LIFE CYCLE ASSESSMENT OF ELECTRIC VEHICLES – AUSTRIAN RESULTS IN AN INTERNATIONAL CONTEXT

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ABSTRACT

The Renewable Energy Directive aims reaching a share of 10% of renewable fuels in Europe in 2020. These renewable fuels are transportation biofuels, renewable electricity and renewable hydrogen. Electric vehicles can significantly contribute towards creating a sustainable, intelligent mobility and intelligent transportation systems. But the broad market introduction of electric vehicles is only justified due to a significant improvement of the environmental impact compared to conventional vehicles. This means that in addition to highly efficient electric vehicles and renewable electricity, the overall environmental impact in the life cycle - from building the vehicles and the battery to recycling at the end of its useful life – has to be limited to an absolute minimum. There is international consensus that the environmental effects of electric vehicles (and all other fuel options) can only be analysed on the basis of life cycle assessment (LCA) including production, operation and end of life treatment of the vehicles. The LCA results for different environmental effects e.g. greenhouse gas emissions, primary energy consumption, eutrophication are assessed in comparison to other fuels e.g. transportation biofuels, gasoline, natural gas and the key factors to maximize the environmental benefits are identified: 1) source of electricity, 2) energy consumption of vehicle, 3) energy demand for heating and cooling, 4) end of life treatment of batteries and 6) battery life time. The presented results are mainly based on a national research projects. These results are currently compared and discussed with international research activities within the International Energy Agency (IEA) in the Implementing Agreement on Hybrid and Electric Vehicles (IA-HEV) in Task 19 "Life Cycle Assessment of Electric Vehicles" that is led by the author.(http://www.ieahev.org/tasks/task-19-life-cycle-assessment-of-evs).

1. INTRODUCTION

The Renewable Energy Directive aims reaching a share of 10% of renewable fuels in Europe in 2020. These renewable fuels are transportation biofuels, renewable electricity and renewable hydrogen. In most European countries transportation biofuels are already on the transportation fuel market in significant shares, e.g. in Austria 7% by blending bioethanol to gasoline and biodiesel to diesel.

Electric vehicles can significantly contribute towards creating a sustainable, intelligent mobility and intelligent transportation systems. They can open new business opportunities for the transportation engineering sector and electricity companies. But the broad market introduction of electric vehicles is only justified due to a significant improvement of the environmental impact compared to conventional vehicles. This means that in addition to highly efficient electric vehicles and renewable electricity, the overall environmental impact in the life cycle - from building the vehicles and the battery to recycling at the end of its useful life – has to be limited to an absolute minimum.

2. LIFE CYCLE ASSESSMENT

There is international consensus that the environmental effects of electric vehicles (and all other fuel options) can only be analysed on the basis of life cycle assessment (LCA) including the production, operation and the end of life treatment of the vehicles. According to ISO 14,040 life cycle assessment is defined as follows:

“Life cycle assessment is a method to estimate the material and energy flows of a product (e.g. transportation service) to analyse environmental effects over the entire life time of the product - from cradle to grave”.

The principle life cycle assessment framework is shown in Figure 1.

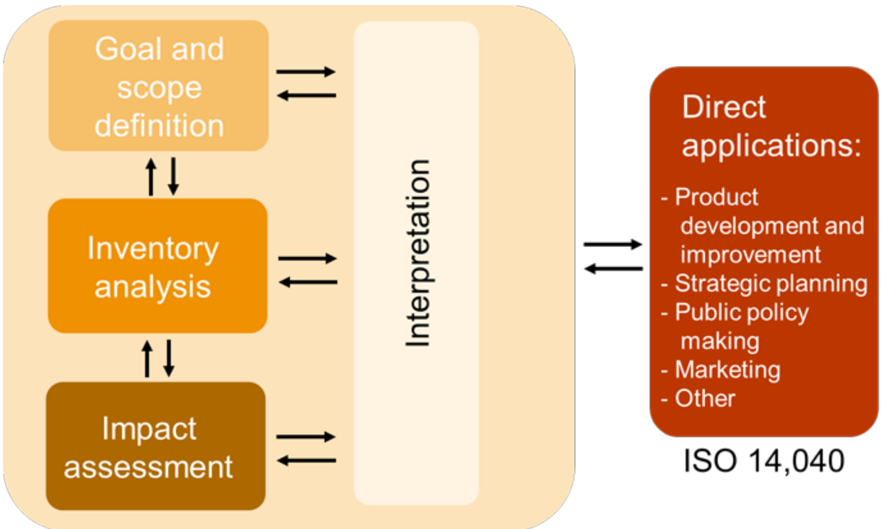

Fig 1: The life cycle assessment framework

For the following seven essential processes within a life cycle of electric vehicles the environmental effects are analysed (Figure 2):

1. Electricity production,
2. Electricity grid,
3. Charging infrastructure,

4. Electric vehicle,
5. Vehicle production,
6. Battery production and
7. Residue and waste management of vehicle and battery recycling.

In LCA the cumulated environmental effects in the three phases of the life cycle of a vehicle are calculated.

