Thermoelectrics for Automotive Applications

EPSRC Thermoelectric Network

26th February 2014

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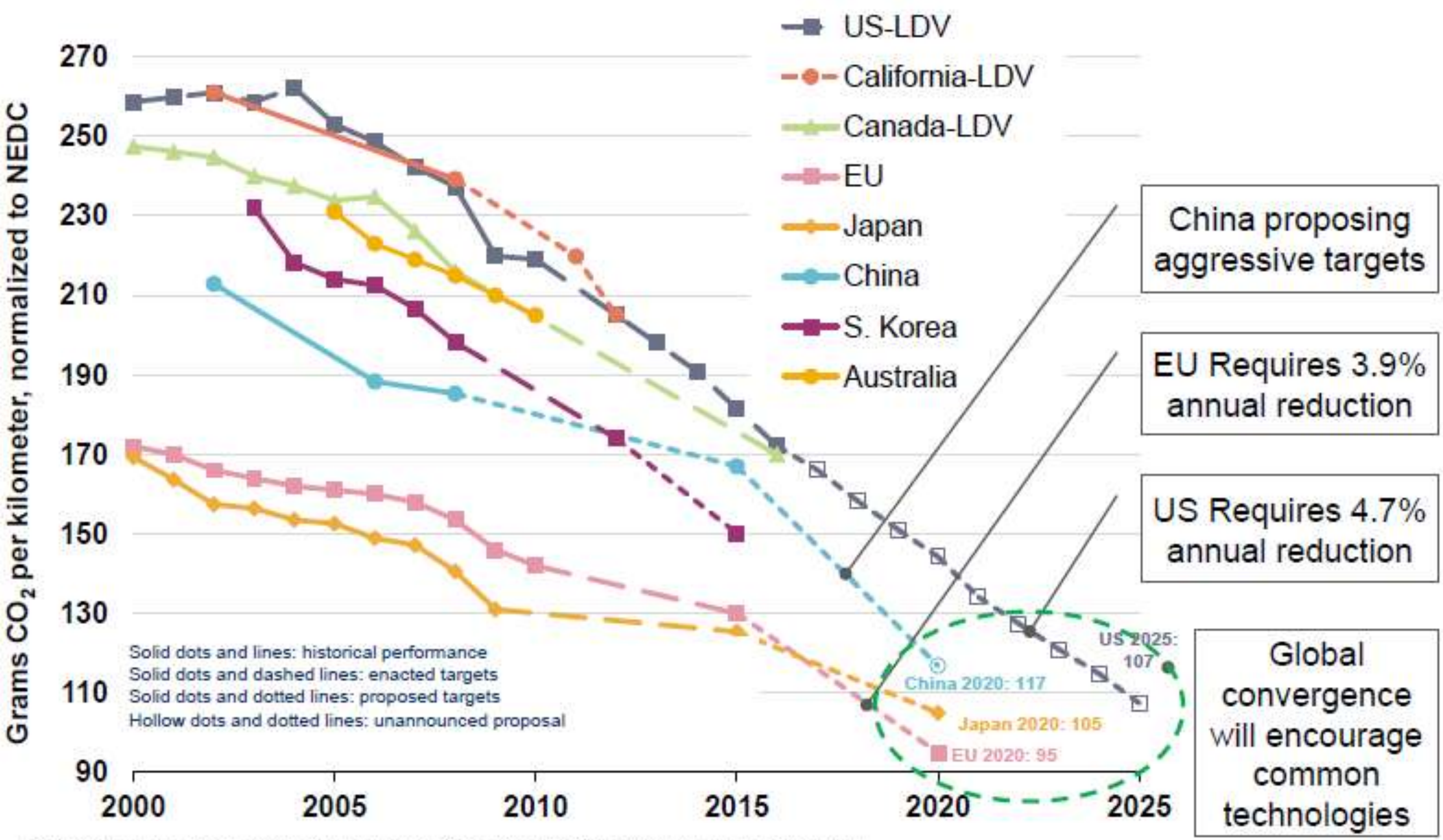
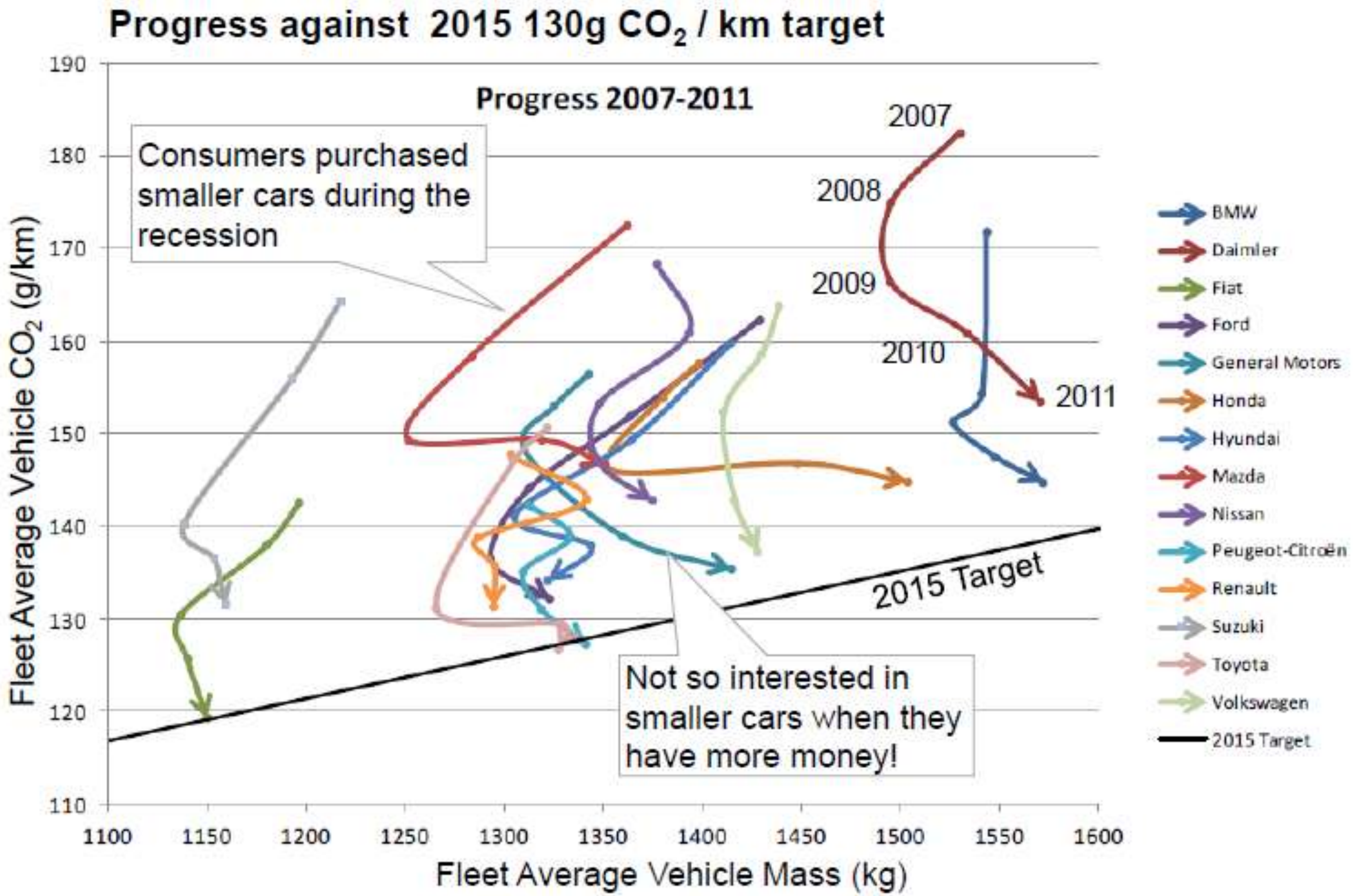
The growth of both regulation and targets for Low Carbon Vehicles sets a major challenge for the road transport sector



[1] China's target reflects gasoline fleet scenario. If including other fuel types, the target will be lower.
[2] US and Canada light-duty vehicles include light-commercial vehicles.

