Visions of Possible Thermoelectrics for Vehicle Application.

Andreas Eder, Michael Bertram, Johannes Liebl

2004 DOE/EPRI High Efficiency Thermoelectrics Workshop
San Diego, Feb 17-20, 2004

BMW Group

Visions of Thermoelectric Application.

Outline.

- Introduction
- Future Engine Efficiencies
- Available Exhaust Heat of an IC-Engine
- Estimations
- TEG Application:
  - Benefits
  - Prerequisites
  - Concerns
- Summary

Visions of Thermoelectric Application.
BMW Energy Management Systems.

Reduction of car emissions:

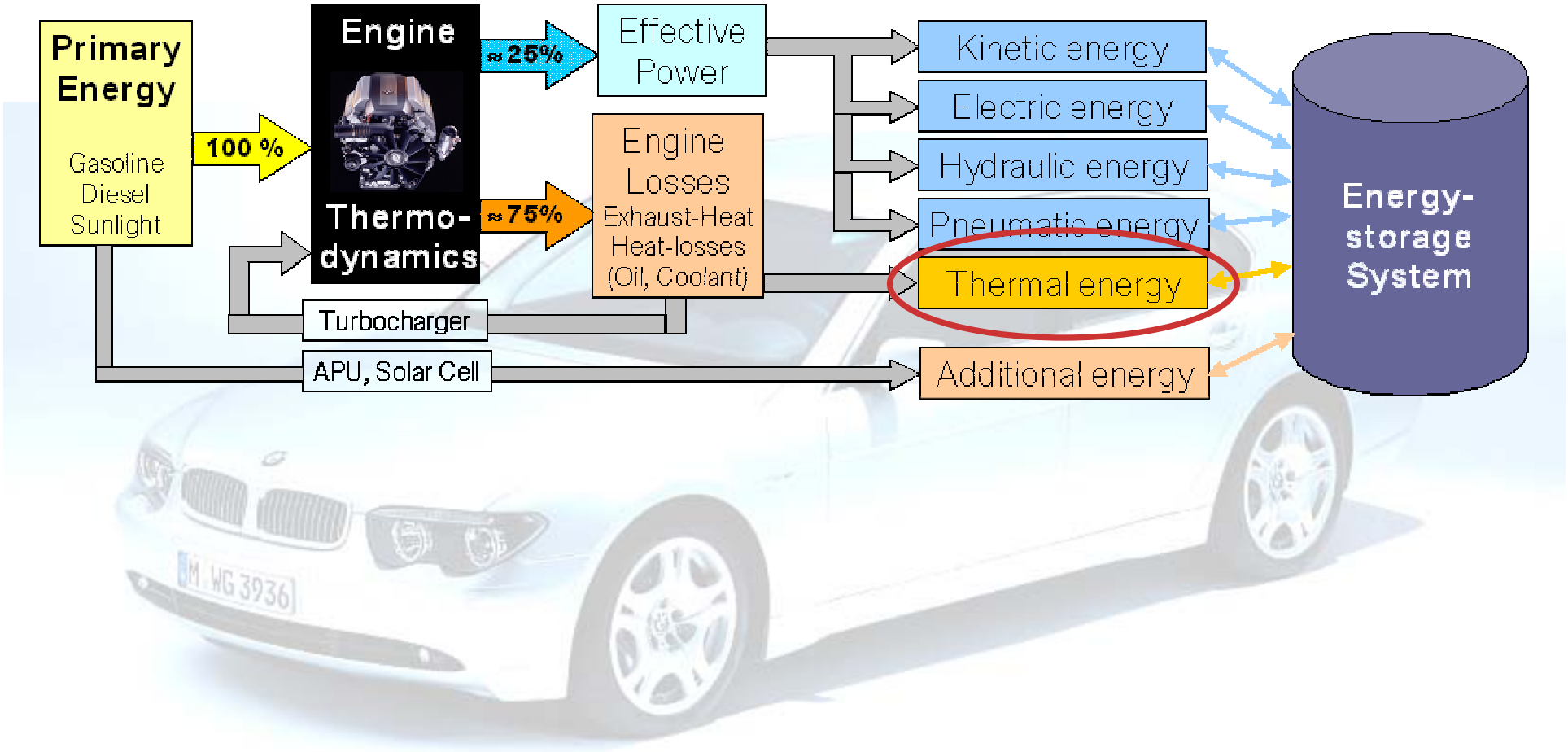
- Meeting emission standards (SULEV, PZEV, ZEV).

Reduction of CO_2 emissions

- Increased engine and overall vehicle efficiency.
- Sophisticated energy management systems.
- Energy regeneration in connection with energy storage system.
- Utilization of exhaust heat.

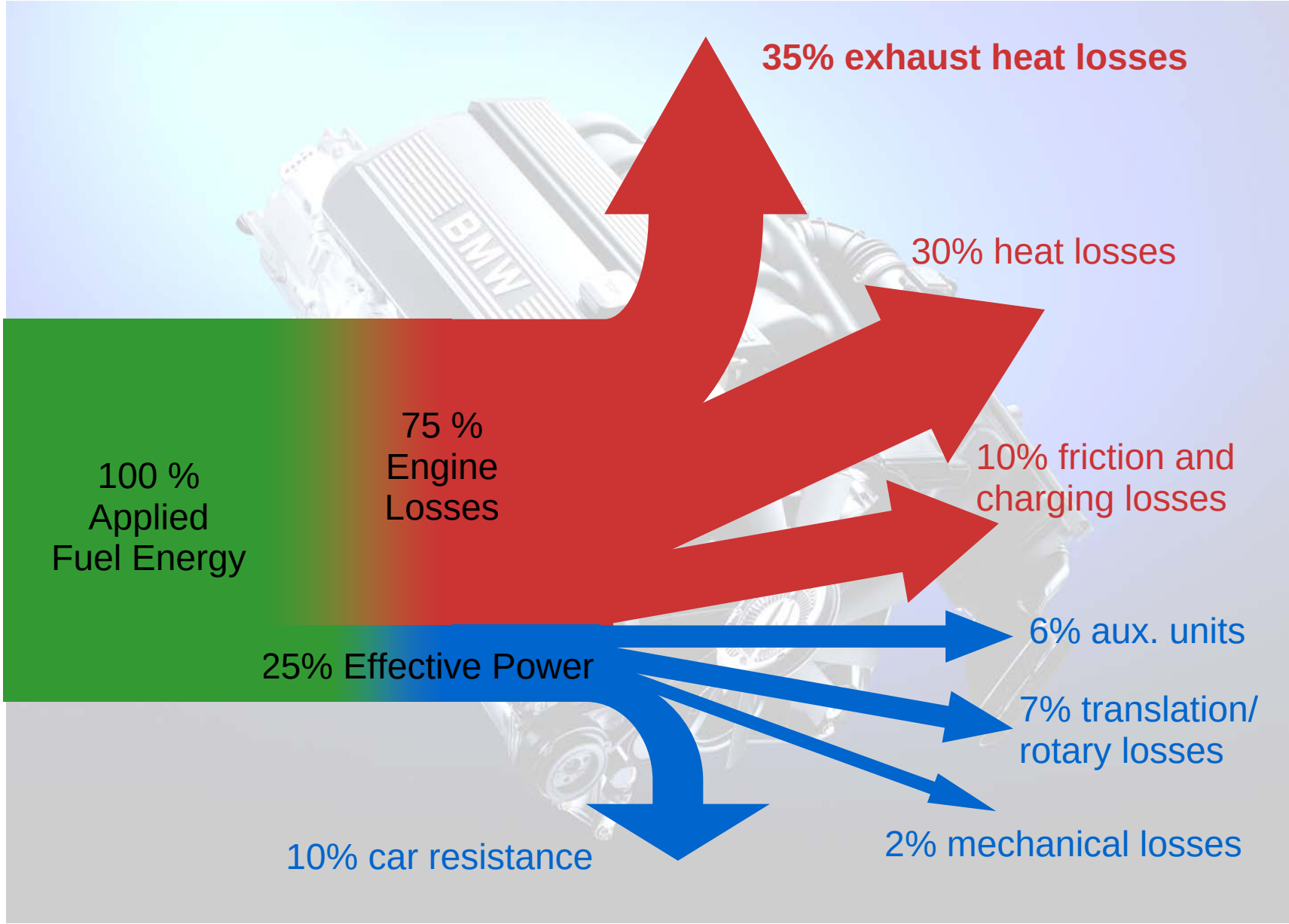
Energy Split of an IC-Engine.

