Energy Storage Technologies: Renewable and Sustainable.

A. Rufer, LEI, EPFL

ISGT 2010

Content

-The energy context, today, tomorrow

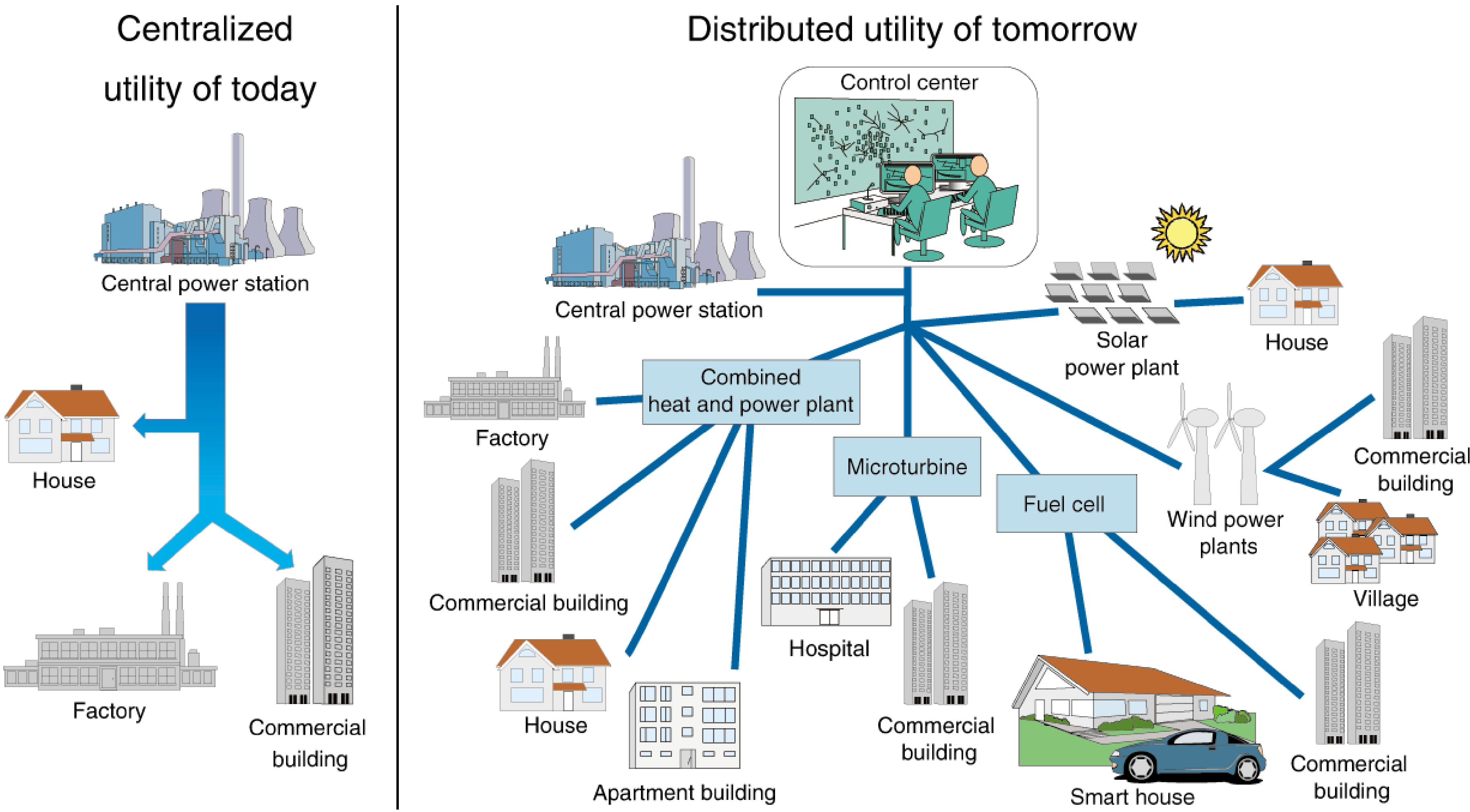
- Energy density and power density

- Life cycle aspects

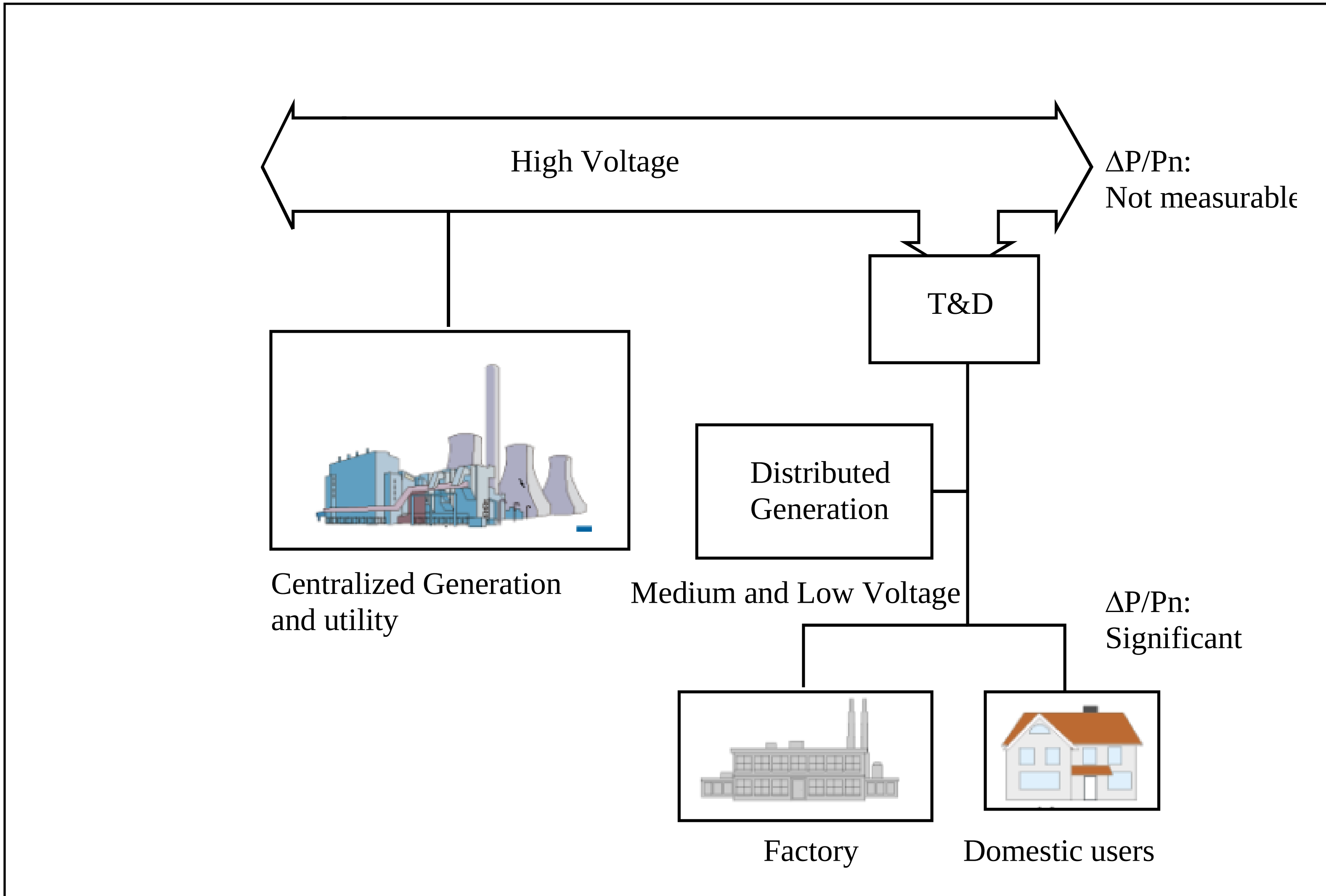
- From aging batteries to solutions from the reversible physics

