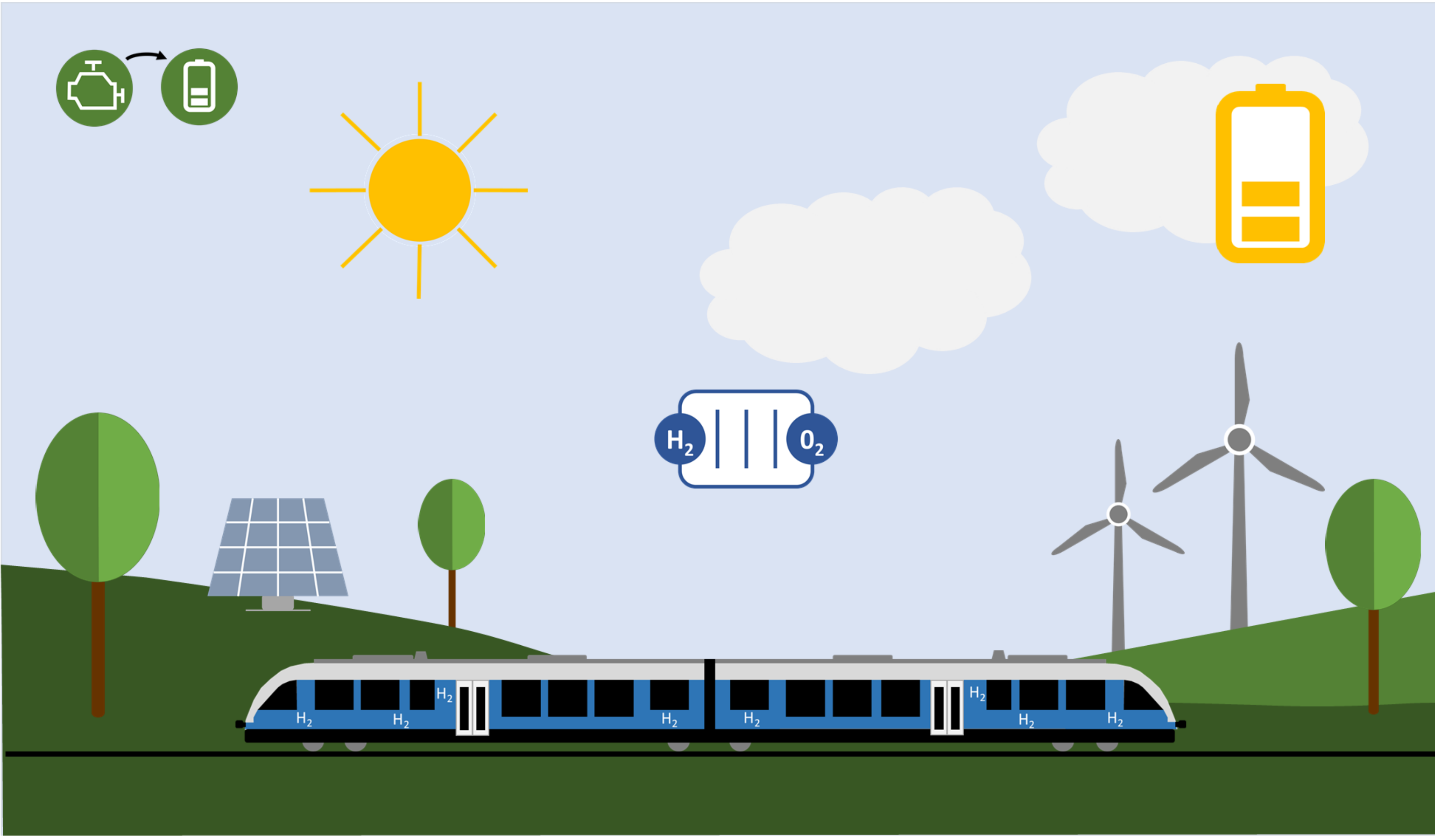
The Modelling of Vehicle Dynamics, Performance and Energy Consumption Using Alternative Fuel Vehicles



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Alternative Fuel Vehicles: Soon to Become Part of Everyday Life

In contrast to motor vehicle traffic, electromobility has been a widespread technology on railways for decades. Of course, there are still routes - usually on less busy sections - that do not have overhead wiring (Deutsche Bahn: approx. 39 % of the network, in 2020) and are used by fossil fuel powered vehicles.