Customer Driving Cycle.



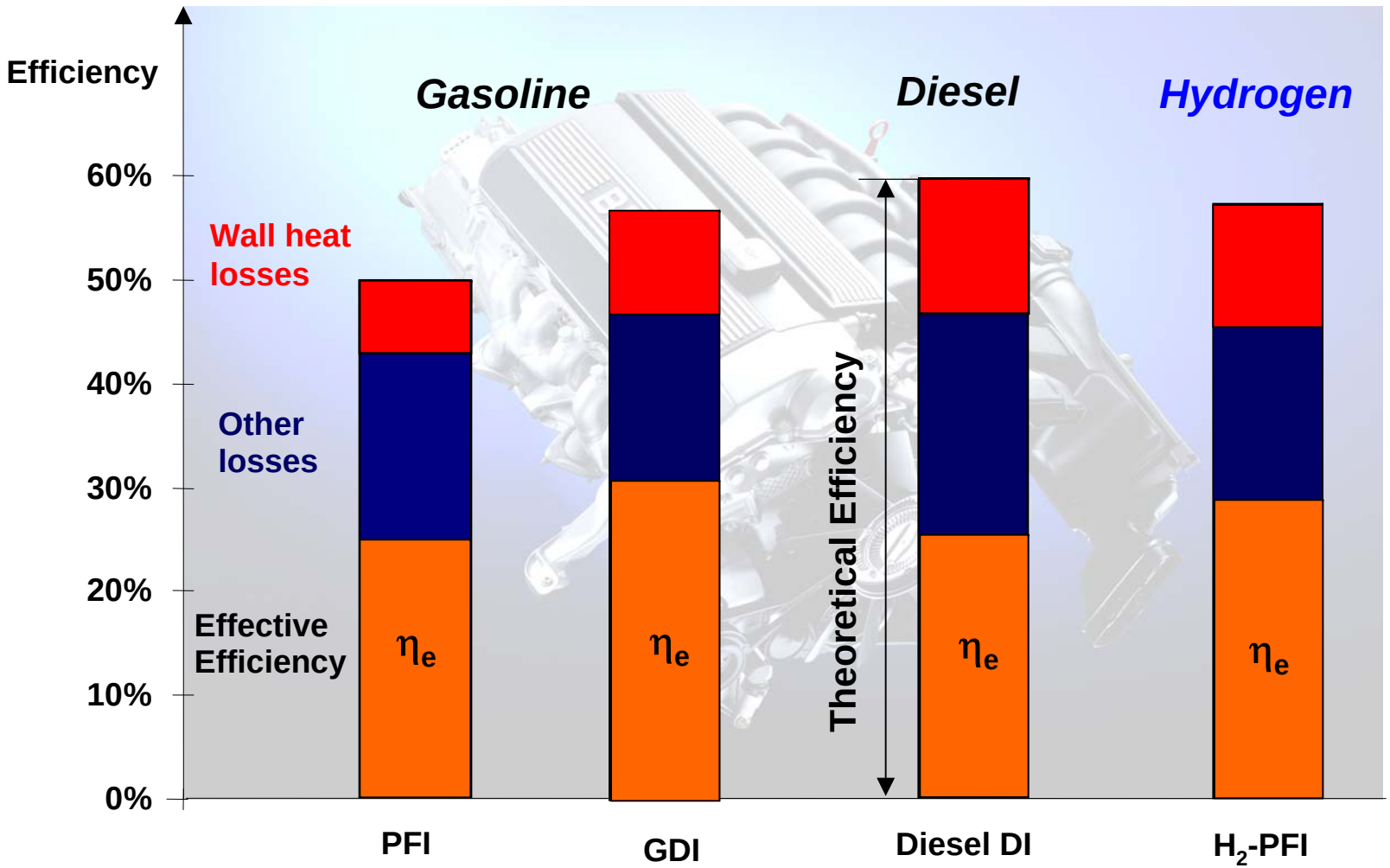
Energy Split of an IC-Engine.

Customer Driving Cycle.



