IEA Technology Collaboration Programmes/ Implementing Agreement on Advanced Materials for Transportation TCP/IA-AMT

Potential gaps and barriers for energy technology development and deployment

"A view from a materials perspective"

Jerry Gibbs, Chair TCP-AMT

Presentation represents
an IA-AMT Perspective and <u>does not</u> represent US-DOE

Outline

- Introduction to TCP/IA – AMT
- Potential Impact
- Gaps
- Barriers
- Opportunities

IA / TCP Advanced Materials for Transportation

- Task shared organization
  - There are no annual dues, but participation is expected
  - New members are welcome
- Meet twice a year, rotating among members
  - Each meeting has an open technical symposia and
  - An Executive Committee meeting
  - New annexes can be proposed at these meetings
- Annexes may have additional meetings
  - Annex Data is freely disseminated to all annex participants

Materials Impact of Energy Efficiency

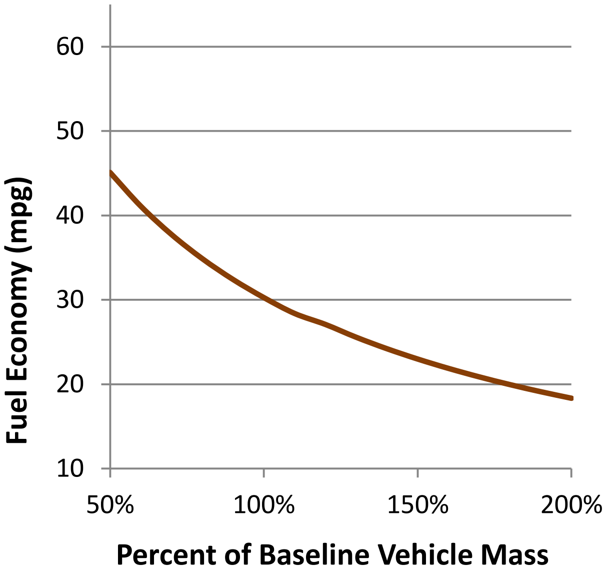
- Light-weighting impacts every vehicle size class regardless of the powertrain
- Changing the materials in the powertrain can change the design constraints placed on engine designers, leading to higher power density or efficiency
- New materials can allow designers to harvest energy that would normally be wasted

