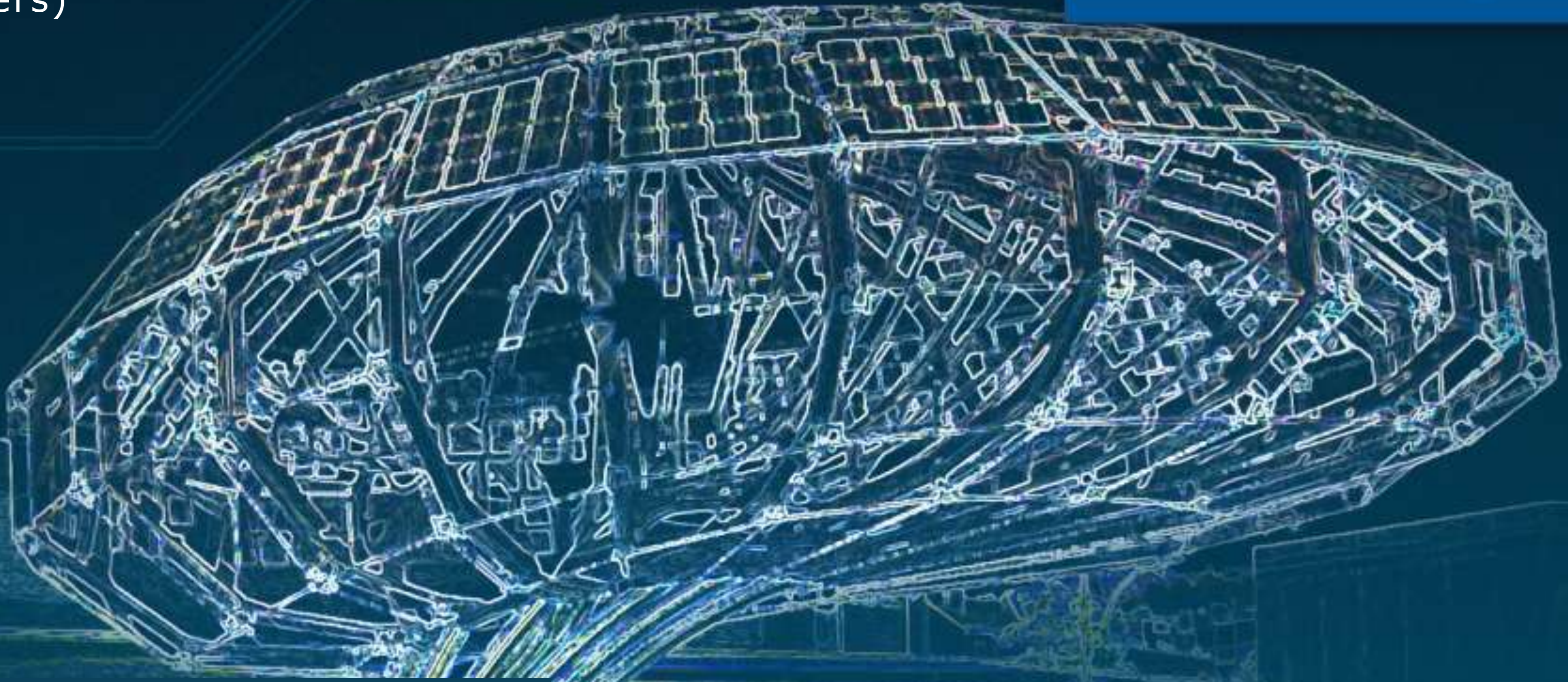
AVL List GmbH (Headquarters)



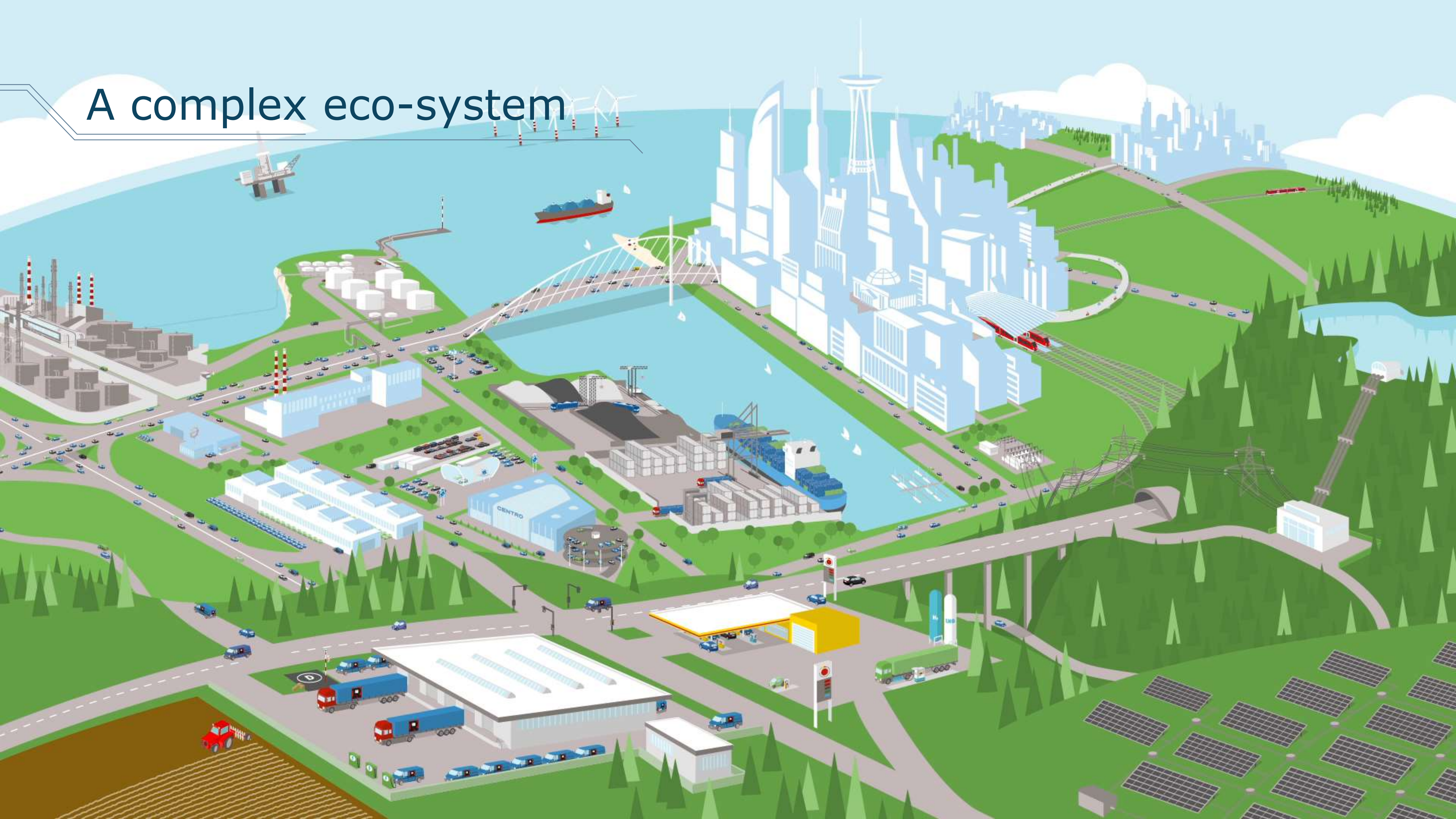
Energy Landscape

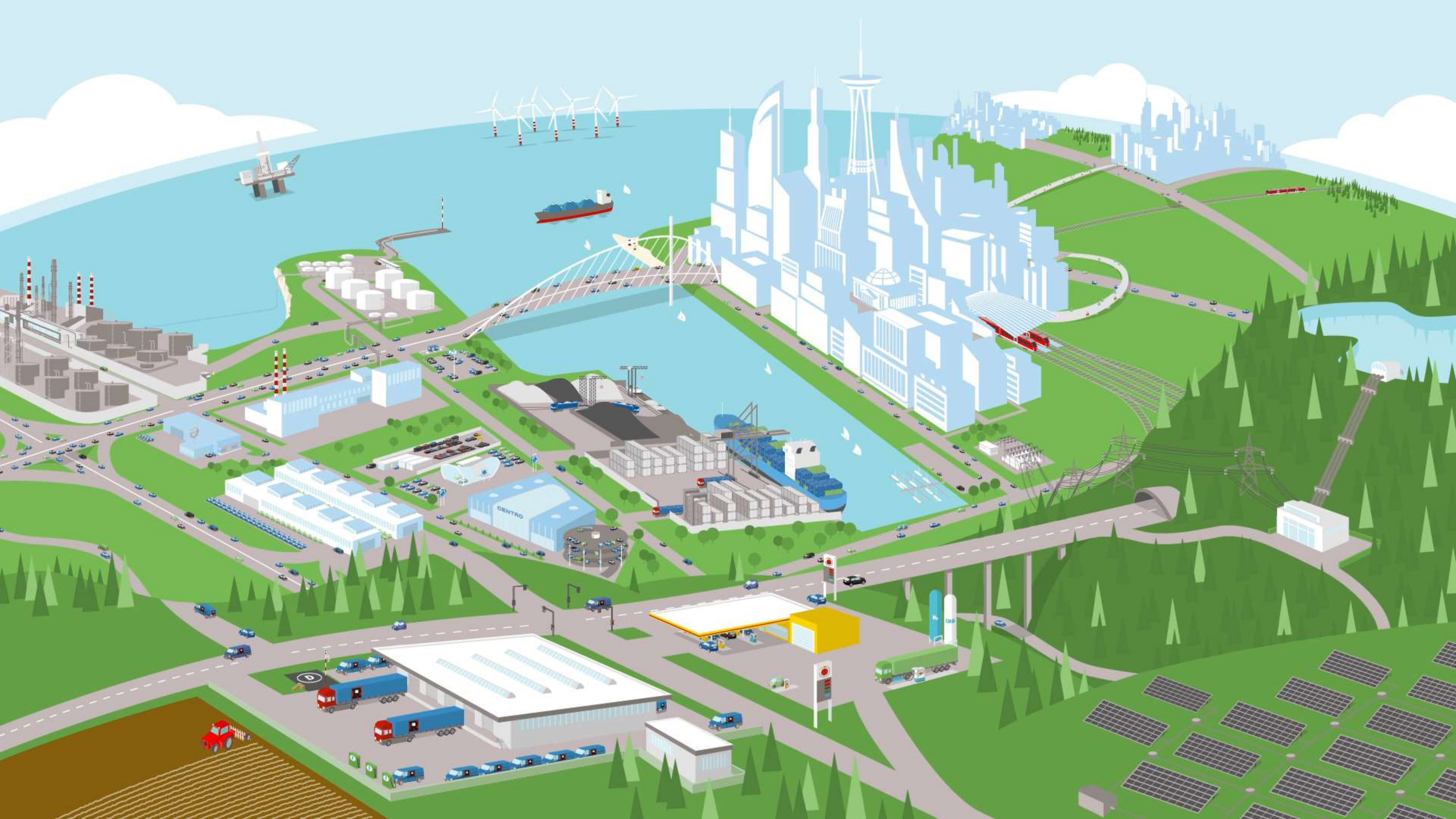
How is the energy sector influencing the future powertrain?
Product Development in Motion, 28/11/2019, Gothenburg

Martin Rothbart

Public

A complex eco-system

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Energy Availability

Annual Global Energy Potentials

2019 | 2020 | 2021 | 2022 | 202

- Solar 23,000 TWy
- Wind 75 – 130 TWy
- Biomass 2 – 6 TWy
- Hydro 3 – 4 TWy
- Geothermal 0.2 – 3 TWy
- Wave 0.2 – 2 TWy
- Tidal 0.3 TWy

