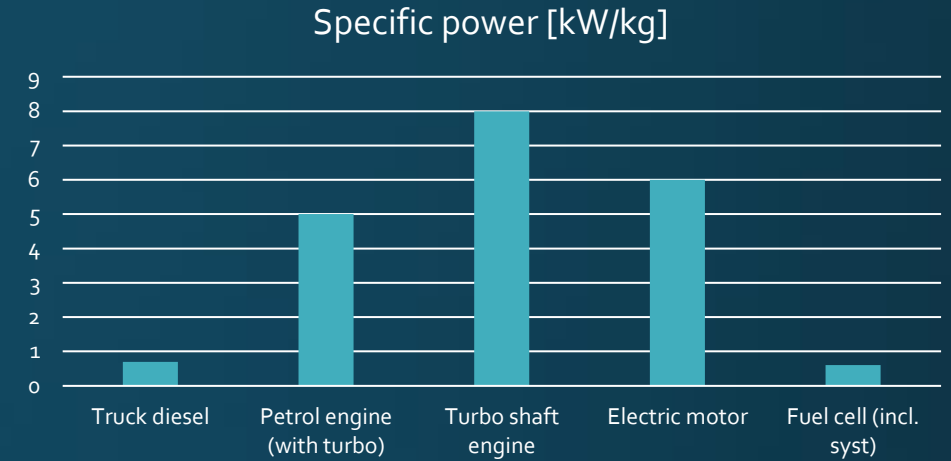


# Flyget i proportion till annat

- Svenskars flygande 2019 ca 10 milj ton CO<sub>2</sub>
- Svenskars bilåkande 2019 ca 10 milj ton CO<sub>2</sub>
- SSABs direkta CO<sub>2</sub> utsläpp på 9,8 miljoner ton
- Tunga vägtransporter 5 milj ton CO<sub>2</sub>
- Arbetsmaskiner 3.5 milj ton CO<sub>2</sub>
- Fartyg till och från Sverige, 8 milj ton CO<sub>2</sub>

# Specific Power

Truck diesel	0.7 kW/kg
Petrol engine (with turbo)	1-8 kW/kg
Turbo shaft engine	6-10 kW/kg
Electric motor	1-10 kW/kg
Fuel cell (incl. syst)	0.4-0.8 kW/kg
1932 Pratt & Withney	1.2 kW/kg



GeeBee racer 1932  
Max speed 476 km/h  
Engine 50% of empty weight



Saab 340  
Max speed 502 km/h  
Cruise 467 km/h  
Engine 5% of empty weight



# Specific Energy

	Specific Energy	Energy density
Kerosene (about the same as petrol and diesel)	12000 Wh/kg	9200 Wh/l
Battery (Tesla, pack level)	177 Wh/kg	711 Wh/l
Hydrogen	30000 Wh/kg	2800 Wh/l
Pressurized Hydrogen tank (700 bar)	3000 Wh/kg	767 Wh/l

