Methodical Concept Development of Automotive Thermoelectric Generators (TEG)

3rd International Conference „Thermoelectrics goes Automotive“

Institut of Vehicle Concepts

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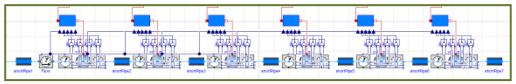
DLR

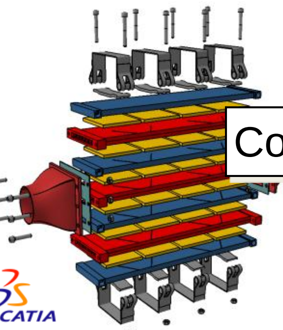
Outline

- Development of TEGs for application at the DLR
- Goals / Procedural method
- List of requirements / Interactions of TEG and vehicle system
- TEG concept development
- Thermodynamic and overall system simulations
- Technical/economic assessment
- Summary and outlook

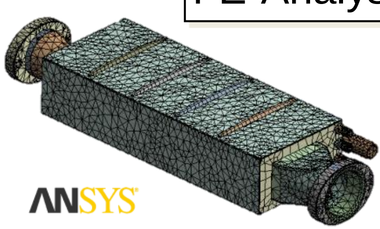
Development of TEGs for use in vehicles at the DLR
From simulation to a demonstrator