World Energy Consumption

18.5 TWy

Total Reserves

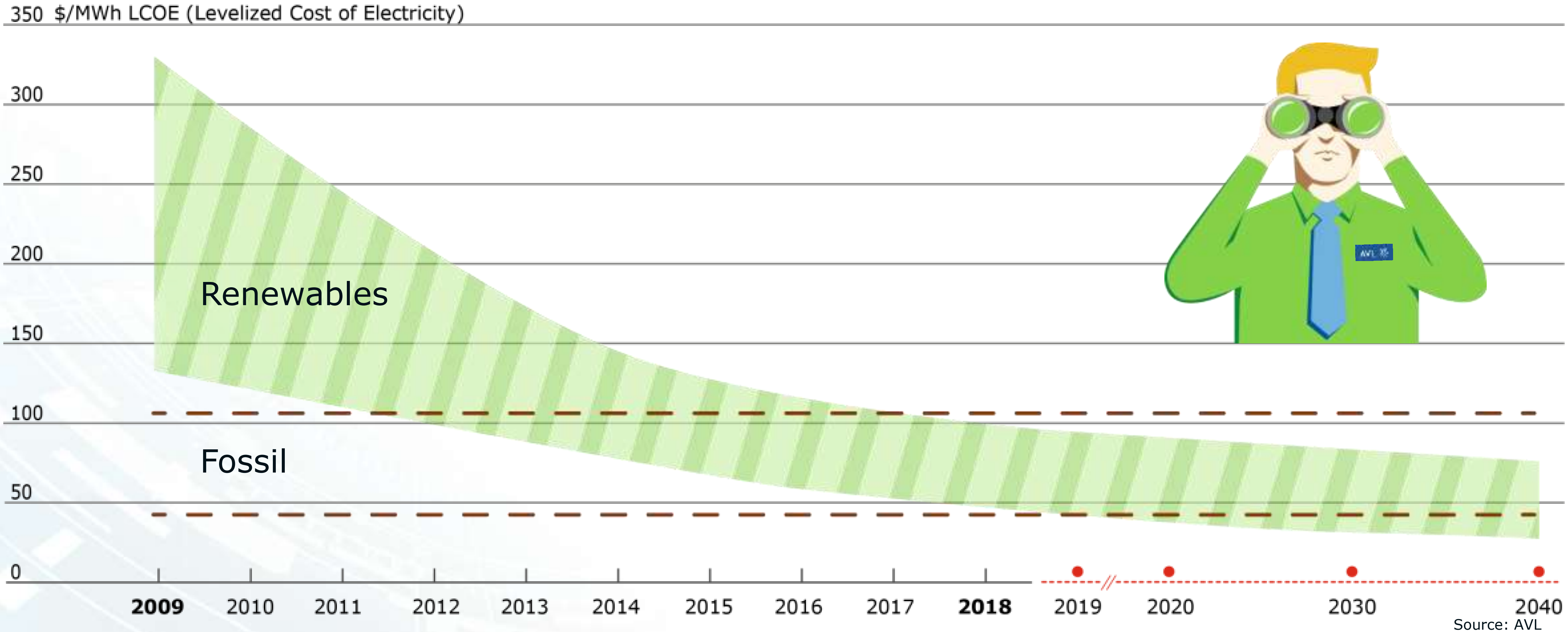
- **220** TWy — Natural Gas
- **335** TWy — Oil
- **185+** TWy — Uranium
- **830** TWy — Coal

Source: Perez, A fundamental look at energy reserves for the planet, 11/2015

1TWy … 1 Terra Watt year equals 8766 Terra Watt hours

Energy Reserves are much higher than the global demand – The challenge is how to harvest and store them for further use

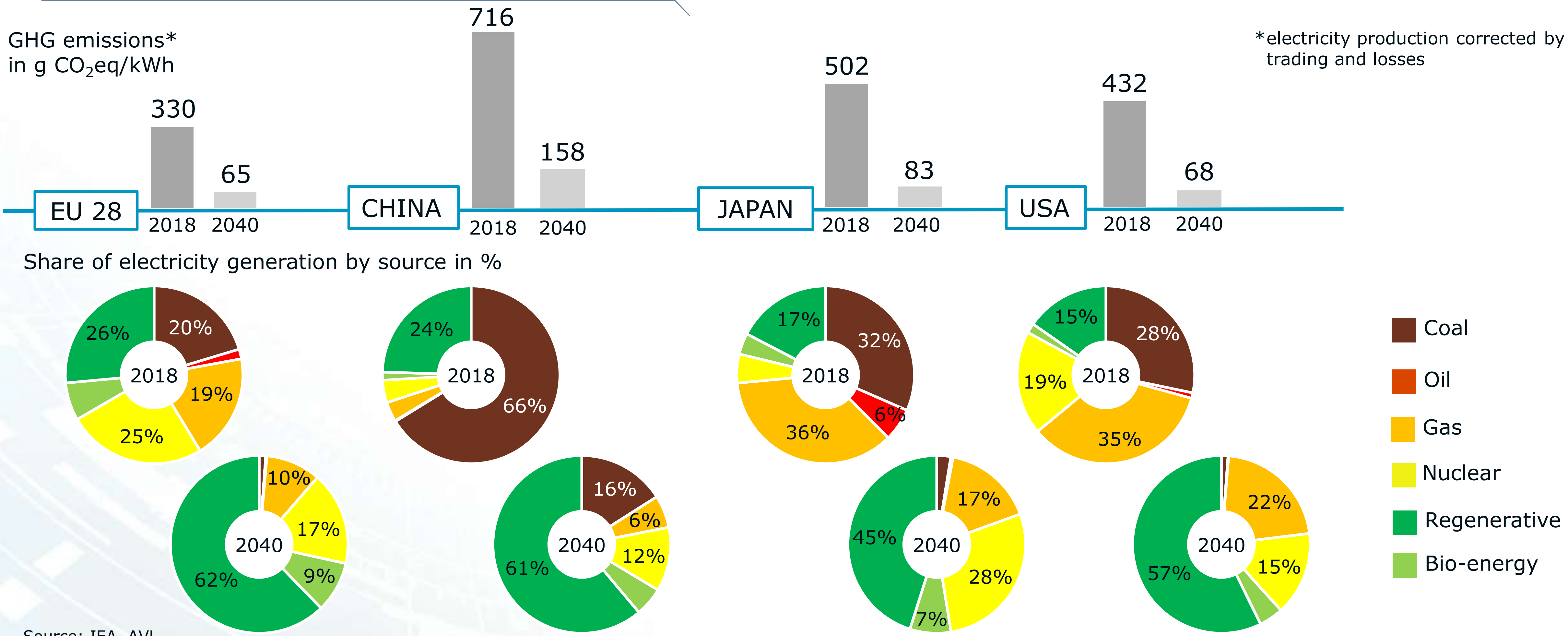
Primary Electricity Sources Cost Predictions



Source: AVL

The costs of renewable electricity are already in the same range as electricity from fossil sources – BUT intermittency of renewables an issue

GHG Emissions of Electricity Production



Source: IEA, AVL

Power Sector plans to be 75 – 90 % less carbon intense in 2040

Wind energy in Germany

- Quantity: 30,518 turbines[1)]
- Capacity: 59,313 MW[1)]
- Electricity production 2018: 108.3 TWh[1)]
  - (20% of the total energy production)

Source: 1) Deutsche WindGuard GmbH, 2018, Onshore and Offshore, with grid connection

Intermittency: The energy is available when the wind blows!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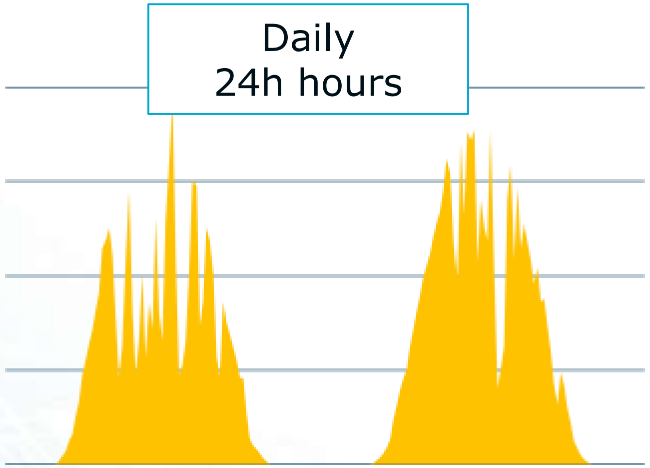
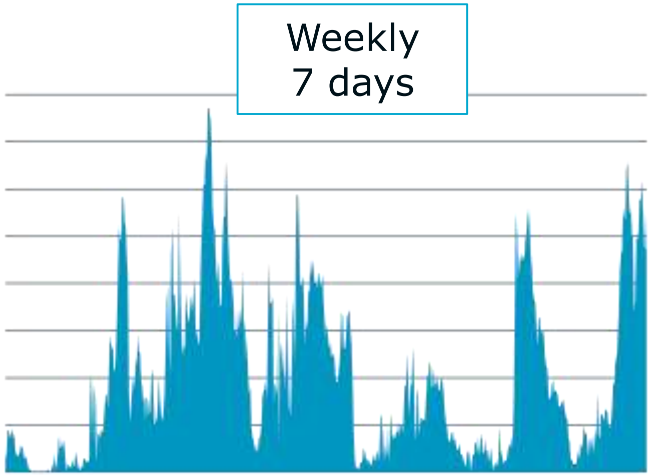
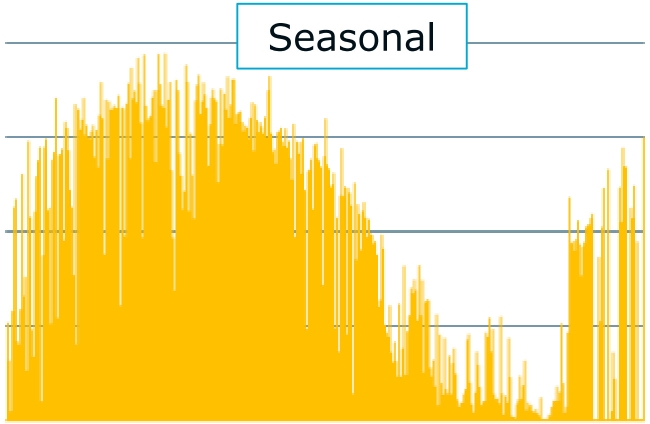
Intermittency – Variability of renewable energy



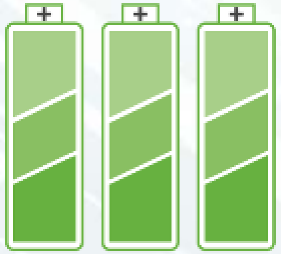
Source: PV park Germany, 99.6kW



Source: wind park Germany, 2000kW



Source: PV park Germany, 99.6kW



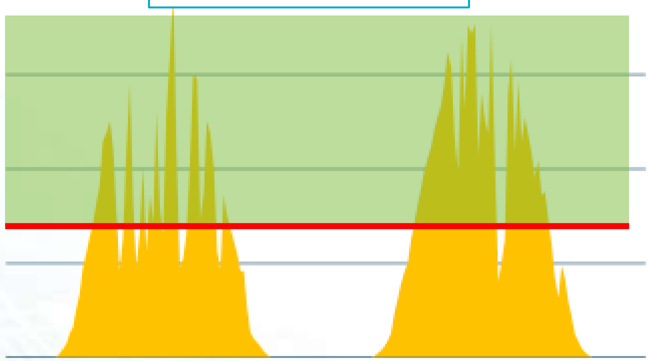
Electrochemical Storage (Decentral)

Chemical Storage (Central)

Different types of intermittency require energy storage methods adapted to the use case

