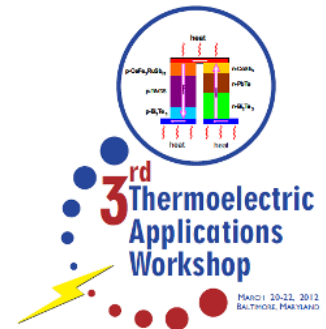


**RENAULT  
TRUCKS**

Joint Company  
**Volvo Group**

## RENOTER Project

3<sup>rd</sup> Thermoelectric Applications Workshop: 20-22 March 2012 in Baltimore (MI)



# Introduction - Volvo Group

Volvo Trucks

Renault Trucks

Mack Trucks

UD Trucks



Buses

Construction Equipment

Volvo Penta

Volvo Aero

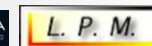
Financial Services



Renault Trucks Joint Company - Volvo Group

RENTER project presentation

2 Luc Aixala (March 20th 2012)



# 1) Introduction

RENTER acronym for:

“Récupération d’ENergie à l’échappement d’un mOteur par ThERmoélectricité”

- 8 partners (and 3 laboratories)
- Q4-2008 to Q2-2012
- 4M€ project
- Partially funded by French Government



*mov'eo*  
French Automotive Cluster

LYON  
URBAN  
TRUCK  
& BUS

# 1) Project Goals



- Diesel : **100We** NEDC and **300We** customer cycle
- Gasoline : **500We** on customer duty cycle



- **1kWe** on cruise point (50% load)

- Focus on **cheap, efficient, and sustainable** TE materials
- Work on **material integration** and scaling-up **process**
- Target cost is 0.3 – 1.3  $\$/W_e$  (all included)

## 2) Targeted applications



- 2.0L diesel passenger car (150hp)
- FE = 45 mpg
- Exhaust line chosen as heat source (330°C – 25g/s)\*



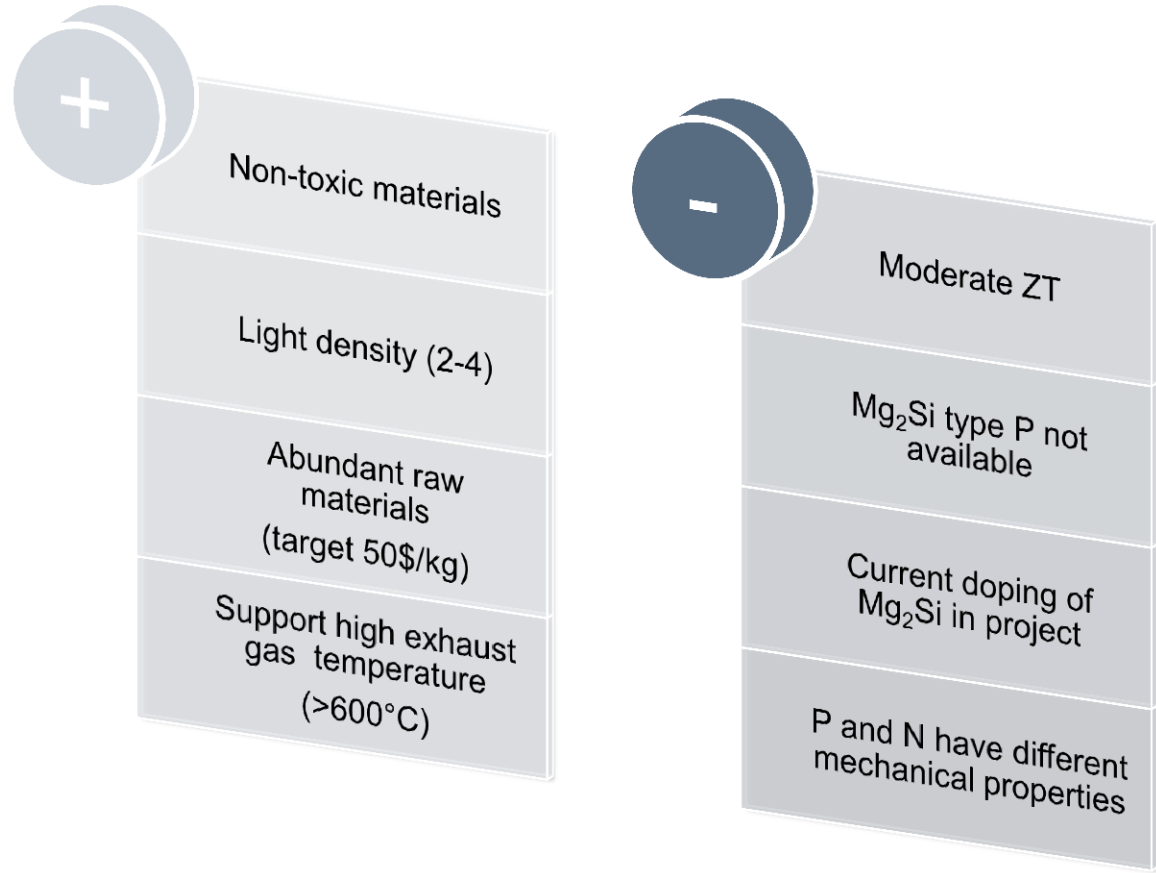
- Heavy duty truck with 11L displacement engine (460hp)
- FE = 6.8 mpg
- EGR Cooler selected as heat source (400°C – 70g/s)

\*EGR flow ~0 at full load

### 3) Material development

Choice of **Silicide's** (made by hot pressing)

- N-type :  $Mg_2Si$
- P-type :  $MnSi_{1.77}$



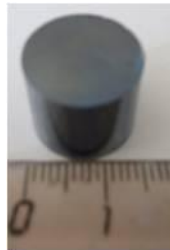
### 3) Materials development

Iterative process of scaling-up in order to maintain ZT value

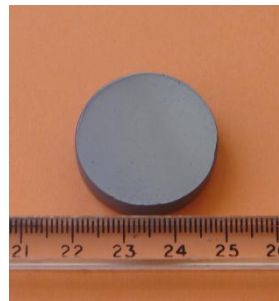
(MEB analysis and properties measurement)



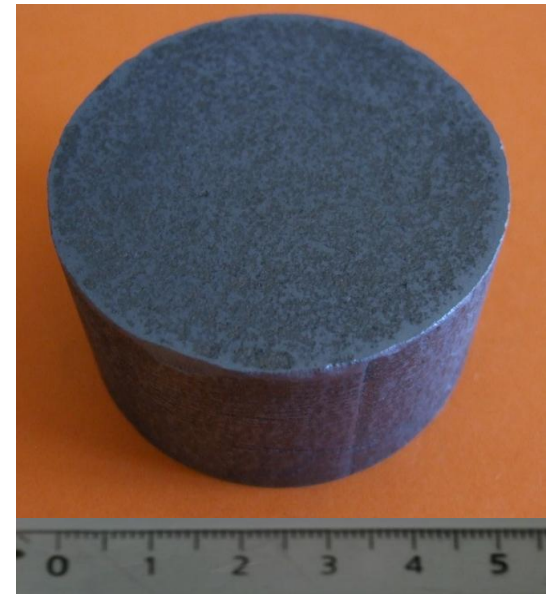
Ø8mm



Ø15mm

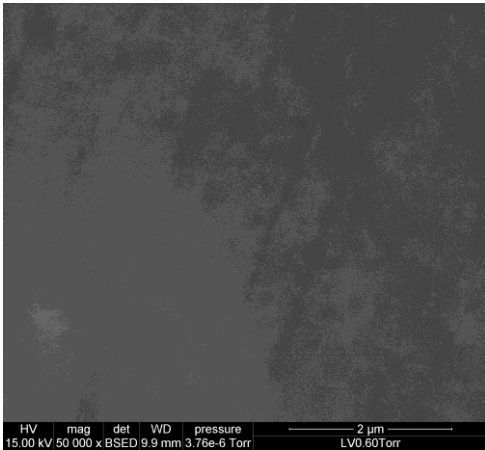
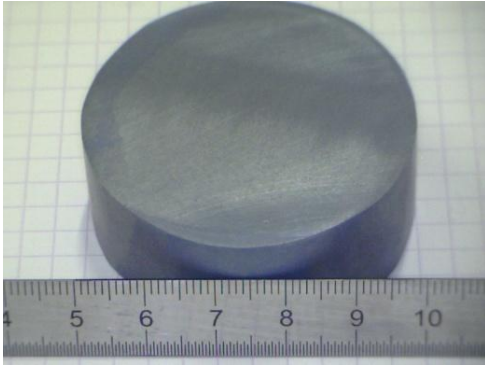


