Well-to-wheel visualization

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Abstract

The analysis of energy consumption, emissions, cost and other parameters from the source of the primary energy carriers (well) to the end user (wheel of the Light Duty Vehicle) has become more and more important in the last years, when different options for alternative drive trains and fuels for road transport have been compared. Up to now a huge sum of data from different well-to-wheel studies is available. Due to the large variety of combinations of primary energy, process, fuel and drive train, it is often not easy to find the relevant data sets quickly. Thus, a software for the visualization of the energy consumption and greenhouse-gas emissions has been developed to facilitate the comparison of different fuel-drive trains options. The function of the software and some illustrative results are presented.

Keywords: Conventional and alternative drive trains, conventional and alternative fuels, well-to-wheel-analysis

1 Introduction

Alternative fuels and alternative drive trains have gained a high interest of industry and politics in the last years. After a period of about 100 years road transport which relies mainly on crude oil as energy source and the internal combustion engine as the compatible drive train, many new options for a sustainable mobility of the future are investigated. Natural gas, ethanol, biodiesel, synthetic fuels and hydrogen are only the most prominent fuel options, whereas improved internal conbustion engines , pure electric vehicles, hybrids and fuel cell vehicles are the most discussed options on the vehicle side. The vehicle and the fuel are not the only determining elements of the whole supply chain for road transport. The fuel has to be produced from a primary energy source by using a dedicated process, energy carriers have to be transported using different ways. Thus the combination of primary energy source, production and distribution process for the fuel, the produced fuel itself and the different vehicle trains lead to a large variety of possible options. Furthermore, the analysis, comparison and evaluation of different fuels and traction systems (energy chains or energy paths) for vehicles based on classic “Well-to-Wheel” diagrams are limitative because of all the predefined and invariable assumptions and conditions. It is well known that under different conditions the same technical solution might turn out to be better or worse. DaimlerChrysler therefore decided to realize a tool for an easy query and scenario visualization of more than 1000 different paths from Well to Wheel, entrusting Protoscar SA with the development and the realization of such a software (OPTIRESOURCE®) . The used data were taken from the Well-to-Wheel report [1] done by EUCAR and CONCAWE in cooperation with the European Joint Research Center. Additional data were calculated by Ludwig Bölkow System Technik, München.

Comparing traction systems and fuels for vehicles, since ever, the discussion about “what is the better system” brings to uncertain and unclear results, because of the different assumptions and calculation methods. Moreover, this topic is often treated as “dry scientific data”, and leaks of visual help in order to better compare the scenarios. Therefore DaimlerChrysler has decided to develop a modern interactive visualizer of “Well-to-Wheel” results, comprising:

1. A complete, detailed and interactive visualization of the “Well-to-Wheel” paths, in terms of Energy (overall efficiency) and greenhouse gas emissions (CO_2 and other emissions which contribute to the greenhouse-effect) to help understanding WHY and WHICH alternative fuel systems are interesting, and HOW they compare towards other alternative systems.
2. The visualization (graphics, type of input) and the tools to visualize it, personalized for different auditor levels (children, normal people, specialists etc.).
3. The project is realized in expandable modules. The system is be open to additional criteria like pollution, cost, etc. which may be implemented in the future.

2 Software description

2.1 Specifications

The base philosophy is to use existing data implemented in a purpose-made database and several input/output interfaces, according the kind of user. The database plus the user interface constitute the Well-to-Wheel (WtW) system. In the first phase, the data of the WtW- analysis done by EUCAR and CONCAWE in cooperation with the European JRC [1] , are used. Pathways which have not yet been covered in this study have been calculated by LBST using the E3 database. All data from the study and these of the additional chains were incorporated in the database of the visualization software. This database contains the data defining the different energy paths from Well-to-tank (WtT) and Tank-to-Wheel (TtW) in terms of energy efficiency, greenhouse gas emissions or any other available parameter. The users do a query to the database and they get the results in term of visualization of the absolute or relative values of the efficiency, CO_2 emission, etc. of each energy path. The way the query is done and the way the results are displayed depend on the kind of users, but anyway they work on the same data.
The data base stores and elaborates the data, the user interface manages how the query are done and how the results are displayed.

The data base has the following hardware and software requirements:

- PC with Windows 2000/XP and a CD-ROM reader;
- The library of the Microsoft .Net Framework must be installed on the hard disk;
- The execution must be done from the CD-ROM, neither installation on the hard disk nor writing operation on the hard-disk are allowed; the libraries of the .Net Framework or a link for the downloading from the MS web site are included in the CD-ROM;
- Languages: english and german.

