

# Efficient and Dynamic – The BMW Group Roadmap for the Application of Thermoelectric Generators.

**BMW EfficientDynamics.**  
Less emissions. More driving pleasure.



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Manager Advanced Development –  
BMW EfficientDynamics / Thermal Management

San Diego, January 3rd, 2011

**BMW Group**



# BMW EfficientDynamics.

Mobility is essential for economic success and quality of life.



# BMW EfficientDynamics.

Hybrid technology and CO<sub>2</sub> edition models complete our premium products.

## ActiveHybrid 7



Performance: 342 kW  
CO<sub>2</sub>-Emission: 219 g/km\*  
Consumption: 9,4l/100 km (25mpg)\*

## X6 ActiveHybrid



Performance: 430 kW  
CO<sub>2</sub>-Emission: 231 g/km\*  
Consumption: 9,9l/100 km (23mpg)\*

## 320d EfficientDynamics Edition



Performance: 120 kW  
CO<sub>2</sub>-Emission: 109 g/km\*  
Consumption: 4,1l/100 km (57mpg)\*

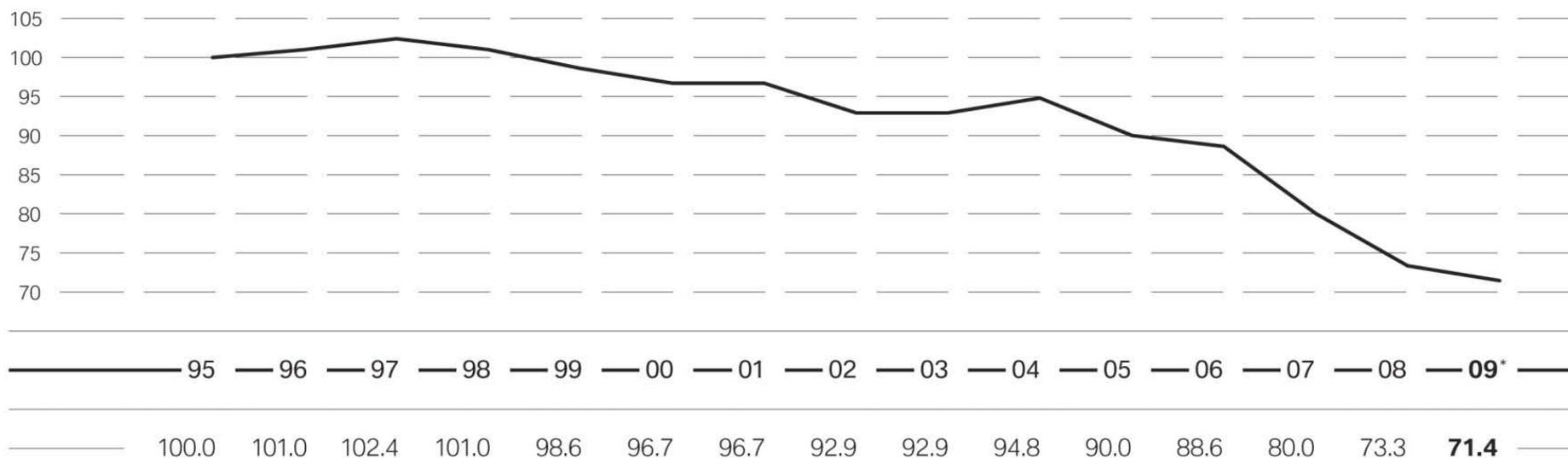
\* Basis: New European Driving Cycle

# BMW EfficientDynamics.

The BMW Group reduced the CO<sub>2</sub> emissions of its fleet by ~29 % (1995-2009) in Europe.

## Development of CO<sub>2</sub> emissions of BMW Group cars in Europe

(Index: 1995 = 100; Basis: fleet consumption of newly registered cars in Europe (EU-15) measured on the basis of the New European Driving Cycle in accordance with the ACEA commitment)



\* measured only on EU-27 basis with effect from 2009

- The BMW Group fulfilled its ACEA commitment and reduced CO<sub>2</sub> emissions for its fleet by almost 29 % during the period from 1995 to 2009.
- This reduction is unmatched by any other car company.

# BMW EfficientDynamics.

## Our strategy middle and long-term.

### BMW EfficientDynamics strategy

2007 / 2008

2009

2010

BMW 116i 8,111 130 g	BMW 116d 5,311 140 g	BMW 116d 4,811 130 g	BMW 116d 4,811 130 g	BMW 116d 4,811 130 g
BMW 116d 5,311 140 g	BMW 116d 4,311 130 g			
BMW 116d 4,311 130 g				
BMW 116d 4,311 130 g				
BMW 116d 4,311 130 g				



