The Future of Automotive
Future of Automotive in 1882

"Wenn ich mal Muße und Geld habe, will ich mir eine elektromagnetische Droschke bauen"

Werner Siemens 1847
Future of Automotive in 1953

„If the driver had an automativ steering system for his car, all his deficiencies would be eliminated and on our motorways hardly any accident would occur.“

30cm wide metal track in the middle of every lane

2 magnetic detectors, radar and control systems in the car

Automatic Safety distance

Warning signals if obstacles occur and beam signals for a secure speed
Future of Automotive in 2007
The vision of the car of the future

Global Trends

- Increasing mobility
- Shortening of natural resources
- Growing need for environmental care
- Growing demand for safety and security, information & communication
- Shift of economic gravity among regions

Automotive-Specific Trends & Visions

- Sustainable Mobility
  - "Zero Emissions"
- Increasing Safety & Comfort
  - "Zero Accidents"
- Seamless Connectivity
  - "Always On"
- Managed Complexity
  - "Always Easy"

"Zero Emissions"
"Always On"
The car of the future: Manage complexity with integration

<table>
<thead>
<tr>
<th>Year</th>
<th>Zero emission</th>
<th>Zero accidents</th>
<th>Always on</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>130 g CO₂</td>
<td>30 - 40% accident reduction</td>
<td><strong>Networking components</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nightvision</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Non-distractive and situation-specific information</td>
</tr>
<tr>
<td>2020</td>
<td>70 g CO₂</td>
<td>50 - 70% accident reduction</td>
<td><strong>Networking cars</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Connected to the world</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Internet services</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Avoid traffic jams</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Online car diagnosis</td>
</tr>
<tr>
<td>2030</td>
<td>0 g CO₂</td>
<td>Accident-free car</td>
<td><strong>Seamless information management</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fully autonomous driving</td>
</tr>
</tbody>
</table>

- Hybrid electric vehicles
- Combined systems of fuel cell, H₂-internal combustion engine (ICE) and hybrid
- In-wheel-motor
- Adaptive cruise control
- Steer-, Brake by Wire
- Fully autonomous driving
- Nightvision
- Non-distractive and situation-specific information
- Connected to the world
- Seamless information management
"Zero Emission": Reduced emissions, optimized fuel economy, and excellent driveability
Engine control systems for sustainable mobility

- MAF (Frequency output)
- PUT Sensor
- ETC 10.1 Optional SENT
- Optional Turbo Speed Sensor
- AGR Valve
- Bypass valve for EEGR Cooler
- Piezo Direct Injector
- Dual Cont. Var. Cam Phaser
- CAM Position Sensor
- Single coil ignition w/ ext. IGBT and Diag. feedback
- Optional T3 exhaust temperature sensor
- Lin upstr. O2 sensor
- Bin downstr. O2 sensor
- SCR temperature sensor
- Optional Turbo Speed Sensor
- PUT Sensor
- Wastegate
- MSA Sensor (CPDD)
- High Pressure Fuel Pump with Flow Control Valve (Single Piston)
- Fuel pressure sensor
- DME engine mounted
- Combined oil temperature sensor
- MSA Sensor (CPDD)
- Knock Sensor
- 2x coolant water temperature
- EWAPU
- Urea pump
- Temperature sensor
- Heated Urea level sensor
- Optional Ethanol Sensor
- SMART NVLD 2
- Canister Purge Solenoid
- Low pressure fuel pump (PWM controlled)
- High Pressure Fuel Pump with Flow Control Valve (Single Piston)
- Fuel pressure sensor
- DME engine mounted
- Combined oil temperature sensor
- MSA Sensor (CPDD)
- Knock Sensor
- 2x coolant water temperature
- EWAPU
- Urea pump
- Temperature sensor
- Heated Urea level sensor
Piezo direct fuel injection – history

... 20 years from first Prototypes to PDI Products
... Innovative System Components need visionary people
and long term R&D

1980 ...1981 1987...1988 2000 ... 2006
Piezoceramic multilayer actuator (PMA)

... first time Piezo Actuator stacks for power mechanics
... technology must meet customer demands...