Vehicle Weight Reduction

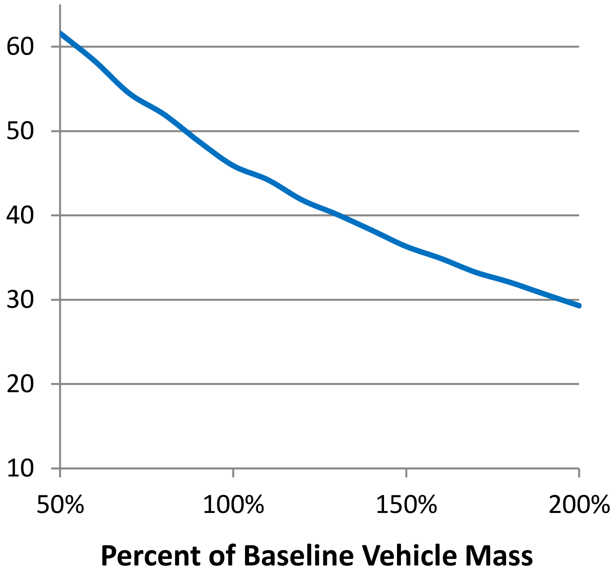
Conventional ICE

Hybrid/Electric Vehicles

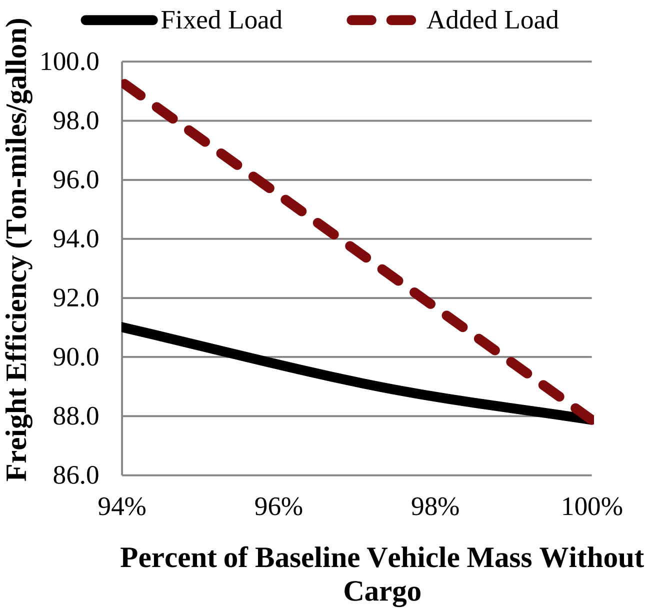
Commercial/Heavy Duty



NREL 2011



NREL 2011

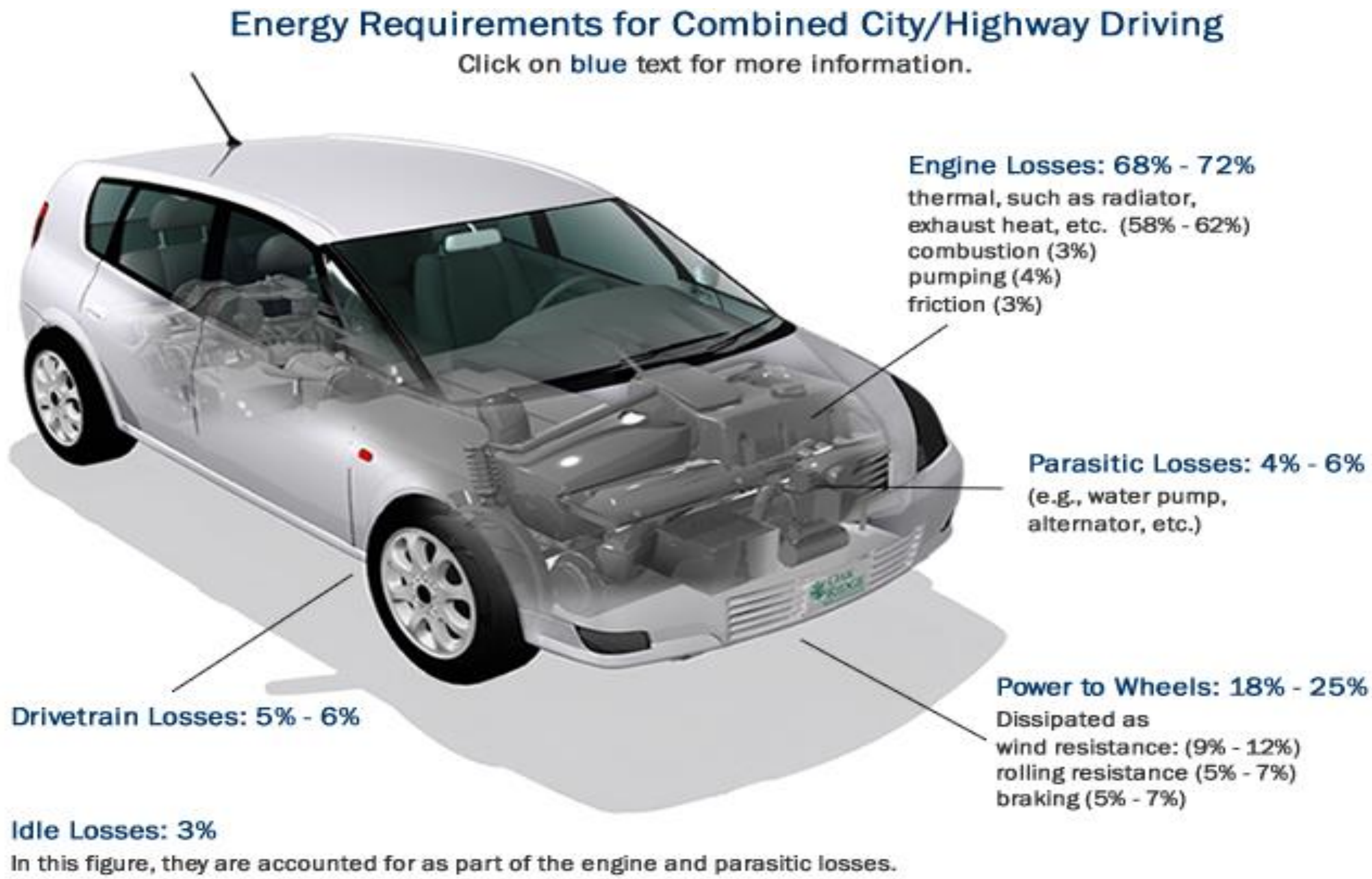


Ricardo Inc., 2009

6%-8% improvement in fuel economy for 10% reduction in weight

Improvement in range, battery cost, and/or efficiency

13% improvement in freight efficiency for 6% reduction in weight



Internal combustion engines have the potential to become substantially more efficient, with laboratory tests indicating that new technologies could increase passenger vehicle fuel economy by more than 50%.