Otto / Diesel

Efficient Dynamics

Hydrogen

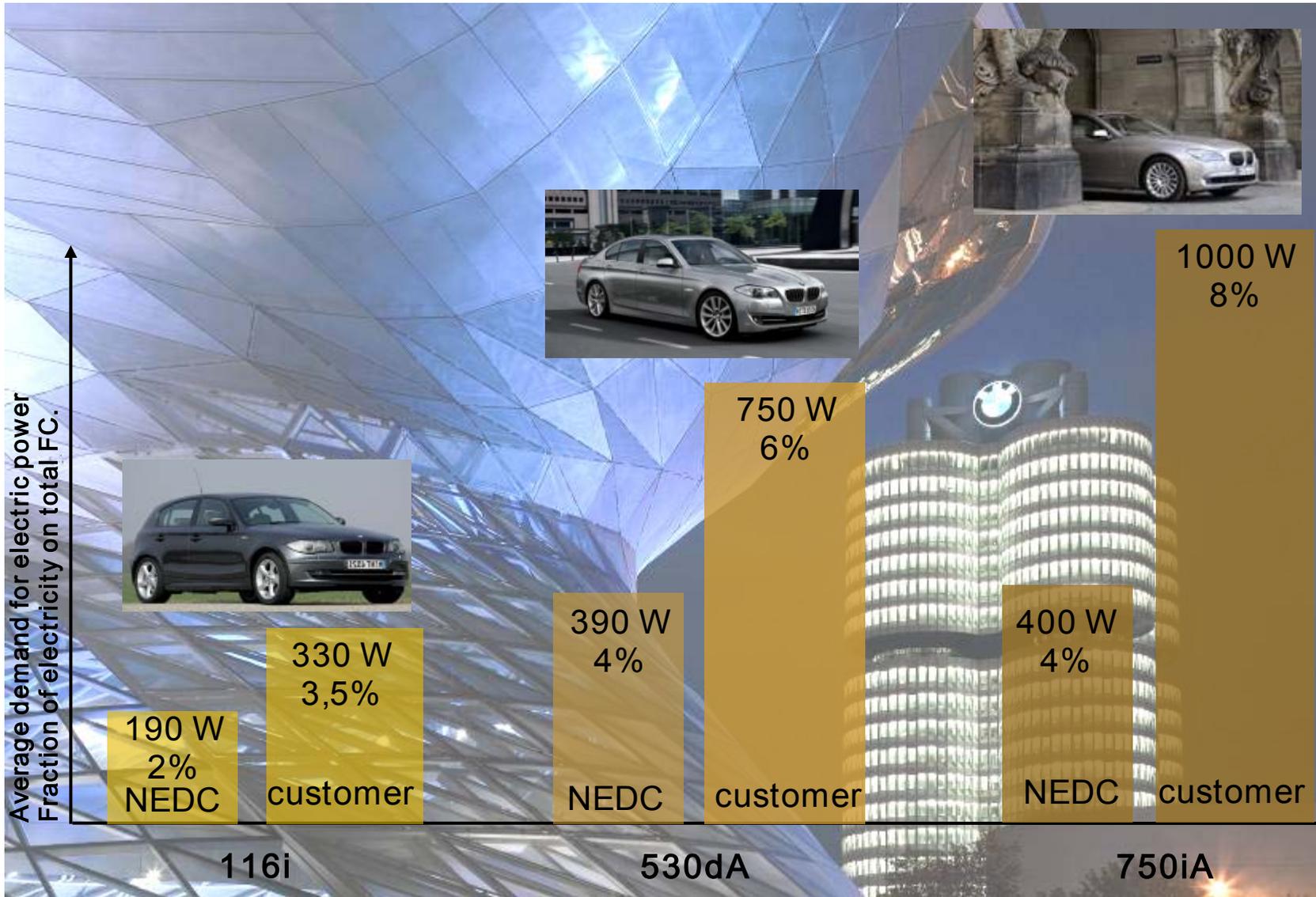
Mild Hybrid

Full Hybrid

Electric vehicle

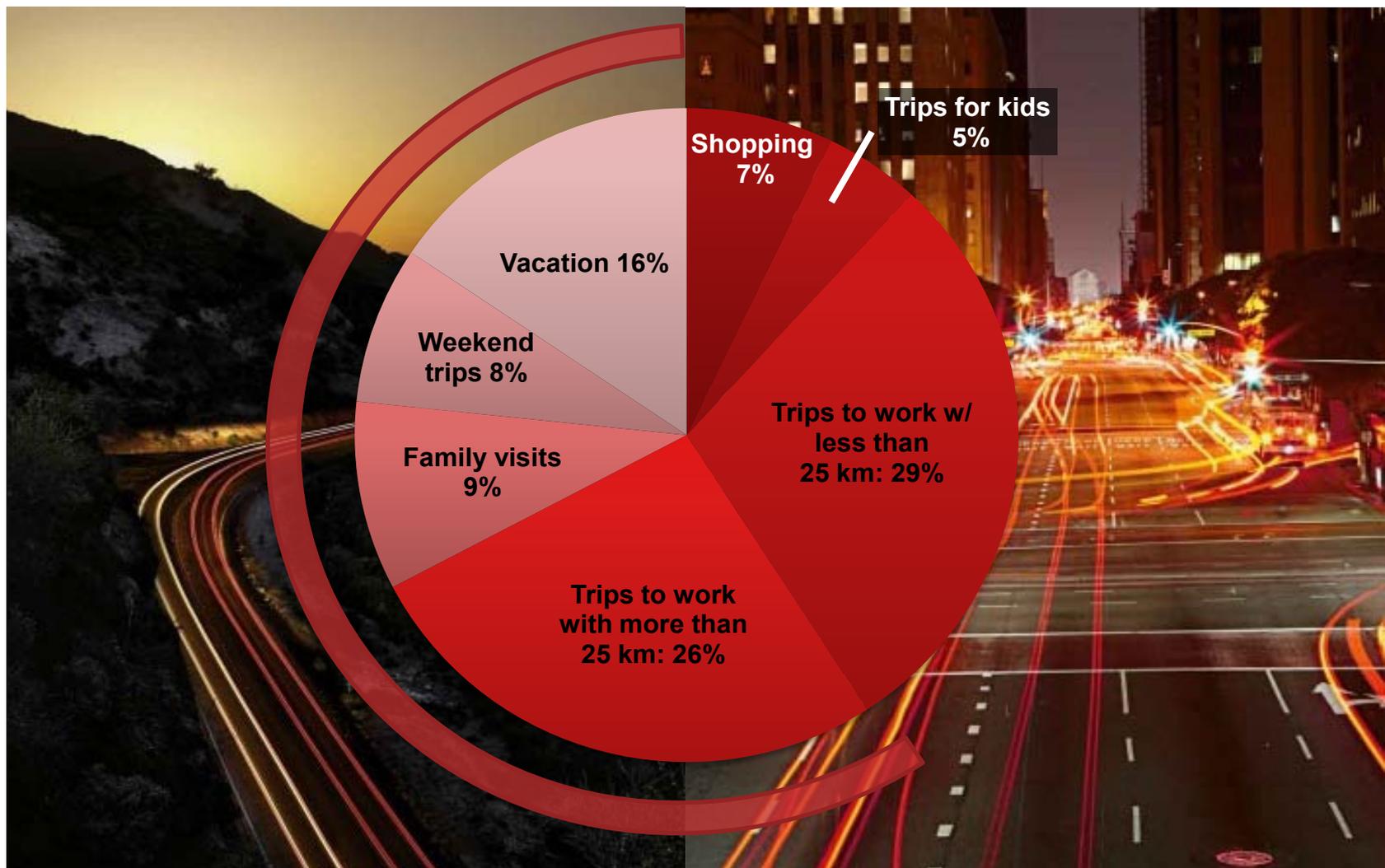
# BMW EfficientDynamics.

