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Dear readers,

The only way to come up with answers to humankind’s current problems – increasing shortages of raw materials and the spread of greenhouse gases – is to tackle them on a broad front. In view of this, we draw up detailed life cycle assessments for every new model line we develop.

In this way, Audi is able to demonstrate how a vehicle’s effects on the environment have changed as compared with the previous model when assessed over the vehicle’s entire life cycle, from production through use all the way to recycling. The aim of Audi is to achieve a decisive reduction in environmental effects from each model to the next.

Certified life cycle assessments of this kind are ‘hard currency’, because they reveal the size of the ‘CO₂ backpack’ that the vehicle has to carry when it leaves the factory and takes to the road – as well as how efficient the car is.

Because of the holistic perspective taken, there are many factors that influence the results of the life cycle assessment. The use phase has the greatest influence: about 80 percent of total emissions occur in this phase. Audi is therefore devoting massive effort to increasing the efficiency of all its vehicle drivetrains. The TDI and TFSI engines, both developed by the Audi brand, and the efficiency modules still offer great potential in this respect. In addition, we are introducing alternative drivetrains for road vehicles and playing a leading role in the development of alternative fuels.

Introduction
We also regard the overall topic of environmentally acceptable lightweight construction as one of our most important tasks for the future. This means pioneering lightweight construction concepts both for existing drivetrain concepts using combustion engines and new forms of propulsion for electromobility. We are conscious of the fact that we can only adopt new technologies and materials in series production if their environmental characteristics also satisfy our high standards.

The life cycle assessment for the current Audi A6 has confirmed that Audi is on the right track. We have now succeeded in considerably reducing the new Audi A3’s total emissions as well. The proof is to be found on the following pages.

Michael Dick
Technical Development Director
AUDI AG
Audi balanced mobility

Ecology and economy in harmony: this is the biggest challenge we will face in the future. If we are to succeed, we must achieve equilibrium in the entire field of mobility – including human beings, their new values and their environment. **Our objective is CO₂-neutral mobility. In the words of Audi CEO Rupert Stadler:** “We […] are establishing a new attitude with our entire company behind it. This is the aim of Audi balanced mobility.”

Audi balanced mobility – this term makes it clear that Audi accepts responsibility for the entire value creation chain. Audi intends to bring about the vision of CO₂-neutral mobility by means of a continual optimization process throughout all phases of the vehicle’s life cycle. At Audi, we regard progress in the economical use of resources as an holistic task that applies to every field of activity. Cutting-edge technologies help us to develop our vehicles further, with efficient drivetrains and by using sustainable materials. Even when the very first basic concepts are examined at the start of the development process, strategic decisions are made that exert considerable influence on our production processes and on the entire supply chain. Instead of assessing individual modules, we look at the complete system comprising production, use and recycling. Life cycle assessments are important elements in this procedure: they help to reduce the impact our vehicles have on the environment. This is why Audi, within the context of Audi balanced mobility, will be drawing up a life cycle assessment for every new model line.
The mission of Audi balanced mobility: responsibility for the complete value creation chain

Targets:
zero emissions, CO₂-neutrality and economical use of resources

Production  
Use  
Recycling

Life cycle assessments for evaluation
Life cycle assessment – what’s involved

The life cycle assessment analyses the effects of a product on the environment during its entire existence, from production through its period of use and its end-of-life recycling. It is a quantitative evaluation of ecological aspects such as the emission of greenhouse gases (including carbon dioxide [CO₂]), energy consumption and acidification or ‘summer smog’. Audi compiles its life cycle assessments according to the procedure laid down in the international ISO 14040 series of standards.

Assessment of a vehicle’s complete life cycle as a major contribution to more sustainable treatment of the environment
- **Development phase**: assessment of materials and semi-finished product manufacturing chains
- **Production phase**: assessment of components and complete vehicles
- **Use phase**: assessment of fuel/electricity (including production)
- **Recycling phase**: assessment of process chains of valuable materials

**Stages in motor vehicle life cycle assessment**
Life cycle assessment – the boundaries

Before a life cycle assessment is compiled, its boundaries must be defined by deciding which processes should be examined. The available means, the time framework and data availability all have to be taken into account. Audi has laid down broad limits for its complete vehicle life cycle assessments.

The examination starts with the manner in which raw materials are obtained, and how individual components are manufactured. Even during the first new model development stages, the engineering teams have to make decisions that have a major impact on in-house production and the entire supply chain.

