Smart Energy Network
Workshop on E-mobility

Oslo Science Park,
University of Oslo

5 March 2020

Renewable Energy & Zero-Emission Electrical Transport Systems

Øystein Ulleberg

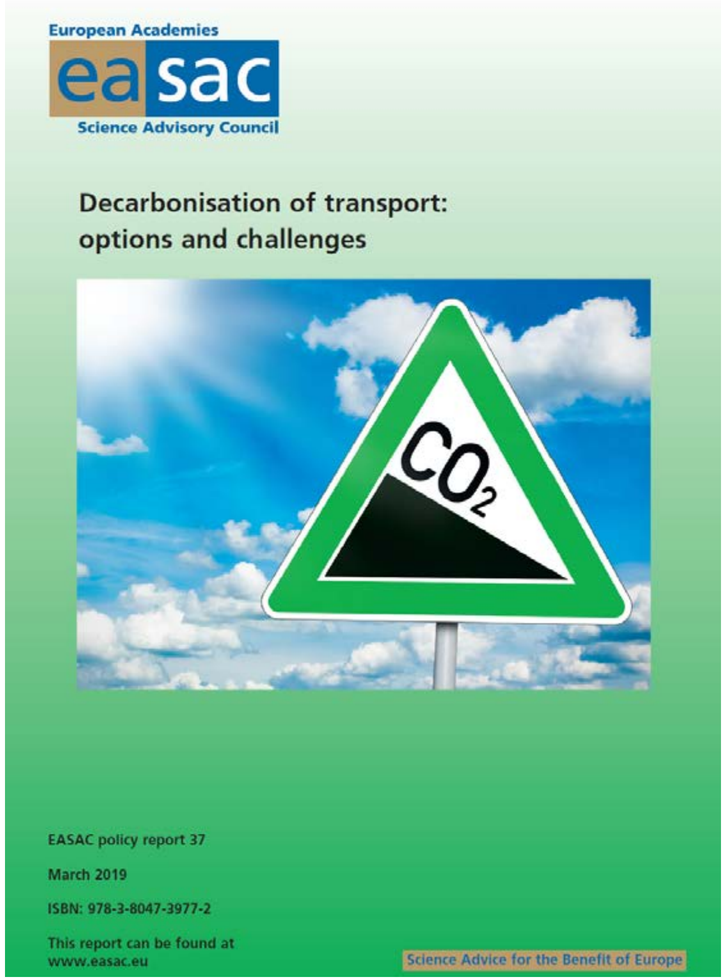
Principal Scientist, Institute for Energy Technology, Kjeller

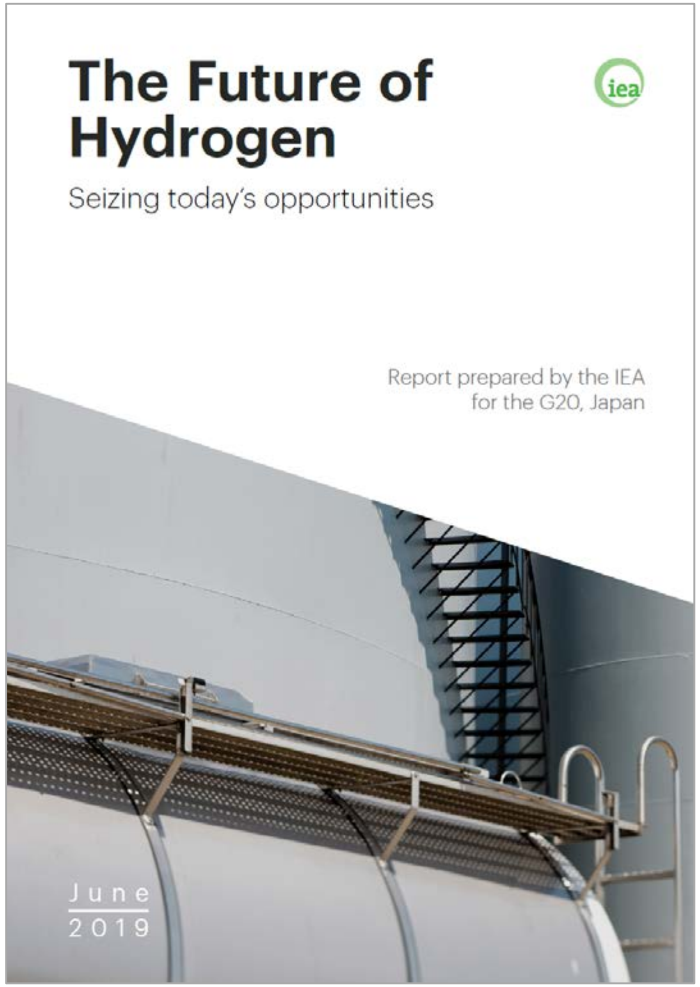
Associate Professor, University of Oslo

Director, MoZEES Research Center

Contents

Background & References





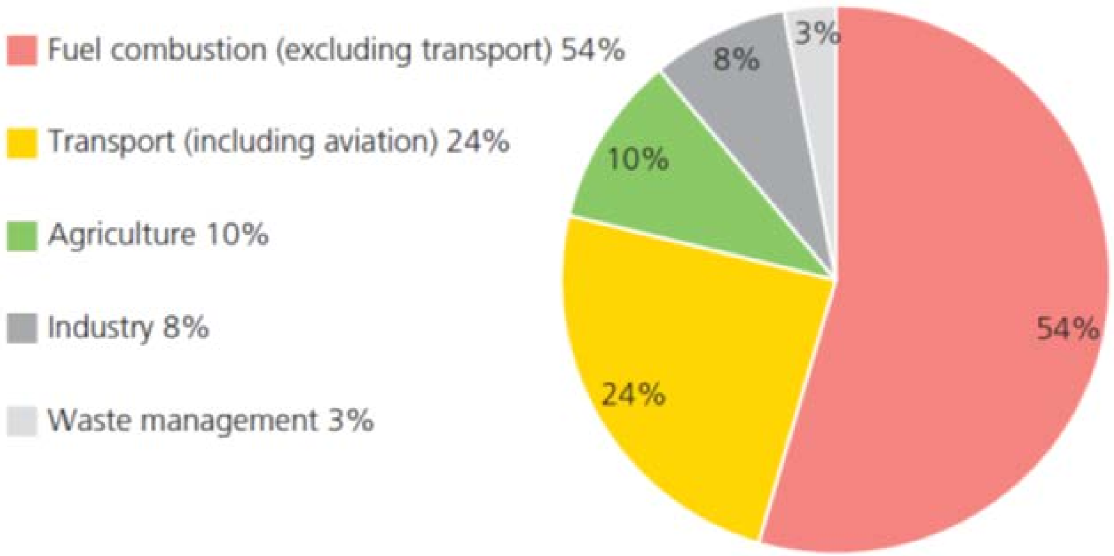
FME
CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH
The Research Council of Norway

