

Energy Consumption and CO₂ Emission Simulation of Cars with Electric Powertrain Systems

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CONTENTS

- Motivation for New Propulsion Systems
- Research Methodology
- Vehicle and Powertrain Concepts
- Calculation Results of the Simulations
- Summary

Motivation

Road transport has three main environmental issues:

- Carbon dioxide (CO₂)
- Nitrogen dioxide (NO₂)
- Particulates (PM)

Additionally:

Security of energy supplies

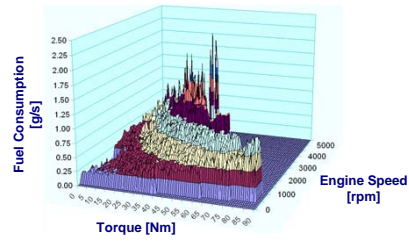
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Methodology



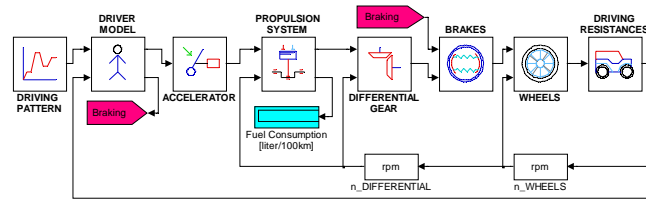
Real world On-board Measurements



Characteristic Maps

$$FC = f(FC_{idle}, v, F)$$

Analytic Function



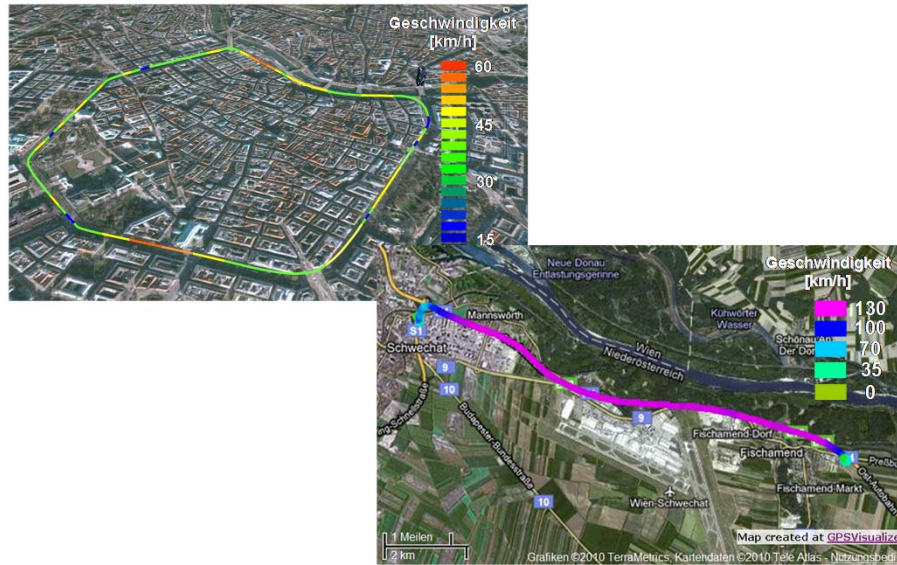
Simulation



Real-World On-Board Measurements



Representative Real-World Driving Routes



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Real-World Scenario (Annual Average) (10°C Ambient Temperature)

Powertrain Technology	Auxiliary System	Power Demand Auxiliaries [kW]
Internal Combustion Engine (CI-ICE)	Heating system	0
	Air Conditioning	0,5
	Other	0,5
	Total	1
Plug-in Hybrid (Battery Mode)	Heating system	2
	Air Conditioning	0,5
	Other	0,5
	Total	3
Fuel Cell Electric	Heating system	0
	Air Conditioning	0,5
	Other	0,5
	Total	1



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Diesel Internal Combustion Engine Vehicle



General CI Vehicle

Curb Weight	1400 kg
Air Drag Coefficient, c_w	0.31
Cross Sectional Area, A	2.22 m ²
Rolling Resistance	0.012
Tank Capacity	50 Liters (Diesel)
CI Engine	
Max. Power	105 kW
Gearbox	
Type	6-Speed Manual

