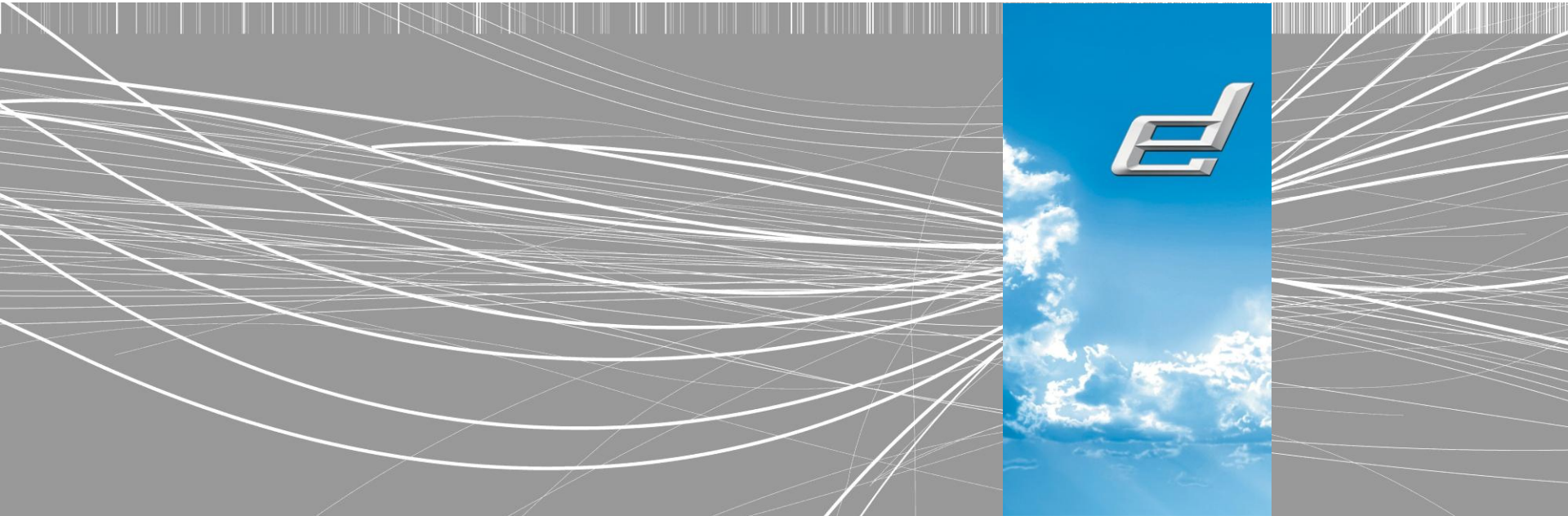


# **BMW Forschung u. Technik GmbH.**

## **25th Anniversary of a Think Tank.**



**Efficient Dynamics.**

**BMW Group**



# **Efficient Dynamics.**

## **Contents.**

**Introduction.**

**Hydrogen engines.**

**Reformer system.**

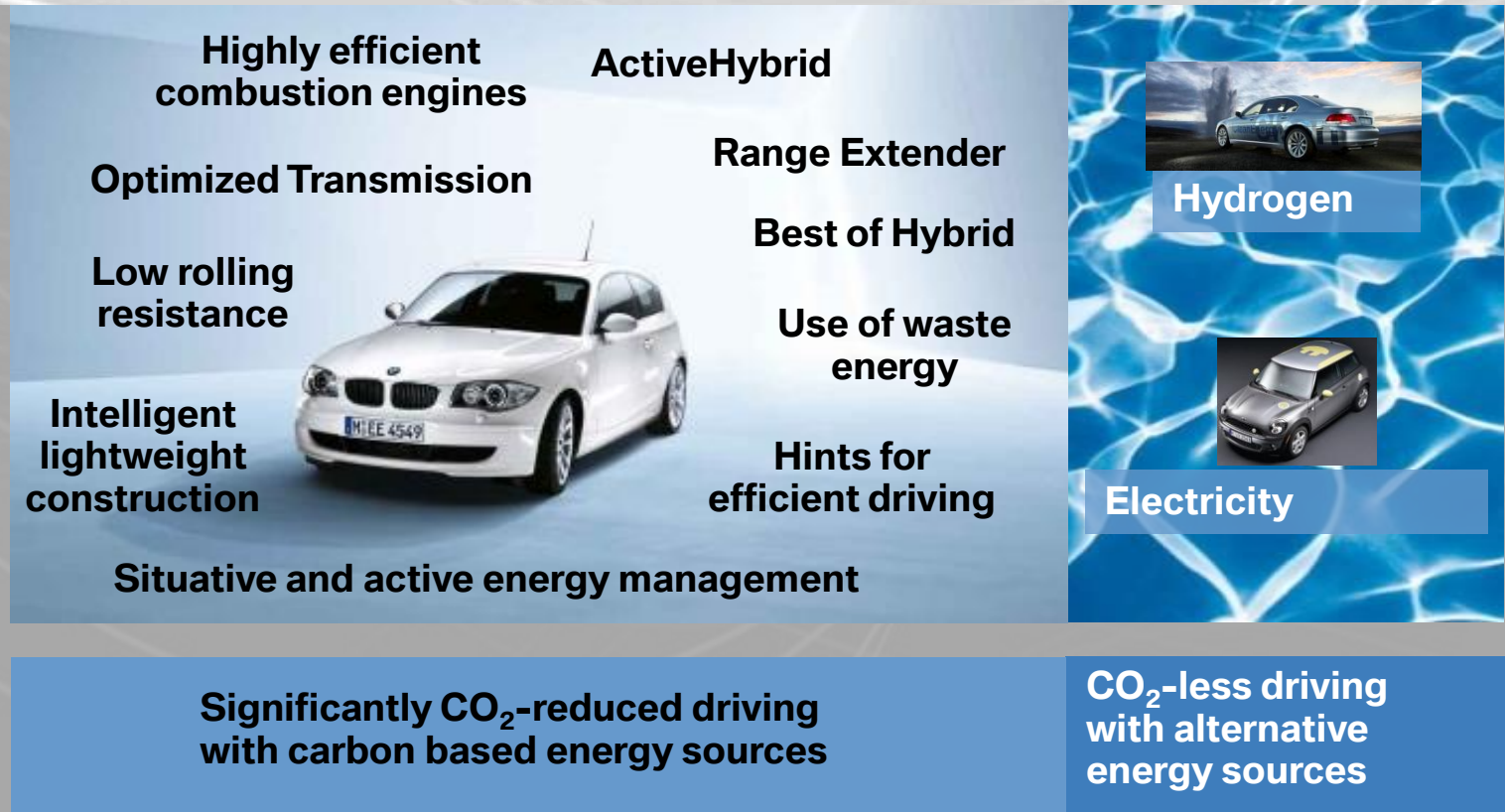
**Fuel cell as Auxiliary Power Unit.**

**Fuel cell hybrid vehicle.**

**Hybrid research.**

# Efficient Dynamics.

## Our strategy is sustainable.



# **Efficient Dynamics.**

## **The Most Important Challenges.**

**New storage systems for electricity and hydrogen.**

**Combustion engines and electric motors with high specific performance and efficiency.**

**Cost effective hybrid systems.**

# Efficient Dynamics.

Future hydrogen vehicles aiming at:  
1 kg H<sub>2</sub>/100 km.

