Vehicle concepts for tomorrow’s demand:
a European research perspective

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DLR
German Aerospace Center

- Research Institution
- Space Agency
- Project Management Agency
Locations and employees

Approx. 8000 employees across 33 institutes and facilities at 16 sites.

Research areas

- Aeronautics
- Space Research and Technology
- Transport
- Energy
- Defence and Security
- Space Administration
- Project Management Agency
Outline

• Introduction
  • Drivers, CO₂ regulation in Europe, mid-term goals

• Today‘s EV trends in Europe
  • Stock, new registrations

• What about the future of vehicle electrification?
  • European scenarios to the year 2030
  • Challenges of alternative fuels and hydrogen

• Game changers for vehicle concepts?
  • Automation and connectivity, other business models

• DLR Next Generation Car - vehicle concepts
  • Concepts and technology highlights

• Summary
Megatrends

- Growing awareness of limited natural resources
- Climate change in progress
- Increasing population, agglomeration in big cities and suburban areas
- Demographic change

- Increasing efficiency
- Lower fuel consumption and lower CO₂ emissions
- Alternative and regenerative power
Drivers for new developments in the automotive industry – reducing fuel consumption and emissions

**Emission issues**
- CO₂ legislation for passenger cars until 2020
- Mismatch regulation / real-world
- Local air quality

**Emission goals, long-term, examples**
- Netherlands: As of 2035 ‘zero emission’ for new passenger cars
- India: plans for 100 percent electric vehicles by 2030
- Norway: target that in 2025 all newly-registered cars are zero emission*
- European Union: Until 2050 60% less GHG emissions in transport compared to 1990 §
- G7++: Until 2050 40-70% less GHG emissions worldwide compared to 2010
- COP21**: Zero net emissions until mid-century / closed carbon cycle

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Trends in electrification of powertrains (1)
Growing number of PEVs from German carmakers

Source: Audi, BMW, Ford, Daimler, Opel, Porsche, Volkswagen
Trend in electrification of powertrains (2) - 58 models eligible for German incentives – more to come!

- **Audi:** A3 e-tron, R8 e-tron, Q7 e-tron, A2 e-tron, Q5 e-tron, Q6 e-tron, Q3 e-tron
- **BMW:** i8, 330e, X5 xDrive40e, 225xe, i5, Mini Countryman, i3
- **Daimler:** B-Class ED, C 350 e, GLC 350e, E 350 e
- **Porsche:** Panamera S E-Hybrid, Cayenne S E-Hybrid, Mission-E, 911 S E-Hybrid
- **Volkswagen:** XL1, Golf GTE, B-Class ED, Passat GTE, C Coupé GTE, Tiguan GTE

BEV PHEV
Trends in EV stock development international

Source: ZSW (2016)
PEV trends in the European Union

New registrations for PEV (M1) in the European Union

Top PEV (M1) market share Countries in the European Union

PEV (M1) market share in the European Union

Source: European Alternative Fuels Observatory, www.eafo.eu
PEV trends in Europe

**EV Market share in 2016 YTD**

- Norway
- Sweden
- Iceland
- Netherlands
- Austria
- Belgium
- Average

**Best selling PEV models (M1) in Europe last 12 months**

- Mitsubishi Outlander PHEV (14%)
- Renault Zoe (10.8%)
- Nissan Leaf (8.7%)
- Volkswagen Golf GTE (8.5%)
- Tesla Model S (7.8%)
- Others (50.1%)

**Share new registrations last 12 months**

- BEV (M1)
  - France (21%)
  - Norway (26.8%)
  - Germany (10.9%)
  - United Kingdom (12.4%)
  - Denmark (25.2%)
  - Others

- PHEV (M1)
  - Netherlands (31.9%)
  - United Kingdom (18.9%)
  - Norway (10.8%)
  - Germany (12.7%)
  - Sweden (18.7%)
  - Others

www.eafo.eu
Trends in EVSE

Geographical distribution of the 2015 stock of EVSE outlets by charger type

- estimated total of 1.45 million electric car charging points worldwide in 2015
- United States and China account for more than 55% of private outlets
- China and Japan account for more than 65% of fast-charging outlets
- Problem: business models of charging infrastructure!
What about the future of electrified powertrains?
How to reach the EU- CO₂ target in the new vehicle fleet? What could be the target in 2030?

