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## Market Prospects of Electric Passenger Vehicles and Their Effect on CO<sub>2</sub> Emissions up to 2030 (*VECTOR21*)

PHEV'09 – Plug-In Hybrid and Electric Vehicles  
Montreal, Sept. 29, 2009



## Introduction German Aerospace Center (DLR)

- 5.700 employees at 29 research institutes and facilities in 13 locations
- Offices in Brussels, Paris and Washington D.C.
- 4 main research fields:
  - Aeronautics
  - Space
  - Transport
  - Energy





## Introduction Motivation and framework

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### 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 process, ...
- new computer model for market scenarios up to 2030: **VECTOR21**



## Overview

### 3-step approach

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- 1** Set up a technology database
- 2** Develop a model to reflect the market
- 3** Apply the model to get to scenarios of the future



## Technology cost and energy consumption assessment Vehicle types currently included in the analysis

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- 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)



# Technology cost and energy consumption assessment

## Example medium size gasoline vehicle

								Costs / Price: Start		
		Start	End	Packages	Energy Cons.	Production	Markup	Retail		
P A R T S	Baseline Gasoline Vehicle	1994	---			9.350 €	35%	15.021 €		
	G_EURO5 (Euro 5 Compliance)	2009	---			50 €	35%	80 €		
	G_EURO6 (Euro 6 Compliance)	2014	---			50 €	35%	80 €		
	<b>SUM</b>	<b>2008</b>	<b>---</b>		<b>2,65 MJ/km</b>	<b>9.450 €</b>	<b>35%</b>	<b>15.181 €</b>		
=> 0,74 kWh/km => 8,2 l/100 km										
A D D O H S	Reduced engine friction losses	2009	---	X X X X X	-3,0%	70 €	35%	112 €		
	Direct injection: homogeneous charge	2010	---	X X X	-2,0%	150 €	35%	241 €		
	Direct injection: stratified charge	2013	---	X	-8,0%	700 €	35%	1.125 €		
	Medium Downsizing with turbocharging	2010	---	X X	-5,0%	200 €	35%	321 €		
	Strong Downsizing with turbocharging (twin charger)	2011	---	X X	-8,0%	450 €	35%	723 €		
	Variable Valve Timing	2010	---	X	-3,0%	150 €	35%	241 €		
	Variable Valve Control	2012	---	X X	-7,0%	350 €	35%	562 €		
	Start Stop	2009	---	X X X	-4,0%	200 €	35%	321 €		
	Start Stop + Regenerative Braking (Micro Hybrid)	2011	---	X X	-7,0%	600 €	35%	964 €		
	Low friction tyres	2009	---	X X X X X	-2,0%	30 €	35%	48 €		
	Optimised cooling circuit, electric water pump	2011	---	X X X	-2,0%	120 €	35%	193 €		
	Exhaust heat recovery	2012	---	X X	-1,0%	50 €	35%	80 €		
	Improved aerodynamic efficiency	2012	---	X X	-1,5%	75 €	35%	120 €		
	Electrically assisted steering, auxiliary power steering	2010	---	X X X X	-2,0%	100 €	35%	161 €		
	Improved transmission (e.g. Dual-Clutch)	2011	---	X X X	-4,0%	350 €	35%	562 €		
	Weight reduction: package 1 (mild) = 1,5% veh. weight (20 kg)	2010	---	X X	-1,0%	120 €	35%	193 €		
	Weight reduction: package 2 (medium) = 3,5% veh. weight (50 kg)	2011	---	X	-2,0%	300 €	35%	482 €		
	Weight reduction: package 3 (strong) = 9,0% veh. weight (120 kg)	2013	---	X	-5,0%	720 €	35%	1.157 €		
	G_FE#01	2009	---	X	-8,0%	300 €	35%	482 €		
G_FE#02	2010	---	X	-17,0%	870 €	35%	1.398 €			
G_FE#03	2011	---	X	-24,0%	1.490 €	35%	2.394 €			
G_FE#04	2012	---	X	-34,0%	2.645 €	35%	4.249 €			
G_FE#05	2013	---	X	-40,0%	3.615 €	35%	5.807 €			
<b>Best available vehicle</b>	<b>2013</b>	<b>---</b>		<b>X</b>	<b>1,59 MJ/km</b>	<b>13.065 €</b>	<b>35%</b>	<b>20.989 €</b>		
=> 0,44 kWh/km => 4,9 l/100 km + 38 %										