Ø30mm

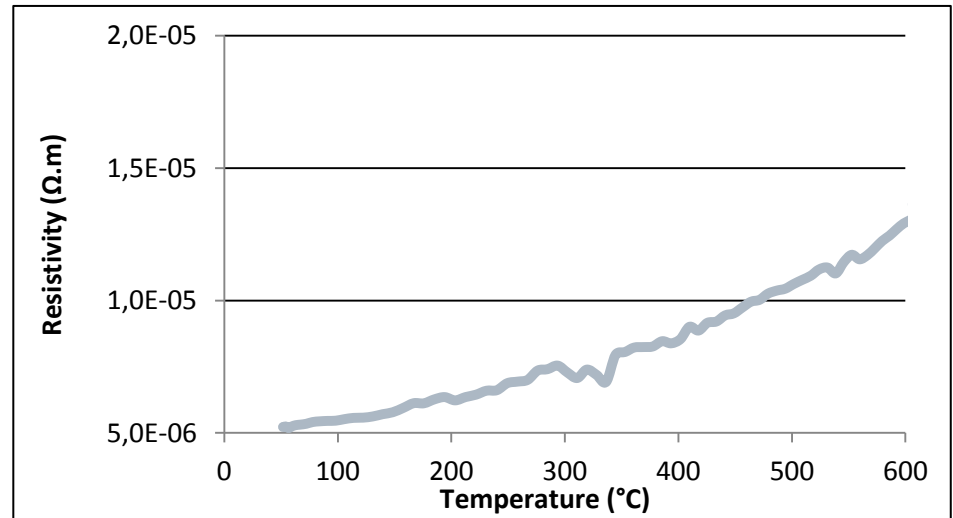
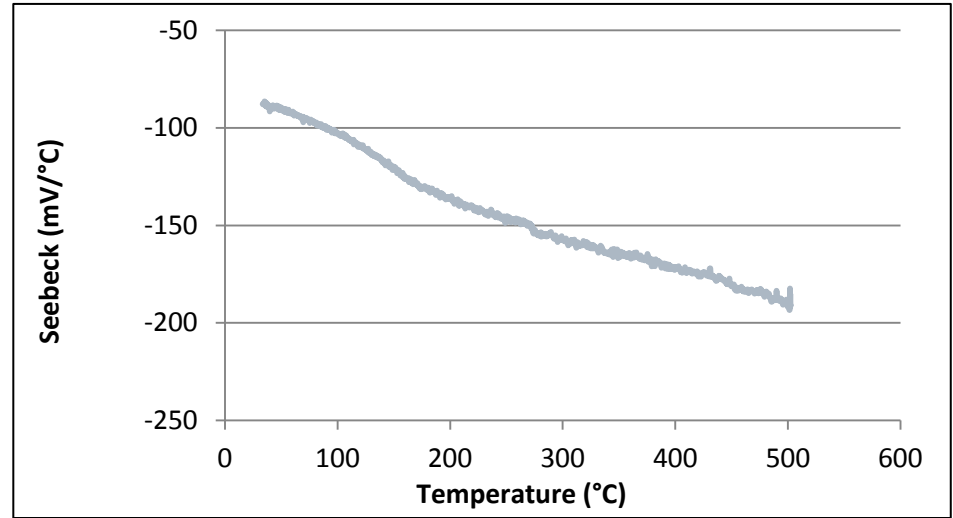


Ø50mm

# 3) Materials development



Homogeneous samples



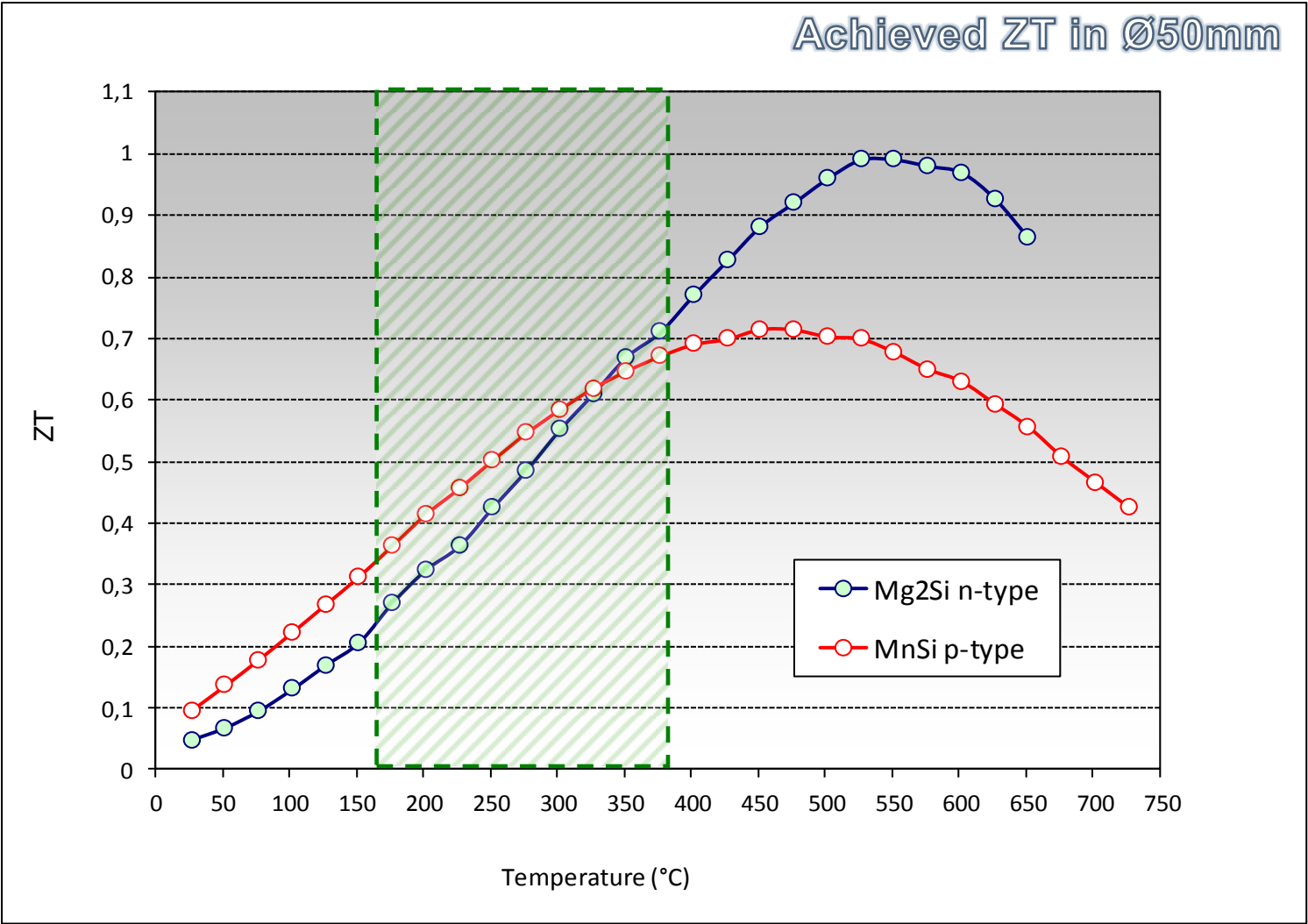


### 3) Materials development

Successful lab. production of the legs for the project prototype (>1500)