- 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



The development of the future energy technologies, that means the « after cheep 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

42.5 MJ/kg (Gasoline) 50 kg 590 kWh 800 km

(1)

132 Wh/kg (Li-ion) 400 kg 53 kWh 248 km

(10 x less)

30 Wh/kg (Pb-acid) 200 kg 6 kWh 80 km

(100 x less)

50 Wh/m3 (air, 300bar) 200 l 10 kWh 200 km ?(MDI)

42.5 MJ/kg (Gasoline) 1 l (eq.) 8.6 kWh 5385 km!

(world record)

- 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

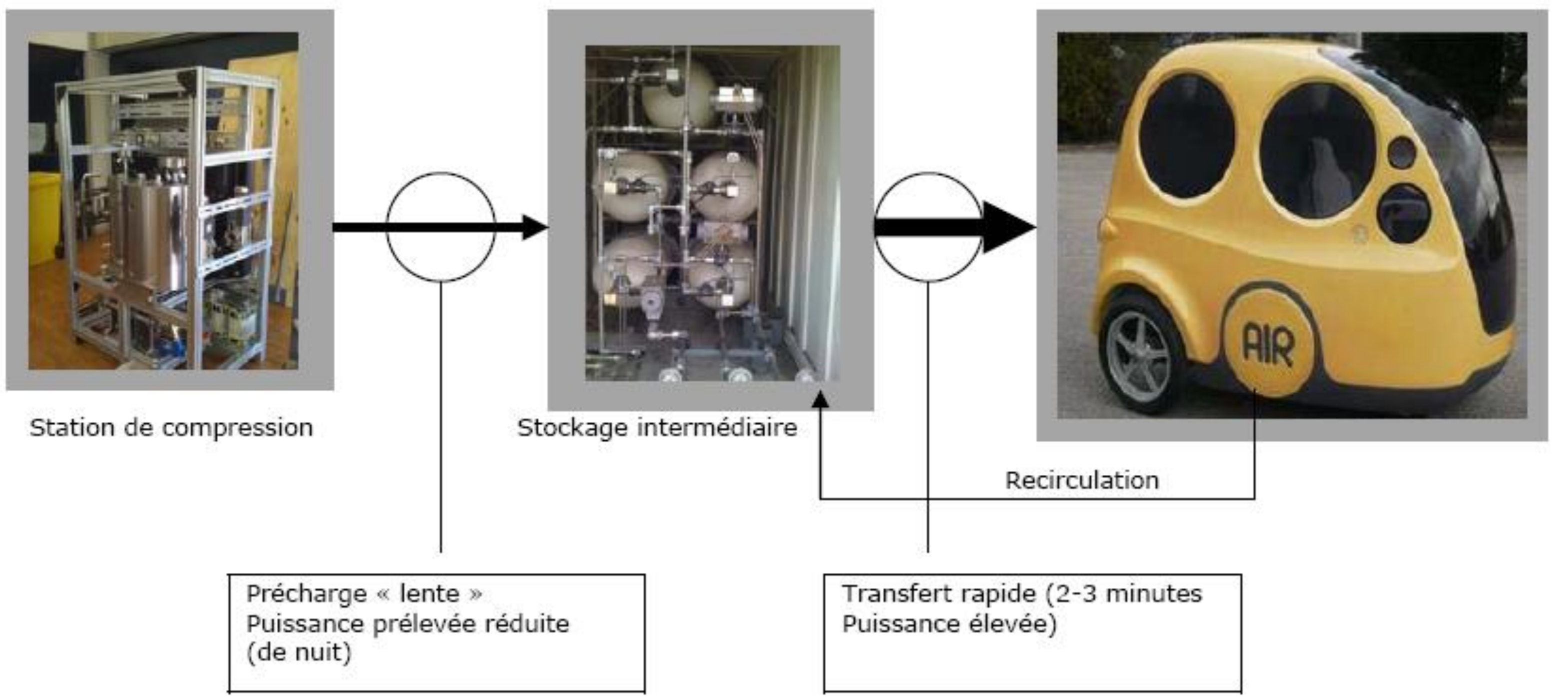
Gasoline car: 600 kWh in 2 minutes: 600*60/2 = 18’000 kW!

