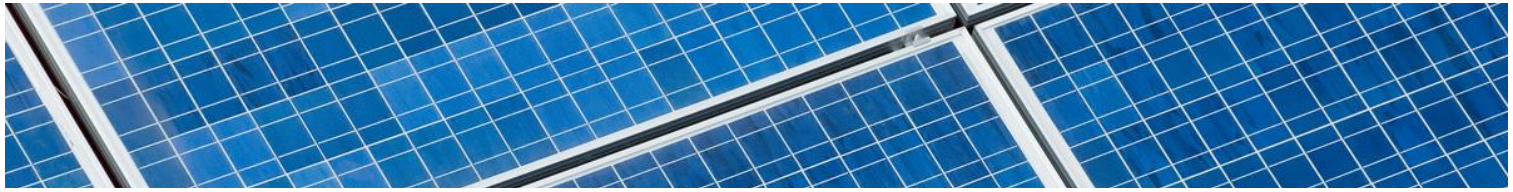
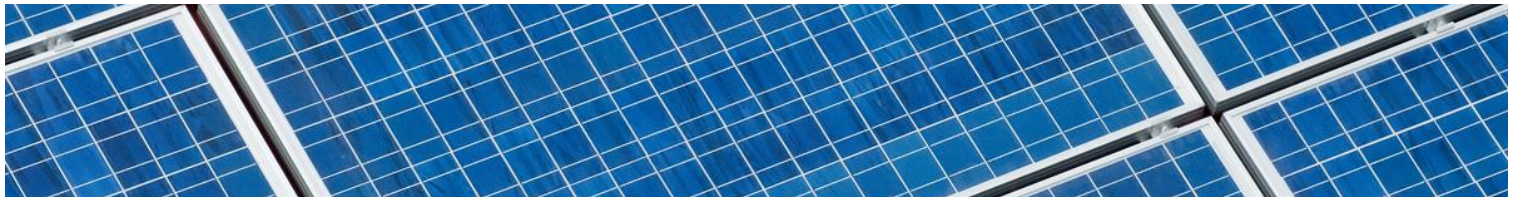
GREEN SCANS



Impact of storage on PV attractiveness



Mariska de Wild-Scholten

Repowering Europe, 'Photovoltaics: centre-stage in the power system',
18 May 2016, Brussels

