THERMO-ELECTRIC GENERATION, AN END USERS PERSPECTIVE

– THERMOELECTRIC NETWORK: WORKSHOP & TRAINING EVENT

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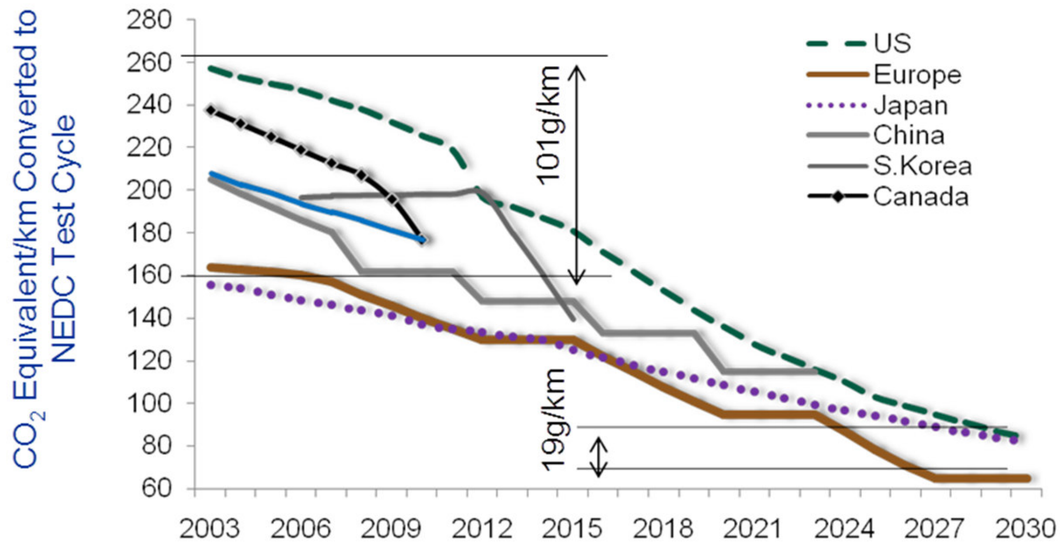
THERMO-ELECTRIC GENERATION, AN END USERS PERSPECTIVE

Contents

- Why are OEM’s so interested in waste heat recovery?
- What exactly does a full TEG system look like?
- What are the current issues?
- What are the current material issues?
- The supply chain is not to be forgotten
- Modelling a route to speed to market and acceptance
- Summary
- Final thoughts
- Questions

WHY ARE OEM'S SO INTERESTED IN WASTE HEAT RECOVERY?

Key grand challenge is CO_2 (Fuel Economy)