Sources: http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/Oct2010_Summary_Report.pdf www.theicct.org/info/documents/PVstds_update_apr2010.pdf;

Progress made against CO2 regulations but fleet average emissions depend on consumer purchasing behaviours

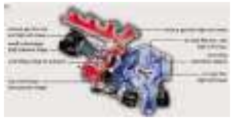


Source: http://www.transportenvironment.org/sites/te/files/publications/2012_12_TE_cars_CO2_report_web_final.pdf

Vehicle OEM's have implemented a wide range of measures to reduce CO_2 emissions - with scope for further improvements

OEM Approaches to CO_2 Reduction

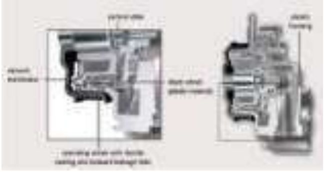
Base Engine Updates
Combustion + Air System Match
Minor Friction Improvements



Calibration for CO_2
Often with some compromise to NVH

Downspeeding
Longer Final Drive Ratio

Thermal Management e.g.
Map Controlled Coolant Temp
Switchable Piston Cooling
Variable Speed Water Pump



Downsizing
e.g new Ford EcoBoost:
Same power, lower friction

Reduced Rolling Resistance Tyres

Energy Management
e.g. Smart Alternator, Adaptive PAS

Stop-Start

Aero Improvements
e.g ride height, reduced/active grill

Vehicle Weight Reduction

Source: Ricardo Research

There are three interlinked phases of change required to current light duty powertrain technology and strategy

SHORT TERM: ~2015

- Boosting & downsizing
  - Turbocharging
  - Supercharging
- High BMEP combustion
  - EGR for Gasoline knock mitigation
- Low speed torque enhancements
- Friction reduction
- Advanced thermal systems
- Stop/Start & Micro-Hybrid
- Niche HEVs & EVs
- Weight reduction

MEDIUM TERM: ~2025

- High Efficiency Lean Stratified Gasoline
- Advanced Aftertreatment
- Combined turbo/ supercharging systems
- Advanced low carbon fuel formulations
- 48 Volts micro hybrid systems
- PHEV in premium & performance prducts
- EVs for city vehicles
- Downsizing, 2 & 3 cylinder engines
- Significant weight reduction

LONG TERM: ~2050

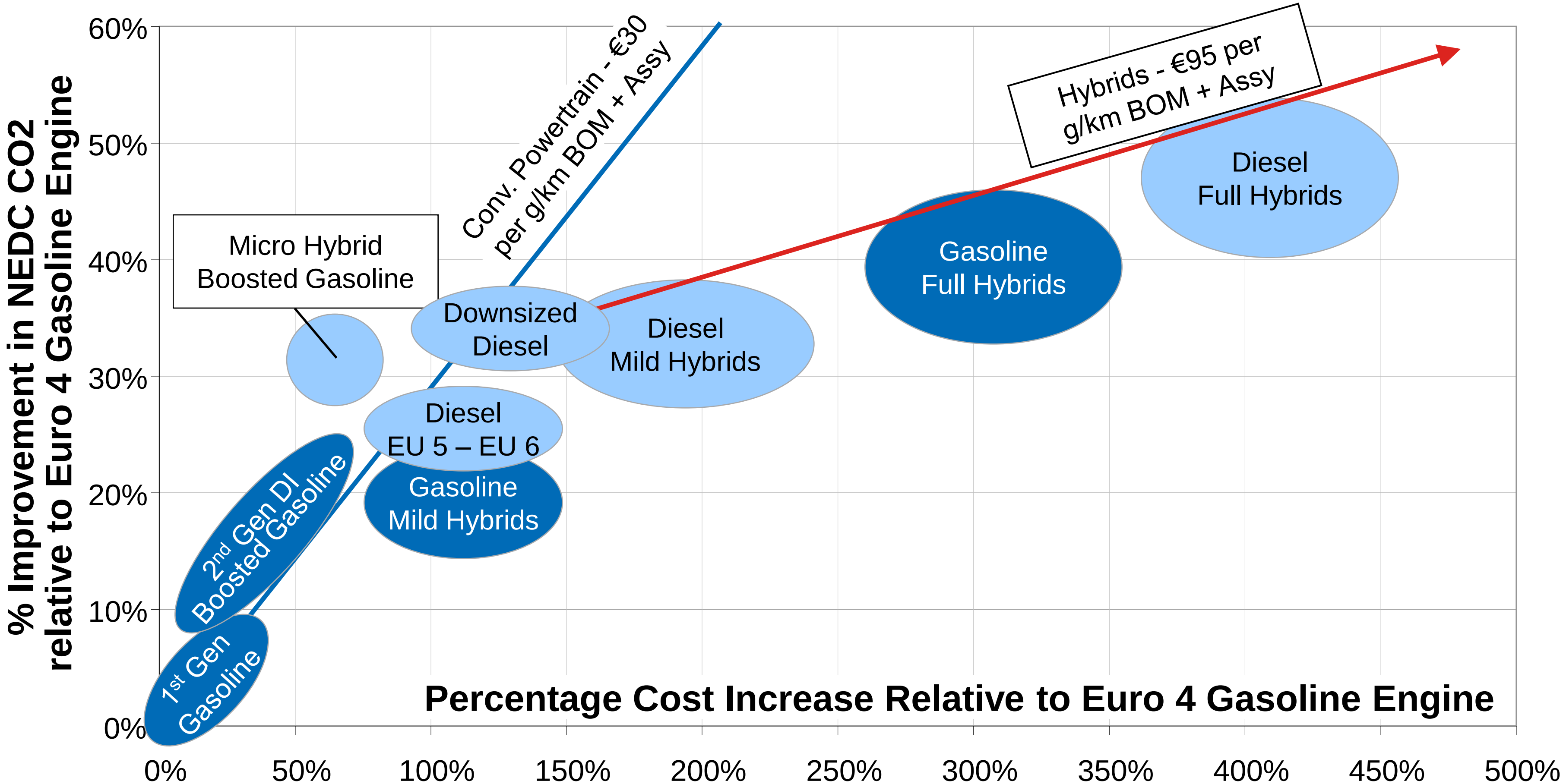
- Plug-in/Hybrid electric systems dominate
  - Very high specific power ICE's
- 50% lower weight
- Range of application specific low carbon fuels
- Exhaust & Coolant energy recovery
- Advanced thermodynamic Cycles
  - Split Cycle?
  - Heat Pumps?