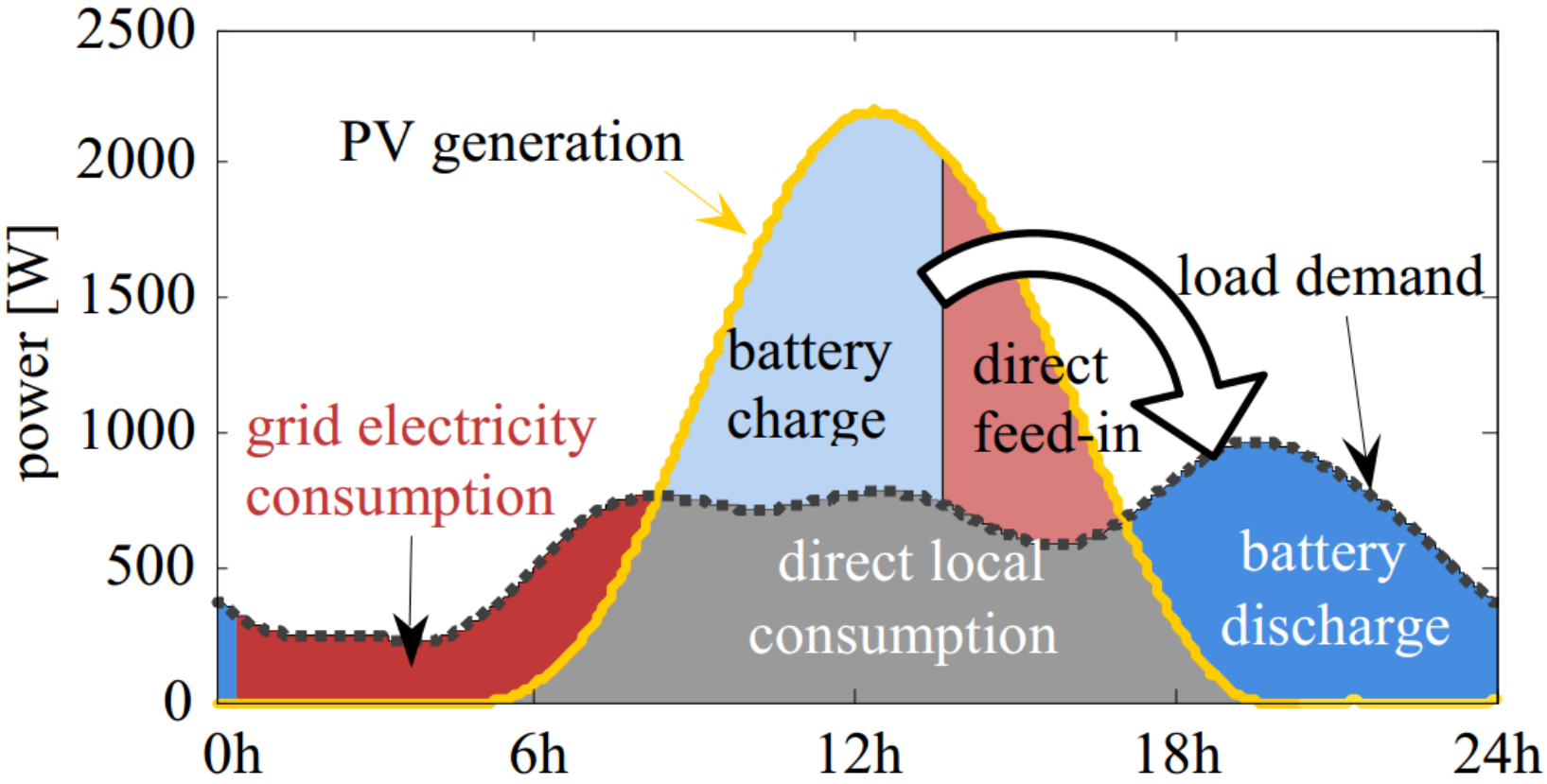
Outline

How does storage affect the environmental balance of PV?

Life Cycle Assessment

- **Greenhouse gas emissions**
- **Toxicity**
- **Depletion**

Mismatch of generation & consumption of electricity



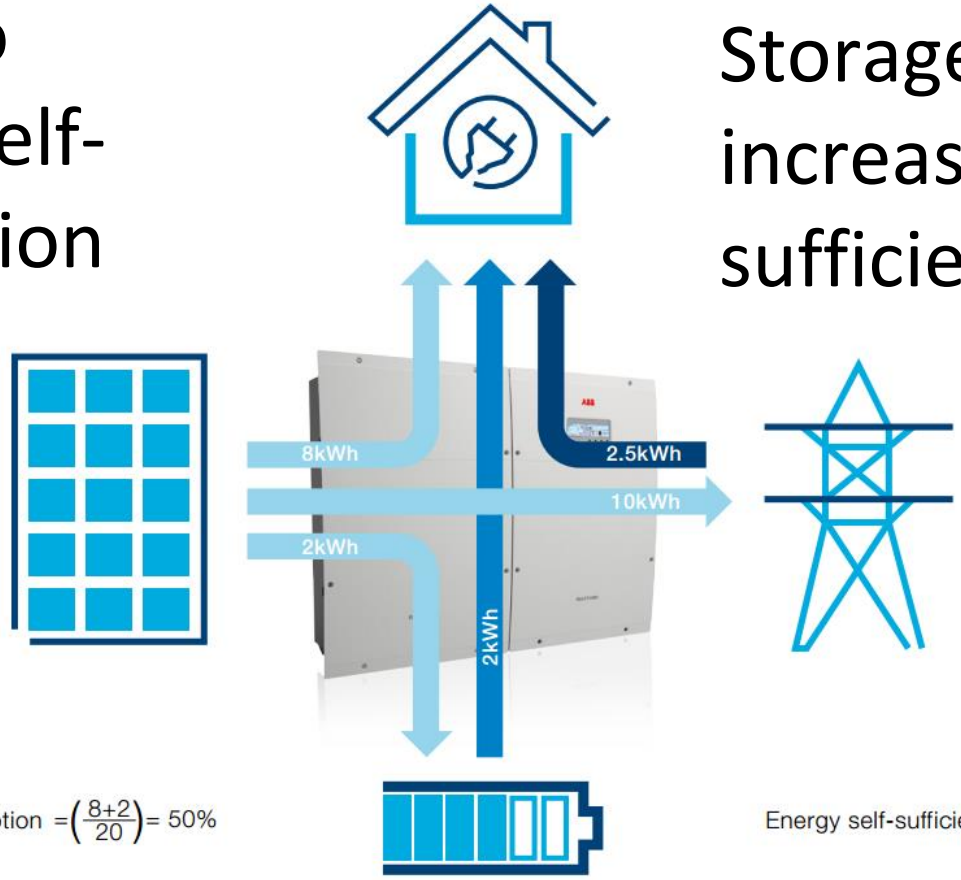
Martin Braun 2009 EPVSEC24 4BO.11.2

Why storage @ home?

High grid electricity price?

