PLUG-IN 2009

Assessment of Future Li-Ion Battery Production Costs

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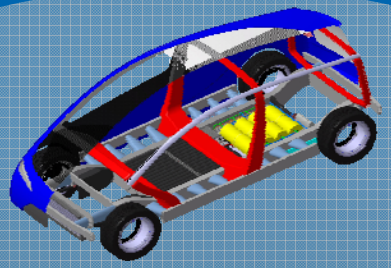
Introduction
German Aerospace Center (DLR)

- 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
Institute of Vehicle Concepts



Innovative Vehicle Concepts
For Road and Railway

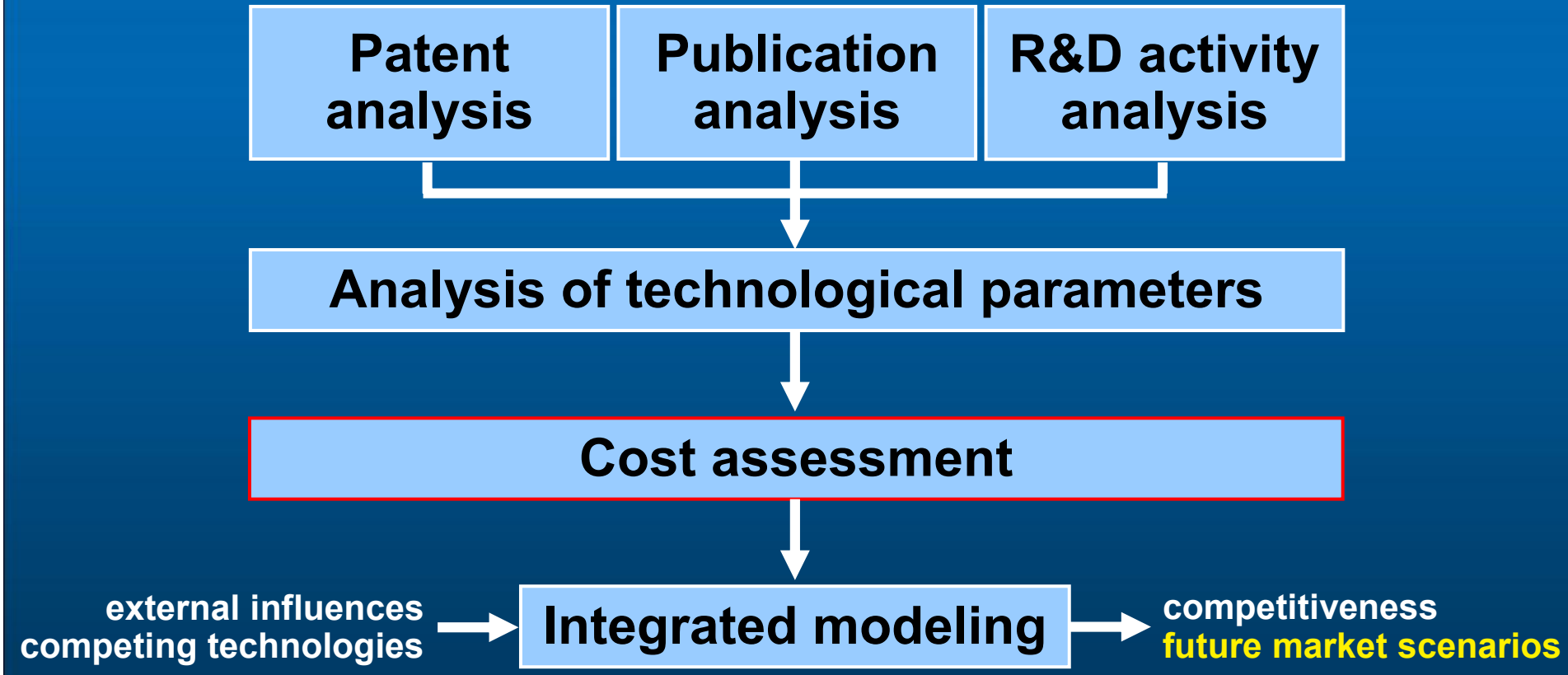
Alternative Power Trains & Energy Conversion

