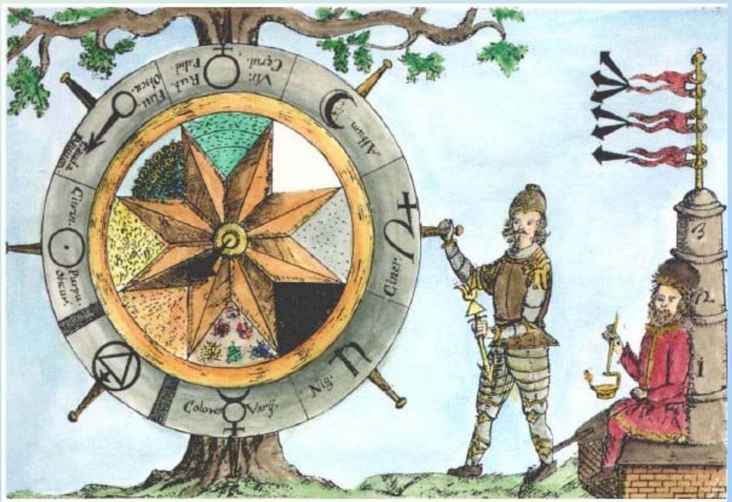
SUBAT

"Sustainable Batteries”

Action 8.1.B.1.6
Assessment of Environmental Technologies
for Support of Policy Decision



Frederic Vergels

SUBAT

January 2004 to Mach 2005

Partners

Universities

Vrije Universiteit Brussel
Vakgroep Electrotechniek en Energietechnologie (ETEC)

Pisa University

ULB
Centre d'Etudes Economiques et Sociales de l'Environnement

Associations

AVERE

CEREVEH

CEI CIVES

CITELEC

Background of the project

- European end-of-life directive (2000/53/EC), limiting the use of heavy metals in all vehicles put on the market after 1 July 2003
- Exemption for nickel-cadmium batteries in electric vehicles until 31 December 2005 (Annex II)
- Study to examine
  - advisability to maintain Ni-Cd in electric vehicle applications
  - progressive substitution

SUBAT Objective

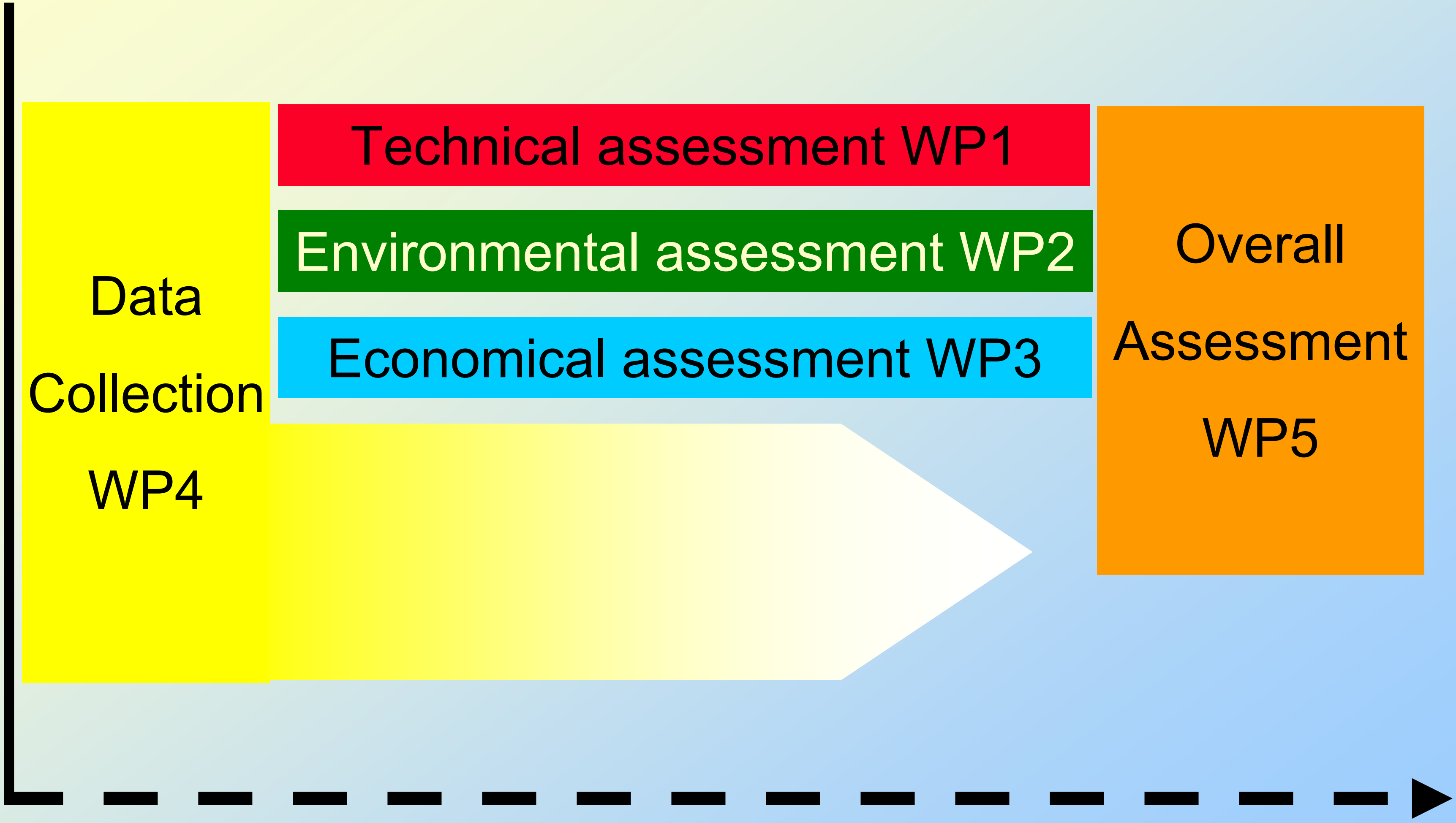
- Deliver a complete assessment of commercially available and forthcoming battery technologies for battery-electric and hybrid vehicles

Scope of SUBAT

- TRACTION batteries
- Providing energy and power for the propulsion of vehicles
- Traction batteries are industrial batteries
- Not automotive (SLI) or consumer batteries!

SUBAT

Organization and results



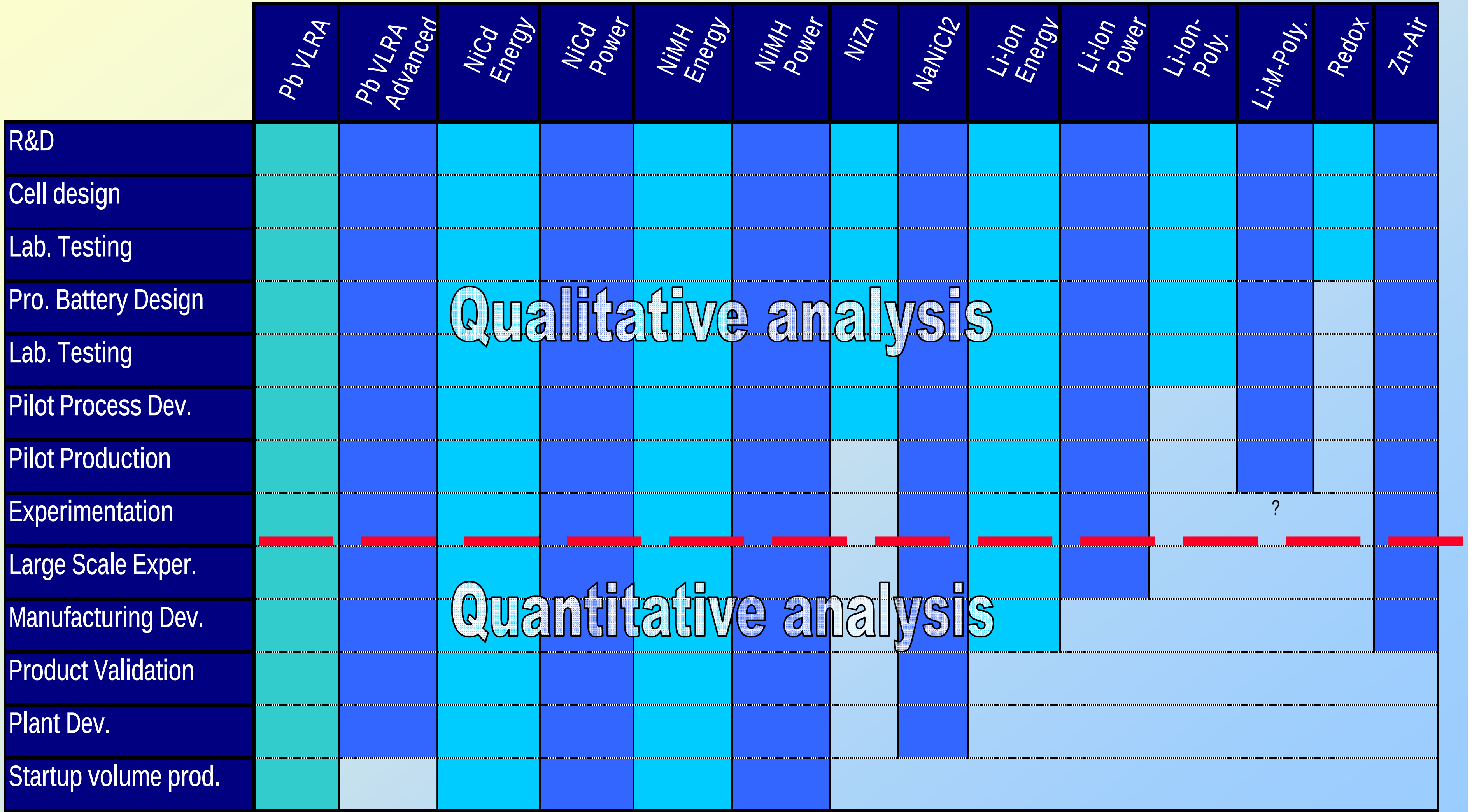
WP1: Technical Assessment

Peter Van den Bossche

Technical Assessment

SUBAT

Level of Development



Lead-acid battery

- Widespread in industrial traction applications
- Low specific energy (30Wh/kg) hampers use in high-performance road vehicles
- Used for heavy-duty road vehicles
- VRLA: life performance to improve

Nickel-Cadmium

- Specific energy 50 Wh/kg
- Specific power 200 W/kg
- Good cycle life (> 1300)
- Most widespread use for battery-electric road vehicles in Europe today

Nickel-Metal Hydride

- Slightly better performance compared to NiCd
- Power-optimised types now widely used in hybrid vehicles
- Energy-optimised types not industrially manufactured

Nickel-zinc

- Good energy density
- Limited life?
- Promising research at cell level
- Vehicle batteries not available yet

Lithium batteries

- Technologies
  - Lithium-ion
  - Lithium-ion-polymer
  - Lithium-metal-polymer
- High specific energy and power
- Operational issues
  - Abuse tolerance
- Pilot phase

Sodium-Nickel-Chloride

- Good specific energy (100 Wh/kg)
- Operates at 300 °C
- Particularly suited for intensively used vehicles
- Small-scale production facilities

Zinc-air battery

- Not a battery, but a kind of fuel cell
- Mechanical recharging
- Logistic burden!

	Pb VLRA	Pb VLRA Advanced	NiCd Energy	NiMH Energy	NiZn	NaNiCl2	Li-Ion Energy	Li-Ion-Poly.	Li-M-Poly.	Zn-Air
ENERGY (Wh/kg)	36	40	60	70	75	125	125	125	130?	Not a Battery, chemical refuelling
LIFE (~years)	2	3	6	6	?	5?	6	?	?	
BMS										
SAFETY									?	
EFFICIENCY (Wh %)	80	80	75	70	70	90	90	90	?	
SELF DISCHARGE					?					
MAINTENANCE									?	
POWER (W/kg short)	250	250	200	350	200	200	400	400	?	
POWER (low temp.)					?				?	
CHARGE friendl.									?	

good or high — bad or low

TECHNOLOGIES for BATTERY ELECTRIC VEHICLE (Cell Level)

Technical Assessment

	Pb VLRA	Pb VLRA Advanced	NiCd Power	NiMH Power	NiZn	NaNiCl2	Li-Ion Power	Li-Ion-Poly.	Li-M-Poly.	Zn-Air
POWER (W/kg short)	350	500	500	1500	?	?	2000	2000	?	Not a Battery, chemical refuelling
ENERGY (Wh/kg)	25	30	30	55	?	?	70	70	70	
Life (years)	2	3	6	6	?	?	6	?	?	
POWER (low temp.)					?					
EFFICIENCY (Wh %)	80	80	75	70	?	90	90	90	?	
SAFETY										
SELF DISCHARGE					?					
MAINTENANCE					?					

good or high — bad or low

TECHNOLOGIES for HYBRID VEHICLES

(Cell Level)