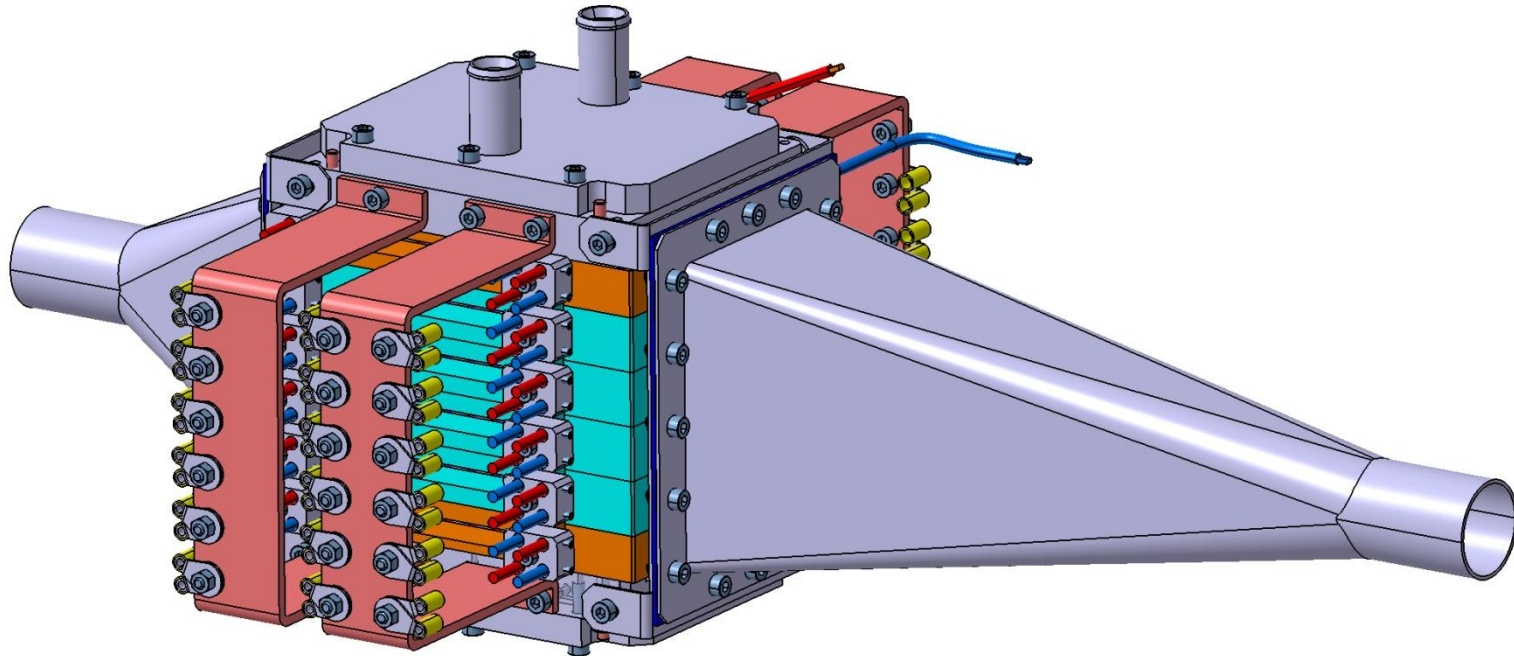


# 3) Materials development

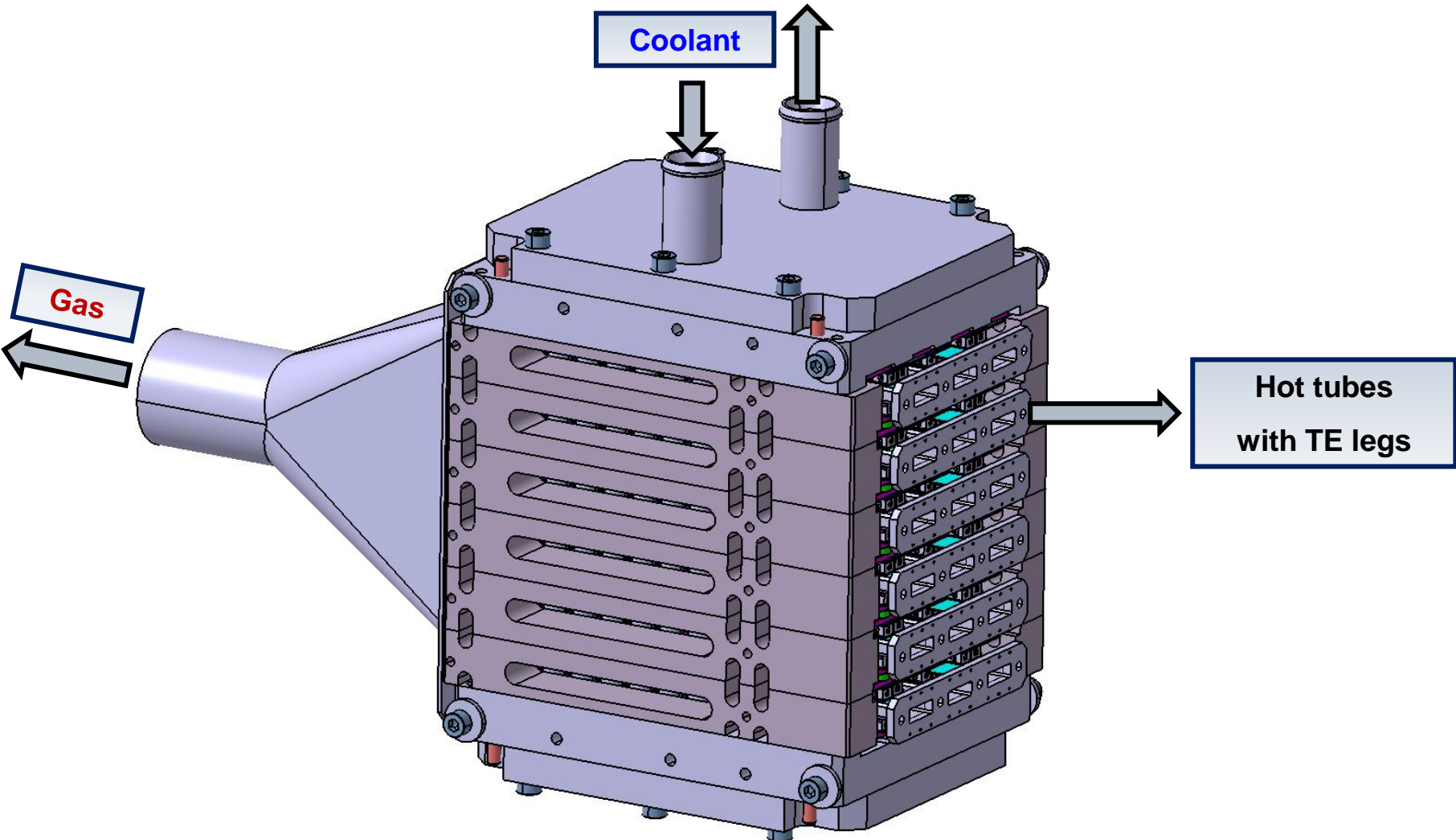


## 4) Integration in heat exchanger

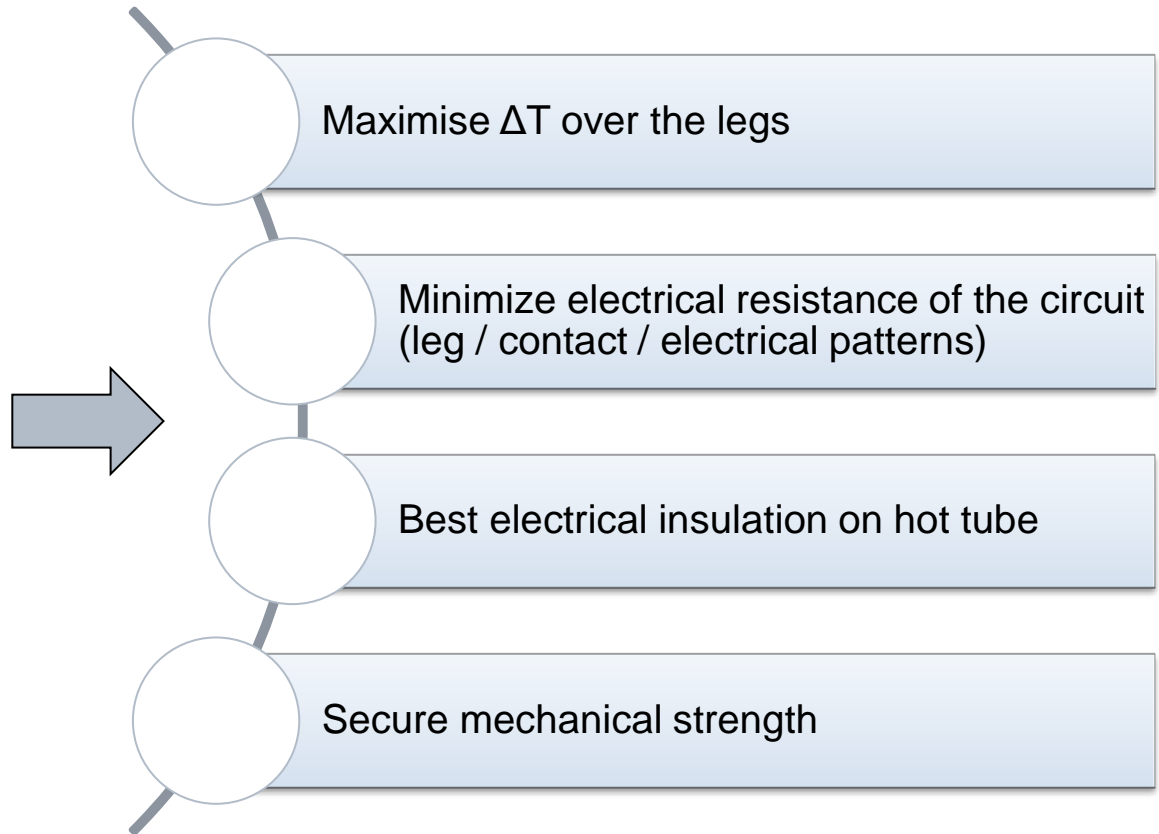
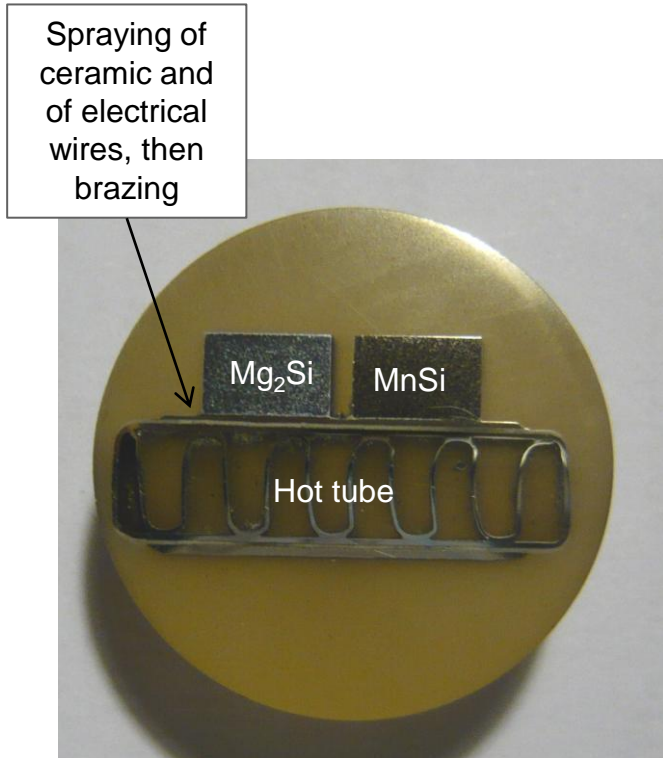
- Novel heat exchanger design already presented ([2010 Workshop](#))