Advantages of Multilayer Piezo Actuators

- **low voltage**
  by multilayer technology (80/1)

- **high blocking force**
  mechanical stiffness

- **full automotive Temp. range**
  -40°C … 150°C

- **extended lifetime**
  10⁹ cycles

- **actuator with integrated sensor**
  by high electro-mechanical coupling

source: EPCOS
Piezo CNG Direct Injection

Objectives:
- Direct injection (DI) system for gas engines
- Fast, extremely high flow DI using Piezo actuator and hydraulic stroke amplifier
- Variable flow

Customer Benefit:
- No power loss compared to gasoline operation
- Full control of injection process
- Low emissions and gas consumption
- Control of burn process (H₂)
- Based on conventional combustion technology

CNG = Compressed Natural Gas
Piezo Direct Fuel Injection – Features

Spray pattern of Gasoline High Pressure Piezo DI (HPDI)

single injection  double injection
Main Advantages of Piezo Injectors

- **Very fast** opening / closing timing
- **Fully controlled combustion** enables shaping of injection rate
- **Reduced fuel consumption** enables lean/stratified combustion by multiple injection
- **Reduced emission / exhaust** optimized atomization, high accuracy
From energy resource to propulsion system

Energy Resource  Conversion  Energy Carrier  Propulsion System

- Oil (Conventional)
- Oil (Non-Conventional)
- Biomass
- Natural Gas
- Coal
- Renewables (Solar, Wind, Hydro)
- Nuclear

Liquid Fuels

Syngas

Electricity

Hydrogen

Conventional ICE: Gasoline/Diesel

ICE Hybrid

Plug-in Hybrid ICE

Range-Extended EV: IC Engine/Fuel Cell

Battery Electric

Fuel Cell Electric

Source: General Motors

ICE = Internal Combustion Engine  EV = Electrical Vehicle
Different vehicle types and their CO₂ reduction potential (well-to-wheel)

- CNG = Compressed Natural Gas
- PDI = Pidzo Direct Injection
- SDI = Single Direct Injection
- PCR = Piezo Common Rail

Bullet size indicates total cost impact
Hybrid Energy Vehicle Technology

Key features
- combination of gasoline-engine and electro motor (future: diesel + e.motor)
- e-motor responsible for starting & low velocity driving (high torque)
- gasoline-engine only supports at high speed

Environmental value
- >20 % fuel saving possible
- reduced CO₂ emission
- energy regeneration through braking (battery reloading)
# Hybrid Electric Vehicle Highlights

## HEV Features

<table>
<thead>
<tr>
<th>Micro Hybrid</th>
<th>Mild Hybrid</th>
<th>Full Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator</td>
<td>+ Boost</td>
<td>+ Pure Electrical Driving</td>
</tr>
<tr>
<td>Start-Stop</td>
<td>+ Recuperation</td>
<td></td>
</tr>
</tbody>
</table>

- **~5% Fuel saving**
  - Applicable to almost any car, allows wide market roll-out
  - More electrical power
  - Improved NVH (Noise, vibration, harshness) comfort due to stop/start function

- **Up to ~15% Fuel Saving**
  - System Cost Target: *Gasoline Hybrid below Diesel*
  - Driving fun with Target: *Gasoline Hybrid has torque like DI Diesel*
  - Green Image: *Get Fuel back into tank: Re-Gen*
  - Energy storage alternatively Battery or DLC (Double Layer Capacitors)

- **>20% Fuel Saving**
  - New Driving experience: Pure Electric Driving Mode
  - Optional Electric AWD for SUVs
  - Optimized Engines and opt./new Transmissions for Hybrid to get max fuel saving
  - Preferred Energy Storages: Battery (NiMH, Li-Ion,..)
First fleet vehicles for hydrogen cars are in use but necessary infrastructure has to be build up for broader operation

