GRANTA
MATERIAL INTELLIGENCE

Vehicle Emissions Reduction and Lightweighting

The Implications for Materials Information Technology

Dan Williams

Introduction

The legal requirements on exhaust emissions and fuel economy—as well as growing consumer demand for more efficient vehicles—are causing a step change in the way automotive companies are thinking about engineering and materials. With these changes come new requirements and challenges in the way *information* relating to these materials flows within and between automotive organizations, and in how this information is applied.

The last decade has also seen the emergence of best practices and fit-for-purpose commercial software to manage materials information and use it to support the needs of different user communities within an engineering enterprise, including Materials & Process teams, Design, Computer-Aided Engineering, and Purchasing Groups.

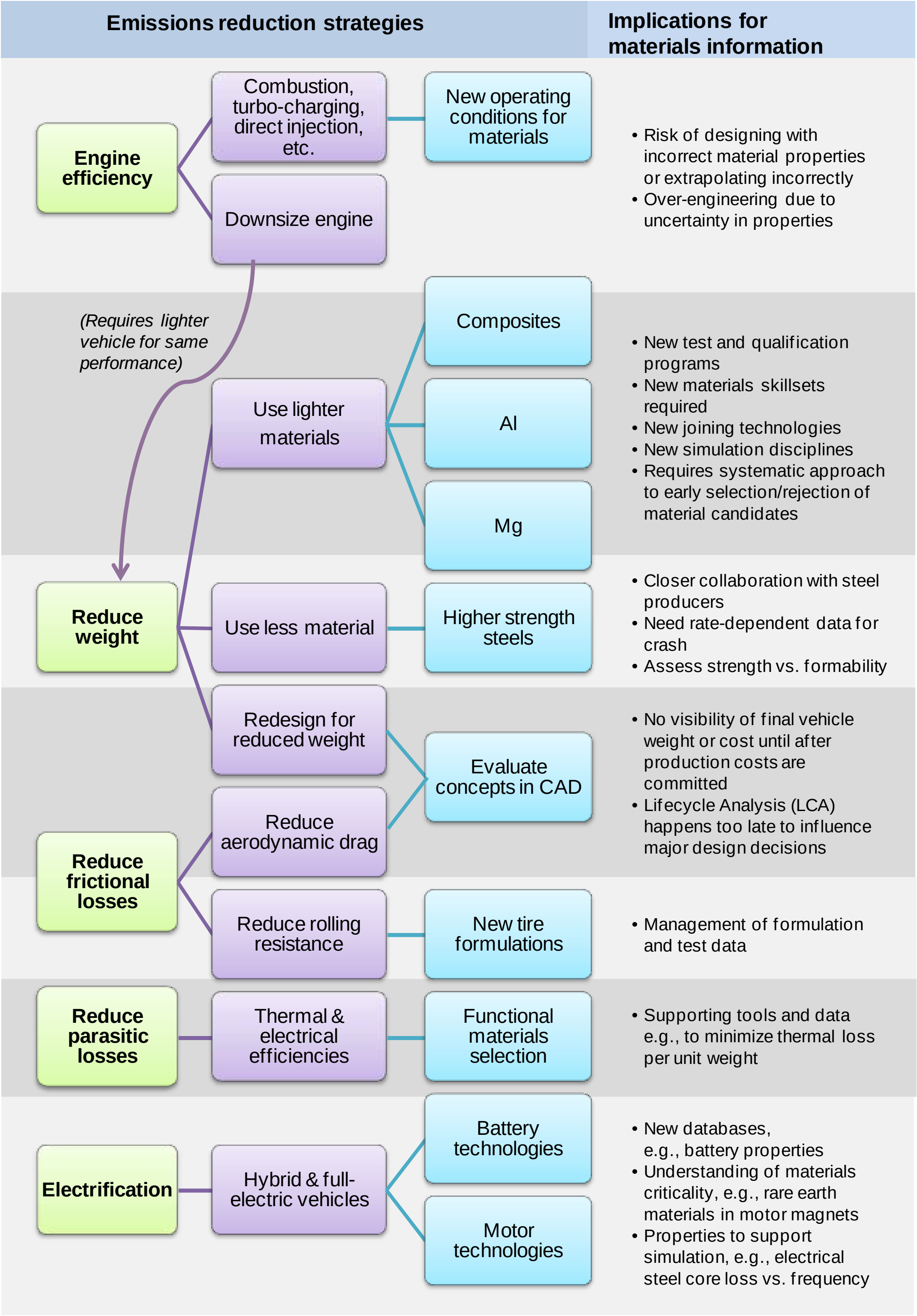
This Guide discusses some specific industry challenges relating to vehicle emissions reduction and lightweighting, and discusses how Materials Information Technology—comprising software tools, data and best practices—can be a critical enabling technology during this period of industry change.

Contents

1. Strategies for reduced emissions

Today, every automotive OEM is pursuing a number of simultaneous strategies to meet its emissions targets and reduce curb weight. Tier 1 suppliers in turn will be exploiting every technology at their disposal to meet and exceed OEM specifications in order to remain competitive.

The good news is that emissions reduction strategies are often self-reinforcing. A lighter body-in-white means that the same performance can be extracted from a smaller engine, which in turn further reduces weight and hence emissions.



- Risk of designing with incorrect material properties or extrapolating incorrectly
- Over-engineering due to uncertainty in properties

- New test and qualification programs
- New materials skillsets required
- New joining technologies
- New simulation disciplines
- Requires systematic approach to early selection/rejection of material candidates

- Closer collaboration with steel producers
- Need rate-dependent data for crash
- Assess strength vs. formability

- No visibility of final vehicle weight or cost until after production costs are committed
- Lifecycle Analysis (LCA) happens too late to influence major design decisions

- Management of formulation and test data

- Supporting tools and data e.g., to minimize thermal loss per unit weight

- New databases, e.g., battery properties
- Understanding of materials criticality, e.g., rare earth materials in motor magnets
- Properties to support simulation, e.g., electrical steel core loss vs. frequency

Figure 1.The Emissions "Decision Tree" and some implications for materials information technology.