- Multi-layer hot tube integrating e-circuit (i.e. TE legs directly on the hot tube) to combine functions



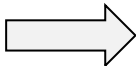
# 4) Integration in heat exchanger

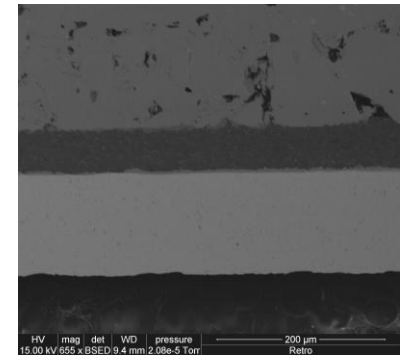
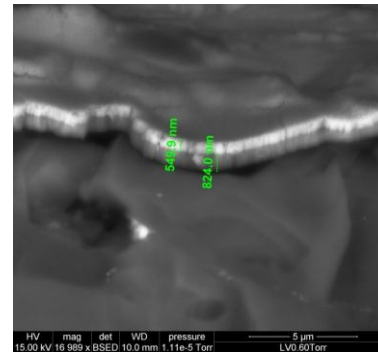
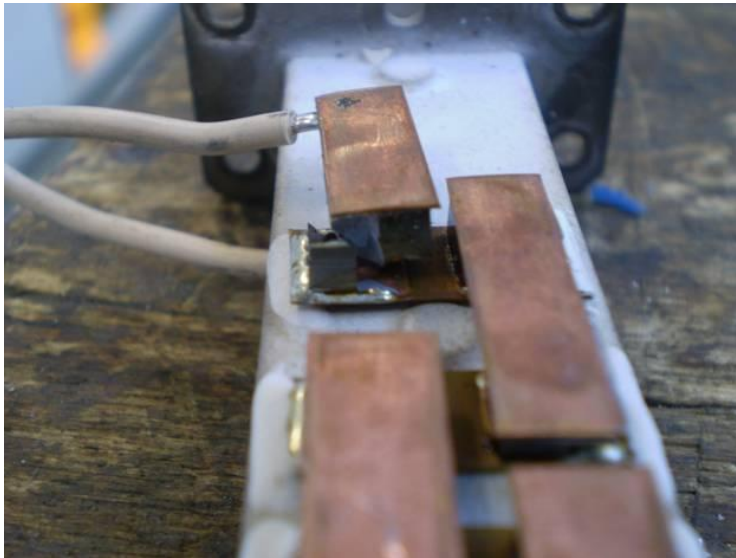