Modelling results / BaU-scenario

- With the **efficiency improvements** and a slight electrification, the average CO₂-emissions of new vehicles can be reduced by **24%** until 2020. Thus, the given limit of **95 g/km** will be reached.

- The onward electrification comes with a reduction of **43%** until 2030 compared to 2010. So the assumed target of **75 g/km** will be achieved.

Ref. DLR, http://www.project-emap.eu/
Model approach VECTOR21
Vehicle Technologies Scenario Model

- Different **customers** are specified
- **Vehicles** are technically, economically and environmentally specified
- **Political** regulations and boundary conditions are modelled
- Expected **development** and changes of key parameters can be considered
- A RCO\(^1\) based purchase decision is implied
- Vehicles with less **CO\(_2\)-emissions** are preferred

[Diagram showing energy consumption, technology costs, fuel prices, vehicle size, customer selection, sales/market shares, and final CO\(_2\) emissions]
Business-as-Usual scenario – EU28

New vehicle sales

- The electrification of the European market takes place. In 2030, almost 50% of the new vehicles have an electric or electrified drivetrain, of which 50% are equipped with a plug-in device.

- High efficient Diesel vehicles can have advantages in CO₂-emissions which brings a largely constant amount of new vehicles in Europe.

- The conventional vehicles are more and more replaced by electrified drivetrains after 2020.

- FCEV do not enter into the market

Ref. DLR (2015), http://www.project-emap.eu/
Business-as-Usual scenario – EU28
New vehicle sales – differences between countries

Ref. DLR (2015), http://www.project-emap.eu/
Development of the German new car market in alternative scenarios / VECTOR21 with utility function

Alternative scenario 1: Conservative
- Low oil price (-40% IEA Current Policy)
- CO₂ limits post 2020 constant (95g)
- No tax privileges for CNG after 2018
- Slow extension of charging/H₂ infrastructure

Alternative scenario 2: Progressive
- Strong increase of oil prices (+40%)
- Strict CO₂ regulation (65g in 2030)
- Continuation of tax privileges for CNG
- Fast buildup of charging/H₂-Infrastructure

Source: Redelbach, DLR
Automobiles and their fuels: All options taken into account? A stronger link to the energy system?
Alternative fuels and powertrains

Primary energy  Conversion  Energy carrier  Powertrain

Oil  FT  Liquid fuels  Internal combustion engine (ICE)
Natural gas  Gasification  Methane  Gasoline (G) / Diesel (D)
Coal  Methanation  Electricity  ICE - Hydrogen
Biomass  BG  ICE - Methane
Solar  Methanation  Electricity  Hybrid (G/D)
Wind  Shift-Reaction  Electricity  Hybrid - Methane
Hydro  Electrolysis  Hydrogen  Plug-In Hybrid
Nuclear  Electrolysis  Hydrogen  Range Extender

ICE - Hydrogen  Internal combustion engine
ICE - Methane

FT: Fischer-Tropsch process
BG: Anaerobic digestion (biogas) process and upgrading the biogas to methane
Power2gas: Electrolysis + methanation
PHEV Challenges:
Emissions in “Hybrid Mode”

Catalyst cools down during WLTC resulting in several cold start peaks (23°C environment temperature, roller dynamometer measurements)
Greenhouse gas emissions (well to wheel)

WTW analysis includes the emissions from fuel production (WTT) and driving (TTW), but not the emissions for the production of vehicles.
Biofuel tank to wheel emissions are considered as "neutral", Wind electricity production emissions are taken as zero.

SI: Spark ignition, CI: Compression ignition, HEV: Hybrid electric vehicle, FC: Fuel cell, BEV: Battery electric vehicle, E5: 5% Ethanol and 95% Gasoline, NG: Natural gas, e-gas: Methane from hydrogen (electrolysis from wind electricity), E100: 100% Ethanol, B7: 7% Biodiesel and 93% Diesel, BTL: Biomass to Liquid, H2: Hydrogen, power2gas wind: electrolysis and methanation of wind electricity

Own calculations based on Concawe (2014), DLR (2014) and DLR database
Development path renewable electricity to 2050 in Baden-Württemberg, a federal state in Germany

Gross electricity production & spec. CO₂ emissions per kWhₑₜ

- How can a maximum share of renewable hydrogen be enforced in Baden-Württemberg?
- How can surplus electricity use from wind and PV plants be maximized?
- How can H₂ mobility contribute to lower (CO₂) emissions from transport sector by 2030?
- What is the possible contribution of H₂ mobility to integrate renewable energies?

