International Conference

Energy Autonomy

through

Storage of Renewable Energies

by

EUROSOLAR and WCRE

October 30 and 31, 2006

Gelsenkirchen / Germany

Physics and Economy of Energy Storage

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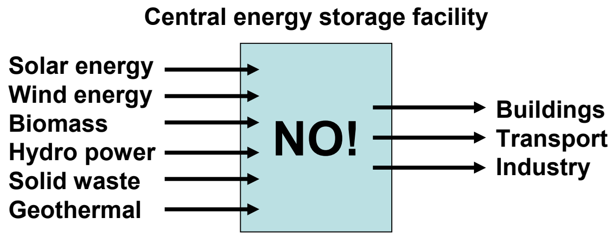
Reduction of Storage Demand by Balanced Management of Renewable Energies

Solar energy	heat	**- 24 hour hot water storage**
	electricity	Synchronous with daily electricity demand **- modest storage needs**
Wind energy	electricity	Supply linked to weather pattern **- need partial storage**
Biomass	wood	Is already stored energy **- use in Winter, not year round**
	biogas	Easy to store for up to 12 hours **- use for peak power production**
	biofuels	Easy to store and transport
Hydro power	flowing water	**- base load**
	storage lakes	**- for balancing wind power**
Solid waste and digester gas		**- continuous base load**

The energy storage problem is drastically reduced by an optimized operation of renewable energy installations

No Central Storage for all Renewable Energies



Wishful thinking of energy companies and „dreamers“

**Most likely,
renewable energy will primarily be stored onsite
in quantity and quality needed for particular applications**

**Energy users will become responsible for
“individual” or “personalized” energy storage solutions**

Storage of Energy

Chemical energy is stored by mass or volume:

Coal: bunks, silos, dumps
Oil: tanks, barrels, drums
Gas: tanks,
Biomass: wood stacks, silos, dumps

This is not the topic of this talk

Need physical energy storage solutions

This is the topic of my presentation

Energy Challenge

Matching of physical demand to physical supply

With the exception of food
people need **physical energy**
motion, communication, lighting, heating and cooling
(space conditioning and cooking), industrial processes

With the exception of biomass
nature provides **physical energy**
kinetic energy of wind, water, waves
solar radiation, geothermal heat

The challenge is the direct transfer of physical energy from source to service

Physical Energy Storage Options

Electricity:

Pumped storage
Batteries
Fly wheels
Compressed air

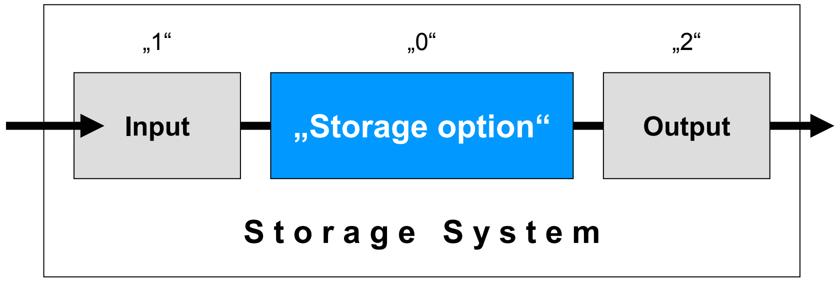
Heat & Cold:

Water tanks (sensible heat)
Bricks (sensible heat)
Ice (latent heat)
Steam (latent heat)

This presentation is concerned with physics and economics of physical energy storage

