

# Young Researchers Seminar 2009

Torino, Italy, 3 to 5 June 2009

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## Market shares of passenger vehicle technologies and their influence on CO<sub>2</sub> emissions up to the year 2030

Peter Mock, German Aerospace Center (DLR), Institute of Vehicle Concepts, Germany

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# Agenda

- Introduction
- Technology Database
- Model Development
- Scenario Results
- Conclusion

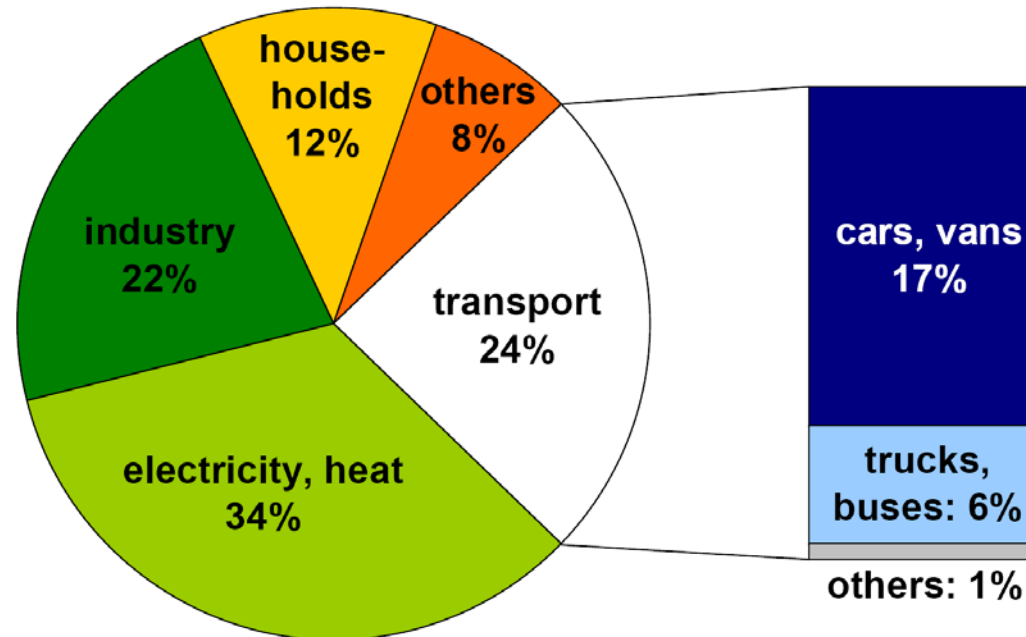
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# CO<sub>2</sub> emissions from transport



- EU-commitment: reduce greenhouse gas emissions (-20 / 30 % by 2020)
- transport responsible for 24 % of all CO<sub>2</sub> emissions in the EU
- mostly cars and light duty vehicles

data source: IFCCC / TREMOVE

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# Focus of the analysis



## What are the vehicle technologies and fuels of the future ???

- complex system of concurrency, prospects of success unknown
- to be taken into account: technology costs, energy prices, taxation, customer decision, ...
- new computer model for market scenarios up to 2030: *VECTOR21*

## Types of vehicles covered by the analysis:

- conventional gasoline and gasoline hybrid electric (HEV) vehicles
- conventional diesel and diesel HEV vehicles
- conventional compressed natural gas (CNG) and CNG HEV vehicles
- extended range electric vehicles (EREV)
- battery electric vehicles (BEV)
- fuel cell hybrid electric vehicles (FCHEV)

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# Vehicle energy consumption



	Fuel Econ. Packages	Energy Cons.	Production Cost	Retail Price
<b>Baseline Vehicle</b>		2,65 MJ/km	9.337 €	15.000 €
<b>Individual Measures</b>				
Reduced engine friction losses	X X X X X	-3,0%	70 €	112 €
Direct injection: homogeneous charge	X X X	-2,0%	150 €	241 €
Direct injection: stratified charge	X	-8,0%	700 €	1.125 €
Medium Downsizing with turbocharging	X X	-5,0%	200 €	321 €
[...]				
Improved transmission (e.g. Dual-Clutch)	X X X X	-4,0%	350 €	562 €
Weight reduction: package 1 (mild) = 1,5% veh. weight (20 kg)	X X	-1,0%	120 €	193 €
Weight reduction: package 2 (medium) = 3,5% veh. weight (50 kg)	X	-2,0%	300 €	482 €
Weight reduction: package 3 (strong) = 9,0% veh. weight (120 kg)	X	-5,0%	720 €	1.157 €
<b>Fuel-Economy Packages</b>				
G_FE#01	X	-8,0%	300 €	482 €
G_FE#02	X	-17,0%	870 €	1.398 €
G_FE#03	X	-24,0%	1.490 €	2.394 €
G_FE#04	X	-34,0%	2.645 €	4.249 €
G_FE#05	X	-40,0%	3.615 €	5.807 €
<b>Best available vehicle (medium size gasoline, no hybrid)</b>	X	1,59 MJ/km	12.952 €	20.807 €

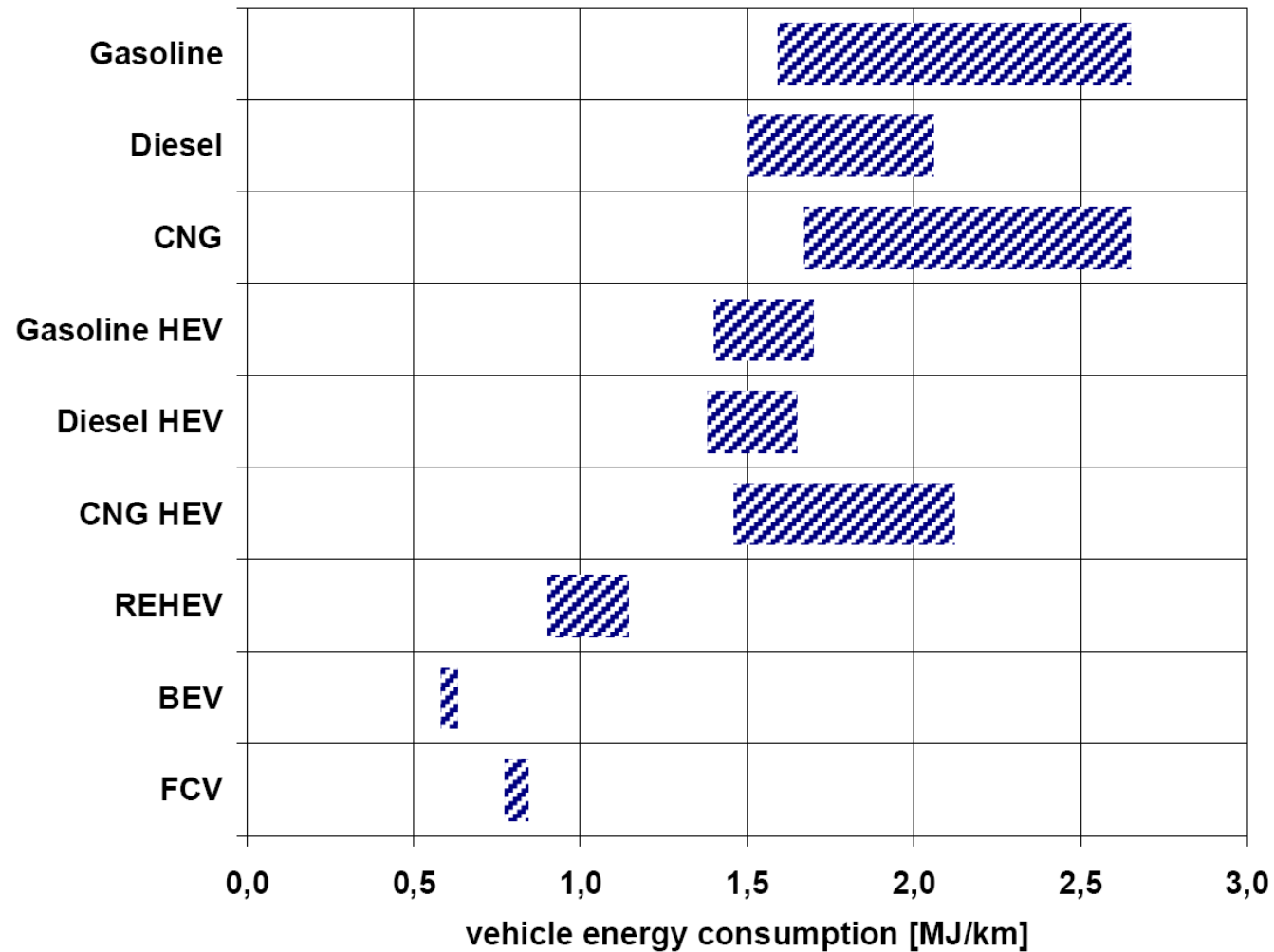
- 3 size categories: small, medium, large
- data from literature and in-house simulations
- fuel-economy packages as add-ons for baseline vehicles