Increasing importance of electrification

Source: Ricardo Technology Roadmaps, Ricardo Analysis

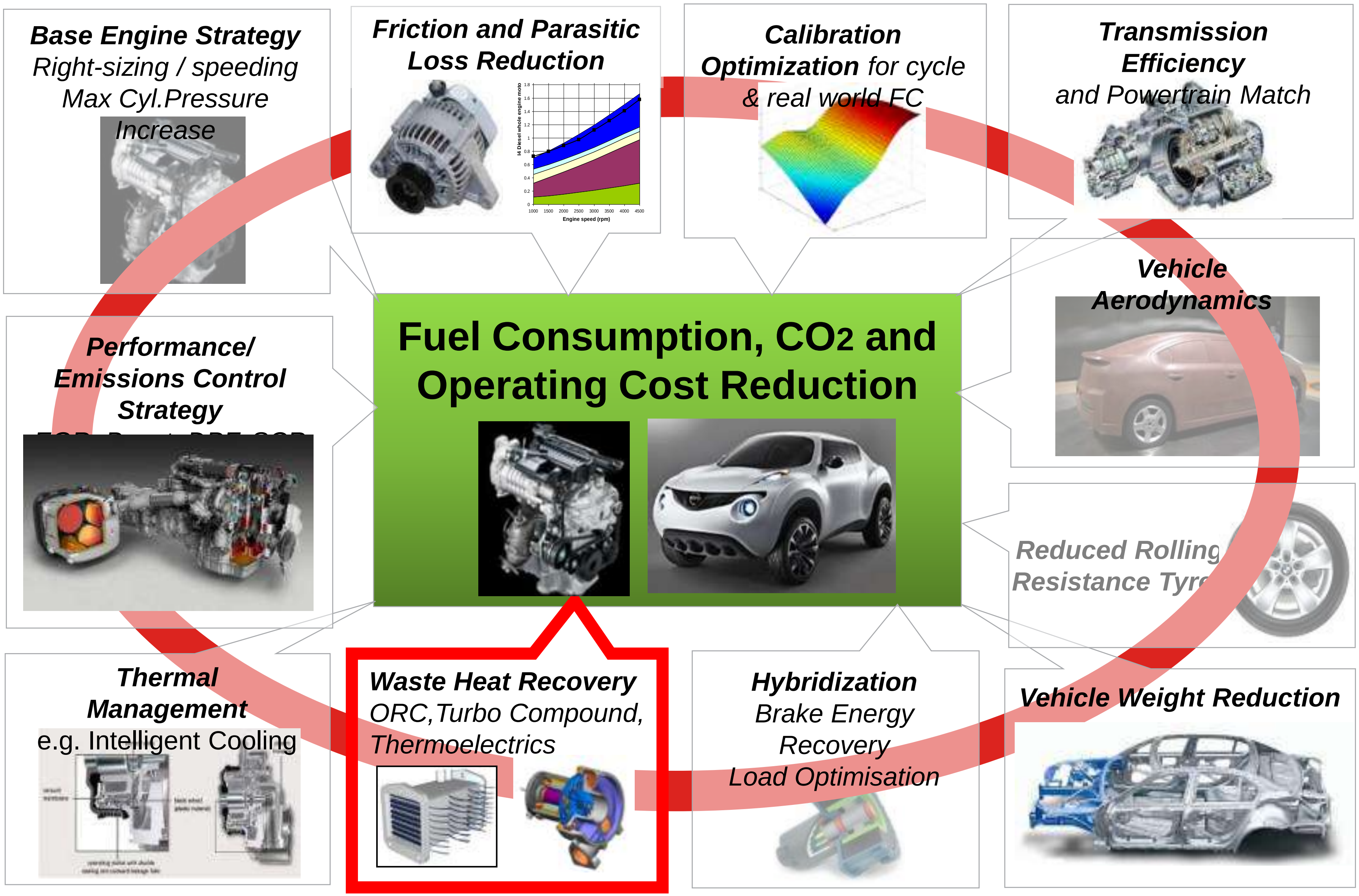
Incremental improvements are the most cost effective route and make sense in context of CO_2 / fuel consumption penalties

Benchmark Europe Passenger Car: CO_2 Cost Benefit for Powertrain Technologies

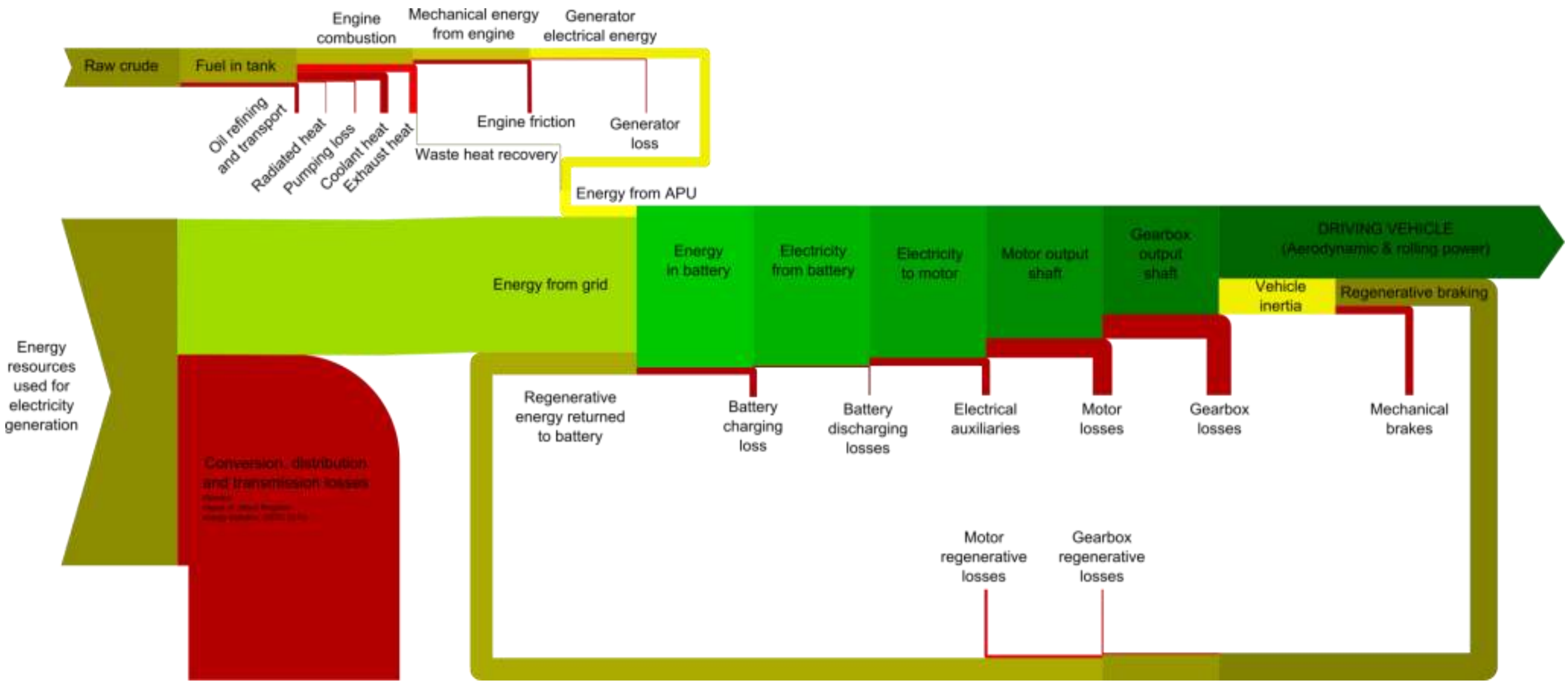


- Consumers usually buy vehicles – not powertrains – technologies must also compete on image, utility and lifestyle requirements and deliver fundamentally **Good Cars**

Engine technology must be integrated with powertrain and vehicle strategy to optimize Fuel Consumption, CO2 and Operating Cost



