Sustainable energy storages for mobile machines

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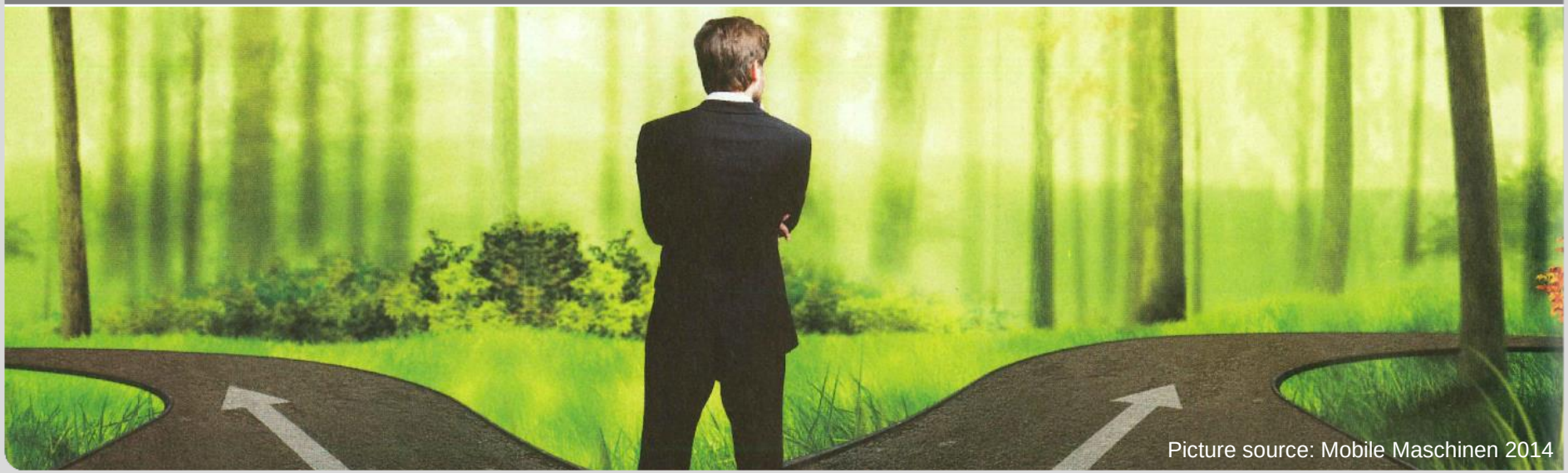
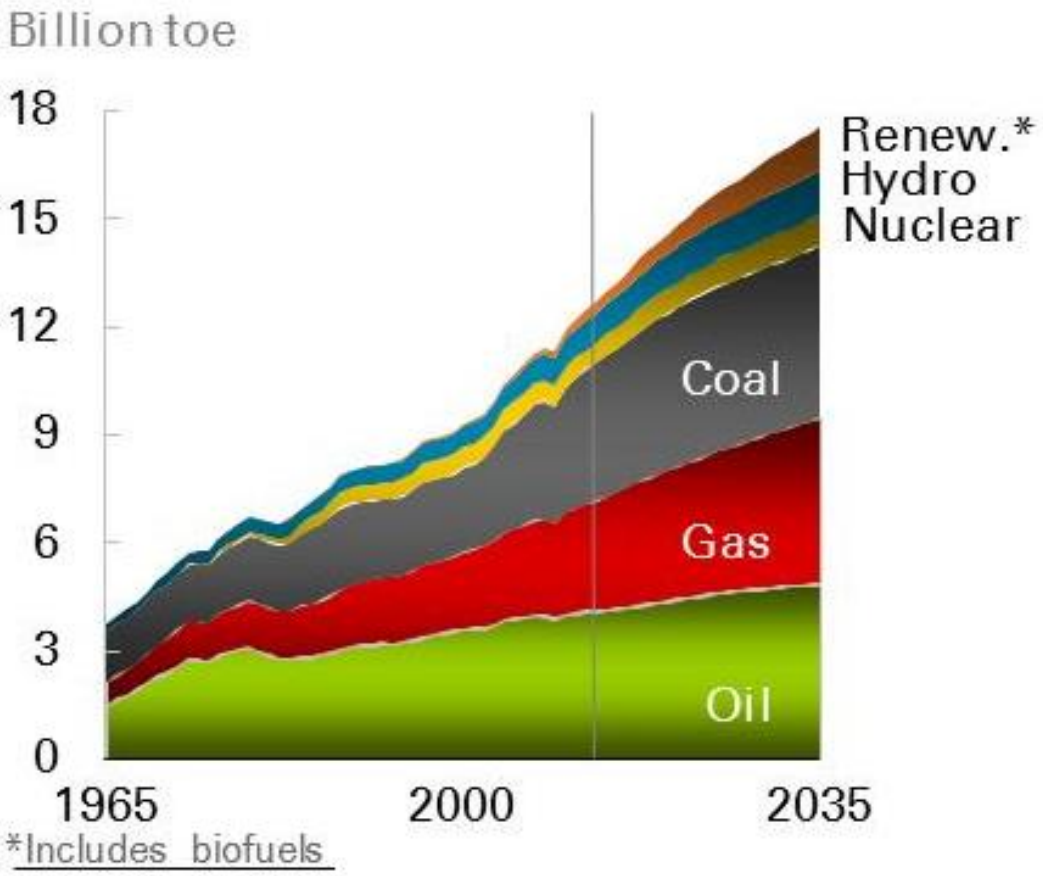


