Rechargeable batteries bridging the gap between the smart grid and electrical vehicles

Peter H.L.Notten[1,2]

[1] Eindhoven University of Technology, Netherlands
[2] Forschungszentrum Jülich, Germany

p.h.l.notten@tue.nl
p.notten@fz-juelich.de

Present-day Energy Chain

Power plant

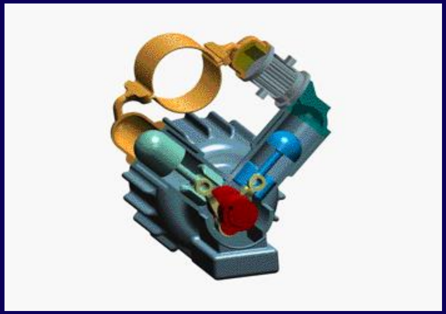
Future Sustainable Energy Chain

Power plant

Wind

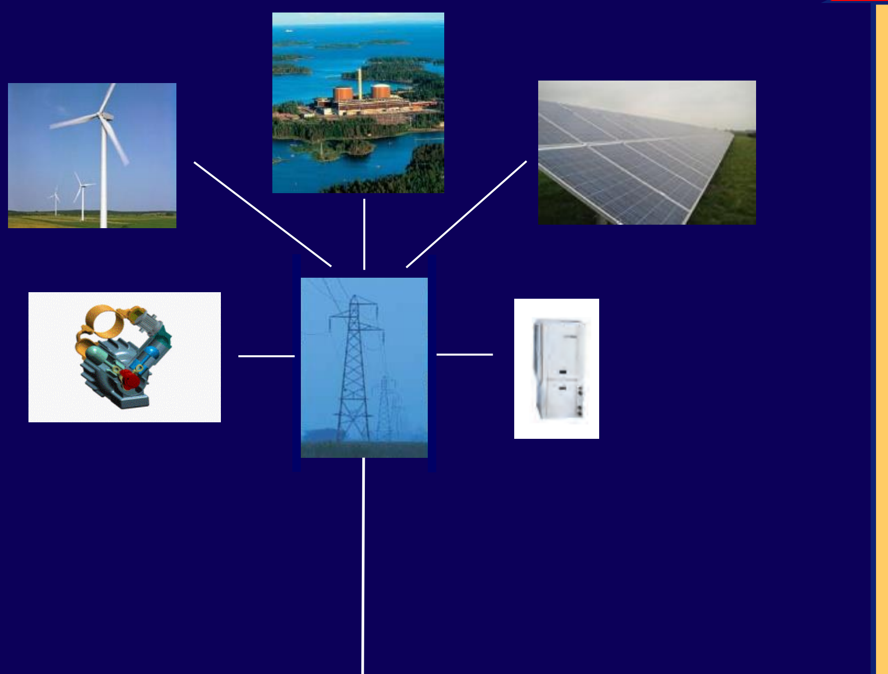
Solar

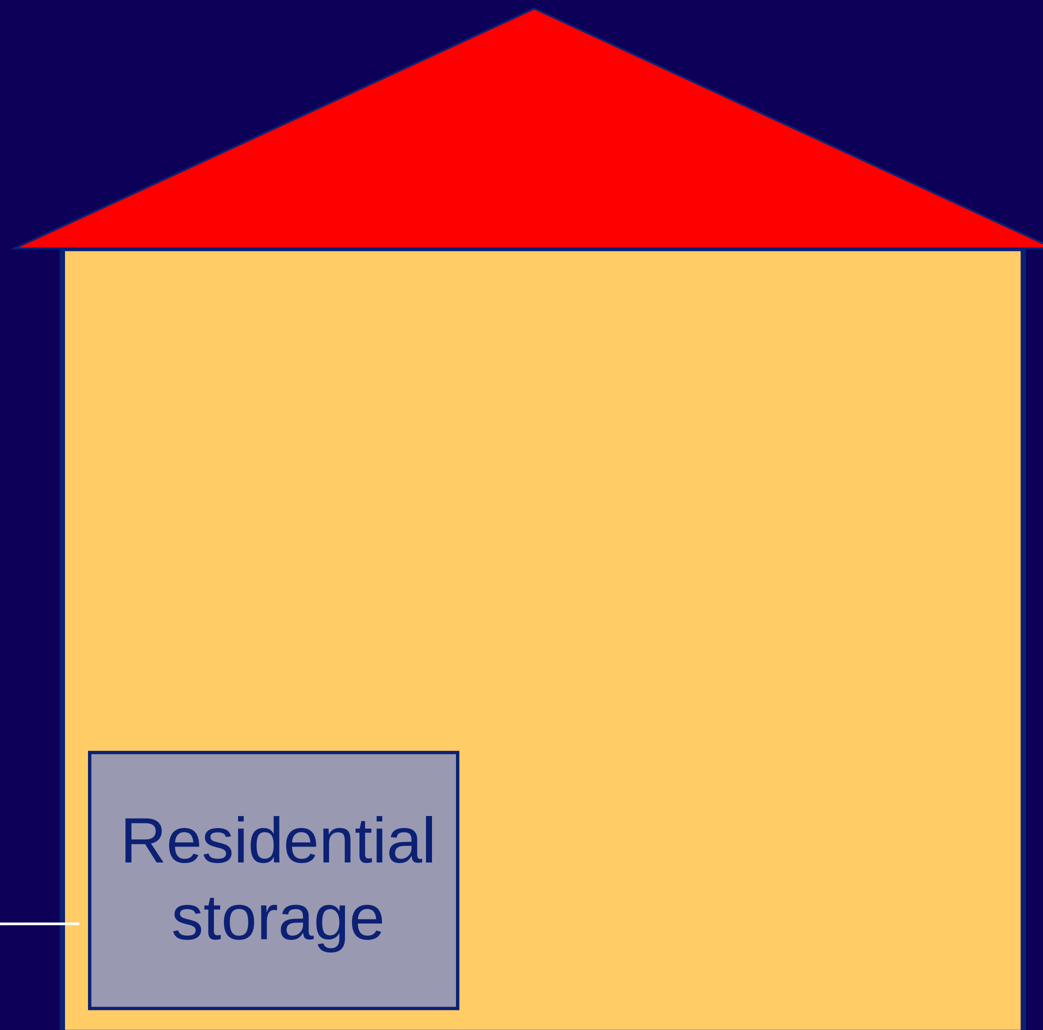
µ-Heat-Power



Heat pumps

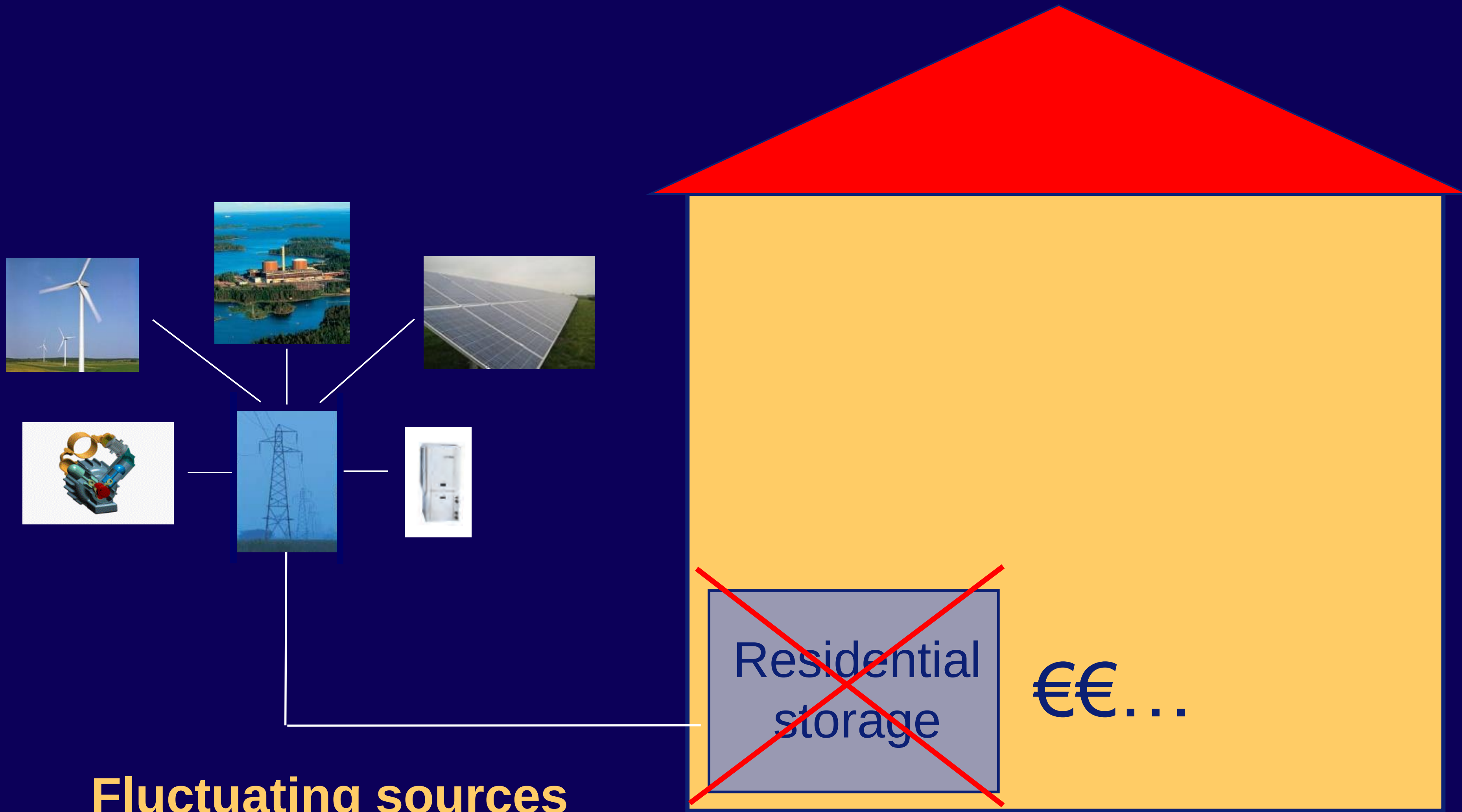
Residential Storage





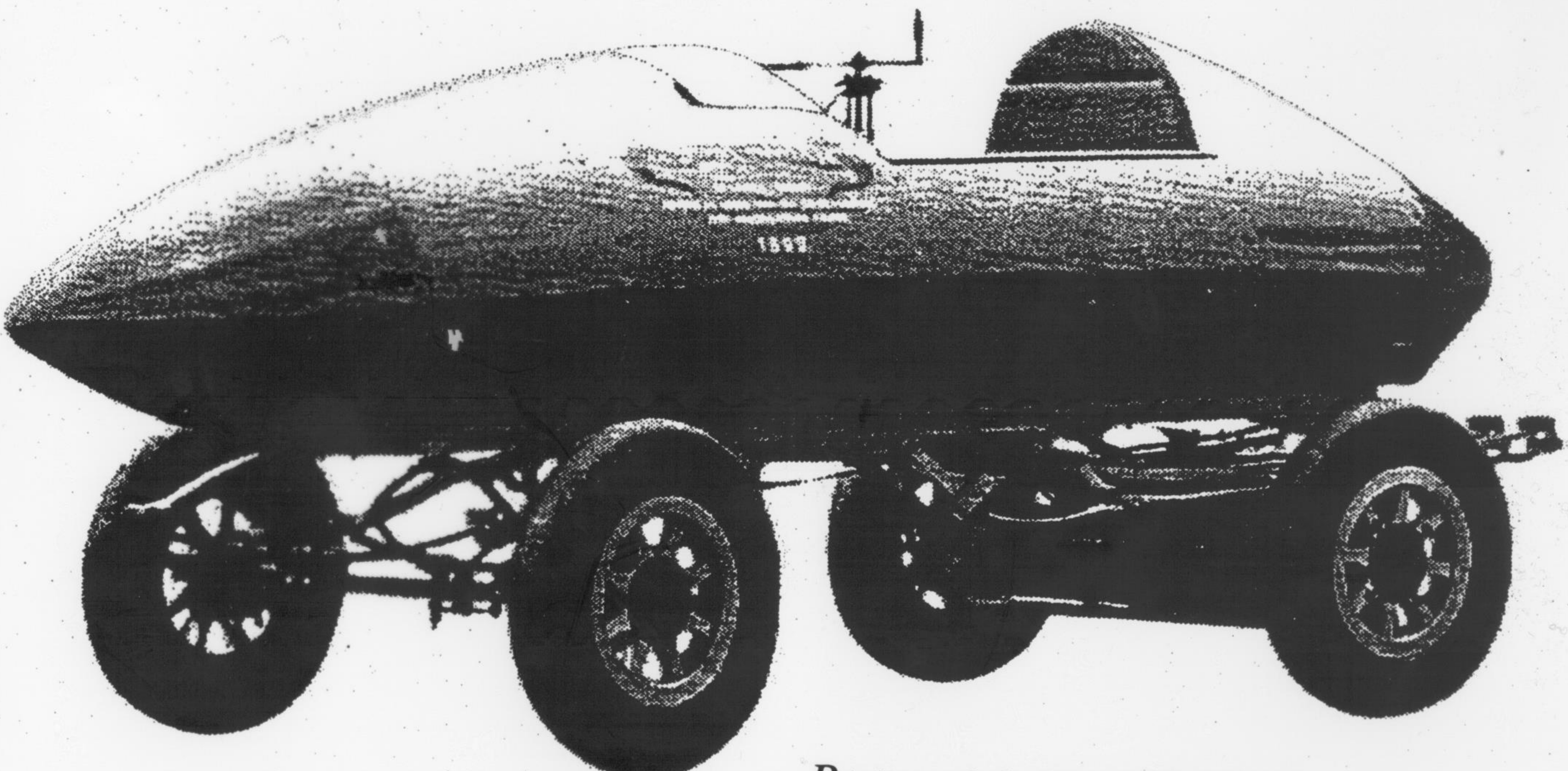
Fluctuating sources
Require ~20% storage…!

Residential Storage



Fluctuating sources
Require ~20% storage…!

“Electrical vehicles”: The dream

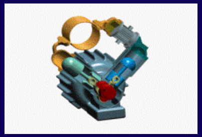


Réplique de la "jamais Contente"

La jamais Contente, 1ère voiture électrique construite en 1899 par Jenatzy

Smart Grid



Eureka…!

