Towards a LIFE CYCLE economy

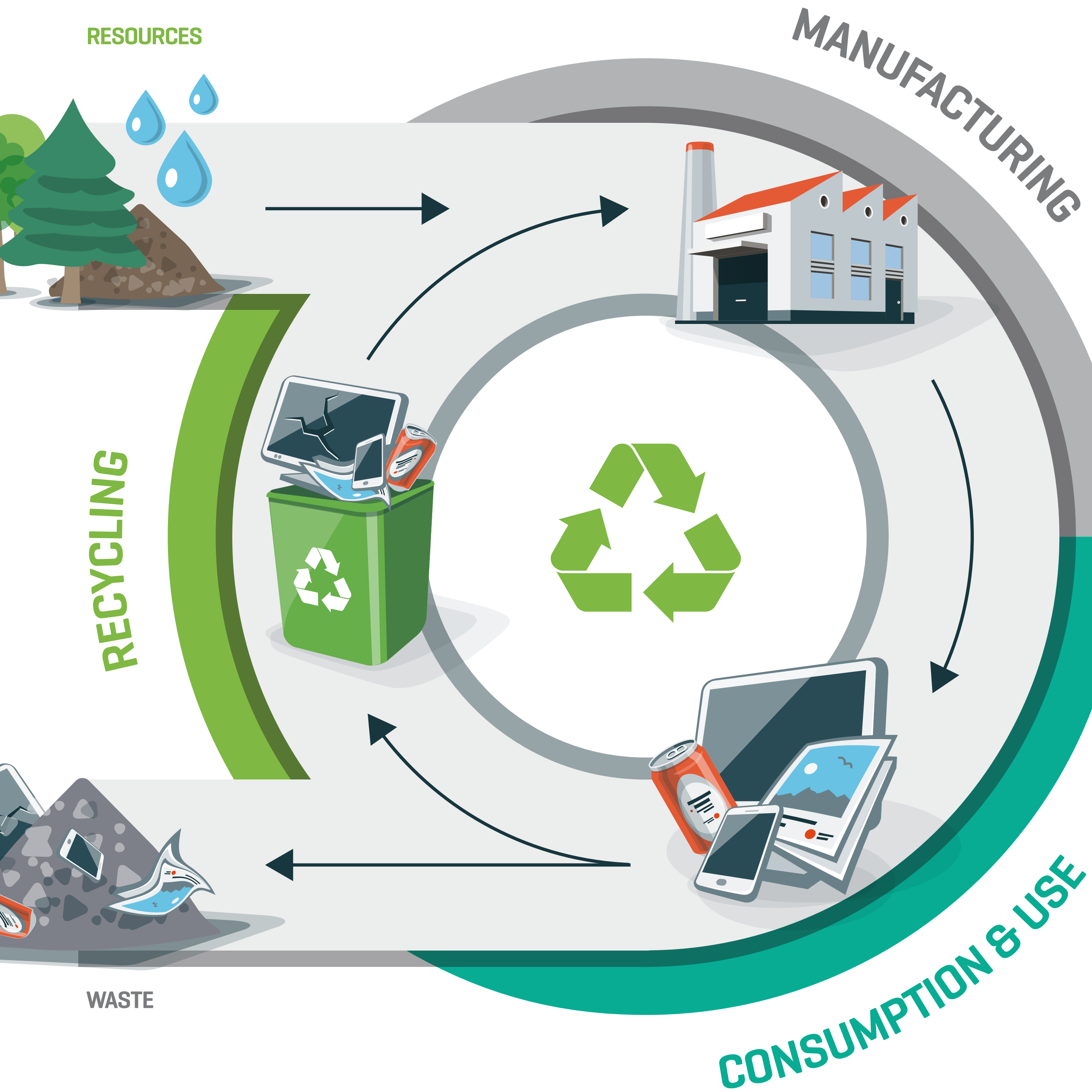
With tightening legislation forcing us to rethink our attitudes to resource consumption, energy use and harmful emissions, a long-established mindset is fast gaining new ground. Life Cycle Assessment (LCA) is a valuable instrument in the planner's toolbox for examining policies, projects and products to assess their environmental impact over their complete lifespan – and, as **Tony Lewin** reports, Ricardo is an important LCA player on the international stage

Should I buy organic vegetables or the ordinary varieties? Shop on the high street or online? Take the plane or the train? Choose a woollen sweater instead of one made of synthetic fibres? Or, raising the budget somewhat, should I replace my car with a standard gasoline model, a hybrid or an electric?