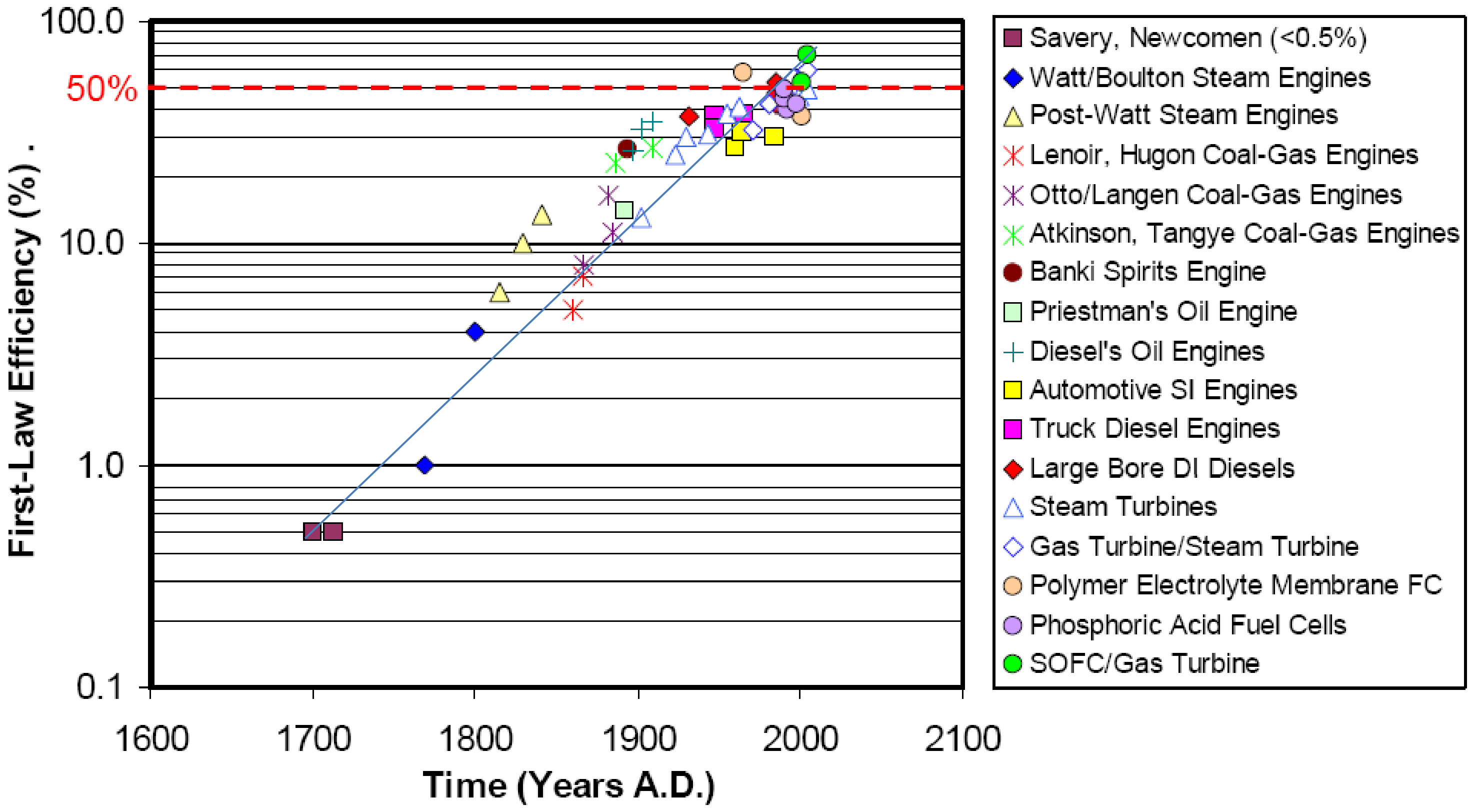
https://www.energy.gov/eere/success-stories/articles/eere-success-story-fca-and-partners-achieve-25-fuel-economy

Importance of Internal combustion engines (ICEs)

- Total vehicles in the world is about 1.2B in 2014 and is projected to be 2B by 2035
- Total world vehicle production is about 85M units per year (2015 data)
- Average of 14 years life cycle
- They consume 60-70% of the petroleum with about 16% of carbon emission worldwide
- Improving fuel economy in the near term will conserve energy and reduce emission