Intermittency – Variability of renewable energy

Daily
24h hours

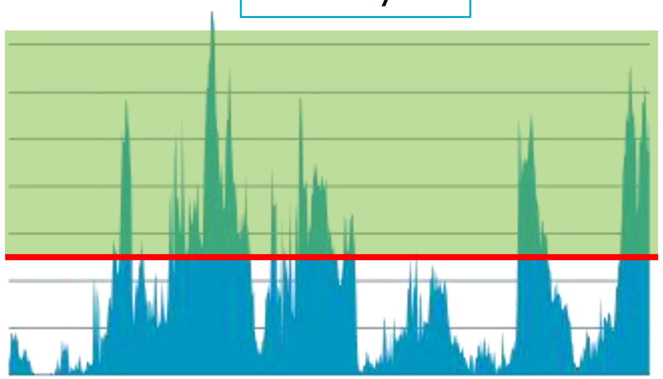


Source: PV park Germany, 99.6kW

318 kWh

7.8 kg H_2
1027 km with Toyota Mirai

Weekly
7 days

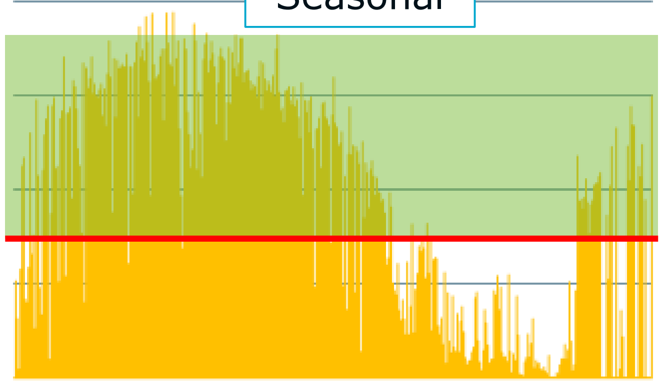


Source: wind park Germany, 2000kW

12 MWh

286 kg H_2
37,670 km
2.5 Toyota Mirai’s for one year

Seasonal



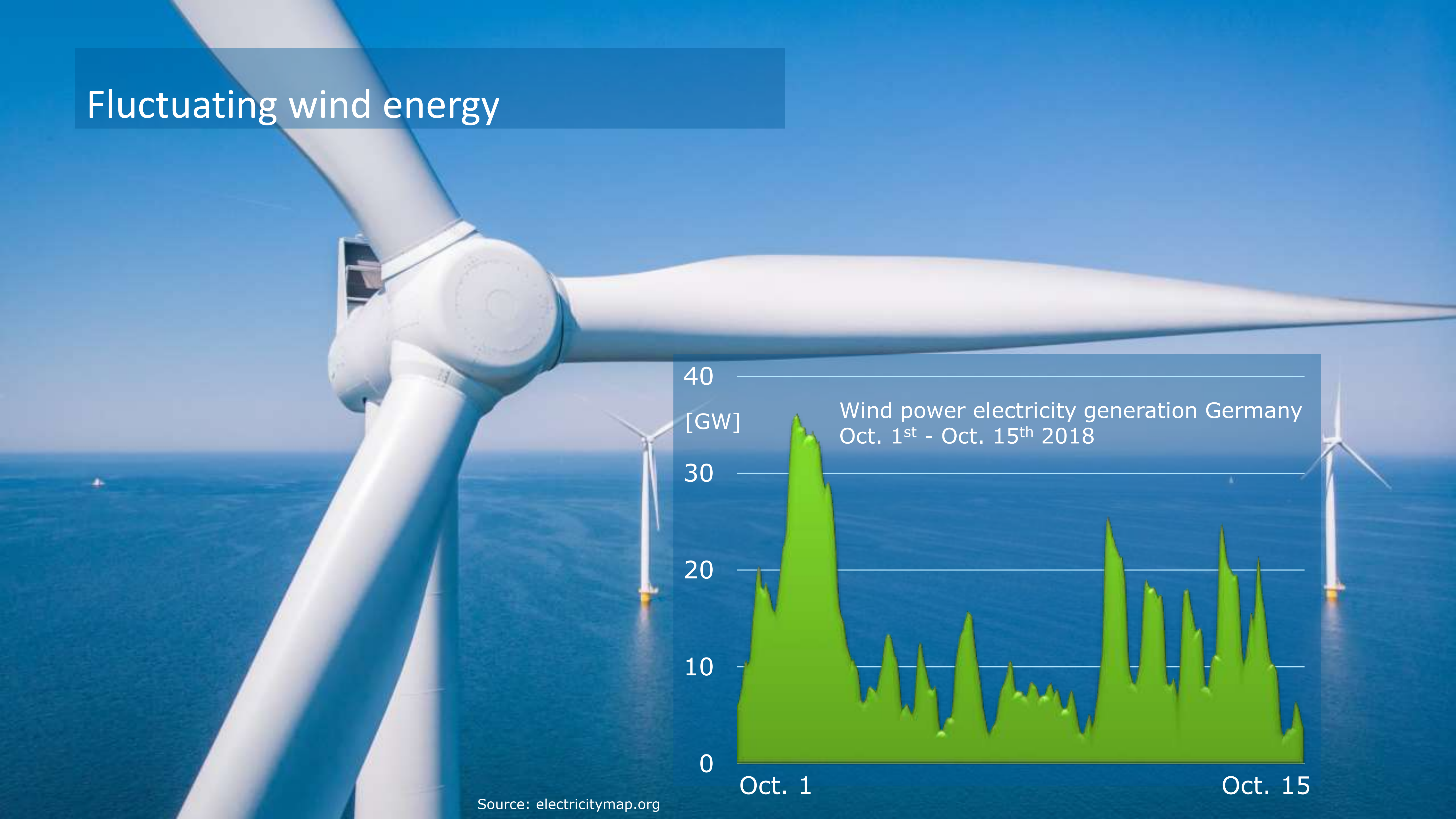
Source: PV park Germany, 99.6kW

24 MWh

583 kg H_2
77,780 km
5 Toyota Mirai’s for one year

Different types of intermittency require energy storage methods adapted to the use case

Fluctuating wind energy

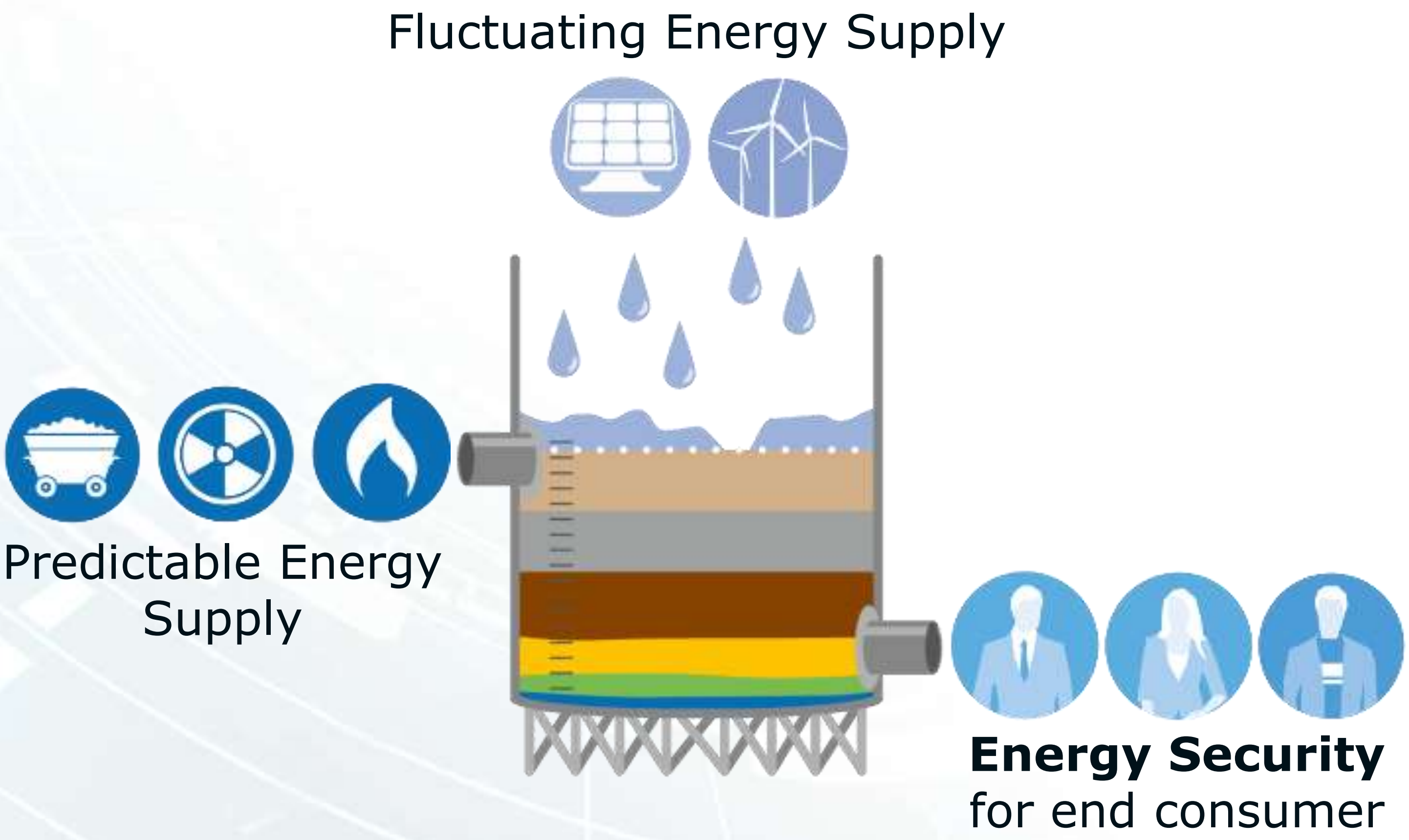


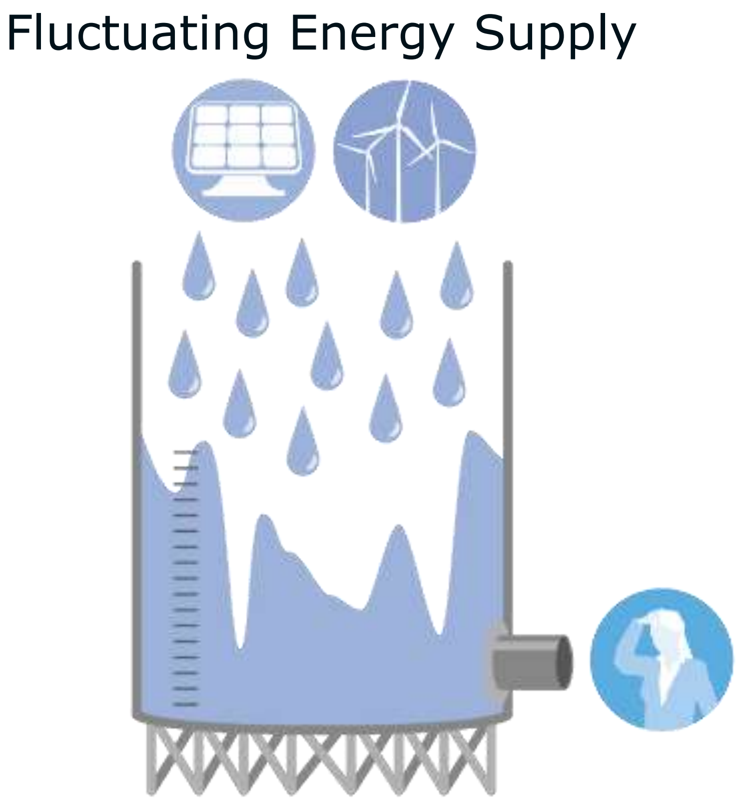
Source: electricitymap.org

Energy Storage Metaphor: Water-Tower

2019 Base load from fossil and nuclear, renewables are used on top

2050 Renewables are to fill base as well



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Options for Alternative Fuels