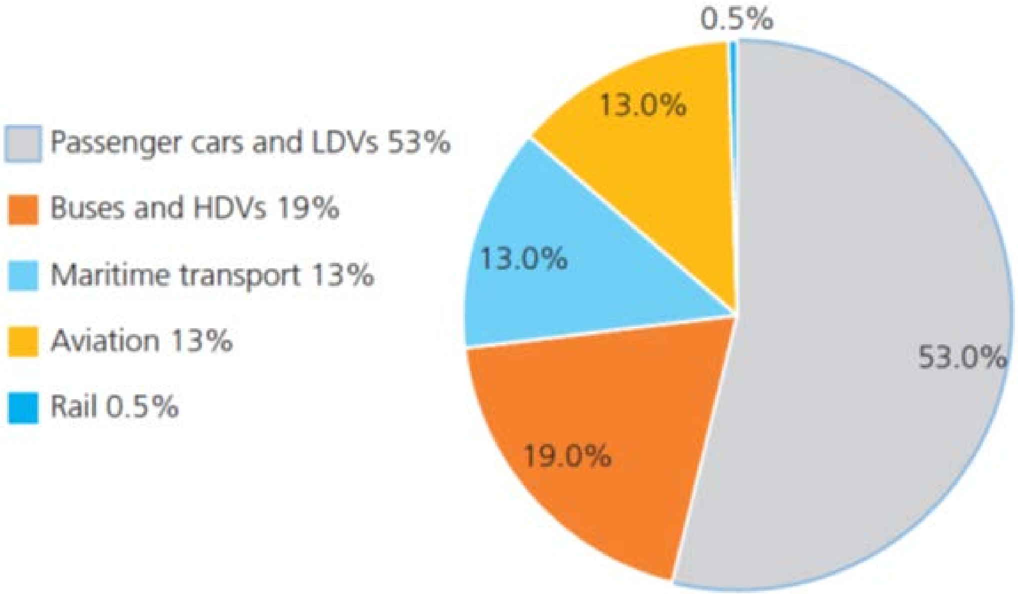
MoZEES
Mobility Zero Emission Energy Systems

Greenhouse Gas (GHG) Emissions in the EU

Overall:
22% reduction since 1990

Transport:
20% increase to 857 $MtCO_2$-eq.





Source: EASAC (2019)

EU Carbon Emission Targets (wrt. 1990)

- **Overall GHG Targets**
  - 40% reduction by 2030
  - 60% reduction by 2040
  - 80-95% reduction by 2050

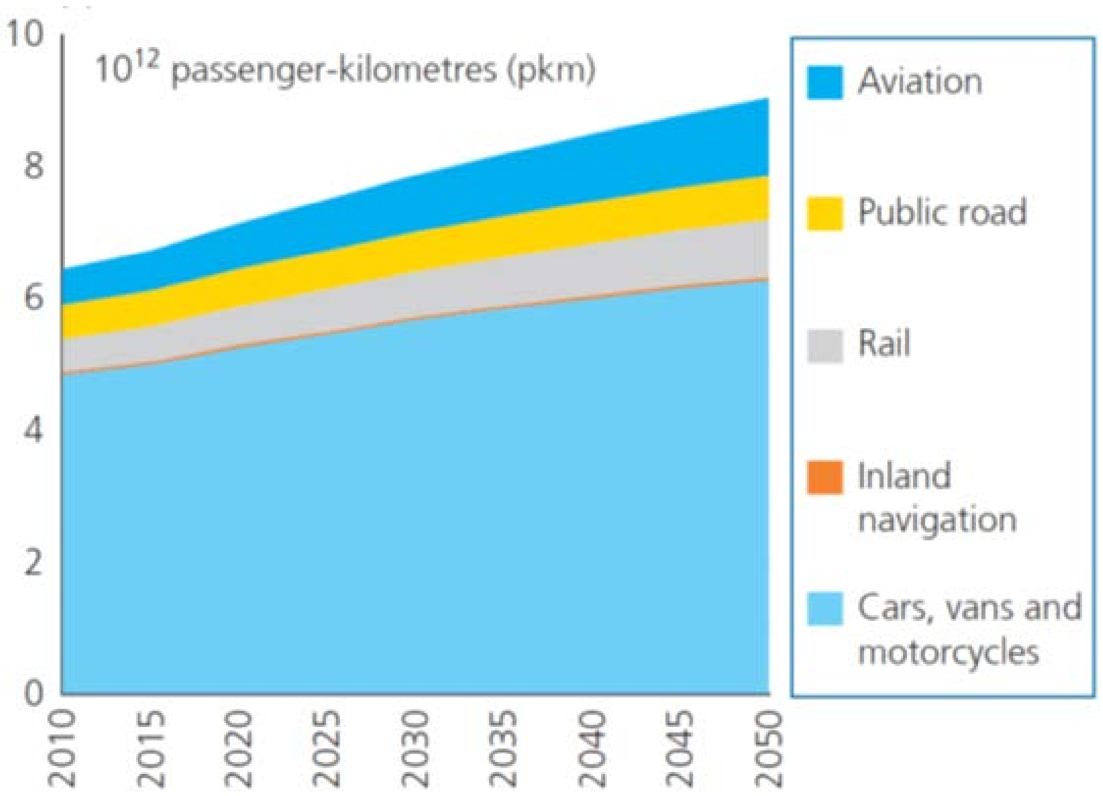
- **Transport GHG Targets**
  - 60% reduction by 2050
  - New Cars: 95 g CO_2/km in 2021 (130 g CO_2/km in 2015)
  - New Vans: 147 g CO_2/km in 2021 (3.5 t LDVs)

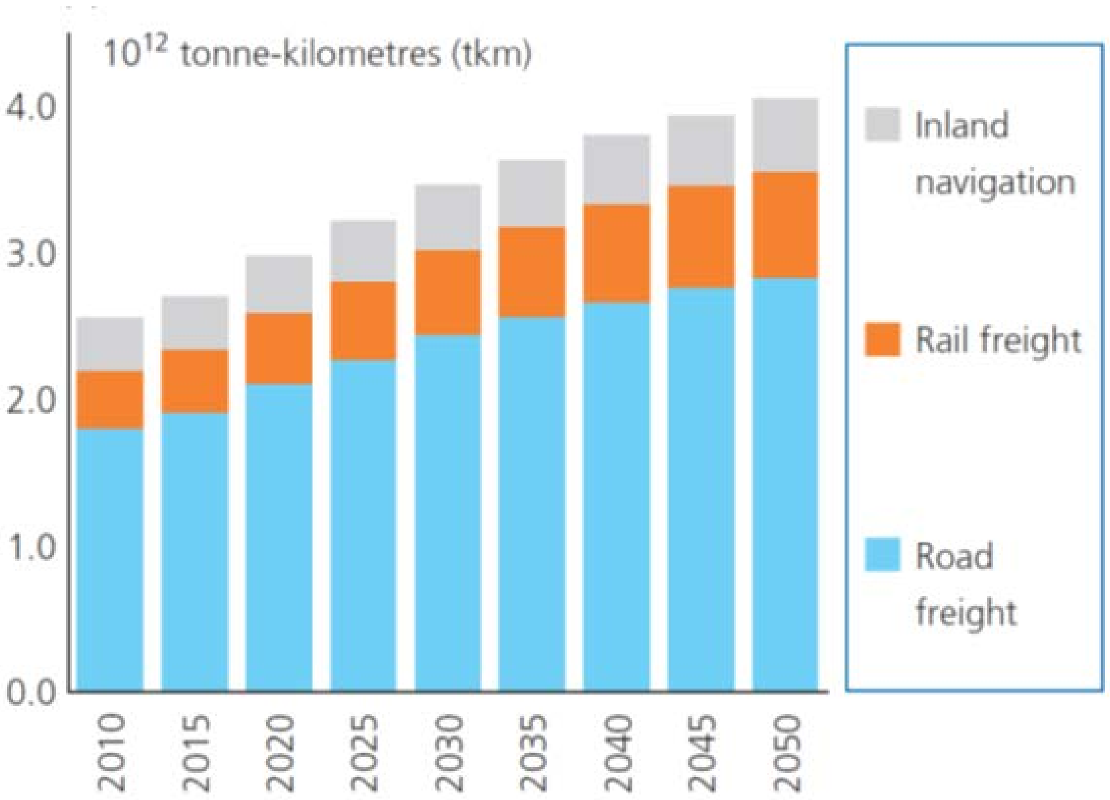
Source: EASAC (2019)