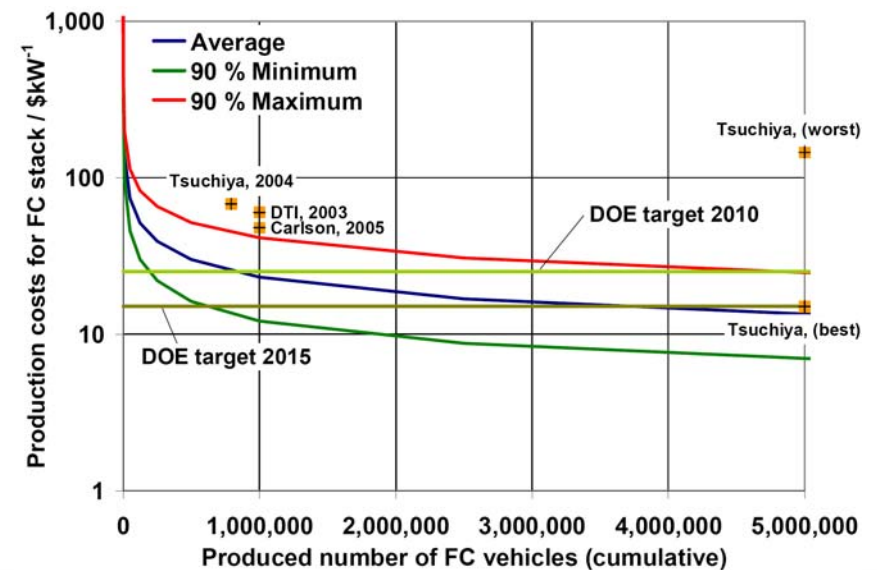
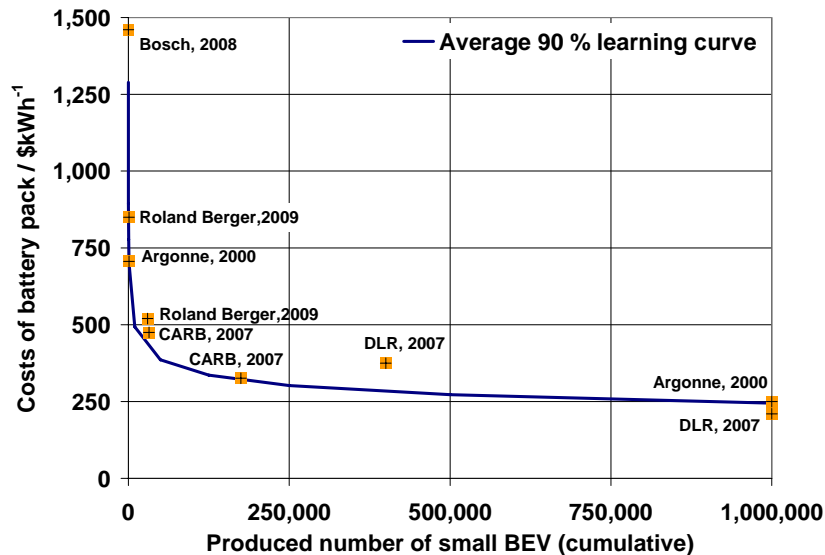
# Technology cost and energy consumption assessment Learning curve approach for electric vehicles

## ➤ Internal combustion engines

- manufacturing costs / retail prices for **baseline vehicles**
- individual technical measures summarized into **fuel economy packages**
- **potential for future fuel economy improvements** taken into account