Natural Gas CNG/LNG

Use of clean burning fossil or bio gas

Biofuels

Conventional & advanced biofuels

Synthetic Fuels

PtX: Fuel produced from Renewable Energy

GtL: Liquid fuel from Natural Gas

Hydrogen

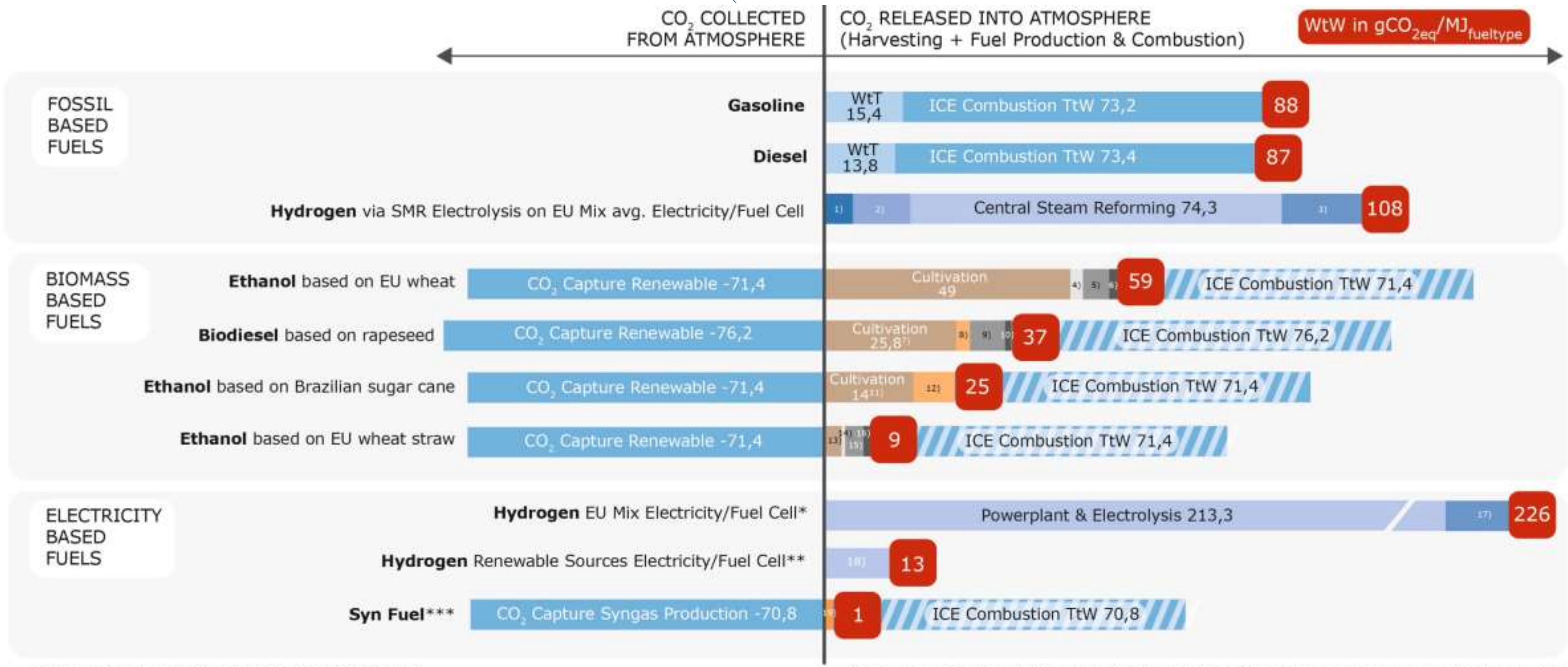
Steam methane reforming or Electrolysis for H_2 production – Fossil or Renewable

Electricity

Providing fossil or renewable Electrons to charge EVs

PtX … Power to Hydrogen, Gas or Liquid
GtL … Gas to Liquid

GHG Emissions for Fuels
Well-to-Tank / Tank-to-Wheel



(CO_2 equivalents) - all GHG emissions summed up to CO_{2eq}
Data based on JEC (WELL-TO-TANK Appendix 4 - Version 4a)

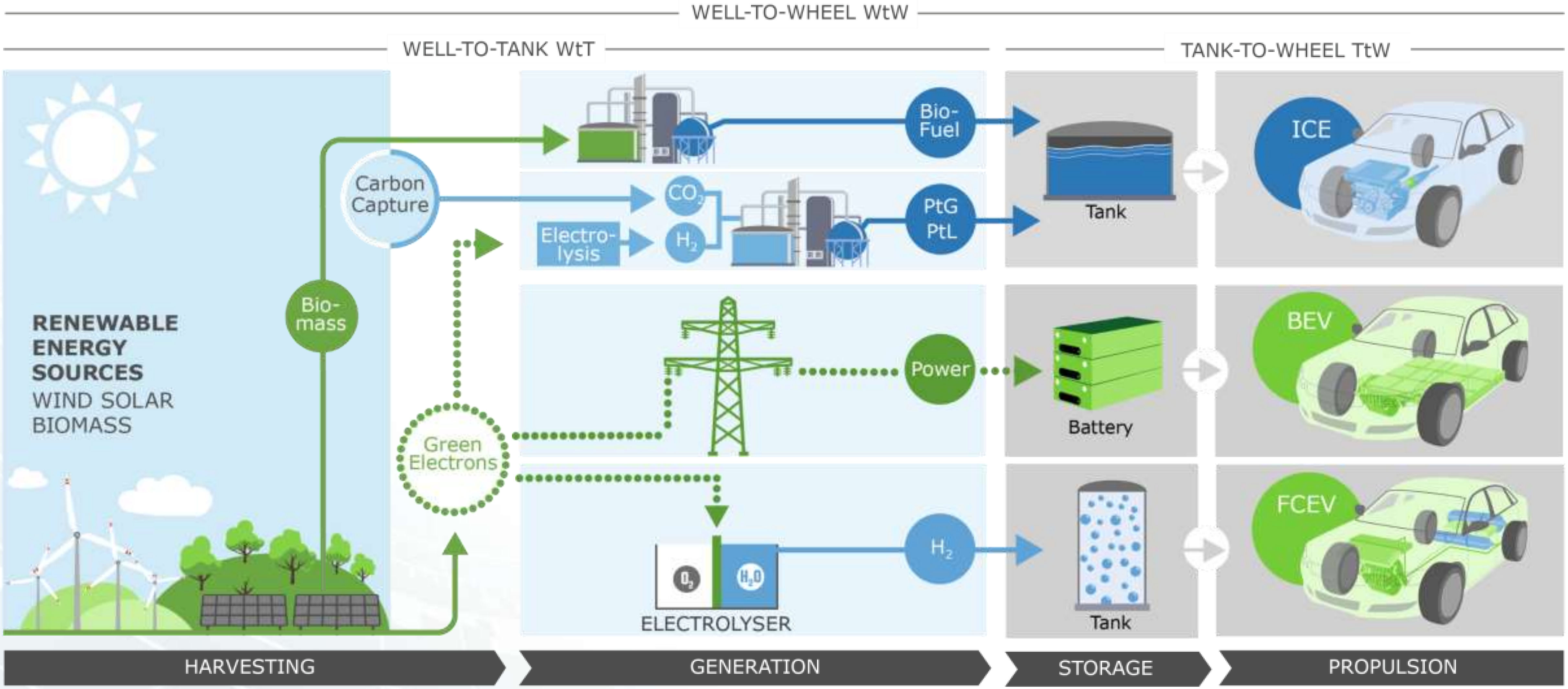
*High voltage supply, central electrolysis, 880 bar at Retail site.

**Central electrolysis, H_2 pipeline transport, 880 bar at Retail site. Fuel conditioning at dispencer based on avg. EU mix electricity.

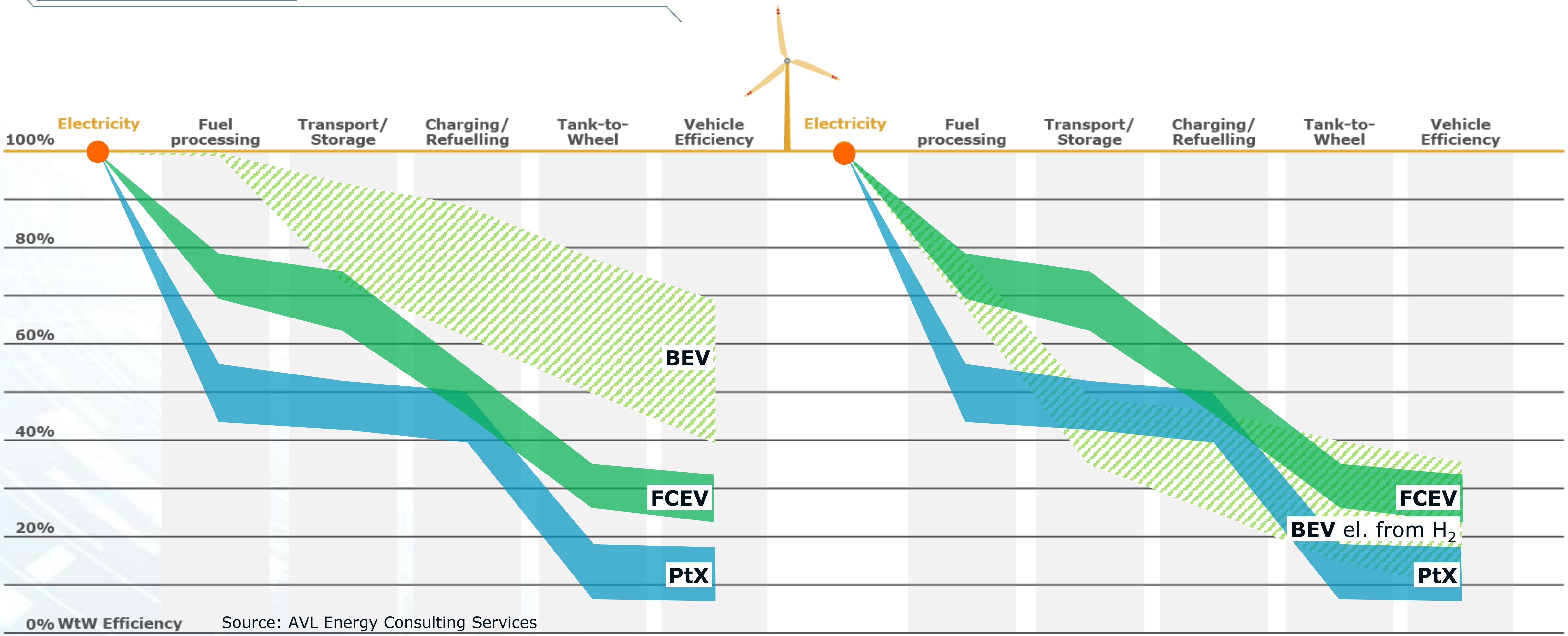
***Power to Liquid (ren. Electricity) to SynDiesel via methanol/CO_2 from flue gas. Fuel conditioning at dispencer based on avg. EU mix electricity.