2.2 System architecture

The system has 2 main sub-systems, the processor unit and the user interface, both based on a purpose made software. The system can be set up for different languages and will have two working modalities (up to now, only the query mode has been realized, the scenario mode is currently being developed):
- mode “query”,
- mode “scenario”,
In the “query” mode the user can compare different pathways according primary energy use and greenhouse-gas emissions. The result is displayed as energy or GHG-emissions per pathway, but the overall influence of the deployment of the respective pathway on total energy consumption and GHG-emissions of a region or a state cannot be evaluated.

For this purpose, the the “scenario” mode is currently being developed. In this mode users can do assumptions about the energy mix, the vehicle fleet, the technical improvements etc. and see the impact on total energy consumption and GHG-emissions.

2.3 Query mode

The user chooses the quantities they like to see (energy, GHG or both in the first version), the time period to which these quantities refer (now, 2010 or both for the first version) and the energy chains. To select the energy chains, the user can select one or more primary energies and/or one or more processes, one or more fuels and/or one or more powertrains. It is possible to select all the chains with one single command. The selection can be done in a random way (the sequence of the choices is free). The system automatically pre-selects all the possible choices, according the selections made in the previous step. At the end of the query, the results are displayed in a bar diagram. The system is already designed to include the choice of various geographical contexts.

The query is completed defining:

- the quantity or quantities to be displayed as results, divided in quantities related to the technology (e.g. MJ/100 km , liter/100km or miles/gallon, MJ (primary energy)/MJ (fuel supply)) or related to the environment (e.g. g CO_{2equ}/km or CO_{2equ}/miles, CO_{2equ}/ MJ (fuel));
- how to display the results, i.e. if as absolute values or relative values (%).

Of course, there are already pre-selected default choices to fasten the selection.
During the definition of the query, the results are displayed in the same window as a graphic. The users can change one or more criteria, looking immediately the effects. The results can be printed and can be exported as a text file for an importation into a spreadsheet (e.g. Excel). The option to visualize the WtT and TtW is implemented too.
The query level described above is the most complete and it can be assumed that it is devoted to the professional users. For other users, like children, motorshow visitors etc. a different interface with a simpler query mechanism is implemented.

2.4 Scenario mode

In this modality the user defines the energy mix, the composition of the vehicle fleet (type and quantities) the technical improvements of a certain geographical area. The results show what happens in that area in terms of quantities related to the technology (e.g. MJ/100km, liter/100km, etc.) and/or related to environmental aspects (e.g. g CO_2/km,

3 Results

In this section, a few representative results visualized with the OPTIRESOURCE software are shown.

3.1 WTT-visualization

In figure 1 an example for the visualization of well-to-tank data for three different pathways for the production and delivery of hydrogen as fuel direct to the filling station. For this example hydrogen production by central reforming of natural gas which is delivered from a region which is 4000km away from the reforming facility has been chosen. In these pathways hydrogen is produced in large facilities and has to be transported to the filing stations. Three principal transport modes are possible: hydrogen transport via a pipeline grid, transport of hydrogen on the road with trucks after compression (CGH_2) and transport of hydrogen with trucks after liquefaction (LH_2). Figure 1 displays the total primary energy which is necessary to deliver 1 MJ hydrogen to the filling station. In the case of the two pathways with gaseous hydrogen, the primary energy needed is about 0.7 MJ/MJ_{H2}. The energy of the hydrogen itself is not included in this value. The delivery of liquid hydrogen to the fueling station causes an energy consumption of more than 1.1 MJ/MJ_{H2} (again without the energy content of the hydrogen itself); that means also, that the energy efficiency for supplying liquid hydrogen to the filling station is about 48 % (1/(1+1.1) x 100)

The GHG-emissions of these three pathways show a similar behaviour as the energy consumption. As in this example the primary energy source is natural gas, this result is no surprise as the carbon dioxide emitted during production of hydrogen is proportional to the amount of energy needed.