Based on IEKK (2014) – Integrated Energy- and Climate-Protection plan for Baden-Württemberg

Ref.: LBST, DLR (2016): Commercialisation of hydrogen technology in Baden-Württemberg
BW: Surplus electricity no business-case for electrification of H₂ – scenario „Flex-“

Electricity generation Baden-Württemberg [GW]
Selected period / 1 week in March

Residual load [GW]
(Annual load duration curve)

Stuttgart as example

Installed power shares [MW]

Synthetic average meteorological year / load of 2030
Simulation by REMIX-Modell, DLR-TT STB

Total hydrogen demand scenario
Surplus electricity BaWü 2030 (ca.) 3.8 TWh
REL production BaWü 2030 (IEKK*) 2.9 TWh
Electricity demand BaWü 2030 (IEKK*) 37.6 TWh

Ref.: LBST, DLR (2016): Commercialisation of hydrogen technology in Baden-Württemberg
Market perspective REN H₂ – Positive business case for transport

- Significant differences in expectations of potential business cases in hydrogen market sectors
- Largest negative gap between achievable H₂ prices (1.67 €/kg) and real H₂ production costs (5.12 €/kg) for use in NG sector results from seasonal NG demand fluctuations
- Differences are caused by other electrolyzer utilization and variation of H₂-infrastructure design between sectors
- For all markets electricity makes up the highest H₂ production cost share
- Hydrogen production costs are topped by 1-2 €/kg₇H₂ by (a) H₂ fuel infrastructure for mobility and (b) poor early electrolyzer utilization (out of which ca. 0.8 €/kg₇H₂ attribute to refuelling stations)

→ Under current policy conditions the only sector allowing positive business cases for the development of REN-based electrolytic hydrogen in the medium term is the transport sector

Ref.: LBST, DLR (2016): Commercialisation of hydrogen technology in Baden-Württemberg
GAME CHANGER AHEAD
Growing Urbanization – the limits of individual mobility?
Challenges for the German transport system in numbers

| Ecological damage                                                                 | • 18 percent of CO₂ emission attributable to transport sector  |
|                                                                                   | • 1.3 kg CO₂ on 4.5 km drive when looking for parking space    |
| Traffic jam                                                                       | • Population growth, urbanization and growth of freight transport |
|                                                                                   | • Every car driver spends 38 hours per year in traffic jam     |
| Accidents                                                                         | • 3,475 fatalities and 392,744 casualties in road traffic (2015) |
|                                                                                   | • 88 percent of accidents are caused by drivers’ mistake      |
| Mobility in old age                                                               | • Demography: share of over 65 year-old rises from today 21 percent to 27.5 percent in 2030 |
| Digitalization                                                                    | • individual, intermodal, efficient through information and communication |
|                                                                                   | • business models are changing from product- to user-oriented |

Ref.: Prof. Karsten Lemmer, DLR, (04/2016) Presentation „Fragen zukünftiger Mobilität“; own translation
Automatisation – a dream becomes reality?
The connected transport system: possible use cases

Hurdles
- legally
- technically
- ergonomic
- socially
- acceptance
- migration
- infrastructure

Source: acatech.de by DLR
Areas where connected car technology can increase efficiency and safety

**Mobility management**
Functions that allow the driver to reach a destination quickly, safely, and in a cost-efficient manner

**Vehicle management**
Functions that aid the driver in reducing operating costs and improving ease of use

**Entertainment**
Functions involving the entertainment of the driver and passengers

**Safety**
Functions that warn the driver of external hazards and internal responses of the vehicle to hazards

**Driver assistance**
Functions involving partially or fully automatic driving

**Well-being**
Functions involving the driver's comfort and ability and fitness to drive

Source: Management Engineers at Strategy&Analysis
Potentials of combining active and passive safety

- Pre-pulse (e.g. by seat movement) can significantly lower the maximum crash pulse for the front seated occupants.
- Active crash absorbers can modulate crash pulses to optimize the structural behaviour for best occupant safety in each situation.
- All these solutions can be utilized best in a connected traffic scenario.