Technical solutions will be discussed by the following speakers

Energy Storage Systems



Examples

48V=/12 V= | **battery** | 12 V=/220V≈

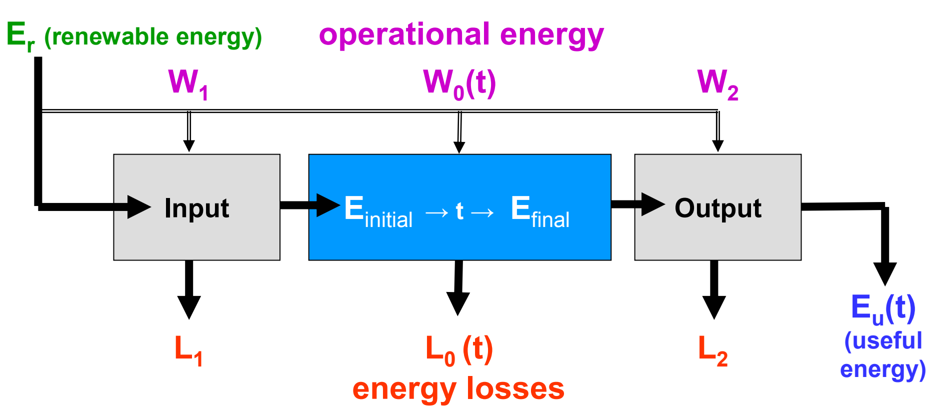
380V≈ motor + compressor | **pressure tank** | expansion turbine + generator 220V≈

heat exchanger + pump | **hot water storage tank** | heat exchanger + pump

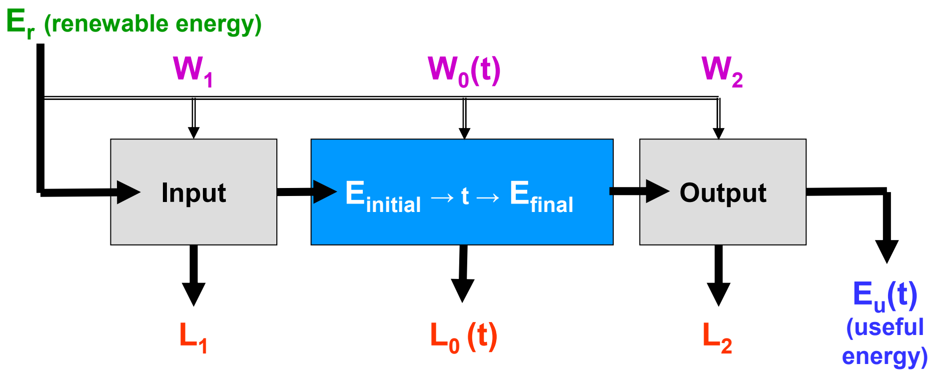
380V≈/100V= + electrolyzer + compressor | **hydrogen tank** | fuel cell + 48V=/220V≈

Need to consider the entire storage system
(not just the storage option)

Energy Balance of Energy Storage



Energy Storage Balance Equation



useful energy = renewable energy – operational energy – energy losses

$$E_u(t) = E_r - [W_1 + W_0(t) + W_2] - [L_1 + L_0(t) + L_2]$$

Energy Storage Efficiency

$$E_u(t) / E_r = 1 - [W_1 + W_0(t) + W_2] / E_r - [L_1 + L_0(t) + L_2] / E_r$$

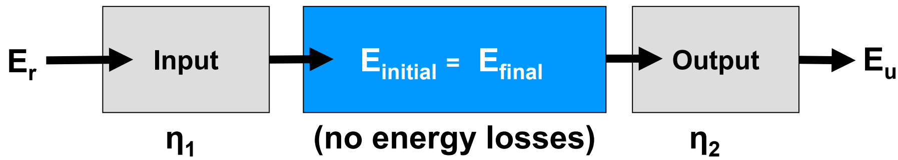
$$\eta_s(t) = E_u(t) / E_r = 1 - \eta_W(t) - \eta_L(t)$$

Overall energy storage efficiency can be increased by

- lowering operational energy consumption
  (input, storage operation, output)
- lowering energy losses
  (input, storage losses, output)

Energy consumption and energy losses of input and output equipment depend on type of storage, chosen equipment, operational parameters etc. These engineering details shall not be considered in this context.