## On-board electricity is not for free.



# BMW Efficient Dynamics.

## When is most of the fuel used?

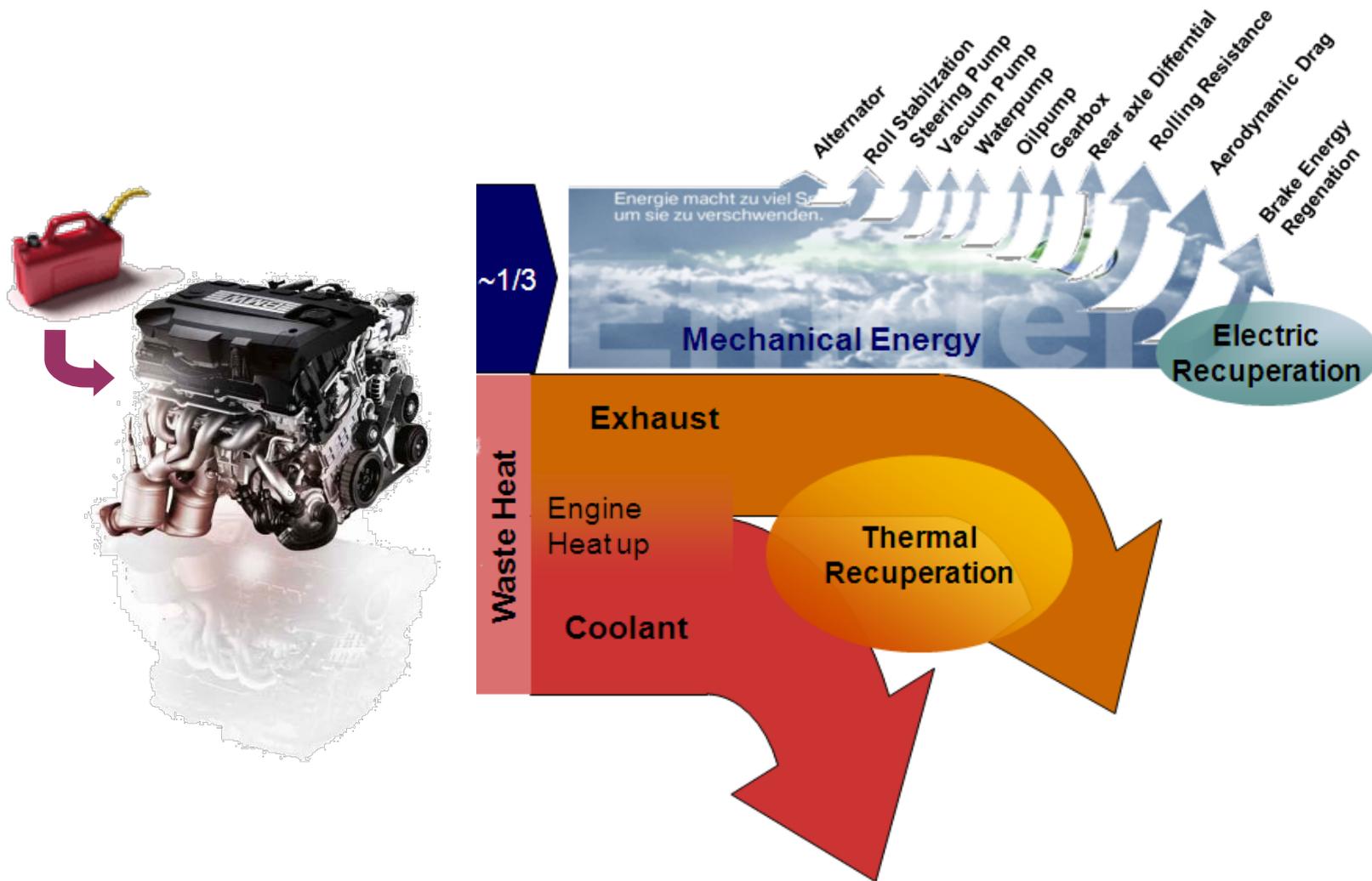


→ ~60% of the fuel is used for long-distance trips per year in Germany.

Source:

- R. Thom, Fa. CAR
- Federal Statistical Office, Germany

# BMW EfficientDynamics. Energy fluxes for a BMW Powertrain.



~2/3 of the energy contained in the fuel is converted into heat which is not used today.