Storage to increase self-consumption

Storage to increase self-sufficiency



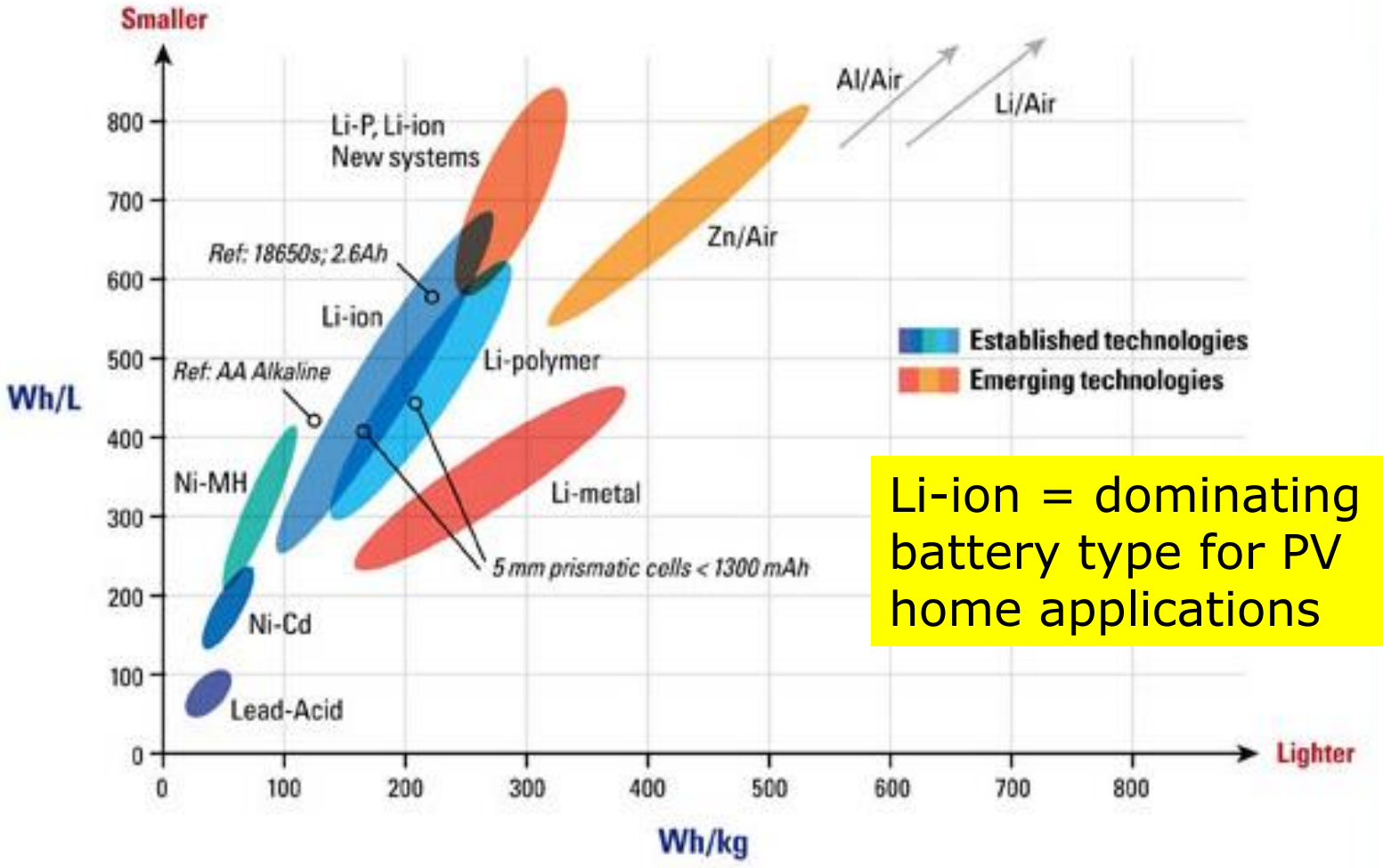
Self-consumption $= \left(\frac{8+2}{20}\right) = 50\%$

Energy self-sufficiency $= \left(\frac{8+2}{12.5}\right) = 80\%$

Storage System

- Module with **battery** cells ..... this presentation
- Energy management system
- Inverter
- Etcetera