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

Lead-Acid Battery car: 6 kWh in 20 minutes: = 18 kW

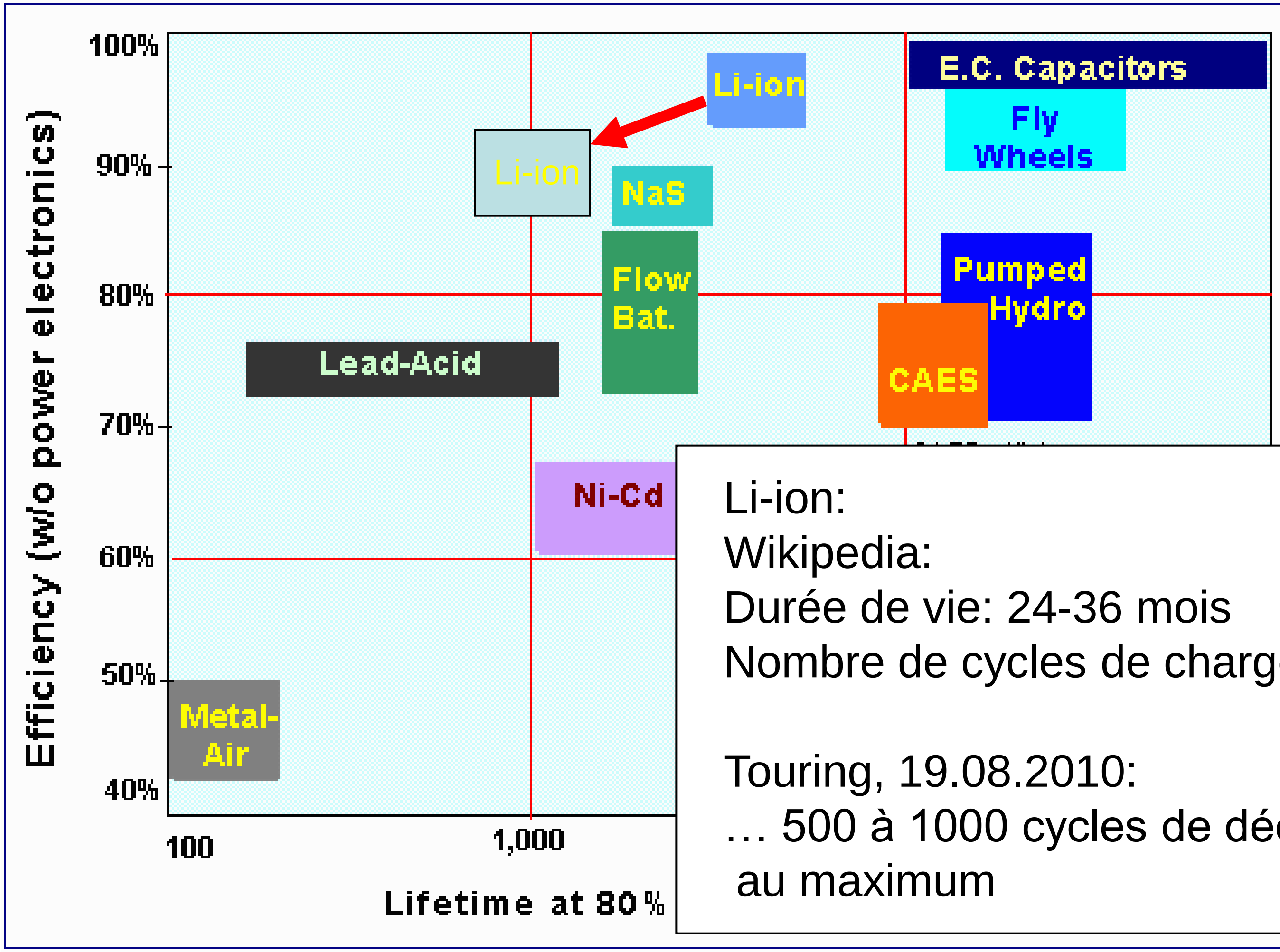
A new concept actually under study

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

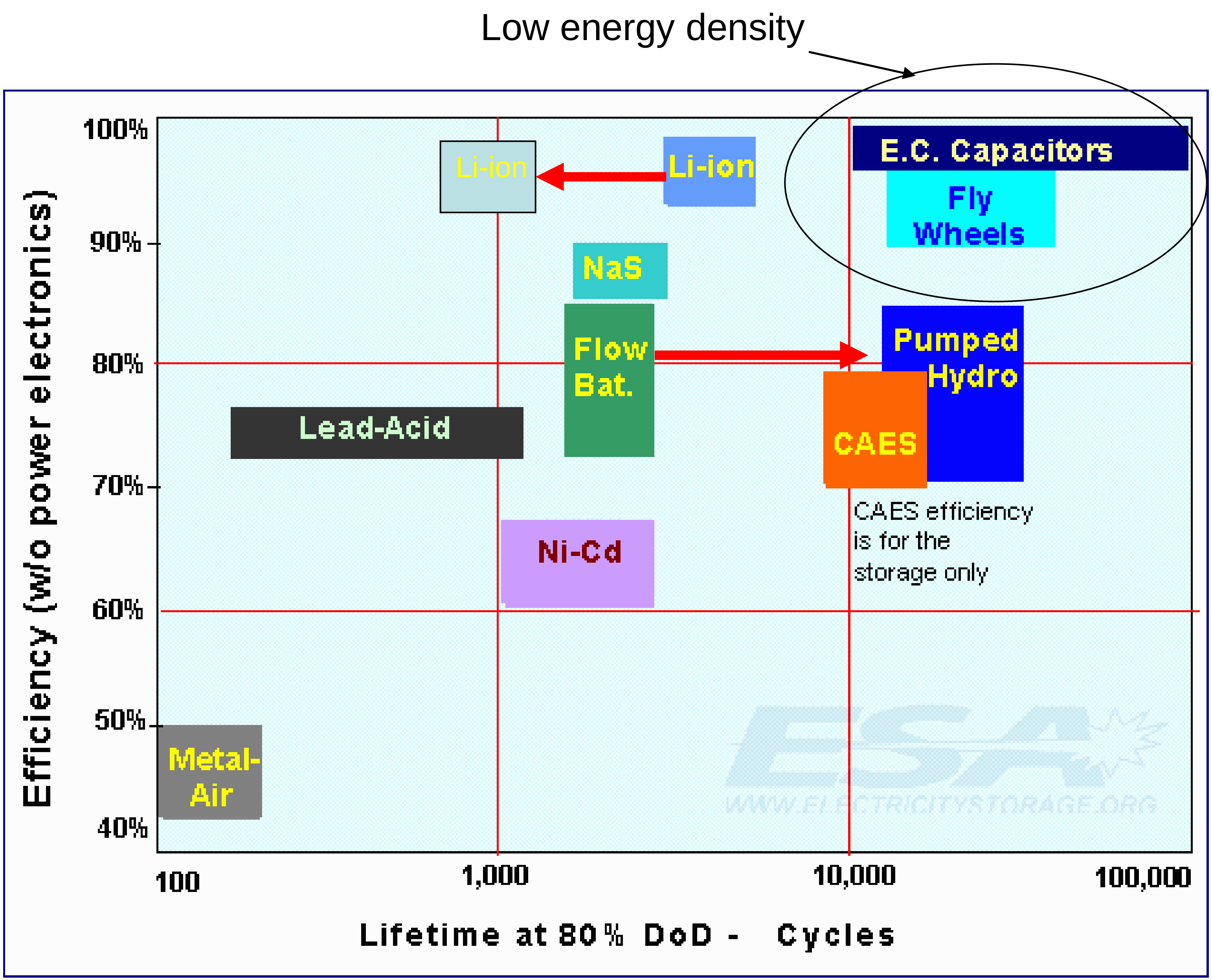
Touring, 19.08.2010:
… 500 à 1000 cycles de décharge et recharge au maximum