- Well-To-Wheel efficiencies of H₂-fuel cell vehicles are significantly higher than for combustion engines
- Best efficiencies of fuel cell vehicles achieved at part load in contrast to ICE which favors fuel consumption in usual drive cycles
- Typically 5kg of hydrogen is required to power a fuel cell car over 500km, for a comparable H₂-ICE car ca. 9kg are needed
From Hybridisation to Fully electrical vehicle

1. Hybridization as a constant within the propulsion system
2. Decentralize the hybrid drive into the wheels (brakes, damping and steering in one module)
3. Fuel cells for zero emissions
4. Electric energy generated exclusively and directly onboard
## Comparison of different vehicle concepts

<table>
<thead>
<tr>
<th>Transportation sector – well to wheel</th>
<th>η</th>
<th>Investment cost*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gasoline</strong></td>
<td>20.2%</td>
<td>2010: 20T€</td>
</tr>
<tr>
<td>Usage of gasoline cheapest solution for transportation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New hybrid cars to increase efficiency but still behind FC and full electric</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hydrogen</strong></td>
<td>24.8%</td>
<td>2010: 120T€</td>
</tr>
<tr>
<td>Hydrogen Fuel Cell cars in transport sector with distinct advantages over conventional technologies using combustion engine; FC costs have to drop by factor of 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Electric vehicle</strong></td>
<td>27.0%</td>
<td>2010: 60T€</td>
</tr>
<tr>
<td>Full electric vehicle with highest efficiency. Main critical aspects; short driving range and high battery costs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Investment costs for a middle-class passenger car, inflation not considered
In the transport sector, FC systems will be superior to combustion engines in the long term, but investment costs are much higher.

Value Chain Transport - Gasoline combustion engine vs. hydrogen ICE and FC - 2020

<table>
<thead>
<tr>
<th>Value Chain</th>
<th>Gasoline - tank</th>
<th>Hydrogen - tank</th>
<th>Tank-to-wheel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well-to-tank</td>
<td>Dispensing 0% losses</td>
<td>Conditioning at gas station 4% losses</td>
<td>22% Balance of plant 5% losses</td>
</tr>
<tr>
<td>Transport gaseous hydrogen 8% losses</td>
<td>PEM Fuel Cell 40% losses</td>
<td>DC converter 6% losses</td>
<td>28% Electric Motor 11% losses</td>
</tr>
<tr>
<td>Compression 10% losses</td>
<td>Balance of Plant 12% losses</td>
<td>Exhaust system 2% losses</td>
<td>21%</td>
</tr>
<tr>
<td>Gas Clean up 20% losses</td>
<td>Gasoline ICE 2.3€/100km (+0.35€/100km at 25€/t CO2)</td>
<td>13.3%</td>
<td>20.2%</td>
</tr>
<tr>
<td>Exploration 3% losses</td>
<td>Hydrogen FC 1.6-2.5€/100km (+0.3€/100km at 25€/t CO2)</td>
<td>21.4-24.8%</td>
<td></td>
</tr>
<tr>
<td>Exploration + Transport 12% losses</td>
<td>Dispensing 0% losses</td>
<td>Condensation at gas station 4% losses</td>
<td>4.4ct/kWh w/o tax</td>
</tr>
<tr>
<td>Transportation 2.5% losses</td>
<td>PEM Fuel Cell 40% losses</td>
<td>DC converter 6% losses</td>
<td>34%</td>
</tr>
<tr>
<td>Raffination 9% losses</td>
<td>Balance of Plant 12% losses</td>
<td>Exhaust system 2% losses</td>
<td>28%</td>
</tr>
<tr>
<td>Transportation 2.5% losses</td>
<td>PEM Fuel Cell 40% losses</td>
<td>DC converter 6% losses</td>
<td>30%</td>
</tr>
<tr>
<td>Exploration 3% losses</td>
<td>PEM Fuel Cell 40% losses</td>
<td>DC converter 6% losses</td>
<td>30%</td>
</tr>
<tr>
<td>Primary energy 100% oil</td>
<td>Primary energy 100% gas</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources: EU WTW-Report 2007, FZ Jülich, LBST
But, electric vehicles already today have advantages in efficiencies and CO2 emissions over hydrogen FC vehicles.