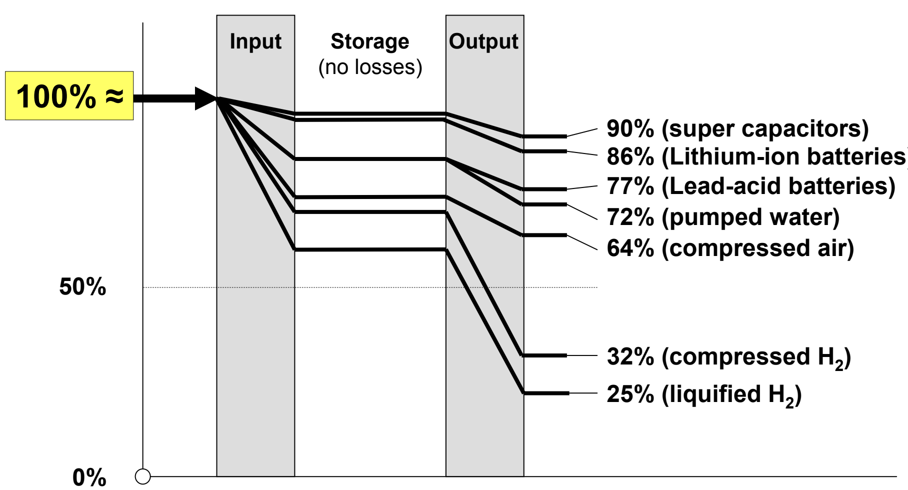
Energy Storage Transfer Efficiency



Efficiency	Input V≈	Output V≈	Total
Super capacitors	0.95	0.95	0.90
Lithium-ion batteries	0.93	0.93	0.86
Flywheel storage	0.90	0.90	0.81
Lead acid batteries	0.85	0.90	0.77
Pumped water storage	0.85	0.85	0.72
Compressed air storage	0.75	0.85	0.64
Gaseous H_2 storage	0.70	0.45	0.32
Liquid H_2 storage	0.50	0.45	0.25
Hot water storage	0.95	0.95	0.90

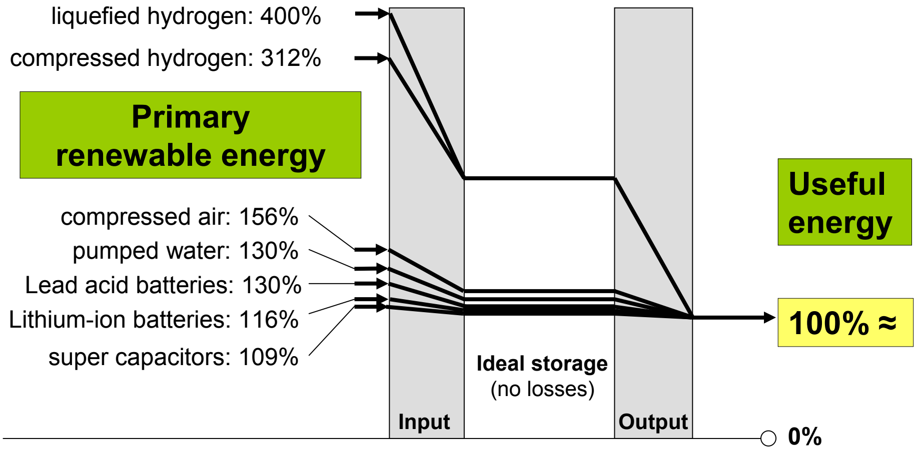
Super capacitors and batteries much better than hydrogen

Energy Storage Transfer Losses



Only 1/3 of the original energy for hydrogen storage

Renewable Energy Demand to Cover Storage Transfer Losses



Storage transfer efficiency essential for economic use of renewable energy

Energy Storage Losses

Amount of energy stored = C x „quantity“ x „quality“

(C = proportionality constant)

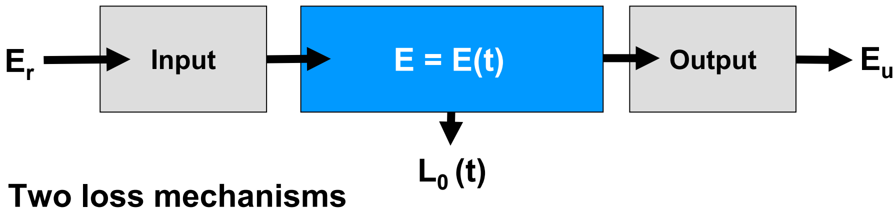
Batteries	C x electrical charge x voltage
Pumped storage	C x water mass x vertical drop
Compressed air	C x volume x pressure
Hot water storage	C x water mass x temperature
Flywheel	C x moment of inertia x speed of rotation