Projections for Transport Activity in the EU

Passenger Transport:
40% increase from 2010 to 2050

Freight Transport:
50% increase from 2010 to 2050

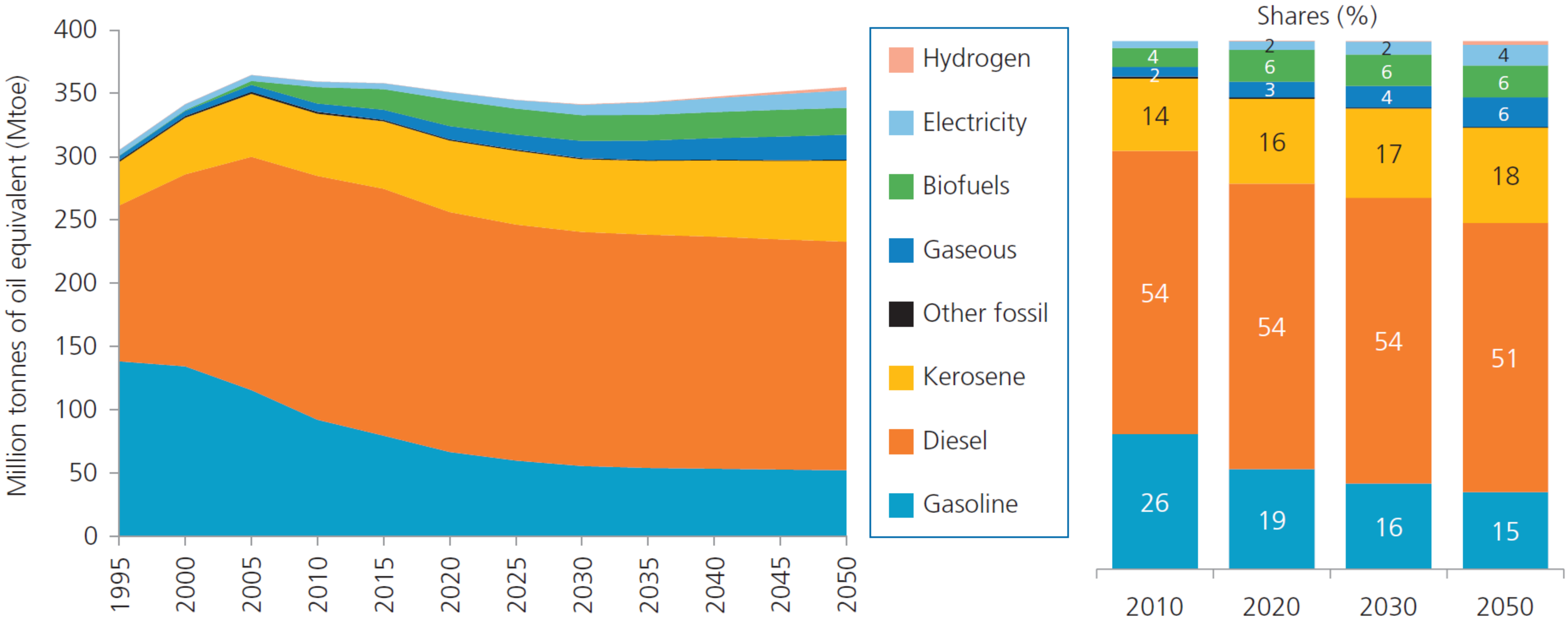




Source: EASAC (2019)

Future Projections for Passenger and Freight Transport

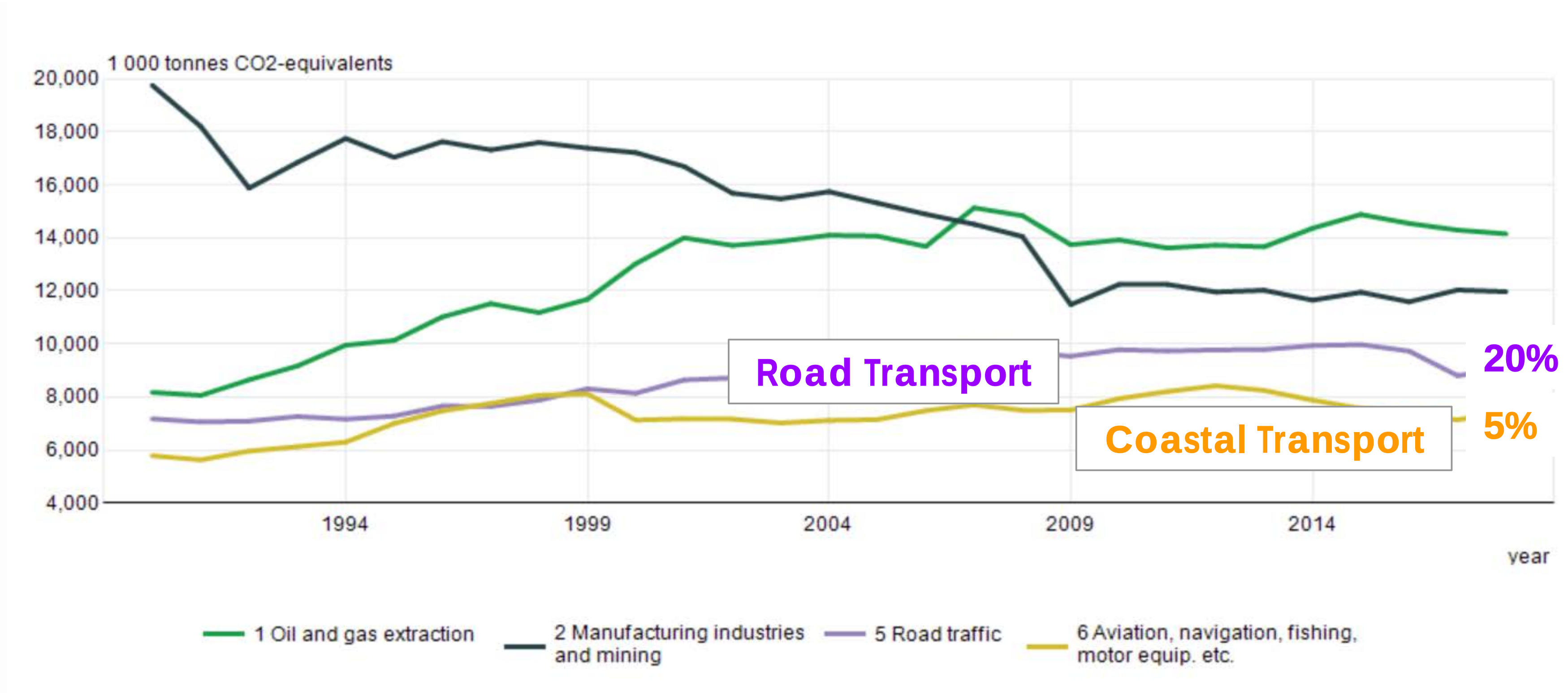
- Energy demand by fuel type projected in EU Reference Scenario (2016)



Source: EASAC (2019)

Greenhouse Gas Emissions from Transport in Norway

- 52 million tonnes of CO_2-equivalents in 2018: ca. 30 % from transport



Source: SSB (Nov 2019)

Greenhouse Gas Emissions from Transport in Norway

- 52 million tonnes of CO_2-equivalents in 2018: ca. 30 % from transport

Norway's National Transport Plan (NTP 2018-2029):

Road Transport:

- 2025: 100% zero emission light-duty trucks
- 2030: 100% zero emission medium-heavy trucks