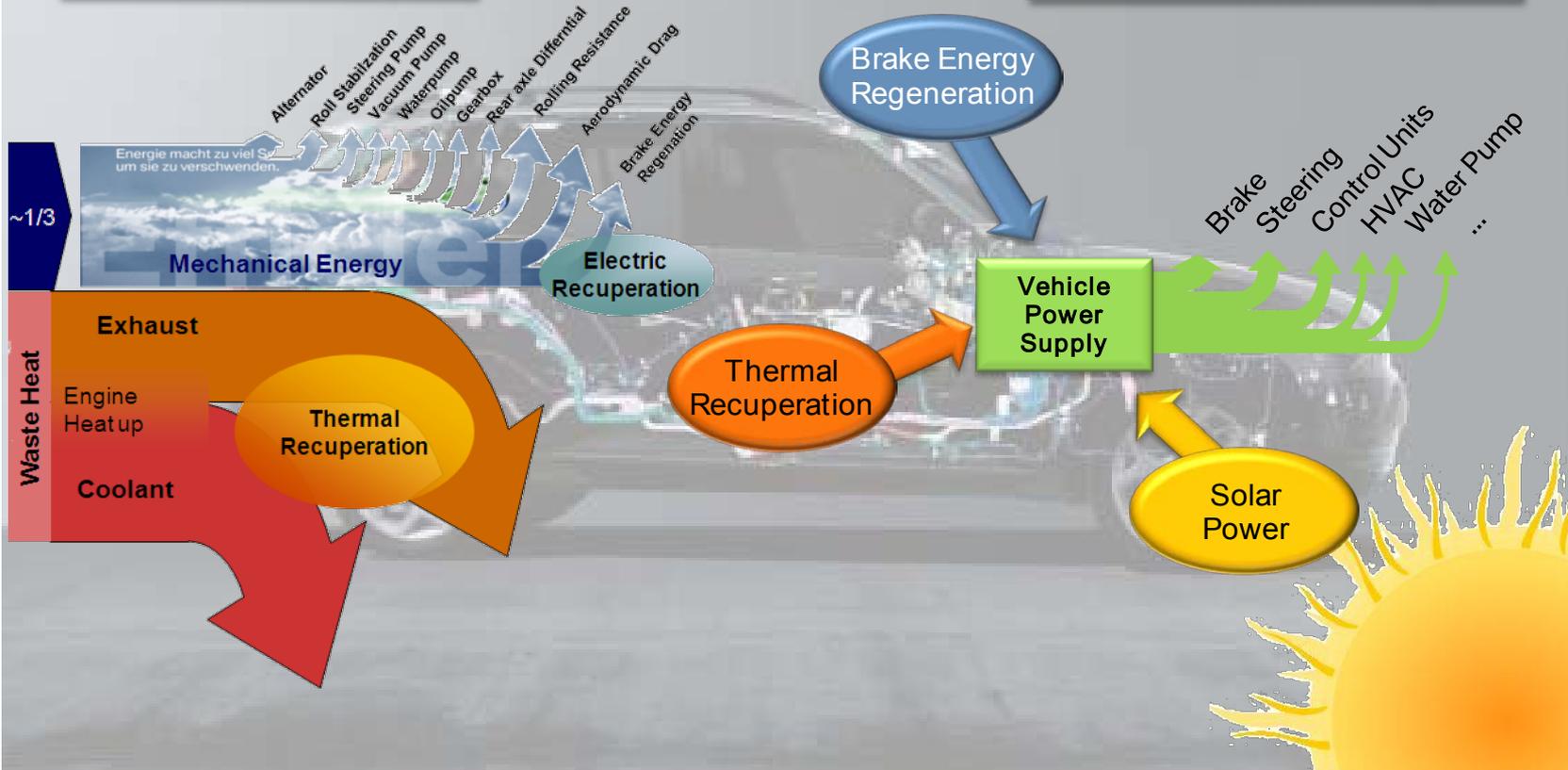
# BMW EfficientDynamics

Waste Heat Recovery is one essential component to uncharge the alternator in future.

## Our Vision:

The engine will only be switched on for acceleration and at cruising speed

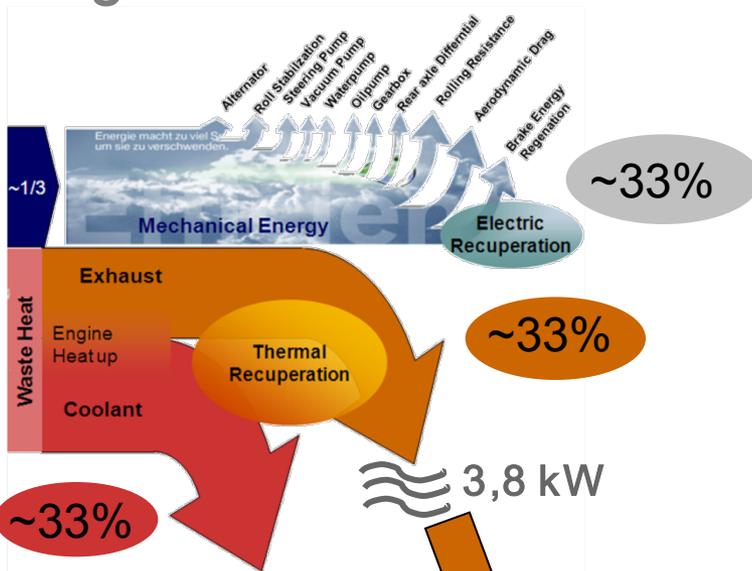
Ancillaries are all powered by electrical power from the following sources:



# Thermoelectric Waste Heat Recovery.

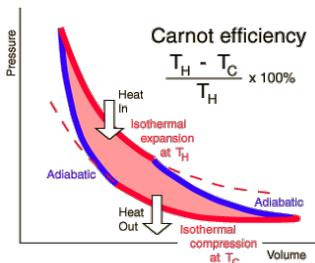
The maximum power which can be recovered from the exhaust gases is attractive!

Basis: BMW 535i, NEDC



Heat loss in the exhaust gas heat-exchanger.

3,8 kW  
 2,4 kW



Ideal cycle (Carnot)

Real cycle:  
 ~ „50% of Carnot Efficiency“

0,9 kW

0,45 kW

Conversion into FC-reduction:  
 („Willans Approach“ for the NEDC)



Conversion into mech. power: 0,4 l/100km



Conversion into electr. power: 0,6 l/100km  
 (in case the electr. power is completely used)

NEDC: (European Driving Cycle)

100 W correspond to  
 0,13l/100km  $\cong$  3g CO<sub>2</sub>/100km (gas.)  
 0,10l/100km  $\cong$  2,7g CO<sub>2</sub>/100km (Diesel)

US-Combined Driving Cycle

100 W correspond to  
 0,10l/100km  $\cong$  2,3g CO<sub>2</sub>/100km (gas.)

Penalties per Gram CO<sub>2</sub> in the EU:  
 95€/g in 2020

# Thermoelectric Waste Heat Recovery. TEG vehicle implementation.

**Bi<sub>2</sub>Te<sub>3</sub> TEG (2007)  
and  
High-temperature TEG,  
P<sub>max</sub>=300W (2009)**

**Eco-Globe 2008 for the  
BMW development of a  
prototype TEG system**



**BMW 535i (US)**

# Thermoelectric Waste Heat Recovery.

## Possible locations for a TEG.

### A TEG in a vehicle requires:

- Water supply
- By-pass (backpressure / max. cooling power)
- Heat Exchanger
- High Temperature / high massflow