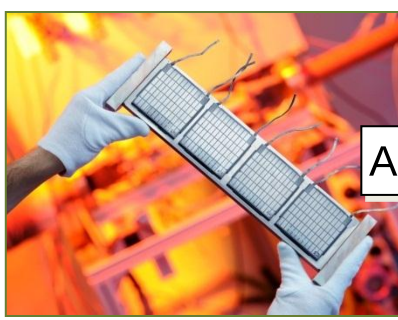
Simulation



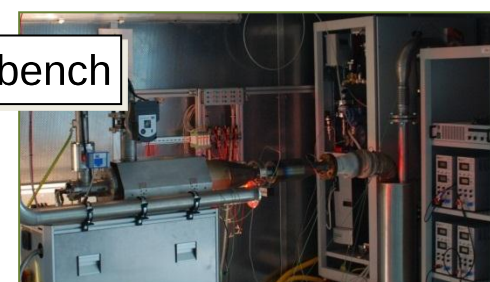
Construction



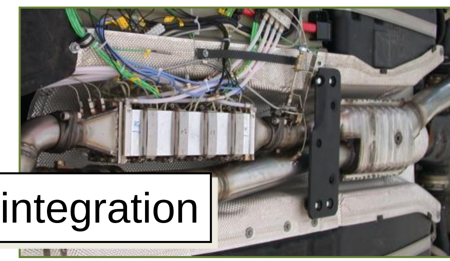
FE-Analysis



Assembly

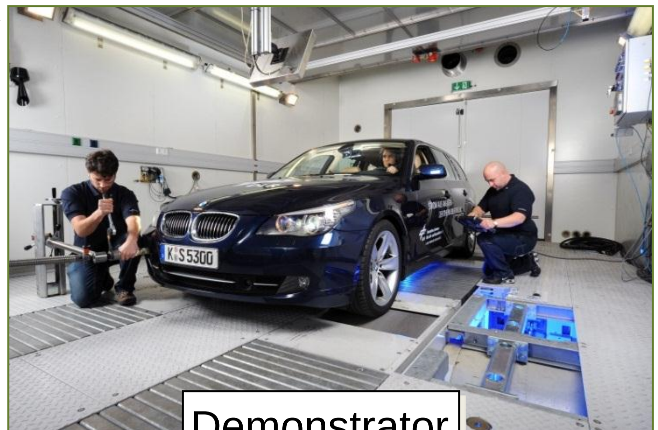


Hot gas test bench



Vehicle integration

Dyno test bench



Demonstrator

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Goals

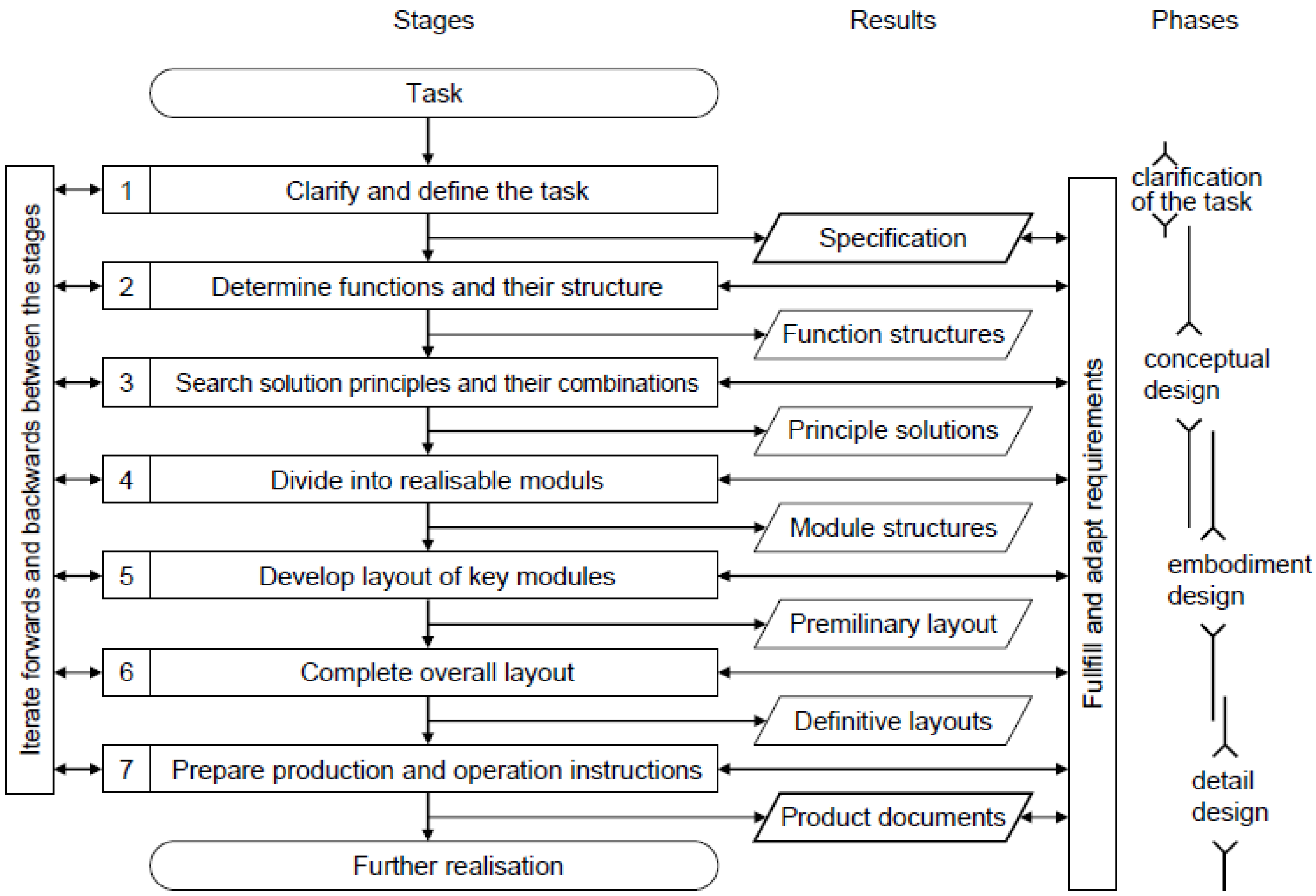
- Find the best TEG architecture for vehical application
- Maximization of the reduction of fuel consumption on a existing vehicle system
  - as a add on technology and
  - as a optimized vehicle system with TEG

Procedural method

- Concept determination
- Optimization by variing of all geometrical parameters
- Concept assessment through weighting of the solutions

Procedural method

VDI Guideline 2221



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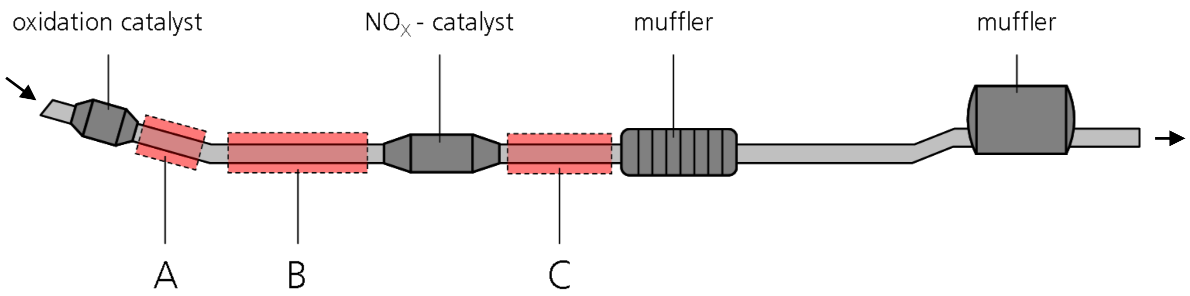
List of requirements

