Comparison of energy consumption and costs of different hybrid and plug-in hybrid vehicle concepts in European and American context

IEA Implementing Agreement, Hybrid and Electric Vehicles
Task 15: Plug-In Hybrid Electric Vehicles

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References

The presentation is based on the international cooperation between ANL, IFP and DLR in context of the IEA Implementing Agreement HEV

Joint Publications

B. Propfe, M. Redelbach, D. Santini, H. Friedrich:
Cost analysis of Plug-in Hybrid Electric Vehicles including Maintenance & Repair Costs and Resale Values. EVS26 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium, May 6.-9. 2012, Los Angeles, USA.

A. Rousseau, F. Badin, M. Redelbach, N. Kim, A. Da Costa, D. Santini, F. Le Berr, H. Friedrich:
Comparison of Energy consumption and costs of different HEVs and PHEVs in European and American context, European Electric Vehicle Conference (EEVC), 19.-22. November 2012, Brussels, Belgium.

Argonne NATIONAL LABORATORY

ifp Energies nouvelles

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Agenda

The presentation analysis the competitiveness of different hybrid electric vehicle concepts

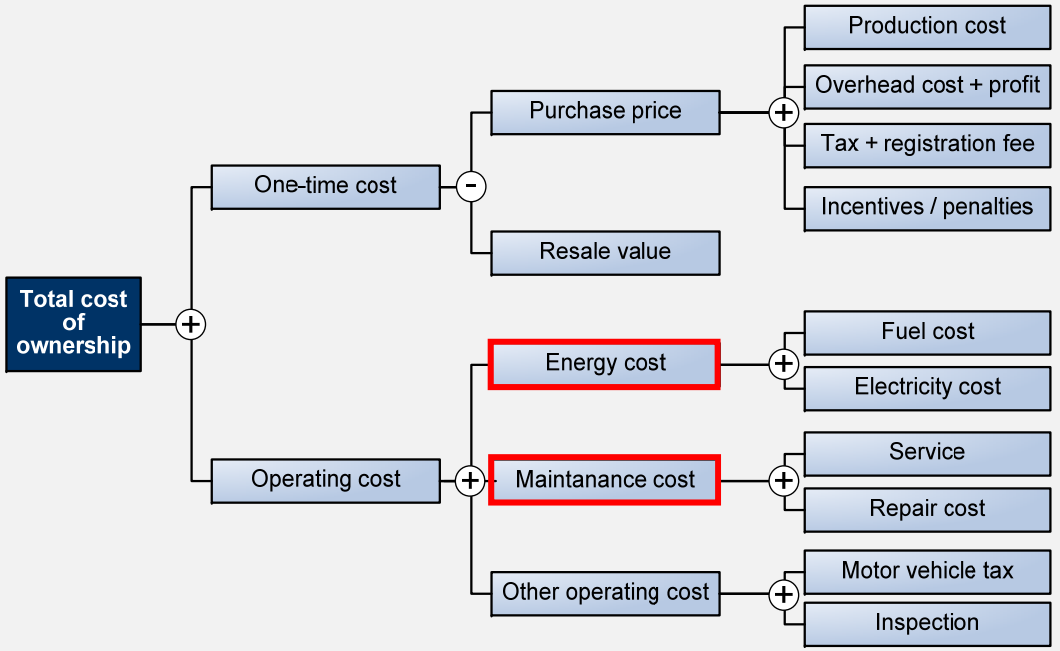
- Objective and approach
- Vehicle architecture
- Energy consumption (certification vs. real world)
- Maintenance and repair cost
- Total cost of ownership analysis
- International comparison of cost efficiency

Objective and approach

The presentation analysis the competitiveness of different hybrid electric vehicle concepts

- **Current challenges**:
  - Ambitious CO_2 reduction targets,
  - rising energy prices
  - growing awareness of fuel economy
- **Electrification of drivetrains** as main levers to improve energy efficiency
- **Cost competitiveness of electric vehicles:**
  - Production costs are higher conventional
  - Operating costs are lower due to low energy consumption

Total cost of ownership model (developed by DLR)

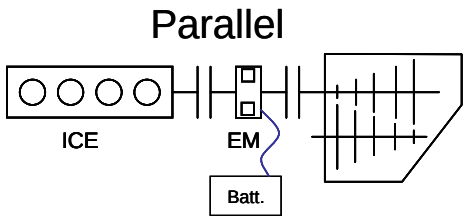


→ Fair comparison of cost efficiency across different powertrain alternatives from customer perspective

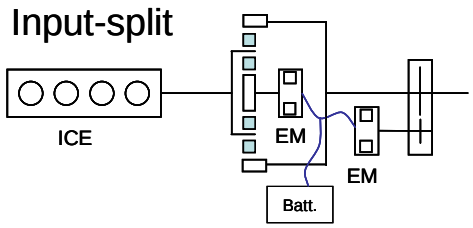
Vehicle architecture and setup

3 different hybrid electric powertrain concepts have been analyzed and compared to a conventional vehicle in midsize car segment

