RENAULT TRUCKS

Joint Company
Volvo Group

RENOTER Project

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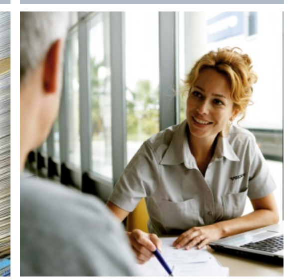
2nd Thermoelectric Applications Workshop: 3-6 January 2011 in San Diego

U.S. DEPARTMENT OF ENERGY

Introduction - Volvo Group

Volvo Trucks	Renault Trucks	Mack Trucks	UD Trucks

Buses	Construction Equipment	Volvo Penta	Volvo Aero	Financial Services



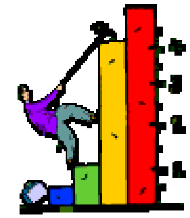
1) Introduction

RENOTER acronym for:

"**R**écupération d'**EN**ergie à l'échappement d'un m**O**teur par **T**h**ER**moélectricité"

- 8 partners including 3 laboratories
- Started Q4/2008 – duration 3 years
- Budget 4.2M€
- Partially funded by French Government
- Supported by French Automotive Clusters

1) Project Goals



Passenger Car

- Diesel : **100W** NEDC - **300W** on customer cycle
- Gasoline : **500W** on customer

Heavy-Duty Truck

- **1kW** on cruise point

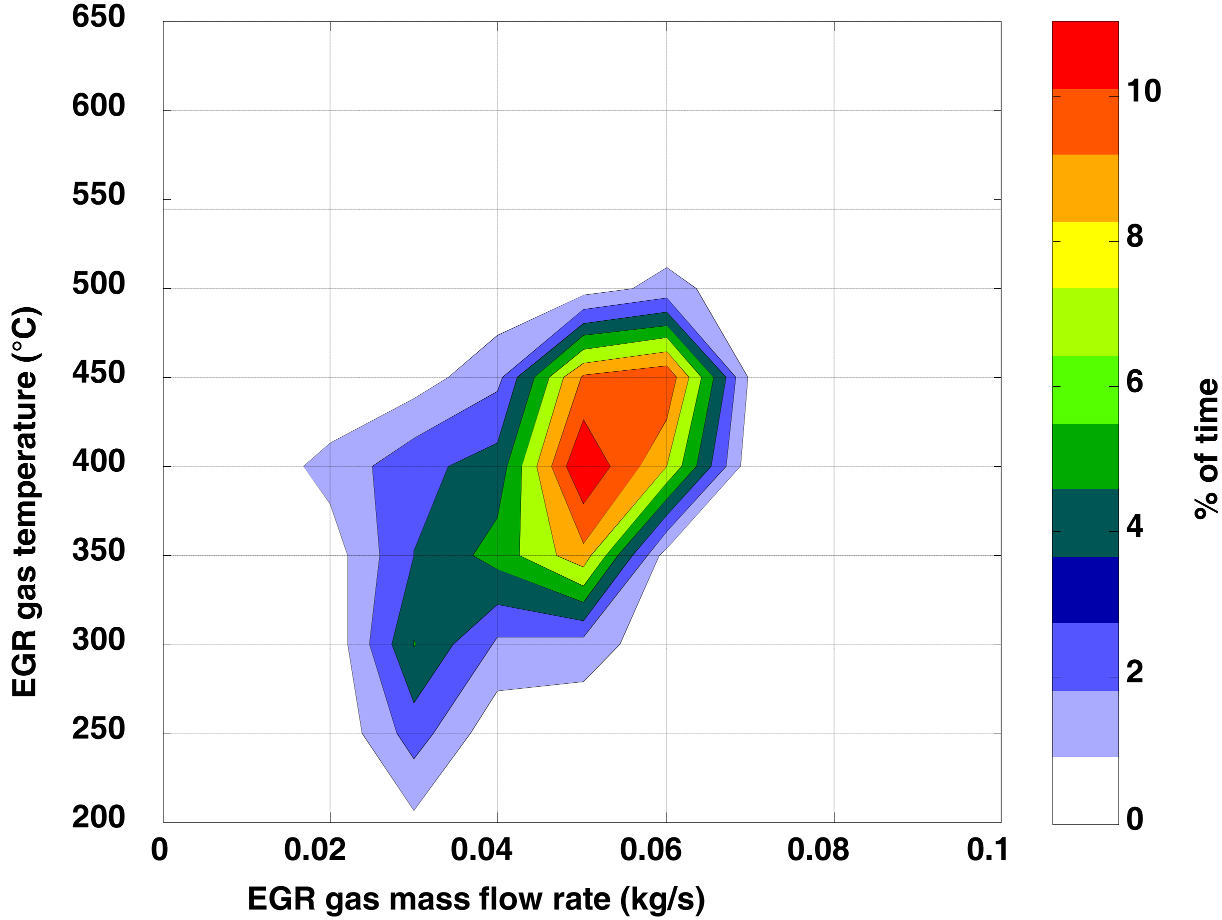
- Focus on **cheap, available**, **efficient**, and **sustainable** TE materials.
- Work on efficient **material integration** and production **process**
- Target cost of 0.3 – 1.3 $\$/W_e$ all included