The not-so-good news is that reduced emissions are not the only goal. The automotive industry is constrained by the eternal battle between three considerations: customer demand; business forces; and legislation. Consumers want more miles to the gallon and more fun-to-drive vehicles, but will not pay any price to get them. New materials (carbon fiber reinforced polymers, magnesium, aluminum, etc.) abound, but the basic economics of high volume production limit their adoption—not to mention practical considerations such as vehicle repair.

Nonetheless, the automotive industry is making great strides towards lighter and cleaner vehicles; some of the most common strategies are laid out it the strategy 'decision tree' (Figure 1). At the end of each branch of the decision tree we have listed some challenges relating specifically to the materials information required to support each strategy. We will now consider each of these challenges in detail.

2. Implications for Materials Information Technology

2.1 Engine efficiency

What's the challenge?

In Section 2.3 we consider redesign, which could include design of alternative drive systems. But here we focus on more efficient designs of standard gasoline and diesel internal combustion engines. It could be argued that, given the general trend of increasing vehicle weight and power, the improvements to fuel economies seen in the last 30 years are almost entirely due to internal combustion engine efficiency gains (1).

Design and simulation engineers will be testing new designs, using new materials, under new conditions.

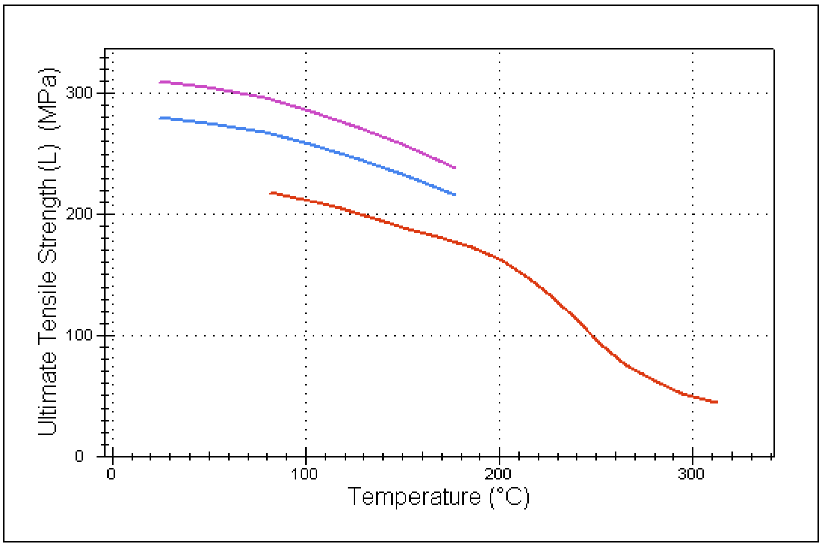
A number of strategies for more efficient engine design exist, the choice depending on a difficult balance of customer expectations, business drivers, and emissions goals. Today's engines comprise many complex and interrelated systems, and redesigns could impact areas as varied as combustion, fuel delivery, turbocharging, exhaust gas after treatment, and many others. Design and simulation engineers will be testing new designs, using new materials, under new conditions.

This brings a new challenge. The mechanical, physical, and durability properties of materials can be highly dependent upon environmental conditions such as temperature, pressure, and chemical exposure. The first example in Figure 2 shows an example of a temperature-dependent material property.

As engine designs evolve, the operating conditions to which materials will be exposed change. This exposes the engineer to a number of risks:

- Are we designing using the correct properties?
- Is it safe to extrapolate properties (e.g., at higher temperatures) from the dataset we have available?
- Does the uncertainty in the validity of our material property data require us to over-engineer our products, leading to additional engine weight and sub-optimal performance?
- Do we have the data to enable the optimal choice of material for a particular part?

Example 1



This graph (*right*) shows strength as a function of temperature for three different engine casting materials viewed in GRANTA MI™.

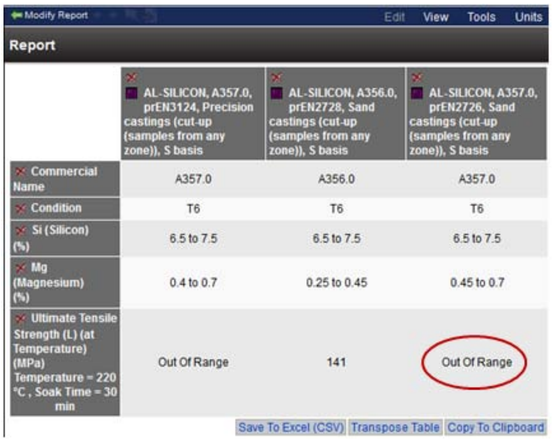
A fit-for-purpose materials information management system must be able to handle such multi-dimensional data, and allow users to compare materials, change units, and export properties directly to simulation software.

Example 2

It is possible to extract strength data from the three alloys above at a particular temperature, in this case 220°C, as shown (*right*).

Note that in this implementation the software interpolates a value for the A356.0 material but refuses to extrapolate data for the other castings as the curves do not extend to this range.

This ensures designs are not taken beyond limits laid down by the organization’s material experts.



	AL-SILICON, A357.0, prEN3124, Precision castings (cut-up (samples from any zone)), S basis	AL-SILICON, A356.0, prEN2728, Sand castings (cut-up (samples from any zone)), S basis	AL-SILICON, A357.0, prEN2726, Sand castings (cut-up (samples from any zone)), S basis
Commercial Name	A357.0	A356.0	A357.0
Condition	T6	T6	T6
Si (Silicon) (%)	6.5 to 7.5	6.5 to 7.5	6.5 to 7.5
Mg (Magnesium) (%)	0.4 to 0.7	0.25 to 0.45	0.45 to 0.7
Ultimate Tensile Strength (L) (at Temperature) (MPa) Temperature = 220 °C , Soak Time = 30 min	Out Of Range	141	Out Of Range

Example 3

In the final graph (*below*), material properties are being compared to enable the selection of reinforced PPS for a turbocharger charge air cooler component to replace an aluminum part, as in a recent case study by Ticona (2).