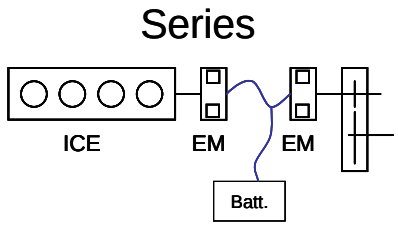
HEV



PHEV30



PHEV70



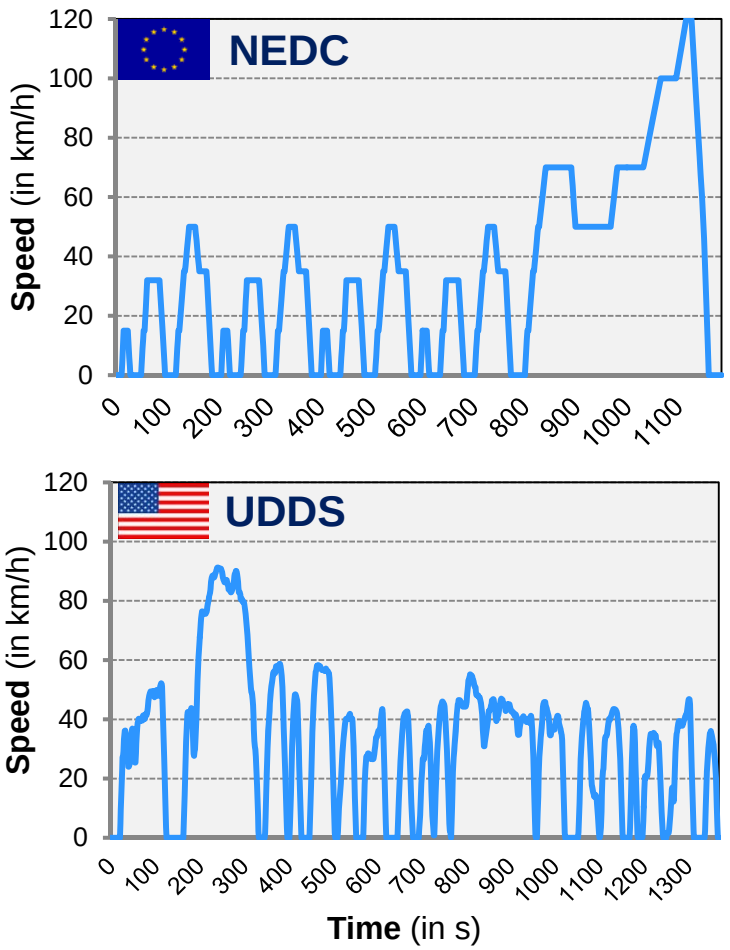
Component sizing

		Conventional	Parallel Hybrid	Input split Hybrid	Series Hybrid
		Automatic	HEV	PHEV 30	PHEV 70
Vehicle Mass	kg	1220	1271	1340	1614
ICE power	kW	105,9	80,2	50,7	78
El. machine 1 power	kW		25	70,3	103
El. machine 2 power	kW			34,9	78
Battery power	kW		30	60,5	135
Battery energy	kWh		0,97	5,44	13,56
Battery P/E ratio	h^{-1}		31	11	10

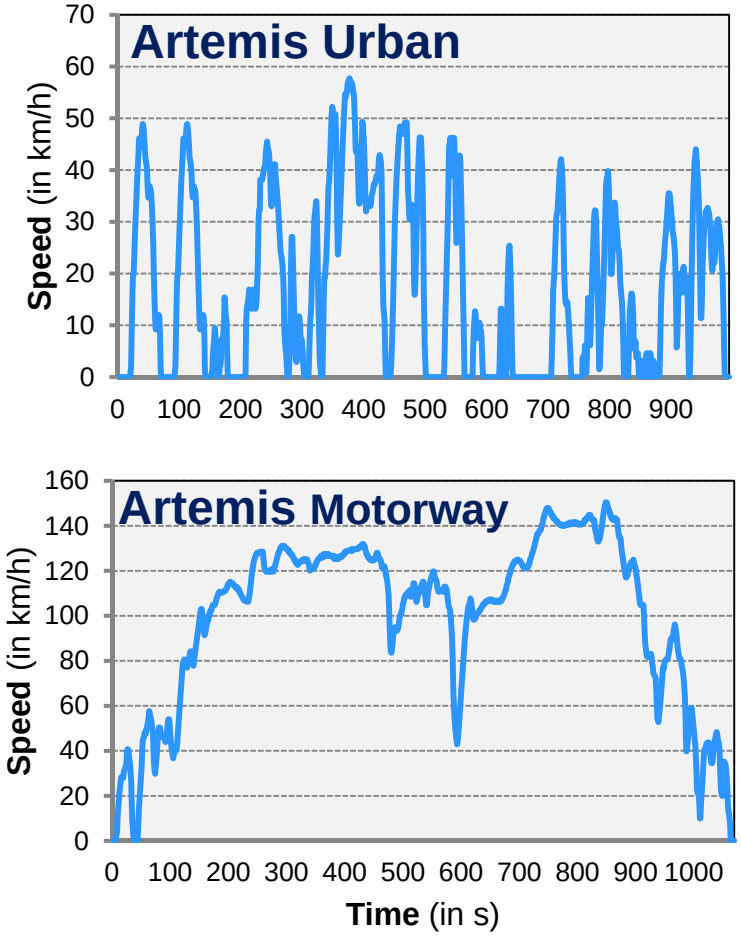
Energy consumption

Different standardized driving cycles have been simulated

Certification test cycle



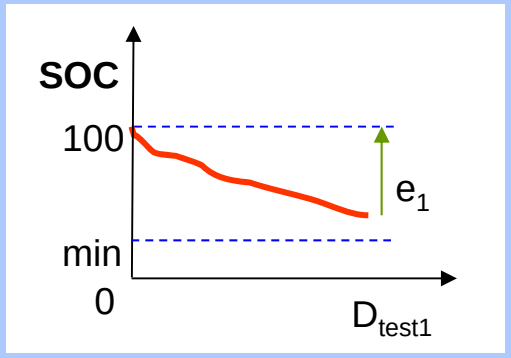
Real-world test cycle



Energy consumption

European certification procedure for plug-in hybrid electric vehicles[1]