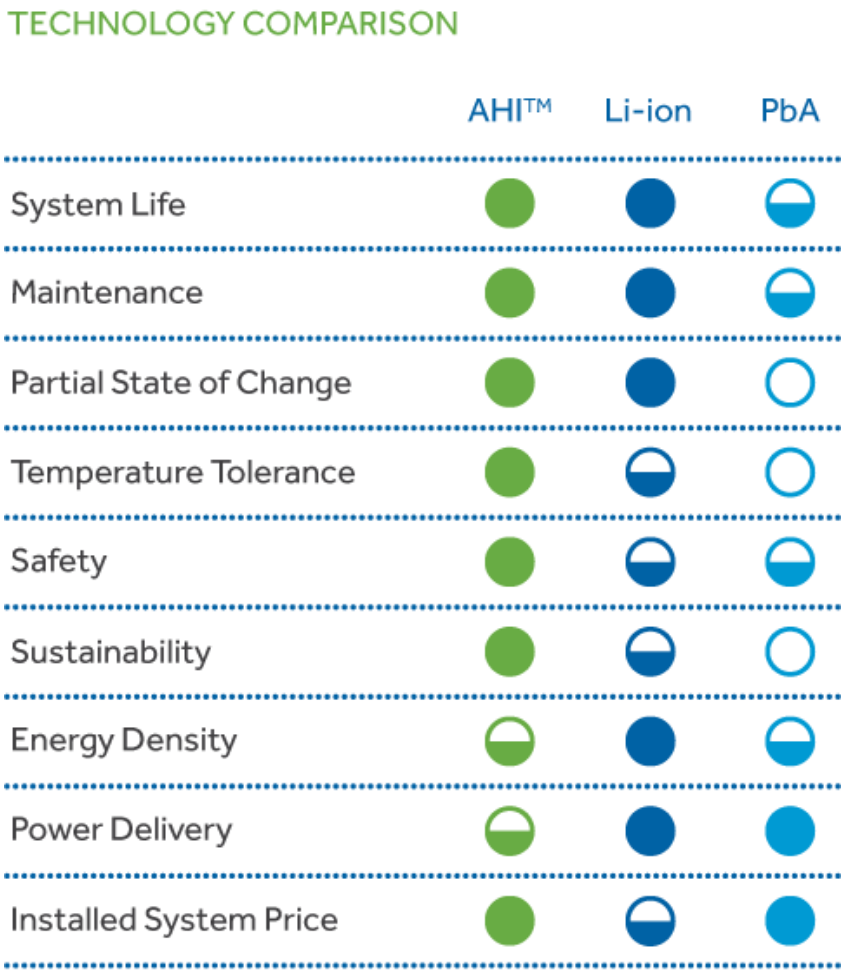
Which battery type?



Li-ion = dominating battery type for PV home applications

http://www.estquality.com/technology

Battery technology comparison



Aquion Energy

Li-ion = dominating battery type for PV home applications

Calculation of carbon footprint of stored electricity in life time of battery

Global Warming Potential (GWP) of stored electricity

g CO_2-eq/kWh

GWP (g CO_2-eq) / kg battery .....step 1

x Battery weight (kg)

/ usable capacity of battery (kWh) .....step 2

/ number of charge cycles .....step 3

Global Warming Potential (GWP) of battery with LMO: Lithium Manganese Oxide ($LiMn_2O_4$)

GWP = 5.89 kg CO_2-eq/kg battery cell using IPCC2007 GWP100a

Battery, LiIo, rechargeable, prismatic, at plant/GLO U	IPCC2013 GWP100a	
	kg CO2-eq/kg	
Total:	5.891	100.00%
Direct emissions	0.00E+00	0.00%
Transport, transoceanic freight ship/OCE U	8.40E-02	1.43%
Transport, lorry >16t, fleet average/RER U	1.37E-01	2.32%
Metal working factory/RER/I U	4.73E-02	0.80%
Electricity, low voltage, production UCTE, at grid/UCTE U	6.44E-02	1.09%
Single cell, lithium-ion battery, lithium manganese oxide/graphite, at plant/CN U	4.31E+00	73.15%
Printed wiring board, surface mounted, unspec., solder mix, at plant/GLO U	8.57E-01	14.54%
Cable, three-conductor cable, at plant/GLO U	6.24E-02	1.06%
Cable, data cable in infrastructure, at plant/GLO U	6.43E-02	1.09%
Reinforcing steel, at plant/RER U	2.14E-01	3.63%
Sheet rolling, steel/RER U	5.25E-02	0.89%