1. Production phase
2. Operation phase and
3. Dismantling or "end of life" phase.

In Figure 3 the cumulated emissions of three different vehicles A, B and C are shown. In case of vehicle C the effects of the energy and/or material recovery in the "end of life" phase lead to a decrease in the cumulated effects due to crediting of the recovery of material and/or energy.

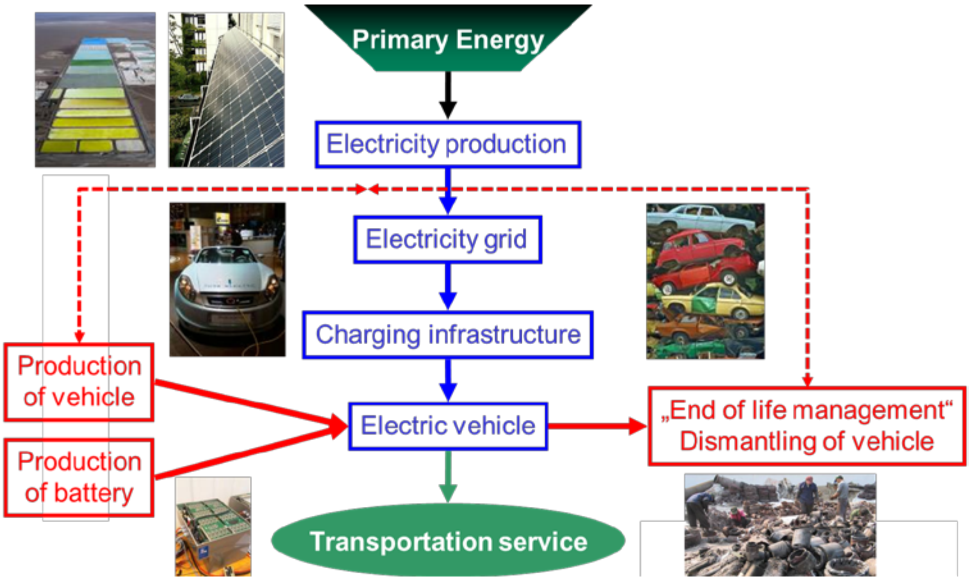

Fig 2: Assessment of LCA-Aspects over "Full Value Chain" of vehicles with an electric drivetrain [2]

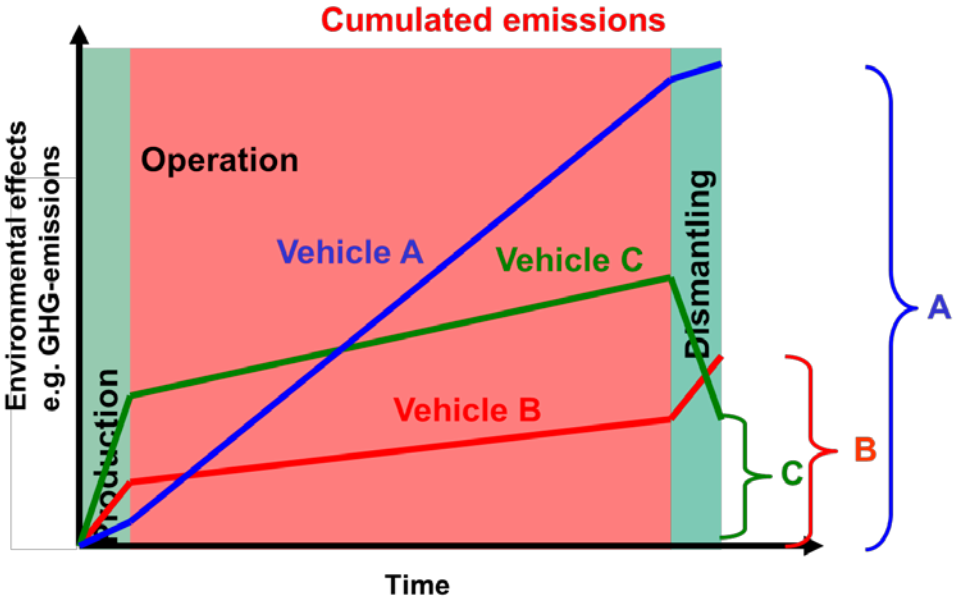

Fig 3: The three phases in the life cycle of a vehicle

In the following chapter selected results of the Austrian research project ELEKTRA [1] are shown, in which in total about 400 different vehicle concepts were compared based on a life cycle assessment.