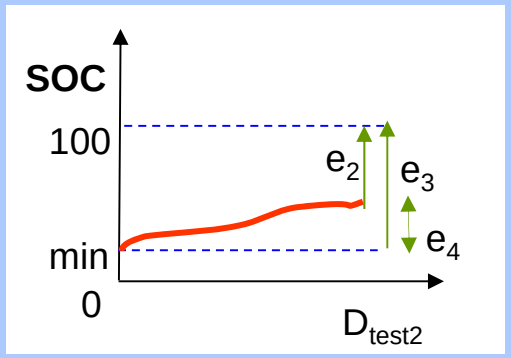
A **Battery fully charged (CD-Mode)**



$M_1 = m_1 / D_{test1}$

$E_1 = e_1 / D_{test1}$

B **Battery fully discharged (CS-Mode)**



$M_2 = m_2 / D_{test2}$

$E_4 = e_4 / D_{test2}$

CO_2 emission (in g/km)

$$M = \frac{AER \cdot M_1 + 25 \cdot M_2}{AER + 25}$$

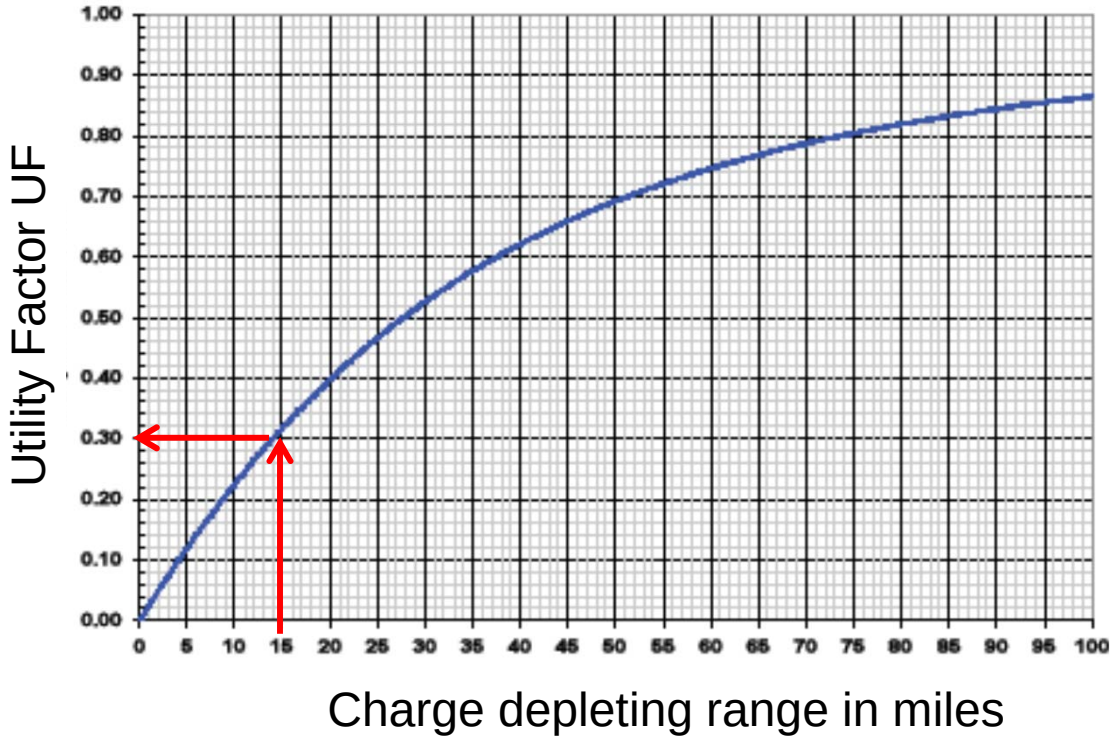
Electric energy consumption (in Wh/km)

$$E = \frac{AER \cdot E_1 + 25 \cdot E_4}{AER + 25}$$

1) Accoding to regulation 101; AER = all electric range

Energy consumption

US certification procedure for plug-in hybrid electric vehicles[1]