  50% zero emission heavy-duty trucks

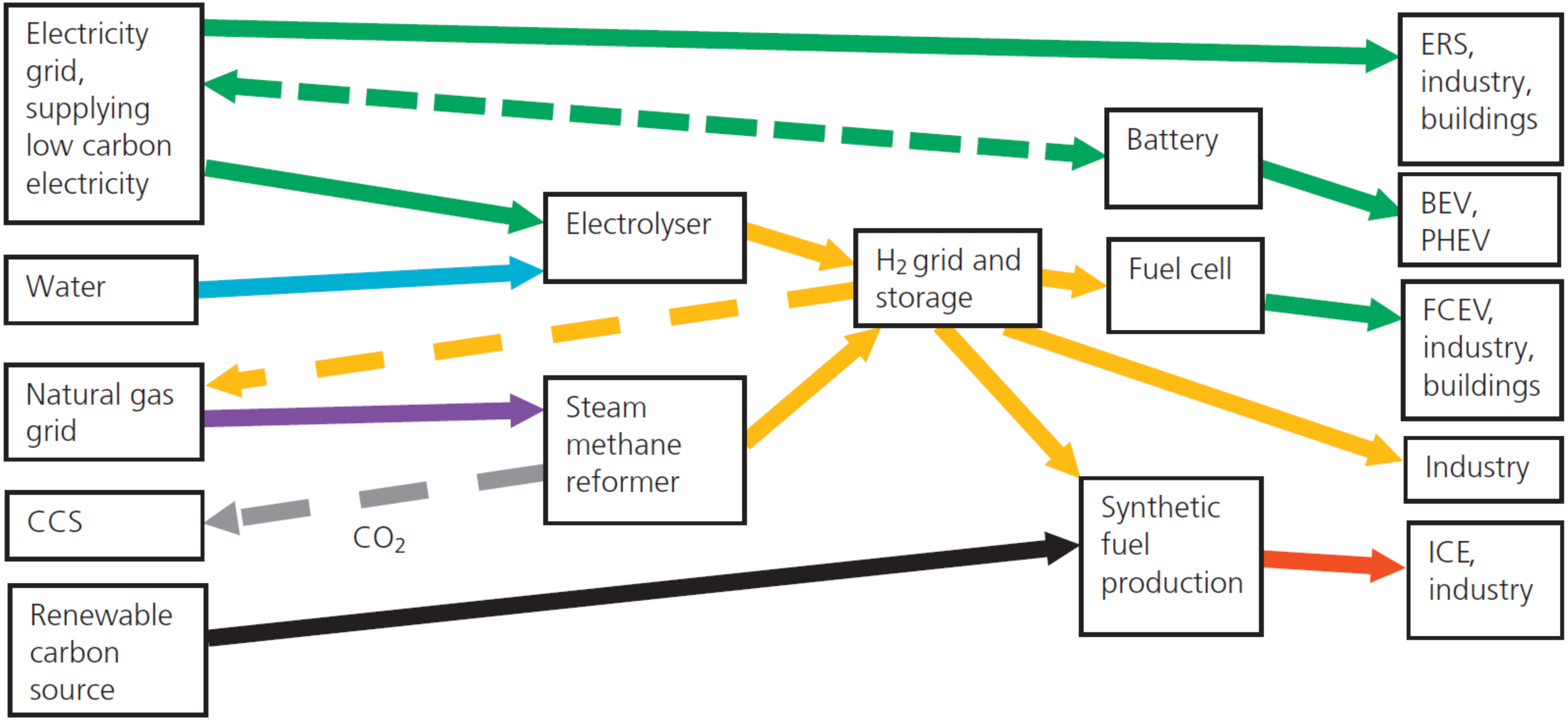
  CO_2-neutral distribution in cities

Ferries:

- Low- and zero emission, *when the technology is ready for use*

Contents

Sector Coupling – Energy & Transport Systems



Source: EASAC (2019)

Sector Coupling – Energy & Transport Systems

Example 1 – Battery Electric Vehicles (EU)

- 250 million passenger BEVs (100%) → 0.9 TW*

  *EU maximum power capacity = 1 TW (0.5 TW peak demand)

Example 2 – Hydrogen Fuel Cell Trucks & Buses (EU)

- 1 million FCETs (15%) + 0.25 million FCEBs (25%)

  → 50 000 tpd of hydrogen*

  *50 000 H2 Refueling Stations (each 1 tpd)

Source Ø. Ulleberg, IFE (2019)

Energy & Transport Systems

- **Example 3 – Hydrogen for Maritime Transport (Norway)**

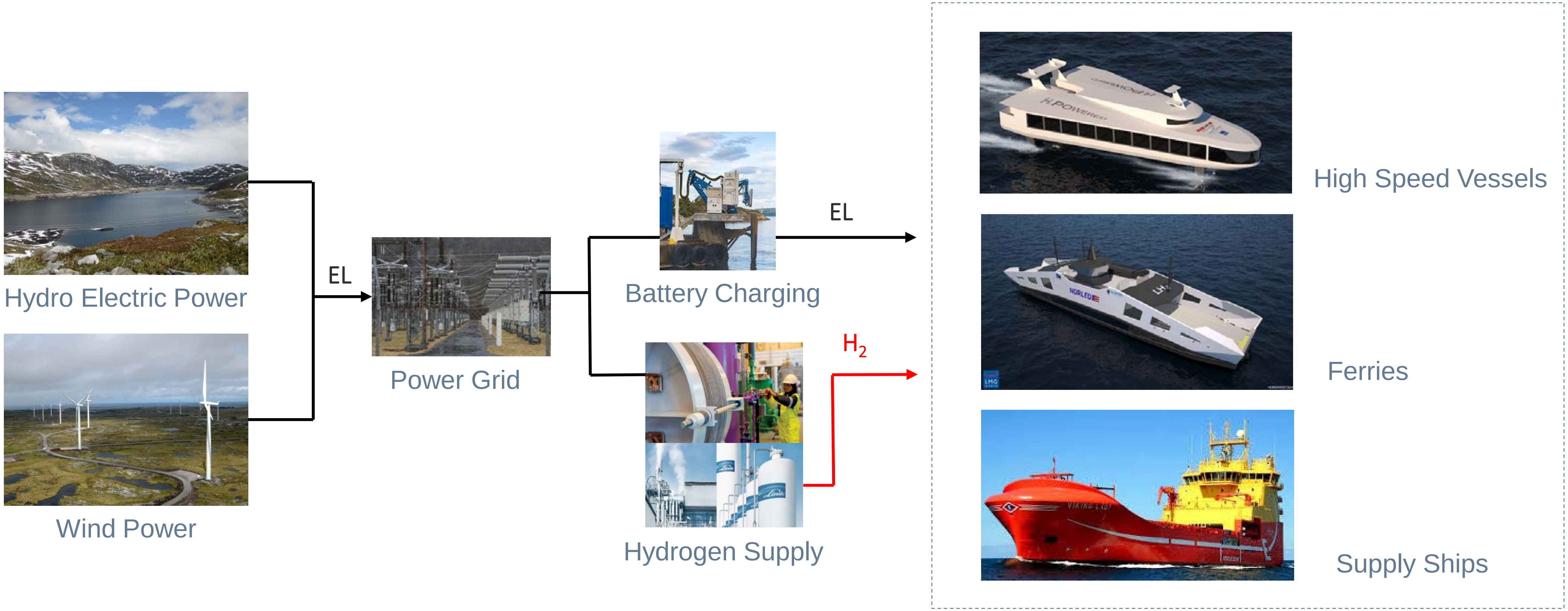


Illustration: Ø. Ulleberg, IFE (2019)

Energy & Transport Systems

- **Example 3 – Hydrogen for Maritime Transport (Norway)**

Possible Hydrogen marked in 2030: 60 tpd*

*Equal to 3 GW Water Electrolysis (1 TWh/year)