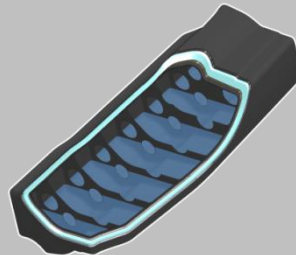
Infrastructure  
coverage



Monovalent vehicle,  
function-related Design



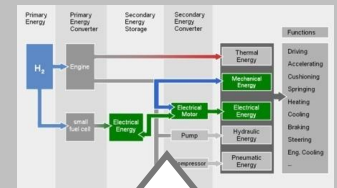
integrated  
light-weight tank



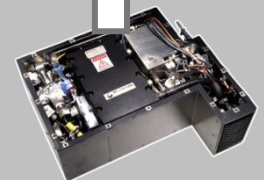
high  
power  
density



intelligent energy  
management



with a  
small  
fuel cell





# **Efficient Dynamics.**

## Research in hydrogen engines.



# **Efficient Dynamics.**

## **Research in hydrogen engines.**

### **Milestones**

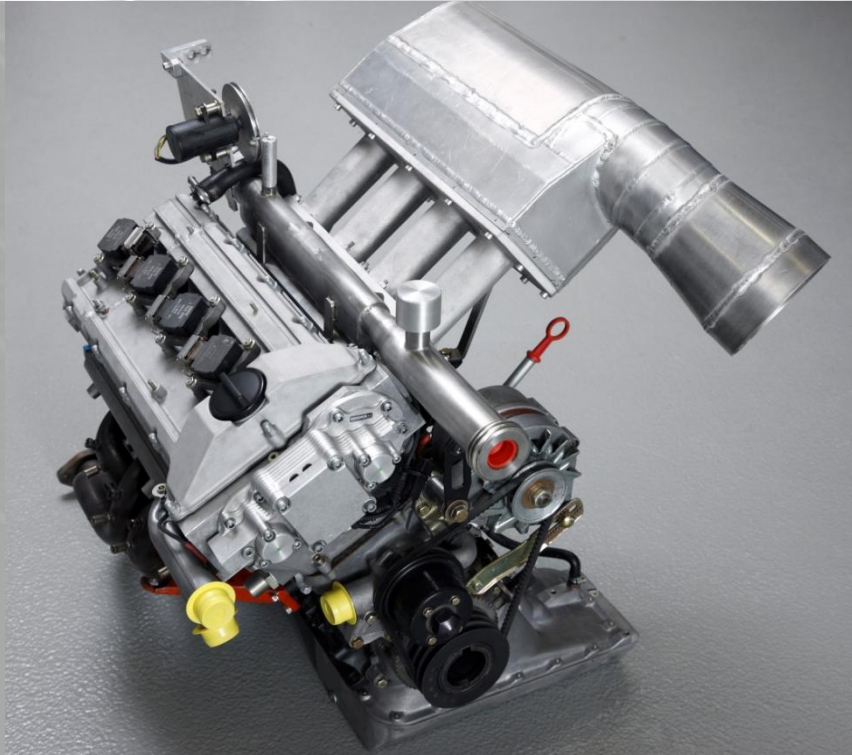
**2005: Sports-car engine with cryogenic mixture formation  
record for naturally aspirated H<sub>2</sub> engines  
specific performance 67 kW / l displacement**

**2007: Single-cylinder research engine with Otto geometry  
record for turbocharged H<sub>2</sub> engines  
specific performance 109 kW / l displacement**

**2009: Single-cylinder research engine with Diesel geometry  
record for H<sub>2</sub> engines  
effective efficiency  $\eta_e = 43 \%$**

# Efficient Dynamics.

## H<sub>2</sub> four-cylinder engine with sportive genes.



„Two small BMW subsidiaries  
achieve something great.“

BMW Forschung und Technik GmbH:  
H<sub>2</sub> technology with cryogenic mixture formation

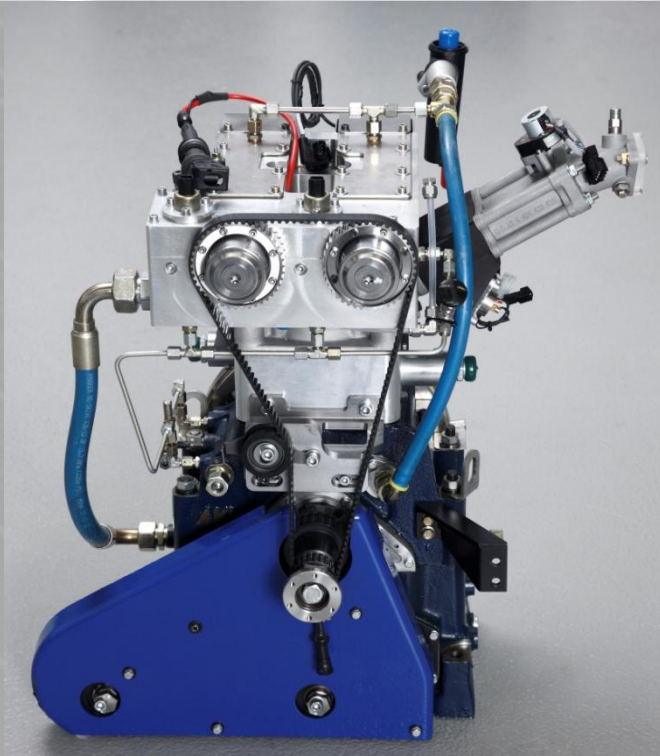
Record for naturally aspirated H<sub>2</sub> engines:  
specific performance 67 kW / l displacement

BMW M GmbH:  
sports-car engine for high rpm



# Efficient Dynamics.

H<sub>2</sub> single-cylinder research engine  
with Otto geometry.