“Residential storage” in Electrical Vehicles

Electricity storage

Physical

- Super-capacitors
- Pseudo-capacitors

Electrochemical

- Batteries
- Redox-flow cells
- Metal-air systems

Physical storage in (Super)capacitors

Based on Electrochemical double layers

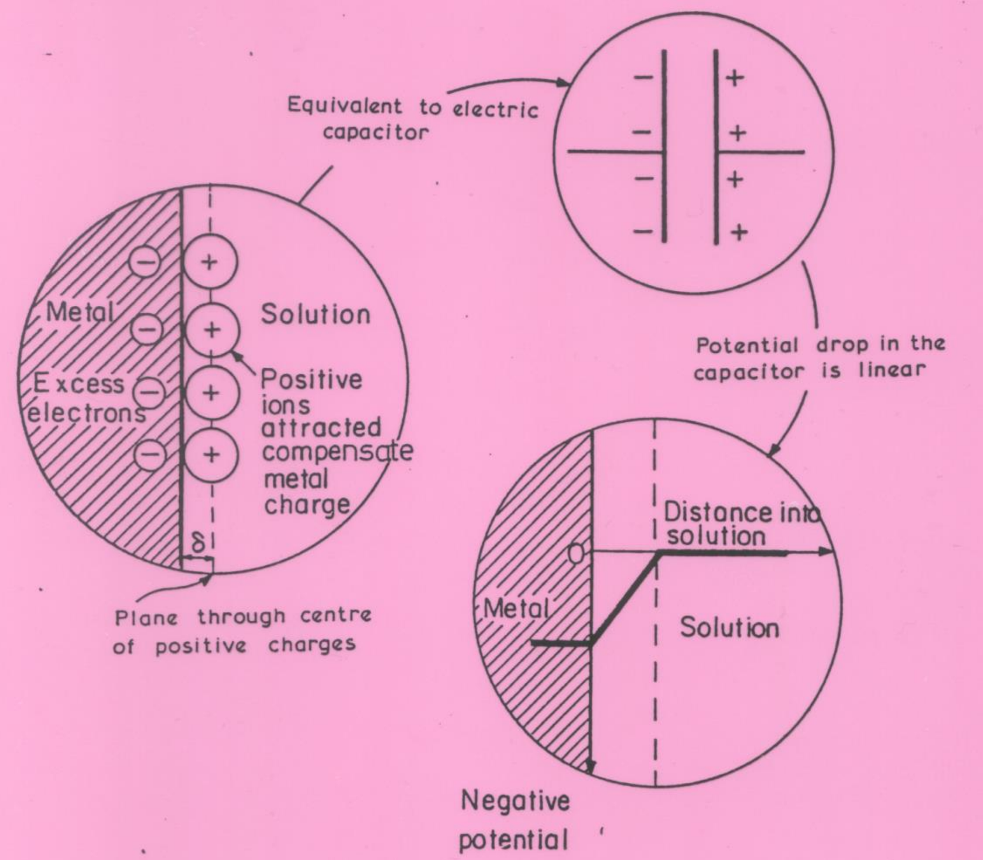


Fig. 2.2. The simplest-imaginable double layer.

$$C = \frac{\varepsilon \varepsilon_o A}{d}$$

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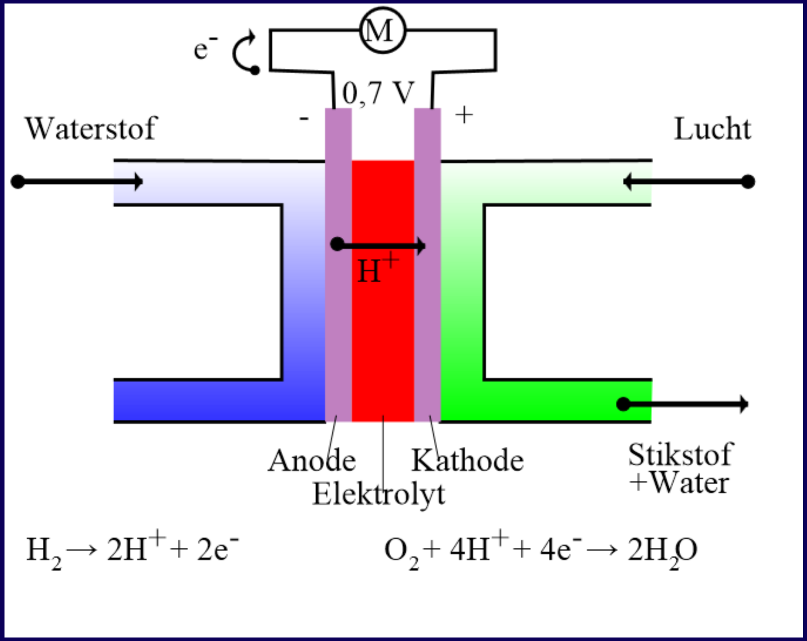
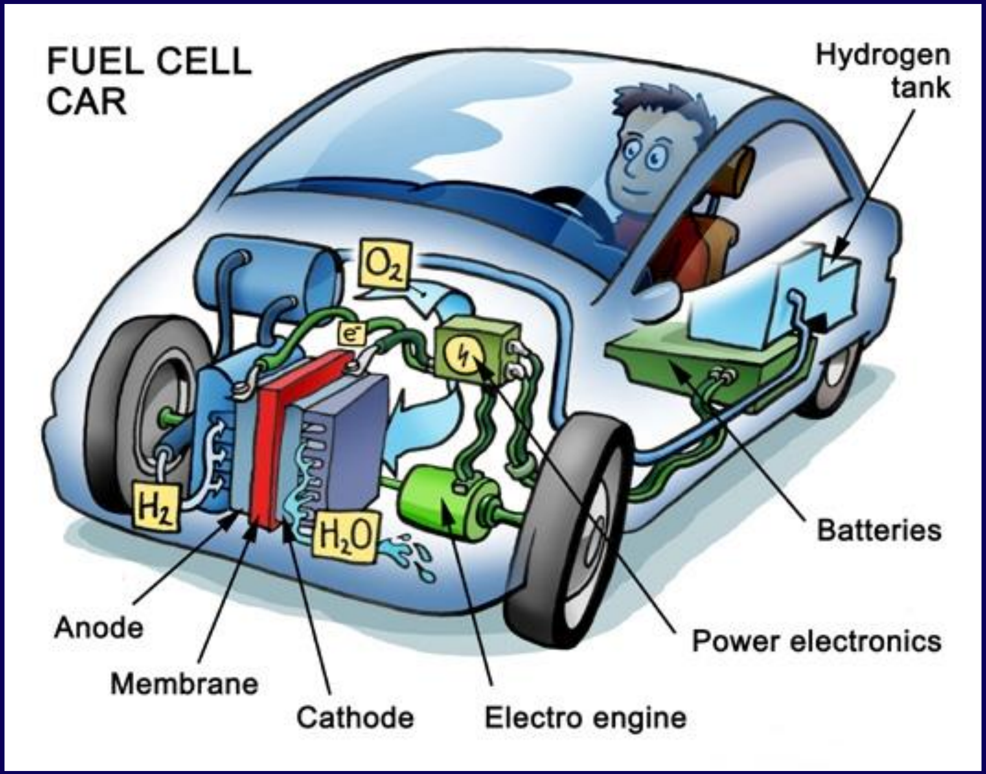
Fuel cells



e^-
M
0,7 V
-
+
Waterstof
Lucht
H^+
Anode
Elektrolyt
Kathode
Stikstof
+Water
$H_2 \rightarrow 2H^+ + 2e^-$
$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$



FUEL CELL
CAR
Hydrogen
tank
O_2
e^-
H_2
H_2O
Batteries
Anode
Power electronics
Membrane
Cathode
Electro engine

Rechargeable battery chemistries

System		
• Sealed Lead Acid (SLA)		
• NiCd		
• NiMH		
• Li-systems - Li-ion - Li-gel - Li-polymer - Li-metal		

Rechargeable battery chemistries

System	Advantages	Disadvantages
• Sealed Lead Acid (SLA)	• Cheap	• Heavy • Overdischarging
• NiCd	• Power density	• Pollution
• NiMH	• Energy density - Volumetric	• Gas formation
• Li-systems - Li-ion - Li-gel - Li-polymer - Li-metal	• Energy density - Gravimetric	• Expensive • Electronics - Control - Safety

Research

JÜLICH FORSCHUNGSZENTRUM
TU/e technische universiteit eindhoven

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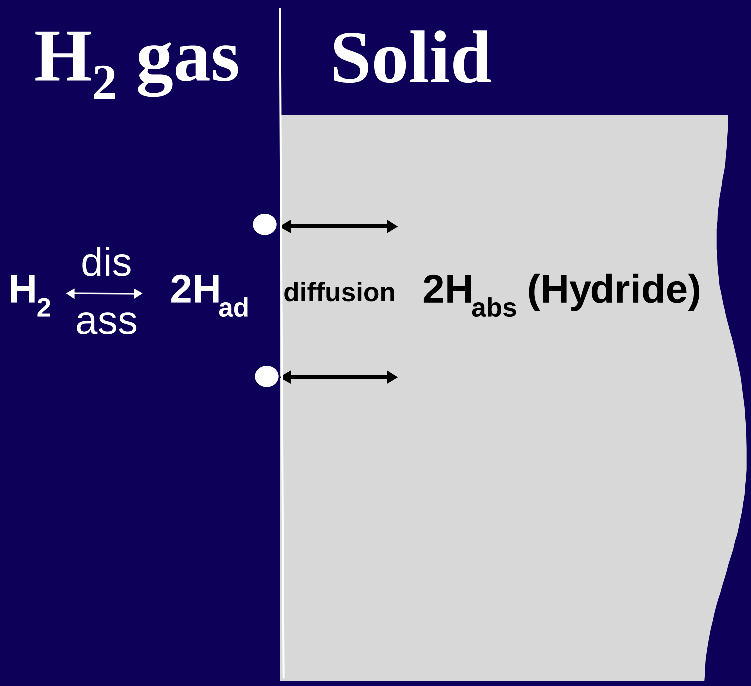
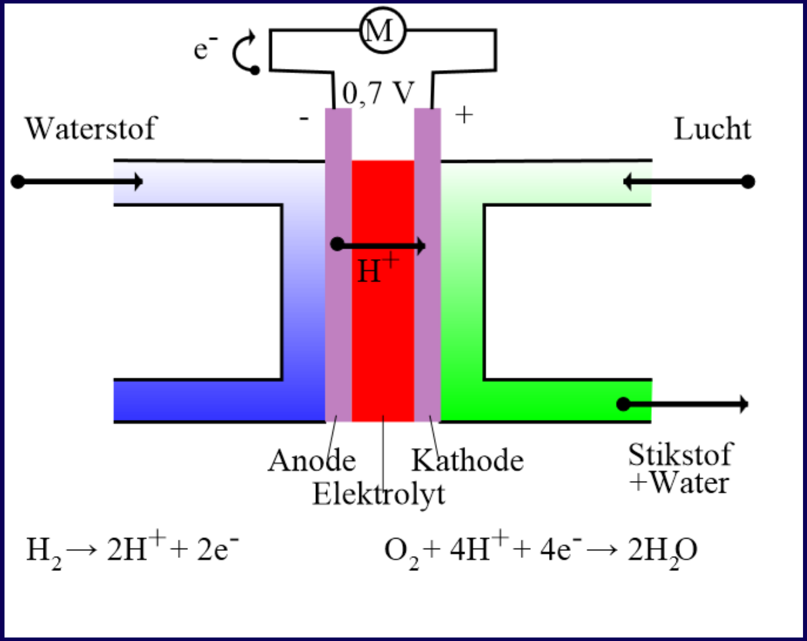
Research

Two ways to form a hydride

1. Gas phase



Fuel cells



e⁻
M
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$H_2 \rightarrow 2H^+ + 2e^-$
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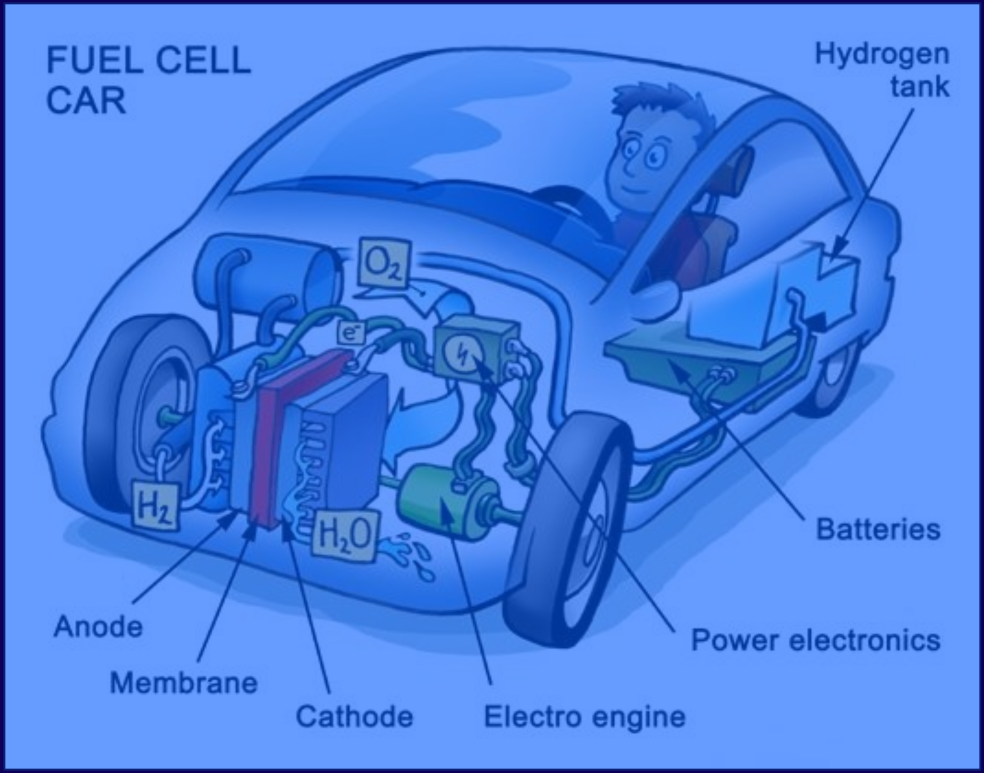
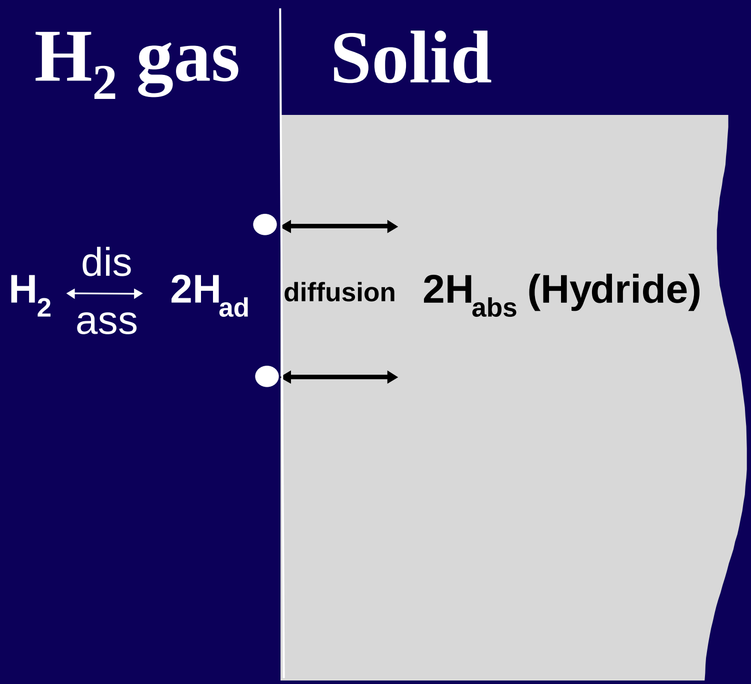