e.g. Vehicle boundary conditions

DLR – test vehicle

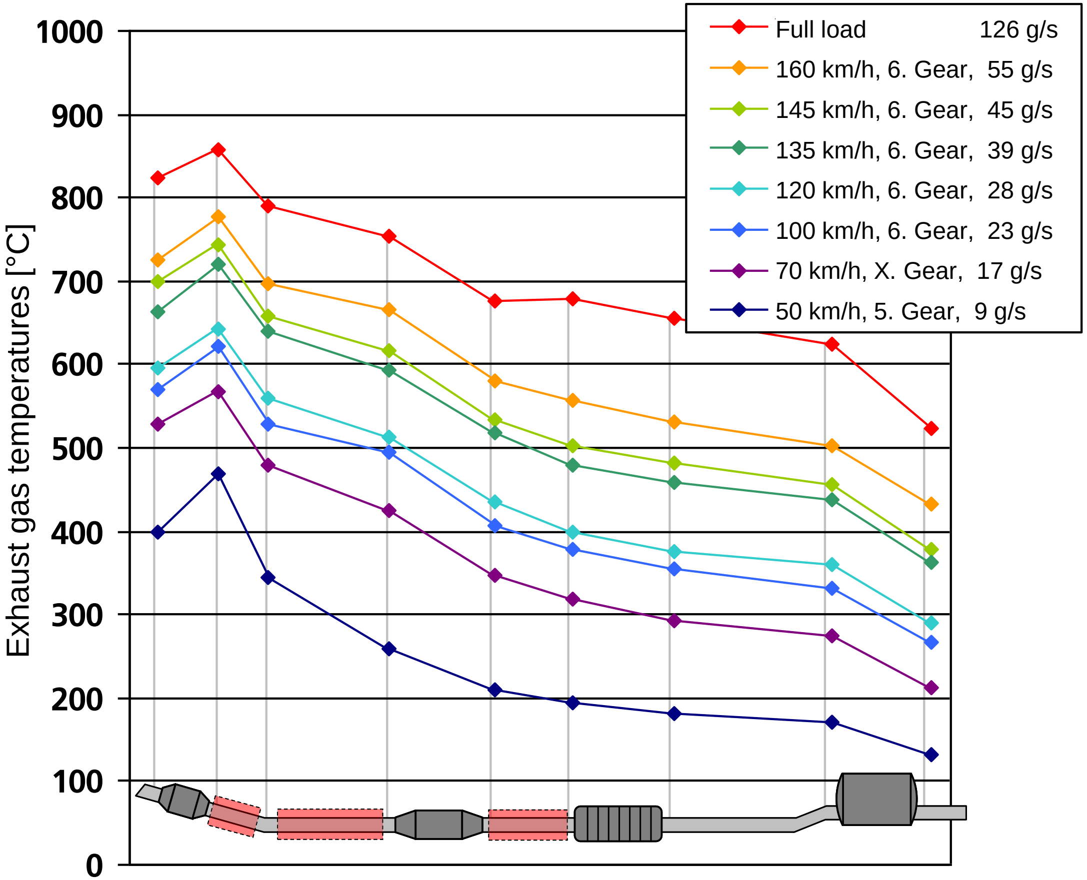
- BMW 535i
- 3l, 6 cylinder, spark ignition
- 190kW @ 6600 1/min



	A	B	C
installation space			
length	210mm	400mm	440mm
width	290mm	170mm	270mm
height	190mm	150mm	170mm

List of requirements

e.g. Gas temperatures along exhaust system

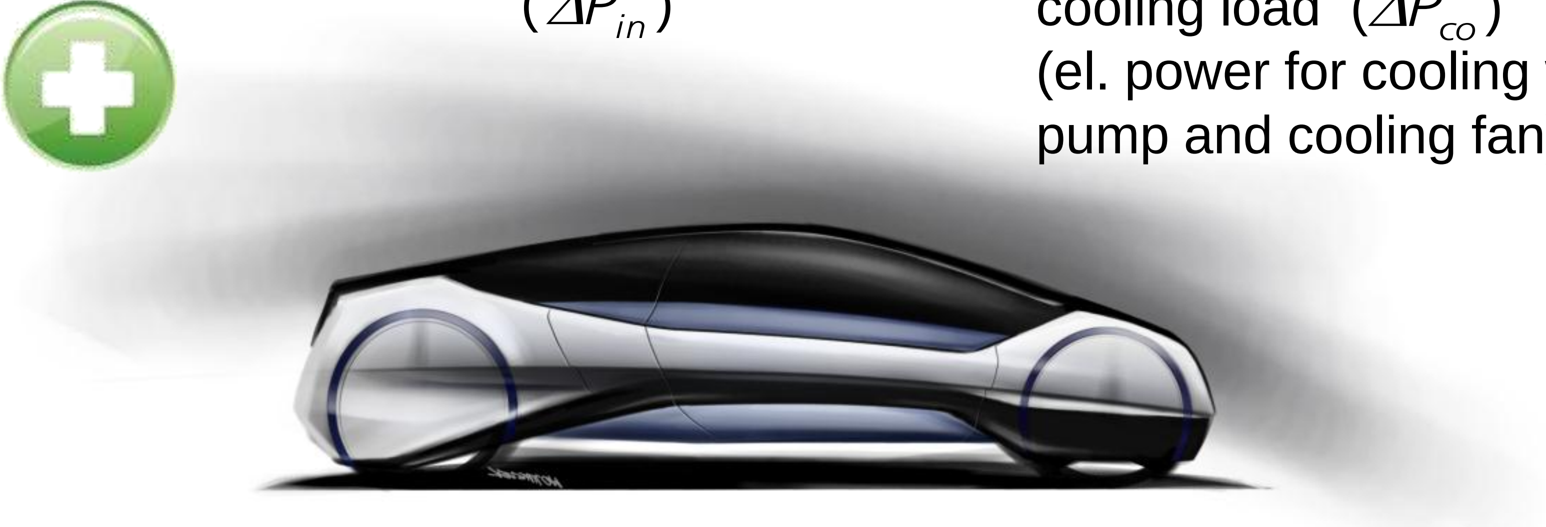


- Gas temperatures along exhaust system at different steady state driving conditions with replaced NO_x-catalyst.