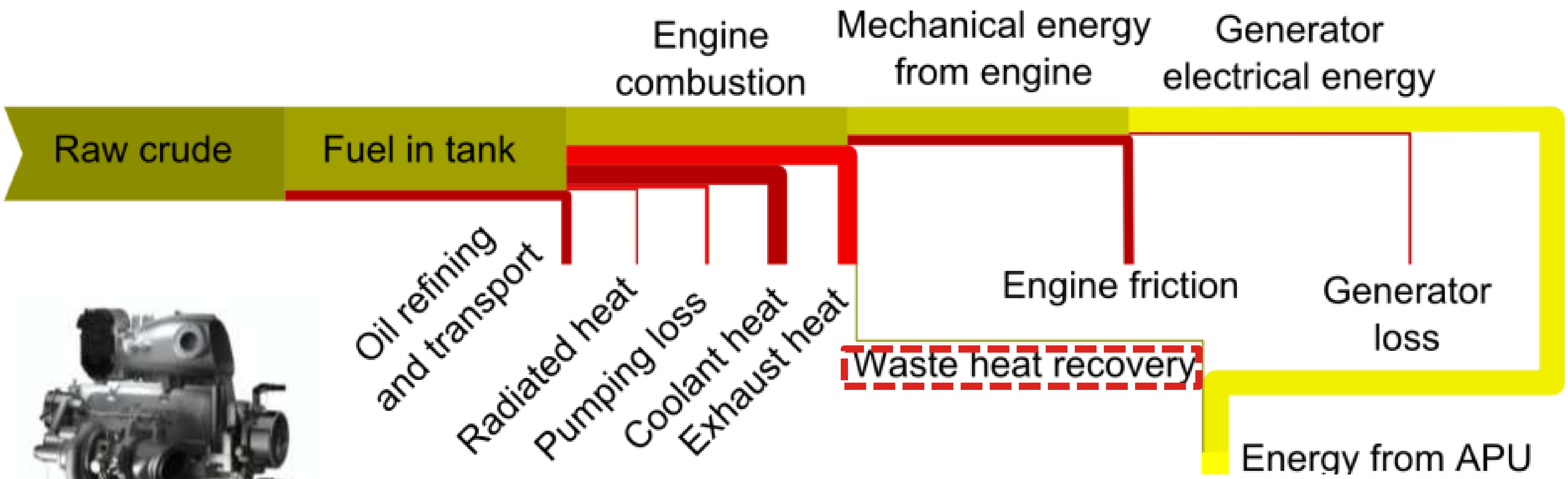
Energy balance – example from LCVTP – REEV application



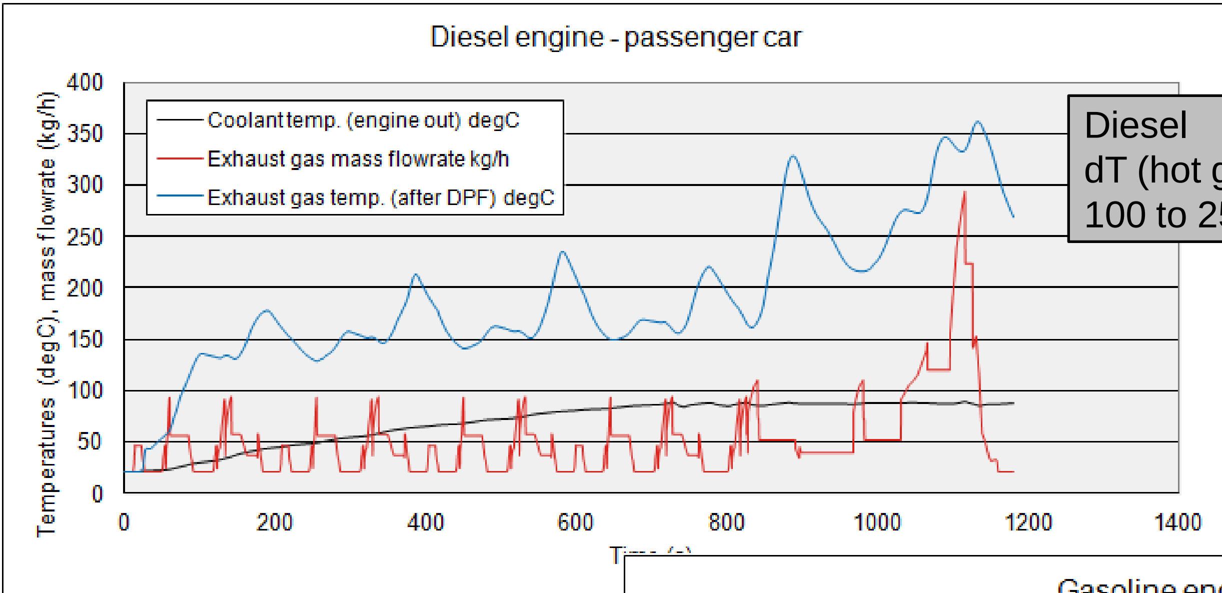
Energy balance – example from LCVTP – REEV application

Initial Focus for Waste Energy Recovery

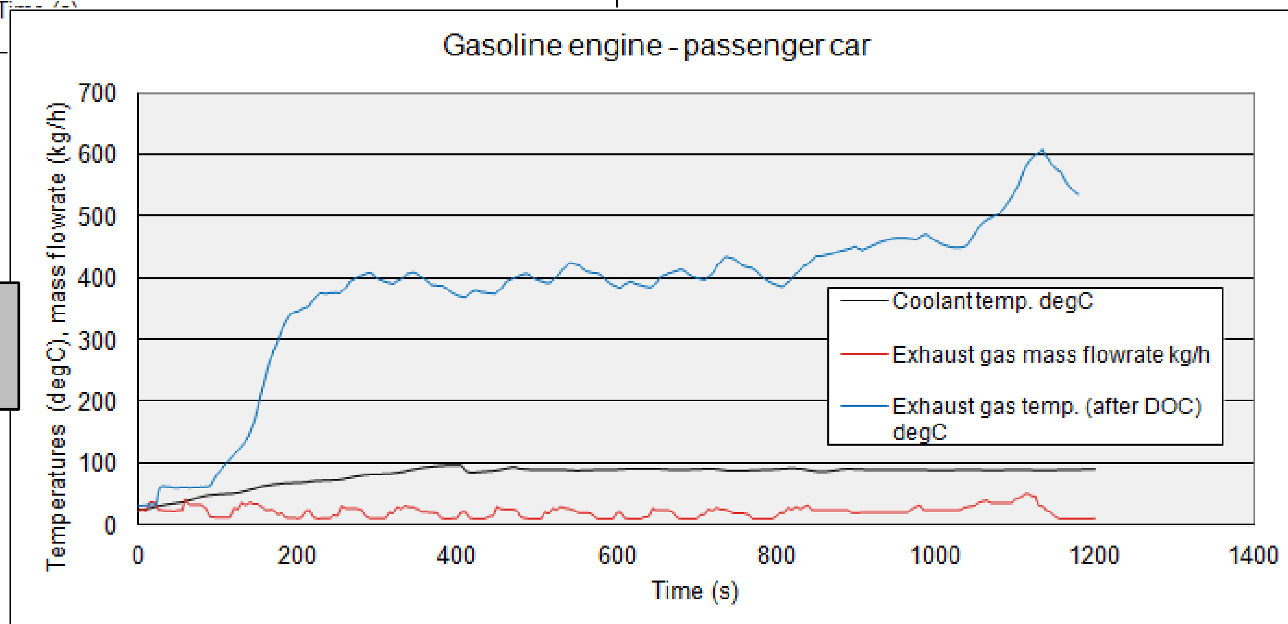
- Quality and quantity



Typical hot / cold sources temperatures – passenger car – gasoline and Diesel engines – on NEDC