FUEL CELL CAR
Hydrogen tank
O_2
e^-
H_2
H_2O
Batteries
Anode
Membrane
Cathode
Electro engine
Power electronics

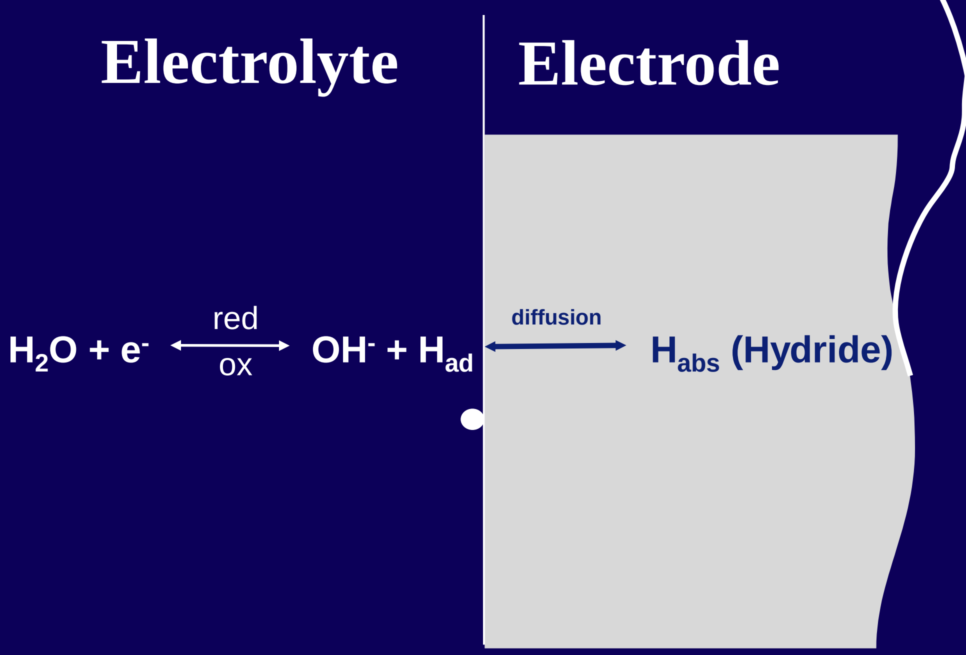
Two ways to form a hydride

1. Gas phase

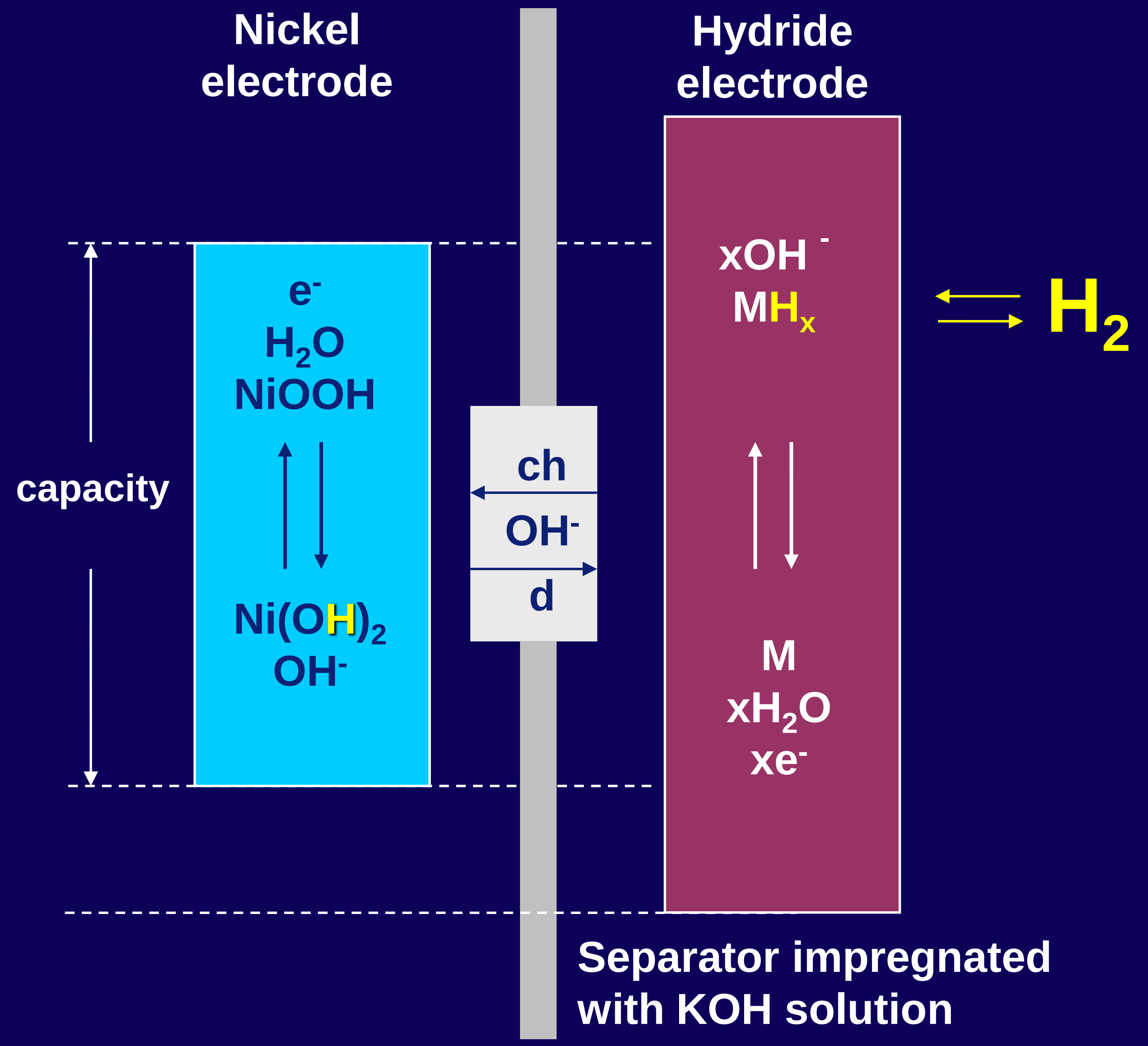


2. Electrochemically

e^-



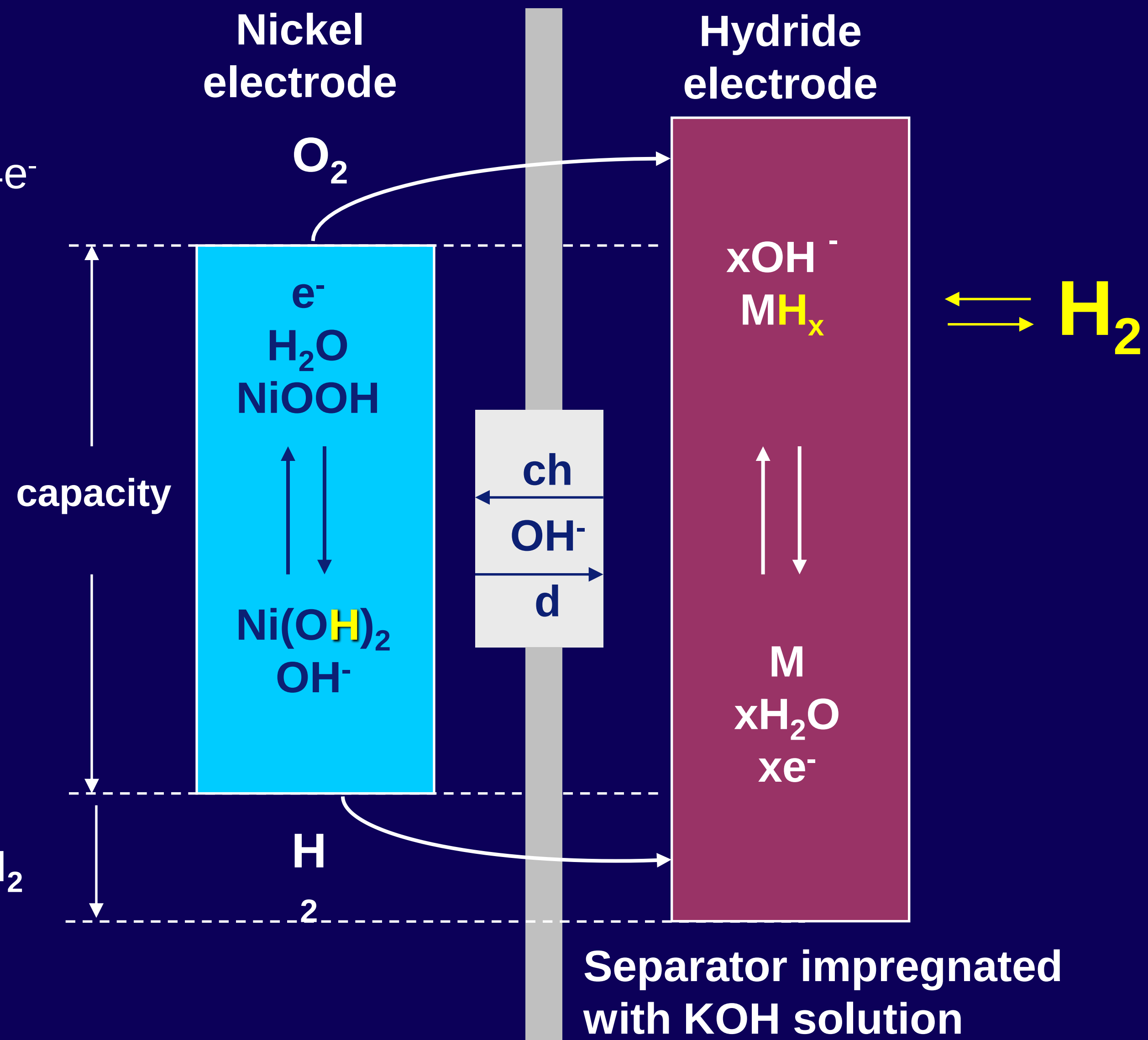
NiMH battery concept



NiMH battery concept

Overcharge

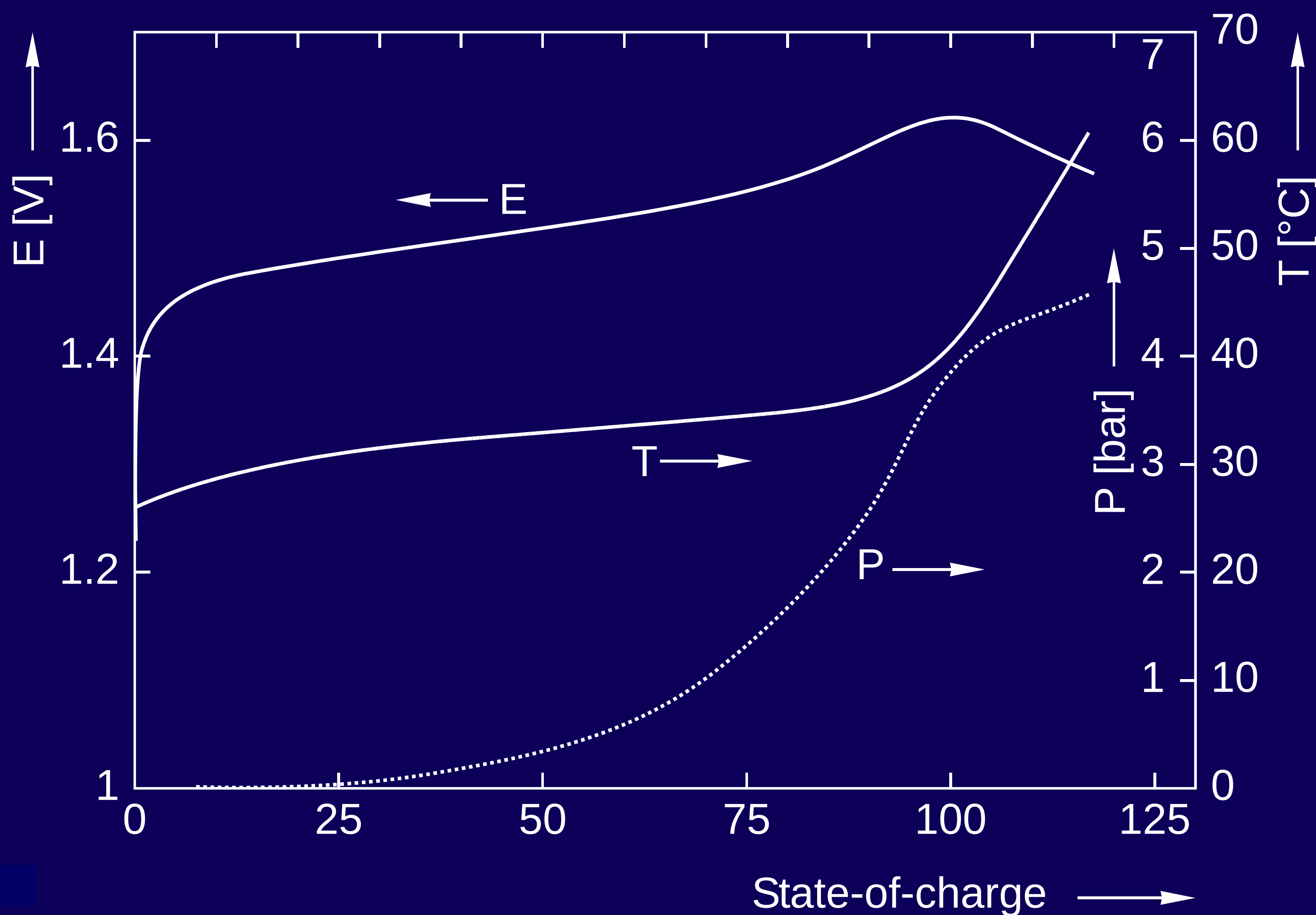
$$4\,OH^- \underset{MH}{\overset{Ni}{\rightleftharpoons}} 2H_2O + O_2 + 4e^-$$