## ➤ Electric vehicles

- identification of **learning curves**, costs dependent on production volume





## Overview

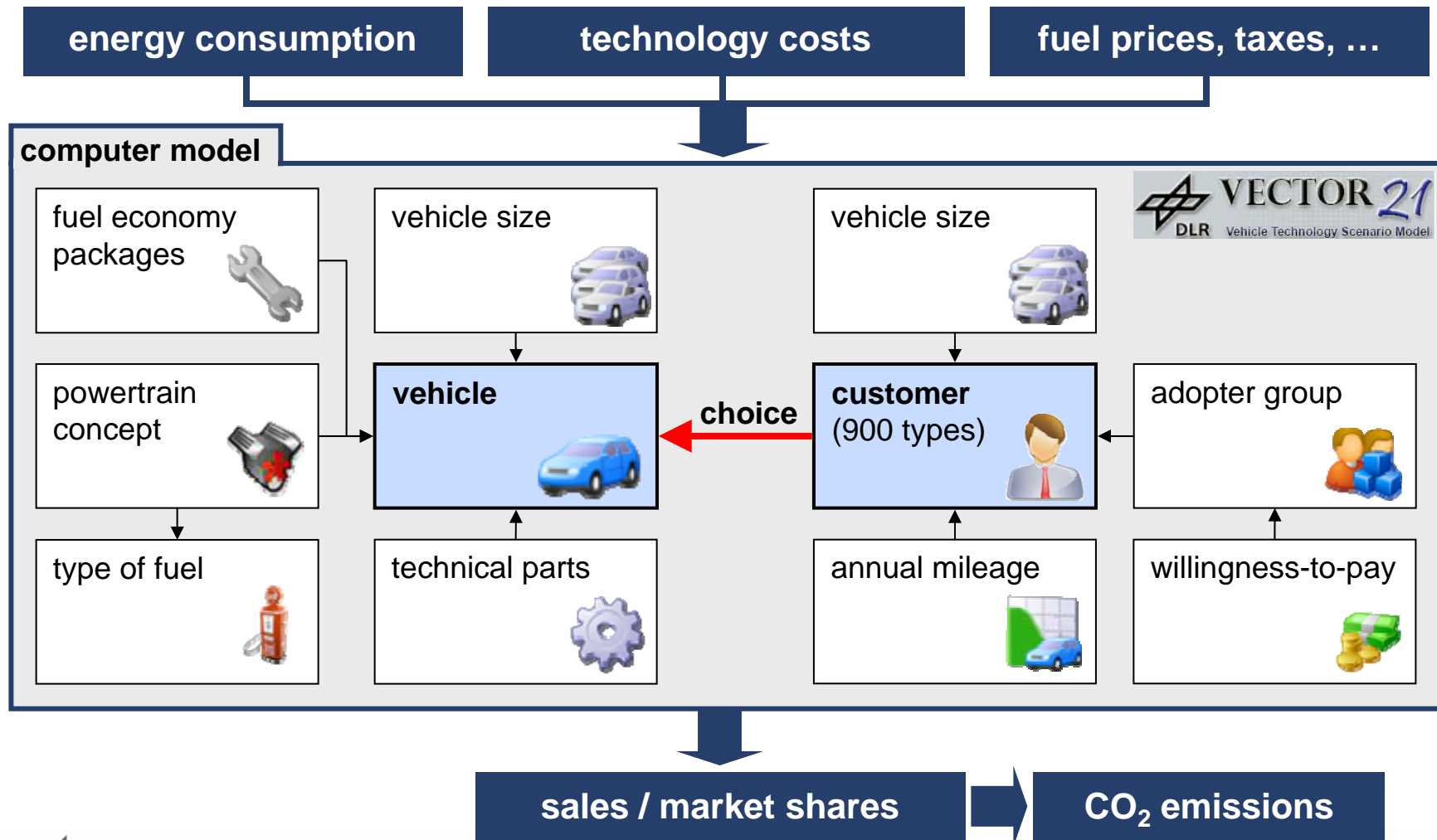
### 3-step approach

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- 1 Set up a technology database ✓
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# Scenario model (VECTOR21) Modeling technology supply and customer demand





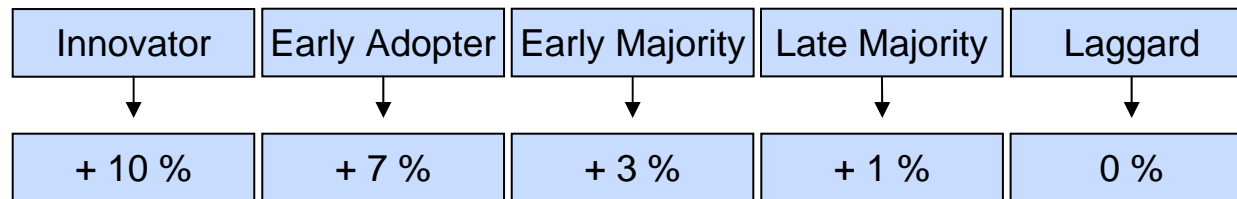
# Scenario model (VECTOR21)

## Relevant cost of ownership as main purchase criteria

Total cost of ownership (TCO) = all costs

Relevant cost of ownership (RCO):

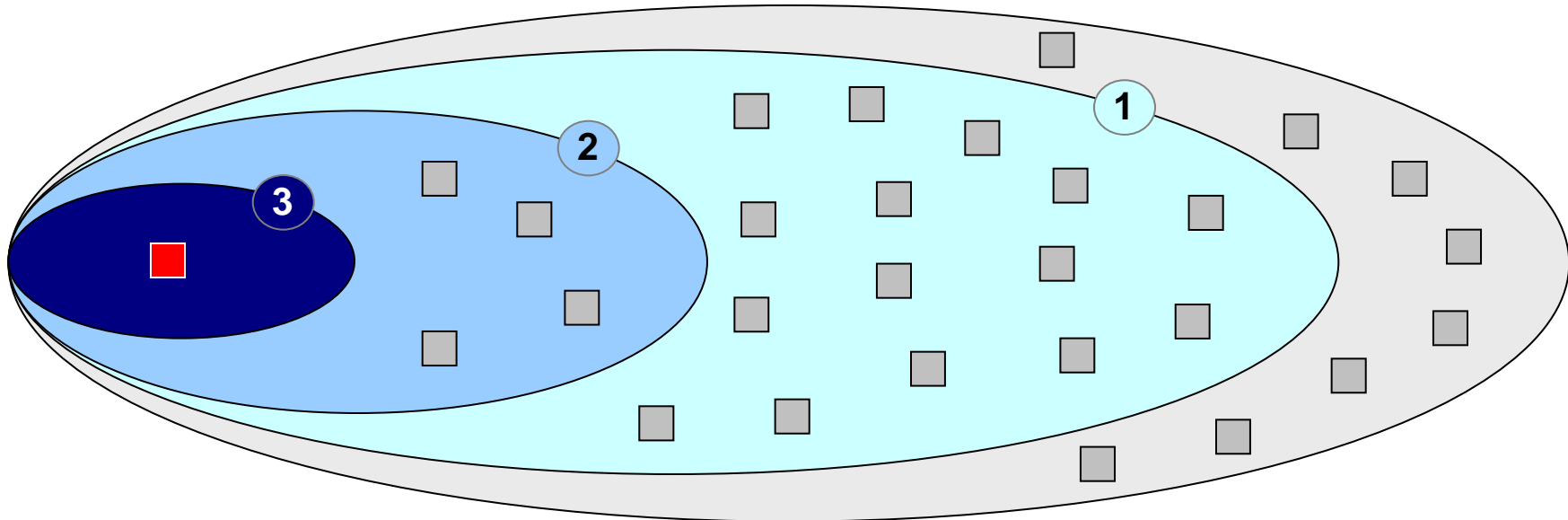
=	vehicle price	-	subsidies	+	penalties	purchase price
+	vehicle tax	x	time for break-even (4 years)			annual costs
+	fuel costs per km	x	annual mileage	x	time for break-even	mileage depending costs



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



## Scenario model (*VECTOR21*) Illustration of selection process



■ **vehicle variants** (combination of vehicle technology and fuel)