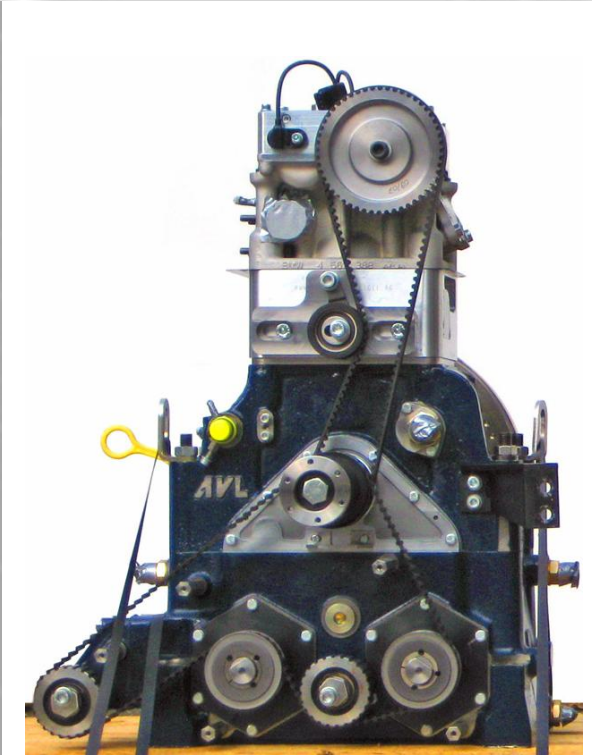


„High Tech for maximum performance.“  
with high-pressure H<sub>2</sub> direct injection

Record for turbocharged H<sub>2</sub> engines:  
specific performance 109 kW / l displacement

# Efficient Dynamics.

## H<sub>2</sub> single-cylinder research engine with Diesel geometry.



„High Tech for maximum efficiency.“

with high-pressure H<sub>2</sub> direct injection  
and a very high compression ratio

Record for H<sub>2</sub> engines:  
effective efficiency  $\eta_e = 43 \%$

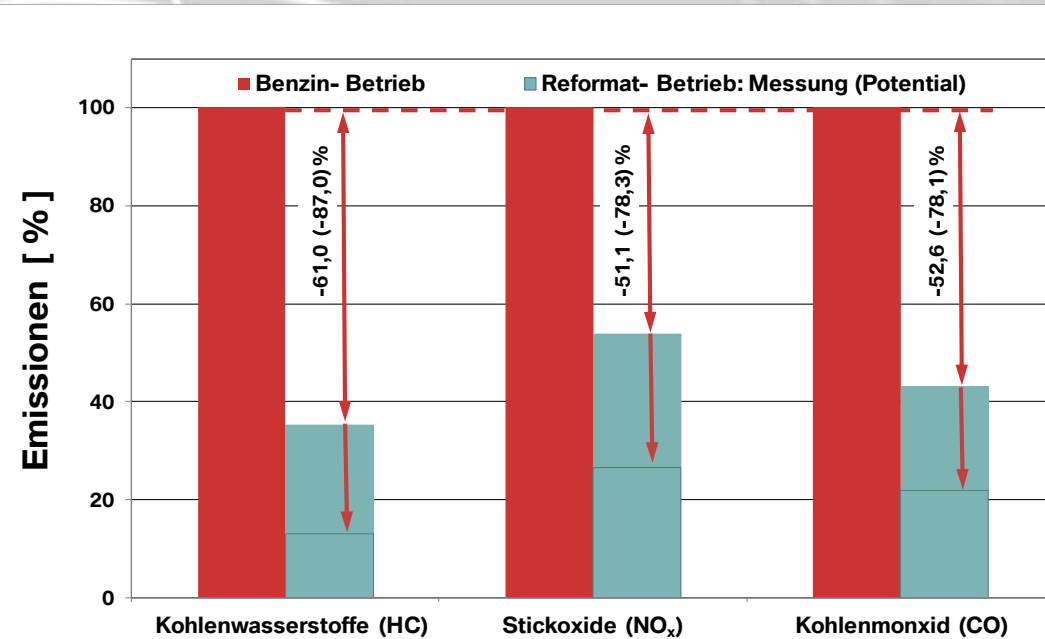
this corresponds with the best conventional Diesel  
engines even after a very short development time

# Efficient Dynamics. Reformer System.



# Efficient Dynamics.

## Reformer System. Emission potential.

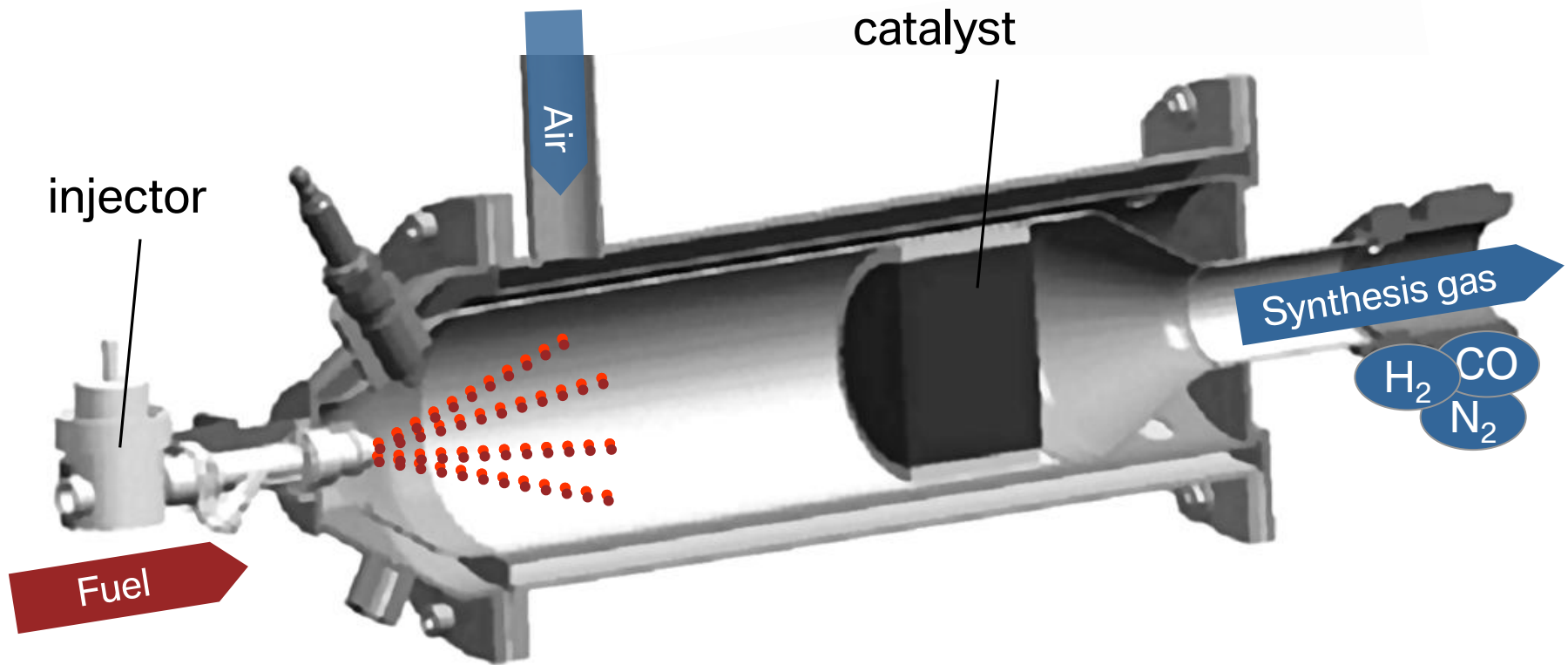


EU5<sup>1)</sup>- emission results  
for petrol resp. reformer operation  
(warmed up).  
(petrol results = 100 %)

<sup>1)</sup> EU5- limits:  
HC= 0,1 g/km;  
NO<sub>x</sub>= 0,06 g/km;  
CO= 1 g/km

# Efficient Dynamics.

## Reformer System. Functionality.



**POX-Reformer**

fuel + air  
( $\lambda \approx 0,33$ )