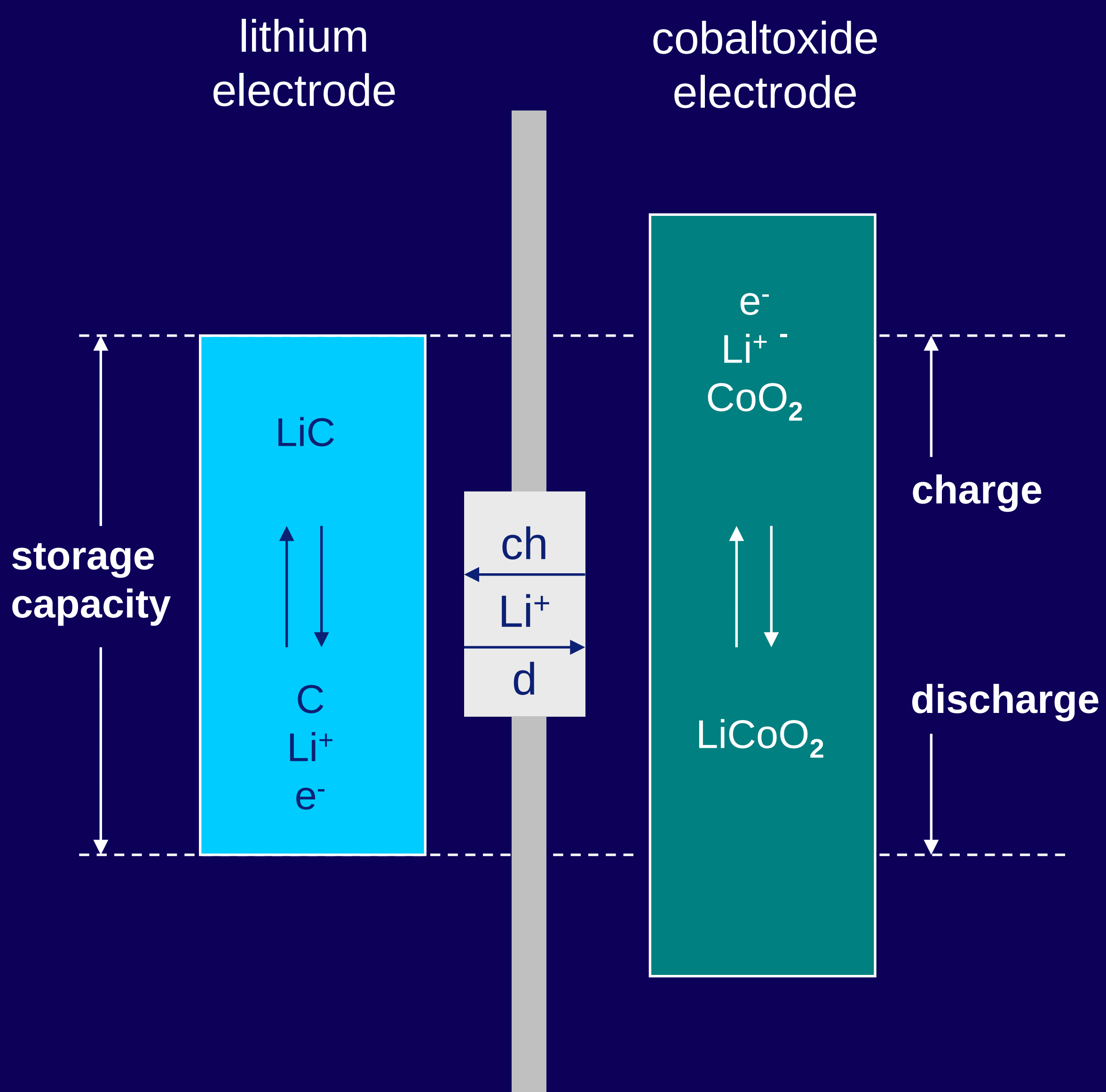
Overdischarge

$$2e^- + 2H_2O \underset{MH}{\overset{Ni}{\rightleftharpoons}} 2OH^- + H_2$$

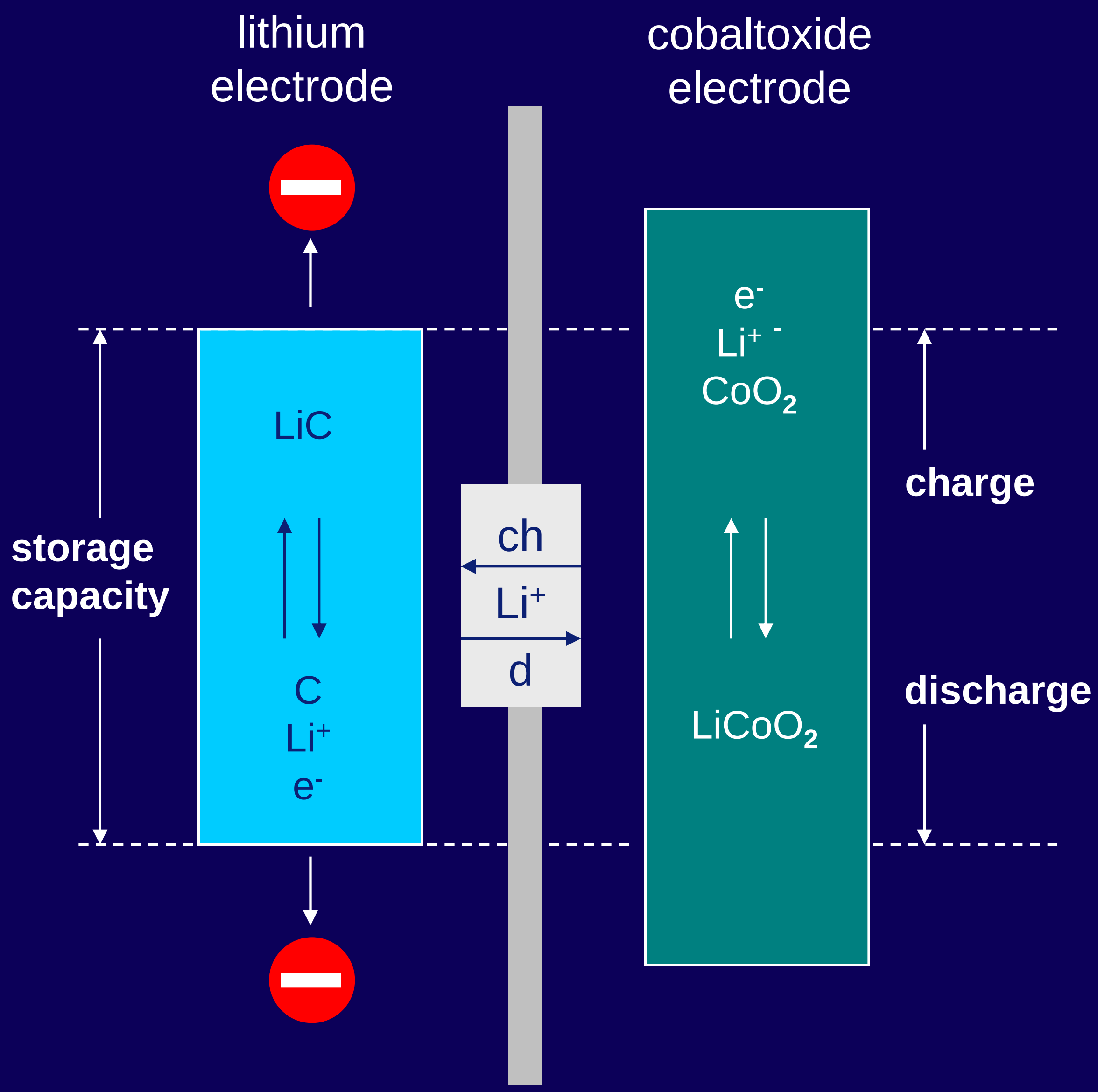
Simple CC-charging NiMH batteries



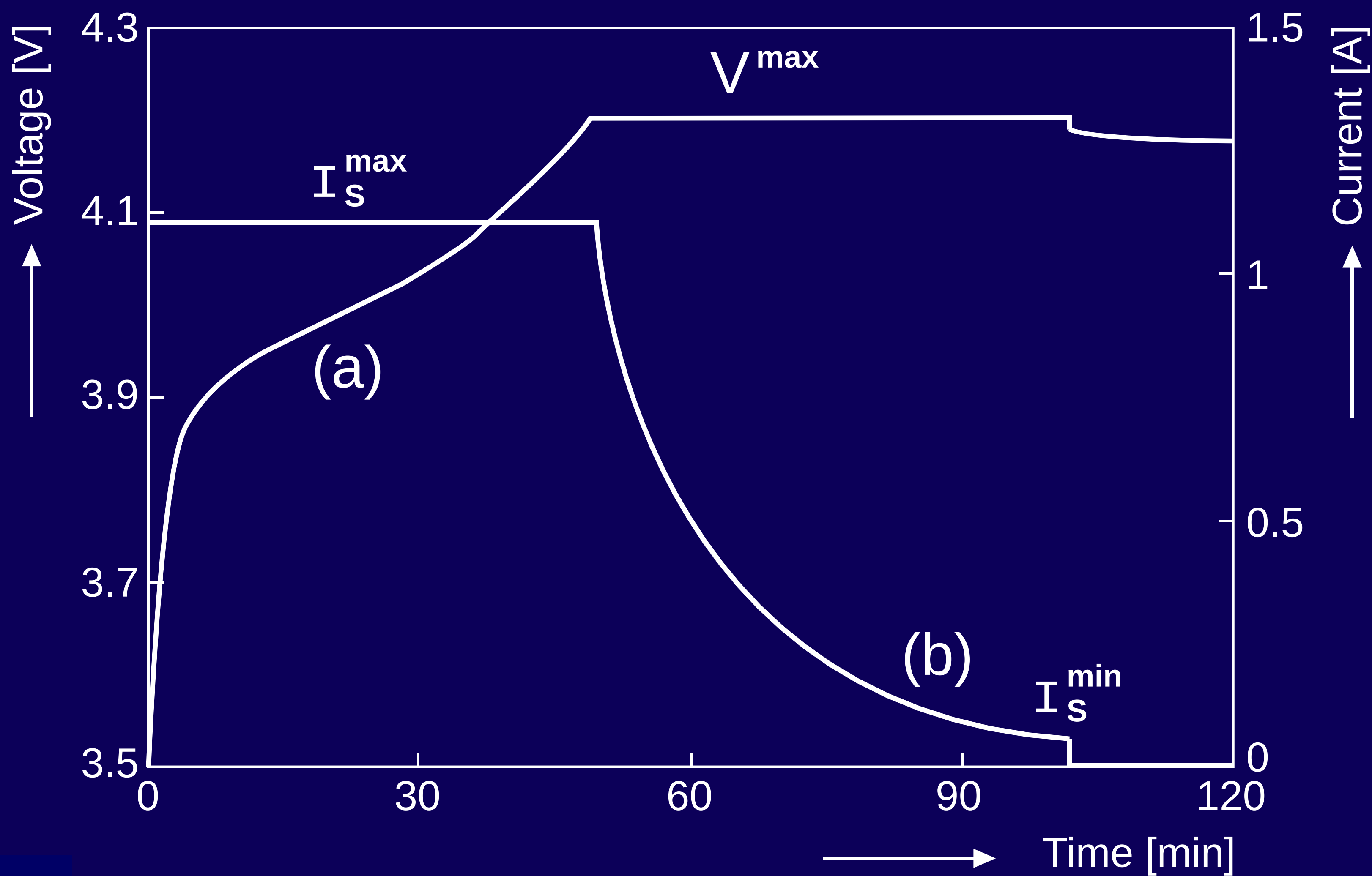
Li-ion battery concept



Li-ion battery concept



More complex CCCV charging Li-ion

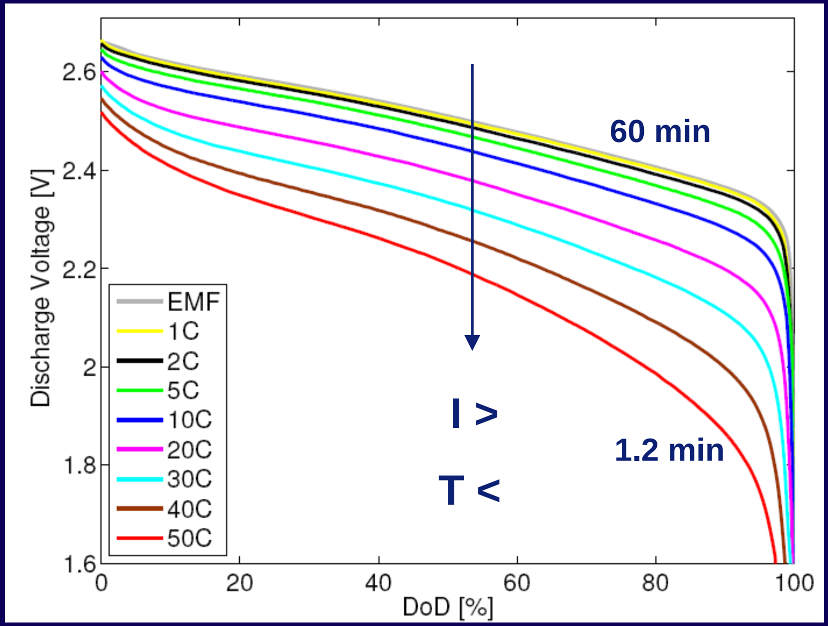


Efficiency rechargeable batteries excellent

Not affected by an inefficient Carnot cycle

$$\eta = 1 - \frac{T_{cold}}{T_{hot}}$$

Discharge voltage curves as f(I)