Combustion Engine Efficiency

Fuel Conversion Efficiency of Engines

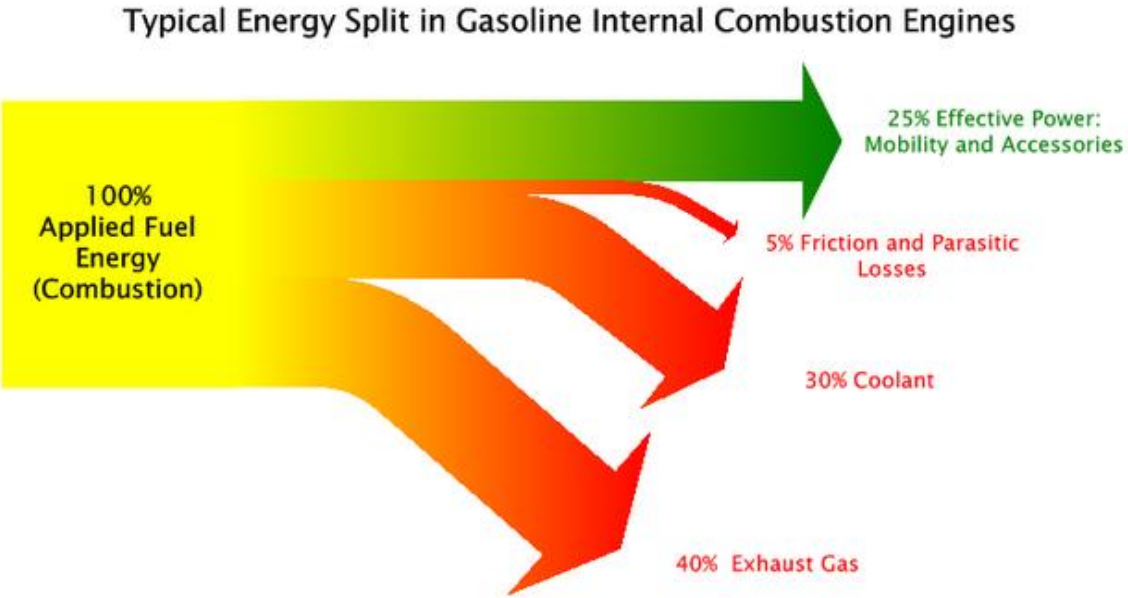


After three centuries of development, combined-cycle efficiency just exceeds 50%, simple-cycle remains below.

Chris Edwards (Stanford), ***Remarks on the Efficiency Potential of Chemical Engines***

2010 Combustion Engine Efficiency Colloquium

Internal Combustion Engine (ICE) Losses



Friction reduction via low viscosity lubricants

- Use low viscosity lubricants to reduce hydrodynamic and EHL friction and drag
- Japanese OEMs reported significant fuel economy gains using ultra-low viscosity lubricants and requested new SAE viscosity grades
- SAE J300 has set up SAE 16 (2.3 mPa.sec at 150^{o}C), 12 (2.0), 8 (1.7) as measured by the HTHS at 150^{o}C)
- Concern on long term engine durability
  - From Start and Stop cycles
  - Higher frequency surface contacts due to thinner oil films from low viscosity
  - Potential for higher wear in the hot zone

Potential Impact

- Light-weighting, Up to 30% increase in transport efficiency in ground vehicles, regardless of powertrain
- Internal combustion engine, materials may enable efficiencies >50%, representing a 25% improvement in heavy duty and a 60% improvement in light duty ICE efficiency.
- Friction reduction represents up to a 5-7% improvement in vehicle efficiency
- Energy conversion technologies represents up to an 10% efficiency improvement in ICE vehicles

GAPS

- Technology
  - Actual properties vs reported
    - Materials properties
    - Fuel economy measurements, test cell vs real world
  - Performance Measurements
  - Material interactions, joining, fuels, environment
  - Materials, Fundamental understanding
- Communications
  - Best Practice for measurements
  - System operating parameters (Temperatures and Pressures)
  - Materials property datasets
    - Necessary for design engineers

Gaps: Example of TE Property Measurements

- Thermoelectric Materials properties measurements were being reported with a wild range of properties, Zt’s properties were ranging from 0.97 to 7 often for similar materials
- In trying to verify reported data members of the IA-AMT realized the problem and proposed an Annex.

International Energy Agency (IEA)
Advanced Materials for Transportation (AMT)

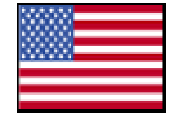
Annex VIII Participants: 20 Labs, 6 Countries

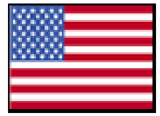
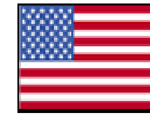
IEA-AMT Thermoelectric Annex

- Annex Lead: Oak Ridge National Laboratory (H. Wang)
- USA, 11 Labs: Marlow , GM R&D, Army Research Laboratory , Air Force Research Lab, Corning Inc., GMZ Energy, University of Houston, Clemson University, NIST, ZT-Plus
- China: SICCAS (S.Q. Bai, L. Chen)
- Canada, 4 Labs: CANMET, University of Waterloo, University of Quebec at Chicoutimi, Ecole Polytechnique de Montreal
- Germany: Fraunhofer IPM
- United Kingdom: NPL
- Korea, 2 Labs: KERI, Hanbat University

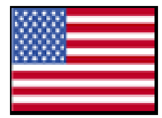
Four Major Publications and One IEA Topical Report