Picture source: Mobile Maschinen 2014

Agenda

1. Characteristics of energy storages and comparison basis
2. Gaseous energy storages
3. Liquid energy storages
4. Solid energy storages
5. Summary

Energy outlook of fuel consumption



Source: BP 2014

Definition: Sustainable

Picture source: Internet

Boundary conditions

- Discontinuous supply of energy
- Comparison basis: combine harvester with 500 l fuel tank
- Today known and confirmed technologies
- Prediction time:
  20 years

Picture source: [2]

Calculation basics

- Energy capacity:
  E [MJ] = tank volume [l] * spec. weight [kg/l] * energy density [MJ/kg]
- Efficiency of the combustion engine:

$$\eta = \frac{1}{b_e \cdot h_u} \approx 34\ \%$$

$$b_e = 250\ \text{g/kWh}$$

- Effective energy:

$$E_{Eff} = E * \eta$$

- Mass of the electric storage:

$$m_{Batt} = \frac{E_{Eff}}{\text{energy density} \cdot \text{electric efficiency } [\eta=0{,}8]}$$

Energy density

Elements	Energy density [MJ/kg]	Source
Electric double-layer capacitor	0,00036 to 0,036	[3]
Lead battery	0,09	[4]
Lithium-Ion battery	< 0,54	[4]
Lithium-Air battery	0,5-1,62	[5]
Ethanol	26	[6]
Dimethyl ether	30,8	[7]
Rape oil	37,2	[6]
Diesel	43,2	[6]
Petrol	44	[6]
Natural gas	45	[6]
Biogas	50	[8]
Hydrogen	120	[6]
Nuclear fission	79.000000	[9]

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Gaseous sustainable energy storages

- Hydrogen (H_2):

  electrolysis: $2\ H_20 + \text{energy} \rightarrow 2\ H_2 + O_2$

  (sustainable electric energy is needed, process today well known)

- Biogas
  microbial degradation of organic substance (anaerobic fermentation)
  i.e. biogas plant
  product:
  ~ 75 % methane & ~ 25 % CO_2

- Methane (CH_4)
  → see next page

Picture source: Internet

Methane

- Methanisation:

  $CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$

- Efficiency of the process [10,11]
  - Electric power → hydrogen (H_2): 54 .. 80 %
  - Hydrogen (H_2) → methane (CH_4): 75 .. 95 %
  - Overall efficiency: electric power → methane: 50 .. 70 %

Picture source: Internet

Evaluation of the gaseous sustainable energy sources

Karlsruhe Institute of Technology

1 2 3 4 5

- Reference: diesel fuel with: 500 l / 415 kg
- Hydrogen:
  - 200 bar storage: 8.788 l / 149 kg
    (energy density: 120 MJ / kg, density: 0,017 kg / l)
  - Metal hydride storage: … l / 3.311 kg
    (weight ratio: today known as 1,7 .. 4,5 %, calculation: 4,5 %)
  - Liquefied 2.074 l / 149 kg
    (energy density 120 MJ / kg, density: 0,071 kg / l)
- Methane / biogas
  - 200 bar storage: 2.656 l / 359 kg
    (energy density: 50 MJ / kg, density: 0,135 kg / l)
  - Liquefied: 854 l / 359 kg
    (energy density: 50 MJ / kg, density: 0,42 kg / l)