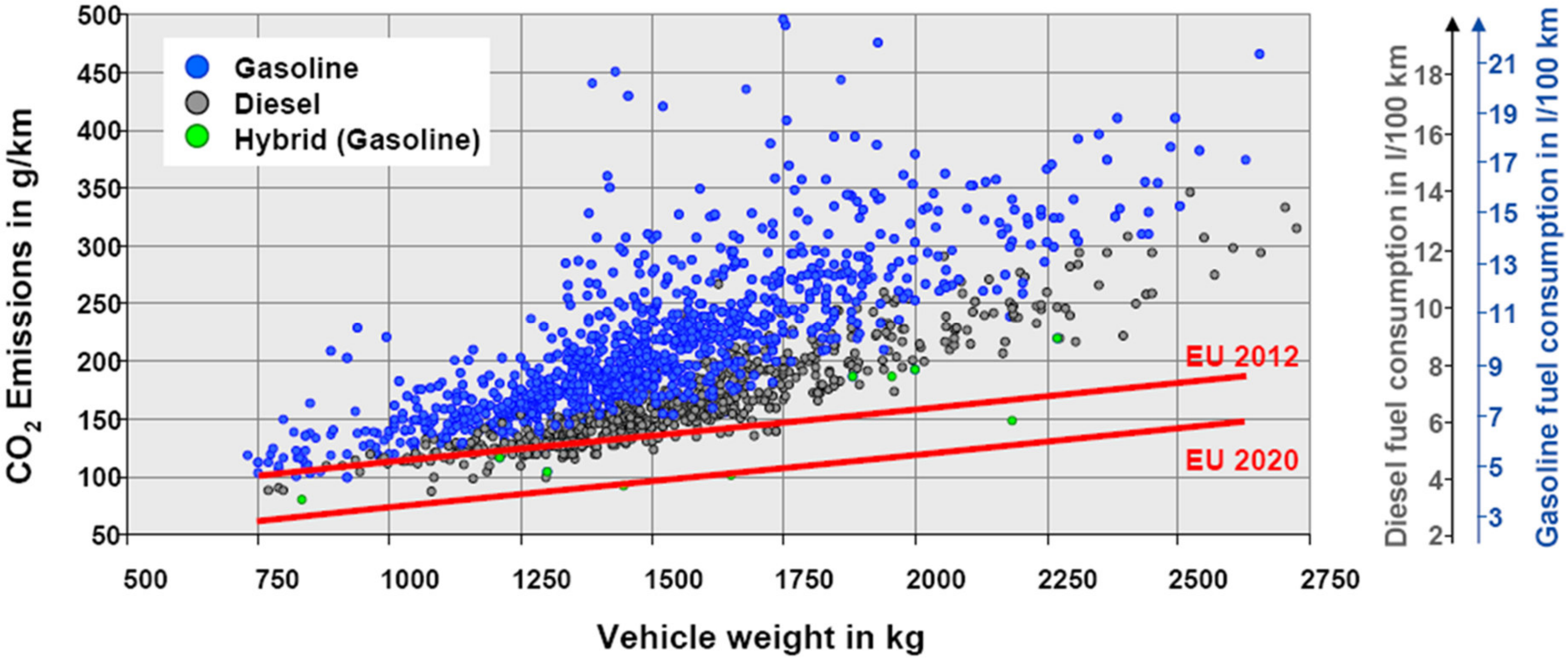


- Global CO_2 target number range now starting to converge
- Global non-CO_2 emission 'norms' continue to tighten and converge
- Various technologies available are now becoming globally applicable

Technological discontinuity exists if we are to meet future global requirements

WHY ARE OEM'S SO INTERESTED IN WASTE HEAT RECOVERY?

End user will be fined per vehicle sold if they do not meet fleet averages

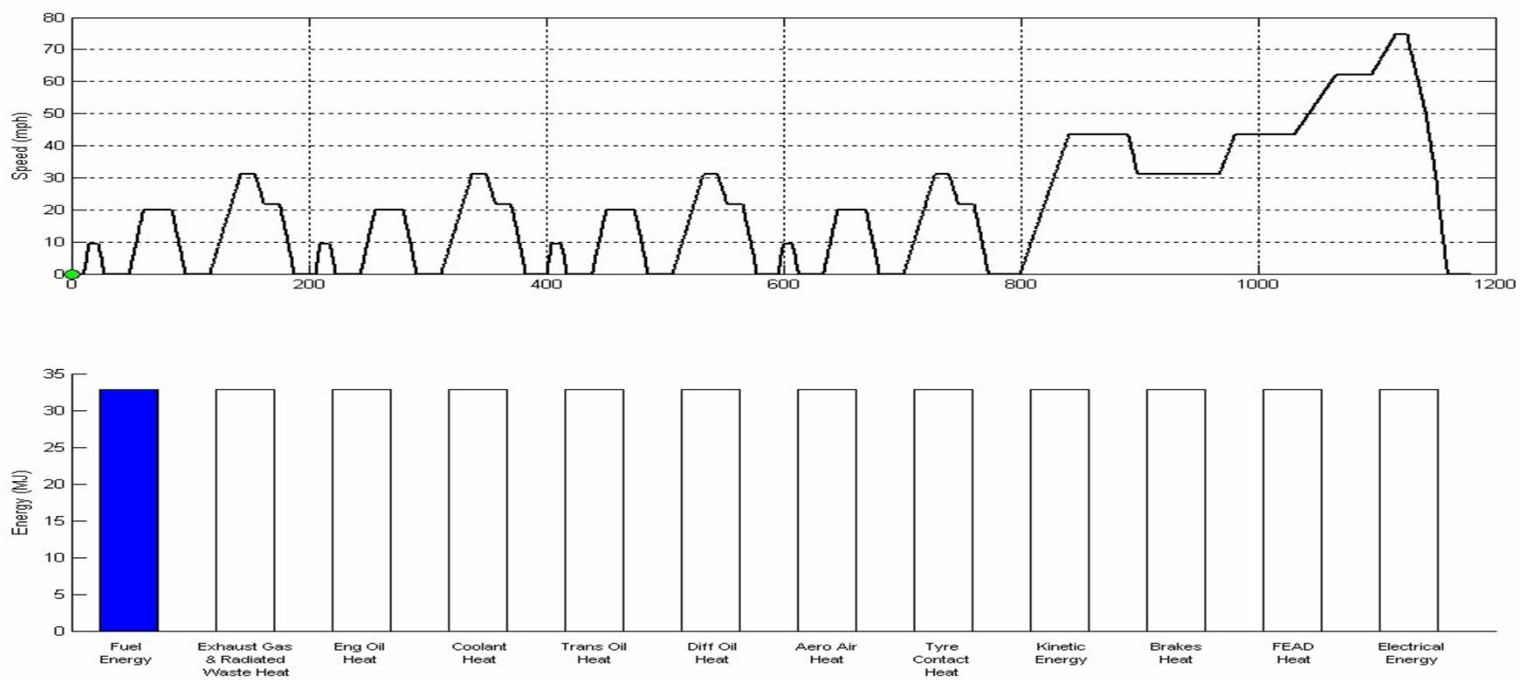


More than 80% of current passenger vehicles produce too high CO_2 emissions

OEM's will have to pay a fine per vehicle, per gram CO_2 exceeding the limit (Other countries are likely to follow suite)

WHY ARE OEM'S SO INTERESTED IN WASTE HEAT RECOVERY?

A high proportion of the fuel energy disappears down the exhaust on a NEDC



WHY ARE OEM'S SO INTERESTED IN WASTE HEAT RECOVERY?