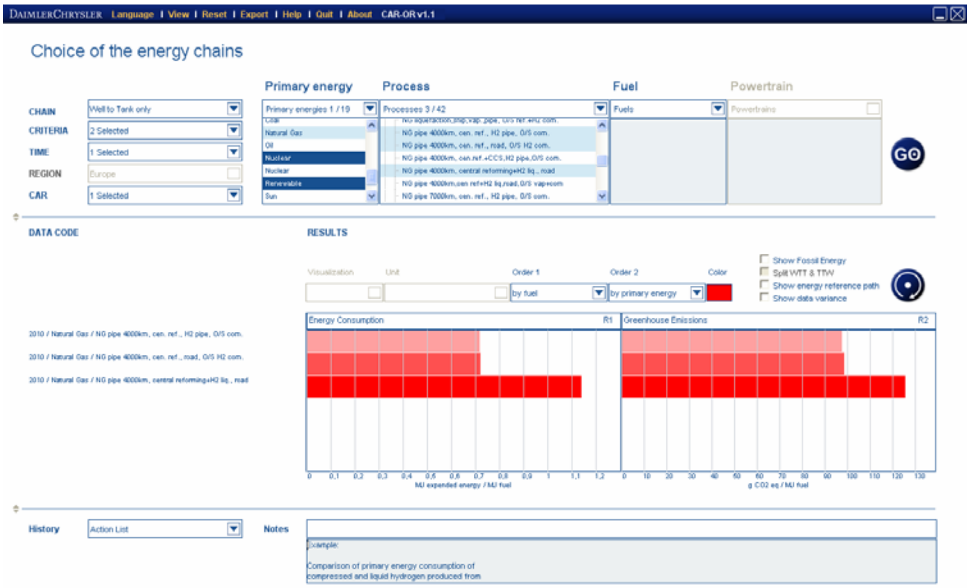

Figure 1: Example for the visualization of WTT-energy consumption and GHG-emissions for three different pathways of hydrogen production

3.2 TTW-visualization

Figure 2 shows a typical example for the visualization of TTW values, here a comparison of a fuel cell vehicle and a vehicle with internal combustion engine, both fueled with hydrogen. The unit $l_{equ\ (gasoline)}$ /100km is chosen, but it is also possible to choose other units like miles/gallon. It can be seen that the fuel cell vehicle consumes significantly less energy than the vehicle with an H_2-ICE. The GHG-emissions are zero or almost zero in both cases as no carbon is contained in the fuel itself. Only the H_2-ICE is emitting a very low amount of nitric oxide which is also a greenhouse-gas.

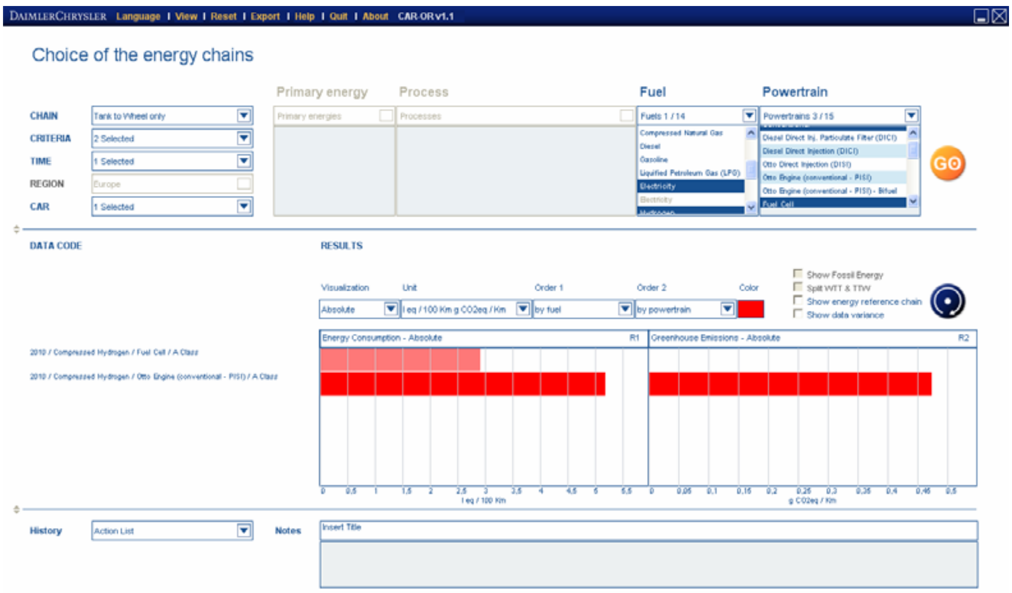

Figure 2: Example for the visualization of TTW-energy consumption and GHG-emissions for two different hydrogen drive trains

