The energy transition and where mobility will go to – Part 2

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Joint EPS-SIF Int. School of Energy, I-Varenna, Jul 22-27, 2019
The idea of green fuels was prominently described very early.

Water is the coal of the future. The energy of tomorrow is water, broken down into hydrogen and oxygen using electricity. These elements will secure the earth's power supply for an indefinite period.

Jules Verne, The Mysterious Island, 1870
The Petroleum age
only a blink of an eye in the time-scale of earth

It is not only the CO₂-discussion
to think about alternatives to fossil oil
for transportation
The vision of eCars started very early

"As soon as I will have time and enough money I will build an electric vehicle"

Model "Victoria"
built: 1905 by Siemens-Schuckert
range: 80 km (based on lead-acid batteries)

source: https://img3.auto-motor-und-sport.de/Siemens-Elektromobilitaet-Elektrische-Viktoria-articleDetailWide-b7e1ef24-341462.jpg
Battery technology was well established at the beginning of the 20th century.

1.000 miles endurance with an electric car in 1910 !!!

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-> higher maturity level compared to cars with combustion engine at that time
CO₂-emission reduction targets and reality
Example: Germany

Becoming serious – CO₂-emission reduction targets DE

Electricity sector (target: -92.5%)

Industry (target: -81%)

Households/SMEs (target: -92.5%)

Mobility (target: -92.5%)

Agriculture (target: -60%)


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Hydrogen from renewables enables large-scale long-term storage and sector coupling.
The future of automotive
The philosophy of Toyota is shared also by other big players

• Hybrids have two drivetrains: the combustion engine plus the electric system → challenge of costs and weight

• However, they provide the capability of recuperation

• The learning curve of hybrids is an excellent base for full-electric vehicles on basis of batteries or fuel cells
Electric vehicles
Batteries vs fuel cells  (1/4)

Many car manufacturers follow battery and fuel cell systems in parallel.

Both technologies have clear pro’s and con’s.

Their choice is based on two main criteria: vehicle size and travel distance.
There is no alternative to oil-based fuels regarding range of operation due to their high volumetric energy density.

Hydrogen has ultimate gravimetric energy density, but requires high effort for storage and energy conversion.

Batteries suffer from their notably lower energy density, but do not require an addition energy converter (like a fuel cell).
Electric vehicles
Batteries vs fuel cells  (3/4)

• Charging time of batteries requires extended acceptance from the user
• Quick-charging capabilities of batteries can be improved but always only with losses in energy density
• Battery charging will challenge grid frequency (end user driven)
• Regarding refueling time there is no alternative to gasoline as well, but hydrogen comes close.
• Mass of the electric system (storage and converter) and intended range of operation decide on the best choice
Batteries versus fuel cells
both electric systems will have their right to exist

• Regarding mass production batteries still have a technical lead compared to fuel cells

• Most major car manufacturers follow both routes

• Following trend is emerging:
  - batteries for smaller urban cars
  - fuel cells for bigger cars

• Hybrids will be the minimum standard to follow pure ICEs
Electric Vehicles
China is speeding up very rapidly

II. Development of FCVs in China

Fuel Cell Trucks

- Dongfeng launched 760 fuel cell logistic trucks in 2017 and 500 were licenced in Shanghai;
- The truck use 30kW fuel cell module from Refire and could loaded 3.2 tons of goods, with 400km milage;
- A factory of Dongfeng is in constructing in Yunfu city near Synergy to produce fuel cell trucks.

- China is far behind other countries in ICE technology. They strategically decided to stress the disruptive electric route
- In battery technology China improved very fast in the last two decades
- Fuel cell propulsion is aggressively pushed in the last decade.
Hydrogen refueling stations are still the bottleneck but roll out continuously

- All car manufacturers agreed on the H\textsubscript{2} storage concept of 700 bar compressed gas
- The association ‘H2 Mobility’ was established to roll out H2 refueling stations.
- Several oil companies and gas suppliers have developed their own H2 marketing plans and contribute to the roll out
- Buses, trucks and trains will further stimulate the fuel cell age as they typically are fueled at hubs
Hydrogen Technology: The safety issue