Value chain transport - hydrogen FC vehicle versus all electric vehicle - 2020

- **Li-Ion Battery**
  - Charging efficiency: 37% losses
  - Self Discharge: 35% losses
  - PEM Fuel Cell: 40% losses
  - DC Converter: 6% losses
  - Electric Motor: 11% losses

- **Hydrogen - tank**
  - Conditioning at gas station: 56% losses
  - Transport gaseous hydrogen: 58% losses
  - Compression: 58% losses

- **Value chain transport**
  - Primary energy: 100% fossil fuel mix
  - Electricity Generation: 40% losses
  - Electricity Transmission: 8% losses

- **Electricity Transmission**
  - Exploration + Transport: 12% losses

- **Primary energy**
  - Exploration + Gas Clean up: 20% losses

- **Electric motor**
  - Self Discharge: 8% losses

- **Comparative investment cost per car**
  - Li-Ion Battery: ~30T€
  - PEM Fuel Cell: ~40T€

- **Cost per kWh**
  - Li-Ion Battery: 4 ct/kWh w/o tax
  - PEM Fuel Cell: 6.1 ct/kWh w/o tax

- **CO2 emissions**
  - Li-Ion Battery: 33%
  - PEM Fuel Cell: 27%

Sources: EU WTW-Report 2007
"Zero accidents": segment Safety and Chassis focuses on complete integrated solutions for active and passive safety

Support daily driving
- Increase comfort
- Automatize standard situations
- Provide safety infrastructure
- Avoid critical situations
- Conduct safety diagnostics which are self-learning

Master critical situations
- Driver information
- Driver support with corrective actions

Pre-crash preparation
- Enable active and passive safety systems

In-crash protection
- Reduce severe personal injuries
- Occupant protection
- Pedestrian protection

After crash
- Check systems
- Inform telematics

"The safety circle"
How does an airbag work?
Overview: State of the Art Restraint System

1: Airbag Control Unit (ACU)
2: Side Satellites front
3: Side Satellites rear
4: Occupant Classification System (OCS)
5: Early Crash Sensor (ECS)
6: Dual Stage Front Airbags
7: Front Side Airbags
8: Head Curtain
9: Rear Side Airbags
10: Buckle-Switch
11: Belt-Pretensioner front
12: Belt-Pretensioner rear
Pressure Sensing System for Side Impact
Physical Principle

- Crash events cause deformation in door cavity.
- Air is compressed and causes increasing pressure in door cavity.

\[
\frac{\Delta p}{p_0} = \kappa - \frac{\Delta V}{V_0} \quad \text{(air: } \kappa = 1.4)\]
ADAS – Advanced Driver Assistance Systems

100% ADAS

- Automatic distance regulator
- Sensitive Guidance / Steering
- Congestion Assistant
- Traffic Sign recognition
- Parking assistance
- Lane Changing warning
- Safe Exit Assistant
- Lane Changing Assistance
- Nightvision

H. Requardt, Uni Frankfurt 06.12.07
Advanced Driver Assistance Systems

Night Vision

**Functionality**
Infrared technology to enhance vision at night, e.g. visually highlighting pedestrians and edges of the road

**Components**
CMOS Camera (NIR)
Head-up display
Near Infrared Headlights
Secondary Display
Advanced Driver Assistance Systems

Augmented Guidance

Functionality
Augmented Guidance overlays a live video picture and the navigation route and shows the highlighted route and the next maneuver by means of a colored bar or arrow.