These are everyday dilemmas faced by environmentally conscious consumers in many parts of the world, and they touch on several sensitive issues – ethics, cost, health, convenience and personal politics. On a much broader level the consequences of decisions like these present a dilemma for planners, too. Take the car example: just as the rush to diesel in the past two decades has had air-quality knock-on effects in Europe, so a wholesale migration to electric vehicles might have other unforeseen consequences besides the obvious one of pressure on the electricity supply industry.

These are all areas where the technique of life cycle thinking can be useful in helping both individuals and public policy makers come to a balanced and level-headed decision – one that weighs up the positive and negative impacts of the various alternative policy choices. The assessment can be framed in many different ways: the most familiar of these metrics is money, central to life cycle cost analysis and the total cost of ownership (TCO) calculations that help operators of costly trucks, aircraft and other machinery to decide which vehicle packages will offer them the best return on their investment.

Increasingly, however, life cycle techniques are being employed to examine much broader aspects of issues than just the familiar question of cash. Life cycle assessment (LCA) looks to evaluate the environmental (and sometimes social) impacts of a product or service, across its entire life cycle. A good example is provided by the recent analysis conducted by Ricardo on behalf of the fuels industry



research body Concawe, and reported on in the Q4 issue of RQ last year. The study looked at two contrasting pathways to achieve net-zero greenhouse gas (GHG) emissions from Europe's vehicle fleet by 2050, comparing an all-electric approach with one in which low-carbon liquid fuels play a major part. The report took in a broad spectrum of parameters, from biofuel supply chains to rare-metal resource scarcity, and concluded that a halfway house position, with a more limited role for liquid fuels, could provide the optimum balance between cost, environmental impact and security.

On a more micro level, as we show below, LCA can also flag up important warnings when it comes to engineering choices – such as deciding on the optimum capacity for an electric vehicle's battery.

High-level planning tool

In recent years LCA has taken on a whole extra dimension as a valuable tool to inform governments and legislators and to aid them in key macroeconomic policy decisions, especially when it comes to weighing up the environmental consequences of alternative courses of action under consideration.

LCA is becoming increasingly important in the public sphere, says Simon Gandy, principal consultant in sustainability and LCA knowledge leader at Ricardo Energy & Environment. "If you look at what's going on at the European Commission, they are advocating for all their environmental policy that decisions be taken on a lifecycle basis," he reveals. "And initiatives like the circular economy and trying to make things last longer, a lot of that is predicated on LCA."

Ricardo Energy & Environment (REE) is working with Zero Waste Scotland, for instance, to reduce the nation's waste. "Life cycle thinking underpins a lot of what they do," says Gandy, "and the same is true of the UK Department for Food and

The circular economy model re-uses and upcycles waste materials to minimise the exploitation of primary resources. It contrasts with the conventional linear practice of extract, make, use, dispose

The circular economy

The Ellen MacArthur Foundation describes the concept of the circular economy as "looking beyond the current take-make-waste extractive industrial model, and aiming to redefine growth, focusing on positive society-wide benefits. It entails gradually decoupling economic activity from the consumption of finite resources, and designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital."

It is based on three principles:

- **Design out waste and pollution**
- **Keep products and materials in use**
- **Regenerate natural systems**

Ricardo is one of the lead participants in a European Commission Joint Research Centre study looking at options to develop a circular economy for EV batteries.

