Thermoelectric Power Generation - The Next Step to Future CO₂ Reductions?!
1998 - 2002:

How will BMW Group continue to be successful in times of climate change, tougher fuel economy legislation, skyrocketing oil prices and a growing environmental awareness in the broad public?
BMW EfficientDynamics.
Measures to reduce fuel consumption throughout the entire fleet.

- Over 1.35 million vehicles sold with BMW EfficientDynamics.
- 22 BMW and 7 MINI models with a max. output of 140 g CO₂/km.
- Reduction of CO₂ emissions from 2005-2008: -25%.
- CO₂ emissions in vehicle production: -17% in the last four years.
BMW EfficientDynamics.

CO₂-regulations are intensifying worldwide. Guidelines are heterogenous.

- Energy Conservation Law
  - 2010 Stage 1
  - 2015 Stage 2
  - Social Exclusion,

- Self Commitment 2008
  - Law 120g CO₂
    - in 2012 w/ Penalties (up to 95€/g)
  - Law 95g / CO₂ / 2020

- Amendment of CAFE Penalties
- Greenhouse Gas EPA
- Restriction of Admission
- National Standard 2012
- Tightening 2016

- Penalty for single vehicles

Thermal recuperation is a very interesting technology for future CO₂ reduction.
Thermoelectric Power Generation –
The Next Step to Future CO₂ Reductions.
Onbord electricity is not for free!
Thermoelectric Power Generation - The Next Step to Future CO₂ Reductions.
There are smarter ways to generate electricity!

Onbord electricity is not for free!

Target for el. Power from BER+TEG

BER: Brake Energy Regeneration
Thermoelectric Generators can be integrated into vehicles.

Prototype vehicle: BMW 535i (US)
The 2nd Generation is using high-temperature modules.

- 6 Low-temperature-Modules (LT1)
- 6 Low-temperature-Modules (LT2)
- 6 Low-temperature-Modules (LT3)

2. Gen. Prototype (2009): P_{el} > 300W
TEGs can be efficiently integrated into the onboard electric system.

The TEG directly unloads the alternator.
Possible Locations of a TEG.

Pretube position possible for TEG integration in existing vehicles (prototype)
After flange position possible for a series application (new developed veh.)
The potentials are very attractive, especially for the customers!

<table>
<thead>
<tr>
<th></th>
<th>NEDC</th>
<th>FTP75</th>
<th>US-Combined</th>
<th>50 km/h</th>
<th>90 km/h</th>
<th>135 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position: After flange</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without insulation of the exhaust system</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>With insulation of the exhaust system</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>NEDC</th>
<th>FTP75</th>
<th>US-Combined</th>
<th>50 km/h</th>
<th>90 km/h</th>
<th>135 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position: Pre-tube</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without insulation of the exhaust system</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>With insulation of the exhaust system</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

ZT_{average} = 0.85 to 2

Electric load corresponds directly to CO₂ Emissions.

NEDC: (European Drive Cycle)

100 W correspond to
0,13l/100km ≈ 3g CO₂/100km (gasoline)
0,10l/100km ≈ 2,7g CO₂/100km (diesel)

US-Combined Drive Cycle

100 W correspond to
0,10l/100km ≈ 2,3g CO₂/100km (gasoline)

Penalties per g CO₂ in the EU: 95€/g
Thermoelectric Power Generation –
The Next Step to Future CO₂ Reductions.
BMW is developing solutions for different applications.

Technical solution:
- ActiveHybrid
- eDrive
- Hydrogen CleanEnergy
- Advanced Diesel

Use area:
- city
- suburban
- highway

Requirements:
- Emission-free Driving
- Connected traffic
- Range
- Intelligent route selection
Thermoelectric Power Generation –
The Next Step to Future CO₂ Reductions.
Thermoelectric waste heat utilization is a very attractive technology.

BMW CTO Dr. Draeger was awarded with the Eco-Globe 2008 for BMW’s Thermoelectric Generator activities.

Thanks to DoE for initiating the development of this technology!
Thermoelectric Waste Heat Recovery…
…stands for energy recuperation with sheer driving pleasure!
BMW EfficientDynamics.
Individual mobility with further reduced fuel consumption and exhaust emission levels.

BMW EfficientDynamics.
Less emissions. More driving pleasure.
BMW EfficientDynamics™ – BMW’s Approach to Reduce CO₂. A TEG can Cover the Averaged Demand on Electricity in Future.

![Graph showing the prediction of TEG power for a BMW 5-Series (gasoline) and today's demand on electric power for a BMW 5-Series customer.]

- X-axis: Vehicle Speed [km/h]
- Y-axis: Electric Power [W]
BMW EfficientDynamics.
Innovations in engine technology.

- 9 % fuel consumption
  In-line 6-cylinder petrol engine with BMW TwinPower Turbo

- 4 % fuel consumption
  In-line 6-cylinder diesel engine with BMW Variable Twin Turbo

- 6 % fuel consumption
  8-speed automatic transmission
The BMW Group demonstrated with its partners the feasibility of thermoelectric power generation with a BMW 535i prototype vehicle. FE improvement of ~5% in customer driving is achievable with improved thermoelectric materials.

TEGs are considered as Eco-innovations in Europe (US?).

Risks: cost, durability, joining technologies, environmentally friendly materials.

A Thermoelectric Generator is an ideal combination to the BMW Brake Energy Regeneration.