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# Vehicle energy consumption

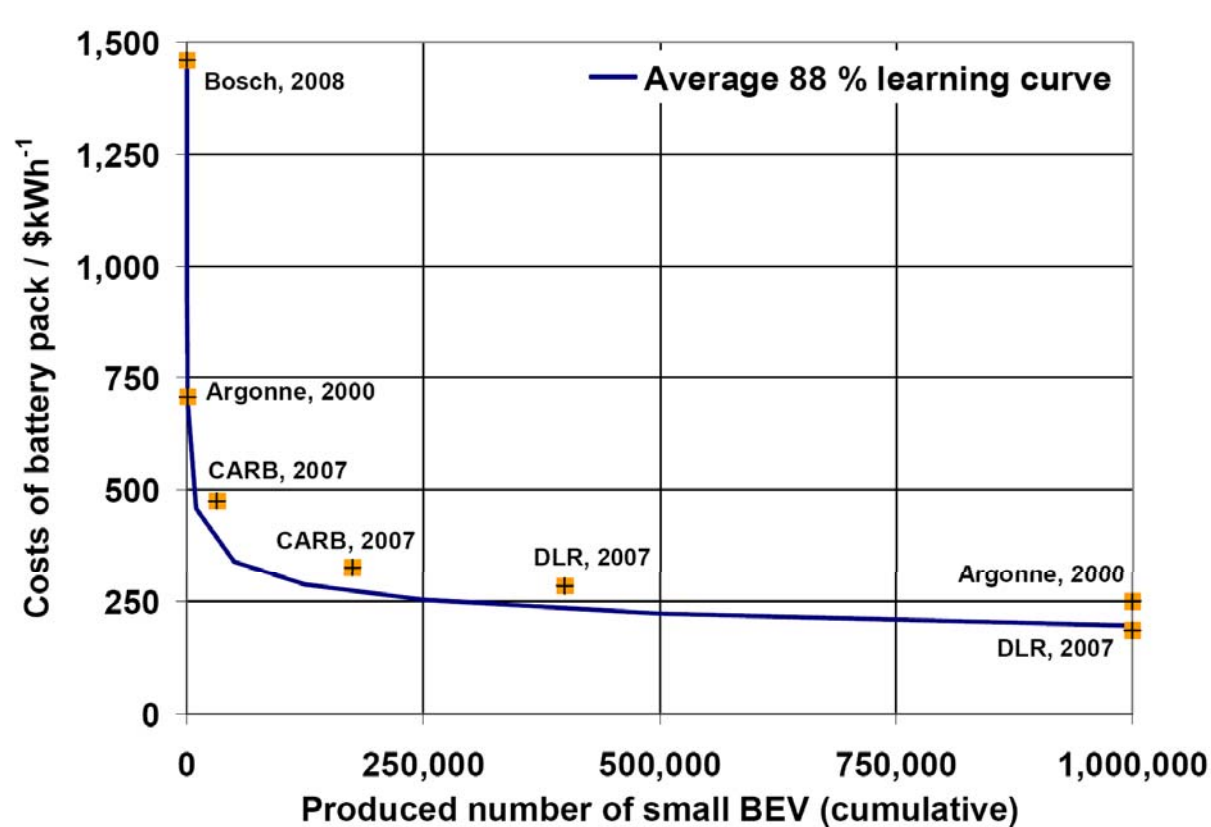


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# Production costs for batteries



- learning curve approach for “new” technologies
- potential for cost reduction: improved materials (electrodes, conducting salts), optimization of production processes, economies of scale

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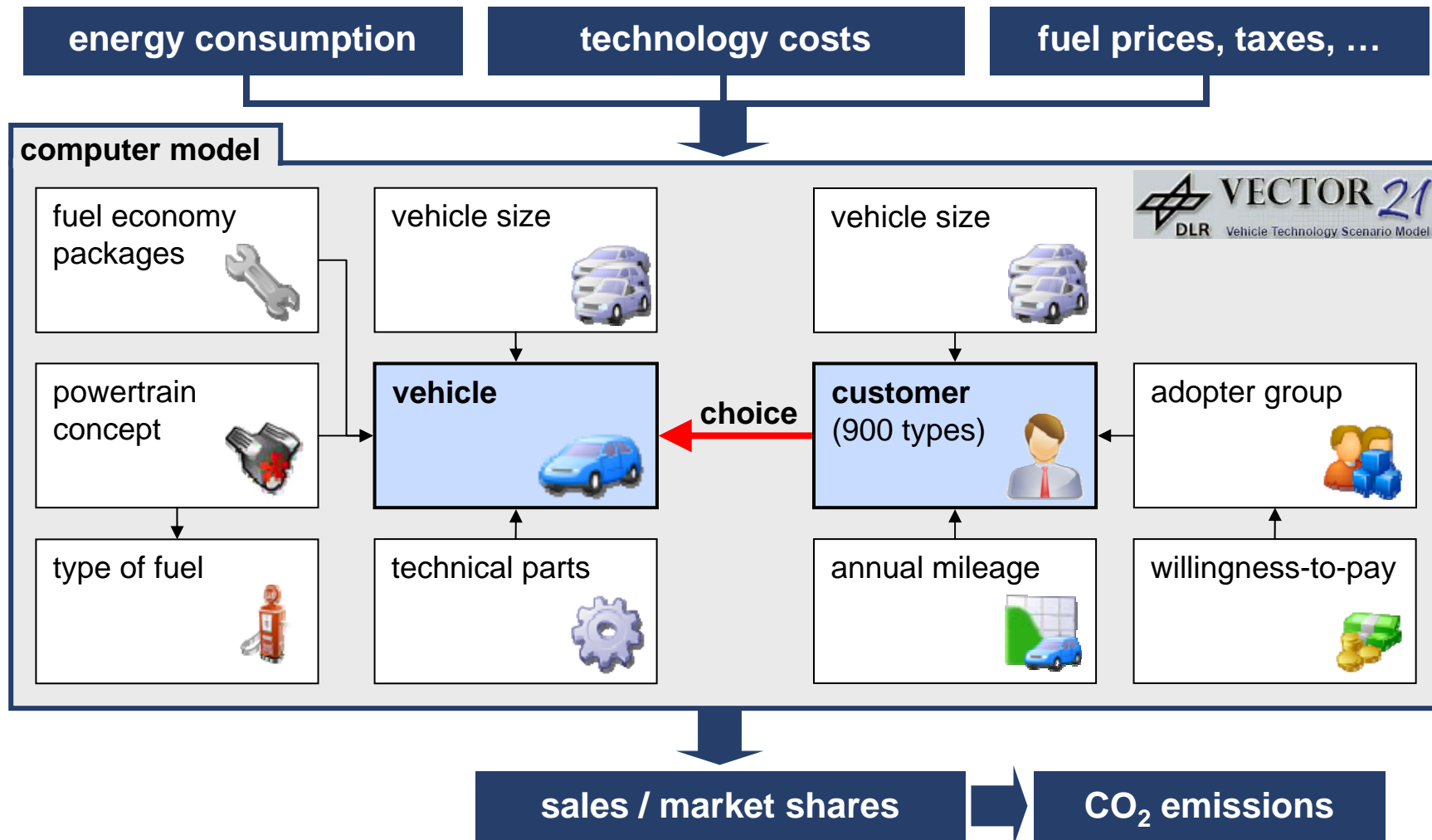
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# Model structure