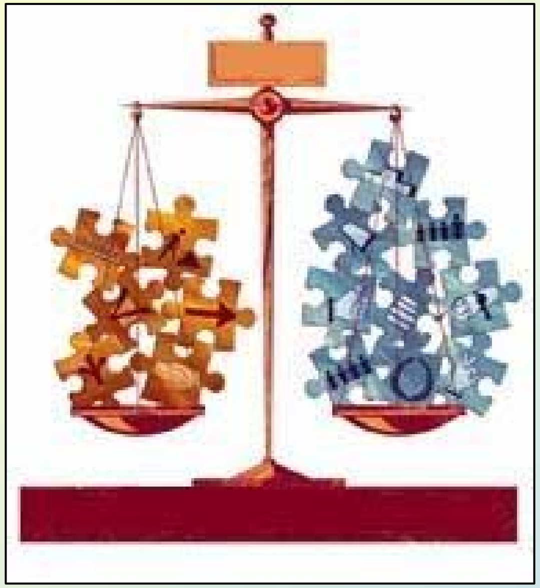
Technical Assessment

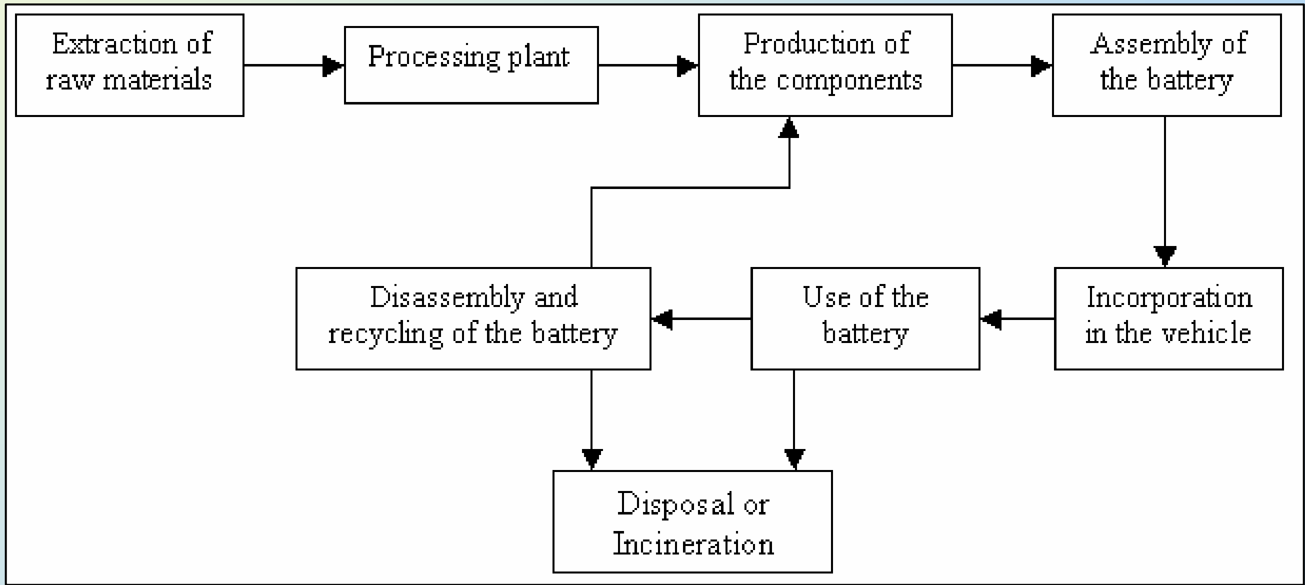
WP2: Environmental Assessment

Julien Matheys

Life-cycle of a battery

- **"Cradle-to-grave" approach**





- **Eco-indicator 99 →Eco-indicator points**
- **Software → Simapro 6.01**

Functional Unit BEV

- **3000 cycles**
- **60 km range**

} **180000km**

	$E_{density}$ (Wh/kg)	# Cycles	Energy efficiency	Losses due to heating
Pb-acid	40	500	82.5%	
NiCd	60	1350	72.5%	
NiMH	70	1350	70.0%	
Li-ion	125	1000	90.0%	
NaNiCl	125	1000	92.5%	7.2%

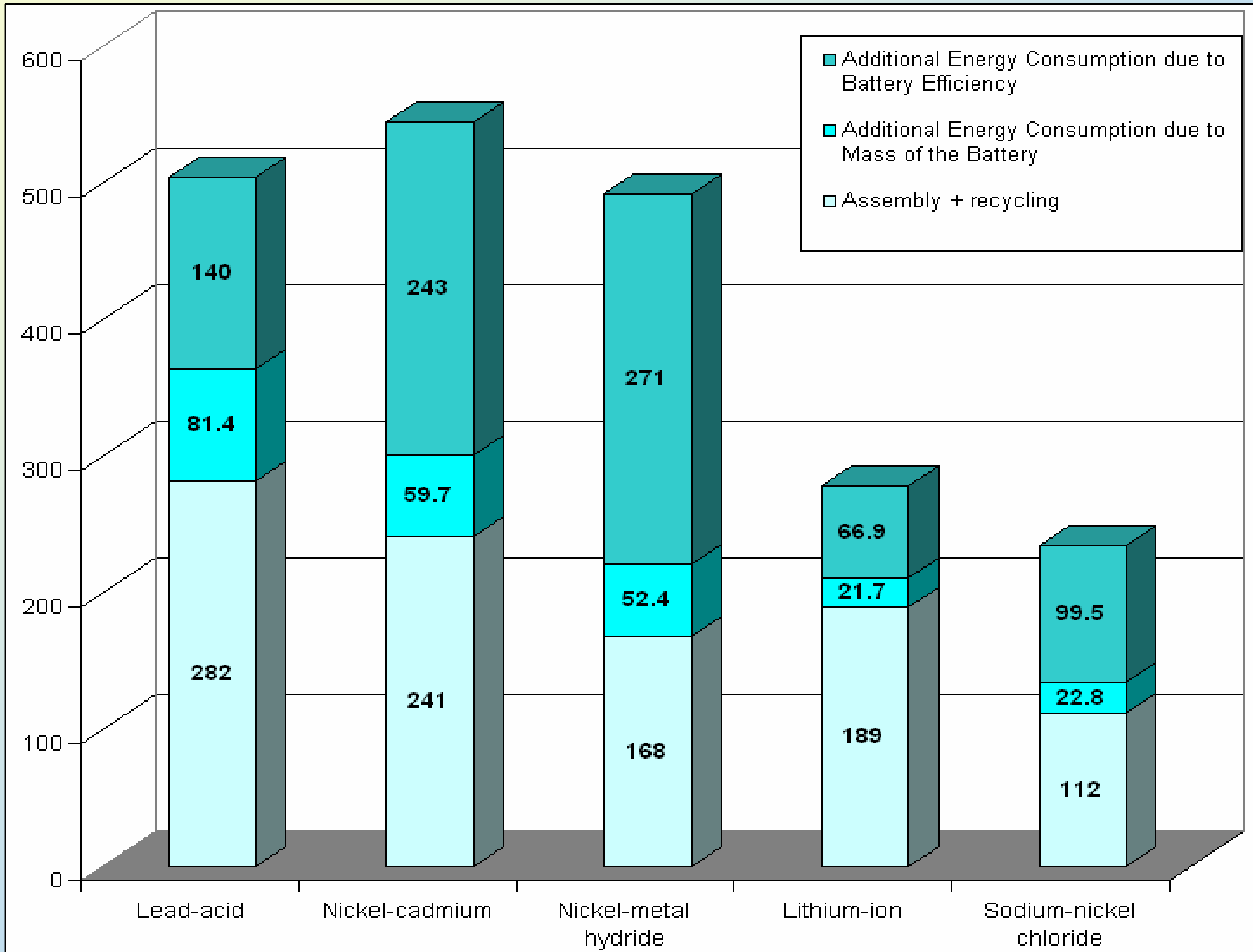
Environmental Impact Assessment

Including:

Additional energy consumption **battery efficiency**

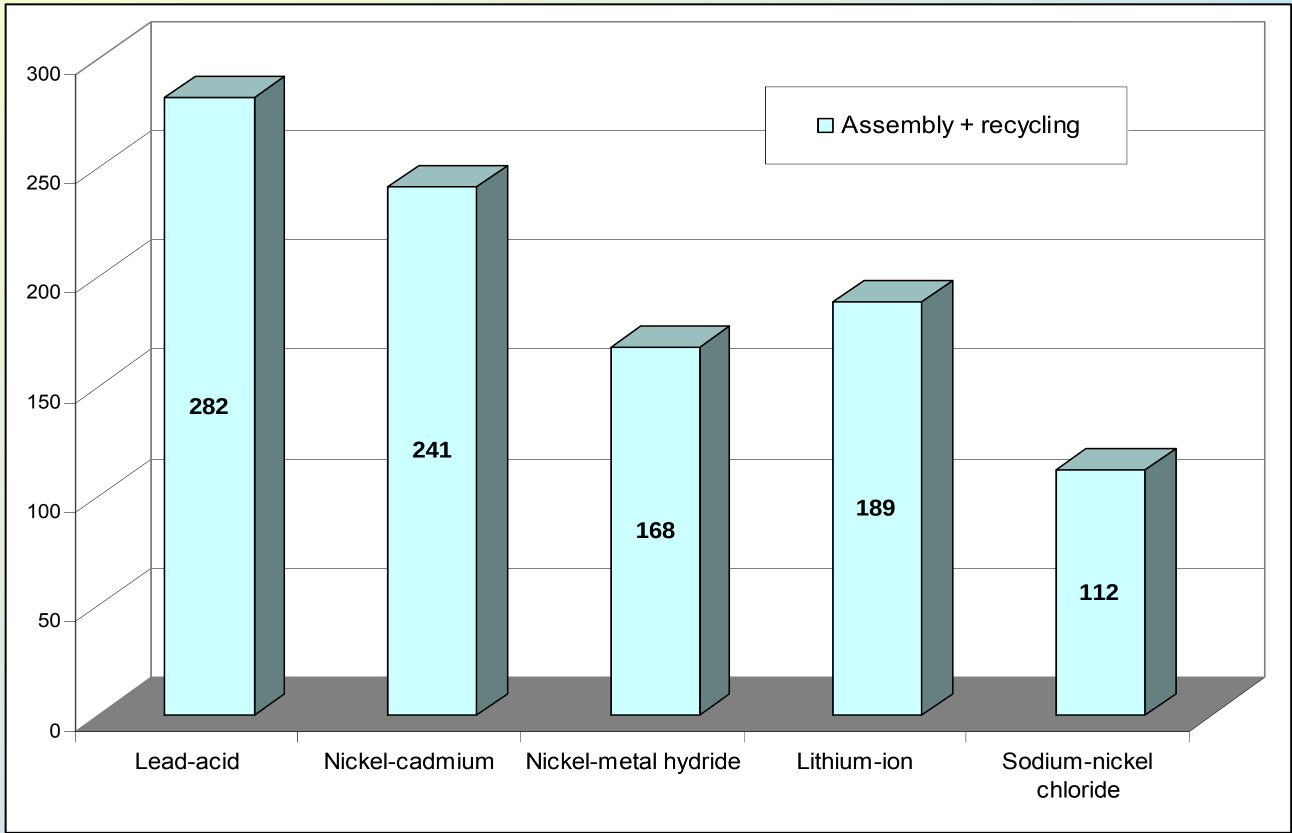
Additional energy consumption **battery mass**

Assembly and recycling



Environmental Impact Assessment

Including Assembly and Recycling
(without additional energy consumption due to battery)



Importance of Battery efficiency

(Environmental impact is depending on electricity production method)

Overall impact

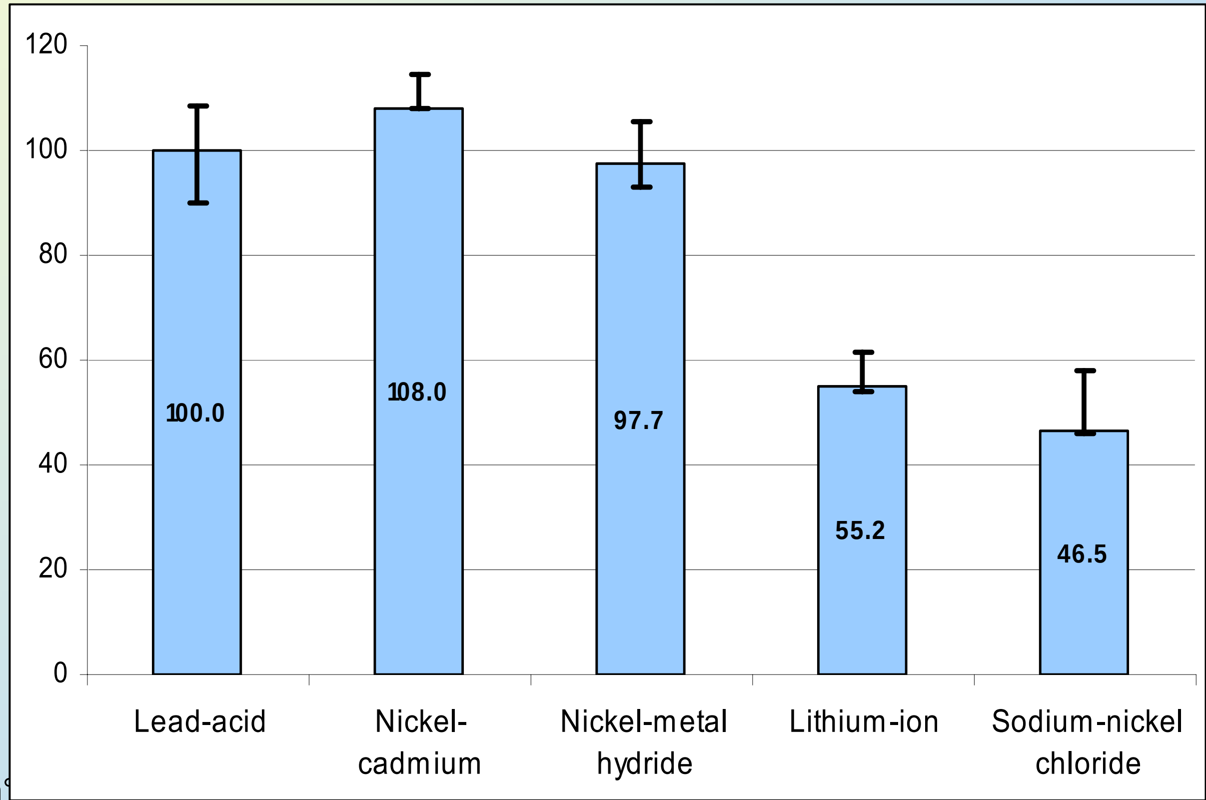
	Production	Additional Energy Consumption due to mass & battery efficiency	**Recycling**	Total
Pb-acid	**1091**	221	**-809**	503
NiCd	**861**	303	**-620**	544
NiMH	**945**	323	**-777**	491
Li-ion	**361**	89	**-172**	278
NaNiCl	**368**	122	**-256**	234

⇨ Importance of Recycling!!!