# Efficiency

Fuel cell+electric motor  
comparable to combustion  
engine

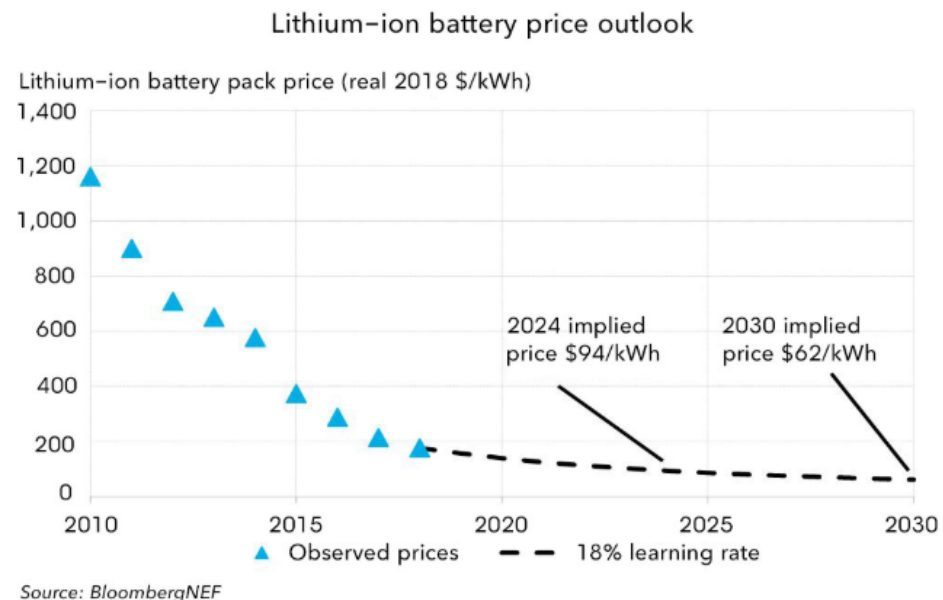
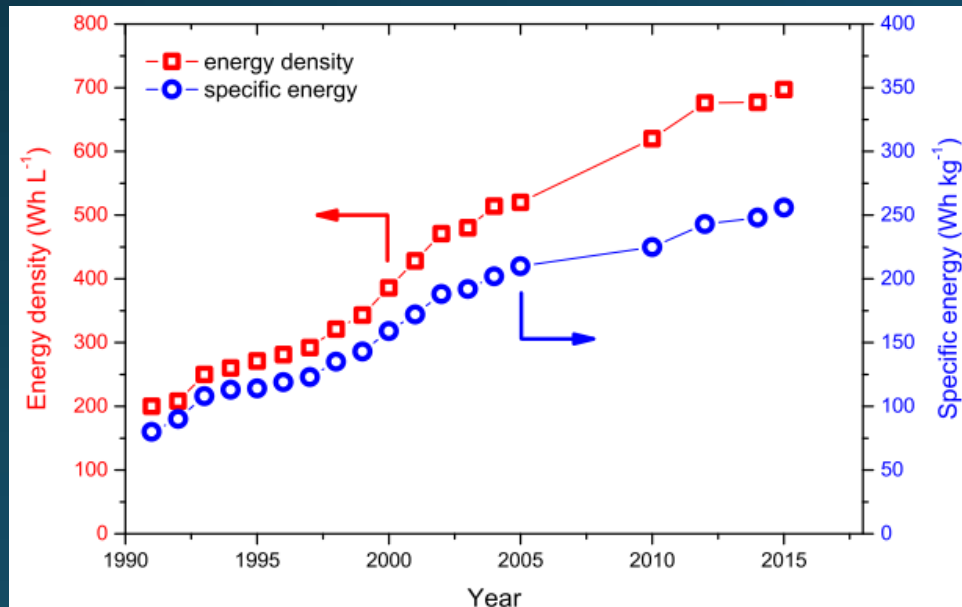
Truck diesel	0.4
Petrol engine (with turbo)	0.25
Turbo shaft engine	0.5
Electric motor	0.95
Fuel cell (incl. syst)	0.4-0.6
Battery	0.96

# Technology Forecasting:

## Batteries for Electric Cars

- Assuming incremental refinement of Li-ion technology
- (Placke et al., 2017) suggests about 3 Wh/kg/year.