Heavy-duty truck application

- Renault Trucks Premium model
- 11L engine (460 hp - 1620 lbft)
- Avg. FE = 6.8 mpg*
- Exhaust Gas Recirculation Cooler selected as heat source

** =32M/100km - for the duty cycle of the project*

1) EGR specifications



Avg. T° ~400°C – Avg. Q ~45g/s

Passenger car application

- Laguna III model
- 2.0L dCi engine (150hp – 250lbft) Euro5
- FE = 45 mpg
- Exhaust line chosen as heat source (EGR flow ~0 at full load)

** On Mix NEDC*

Available exhaust energy

Specifications for diesel engine			
	Avg. Temperature	Avg. flow	TEG Power (Target)
NEDC	165 °C	12 g/s	100 W
Constant speed 100 km/h	**328 °C**	**25 g/s**	**300 W**
Constant speed 120 km/h	398 °C	53 g/s	500 W

3) Materials

- Many TE materials available
- Project specification includes performance, cost, working temperature, manufacturing…

⇒

Best ZT @ 200 - 400°C

Peak Temperature ~500-600°C

Sustainable and low-cost materials

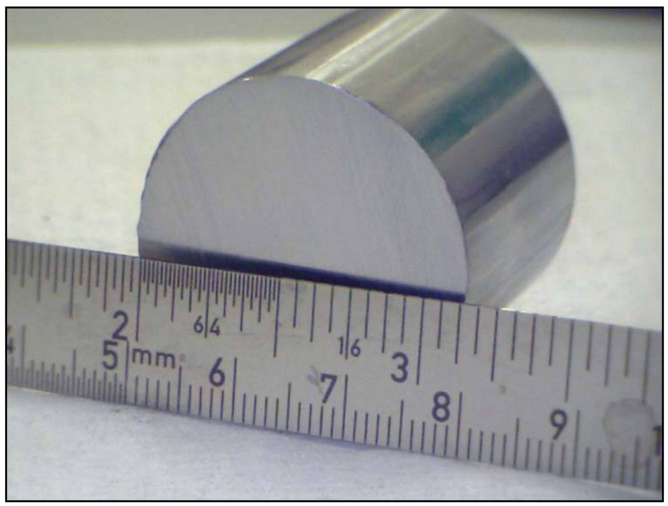
3) Materials

TE Material State-of-art	N-type	P-Type	ZT 200°C	ZT 400°C	OK for 600°C Max Temperature	Est. € per dm^3
Bi_2Te_3	✓	✓	1	-	NO (250°C)	800-900
PbTe	✓	✓	0.75	1.0	YES (600°C)*	700
LAST *(Ag-Pb-Sb-Te)*	✓	✓	0.8	1.4		500-800
TAGS *(Te-Ag-Ge-Sb)*	-	✓	0.7	1.2		
Zn_4Sb_3	-	✓	0.7	1.2	NO (400°C)	25
Mg_2Si	✓	~	0.3	0.8	YES (600°C)	80-450
HMS	-	✓	0.4	0.6	YES (800°C)	150
Skutterudites *(CoSb)*	✓	✓	0.5	0.7	YES (700°C)	300-450
SiGe-nanostructured	✓	✓	0.2	0.4	YES (1200°C)	2900
Clathrates (GaGe)	✓	✓	0.2	0.7	YES (>1000°C)	3000