The committee's report, due to be finalized later this year, includes a look at life-cycle impacts of the various value and materials chains. Its interim recommendations state that while in some areas the costs of establishing standardized structures may outweigh the benefits, "the overall range of expected benefits outweighs the identified costs," delivering "positive impacts ranging from industrial growth, job creation and enhanced environmental protection."

Rural Affairs (Defra)."

Businesses in the transportation sector are becoming much more conscious of their public image, notes Nik Hill, also of Ricardo Energy & Environment. "They are already using LCA in a variety of ways, not just for costs but also for environmental impacts. They are very conscious of their corporate responsibilities to minimize the environmental impact of their activities."

While climate impact assessments are central to most of today's analyses, Simon Gandy also notes a broadening of LCA applications: "We're seeing a lot more interest in things other than global warming: companies come to us as they want to think about resource consumption – and I think that is going to be the biggest issue we face in the future."

LCA can also address other issues such as local air quality, pollution, acidification, and ozone depletion, says Gandy. "These are existing issues, but also very important looking into the future."

Life cycle assessment can be used to weigh up potential impacts for many different types of pollution, allowing policymakers to come up with informed decisions

A case in point: EV battery capacity

With almost every international automaker having now woken up to the reality of an electric vehicle future, there is much jockeying between rival brands to offer the longest possible driving range, thus allaying perhaps the greatest perceived concern of potential customers.

But is bigger necessarily better when it comes to car batteries? Does higher capacity equate with a lower overall environmental impact? And how do the various technology choices influence the holistic picture? These are among the many questions being examined in detail by Nik Hill and his team in two significant studies for the European Commission, the first entitled *Circular Economy Perspectives for the Management of Batteries used in Electric Vehicles*, and the second *Determining the Environmental Impacts of Conventional and Alternatively Fuelled Vehicles through Life Cycle Assessment*. Throughout the studies, LCA methodologies are employed to weigh up the multitude of choices available to engineers, policymakers and consumers.

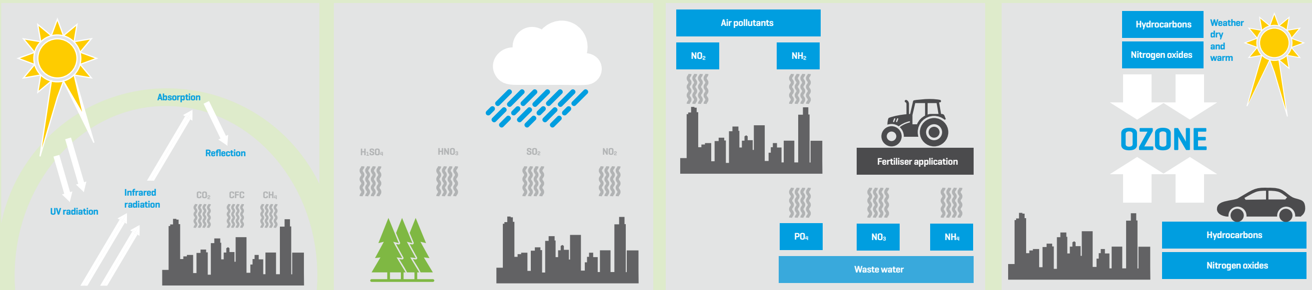
As is often the case in environmental matters, this picture is not as straightforward as it initially appears. Looking across the lifetime of an electric vehicle, and assuming the energy on which it runs is largely renewable, one of the biggest of its environmental impacts typically arises from the manufacture of its battery. The bigger the battery, the higher the vehicle's embedded GHG emissions, the greater its weight and the lower its efficiency – so on the face of it, for drivers who don't cover much daily mileage, a smaller battery might appear better. But, as ever, there are competing factors at work.

A smaller battery, recharged more frequently, could prove a false economy. Though cheaper and lighter and better for short-term economy, it has a higher likelihood of reaching its limit of charge-discharge cycles and, critically, it might need replacement sooner, thus increasing the vehicle's embedded emissions impacts. A larger battery might not need replacement within an average vehicle's lifetime as it would require fewer cycles.