3.3 WTW-visualization

When a new fuel and vehicle drive train is considered, it is important to know the total primary energy consumption and emissions which is implied with the new mobility option in comparison with other fuel and drive train options. Thus, the visualization of the WTW data is a very important part of the OPTIRESOURCE® software. Figure 3 shows the results for the combination of the hydrogen production pathways in figure 1 combined with the vehicle drive trains chosen in figure 2 in terms of $MJ_{(primary\ energy)}$/100 km and CO_{2equ}/km. As can be seen, the fuel cell vehicle with a compressed hydrogen storage leads to much lower energy consumption and GHG-emissions than the H_2-ICE, this result is even pronounced when the hydrogen is stored as liquid hydrogen.

Figure 3: Example for the visualization of WTW-energy consumption and GHG-emissions for six different hydrogen pathways

Figure 4 shows an example for a comparison of a variety of drive trains and fuel options, again in terms of $MJ_{(primary\ energy)}$/100 km and CO_{2equ}/km and including the split WtT and TtW . For the primary energy crude oil, natural gas, wind energy and waste wood has been chosen. The chosen fuels are gasoline, compressed natural gas and hydrogen, the drive trains are fuel cell and internal combustion engine. As process for the production of hydrogen central reforming of natural gas, gasification of wood and electrolysis have been chosen, the hydrogen is delivered via pipeline to the filling station and compressed directly at the filling station. Gasoline comes from a refinery and natural gas is delivered via pipeline and then compressed at the filling station. Concerning the total energy consumption, all chosen pathways with a fuel cell vehicle lead to a significant reduction in comparison to the internal combustion engine fueled with gasoline, whereas the comparable pathways with a hydrogen ICE lead to a significant increase. Compressed natural gas as fuel for an ICE doesn´t show a big change, but is in any case causing less energy consumption than the H_2-ICE. For the GHG-emissions the picture is a bit more complex, the overall result is that all pathways with renewable energies (here wind and waste wood) lead to a significant reduction of GHG emissions but not zero GHG emissions. Hydrogen produced from natural gas is beneficial to GHG-emissions only when used in fuel cell vehicles and natural gas directly burned in an ICE leads to a slight reduction of GHG-emissions.

Figure 4: Example for the visualization of WTW-energy consumption and GHG-emissions for eight different fuel / drivetrain options

The Optiresource software offers a few more options which can be chosen by the user depending on the current application. As an example in figure 5 the options “show energy reference chain” and “show data variance” are chosen. Additionally the data for 2002 and those for 2010 can be displayed, however for some options (e.g. the fuel cell vehicle) only data for 2010 are available. Currently, all chains are calculated with one size of vehicle which has been chosen by EUCAR, CONCAWE and the JRC for the underlying WTW-analysis. It is a medium size car type which is representing the most sold class of passenger cars in Europe. However, it is planned to implement additional cars in the software.