*(*encapsulated)*

3) Low temperature material: Bi_2Te_3

- Material worked by Nancy University
- Doping both types (p-n) for automotive application + up-scaling process



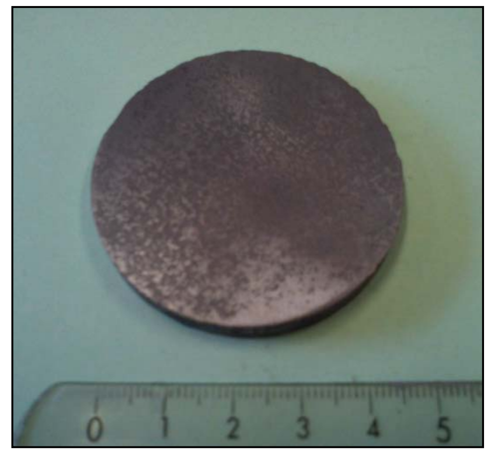
Bi_2Te_3 after Hot Pressing (Ø30mm)

3) High temperature materials

- HMS and Mg_2Si worked by Montpellier University
- Good results so far for HMS p-type

HMS Ø8mm

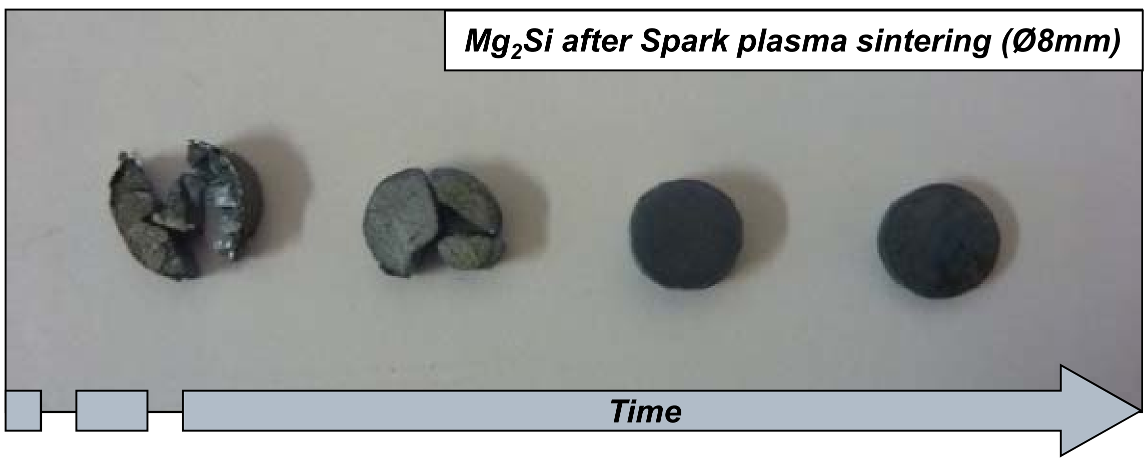
HMS Ø20mm



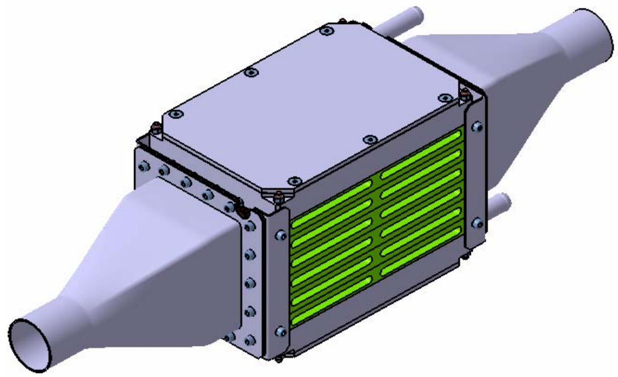
HMS Ø40mm

3) High temperature materials

- Consistent n-type samples obtained but up-scaling difficult
- Replacement of **Germanium** dopant by cheaper one ongoing
- Work on p-type