ecoinvent 2.2, calculated with IPCC2013 GWP100a method

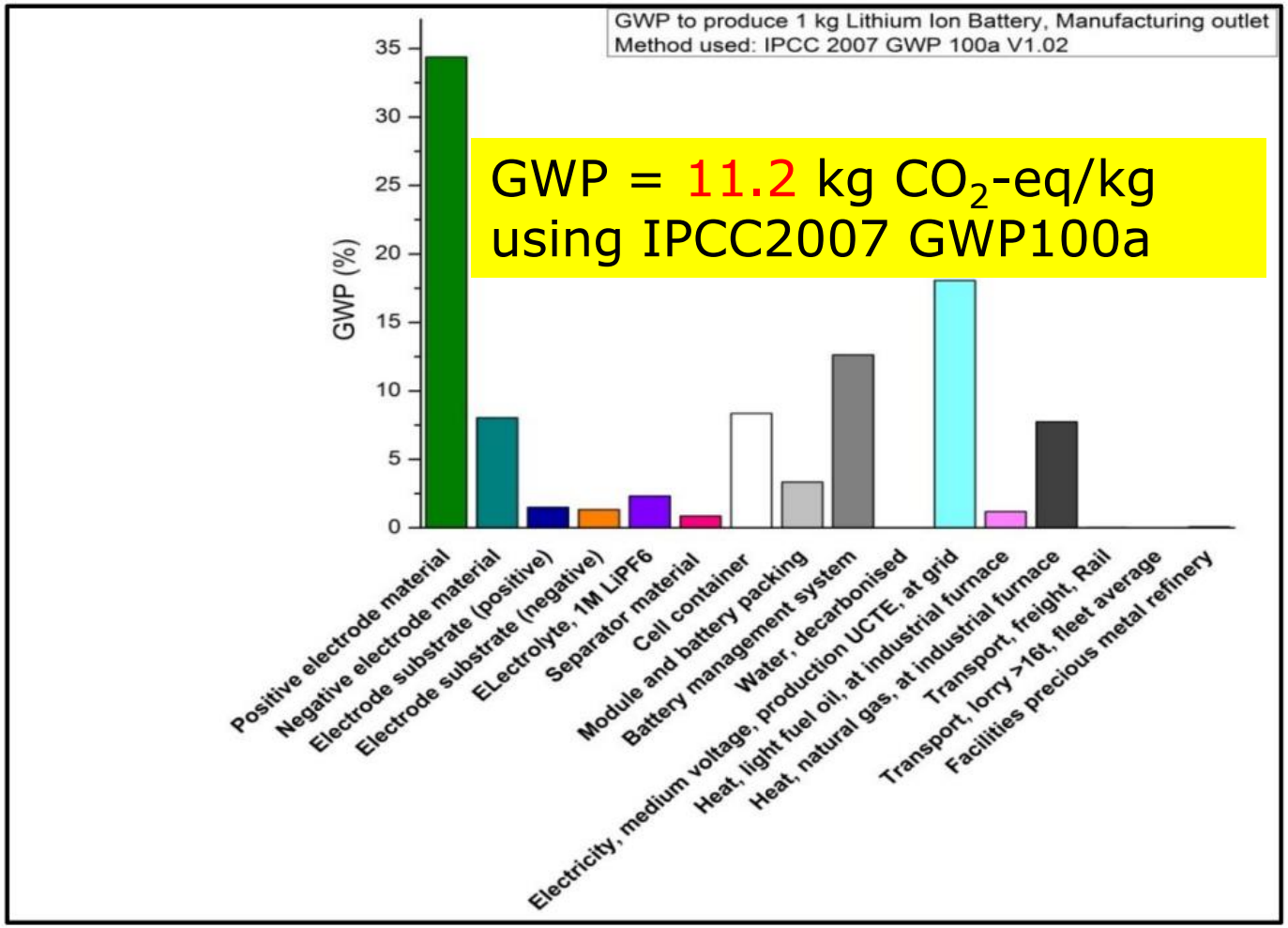
Global Warming Potential (GWP) of battery with LMO: Lithium Manganese Oxide (LiMn2O4)

GWP = 5.39 kg CO_2-eq/kg battery using IPCC2007 GWP100a

		Single cell, lithium-ion battery, lithium manganese oxide/graphite, at plant/CN U						
			Unit	Value	%		IPCC2013 GWP100a	%
							kg CO2-eq/kg	
				1.050	100.0%		5.390	100.0%
		Transport, freight, rail/RER U	tkm	0.167			6.63E-03	0.1%
		Transport, lorry >16t, fleet average/RER U	tkm	0.028			3.73E-03	0.1%
		Chemical plant, organics/RER/I U	p	0.000			4.97E-02	0.9%
		Electricity, medium voltage, at grid/CN U	kWh	0.106			1.28E-01	2.4%
		Heat, natural gas, at industrial furnace >100kW/RER U	MJ	0.065			4.73E-03	0.1%
Inert atmosphere:		Nitrogen, liquid, at plant/RER U	kg	0.010			4.37E-03	0.1%
Electrolyte salt:	LiPF6	**Lithium hexafluorophosphate, at plant/CN U**	kg	0.019	1.8%		4.75E-01	8.8%
Electrolyte solvent:	Ethylene carbonate	**Ethylene carbonate, at plant/CN U**	kg	0.160	15.2%		2.35E-01	4.4%
Separator:	Coated polyethylene film	**Separator, lithium-ion battery, at plant/CN U**	kg	0.054	5.1%		3.23E-01	6.0%
Cathode:	LiMn2O4	**Cathode, lithium-ion battery, lithium manganese oxide, at plant/CN**	kg	0.327	31.1%		2.68E+00	49.7%
Anode:	Graphite	**Anode, lithium-ion battery, graphite, at plant/CN U**	kg	0.401	38.2%		1.04E+00	19.3%
Electrode tab:	Al	**Aluminium, production mix, wrought alloy, at plant/RER U**	kg	0.016	1.6%		1.80E-01	3.3%
Package:	Polyethylene	**Polyethylene, LDPE, granulate, at plant/RER U**	kg	0.073	7.0%		1.60E-01	3.0%
		Processing:						
Processing of input materials:		Extrusion, plastic film/RER U	kg	0.073			3.87E-02	0.7%
		Sheet rolling, aluminium/RER U	kg	0.016			1.00E-02	0.2%
		Emissions to air:						
		Heat, waste	MJ	0.380				
		Waste to treatment:						
Ecoinvent assumption 5%		Disposal, Li-ions batteries, mixed technology/GLO U	kg	0.053			4.91E-02	0.9%