Sensitivity analysis BEV

Including:

- different relative sizes of the components
- varying recycling rates
- varying recycling efficiencies
- varying required amounts of energy for production&recycling



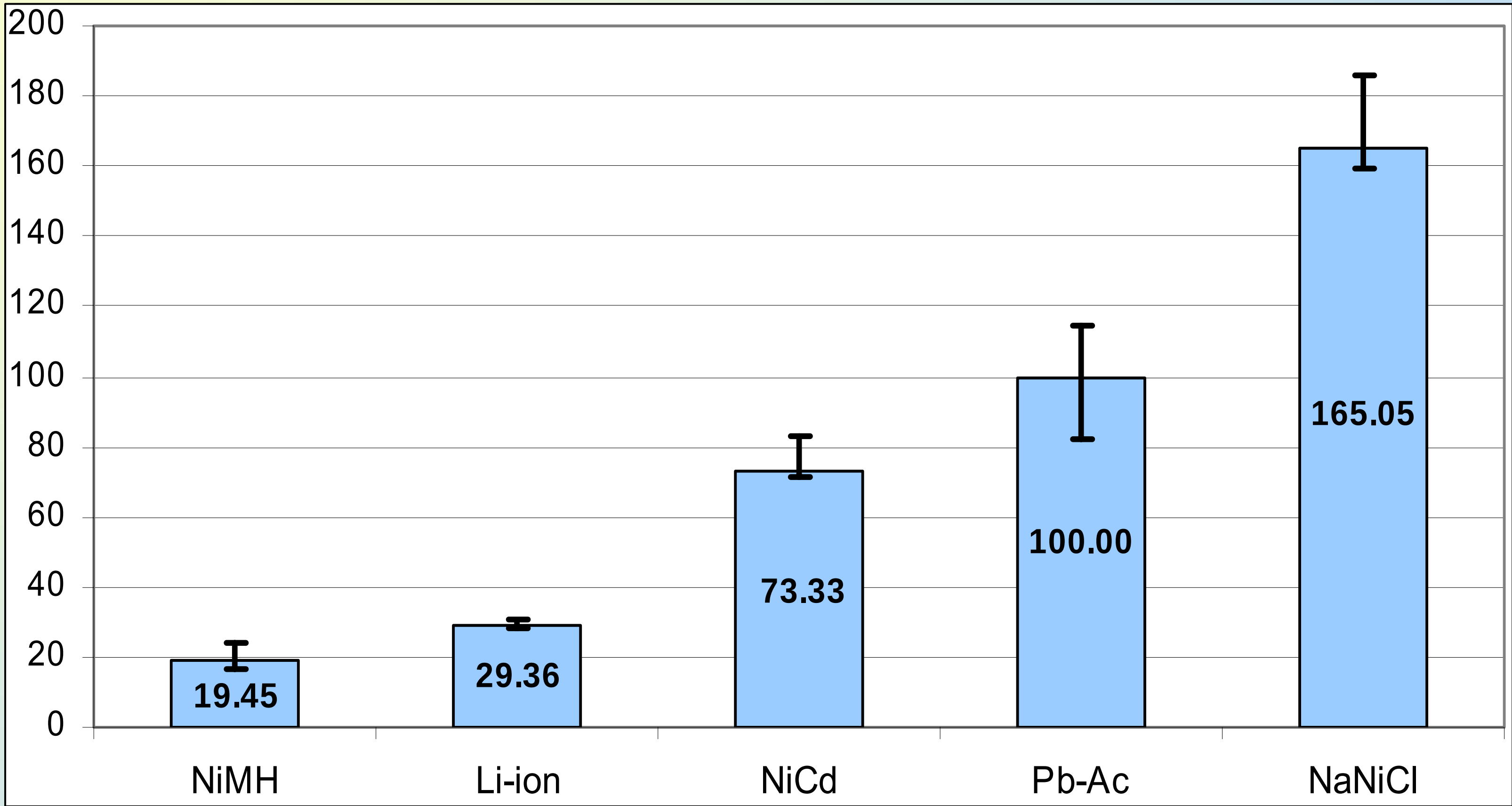
LCA-Functional Unit HEV

21kW

	Specific Power (W/kg)	Relative number of Cycles	Number of Batteries	Mass (kg) of F.U.
Pb-acid	350	1	3	60
NiCd	500	3	1	42
NiMH	1500	3	1	14
Li-ion	2000	3	1	10
NaNiCl	200	3	1	105

Sensitivity analysis HEV

Practically, only NiMH and Li-ion batteries
are considered for HEV applications



LCA Conclusions

BEV:

- Li-ion and NaNiCl
  - Somewhat more environmentally friendly than Pb-acid, NiCd and NiMH (incl. or excl. use phase)
- Impact of the use phase can be decreased by using renewables for electricity production

HEV:

- Li-ion and NiMH
  - Lowest environmental impact

Importance of

- Recycling
- Technical parameters
- Application

WP3: Economical Assessment

Claude Ades

Economical Assessment
Cost and Price of Battery Technologies

Method used

(All 2012 prices in 2004 € with €/$=1.25)

All Costs and Prices are estimated for typical battery packs:

- BEV 30 kWh
- Mild HEV 0.4 kWh, 12 kW (short)
- Full HEV 1.2 kWh, 40 kW (short)

- ***Lead-Acid***
  - 2005 Standard VLRA AGM mean prices (Battery Manufacturers)
  - 2012 Standard VLRA AGM mean prices + evaluation of 7 years increase influence of advanced VLRA techno. and Lead price
- ***NiCd***
  - 2005 Standard energy and power battery mean prices (Battery Manufacturers)
  - 2012 Same prices (2004 €)
- ***$NaNiCl_2$*** (Zebra) only Energy
  - 2005 Standard prices (Battery Manufacturer)
  - 2012 New evaluation of mass production cost, manufacturing cost and price using the world market and Battery Manufacturer data

Economical Assessment
Cost and Price of Battery Technologies

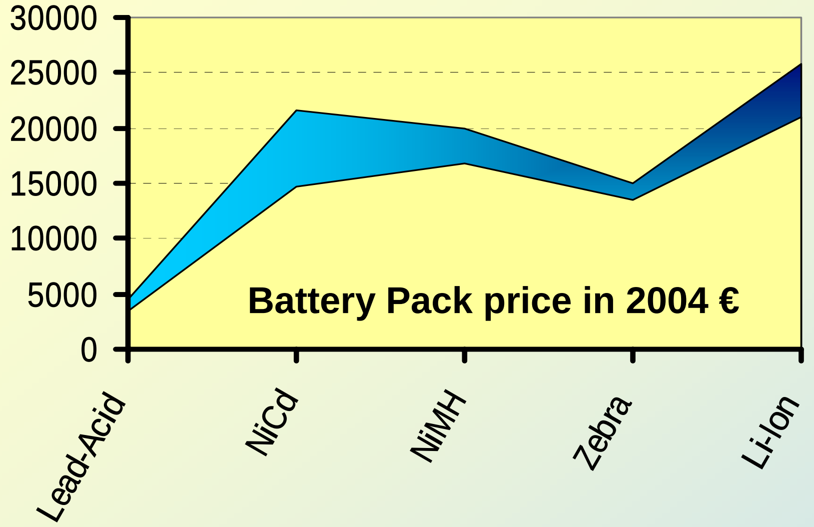
- ***NiMH and Lithium-Ion*** (2005 and 2012)
  - Mean Chemical Composition study vs Energy and Power versions
  - Typical cells for estimation
  - Material prices study in the case of battery mass production
  - Cell cost of goods estimations (power and energy)
  - Cell cost of production
  - Module and/or battery cost of production
  - Accessories costs
  - Manufacturing cost
  - Battery price (mass production)

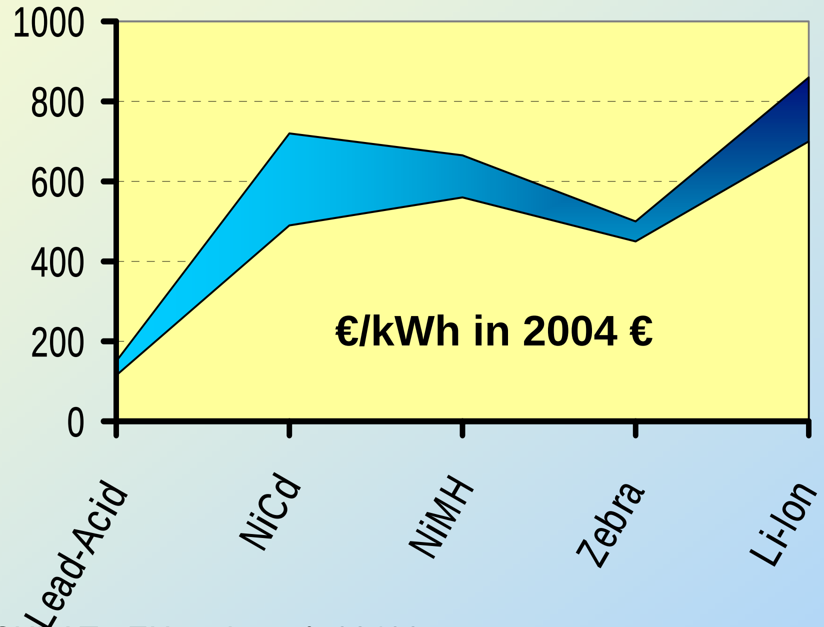
And for all **mass production hypothesis in 2012**

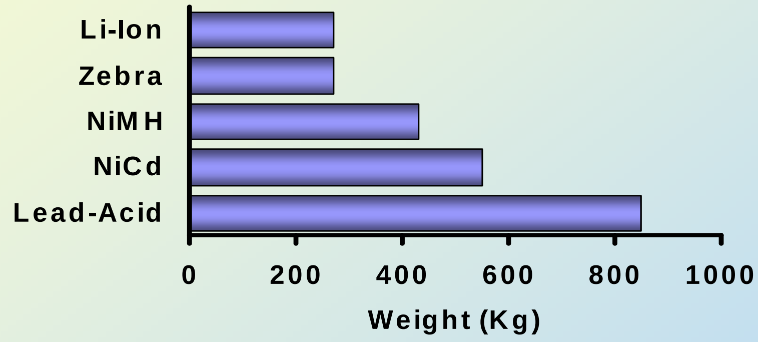
BUT…

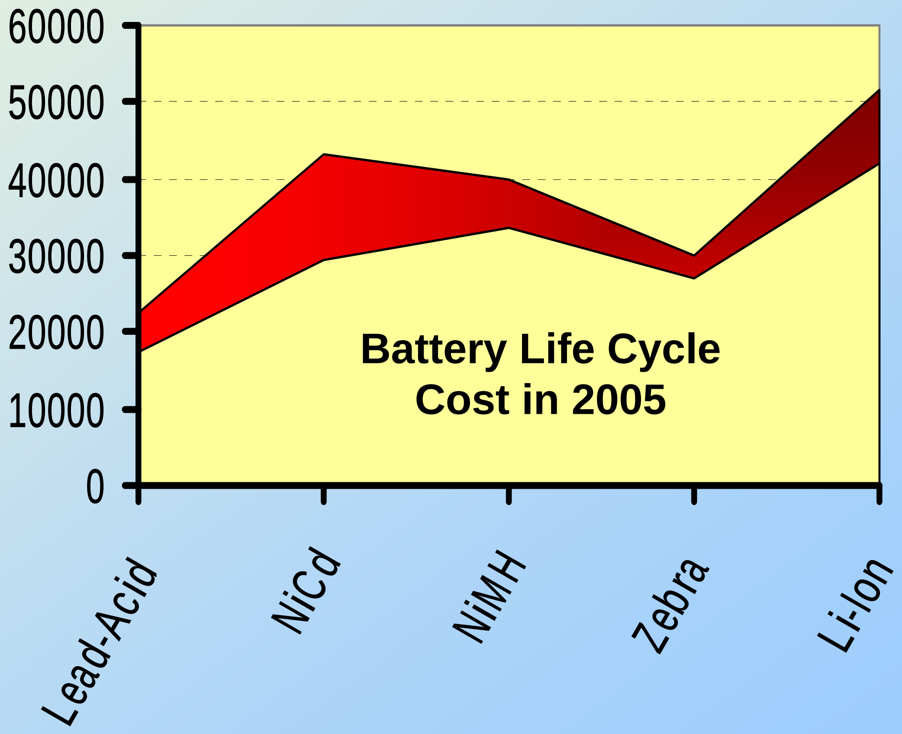
- Prices are not real future prices
- Only a proportional value of production cost
- Influence of the market pressure