Fuel & Energy Storages

Lightweight & Hybrid Design Methods

Innovative Technological Systems & Technology Evaluation

Technology Assessment
General Scheme



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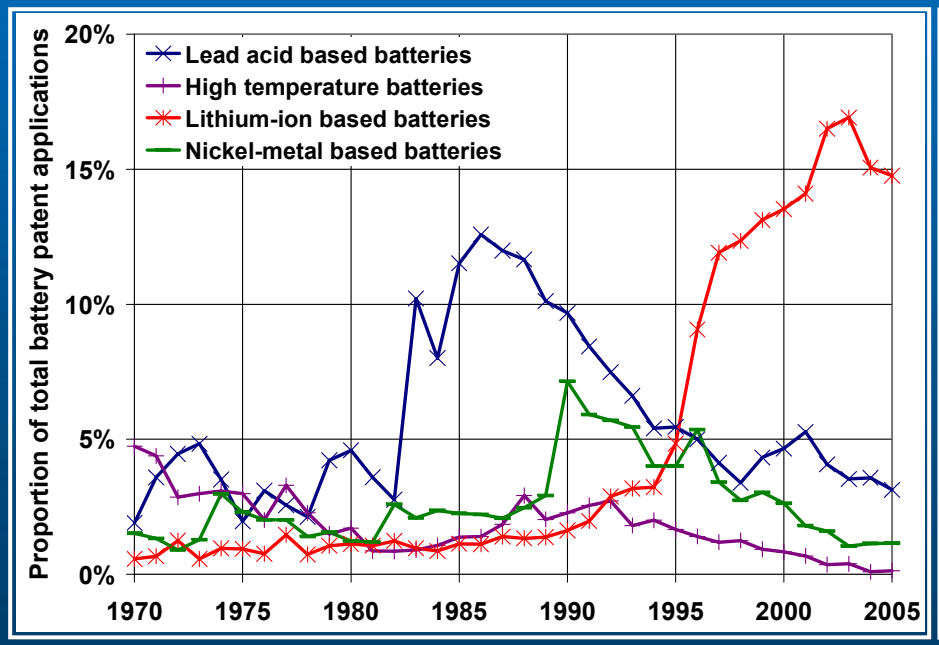
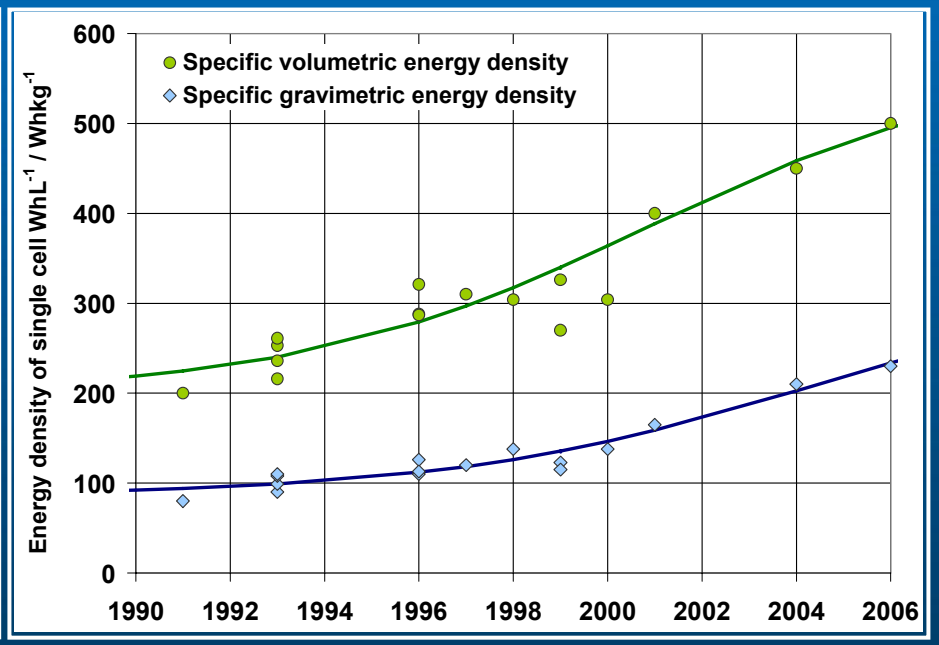
Technology Assessment
Patent & Technological Analysis

Example: Worldwide battery related patent applications by chemistry type



Data source: ISI Web of Knowledge

Example: Historical development of energy density of Lithium-Ion single cells



Data source: manufacturer data, scientific publications

Cost Assessment
General Scheme

1 RAW MATERIALS	2 COMPONENTS	3 CELL	4 BATTERY
• availability • market price • outlook	• technical parameters • cost • learning effects • economies of scale	• composition • technical parameters • cost • volume • weight	• no. of cells • technical parameters • cost • mass • volume

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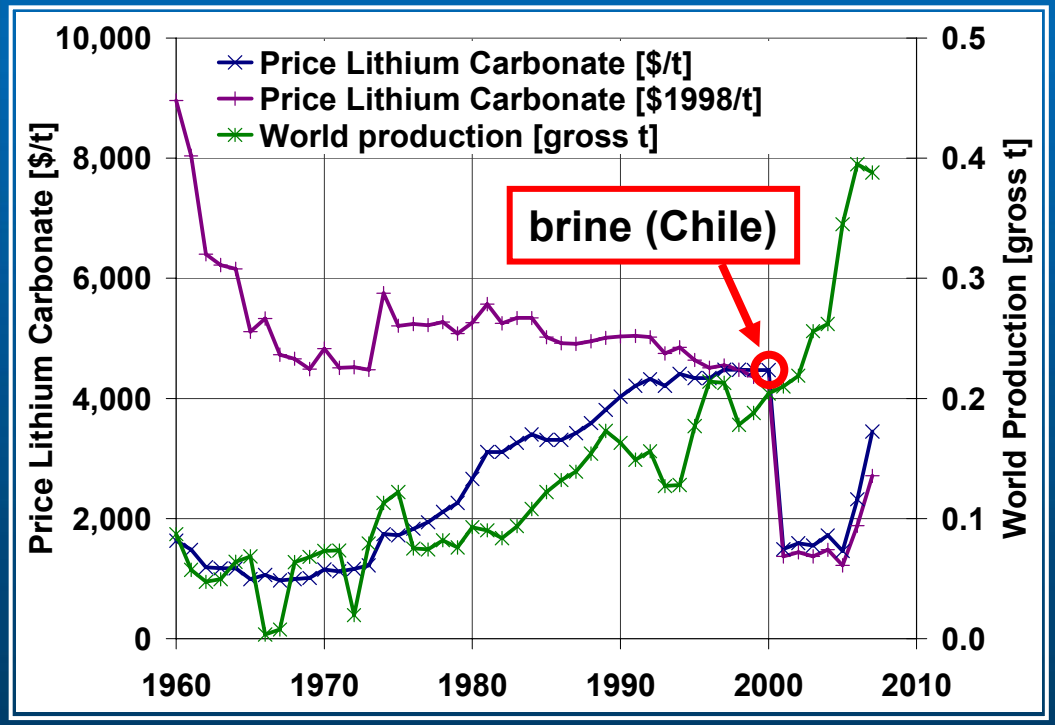
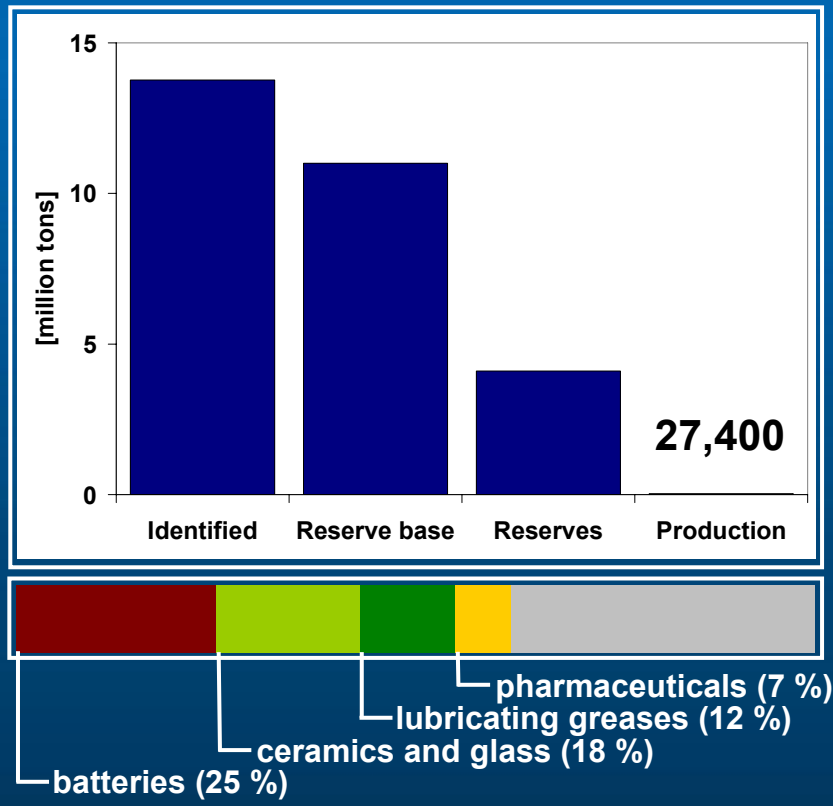
Cost Assessment
Raw Materials - Lithium