Diesel
dT (hot gas – cold coolant) = 100 to 250ºC



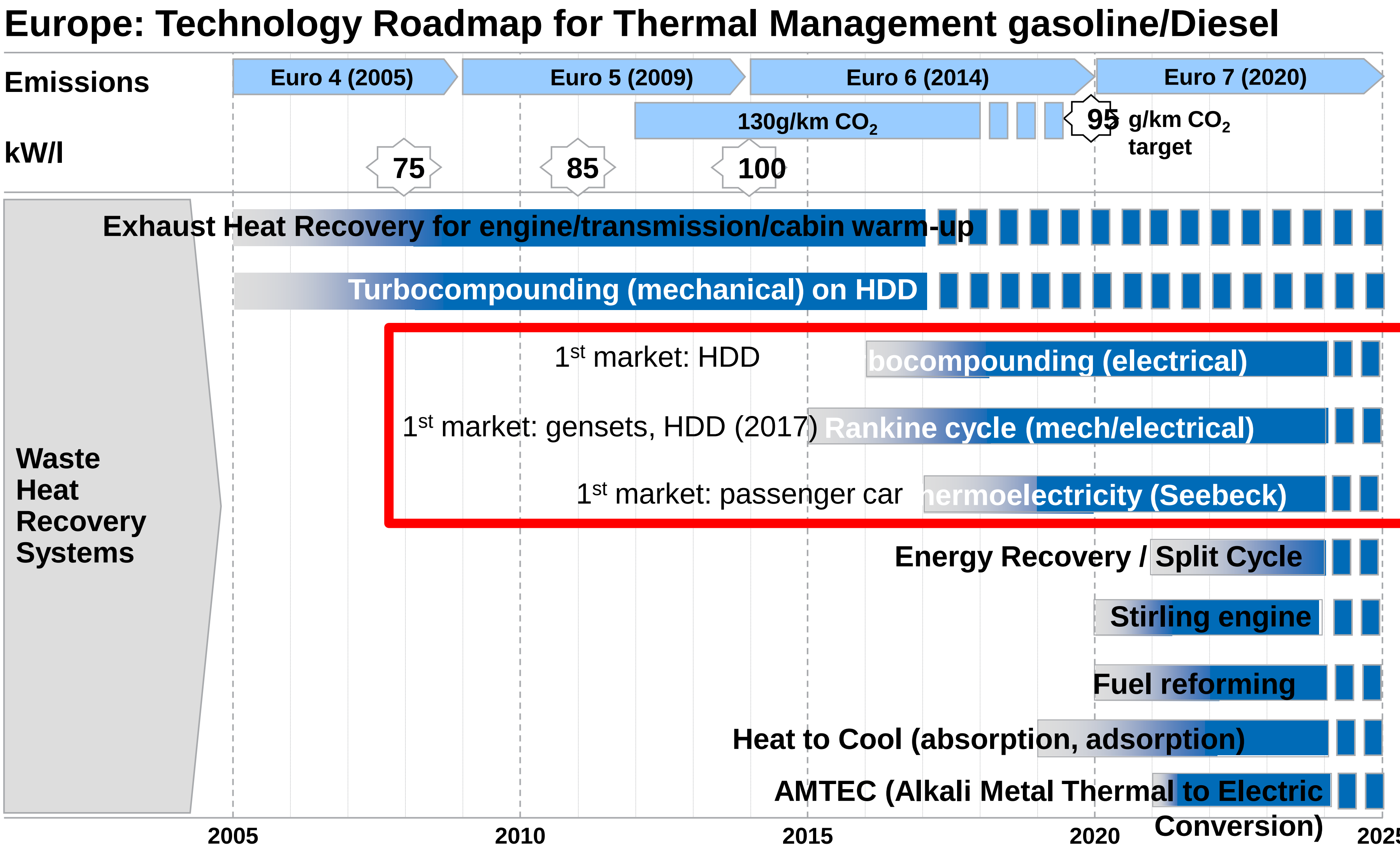
Gasoline
dT (hot gas – cold coolant) = 300 to 500ºC

All WHR systems are costly relative to many application needs – Solutions in bold are being studied actively for HDD/...

< 2020	Heat energy recovery	Typ' FE improve-ment	Applications	Issues	Trans iency	Cost	Technology maturity
Turbo compounding (m)	5 %	3 - 5%	Heavy duty Truck, Off Highway, Marine, Rail & Power **Passenger car**	Mechanical losses at low load	+++	-	Commercialised in premium products
Turbo compounding (e)	**15%**	**3 -10%**		Need for electrical power consumer or motor	+++	- -	Commercially-ready systems available
Rankine cycle / ORC	**20%**	**3 -10%**		Condenser cooling, bulk and cost	++	- -	Working prototypes developed
Thermo electrics (Seebeck)	**10%**	**3 -5%**	**Passenger cars** Heavy duty diesel	Cost	+++	- -	Concept (Automotive) Comm'd (Space)
Fuel reforming		3-10%	Combustion improvement – any ICE	Reformate management, transients, Cost	+	- - -	Concepts and prototypes
AMTEC	20-30%	3 - 10%	Passenger cars	High temperature operations Material (Na, K), BASE	++	--	Concepts and prototypes
Stirling engines	20%	3 - 12%	Micro CHP Marine engines	Requires precise matching, Cost	++	- - -	Commercialized as standalone devices
Split cycle engines	60%	36%	Power generation Automotive	Complexity, risk, Cost	++	- - -	Prototype (Power) Concept (Automotive)

> 2020

The high level technology roadmap for Waste Heat Recovery Systems are using Exhaust gas and/or any other fluids available on gasoline/Diesel vehicles (coolant, oil, EGR, charge air)