BEV Battery of 30 kWh 2005

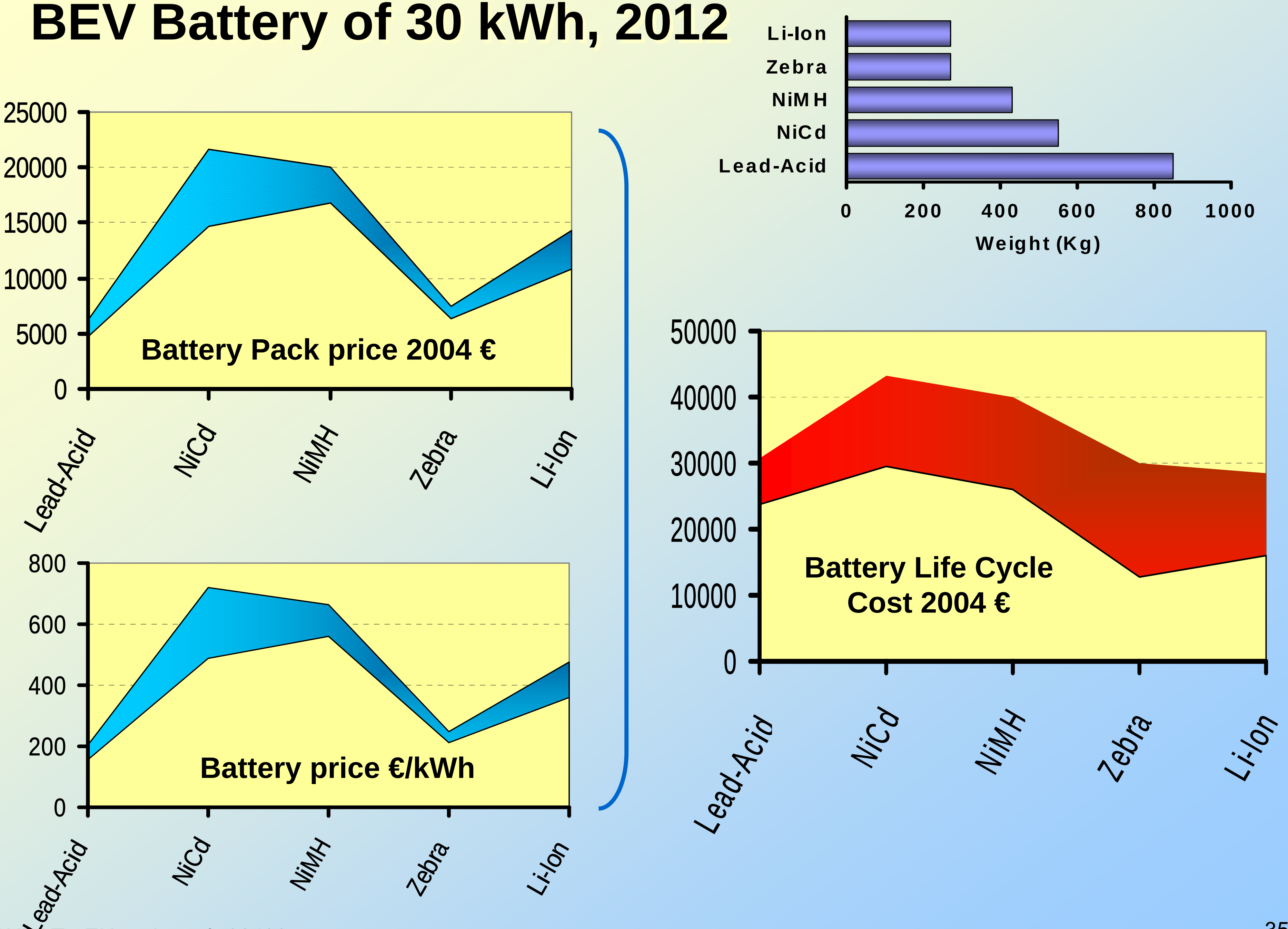




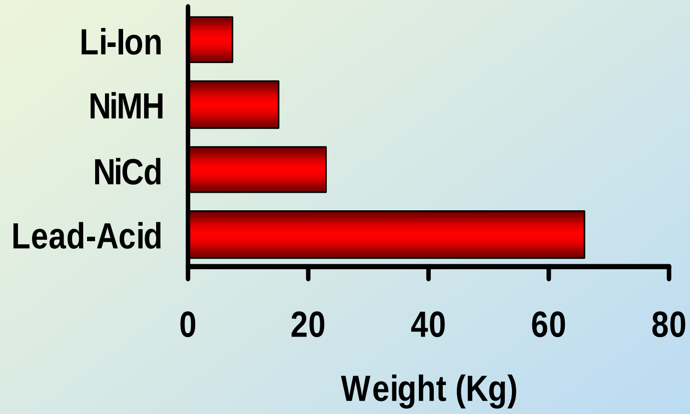


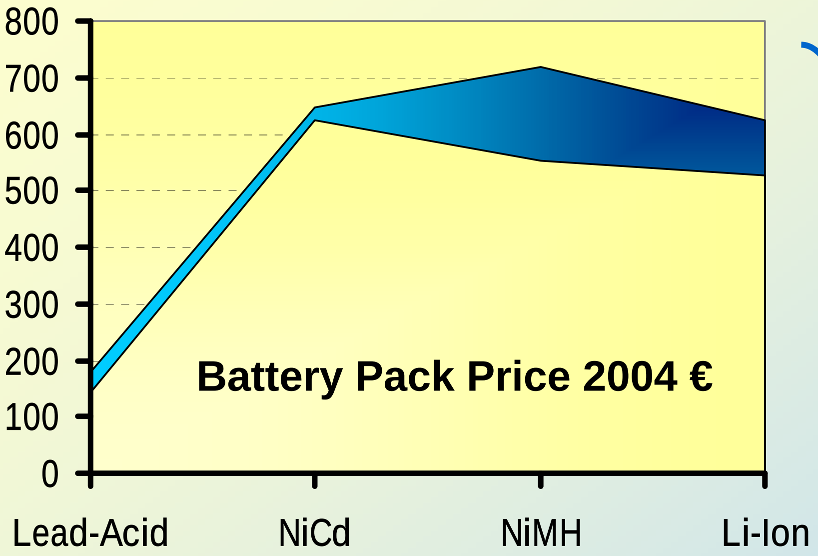


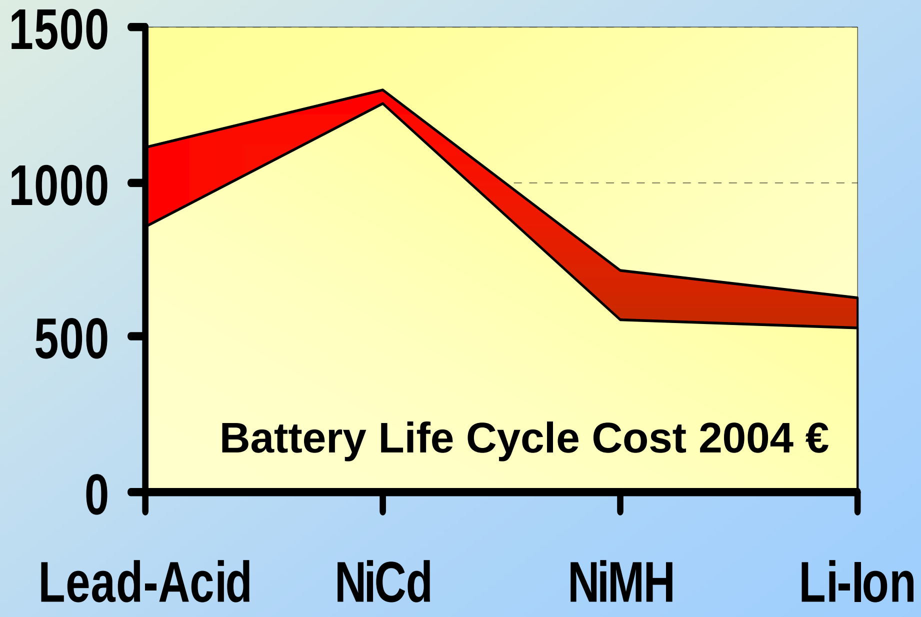
BEV Battery of 30 kWh, 2012

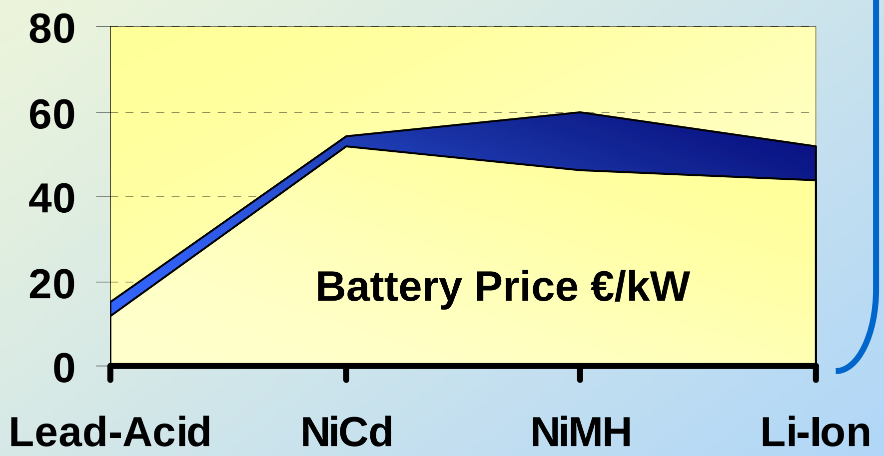


Mild Hybrid Battery (0.4 kWh, 12 kW) 2005

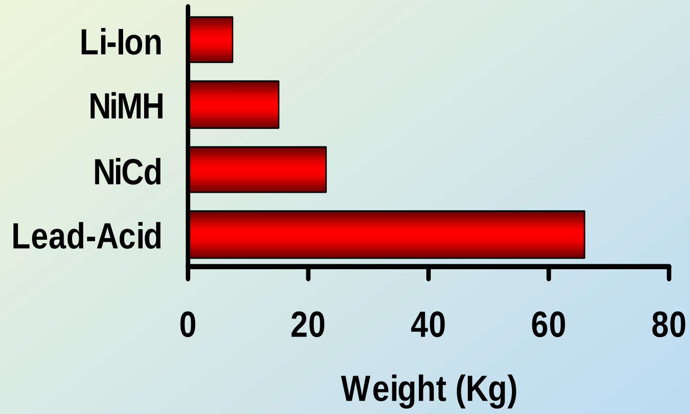


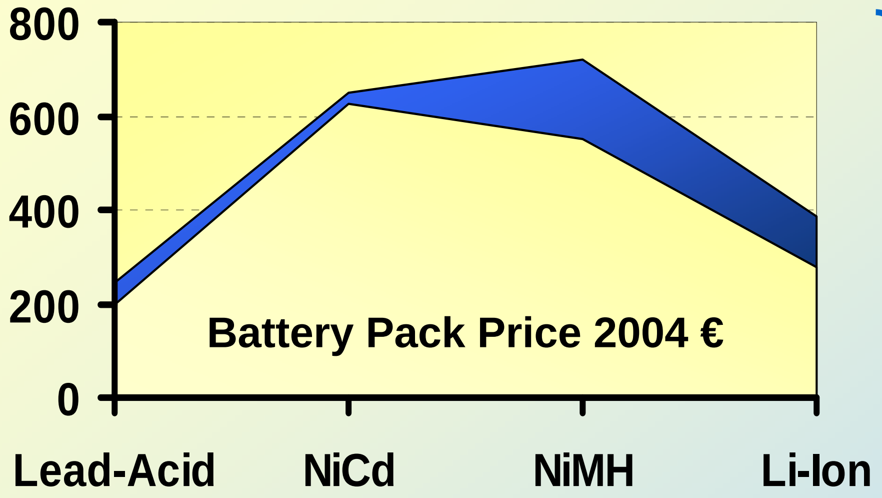


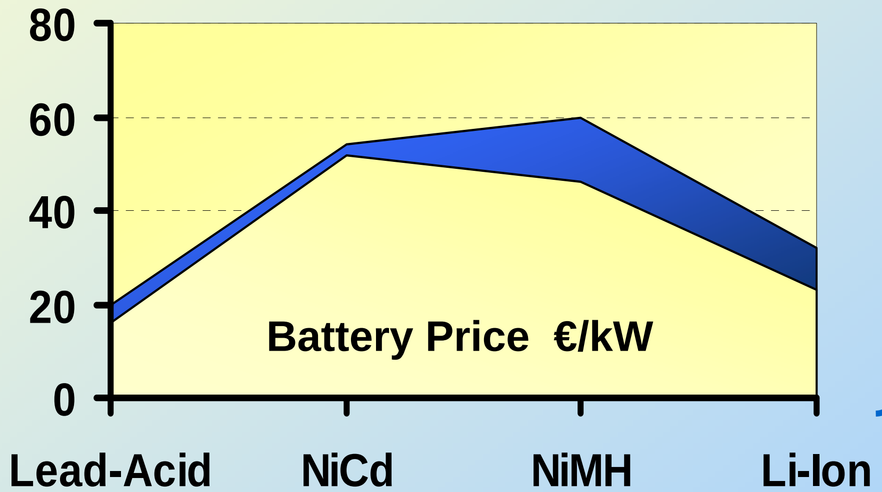


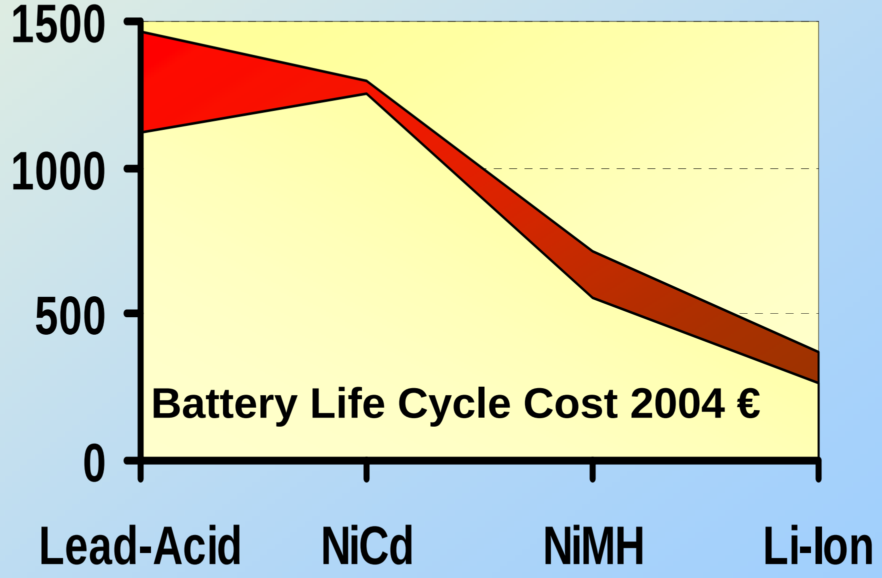


Mild Hybrid Battery (0.4 kWh, 12 kW) 2012