An energy balance reveals where we can make a difference

PF – Piston friction (skirt & rings)

WP – Coolant pump friction

VT – Valve train friction

CB – Conn rod friction

BS – Balancing system friction

OP – Oil pump friction

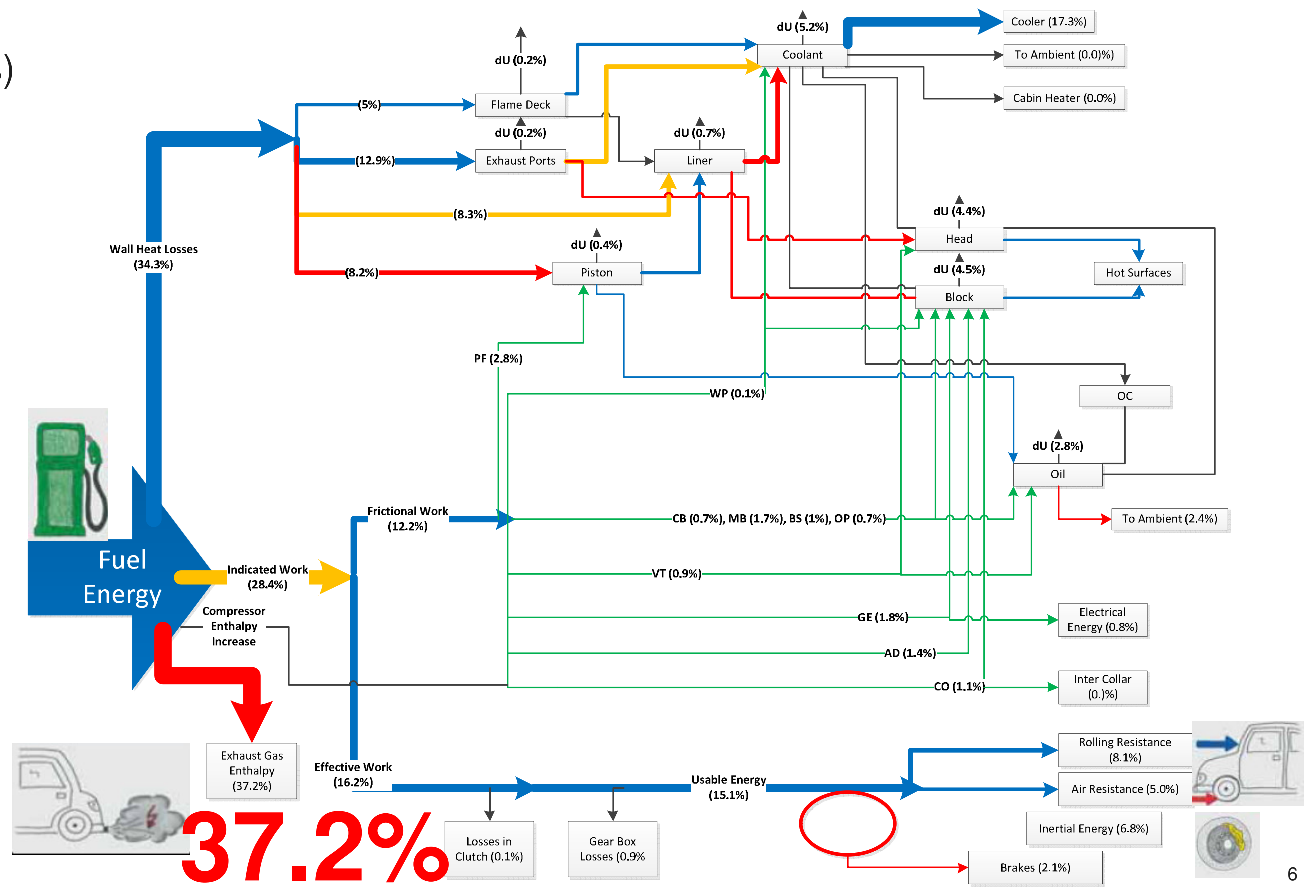
GE – Generator friction

AD – Accessory drives

CO – Supercharger friction

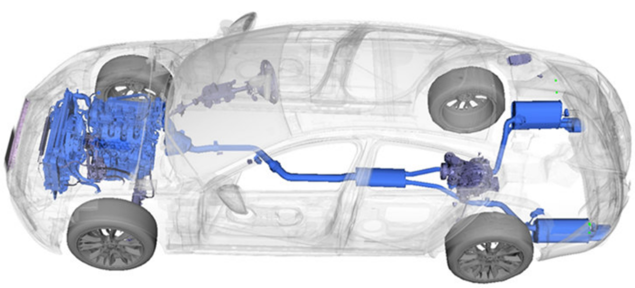
OC – Oil cooler

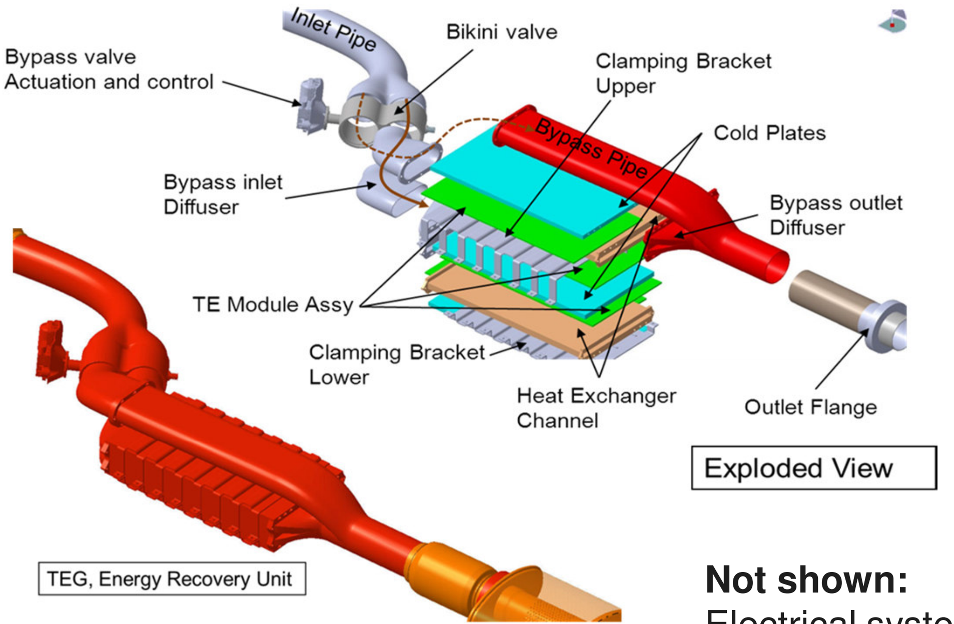
dU – Change of internal energy



WHAT EXACTLY DOES A FULL TEG SYSTEM LOOK LIKE?

It is not just the TEG unit that we must consider!

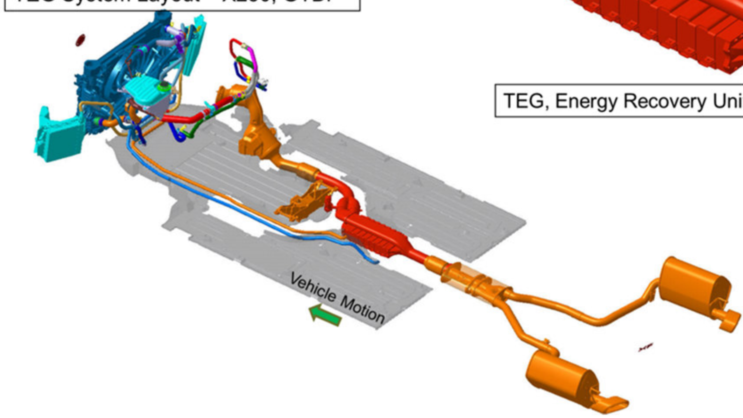