• 2019	156 Wh/kg	135USD/kg	=1283 SEK/kg
• 2024	171 Wh/kg	94USD/kg	=902 SEK/kg

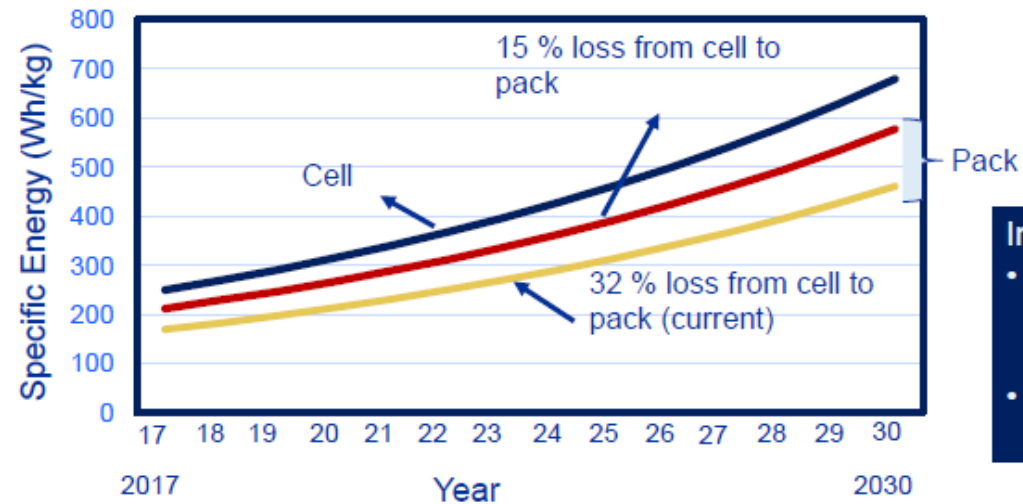


# Technology Forecasting for Aviation (NASA)

## Projected Advances in Battery Technology

Rate of increase in specific energy is typically on the order of 5 – 8% per year  
Specific energy loss from cell to pack is typically 50 to 60%

Assuming 8% increase per year at cell level

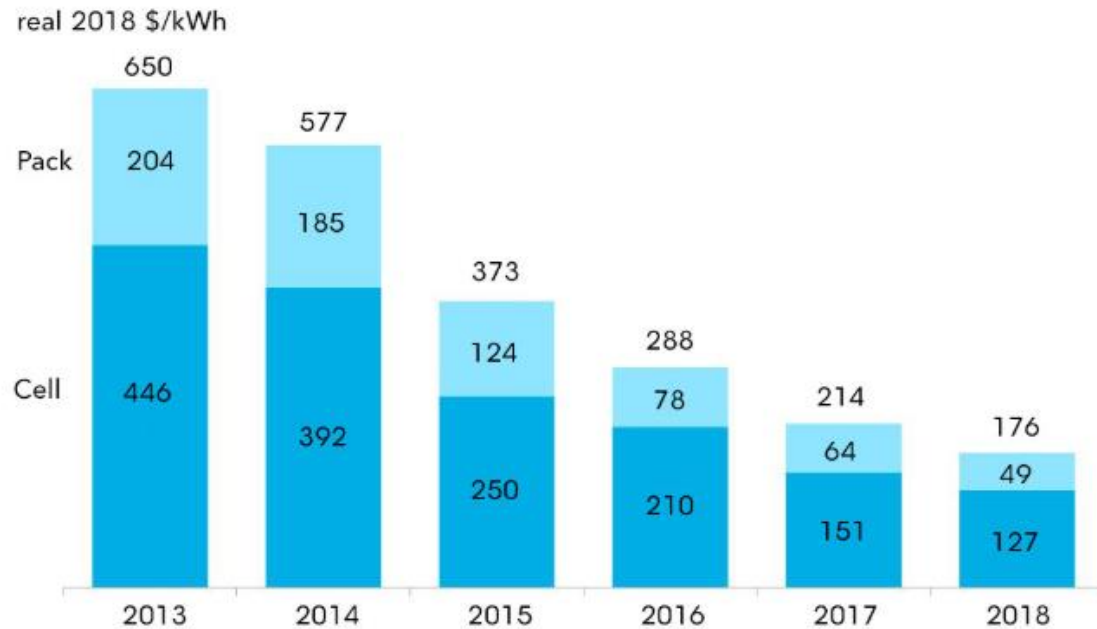


- Innovation required in:
- New chemistries and materials for cells
  - Pack design and integration