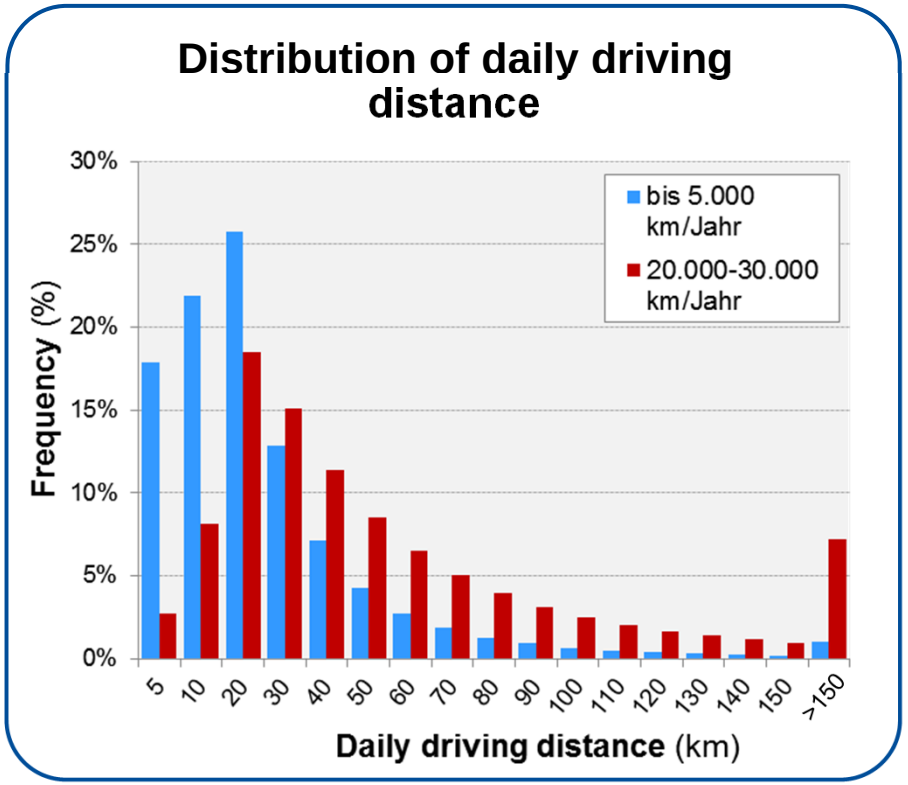


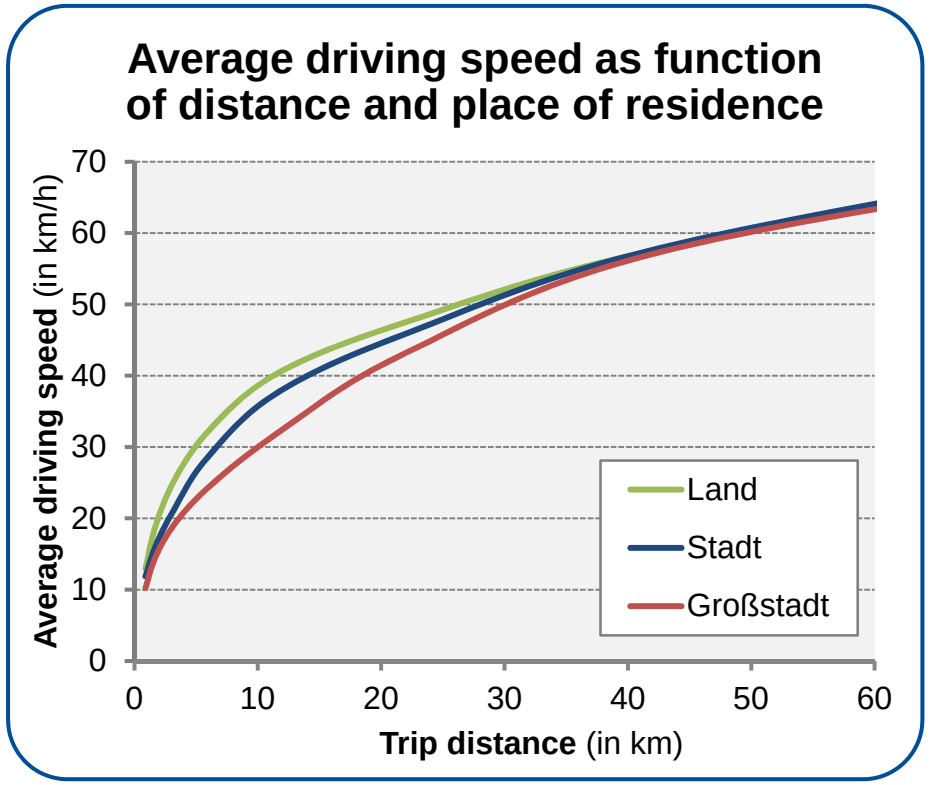
$$FC_{glob} = FC_{dep} \,.\, UF + (1\text{-}UF) \,.\, FC_{sus} \;\; (gpm)$$