[1] Natural gas production 5,6 / [2] Pipeline transport & distribution 11,5 / [3] Compression, road transport & compressionat retail site 16,8 / [4] Grain Prep & Transport 2,5 / [5] Ethanol Production 5,3 / [6] Distribution & Dispensing 1,7 / [7] 55g - 29,2 Rapeseed Oil production credits / [8] Rapeseed Drying & Transport 3,1 / [9] Biodiesel production 7,1 / [10] Transport, Distribution & Dispensing 1,3 / [11] 17,9 Cultivation - 3,9 Ethanol production credits / [12] Transport, Distribution & Dispensing 8,3 / [13] Straw Baling 3,1 / [14] Straw transport 0,7 / [15] Ethanol Production 3,7 / [16] Distribution & Dispensing 1,6 / [17] Compression & dispensing at retail site 13 / [18] Conditioning & Distribution 13 / [19] Fuel Distribution & Dispensing, EU electricity mix 1,3

Pathways to clean and sustainable Propulsion Systems



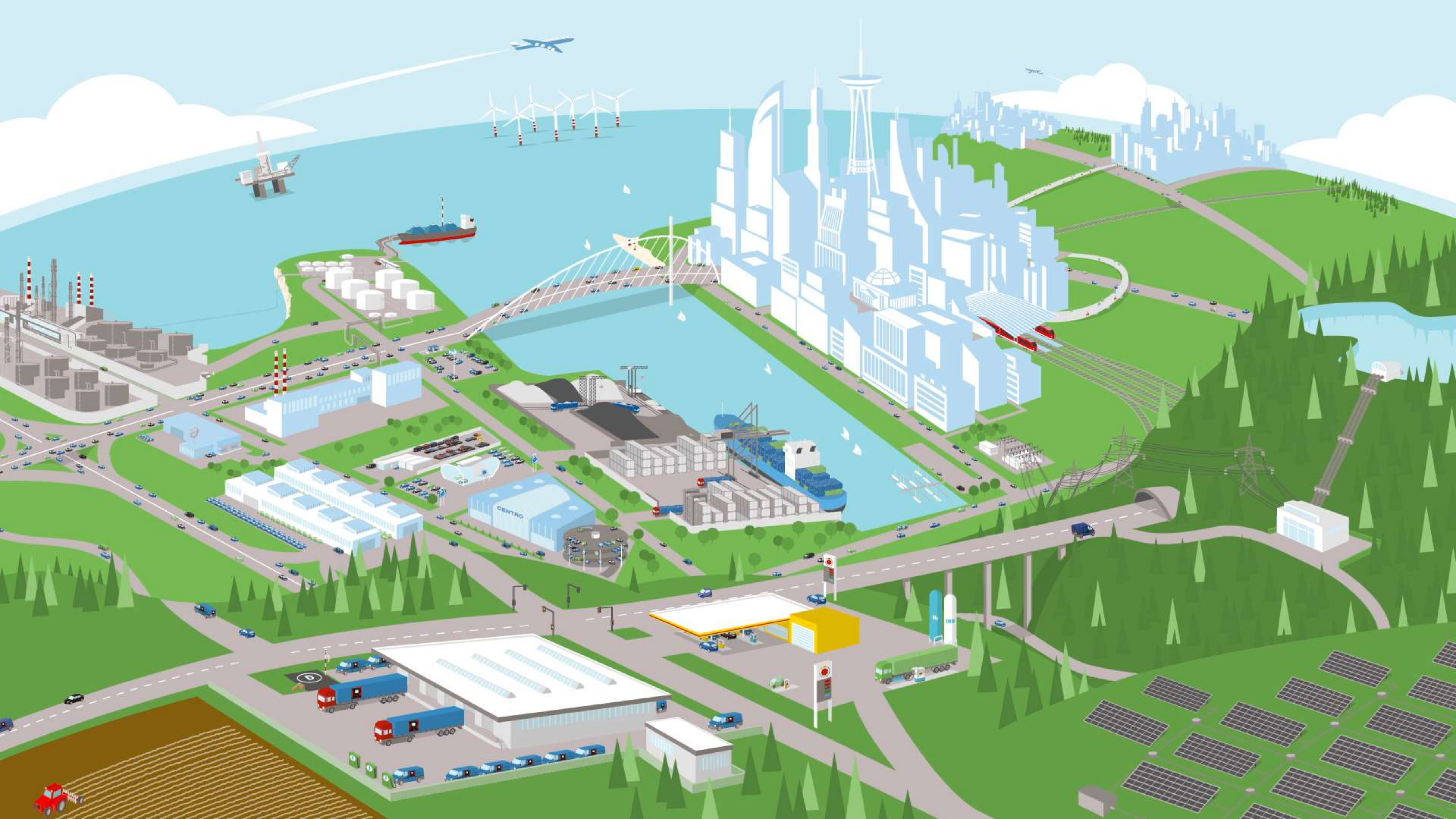
Efficiency Chain: from Source to Wheel (PC)



Source: AVL Energy Consulting Services

BEV: direct use of green electricity in Europe
FCEV: green electricity to produce H_2 , use in FC Vehicle
PtX: green electricity to produce eFuel, use in ICE Vehicle

BEV from H_2: Europe electricity to produce H_2, reconversion to electr.
FCEV: green electricity to produce H_2, use in FC Vehicle
PtX: green electricity to produce eFuel, use in ICE Vehicle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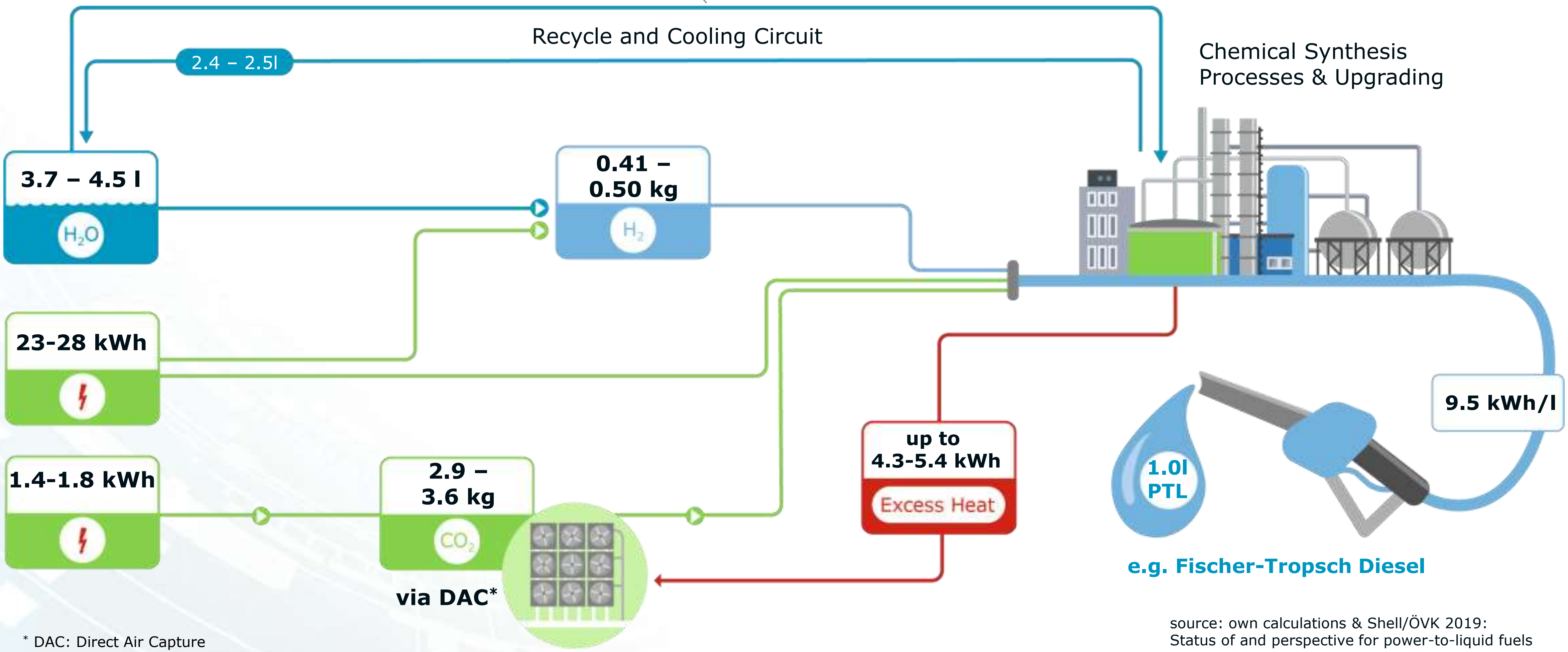
Resources required for 1 liter of e-Fuel

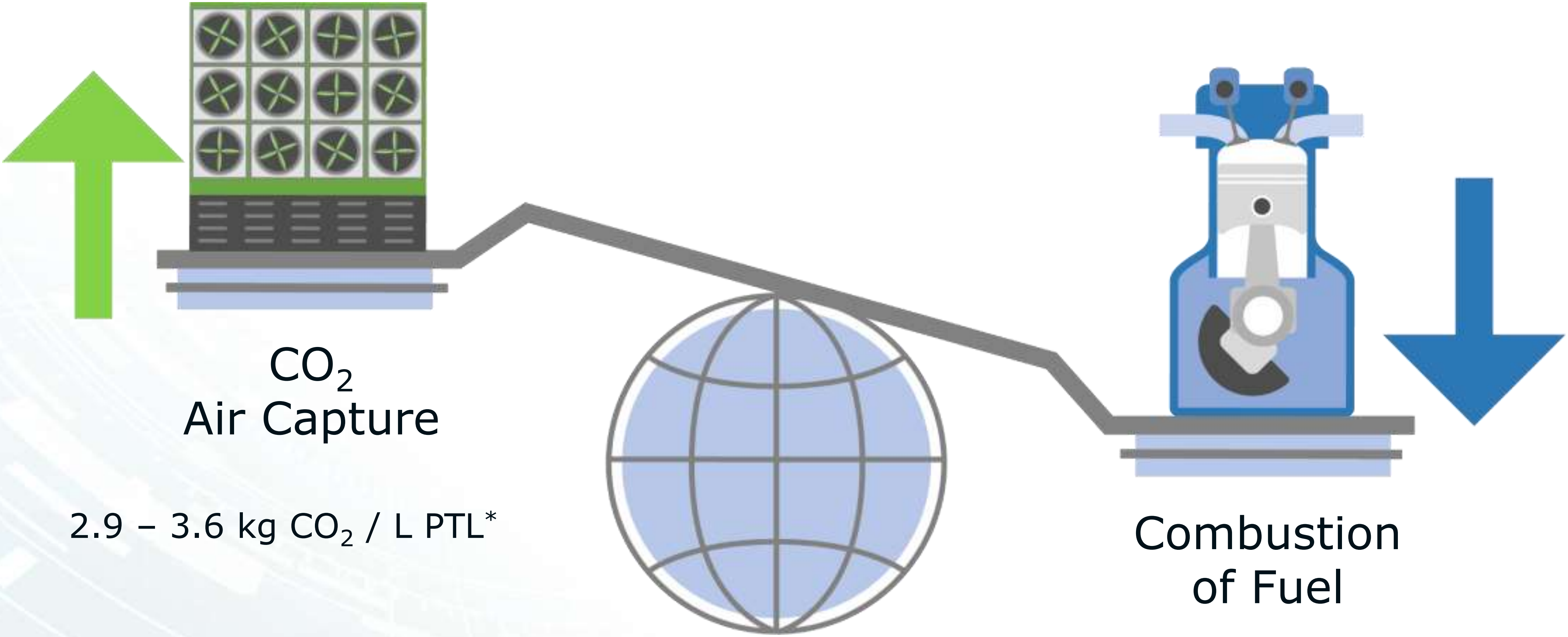


* DAC: Direct Air Capture

source: own calculations & Shell/ÖVK 2019: Status of and perspective for power-to-liquid fuels

e-Fuel production needs major supply of electricity, water and CO_2
Continuous conversion process requires continuous feed

CO_2 Balance of e-Fuel



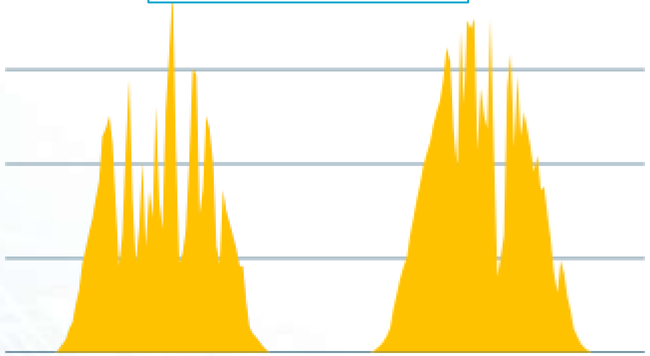
Well-to-Tank

Tank-to-Wheel

*Source: SHELL, Vienna Motor Symposium 2018
PTL production, excluding transport and distribution