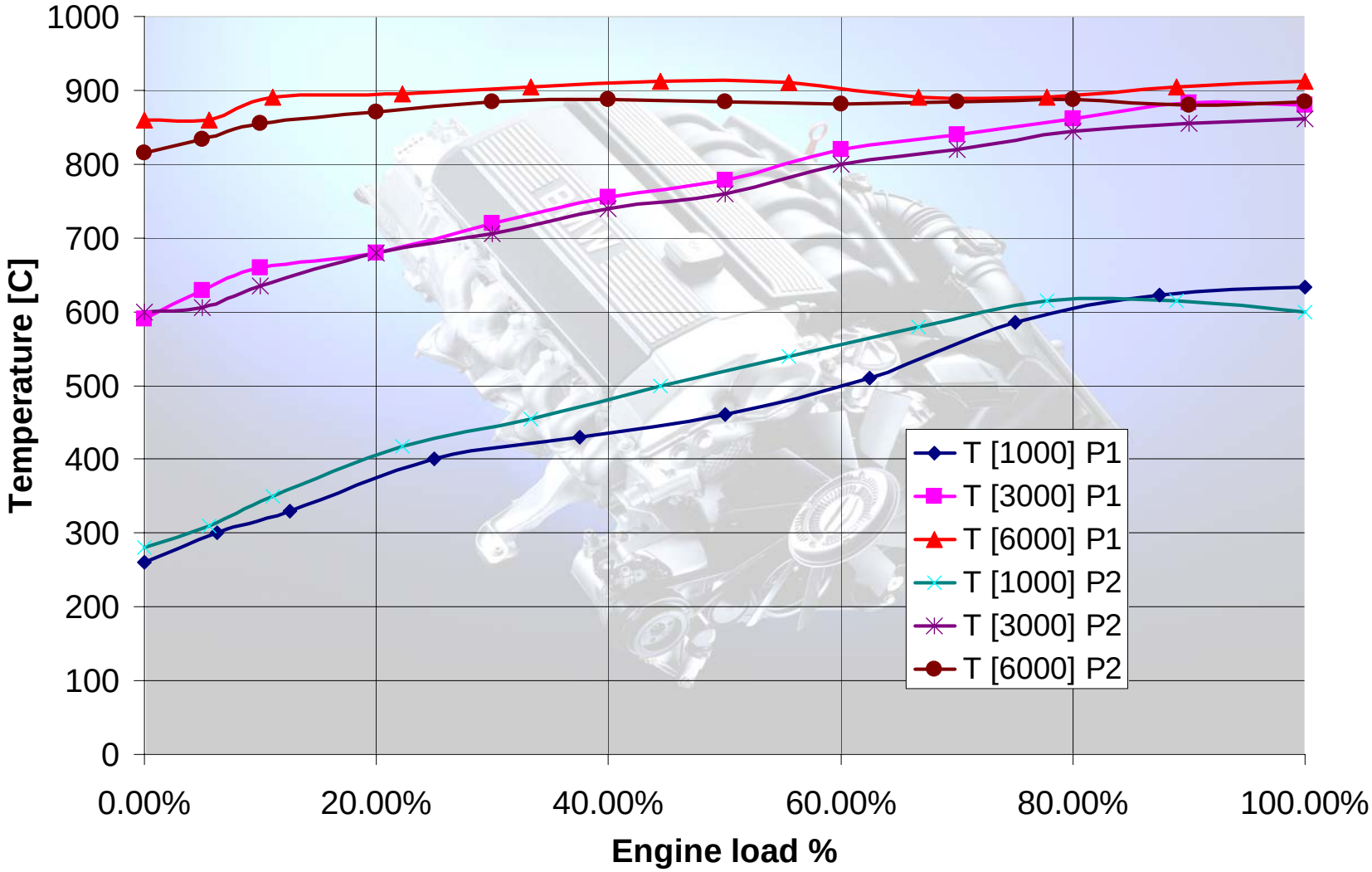
Efficiency of State-of-the-Art IC-Engines.

Map point: n=2000rpm - w_e=0.2 kJ/l (Partload).



Exhaust Gas Temperatures of an IC-Engine.

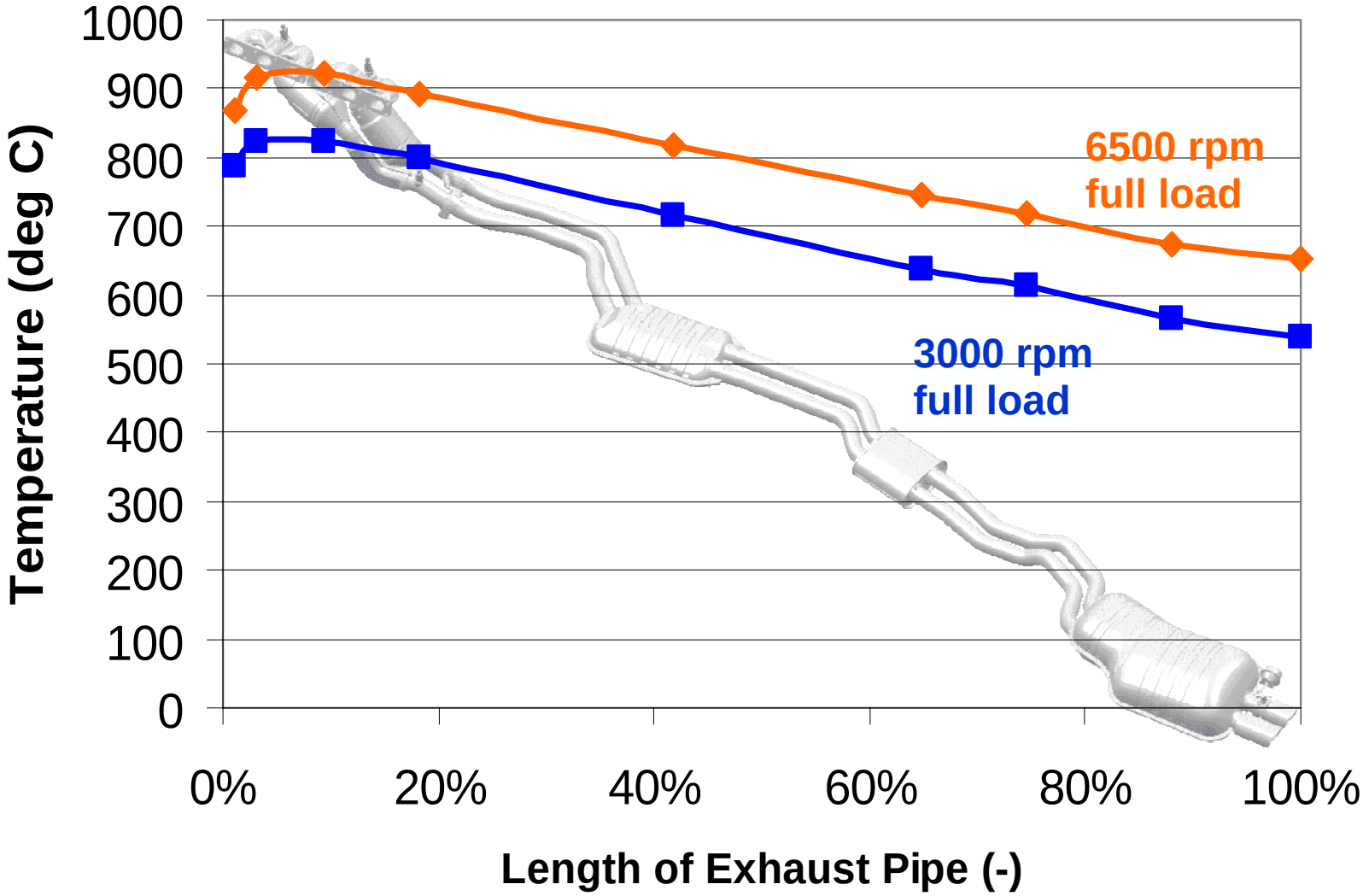
Dependency of Engine Laod.