Efficiency rechargeable batteries

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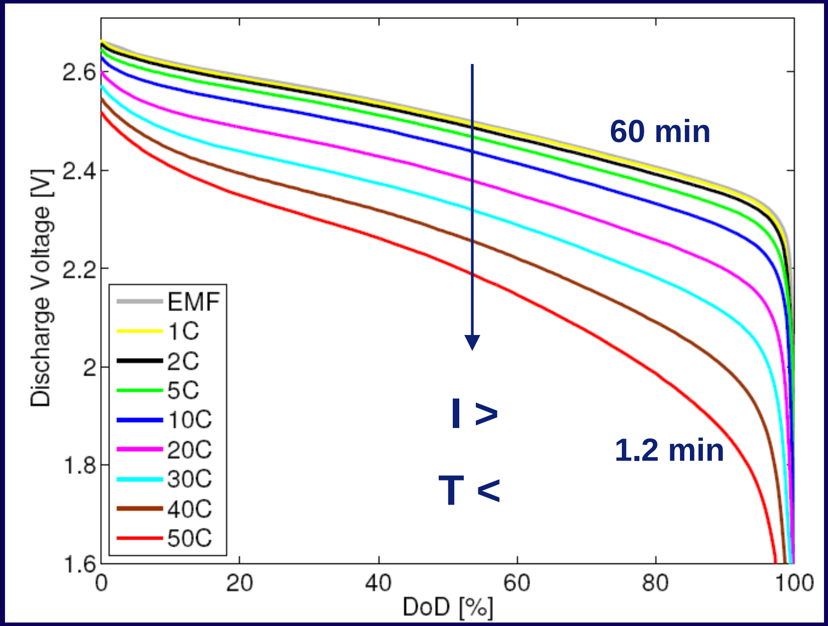
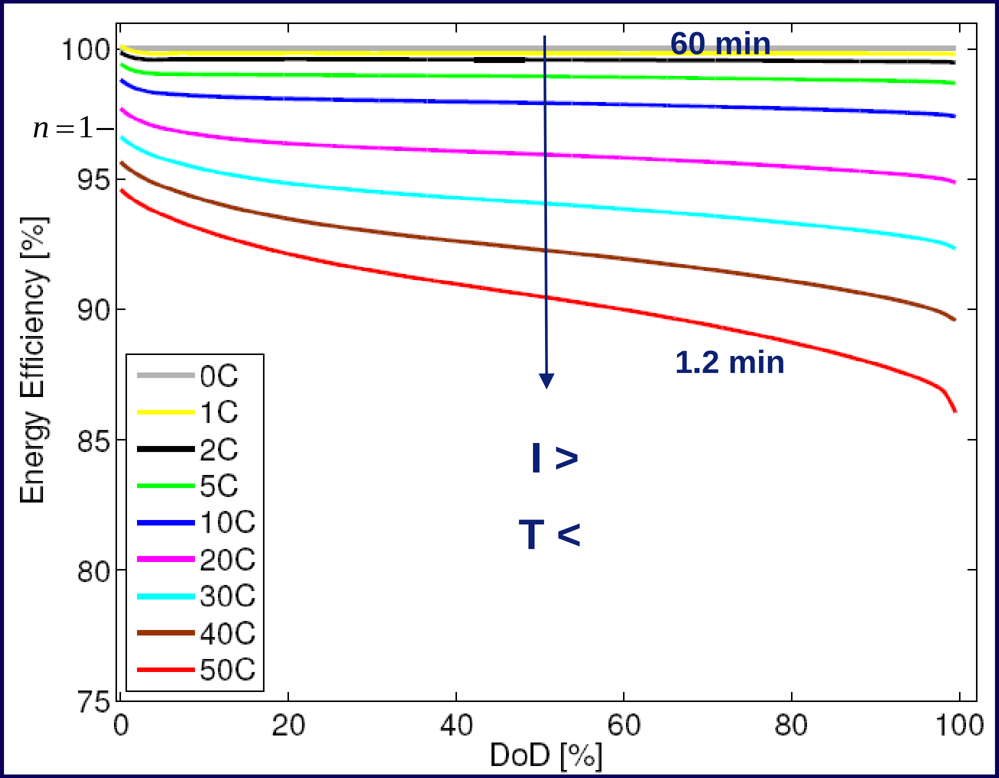
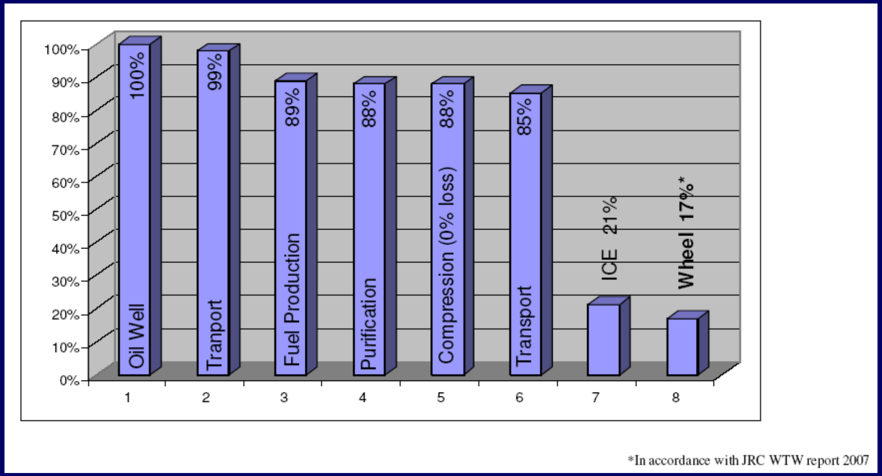


Discharge Efficiency as f(I)



New generation $LiTiO_2$ + $LiMn_2O_4$ batteries

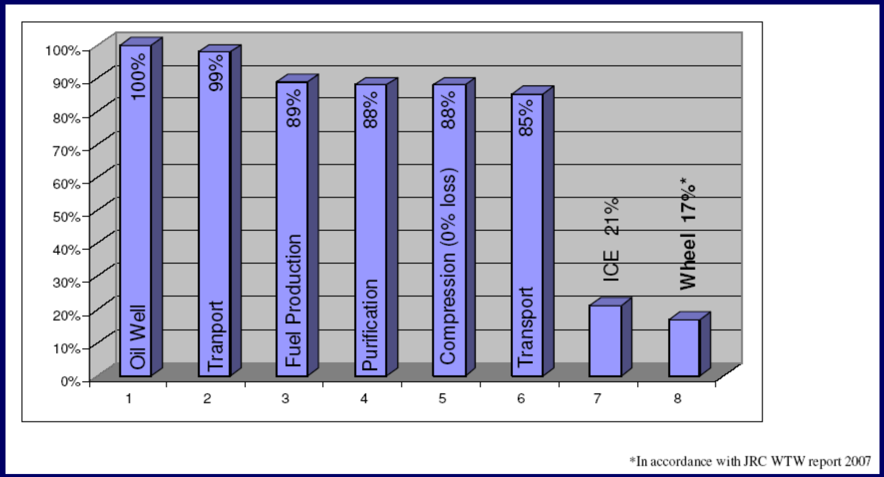
Well-to-wheel efficiency
Internal Combustion Engine (ICE)



$\eta_{ICE} \approx 17\%$

Efficiency battery-powered vehicles

ICE *vs* Conventional electricity generation



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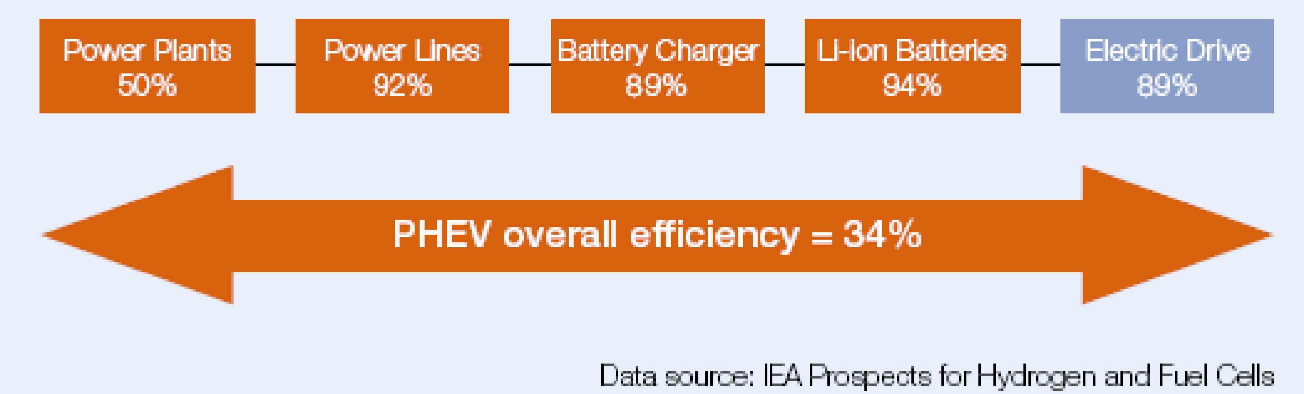


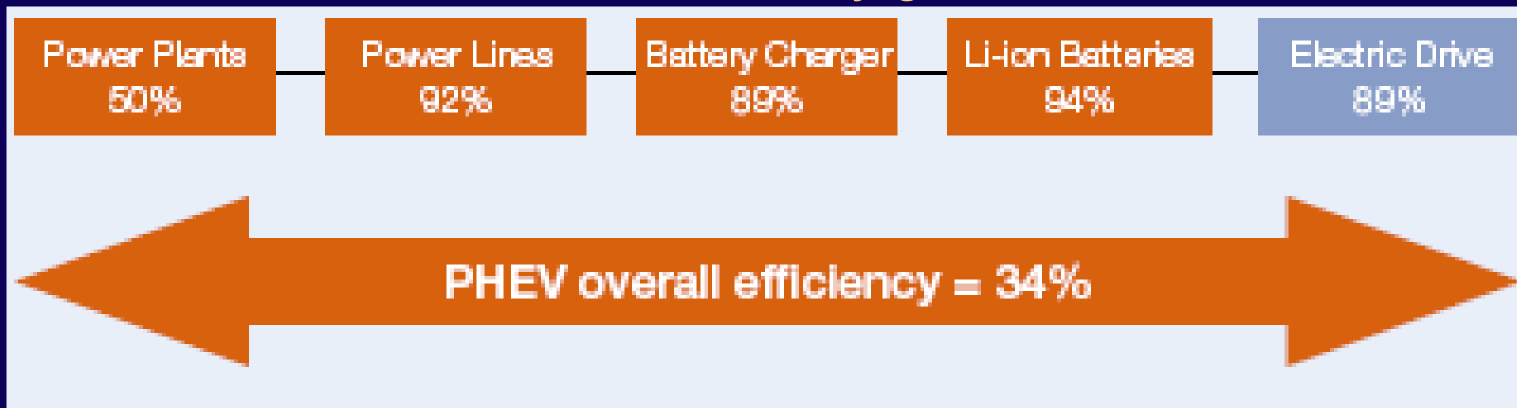
Figure 22. WTW analysis of FCEVs and PHEVs based on primary energy efficiencies, assuming PHEV use only grid-supplied electricity which implies limited range.

$\eta_{PHEV} \approx 34\%$

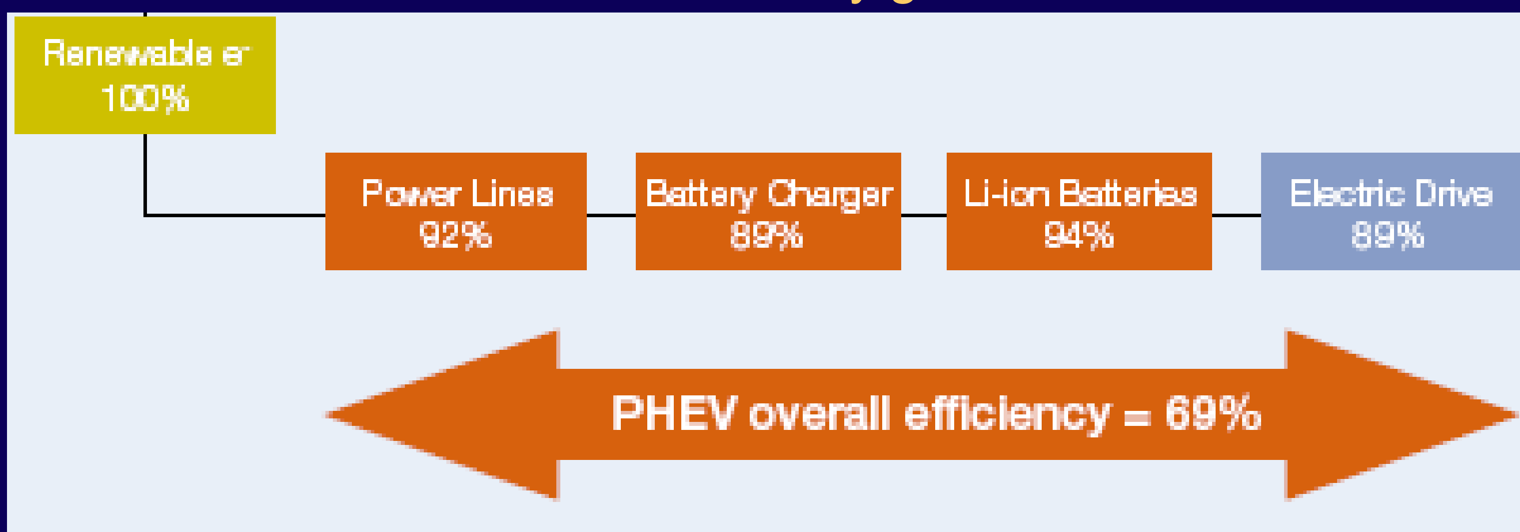
IEA Prospects for Hydrogen and Fuel Cells

Efficiency battery-powered vehicles

Conventional electricity generation



“Renewable” electricity generation



IEA Prospects for Hydrogen and Fuel Cells

Plug-in (Hybrid) Electrical Vehicles

Advantages:

- Much more efficient than ICE (> 2x)
- Significant reduction in CO_2 emissions (< 2x)
- Zero emission with sustainable energy sources…!
- Environmental friendly, no urban pollution…!
- Cost effective during life-time already now…!
- Grid stabilization *versus* electricity trading
- Silent driving…!

Disadvantages:

- High initial investment
- Limited driving range
- Recharging time not “instantaneous”
- Silent driving…!

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"The kWh feeling"

1 kWh = 3.6 MJ electricity
1 kWh storage in water (mgh) = pumping 360.000 liter 1 m high

1 kWh Li-ion battery weighs ~ 5-10 kg
1 kWh Li-ion battery you can drive about 7 km

If you want a driving range of 140 km
that correspondents to a 20 kWh pack
which weights 100 - 200 kg
and costs ~10.000 €…!