Components
CMOS Camera
Navigation display
Advanced Driver Assistance Technologies – Operating Distance

Radar 24GHz UWB PreCrash
Lidar ACC
CAMS Camera NiVi (FIR)
FIR Camera NiVi (NIR)
CMOS Camera BSD
CMOS Camera LDW

Sensor Operating Distance

- up to 300m
- >200m
- ~150m
- ~60m
- 1.5 - 4m
- ~30m
- > 90 m
Conventional Brake System
The Electronic Wedge Brake
Components of the Hydraulic Brake System vs. Components of the EWB

Hydraulic Brake System
- Brake Caliper
- Brake Booster
- Brake Pedal
- Handbrake
- ESP
- Hydraulic Line
- Vacuum Pump

Electronic Wedge Brake
- EWB Caliper
- Backup-Battery
- e-Pedal
- Main Brake Controller
- Cable Harness
## Wedge Principle
### Comparison of Braking Philosophies

<table>
<thead>
<tr>
<th>Method of Braking</th>
<th>Power Generation</th>
<th>Reinforcement Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>normal power</td>
<td>Conventional Brake</td>
<td>linear</td>
</tr>
<tr>
<td></td>
<td>The actuator has to actively generate the full clamping force.</td>
<td>$C^* = 2\mu$</td>
</tr>
<tr>
<td>wedge power</td>
<td>EWB Technology</td>
<td>non linear</td>
</tr>
<tr>
<td></td>
<td>controlled electro-mechanical wedge brake with infinite self-reinforcement</td>
<td>$C^* = \frac{2\mu}{\tan\alpha - \mu}$</td>
</tr>
</tbody>
</table>
ABS: Hydraulic Pressure Decrease over Time

ABS: Comparison of Control Strategies

Δt1 >> Δt2

Room temperature

Low temperature

High µ

Low µ

Δp1

Δp2

Δt2
X-by-wire

Steps of mechanical integration after electronical with Drive-by-Wire Concept

first step  
EWB

second step  
IWM

last step  
eCorner

IWM = In-Wheel-Motor
The Integrated Corner Module

- Damping Satellite
- Tire Pressure
- Chassis Dynamics Controller
- FlexRay
- ABS Sensor
- Brake Actuator
- In-Wheel-Engine
- Wheel-ECU
Roadmap to eCorner

New Technologies

- 5-Module-architecture
- ADAS
- Steering
  - D-EPS
- Electric motors
- Hybridt Technology
- Brakes
- EWB
- Sensors
- Absorption

Brake-By-Wire-Module

- Integrated Corner Module
  - EWB + regenerative Braking
- Integration of ABS-Sensors in wheel control unit
- Integration of absorption control

Semi-By-Wire partial Integration

- Steer by Wire

Full-By-Wire complete Integration

- eCorner
  - Steer-by-Wire
  - EWB + regenerative Braking

H. Requardt, Uni Frankfurt 06.12.07
The Evolution of Robot and Car

Leonardo Da Vinci

- Motorized carriage (Daimler) - 1600
- Citroen DS - 1955

1495

Unimate (GM)

- Stanford Arm - 1969
- Aibo (Sony) - 1999

1961

Asimo (Honda)

- Toyota Prius - 1997
- IMTS – Bus (Toyota) - 2004
Robotic frame study

Our cars are lightweight, and – like surfboards and rollerblades
AUTOnomy “skateboard” chassis

re-think the fundamental core architecture of mobility
Lunar Rover
In-wheel Motor Drive System

A Lunar Rover was used during Apollo missions 16 and 17. Altogether, three Rovers were used on the Lunar surface and driven a total of 88.3 kilometers (54.8 miles).
The eCorner – drivers and benefits

Benefits in comparison to conventional systems

- **Safety** benefits (no steering column with steer-by-wire)
- More safety through **driver assistance systems**
- Decrease in **fuel costs**
- **Cost reduction** over the whole product life cycle
- Benefits for the **environment**: automobile without hydraulic liquids
- Possibility of **self-managed driving**
- More **freedom during the production**: no difference between right-hand and left-hand steering due to flexible positioning of steering gear and steering column
Toyota Fine-X: Fuel Cell and Wheel Hub Motor Concept Car

- Electric motors in each of the four wheels
- Compact fuel-cell hybrid powertrain
- Each wheel can steer independently (90 degrees) for extraordinary maneuverability.
- It can rotate on its own axis a full 360 degrees