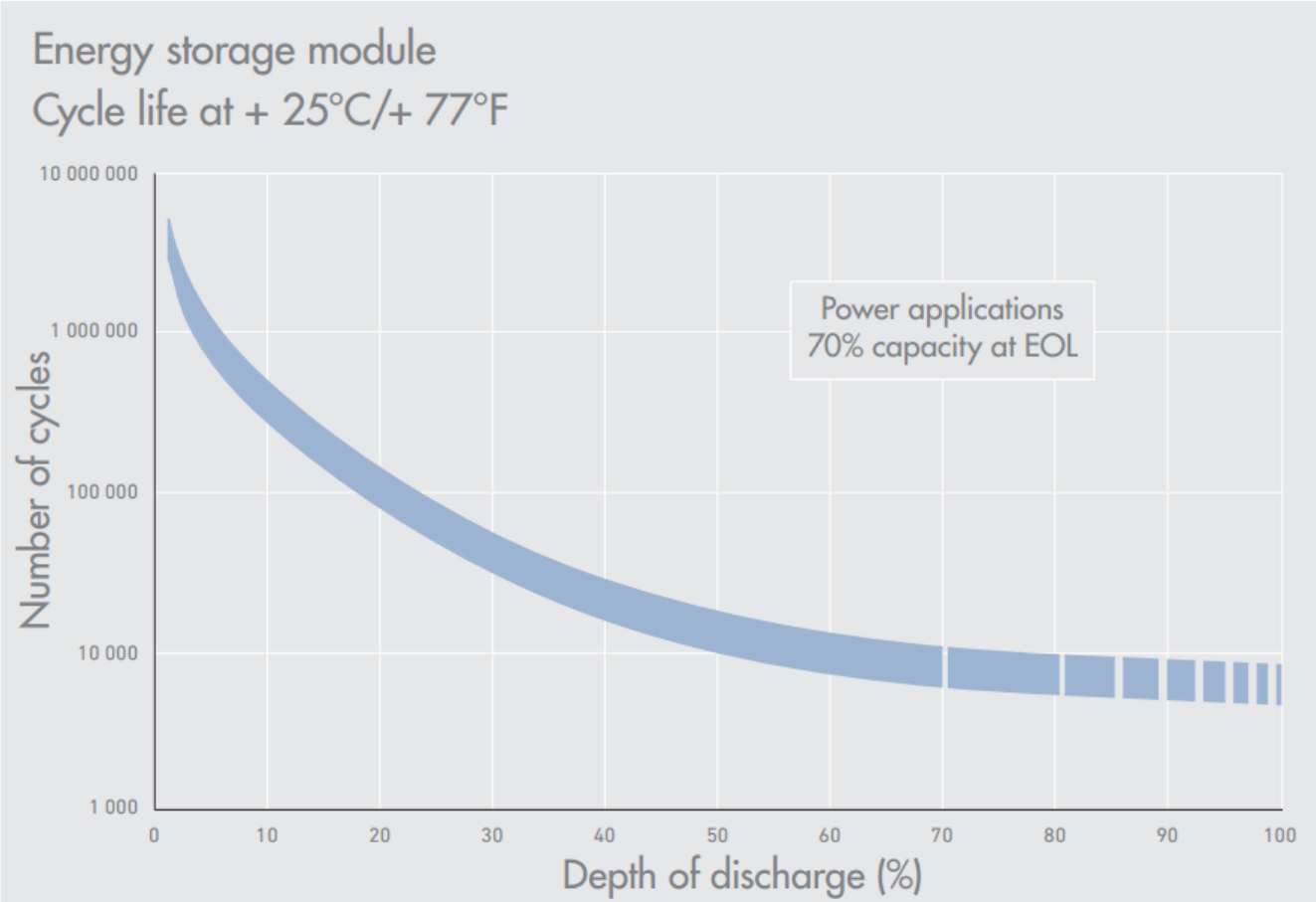
ecoinvent 2.2, calculated with IPCC2013 GWP100a method