The main characteristics of the vehicle concepts are:

– Propulsion systems: internal combustion engine (ICE), micro hybrid, mild hybrid, full hybrid, electric engine with battery, fuel cell

– Vehicle sizes:: Small passenger car, medium sized passenger car, big/high class passenger car

– States of technology: 2010, 2050

– Electricity: hydro power, wind, PV, wood chips, natural gas, Austrian grid mix (2008)

– Hydrogen: hydro power, wind, PV, biogas, wood chips, natural gas

– Fossil fuels: gasoline, diesel, natural gas

– Transportation biofuels: bioethanol, biodiesel, synthetic natural gas (SNG), biomethane (made of biogas), Fischer-Tropsch-(FT)biofuels

– Feedstocks for transportation biofuels: maize, wheat, sugar beet, wood, straw, rape, sunflower, used cooking oil, manure, maize silage, mix of energy crops

3. RESULTS

3.1 Vehicle production

Based on the weight of different vehicle concepts (Figure 4) the greenhouse gas emissions of the vehicle production are calculated, that are shown in Figure 5. It is evident, that the fuel cell vehicle has the highest emissions and the conventional diesel ICE vehicle the lowest emissions. The hybridisation leads to additional emissions compared to the pure ICE vehicle. The battery electric vehicle has a little lower emission than the fuel cell vehicle.

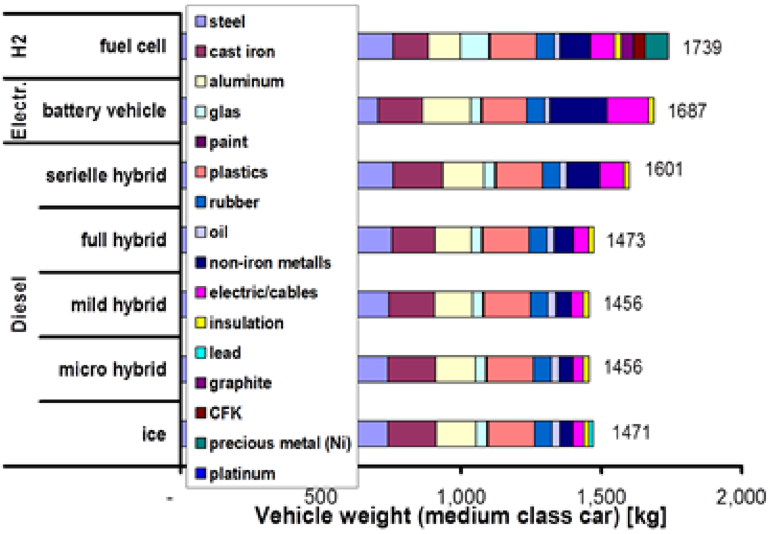

Fig 4: Weights of different vehicle concepts [1]

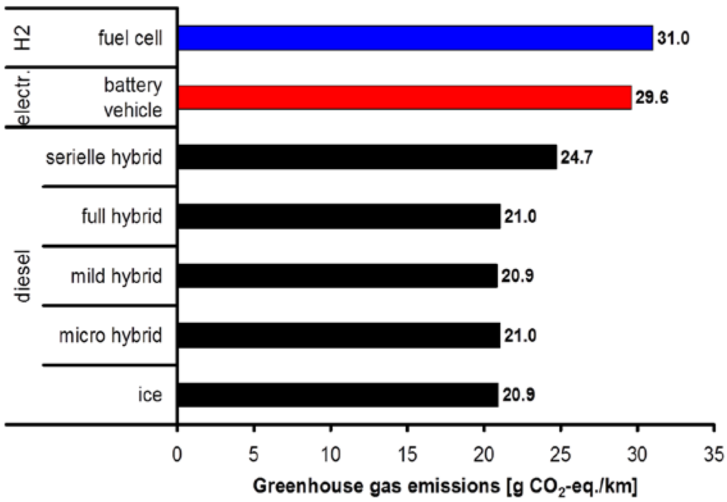

Fig 5: Greenhouse gas emissions of vehicle production [1]

3.2 Electricity production

In Figure 6 the life cycle based greenhouse gas emissions of electricity production in Austria are shown. Renewable electricity has significant lower greenhouse gas emissions than fossil fuel based electricity.