International Module Efficiency Round-Robin

China: SICCAS  -> Korea  -> GM R&D 

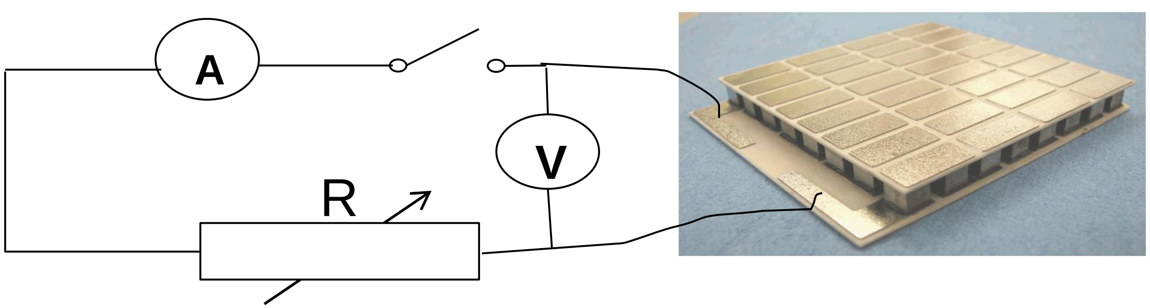
-> Army Research Lab  -> Air Force Research Lab 

-> NPL (UK)  -> Fraunhofer IPM (Germany) 

-> Canada  -> ORNL 

Paper #4 TE Modules

$$\eta = \frac{T_H - T_C}{T_H}\left(\frac{\sqrt{1+ZT}-1}{\sqrt{1+ZT}+T_C/T_H}\right) = \frac{P}{Q_{in}}$$



Determination of Thermoelectric Module Efficiency: A Survey

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The development of thermoelectrics (TE) for energy conversion is in the transition phase from laboratory research to device development. There is an increasing demand to accurately determine the module efficiency, especially for the power generation mode. For many TE, the figure of merit, ZT, of the material sometimes cannot be fully realized at the device level. Reliable efficiency testing of thermoelectric modules is important to assess the device ZT and provide end-users with realistic values for how much power can be generated under specific conditions. We conducted a general survey of efficiency testing devices and their performance. The results indicated a lack of industry standards and test procedures. This study included a commercial test system and several laboratory systems. Most systems are based on the heat flow meter method, and some are based on the Harman method. They are usually reproducible in evaluating thermoelectric modules. However, different systems often showed large differences that are likely caused by uncertain heat loss and thermal resistance. Efficiency testing is an important capability for the thermoelectric community to improve. A follow-up international standardization effort is planned.

Key words: Thermoelectric, module, efficiency, figure of merit

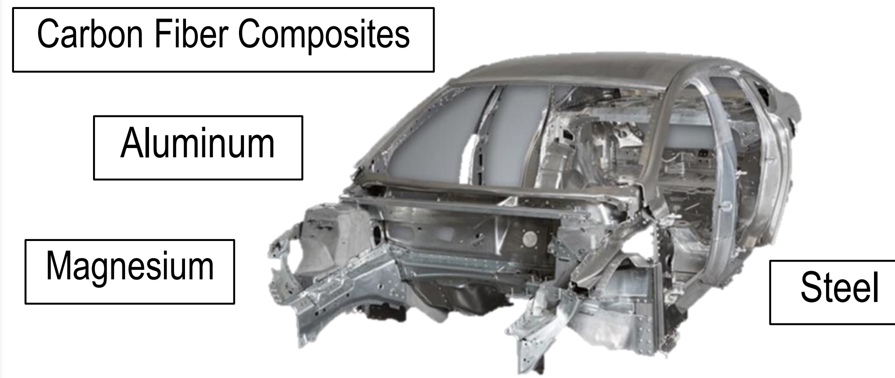
Light-weighting for Ground Vehicles (Light duty examples)

Composites Carbon Fiber

Light Metals

Magnesium, Aluminum, & Advanced High Strength Steel

Lightweight high performance alloys (for engines)