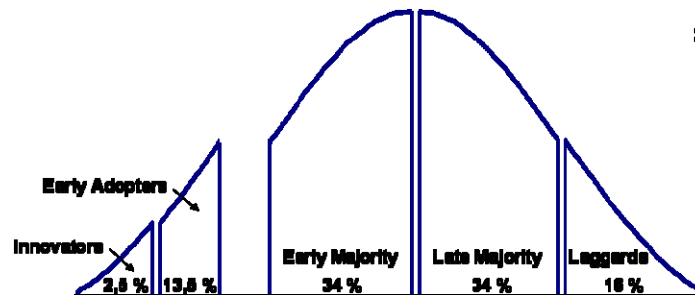
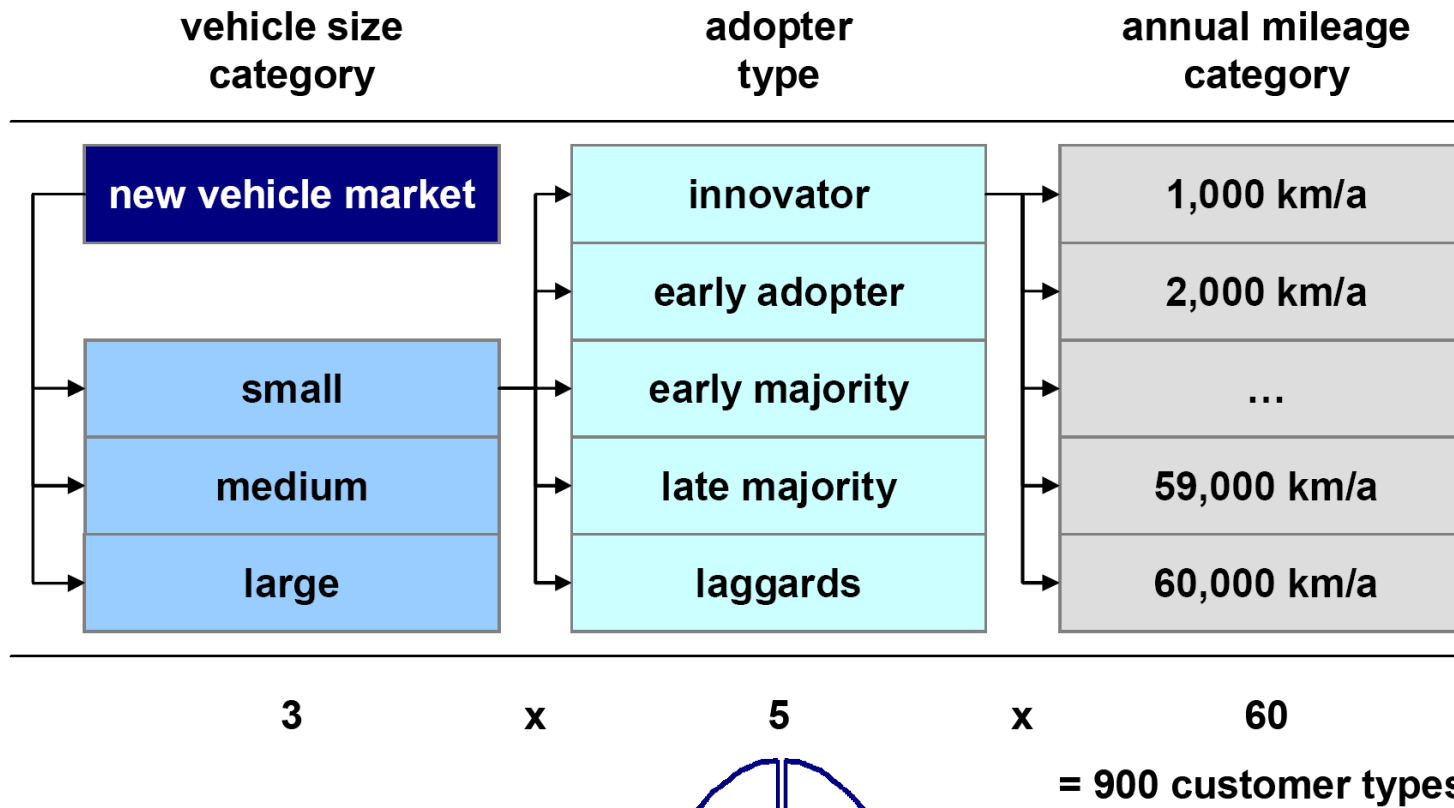


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# Demand side (customers)



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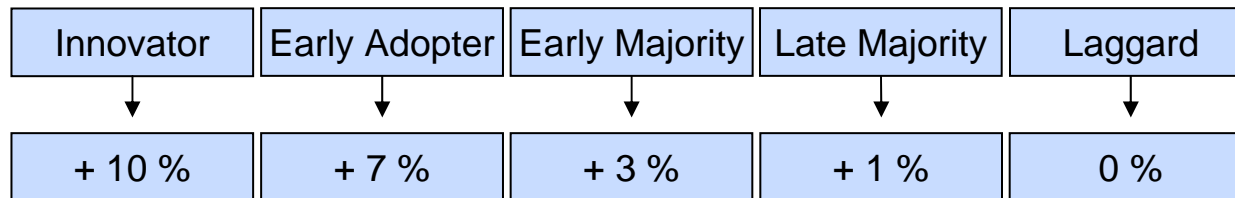
# Relevant cost of ownership (RCO)