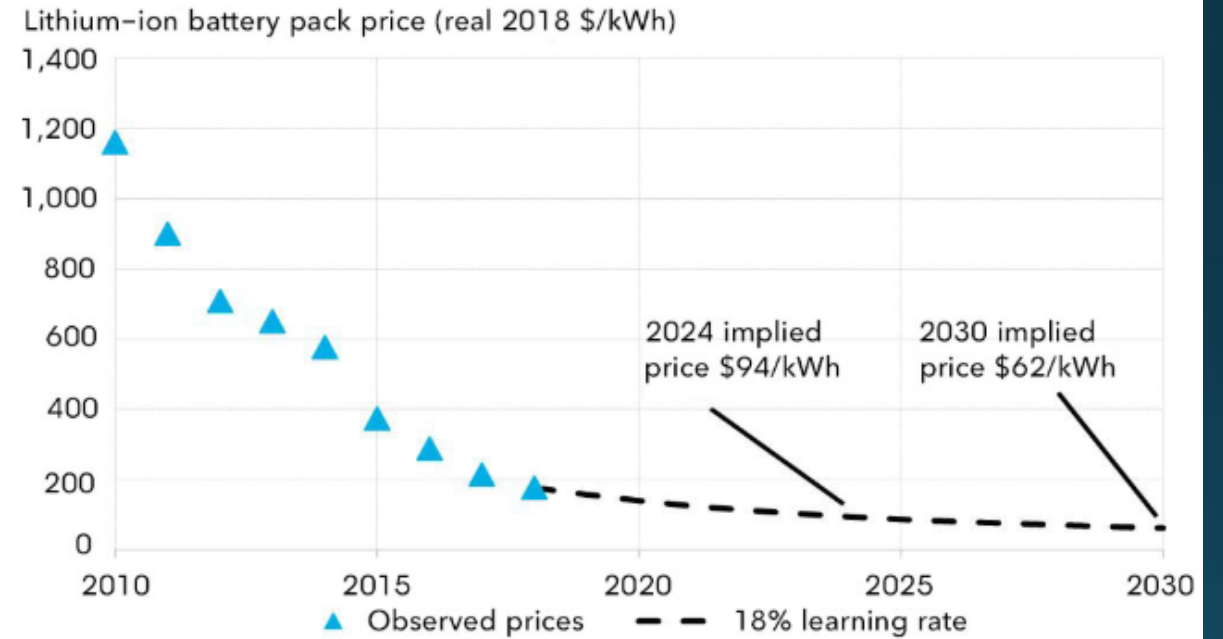
# Battery cost

Lithium-ion battery price survey: pack and cell split



Source: BloombergNEF

Lithium-ion battery price outlook



Source: BloombergNEF

# Electric Trucks



Cars are rapidly going into the technology comfort zone for batteries.



Short and medium range trucks could use battery.  
*Technology comfort zone*



Long haul trucks requires 4.5 h driving and 45 min rest.



A 40 ton long haul truck could do this with about 2 ton of batteries (4 with reserves). 10% should be doable if required.  
*Technology sensitive*

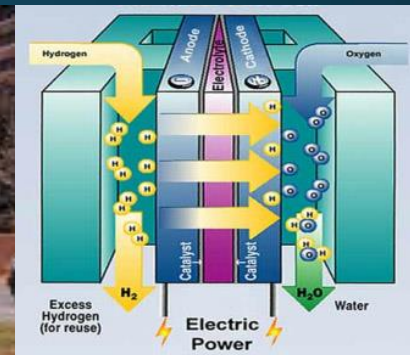


Would require charging of >0.5MW.



Fire safety?

- Hydrogen storage and Fuel cells could be a viable option.
- System weight would be between that for a diesel truck and a battery truck
- Electric roads? ...not likely, huge investment (60-100 billion SEK in Sweden)...



# Electric Construction Machines

- Excavators have an average power much less than trucks.
- A workday on a battery charge could be done. *Technology sensitive*
- Construction on sites often without a charging infrastructure.
- Fuel cell is interesting.



# Aircraft

- Burning hydrogen directly in the engines.
- Hydrogen storage system is a problem especially for long haul (low energy density, J/m<sup>3</sup>)
- Airbus points at this for short and medium range aircraft.
- Battery is hardly relevant
- An optimistic theoretical range is about 560km with 50% takeoff weight with batteries. Commercial range means that an alternative airport should be reached and an extra 45 min loitering, severely restricting the operations making it CO<sub>2</sub> irrelevant.
- *Technology critical/impossible*



Airbus concept  
from 2001

# Aircraft

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Fuel cells have low power density making it useful for only slow aircraft (commuters). *Technology sensitive*