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

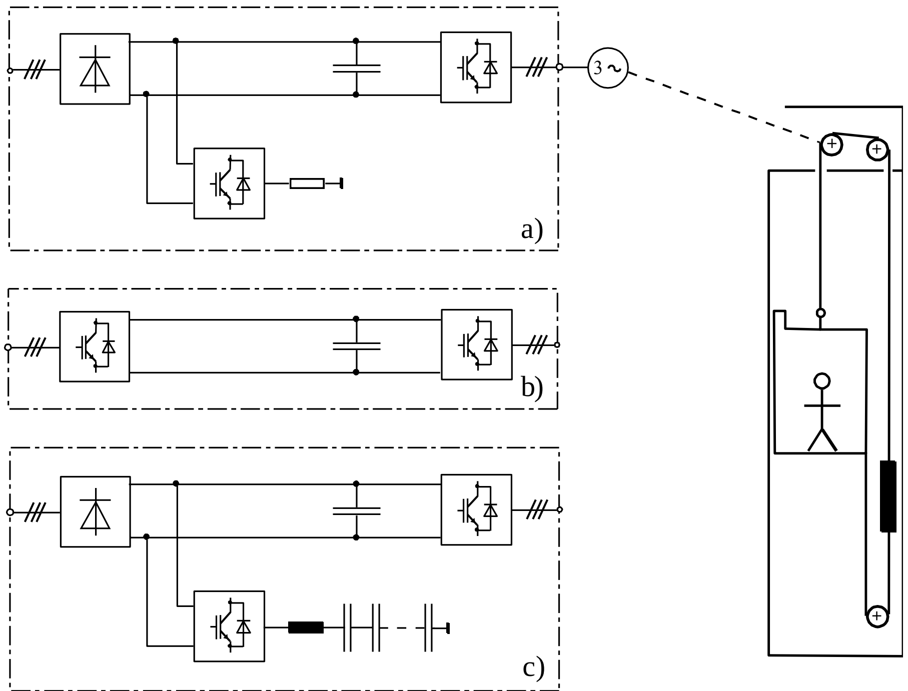
C.Blanc 2009

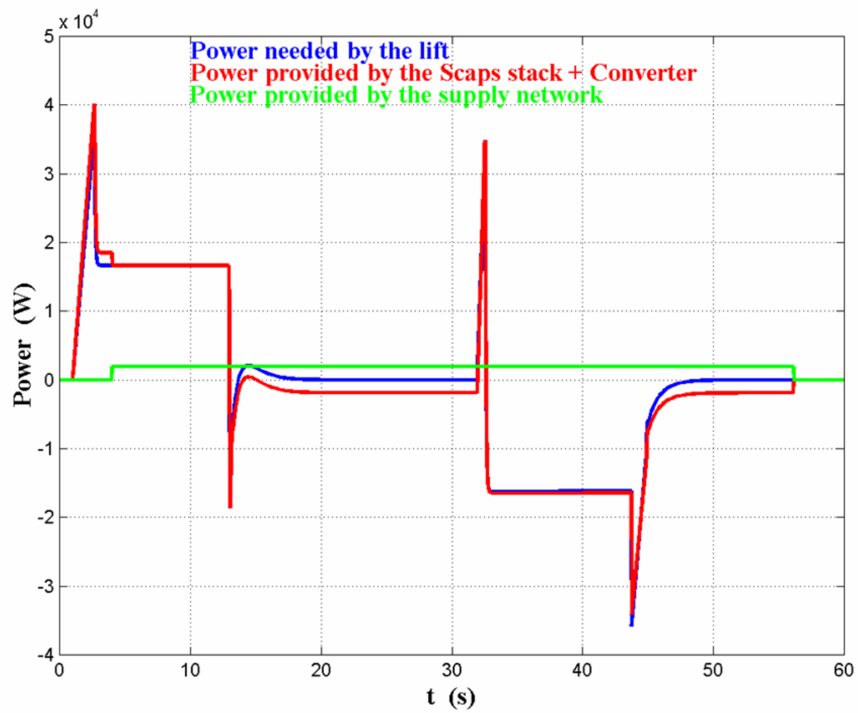


Low energy density
100%
90%
80%
70%
60%
50%
40%
Li-ion
Li-ion
E.C. Capacitors
Fly Wheels
NaS
Flow Bat.
Pumped Hydro
Lead-Acid
CAES
CAES efficiency is for the storage only
Ni-Cd
Metal-Air
100
1,000
10,000
100,000
Efficiency (w/o power electronics)
Lifetime at 80% DoD - Cycles

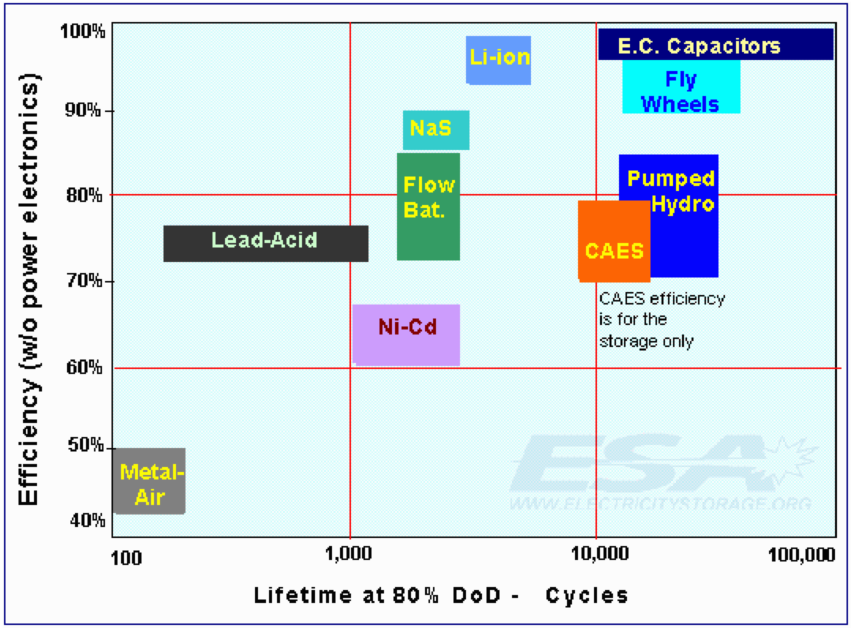
An example of application: the elevator (peak shaving) with the help of Supercapacitors