Plug-in (Hybrid) Electrical Vehicles

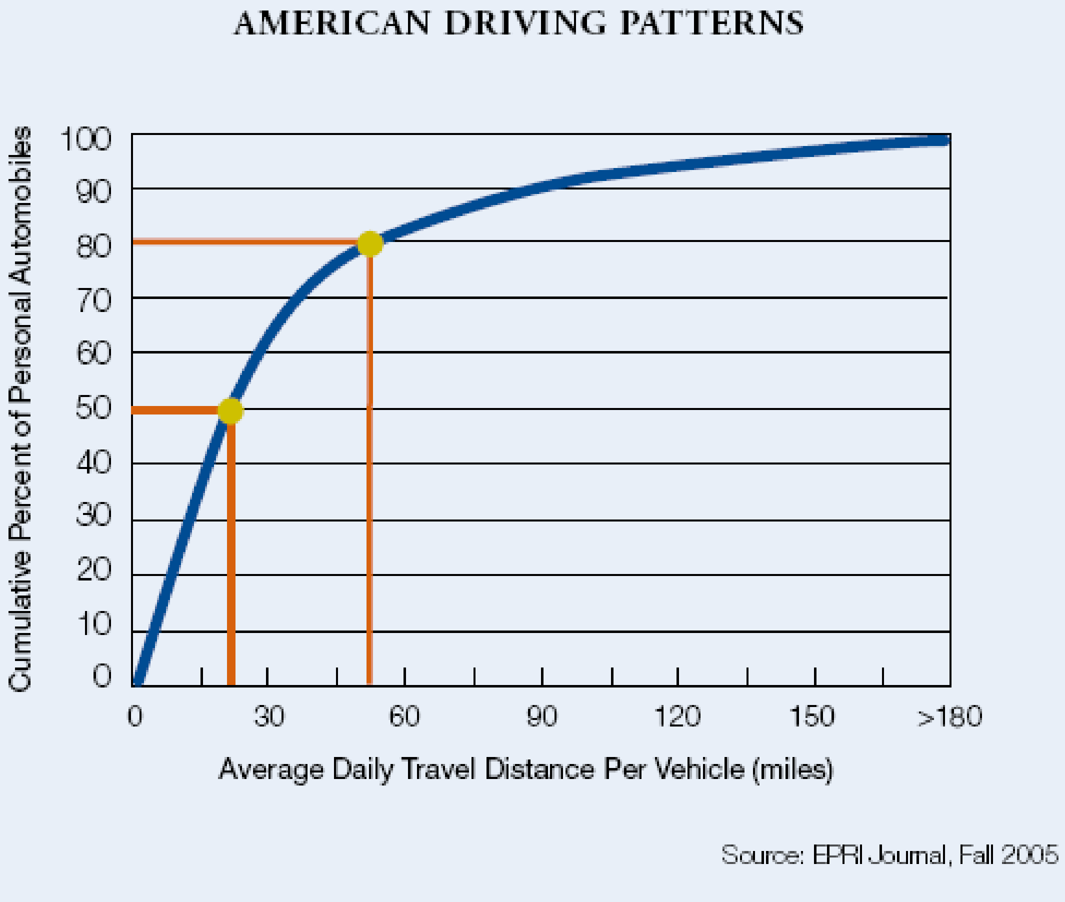
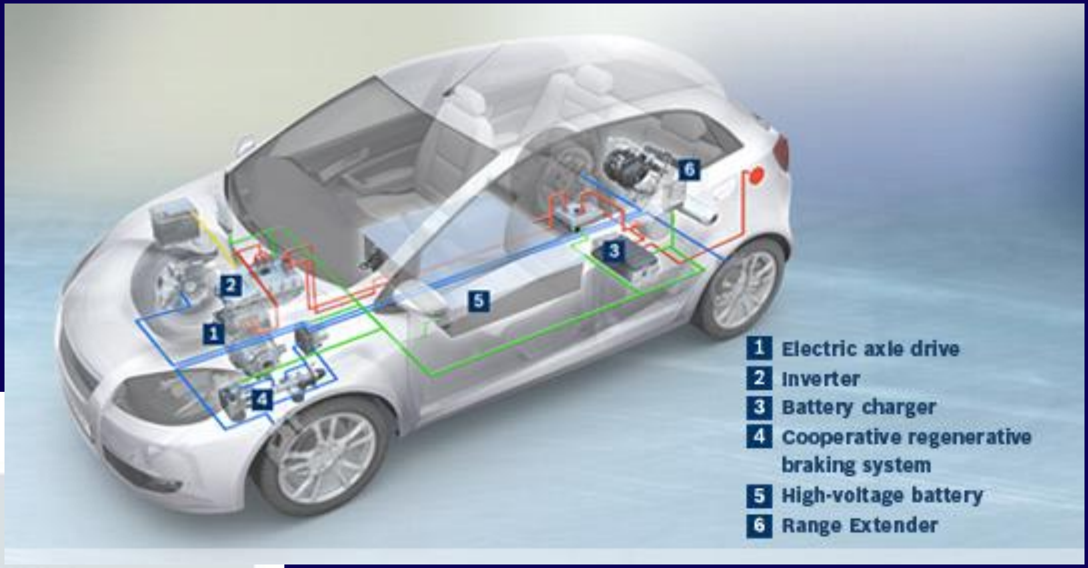
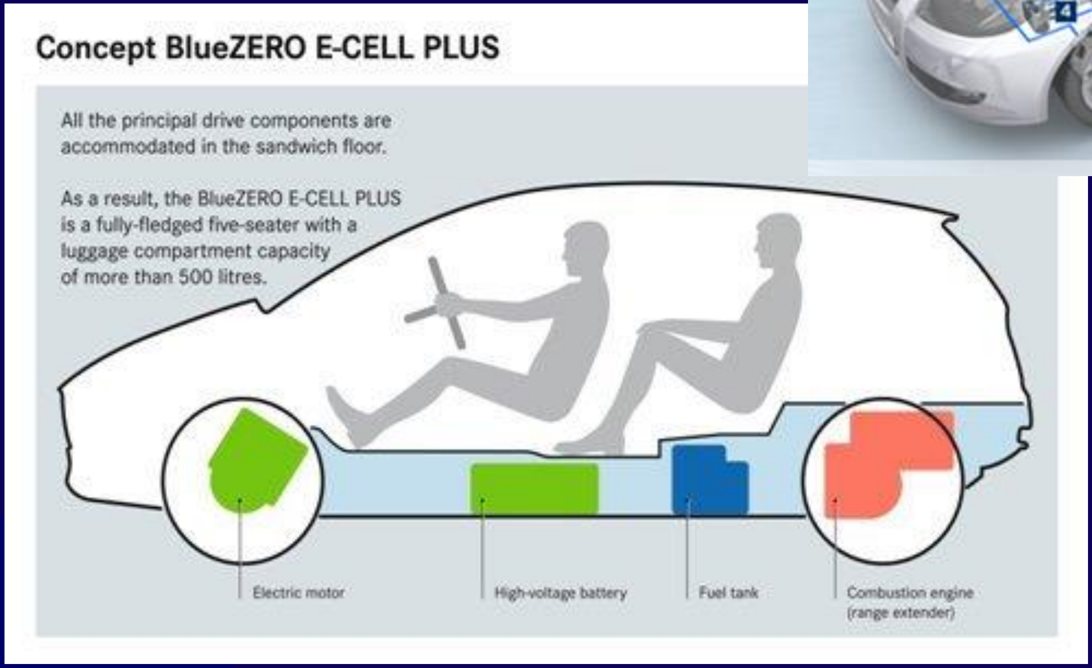


Figure 17. Half of all personal automobiles in the US travel 25 miles (40 km) or less each day, while eighty percent travel a maximum of 50 miles (80 km).[165]

Plugged in: The end of the oil age, World Wide Fund for Nature 2008.

Limited driving range solutions:
(i) Range Extender (ICE, Fuel Cells)
(ii) Exchanging packs





Hyundai announcement Paris
Fuel cell-Battery Hybrid in production

Hyundai press release, September 2012

Limited driving range solutions:

(i) Range Extender (ICE, Fuel Cells)

(ii) Exchanging packs "Better Place" concept

Recharging time not “instantaneous”

New rapid charging strategies (Epyon/ABB)

EPYON

Electric vehicle 15-30 min. charging solutions

Small vehicle chargers

- 4 & 8 kW (20–60 VDC)

Large vehicle chargers

- 20 kW (20–90 VDC)

Electric fuel stations

- 50 kW (200-460 VDC)
- 100 kW (100- 600 VDC)

http://www.epyonpower.com

Battery challenges to be met to enable electrical transportation

- Energy density
- Power density
- Cycle life
- Safety
- Cost

New Materials for Li-ion Batteries

New chemistries and Nano-structuring

Anode materials

Graphite

↓

- Si-based
- Sn-based
- Ti-based

Cathode materials

$LiCoO_2$

↓

- $LiNi_{0.33}Co_{0.33}Mn_{0.33}O_2$
- $LiNi_{0.33}Co_{0.33}Mn_{0.33}AlO_2$
- $LiFePO_4$ (-30% + safer)
- $LiMn_2O_4$ (-30% + very safe)

New Materials for Li-ion Batteries

Anode materials

Cathode materials

Graphite

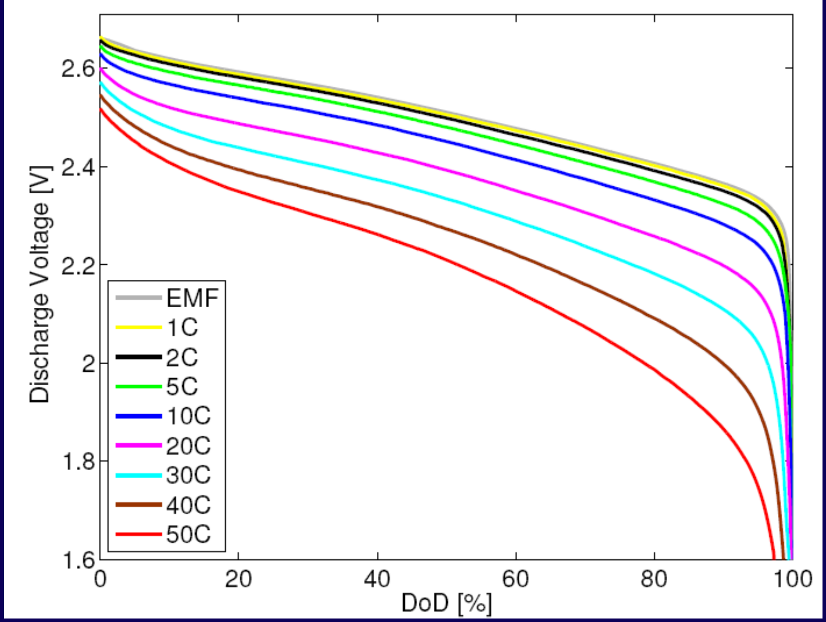
↓

Ti-based

$LiCoO_2$

↓

$LiMn_2O_4$



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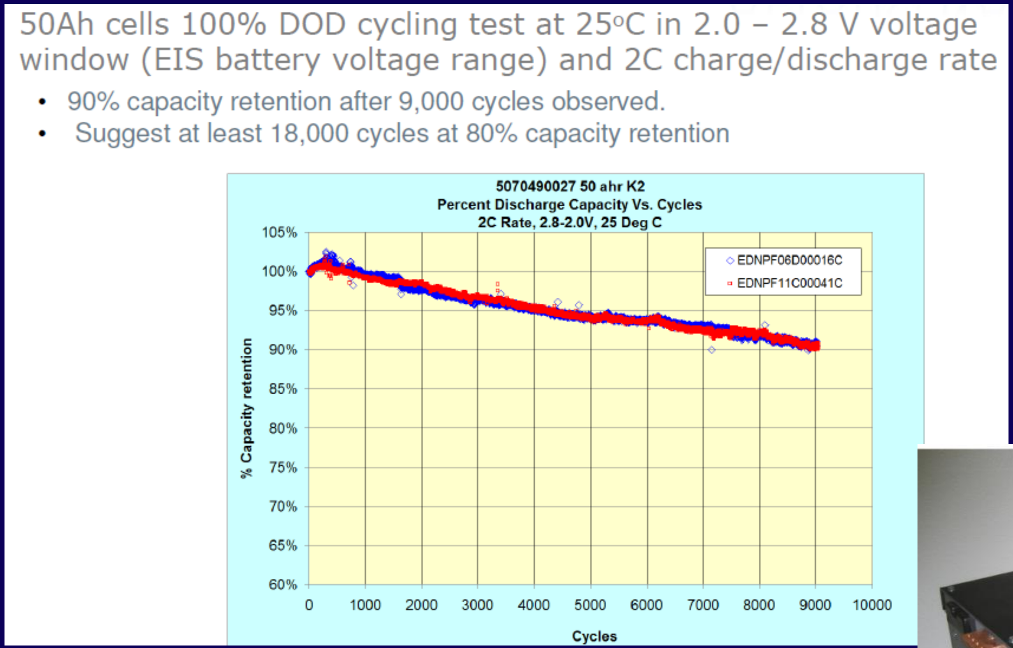
Cathode materials



9000 cycles x 6.2 kWh x 7 km/kWh

~ 400.000 km…!