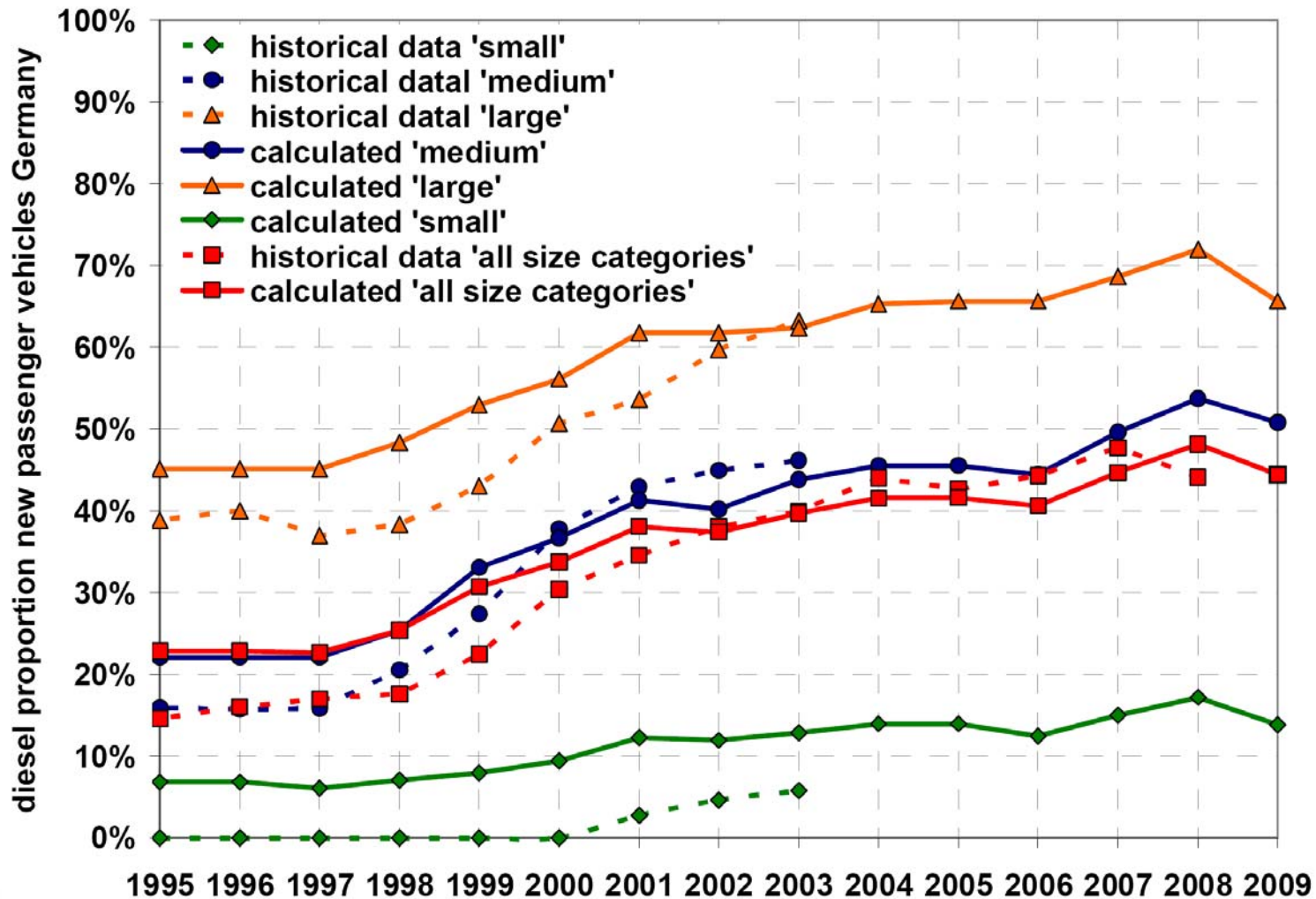
① **step 1: filter for vehicle size category and general compulsory requirements**