Hybrid Electric Vehicle



Hybrid Electric Vehicle

Curb Weight	1500 kg
Max. System Power	100kW
Air Drag Coefficient, c_w	0.31
Cross Sectional Area, A	2.22 m ²
Rolling Resistance	0.012
Tank Capacity	45 Liters (Gasoline)
SI Engine	
Max. Power	75 kW
Electric Motor/Generator	
Max. Power Output	60 kW
Battery	
Capacity	1.5 kWh
Weight	50 kg



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Plug-In Hybrid Gasoline Electric Vehicle & Electric Vehicle with Diesel Range-Extender

	Plug-In Hybrid Gasoline	Electric Vehicle with Diesel Range-Extender
Curb Weight	1800 kg	1850 kg
Max. System Power	100kW	125 kW
Air Drag Coefficient, c_w		0.32
Cross Sectional Area, A		2.38 m ²
Rolling Resistance		0.012
Tank Capacity		45 Liters
IC Engine	Gasoline	Diesel
Max. Power	75 kW	105 kW
Electric Motor/Generator		
Max. Power Output		75 kW
Battery		
Capacity		16 kWh
Weight		200 kg



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Fuel Cell Electric Vehicle

Fuel Cell Electric Vehicle

Curb Weight	1500 kg
Air Drag Coefficient, c_w	0.32
Cross Sectional Area, A	2.38 m ²
Rolling Resistance	0.012
Tank Capacity	4 kg H ₂ @ 700 bar
Electric Motor/Generator	
Max. Power Output	75 kW
Battery	
Capacity	1.5 kWh
Weight	50 kg

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Comparison Tank to Wheel Consumption Test Cycle: NEDC under Real-World Conditions		
Powertrain Technology	Consumption	Maximum Range [km]
ICE Diesel	5,3 Liter Diesel/100km	941
Hybrid Gasoline	4,9 Liter Gasoline/100km	912
Plug-in Hybrid Gasoline	5,6 Liter Gasoline/100km	806
	31 kWh/100km (electric mode)	52
Electric Vehicle with Diesel Range-Extender	5,6 Liter Gasoline/100km	805
	31 kWh/100km (electric mode)	51
Fuel Cell Electric	0,9 kg H ₂ /100km	445

Comparison of Vehicle Concepts Test Cycles under Real-World Conditions					
Test Cycle	Energy Consumption in [MJ/100km]				
	ICE Diesel	Hybrid Gasoline	Plug-in Hybrid Gasoline	Electric Vehicle with Diesel Range-extender	Fuel Cell Electric
NEDC	188	161	182 / <u>111*</u>	197 / <u>112</u>	108
UDC	230	169	189 / <u>132</u>	204 / <u>134</u>	116
EUDC	162	156	178 / <u>98</u>	193 / <u>99</u>	105
Downtown	332	195	209 / <u>185</u>	224 / <u>187</u>	142
Freeway 100 km/h	159	159	180	194	110
Freeway 130 km/h	207	218	246	265	161

* Underline values refer to battery mode

Comparison of Energy Consumption Test Cycle: NEDC under Real-World Conditions			
Powertrain Technology	Tank to Wheel [MJ/100km]	Primary Energy Consumption [MJ/100km]	
ICE Diesel	188	208	
Hybrid Gasoline	161	179	
Plug-in Hybrid (Gasoline)	182 / <u>111*</u>	202 / <u>296</u>	
Electric Vehicle with Diesel Range-extender	197 / <u>112</u>	219 / <u>299</u>	
Fuel Cell Electric	108	Methane Reformation	Electrolysis
		169	338

* Underline values refer to battery mode

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Summary

A methodical comparison of a statistically average car with a new electric powertrain such as hybrid, plug-in, range-extender and fuel cell relative to the conventional combustion engine was carried out.

For typical usage in urban, extra urban, and freeway real-world traffic the hybrid system and, with some range limitations, the fuel cell system can provide a similar usability compared to regular systems with internal combustion engines.

Based on a primary energy calculation in general, the energy consumption of the hybrid and the fuel cell vehicle is better than the consumption of the other propulsion concepts that were examined.