Total cost of ownership (TCO) = all costs

Relevant cost of ownership (RCO):

=	vehicle price	-	subsidies	+	penalties	purchase price
+	vehicle tax	x	time for break-even (4 years)			annual costs
+	fuel costs per km	x	annual mileage	x	time for break-even	mileage depending costs



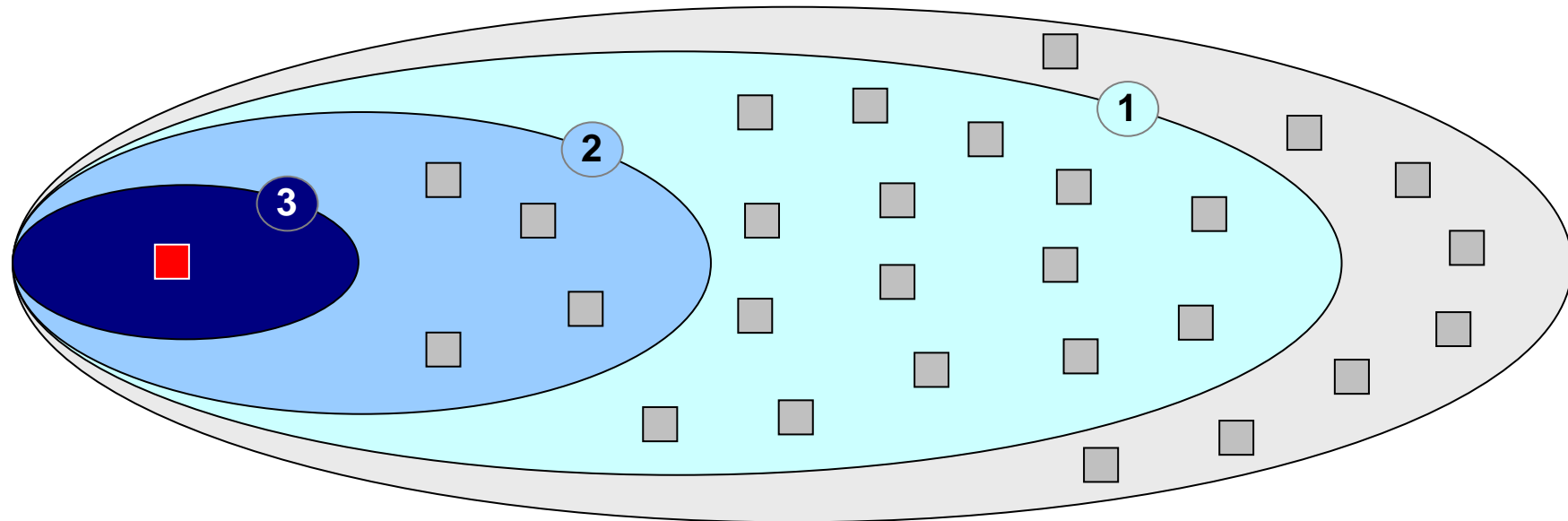
- assumption: purchase decision within vehicle category rational
- basis for decision: relevant cost of ownership (RCO)
- additional willingness-to-pay depending on customer type

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# Decision process



- **vehicle variants** (combination of vehicle technology and fuel)
- ① **step 1: filter for vehicle size category and general compulsory requirements**
- ② **step 2: choose lowest total cost of ownership (TCO)**
- ③ **step 3: choose lowest well-to-wheel CO<sub>2</sub> emissions**

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# Model layout



The screenshot shows the 'Edit Scenario Attributes' page in a Microsoft Internet Explorer browser. The page title is 'Edit Scenario Attributes - Microsoft Internet Explorer provided by DaimlerChrysler'. The browser address bar shows the URL: <http://stfki153du.fk.st.dlr.de:7777/pls/htmlb/f?p=2015:65:2192090335218997::NO::>. The page features the VECTOR 21 logo and navigation tabs for Home, Data, Scenario, and Run. The main content area is titled 'Select Scenario' and includes dropdown menus for Scenario (BaselineScen\_9430), Country (Germany), and Vehicle (M\_FC\_Hyb\_01). It also has input fields for 'Vehicle is on market' (from 2012 to 2030) and 'Driving Range' (from 1000 to 60000), each with a 'Save' button. A 'Parts' list on the left includes items like EV\_CreditCatalyst, EV\_CreditEngineTransm, FCV\_CH2\_Storage\_700, FCV\_CreditGasolineTank, FCV\_Motor\_80, FCV\_Stack\_80\_NoPt, FCV\_Stack\_80\_Pt, FCV\_System\_80\_NoStack, HEV\_AltTransmission, HEV\_Components, HEV\_CreditAlternator, HEV\_LiIonBattery, and MediumOttoVehicle. An 'Add Ons' section shows FCV\_FE#01 and FCV\_FE#02. A 'Scenario Info' panel on the right displays details for 'BaselineScen\_9430', including its name, period (1994-2030), and countries (Germany). A sidebar on the left contains an 'Infobox' with instructions and a 'Scenario' navigation menu.

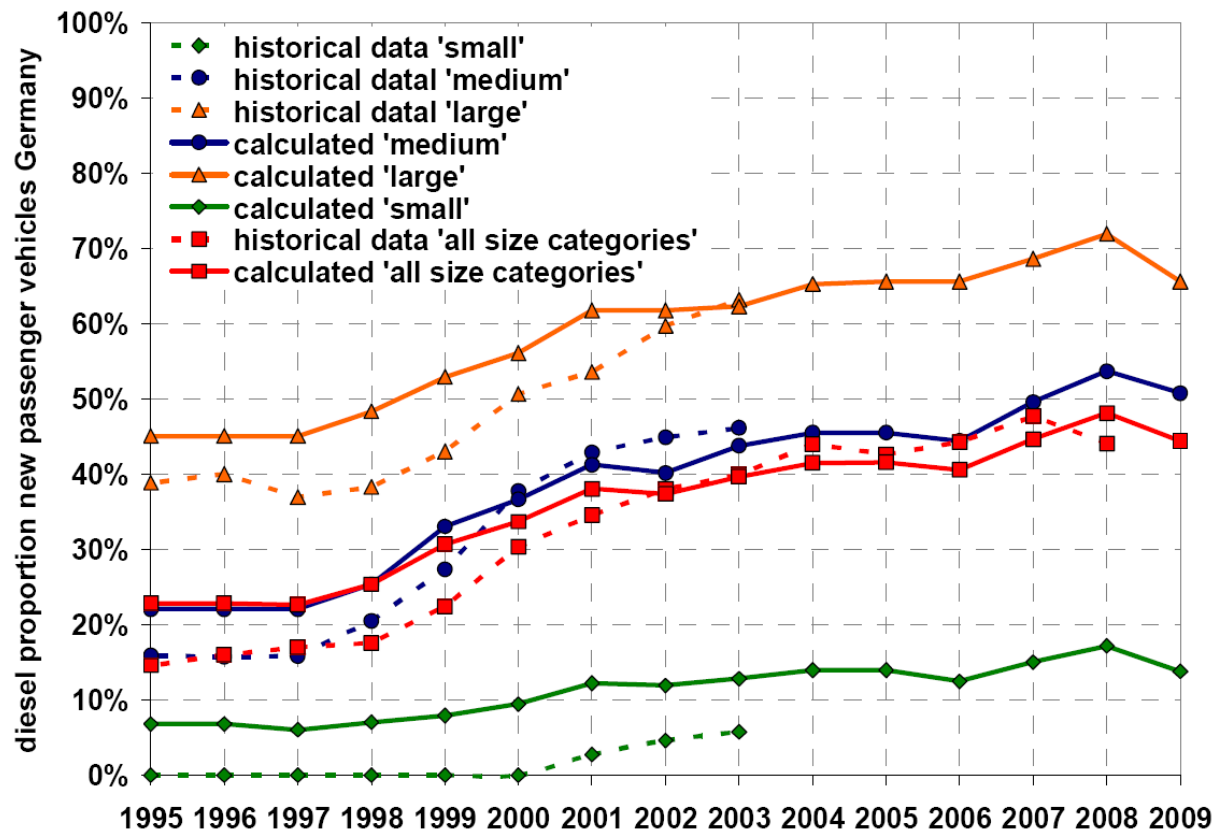
- Oracle database for handling large data sets
- user-friendly input / output interface