### Integration into the main exhaust system of a gasoline engine („underfloor location“):

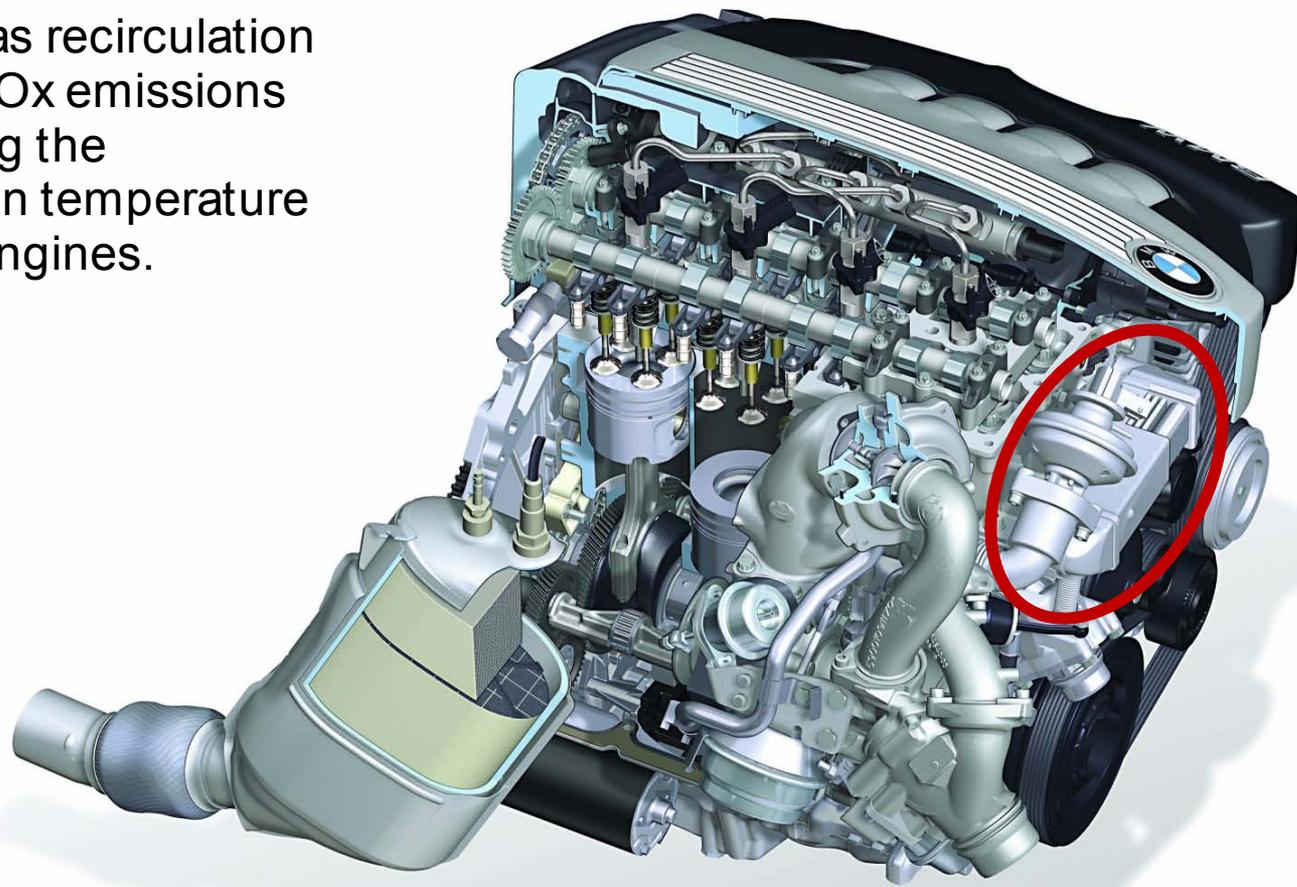
- very high integration effort
- Obstacles:
  - Bypass (flap: possible but expensive)
  - connection to cooling system
- + Advantage: highest recuperation potential



# Thermoelectric Waste Heat Recovery.

We were looking for locations for an efficient TEG integration solution: The EGR cooler!

Exhaust gas recirculation reduces NOx emissions by reducing the combustion temperature in Diesel engines.



# Thermoelectric Waste Heat Recovery.

## Possible locations for a TEG.

### A TEG in a vehicle required:

- Water supply
- By-pass (backpressure / max. cooling power)
- Heat Exchanger
- High Temperatures / Massflow

### Integration into the main exhaust system of a gasoline engine:

- very high integration effort
- Obstacles:
  - Bypass (flap: possible but expensive)
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### Integration into the EGR cooler for a Diesel engine:

- Easier to integrate:
  - + Control for massflow (EGR Valve)
  - + Cooling water already there!
- Disadvantage: Reduced recuperation potential compared to the integration into the main exhaust line



# Thermoelectric Waste Heat Recovery.

The EGR TEG does not require much room in the engine compartment.

Current series product (4-cyl. Diesel)