Interactions of TEG and vehicle system

electrical TEG input power (ΔP_{in})

cooling load (ΔP_{co})
(el. power for cooling water pump and cooling fan)

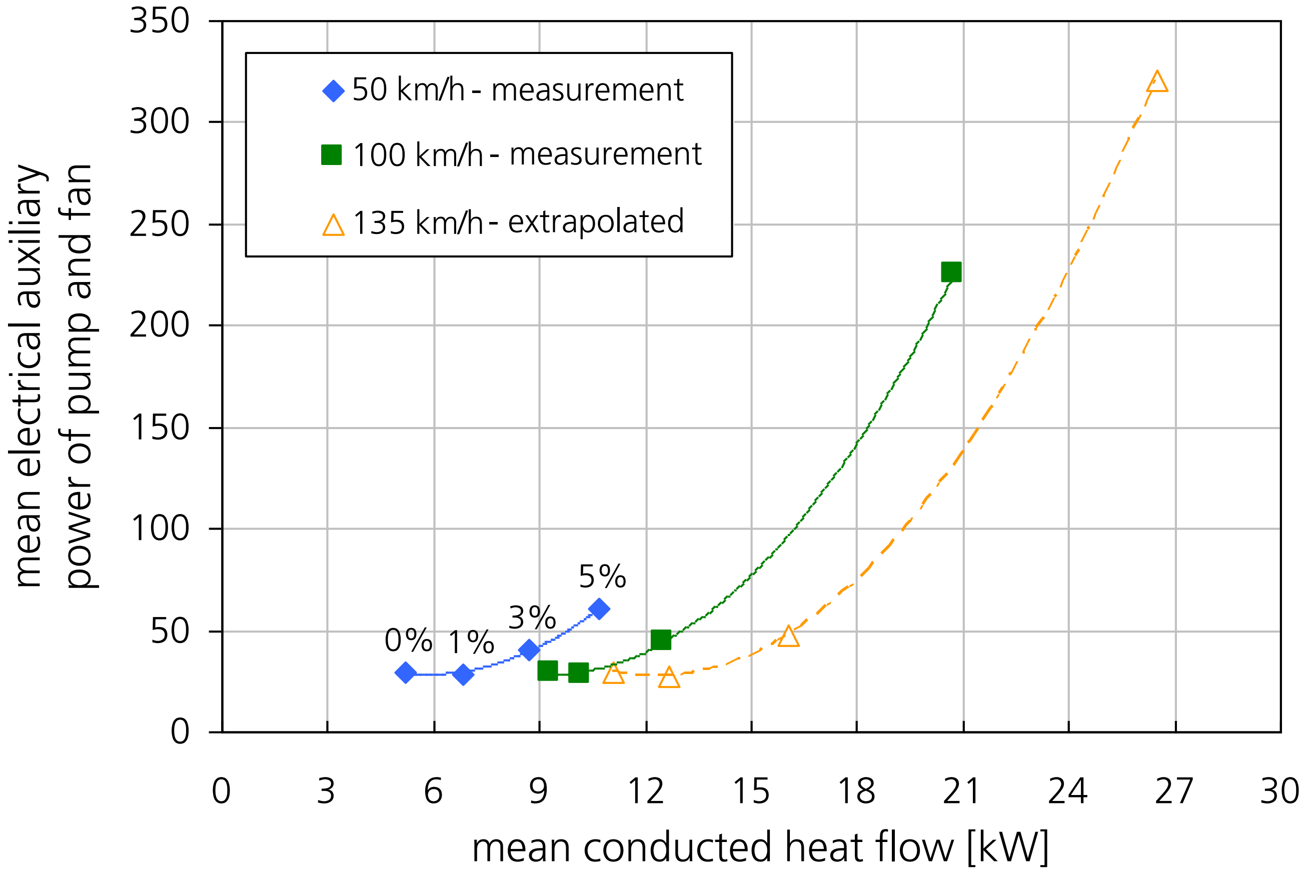


back pressure / cooling of exhaust (ΔP_{pr})

rolling resistance (ΔP_{ro})
(weight increse)