80 %

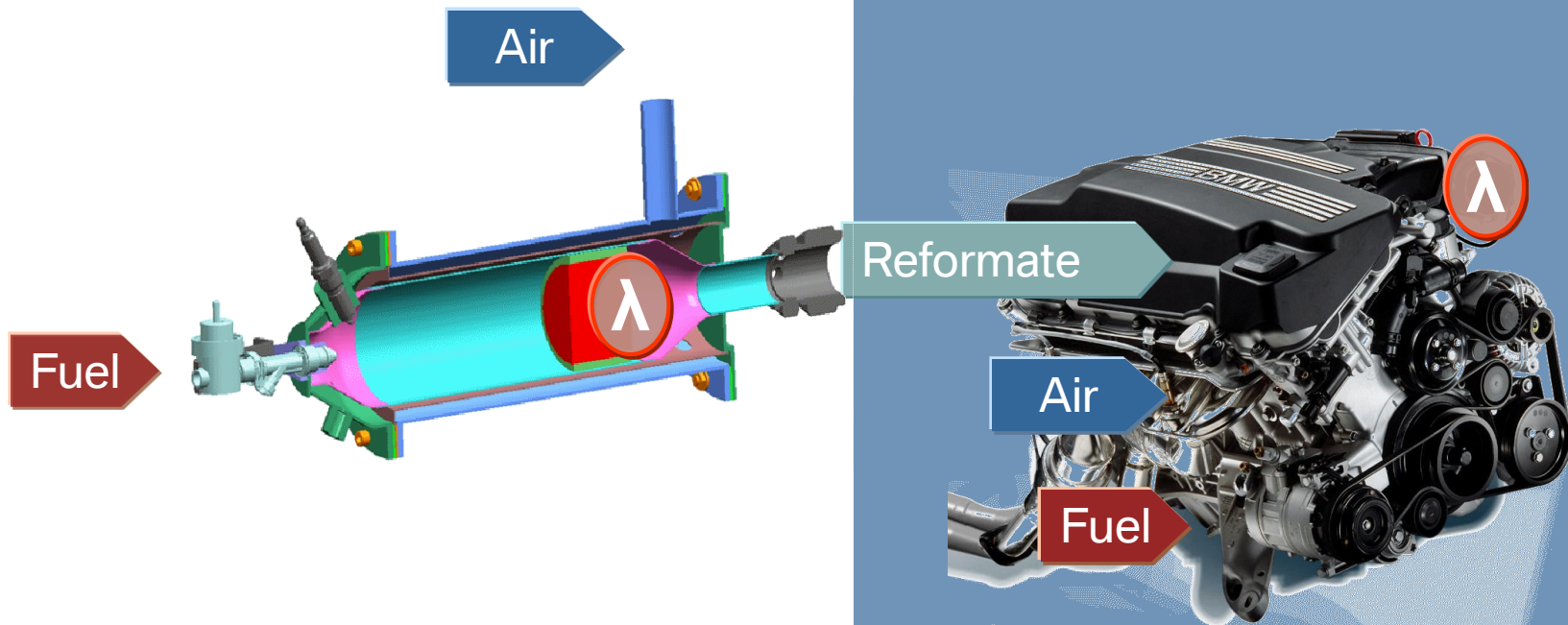
20 %

$\approx H_2 + CO + 2 N_2$  Reformat  
 $\dot{Q}$  Heat



# Efficient Dynamics.

## Reformer-System. Functionality.



# Efficient Dynamics.

## Fuel cell as Auxiliary Power Unit.



# Efficient Dynamics.

## Fuel cell as Auxiliary Power Unit.



Quick Refueling



Electric  
Power





# Efficient Dynamics.

## Fuel cell as Auxiliary Power Unit.

„Mobile Powerplant“



5 kW High Efficiency

City  
Cruising



Office



19.0 °C

Air Condition



# Efficient Dynamics.

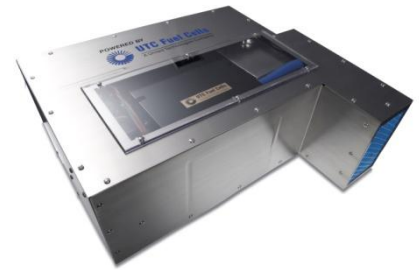
## Fuel cell as Auxiliary Power Unit.



First fuel cell



Car Integration



System package

1997

2000

2003

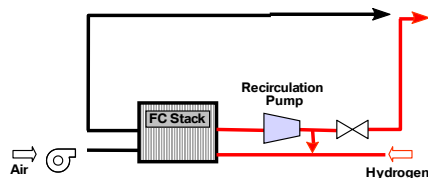
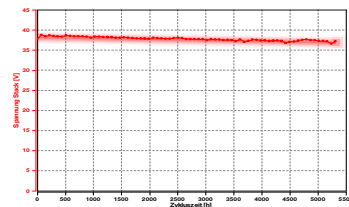
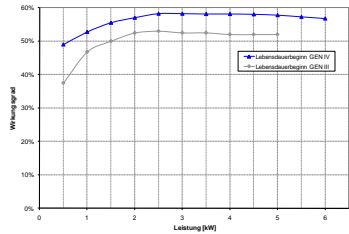
2006

2009



# Efficient Dynamics.

## Fuel cell as Auxiliary Power Unit.



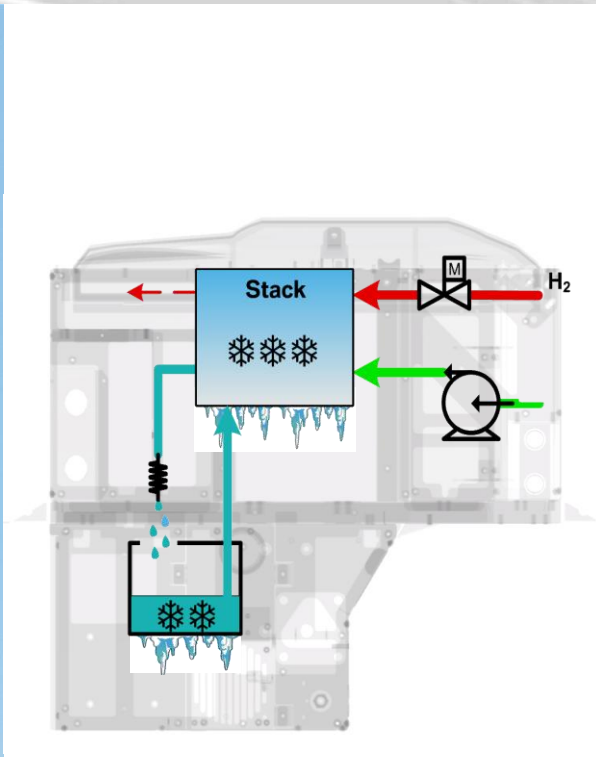
**High Efficiency**  
**Ultra low Pressure PEM System**  
**(no supercharger)**

**Extended lifetime**  
**5000h (vehicle lifetime)**  
**successfully confirmed**

**Reduced System complexity**  
**Internal humidification**  
**Lower costs**

# Efficient Dynamics.

## Fuel cell as Auxiliary Power Unit.



### Cooling by Evaporation

- Advanced water management

### Natural Water Drainage (supported by gravity)

- Reduced startup and shutdown time

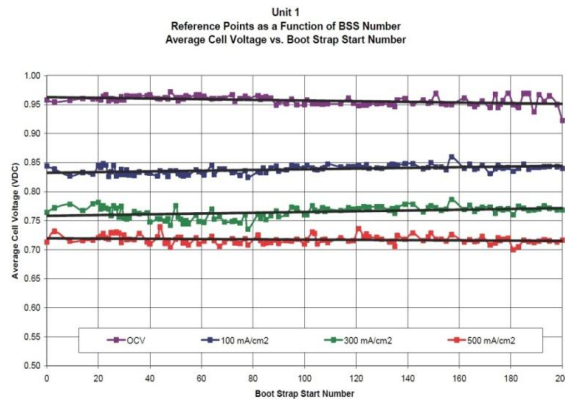
# Efficient Dynamics.