Audi’s experts assume for assessment purposes that vehicles will cover a distance of 200,000 kilometers. They not only take into account the emissions caused when the vehicle is being driven, but also those that occur when the fuel is produced. At the end of the vehicle’s life cycle, the energy needed for recycling is also included in the assessment.
System boundaries of total vehicle LCA

Manufacture
- raw material extraction
- semi-finished product manufacture
- component manufacture

Production

Use
- Supply → pipeline
- Transport → refining
- Provision of fuel

Recycling
- Recovery of energy and raw materials

Maintenance

Credits

= Product system
Life cycle assessment – effect categories

The main emphasis in life cycle assessments is currently the evaluation of greenhouse gases. But Audi is also carefully monitoring other environmental effects as well: eutrophication of water and soil, ‘summer smog’, acidification of eco-systems and the damage to the ozone layer.

In accordance with the procedure laid down in the ISO 14040 standard, the results from data collection (inventory analysis) are converted into effect indicators, which are then grouped together in effect categories.

The effect categories describe the major ecological problem areas. When Audi’s specialists assess the greenhouse effect as an important indicator, they list the effects of all gases that affect the climate. These are included in the evaluation according to the intensity of their effect as compared with CO₂.
Effect of substances on the environment

Inventory analysis:
- Extraction of raw materials
- Manufacture
- Production
- Use/transport
- Recovery/recycling

Effect indicators:
- $\text{CO}_2$
- $\text{CH}_4$
- $\text{SO}_2$
- $\text{NO}_x$
- $\text{HC}$
- $\text{R}_{11}$

Estimated effect:
- Global warming potential
- Eutrophication potential
- Photochemical ozone creation potential
- Acidification potential
- Ozone depletion potential
Audi A3 – the life cycle assessment

Audi has drawn up a detailed life cycle assessment for the new Audi A3. This was also the first time that diesel and gasoline engine models have been assessed separately. In each case, the top-selling version from the previous model line was examined: the 103 kW Audi A3 2.0 TDI and the 92 kW Audi A3 1.4 TFSI, both with six-speed manual transmission.*

As with the current Audi A6, it has proved possible to reverse the vicious circle of increasing weight on the new Audi A3. The new 110 kW Audi A3 2.0 TDI is 40 kilograms and the new 90 kW Audi A3 1.4 TFSI no less than 80 kilograms lighter.

These weight reductions were primarily achieved by applying intensive weight-saving measures to the body, engine, drivetrain and chassis. The diagram shows all the areas that made a significant contribution to weight savings.

* Fuel consumption acc. to NEFZ test cycle:
  
  **Audi A3 2.0 TDI, 103 kW (2011 model year):**
  fuel consumption: urban 5.5 l/100km; country 3.8 l/100km; combined 4.4 l/100km; CO₂ emissions: 115 g/km; energy efficiency category A

  **Audi A3 2.0 TDI, 110 kW (2012 model year):**
  fuel consumption: urban 4.9 l/100km; country 3.6 l/100km; combined 4.1 l/100km; CO₂ emissions: 106 g/km; energy efficiency category A

  **Audi A3 1.4 TFSI, 92 kW (2011 model year):**
  fuel consumption: urban 7.3 l/100km; country 4.8 l/100km; combined 5.7 l/100km; CO₂ emissions: 132 g/km; energy efficiency category C

  **Audi A3 1.4 TFSI, 90 kW (2012 model year):**
  fuel consumption: urban 6.5 l/100km; country 4.4 l/100km; combined 5.2 l/100km; CO₂ emissions: 120 g/km; energy efficiency category B
Exhaust manifold integrated into cylinder head on all gasoline engines.

Aluminium bonnet

Aluminium wings

Aluminium crash management system
Lightweight thin-walled cast iron and pressure-diecast aluminium crankcase

Balancer shaft integrated into crankcase

Systematic use of aluminium pivot bearings (depending on engine)

One-piece aluminium front subframe

Control unit position, no wiring needed

Weight-optimized steel occupant cell with aluminium add-on components

Optimized exhaust system

Optional 18" flow-formed aluminium wheels

Wheel arch liners made from acoustically effective fleece material

Optimized seat structure
Center armrest with pressure-diecast magnesium connection
Audi A3 – materials

The materials that are used have a major influence on the results of the life cycle assessment. For example, more energy is consumed when producing light metals such as aluminum and magnesium than for steel; this has the effect of increasing greenhouse gas emissions during their production phase. The inventory of materials was determined for the models under examination and summarized according to VDA classification 231-106.