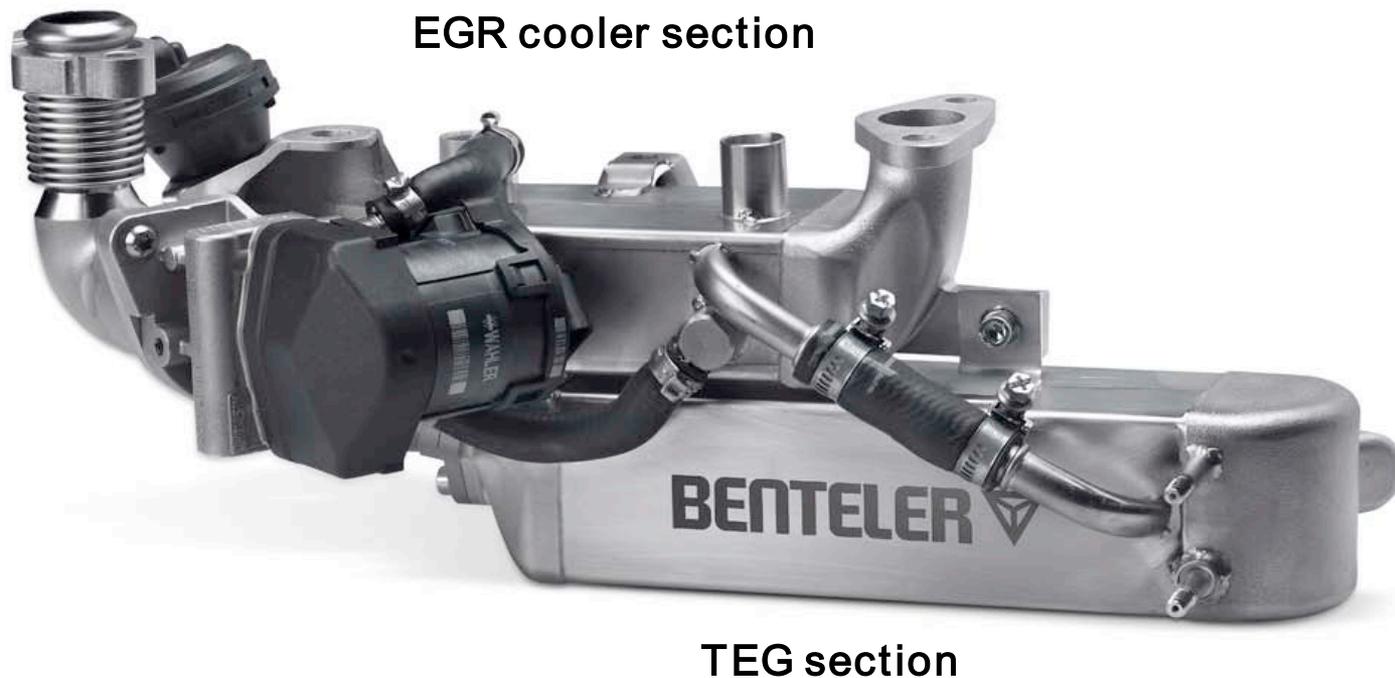


Engine with EGR-TEG prototype.



# Thermoelectric Waste Heat Recovery.

The EGR-TEG unit consists of a TEG section and a conventional cooler section.



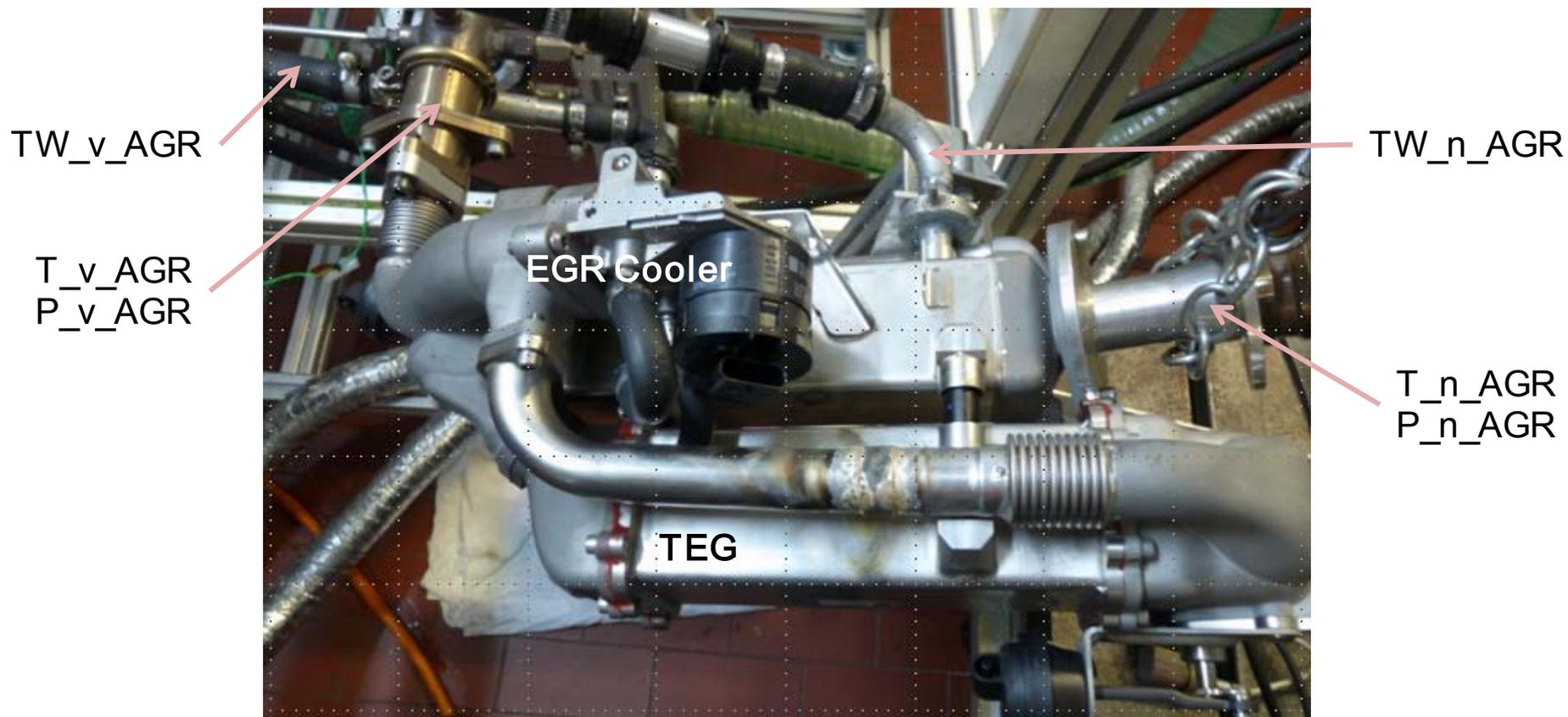
# Thermoelectric Waste Heat Recovery. The EGR TEG unit – TEG section.