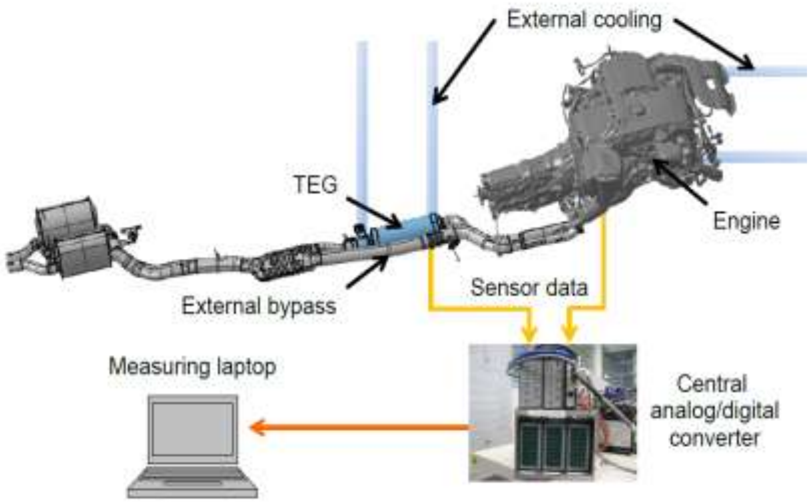


Source: Ricardo Analysis

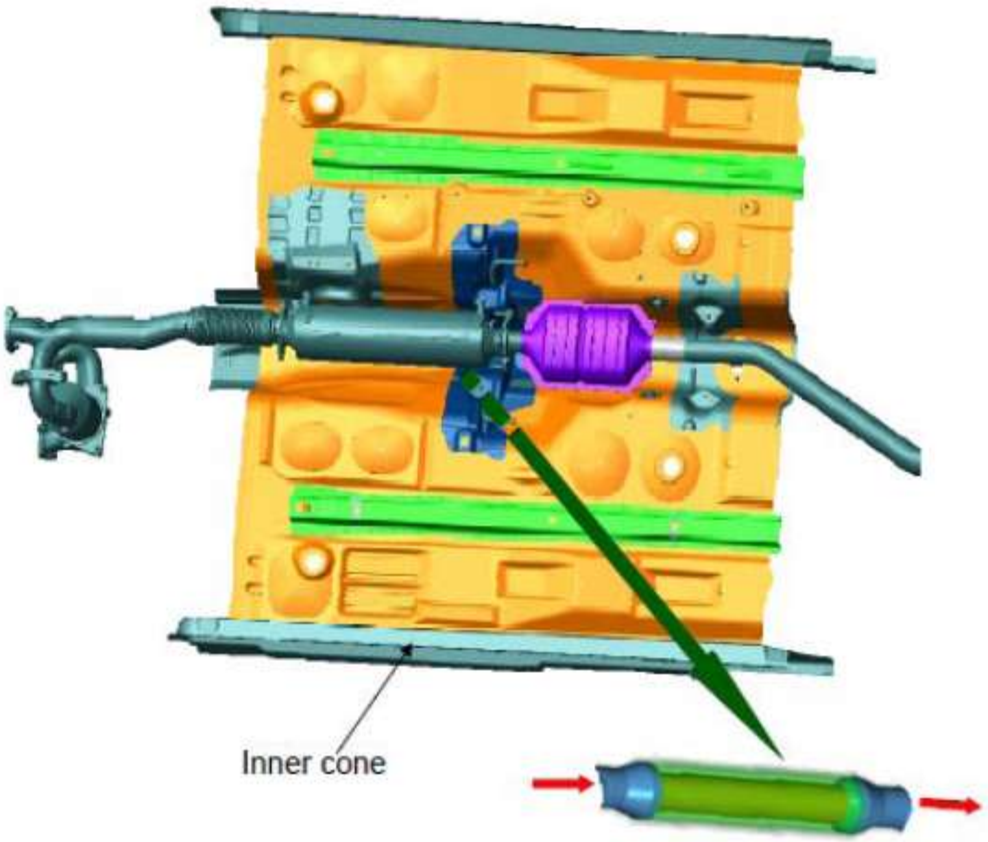
Approach

- 40 kW available (but not reachable) in exhaust gas after catalyst at > 130 km/h
- 70% efficient heat exchanger => 12 kW through the thermogenerator
  - 28 kW goes to ambient through tail pipe
- 10% efficient TE materials => **1.2 kW electric generation**
  - 10.8 kW into the coolant and radiation/convection to ambient
- But… 70% effectiveness is high and 10% TE efficiency is also high
  - **Target: 300-500 Watts at 130 km/h**
- 100W on Real life driving conditions⇔ 0.1 L/100 km fuel consumption
  - 600W = 0.6 L/100 km fuel consumption reduction (equ. 5-10% FC reduction)

Packaging/installation on vehicle

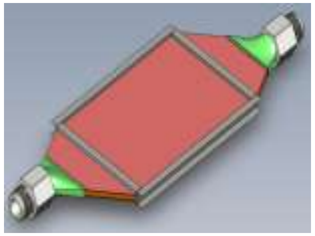


Source: BSST for BMW solution - 2010

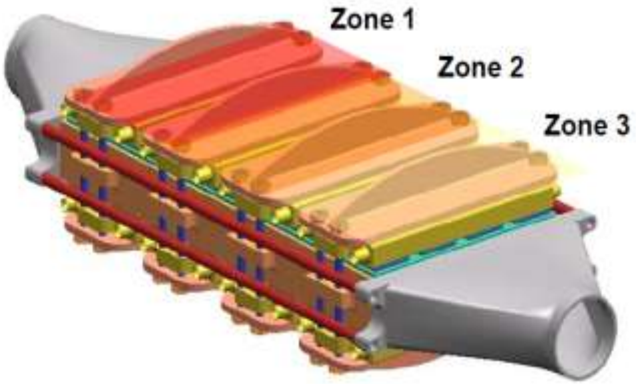


Source: BSST for Ford solution - 2010

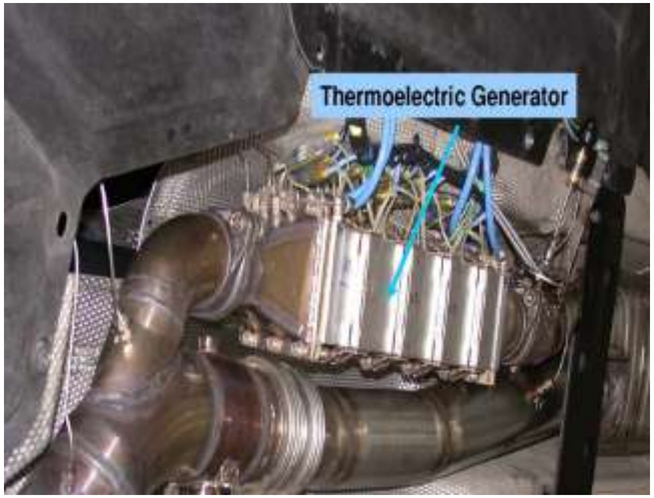
Thermogenerator examples

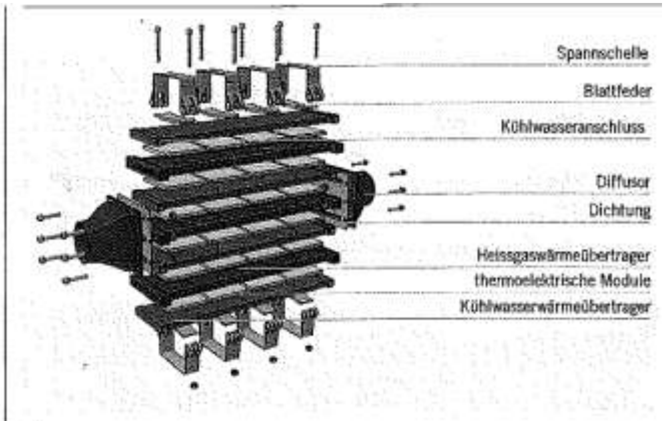


Exhaust gas side (BSST)



Source: GM in DEER09 – also Fairbanks
Possibilities to have different materials in each zone?