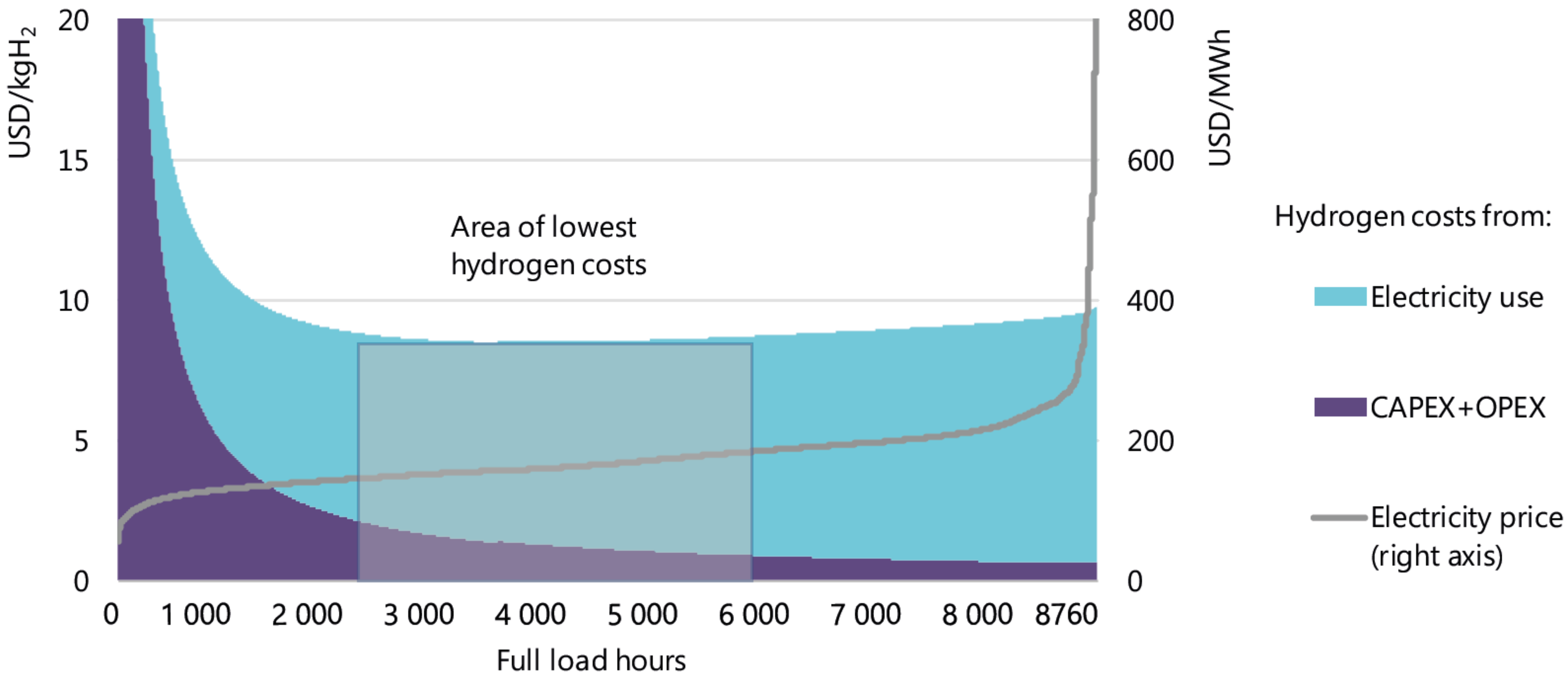
High Speed Vessels

Ferries

Supply Ships

Source: Norwegian Center of Excellence Maritime Clean Tech (2019)

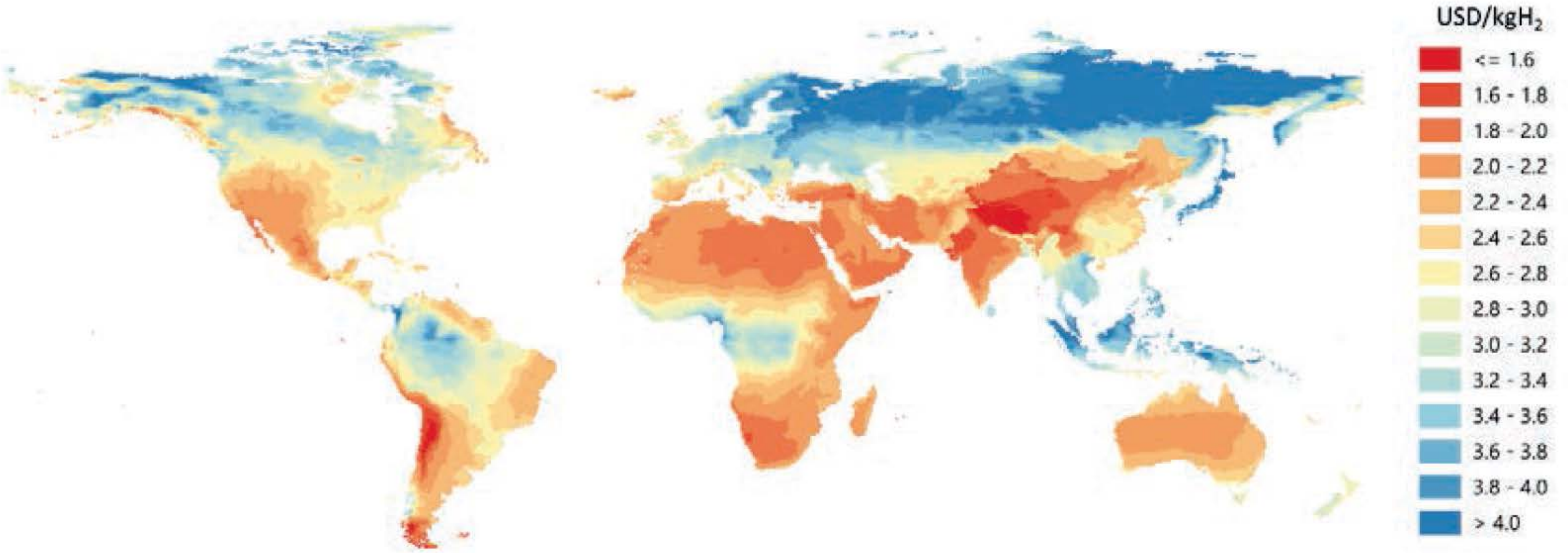
Hydrogen Costs using Grid-based Water Electrolysis



Source: IEA (2019)

Future Hydrogen Cost from PV & Wind Water Electrolysis

2 - 4 USD/kgH_2



Source: IEA (2019)