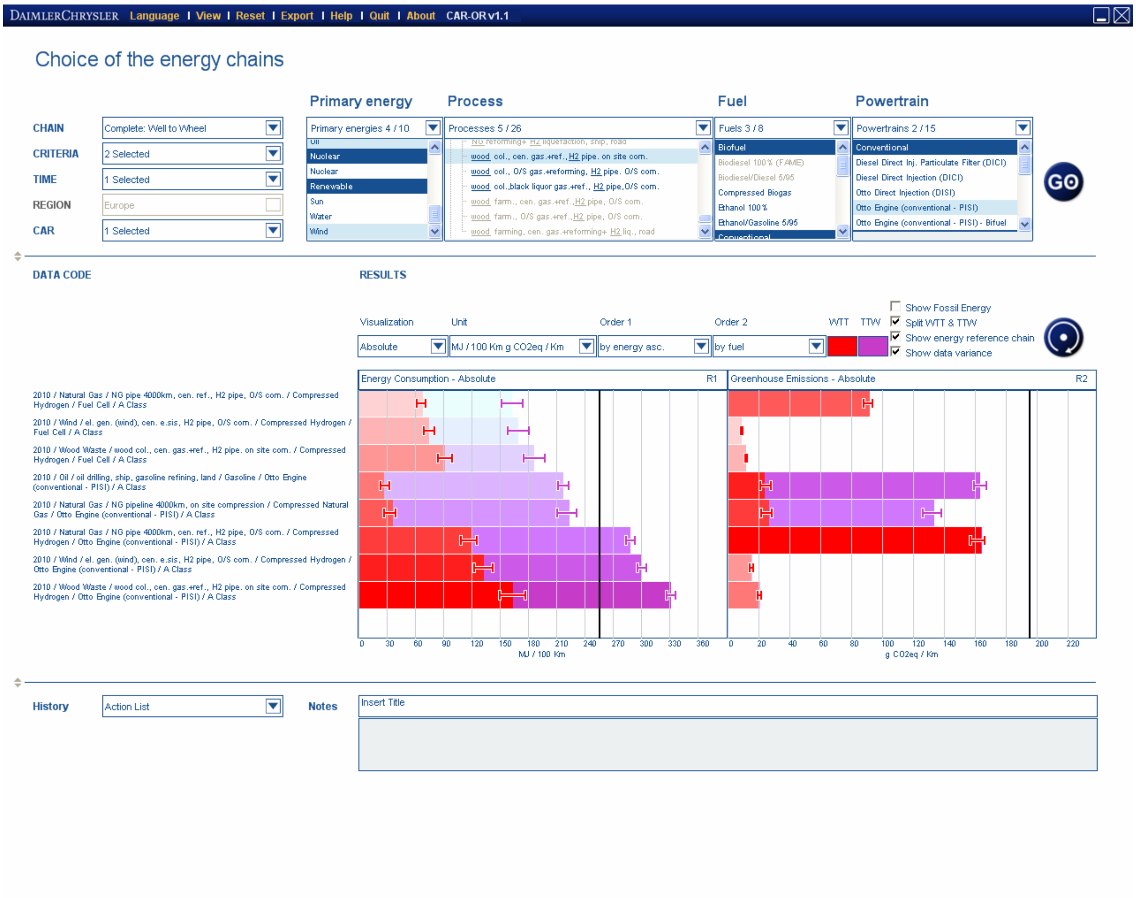

Figure 5: Example for the visualization of WTW-energy consumption and GHG-emissions for eight different fuel / drivetrain options includiung energy reference chain and data variance

4 Outlook

The shown examples are only an insight in the possibilities of the software. During the EVS-22 presentation, several sample-results will be shown LIVE according the audience requests, which will be invited to propose their inputs. For a less scientific educated target group a software with a more simplified user interface has been developed. This software can be operated on a personal computer or on the interactive wall which has especially been developed for this purpose. The interactive wall is displayed at the DC booth of the EVS 22. Currently the scenario mode is developed, the first version is currently being tested.

References

[1] R. Edwards, J.-F. Larivé , V. Mahieu, P. Rouveirolles: Well-to-Wheel Analysis of Future Automotive Fuels and Powertrains in the European Context, 2006, http://ies.jrc.ec.europa.eu/wtw.html

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Dr. Jörg Wind, born in 1960, has studied physics at the Technical Unversity of Munich (TUM). After doing his Ph.D. in the field of semiconductor physics and sensor technology at the TUM in 1992, he started working in the field of fuel cells and hydrogen. As a project manager, he was responsible for material development for high temperature fuel cells and exhaust aftertreatment at DASA and DaimlerChrysler from 1992 until 1998. From 1998 until 2002, he was responsible for PEM stack development at DaimlerChrysler. Since 2002, he is responsible for strategic energy projects, comprising hydrogen related projects (including energy systems analyses and WTW-analyses) and European projects in the field of hydrogen and fuel cells.

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Having joined DaimlerChrysler in 1994, today Peter Froeschle is the head of the Strategic Energy Projects & Fuel Cell Market Development. As a program manager from 2000 until 2004 he was responsible for DaimlerChrysler’s worldwide F-Cell Fuel Cell fleet program. From 1998 until 2000 he integrated the Fuel Cell & Hybrid Powertrain Vehicle activities into the regular car development processes at DaimlerChrysler. Before that Peter Froeschle held various technical planning positions in the Mercedes-Benz production and development organizations. Peter Froeschle, born in 1965, graduated from the Technical University of Stuttgart, Germany in technical & economic cybernetics. He later completed his management skills with an MBA at St. Gallen Business School.

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Marco Piffaretti has studied Car-Design at the “Scuola d’Arte Applicata & Design of Torino” and the “Art Center College Europe”. In 1984 he started developing solar race cars and in 1987 he set up his own design company Protoscar, a “non-conventional-vehicle”-design consultant company.
From 1994 to 2001 he also was director of the most important European EV-demonstration project: the “VEL-1”, in Mendrisio (Switzerland).