Picture source: Internet

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Liquefied energy storages

- Bio-chemical conversion
  - Alcoholic fermentation:
    sugar, grain or cellulose is transferred to ethanol (C_2H_3OH)
    → today already well known in E10 petrol (10 % ethanol)
  - Anaerobic fermentation:
    → see biogas plant
  - Composting:
    high time constant, i.e. not taken into account here
- Physic-chemical conversion:
  - Squeezing of plants (in Europe: rape seeds) and additional ester interchange: oil/grease + methanol → biodiesel + glycerine
    (the use of 100 % biodiesel needs a modification of the combustion engine)

Picture source: http://www.bioliq.de

Liquefied energy storages

- Thermo-chemical conversion
  - i.e. pyrolysis, Fischer-Tropsch-synthesis, dimethyl ester-synthesis:

    pyrolysis: organic substances are cracked at high temperature
    result: pyrolysis oil and H_2, CO, CO_2 and methane (CH_4)
    → pyrolysis oil is under research today
    gaseous parts are used for Biomass-to-Liquid (BtL) fuels

    synthesis: composition of two or more parts into a product
    → production of liquefied fuels are of interest

    Fischer-Tropsch-synthesis: developed to produce liquefied fuels from coal
    → production of fuel from methane is possible:
    $CH_4 + H_2O \rightarrow CO + 3\ H_2$; $2\ CH_4 + O_2 \rightarrow 2\ CO + 4\ H_2$
    → hydrocarbons: $2n\ H_2 + n\ CO \rightarrow n(-CH_2-) + n\ H_2O$

Picture source: http://www.bioliq.de

Liquefied energy storages

- Thermo-chemical conversion
  - i.e. pyrolysis, Fischer-Tropsch-synthesis, dimethyl ester (DME)-synthesis:

    dimethyl ester synthesis:
    $3\ CO + 3\ H_2 \rightarrow H_3C\text{-}O\text{-}CH_3 + CO_2$
    diesel motor has to me modified at the injection system
    DME also possible for petrol motors, comparable to LPG

Picture source: http://www.bioliq.de

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Solid energy storages

- Electric batteries
  - Very poor energy density (0,09 .. 1,62 MJ / kg)
  - Lithium-air battery:
    energy density: up to 1,62 MJ / kg expected → mass = 4.703 kg
    (today possible: 0,5 MJ / kg → mass = 15.239 kg
- Oxidation of aluminium:

$$2\ Al + 2\ H_2O \rightarrow Al_2O_3 + 3\ H_2 + energy$$

possible reaction: nano or liquid aluminium + liquid or heated water
heat can not be used in mobile machines; H_2 use is possible:

$$1\ kg\ Al + 1{,}0015\ kg\ H_2O \rightarrow 1{,}8995\ kg\ Al_2O_3 + 0{,}112\ kg\ H_2$$

➡ 2.662 kg Al + H_2O used as energy equivalent

Picture source: http://www..kit.edu

Size of energy storages for 6.096 MJ

Energy storage	Calorific value [MJ/kg][1]	Volume [l]	Mass [kg]
Diesel	43,2	500	415
Petrol	44,0	543	407
Methane (15°C; 200 bar)	50,0	2.656	359
Methane (-167°C; 1 bar)	50,0	854	359
Hydrogen (200 bar)	120,0	8.788	149
Liquefied hydrogen	120	2.074	149
Biogas (15°C; 200 bar)	50,0	2.656	359
Ethanol	26,0	878	690
Dimethyl ether (DME) (at -25°C)	30,8	882	583
Raps methylester	37,2	548	482
Lithium-air battery	0,5-1,6	-	4.150 - 12.450
Aluminium oxidation		Al & Water: 1.823	Al & Water: 2.662

[1] sources: [6,7 and 8]

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Sustainable energy storages for mobile machines

- Methane:
  - 200 bar pressure: known technology, like CNG
  - Liquefied: LNG technology known in ships and trucks
    → technology has to be adapted
- Bio-fuels (ethanol, dimethyl ether, biodiesel):
  → combustion engine has to be modified, know technology
- Electrical storages
  → no potential for a wide range of use in mobile machines
  (niches like forklift trucks are widen)

Picture source: Mobile Maschinen 2014

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