Future Efficient Dynamics with Heat Recovery.


BMW Group
Research and Technology
Future Efficient Dynamics with Heat Recovery.

Outline.

1. Efficient Dynamics
2. Heat Recovery
3. Heat Recovery Systems
4. BMW Turbosteamer
5. Conclusions
CO$_2$ – The Challenge.
Our Answer – Efficient Dynamics.

<table>
<thead>
<tr>
<th>Model Year</th>
<th>BMW 323i Model year 1983</th>
<th>BMW 325i Model year 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel consumption 1</td>
<td>10.3 l/100 km (~22 MPG)</td>
<td>7.1 l/100 km (~33 MPG)</td>
</tr>
<tr>
<td>Power output</td>
<td>102 kW</td>
<td>160 kW</td>
</tr>
<tr>
<td>Torque</td>
<td>205 Nm</td>
<td>270 Nm</td>
</tr>
<tr>
<td>Acceleration 2</td>
<td>9.2 s</td>
<td>6.7 s</td>
</tr>
<tr>
<td>Emission quality</td>
<td>ECE R15-04</td>
<td>EU 4</td>
</tr>
<tr>
<td>Weight</td>
<td>1080 kg</td>
<td>1505 kg</td>
</tr>
<tr>
<td>Drag</td>
<td>0.40 x 1.85 m$^2$</td>
<td>0.27 x 2.17 m$^2$</td>
</tr>
</tbody>
</table>

1 EU fuel consumption MVEG
2 0 - 100 km/h
Efficient Dynamics.

BMW’s Approach to Reduce CO₂.

Powertrain
- Direct fuel injection
- DI2 lean stratified
- Piezo injectors
- High precision injection
- Turbo
- Twin turbo
- Variable twin turbo
- Downsizing
- Gearbox efficiency
- Gearbox spreading

Energy management
- Auto Start Stop function
- Brake energy regeneration
- Electr. assist
- Electr. driving
- Demand-oriented drive
- Electr. waterpump
- Electr. steering
- Air conditioning compressor division
- Electr. driving dynamic systems

Aerodynamic
- External flow
- Internal flow
- Wheel/enclosed wheel
- Flexible flaps

Rolling resistance
- Tires with reduced rolling resistance

Lightweight construction
- Conceptual
- Materials
- Production

Heat management
- Aggregate cooling on demand
- Rapid heat-up
- Insulation
- Friction reduction

Energy source
- Fuel
- Diesel
- Natural Gas
- Alternative fuels
- GTL, BTL
- Hydrogen
Efficient Dynamics.
BMW’s Approach to Reduce CO$_2$. 

Driving dynamics
Fuel consumption
Vehicle mass

Innovation

Efficient Dynamics
Future Efficient Dynamics with Heat Recovery.

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Energy Efficiency of Vehicles.
The Target is to Increase the Overall Efficiency.

~1/3

Mech. Energy

Transmission

Road resistance

Deceleration

Efficient Dynamics

Hybrid

Coolant/Oil

Engine heat-up

Exhaust

Thermal Recuperation

Environment

~2/3 of the energy contained in the fuel is converted into heat
Energy Conversion.
Different Possibilities.
Efficient Dynamics.
Steps towards Heat Recovery.

1. Direct Conversion
   Highly efficient primary energy conversion:
   - High Precision Injection
   - TwinPower Turbo
   - Valvetronic

2. Warming-up
   Faster warming-up: No coolant circulation with electrical water pump switched off.

3. Waste Heat Recovery
   Example of waste heat utilization:
   Turbosteamer
## Future Efficient Dynamics with Heat Recovery

### Outline

<table>
<thead>
<tr>
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<tbody>
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<td>Heat Recovery Systems</td>
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<tr>
<td>4</td>
<td>BMW Turbosteamer</td>
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<tr>
<td>5</td>
<td>Conclusions</td>
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</table>
Energy Efficiency of Vehicles.
Thermal Recuperation offers the Potential of Additional CO₂ Reduction.