1) Accoding SAE J1711 procedure

Energy consumption

Real world energy consumption depends on individual driver behavior





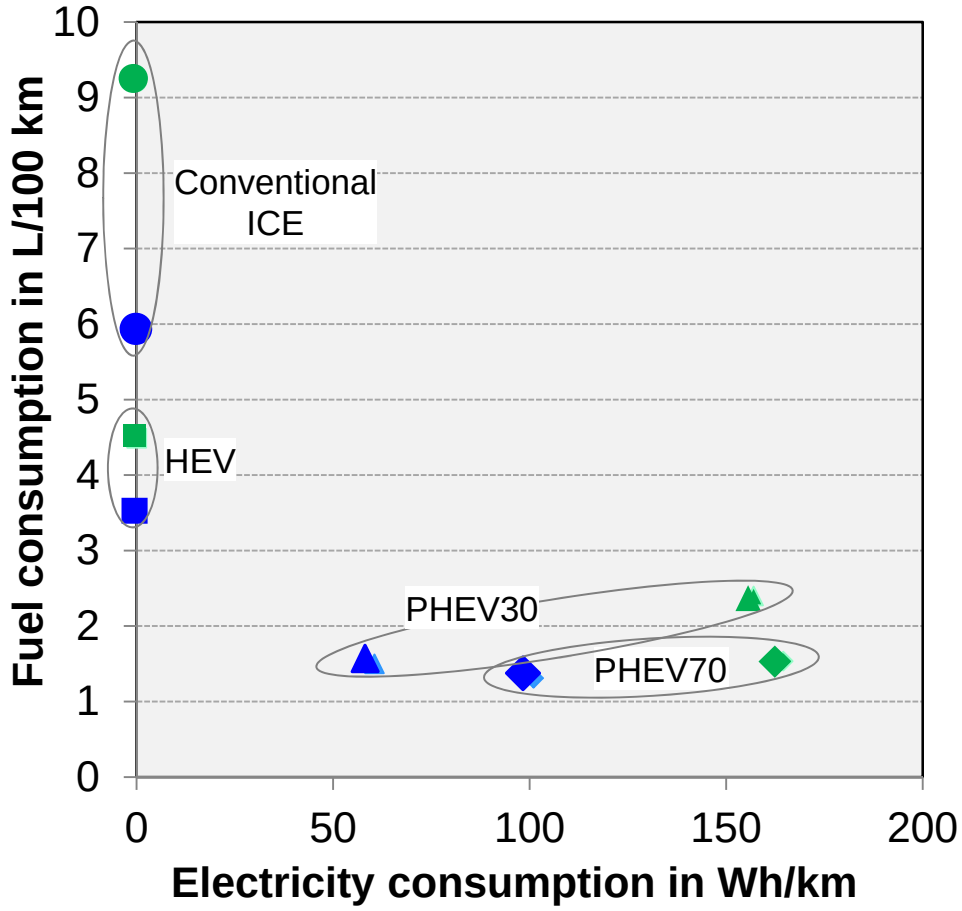
- Electric driving share
- Weighting of CD/CS-energy consumption

- Average driving seed
- Weighting of urban/motorway cycles

Source: DLR analysis of MiD 2008 data

Energy consumption

Comparison of gasoline and electricity consumption for standard EU test procedures and real world driving[1]



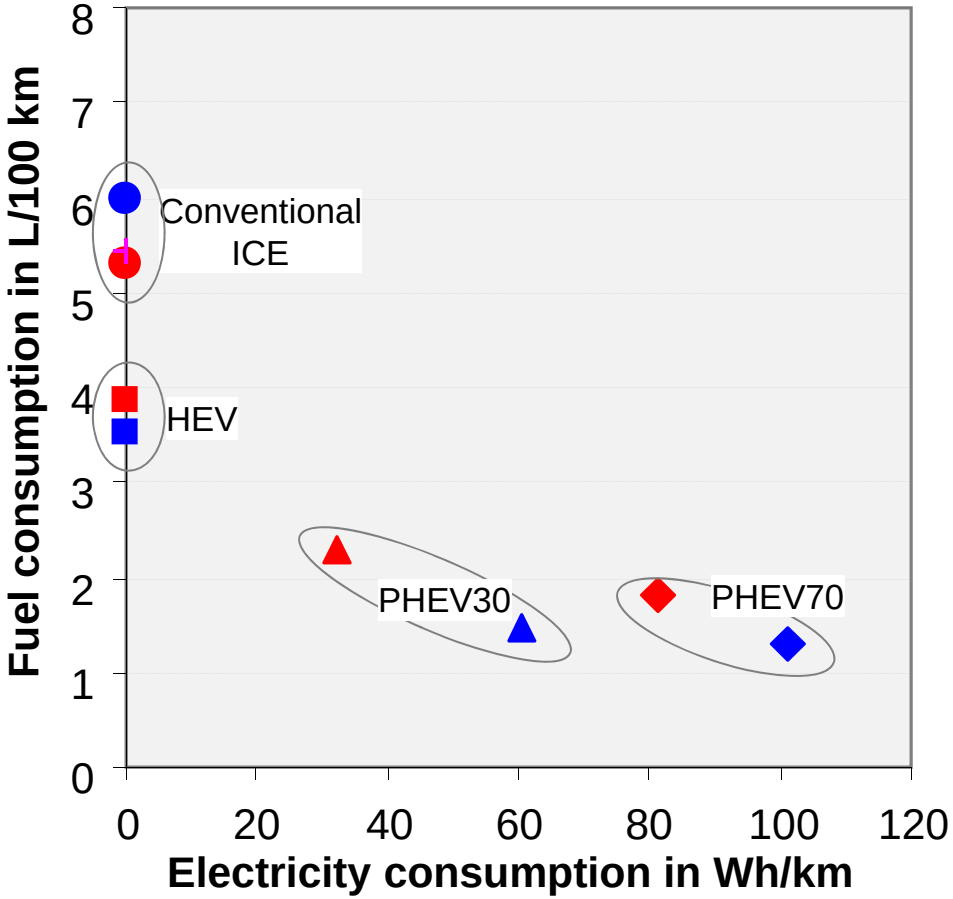
EU norm	Powertrain	Real world
●	Conventional	●
■	HEV	■
▲	PHEV30	▲
◆	PHE70	◆

Energy consumption is significantly higher in simulated real-world driving conditions than in EU test cycle (15-60% for fuel consumption)

1) Real world consumption calculated as weighted average of Artemis Urban and Motorway
Source: Based on ANL and IFP simulation results

Energy consumption

Comparison of gasoline and electricity consumption for standard EU and US test procedures