Storage losses result from loss of „quantity“ (a) or loss of „quality“ (b)

Batteries	loss of charges by self-discharge (a)
Pumped storage	Water evaporation, leakage (a)
Compressed air	leakage (a)
Hot water storage	temperature loss (b)
Flywheel	speed of rotation (b)

Energy storage losses depend on design features of storage system and time

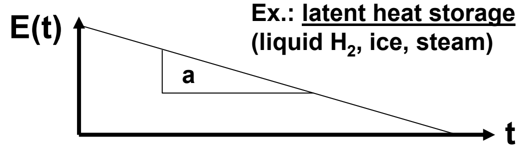
Time-Dependence of Energy Losses



Two loss mechanisms

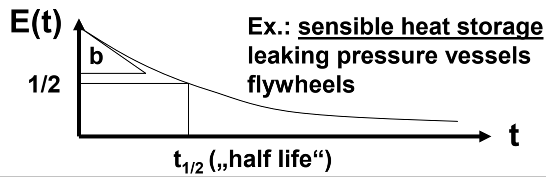
1. Linear decay of energy content

   $E = E_0 [1 - a \times t]$



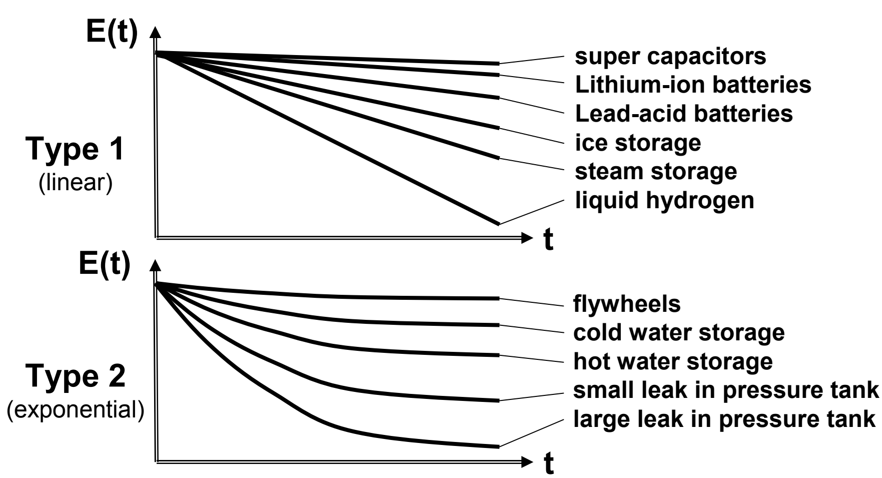
2. Exponential decay of energy content

   $E = E_0 [1 – b \times \exp(t/t_{1/2})]$



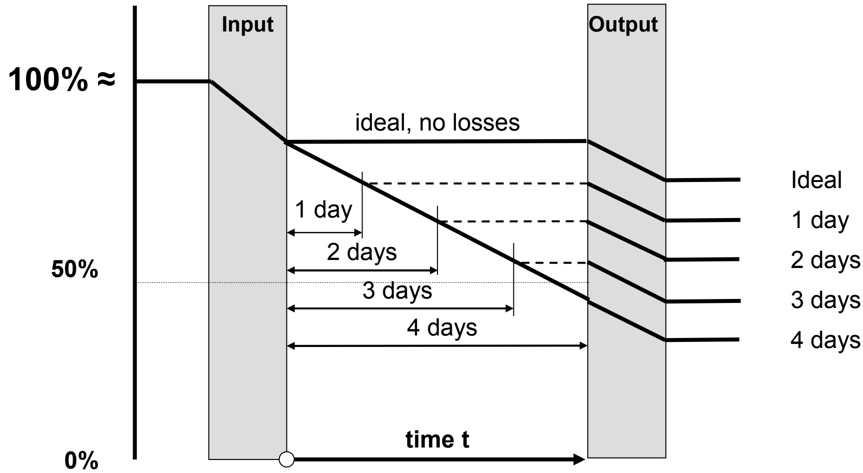
Constants a, b and $t_{1/2}$ are given by storage system design