Although the publicly announced intention is to further increase the share of electrified railway infrastructure, for reasons of economic efficiency and very long planning and construction periods, no short-term substitution of environmentally outdated diesel transports can be expected. Supplementary technical solutions are required: alternative fuel vehicles.

Innovative designs are used here for rail vehicles that have traction motors but do not (or not only) draw their operating voltage from the overhead wire (or conductor rail) - and of course not with the help of the familiar diesel-electric system.

(Credit: Dirk Bräuer, iRFP)

These railway vehicles - often referred to as BEMU (Battery Electric Multiple Unit) or HEMU (Hydrogen Electric Multiple Unit) - will soon find increasingly widespread use: In Germany, public transport authorities are already tendering local transport networks on the premise of their use (e.g. in the "XMU network" Schleswig-Holstein, planned from Dec. 2022 or network East Brandenburg, planned from 2024) or lines whose classic electrification with 15 kV, 162/3 Hz is planned in the medium term are already to be operated battery electrified on a transitional basis (e.g. Leipzig - Chemnitz, planned from 2023).

Energy and Performance Aspects of Traction Using Fuel Cells or Battery Electrics

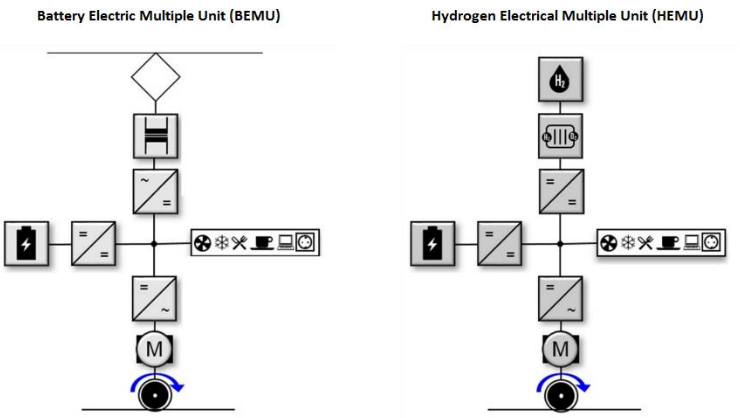
Vehicle-specific performance data and the tractive effort/speed diagram based on it are the foundation of computer-aided travel time calculations. In the case of classic traction concepts, the motors generally have their full traction power available for acceleration when needed.

Rail vehicles with fuel cell propulsion and those that not only have traction batteries but also allow catenary operation are considered as hybrid vehicles: The energy required for the (nominal) power of traction motors is obtained, partly in parallel, from different sources, e.g.:

- Fuel cell and battery (HEMU)
- Overhead wire and battery (BEMU in overhead wire mode)

The electrical energy generated in the fuel cell recharges the traction battery - where the course of the journey allows to do so.

In battery-electric operation, this takes place under the overhead wire. However, when the vehicle is stationary (stops, turns), the charging current is technically limited and the time window for recharging is an important factor.



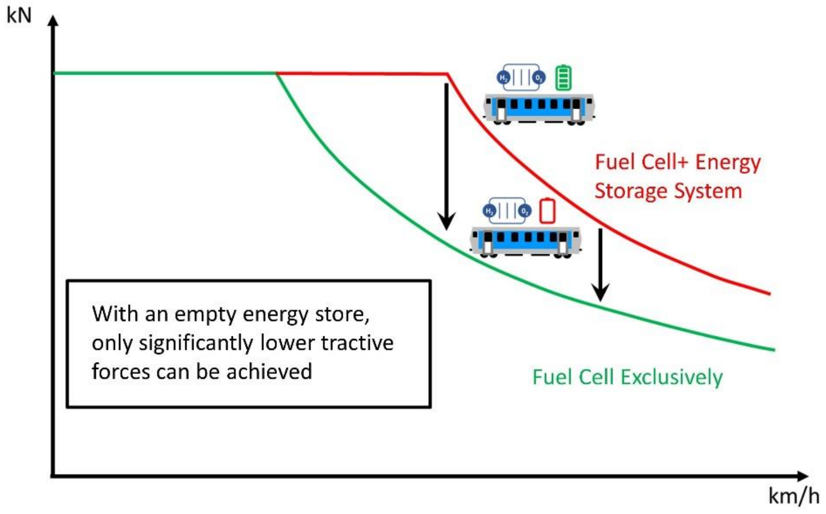
This means that if the vehicle does not have energy available from all the resources involved (e.g. if the battery is exhausted), the traction motors can only operate in the partial power range. Of course, this has a direct effect on driving dynamics and thus on run time and route construction.