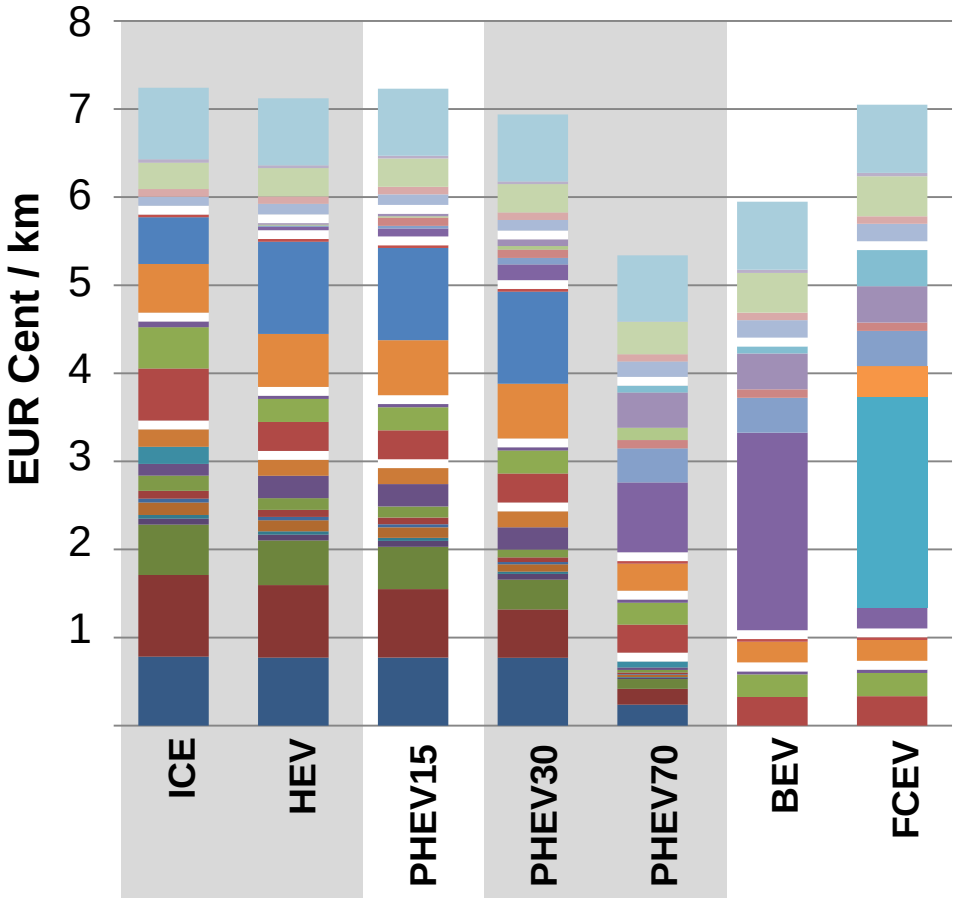
EU	Powertrain	US
●	Conventional	●
■	HEV	■
▲	PHEV30	▲
◆	PHE70	◆

Fuel consumption of PHEVs is 30-40% higher in US test procedure compared to EU; electric energy consumption 20-50% lower