Exploded View

TEG, Energy Recovery Unit

TEG System Layout – X250, GTDi

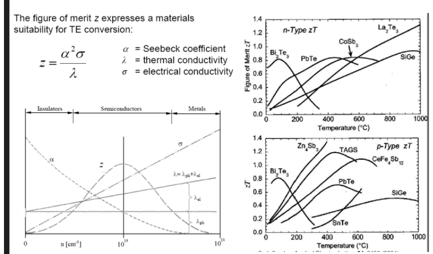


Not shown:

Electrical system
Body in white
Control
Charging system

WHAT ARE THE CURRENT ISSUES?

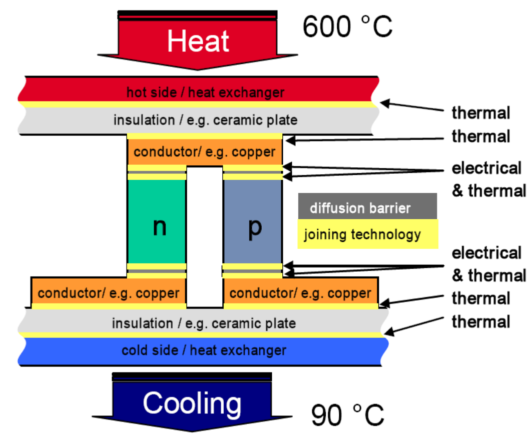
There are a lot of factors to be considered in system engineering



Material Development
Costs
Performance
Durability
Environmental friendliness
Availability
Stability
Operating range
Process development

System Integration
NVH
Back pressure
Weight
Complexity
£/gCO_2
Control & OBD
Packaging
Operating strategies
Service & Life cycle considerations