This study does not examine the constructional limitations of this kind of traction elements dimension. Rather, it shows why the impact of those still new technologies on the timetable needs to be considered.

Effects on Computer-Aided Timetable Construction

For vehicles with alternative fuels, energy calculations and balance considerations are a necessary part of the run time calculation and thus of the timetable design, provided that they are executed realistically.

In the case of hybrid or alternative fuel systems, factors such as line resistance and train path characteristics (e.g. planned stop times, running time surcharges) are much more decisive than in the case of classic types of traction as to whether a specific traction unit would be suitable at all for providing a defined operating performance, i.e. to what extent it is "drivable" with the desired rolling stock.



The tractive force/speed diagram with individual power hyperbola usually used for calculations is no longer sufficient to capture the effects mentioned. The energy and power balance, which is specific to each vehicle and driving position at each point, would have to be permanently included in the design of the timetable in a modelling approach that is as fully integrated as possible by the design software and fed back to the run time calculation.

In concrete terms, this could mean, for example, that the journey time between two operating points (i.e. the inclination of the train line in the graphic timetable) depends on whether the stop time at the previous stop is varied and thus the battery charge level is changed. Ideally, the timetable planner would be alerted by the software if a path contains run time extensions that are due to energy balance-related power drops.

Exemplary Model Calculations - Journey Time Aspects, Power Balance and Energy Curve with the Use of Alternative Drive Technologies:

A selection of possible scenarios for the course of the energy balance is illustrated in the following graphics. All graphics are taken from the energy calculation module integrated in FBS.

For the calculations, two fictitious vehicles with the performance data mentioned here were used as examples:

Battery Electric Multiple Unit (BEMU)

2-Section Railcar	
Vehicle Weight:	75 t
Speed:	160 km/h
Driving Wheel Power:	1.165 kW
Transformer Power:	1.000 kW

Battery Parameters:

Rated Capacity:	270 kWh
Driving Performance:	600 kW
Charging Power:	800 kW

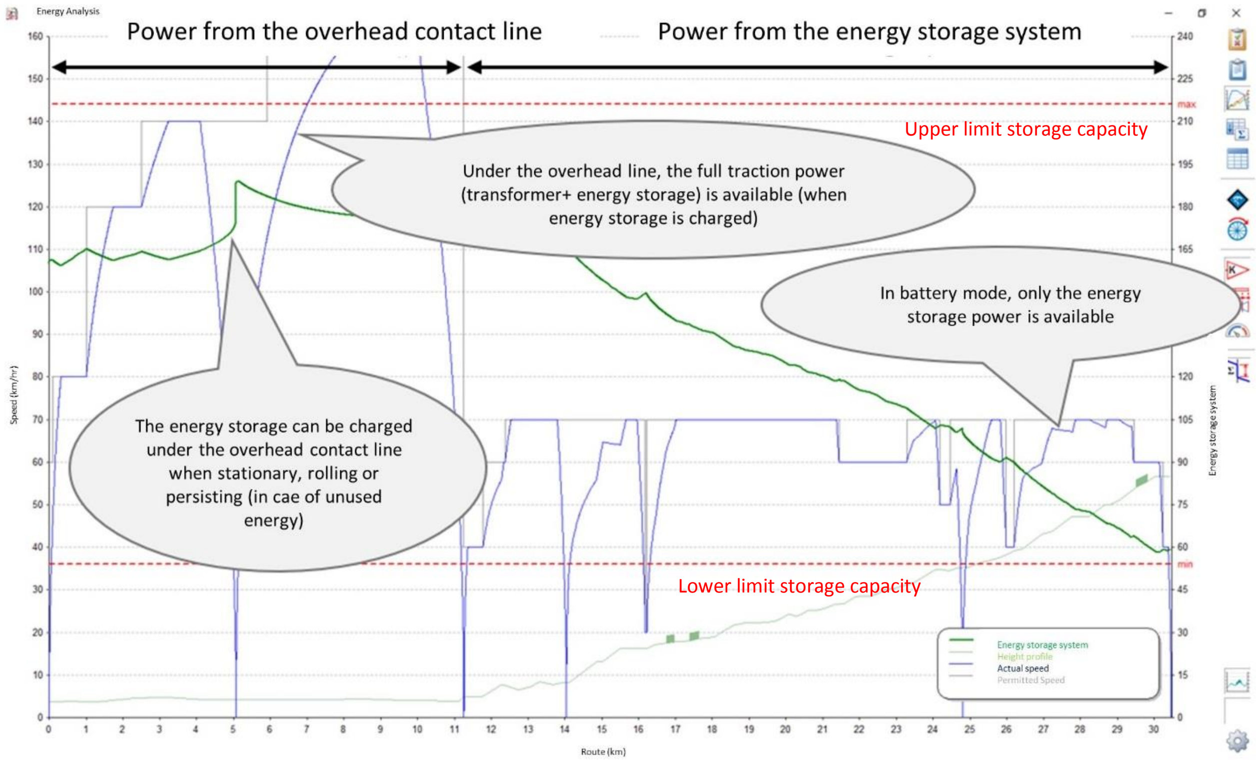
Hydrogen Electric Multiple Unit (HEMU)

2-Section Railcar	
Vehicle Weight:	128 t
Speed:	160 km/h
Driving Wheel Power:	1.030 kW
Fuel Cell Power:	400 kW

Battery Parameters:

Rated Capacity:	180 kWh
Driving Performance:	1000 kW
Charging Power:	800 kW

Scenario 1 - Battery Railcar on Scheduled Run:

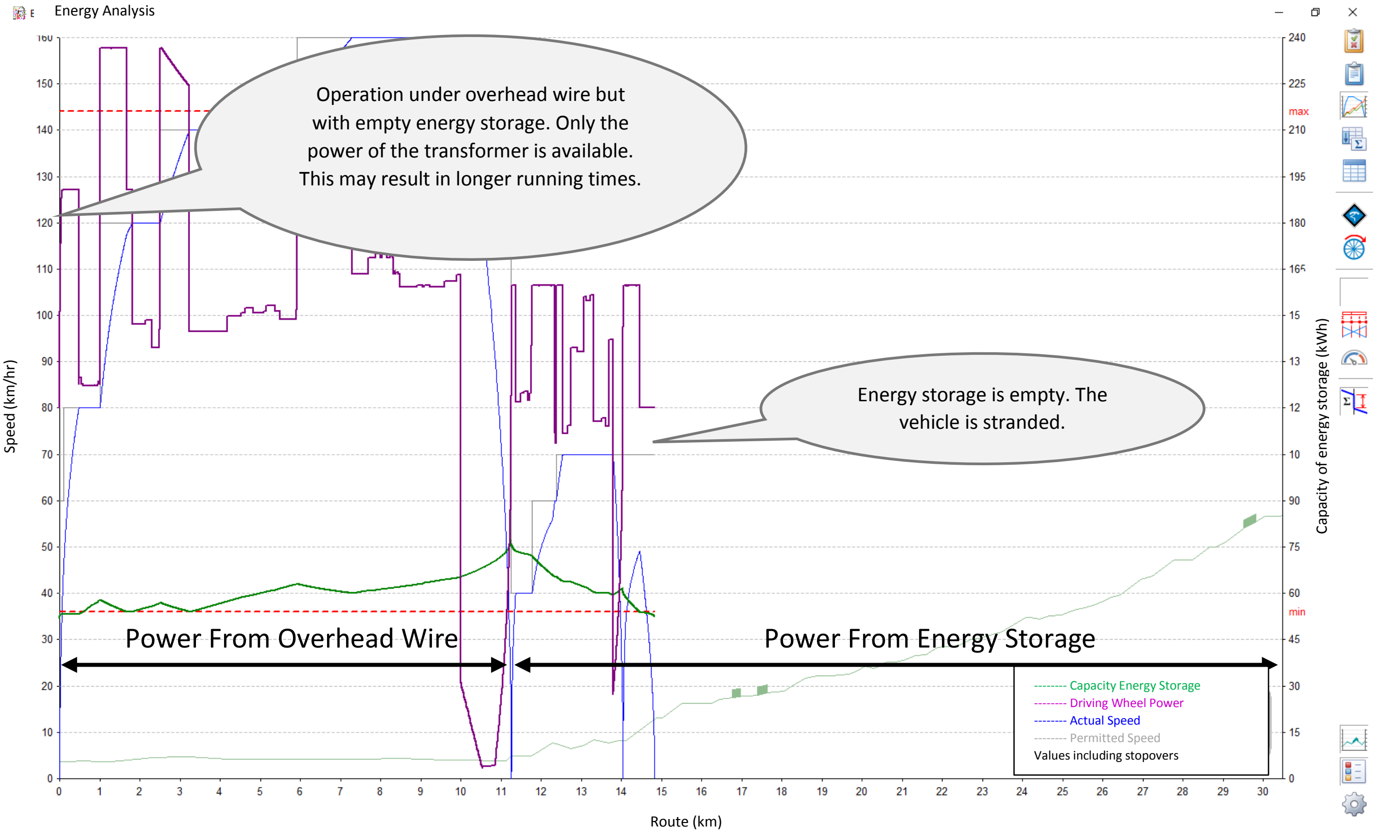


Under the overhead line, the full traction power (transformer+ energy storage) is available (when energy storage is charged)

In battery mode, only the energy storage power is available

The energy storage can be charged under the overhead contact line when stationary, rolling or persisting (in cae of unused energy)