The grey bubbles represent materials which do not meet the criteria of temperature resistance, toughness (to support a crimping process), manufacturability, and chemical resistance. The remaining materials are ranked on the relative cost and mass required to achieve a given mechanical performance under pressurized conditions. Such technology enables fast go/no-go material selection decisions in early stage design.

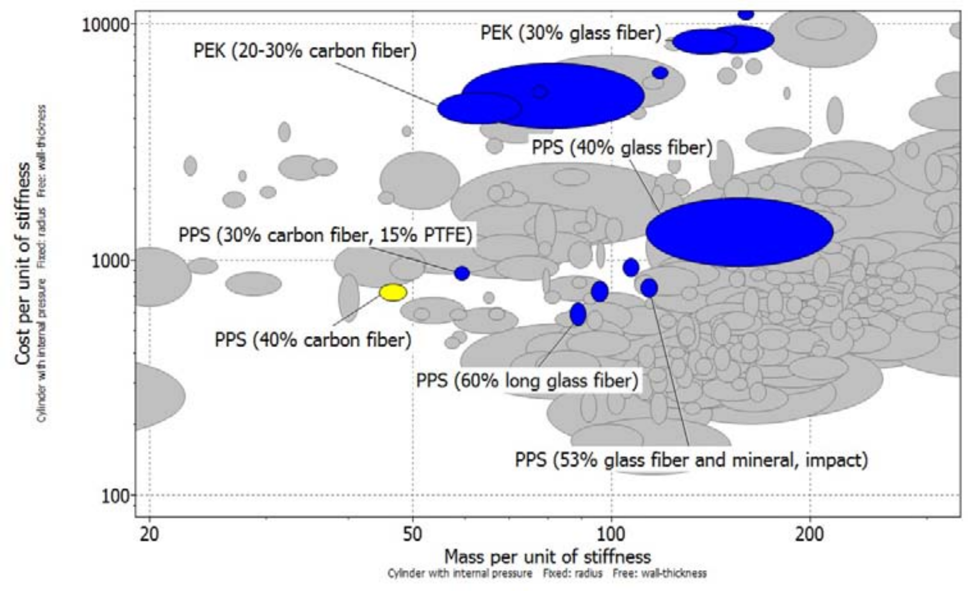


Figure 2. Three example applications of materials information technology in the field of engine design.

How can Materials Information technology help?

To support the challenges of efficient ICE design, a fit-for-purpose materials information management system must support:

- The capture, display and efficient query of multi-dimensional data, such as mechanical properties which vary with temperature.
- A set of best practices for materials selection, such as the allowing of *interpolation* between data points but not *extrapolation* beyond them.
- An underlying system of access and version control to ensure that appropriately-qualified material experts can determine which data is appropriate for use in which applications, and release it with suitable conditions to the design community.
- Interoperability with all relevant CAE platforms to ensure that consistent, appropriate data is being used for all simulations.
- The flexibility to bring together all aspects of a material (mechanical, durability, processing, physical, economic) in one system, supporting the systematic selection and rejection of material options during early stage R&D.

What are the benefits?

Some of the benefits identified by engineering organizations that have adopted materials information technology for similar applications include:

- Confidence in the numbers used for simulation, leading to faster design cycles with less over-engineering.
- Fewer design bottlenecks caused by materials experts answering the same questions again and again—with the subsidiary benefit that Material & Process Groups get to spend more time innovating and less time responding to simple questions.
- Faster rejection of inappropriate material candidates, earlier in the innovation process.
- The reduced warranty risk that comes with having a systematic approach to selecting and designing with new materials.

Benefits include faster design cycles with less over-engineering, fewer bottlenecks, faster rejection of inappropriate material candidates, and reduced warranty risk.

2.2 Lightweighting through material selection

What's the challenge?

There are three basic ways to reduce the weight of a vehicle: make parts thinner by using stronger materials; use a lighter material; or redesign parts of the vehicle so that certain components become unnecessary. We'll look at the general subject of redesign in the next section, but here we focus on the first two options.

We will consider the main classes of material used in structural components of vehicles—both safety-critical and otherwise: steels; aluminum and magnesium; and composites.

1. Steels

For many high volume body-in-white applications, steel remains the only competitive option, although the amount of mild steel in a typical high volume car has dropped significantly in the last ten years (3). The trend is instead towards ever stronger steels, which give the same structural and safety performance for less material. The usual trade-off is between strength and elongation—the stronger the steel, the less formable it becomes. Figure 3 shows the typical landscape of automotive steels in this property space; the goal is to push development towards the top right hand corner.

How can companies ensure the data flows efficiently from supplier to test house to materials group to simulation group?

As new steels are developed—from dual-phase and TRIP steels to the newer press-hardened boron steels and advanced high strength (AHSS) steels—a number of challenges become apparent:

- How can automotive companies quickly assess the suitability of innovations in steel?
- No steel can be used in a safety critical part without extensive qualification. From strain-rate dependent material tests, to CAE models, how can companies ensure the data flows efficiently from supplier to test house to materials group to simulation group without errors, inconsistencies, or loss of data traceability?
- Will new steels require the development of new simulation models altogether? In which case, what new experimental parameters might need to be captured and published?