A high inertia system: Cabin and conterweight must be accelerated



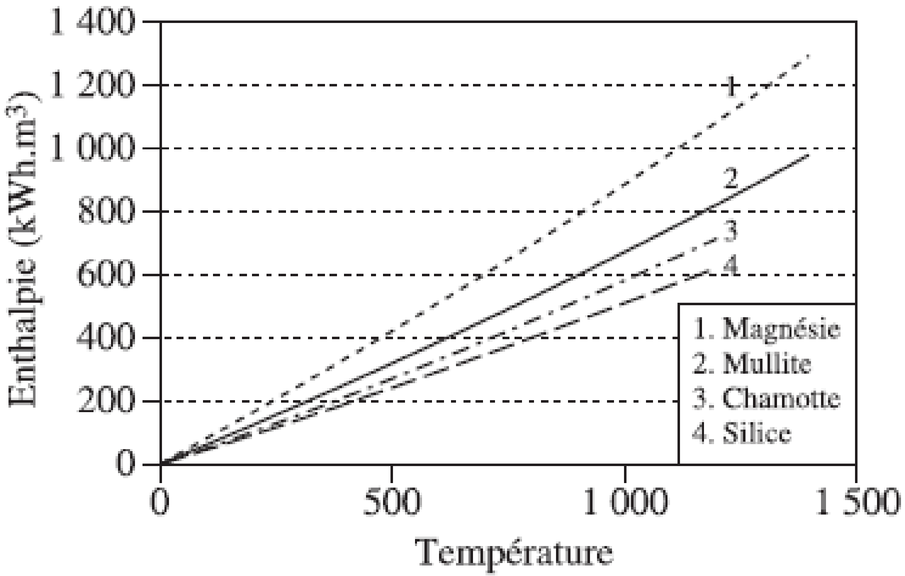


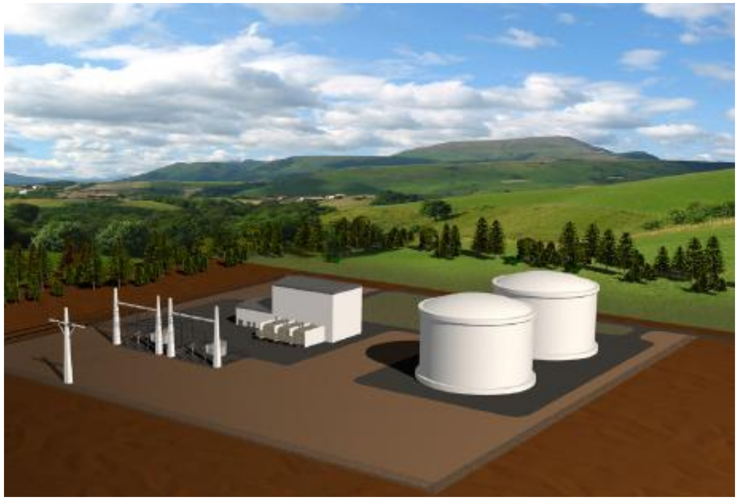
Barrade, Rufer 2002



Not considered in this diagram: THESE:
THermal Energy Storage of Electricity

- Needs detailed analysis regarding efficiency
- Needs technology developments



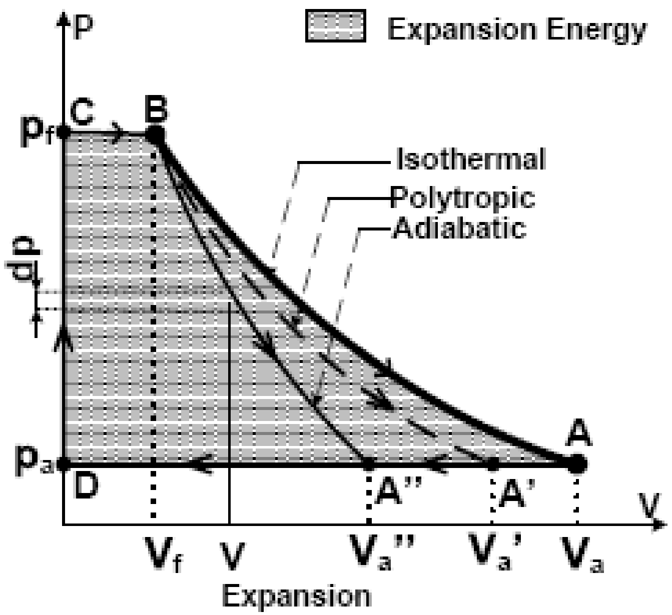


From aging storage components of the electrochemical sector, to new approaches in the field of reversible physics:

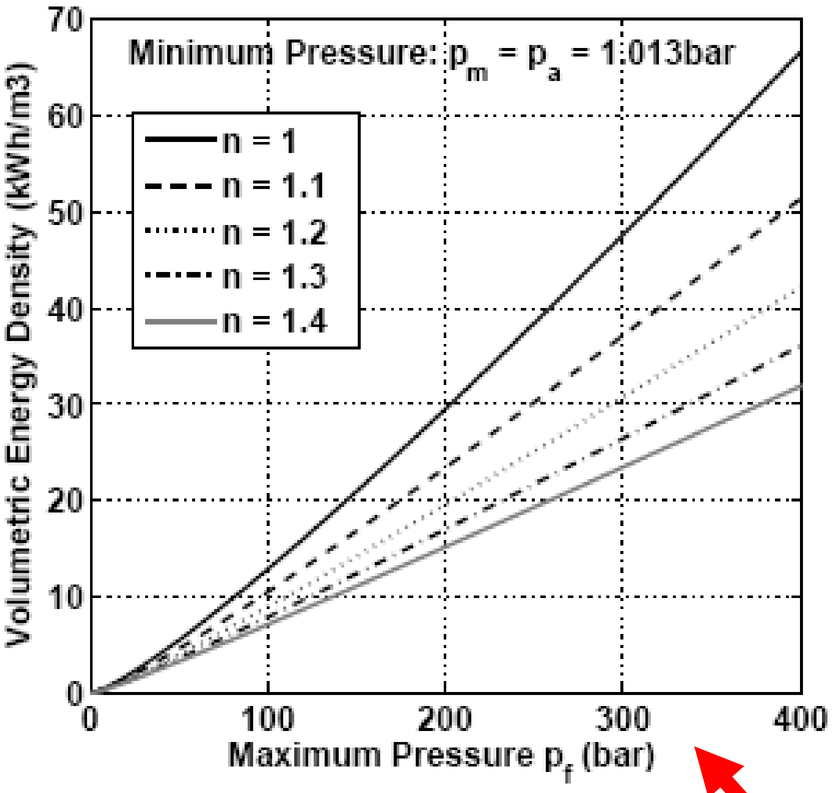
- Long life cycle,
- No materials difficult to recycle
- Repairable equipments