Global Warming Potential (GWP) of battery with LFP: Lithium Iron Phosphate ($LiFePO_4$)



Hiremath (March 2014) Master Thesis Carl von Ossietzky University of Oldenburg, Germany

Number of cycles depend on depth of discharge



Cycle life depends on both depth of discharge (DOD) and charging rates. The above results are based on testing at a fixed DOD and varying charging rates. The end of life (EOL) is reached when the remaining capacity is 70% of the initial capacity.

Carbon footprint of stored electricity

Lowest value from my preliminary analysis:

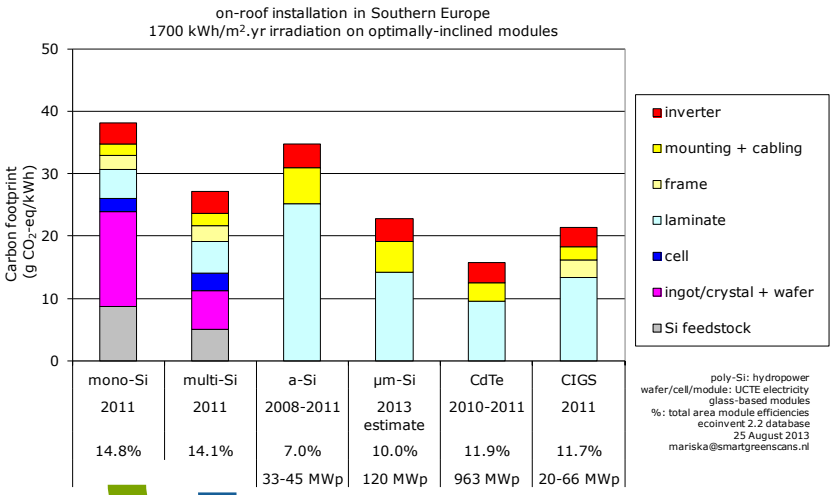
12 g CO_2-eq/kWh stored electricity

How much kWh storage needed / kWh generated?