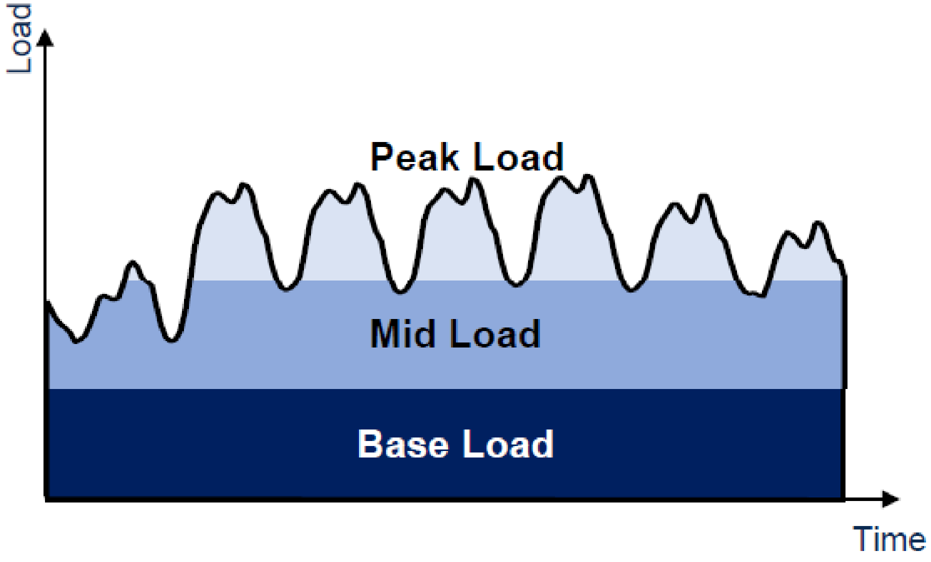
Contents

UiO : Department of Technology Systems
University of Oslo

Energy Flow in Power Grids

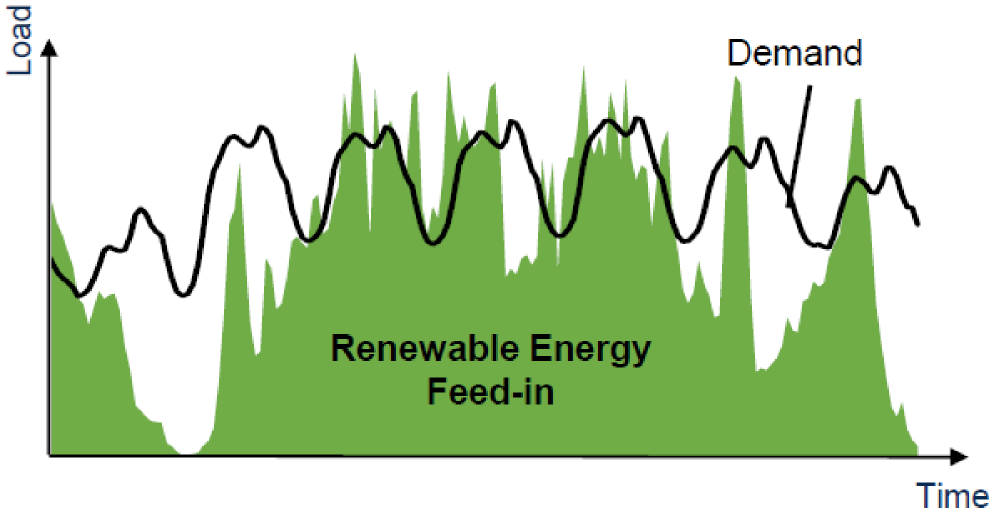
Existing vs. Future Systems

Fundamental Principle of Supply and Demand in the existing Electricity System



- Supply follows demand

Supply and demand in a RES-based Electricity System



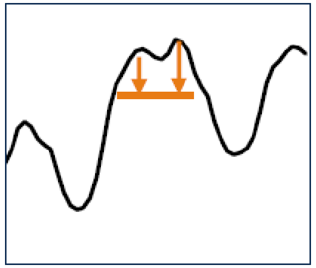
- Supply cannot always follow demand

Source: TU Dresden

Energy Flow in Power Grids

How to match *Supply vs. Demand ?*

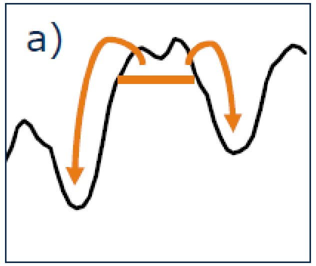
Load Shedding

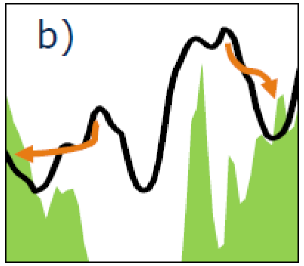


Reducing electricity demand

Energy intensive industry processes

Load Shifting



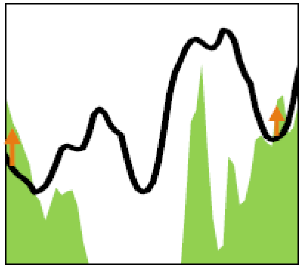


a) Smoothing the load curve

b) Demand follows RES feed-in

Applications connected to (heat or cold) storages