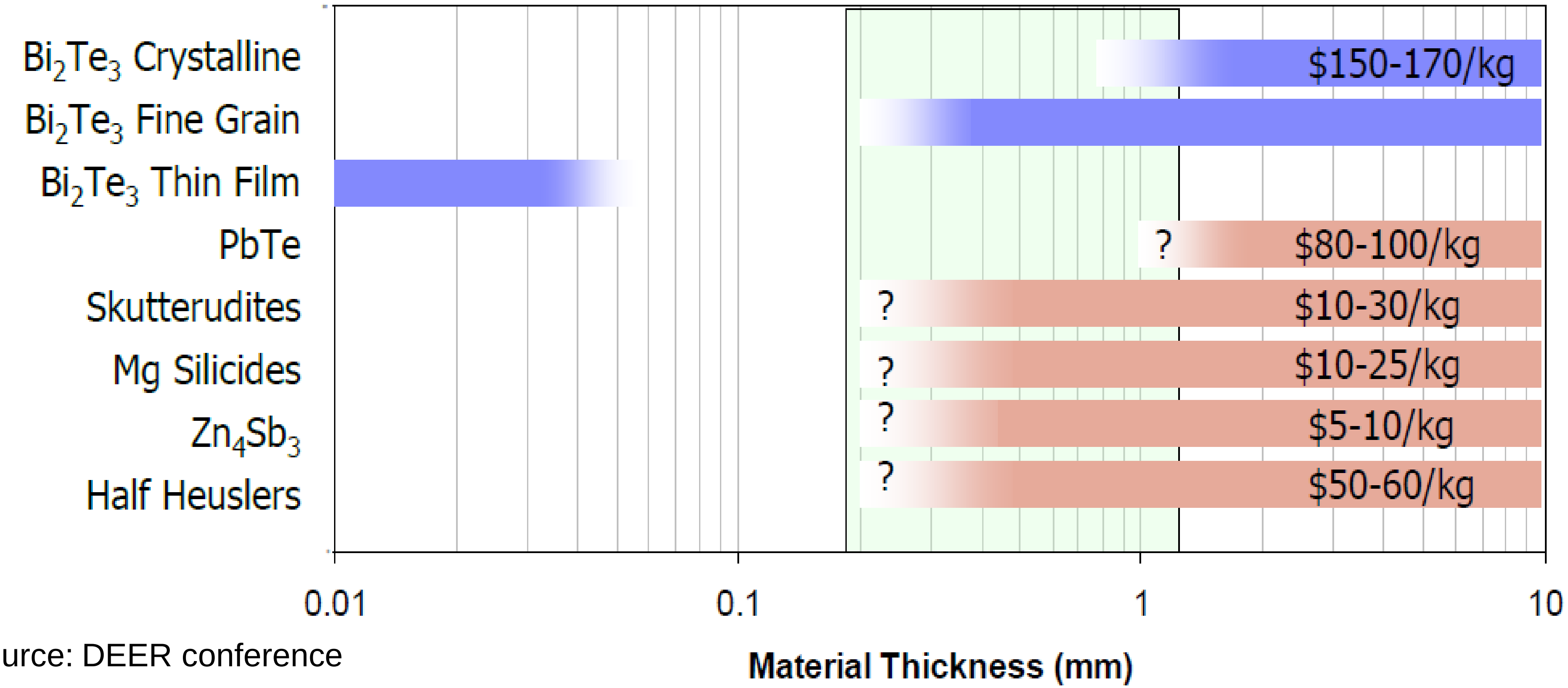




❼ CAD-Explosionsdarstellung eines TEG in Stapelbauweise mit 24 Bi_2Te_3-Modulen [2]

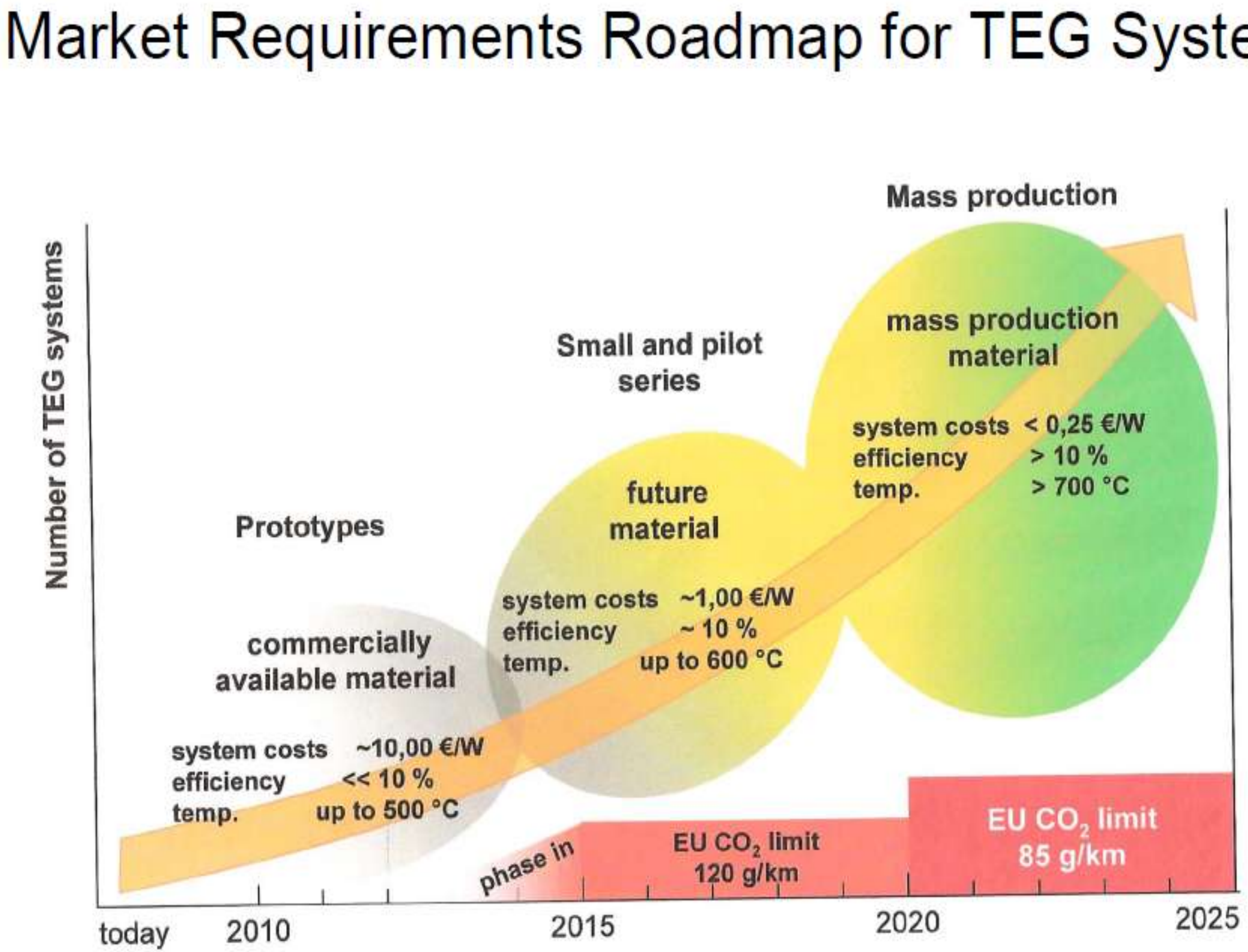
BMW - MTZ

Cost comparison



Source: DEER conference

Roadmap for TEG systems

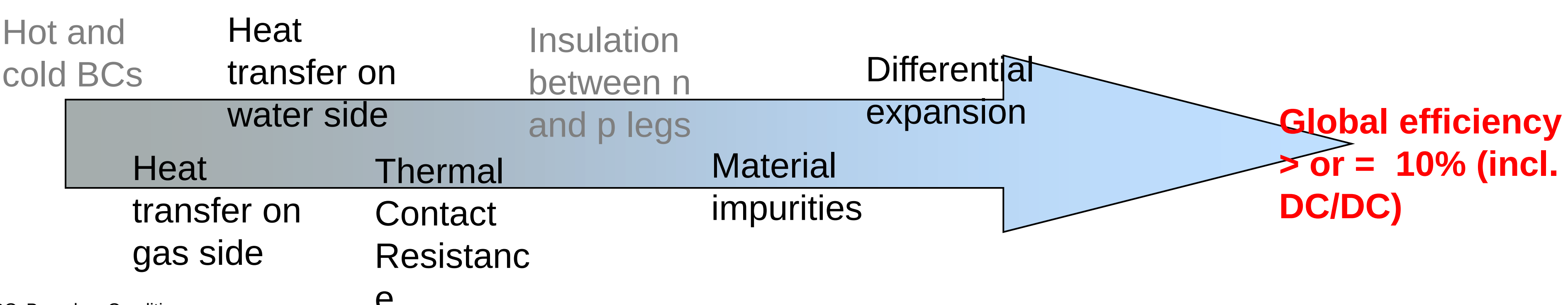


Source: Cardiff University

Project challenges

- Challenges in simulations, specifications, tests, FMEA, risk & hazard analysis with the aim of developing a 10% efficiency thermoelectric generator
- **Thermoelectric components :**
  - Assembly process / High T° brazing and differential expansion
  - Insulation for reducing thermal losses between p and n joints (aerogel) => no issue/risk with Silicides
  - Improvement merit coefficient ZT (now 0.8 – objective 1.5-2) : segmentation for materials for optimising ZT / T°
- Efficient heat transfer on exhaust line without increasing the pressure drop (usually: + 100 mbar on exhaust line => - 1 kW on the engine's shaft)
- Electric production strategies (HW / SW) : electric auxiliaries / strategy / DC/DC – MPP Tracker

Interface risks: control of « global efficiency » (holistic approach)