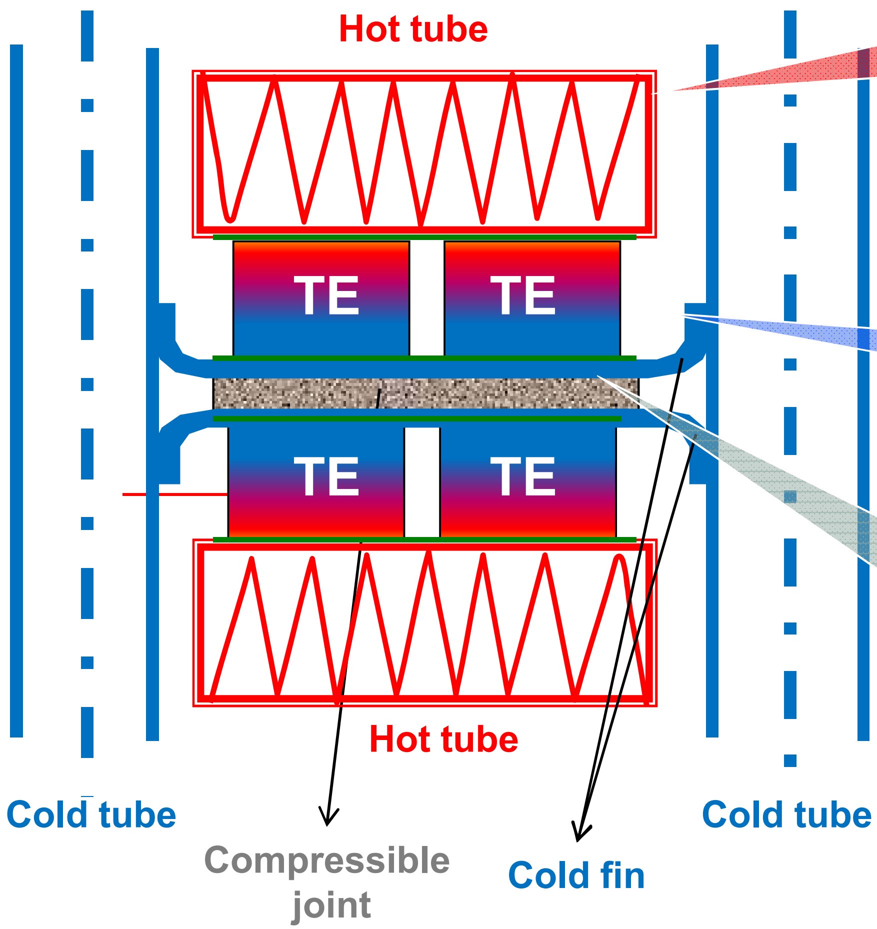
4) TEG design



REQ.

- Good **thermal efficiency**
- Low **backpressure**
- Ensure **reliability** through thermal & mechanical stress control
- Ease of **manufacturing**

4) Novel TEG design



To reach a good heat transfer between hot gas and TE face:

- Rectangular tubes in stainless steel with turbulator inside
- Direct contact TE & hot tube