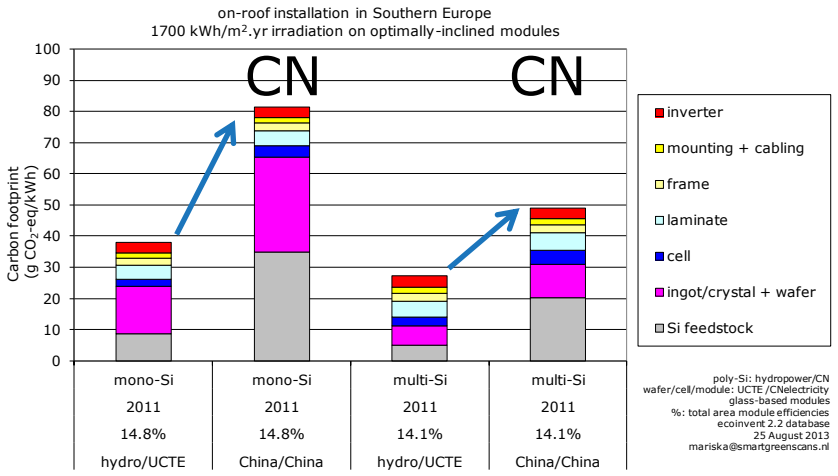
Carbon footprint - gram CO_2-eq/kWh

☹ Status of inventory data 2011

hydropower / UCTE



China electricity mix



mono multi

World average carbon footprint ≈ 55 g CO_2-eq/kWh

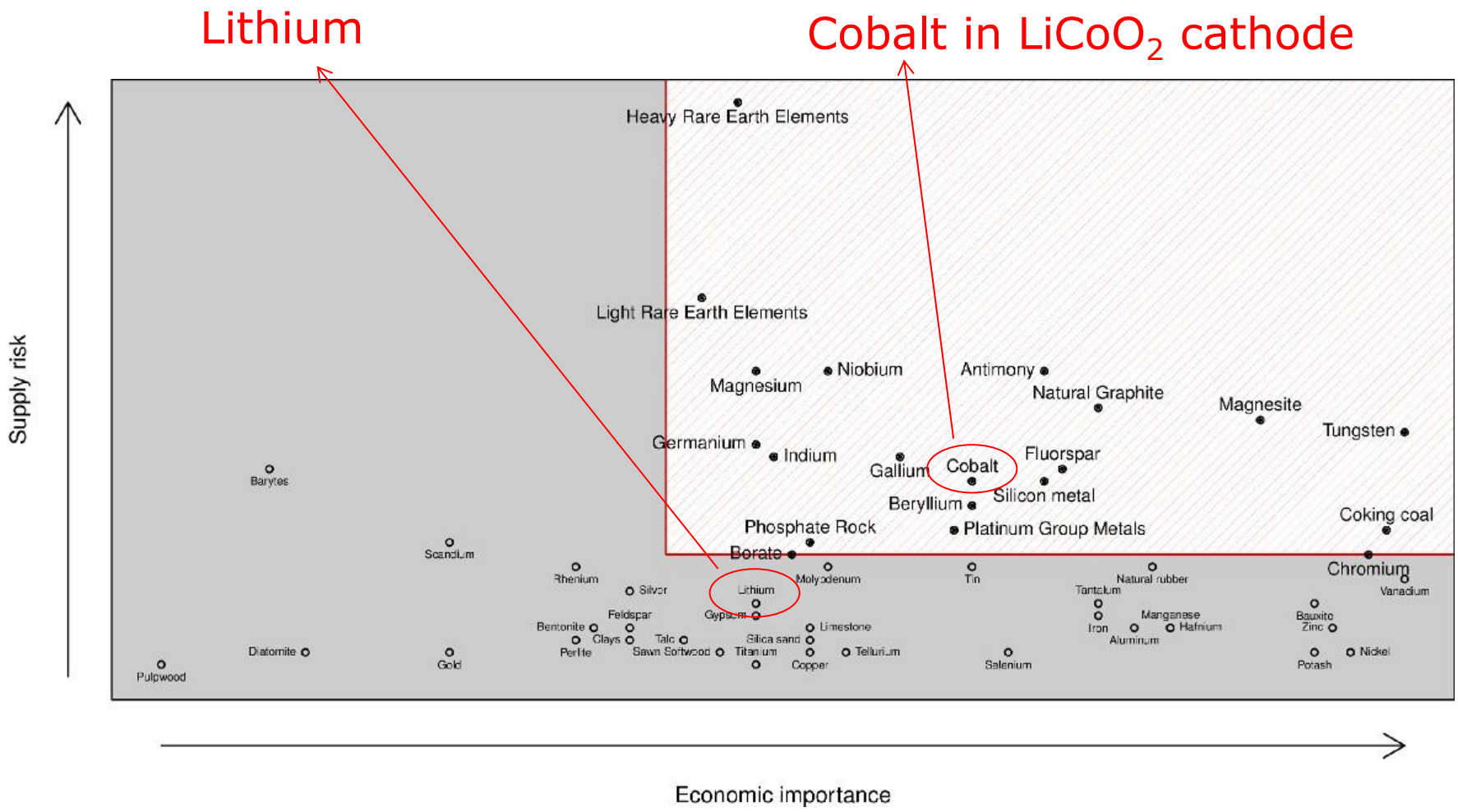
Many uncertainties

- GWP value based on 2010 or older inventory data of the battery
- Reliable manufacturer data missing
- Number of charging cycles depend on depth of discharge
- Only battery calculated, not a complete storage system
- How much storage is needed / kWh electricity generated from PV?

Toxicity

- N-methyl-2-pyrrolidone (NMP) solvent in electrolyte
  - Alternative: Water based is not possible because some electrodes are moisture sensitive
  - Alternative: Electrovaya SuperPolymer® 2.0
- Polyvinylidene fluoride-based binders in electrolyte
  - Replace with chlorine

Critical Raw Materials: cobalt



Depletion of materials

- Cobalt in $LiCoO_2$ electrode
  - replace Co with Mn, Fe, Ti
    - $LiFePO_4$
    - Lithium Titanate ($Li_4Ti_5O_{12}$)
- Lithium
  - replacement with Na, Ka, Mg, Ca...
  - recycling

Cradle to cradle battery
Aquion Energy

CERTIFIED cradletocradle BRONZE

$NaSO_4$ solution
(AHI™)

Recommendations

To get a reliable evaluation of the environmental impact of current storage systems it is recommended that LCA studies are performed

- with data collected by manufacturers of Battery Storage Systems,
- in EU / National projects.

References / Funding

References:

- D. Larcher, J-M. Tarascon (2014) Towards greener and more sustainable batteries for electrical energy storage, Nature Chemistry 7: 19-29
- PV Magazine Storage Special July 2015 with Market Survey of Batteries

Funding: none

Thank you for your attention!

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La Duna, Casas Bioclimáticas ITER, Tenerife