② **step 2: choose lowest Relevant Cost of Ownership (RCO)**

③ **step 3: choose lowest well-to-wheel CO<sub>2</sub> emissions**



# Scenario model (VECTOR21) Model results vs. real historical developments





## Overview

### 3-step approach

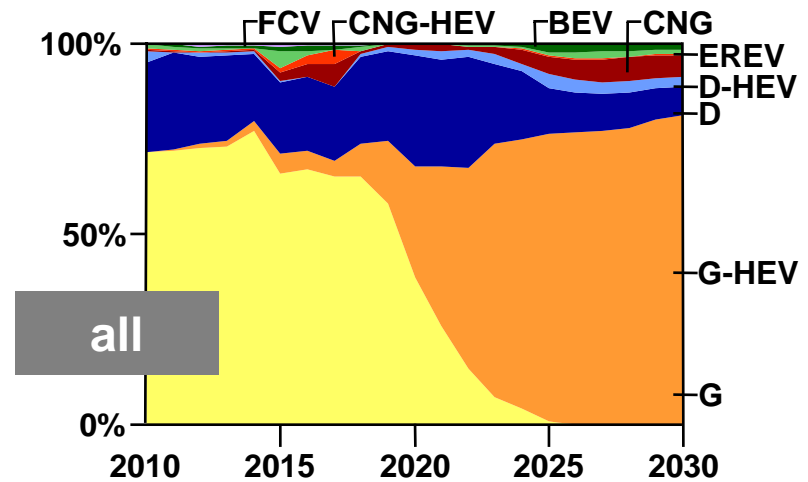
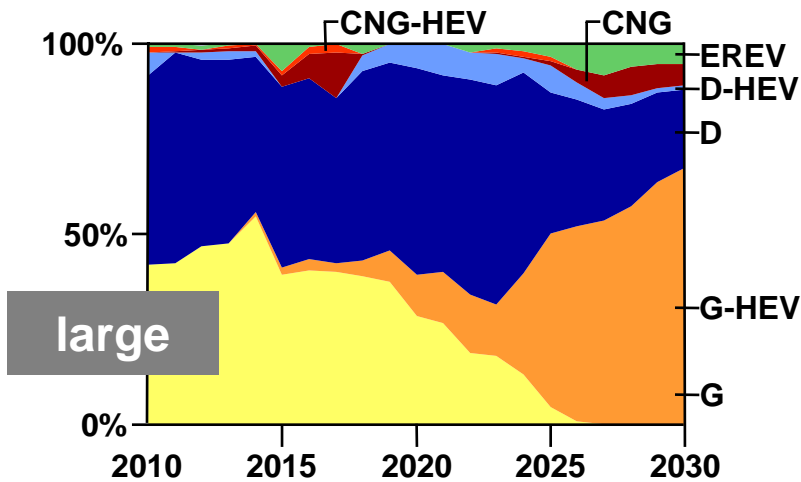
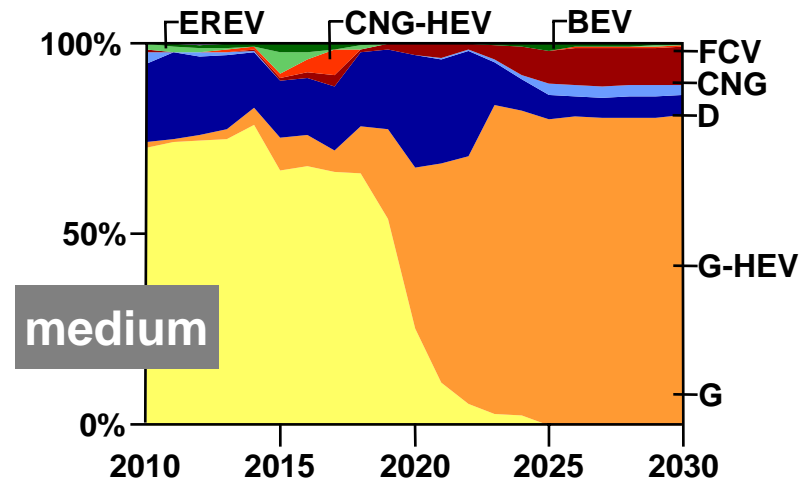
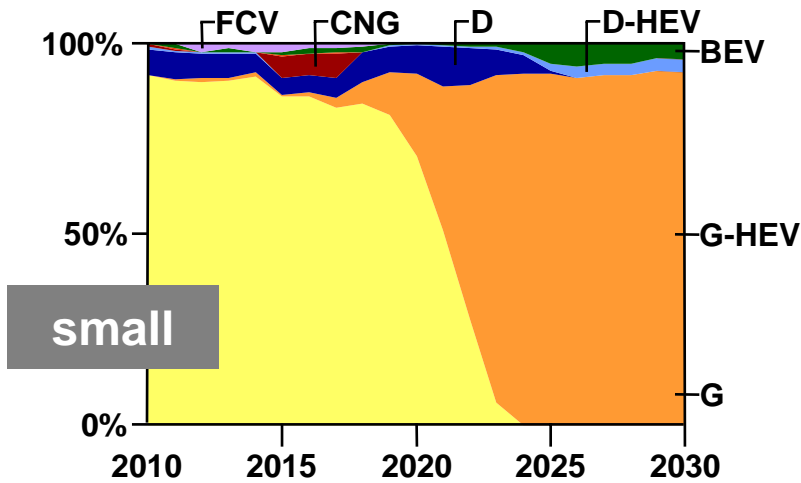
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- 2 Develop a model to reflect the market ✓
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# Scenario calculations