Load Increase



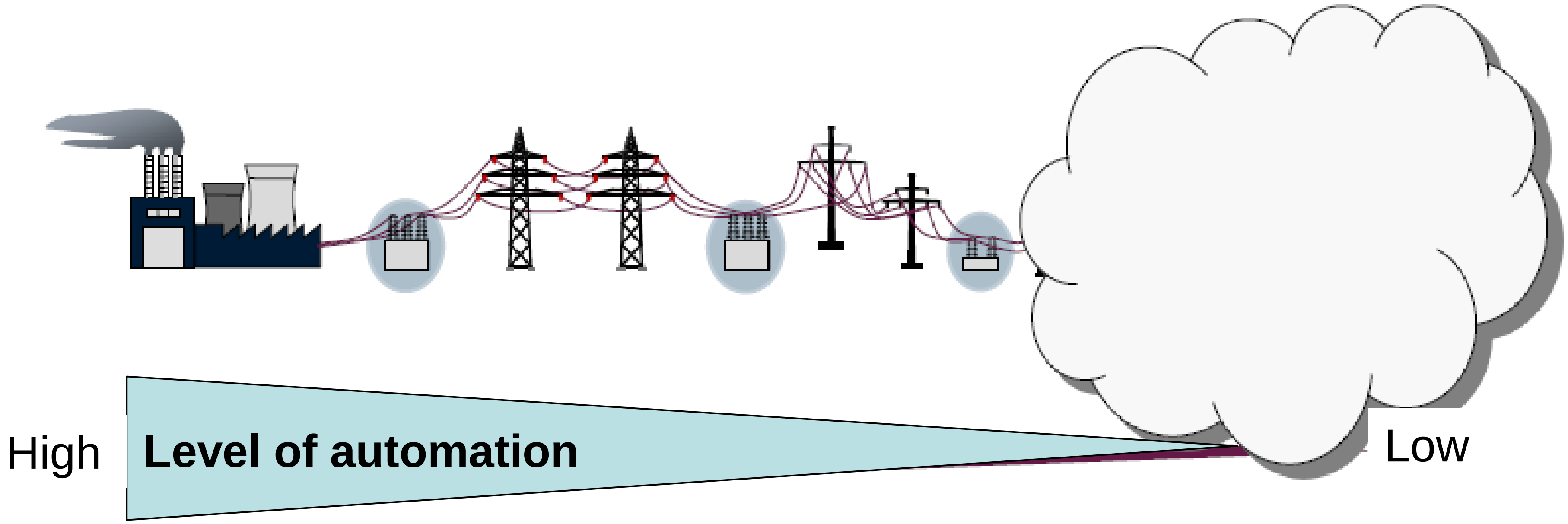
Additional electricity demand

Technologies which produce other energy carriers with electricity

Source: TU Dresden

Power System Management

Centralized vs. Distributed Systems

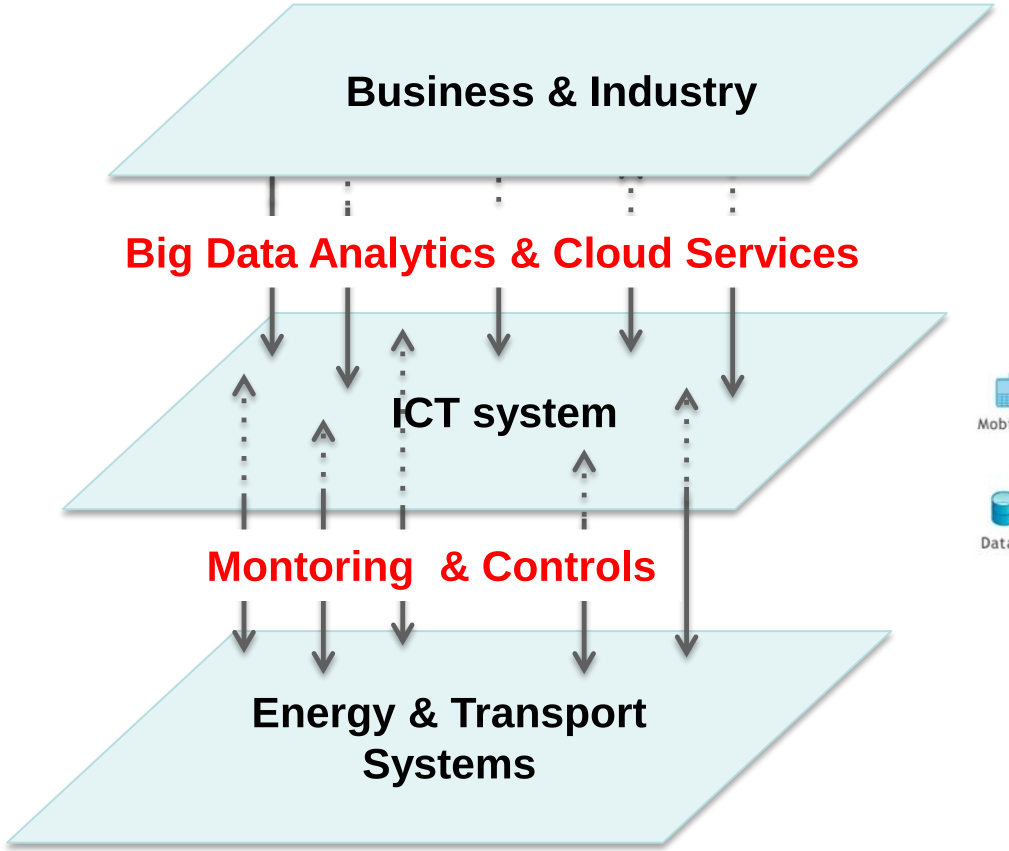


Energy Systems & ICT Infrastructures

End Users

Cyber

Physical

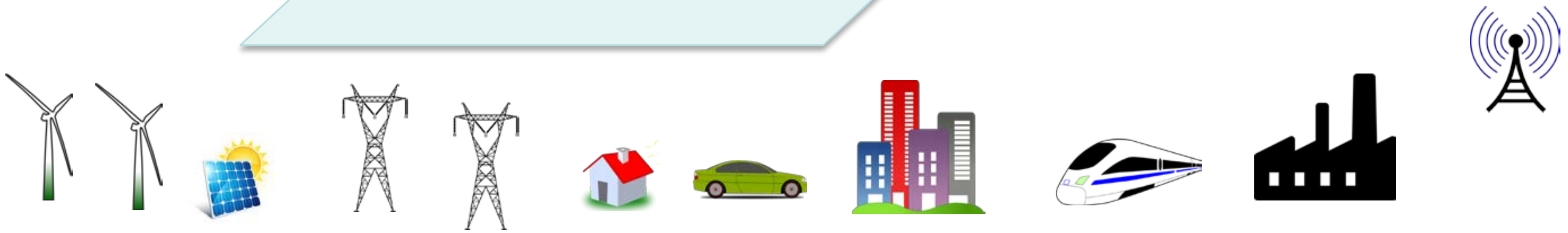


Smart Grid Services

Artificial Neural Networks

Block-Chain Technology

Sector Coupling



Future Electricity Systems

Flexibility is the key value

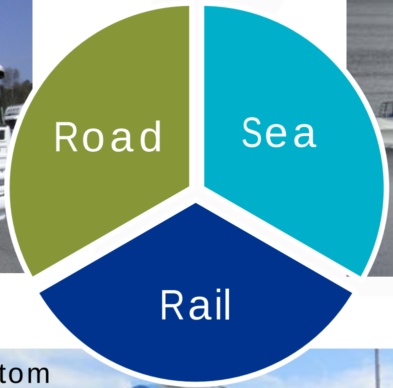
Source: SIEMENS

Contents

MoZEES – A Research Center on Zero Emission Transport

Battery & Hydrogen
– Technology Value Chains

***Heavy Duty* Transport: Road, Rail, Sea**
– Areas for Innovation & New Business



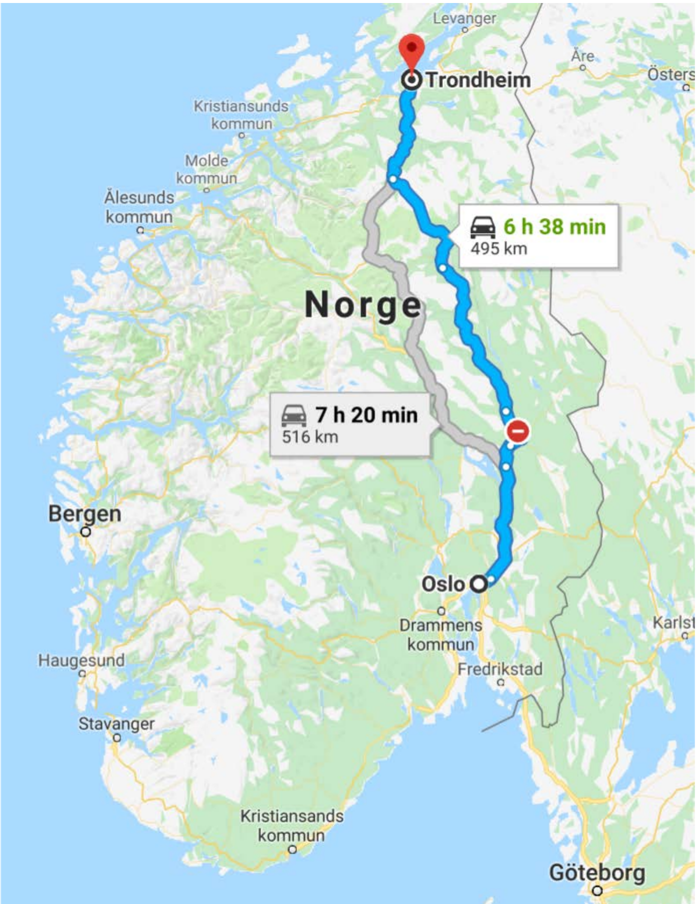
Materials → **Components** → **Systems**