# Thermoelectric Waste Heat Recovery.

## The EGR TEG unit – interactions with the Diesel engine are investigated.

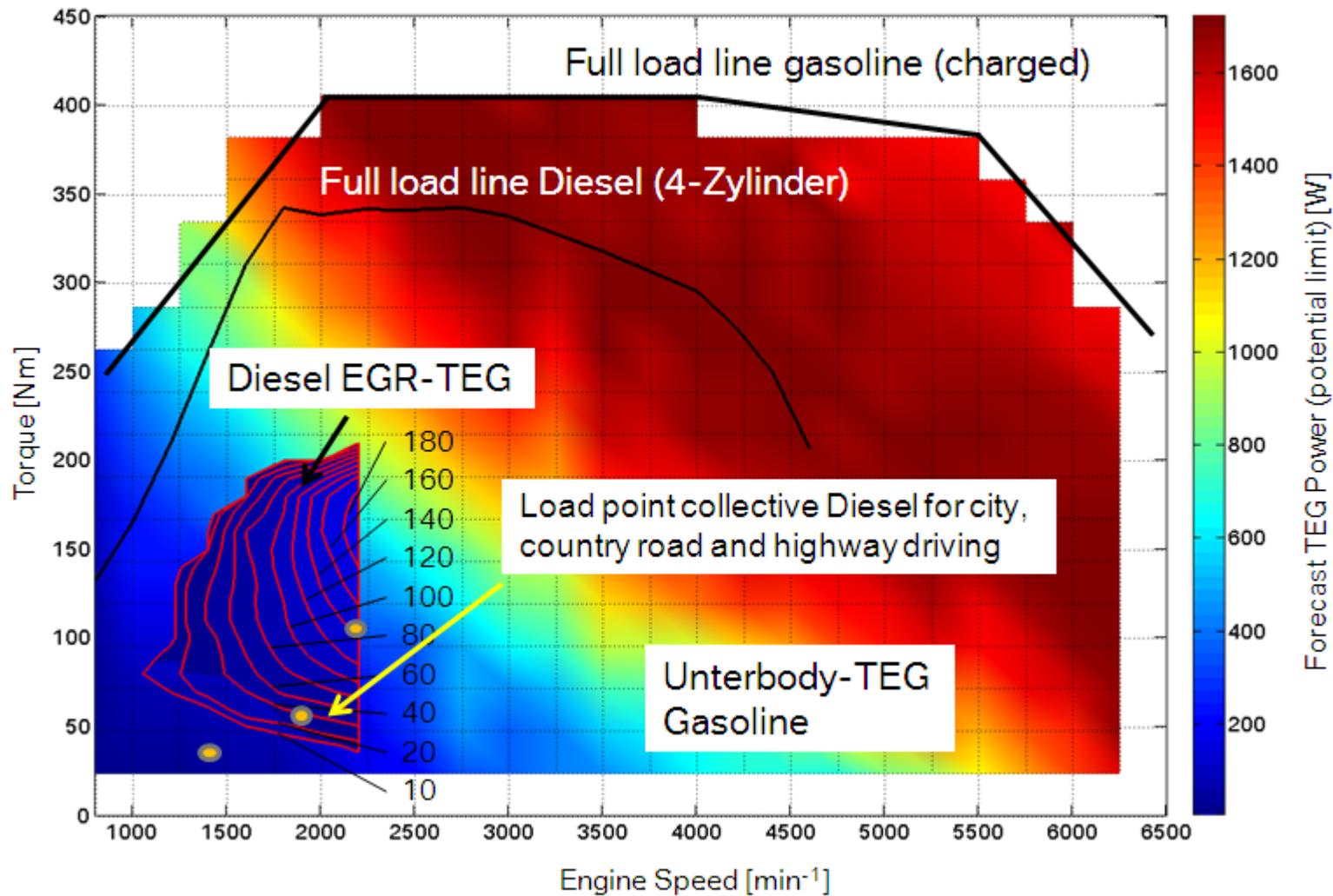
Fouling, Operating Strategy, ...



<b>Test bench:</b>	<b>Gas:</b>	<b>350 C</b>	<b>70...10kg/h</b>
	<b>Water:</b>	<b>50 C</b>	<b>0,75m<sup>3</sup>/h</b>

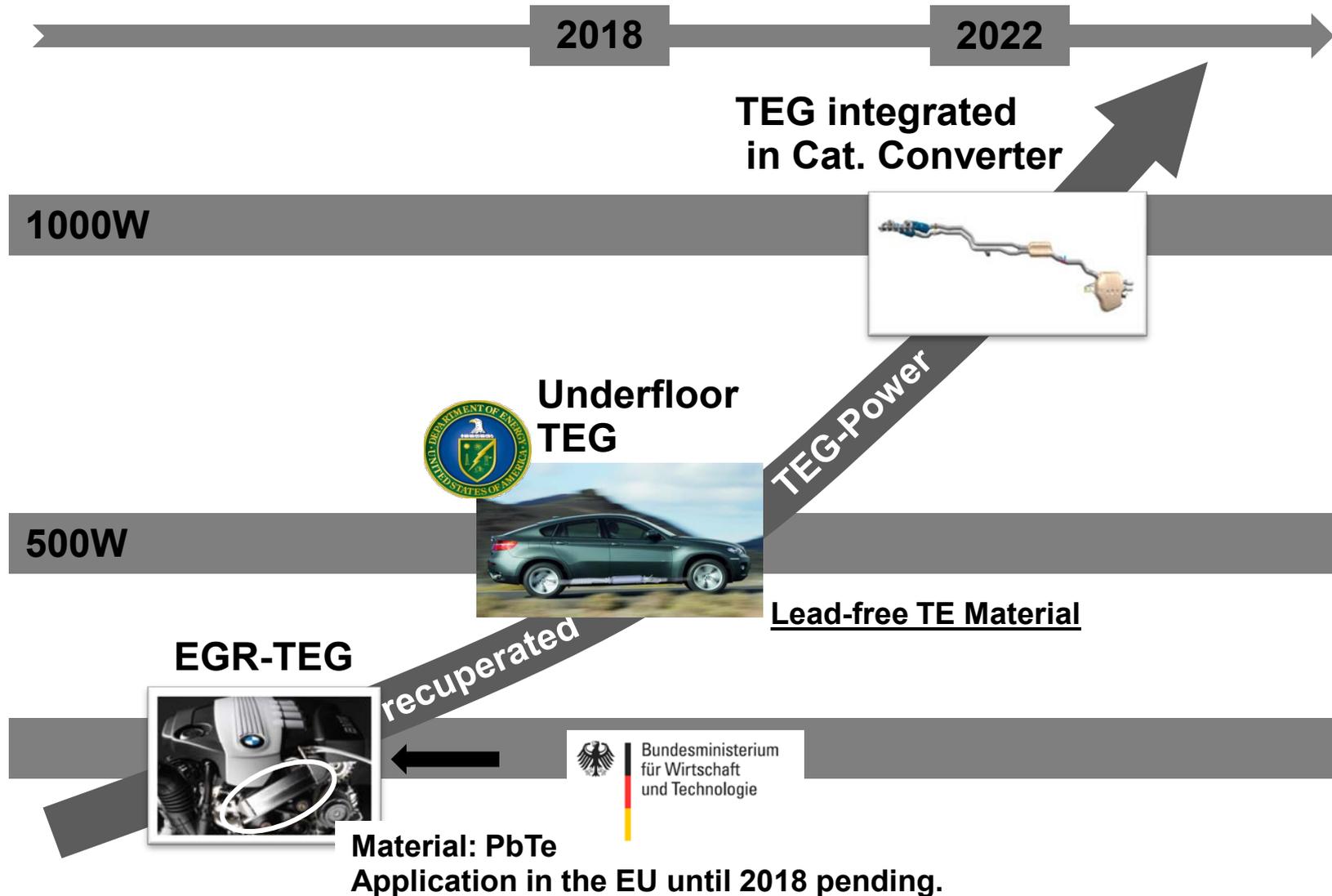
# Thermoelectric Waste Heat Recovery.

