Energy Storage Technologies: Renewable and Sustainable.

A. Rufer, LEI, EPFL

ISGT 2010
The energy context, today, tomorrow

- Energy density and power density

- Life cycle aspects

- From aging batteries to solutions from the reversible physics

- Conclusions
Electricity storage for DG (Decentralised Generation):
- Stochastic generators can be made dispatchable for grid integration
- Stochastic loads can be made compatible with grid disponibility
Decentralized generation: power fluctuations

Centralized Generation and utility

Distributed Generation

T&D

High Voltage

ΔP/Pn: Not measurable

Medium and Low Voltage

Factory

Domestic users

ΔP/Pn: Significant
The development of the future energy technologies, that means the « after cheap oil » era, goes evidently through a re-definition of the criteria and values concerning two fundamental parameters, namely the **energy density** and also the **power density**.

The fundamental parameters to be rediscussed
• Energy density
What quantity of energy in what volume or for what weight?

• Power density
How fast can one load and unload the energy carrier?
Energy on board

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Weight (kg)</th>
<th>Energy (kWh)</th>
<th>Distance (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>42.5 MJ/kg (Gasoline)</td>
<td>50</td>
<td>590</td>
<td>800</td>
</tr>
<tr>
<td>132 Wh/kg (Li-ion)</td>
<td>400</td>
<td>53</td>
<td>248</td>
</tr>
<tr>
<td>30 Wh/kg (Pb-acid)</td>
<td>200</td>
<td>6</td>
<td>80</td>
</tr>
<tr>
<td>50 Wh/m³ (Air, 300bar)</td>
<td>200 l</td>
<td>10</td>
<td>200</td>
</tr>
<tr>
<td>42.5 MJ/kg (Gasoline)</td>
<td>1 l (eq.)</td>
<td>8.6</td>
<td>5385</td>
</tr>
</tbody>
</table>

Notes:
- (1) 200 km (MDI)
- 800 km (world record)
- 248 km (10 x less)
- 80 km (100 x less)
• Energy density
What quantity of energy in what volume or for what weight?

• Power density
How fast can one load and unload the energy carrier?
Again the examples of cars:
A filling time of 2 minutes

Gasoline car: 600 kWh in 2 minutes: $600 \times 60 / 2 = 18'000$ kW!

Li-ion Battery car: 60 kWh in 20 minutes: $= 180$ kW!

Lead-Acid Battery car: 6 kWh in 20 minutes: $= 18$ kW
A new concept actually under study

Properties of the fast transfer of air under pressure

The fast fill power level: 10kWh/2 min: 300 kW, possible under high efficiency
To the elementary properties as energy density or power density, the life cycle of a given technology belongs to the most important criteria that can lead to sustainable development. **Recycling** belongs also to the new considerations.

**Li-ion:**
Wikipedia:
Durée de vie: 24-36 mois
Nombre de cycles de charge: 1200

Touring, 19.08.2010:
… 500 à 1000 cycles de décharge et recharge au maximum
Vanadium Redox Flow Battery: A step in the direction of higher life cycles (10-15’000)

Cellstrom (A) : « Solartankstelle » 10 kW / 100 kWh

www.cellstrom.com

C.Blanc 2009
Low energy density
An example of application: the elevator (peak shaving) with the help of Supercapacitors

A high inertia system: Cabin and counterweight must be accelerated

Barrade, Rufer 2002
Not considered in this diagram: THESE:
- Thermal Energy Storage of Electricity
  - Needs detailed analysis regarding efficiency
  - Needs technology developments
From aging storage components of the electrochemical sector, to new approaches in the field of reversible physics:
- Long life cycle,
- No materials difficult to recycle
- Repairable equipments

Energy storage with compressed air
Physics

(a) Available expansion energy

(b) Volumetric Energy Density
From "pneumatic" to "hydro-pneumatic"

⇒ The concept of the "liquid piston"
And finally a hybrid structure:

Lemofouet 2006
From research to industrialization

Clean Energy Efficiency and Autonomy

→ Goal: Provide Clean Energy Efficiency or Autonomy only from Renewable Energy Sources
Another interesting solution: Compressed air with « closed » gas cycle
Compressed air with « closed » gas cycle

Optimization

\[ p_{\text{final}} = \frac{p_{\text{max}}}{2} \]

Little amount of water pumped at a high mean pressure

\[ p_{\text{final}} = \frac{p_{\text{max}}}{5} \]

More water pumped at a lower mean pressure

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Compressed air with « closed » gas cycle

Maximum stored energy

- $\alpha$ : compression ratio,
  $V$ : storage volume,
  $p_{\text{max}}$ : maximum working pressure

- stored energy $W = p_{\text{max}} \cdot (V - V_0) \cdot \frac{\ln(\alpha)}{\alpha}$

- maximum obtained for $\alpha = e = 2.718$

$$W_m = \frac{1}{e} \cdot p_{\text{max}} \cdot (V - V_0) = 0.368 \cdot p_{\text{max}} \cdot (V - V_0)$$

- in kWh $W_m = \frac{p_{\text{max}} \cdot (V - V_0)}{100}$ with $p_{\text{max}}$ in bars

- Practically : 1 kWh per m$^3$ and hectobar
Compressed air with « closed » gas cycle

Order of magnitude

<table>
<thead>
<tr>
<th>Maximum working pressure $p_{\text{max}}$</th>
<th>Available energy per m$^3$</th>
<th>Stored energy in 100 m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 bars</td>
<td>0.5 kWh</td>
<td>50 kWh</td>
</tr>
<tr>
<td>120 bars</td>
<td>1.2 kWh</td>
<td>120 kWh</td>
</tr>
<tr>
<td>200 bars</td>
<td>2 kWh</td>
<td>200 kWh</td>
</tr>
<tr>
<td>300 bars</td>
<td>3 kWh</td>
<td>300 kWh</td>
</tr>
</tbody>
</table>

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Compressed air with « closed » gas cycle

Comparison between gravity and pressure storages

- **Pumped Hydro Storage with 250 m head**
  - 1 MWh : 2000 m³ of water pumped

- **Hydropneumatic at 200 bar**
  - 1 MWh : 500 m³ pipes volume
  - 200 m³ of water pumped
  - 48 ” pipes – Ø 122 cm
  - 430 m linear → 35 x 12 m pipes
  - 7 rows of 5 pipes
  - area 10 m x 60 m
One Example of Pumped Hydro Facility under construction:

The project « Nant-de-Dranse », an existing complex (Vieux Emosson and Emosson) New added equipment for 600 MW pump/turbine with variable speed
Conclusions

• The redefinition of fundamental parameters: Energy Density, Power Density
• Storage of electric energy remains one of the main challenges
• Energy technologies based on reversible physics are preferable for long life cycles