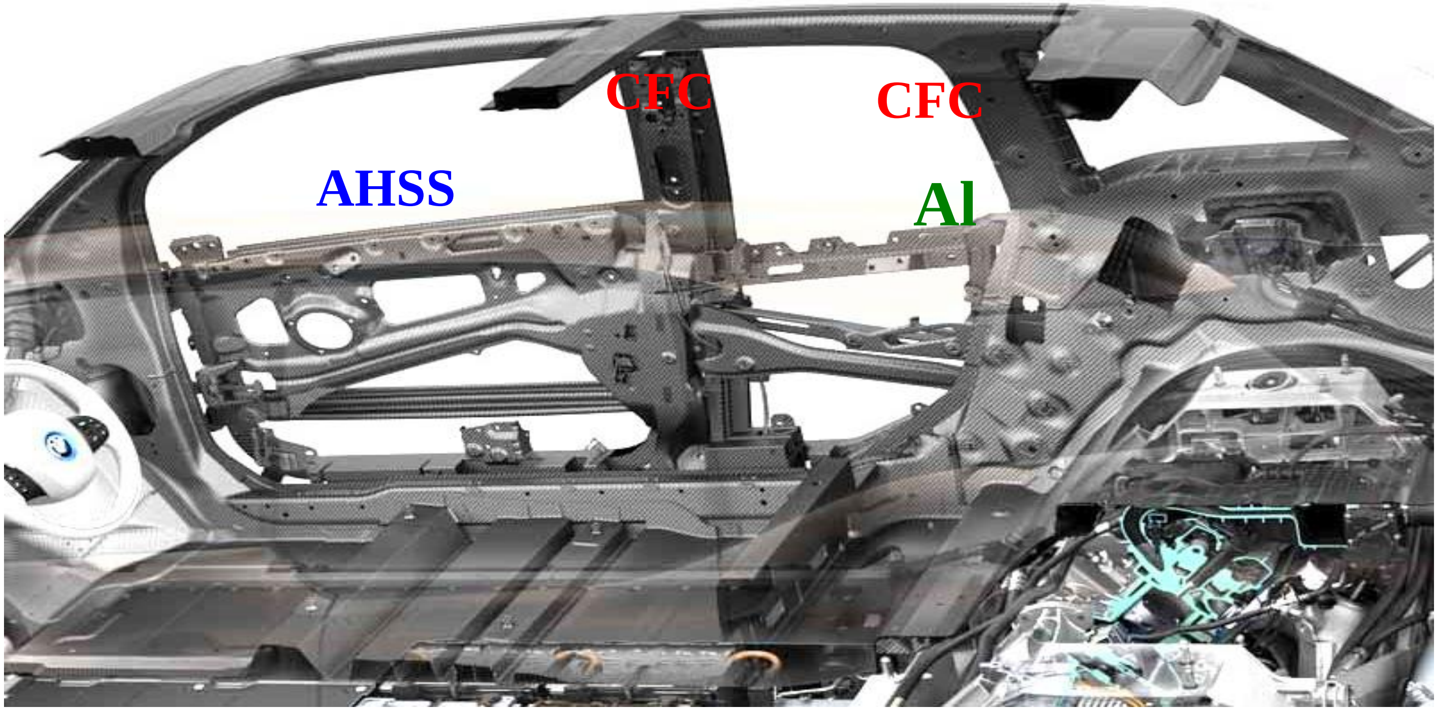


Joining dissimilar materials

Multi-Materials Joining Technology - IEA Annex X
Comparison Testing of Various Joining Methods for Dissimilar Material Joints

Focus: The joining of likely combinations of carbon fiber composites, aluminum alloys, magnesium alloys and advanced high strength steels.

Issue: There is no systematic approach to comparing different joining methods. *(i.e. self-piercing riveting, friction stir welding, friction bit joining, friction stir scribe technology, thread-form fasteners, advanced resistance spot welding, wire-fed laser welding, ultrasonic welding, adhesive bonding, weld bonding to combine adhesive bonding with other processes above, overmolding, and* ***more****.)*



Comparison Testing of Various Joining Methods for Dissimilar Material Joints

Objective - Develop and evaluate joining methods of various lightweighting materials to enable the assembly of an optimum light weight vehicle with high energy efficiency. Emphasis is being placed on the evaluation **different joining methods** for assembling structures from **dissimilar materials** using a **consistent set of materials** and **consistent test methods.** (i.e. an apples to apples comparison as much as is practical.)

<u>Each task is performed for a different organization but the same task is always performed by the same organization.</u>

ORNL – Procures and serves as the repository for materials.
CANMET – Cuts all samples.
Brazil – Fatigue Conditioning
BAM – Microscopy
Etc.

Materials are provided to the technology development team who makes the material samples and then submits them to the test matrix.

1. Material Selection

Received input from multiple OEMS and got agreement on what the standard material systems for comparison would be:

Thermoplastic Composite	Thermoset Composite	Aluminum Alloy	Magnesium Alloy	Advanced High Strength Steel
BASF Ultramid® Advanced N UF107AA	T70 Prepreg – 5 Ply	5182	AZ31	DP980
Nylon resin containing 40% chopped carbon fiber for injection molding. Targeted at structural integrated component applications.	A prepreg made with continuous, uni-directional T700 fiber in an epoxy matrix used for roof and hood applications.	A standard alloy used for hot pressed doors, hoods and roofs.	An formable alloy currently being developed for closures and brackets.	A primary structural material used for mass reduction and high performance applications.

CF/Nylon Laminate – BASF

Al 5182 – Alcoa

DP980 – ArcelorMittal

Cutting of samples is now beginning.

T70 Prepreg-5 ply – ORNL (Clearwater)

AZ31 – Magnesium Electron

All Materials on order or received.

2. Thicknesses and Fabrication

A standard stock of these will be kept at ORNL and sent out to any researchers for joint production. This will give consistent specimens.