Typical Energy Loss Categories



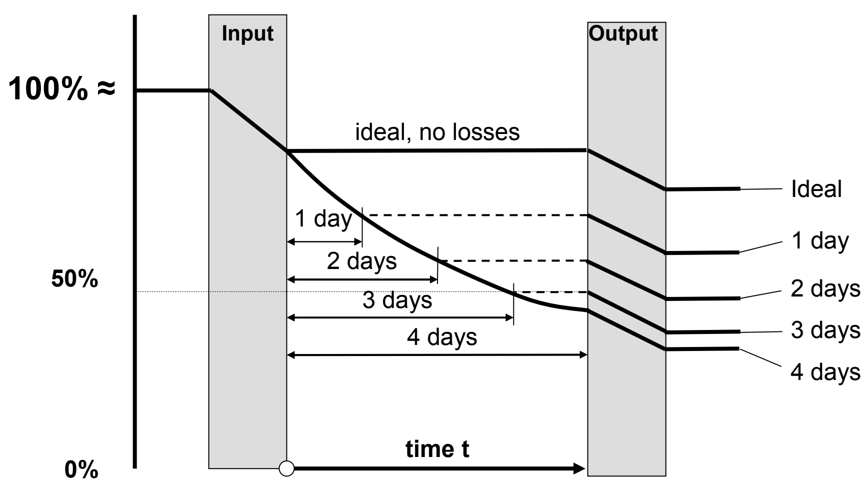
Slope of curves depends on system design

Linear Energy Losses with Time



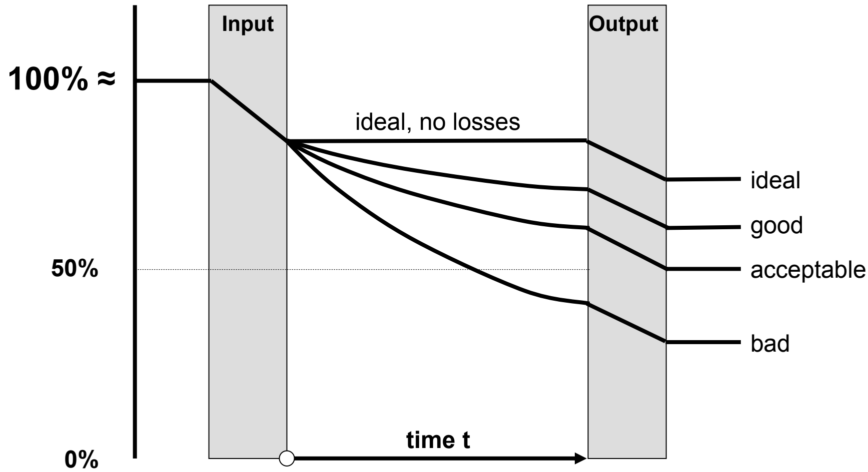
Same energy losses every day

Exponential Energy Losses with Time



Highest energy losses on 1st day, then falling

Energy Storage Losses and Design



Total energy storage losses depend on storage design

Economics

Basis of all business

1. Profit per transaction (P)
(Value of sales must exceed value of purchases)

2. Number of transactions per year (n)
(as many as possible)

Good business: product of both is maximized
(P x n = max)

Energy Storage Economics

Profit per Energy Storage Cycle (P)

=

energy sold from storage (E_u) x energy sales price ($\$_u$)

minus

energy purchased (E_r) x energy purchase price ($\$_r$)

$$P = E_u \times \$_u - E_r \times \$_r$$
$$= E_u \times \$_u \,(1 - E_r/E_u \times \$_r/\$_u)$$
$$= E_u \times \$_u \,(1 - 1/\eta_s \times \$_r/\$_u)$$