Interactions of TEG and vehicle system

e.g. Cooling load



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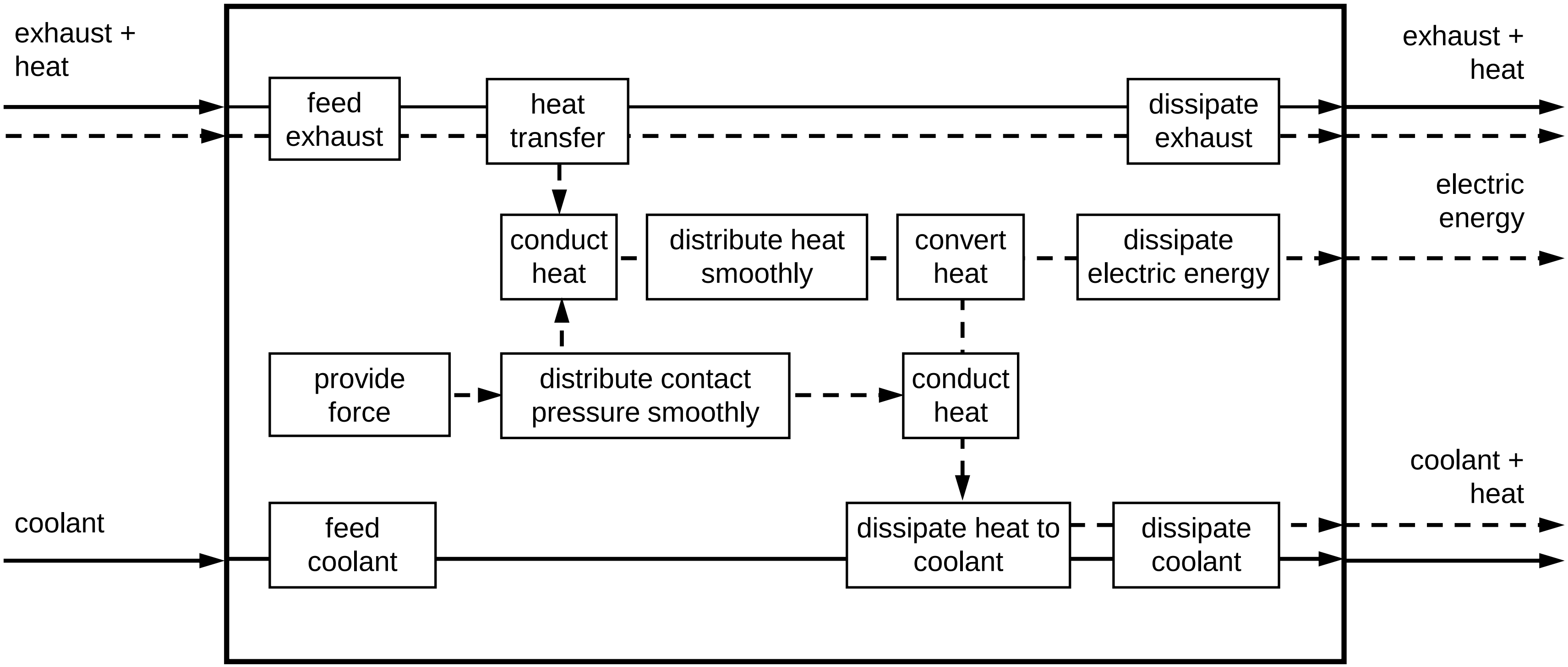
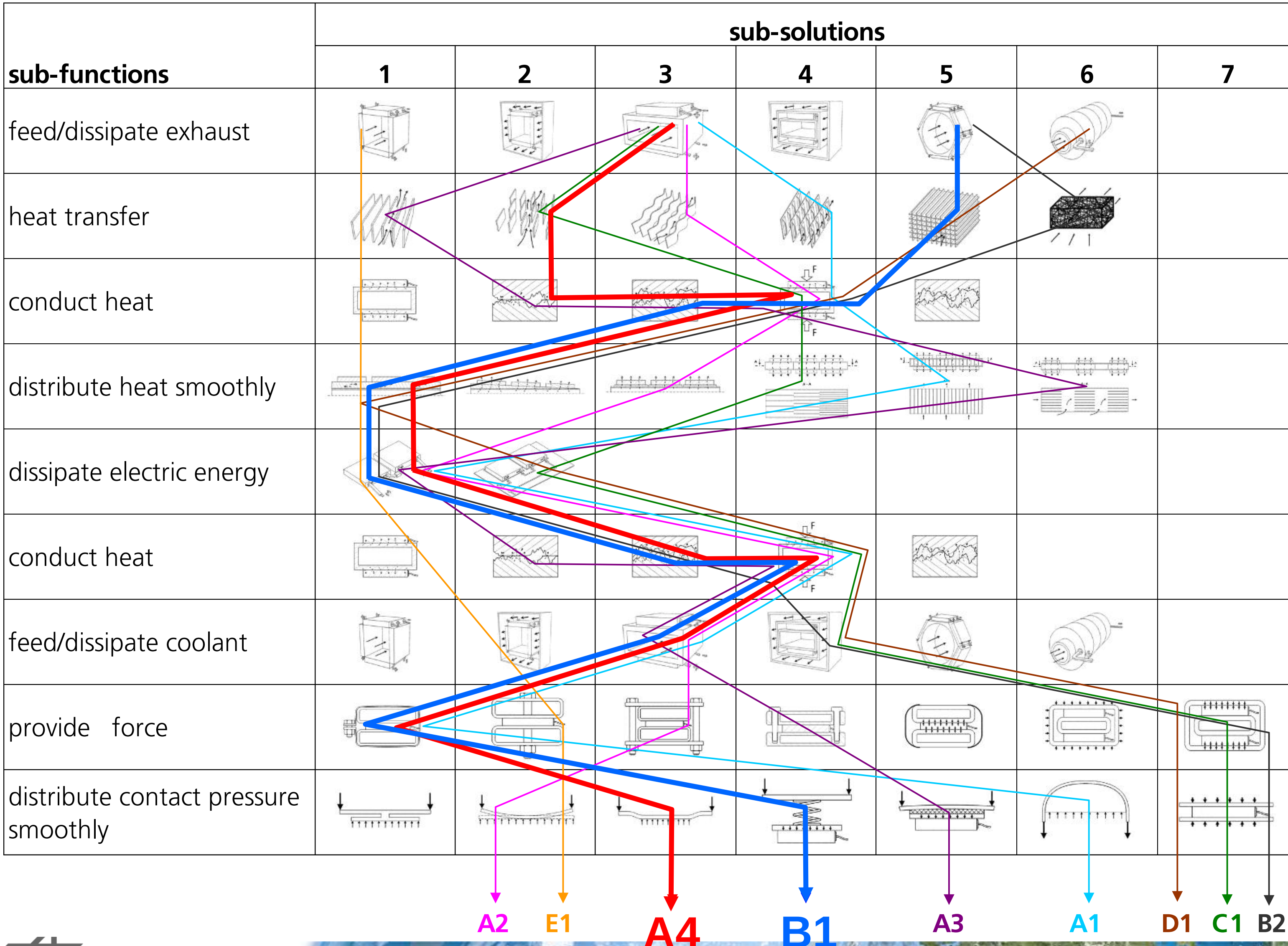
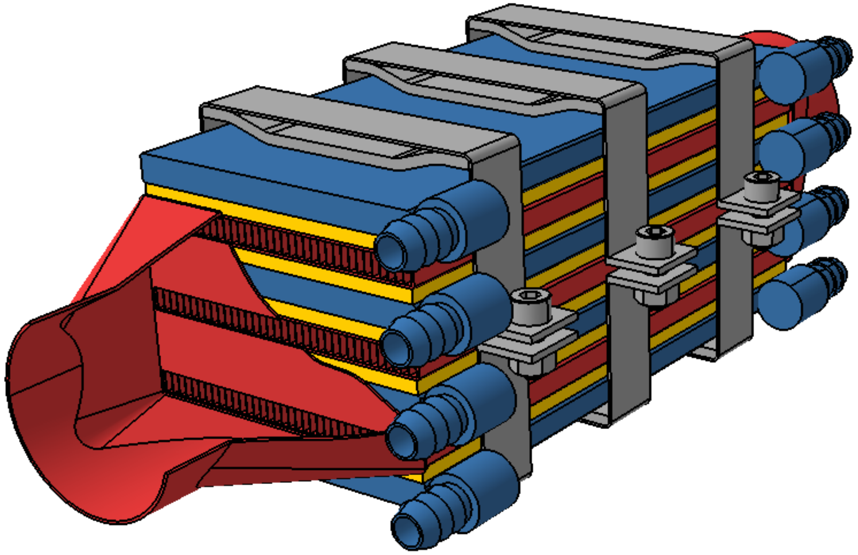
TEG Concept development – Function structure