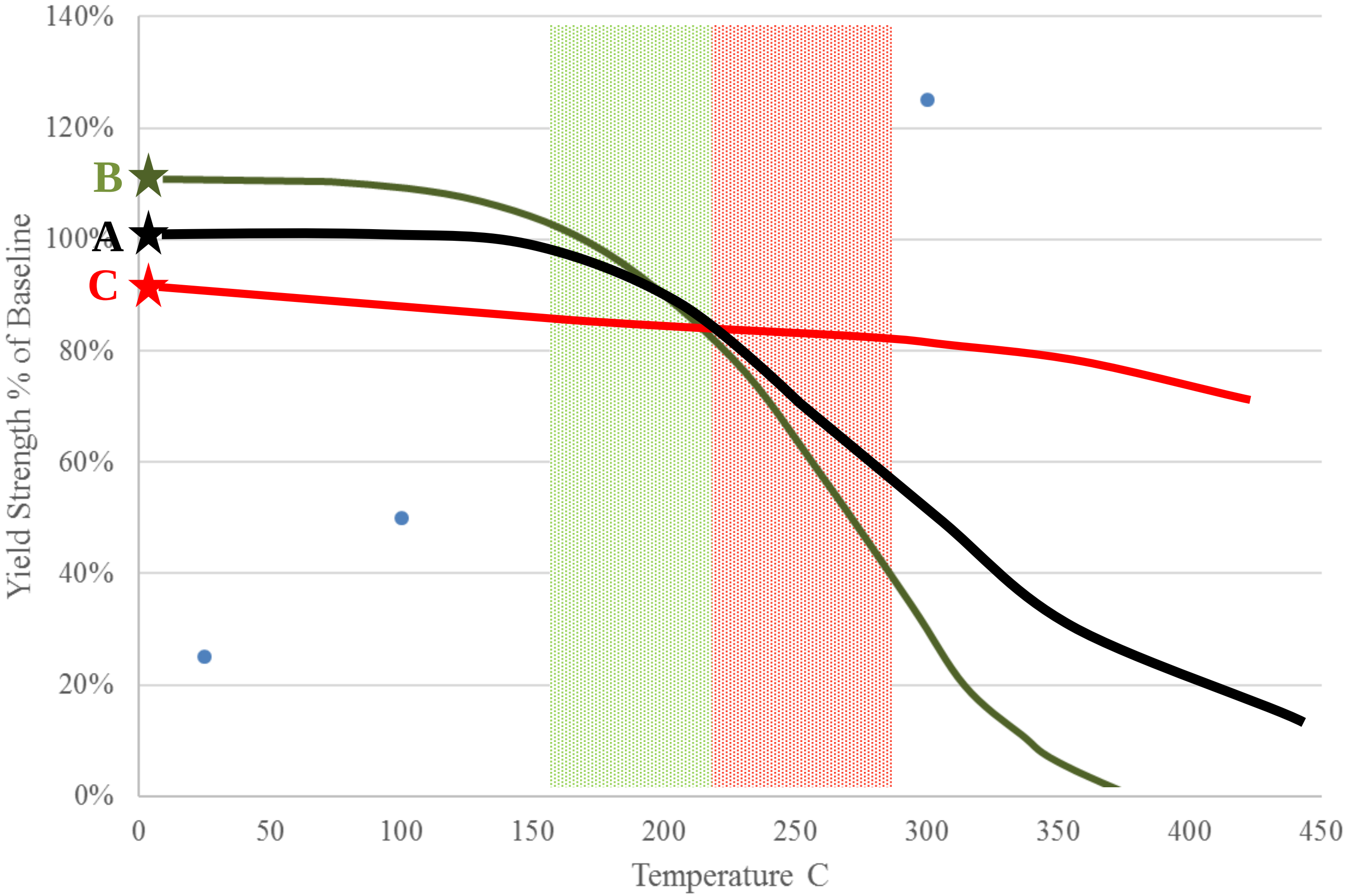
Single Lap Shear (25mm x 100mm with a 25.4mm overlap)

Super Lap Shear (100 mm x 300 mm with a 40mm overlap)

T-Peel (25mm x 100 mm with a 25.4 mm tab) radius TBD.

ORNL and CANMET will cut samples.