Market price & world production



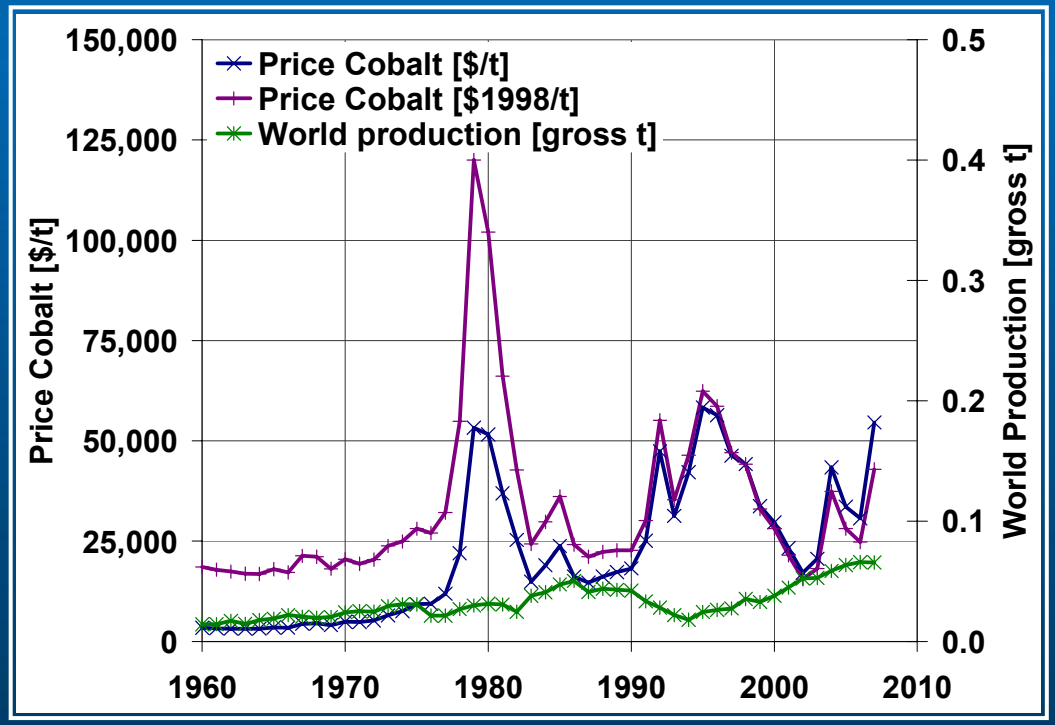
Reserves & consumption



Data source: U.S. Geological Survey (USGS), Data Series 140
Price is for Lithium Carbonate, world production is for lithium minerals and brine
USGS Mineral Commodity Summaries, USGS Minerals Yearbook
Reserves & consumption is for lithium contained in minerals and compounds

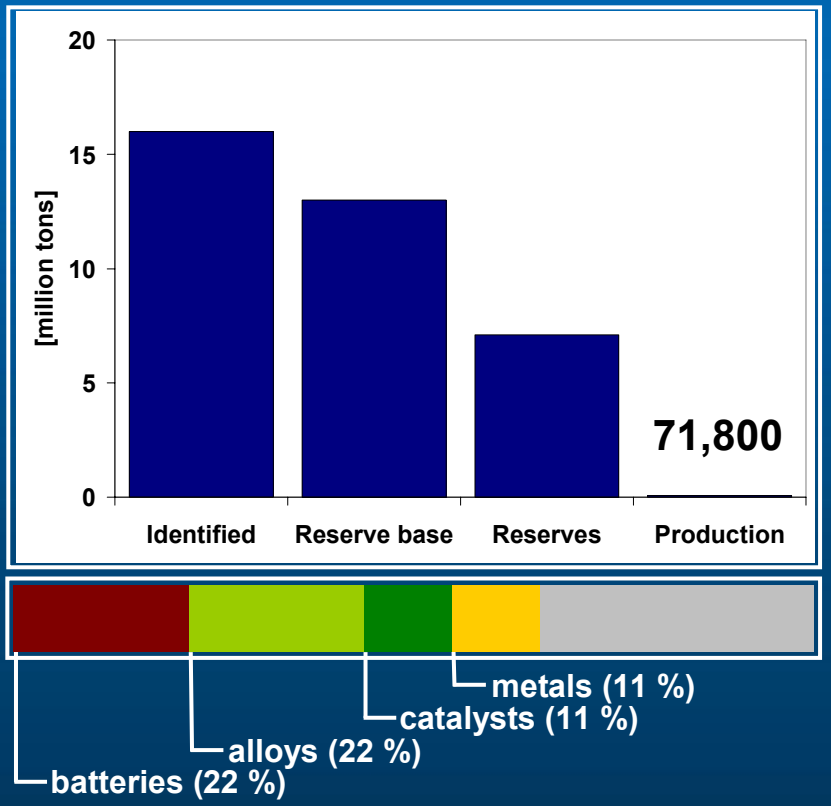
Cost Assessment
Raw Materials - Cobalt

Market price & world production



Data source: U.S. Geological Survey (USGS), Data Series 140
USGS Mineral Commodity Summaries, USGS Minerals Yearbook