BC: Boundary Condition

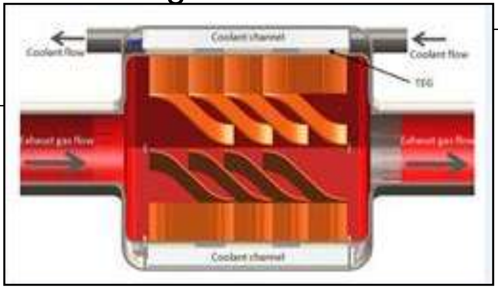
Collaborative research project proposal:

Powerdriver project started March 2012 (target > 300 W for passcar and study on Marine application)

<u>JLR:</u>
Specifications, boundary conditions
<u>JLR (after project):</u>
Install prototype on vehicle and engine's test bed
Tests on vehicle and engine's test bed

<u>Ricardo :</u>
Heat exchanger development
<u>Ricardo:</u>
Tests of thermogenerator on a bench
Simulation (3D CFD, FEA) / tests

Seebeck Thermogenerator



<u>ETL</u>
Build prototype
Supported by Ricardo

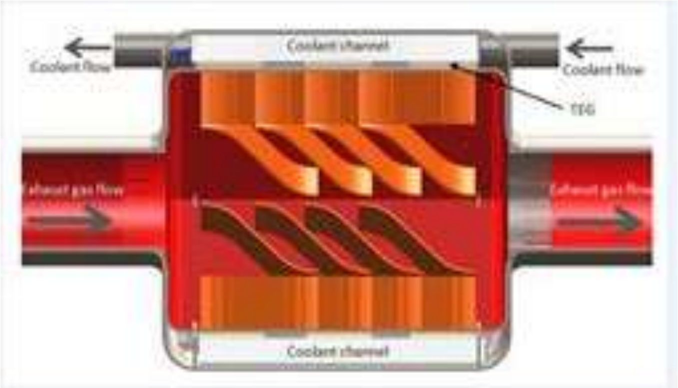
<u>Ben-Gurion, QMUL, Intrinsiq, Tecnalia, FCT:</u>
Supply ThermoElectric materials
Ex: Silicides MnSi, Mg_2Si
(Thermophysical properties, ZT ThermoElectric materials and small prototype tests)

<u>Ricardo</u>
Thermal and electric simulations of Thermogenerator
Fuel consumption assessment

<u>ETL</u>
DC/DC converter

Powerdriver – Press release / website

- Objective: Develop a thermogenerator prototype able to deliver > 300 W on NEDC (passenger car application) and several kW on Marin application, using silicides as thermoelectric materials in order to get competitive cost/benefit ratio
- Website: www.powerdriver.info
- Press release 2013: http://r-world/en-GB/News--Media/Press-releases/News-releases1/2013/PowerDriver-passes-key-milestones-towards-fuel-saving-through-waste-heat-recovery-/



Summary

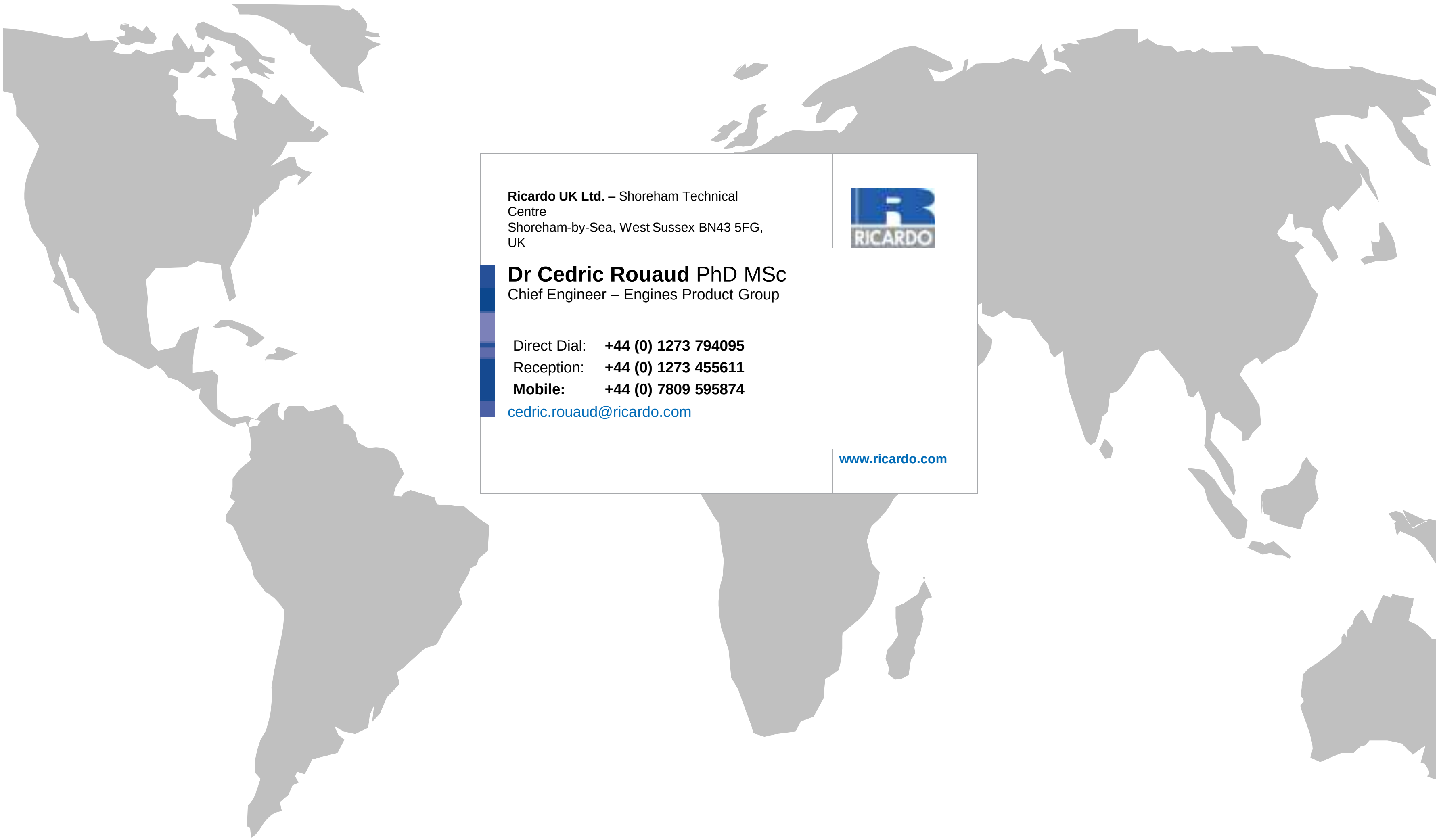
- Several waste heat recovery solutions exist on exhaust line, cooling circuit in order to reduce CO_2 emissions

- The 1st solutions applied on the market are: Exhaust heat recovery for cabin/engine warm-up for passenger cars, mechanical turbocompound for HDD, ORC and e-turbine for gensets
- Solutions such as ORC for HDD and themoelectric generator for passenger cars are under development in order to start production before 2020
- Those solutions present cost/benefit ratios > 30 € / gCO_2/km (< 100 € / gCO_2/km) and may be promoted thanks to “Eco-Innovation” technology label before 2020

- The solutions that will have the label may get a CO_2 emission reduction of up to 7 gCO_2/km – if those solutions can demonstrate a good reduction in fuel consumption during real-life driving operations
- After 2020, Waste Heat Recovery Systems should be more widespread as the share of hybrid electric powertrains will increase – eg leading to a good synergy with electrified powertrain / electric ancillaries (EV mode in urban conditions, HEV mode with WHRS from Internal Combustion Engine on motorways/highways)

Thank you for your attention and questions

Contact details



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