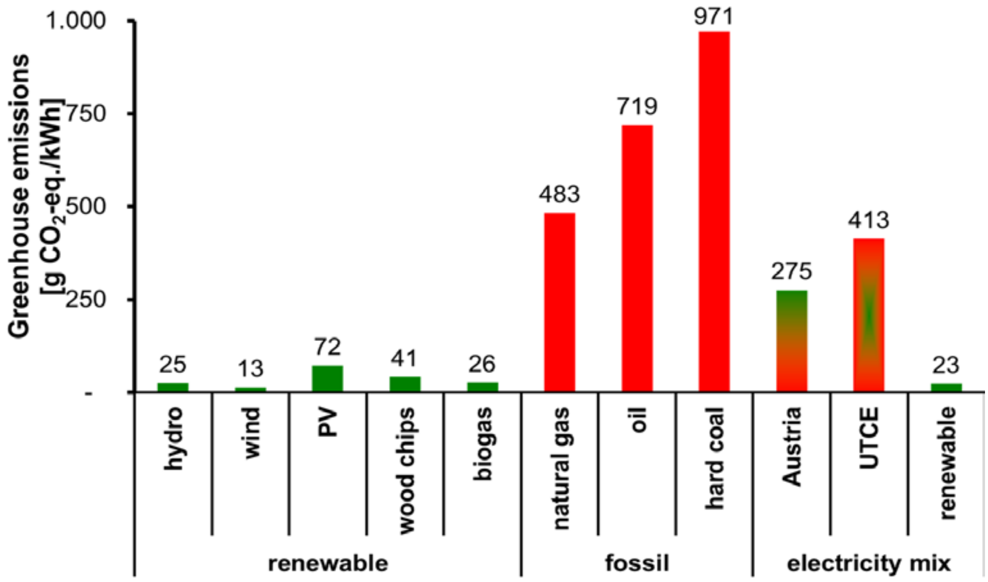

Fig 6: Greenhouse gas emissions of electricity production

3.3 Transportation service

In Figure 7 the greenhouse gas emissions of transportation service with a medium class vehicle are shown. The battery electric vehicle using renewable electricity has significant lower greenhouse gas emissions com-pared to the diesel vehicles. If the electricity for the electric vehicle is supplied by natural gas a hybrid diesel vehicle has slightly higher emissions.

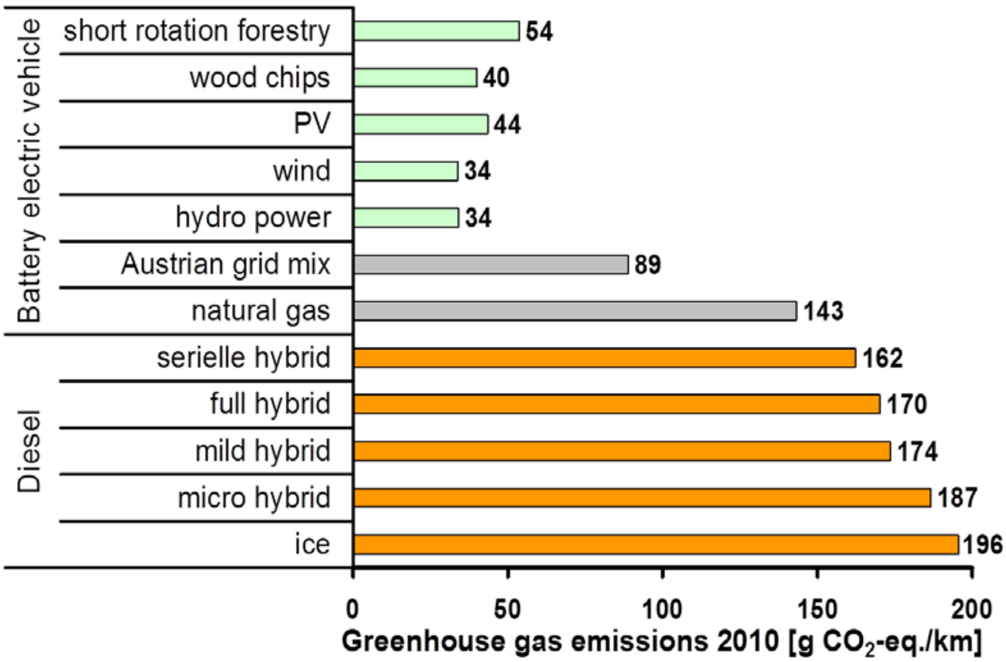

Fig 7: Greenhouse gas emissions of transportation service with a medium class vehicle [1]

In Figure 8 the cumulated primary energy demand of transportation service with a medium class vehicle is shown. All renewable fuels have lower cumulated fossil primary energy demand than conventional fossil fuels. But due to the partly lower conversion efficiency from renewable primary energy to transportation service some renewable fuels have a higher overall cumulated primary energy demand of which the main share is renewable energy.

In Figure 9 and figure 10 more details on the green-house gas emissions of transportation services provided by electricity battery vehicles and hydrogen fuel cell vehicles are shown.

The key factors to maximize the environmental benefits are identified:

1. source of electricity,
2. energy consumption of vehicle,
3. energy demand for heating and cooling,
4. end of life treatment of batteries and
5. battery life time.