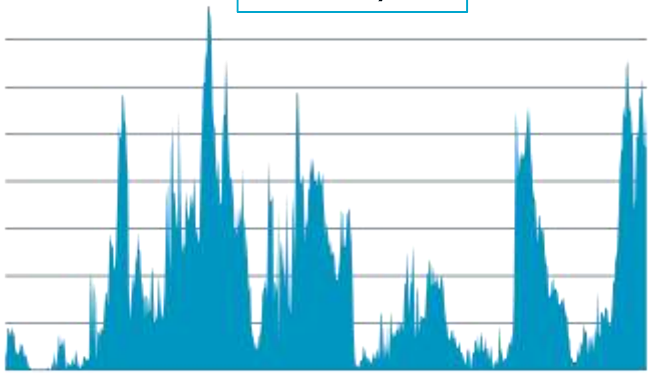
Intermittency –
Variability of renewable energy

Daily
24h hours



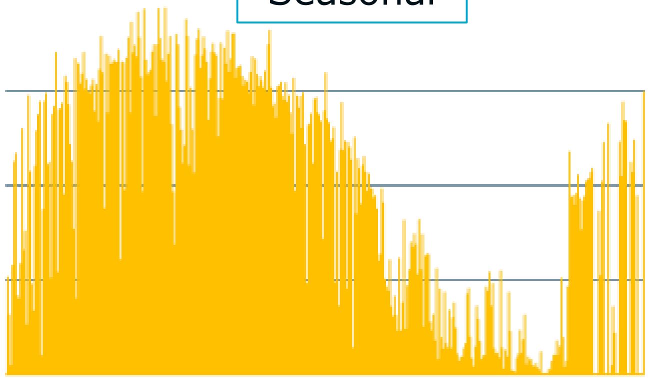
Source: PV park Germany, 99.6kW

Weekly
7 days

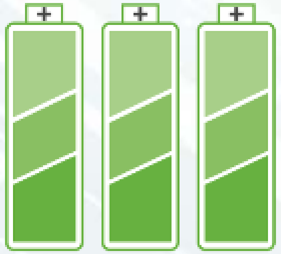


Source: wind park Germany, 2000kW

Seasonal



Source: PV park Germany, 99.6kW

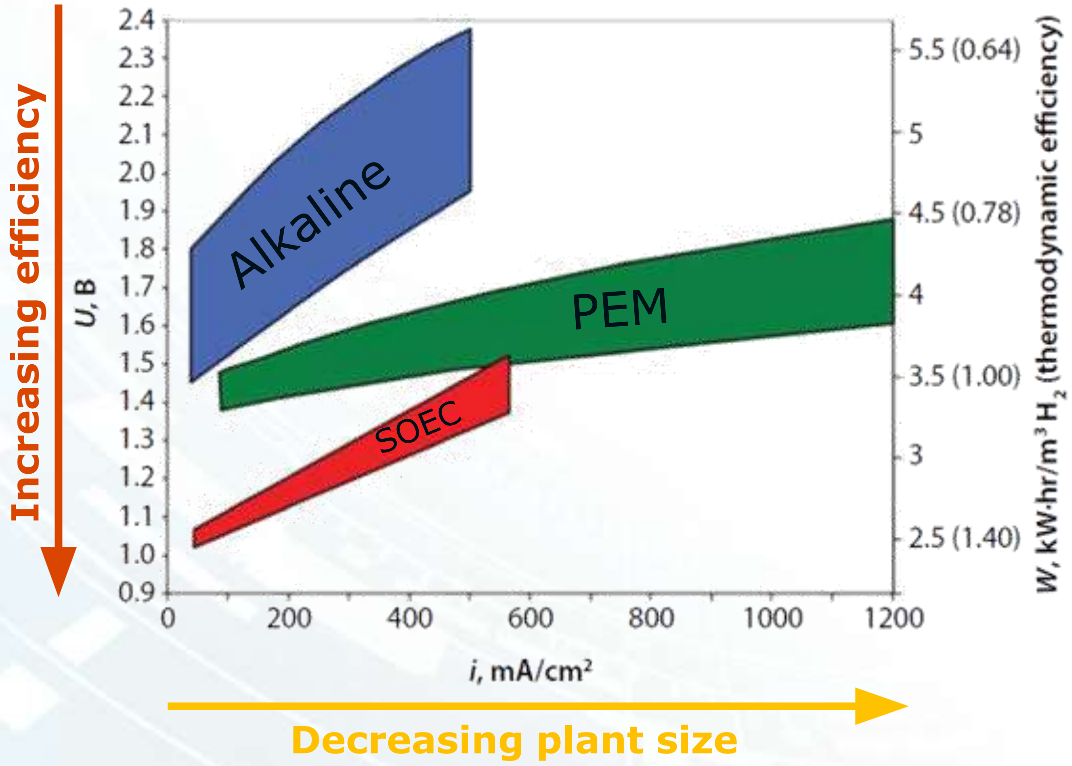


Electrochemical
Storage
(Decentral)

Chemical
Storage
(Central)

Different types of intermittency require energy storage methods adapted to the use case

Technology Comparison
Overview Status of Electrolysis Technologies



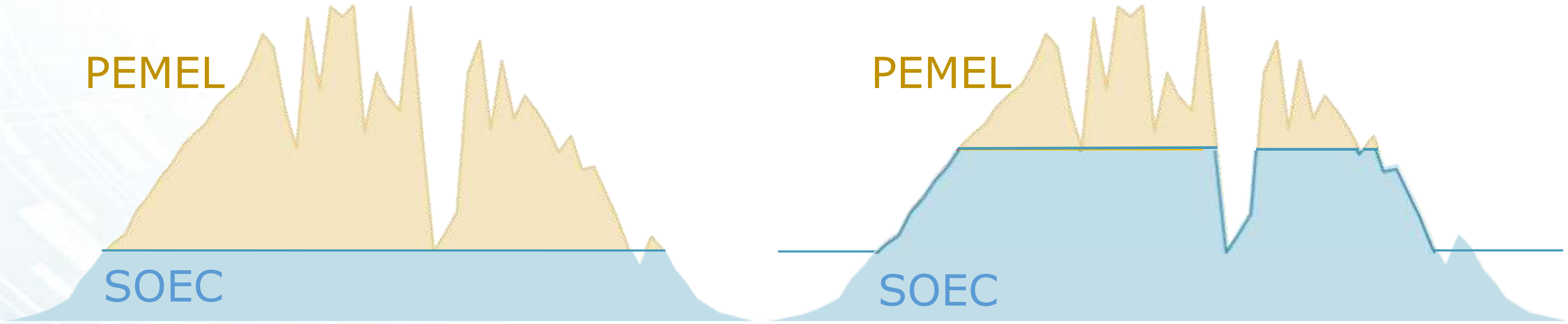
	Alkaline	PEM	SOEC
Status	Mature		R&D
Market Share	>90%	<10%	0%
Temperature	Amb-120 °C	Amb-90°C	600-800 °C
Pressure	1-200 bar	1-350 bar	1-25 bar
Efficiency	55-70 %	65-80%	75-90 %
Dynamics	weak	good	medium

PEM…Proton Exchange Membrane
SOEC…Solid Oxide Electrolysis Cell

Sources:
Flexible combined production of power, heat and transport fuels from renewable energy sources, VVT;2018
Hydrogen Production Technologies, Sankir; 2017

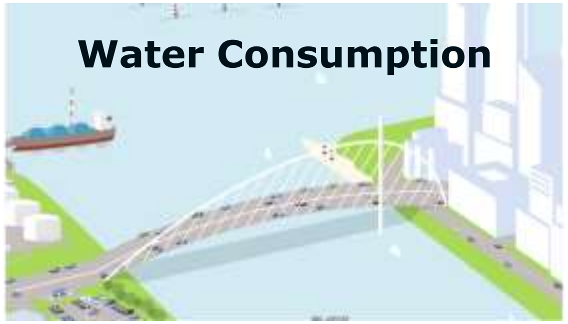
Different Characteristics of Electrolysis Technologies

Proton Exchange Membrane Electrolysis (PEMEL) can cover fast dynamics



Solid Oxide Electrolyzer Cell (SOEC) can cover baseload and slow dynamics

What do we need to produce e-Fuel at scale?



Fuel Production and Demand

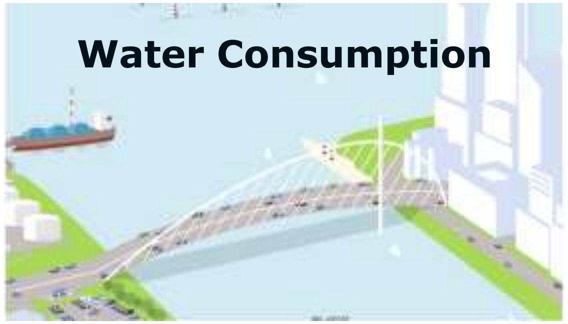
Fuel Production and Demand	Energy Demand	Water Consumption	Land use for GtL Plant
2.8 Mio. t Capacity one GtL Plant[1)]	100 TWh	14 Mio. t	7 km² depends on location*
6.7 Mio. t Annual demand Sweden[2)]	240 TWh approx. 150% of electricity generation Sweden[3)]	34 Mio. t 2 % of industry water demand of Sweden[4)]	17 km² 10% of Stockholm

Domestic generation impossible
Energy needs to be imported in any scenario

[1)] Shell Plant, Qatar, cost ca. 20 Bn€, [2)] SPBI Branschfakta 2019, [3)] Swedish Energy Agency 2019, [4)] Statistic Sweden, 2015

Significant resources and major investment required to build up e-Fuel at relevant capacity
Major non-technical hurdle: Time-to-market (10 years)

What do we need to produce e-Fuel at scale?


Fuel Production and Demand


Fuel Production and Demand	Energy Demand	Water Consumption	Land use for GtL Plant
2.8 Mio. t Capacity one GtL Plant*	100 TWh	14 Mio. t	7 km² depends on location*
56 Mio. t Annual demand Germany	2.000 TWh approx. 4x electricity demand Germany	280 Mio. t 5 % of industry water demand	140 km² Urban Area of Darmstadt

Domestic generation impossible
Energy needs to be imported in any scenario

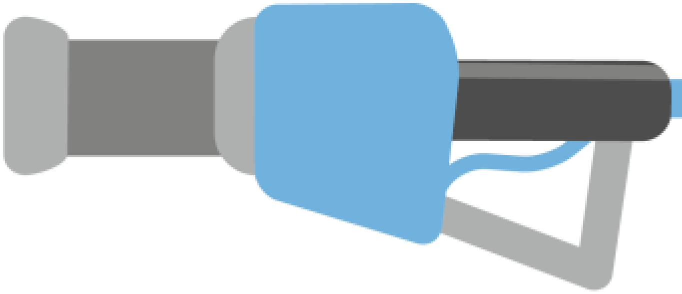
*Shell Plant, Qatar, cost ca. 20 Bn€

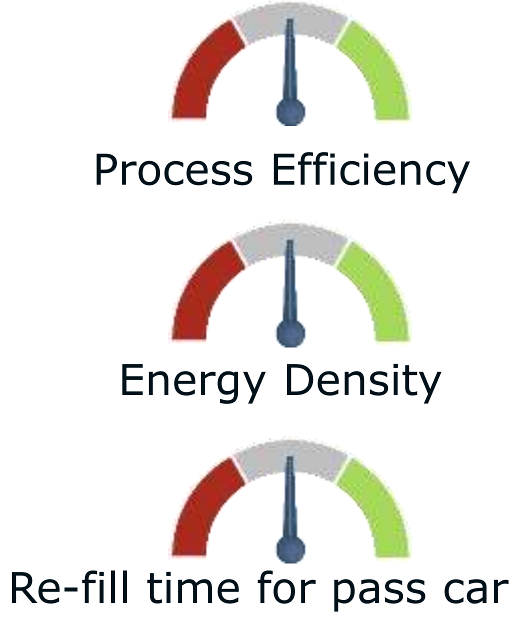
Significant resources and major investment required to build up e-Fuel at relevant capacity
Major non-technical hurdle: Time-to-market (10 years)

What if Renewable Hydrogen is available?