Yet there could be further mitigating factors. What would be the influence of alternative battery chemistries better suited to frequent charge-discharge cycles? And what if the potential second lives (in domestic energy storage, for instance) of ex-automotive batteries are taken into account? Again, the range of factors in the equation is immense, but, as Hill reveals, there may be a sweet spot.

"How these things play out is really complicated," he says. "It's not like saying a smaller battery is better and a big one worse. It may be that if you have a bigger

Environmental impact categories



Global Warming Potential (GWP) · **Acidification Potential (AP)** · **Eutrophication Potential (EP)** · **Photochemical Ozone Creation Potential (POCP)**

battery you don't have to replace it. What this illustrates is that you have to be careful. LCA is a brilliant tool, but if you miss or over-simplify certain elements you can end up making the wrong decisions."

It all comes back to thinking more holistically about the issue, argues Jane Patterson, technology strategy consultant at Ricardo Strategic Consulting. "It's not necessarily bigger or smaller," she says. "What matters is to right-size the battery. It's not so much the vehicle segment, either: it comes back to who is the operator, and how they want to use the vehicle. The powertrain solution for someone who has a daily commute of 10 miles each way would be very different to that for the driver who's up and down the motorways all day."

In addition, she points out, other likely future EV applications such as on-demand mobility services will further tax the ingenuity of engineers when it comes to providing the best possible battery configuration for each purpose. And again, LCA can be a very useful tool in exploring the multitude of variables and identifying the more environmentally favourable solutions.

Auto industry perspective

Viewed through the eyes of automotive industry decision makers, the political and regulatory landscapes have become vastly more complex in the last decade. The once-narrow focus on CO_2 and greenhouse gas performance in the laboratory has broadened to take in emissions of a wide spectrum of other pollutants in real-world driving. Nitrogen oxides, hydrocarbons, particulate matter, sulfur, volatile compounds, even noise – so broad is the legislative matrix and so intricate the network of trade-offs and compromises that only a multi-dimensional analysis can make sense of the picture.

Again, says Patterson, LCA techniques

> **"The powertrain solution for someone who has a daily commute of 10 miles each way would be very different to that for the driver who's up and down the motorways all day"**
> **Jane Patterson, technology strategy consultant, Ricardo Strategic Consulting**

Whole-life emissions: vehicle types and life cycle stages

Relative contributions of each life cycle stage by vehicle type and powertrain technology

Vehicle Type	Conventional ICE Powertrain Technology				BEV Powertrain Technology			
	Vehicle Production	Well to Tank	Tank to Wheels	End of Life	Vehicle Production	Well to Tank	Tank to Wheels	End of Life
Motorcycle	c.10-30%	c.10-15%	c.60-75%	>5%	c.45-75%	c.25-55%	–	>5%
Passenger Car	c.15-30%	c.10-15%	c.60-70%	>3%	c.20-60%	c.40-60%	–	>3%
Heavy Duty Truck	c.1-3%	>95%		>1%				
Bus	c.15>95%%	>95%		>5%	c.30-40%	c.60-70%	–	>5%

The relative contribution of embedded emissions (from vehicle production and end-of-life to in-use (WTW) is highly dependent on the **vehicle type, lifetime mileage and duty cycle**

The contribution of end-of-life is difficult to quantity since most studies assume high recycle rates and some apply 'credits' for producing recycled material. However the general consensus that its portion of overall life cycle emissions is relatively low (<5%)

Carbon intensity for electricity could be nearly zero if renewable, sustainable electricity is used in the vehicle. This should shift all life cycle environmental burdens to vehicle production and end-of-life

Source: Understanding the life cycle GHG emissions for different vehicle types and powertrain technologies, Ricardo report for LowCVP (2018) (RD18-001581-2

Objective answers to everyday questions

As mentioned on page 10, Life Cycle Assessment (LCA) is a useful tool in making major strategic decisions – but it can be employed to resolve everyday dilemmas, too.