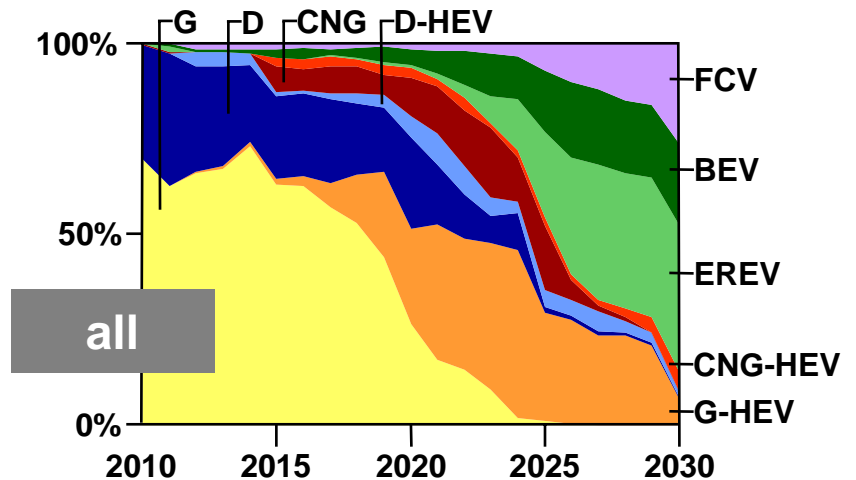
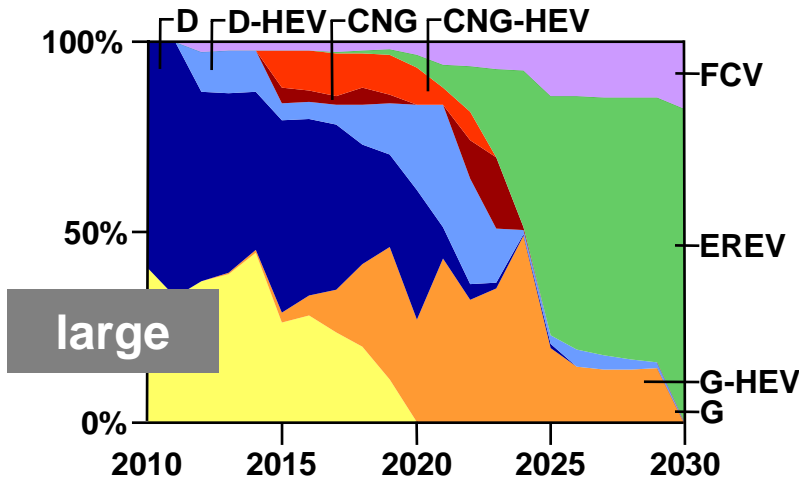
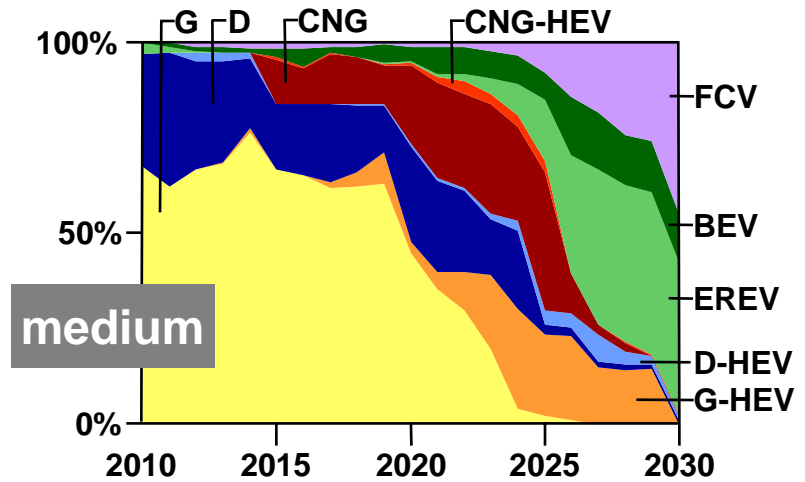
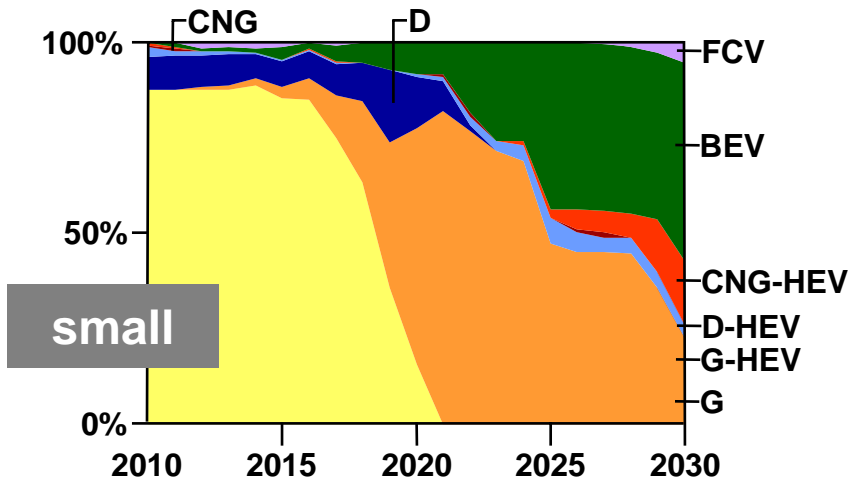
## Scenario 1 (Baseline) – New vehicle fleet