Public association with hydrogen:

- Hindenburg accident
- Fukushima

but:

- about 500 Billion norm cubic meter of hydrogen are safely handled worldwide today in various industrial processes
- several 100 km of H2 pipeline operated safely for decades (e.g. in Germany: Ruhr area, Leuna area)
- up to the 70’s `city gas´ (made of coal) contained more than 40 % of hydrogen. It was common for residential use.
- H₂ caverns are reliably operated for more than 10 years in UK and US
- safety benchmarks with gasoline outline that H₂ is less dangerous than gasoline regarding explosion and reaction to fire
- H₂ bulk logistic (road transport) without major incidents.
- 700bar storage on-board of passenger cars have been qualified in stringent safety tests.

source: Linde Group
The future of battery technology
Quick charging still a challenge; properties must be seriously balanced

Catch 22 for automotive batteries

- Current state of the art are LiFePO4 and LiNMC batteries due to their high intrinsic safety
- Quick charging is possible, but notably diminishing energy density
- Increase of energy density is possible, but diminishing safety and cycle life
- Ultimate goals are Li-air batteries. Safety and cycle life are serious challenge.
- A mid-term improvement for Li- batteries can be expected by using solid state electrolytes.

2009: Toshiba Li-ion (high-power prototype):

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specified charge time</td>
<td>6 min (80%)</td>
</tr>
<tr>
<td>Nominal energy density</td>
<td>90 Wh/kg</td>
</tr>
<tr>
<td>Weight (incl. terminals)</td>
<td>210 g</td>
</tr>
<tr>
<td>Real energy density</td>
<td>48 Wh/kg</td>
</tr>
<tr>
<td>For comparison:</td>
<td></td>
</tr>
<tr>
<td>Lead acid:</td>
<td>25-40 Wh/kg</td>
</tr>
<tr>
<td>Li_{high energy}:</td>
<td>&gt;200 Wh/kg</td>
</tr>
</tbody>
</table>

source: Toshiba, 2009
CO$_2$-reduction by cars will be extended to production and plant operation

- Zero-CO$_2$ targets will be extended to the whole cycle life of a car (including its production)
- Plant operations will included as well in the CO$_2$-footprint argument
- Zero-targets will be extended a total environment view (water usage, recycling, etc)
- All major car manufacturers follow that approach
Autonomous driving technically already on a very high level

- Very high safety requirements (<10-8 fatal errors/h). A human typically has around 10-3 fatal errors/h.

- Further targets: onboard connectivity with street infrastructure and other near-range road vehicles.

- Laser-based LIDAR (light detection and ranging) is the key sensor technology for autonomous driving:
  - high special resolution (better than RADAR)
  - information on direction and speed

- Connected systems allow detection of shadowed road users.

- Legal responsibilities in case of an accident have to be clarified.

- Secure and ultra-fast data communication has to be established and standardized.

Source: FhG IMS
Heavy duty transport
An established approach for well defined tracks

Even in the past, heavy duty transport has been electrified for catenary operation when routes are:

- well defined
  and
- frequently operated

Motivation:
- higher efficiency of electric motors compared to ICEs
- locally free of emissions
Heavy duty transport
The surface freight density will further increase

The analysis of the German road network leads to the following key messages:

1. 60% of the HDV emissions occur on 2% of the road network (BAB = 12,394 km)

2. The most intensely used 3,966 km handle 60% of all ton-km on the BAB

Focusing first on the main freight transport routes, a significant decarbonization step can be achieved. This approach can be applied all over the world.

source: ITF, Transport infrastructure needs, 2016

Concept eHighway:

source: Akerman, Siemens MO TI EH
## eHighway – current demonstrations in Germany, Sweden and US

### Demo projects on public roads

- **Ports of Los Angeles, CA**
  - connection to the rail terminal (distance 1 mile)
  - cooperation with Volvo and local truck manufacturer

- **Sweden – motorway**
  - test track on a public road between industrial area and port
  - benchmark of different electrification concepts for log-distance transport
  - cooperation with Scania