P1: In front of Catalytic Converter
P2: After Catalytic Converter

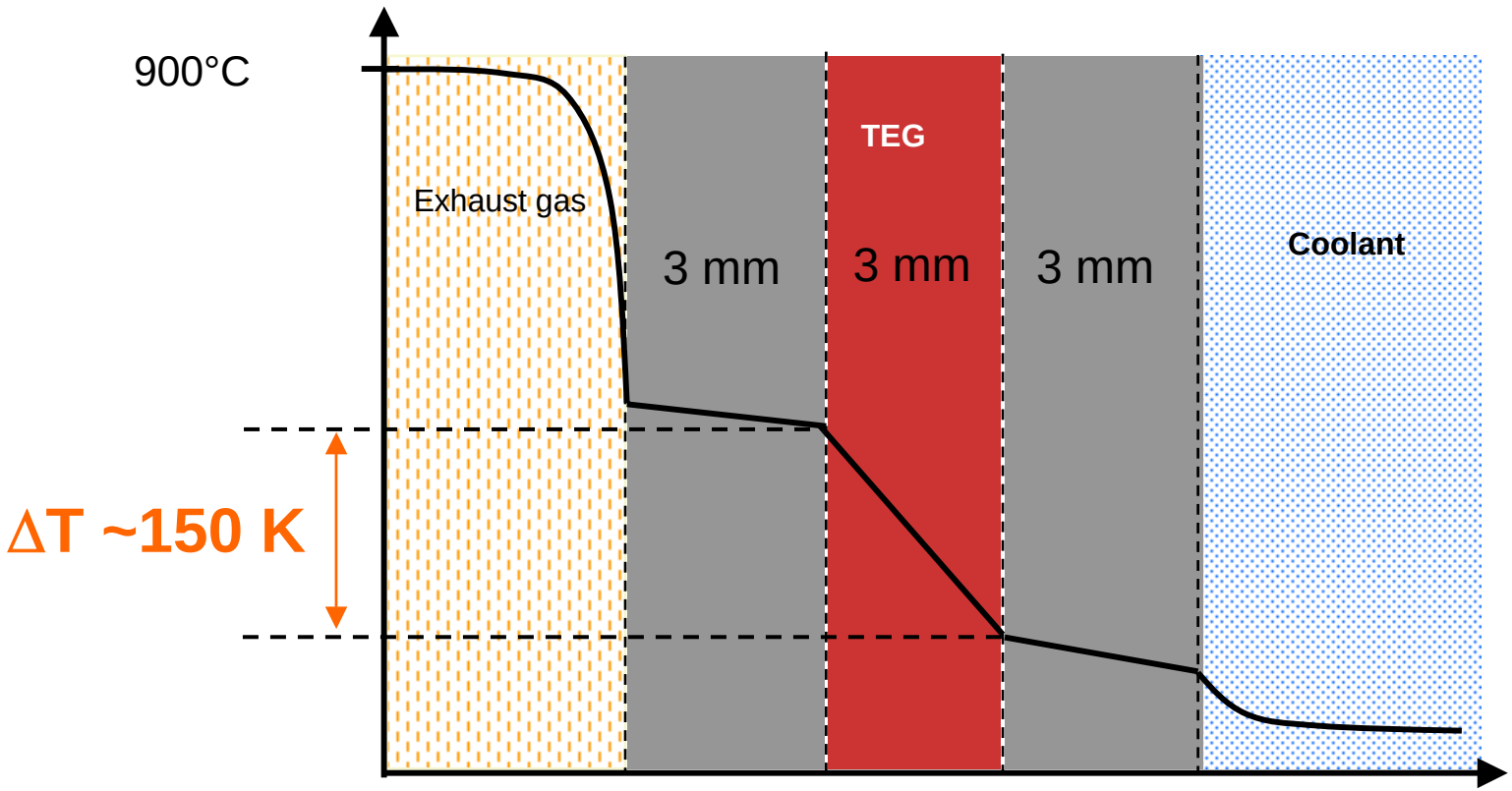
Exhaust Gas Temperatures of an IC-Engine.

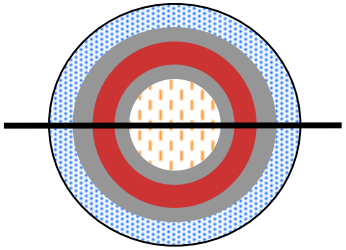
Temperatures Range - Engine to Tailpipe.



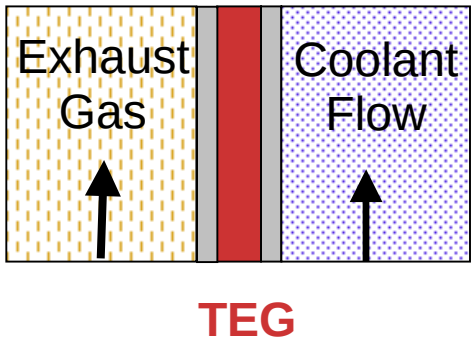
Heat Transfer Estimations of a TEG Application