## Fuel cell as Auxiliary Power Unit.



**Freeze Capability Validated**  
200 Starts without degradation

**Result Summary Freeze Test**

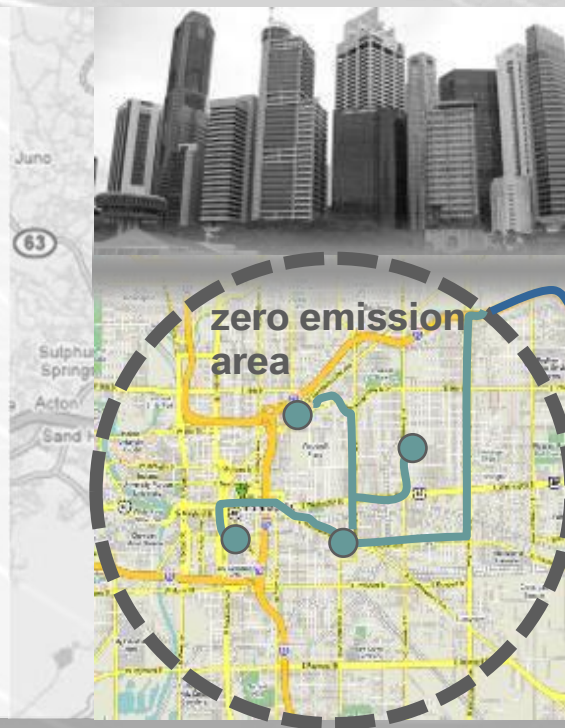


# Efficient Dynamics. Fuel cell hybrid vehicle.



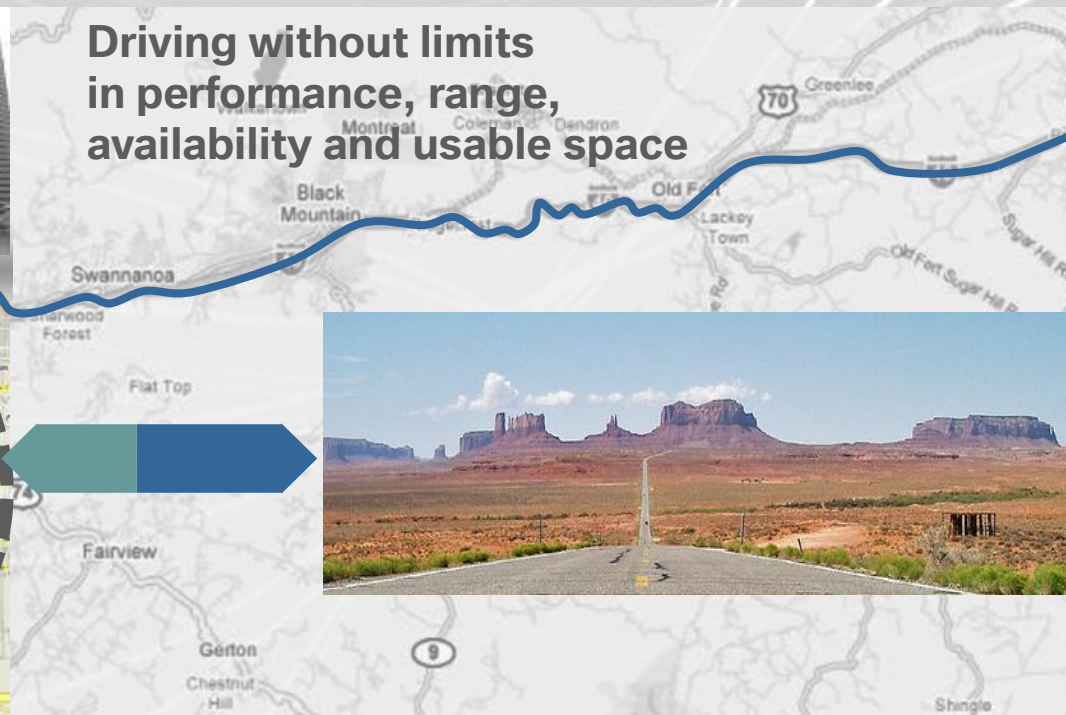
# Efficient Dynamics.