## 4) Integration in heat exchanger



## 4) Integration in heat exchanger

- “One shot” brazing of P&N legs onto hot tubes
- Extended multi skill step-by-step team work to address successfully all technical issues
- Achievements  No legs failures, and  $R_{\text{brazing}} < 20\%$  of  $R_{\text{legs}}$



Typical  $R_{\text{leg}}=1.3-1.7\text{m}\Omega$

# 5) Simulation and testing

Mock-up sizing for feasibility test based on car application

**Simulateur Echangeur Statique (5.4)**

Mode données IHM

**Architecture**

**Paramétrage**

08-Mar-2012

**Plots**

hauteur plots (mm) 4  
matériau N Mg2Si\_n  
matériau P MnSi\_p  
T alarme (°C) 500

dimension (mm)  
largeur plots 6  
profondeur plots 6  
largeur entre plots 1  
profondeur entre plots 2

prix plots (€/kg)  
N 100  
P 100

nombre  
plots / quadrant 1

**Echangeur**

hauteur (mm) matériau dimension (mm)  
isolant élec sc 0.08 Alumine hauteur sc 5  
pistes chaudes 0.015 Nickel largeur sc 16  
pistes froides 0.02 Cu diamètre int sf 6.7  
soudure 0.0026 Nickel largeur entre sources 3  
nappe de maintien 0.8 Silicone profondeur entre modules 1  
anodisation 0.05 Anodisation modules / x 3  
aillette 1 Alu modules / y 6  
joint inter-aillette 2 Silicone nb rangées de plots par tube sc 19

épaisseur (mm) matériau  
paroi sc 0.25 Inox  
paroi sf 0.35 Alu

**Paramétrage**

source chaude (sc) source froide (sf) environnement  
matière Air\_1p2barabs EauRefrroid Air\_1barabs  
température (°C) 450 60 20  
débit total (kg/s) 0.02 0.3  
coeff d'éch. (W/m2K)

coefficient d'échanges therm. de contact (W/m2K)  
soudure contact sec aile / tube  
3000 5000 200000

résistance élec de contact (ohm.m²)  
4.9e-9

calage plot Seebeck (K°S) 1  
calage plot résistivité (K°Rint) 1

résistance électrique de câblage (ohm) 0

tolérance visée (W) 0  
itérations maximum (garde-fou) 2000

**Résultats**

prétraitement

débit sc / tube (kg/s)	0.0011	h sc (W/m2K)	192.5
débit sf / tube (kg/s)	0.021429	h sf (W/m2K)	2773
plots total	1368	largeur total (mm)	97
masse plots (kg)	0.7486	hauteur total (mm)	109
prix plots (€)	74.86	profondeur total (mm)	148
densité plots sc (%)	56		

**Posttraitement**

incertitude (W)	-	rendement (%)	-
T out sc (°C)	-	Pthsc (W)	-
T out sf (°C)	-	Pthsf (W)	-
Tension (V)	-	Pelec (W)	-
delta p (mbar)	-	Intensité (A)	-
		R (Ohm)	-

**1368 legs**

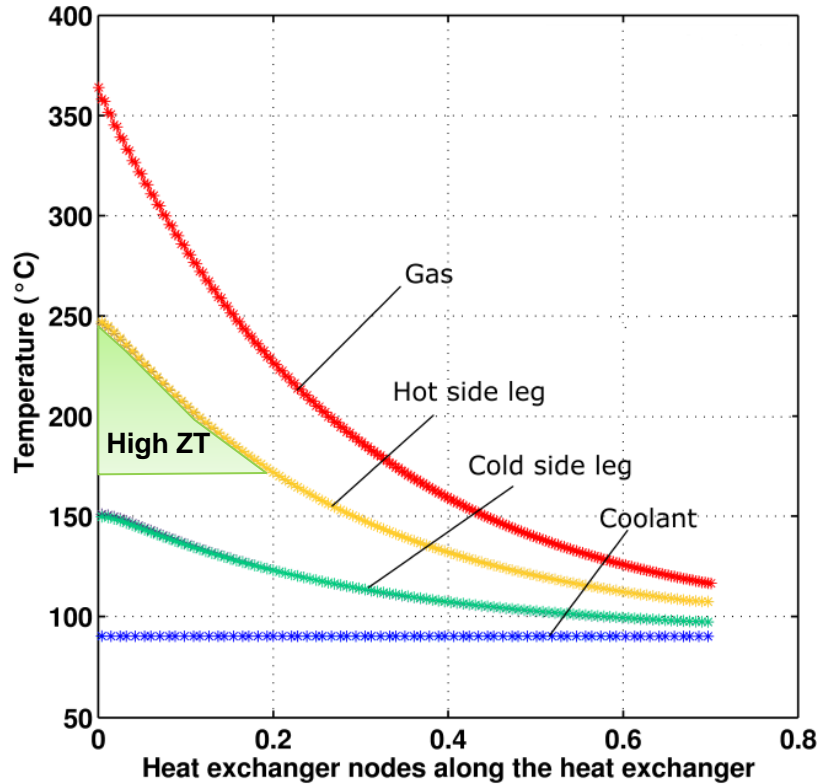
**1 kg of materials**

**3 L of volume**

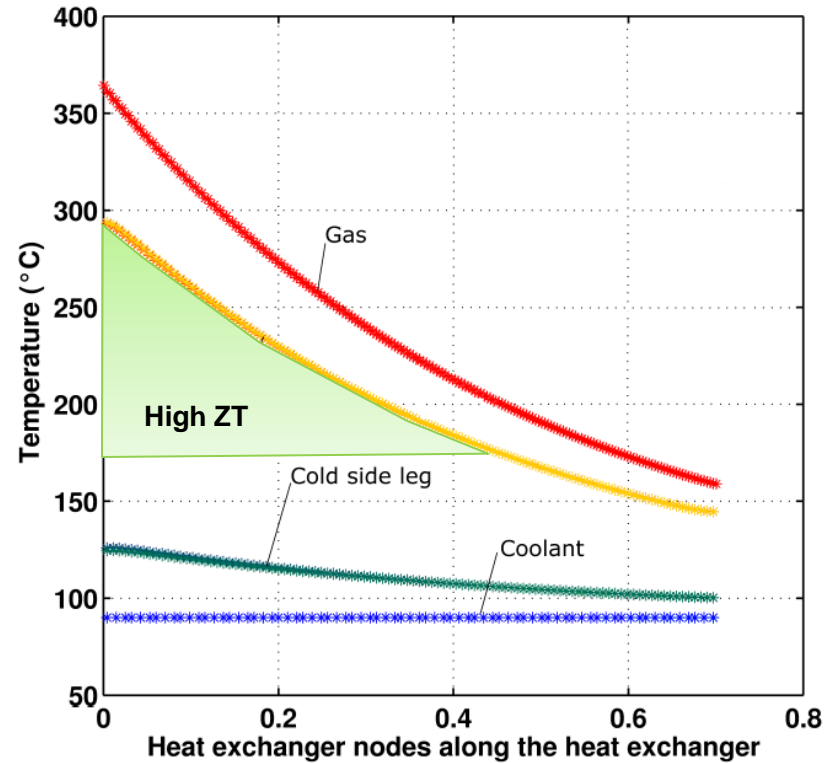
**500°C**

**250 We**

# 5) Simulation and testing



(a)