Heat Sink = Coolant Flow



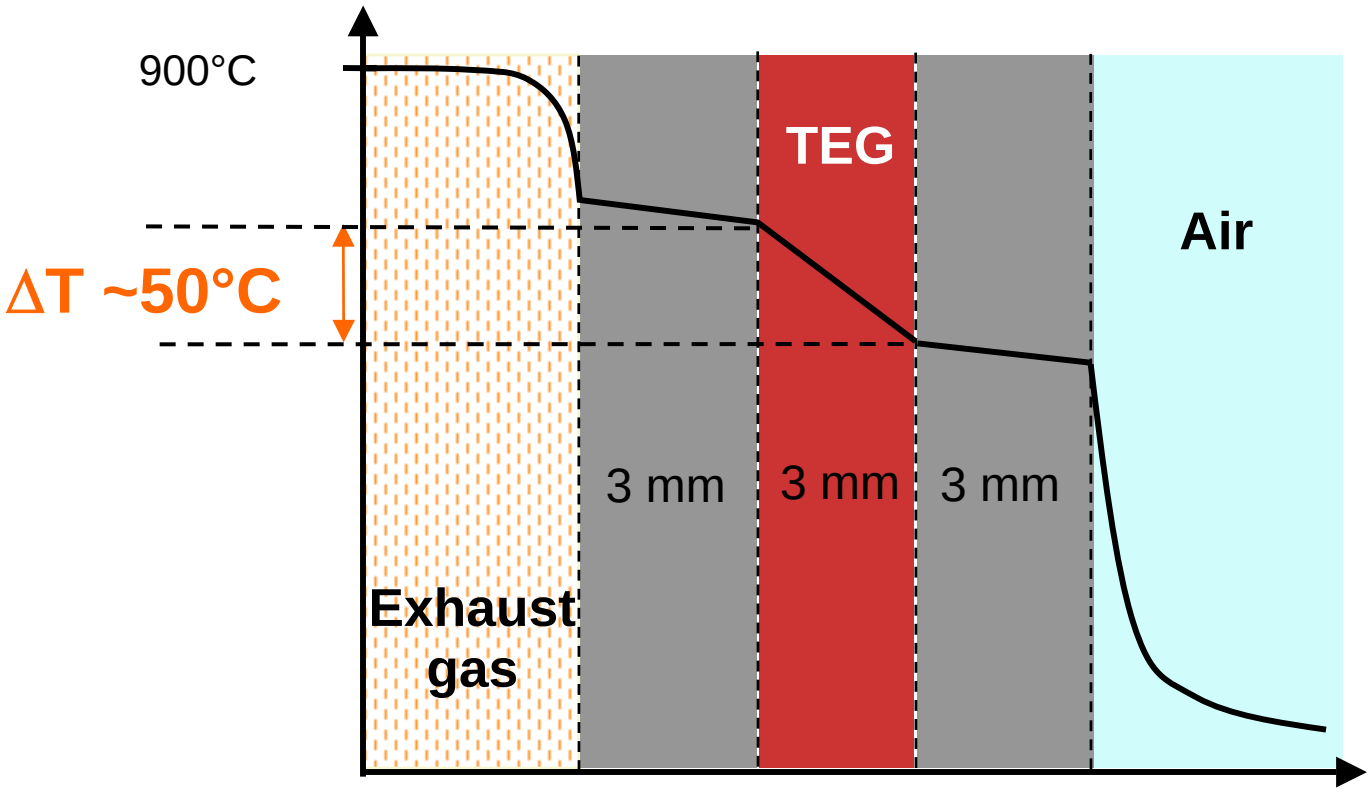


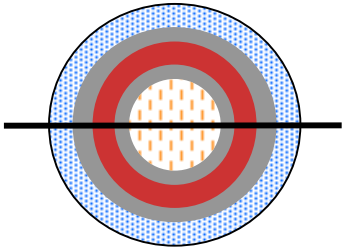
$$\dot{Q} = \alpha\ A\ \Delta T$$



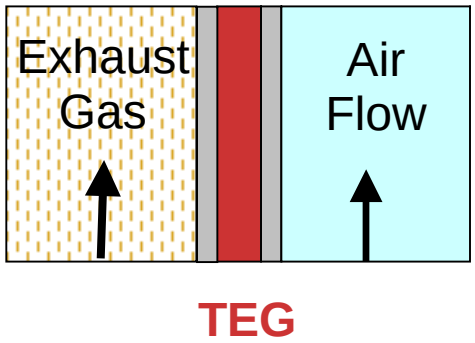
Heat Transfer Estimations of a TEG Application

Heat Sink = Air Flow.





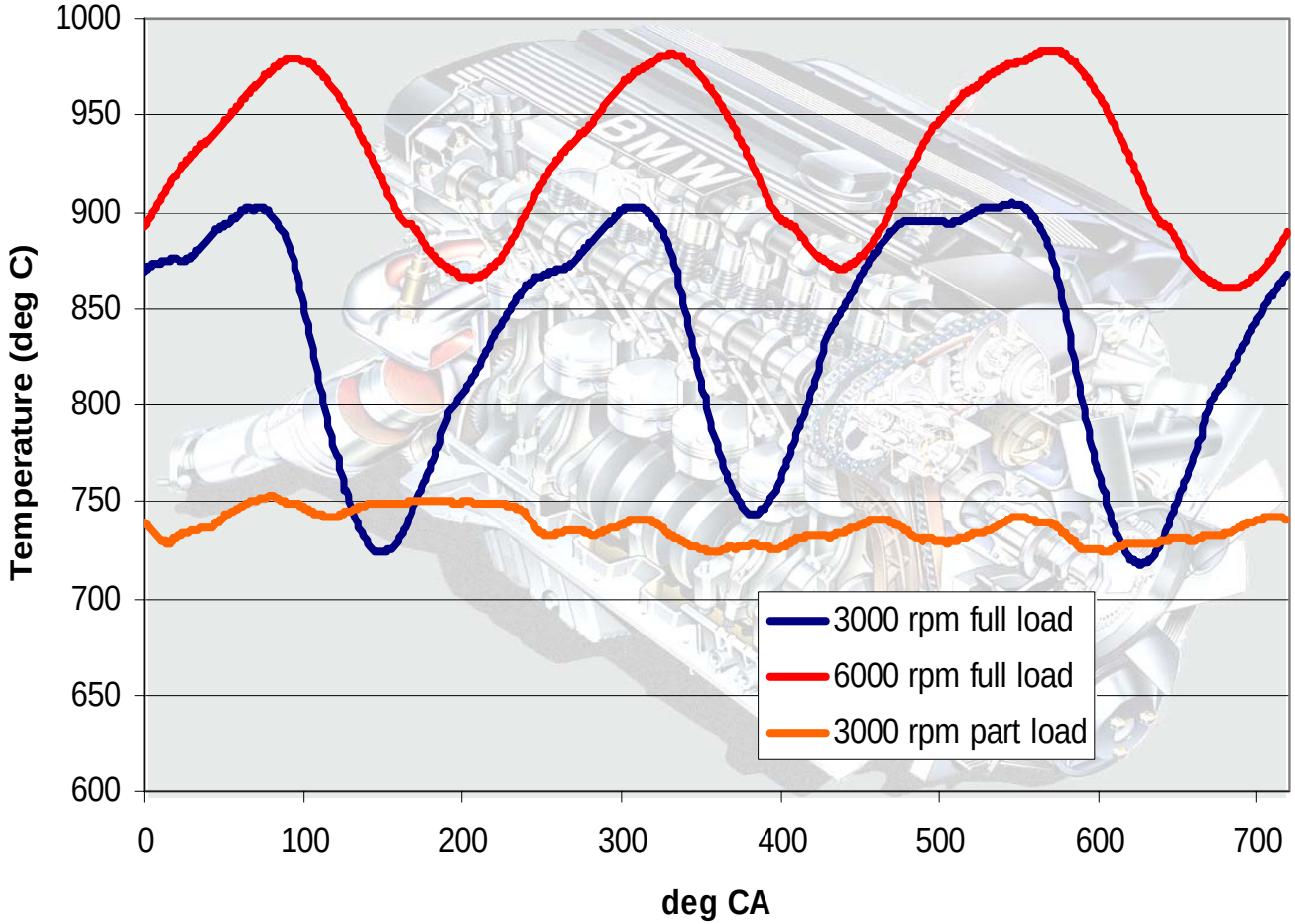
$$\dot{Q}=\alpha\ A\ \Delta T$$



Heat Transfer Estimations of a TEG Application

Exhaust Gas Temperatures for Different Engine Loads.