Reserves & consumption



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Cost Assessment
Overview Cost Model

material level

component level

cell level

module/ pack level

Materials

Roh-, Hilfs- und Bedarfsstofe

Educt	Price $/kg	$/l	Ec. of Scale Factor
Graphit	30		0,67
$Li_4Ti_5O_{12}$ (nano)	16,5		0,85
Copper	22		0,9
Polyvinyliden-Fluorid	36,06		0,7
N-Methyl-Pyrrolidon	30		0,7
Leitruß	10		0,7
Acetylene black	25		0,7
	20		0,9
	30		0,9
	27		0,9
	28		0,9
	23		0,75
	15		0,85
$LiN(SO_2CF3)_2$	k. A.		
$LiC(SO_2CF3)_3$	252,9		0,8
$LiCF_3SO_3$	101,2		0,8
$LiBF_4$	101,2		0,8
$LiAsF_6$	252,9		0,8
$LiPF_6$	120,7		0,8
Propylencarbonate	1,3		0,9
Ethylencarbonate	1,3		0,9
Diethylcarbonate		1,3	0,9
Dimethylcarbonate	1,3		0,9
Dimethoxyethane		1,3	0,9
Separator	80		0,75
Polyethylene	1,3		1
Polypropylene	1,3		1
Mantle (Alu)			
Security parts			
Overhead			

Elektrolyt-Zuschlag 4

Components

Anode

Component	Capacity	Density	Potential
Graphit	334,8	1,5	-0,2
$Li_4Ti_5O_{12}$ (nano)	150	2,5	-1,5
Leitruß	-	-	
PVdF (Anode)	-	1,78	
N-Methyl-Pyrrolidon	-	-	
Copper	-	8,9	

Cathode

Component	Capacity	Density	Potential
$LiCoO_2$	155	2,6	3,7
$LiNi_{0,9}Co_{0,1}O_2$	220	2,5	3,7
$LiNi_{0,7}Co_{0,3}O_2$	190	2,5	3,
$LiNi_{0,33}Co_{0,33}Mn_{0,33}O_2$	140	2,3	3,
$LiFePO_4$ (nano)	160	2,00	3,
PVdF (Kathode)	-	1,78	
N-Methyl-Pyrrolidon	-	-	
Acetylene black	-	2,05	
Aluminium	-	2,7	

Separator

Component	Capacity	Density	Potential
Polypropylene	40	0,907	0,3
Polyethylene	40	0,94	0,3
PP/PE/PP	40	-	0,3

Elektrolyte

Component	Capacity	Density	Potential
LiN(SO2CF3)2			0,3
			0,2
			0,1
			0,0
			0,1

Dichte

1,2
1,4
0,9
1,0

Cell

High-Energy 1

Component	Amount Weight (kg)	Volume (l)	Area (dm^2)	Technology Potential (V)	Cost/cell $ Mass	Niche
LiNi0,7Co0,3O2	0,105	0,042	30,769	3,7	2,65	**2,95**
Graphit	0,063	0,042	30,769	-0,22	1,26	**1,88**
Separator	0,004	0,010	67,692			
PVdF (Kathode)	0,005	0,002				
PVdF (Anode)	0,003	0,002				
Acetylene black	0,005	0,002				
LiCF3SO3	0,006	-				
Propylencarbonate	0,048	0,040				
Aluminium	0,006	0,002			0,11	**0,12**
Copper	0,014	0,002			0,27	**0,30**
Hülle	0,026		Cath. Thickn.		1,06	**1,25**
Sicherheit:	see module cost		150 µm		0,00	**0,00**
Gemeinkosten					0,00	**0,00**
Total	**0,286 kg**	**0,104 l**	**0,07 kWh**	**3,48 V**	**7,96**	**9,82**
					114,312	141,0377

High-Energy 2

Component	Amount Weight (kg)	Volume (l)	Area (dm^2)	Technology Potential (V)	Cost/cell $ Mass	Niche
LiNi0,9Co0,1O2	0,091	0,036	27,157	3,76	2,21	**2,45**
Graphit	0,063	0,042	27,157	-0,22	1,26	**1,88**
Separator	0,004	0,009	59,745		0,23	**0,30**
PVdF (Kathode)	0,005	0,003			0,11	**0,16**
PVdF (Anode)	0,003	0,002			0,08	**0,11**
Acetylene black	0,005	0,002			0,03	**0,05**
LiPF6	0,006	-			2,19	**2,74**
Propylencarbonate	0,045	0,037			0,05	**0,06**
Aluminium	0,005	0,002			0,10	**0,11**
Copper	0,012	0,001			0,24	**0,27**
Hülle	0,022		Cath. Thickn.		0,90	**1,06**
Sicherheit:	see module cost		150 µm		0,00	**0,00**
Gemeinkosten					0,00	**0,00**
Total	**0,260 kg**	**0,097 l**	**0,0708 kWh**	**3,54 V**	**7,40**	**9,19**

High-Power 1

Component	Amount Weight (kg)	Volume (l)	Area (dm^2)	Technology Potential (V)	Cost/cell $ Mass	Niche
LiFePO4 (nano)	0,125	0,063	250,000	3,4	1,59	**1,88**
Graphit	0,063	0,042	250,000	-0,22	1,26	**1,88**
Separator	0,005	0,083	550,000		0,31	**0,41**
PVdF (Kathode)	0,006	0,003			0,16	**0,23**
PVdF (Anode)	0,003	0,002			0,08	**0,11**
Acetylene black	0,019	0,009			0,33	**0,47**
LiBF4	0,008	-			2,44	**3,06**
Ethylencarbonate	0,114	0,081			0,13	**0,15**
Aluminum	0,051	0,019			0,91	**1,01**
Copper	0,111	0,013			2,20	**2,45**
Hülle	0,068		Cath. Thickn.		2,79	**3,28**
Sicherheit:	see module cost		30 µm		0,00	**0,00**
Gemeinkosten					0,00	**0,00**
Total	**0,572 kg**	**0,233 l**	**0,064 kWh**	**3,18 V**	**12,21**	**14,92**
					192,019	234,6618