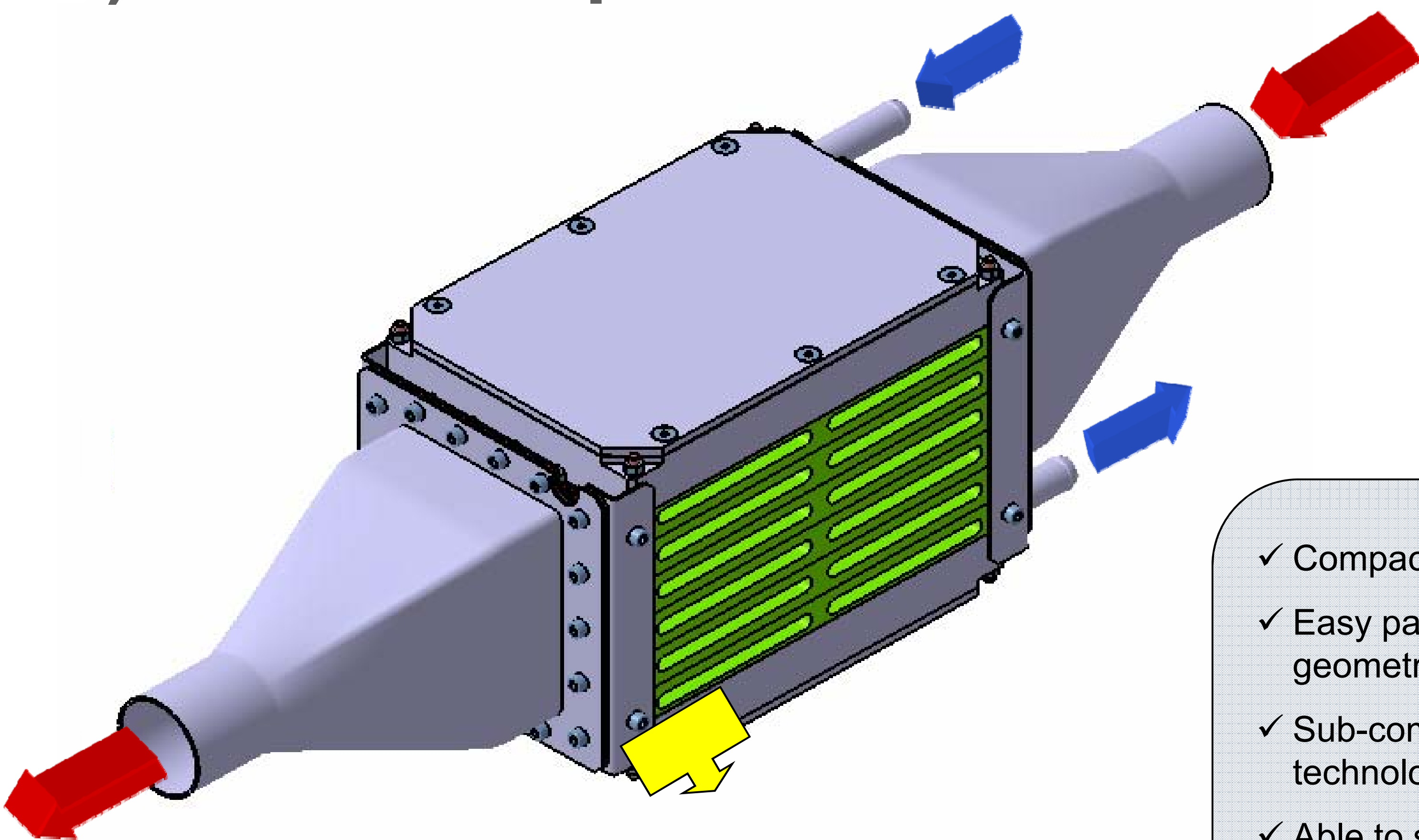
To minimize heat exchanger structure and weight

- Indirect contact TE and cold tube through a fin
- Cold tubes in aluminum for 2 functions: heat sink and tie rod

To be reliable vs. Thermal and Mechanical stress

- In- between fin, compressible material to absorb TEG internal constraint
- Electrical insulation layer between TE / Hot Tubes, TE / Cold fins

4) TEG description

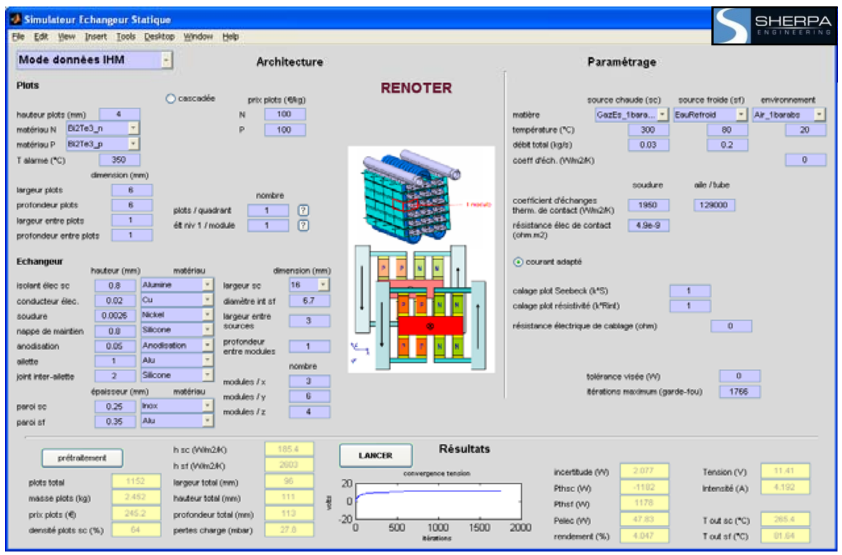


- ✓ Compact + light weight
- ✓ Easy packaging (flexible geometry)
- ✓ Sub-components technologies validated
- ✓ Able to support any type of TE material + resists to high T°

