DAIMLER

Holistic Energy Analysis of Various Drivetrain Topologies Close to Reality

Benedikt Hollweck / Christian Schnapp / Thomas Kachelriess

European GT Conference, Frankfurt am Main, 9th October 2017
Agenda

1. What is a well-to-wheel analysis and why do we need realistic boundary conditions and user behaviour?

2. Methodology for the approach to represent realistic boundary conditions and user behaviour for a well-to-wheel analysis

3. Drivetrains modelled with GT-SUITE
   • Plug-In Hybrid Electric Vehicle (ICE-PHEV)
   • Range Extender Electric Vehicle (ICE-REEV)

4. Validation/Results of a previous FCEV simulation model

5. Analysis of power losses due to tire rolling resistance

6. Summary
Well-to-Wheel Analysis

A well-to-wheel analysis is the rating of energy consumption and greenhouse gas emissions arising on the path from the energy source to the wheel.

Well-to-Wheel Analysis (WtW)

Well-to-Tank (WtT)

Tank-to-Wheel (TtW)

Evaluation criteria:

- Energy consumption
- Greenhouse gas emissions
WtW-Analysis: CO$_2$- and Energy comparison of EUCAR reference vehicles 2020+

**Fuel Cell:** High range (> 500 km), short refueling time (3 min), applicable for different vehicle concepts

**Battery:** Optimal operation in compact cars for the city traffic (200 - 250 km), recharging over night

---

*GHG: Green House Gas

---

Electric drivetrains are a real step to reduce energy consumption and GHG-emissions. Using EVs means a significant step forward.
Methodology for the approach to represent realistic boundary conditions and user behaviour for a WtW-analysis

Starting time in h

Driving distance

Driving performance (MiD)

Cluster 1
0–9 am
23.59%
Region of the study: „Mobilität in Deutschland“ (MiD 2008)

Cluster 2
9 am – 1 pm
23.39%

Cluster 3
1 – 4 pm
19.82%

Cluster 4
4 – 7 pm
23.16%

Cluster 5
7 – 12 pm
10.05%

Frequency in %

Starting time in h

Driving performance (MiD)

Reference vehicles

3 Artemis driving cycles

User behaviour

(Track-type, traffic flow, typical driver)

GT-SUITE vehicle simulation model

Reference vehicles

(small, medium, large)

Evaluation by track type and track length

4*5 climate clusters for Germany

Climate boundary conditions and start conditions

Results:
Realistic energy consumption of a specific user

Weighting factors of the study “Mobilität in Deutschland”

Results:
Realistic energy consumption for a typical German driver

Evaluation by track type and track length

Data of the study: „Mobilität in Deutschland“ (MiD 2008)

Starting times (MiD)

Frequency in %

Source: B. Hollweck, et. al., Energy analyses of fuel cell electric vehicles (FCEVs) under European weather conditions and various driving behaviours, 6th European PEFC and Electrolyser Forum, Luzern 2017

GT-Conference / Benedikt Hollweck, Christian Schnapp, Thomas Kachelriess / 09.10.2017 / Page 5
Methodology – Modular vehicle simulation with GT-SUITE

**Drivetrain:**
- BEV
- FC-PHEV / FC-RE
- FCEV
- PHEV / REEVE
- ICE gasoline
- ICE diesel
- HEV

**Thermal management:**
- Drivetrain BEV
- Drivetrain ATS FCHEV
- Drivetrain ATS FCEV
- Drivetrain ATS PHEV
- Drivetrain ATS HEV
- Drivetrain ATS ICE gasoline
- Drivetrain ATS ICE diesel

**Vehicle architecture:**
- Reference vehicle small
- Reference vehicle medium
- Reference vehicle large
- Driving cycle NEDC
- Driving cycle WLTP
- 3 x Driving cycles user behaviour

**Vehicle cabin:**
- Vehicle cabin small
- Vehicle cabin medium
- Vehicle cabin large

---

Source: B. Hollweck, et. al., Energy analyses of fuel cell electric vehicles (FCEVs) under European weather conditions and various driving behaviours, 6th European PEFC and Electrolyser Forum, Luzern 2017
Simulation model – ICE Range Extender Electric Vehicle (ICE-REEV)

Combustion engine
Generator

Fuel tank
RE-module

1. ICE Off
2. ICE LPM
3. ICE Alone
4. Recuperation
Validation/Results of a previous FCEV simulation model

NEDC Energy consumption:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂ consumption [kgH₂/100km]</td>
<td>0.624</td>
<td>0.634</td>
<td>0.448</td>
<td>0.434</td>
</tr>
</tbody>
</table>

Cabin heat-up and cool-down:


Analysis of power losses due to tire rolling resistance

• Tire rolling resistance depends on the velocity and tire shoulder temperature

• Model was validated on stationary points and verified on a four-mass-model which was validated on stationary and transient measurements

• Model consists of two masses

• Model contains all basic thermal transfers and main geometries

• Model fits our needs best: short calculation time and good accuracy
Analysis of power losses due to tire rolling resistance

→ Difference of Rolling Resistance Factor due to different tire shoulder temperature is <5 % in the range from -20 to 40 °C.

Summary

• The approach of a Well-to-Wheel analysis was introduced and the need to compare different drivetrain topologies under realistic boundary conditions and user behaviour was explained.

• A methodology to represent realistic boundary conditions and user behaviour for a Well-to-Wheel Analysis was presented.

• The simulation models of a Plug-In Hybrid Electric Vehicle and a Range Extender Electric Vehicle were shown and explained.

• Validation for energy consumption during NEDC and cabin heat-up for a FC-BEV was shown

• Simulation model for power losses due to tire rolling resistance was explained and results compared
Thank you for your attention!