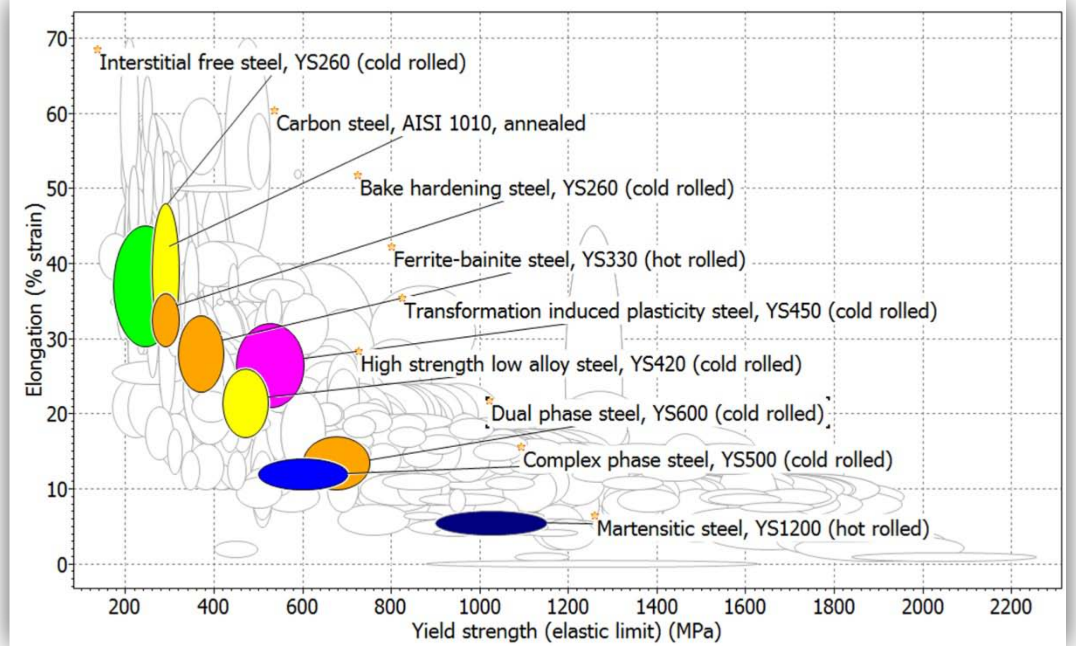


Figure 3. A typical landscape of the strength and elongation of automotive steels generated using the CES Selector 2013 software; the goal is to push steel development towards the top right hand corner.

2. Aluminum and Magnesium

The industry abounds with success stories of lighter alloys replacing traditional steel parts, particularly in the luxury end of the market (4). With the exception of a few critical areas, it is now possible to make an entire body-in-white from aluminum, resulting in significant weight reduction and performance increases.

Apart from the obvious economic implications of the up-front investment needed to switch production from steel to something else, there are materials information challenges here too:

- What different skillsets are required in the Material & Process group to deal with new alloys? How much re-learning is required?
- Can legacy databases / analysis tools designed for steels be adapted at a reasonable cost? Does it make sense to re-use these systems for all the new test data that will be generated for new alloy qualification—are they *fit for purpose*?
- New joining technologies are required for joining dissimilar materials—what material testing is required to support this, and how can it be captured and disseminated to engineers?
- Once production begins, new kinds of specifications will be flowing up the supply chain, and new kinds of supplier certifications will need to flow down. Is the data infrastructure in place to ensure the appropriate QA can take place, to check incoming batches of material are on-spec, and to allow metallurgists to carry out the appropriate forensic analysis in the case of failure?

3. Composites

Structural, safety-critical body-in-white applications for composites are currently limited—mostly by price and repair considerations—to high end, low volume sports car markets, although there is a huge amount of industry interest and research in this area and it is possible that these material technologies will make their way to progressively higher volume segments in the coming years. It is estimated that if the cost of carbon fiber can be halved, its demand for automotive applications in 2017 will be three times what it is today (5).

Even so, there have been a number of successful uses of composite or hybrid materials, particularly glass or natural-fiber reinforced polymers, in non-safety-critical parts in the high-volume car industry: parts such as engine covers, trim, glove box covers, and instrument panels make excellent candidates for weight reduction using such technologies.

Composites require a different set of properties to be captured compared to more 'traditional' materials, both in terms of material description and test types.

It seems clear that use of composites will only increase in automotive in the future—so what are the materials information challenges that will result?

- Composite materials cannot be described with a simple designation or grade name. Their identity, or pedigree, depends on a complex hierarchy of constituent parts and processing. Efficiently capturing and maintaining test and design data is meaningless without a system to handle such a hierarchy.
- Composites are anisotropic, meaning that their properties must be captured as functions of variables such as fiber orientation and laminate direction. These variables in turn will depend upon the part geometry and processing route.

- Further complexities such as cure cycle and storage conditions add to the difficulty of representing a composite material electronically.
- Composites require a different set of properties to be captured compared to more ‘traditional’ materials, both in terms of material description and test types. Existing databases, which may have been optimized for steels or other materials, may be unsuitable.
- All the problems above mean that there is also a rapidly evolving set of disciplines for the simulation and virtual prototyping of composites—each of which will have its own demands on data and model generation.

Pursuing a composites strategy means that automotive companies will need to completely re-think the way they capture, manage and deploy materials information across their engineering lifecycle. The good news is that many of these considerations have been addressed by other industries, such as aerospace, and the materials information technology already exists to make this transition possible.

How can Materials Information technology help?

Again, let us consider what it means for a materials information management system to be ‘fit for purpose.’ Drawing from the challenges above, it is clear that companies will need systems that:

- Support the rapid exchange of materials information between suppliers and OEMs.
- Support the varied and rapidly evolving demands of simulation and virtual prototyping software.
- Allow systematic, fast, early decisions to be made about new materials so that R&D groups can quickly reject unpromising candidates and pursue only valuable lines of enquiry.
- Combine engineering, cost, and environmental objectives together so that objective decisions can be made.
- Have the flexibility to support the varied requirements of *any* new material program, whether steel, light alloy, or composite. Composites in particular will require extremely challenging sets of properties to be managed.
- Draw upon the experience and best practice of other industries—such as aerospace—so that automotive companies are not starting from scratch in designing materials databases for their new material test programs.