- Complexity
- Heat utilization

- Turbocharger
- Twin Turbocharger
- Acoustic
- Catalytic
- Seebeck
- Joule
- Joule
- Stirling
- TwinTurbocharger

BMW projects:
- Turbosteamer
- Thermoelectric Generator
Heat Sources.
Exhaust Gas.

**Engine type:** 4-cylinder gasoline engine $\lambda=1$
Heat Sources.

Coolant.

**Engine type:** 4-cylinder gasoline engine $\lambda=1$
Utilization of Exhaust Heat.
Temperature Distribution.
Future Efficient Dynamics with Heat Recovery.
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What is a Turbosteamer (TS)?
Cogeneration a well known Principle.
Basic System Layout of a Turbosteamer.

- **Pump** (1)
- **Condenser** (4)
- **Heat exchanger** (3)
- **Expansion machine** (4)

The diagram shows the flow of the process with labeled points:

1. Pump (1)
2. Temperature [°C]
3. Entropy [kJ/(kg K)]
4. Enthalpy [kJ/kg]

Key points:
- Temperature and Entropy values are shown for various stages.
- Enthalpy values at different points:
  - h=3500
  - h=3300
  - h=3100
  - h=3000
  - h=2900
  - h=2800
  - h=2700

The cycle includes the pump, heat exchanger, and expansion machine, with fluid flowing through each component.
Dual-Loop-Rankine.
Maximal Utilization of Exhaust and Coolant.
Dual-Loop-Rankine Engine Map.

Additional power output [%]

Engine speed $n_{Mot}$ [rpm]

Engine torque $M_{d}$ [Nm]
**Single-Loop-Rankine.**

**Simplification of the System.**

**Dual-Loop-Rankine**
- 2 Expanders, 2 Loops
  - maximum potential
  - complete use of heat
  - complex system

**Single-Loop-Rankine**
- 1 Expander, 1 Loop
  - Simplification
  - improved ratio of effort/use

Diagram:
- **Steam generation**
  - $Q_{KW}$
  - $Q_{radiator/Condensor}$
- **Steam expansion**
  - $Q_{Exhaust}$
Single-Loop-Rankine.
Significant Increase in Fuel Efficiency.
Turbosteamer in Operation.

Turbosteamer Test Bench Setup.

Exhaust gas temperature

50°C

800°C

Steam
A similar System in almost every Car Today: Have a look on Air Conditioning.
Turbosteamer Components.
For Example: Expander.

A/C Compressor
1976

First Generation Turbosteamer Expander

Today’s Generation A/C compressor

Future Generation Turbosteamer Expander
Waste Heat Recovery with the Turbosteamer.

Next Steps.

TS test bench

Weight and designed-space reduction

Cost reduction

TS vehicle integration
Efficient Dynamics and Energy Recovery.
Potential Savings.
Heat Recovery.

<table>
<thead>
<tr>
<th>What are the savings for a long distance driver at mileage of 120,000 miles?</th>
<th>Today</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take for example a car with 25 mpg</td>
<td></td>
<td>35 mpg</td>
</tr>
<tr>
<td>... the overall consumption would be 4,800 gallon</td>
<td></td>
<td>3,400 gallon</td>
</tr>
</tbody>
</table>

Assuming that additional 5 to 10% of fuel could be saved:

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<tr>
<th>That is less 240-480 gallon</th>
<th>170-340 gallon</th>
</tr>
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<tbody>
<tr>
<td>With a price of 3$/gallon</td>
<td>5$/gallon</td>
</tr>
<tr>
<td>... the saving for this driver is $720-1,440</td>
<td>$850-1,700</td>
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1. Thermal recuperation offers the potential of additional CO$_2$ reduction.

2. The Rankine steam process is one favourable approach for waste heat recovery.

3. A 15% increase in engine performance could be demonstrated with a Dual-Loop-Rankine and 10% increase in engine performance could result from a Single-Loop-Rankine.
Vision.

Thermal Recuperation could make a valuable Contribution to the Increase in Fuel Efficiency.

Thank you for your attention!