New Materials for Li-ion Batteries

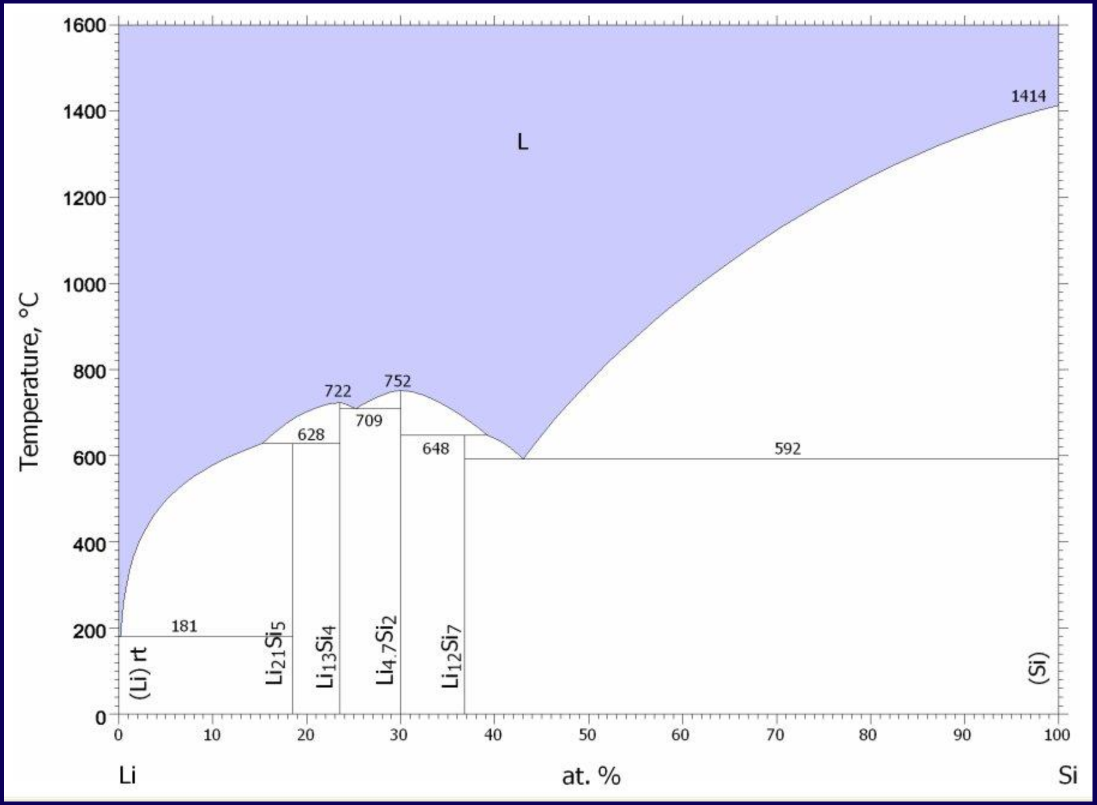
Anode materials

Graphite

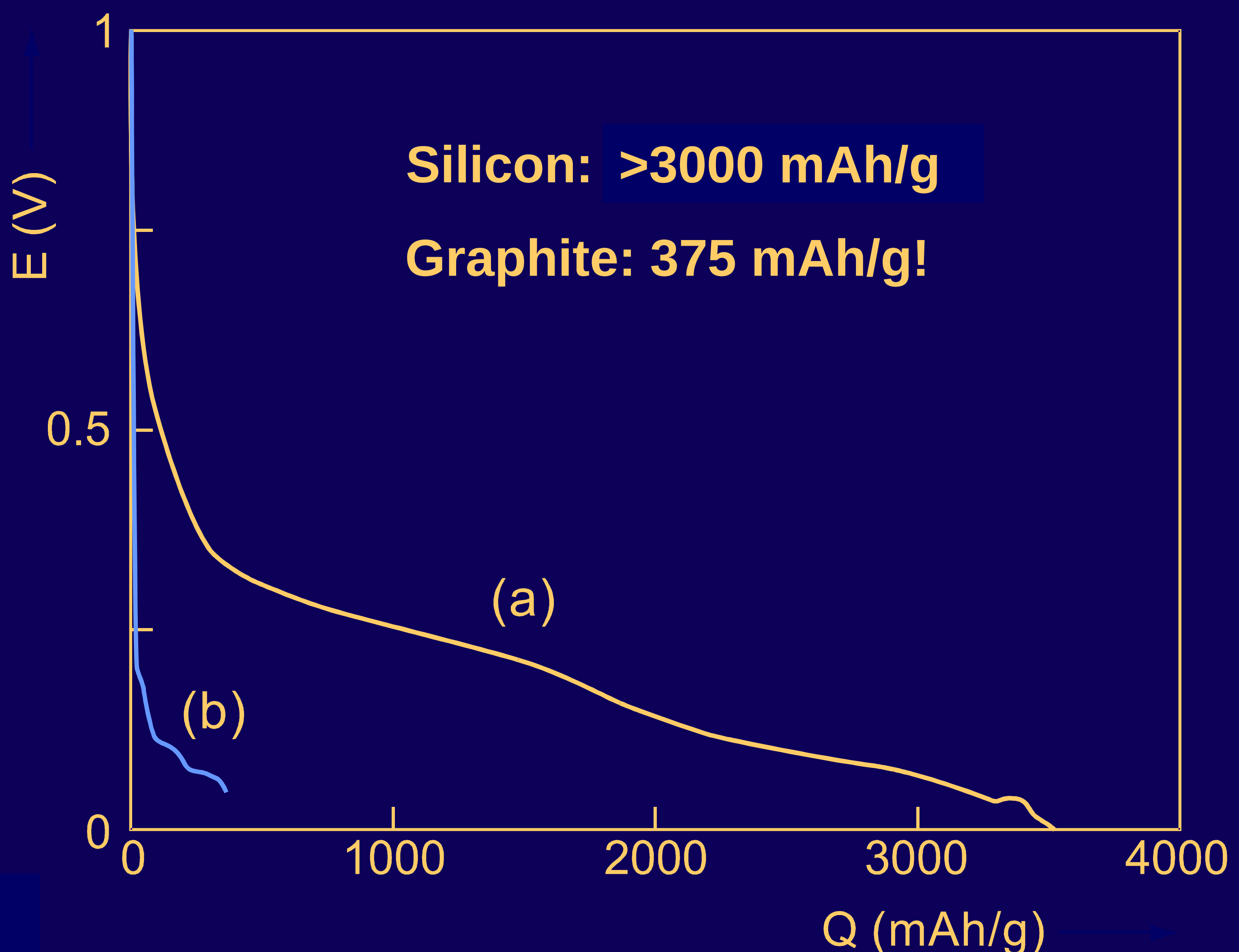
↓

- Si-based

Phase diagram LiSi

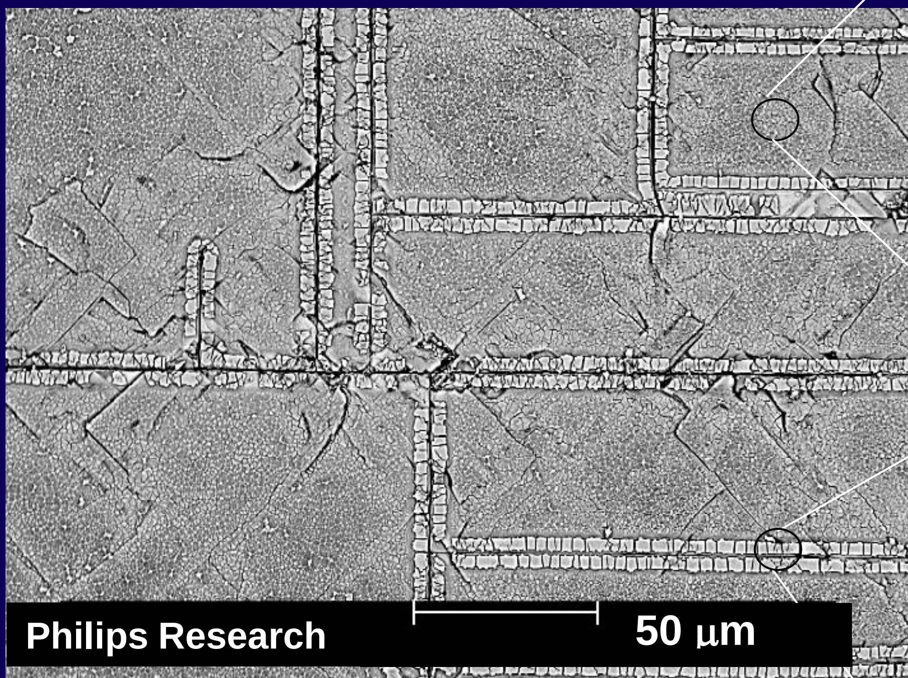


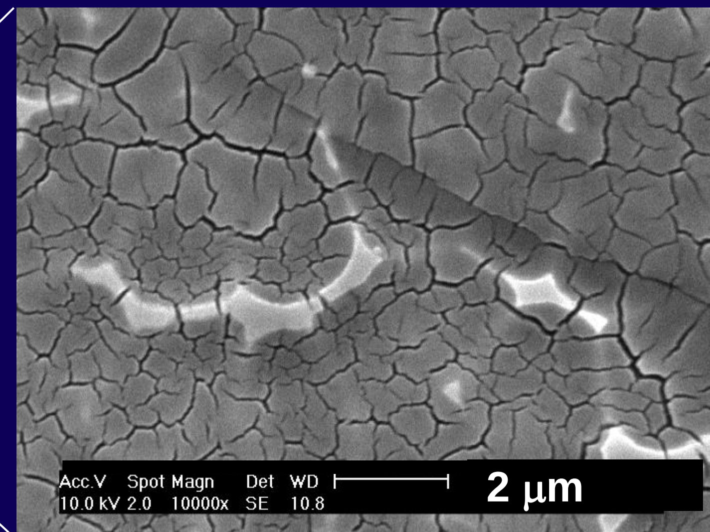
Thin film Si-electrode

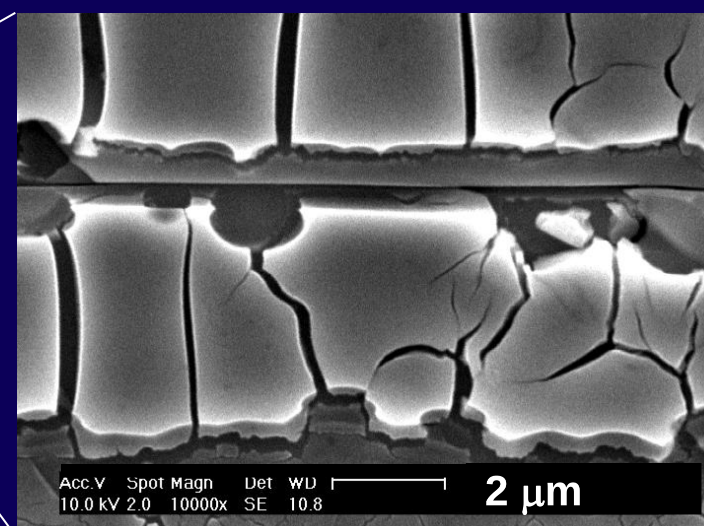


Morphology after Li-intercalation

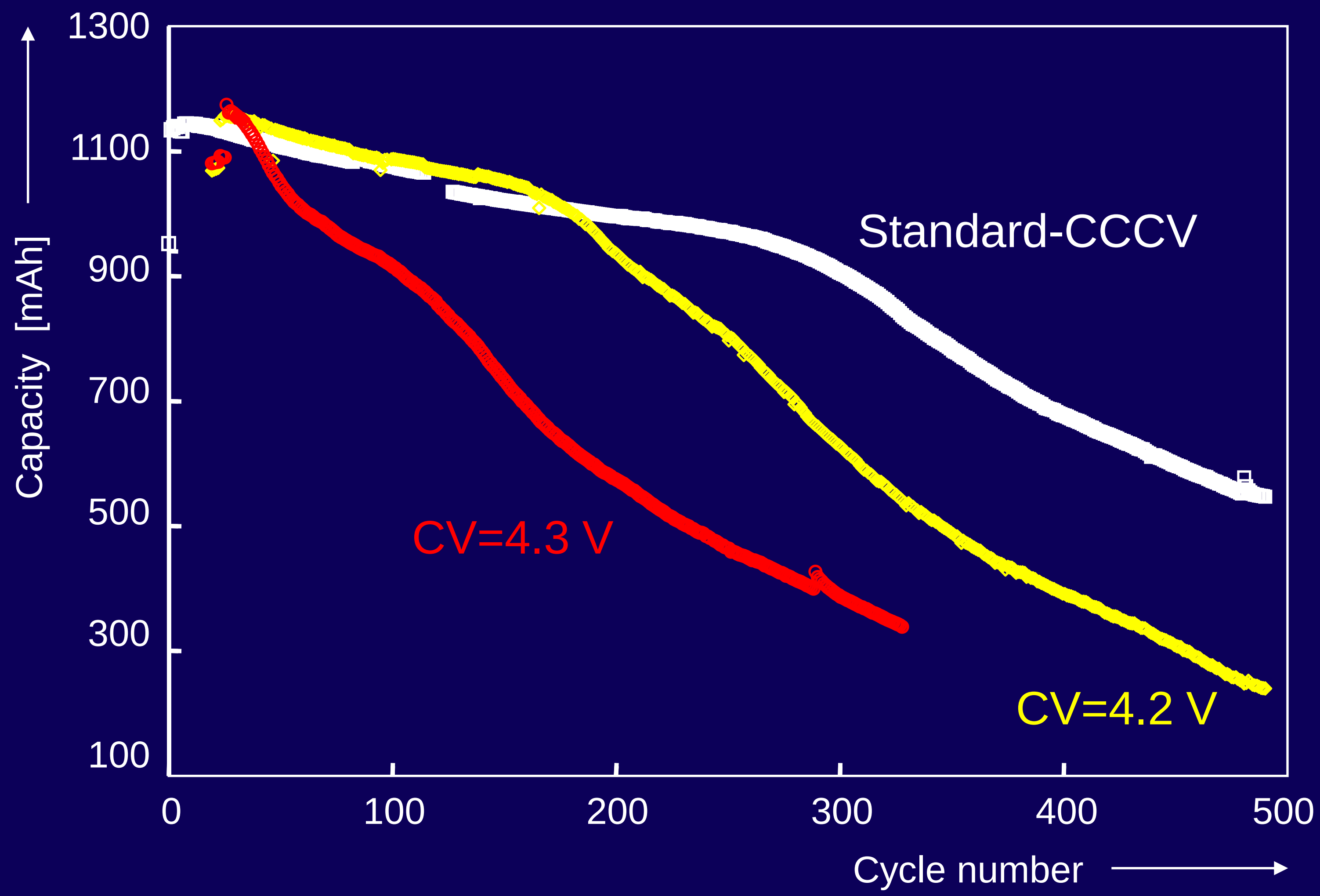
crystalline-Si







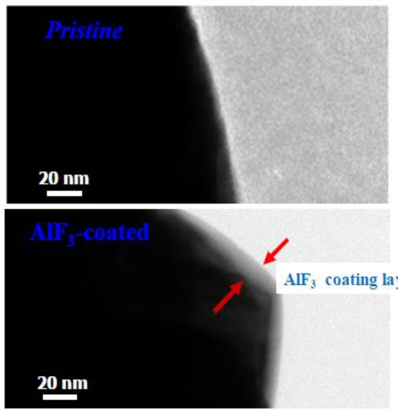
Impact CV-charging on cycle-life



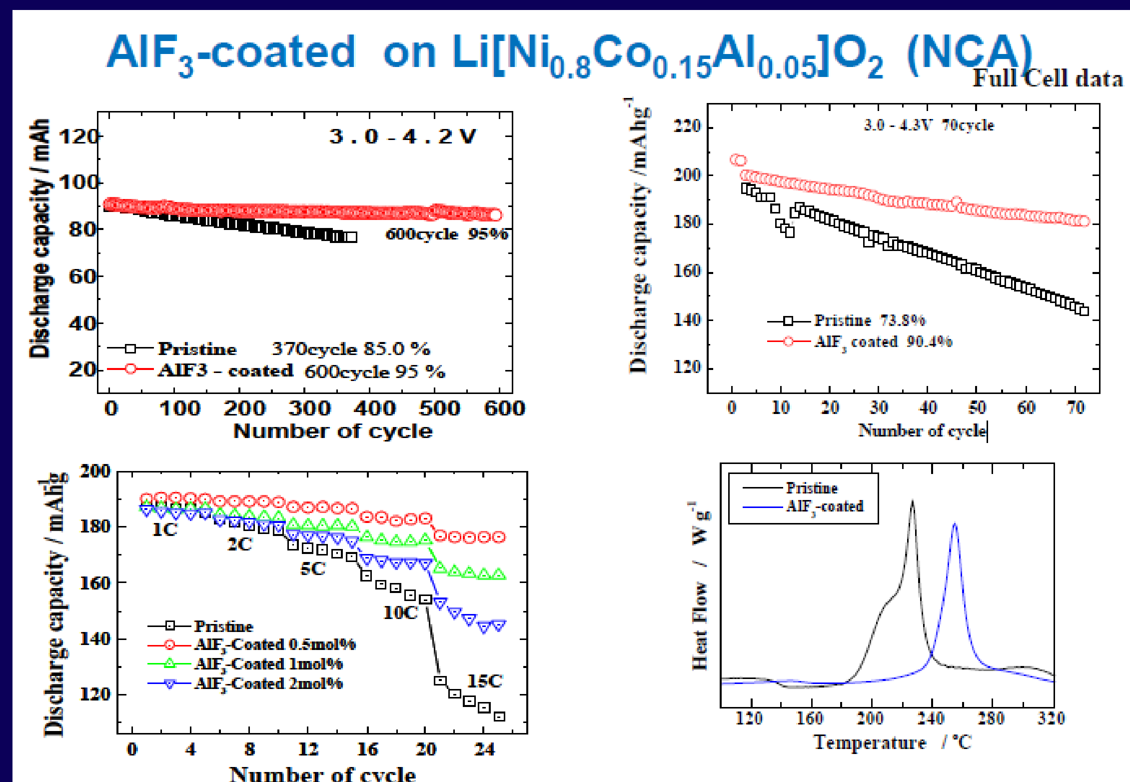
Surface protection

Improving the performance of Li-batteries by surface coating of positive electrode materials with AlF_3

TEM Images of the Pristine and AlF_3-coated $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$

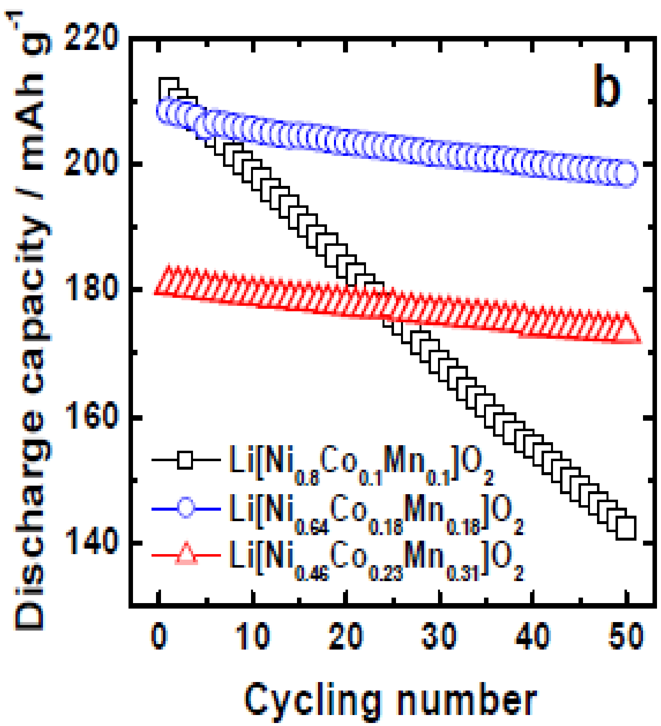


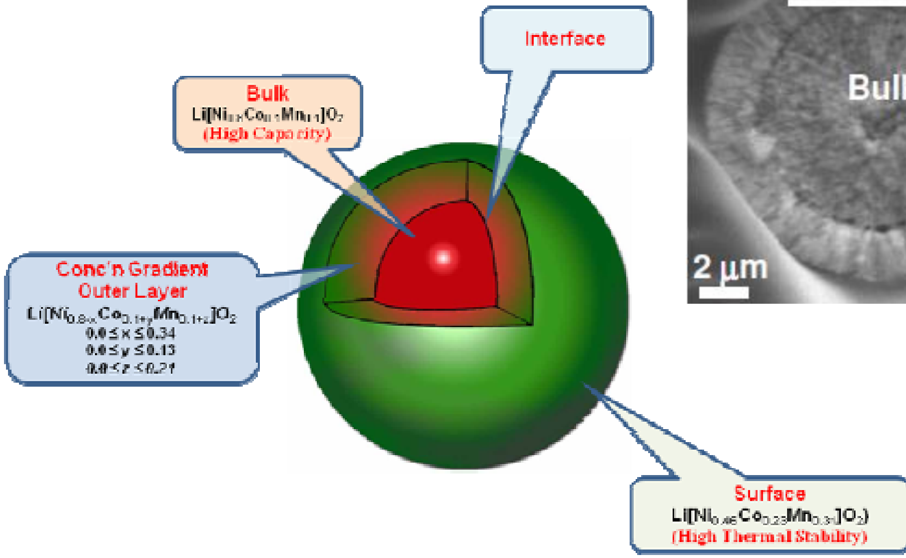
ALD process under development…!