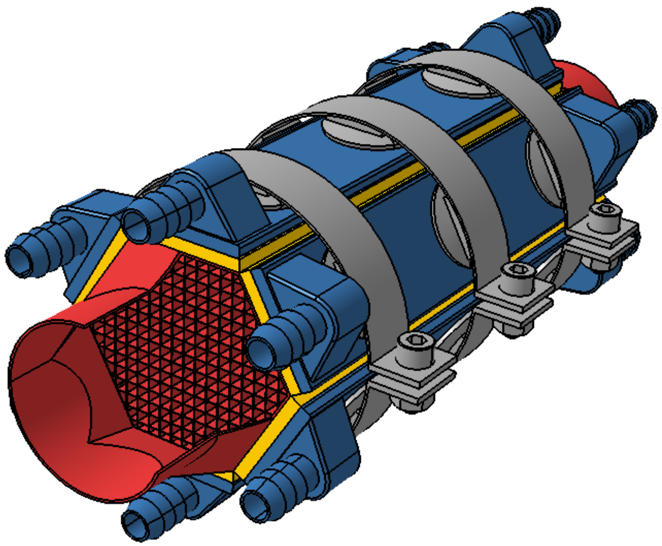


TEG concept development – Sub-solutions



Detail design of choosen TEG variants





A4 – stack architecture

First hardware demonstration in a cooperation between BMW and DLR in 2007 [1)]

B1 – hexagon architecture

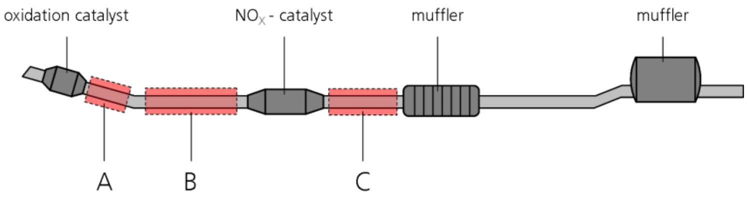
Inspired by a design of Hi-Z inc.[2)] and later on a design of Toyota[3)]