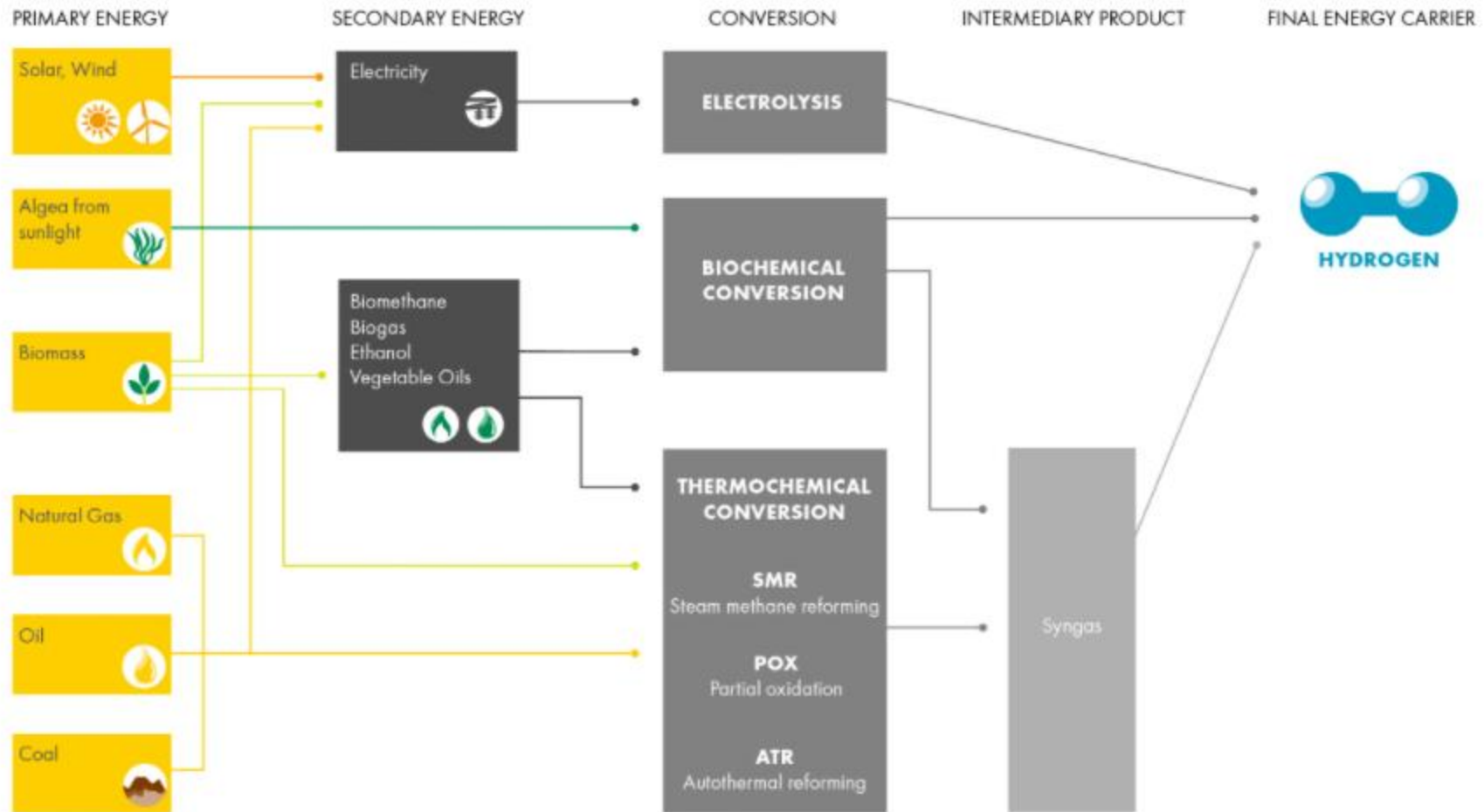
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They have to compete head-on with hydrogen burning aircraft of comparable efficiency.

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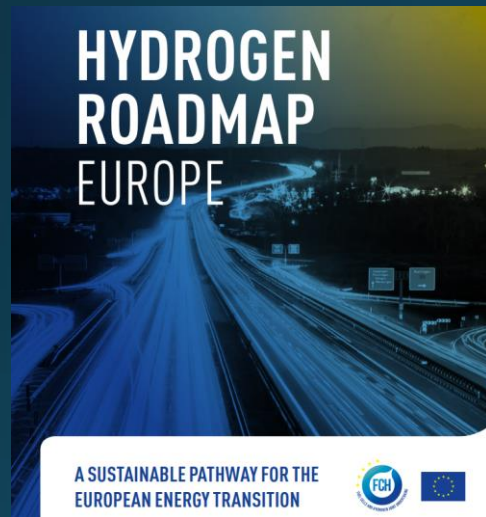
Business case have to build on secondary aspects, e.g. maintenance.