For profit:

$(1 - 1 / \eta_s \times \$_r / \$_u) > 0$ or $\eta_s > \$_r / \$_u$

For profitable operation of energy storage the storage system efficiency must be better than the ratio of energy purchase and sales price

Profitability of Energy Storage Systems

Electricity purchased for 1.00 €

must be sold from storage for at least

Super capacitors	$\eta_s = 0.90$	1.11 €
Lithium-Ion batteries	$\eta_s = 0.86$	1.16 €
Lead acid batteries	$\eta_s = 0.77$	1.30 €
Pumped water storage	$\eta_s = 0.72$	1.39 €
Compressed air storage	$\eta_s = 0.64$	1.56 €
Gaseous hydrogen storage	$\eta_s = 0.32$	3.13 €
Liquefied hydrogen storage	$\eta_s = 0.25$	4.00 €

Electricity storage with hydrogen not attractive

If electricity can be sold for 4.00 €/unit storage operators will hype profits with batteries

Energy Storage Cycles per Year

100,000	**Regenerative braking of electric cars**
730	**Tidal power plants** (2 or 4 cycles per day)
365	**Photovoltaic and solar thermal power plants** (1 cycle per day, **day → night, if at all**)
365	**Running waters, ocean waves, wind geothermal, solid waste incineration** (1 cycle per day, **night → day, following demand**)
52	**Weekend surplus, wind, solar** (storage for 3 days)
26	**Wind, solar** (storage for two weeks)
1	**Seasonal storage** (storage for 6 months)

**Long-term storage of physical energy difficult.
Most storage needs are met with 1 cycle per day
(same as today!)**

Energy Storage Economics

Annual revenues from energy storage
= profit per storage cycle x number of cycles per year
minus cost of operation
minus cost of maintenance
minus cost of invested capital

**Maximize profit per cycle and cycles per year,
minimize cost of operation, maintenance and capital**

Cycle profits can be raised if electricity is stored
in the form of later use without re-conversion to grid quality

**Value of stored electricity may be far above cost of energy.
(e.g. mobile phones, automobile batteries, laptops)**

Need Electricity Storage Management

Dispersed one-way storage units are grid-connected

They are charged by electric power utility
at times when surplus power is inexpensive
to 80% whenever recharging is needed
to 100% when excess power is available

Parked electric cars stay grid-connected

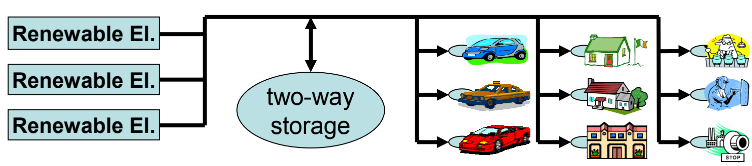
Charging conditions as above.
Need automatic charge transfer platforms in garages and parking lots.
Electricity received is metered on board or by HF-signals
and charged to the car owner by the end of each month

Today: Electricity must be delivered when needed
Future: Electricity will be distributed when available and stored in appliance-connected batteries

Need One-Way Storage Systems

Sustainable future:

Two-way electricity storage facilities will always be needed
One-way electricity storage will become integral part of appliances, cars, electronic equipment, homes etc.



Dispersed one-way electricity storage units could be managed by electric utilities, not by home or car owners

Conclusions

From physics and economics:

1. Long-term storage of electricity difficult
2. Long-term storage of electricity not economic
3. Main storage demand is met by 12-hour storage systems
4. Many small electrical one-way storage systems likely
5. Electricity storage systems in appliances, cars, homes
6. Electricity storage systems owned by energy user
7. But storage systems may be managed by utilities
8. Electricity distributed when available, not when needed
9. Need strategies for decentralized energy storage

Storage demand can be drastically reduced by balanced numbers of renewable energy facilities and their smart operation

Thank you for your attention!

Questions?

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Plan to attend

and

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Thank you!

Ulf Bossel – Gelsenkirchen 301006

2 - 6 July 2007, Lucerne / Switzerland

World

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