Low Carbon Technologies – The Big View

Miran Gaberšček

1 National Institute of Chemistry, Ljubljana, Slovenia
2 Centre of Excellence Low Carbon Technologies, Ljubljana, SLO
3 Faculty of Chemistry and Chem. Techol., University of Ljubljana
CURRENT SITUATION

FOSSIL FUELS MAKE UP 85% OF ALL ENERGY
PROBLEMS WITH FOSSIL FUELS

• Supplies are running out
• Becoming more and more expensive
• Non-renewable
• May be contributing to global warming
• Old technologies
Which are the alternatives?

- Nuclear energy
- Solar energy
- Hydro energy
- Wind energy
- Geothermal energy
- Biomass, biofuels
1. Completely renewable
2. A 10000-fold surplus in energy
3. Exceptional potential

It provides us with possibilities to make great technological development/progress
Hydrogen from the sun

Hydrogen from the sun

Electricity from the sun

POSSIBLE IMPLEMENTATION
Battery vs. gasoline car

The graph compares the energy density (Wh/kg) versus power density (W/kg) for various types of energy storage systems. The graph includes data points for fuel cells, Li-air, Li-ion, Ni-MH, Ni-Cd, Lead, and Internal combustion engine (Intern. comb. eng.). The y-axis represents energy density, while the x-axis represents power density. The graph shows that battery technologies such as Li-ion and Li-air offer higher energy density compared to gasoline engines, which are represented by the Internal combustion engine (Intern. comb. eng.).
<table>
<thead>
<tr>
<th>Type of car</th>
<th>MJ/km</th>
<th>g(CO2)/km</th>
<th>Price of fuel [Cent/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline ICE</td>
<td>2.7</td>
<td>200</td>
<td>7.5</td>
</tr>
<tr>
<td>Diesel ICE</td>
<td>2.0</td>
<td>150</td>
<td>6</td>
</tr>
<tr>
<td>Hybrid</td>
<td>1.2-1.6</td>
<td>90-125</td>
<td>4</td>
</tr>
<tr>
<td>Electric (hydrogen)</td>
<td>1.1-1.2</td>
<td>60-90</td>
<td>2</td>
</tr>
<tr>
<td>Electric (battery)</td>
<td>0.9</td>
<td>45</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Energy storage – a very old concept?

„Baghdad battery“ – 2000 years ago

Copper cylinder
Iron rod
Electrolyte: vinnegar, lemon juice?
Year 1800

Voltaic pile

Electrolyte (brine-soaked cloth)

Zinc copper

1 cell

Tempio Voltiano Museum, Como
Year 1859

Lead-acid rechargeable battery

Schematics of 1st battery by Planté (1859)

Improvement (1860)

Lead plates + sulfuric acid
Today

Lithium rechargeable batteries

Main components:

Ceramic active powders

Organic electrolytes

Polymeric separators
Driving force for battery development

Measurement for quantity of stored energy

Gravimetric energy density (Wh kg⁻¹)
Year
Number of transistors in circuits

- Pb-acid
- Ni-Cd
- Zn-AgO
- Li-MoS₂
- Ni-MeH
- Li-ion

- pentium 4
- pentium III
- pentium II
- pentium I
- proc. 8080
- proc. 4004

1860 1880 1900 1920 1940 1960 1980 2000
Energy density vs. capacity

\[ m = 1 \text{ kg}, \ I = 1\text{A} \]

Energy density \( = \frac{I}{m} \int_{0}^{t_0} U(t) \, dt \)
Electric car

NOT SUCH A NEW CONCEPT
April 1899:
First car crossing the margin of 100 km/h, was an electric car

La Jamais Contente, 1899

USA, around 1900:
40 % cars were propelled by steam engine
38 % electric propulsion
22 % gasoline internal combustion engine
Principle of Li ion battery operation

Anode:
\[ C_6 + xLi^+ + xe^- \leftrightarrow Li_xC_6 \]

Cathode:
\[ LiCoO_6 \leftrightarrow Li_xCoO_6 + (1-x) Li^+ + (1-x)e^- \]
Li ion battery in practice

Structure of Lithium-Ion Battery

- Cathode cover
- Gasket
- Insulator
- Cathode lead
- Safety vent
- PTC
- Separator
- Anode container
- Center pin
- Anode lead
- Cathode
Li ion battery in practice

30-70 μm
aluminum collector  cathode  electrolyte  anode  copper collector

30-70 μm

Human hair

Li-ion battery in practice
Li ion battery in practice

30-70 μm

Carbon black
Active particles

ALUMINUM SUBSTRATE
CATHODE
ELECTROLYTE

Active particles

Li ion battery in practice
Classical electrode vs. Li battery electrode

Classical electrode

- Electrode (electron transfer on its surface)
- electrolyte
- O
- diffusion, convection of O and R

Li battery electrode

- active particles
- carbon black
- current collector (merely electron source)
- Li^+ movement
- electrolyte (ion source)
Classical electrode vs. Li battery electrode

Classical electrode

1 – external electron transport (wiring)
2 – electron transfer
3 – internal electron transport

Li battery electrode

1 – external ion transport (wiring)
2 – ion insertion
3 – internal ion transport
The obvious approach to maximisation of bulk transport:

\[ \tau = \frac{L^2}{D_{chem}} \]

- Active particle \((D_{chem})\)
- \(L\)

A measure of how fast a particle (electrode) can be filled/emptied

<table>
<thead>
<tr>
<th>(L)</th>
<th>(\tau)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (\mu)m</td>
<td>28 h</td>
</tr>
<tr>
<td>10 nm</td>
<td>100 s</td>
</tr>
</tbody>
</table>

\(D_{chem} = 10^{-13} \text{ cm}^2/\text{s}\)
Effect of particle size on charge-discharge curve

**LiFePO₄ (600 nm)**

- $\Delta U_1$
- Rev. capacity

**LiFePO₄ (ca. 100 nm)**

- $\Delta U_2$
- Reversible capacity

Additional graph showing capacity versus cycle number for two different particle sizes: 100 nm and 600 nm.
Where is the problem?

Nanoparticles tend to agglomerate!

Non-agglomerated

Agglomerated
Can we prevent agglomeration?

Almost universal solution: **additon of carbon**

Citric acid 700°C (in Argon)

Carbon coating

Carbon particles

Comparison of materials without and with carbon coatings (2005)

LiFePO$_4$ (a material found in Tesla roadster, in F1 etc...).

Other phenomena complicating the transport in Li ion batteries

1. Many-particle system

2. Non-monotone potential

Dissipation of energy

Limitation of Li ion batteries

Many combinations possible – BUT...!

Future Li batteries

Legend

Max. number of km by electric car having a 200 kg battery

150 km

Battery price (EUR / kWh)
How about Li-S batteries?

Legend

Max. number of km by electric car having a 200 kg battery

150 km

< 400

Battery price (EUR / kWh)
**PROBLEMS:**

Low electric conductivity of sulfur – possible problems in achieving high powers;

Solubility of sulfides can significantly reduce the capacity.
How likely are Li-air batteries?
Li – AIR batteries

**PROBLEMS:**

Hypothesis: formation of superoxide (free radical) which is too reactive in the battery surroundings

Appropriate membrane needed to separate metallic lithium from the oxygen-base cathode
Future of electric cars...

- Production of hybrid cars is increasing fast
- All technology needed for electric (battery) car is already contained in hybrid cars (so development is under way)
- Pure electric cars are too expensive mainly due to (still) expensive batteries
- Mass production of electric cars would decrease their price
- Electric car technology is rather simple…*

*electric twingo made by students of Ljubljana university
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