260 MNOK (2017-2024) | **37 Partners** | **60 Researchers + 20 Students**

MoZEES FME
Mobility Zero Emission Energy Systems

Case Study – Hydrogen Refueling & Fuel Cell Trucks

Oslo - Trondheim

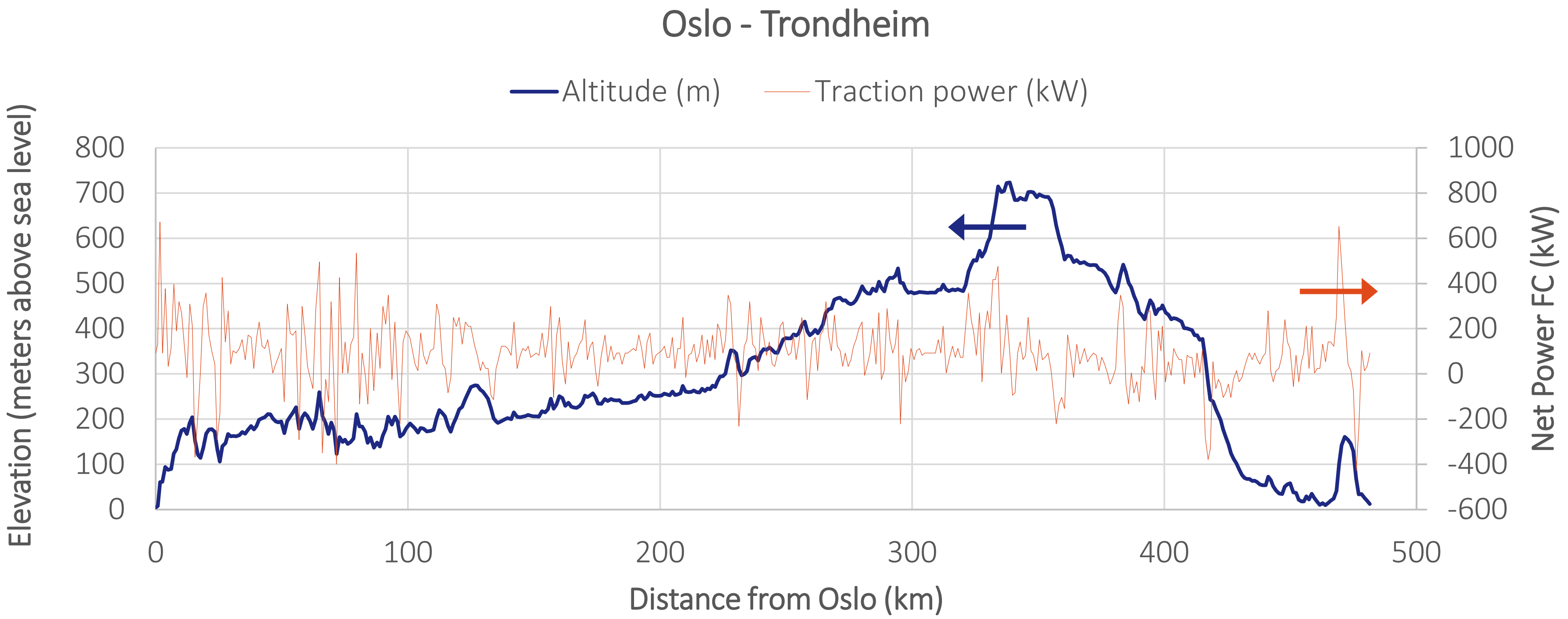


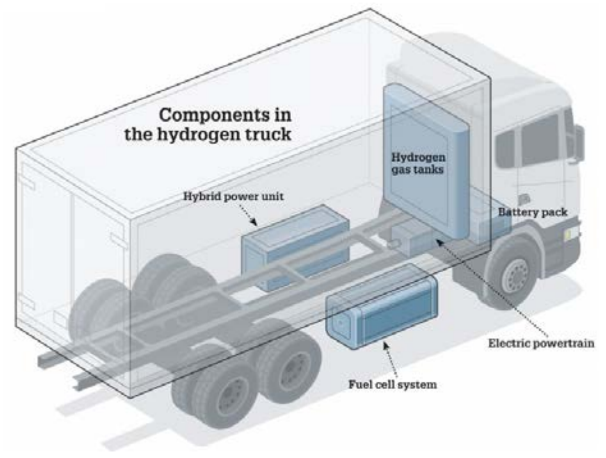
	Today	2030
Annual transport of cargo	930 000 tons (average last 10 years)	1 150 000
Trips per working day	260	330
Zero emission trucks	0	100

Water Electrolysis H2 Station Fuel Cell Electric Truck

Source: Janis Danebergs (2019), Techno-economic study of hydrogen as a heavy-duty truck fuel, Master Thesis, KTH/IFE

Case Study – Hydrogen Fuel Cell Electric Truck (FCET)



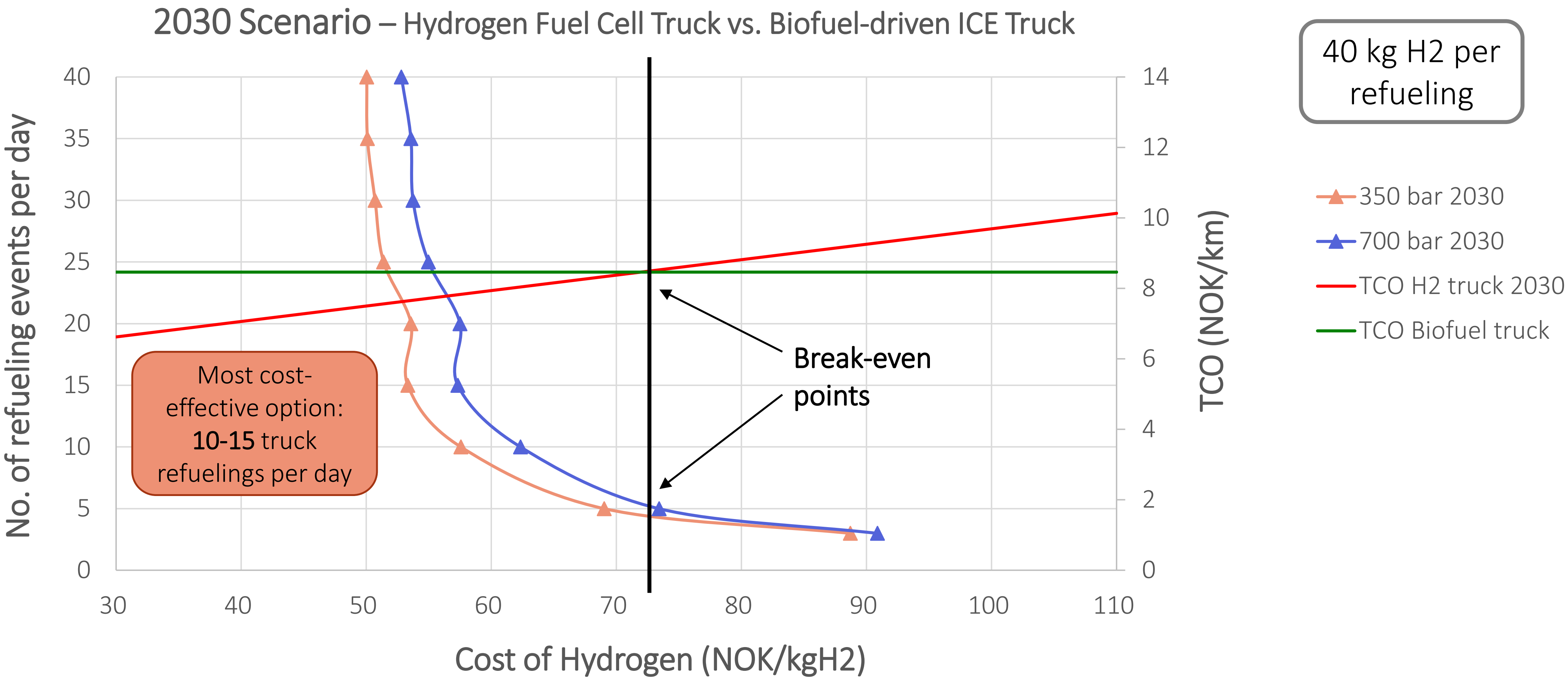


Fuel	Energy Demand per trip	Efficiency of Fuel Cell / Engine	Fuel Demand
Hydrogen	729 kWh	55%	40 kg
Biodiesel	850 kWh	43%	208 l

Batteries for regenerative power increase overall efficiency by **> 10%**

Source: Janis Danebergs (2019), Techno-economic study of hydrogen as a heavy-duty truck fuel, Master Thesis, KTH/IFE

Case Study – H2 Refueling Stations & Fuel Cell Trucks



Source: Janis Danebergs (2019), Techno-economic study of hydrogen as a heavy-duty truck fuel, Master Thesis, KTH/IFE

Conclusions

1. Both passenger and freight **transport demands** are expected to **increase towards 2050**
2. **Battery Electric** most suitable and competitive option for **light-duty vehicles**, due to high efficiency
3. **Hydrogen** and **Fuel Cell Electric** most promising option for **heavy-duty vehicles**, due to high energy storage density
4. **Zero-emission transport** will require huge investments in new **renewable power** production & charging/refueling **infrastructure**
5. **Advanced ICT-systems** needed to optimize highly integrated renewable energy & transport systems

IFE Hynor Hydrogen Technology Center

Thank you for your attention!

Øystein Ulleberg

Principal Scientist IFE | Director MoZEES

oysteinu@ife.no