SOP unknown
"Always On" – Information Management in the car for driver and passengers

- Optimized Human-Machine-Interface
- Optimized information flow
- Car-to-x connectivity
- Devices
- Infrastructure
- Services
- Other cars
Connectivity Segments

Car to Portable Devices (C2D)
- Bluetooth
- Wireless USB
- UWB

Car to Infrastructure (C2I)
- WiFi
- DSRC
- GSM
- GPRS
- CDMA
- UMTS
- WLAN
- WiMax

Car to Car (C2C)
Connectivity Segment “Car to Infrastructure”

**Technologies:**
- Mobile phone technologies & positioning

**Key applications:**
- **Telematic Services**
  - Mobile Security (eCall, bCall, stolen vehicle tracking,...)
  - Location based services (track & trace, pay as you drive, tolling, park info service,...)
  - Car related services (car remote control, remote diagnostics, remote door unlock,...)
  - Non car related services (hotel booking,...)
- **Data transfer for other applications**
  - e.g. Virtual Earth for Navigation
  - Media download / streaming, IP radio

**Benefit:**
- Rescue lives (Zero Accidents)
- Central Information Gateway (Always On)
- Reduce emissions (Zero Emissions)
Connected Navigation: Augmented Map Display

2D Sat Image Map

2,5D only for UMPCs (Ultra Modern PCs)

3D Point of Interest (POI) on 2.5D map (Ultra Modern PCs)
eHorizon—Principle & Usage

Map Matching

ADAS Navigation System

ADAS eHorizon

Sensor Information

Navigation Info

Map Data

Quality Data

Mathematical Probabilities

P (x;y;z): [%]

GPS Position

ADAS Data

3D Data

Route Info

Car Bus Standard Protocol

Safety & Comfort Features

ADAS Horizon Re-constructor („Open Source“)
Audio Islands in Cars & Peace of Mind

Number of audio sources in cars is increasing. Without earphones everyone has to listen to the same sound.

Baltimore based engineering company uses Active Noise Cancelling for Military Applications (submarines, vehicles).

This technology can also create “Personal Sound Spaces”.

Siemens TTB and the Defense Contractor join forces to create “Audio Islands” around each occupant.

Siemens VDO is commercializing the technology.
Always easy...
Overview

**Problem:**

The vehicle is evolving into a “media hub”:
- Occupants have different music tastes
- Generates unwanted “noise” in cabin
- Headphones socially isolate & exclude

**Trends:**

- Navigation, Radio, CD/DVD Player, …
- Gaming devices brought into the car
- Wi-fi downloading MP3s, videos to car

How can all of the occupants listen in a comfortable, sociable and harmonious way?

**Innovation:**

Active Noise Control creates *Personal Sound Spaces* around each occupant:
- Ultra-short Play-out delay for improved anti-sound computation
- Innovative headrest design
Technology

Infotainment Noise Control:

- Leveraged Active Noise Control (ANC) experience from military domain for vehicle infotainment

- Captures model of vehicle interior acoustics

- Headrest based on 5 speaker dipole design:
  Inner speakers emit desired audio to near-field, while outer speakers emit anti-sound to far-field

- ANC yields higher performance by exploiting:
  - all inputs are clean digital signals from the infotainment system
  - a play-out delay allows more time for better anti-sound computation

- Safe & intuitive HMI to select audio and zones
Status

The Project
Technology from Baltimore-based Defense Contractor Siemens TTB and Contractor applied technology on automotive infotainment prototype
Siemens SV has exclusive license for automotive

Applications & Business Potential
Short-term: Solution for premium and family vehicles
Long-term: Expand to buses, trains, airplanes, quieter zones for industrial environments

Status Update
2 zones demonstrated in a 5 Series BMW at CES 2007 (Consumer Electronic Show, Las Vegas)
Transferred to Siemens SV in July 2007

4 zones prototype finalized
Pilots in preparation with a couple of car makers

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Always easy...