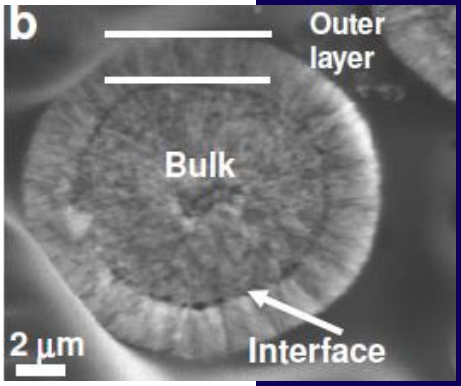


Changing bulk and surface properties

High energy gradient concentration cathode material

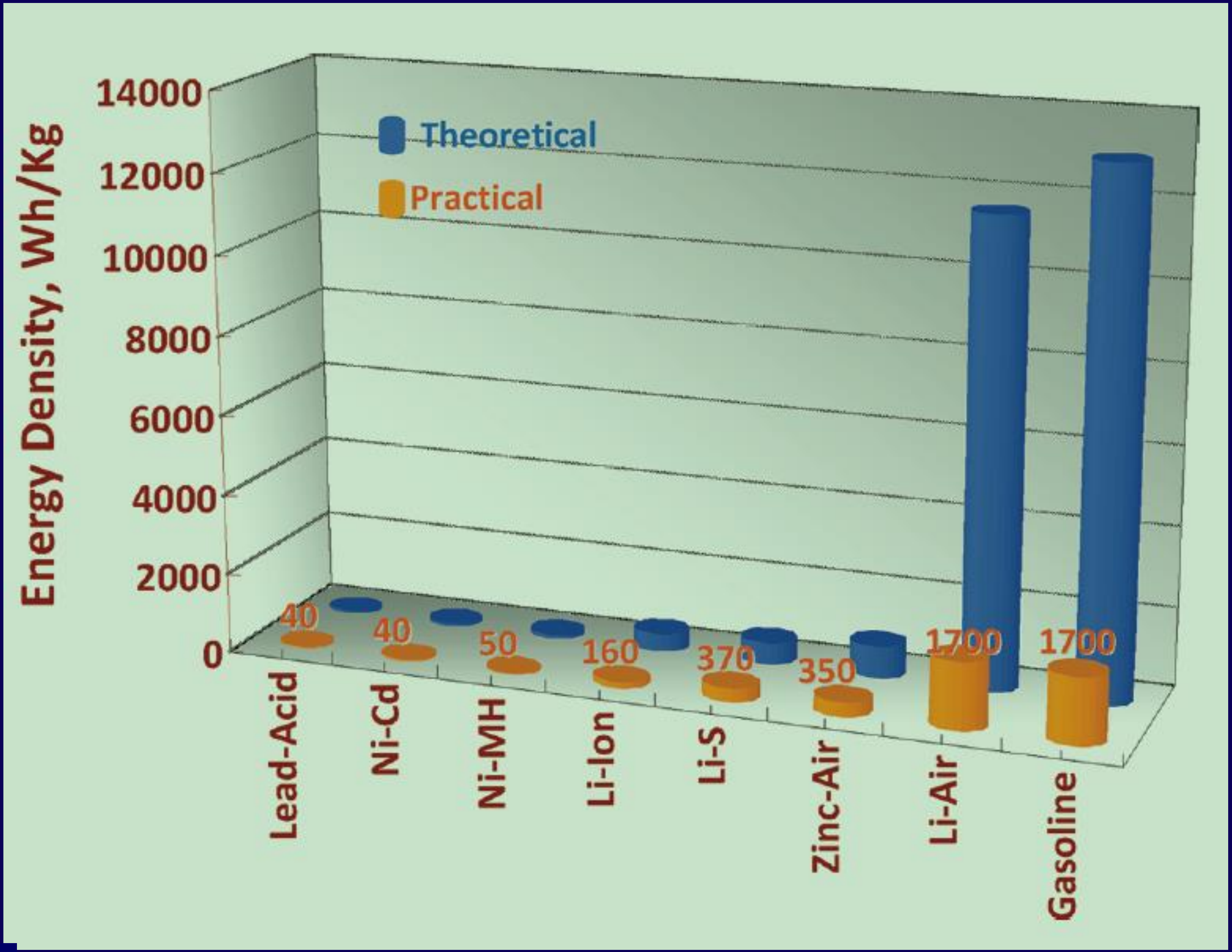






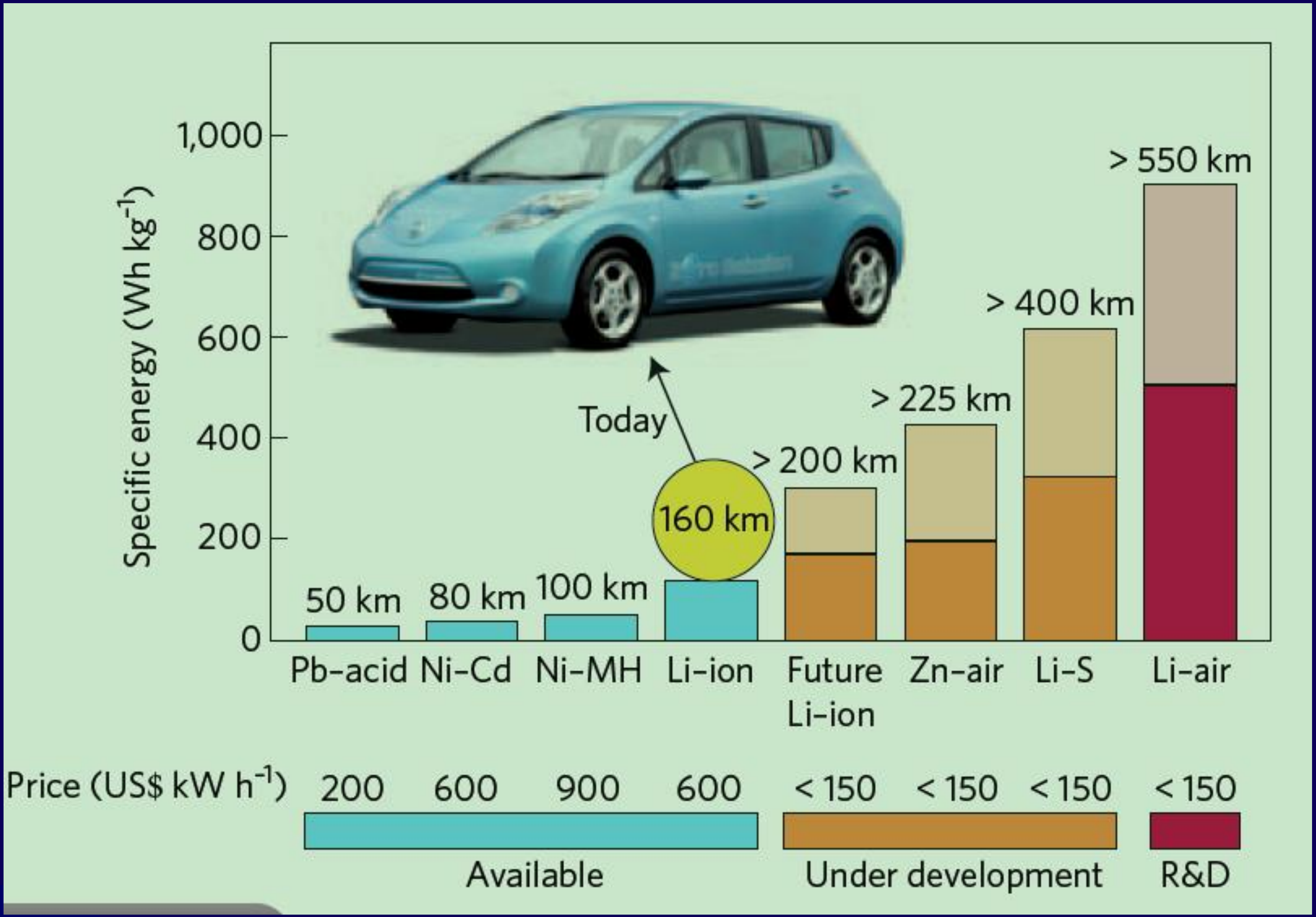
Y. K. Sun and K. Amine
Nature material, Vol 8, pp324, April 2009.

Energy densities of various (battery) systems



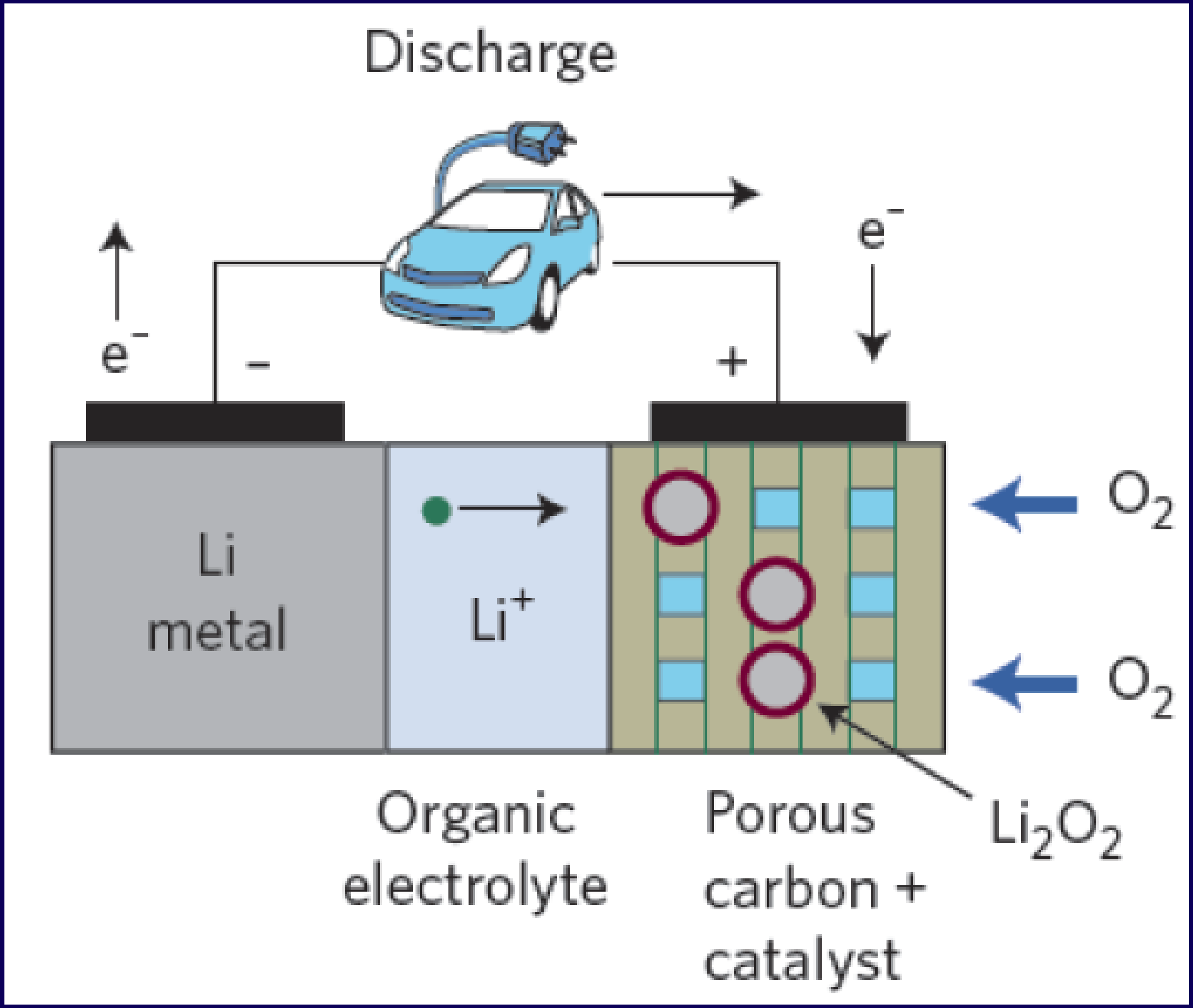
http://mm.seas.upenn.edu/ql/www/reference/Li_air_battery/Girishkumar10.pdf

New Li-based Systems



http://www.nature.com/nmat/journal/v11/n1/pdf/nmat3191.pdf

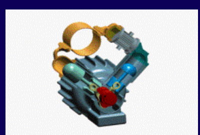
New Li-based Systems



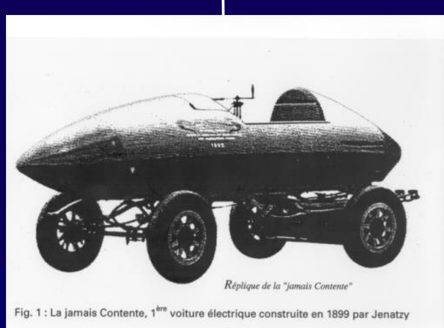
P.G. Bruce et al., *Nature Materials* **11** (2012) 19

Smart Grid



Eureka…!



“Residential storage” in Electrical Vehicles

Electrification of our society offers fantastic new opportunities for both our research and industry...!

Peter H.L.Notten[1,2]

[1] Eindhoven University of Technology, Netherlands
[2] Forschungszentrum Jülich, Germany

p.h.l.notten@tue.nl
p.notten@fz-juelich.de