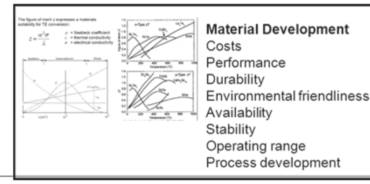
Modelling & Simulation



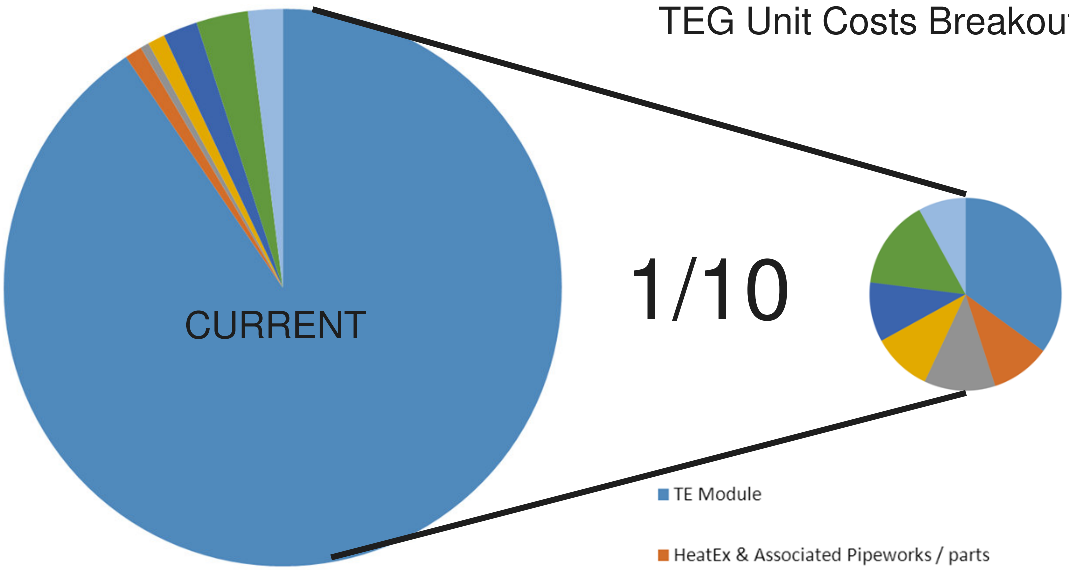
Component Development
Durability
Oxidation
Joining technologies
Flat plate hot & cold heat exchanger tolerance
Heat transfer (Hot & cold sides)
Thermal expansion/cycling stresses
Bulk supply of TE materials
Manufacturing simplicity

WHAT ARE THE CURRENT MATERIAL ISSUES?

TE Module cost is a major issue

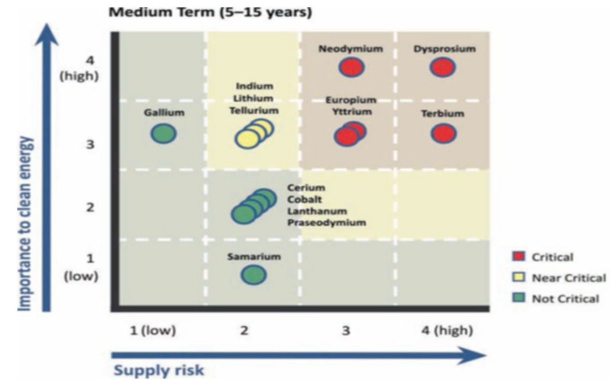


TEG Unit Costs Breakout

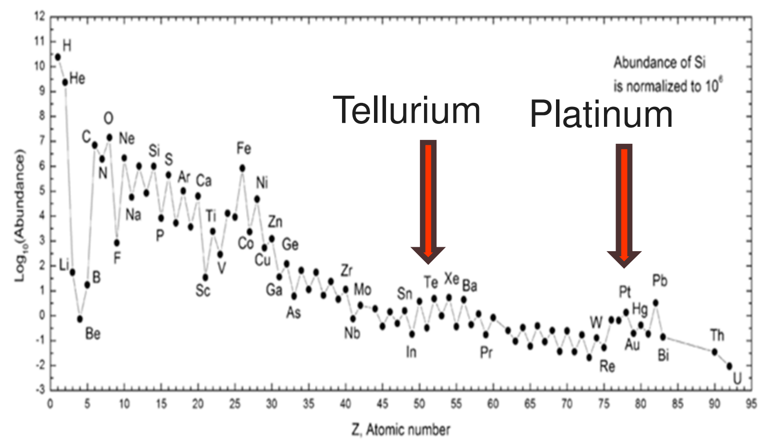


- TE Module
- HeatEx & Associated Pipeworks / parts
- Coldplate & Associated Pipeworks / parts
- Electrical Connectors, Cabling & Cable management
- TEG assembly
- DC/DC Converter Electronics
- Bypass Valve & Pipeworks

Material price depends on quantity, and resources of tellurium are estimated around 20 000 tons. This means that with around 3kg of material (p+n) per vehicle, we are only able to equip 10 millions of them, which is corresponding to about 3 months of automotive world production.

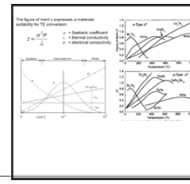


Source: US DoE "Critical Materials Strategy 2010"

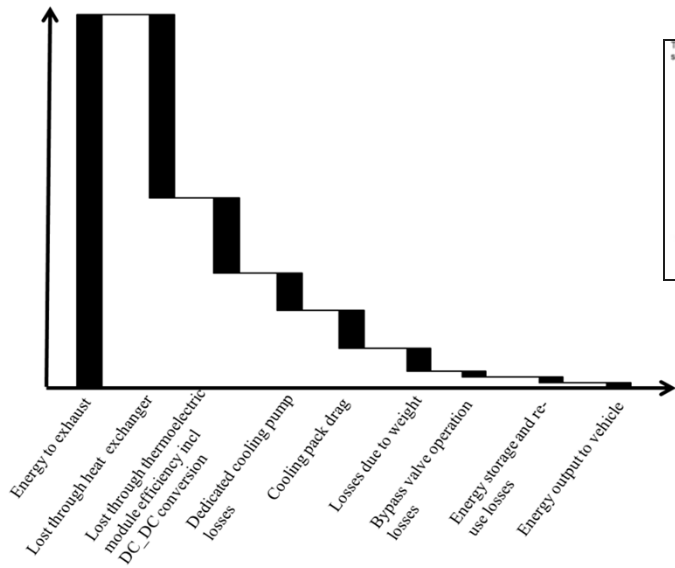


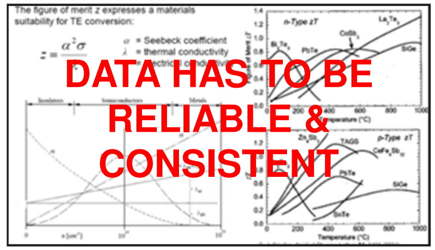
WHAT ARE THE CURRENT MATERIAL ISSUES?