## Fuel cell hybrid vehicle.



Electric driving in the inner city with a fuel cell

Driving without limits in performance, range, availability and usable space



Acceleration with both engines

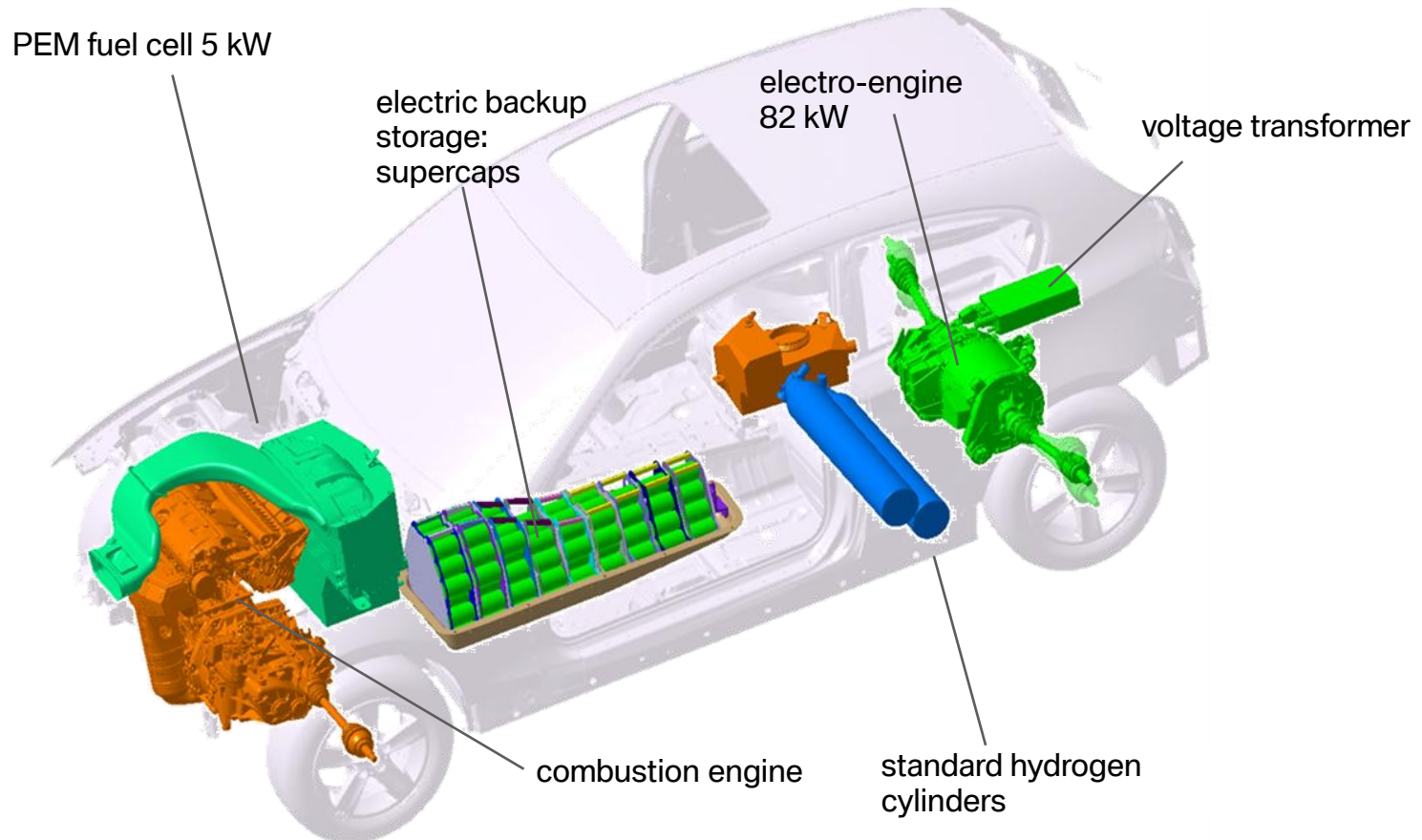
Interurban driving with combustion engine



# Efficient Dynamics.

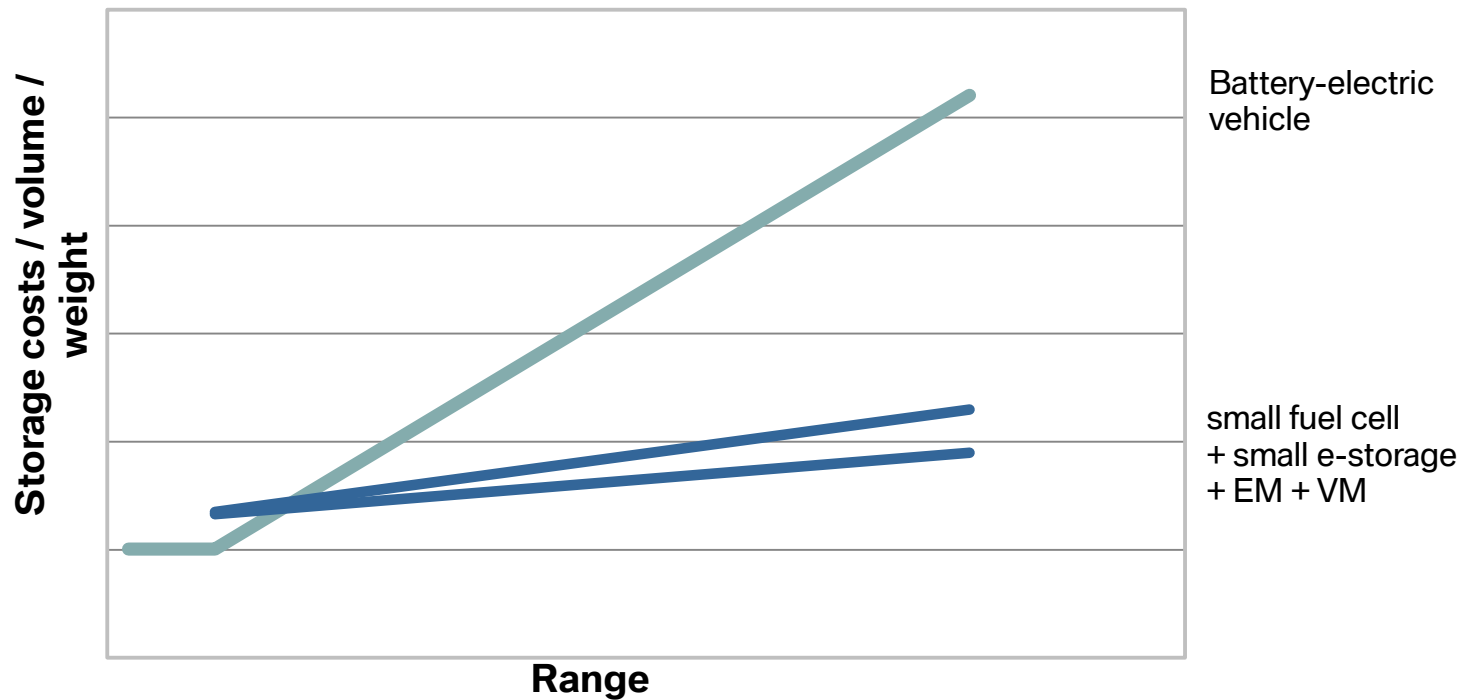
## Fuel cell hybrid vehicle.

### 1. step in a BMW 1 series.



# Efficient Dynamics.

Propulsion concepts. Effort-range ratio.