### R&D projects

#### Germany

Three R&D projects

- 05/2010 – 09/2011 (ENUBA)
- 05/2012 – 12/2015 (ENUBA 2)
- 01/2016 – 09/2019 (ELANO)
eHyWay
Demo project in the ports of Los Angeles

Three hybrid trucks in public road demonstration

- **A - Volvo / Mack**
  - Parallel hybrid
  - Independent propulsion: **Diesel**
  - No significant battery

- **B - Transpower CNG-Truck**
  - Serial hybrid
  - Independent propulsion: **CNG and battery**
  - Mid-sized battery (~ 50 km)

- **C - Transpower Battery-Truck**
  - Pure E-Truck
  - Independent propulsion: **only battery**
  - Mid-sized battery (~ 50 km)

source: Akerman, Siemens MO TI EH
Rail-bound traffic
The history of electrified railways started 1881

- First demonstrator of an electric locomotive in 1879
- Several demo projects followed to benchmark DC, AC and 3phase electricity
- Power supply via overhead contact lines and current bars was still open

source: https://commons.wikimedia.org/wiki/File:First_electric_tram__Siemens_1881_in_Lichterfelde.jpg#/
Rail-bound traffic
A notable share of the rails are still non-electrified

• Most efficient solution for railroad transportation is power supply via overhead contact lines

• Nevertheless, a notable share of the tracks are still non-electrified

• Standard solution for non-electrified railroads propulsion are Diesel modules

• Diesel modules – despite of their CO$_2$-footprint create notable service and maintenance costs

USA: only 3 electrified tracks are longer than 250 km!
Can: less than 200 km in total are electrified

source: Allianz pro Schiene (2012); data basis 2010
Rail-bound traffic
emerging concept for non-electrified tracks

- Notable progress has been made in fuel cells regarding reliability and costs
- Demonstrator locomotive have been tested even before 2000 but never reached product status (reliability, costs, infrastructure)
- Application for public passenger transport since 2018 (e.g. Germany)
- Increasing development activities by major manufacturers (Alstom, Siemens, Chinese manufacturer)
- H2 logistic and fuelling via hubs
Sea transport
… burns fuels which are not allowed elsewhere

„Ship radar“, screenshot, dated Juli 08, 2019

- Roughly 90 % of goods transport is conducted via ships
- It is not only CO\(_2\) (approx. 10\(^9\) t/y) but very severe SO\(_2\), NO\(_x\) and particulates to contribute to the emissions
- Ships contribute to global emissions
  - 3 % of human made CO\(_2\)
  - 15 % of NO\(_x\)
  - 13 % of SO\(_x\)
- Heavy and residual oil is used as a fuel (consistency like tar). It contains up to 3.5 % sulfur and approx. 2.5 % unburnable substances
Sea transport

Clean solutions are under first trial

- New fuel directive for ship fuels announced for 2020
- LNG will notably reduce emissions (significantly SOx and particulates)
- Battery powered ships will be a solution for short distances (e.g. ferries)
- First installations with hydrogen powered systems already decided
e.g. by Norled, Norway: start of operation planned 04/2021

Electric ferry “MF Ampère”

- operated by Norled in Sognefjord, Norway
- battery powered
- under operation since 2014

Air-borne traffic will more than double in the next three decades

- At present there are approx. 100,000 flights per day (small private planes not considered)

- CO₂ emissions by aviation in 2019 are approx. 1.000 Mio tons

- The market is predicted to further expand notably and rapidly (2020: 12.8 EJ; 2050 31 EJ)

- IATA commits to CO₂ reduction
The International Air Transport Association (IATA) has settled concrete plans for CO₂ reduction

The aviation industry’s three emissions goals

- Improving fuel efficiency an average of 1.5% annually to 2020
- Capping net emissions through carbon-neutral growth from 2020 (CNG2020)
- Cutting net carbon emissions in half by 2050 compared with 2005

CO₂ reduction targets (IATA)

- known technologies
- economic measures
- biofuels and new-generation technologies
- no action emissions
- net emission tracectory


source: ATAG 2013; IATA annual review 2015
Electric aircrafts efforts started but are challenging for passenger and freight transport

**Wikipedia:**

An electric aircraft is an aircraft powered by electric motors. Electricity may be supplied by a variety of methods including batteries, ground power cables, solar cells, ultracapacitors, fuel cells and power beaming.

source: https://en.wikipedia.org/wiki/Electric_aircraft

- Electric motors provide better efficiency than air turbines
- Most crucial bottleneck will remain the energy density of batteries, which is nearly 2 orders of magnitude below kerosene
- An Airbus 380 with a max take-off weight of 560 t holds up to 320 t of kerosene (refueling time: 40 min).