Cost has to be balanced with system performance

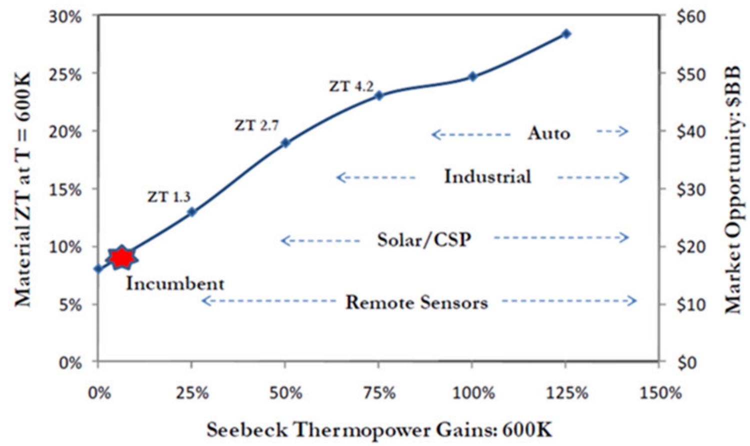


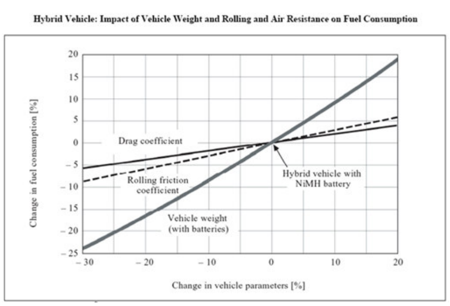
Material Development
Costs
Performance
Durability
Environmental friendliness
Availability
Stability
Operating range
Process development





AVERAGE Zt over cycle & max temp are important





Cold side cooling packs cause drag (c.1g/km CO_2 for 10 counts of drag) & cost

Offset against alternator loading

No. of modules proportional to weight (7.95g/km CO_2 per 100kg) & cost

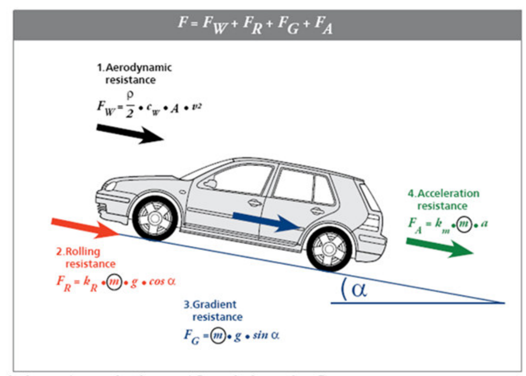


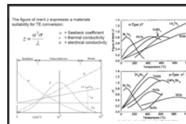
Figure 1: Resisting forces

Sources: SRU German Advisory Council - Reducing CO2 emissions in Cars

Sources: European Aluminium Association - Aluminium in Cars

WHAT ARE THE CURRENT MATERIAL ISSUES?

Materials have to be durable



Material Development
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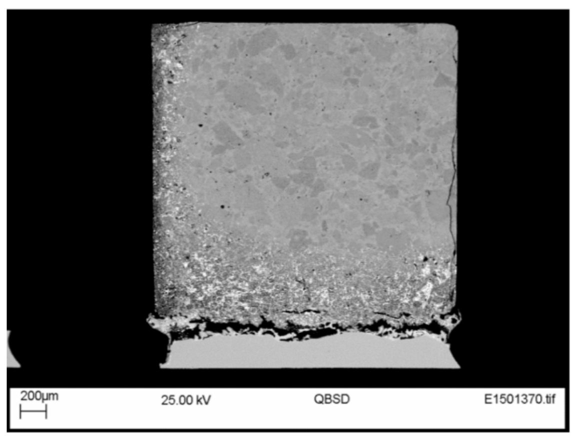
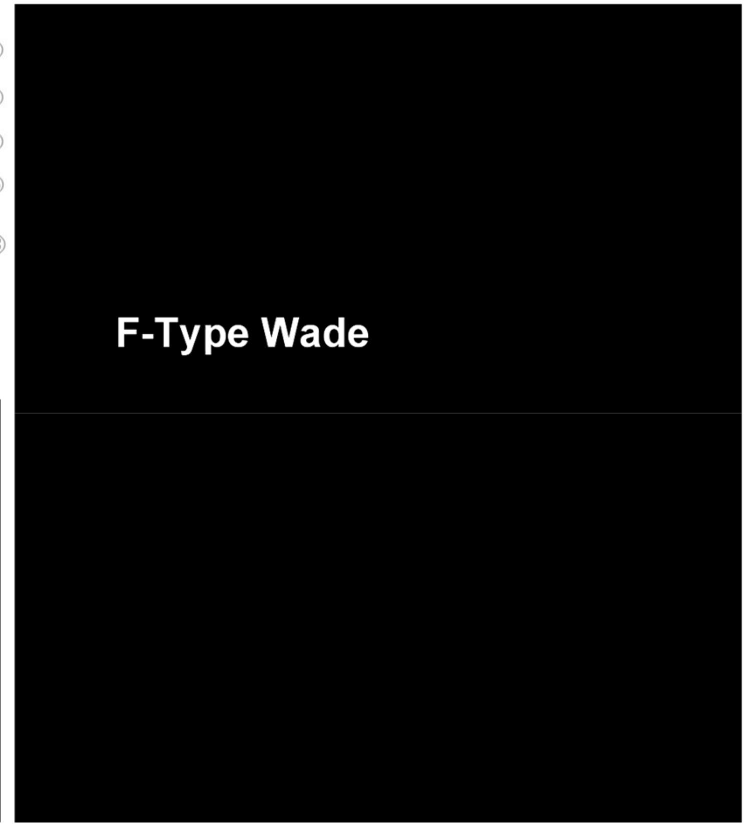
Process development