1) Treffinger, P. ; Häfele, C. ; Weiler, T. ; Eder, A. ; Richter, R. ; Mazar, B. : Energierückgewinnung durch Wandlung von Abwärme in Nutzenergie. In: *Innovative Fahrzeugantriebe 2008 : VDI-Berichte 2030* / VDI Wissensforum (Hrsg.). 2008

2) Bass, J. C. ; Elsner, N. B. ; Leavitt F. A. : *Performance of the 1 kW Thermoelectric Generator for Diesel Engines*. In: Proceedings of the 13th international conference on thermoelectrics (Kansas City 1994)

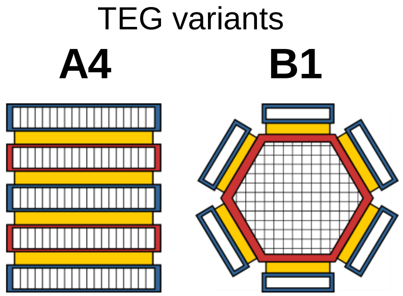
3) Schutzrecht DE 102005005077 A1 (2005-09-08). Shimoji. Pr.: 2004-029334 2004-02-05

Thermotechnical simulations – paramters and goal



vehicle

- 3 different installation positions A, B, C
- 3 different design points: 50km/h, 100km/h, 135 km/h



TEG

- all geometrical parameters were varied
- consideration of the installation space

- thermoelelctric material
  - Skutterudite Yb0.26Co4Sb12/0.2GaSb[1] and DD0.65Fe3CoSb12[2]