# Hydrogen Production



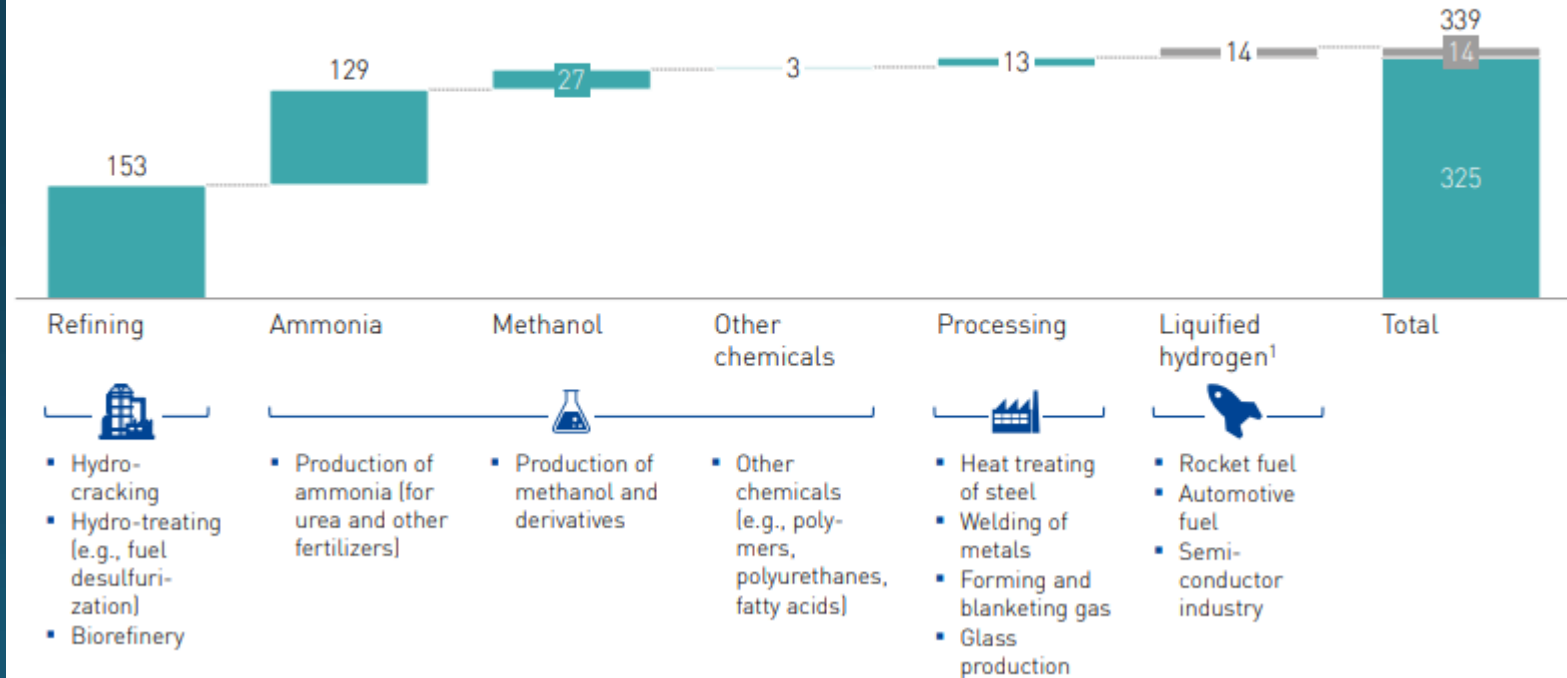


# Hydrogen use today

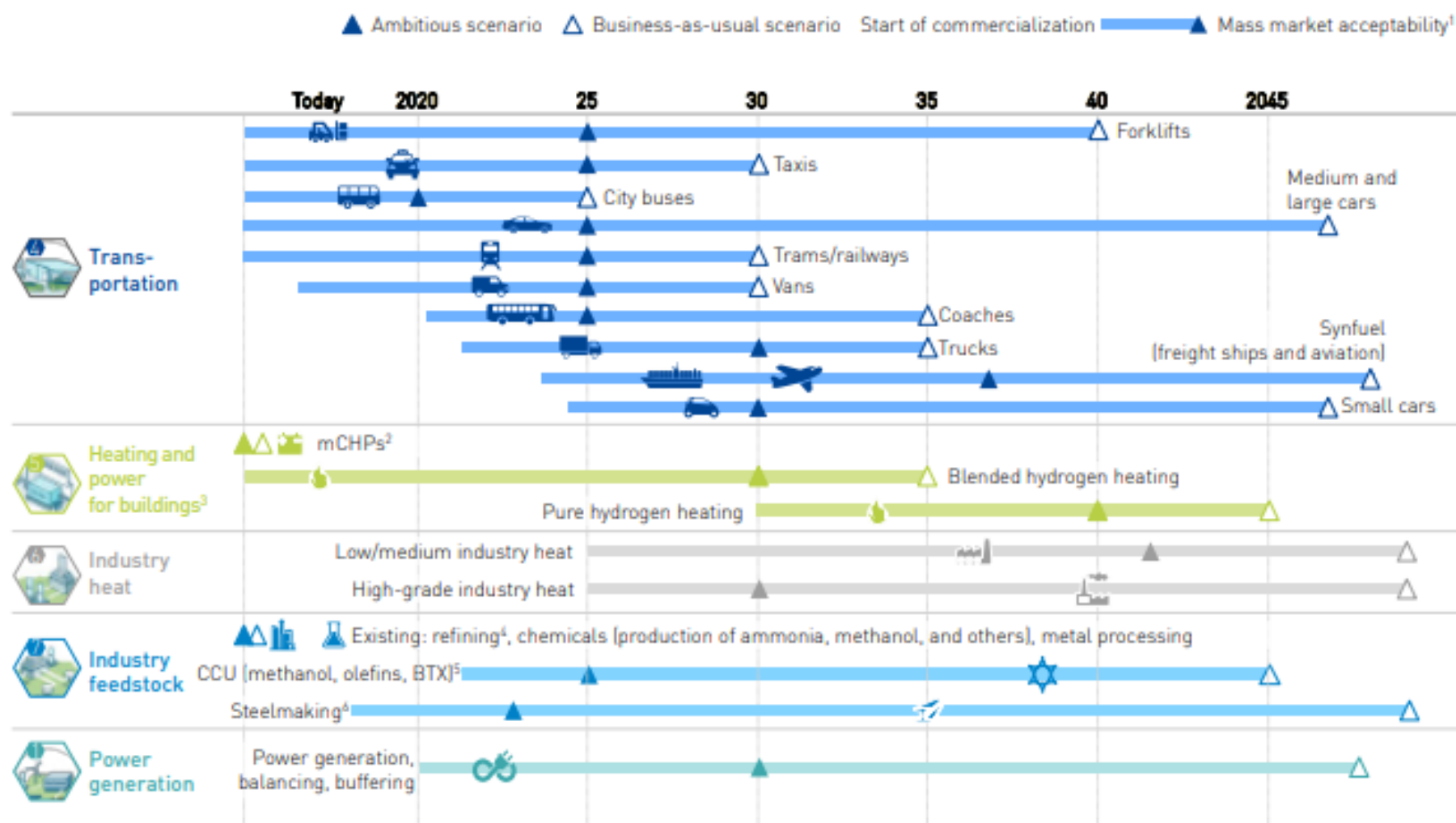


## EXHIBIT 17: USE OF HYDROGEN TODAY

Total hydrogen use in the EU, in TWh



## EXHIBIT 20: HYDROGEN TECHNOLOGY EXISTS AND IS READY FOR DEPLOYMENT



<sup>1</sup> Defined as sales >1% within segment    <sup>2</sup> mCHPs sales in EU independent of fuel type (NG or H<sub>2</sub>)    <sup>3</sup> Pure and blended H<sub>2</sub> refer to shares in total heating demand

<sup>4</sup> Refining includes hydrocracking, hydrotreating, biorefinery    <sup>5</sup> Market share refers to the amount of production that uses hydrogen and captured carbon to replace feedstock

<sup>6</sup> CDA process and DRI with green H<sub>2</sub>, iron reduction in blast furnaces, and other low-carbon steelmaking processes using H<sub>2</sub>



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# Hydrogen Xchange

## Hudiksvalls Hydraulikkcluster HHK & region Gävleborg

- Fri 2020-12-11 13:00 – 16:20
- Seminarium med Sandvik, FCH (Fuel Cells and Hydrogen Joint Undertaking), Region Gävleborg mfl.