- **Over 15 years / 200,000 miles. Without degradation**
- **Material performance has to be stable, or at the very least predictable, over this period. No oxidation – air tight construction or coatings or possible recall scenario**
- **Has to withstand:**
  - **Thermal cycling form -50ºC to maximum material temps**
  - **Thermal shock from wading & snow**
  - **Impact from, gravel, animal strike, grounding**
  - **High-G movements form High Impact Stress Tests (HIST)**
  - **Thermal stresses**
  - **Vibration**
  - **Trailer tow on long high gradient**

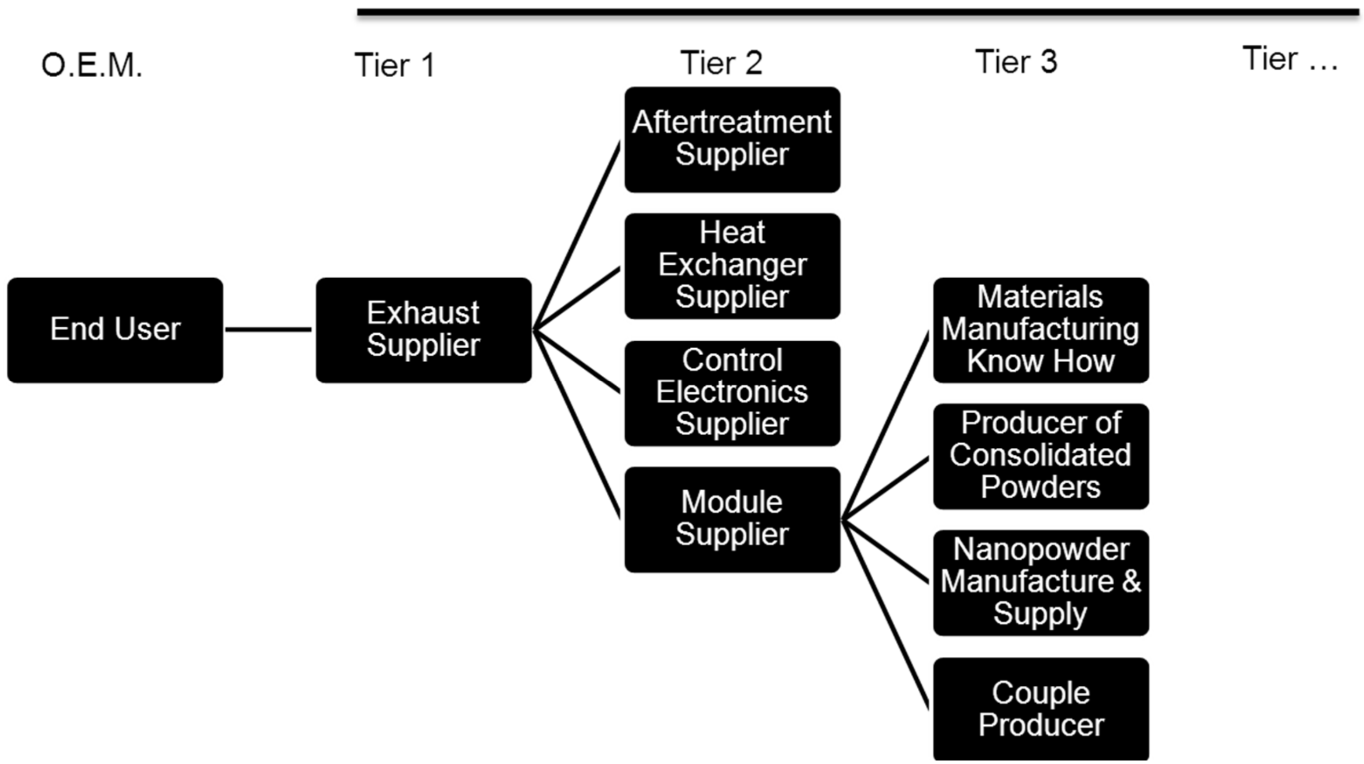




THE SUPPLY CHAIN IS NOT TO BE FORGOTTEN

An OEM will require vast quantities of mat[l] at low cost & high quality

- Materials will have to be:
  - Consistent
  - Of known properties
  - Sustainable
  - Low cost
  - Plentiful
  - Standardised tests
- Suppliers will have to be fully engaged throughout the supplychain in order to maintain quality & cost