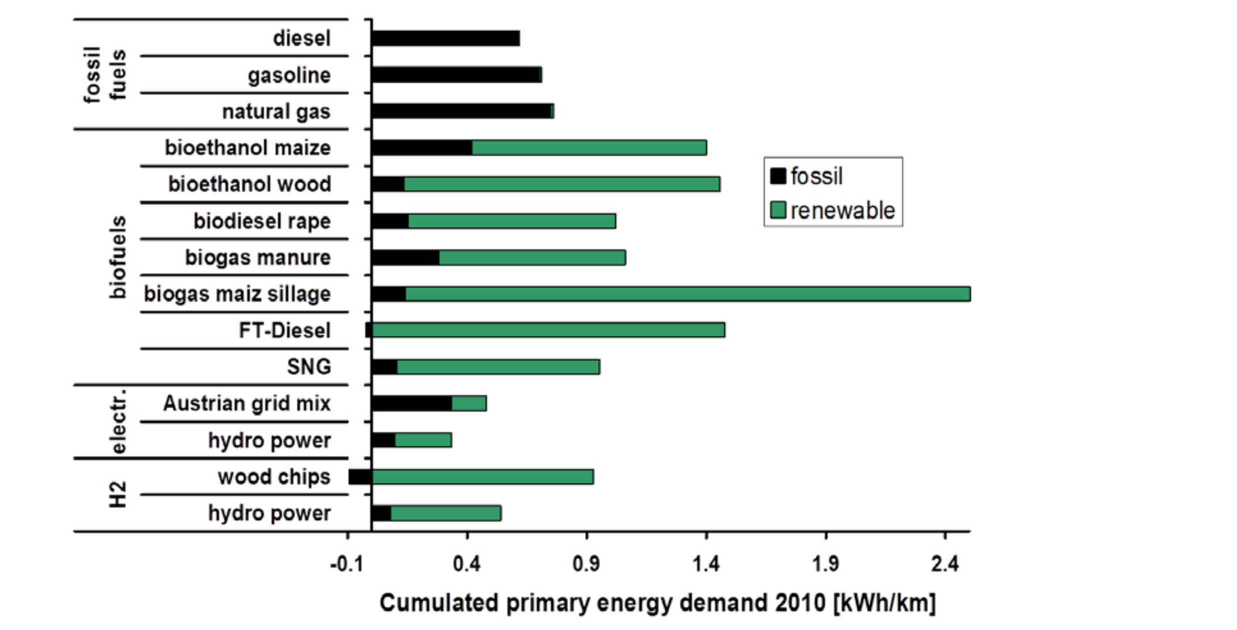

Fig 8: Cumulated primary energy demand of transportation service with a medium class vehicle [1]

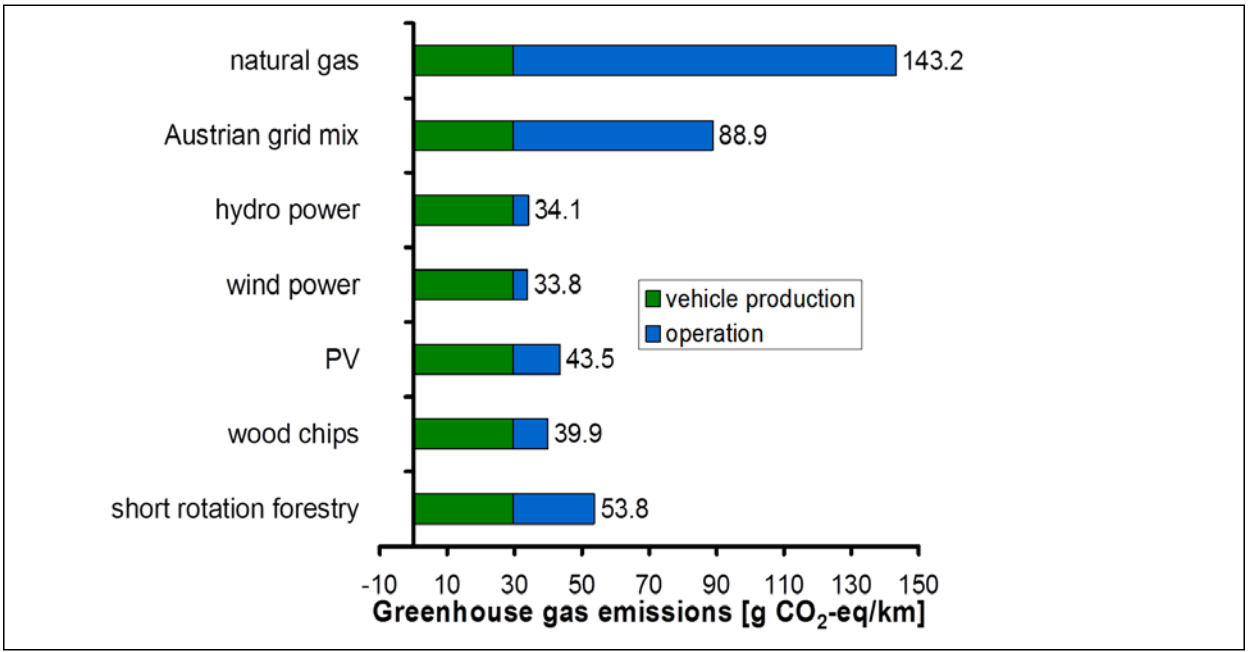

Fig 9: Greenhouse gas emissions of transportation service with an electric battery vehicle [1]