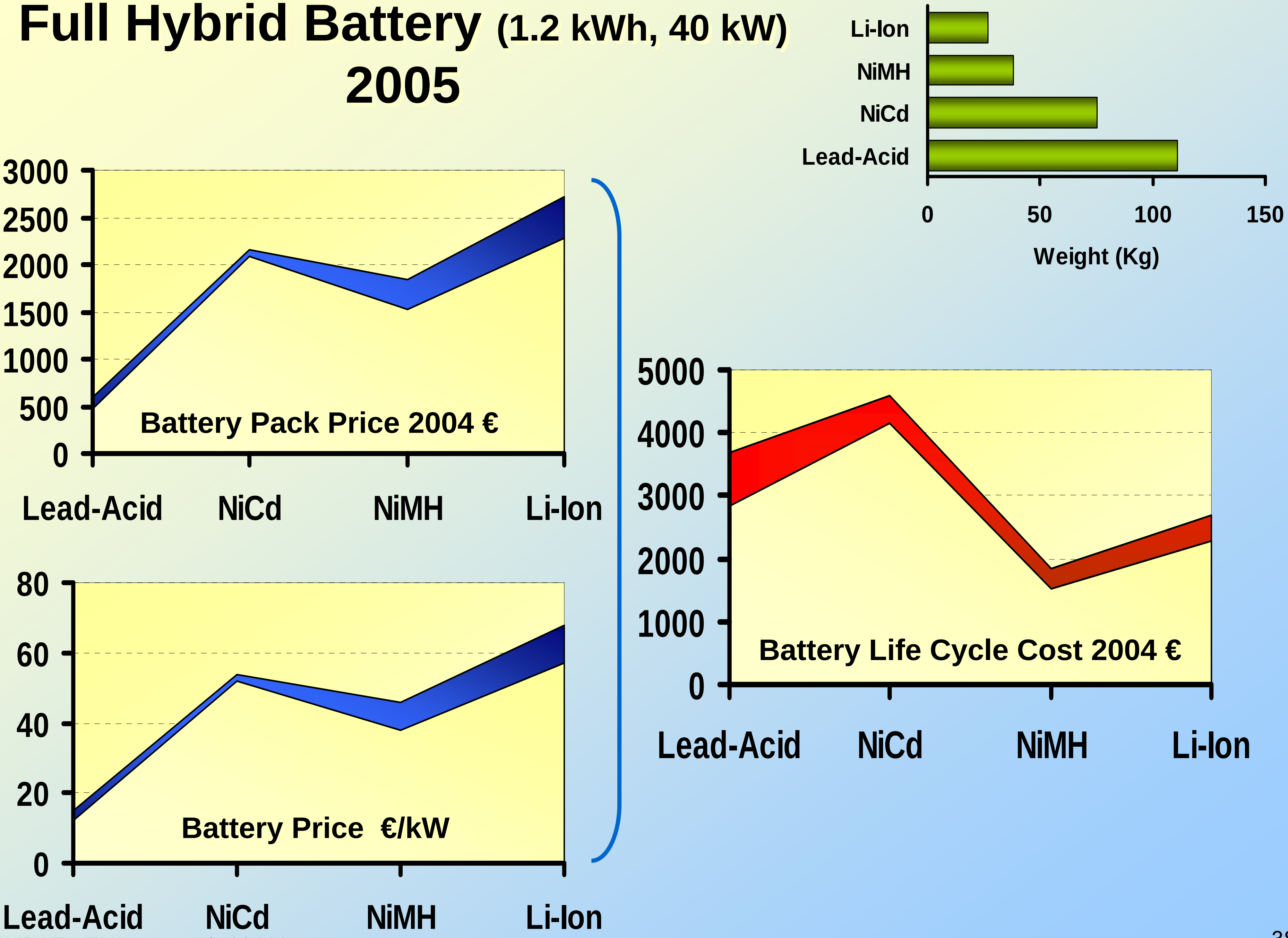




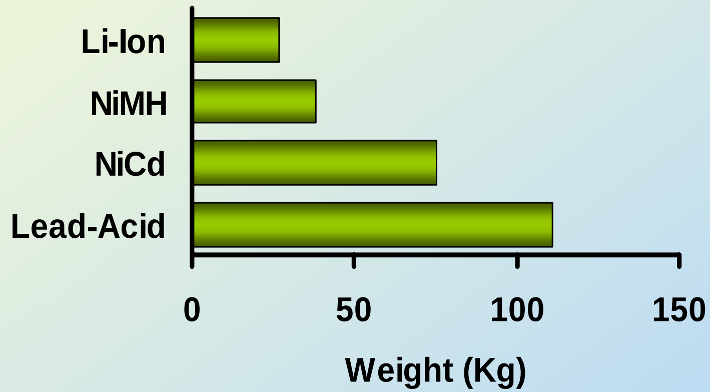


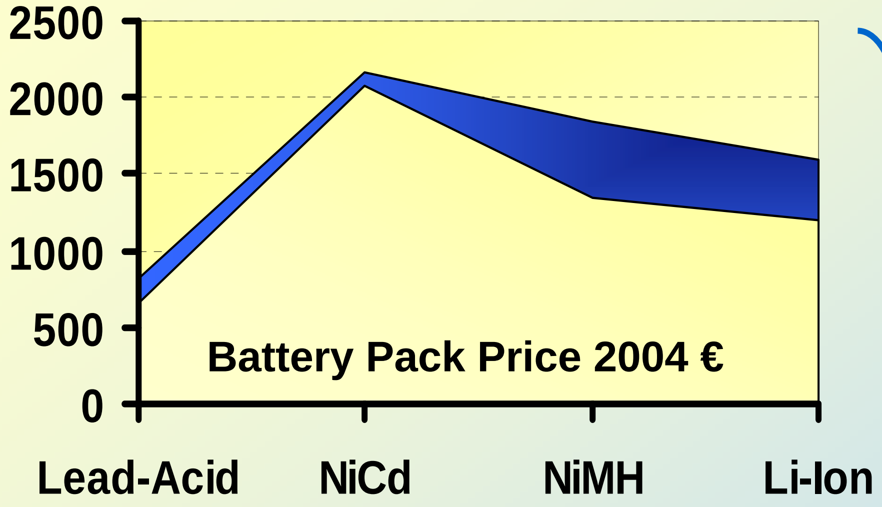


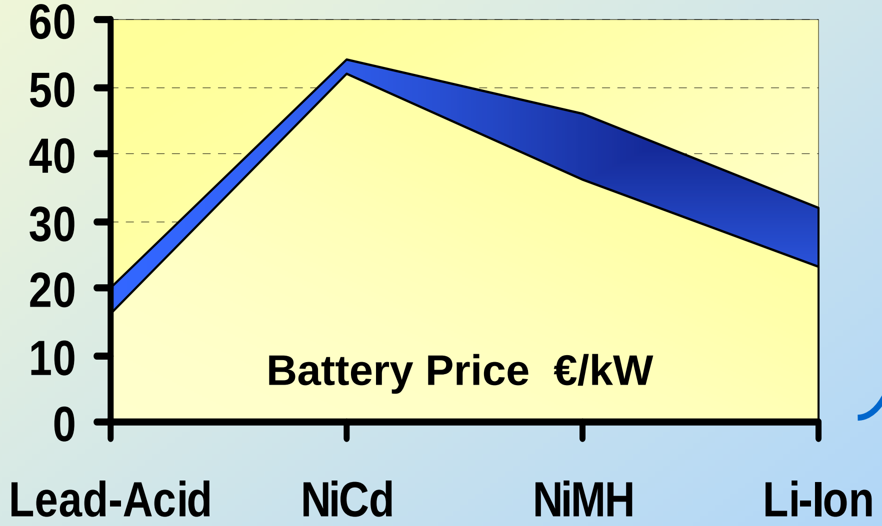
Full Hybrid Battery (1.2 kWh, 40 kW) 2005

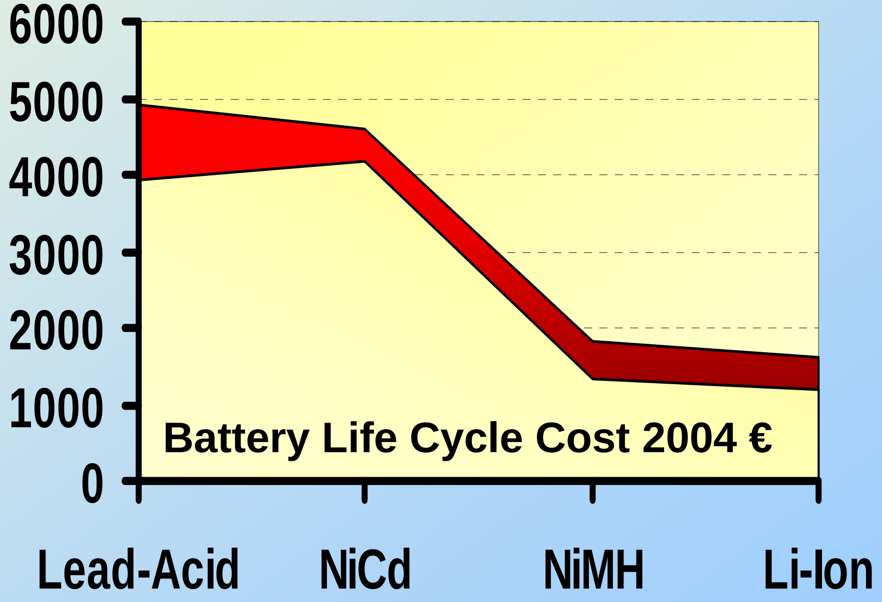


Full Hybrid Battery (1.2 kWh, 40 kW)
2012







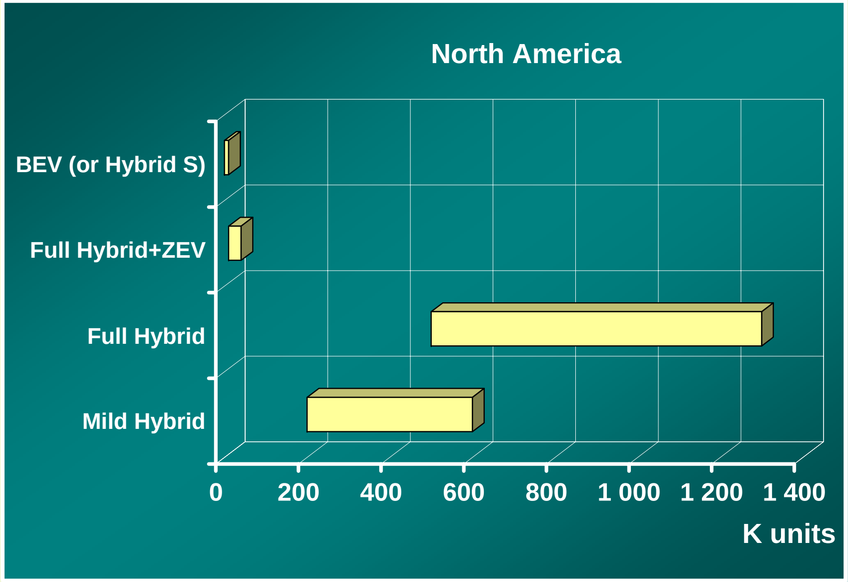


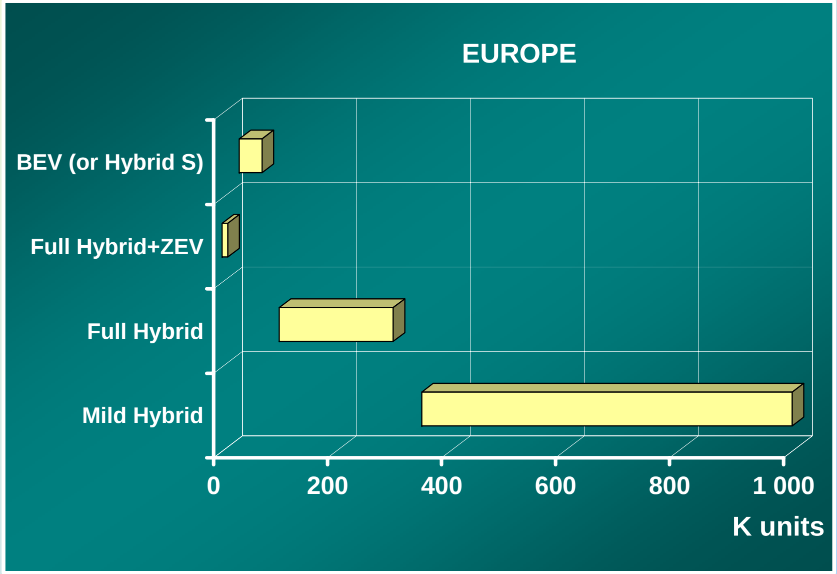
“Traction” Battery Market Study

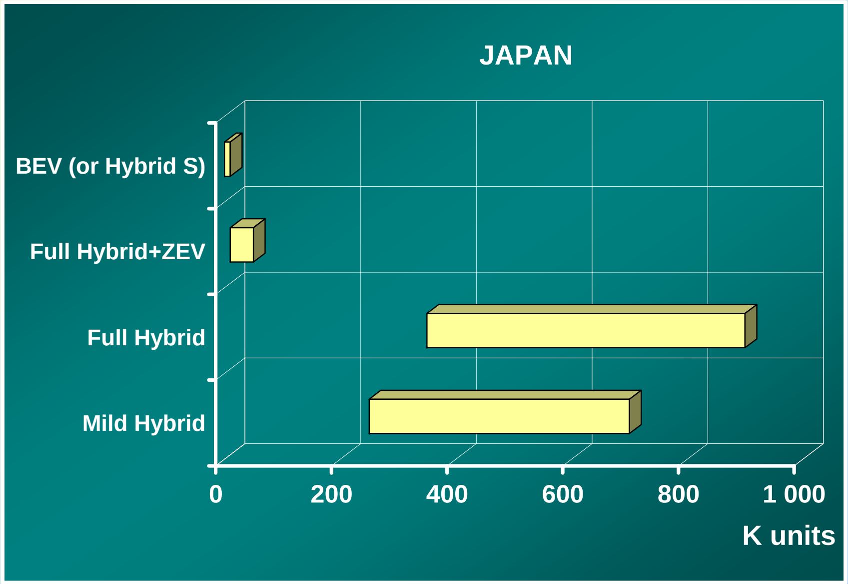
- WP3: Economical Assessment Part II
- What could be the “traction” battery market in 2012 ?