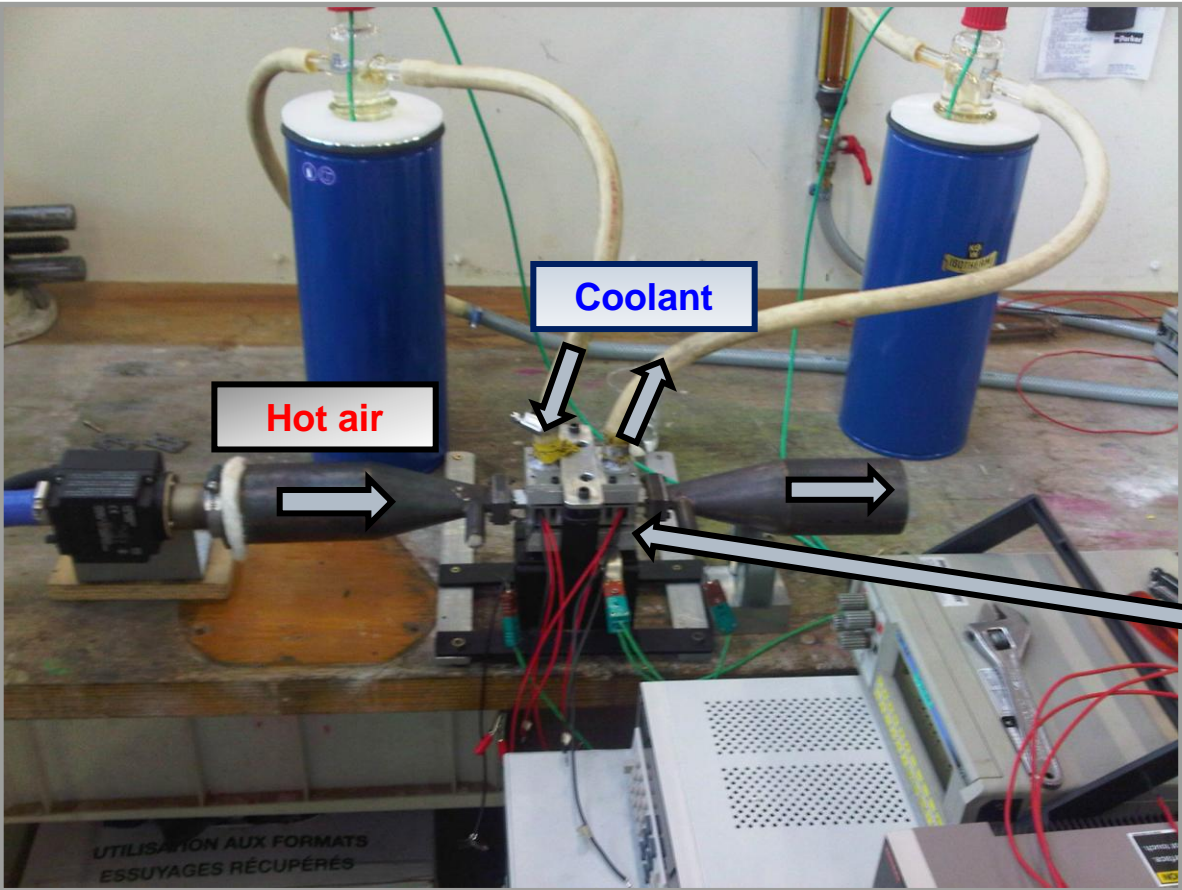


(b)

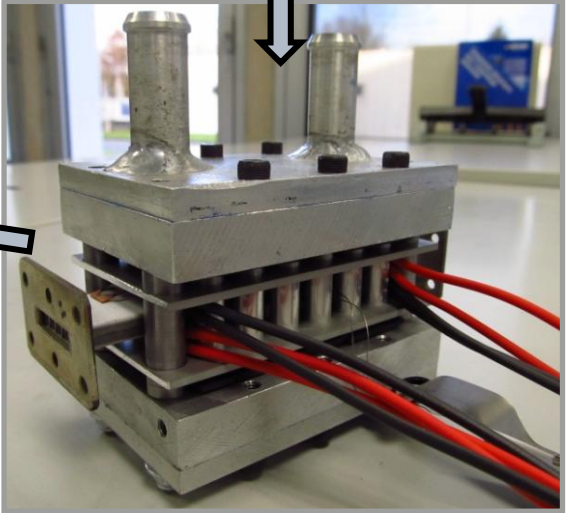
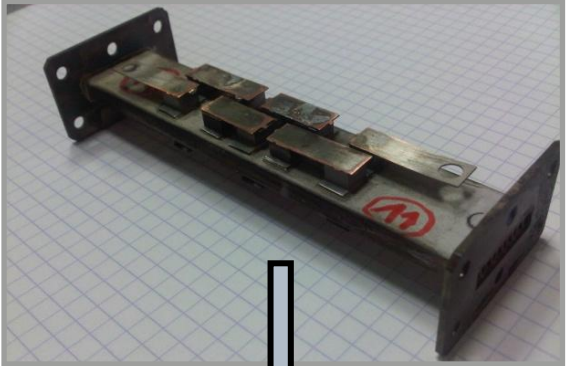
*Effect of plots high (4mm vs. 12mm) on temperatures distribution*