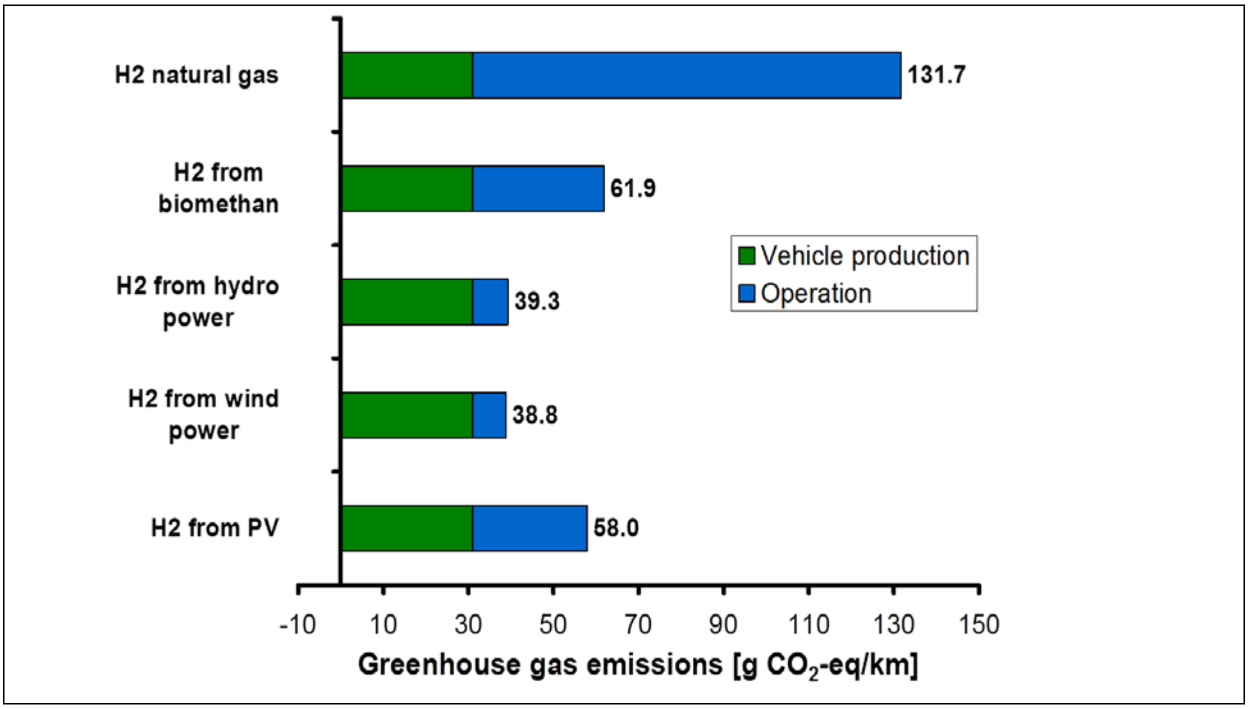

Fig 10: Greenhouse gas emissions of transportation service with an electric fuel cell vehicle [1]

4. COMPARISON TO OTHER RENEWABLE FUELS

Fossil fuels and biofuels have their major impacts in the operation of the vehicle, whereas hydrogen and electricity based on renewable energy have their major contribution in the production and dismantling phase. In Figure 11 the influence of the fuel consumption per km and the greenhouse gas emissions of transportation service with different fuels are shown. Depending on the size of the vehicle and the driving behaviour the fuel consumption is directly linked to the greenhouse gas emissions. For battery electric vehicles the energy demand for heating and cooling is very relevant as well as the origin of the used electricity. If a heavy fast driving diesel vehicle (80 kWh/100km) is substituted by a small, slow driving battery electric vehicle (16 kWh/100km) with electricity from hydro power, the possible greenhouse gas reduction is about 90%; BUT if a small slow driving diesel vehicle (40 kWh/100km) is substituted by a bigger fast driving battery electric vehicle (35 kWh/100km) with electricity from natural gas is substituted, the possible greenhouse gas emission might increase by 30%.

In Figure 12 a comparative assessment for renewable transportation fuels is presented which shows, that none of the renewable transportation fuels is advantageous in each aspect, e.g. biofuels have local emissions, but the filling station infrastructure exists, whereas electric vehicles have no local emissions but the market introduction of battery electric vehicle is at a very early stage. As shown in Figure 13 each of the renewable fuels has its optimal application:

– transportation biofuels are optimal for heavy vehicles and long distances,

– electric battery vehicles are optimal for small vehicles and short distances

– hydrogen vehicles are just between these two.

Concluding we know that in a future sustainable transportation sector we will need all types of renewable transportation fuels to satisfy our mobility and transport demand. As the challenges for renewable transportation fuels in Figure 14 show, all renewable fuels have to guarantee their sustainability, which is only possible under specific conditions, e.g. renewable energy for electricity and hydrogen, certified sustainable biomass for biofuels. All three renewable transportation fuels need further R&D-development and the built up of the necessary infrastructure. Depending on the economic and political framework condition a broad successful market introduction is possible in the medium to long term perspective, in which the renewable transportation fuels significantly contribute to a future sustainable transportation sector.