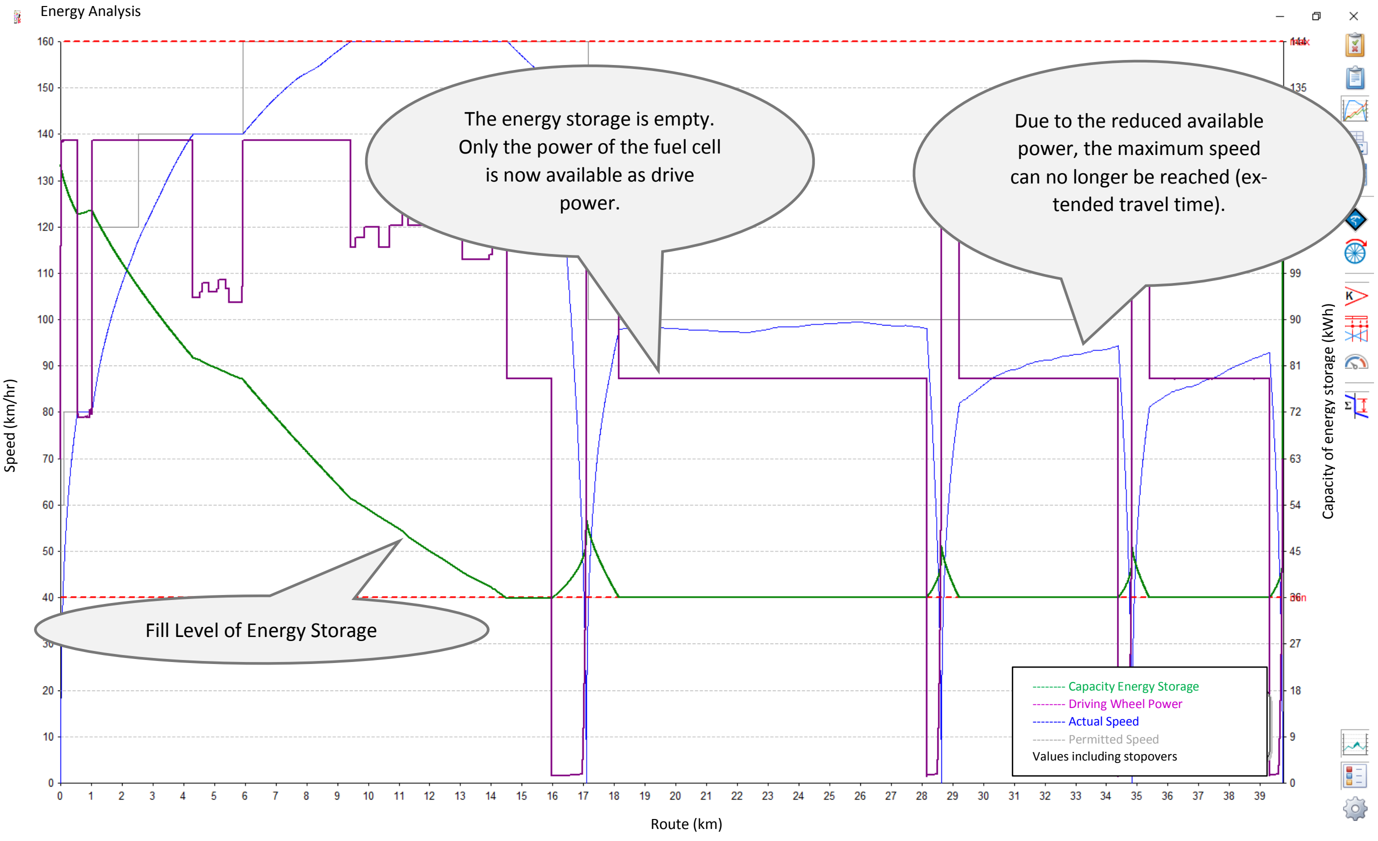
Scenario 2 - Battery Railcar strands/ed with an Empty Battery:



Operation under overhead wire but with empty energy storage. Only the power of the transformer is available. This may result in longer running times.

Energy storage is empty. The vehicle is stranded.

Szenario 3 – Fuel Cell Vehicle Driving with Emptying Energy Storage:



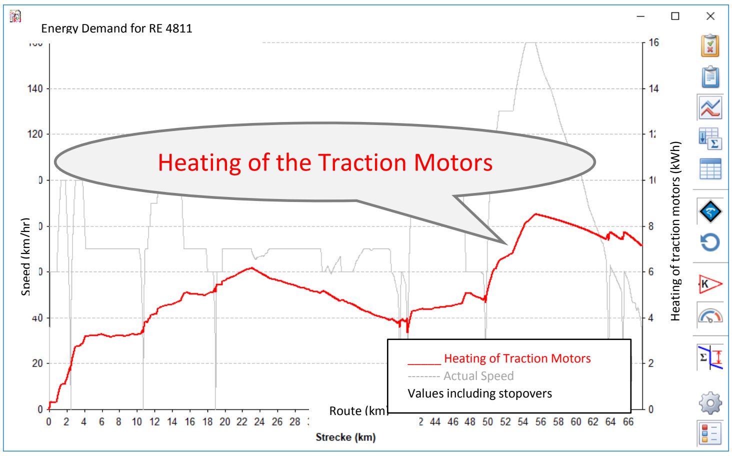
The energy storage is empty. Only the power of the fuel cell is now available as drive power.

Due to the reduced available power, the maximum speed can no longer be reached (extended travel time).