# Scenario calculations

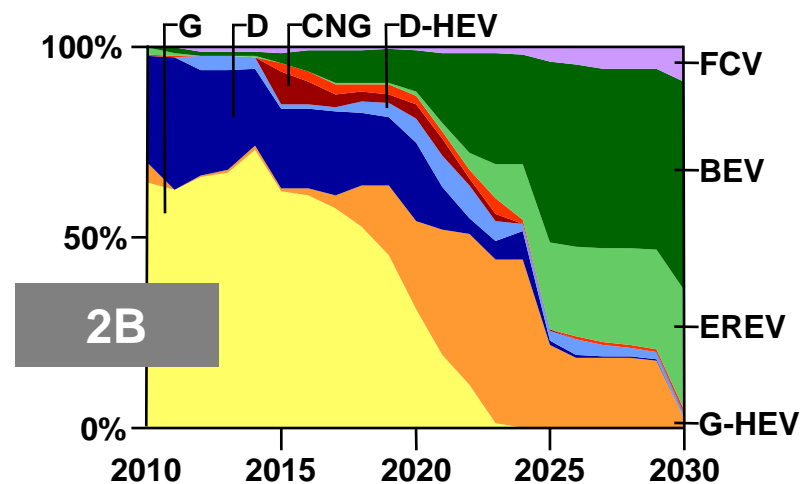
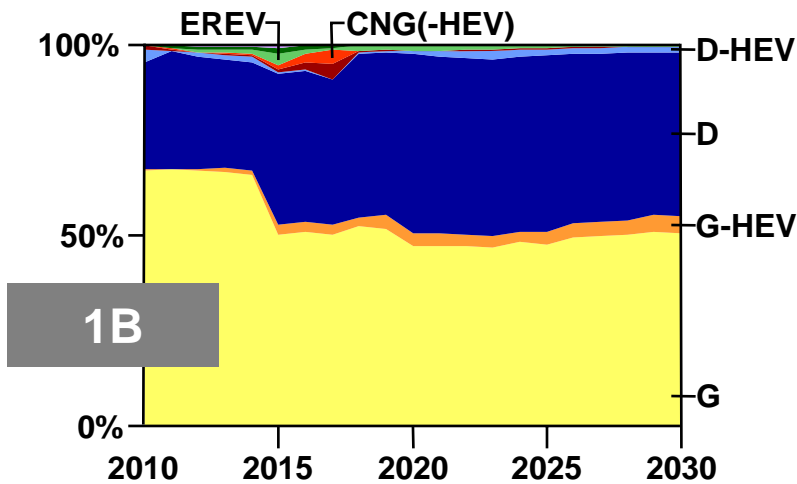
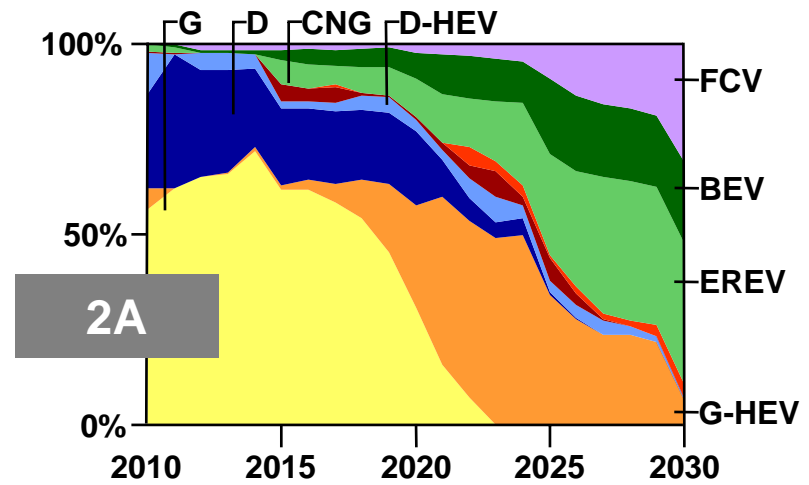
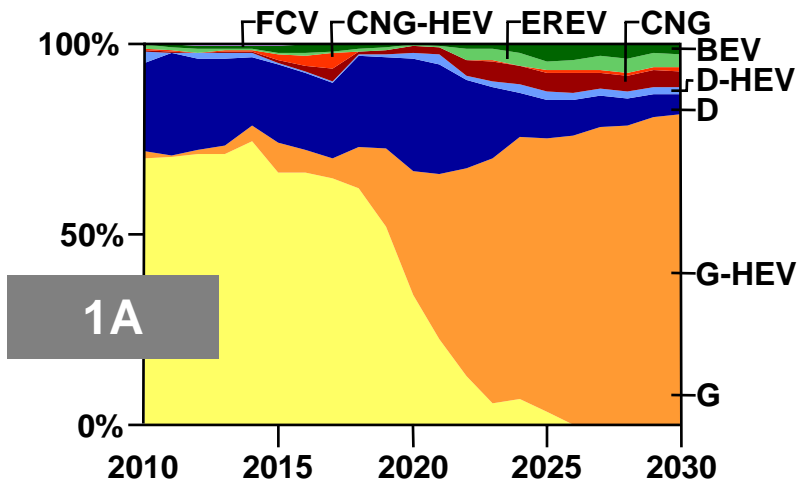
## Scenario 2 (Climate Protection) – New vehicle fleet