# Efficient Dynamics. Hybrid research.



# Efficient Dynamics. Evolution of Electric Powertrain.

## Hybrid



**1994**

518i Parallel Hybrid  
with NiMH battery



**1995**

316i Serial Hybrid  
with NaNiCl battery



**2003**

X5 Active  
transmission  
with supercaps



**2005**

X3 Full Hybrid with  
active transmission,  
battery and  
supercaps

1970

1980

1990

2000

2010

**1972**

BMW 1602  
with lead batteries

**1987**

BMW 325  
with NaS battery

**1992**

BMW 325  
with NaNiCl battery

**1993**

BMW E1  
with NaS battery

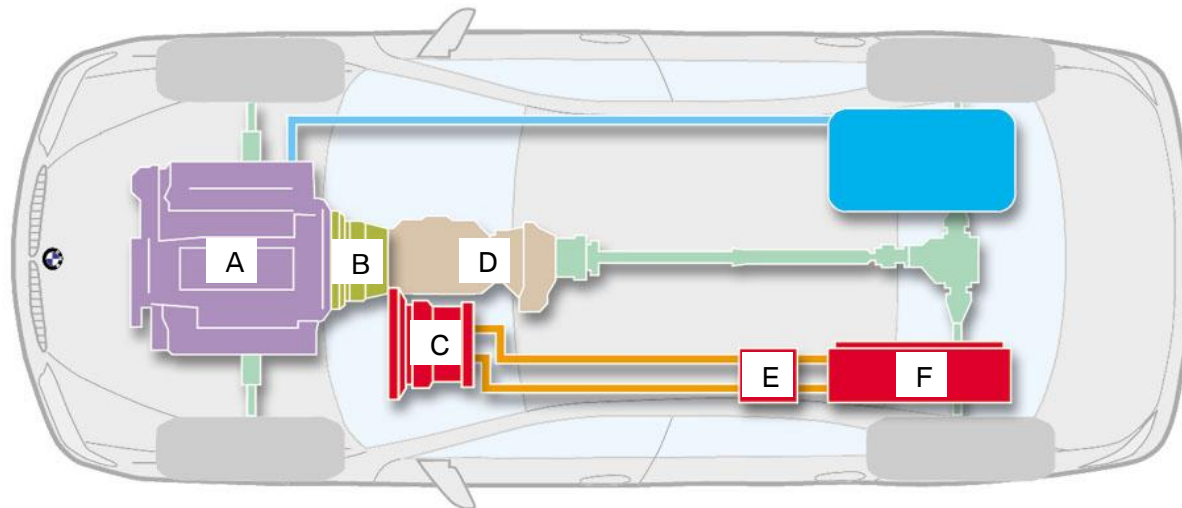


## Electro

# Efficient Dynamics.

## BMW 5 Series 3<sup>rd</sup> generation – parallel hybrid (1994).

Combined Driving with internal combustion engine / electric motor



- A = Internal combustion engine
- B = Clutch
- C = Electric motor
- D = Transmission
- E = Power electronics
- F = Battery

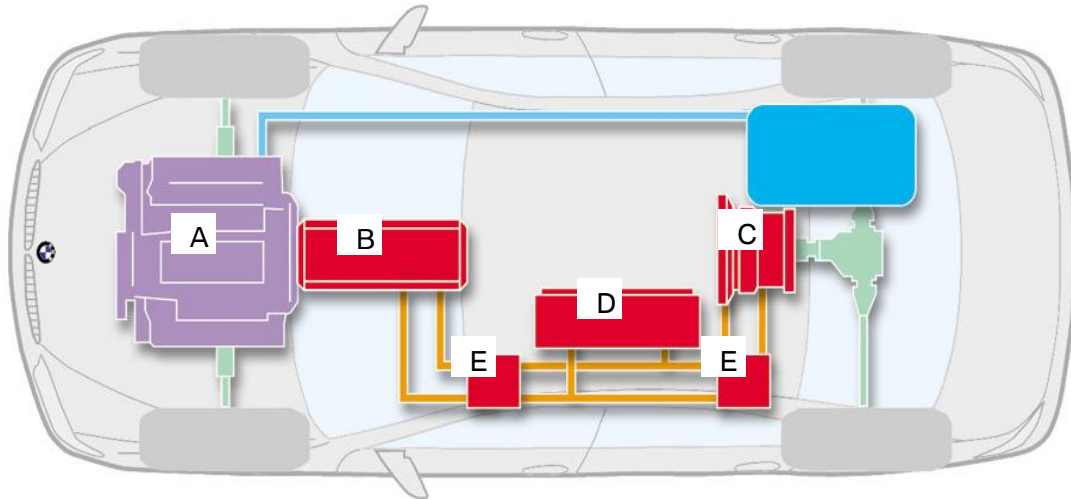
Basic vehicle: BMW 518i  
4-cyl. -1.8l petrol engine, 83 kW  
Asynchronous electric motor,  
18 kW, peak 26 kW/165 Nm  
NiMH battery 3,5 kWh  
Electric range 11 km



# Efficient Dynamics.

## BMW 3 Series 3<sup>rd</sup> generation – series hybrid (1995).

5 kW permanent charge output is adequate for city driving



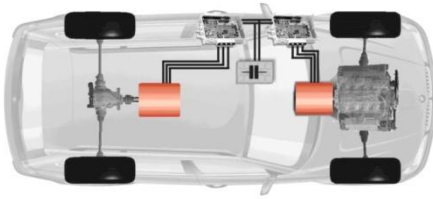
- A = Internal combustion engine
- B = Generator
- C = Electric motor
- D = Battery
- E = Power electronics

Basic vehicle: BMW 316i  
4-cyl. -1.6l petrol engine, 40 kW  
Permanent magnet synchronous motor,  
31 kW continuous output, max. 35 kW  
NaNiCl battery, electric range 38 km

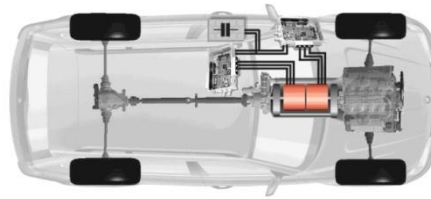
# Efficient Dynamics.

## Evolution hybrid drive, system development.

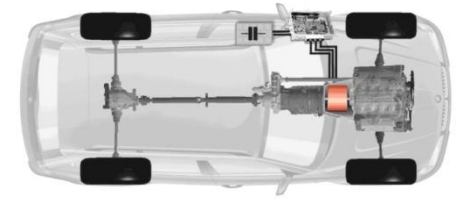
Parallel Hybrid: optimum balance between cost and benefit



**Serial Hybrid**



**Torque-split Hybrid**



**Parallel Hybrid**

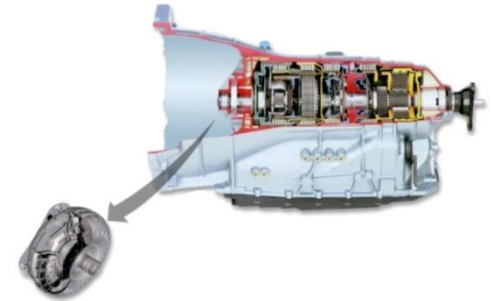
# Efficient Dynamics.

## Evolution of hybrid drive, component development.

Minimisation of space requirements by integration of electric motor in transmission