High-Power 2

Component	Amount Weight (kg)	Volume (l)	Area (dm^2)	Technology Potential (V)	Cost/cell $ Mass	Niche
LiNi0,7Co0,3O2	0,105	0,042	286,804	3,7	2,65	**2,95**
Li4Ti5O12 (nano)	0,160	0,064	286,804	-1,55	2,24	**2,64**
Separator	0,004	0,095	630,969		0,26	**0,35**
PVdF (Kathode)	0,005	0,002			0,13	**0,19**
PVdF (Anode)	0,008	0,003			0,20	**0,29**
Acetylene black	0,096	0,042			0,67	**0,96**
LiPF6	0,015	-			5,82	**7,27**
Propylencarbonate	0,120	0,099			0,14	**0,16**
Aluminum	0,058	0,022			1,05	**1,16**
Copper	0,128	0,014			2,53	**2,81**
Hülle	0,140		Cath. Thickn.		5,71	**6,71**
Sicherheit:	see module cost		30 µm		0,00	**0,00**
Gemeinkosten					0,00	**0,00**
Total	**0,839 kg**	**0,284 l**	**0,043 kWh**	**2,15 V**	**21,40**	**25,48**

	Einheit	Zellen	Module	Batterie
Kapazität	**Ah**	20	20	172,00
Spannung	**V**	3,54	35,4	378
Zelltyp	**1-4**	HighEnergy2	-	-
Anzahl parallel	**Stück**	9,00	**1**	9
Anzahl seriell	**Stück**	114,00	**10**	11

Modul

Komponente	Gewicht (kg)	Volumen (l)	Modulpreis Mengenprod. €		Modulpreis Nischenprod. €	
Zellen	3	1	60		80	
Packaging						
Sicherheit						
Terminals	erstmal alles kombiniert		15	**25%**	23,2	**29%**
Mikrochip?						
Gemeinkosten			18	**30%**	30	**38%**
			13,95	**15%**	33,3	**25%**
		1,1 l	**106,95 €**		**166,5 €**	

Batteriepack

	g)	Volumen (l)	Packpreis Mengenprod. €		Packpreis Nischenprod. €	
Module	326,7	108,9	10588,05		16483,5	
Packaging						
Schütze						
Kühlung	erstmal alles kombiniert		1852,90875	**18%**	3296,7	**20%**
Garantiekosten						
Software						
Mikrochip						
BEV-Marge			1866,143813	**15%**	2967,03	**15%**
Total	**359,4 kg**	**119,79 l**	**14307 €**		**22747 €**	

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Cost Assessment
Cell Materials & Components

	Price today	Price future	Atomic mass
Lithium	5,5 $/kg	6,0 $/kg	6,9
Cobalt	35,1 $/kg	40,0 $/kg	58,9
Manganese	1,0 $/kg	1,5 $/kg	58,7
Nickel	24,0 $/kg	30,0 $/kg	54,9
Oxygen	---	---	16,0

	$LiCoO_2$	$LiMn_2O_4$	$LiNi0_2$	$LiNi_{0,9}Co_{0,1}O_2$	$LiNi_{0,7}Co_{0,3}O_2$	$LiNi_{0,33}Co_{0,33}Mn_{0,33}O_2$
Lithium	7%	4%	7%			
Cobalt	60%	0%	0%			
Manganese	0%	62%	0%			
Nickel	0%	0%	59%			
Today (ca. 2006)						
Price today	**30,0 $/kg**	**17,0 $/kg**	**27,5 $/kg**			
Raw material cost	21,5 $/kg	0,8 $/kg	14,5 $/kg			
Raw material cost	72%	5%	53%			
Manufacturing & overhead	8,5 $/kg	16,2 $/kg	13,0 $/kg			
Future (ca. 2015)						
Raw material cost	24,5 $/kg	1,2 $/kg	18,0 $/kg			
Raw material cost	81%	10%	67%			
Manufacturing & overhead	5,8 $/kg	10,9 $/kg	8,8 $/kg			
Price future	**30,3 $/kg**	**12,1 $/kg**	**26,8 $/kg**	**27,2 $/kg**	**27,9 $/kg**	**22,8 $/kg**

1. determine raw material prices today and in future
2. calculate material composition
3. break down today's material price
4. account for material price developments and learning effects