Fill Level of Energy Storage

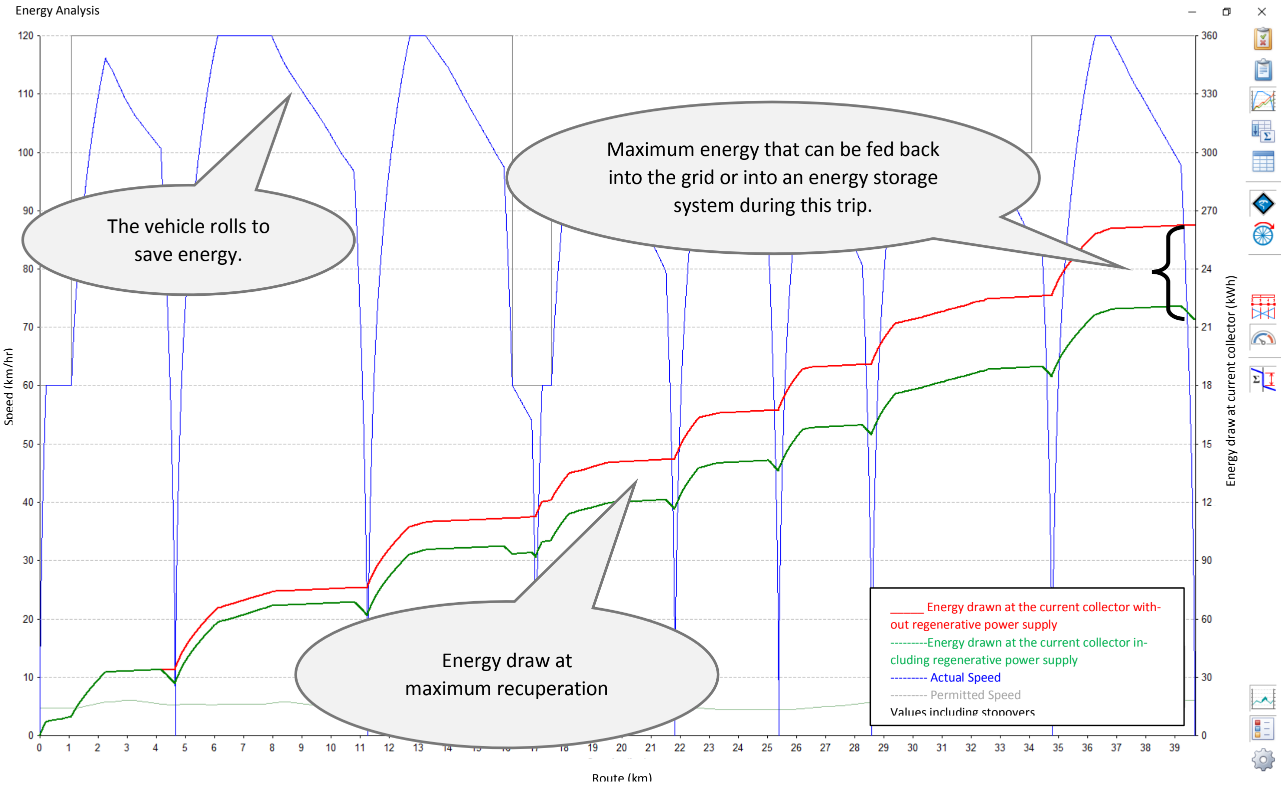
Further Aspects of Energy Calculations with FBS

The energy calculation integrated in FBS covers a wide range of aspects, e.g.:



Heating of the Traction Motors

- energy demand over the course of the journey / of the operating program
- savings through energy-efficient driving
- display of further parameters (e.g. heating, power, efficiencies)
  time-weighted stress duration curve
- recuperation (battery or network)
- circulation-based evaluation
- values also for power transmission components (from current collector to traction wheel)
- different driving modes
- graphical and tabular analysis
- relationship between travel time and energy calculation permanently related to each other
- also includes energy demand of auxiliary operations / while standing
- and many more



The vehicle rolls to save energy.

Maximum energy that can be fed back into the grid or into an energy storage system during this trip.

Energy draw at maximum recuperation

Are you interested in a study on the topics of energy calculation or energy storage hybrid vehicles?

Get in touch!

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The Modelling of Vehicle Dynamics, Performance and Energy Consumption Using Clean Energy Concepts

Attachment Sample Vehicles:

The aspects of the relationship between travel time, performance and energy balance for rail vehicles with alternative fuel concepts explained in this brief study can also be implemented practically in the context of computer-aided timetable design with FBS. For this purpose, the following overview shows some differently configured sample vehicles for battery-electric or fuel cell based traction, whose driving dynamics or power / storage capacity data show realistic orders of magnitude.