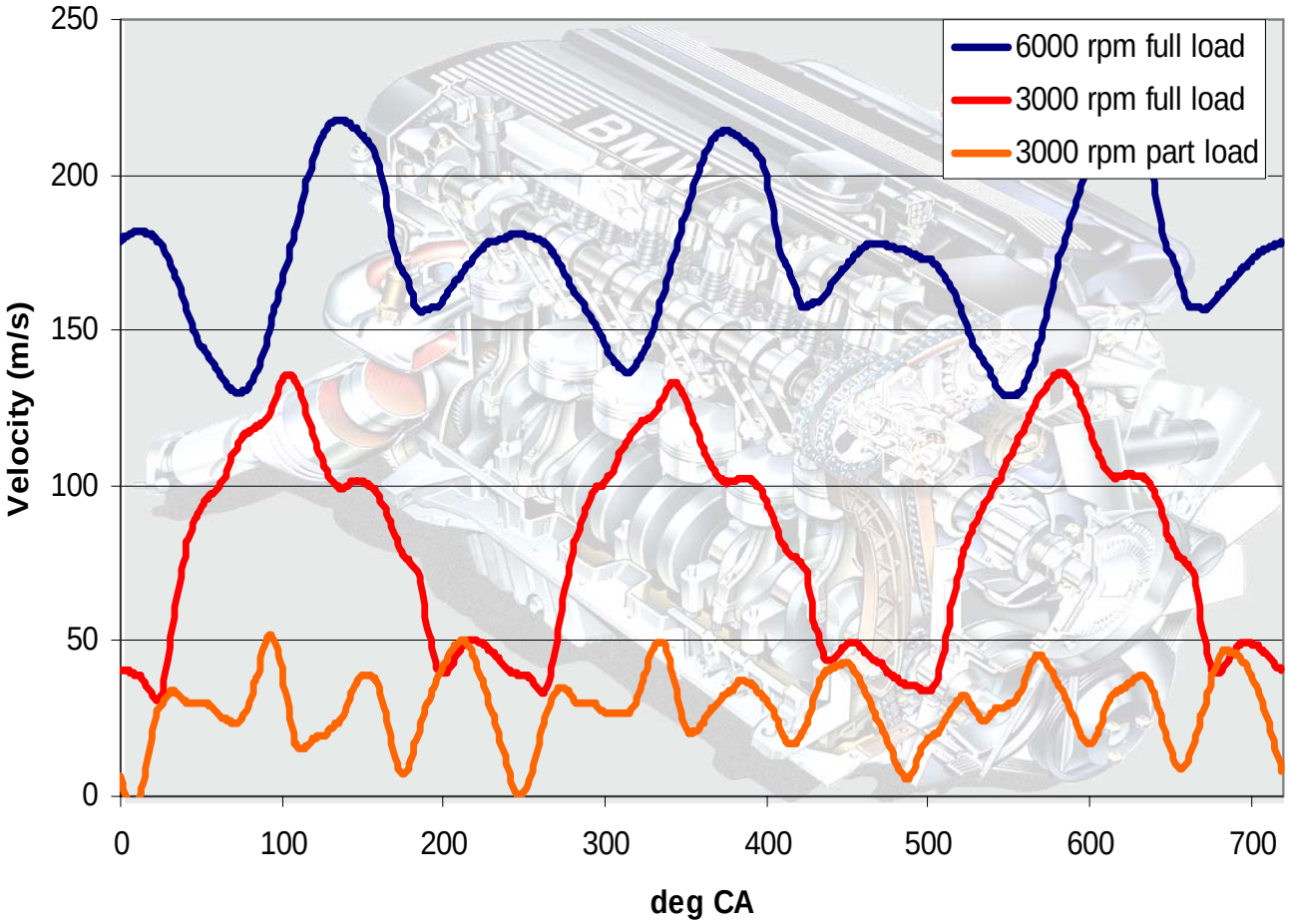
$$\dot{Q}=\alpha\ A\ \Delta T$$



Heat Transfer Estimations of a TEG Application

Exhaust Gas Flow Velocity.

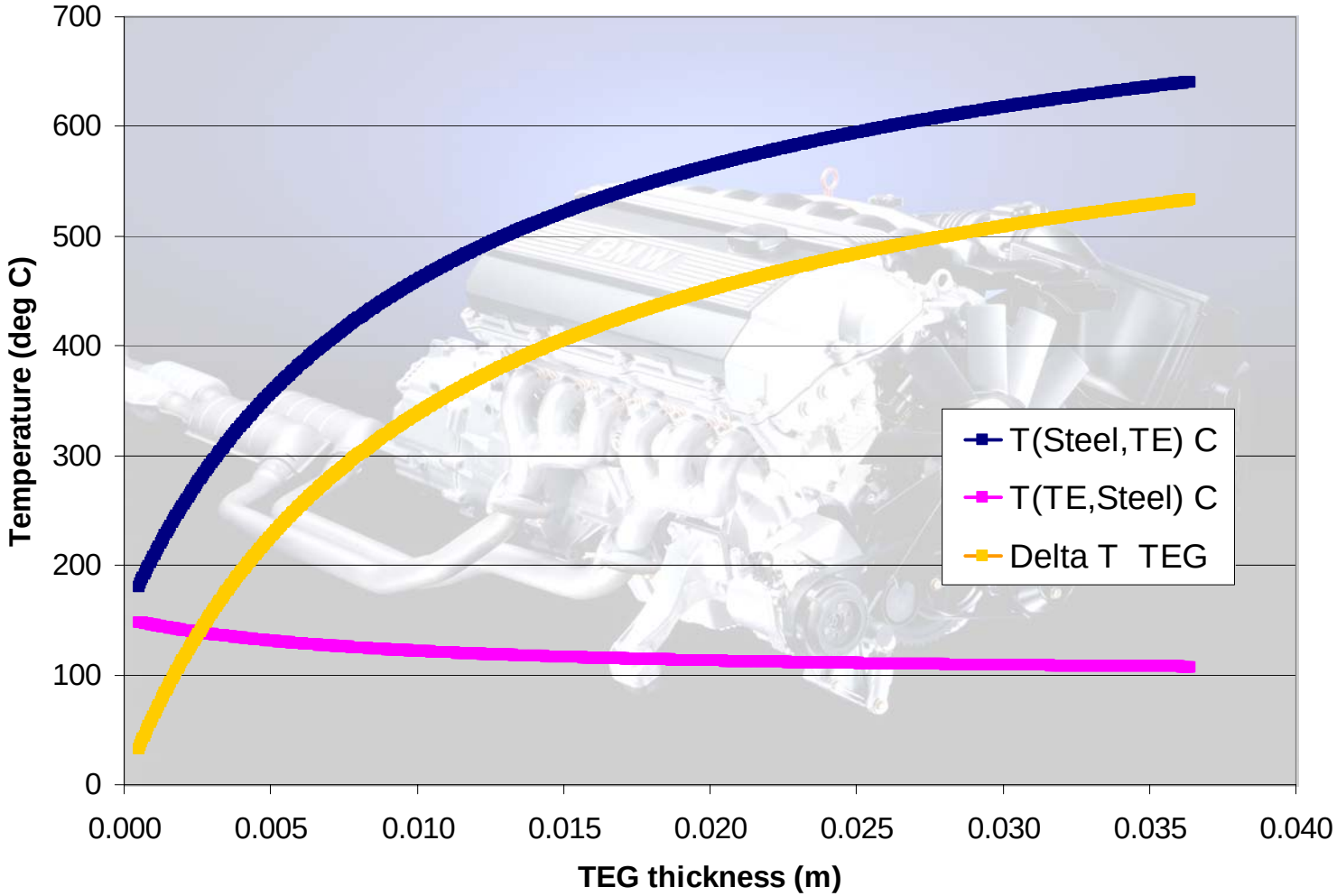
$$\dot{Q}=\alpha\ A\ \Delta T$$



HeatTransfer Coeff. α ~ Flow-Velocity$^{0.8}$ (Nusselt-Reynolds Correlation)