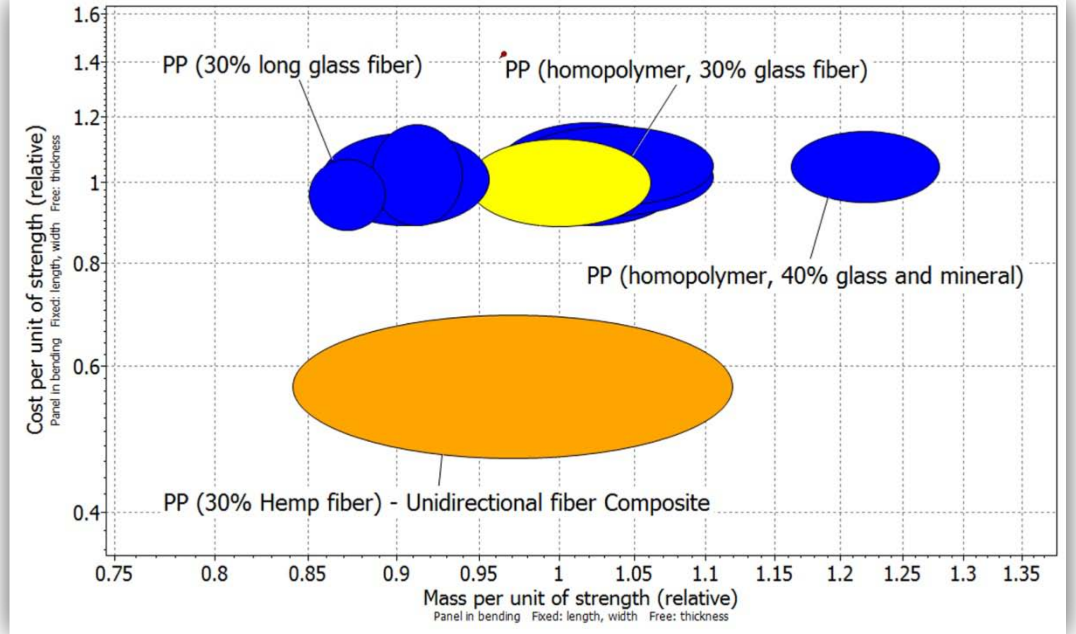
> ***Automotive companies can draw upon the experience and best practice of other industries, so that they are not starting from scratch.***

The last point is particularly significant—other industries often have more experience with composites which can be leveraged to great effect. The Materials Data Management Consortium (6)—a group of leading aerospace and defense organizations—has since 2001 been defining best-practices in the management of materials information, one aspect of which is the development of a database schema and workflow for composites.

On the following pages there are some examples of materials technology in action, supporting lightweighting initiatives (Figure 4), and, in Figure 5, an illustration of a typical database schema, taken from a recent White Paper (7) on the subject.

Example 1

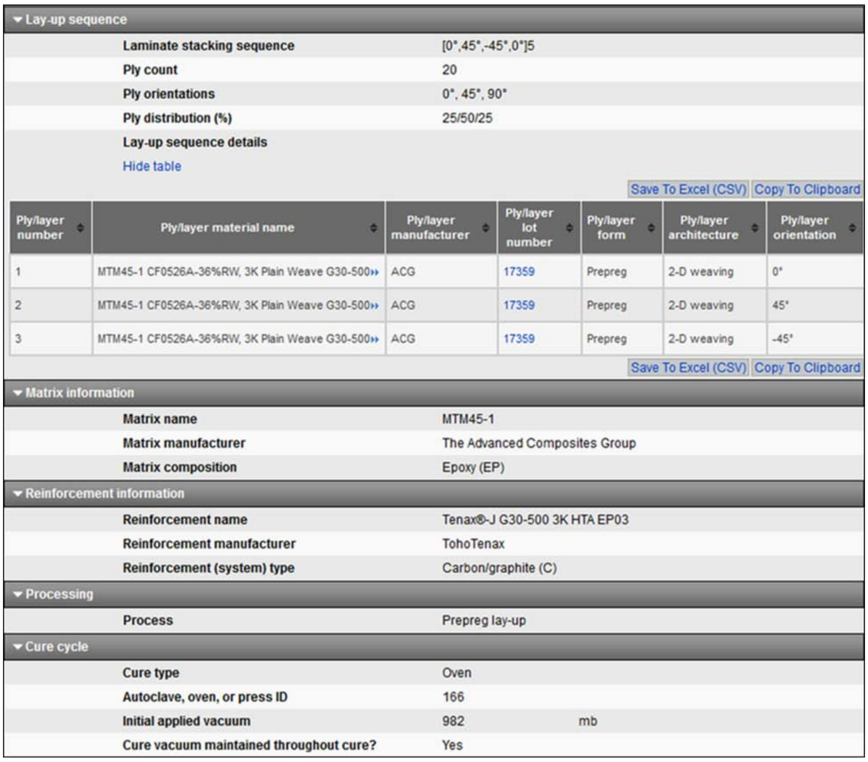
This figure (made using CES Selector™) shows an estimation of the weight benefits of using 30% hemp filled polypropylene compared to a glass filled alternative in a battery carrier application. The orange bubble for the composite was modeled using the properties of the constituent matrix and reinforcement—before any detailed prototyping or analysis. It is clear from the size of the bubble that the uncertainties are large, but as much as 15% weight saving might be theoretically possible. Ford has claimed an 8% weight reduction in a similar application(3). Such early-stage material investigation techniques can save significant time and expense in qualifying new materials.



Example 2

Composites provide particular materials information management challenges in light of the complex interrelationship between design data, test data and materials 'pedigree'.

The screen shot shows how these unique properties can be handled using the MDMC schema illustrated in Figure 5.