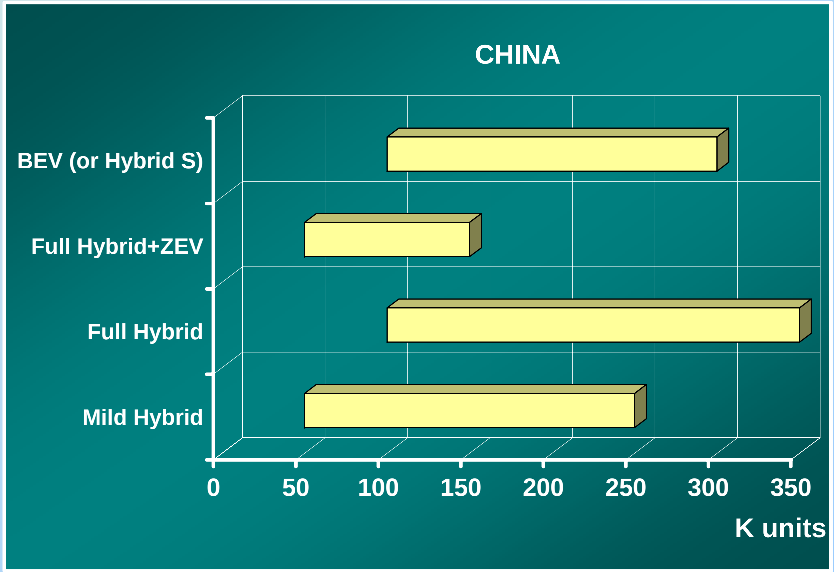
“Advanced” Vehicle World Market in 2012

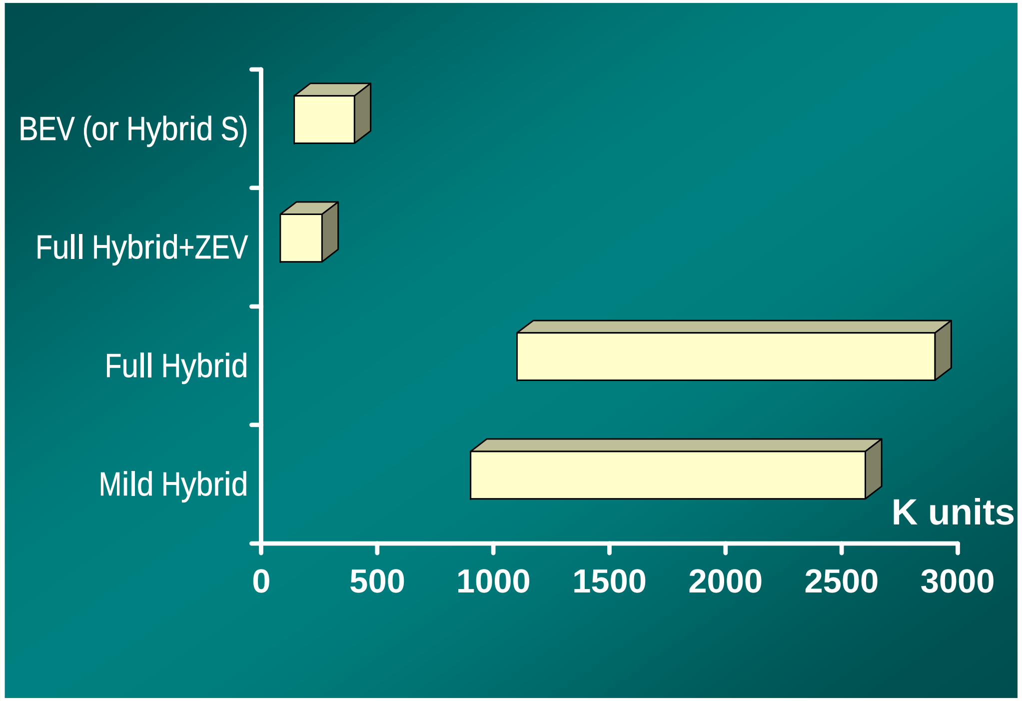
(estimation of passenger car and light duty market)





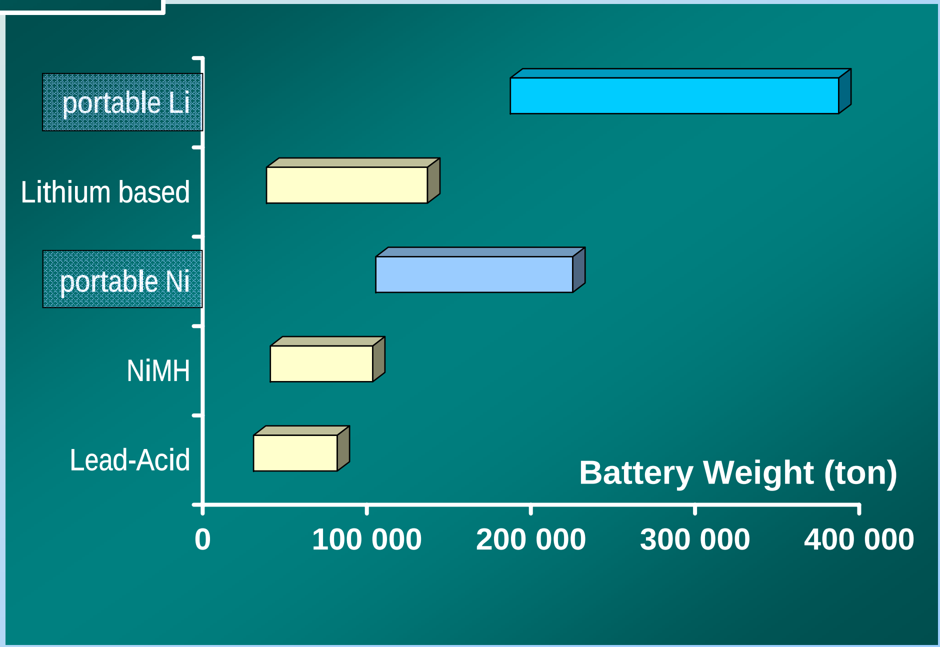






"Advanced" Vehicle World Market in 2012

(estimation of passenger car and light duty market)



Secondary Battery World Market in 2012

("advanced" vehicle market compared to portable one)

WP5: Overall Assessment

Joeri Van Mierlo

Overall Assessment

- Overview and compilation of results of WP1, 2 and 3
  - Technical
  - Environmental
  - Economical
- Qualitative analysis
  - See previous WPs
- Quantitative analysis of
  - 5 battery technologies (Alternatives)
  - 8 parameters (Criteria's)
  - 4 (+1) scenario's
  - 3 perspectives (Weightings)

MultiCriteria Analysis (MCA)

Methodology

PROMETHEE

(Preference Ranking Organisation Method for Enrichment Evaluations)

- Positive preference flows ($\varphi+$ or attractiveness):
  - how much an option is preferred to the others
- Negative preference flows ($\varphi-$ or weakness):
  - how much the other options dominate the option

- PROMETHEE I = partial ranking
- PROMETHEE II = complete ranking (strict ranking)

Overview

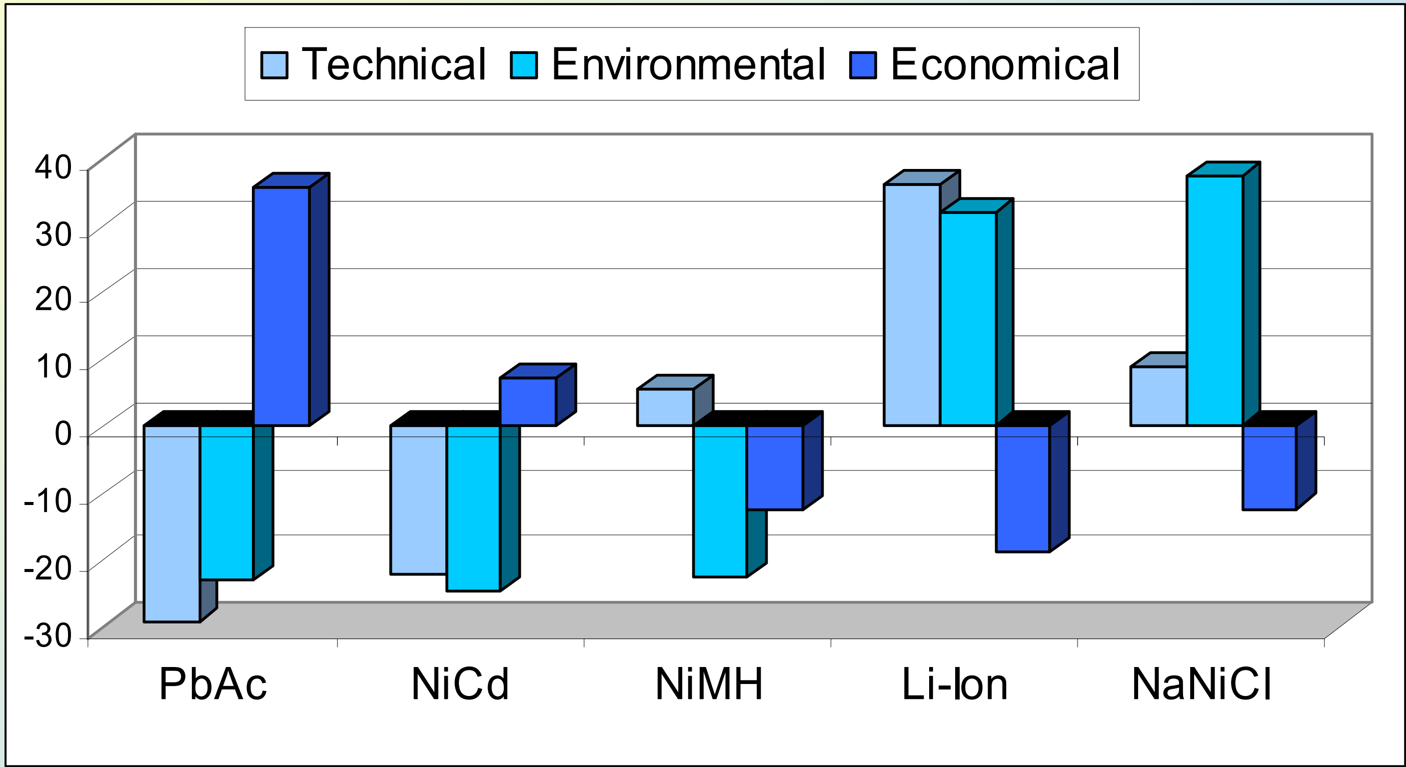
		Scenario's				
		Battery Electric Vehicle		Hybrid Electric Vehicle		Eurobat
		2005	2012	2005	2012	2005
Perspectives	Political	X	X	X	X	X
	Manufacturer	X	X	X	X	X
	Consumer	X	X	X	X	X

Criteria	
Technical	Specific Energy
	Specific Power
	Number of Cycles
	Energy efficiency
Environmental	LCA
Economical	Cost
	Maturity
	User friendliness

Example: BEV 2005 – Politicians

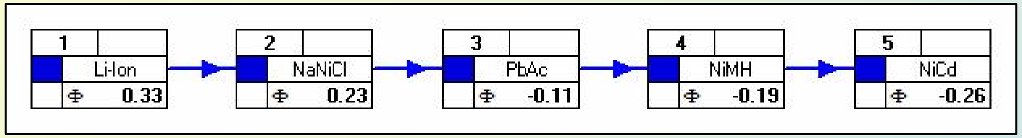
	Technical parameters				Environmental parameters	Economical parameters		
	Energy Density	Power Density	Cycles	Energy Efficiency	LCA	Cost	Maturity	User-friendly
Weights	25	15	5	5	50	30	10	10
PbAc	*40*	*250*	*500*	*83*	*503*	*10085*	*100*	*100*
NiCd	*60*	*200*	*1350*	*73*	*544*	*17355*	*100*	*100*
NiMH	*70*	*350*	*1350*	*70*	*491*	*20254*	*60*	*100*
Li-Ion	*125*	*400*	*1000*	*90*	*278*	*25338*	*60*	*100*
NaNiCl	*125*	*200*	*1000*	*86*	*234*	*17109*	*80*	*60*