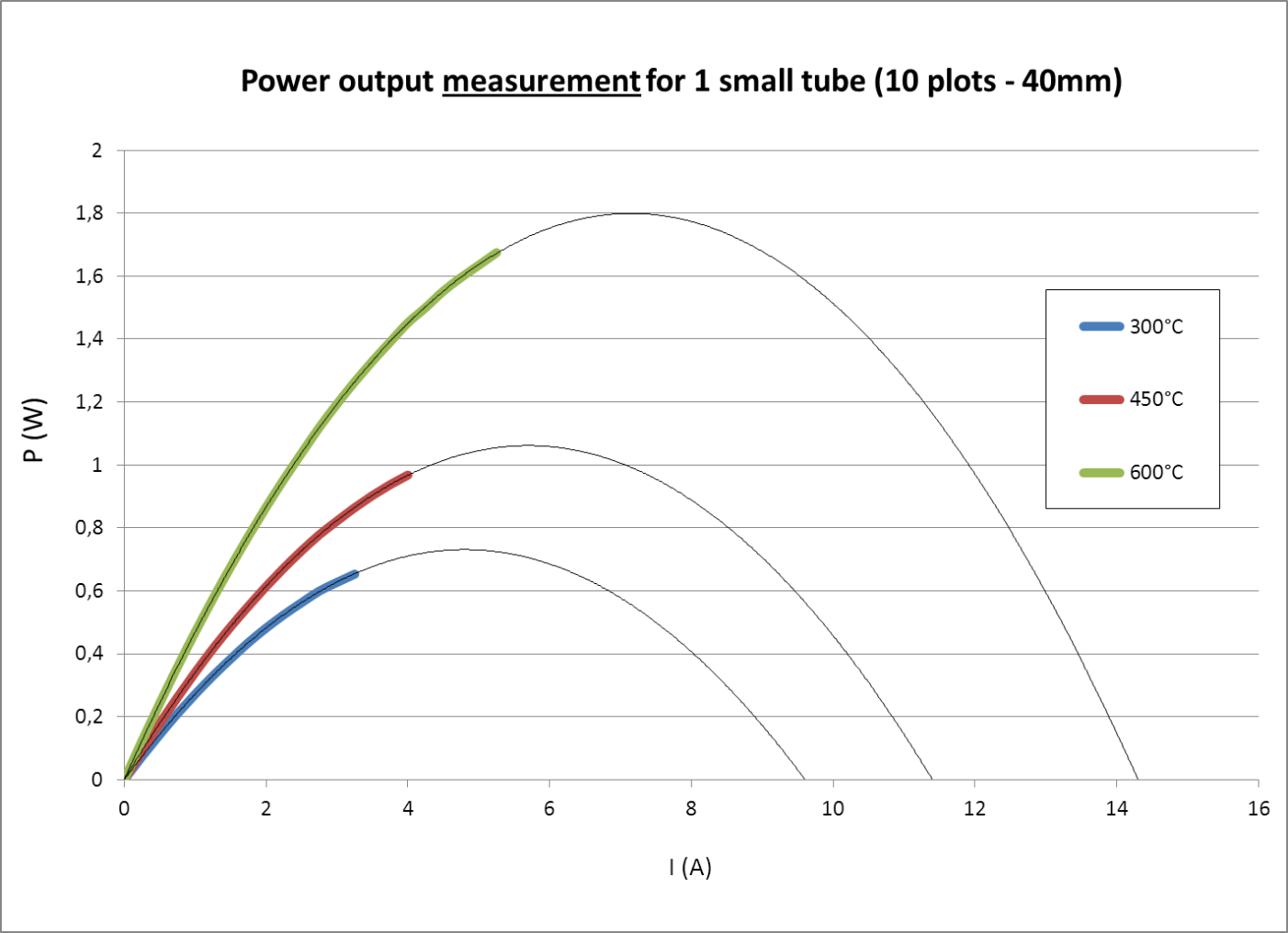
# 5) Simulation and testing



1 small tube (10 legs)