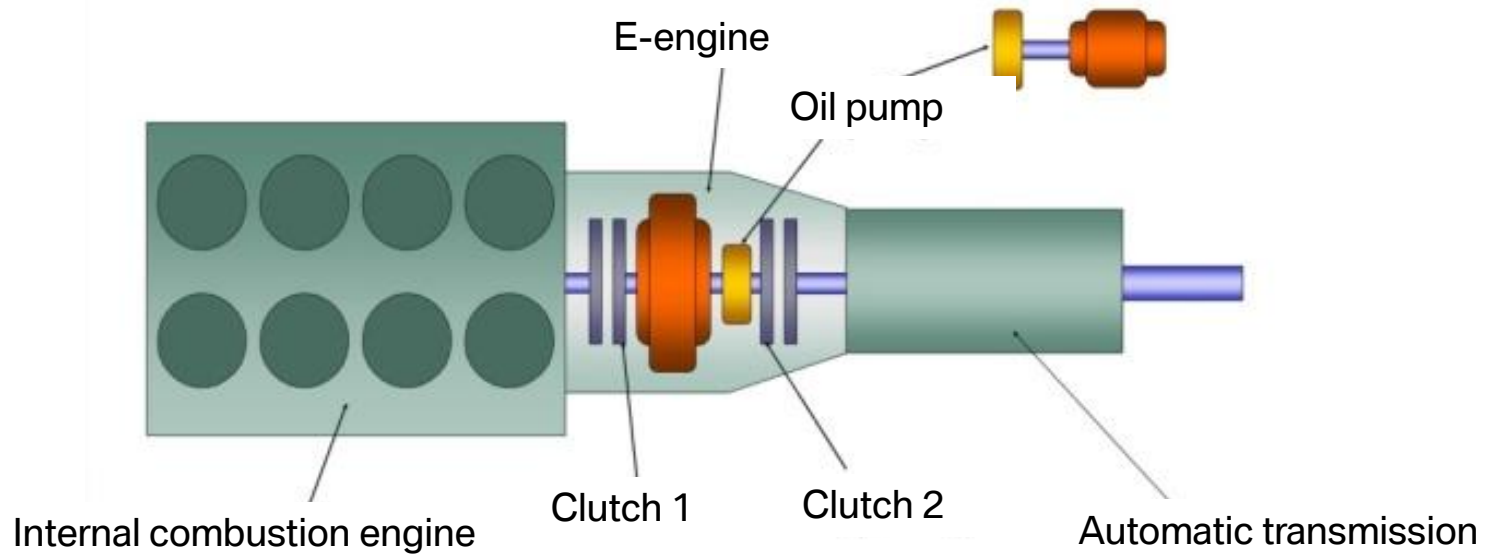
Electric motor  
in transmission



No hydrodynamic  
Converter

# Efficient Dynamics.

## Evolution of hybrid drive, system architecture.



# Efficient Dynamics.

Evolution of hybrid drive, electric storage.



- high power density
- high durability
- very fast charge and discharge cycles possible

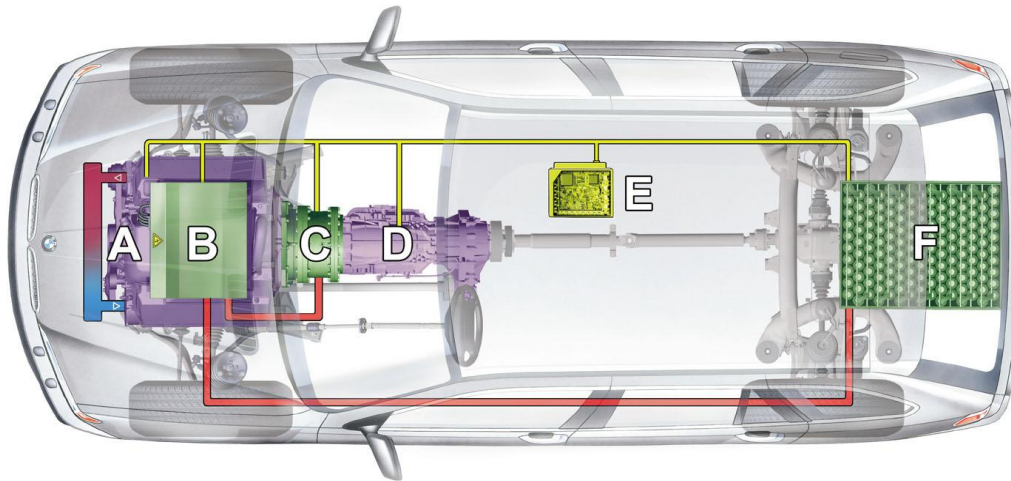
Supercap



# Efficient Dynamics.

## BMW X5 Power Assist ( 2003).

Improved driving pleasure



- A = Internal combustion engine
- B = Power inverter
- C = Electric engine
- D = Transmission
- E = Drive management
- F = Super Caps

### Basic vehicle: BMW X5

8-cyl. – 4.4l petrol engine, 210 kW

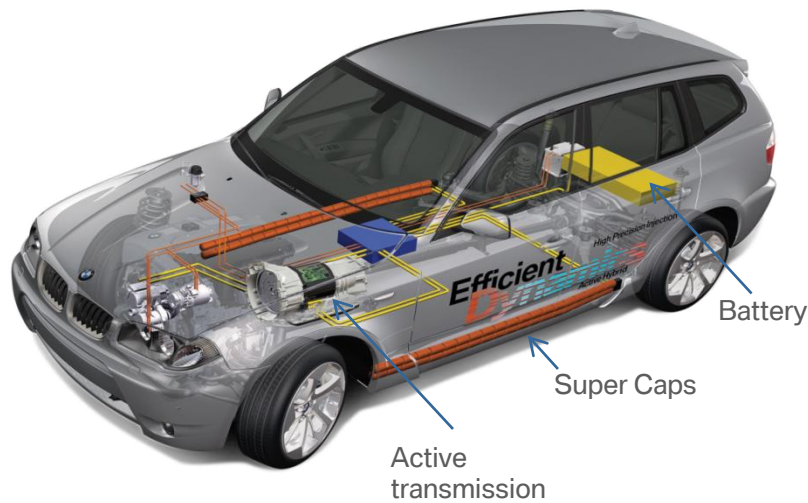
5-speed automatic transmission without converter

Asynchronous electric motor 14 kW continuous output  
max. 70 kW/660 Nm (electric), > 1000 Nm combined

Super Cap energy storage 650 kW

# Efficient Dynamics.

## BMW Concept X3 EfficientDynamics (2005).

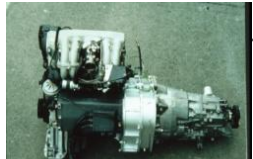


### Premises

- Integration as add-on solution
- No additional package space required
- Low cost of Hybrid system by Design to Requirement and optimized package integration

# Efficient Dynamics.

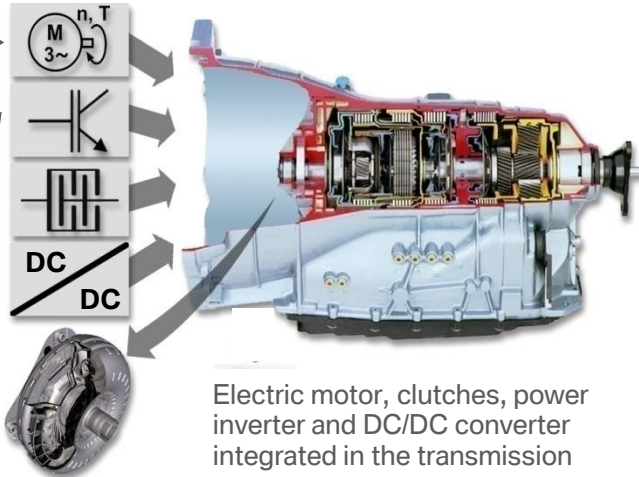
## BMW Concept X3 EfficientDynamics (2005).



Electric motor



Power inverter



Electric motor, clutches, power inverter and DC/DC converter integrated in the transmission



Active transmission

**Efficient Dynamics.**  
Thank you for your attention.

**BMW EfficientDynamics**  
Weniger Emissionen. Mehr Fahrfreude.