Energy storage with compressed air

Physics

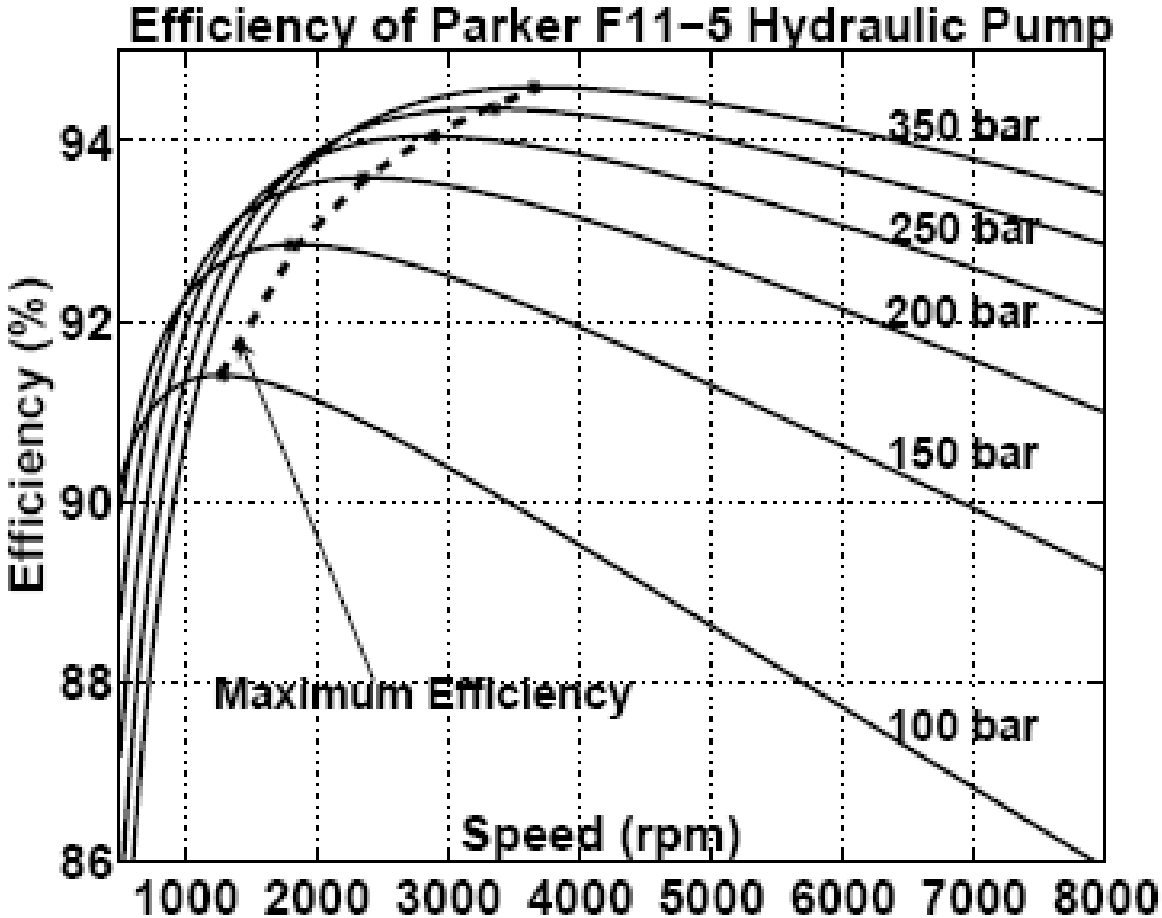


(a) Available expansion energy



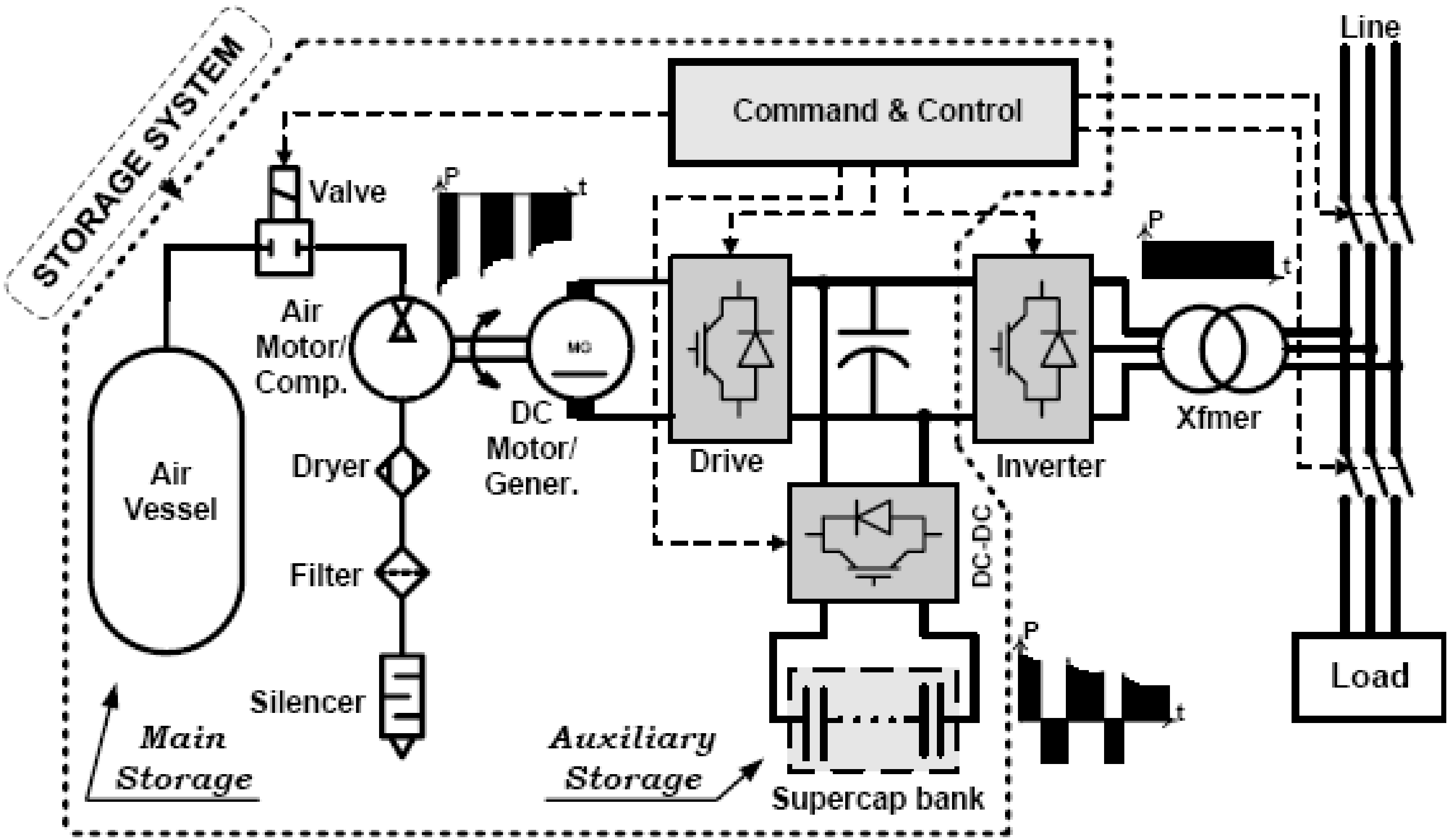
(b) Volumetric Energy Density

From « pneumatic » to « hydro-pneumatic »



⇒ The concept of the « liquid piston »

And finally a hybrid structure:

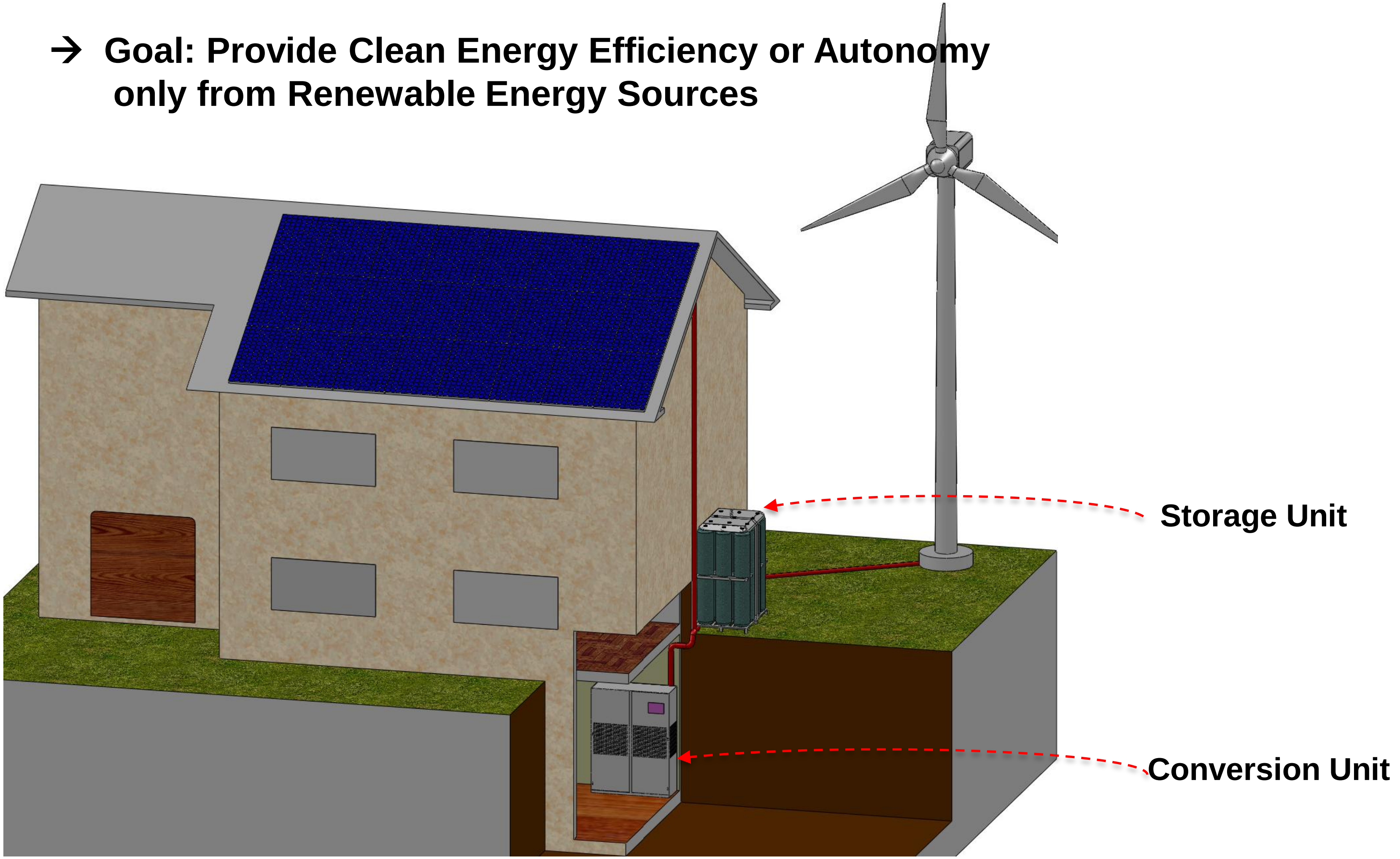


Lemofouet 2006

From research to industrialization

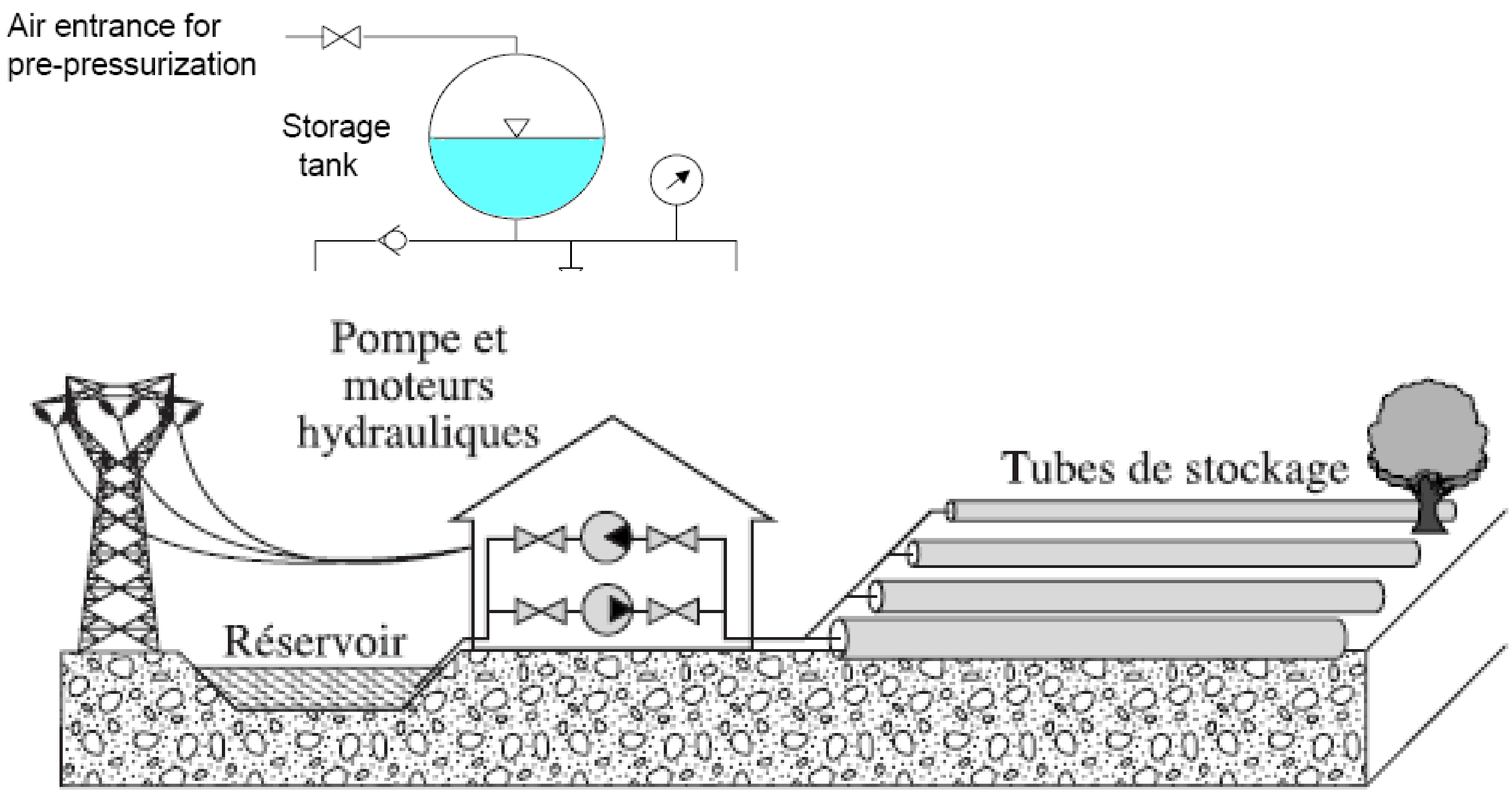
Clean Energy Efficiency and Autonomy

→ **Goal: Provide Clean Energy Efficiency or Autonomy only from Renewable Energy Sources**



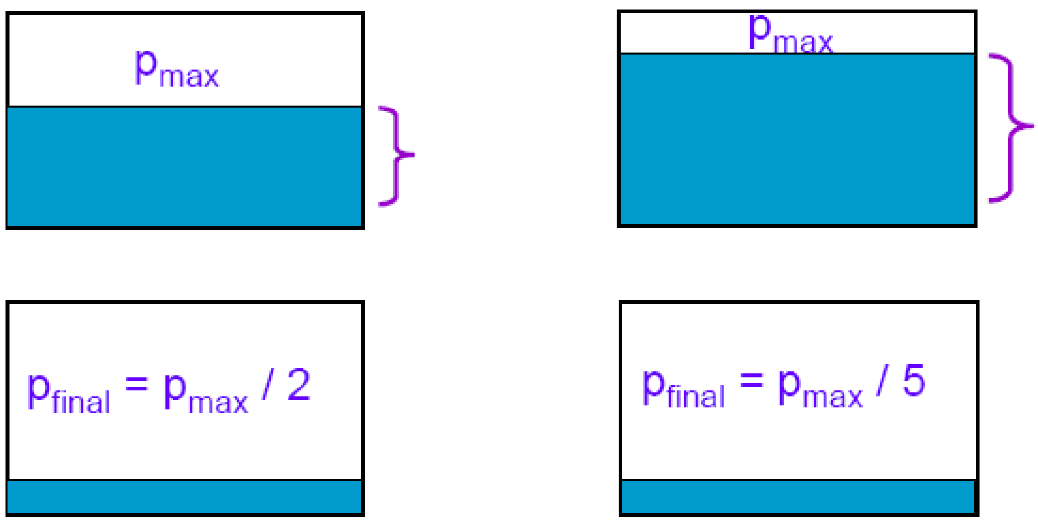
Another interesting solution: Compressed air with « closed » gas cycle

Simplified diagram of a system



Compressed air with « closed » gas cycle

Optimization



Little amount of water pumped at a high mean pressure

More water pumped at a lower mean pressure

Compressed air with « closed » gas cycle

Maximum stored energy

- α : compression ratio,
  V : storage volume,
  p_{max} : maximum working pressure
- stored energy $W = p_{max} \cdot (V - V_0) \cdot \frac{Ln(\alpha)}{\alpha}$
- maximum obtained for α = e = 2,718

$$W_m = \frac{1}{e} \cdot p_{max} \cdot (V - V_0) = 0{,}368 \cdot p_{max} \cdot (V - V_0)$$

- in kWh $W_m = \frac{p_{max} \cdot (V - V_0)}{100}$ with p_{max} in bars
- Practically : 1 kWh per m^3 and hectobar

Compressed air with « closed » gas cycle

Order of magnitude

Maximum working pressure p_{max}	Available energy per m^3	Stored energy in 100 m^3
50 bars	0,5 kWh	50 kWh
120 bars	1,2 kWh	120 kWh
200 bars	2 kWh	200 kWh
300 bars	3 kWh	300 kWh

Compressed air with « closed » gas cycle

Comparison between gravity and pressure storages

- Pumped Hydro Storage with 250 m head
  - 1 MWh : 2000 m^3 of water pumped
- Hydropneumatic at 200 bar
  - 1 MWh : 500 m^3 pipes volume

    200 m^3 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