As regards organic or non-organic food, some studies have found that the greatest emissions occur in the growing of the food, not the shipping, while in the field of clothing the wool/synthetic dilemma impacts on many areas – agriculture, petrochemicals, the consumer society and the circular economy. One suggestion is that temperature at which the garment is washed could be another important factor.

Another earlier external study came up with some interesting answers. Tasked with deciding which hand-drying solution was best for public washrooms, LCA experts looked at all the issues involved in the supply of electricity for hot-air hand dryers, and the environmental balance of the alternative solution, the provision of paper towels.

The hand air dryer manufacturers wanted to make the point that their products are better for the environment than paper towels, even though most people think the opposite. However, the study found that the result depended critically on how many paper towels people use. If you pull out two and two fall on the floor, it is definitely better to use a hand air drier – but if you use two towels it is about the same.

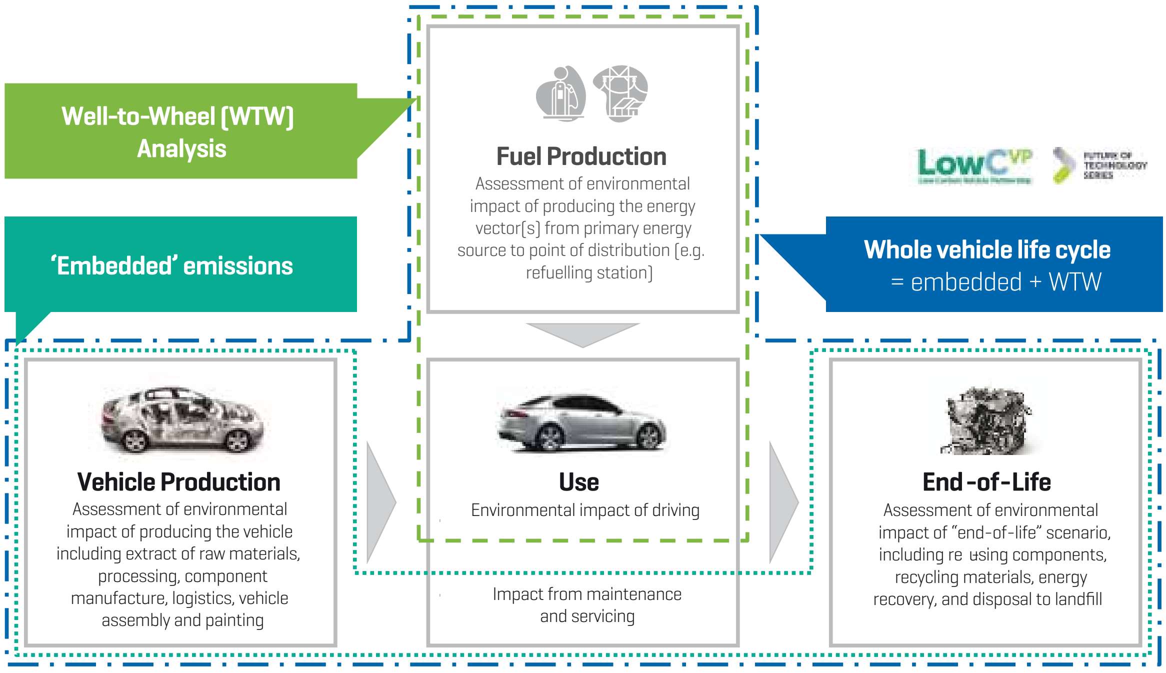
Keeping rail's eco footprint on track

As part of the tendering process for the UK's massive HS2 high-speed rail programme, all companies bidding for contracts have to calculate the climate change impacts per passenger kilometre for the entire life of the equipment on offer. Ricardo has been involved with one potential rolling stock supplier to evaluate the significance of their materials and construction techniques versus their operating performance, to identify the most preferable solution to put into the tender specification.

"This means we have to calculate the CO_2 that's embedded in the materials chosen, as well as the carbon consumed during the life of the components on the train," says Simon Gandy of Ricardo Energy & Environment. "In this case, HS2 is not concerned with the end-of-life of the components. Our client has sent us the bill of materials and the anticipated maintenance schedule, and we can use our software to calculate the associated carbon impacts."