Electric aircrafts may be a solution for short-distance passenger transportation.

source: BBC, Jul 03, 2019; Eviation Inc (Israel)
The demand of kerosene is enormous. Alternatives have to address this specific requirement

• Battery-operated flights are not able to contribute notably to CO₂ reduction

• At present biomass-based additives are used as also used for road traffic *(subsidised market; they will be allowed only to a defined limit)*

• Synthetic fuels provide the most promising specs regarding volumetric and gravimetric energy density.

• Synthetic fuels can be produced out of green hydrogen and CO₂.

Consumption of kerosene for aviation

Data basis: 2010

- Battery-operated flights are not able to contribute notably to CO₂ reduction
- At present biomass-based additives are used as also used for road traffic *(subsidised market; they will be allowed only to a defined limit)*
- Synthetic fuels provide the most promising specs regarding volumetric and gravimetric energy density.
- Synthetic fuels can be produced out of green hydrogen and CO₂.
Different routes to produce synthetic liquid fuels exist
They all require CO2 as feedstock


Realistic process efficiency considering economic perspective

Simulation parameters:
- Electrolysis efficiency: 4.5 kWh/Nm³ (average during operation)
- H2 loss: 1%
- Aux. power consumption: dependent on synthesis
- Synthesis efficiency: dependent on synthesis (thermodynamic limit as reference)

Electrolysis

Water → Hydrolyzer → H2 → Gas treatment/storage (optional) → Upgrading → Chemical synthesis → Product options

- Synthetic Natural Gas: ηLHV = 48.7%
- FT Diesel: ηLHV = 51.6%
- Methanol: ηLHV = 53.3%
- DME: ηLHV = 49.8%
- Ammonia: ηLHV = 49.8%

Compression (optional)

Synthetic fuels are technically viable however production costs are obstacle and require cheap electricity

- Dominant cost factor in the production of electricity-based fuels (e-fuels) is the electricity price
- Based on European electricity price levels e-fuels will have a serious cost problem
- But, there are regions in the world where green electricity is very cheap
Green hydrogen clearly outperforms alternative electricity-based fuels in terms of cost competitiveness.

Expected production costs

Production cost based on:
- Plant size: 150 MW
- CAPEX electrolysis: 500-1200 EUR/kW,
- electricity price: 20-70 EUR/MWh,
- 10 days hydrogen storage,
- CAPEX synthesis 40-90 Mio EUR
...
A commitment to CO$_2$-reduction is mandatory otherwise there will be always a cheaper solution

source: www.pinterest.de
Summary

- The future of road traffic will be electric. Batteries and fuel cells will be complementary.
- Autonomous driving is on the way. Legal responsibilities have to be clarified.
- Progress in battery development will be marginal. Higher energy density always has to be balanced with safety and cycle life.
- Aviation and long-distance sea transport still will need ‘energy carrier’ with an energy density comparable to oil-based fuels.
- Hydrogen will be the future energy vector. E-fuels will be the approach when high volumetric and gravimetric energy density is required.
- Countries with very low renewable energy costs are preparing for the future business with hydrogen and e-fuels.
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Future of Automotive “Out of America”

Would You Like To Know How You Can Easily Convert Your Car To Run On Water and Gas Today To Double Your Gas Mileage and Save Thousands Of Dollars On Fuel Costs?

source: http://www.drivewithwaterfuel.com/?hop=wealthprom
Hydrogen Transport
A serious question for countries with high share of energy imports

Hydrogen can be transported
• as compressed gas
  • in vessels (via trailer or ship)
  • in pipelines
• kryogenic in the liquid phase (at -253°C)
  • via trailer or ship
• chemically bound
  • in metal hydrids
  • organic liquids