Source: Based on ANL and IFP simulation results

Maintanence and repair cost

Bottom-up estimation of maintenance and repair costs of electric powertrains



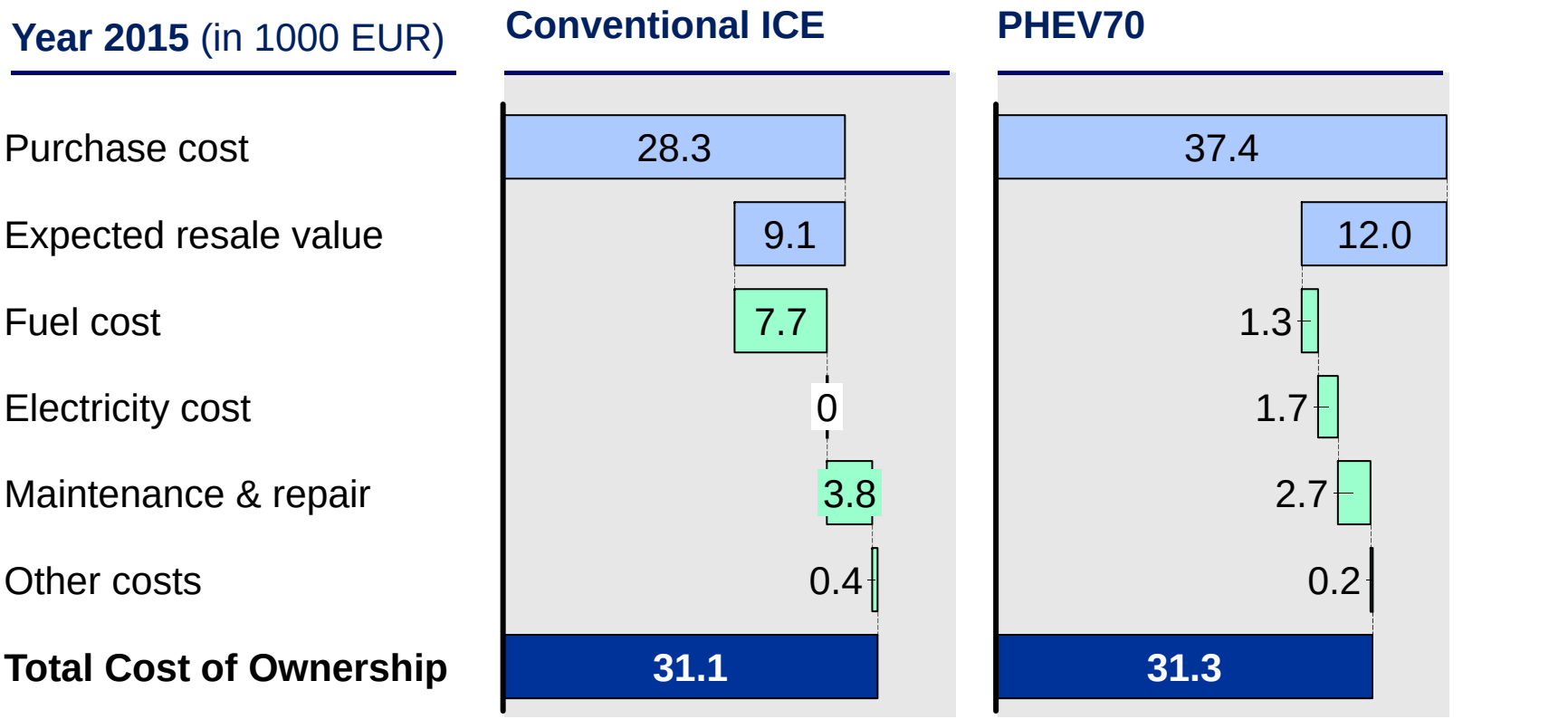
Powertrain components

- **Miscellaneous**
- Coolant
- Cabin air filter
- **Electrified Components**
- PE: DC/AC
- Charger
- H2 storage
- Traction battery (Li-ion)
- Gear oil
- Transmission
- Brake fluid
- Brake pad
- Automotive battery (Pb)
- Starter motor
- Rocker cover gasket
- Timing belt
- Fuel filter
- Exhaust system
- Tires
- Air conditioning
- Multimedia
- PE: DC/DC
- PE: AC/DC
- Traction e-motor
- Fuel cell
- **Transmission**
- Clutch
- **Braking System**
- Brake disk
- **IC Engine**
- Generator
- Spark plug
- Vee belt/Multi-groove belt
- Air filter
- Muffler
- Engine oil

M&R costs for hybrids are lower than for conventional vehicle (up to -30% for PHEV70)