Source: Prof. Dr.-Ing. Rodolfo Schöneburg, Daimler; KREISLAUF DERFAHRZEUGSICHERHEIT, 26.01.2016
Audi’s expectations about the future role of carmakers

„In the future carmakers have not only to build cars, but to act as agents for mobility. Our task will be, to master both worlds. One day the company will probably generate half of it’s turnover within these fields“

Rupert Stadler, CEO Audi AG, Handelsblatt 29.02.2016
Car Sharing

BEEZERO
first hydrogen car sharing in the world (Munich)
50x Hyundai ix35 Fuel Cell

car2go
BEV car sharing, more than 50,000 clients (Stuttgart)
DLR  Next Generation Car – project

Development of novel vehicle concepts
Showcase for DLR’s technological developments
Framework for improved collaboration between different experts and infrastructure within DLR
DLR Next Generation Car
Vehicle concepts

**Urban Modular Vehicle**
- Electric, intelligent, modular

**Interurban Vehicle**
- Comfortable fuel cell vehicle with CFRP body

**Safe Light Regional Vehicle**
- Cost-effective, very light and safe vehicle, class L7e
**Vehicle Concepts**
- Urban compact concept, intelligent, light and save
- ...

**Vehicle Structure**
- Vehicle empty weight 680 kg
- Optimized structures specifically for battery-electric vehicle in the sense of purpose design
- ...

**Vehicle Intelligence**
- Several levels of automation, assist to fully automated (SAE Level 0-5)
- 360° environment detection, C2X-networking
- Cooperation with the traffic
- ...

**Chassis**
- Modular, mechatronic, integrated lightweight chassis with innovative materials
- Steer-by-Wire, Brake-by-wire,
- ...

**Drive Train**
- The modular electric drive with 2 x 25 kW for the basic model, with high speed spreading on the rear axle
- PCM-energy storage
- ...

**Energy Management**
- Intelligent overall vehicle energy management
- Connection of heat and mass flows, Cabine-, battery-, electric motor-management
- ...

**Source:** DLR

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**DLR Next Generation Car**

**Concept highlights of Urban Modular Vehicle**

[Image of vehicle with various features highlighted]
DLR Next Generation Car
Urban Modular Vehicle – Flexibility in future derivates

- One platform for BEV and highly automated (SAE 4/5) during introduction phase
**Vehicle Structure**
- Composite-intensive structure
- Functional integration composites (e.g. structural integrated sensors)
- Additive manufacturing
- Structural weight \( m \leq 250 \text{ kg} \) (compared to MB S-Class \( m = 362 \text{ kg} \))

**Vehicle Concept**
- Upper-class five-seater vehicle
- Family- and business car
- Comfort as priority

**Vehicle intelligence**
- Up to **high automation** (SAE Level 0-4)
- "Connected": Cooperating with the traffic, the infrastructure and other vehicles

**Chassis**
Mechatronic chassis with integrated chassis regulation

**Drive Train**
- Pressure based hydrogen fuel cell system
- Hybrid energy storage

**Energy Management**
- Innovative energy management
- Innovative cooling/heating system
**Vehicle Intelligence**
- Driver assistance and partial automation (SAE Level 0-2)
- Interaction with traffic lights, other traffic and traffic management
- Fully automated emergency actions with drive-by-wire
- Automatic parking

**Chassis**
- Front axle: Crash optimized double wishbone suspension
- Rear axle: Integration of drive motors and chassis
- Integrated chassis control

**Vehicle Concepts**
- Lightweight, safe vehicle in the L7E class
- Empty weight max. 400 kg
- Low drag body shape
- Target quantity: 50,000 / year

**Vehicle Structure**
- Metal-foam sandwich structure
- Weight of the body in white < 90 kg
- State of the art crash safety, comparable to today’s M1-class

**Drive Train**
- 2 x 7.5 kW Motors near the wheels
- Hybrid drive train with fuel-cell system and battery

**Energy Management**
- Use of waste heat of the fuel cell system
- Utilisation of the Insulating properties sandwich structures
- Use of the cooling effect of thermochemical H₂ – storage systems
Summary

• Strong growth rate of electric powertrains (BEV, PHEV) in Europe, but still on low overall numbers

• Lower battery costs and business cases for EV-infrastructure are key for the longterm market success of PEVs

• Alternative carbon neutral fuels, e.g. hydrogen or P2L, need to be developed and we need solutions for the synergies in the renewable energy system

• Automated, assisted and connected driving will lead to several benefits e.g. various aspects of safety and comfort; this will change the vehicle concepts

• DLR is addressing various challenges by technology research in a car system perspective within the Next Generation Car (NGC)-Project
Thank you for your attention!