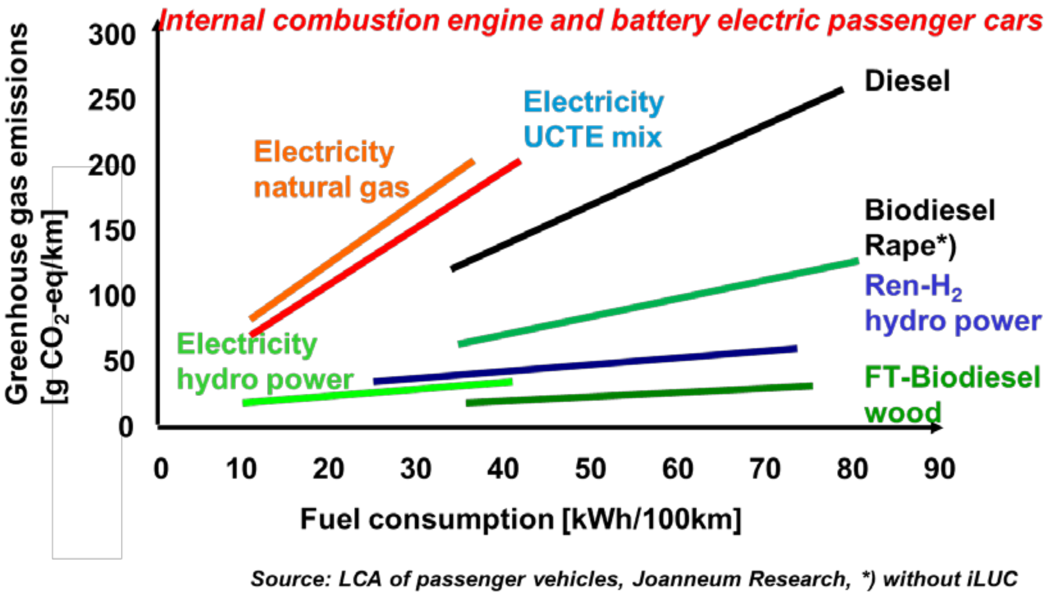

Fig 11: Greenhouse gas emissions of transportation service with different fuels

	"B-Mobility"	"E-Mobility"	"H_2-Mobility"
Primary energy	many options	many options	many options
Fuel production technology	1st generation existing 2nd generation under development	existing	fossil existing renewable under development
Sustainability	food/feed/fibre/fuel	renewable	renewable
Local emission	yes	no	very low
Infrastructure	existing	partly existing	not existing
Vehicle technology	existing	first vehicles on market	under development
Customer needs (Range/Refuel time)	common	uncommon	less common