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# Verification of results



- case study: diesel proportion new cars in Germany (1995 to 2008)
- very good model results for medium and large size category
- customer reaction delayed by one year

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# Scenario assumptions



	Scenario 1		Scenario 2	
	2009	2030	2009	2030
crude oil price	54 [€/bbl]	65 [€/bbl]	54 [€/bbl]	65 [€/bbl]
proportion of bio-fuels	0-8 %	15 %	0-8 %	25 %
electricity – CO <sub>2</sub> emission	600 [g/kWh]	550 [g/kWh]	21 [g/kWh]	20 [g/kWh]
electricity – consumer price	0.18 [€/kWh]	0.35 [€/kWh]	0.21 [€/kWh]	0.37 [€/kWh]
hydrogen – source	natural gas	electrolysis	electrolysis	
hydrogen – CO <sub>2</sub> emission	350 [g/kWh]	650 [g/kWh]	25 [g/kWh]	24 [g/kWh]
hydrogen – consumer price	0.13 [€/kWh]	0.35 [€/kWh]	0.21 [€/kWh]	0.37 [€/kWh]
CO <sub>2</sub> – new vehicle fleet target	---	113 [g/km]	---	76 [g/km]
CO <sub>2</sub> – penalty for exceeding	---	95 [€/(g/km)]	---	120 [€/(g/km)]
market share small / medium / large	25 / 55 / 20%	30 / 45 / 25%	25 / 55 / 20%	30 / 45 / 25%

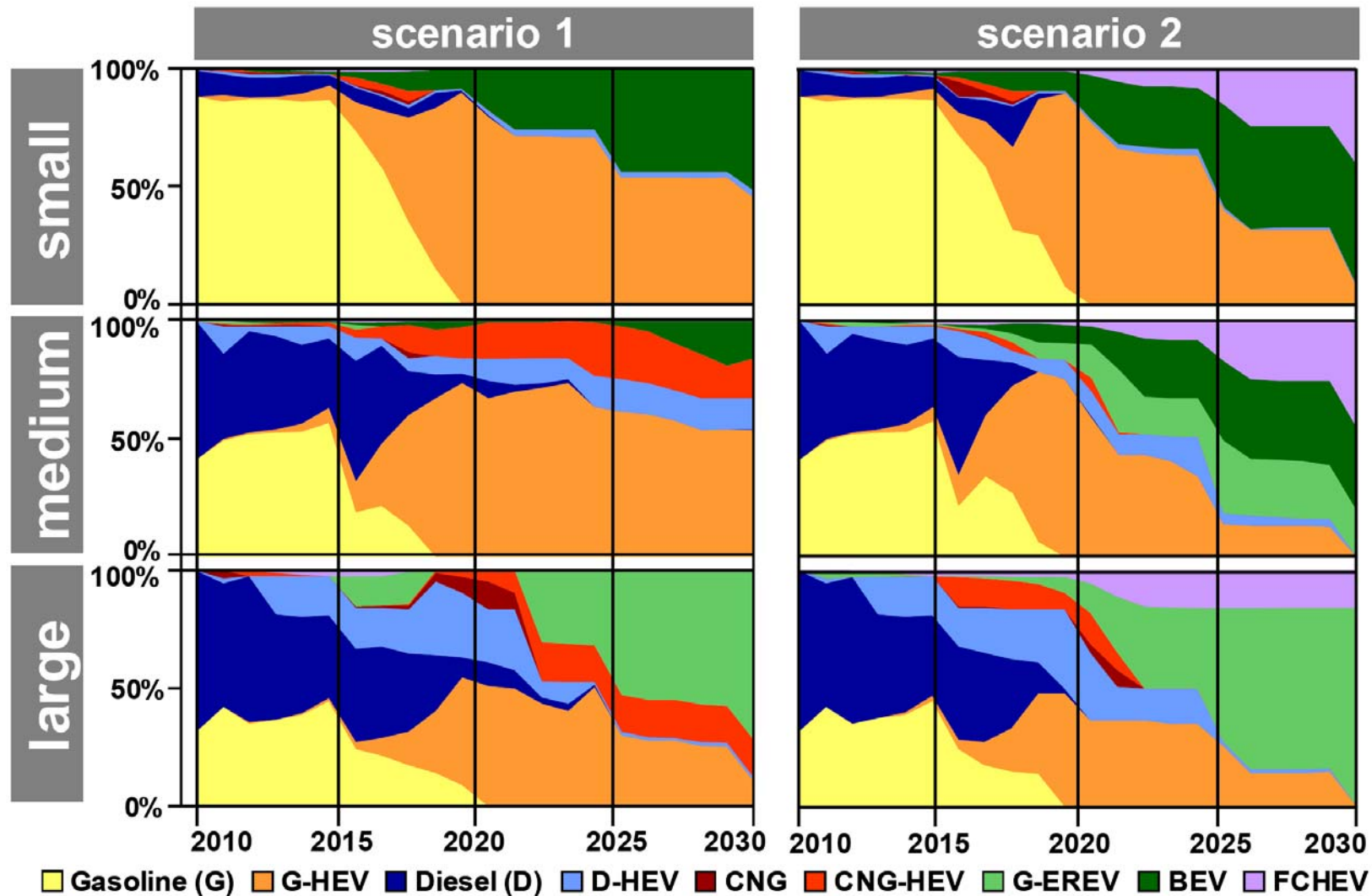
- **focus on German passenger car market**
- **moderate oil price increase, electricity and hydrogen from national mix (scenario 1) / renewables (scenario 2), strict regulations for CO<sub>2</sub>**

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# Scenario results: new vehicle fleet