The material inventory for the Audi A3 2.0 TDI is shown in the adjacent diagram. The vehicle mainly consists of steel and other ferrous materials, followed by an 18 percent share of plastics and polymers. The third largest constituent is composed of light metals, at 8 percent.
In the case of the Audi A3 1.4 TFSI, there is a significant difference between the previous and current model in the proportion of light metals they contain. The weight of aluminum and magnesium used in the new model is 25 percent higher than before. The proportions of steel and other ferrous metals have decreased accordingly. In the other material categories, for example polymers, the changes in the proportions by weight were minimal.
Audi A3 – the results of the life cycle assessment

The results of the two life cycle assessments for the Audi A3 2.0 TDI and the Audi A3 1.4 TFSI are to a large extent influenced by the use phase. The reasons for this are the development of more efficient engines and the weight reduction that has already been referred to. They have the effect of reducing fuel consumption so that fewer emissions are produced during the use phase.

It proved possible to reduce greenhouse gas emissions from the Audi A3 2.0 TDI by a total of 7 percent over the entire life cycle. The vehicle then emits 2 metric tons fewer greenhouse gases during its life cycle. The adjacent chart is a comparison with the previous model.

The new Audi A3 was able to achieve a reduction in environmental effects in other categories too. Photochemical ozone creation and acidification potentials each went down by 4 percent and the eutrophication potential by 2 percent.

<table>
<thead>
<tr>
<th>Reductions in almost all the assessed effect categories</th>
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<tbody>
<tr>
<td>Greenhouse gas potential                          -7 %</td>
</tr>
<tr>
<td>Eutrophication potential                          -2 %</td>
</tr>
<tr>
<td>Ozone depletion potential                          0 %</td>
</tr>
<tr>
<td>Photochemical ozone creation potential           -4 %</td>
</tr>
<tr>
<td>Acidification potential                            -4 %</td>
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</tbody>
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Greenhouse gas emission values for the entire life cycle of the A3 2.0 TDI

![Graph showing greenhouse gas emissions for Audi A3 2.0 TDI from production to recycling.]
Audi A3 – the results of the life cycle assessment

For the Audi A3 1.4 TFSI, the ecological effects were also calculated in the five categories listed above.

Compared with the diesel model, the reduction in greenhouse gas emissions was slightly higher, due to the greater reduction in fuel consumption. The greenhouse gas potential went down by a total of 9 percent, equivalent to a reduction of approximately 3 metric tons in greenhouse gas emissions. The illustration shows the pattern over the entire life cycle as compared with the previous model.

The improvements in all other categories as well were greater for the gasoline engine model than for the diesel. Acidification potential, for example, went down by 9 percent, photochemical smog creation potential by 4 percent, eutrophication potential by 6 percent and ozone depletion potential by 1 percent.

<table>
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</tr>
<tr>
<td>Acidification potential</td>
<td>-9 %</td>
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</tbody>
</table>
Greenhouse gas emission values for the entire life cycle of the A3 1.4 TFSI
Use of secondary raw materials

Another worthwhile contribution to sustainable treatment of the environment and economical use of resources is made by the use of secondary raw and production materials. These are recovered from products after use by recycling and can then be used as material for a new product. This can save considerable quantities of primary materials. In addition to safeguarding resources by reducing the demand for raw materials, less energy is needed to prepare secondary raw materials for re-use, which in turn improves the life cycle assessment rating.

Audi is currently able to demonstrate a recoverability of 95 percent of the vehicle weight. Metals in particular can be almost completely reused. Recycled plastics are also utilized. Audi requires recycled materials of this type to comply with the same quality standards as primary raw materials. In the new Audi A3, plastics of this kind are used for instance in the front and rear bumper covers, the rear wheel arch liners and the lining of the spare wheel well.

The use of secondary raw materials and the creation of closed loops in the material management are important tasks in vehicle development, and thus make a valuable contribution to the efficient use of resources.
Example of the recycling loop of a polymer component
New body construction plant for the Audi A3

In the holistic assessment perspective taken by Audi, the actual car production process naturally plays a role as well as the materials used and their recycling. By employing regenerative forms of energy and more efficient technologies, environmental effects can be reduced here too and the life cycle assessment rating of the complete vehicle improved.

For the new Audi A3, Audi has built a new body construction plant at its Ingolstadt factory. Central aspects of the planning work were sustainability and efficiency. An example of this is the modern photovoltaic installation on the roof of the new building. It covers an area of 7,500 square meters and will supply 460,000 kWh of electric power annually. This will avoid 245 metric tons of CO₂ emissions each year. In addition, an intelligent shutdown concept has been developed for the production machinery as well as for PCs, control desks, monitor screens and the central plant supervisory system. This is to ensure that the entire plant is shutdown on weekends and no electricity is consumed in stand-by mode.