Results: Comparison BEV 2005

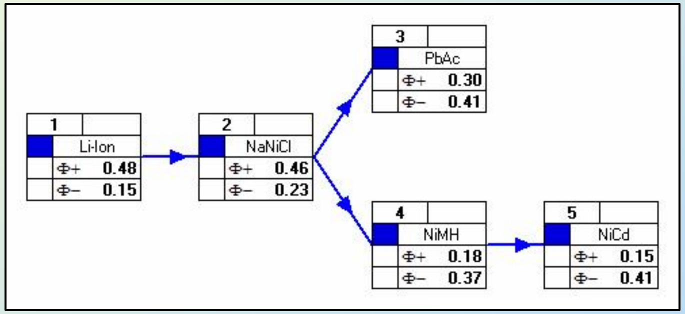


Results for BEV 2005

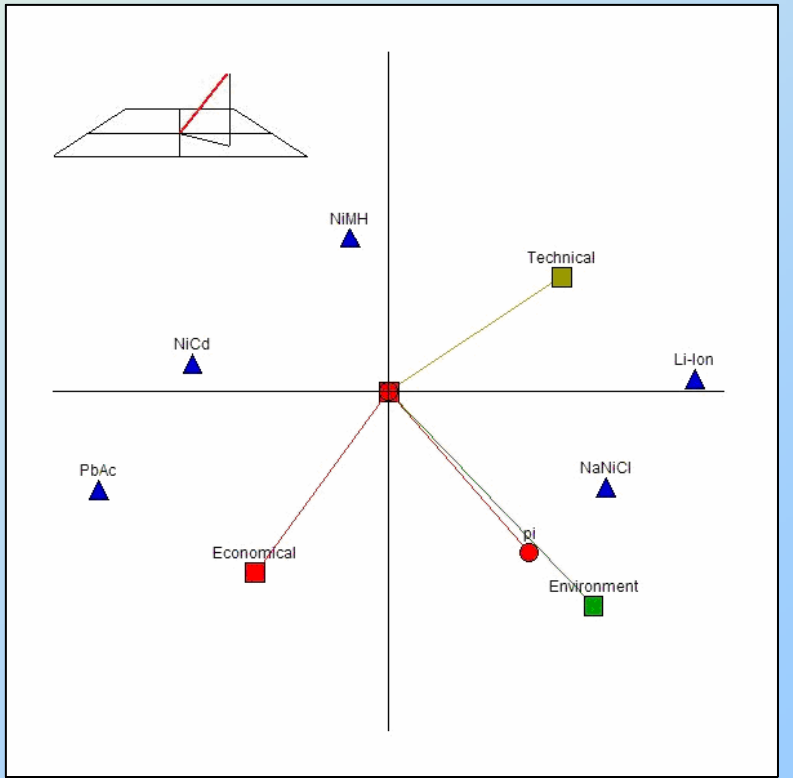
- Complete Ranking PROMETHEE II



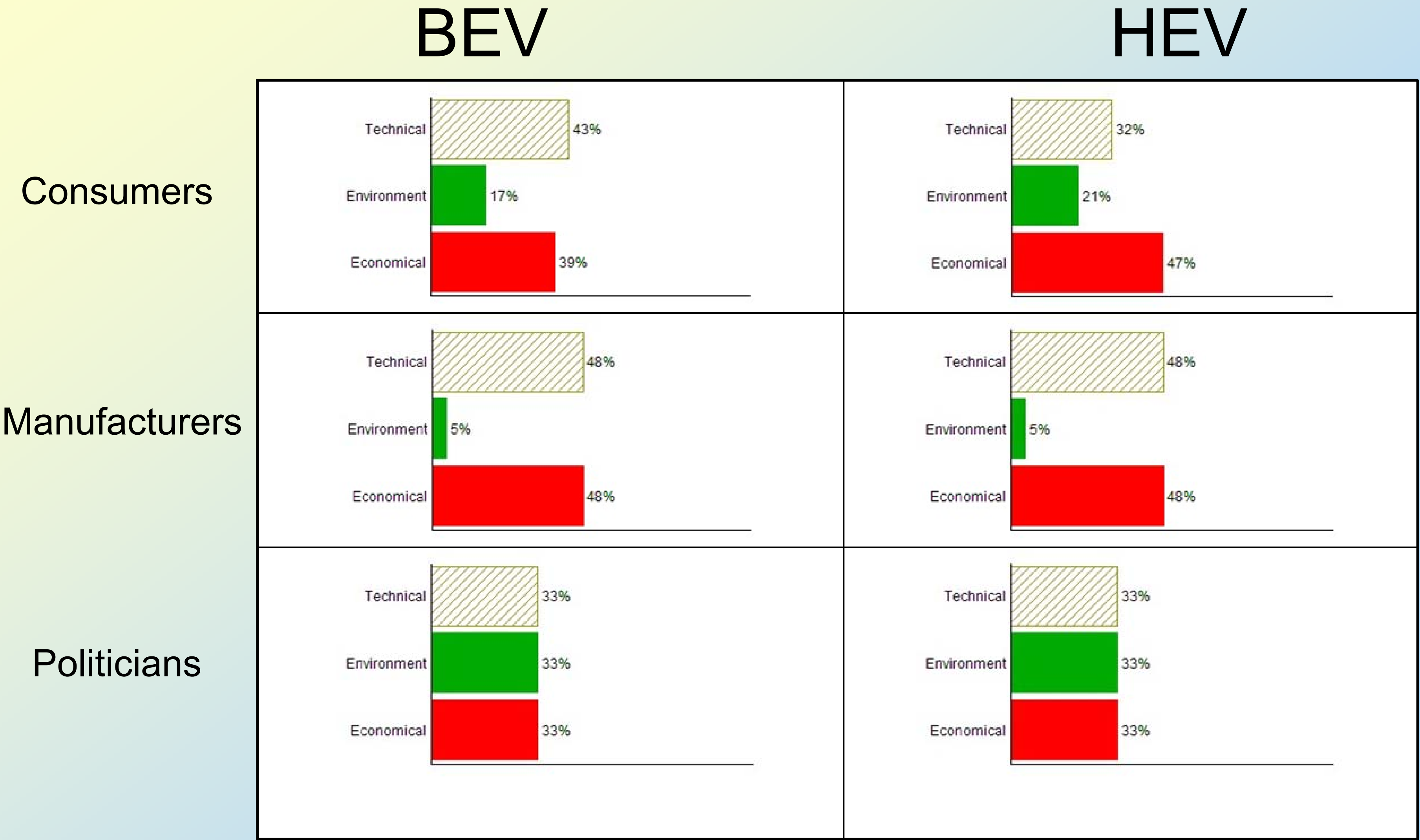
- Partial Ranking PROMETHEE I



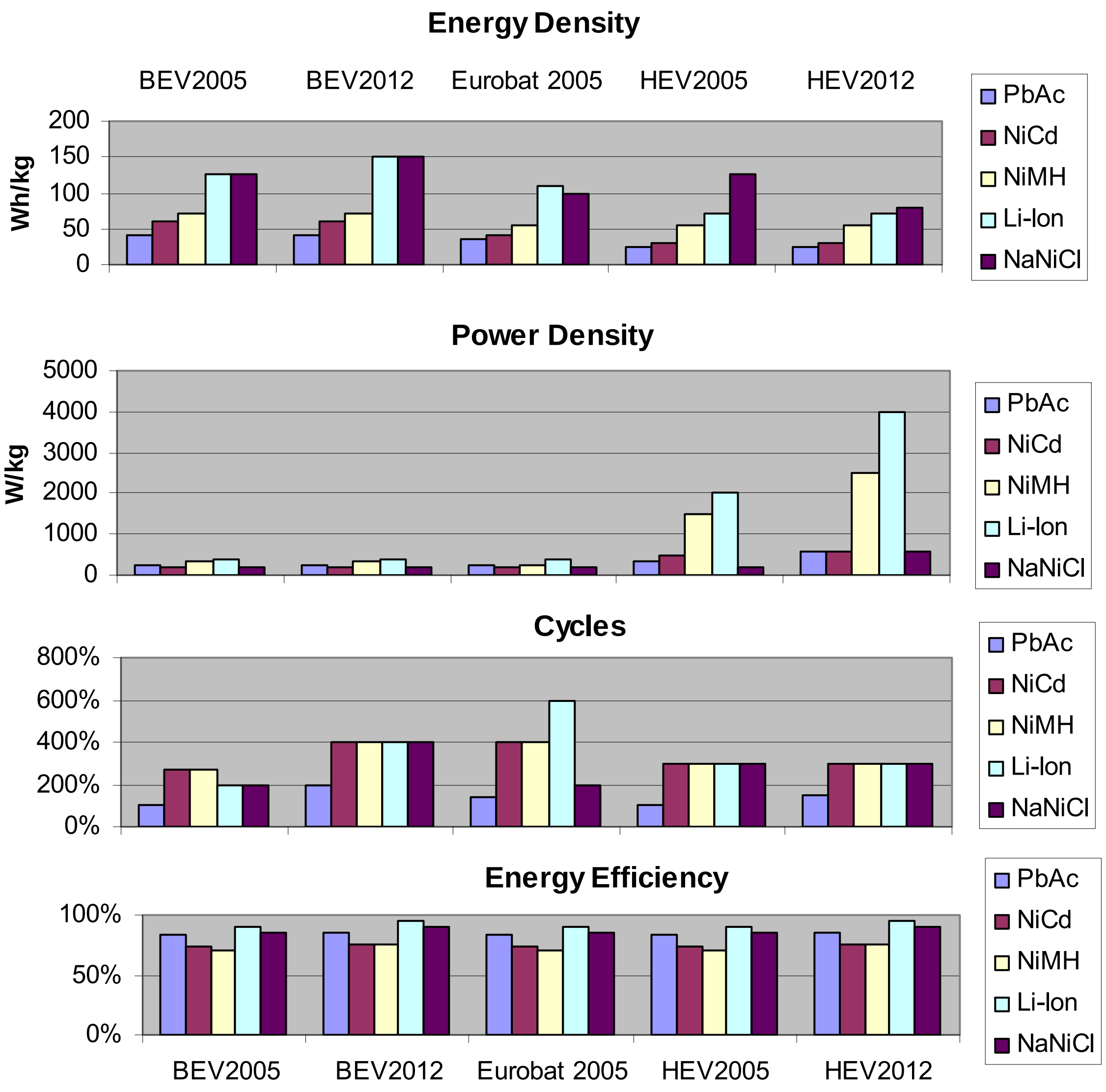
GAIA plane



Perspectives - Weighting



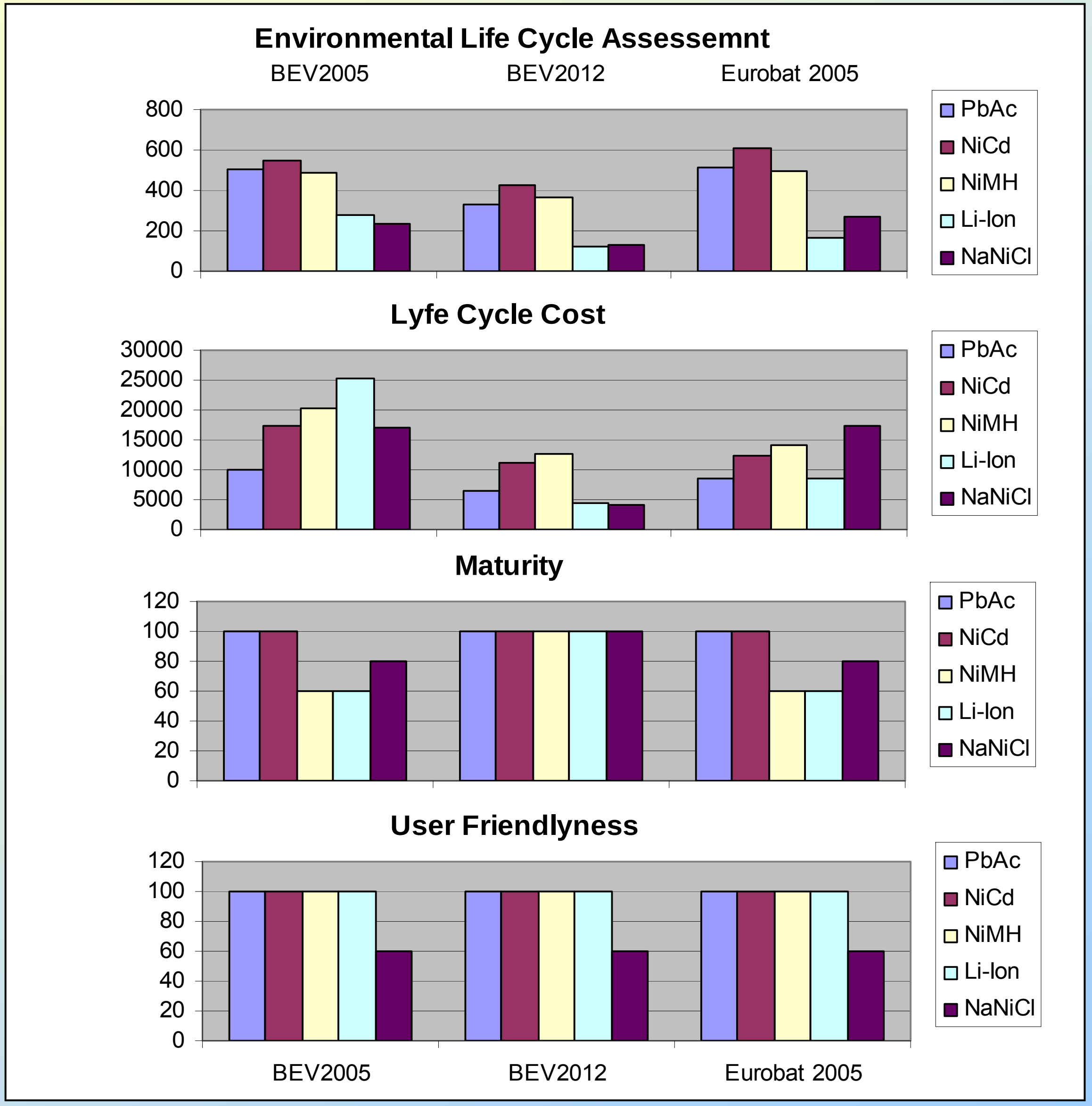
Criteria: Technical Parameters



BEV: relative values cycles (ref: Pb-acid = 500 cycles)