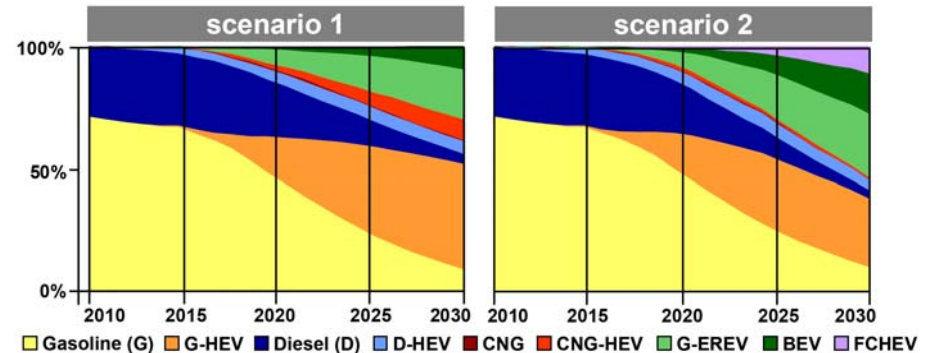
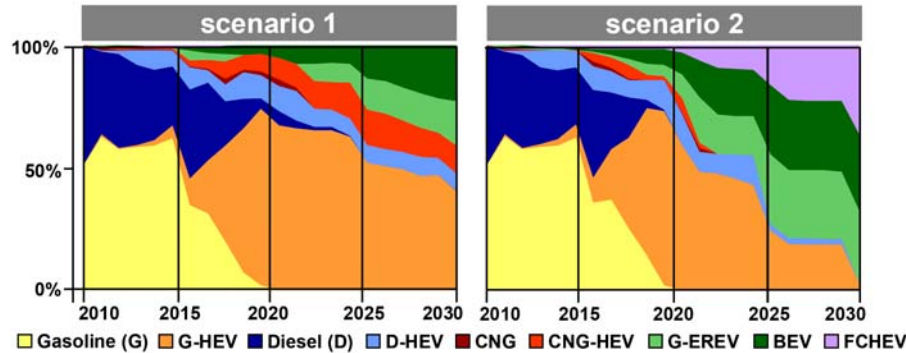


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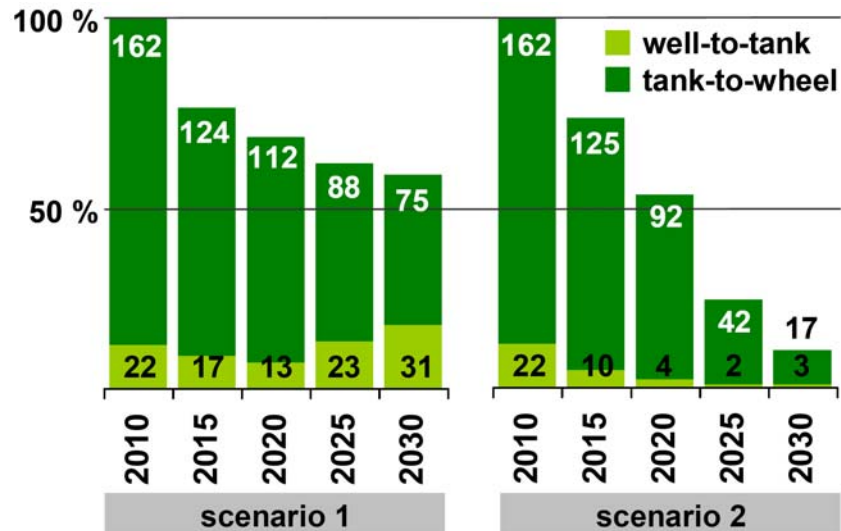
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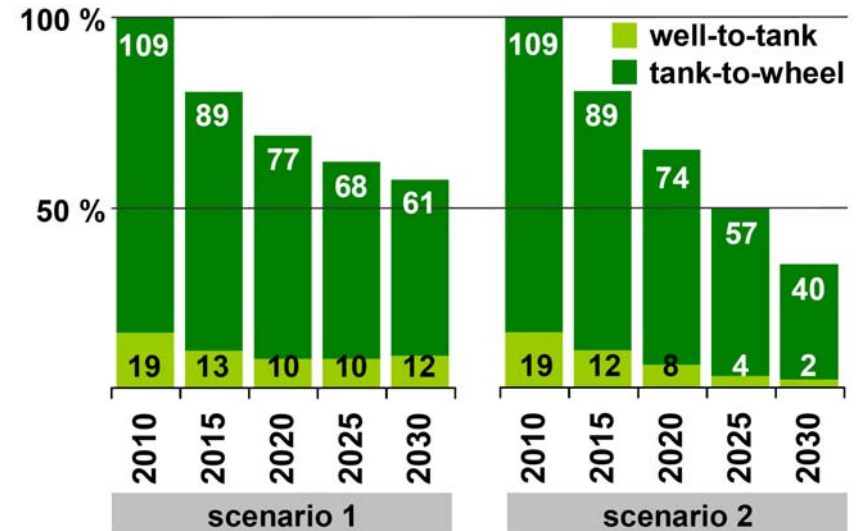
# Scenario results: new vehicle fleet and stock



CO<sub>2</sub>: new vehicle fleet [g/km]



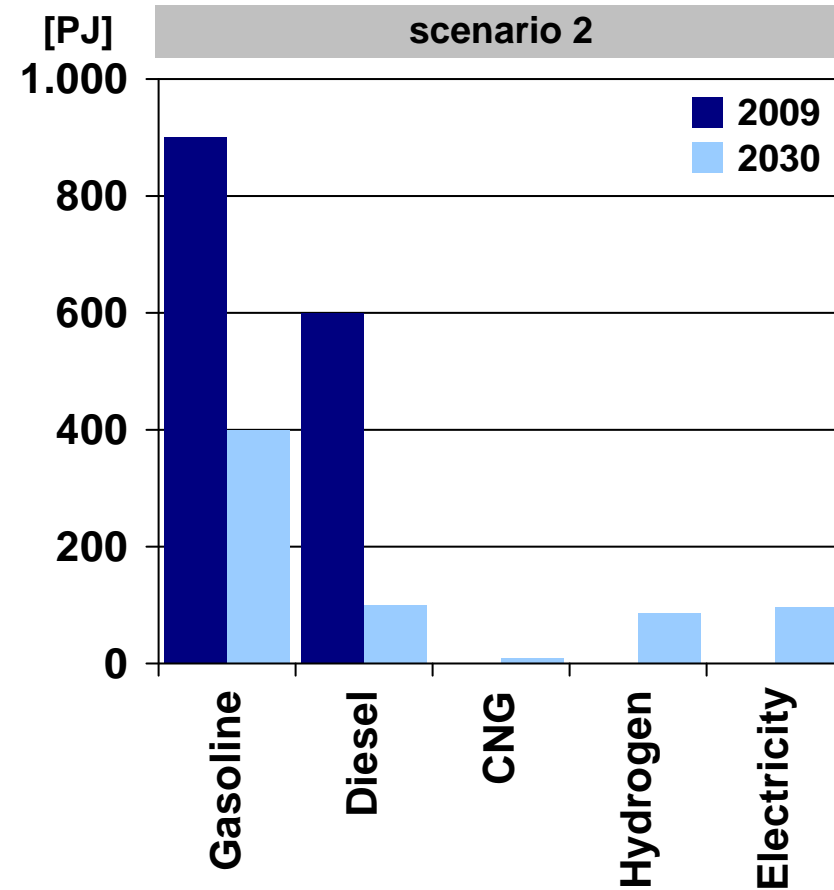
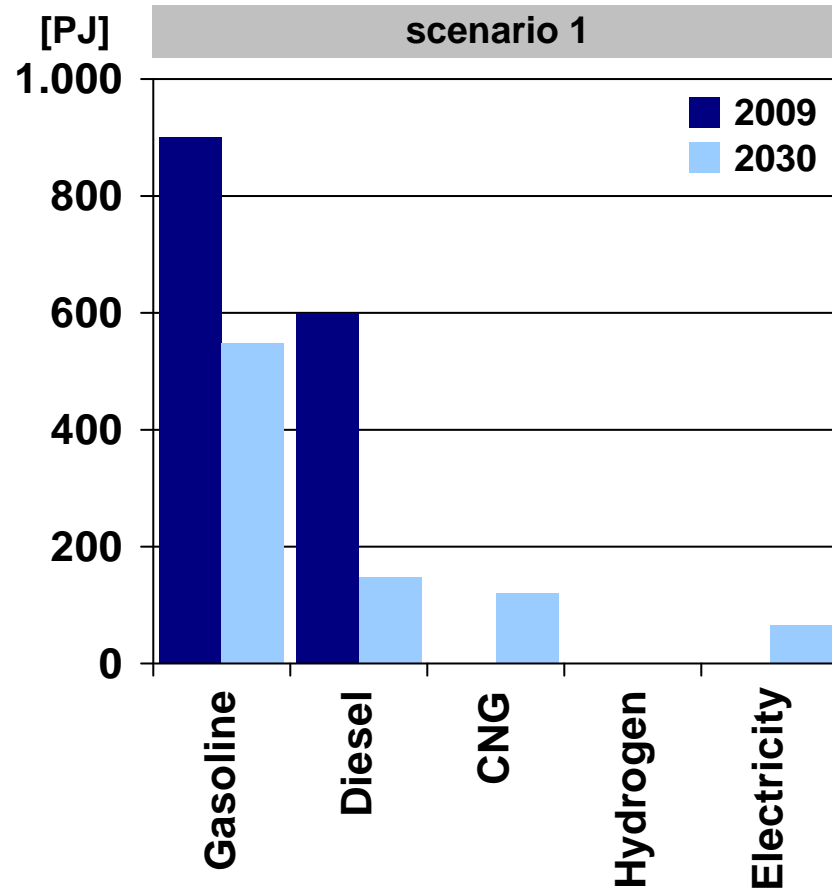
CO<sub>2</sub>: vehicle stock [million t]