Laminate stacking sequence	[0°,45°,-45°,0°]5
Ply count	20
Ply orientations	0°, 45°, 90°
Ply distribution (%)	25/50/25
Lay-up sequence details	

Ply/layer number	Ply/layer material name	Ply/layer manufacturer	Ply/layer lot number	Ply/layer form	Ply/layer architecture	Ply/layer orientation
1	MTM45-1 CF0526A-36%RW, 3K Plain Weave G30-500››	ACG	17359	Prepreg	2-D weaving	0°
2	MTM45-1 CF0526A-36%RW, 3K Plain Weave G30-500››	ACG	17359	Prepreg	2-D weaving	45°
3	MTM45-1 CF0526A-36%RW, 3K Plain Weave G30-500››	ACG	17359	Prepreg	2-D weaving	-45°

Matrix name	MTM45-1
Matrix manufacturer	The Advanced Composites Group
Matrix composition	Epoxy (EP)

Reinforcement name	Tenax®-J G30-500 3K HTA EP03
Reinforcement manufacturer	TohoTenax
Reinforcement (system) type	Carbon/graphite (C)

Process	Prepreg lay-up

Cure type	Oven	
Autoclave, oven, or press ID	166	
Initial applied vacuum	982	mb
Cure vacuum maintained throughout cure?	Yes	

Figure 4. Some examples screenshots showing materials information technology being applied to lightweighting initiatives.

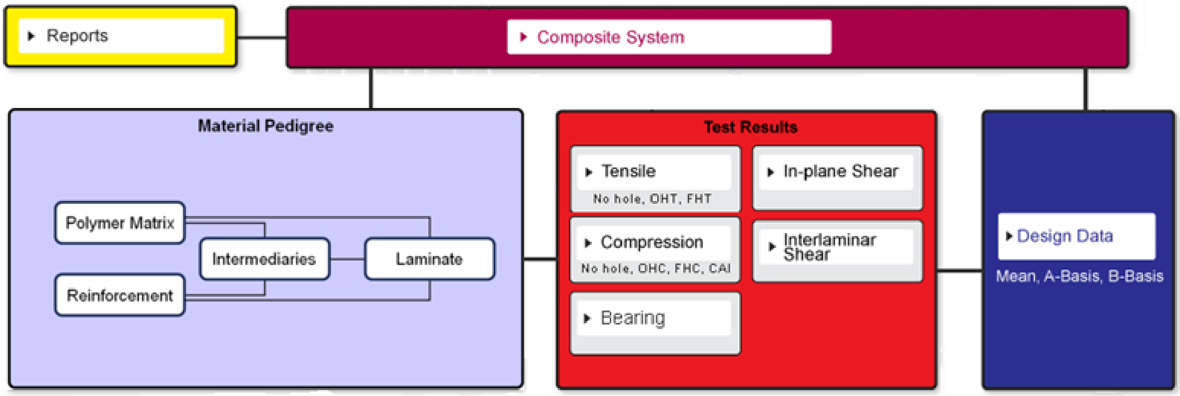


Figure 5. A high level representation of the MDMC schema for composites test data management. Each box in the schema has a Consortium-validated electronic data structure which users can modify for their precise needs.

What are the benefits?

Changing the materials that vehicles are made of can be a huge undertaking, especially given the cost and time pressures that automotive companies are under. Any technology that reduces the time spent qualifying new materials, or that reduces the risk of error or over-engineering, will give automotive companies a competitive edge: they can innovate faster, without compromising engineering quality.

Reduce the time spent qualifying new materials… and reduce the risk of error or over-engineering.

2.3 Lightweighting through redesign

What's the challenge?

All of the strategies discussed so far will require some element of redesign. It is even possible to reduce the weight of a vehicle without changing the material at all—perhaps by replacing several parts with a single casting, or by finding creative ways to remove entire components or features.

The challenge here is one of visibility. Many OEMs comment that they often do not know the complete weight of a vehicle until *after* tooling or other production costs are incurred. And no design is ever done in a single pass—redesign after redesign occurs until all the stakeholders in a project (materials, environmental, compliance, purchasing, etc.) are happy. So how can materials information be *integrated* into the design process so that engineers have *visibility* over the material-related implications of their design decisions as early as possible?

How can materials information be integrated into the design process so that engineers have visibility over the material-related implications of their design decisions as early as possible?

How can materials information technology help?

CAD, CAE and PLM technology has become very powerful, and many companies have invested significant amounts to deploy it across their workforce. When it comes to materials, however, three things are needed to augment this technology infrastructure:

1. A centralized, approved 'Gold Source' of materials information which ensures that there is only one definition of each material used in designs, and that designers, CAE experts, purchasing groups and materials groups all have access to a consistent, traceable source of information.

2. The integrations to allow this data to be fed directly into the CAD, CAE and PLM tools, not only to make the workflow more efficient, but to allow *product analytics* of entire assemblies so that engineers and managers can ask: "what are the implications of my material assignments on the finished product?"

3. Information in the early stages of design which allows companies to assess the environmental impact of a product—not just weight, but the entire lifecycle environmental cost, including raw materials, manufacture, use and disposal.

4. Risk analysis tools to look at design choices and identify what potential legislation may apply to the materials selected—not just current legislation but any potential rulings that may impact the availability of materials over the production and warranty timescales of the vehicle.