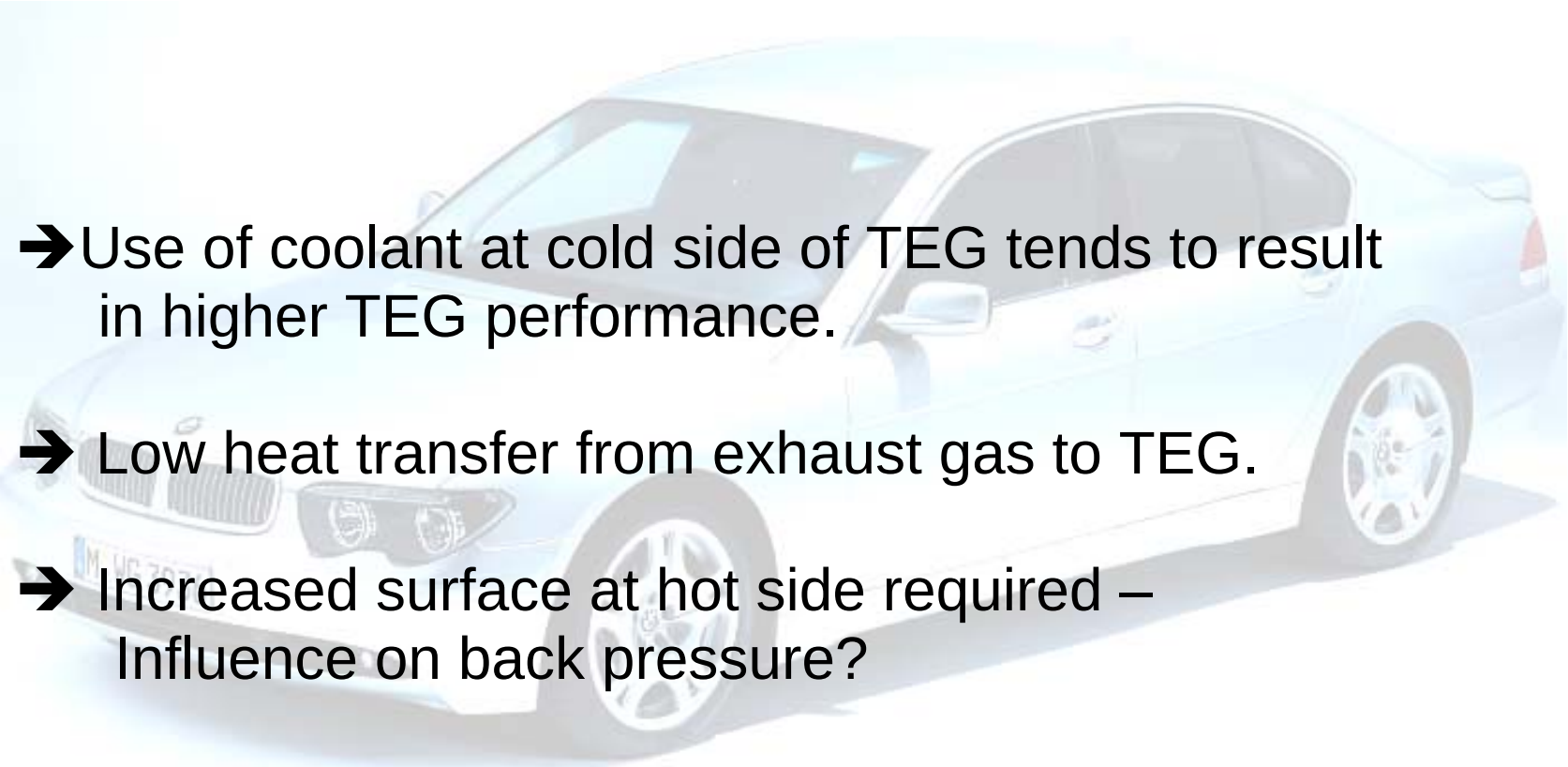
Heat Transfer Estimations of a TEG Application

Dependecy of TEG Thickness.



Heat Transfer Estimations of a TEG Application

Summary of Simulation Results.



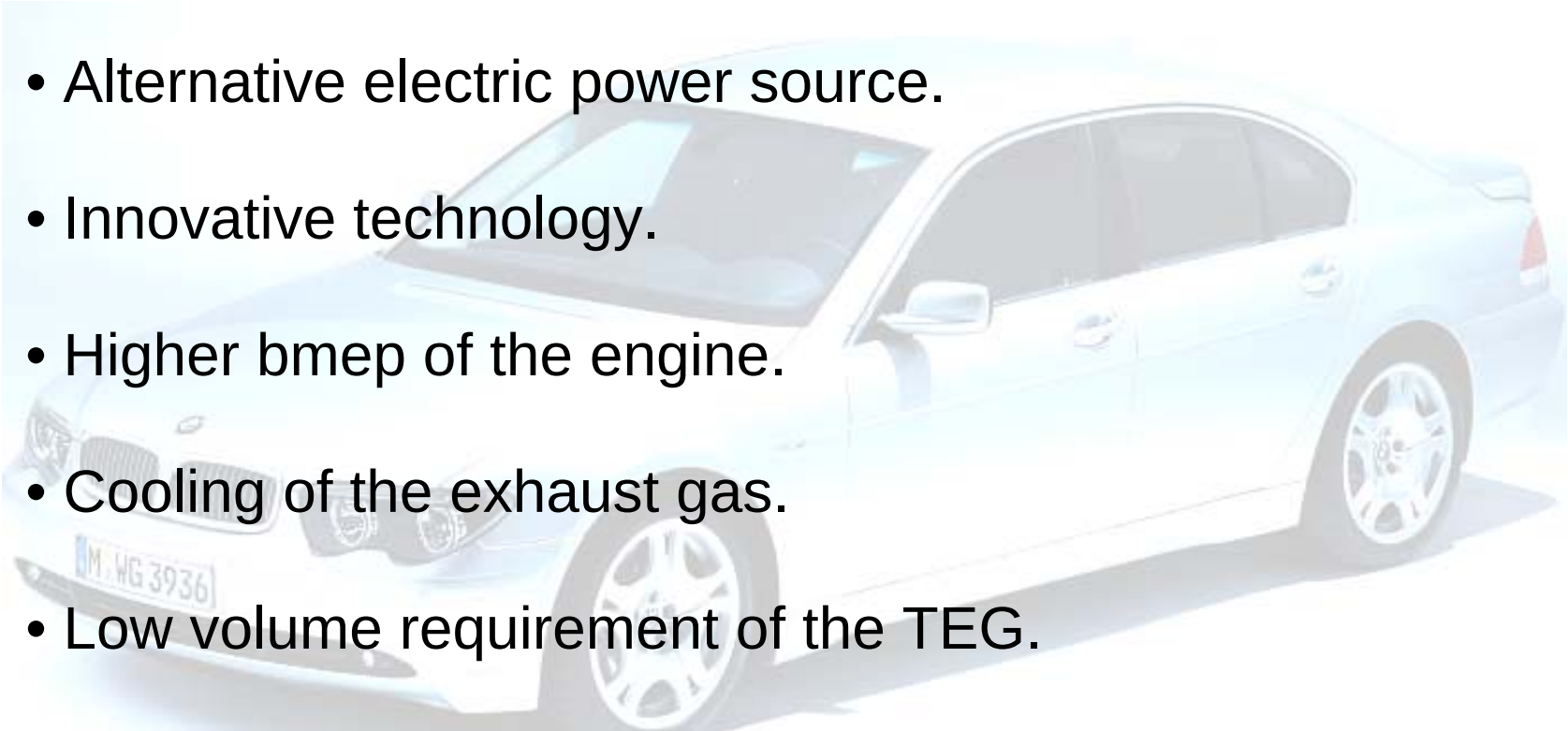
➔Use of coolant at cold side of TEG tends to result in higher TEG performance.