This and other measures will help lower energy consumption and CO₂ emissions still further, thus improving the overall life cycle assessment rating for the new Audi A3.
Audi e-gas project

Future energy demands in Germany will be satisfied by renewable energy sources. However, the generation of electricity from wind and sunlight is subject to fluctuations due to natural phenomena, and only a small proportion of the necessary storage capacity is currently available.

The Audi e-gas-project, a central module in Audi balanced mobility or overall CO₂-neutral mobility, will in future provide a means of storing excess electrical energy until it is needed. For this purpose, Audi is participating in the construction of offshore wind-powered generators in the North Sea. These will generate eco-electricity that will be supplied to the public grid. Audi also plans to produce and operate its forthcoming electrically powered ‘e-tron’ models using eco-electricity. Some of the electricity obtained from this wind power source will be supplied to a plant currently under construction that will produce hydrogen by electrolysis. This hydrogen can then be used as a source of energy for fuel cell electric vehicles, or alternatively methane can be obtained in a further process step.

Audi refers to this methane as ‘e-gas’: it is chemically identical to natural gas and can be used as a fuel in combustion engines. Starting in 2013, Audi will begin series production of models designated TCNG, with engines derived from the TFSI and running on e-gas. A particular benefit of methanization is that the reaction takes place with the aid of CO₂, obtained for example from a biogas plant and therefore unable to escape into the atmosphere. This results in a closed CO₂ circuit that permits long-distance mobility without negative effects on the climate.

The Audi e-gas project is a milestone from which the energy supply industry and society in general can benefit. By using e-gas, the electricity grid is coupled to the underground gas network, in which excess capacity can be stored for many months and fed back into the electricity grid when needed. The gas network is the largest available energy store, with a storage capacity of 217 TWh – enough to keep Germany supplied with electrical energy for two months.
Electricity is converted by electrolysis and methanization into synthetic methane – Audi ‘e-gas’:
Natural gas vehicles

With its e-gas project, Audi makes three largely CO₂-neutral energy carriers available: electricity, hydrogen and methane gas. They are suitable for very different propulsion concepts – for electric cars, fuel-cell vehicles and vehicles using compressed natural gas (CNG) as a fuel.

Starting in 2013, the Audi A3 Sportback will be available for CNG fuel as the 1.4 TCNG, in addition to the gasoline and diesel engine versions. The engine, which is based on the 90 kW Audi A3 1.4 TFSI, and the catalytic converter will be designed for dual-fuel (bivalent) operation. The A3 TCNG will therefore be able to operate on e-gas or, if the gas tank should run dry, on gasoline. Even today, regular refueling in Germany presents no problems, since a widespread network of about 900 natural gas filling stations is available. This is a major advantage of natural gas vehicles compared with fuel cell vehicles that need hydrogen as a fuel.
The life cycle assessment rating of a vehicle operating on e-gas is also positive in all respects. Even if assessment is restricted to the well-to-wheel situation, a compact-class car of this type emits fewer than 30 g of CO₂ equivalents, including those generated when building the wind power generators and e-gas plant. When such a car is being driven, however, it does not emit as much as a single gram of CO₂ that was not previously tied up in the production of e-gas. In other words, a closed CO₂ circuit is formed between the production of the fuel and its combustion. A vehicle running on e-gas therefore produces at least 75 percent less greenhouse gas emissions than one using conventional CNG fuel. Compared with the gasoline engine model, the difference is even greater. As for the Audi A3 3-door today, a certified life cycle assessment will be drawn up for the A3 TCNG Sportback when it reaches the market in 2013.

Comparison of greenhouse gas emissions from a vehicle running on e-gas and those from conventional CNG and gasoline engine vehicles.
Conclusion

The public today tends to judge vehicles to a large extent by their fuel consumption. Here too, Audi looks one step ahead. Its life cycle assessments analyze effects on the environment for the vehicle’s entire lifetime. The use of sustainable materials and manufacturing processes can greatly reduce these effects.

The life cycle assessment that Audi has drawn up for the new Audi A3 as part of the Audi balanced mobility project shows that the new model achieves better results in all the relevant environmental protection categories. Even in the production phase, the two models assessed here were better than the corresponding previous models. This positive tendency can be further enhanced by lower fuel consumption in the use phase.

However, the life cycle assessment is only one module on the systematic path to sustainability and protection of the environment and resources during the value creation process – a path that Audi is pursuing and has entitled “Audi balanced mobility”.

For further information and the latest developments, go to: www.audi-balanced-mobility.com
This booklet was made from chlorine-free bleached pulp and is part of a climate-neutral printing process.