With the help of these exemplary models, FBS users are enabled to simulate whether and under which concrete vehicle (or also infrastructural) -specific framework the operational-technical feasibility of the use of alternative drive concepts would be given and which consumption results could be achieved in this way when setting up future timetable scenarios for planned routes and subnetworks. It is not necessary to rely on rolling stock that may already be available on the market during the conception phase. On the basis of the data obtained in this way, qualified requirements could be exemplarily formulated for vehicle manufacturers if necessary.

The sample data presented here and contained in the traction unit database are not conclusive and may be subject to change. In addition, we recommend that FBS users request the service offered by iRFP if they need advice or if they wish to include the data of further sample vehicles with alternative drive systems or vehicles actually offered on the market (after approval of the data by the respective manufacturer) in the program package.

General Vehicle Characteristics:

Key in FBS	Type	Brief Descript.	MS. Maximum Speed km/h	Weight Timetable Weight t	Length Length Across Coupling m	$E_{Akku,Nenn}$ Nominal Capacity[1] kWh	Seats	Notes
X.MusterBEMU246-1	Battery+ Overhead Line Vehicle	Two parts, B'(2')B'	160	77,6	36,50	540 (80%)	12/88	Vehicle rather conservative
X.MusterBEMU246-2	Battery+ Overhead Line Vehicle	Two parts, B'(2')B'	160	102,9	40,00	900 (80%)	12/88	Vehicle rather progressive
X.MusterBEMU348-1	Battery+ Overhead Line Vehicle	Three parts, B'(2')(2')B'	160	137,0	60,00	800 (60%)	12/146	
X.MusterBEMU348-2	Battery+ Overhead Line Vehicle	Three parts, B'(2')(2')B'	160	130,7	60,00	900 (80%)	12/146	Vehicle rather progressive
X.MusterHEMU248-1	H_2-Vehicle	Two parts B'2' + 2'B'	160	128,0	53,90	270 (60%)	12/146	

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[1] x% of the capacity are actually useable in practical operations

Vehicle Performance Data:

Key in FBS	P_{Akku} Max. Power of the Energy Storage Device (when discharging) kW	P_{brutto} Max. Power via Current Collector / Fuel Cell kW	$P_{T,max}$ Max. Power at Driving Wheel Diameter kW	$P_{T,Akku}$ Max. Power at Drive Wheel With Battery Drive kW	$P_{T,brutto}$ Max Power at Driving Wheel Diameter with Current Collector/ Fuel Cell kW	$P_{T,Akku+brutto}$ Max Power at Driving Wheeler Diameter with Current Collector/ Fuel Cell and Battery DriveFD[2] kW	P_{Hilfsb} Power Support Operations kW	$F_T(0)$ Start-Up Tractive Force kN	$P_{T,Akku}/m$ Power to Mass Ratio for Battery Operation kW/t	$P_{T,brutto}/m$ Power-to-Mass Ratio with current Collector / Fuel Cell. kW/t	$P_{T,A+b}/m$ Power-to-Mass Ratio with Current Collector / Fuel Cell and Battery Drive kW/t	Notes
X.MusterBEMU246-1	800	1000	1165	552	707	1165	80	73	7,1	9,1	15,0	"Limitation of charging power to 600 kW"
X.MusterBEMU246-2	1800	2700	2020	1357	2020	2020	80	140	13,2	19,6	19,6	
X.MusterBEMU348-1	1300	2278	1700	944	1700	1700	98	122	6,9	12,4	12,4	
X.MusterBEMU348-2	1800	3500	2600	1339	2600	2600	100	170	10,2	19,9	19,9	
X.MusterHEMU248-1	1000	800	1030	707	258	1030	80	134	5,5	2,0	8,0	

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[2] PT,Akku+brutto=PT,Akku+ PT,brutto+1xPHilfsb, though restricted to maximum power at driving wheel $P_{T,max}$