Power-to-H (Hydrogen)

- 95% of today’s hydrogen is produced via steam-methane-reforming out of fossil sources
- In a 100% renewable world hydrogen is the chemical energy carrier with the best process efficiency
- It is an ideal starting point for mobility and other industries (e.g. steal production)



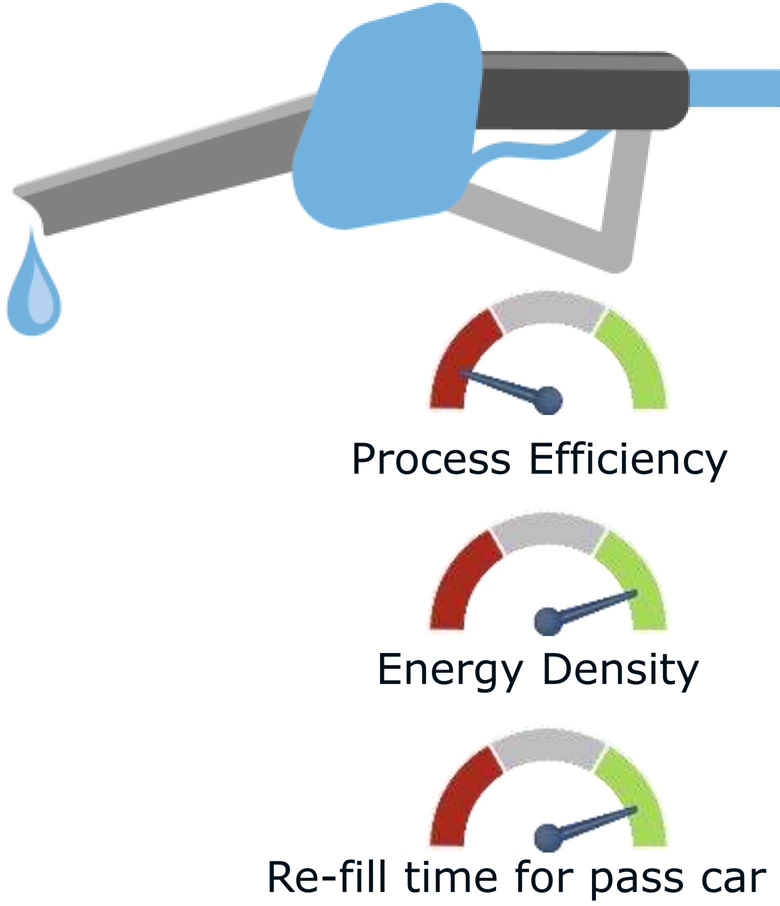


Hydrogen is the energy carrier which keeps all options for further use open

What if Synthetic Fuels are available?

Power-to-X (E-Fuels)

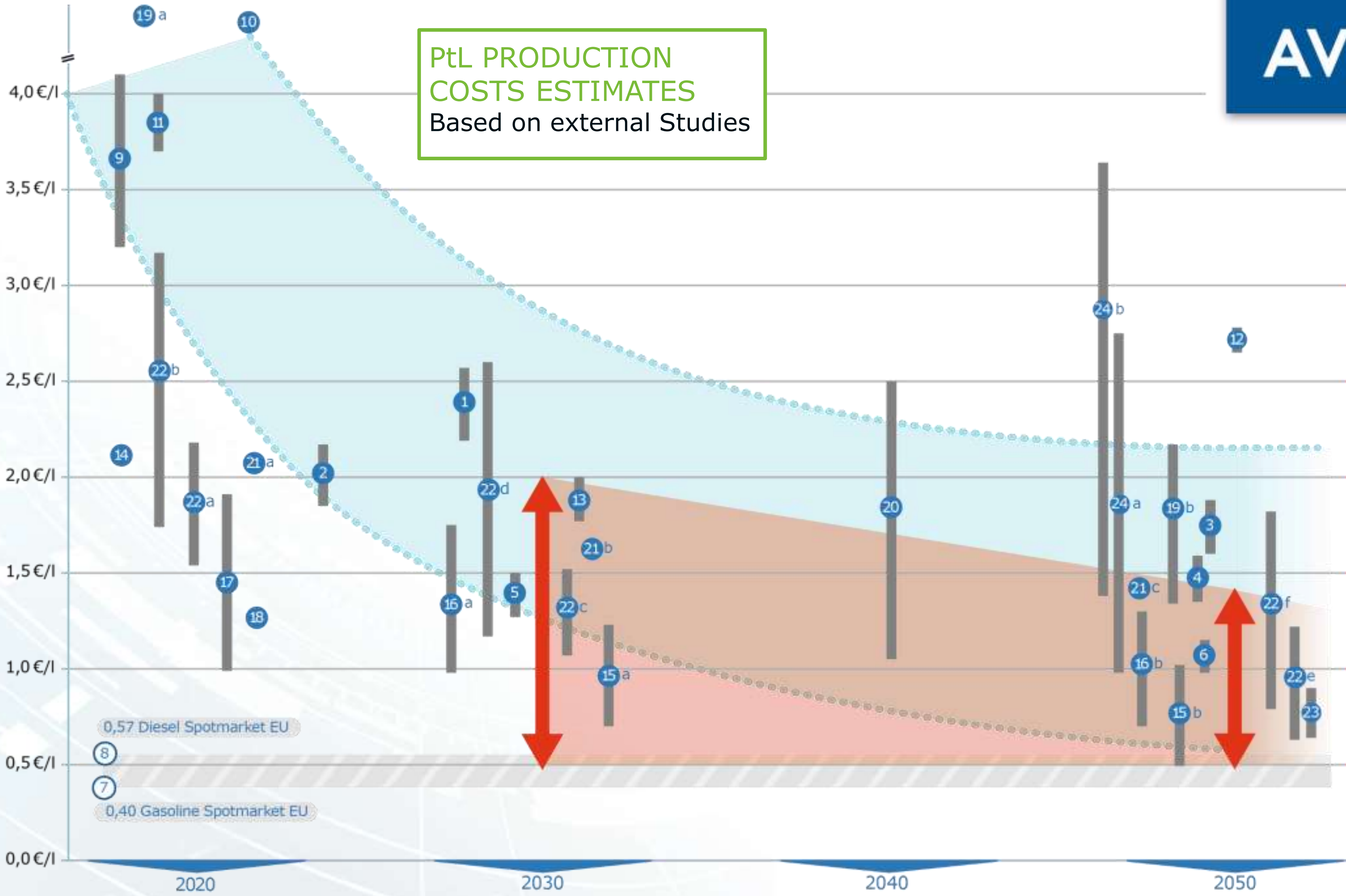
- Feasible scenario – Technologies are fundamentally established
- Interim energy-Storage required to balance fluctuations from wind and solar esp.
- Scale-up by several dimensions and infrastructure built-up need to be started soon to enable sizable volumes mid-term
- Aviation and ocean-going marine likely to be first in line for any liquid e-fuels



PtX Fuels are a favorable option to use as drop-in for existing fleet

PtL PRODUCTION COSTS ESTIMATES

Based on external Studies



AVL

PTL EXPECTED COSTS COMPARED TO TODAYS FOSSIL FUEL

2030 x Factor 3-5

2050 x Factor 2-3

(production costs, w/o taxes)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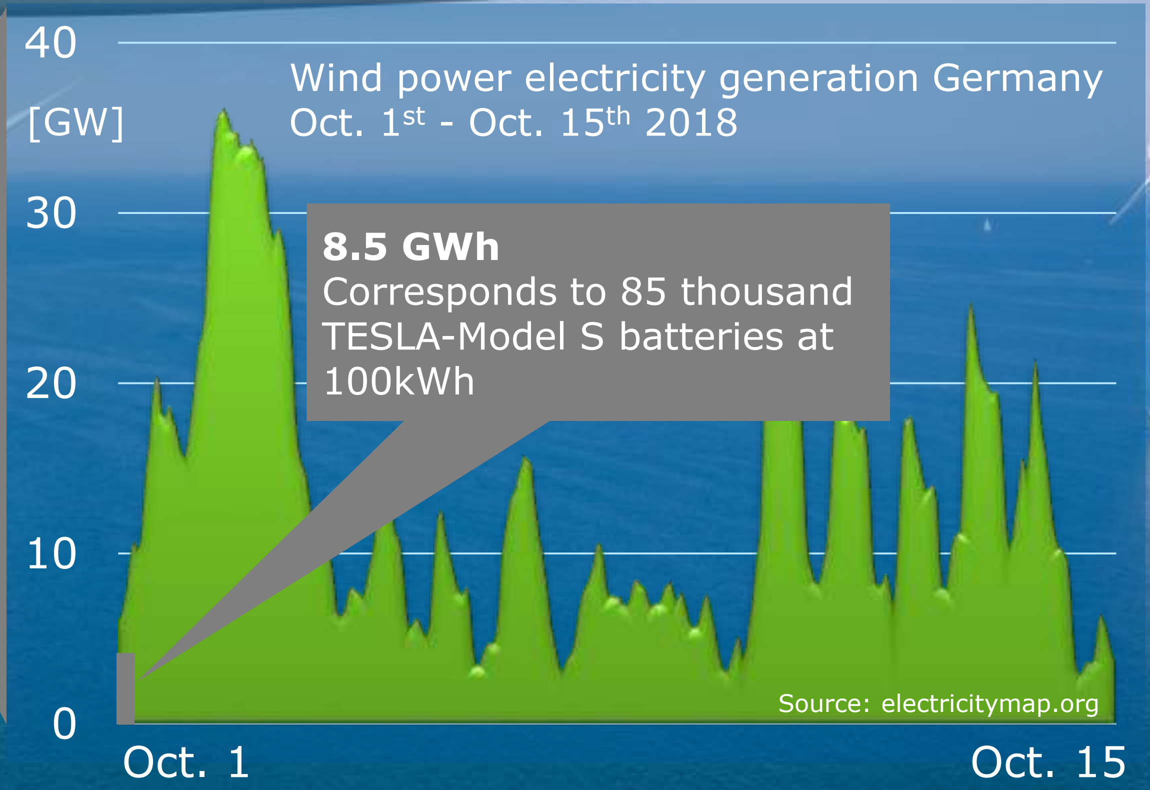
Fluctuating wind energy compared to conventional pump storage capacity