In an earlier rail project Ricardo specialists looked at the relative carbon impacts of using steel versus aluminium versus a composite material. Steel is easiest to make and has the lowest manufacturing impact, aluminium is next and composite the highest. But steel is also the heaviest, and to operate the heavier train over however many years means higher overall emissions. Because of the long lifespan of a train it pays to go for the lightest solution possible, even if you have to use a more environmentally expensive material at the beginning. So, over the lifetime of the train the composite material is the best.

Life cycle assessment as applied to a vehicle



Source: Understanding the life cycle GHG emissions for different vehicle types and powertrain technologies, Ricardo report for LowCVP (2018) (RD18-001581-2

Calculating the life cycle impact of a vehicle is a complex business, taking in not only the emissions from manufacture and in-service fuelling, but also those generated in fuel production, routine maintenance and end-of-life disposal

can be employed to help plan a clearer way forward. "One of the things that has been coming out of Ricardo's recent LCA work is that we need to look at more than just GHG emissions."

To further compound the issue, shifts in many of the key parameters mean that decision-makers have to deal with a series of moving targets. Tailpipe CO_2 emissions, for so long the basis of European automotive regulation, will be significantly tightened in the next decade, something which will increase the relative embedded GHG in conventional vehicles but reduce their emissions in the key in-use phase. And with automakers using ever higher proportions of recycled materials in their new vehicles, new ways of evaluating the overall GHG impacts will have to be agreed.

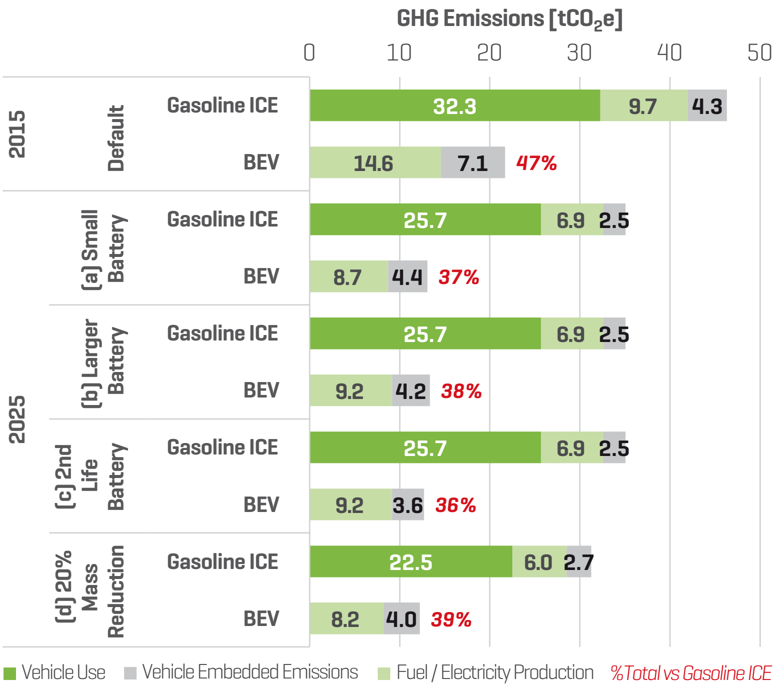
"At some point in our LCA work we may need to go to the next level of understanding," says Patterson. "If we are using these recycled materials, how much processing has to be done to make them to the right grade? And what will be the environmental burdens of that? And, further, for policymakers the concern might be that the use of that recycled material might be offsetting its use for a different purpose, which might then have to take more primary material."