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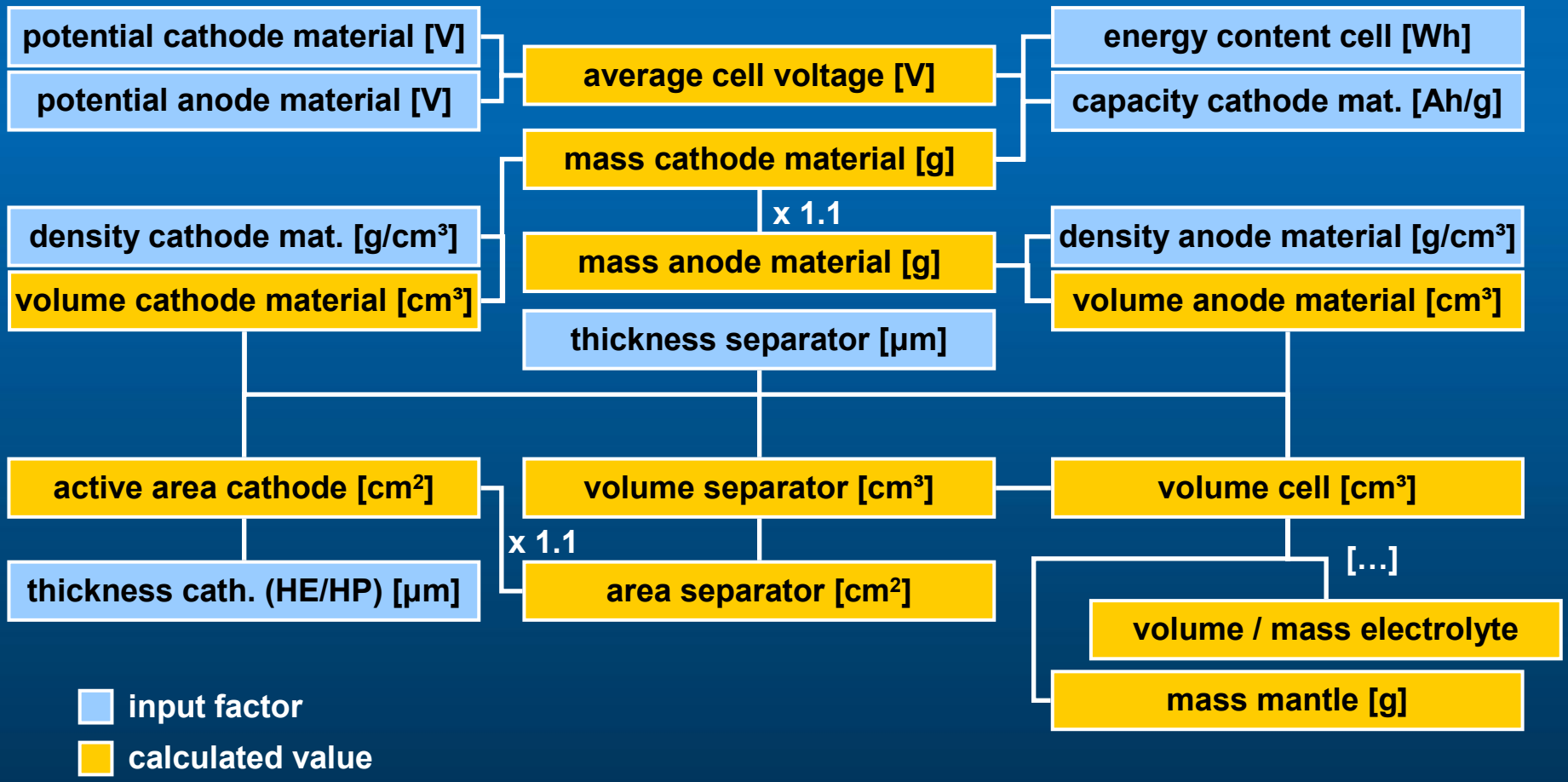
Cost Assessment
Cell Level

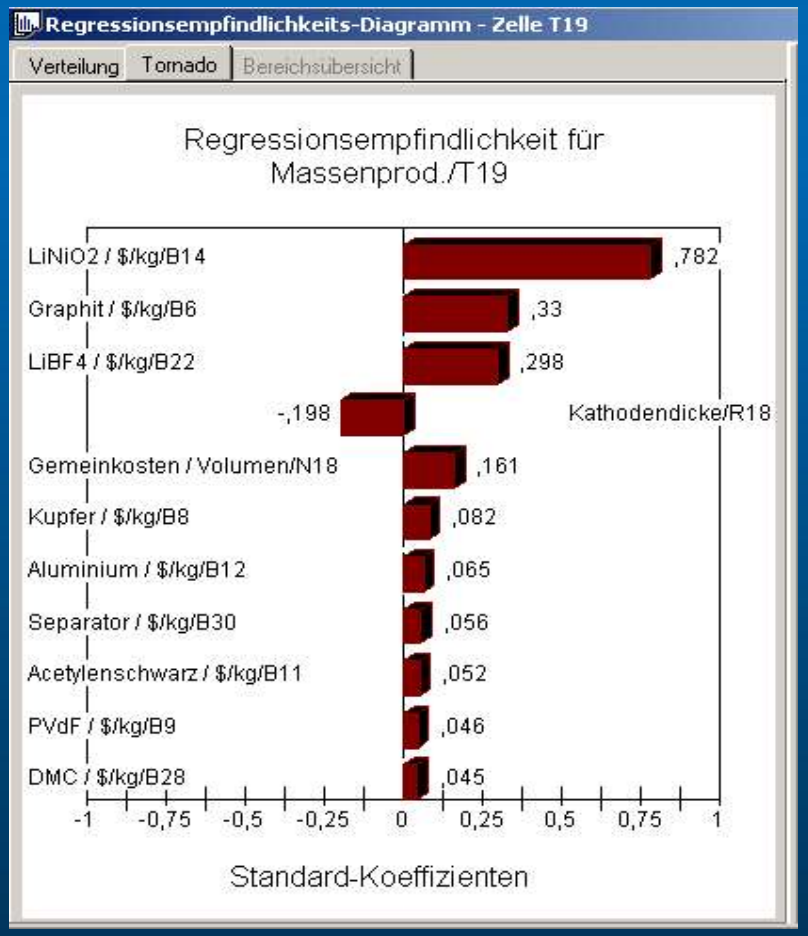


Cost Assessment
Cost Model / Cell Level

High-Energy 1						
Amount				Technology	Cost/cell $	
Component	Weight (kg)	Volume (l)	Area (dm^2)	Potential (V)	Mass	Niche
LiNi0,33Co0,33Mn0,33O2	0,143	0,062	45,071	3,9	2,46	**3,29**
Graphit	0,063	0,042	45,071	-0,22	1,26	**1,88**
Separator	0,005	0,015	99,156		0,32	**0,43**
PVdF (Kathode)	0,007	0,003			0,18	**0,26**
PVdF (Anode)	0,003	0,002			0,08	**0,11**
Acetylene black	0,007	0,003			0,13	**0,18**
LiBF4	0,005	-			1,53	**1,91**
Propylencarbonate	0,061	0,050			0,07	**0,08**
Aluminium	0,009	0,003			0,16	**0,18**
Copper	0,020	0,002			0,40	**0,44**
Hülle	0,032		**Cath. Thickn.**		1,32	**1,55**
Sicherheit:	see module cost		**150 µm**		0,00	**0,00**
Gemeinkosten					0,00	**0,00**
Total	**0,356 kg**	**0,132 l**	**0,07 kWh**	**3,68 V**	**7,92**	**10,32**