The TEG power is very attractive.



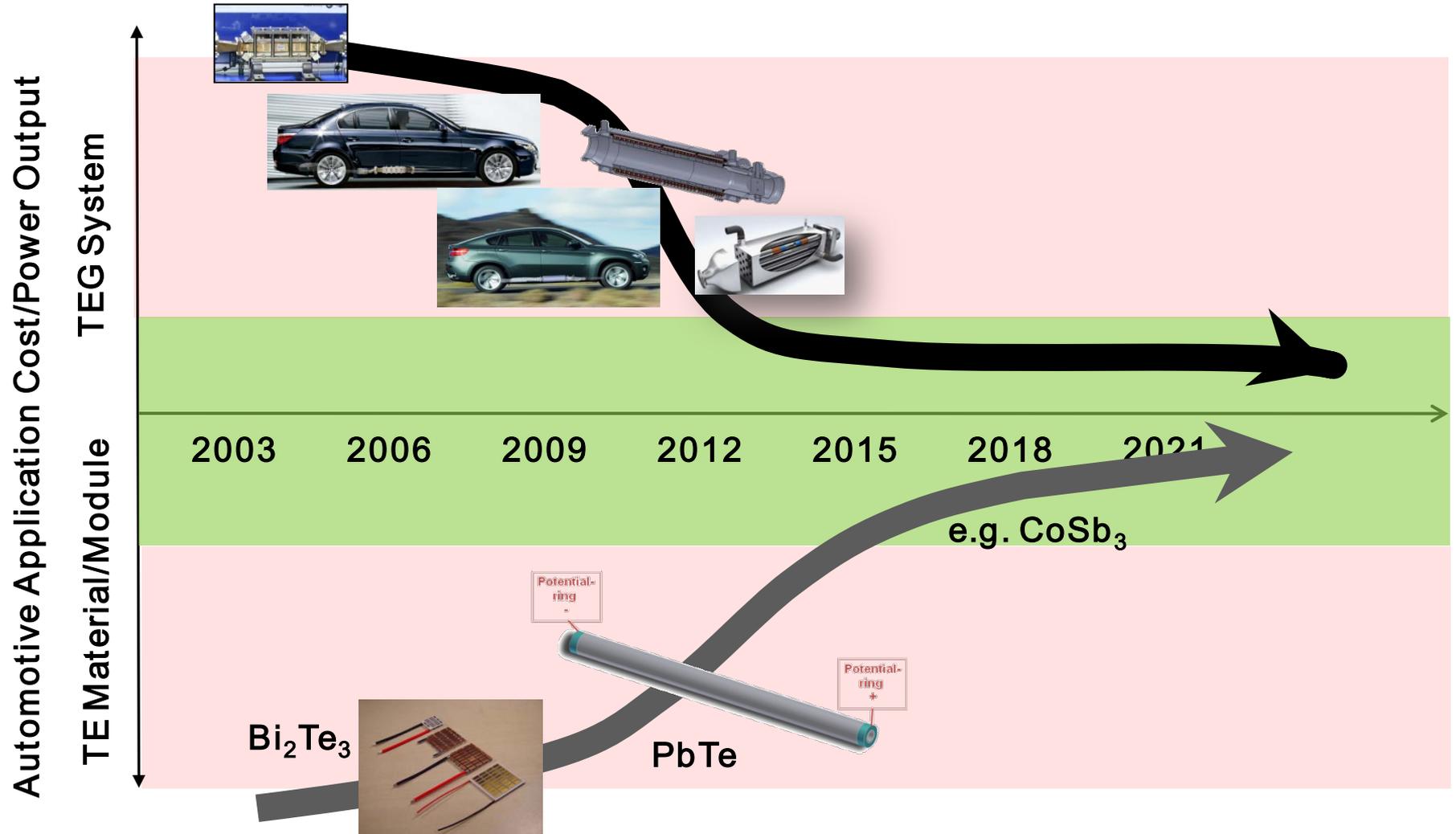
# Thermoelectric Waste Heat Recovery.

The BMW Group roadmap is challenging and possible!



# Thermoelectric Waste Heat Recovery.

The BMW Group roadmap is challenging and possible!



# Thermoelectric Waste Heat Recovery.

The next milestone in the TEG development will be drivable soon...



Thank you for your attention!



Thomas Seebeck

**BMW Group**