5) Simulation and testing

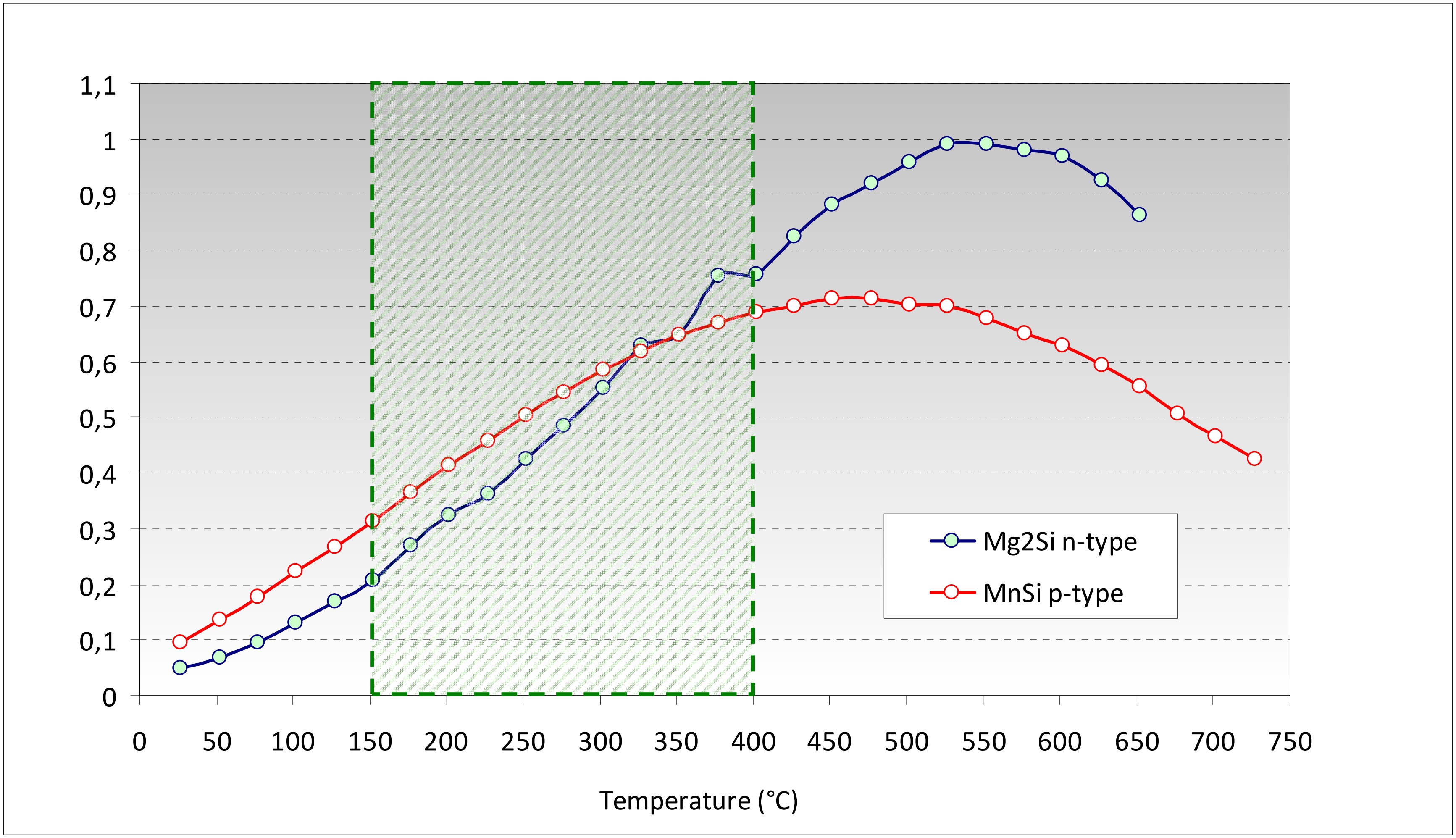
- 7000 legs of Mg_2Si and HMS (4mm x 6mm x 6mm)
- Brazing propertied of Bi_2Te_3 modules
- Heat exchanger data from bench characterization