Cost Assessment
Cell Level – Monte-Carlo-Analysis

- use of Monte-Carlo analysis for evaluating uncertainties
- distributive functions instead of fixed values for input parameters
- „Tornado diagram“
- identification of influencing factors on battery cell costs

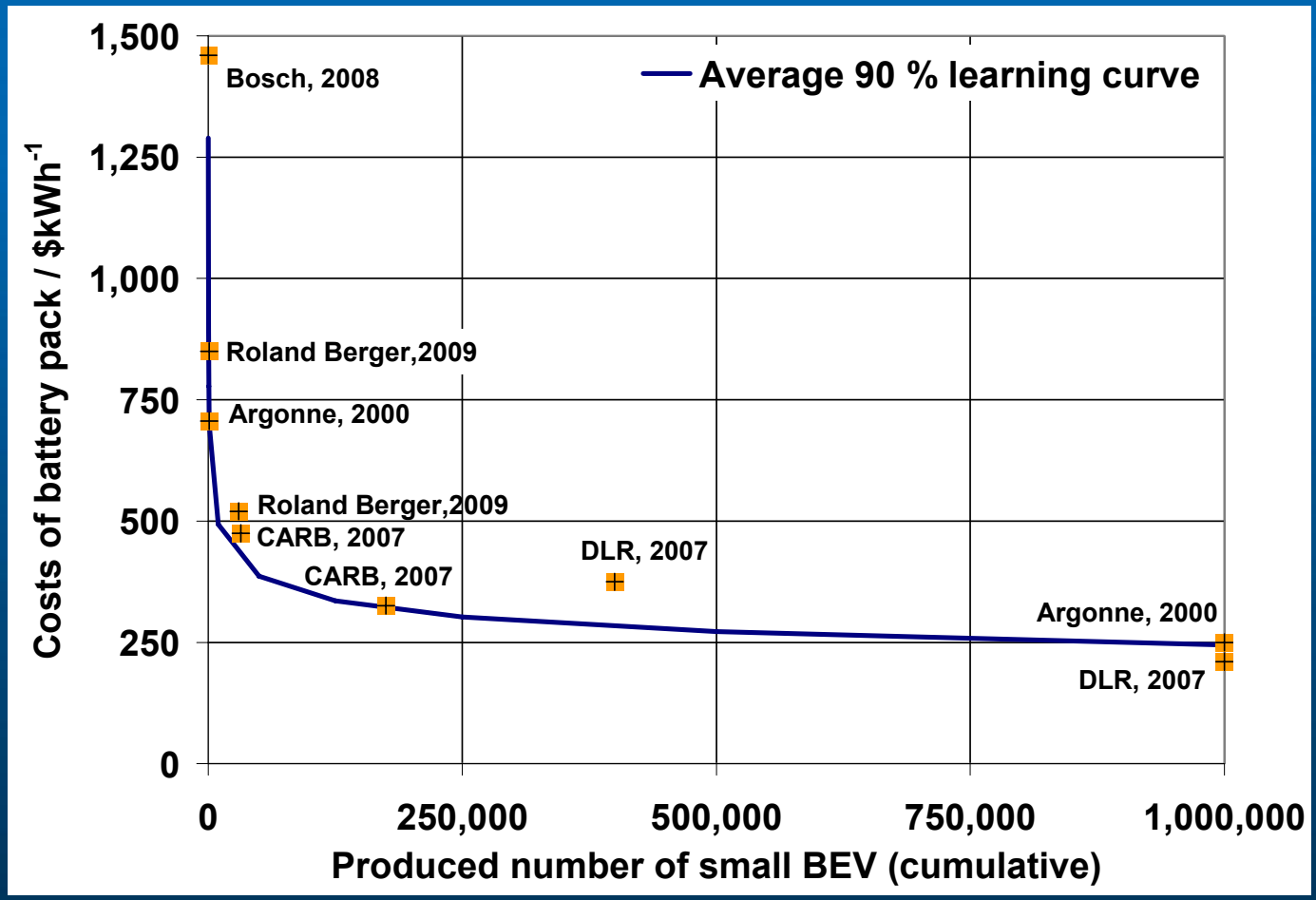


Cost Assessment
Results Pack Level

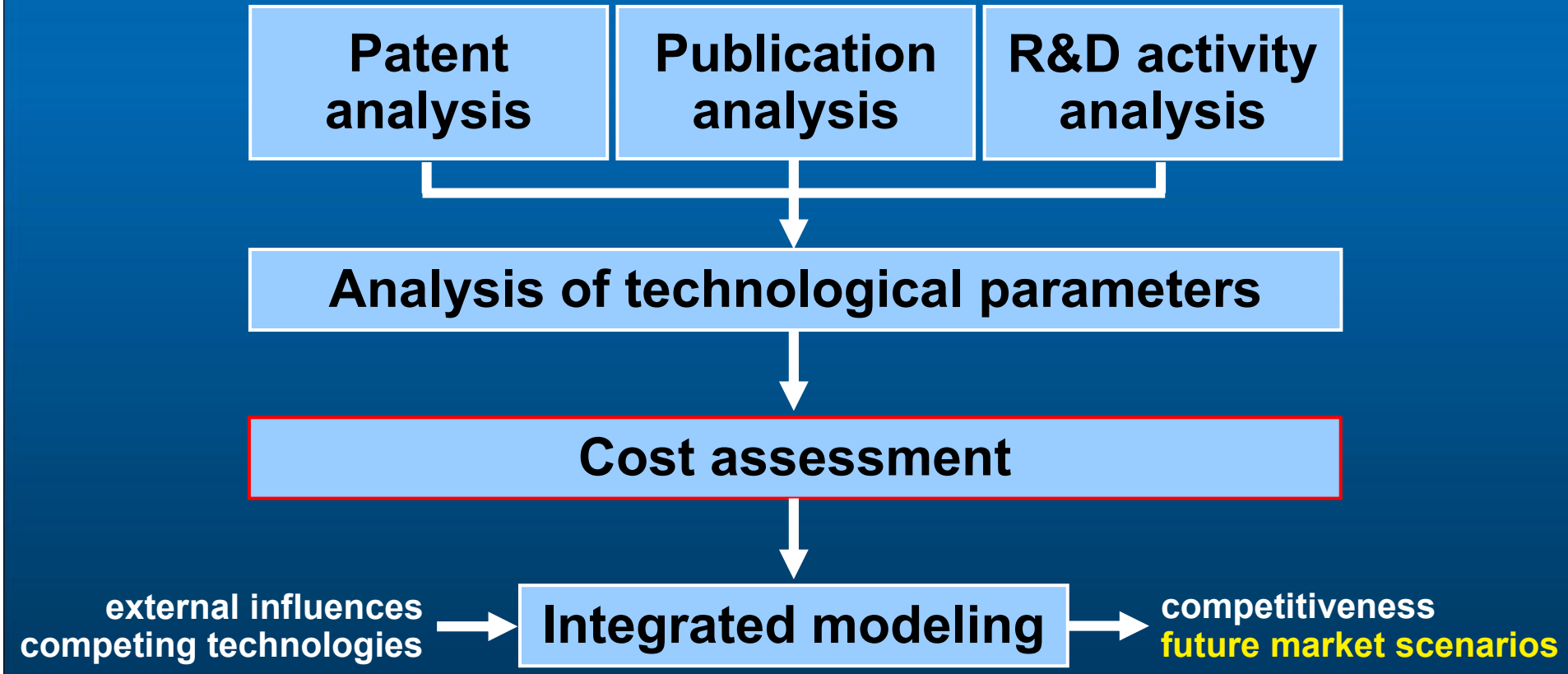
- resulting production costs at pack level:
  - 210 - 375 $/kWh (High-Energy)
  - 400 - 625 $/kWh (High-Power)

  depending on materials and volume

Cost Assessment
Results – Previous studies



Technology Assessment
General Scheme



Integrated Modeling
VECTOR21

vehicle energy consumption

fuel prices

taxes

raw material prices

vehicle costs

customer types

technical measurements

annual mileages

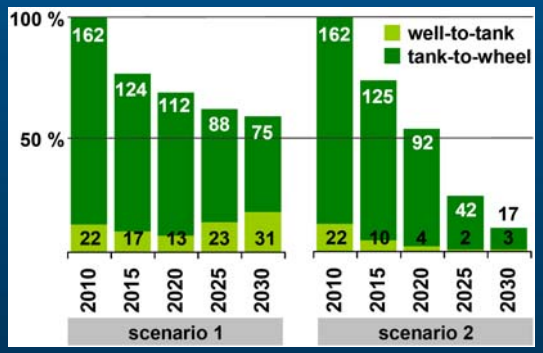
VECTOR21

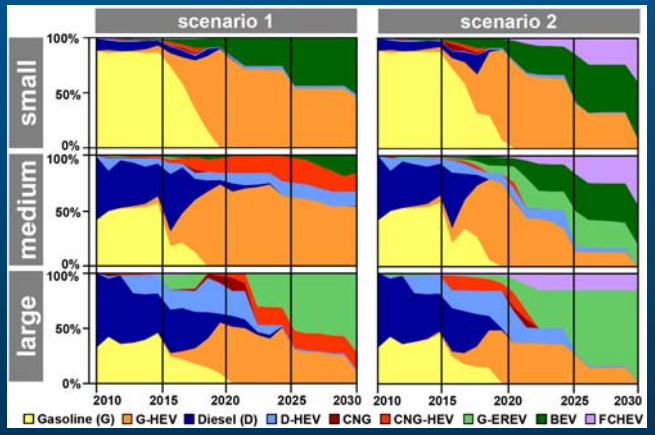