➔ Low heat transfer from exhaust gas to TEG.

➔ Increased surface at hot side required – Influence on back pressure?

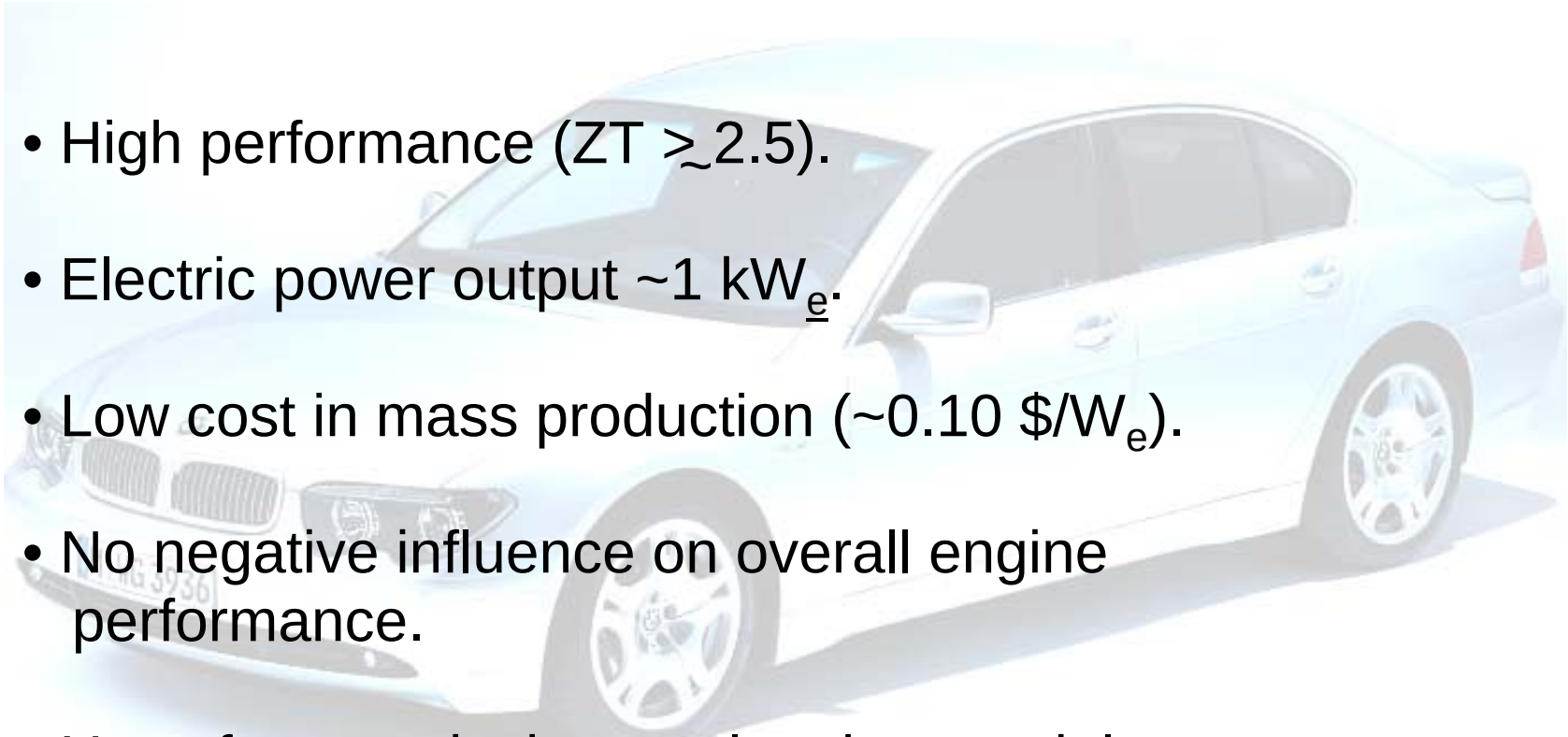
➔"Thick" TEG required! (Weight, Volume, Cost)

Benefits of TEG Application.



- Alternative electric power source.
- Innovative technology.
- Higher bmep of the engine.
- Cooling of the exhaust gas.
- Low volume requirement of the TEG.
- System integration (e.g. catalytic converter)?

Prerequisites of TEG Application.



- High performance (ZT $\gtrsim$ 2.5).
- Electric power output ~1 kW_e.
- Low cost in mass production (~0.10 $/$W_e$).
- No negative influence on overall engine performance.
- Use of non-toxic thermoelectric materials.

Concerns of TEG Application.

- Heat transfer issues.
- Material issues (thermal stress, maximum temperature limitations).
- Mass productivity of thermoelectric materials.
- Cycle performance and durability of at least 150.000 mi.
- Electricity demand at idle speed.
- Competing technology with low cost alternator technology!
- Voltage fluctuations due to rapidly changing engine speeds and loads.

Summary and Outlook.

- Application of high-power thermoelectricity is a interesting technology for vehicle application.
- Further development from both TEG manufactures and engine OEMs for optimized implementation into a vehicle required!
- Additional automotive applications for TEGs should be considered.
- Compromise to be found between optimized heat transfer, required volume and power generation.
- Thermoelectric power generation is not only a matter of high ZT.

Thank you for your attention.