- *1kW*
- *10kg*
- *7L*

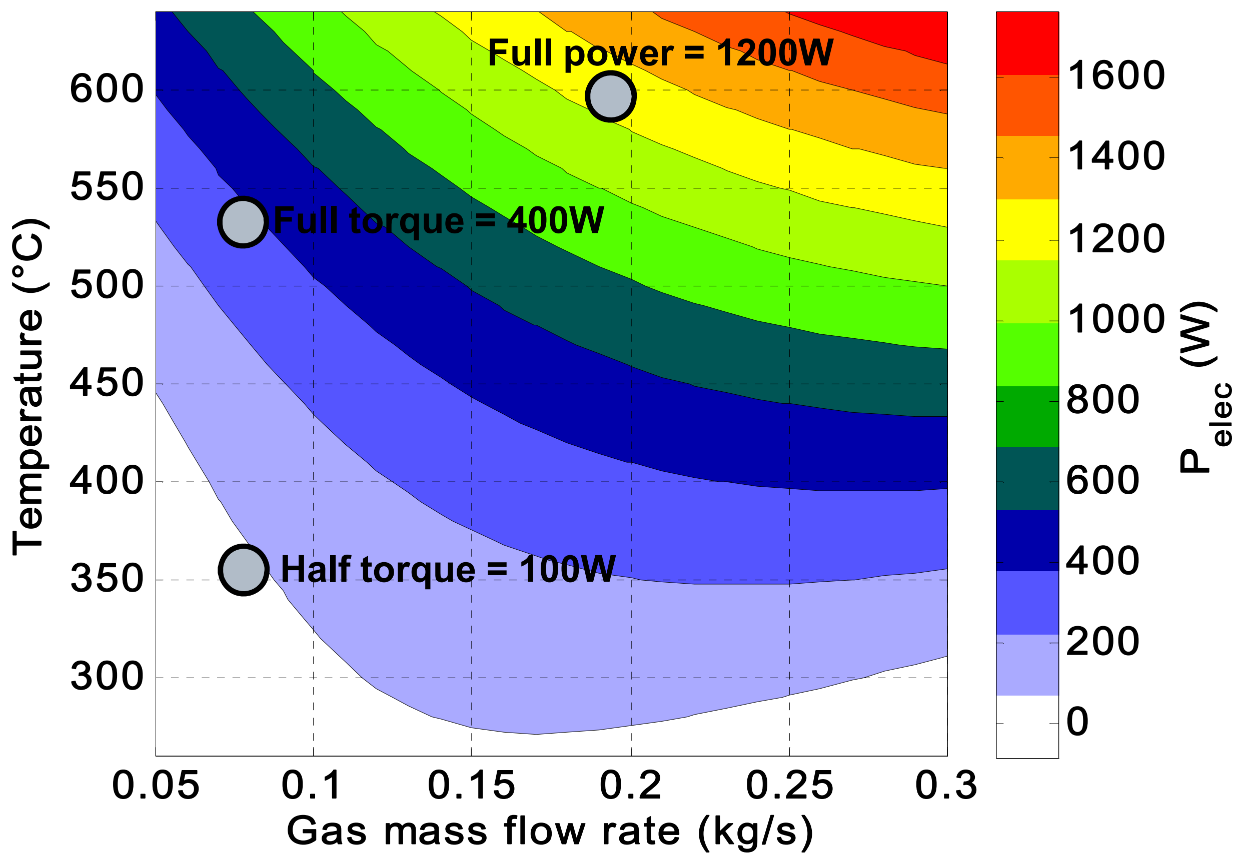


Sherpa Engineering simulation software

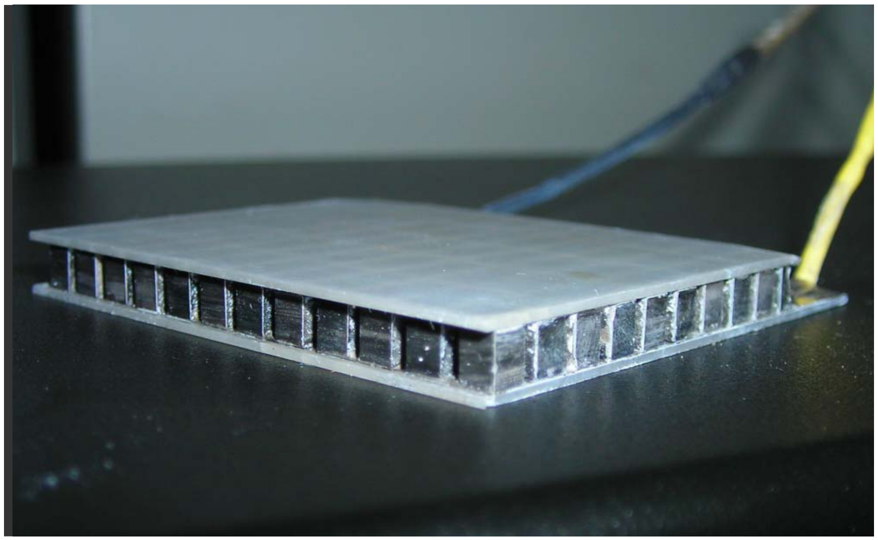
ZT values used for simulation coming from LPM Nancy



Simulation outputs (Truck EGR)



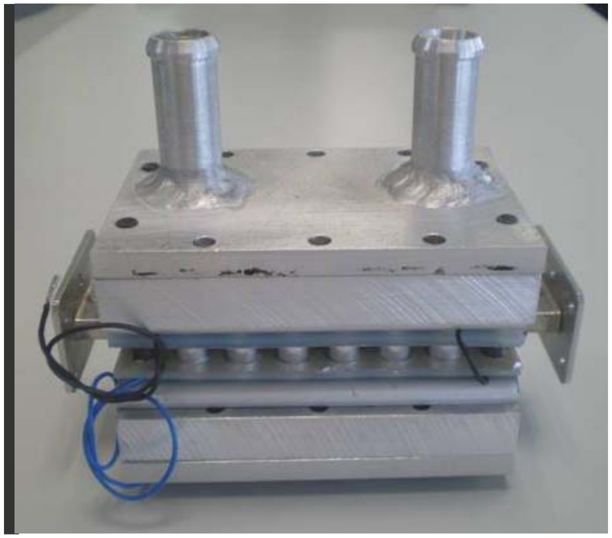
Module testing



120 plots Bi_2Te_3 module built at CRISMAT-CNRT

- Similar performance as literature and commercial modules
- Used to determine thermal and electrical contact resistances
- High temperature + small TEG under work

Module testing

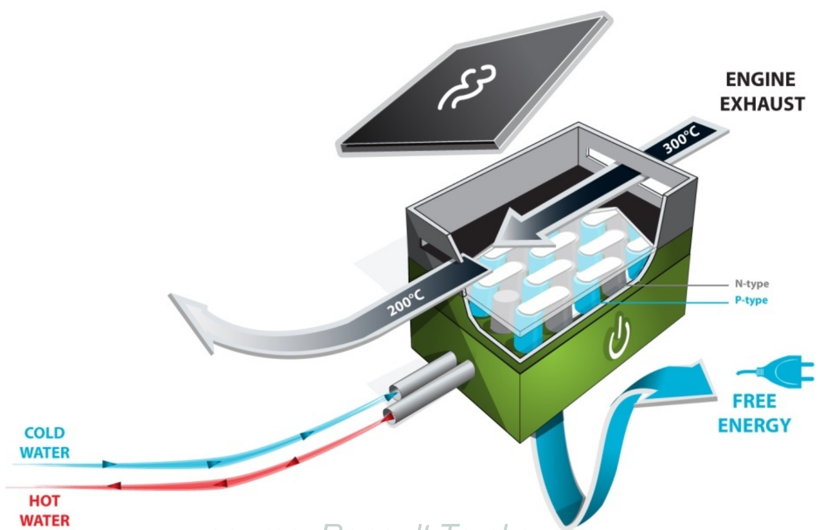


Heat exchanger portion

- Thermoelectrical performances under verification
- Will validate TEG concept and interfaces (brazings, barriers…)

6) Conclusions

- **Non-toxic** and **non-costly** materials (Te and Pb alternatives)
- **Simulation** software tuned with real module tests
- New efficient **TEG design** allowing screening of any novel materials
- 1kW (trucks) and 300W (cars) targets **achievable during this year**
- Mass market application in sight but will **take time** (cost vs. efficiency)



source: Renault Trucks

Acknowledgments

RENOTER project team

DGIS (*Direction Générale de la Compétitivité, de l'Industrie et des Services*)

Région Basse-Normandie