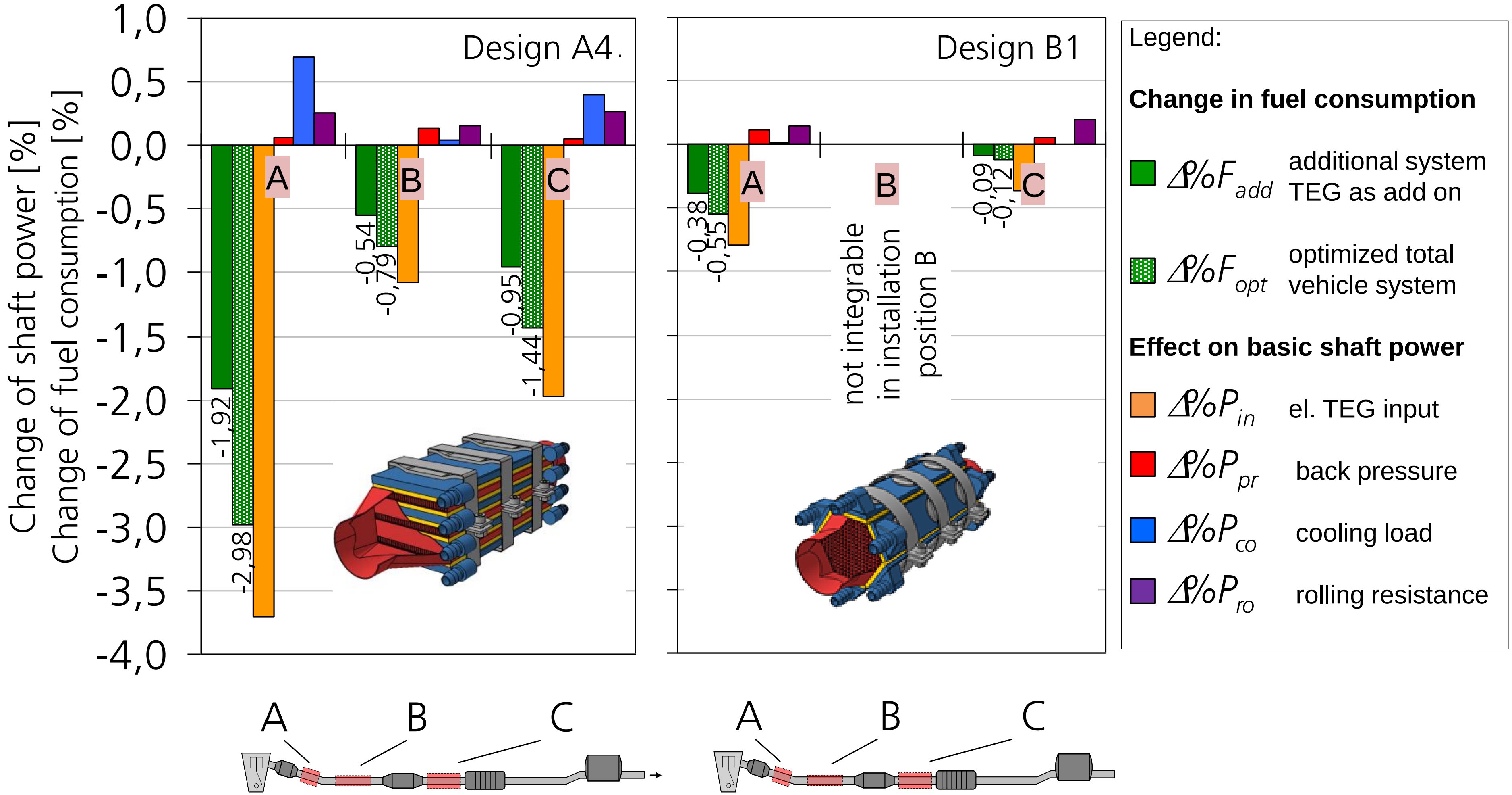
goal of design modifications

- maximum decrease of fuel consumption

1) Xiong, Z. ; Chen, X. ; Huang, X. ; Bai, S. ; Chen, L. : High thermoelectric performance of $Yb_{0.26}Co_4Sb_{12}$/yGaSb nanocomposites originating from scattering electrons of low energy. In: *Acta Materialia* 58 (2010) 2) Rogl, G. ; Grytsiv, A. ; Rogl, P. ; Bauer, E. ; Zehetbauer, M. : A new generation of p-type didymium skutterudites with high ZT. In: *Intermetallics* 19 (2011)

Overall system simulations

Results for design point 135 km/h

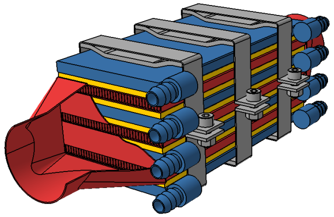
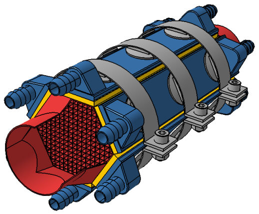


Technical / economic assessment

Classification with marks 1-6 (1=very good)

Sum of weighting factors equals 1

- 3 different design points: 50 km/h, 100 km/h, 135 km/h (weighting factor 0.6)
- Producibility / complexity (weighting factor 0.2)
- Material costs (weighting factor 0.2)

A4	**B1**
Total Mark: 2,4	**Total Mark: 4,0**
	

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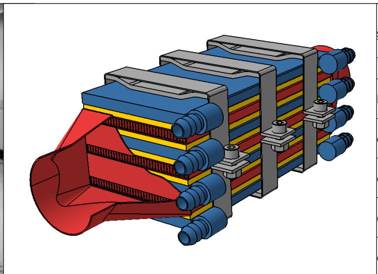
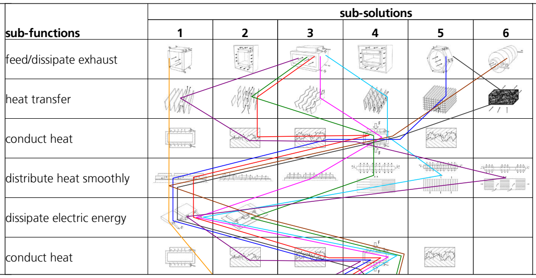
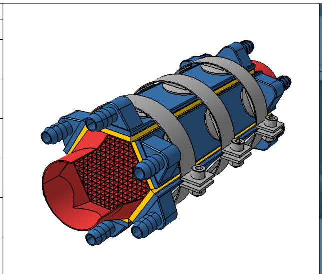
Summary

- Methodical design according to VDI guidline 2221
- Funktional structure and suitable sub-solutions
- Simulative integration of two TEG architectures in a existing vehicle system
- Variation of parameters in sequential arrangement of their effect and according to the bondary conditions
- Analysis of the results in the design points (50, 100, **135km/h**) and different installation positions
- Technical / economic assessment
- Stack design (A4) - architecture with the highest score

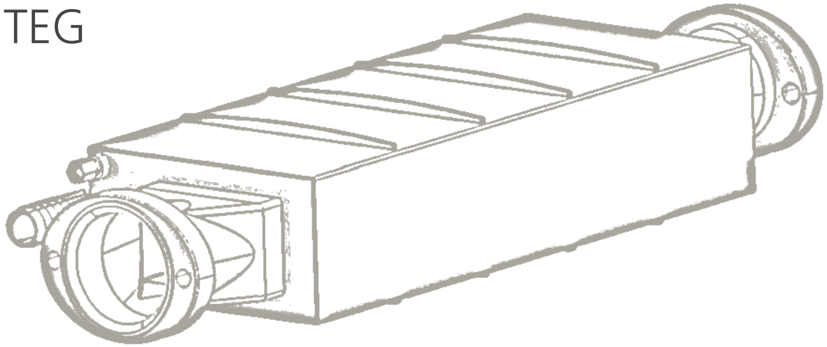






Further development of TEG system

- Architecture – capsule tube design
  - Increase of power density
  - suitable for mass production
- Energy output
  - Improvement of the overall system in steady states and dynamical states within driving cycles
- Hardware
  - Prototypes of high temperature TEG
- Improvement of overall system on
  - conventional vehicles
  - hybrid/range extended vehicles



Thank you for your attention!

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