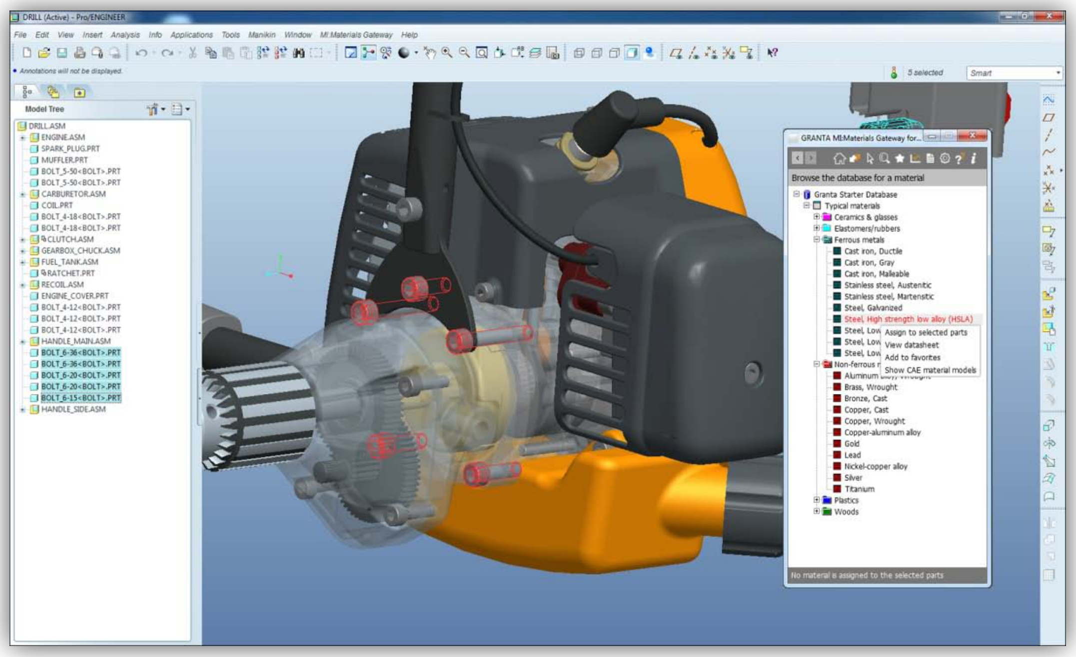
Overleaf are some sample screenshots of common CAD and CAE packages illustrating the requirements above. All three examples are built from the same underlying technology (GRANTA MI:Materials Gateway™) which enables them to feed off the same, consistent underlying database.

What are the benefits?

Technologies such as MI:Materials Gateway mean that, for the first time, companies can standardize their materials information and make it accessible to all the different consumers of data in their organization *without* them needing to leave their familiar working environment. One automotive OEM described this as "*raising the Materials IQ*" of their organization.

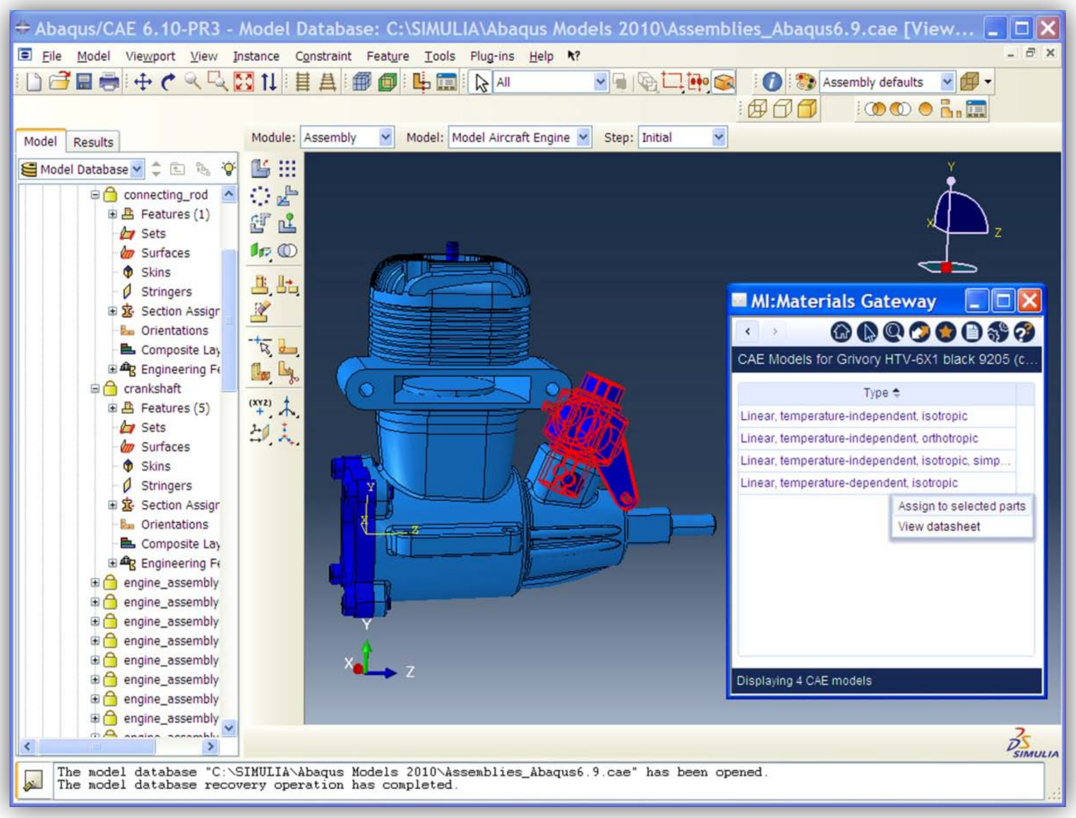
> ***The goal is to raise the Materials IQ of organizations.***

The result is that the 'design revolution' triggered by lightweighting and emissions-reduction goals can work hand-in-hand with the accompanying 'materials revolution', again reducing time and risk in the design process and enabling companies to deliver more innovative, more fuel-efficient vehicles to the market faster than ever before.



No material is assigned to the selected parts

Figure 6. The GRANTA MI:Materials Gateway, providing a direct link between a company's "Gold Source" materials database and design tools, in this case Pro/ENGINEER.



Module: Assembly
Model: Model Aircraft Engine
Step: Initial

CAE Models for Grivory HTV-6X1 black 9205 (c...

- Linear, temperature-independent, isotropic
- Linear, temperature-independent, orthotropic
- Linear, temperature-independent, isotropic, simp...
- Linear, temperature-dependent, isotropic

Displaying 4 CAE models

```
The model database "C:\SIMULIA\Abaqus Models 2010\Assemblies_Abaqus6.9.cae" has been opened.
The model database recovery operation has completed.
```

Figure 7. Assignment of CAE models within Abaqus/CAE, again drawing on data from the same central "gold source" which has been used throughout the design and engineering process.