Pump storage Goldisthal, Thüringen

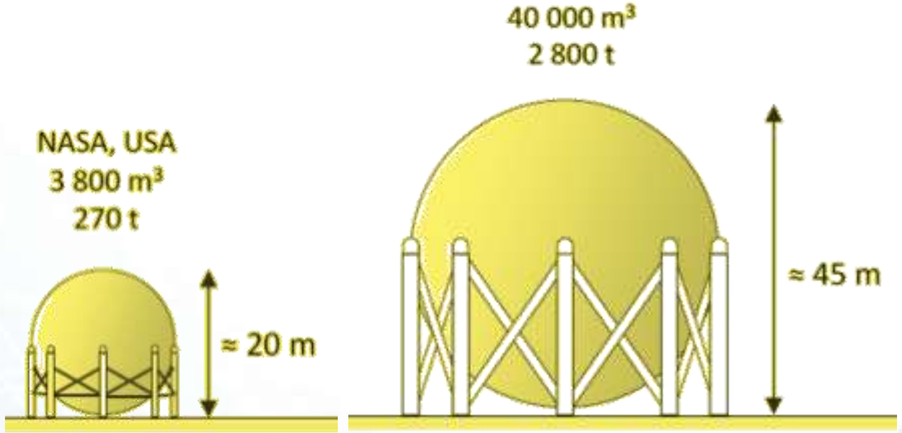


Hydrogen storage technologies

Large-scale Storage

Liquid

Present **Future**



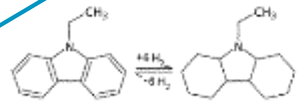
Sintef

Pipeline

FZ Jülich

- $CH_4 + H_2$
- pure H_2

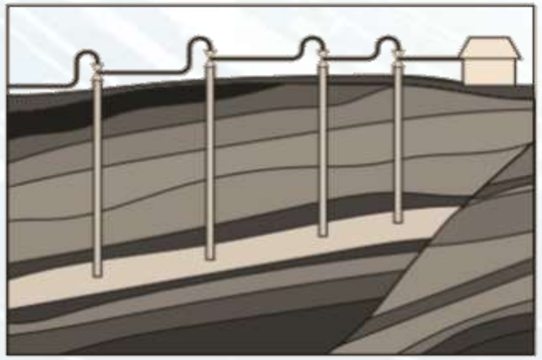
Organic hydrides



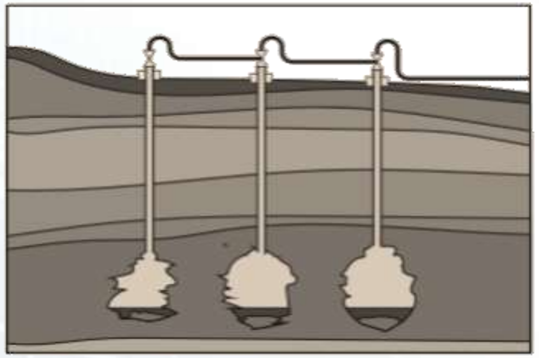
H_2 industries

Gaseous Underground

Depleted reservoirs: $CH_4 + H_2$

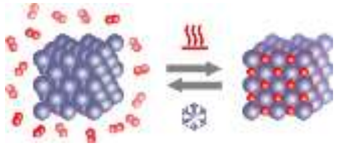


Salt caverns: pure H_2



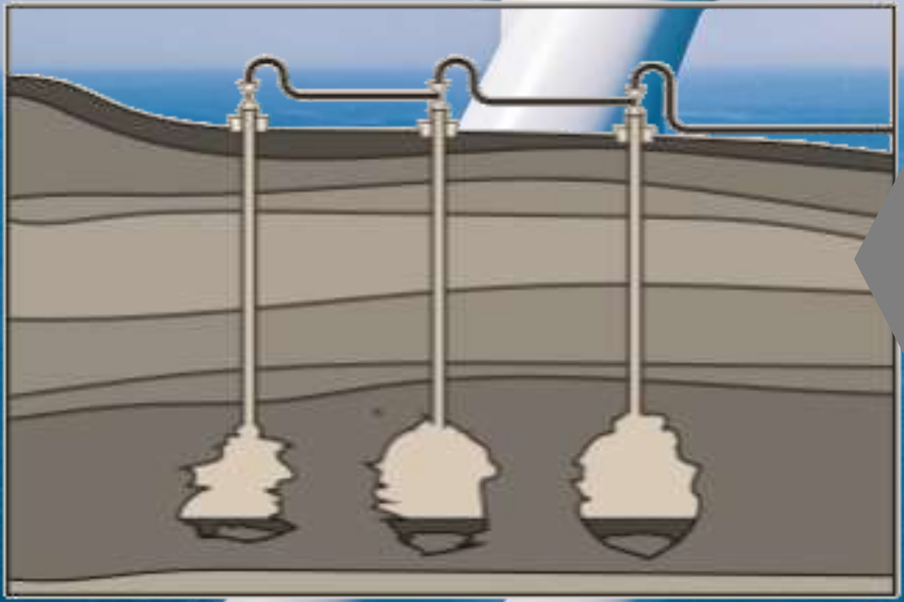
energie-finder.ch

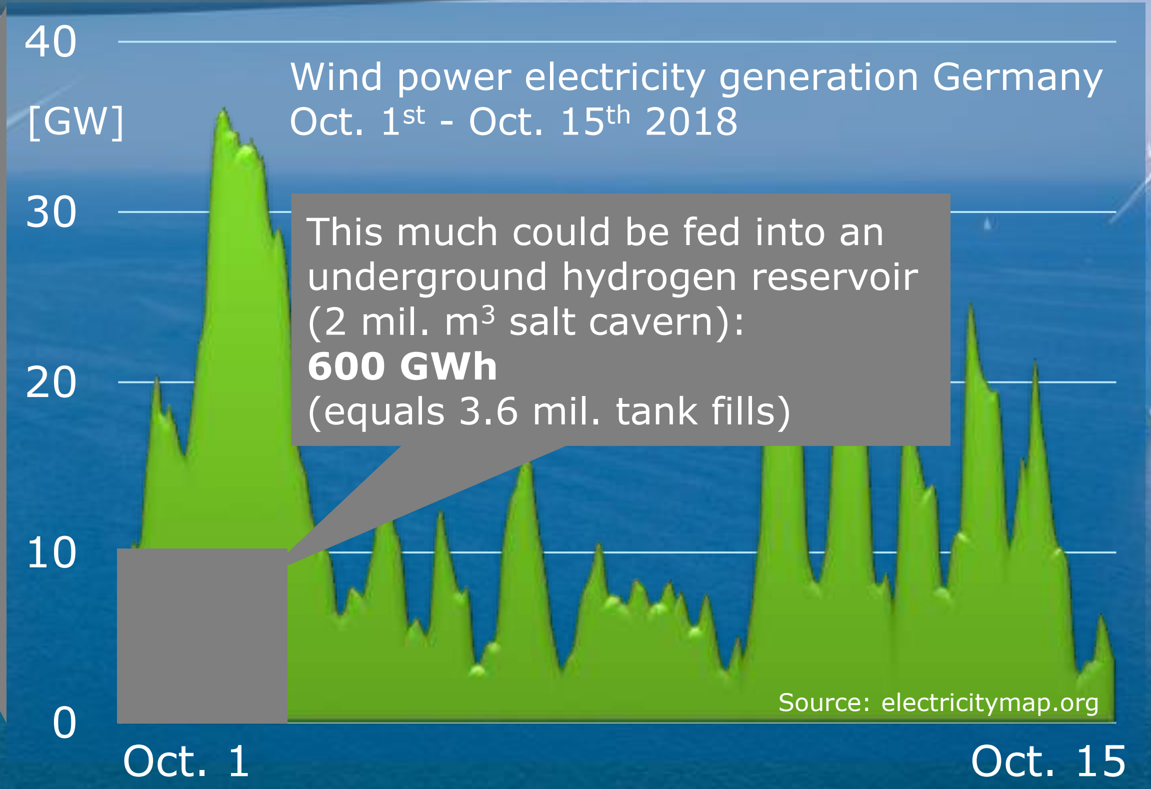
Metal hydrides



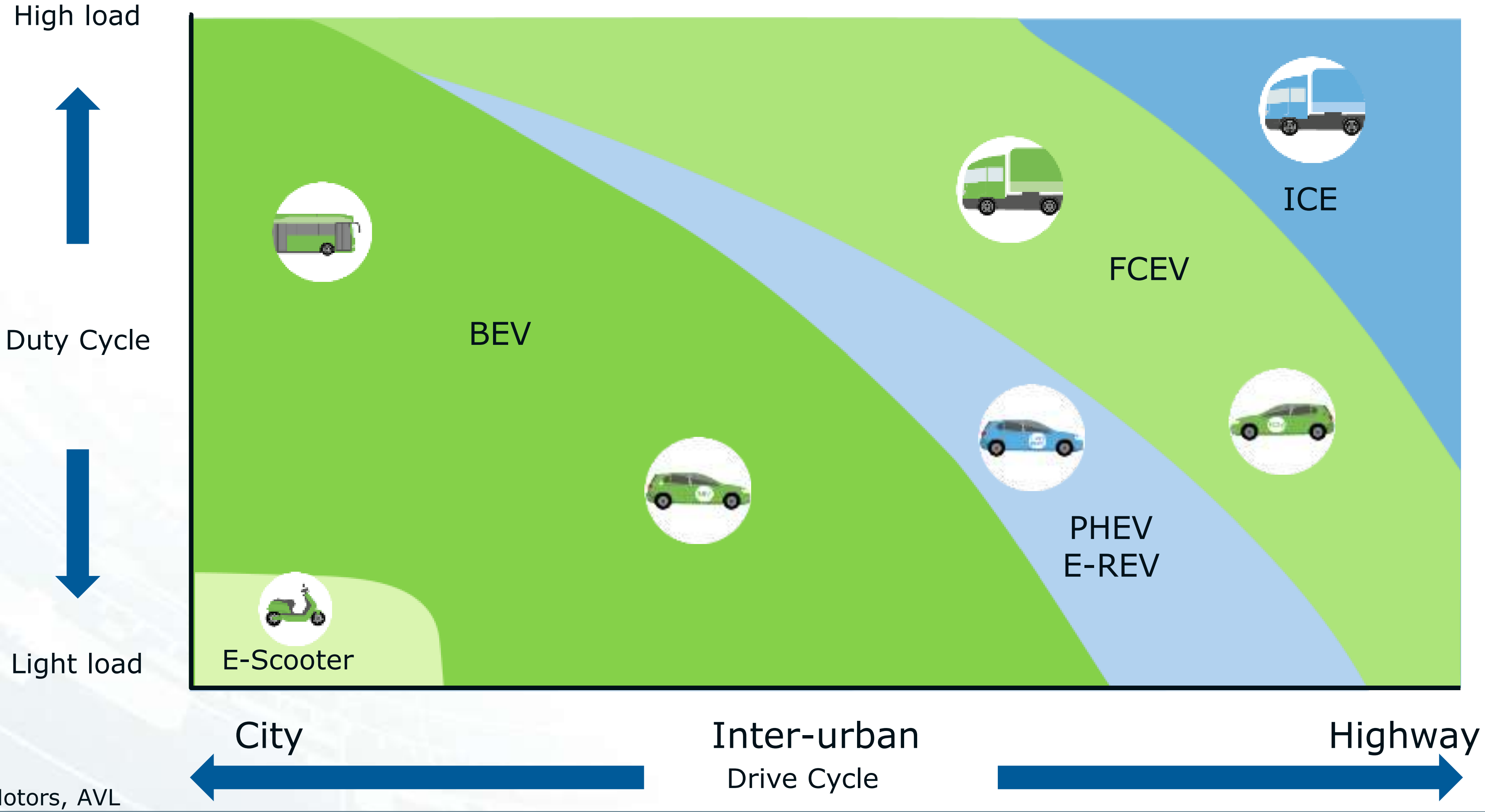
forschung-energiespeicher.info; Pragma Industries, Fraunhofer IFAM, McPhy

Hydrogen – The Inevitable Element in the Renewable Energy System





Vehicle Application Map



Source: General Motors, AVL

A variety of propulsion systems is expected to coexist.
Tank range, recharging time and utility of the vehicle drive diversity.

Summary

- The need of storing excess energy from renewable sources is essential in the next 30 years.
- Chemical energy carrier can support the long-term storage of renewable energy.
- In a 100% renewable future the importance using excess energy will increase and shall be used as well to fill chemical buffer storages.
- The various energy storage methods for hydrogen must be further developed and upscaled.
- In a future scenario with a high degree of energy chemically stored, a powertrain technology openness will remain.

AVL Energy and Sustainability Offerings

AVL Energy Consulting

Strategy Consulting Services for future mobility concepts

Fundamental Future Energy Overview
Specific recommendations for Future Energy Environment

AVL Sustainability Services

Sustainable design and development for powertrains

Life cycle assessment under consideration of manufacturing processes and usage

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Thank You

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