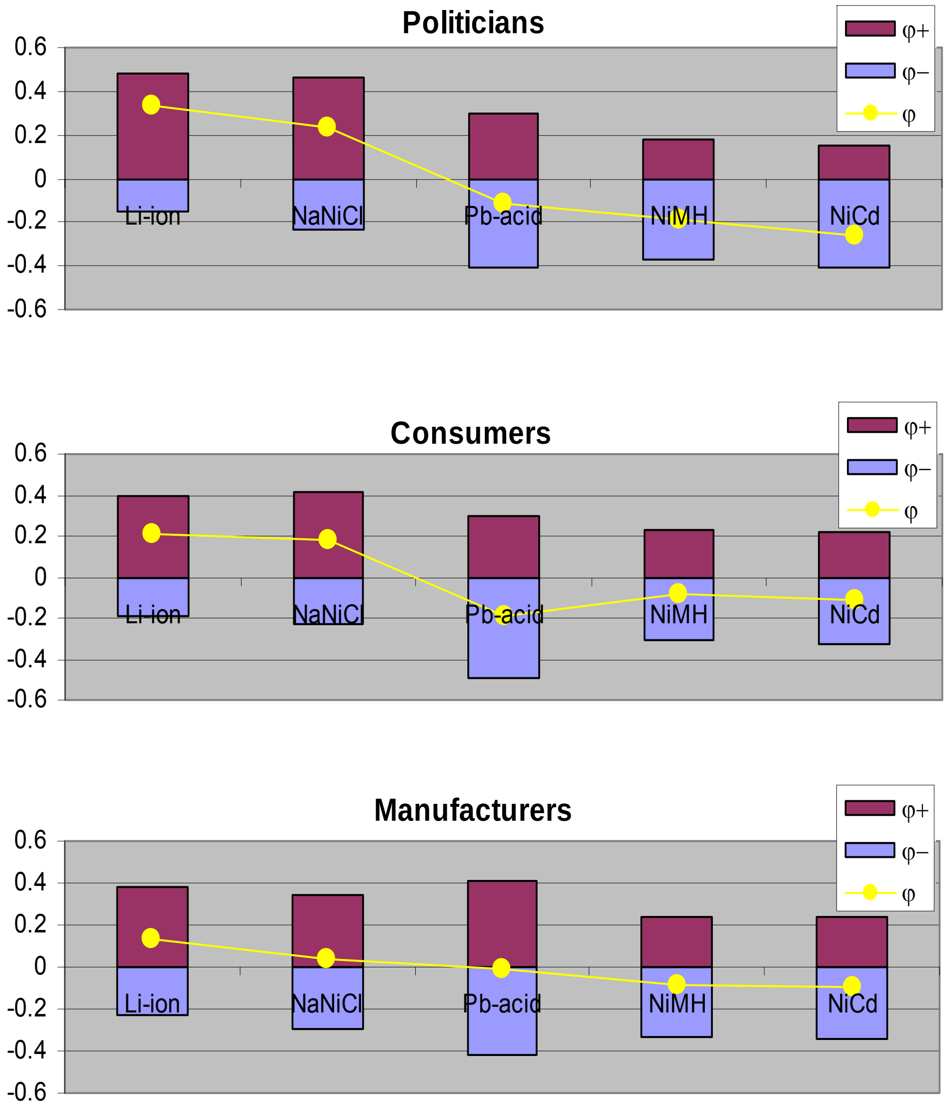
HEV: relative values cycles (ref: Pb-acid = 100%)

Criteria: Envir. & Econ. Parameters

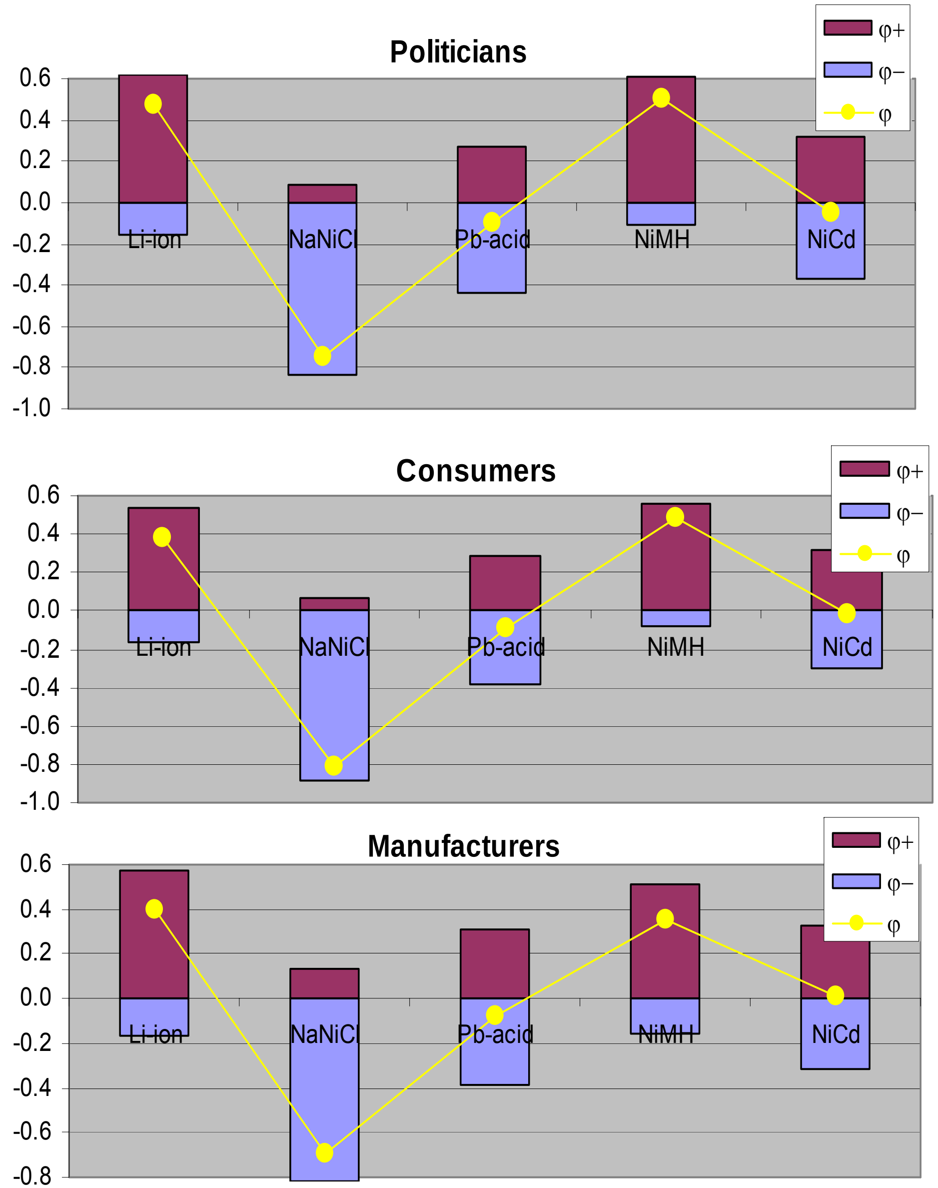


Conclusions Overall Assessement

Battery Electric Vehicle 2005

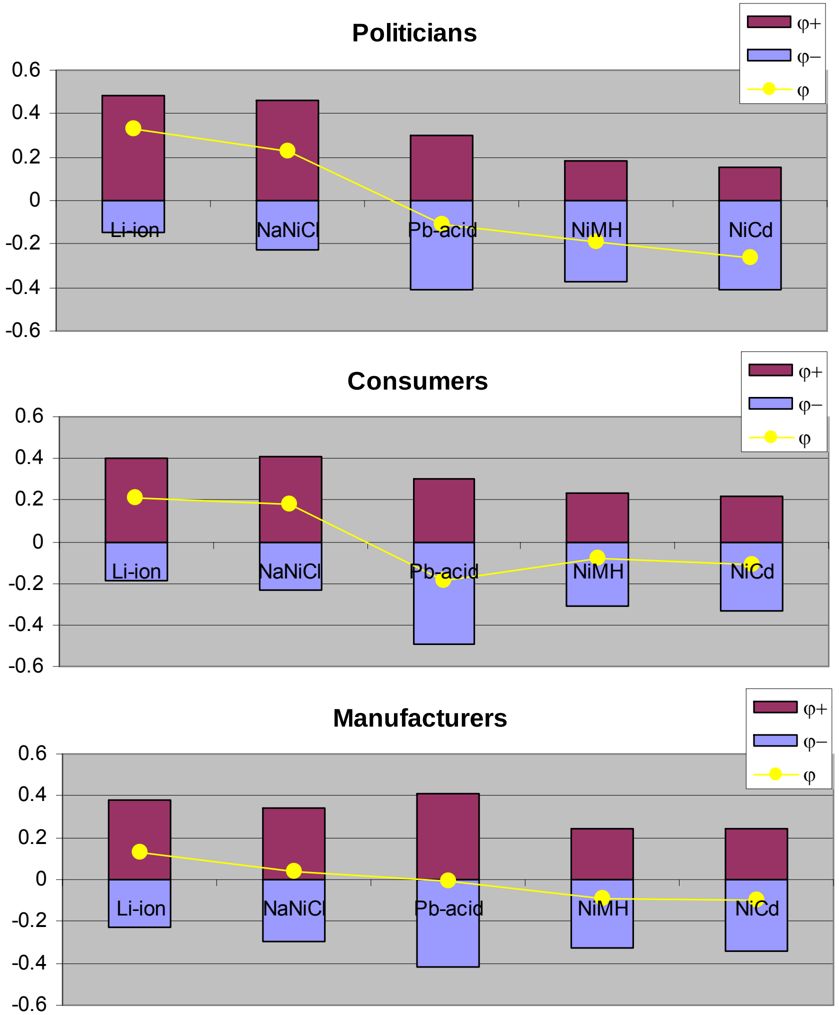


Hybrid Electric Vehicle 2005

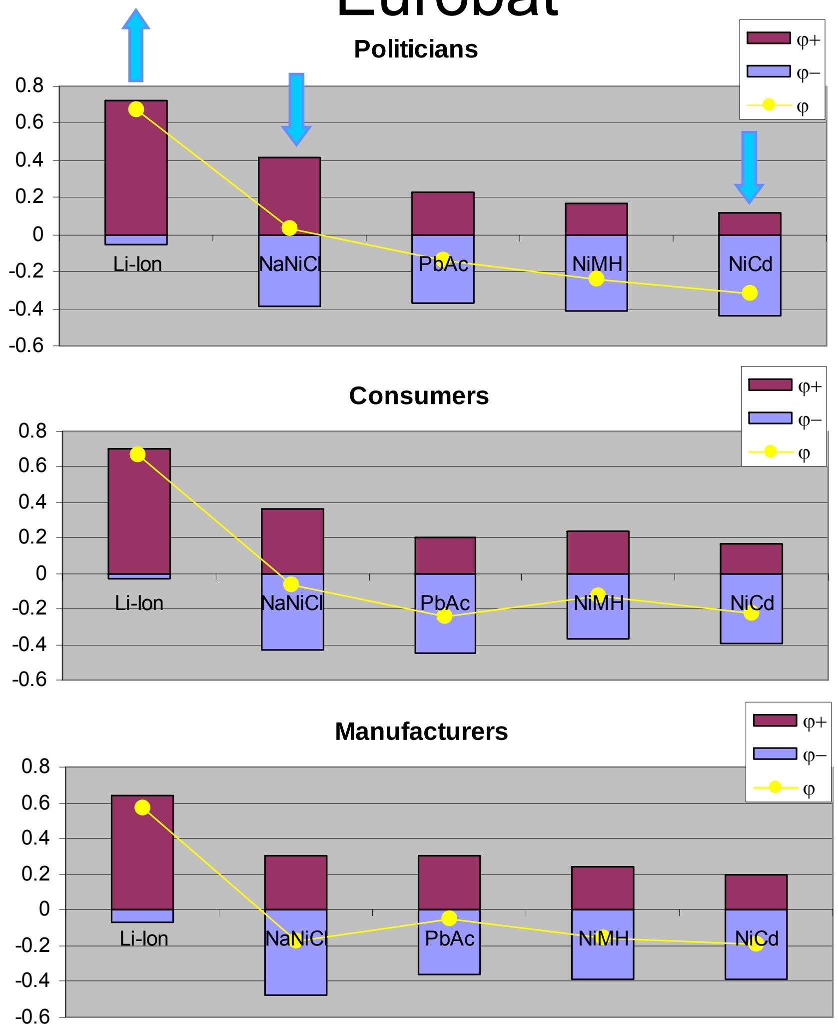


Conclusions Overall Assessement

Subat



Eurobat



MCA results remain consistent independently of the chosen perspective

Conclusions

Conclusions

- Technical assessment
  - Li and NaNiCl best performance
- Environmental assessment
  - Li and NaNiCl lowest environmental impact
  - Cd fatal production issue
- Economical assessment
  - Pb cheapest battery for long time
  - Li price decrease potential

Conclusion

Depends on the Chinese Market

The cheapest for a long time

Depends on Lithium price and performances

	Soft Hybrids	Mild Hybrids	Full Hybrids&Full Hybrids+ZEV	BEV&Series Hybrids
Very Light Vehicles (e-bike etc)				Lead-Acid (short term), NiMH & Lithium based
Light and Light Duty Vehicles	Lead - Acid	Lead-Acid, NiMH, Lithium based	NiMH, Lithium based	NiCd (short term), Lithium based
Heavy Vehicles	Lead - Acid	Lead-Acid, NiMH, Lithium based	NiCd or Lead-Acid (short term), Lithium based or NiMH	NiCd or Lead-Acid (short term), Lithium based
Fleets	Lead - Acid	Lead-Acid, NiMH, Lithium based	NiCd or Lead-Acid (short term), Lithium based or NiMH	Lead-Acid, ZEBRA

Lithium based if.....

Fleet

Lithium based has the best potential for 2012

Starting with Lead-Acid for price reasons

More info

(public report and presentation)

http://www.battery-electric.com

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