Gap Example:
Selecting Materials for modern ICE Applications



Barriers

- Economics
  - Cars and trucks are generally inexpensive on a per mass basis
  - Materials are a commodity
  - Engineering Materials datasets are very slow to change
  - Materials R&D is considered an expense
  - Most atomistic ICME calculations are limited to <300 atoms
- Communications
  - Information on operating conditions is very proprietary
  - R&D specialties are generally informationally stove piped
  - Manufacturing design engineers are generally very conservative
- Other:
  - Highly promising materials may have secondary military applications that make sharing research difficult

Barriers

Social & economical

- Oil price
- Cost
- Safety
- Utility (child sports)
- Family outing
- Mass transit
- Social pressure

Technical

- Cost of advanced mat’ls
- Light weight materials processing cost
- Multimaterials joining
- Friction reduction
- Design guidelines
- Waste heat recovery
- Aerodynamics/drag

Lack of academic-gov.-industry integration leads to ling induction time for lab to product on materials

Opportunities

- Collaborations
  - There may be opportunities for Materials and other TCPs to coordinate research to maximize impacts of both groups
    - Likely linkages, Advanced Combustion and Bio-fuels
- Join an annex:
  - *Testing mechanical properties of nanomaterials for vehicle applications*, *Annex VII*
  - *Thermoelectric Materials and Devices*, *Annex VIII*
  - *Friction reduction and lifetime control by advanced coatings via characterization, modeling and simulation*, *Annex IX*
  - *Comparison Testing of Various Joining Methods for Dissimilar Material Joints*, *Annex X*
- New annexes, have a materials issue or topic you would like to explore?

The next TCP/IA AMT ExCo meeting and Technical Symposia will be held in Vienna, Austria on June 1-2, 2017

Thank You

Jerry Gibbs, Chair TCP-AMT
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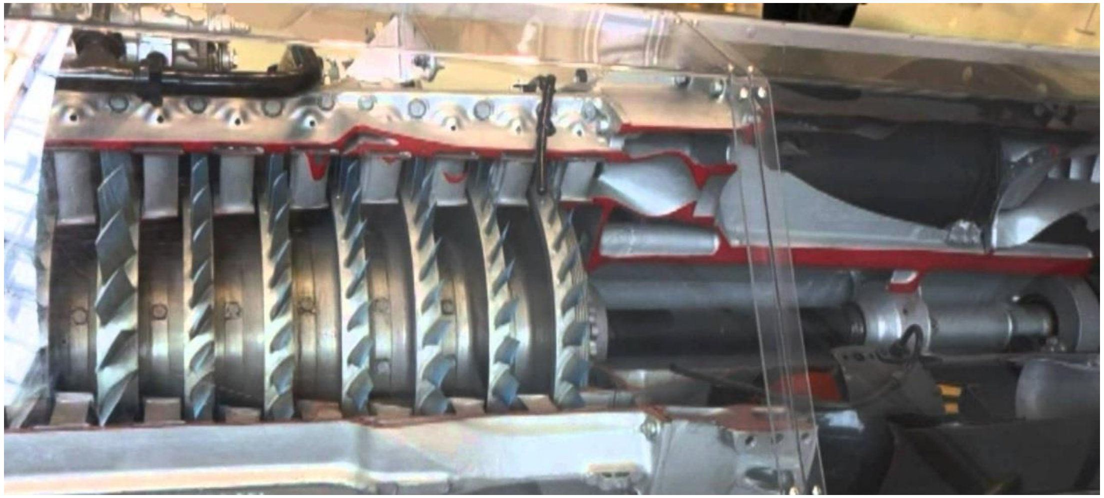
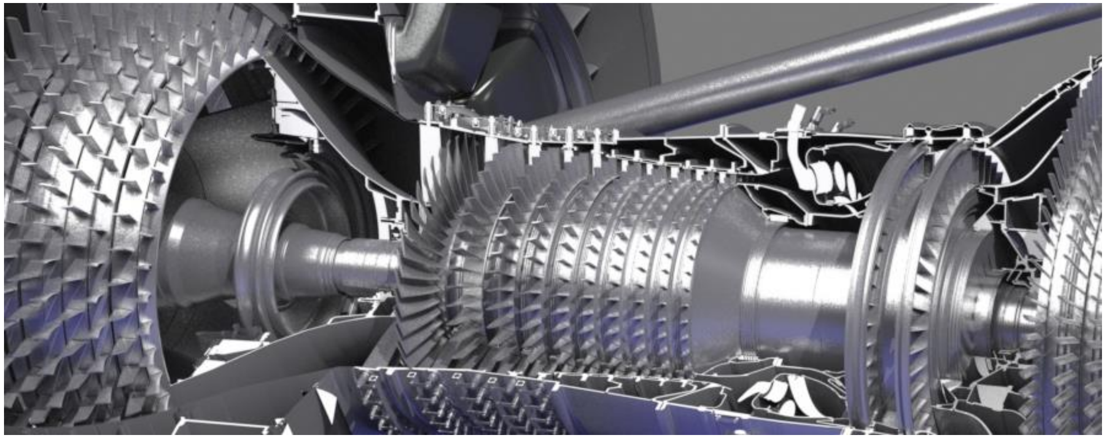
Materials Impact on System Performance and Durability



WWII Jet Engine
300 hr Service life



Modern Jet Engine
30,000+ hr Service life