Fig 12: Comparative assessment for renewable transportation fuels

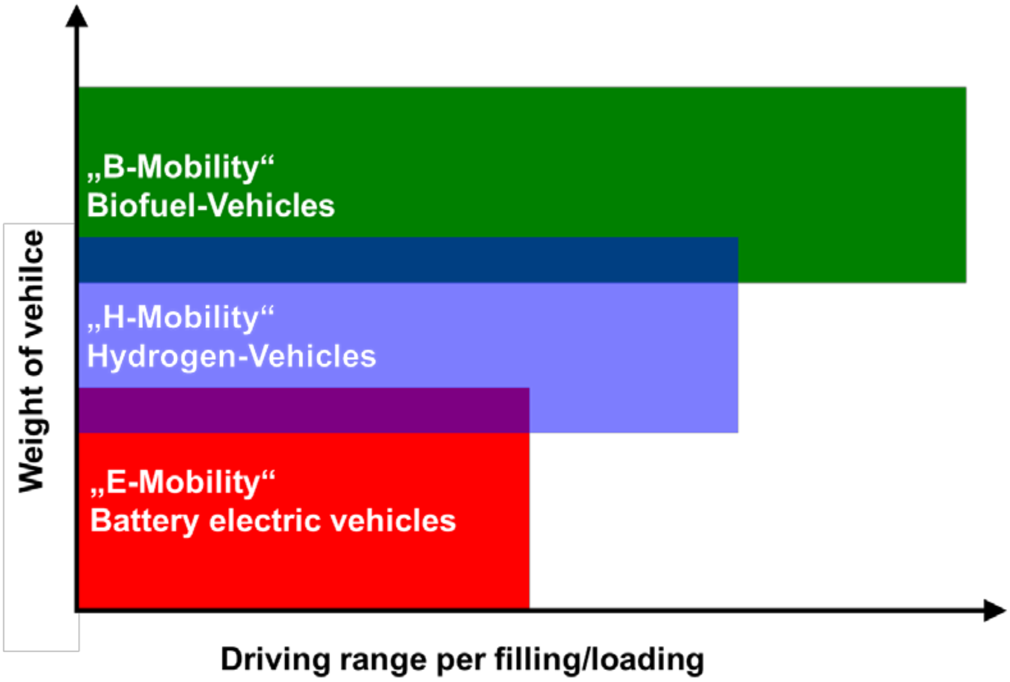

Fig 13: Optimum application of vehicles with renewable energy

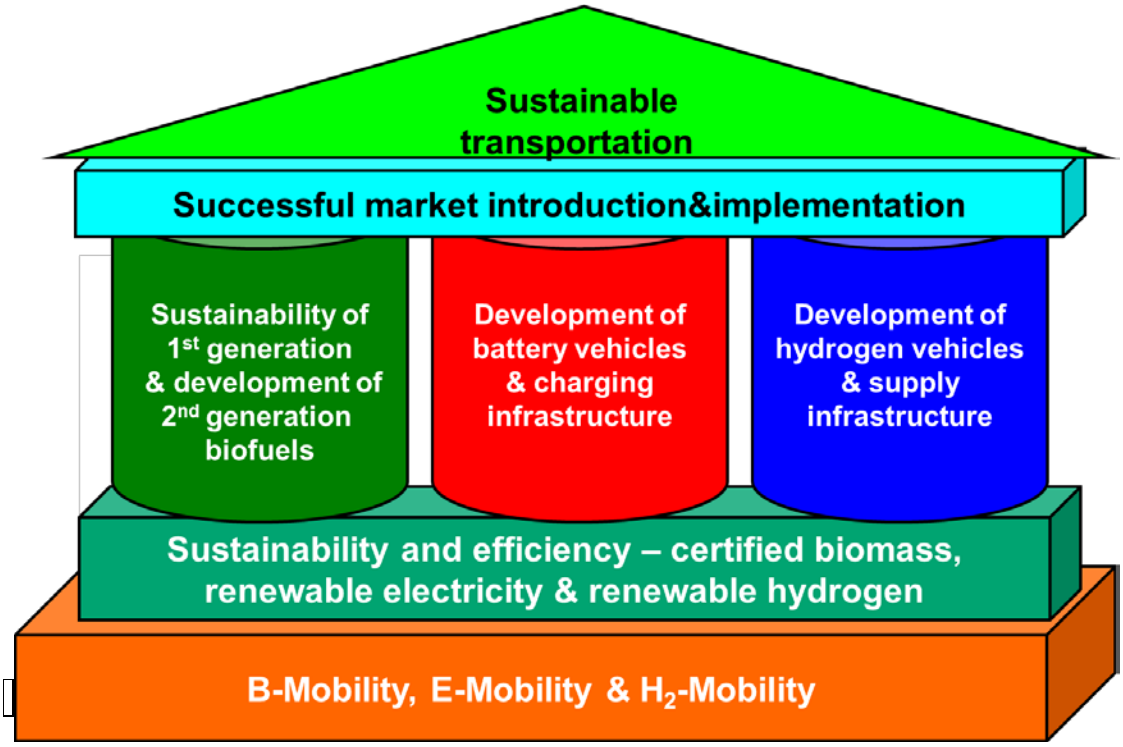

Fig 14: The challenges of renewable transportation fuels

5. CONCLUSIONS

The presented results are mainly based on a national research projects. These results are currently compared and discussed with international research activities within the International Energy Agency (IEA) in the Implementing Agreement on Hybrid and Electric Vehicles (IA-HEV) in Task 19 “Life Cycle Assessment of Electric Vehicles” that is led by the author. Task 19 [2] deals with the environmental effects of vehicles with an electric drivetrain based on life cycle analyses. Task 19 on the life cycle assessment (LCA) of electric vehicles has the objective of learning how electric drivetrain vehicles should be designed for optimal recyclability and minimal resource consumption. It also aims to promote the best available technologies and practices for managing the materials in EVs at the end of their useful life, when the vehicle is dismantled.

Based on the LCA activities in the member countries, the main goals of this Task are:

- Providing policy and decision makers with facts for decisions on EV-related issues
- Improving end-of-life management by identifying the best available technologies
- Improving the design of vehicles and battery systems for optimal recyclability
- Establishing an international research platform for life cycle assessment.

The main topics to be addressed are: 1) LCA methodology, 2) Frequently asked questions on the environmental issues of EVs, 3) Overview of international LCA studies, 4) Parameters influencing the energy demand of EVs, 5) LCA aspects of battery and vehicle production, 6) Vehicle end-of-life management, e.g., recycling, or reuse of batteries, 7) LCA aspects of electricity production, distribution, and vehicle battery charging, 8) Summarizing the further R&D demand.

Task 19 considers the following vehicles and propulsion systems:

- Propulsion systems: battery electric vehicle (BEV), hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), range extender vehicle (REV), hydrogen fuel cell electric vehicle (FCV) (including hydrogen production), diesel and natural gas
- Road vehicles: passenger cars, light utility vehicles, buses, two-wheelers, e.g. motorcycles, electric bikes forklift trucks

The most important networking activity in this LCA platform is the organization of the five workshops in different member countries aiming to involve the different stakeholders in the value chain of electric vehicles. The organization of workshops with participation from industry, research organizations, and technology policy experts provides an international basis for the exchange of information on relevant activities. Task 19 is coordinated by the JOANNEUM RESEARCH.

6. REFERENCES

[1] ELEKTRA - Entwicklung von Szenarien der Verbreitung von PKW mit teil- und voll-elektrifiziertem Antriebsstrang unter verschiedenen politischen Rahmen-bedingungen, TU-Wien, Joanneum, AVL, 2009

[2] http://www.ieahev.org/tasks/task-19-life-cycle-assessment-of-evs

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