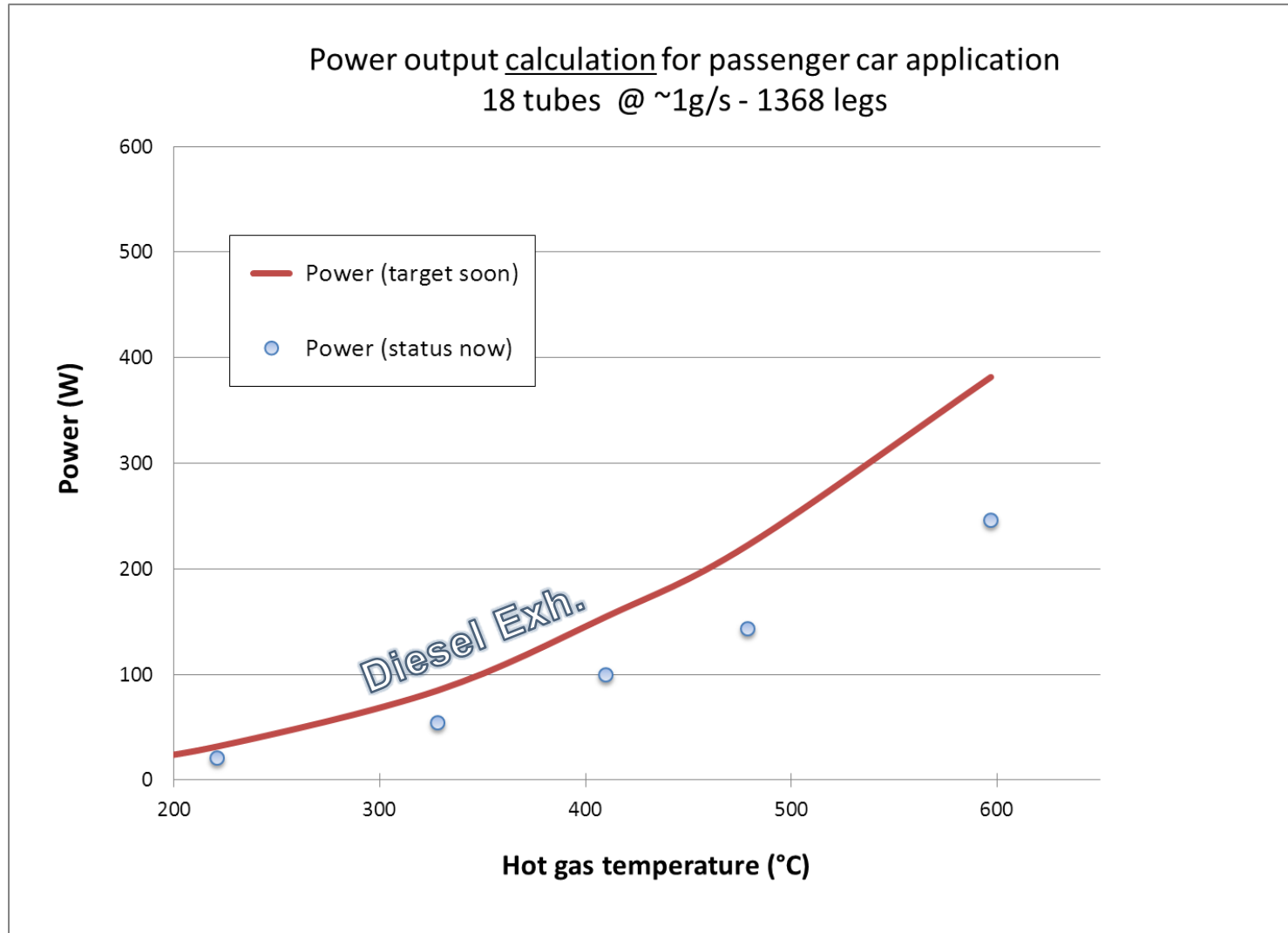


# 5) Simulation and testing

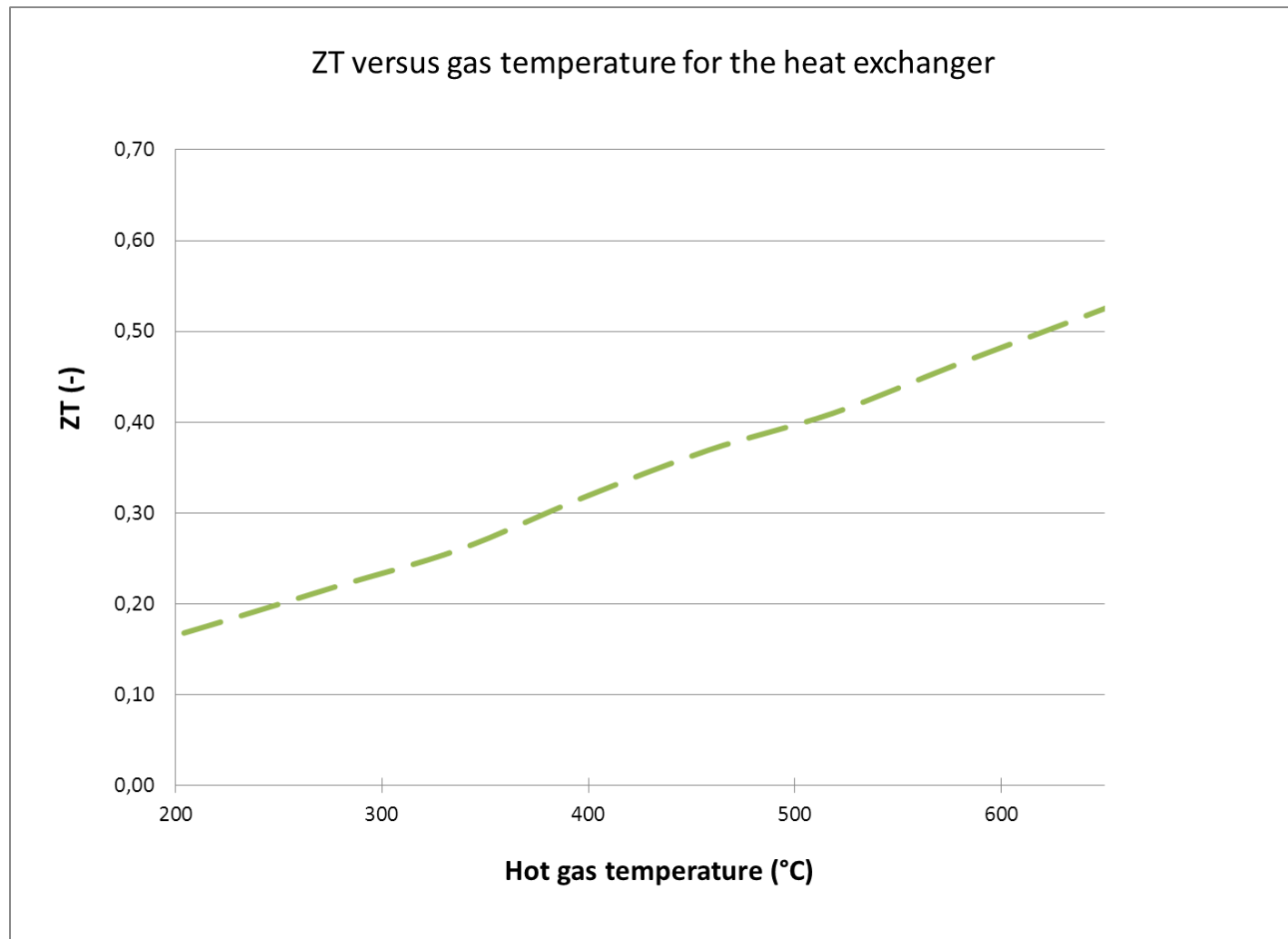


*Note:  $U_0(600^\circ\text{C})=580\text{mV}$*

# 5) Simulation and testing $\Delta P < 30\text{mbar}$



# 5) Simulation and testing



## 5) Simulation and testing



- Diesel : **50We-100We** NEDC, **80We-160We** on customer cycle
- Gasoline: **250We-500We** on customer cycle



- **400We-800We** on cruise point (50% load)

## 6) Conclusions

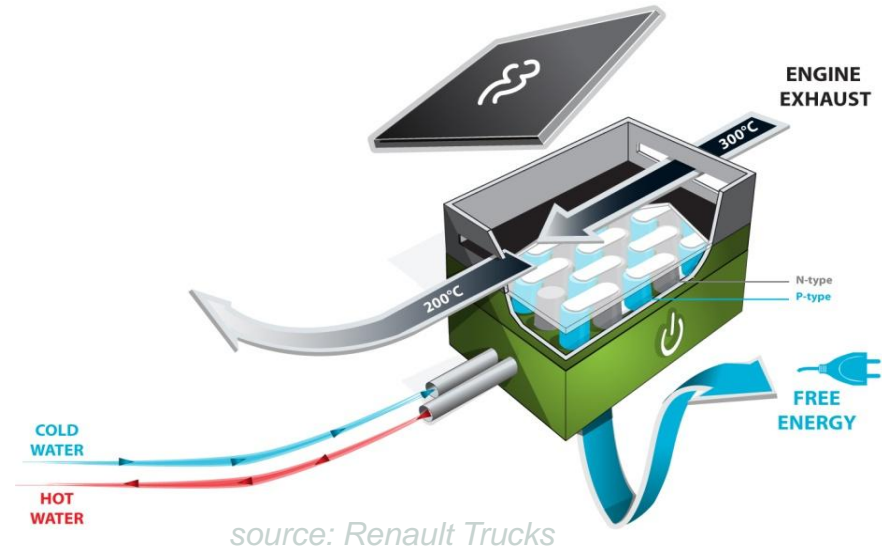
### ➤ Materials:

- ❑ Alternatives to Pb/Te
- ❑ “Reasonable” cost
- ❑ Higher ZT needed  $\sim 200^{\circ}\text{C}$
- ❑ Good  $\text{Mg}_2\text{Si}$  type P required

### ➤ Performance:

- ❑ Benefits of direct integration
- ❑ Issue with low voltage / high current
- ❑ Power below pay-off level

- Material improvement & research should continue if we want a mass market application



# Acknowledgments



RENOTER project team



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

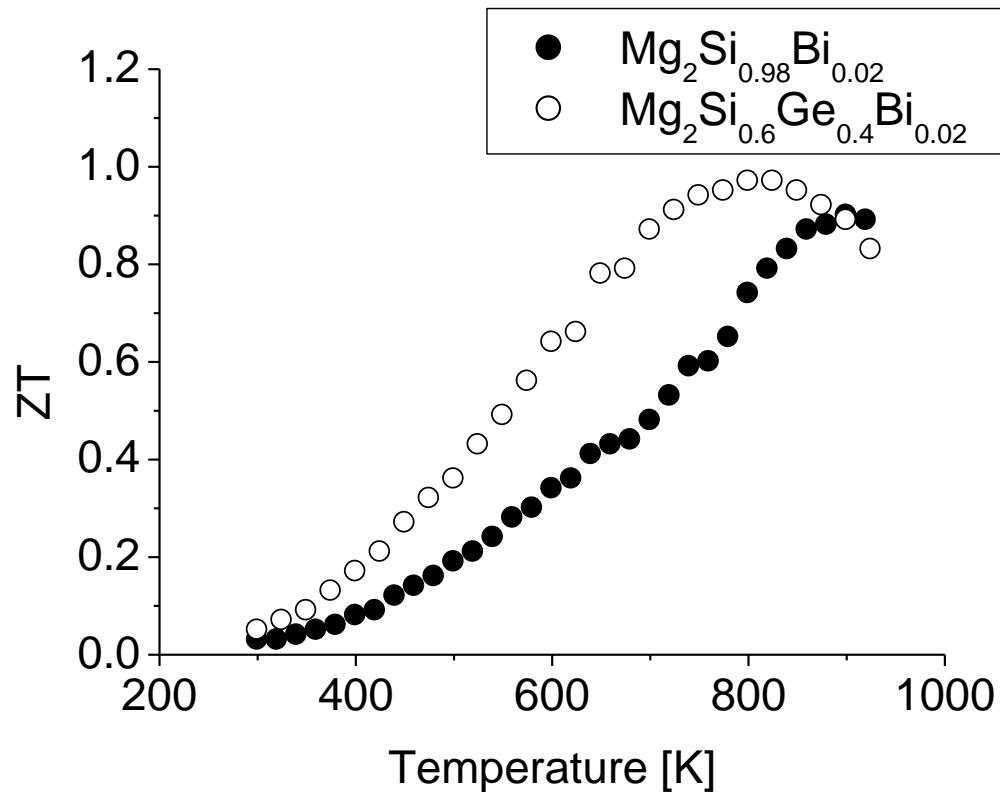


Région Basse-Normandie

# Back-up slides



# Back-up slide on n-Mg<sub>2</sub>Si (Germanium doping)



# Specifications for diesel engine (passenger car)

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