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# Scenario results: fuel and energy demand



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# Conclusion



- **VECTOR21** allows analysis of complex scenarios of future market
- significant CO<sub>2</sub> reductions possible in both scenarios
- renewable energy critical when using electric vehicles
- costs tend to increase in both scenarios
- focus groups for model results: automotive manufacturers, fuel and energy suppliers, politics
- model expansion plans: regions, time horizon, pollutants

source: „Ein Jahrhundert Automobiltechnik Personenwagen“, VDI-Verlage Düsseldorf, 1986

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# Further information




### DLR at a glance

DLR is Germany's national research center for aeronautics and space. Its extensive research and development work in Aeronautics, Space, Transportation and Energy is integrated into national and international cooperative ventures. As Germany's space agency, DLR has been given responsibility for the forward planning and the implementation of the German space program by the German federal government as well as for the international representation of German interests. Furthermore, Germany's largest project-management agency is also part of DLR.

Approximately 5,700 people are employed at thirteen locations in Germany: Köln (Heisequartier), Berlin, Bonn, Braunschweig, Bremen, Goettingen, Hamburg, Langenhagen, Neustadt, Oberpfaffenhofen, Stuttgart, Trauen and Weßling. DLR also operates offices in Brussels, Paris, and Washington D.C.

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German Aerospace Center

Institute of Vehicle Concepts  
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## VECTOR 21 Vehicle Technology Scenario Model

#### Today's Questions

- What will be the most dominant vehicle population technologies in the future?
- Will we be successful in reducing the CO<sub>2</sub> emissions of our new vehicle's fleet?
- What will be the costs and benefits to customers, car manufacturers and society?
- What are the facts to power our cars of the future?
- What are the effects of changes of the taxation system?
- How will overall CO<sub>2</sub> emissions of the vehicle stock evolve in the future?
- What will be the number of plug-in hybrid electric vehicles on our roads by 2020?
- When will we see fuel cell driven cars gaining significant market shares?
- What are the effects of an increasing crude oil price and changing raw material prices?

#### Our Approach

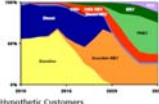
**Powerful Scenario Tool**  
VECTOR 21 is a computer based model, capable of calculating scenarios on future market shares of vehicle technologies as well as their effects on CO<sub>2</sub> emissions and costs up to the year 2020/50.

**Hypothetic Customers**  
Approximately 300 different types of hypothetic customers, each having different attributes (e.g. annual mileage, willingness to pay), represent the new vehicle's marketplace. Focusing on Relevant Cost of Ownership (RCO), taking into account e.g. vehicle price, taxes and costs for fuel, each customer group chooses the vehicle best suited for its needs in every year of the calculation.

Using a vehicle stock turnover module it is possible to differentiate between results for the new vehicle's fleet and the existing vehicle stock. Taking into account various fuels and energy sources, VECTOR 21 states both well-to-tank and tank-to-wheel emissions.

#### Tool Description

**Vehicle Technology Database**  
Data for the algorithm of VECTOR 21 is an extensive vehicle technology database, including estimates for effects on energy consumption and manufacturer costs for various energy efficiency technologies (e.g. variable valve control, hybridization). A matrix of all technology combinations allowed for a year is set up by the model, characterizing each combination package with regard to CO<sub>2</sub> emissions and costs.

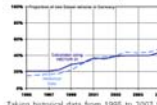


#### Key Features

- Detailed characterization of various vehicles using a differentiation between compulsory assembly parts and optional add-ons.
- Simulation of competition of different vehicle technologies and fuels over time by representing customer decision process for new vehicles.
- Accounting for market introduction effects using learning curves for production cost development of technologies, depending on the cumulative units produced.
- Reflecting price developments of raw materials (e.g. oil, platinum) and their influence on fuel and material costs.
- Differentiation of costs and retail prices for assessment of financial effects for vehicle manufacturers, customers and society.
- Including various types of fuel and energy sources, each with different costs, tax burdens and well-to-tank CO<sub>2</sub> emissions.
- Differentiation of vehicle size categories.
- Possibility to extend assessments to other countries and time periods.
- Powerful Oracle database with easy to use graphical user interface.

#### Validation of Results

Results of the VECTOR 21 calculation process have been validated using the example of diesel passenger cars in Germany.



Taking historical data from 1995 to 2007 for input parameters produces results consistent with real historical development of the market share of diesel passenger cars in Germany.

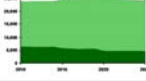
#### Your benefits

**We offer ...**

- Scientific development and simulation of scenarios.
- Preparation of reports and presentations.
- Customization and modification of the model structure and input data.
- Licensing incl. training, support and continuous software-updates.

**You and your company can expect ...**

- Quantified answers to today's questions on future vehicle technology trajectories.
- Support of strategic decision-making.
- Enrichment of in-house knowledge on competitive products and technologies.
- Scientific and independent view.