TCO analysis

Hybrids can compensate higher initial purchase price by lower operating cost

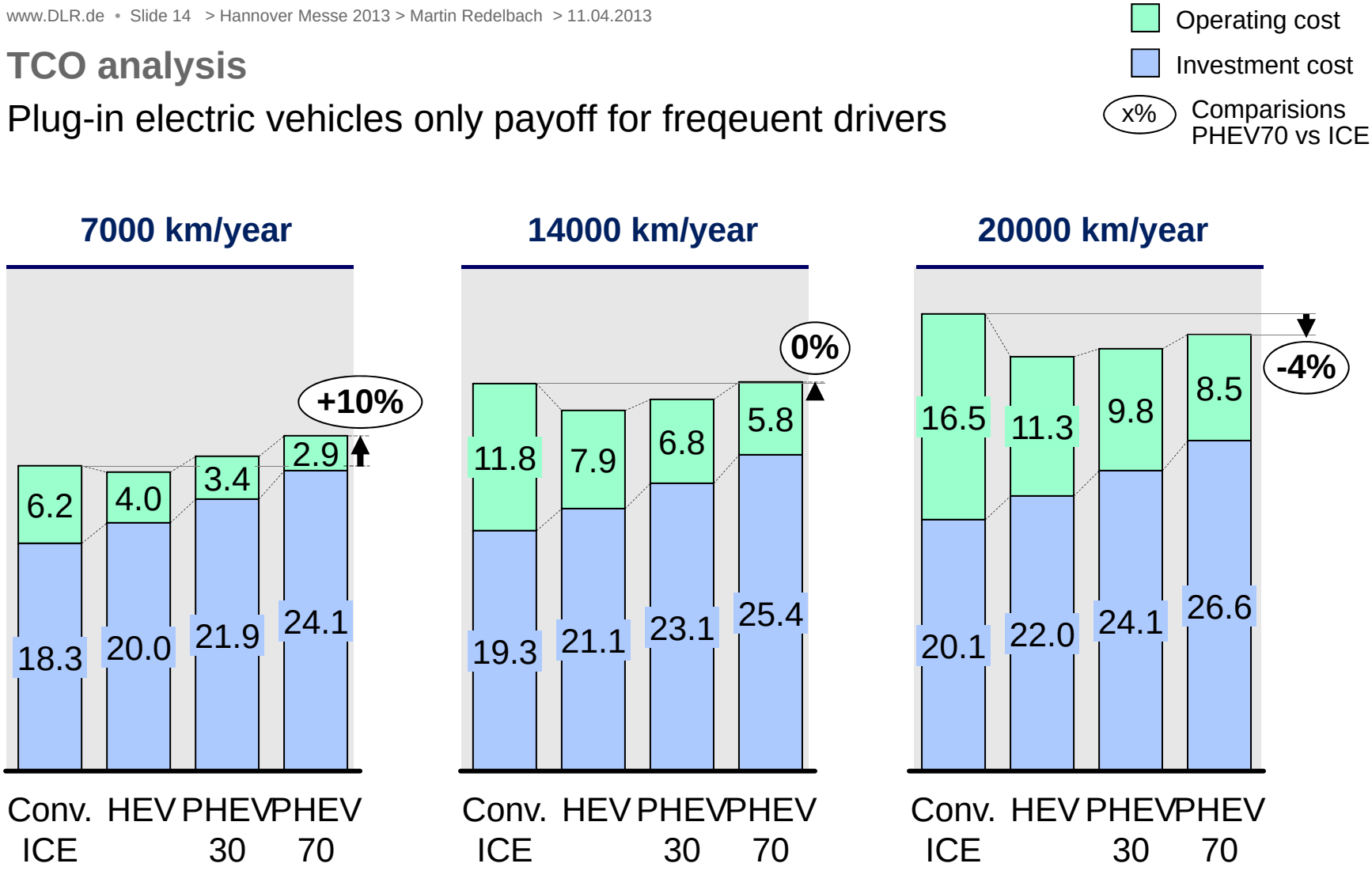


Assumption: 14,000 km/year, 4 year holding period, country Germany

Source: …

TCO analysis

Plug-in electric vehicles only payoff for freqeuent drivers

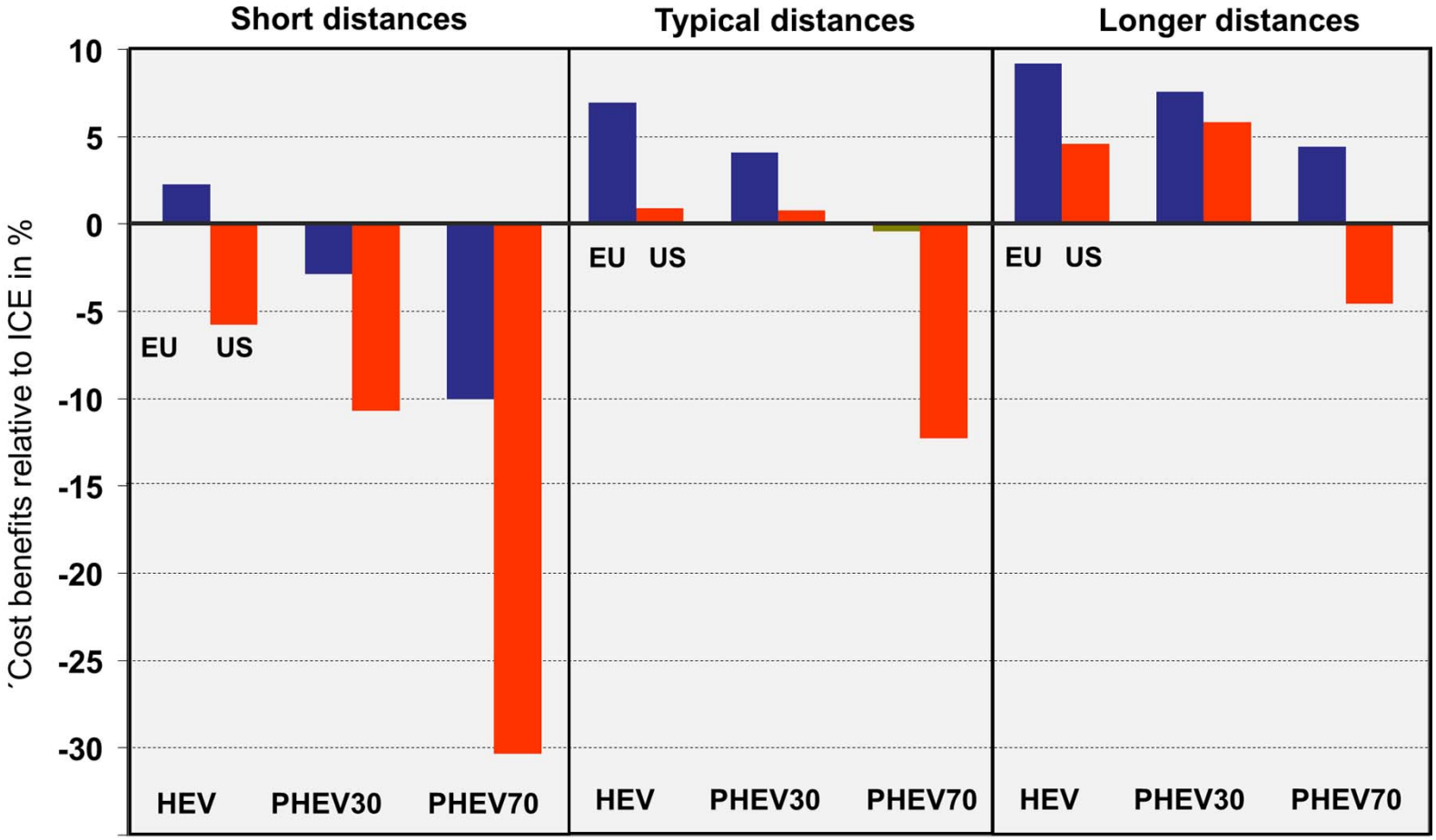


Cumulated cost for car owner over 4 years including resale in 1000 EUR (year 2015)

Source: …

International comparision

PHEV are more attractive for EU than US customer mainly due to higher fuel prices in Europe



US calculation assumes 10 year holding period without resale value,
US: short distance = 6600, typical distance = 18000, long distange = 32000 km

Conclusions

1. US and EU established comparable **test procedures** for electric vehicles → EU norm favors HEV/PHEV in terms of fuel consumption; real world consumption is significantly higher

2. **Operating cost** (energy and maintenance) for hybrids decrease with higher degree of electrification (party compensating the higher purchase price)

3. The **cost efficiency of HEV and PHEV** highly depend on driver behavior and energy prices → Break even is reached at lower mileages in EU case (due to higher fuel prices)

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