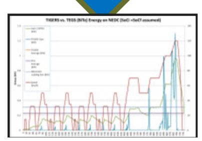
MODELLING A ROUTE TO SPEED TO MARKET AND ACCEPTANCE

Modelling is a vital part of the process

- Powder properties
- Compression & sintering
- Puck machining
- n & p pellets
- Pellet arrays
- Modules
- Exhaust heat exchanger (Ehex)
- Ehex & Modules
- Ehex, Modules & Coolant Hex (Chex)
- Clamped unit
- TEG system
- Electrics & control
- TEG system with electrics & control
- System in vehicle

Mechanical & performance

Modelling Tool Chain



Modelling & testing requirements

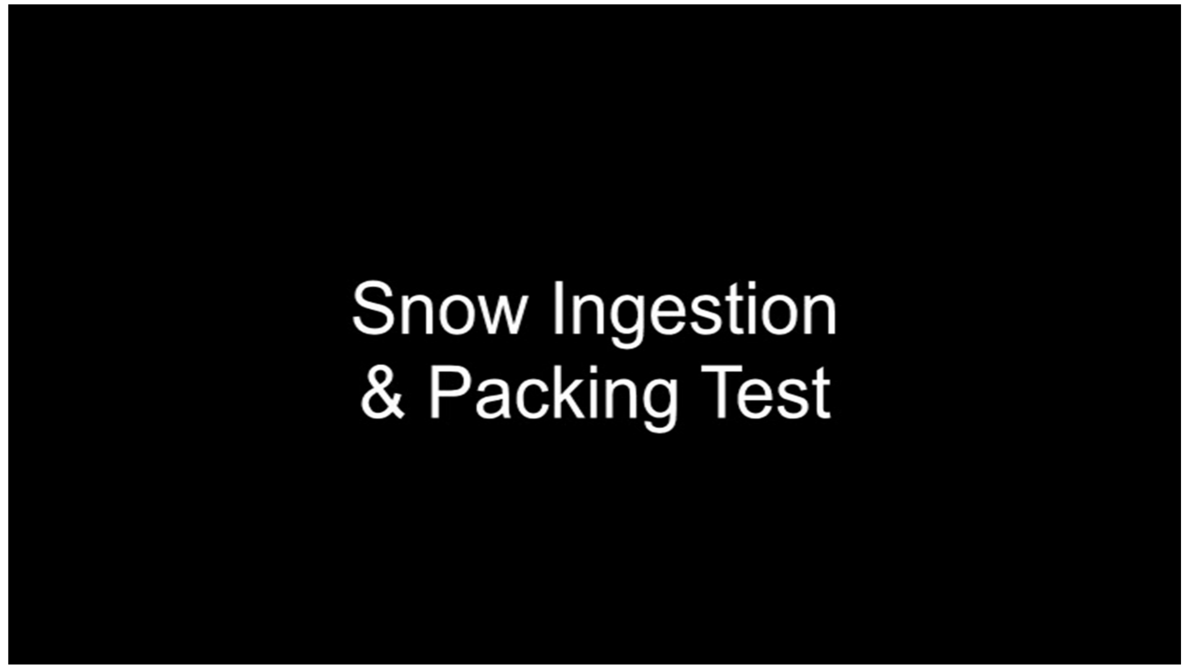
- Thermo-electric material properties
- Interfacing - Joining/brazing effects
- Mechanical – Flow & Stress (Vibration, thermal, mechanical, fatigue, pressure losses)
- Performance modelling
- Electrical & control performance
- Optimisation
- Sensitivity analysis
- Vehicle effects – eg heat rejection

Required for virtual buck

THERMO-ELECTRIC GENERATION, AN END USERS PERSPECTIVE

Summary

- Decrease £/g.CO_2 saved over cycle
- Make it:
  - Light
  - Durable
  - Safe
  - Stable
  - Readily available
  - Quick to market
  - Fully integrated into a supply chain
  - Recoverable/recyclable
  - Sustainable
  - Standardised in characteristics & reproducibility
- Be able to model the characteristics



FINAL THOUGHTS

Seamless & robust integration into a complex product is the greatest challenge

Complexity leads to:

- Long lead-times
- High development costs
- High warranty and customer dissatisfaction if it goes wrong.

How to accelerate innovation against a background of ever increasing complexity is one of the grandest challenges of all

F-22 Raptor
The avionics system in the F-22 Raptor, Air Force frontline jet fighter consists of about **1.7 million** lines of code

Boeing 777
4 million lines of code implemented in 79 different systems to operate its avionics and onboard support systems

F-35 Joint Strike
F-35 joint strike fighter requires about **5.7 million** lines of code to operate its onboard systems

Boeing 787
Boeing's new Dreamliner requires about **6.5 million** lines of code to operate its avionics and onboard support systems

Premium car
Modern luxury car today requires about **100 million** lines of code to operate its control and comfort systems

IN 2008 THE BUSINESS RESEARCH FIRM FROST & SULLIVAN ESTIMATED THAT CARS WILL REQUIRE **200 MILLION** TO **300 MILLION** LINES OF SOFTWARE CODE IN THE NEAR FUTURE

THANK YOU

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QUESTIONS
– RUN VIDEO