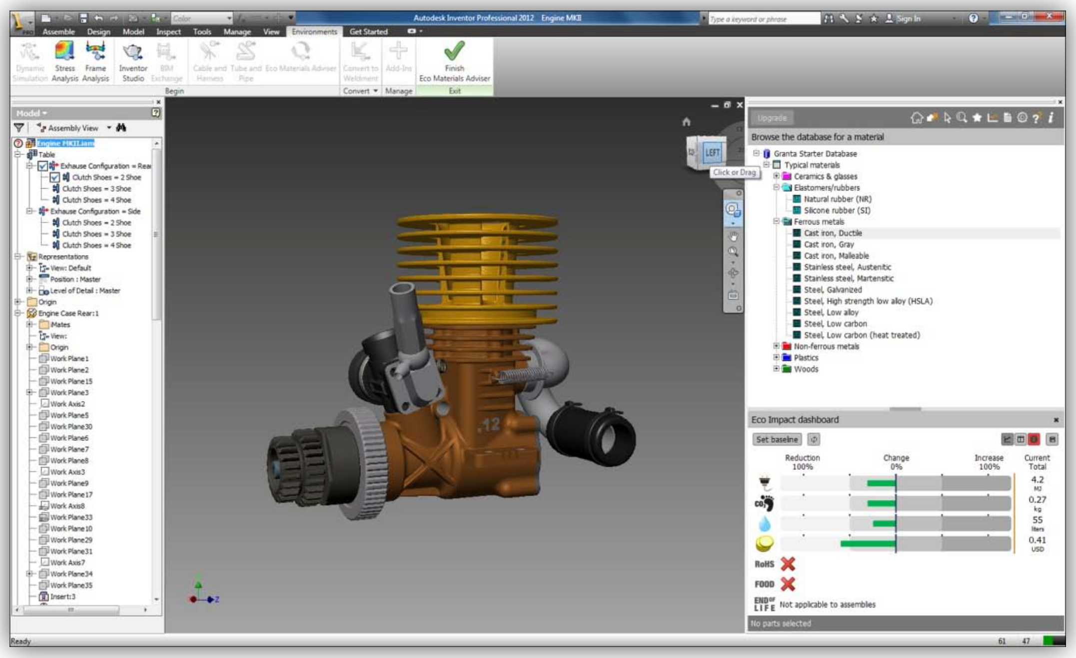


Figure 8. The Eco Materials Advisor in Autodesk Inventor, showing an example of an Eco Dashboard. The Dashboard gives designers immediate feedback on the energy, CO2, water usage, cost, recyclability and legislative impacts of material selections. It can also tie directly to a company's in-house materials database.

2.4 Other strategies

Referring again to Figure 1, it is clear that we have only considered a small part of the 'emissions decision tree' in our analysis above. Rolling resistance reduction, aerodynamic drag reduction, reduced power electronics, air conditioning efficiencies, regenerative braking, Hybrid and Fully Electric Vehicles: the list of innovations is endless. Do all of these strategies have implications for materials information technology? Most of them certainly involve redesign, with all the considerations discussed in the previous section. Beyond that, the influence of materials varies from case to case, but to consider a few final examples:

- PSA views road resistance as one of the three main drivers of 'green materials' in their vehicles (8). Tire manufacturers are essentially material producers, with closely-guarded formulations for their products. Just as for materials producers, materials data is important—from testing and design, where it helps to optimize the product, through to sales and marketing, where it can be used to present the product benefits. An underlying materials database to support the flow of this information increases the chance of success.
- Reducing parasitic losses such as thermal or electrical losses in onboard systems adds a new dimension to materials selection. Materials are now not just being chosen for their mechanical properties, but for other functional reasons. A decision support system, such as that illustrated in the first example in Figure 4, must allow for this kind of selection. For example, an engineer might ask: "what is the trade-off between cost and weight for a material which must give a certain level of thermal insulation?" A better-insulating material might be more expensive, but the design could use less of it, reducing both cost and weight of the overall part.
- While fully electric vehicles are unlikely to represent a significant proportion of the market until at least 2030 (9), they are an extremely active and exciting area of vehicle design. In many cases, entirely new data will need to be managed: how, for example, can companies identify the optimal battery selection? Another major implication of electrification is the use of rare materials which may be in critical supply. By combining all aspects of a material's 'identity' into a single Gold Source database, companies will be able to integrate this kind of risk analysis into the heart of the design process.

3. Conclusions

We have looked at a number of viable strategies for emissions reduction and lightweighting, all of which have implications for the way that materials information is managed, deployed and used within engineering organizations. We have also considered the ways in which Materials Information Technology (comprising software, data and industry best practice) can contribute to the success of these strategies, reducing risk and shortening design cycles.

We conclude by posing some questions about how materials information is currently managed in your own organization:

1. Is your company's materials knowledge integrated with CAD, CAE, and PLM as effectively as it could be?
2. Is your current system for managing materials data flexible enough to be adapted to support your new lightweight materials initiatives? If not, do you have the means to adapt it?
3. Do you have the expertise in-house to develop a materials data management system, with all the necessary underlying technologies such as Version Control, Access Control, Unit Systems, searching and reporting?
4. Do you have the means to compare new material candidates against traditional competition to get an early picture of the trade-off between cost, weight, and performance?
5. Do you have a single, consistent view of materials across your entire organization?

A fit-for-purpose Materials Information Technology may provide significant benefits in helping you to meet your emissions and lightweighting targets.

If the answer to any of these is unsatisfactory, a fit-for-purpose Materials Information Technology may provide significant benefits in helping you to meet your emissions and lightweighting targets. The Appendix below provides information on where to find out more.

Appendix—about Granta software

Granta Design is the world leader in Materials Information Technology. Our software tools, materials data, and materials database solutions help engineering enterprises to manage materials information, enable better material decisions, design for environmental objectives, and provide materials support for design, analysis and simulation.

For more information on the two software packages featured in the examples in this paper, GRANTA MI™ and CES Selector™ see:

www.grantadesign.com/products/

For a detailed discussion of the *Business Case* for materials information management, see:

www.grantadesign.com/papers/whitepaper.htm

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