#### Contact Details

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Mock, P., and Schmid, S.A. (2009). Fuel cells for automotive powertrains – A techno-economic assessment. *Journal of Power Sources*, 190(1), 133-140.

Mock, P., and Schmid, S.A. (2008). Battery and fuel cell vehicles – Hype or trend? *VDI-Berichte Nr. 2030 (Innovative Fahrzeugantriebe 2008)*, 213-231.

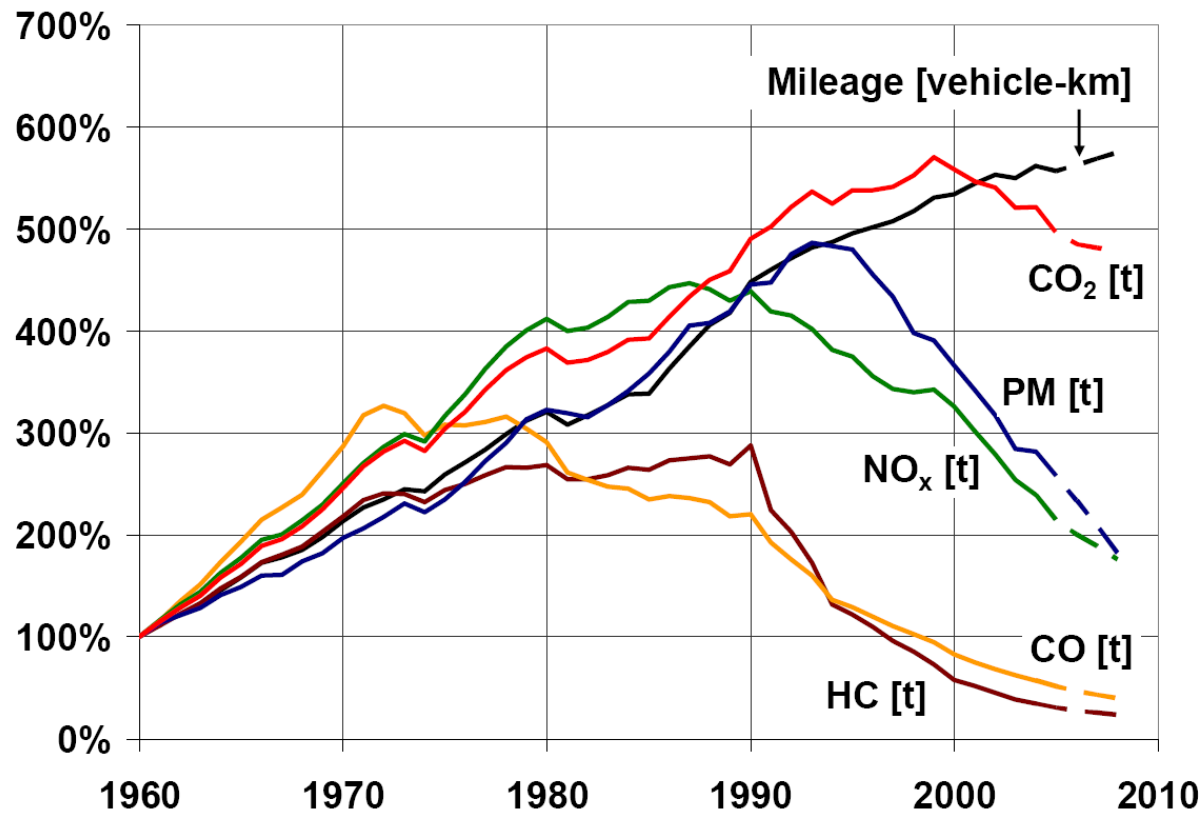
Mock, P., Huelsebusch, D., et al. (2009). Electric vehicles – A model based assessment of future market prospects and environmental impacts. *EVS24 – International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium 2009*.

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# No reversal of trend for CO<sub>2</sub> yet



- emissions from pollutants decreasing, despite of increase in mileage
- for CO<sub>2</sub> emissions no clear reversal of trend observable to date

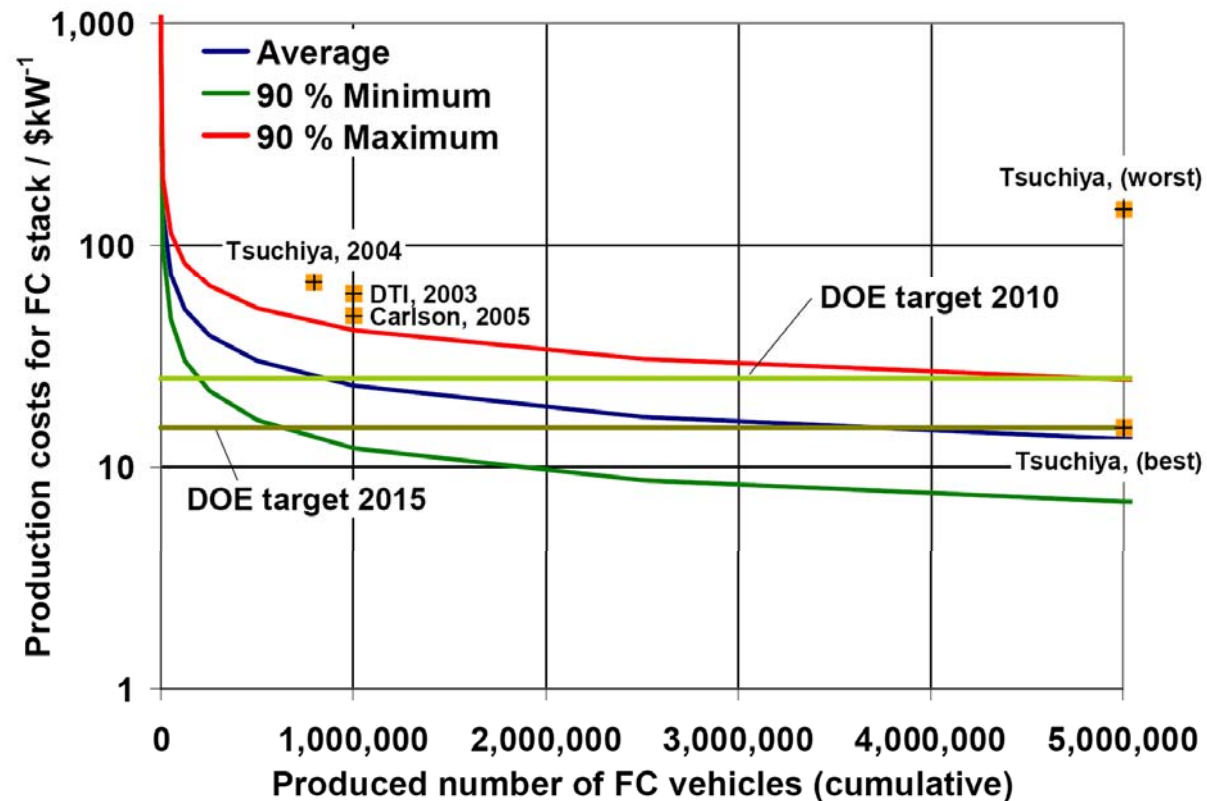
data source: TREMOD

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# Production costs for fuel cells



- potential for cost reduction: reduction of platinum loading, increase of power density, mass production, economies of scale
- significant influence on production costs: market price of platinum

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