# Scenario calculations

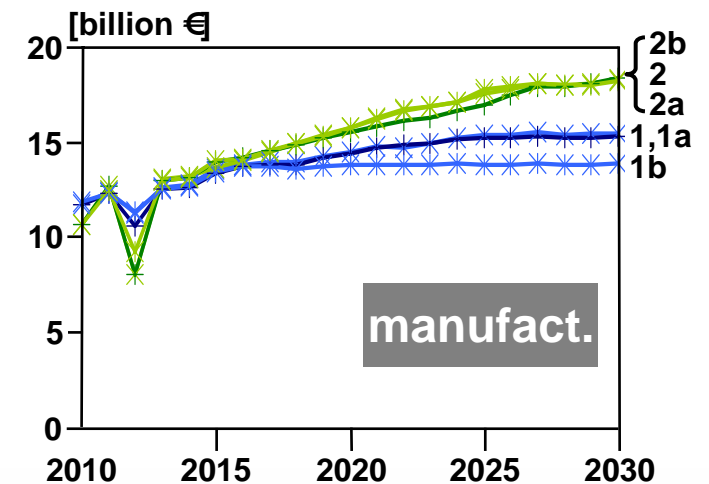
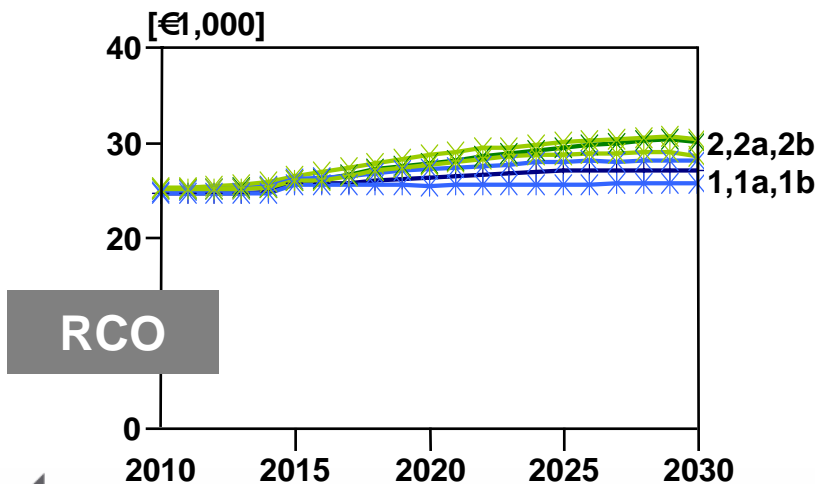
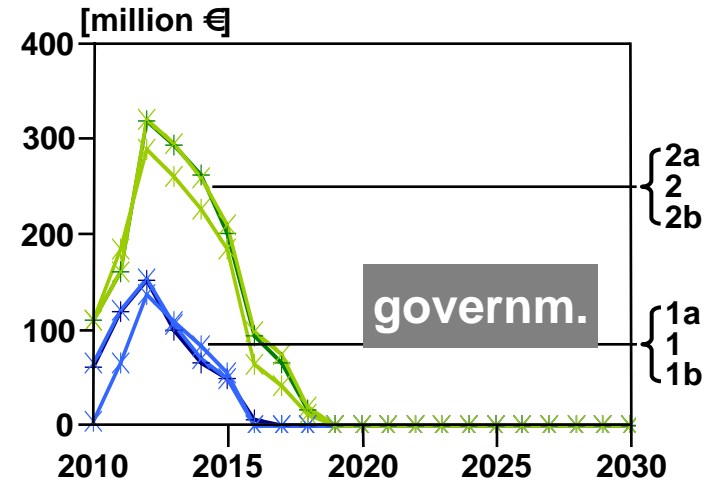
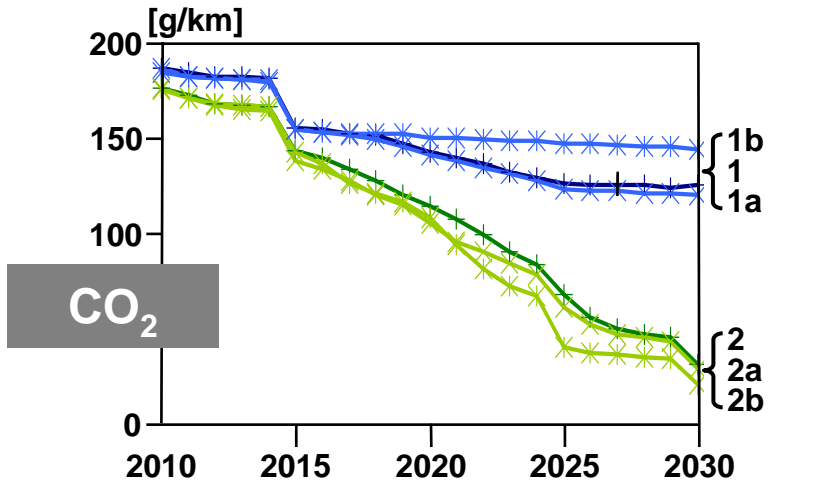
## Scenarios A&B – New vehicle fleet (all vehicles)





# Scenario calculations

## All scenarios – New vehicle fleet (all vehicles)





## Conclusion / Outlook

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- **VECTOR21** allows taking into account **many influencing factors**
- Future market shares of electric vehicles strongly **dependent on calculation assumptions**:
  - **CO<sub>2</sub> target values a key factor**
  - **Oil price less significant** for customer decision
  - Electricity and hydrogen from **renewable sources** important for sustainable reduction of CO<sub>2</sub> emissions
- **Recent applications** of **VECTOR21**:
  - analysis carried out for German automotive manufacturer
  - detail analysis carried out for German electricity supplier
  - extended study on behalf of the German Ministry of Economic Affairs
- **Expansion of assessment** planned for other markets (e.g. China, U.S., Europe) and time horizon (2050), depending on funding and data availability





## Further information

### ➤ please ask for information brochure on VECTOR21:


**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 5,200 people are employed at thirteen locations in Germany: Köln (headquarters), Berlin, Bonn, Braunschweig, Bremen, Göttingen, Hamburg, Lampoldshausen, Neustadt, Oberpfaffenhofen, Stuttgart, Trauen and Weßheim. DLR also operates offices in Brussels, Paris, and Washington D.C.

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**VECTOR 21**  
Vehicle Technology  
Scenario Model

**Today's Questions**

- What will be the most dominant vehicle propulsion 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 effects of changes of the "station 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 2030?
- 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 years 2020-50.

**Tool Description**

Vehicle Technology Database  
Basis 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.

**Hypothetic Customers**  
Approximately 900 different types of hypothetical customers, each having different attributes (e.g. annual mileage, willingness to pay), represent the new vehicle's marketing. Focusing on Relevant Cost of Ownership (RCO), taking into account e.g. vehicle prices, 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 well-to-wheel emissions.

**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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### ➤ recent publications:

- 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.
- 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). Fuel cell and battery electric vehicles – Hype or trend? VDI-Berichte Nr. 2030 (VDI innovative vehicle propulsions conference 2008), 213-231.



## Contact

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