> **"Our client has sent us the bill of materials and the anticipated maintenance schedule, and we can use our software to calculate the associated carbon impacts"**
> **Simon Gandy, Ricardo Energy & Environment**

Drawing the boundaries

As the examples above show, the results of any assessment can be heavily influenced by the assumptions built into the study and the boundaries that determine the scope of the study. But precisely where - and when - to

How design decisions affect life cycle emissions



Left: **Illustrative examples of how powertrain technology choices can affect the cumulative greenhouse gas emissions of a vehicle over a 210,000 km lifespan. Scores for large- and small-battery EVs are very close**

> **"It's not like saying a smaller battery is better and a big one worse. It may be that if you have a bigger battery you don't have to replace it"**
> **Nik Hill, Ricardo Energy & Environment**

draw the line is a tricky issue, as evidenced by several older electric car studies that incorporated the cost of setting up a charging structure but conveniently ignored the sunk costs and embedded emissions in the existing liquid fuel distribution network.

Deciding where that line should be drawn is "precisely the problem," agrees Nik Hill. "It can depend on a lot of things, including what environmental impacts you are looking at," he explains. "And it can depend on your resources, because the wider the net, the more work you have to do. But if you keep the line too close, you'll have to make more compromises and concessions."

Yet to have a good sense of where that line should be drawn in itself requires experience with the whole LCA process and a prior assessment of the likely significance of the different components and the likely consequences of going beyond the boundaries set.

Applying this thinking to the much broader landscape of possibilities that arise in an urban area if personal transportation is pitched against public transport and other intermediate modes, LCA can theoretically still cope, says Patterson. "But," she warns, "it still depends where you draw your boundary of analysis and what you're looking at, as well as what questions you are asking. If the goal of the scope is to work out what mode of transport is going to have the lowest environmental impact over a year's worth of commuting, you could build up a picture of what you want to model. You'd have to bring your assumptions into play, but basically, LCA could be used to answer that question."

Towards an environmental score?

Are LCA techniques robust enough to provide the basis for regulation and legislation, perhaps something like a lifecycle GHG footprint to underpin future vehicle taxation policies? It is a tempting proposition, especially in the transport sector, where it could at last provide a level playing field between the different primary energy sources in play, and it would also give a more accurate reflection of the actual life cycle environmental impact of each type of powertrain.

Yet, caution the Ricardo specialists, it is a complex subject and is already being discussed at a European level. The current frameworks, says Hill, provide rather too much flexibility and mean that outcomes of different studies may not be comparable with one another. The European Commission is now exploring the idea of a product environmental footprint, or PEF, which uses LCA in a much more standardized way – something that would make the assessments much more useful than those carried out under varying assumptions.

In the PEF pilot studies carried out so far, specific methodologies are applied to each category of item, meaning that like can be compared with like. Some 25 product categories have been assessed so far, ranging from photo-voltaic generation to T-shirts, beer and even pasta; the studies on coffee, stationery and marine fish were discontinued because they proved too problematic.

However, adds Gandy, Ricardo was recently commissioned to provide an environmental product declaration (EPD) for a company producing timber I-joists to take the place of the usual steel elements. "As there are already product category rules in place for construction materials, we were able to produce an EPD for the timber joists. So now if you go onto the International EPD System's website you can look at their EPD and compare it like-for-like with those of a Scandinavian company who also make timber joists."

The backers of PEFs, says Gandy, are trying to reduce the number of environmental criteria and, in a really ambitious initiative, distil them into a final environmental score. "This is controversial," adds Hill, "as each of these factors has to be given its own weighting in the determination of the final score. It's tricky, because you are dealing with climate change impacts, toxicity impacts, eutrophication impacts, and each has to be weighted in how much it contributes to the overall score."

Outlook

The type of objective, level-headed assessment that life cycle thinking can deliver is doubly important at a time when so many contrasting technologies are in the frame – not just for our future personal mobility but also for how we feed ourselves, power our homes and spend our leisure time.

And in many ways the example of battery-powered vehicles provides an excellent demonstration. Of course, with their heavily front-loaded environmental footprint because of their manufacturing emissions, BEVs start off on the wrong foot. But when BEVs are treated to the broader scope of a full LCA of everything from monetary and resource costs to their GHG emissions and other pollutant impacts, the comparison becomes clear enough to enable those key long-term decisions to be made. RQ