vehicles ↔ customers

Total Cost of Ownership

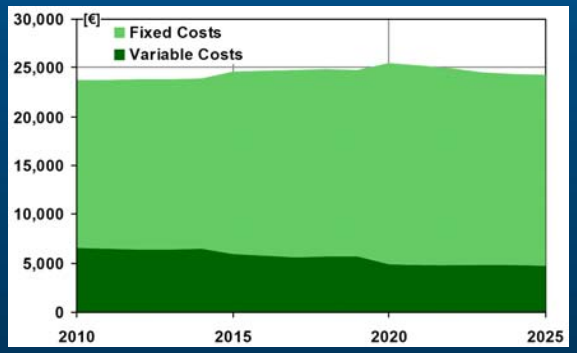
future market shares

CO_2 emissions / fuel demand





costs (customer, manufacturer, society)



Conclusion
Contact / Further Information

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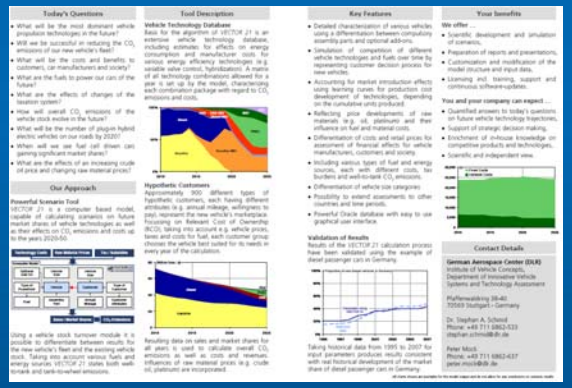

- Mock, P., and Schmid, S.A. (2009). *Techno-economic assessments for fuel cells and batteries*. Encyclopedia of Electrochemical Power Sources. Amsterdam: Elsevier B.V.
- Mock, P., and Schmid, S.A. (2009). *Fuel cells for automotive powertrains – A techno-economic assessment*. Journal of Power Sources, 190(1), 133-140.
- Mock, P., 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. (2008). *Fuel cell and battery electric vehicles – Hype or Trend?* VDI-Berichte No. 2030 (Innovative Vehicle Propulsion Systems 2008, Dresden, Germany), 213-231.