Energy Storage
Key for large-scale grid integration of renewable energies

Dr. Matthias Vetter

Fraunhofer Institute for
Solar Energy Systems ISE

Intersolar North America

Electrical Energy Storage Stage

San Francisco, 14th of July 2015

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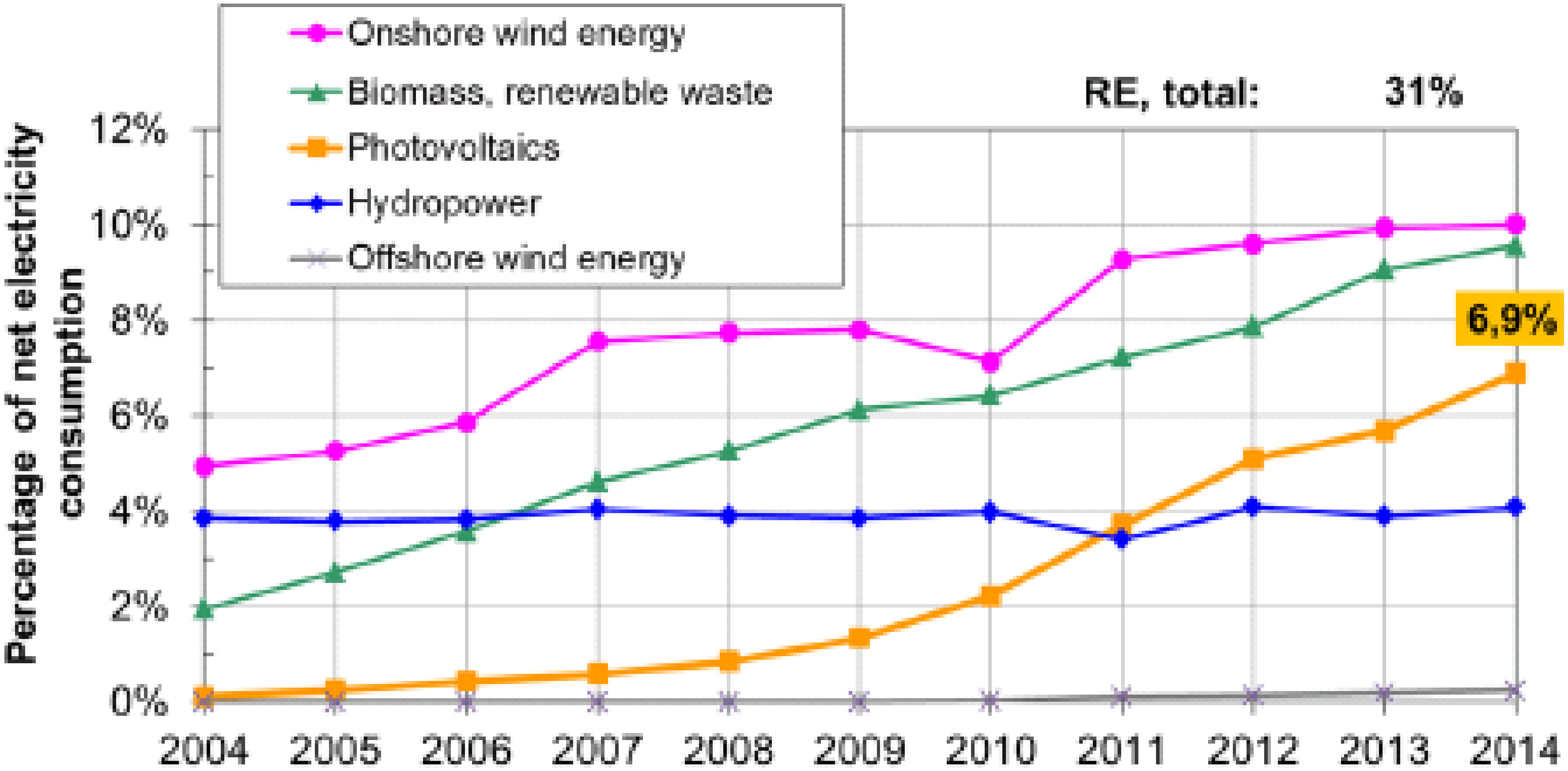
Agenda

- Motivation: Germany as an example
- Stationary storage – Market and classification
- Battery technologies
- System design aspects – Example residential lithium-ion batteries
- System integration of storages
- Mini-grids: The “original” PV application of stationary battery systems
- Conclusions

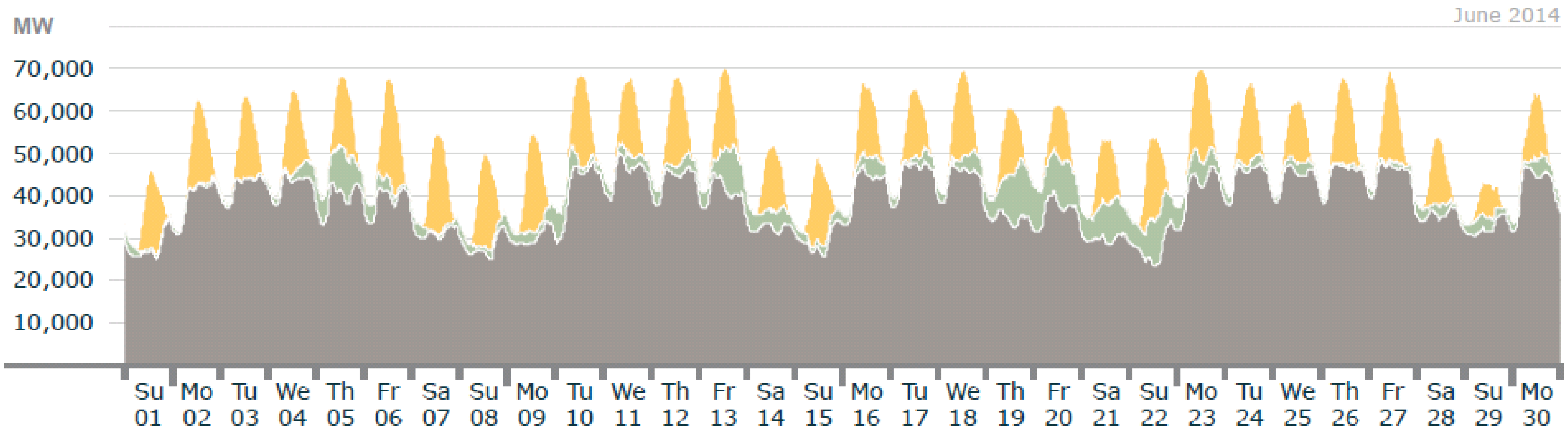
Motivation
Share of renewables in the German grid



Source: H. Wirth, Fraunhofer ISE: Recent Facts about Photovoltaics in Germany, http://www.ise.fraunhofer.de/en/renewable-energy-data, 19.5.2015.

Motivation
Power production: June 2014

Actual production



	max. power	date max. power	monthly energy
Solar	24.24 GW	06.06., 13:00 (+2:00)	4.84 TWh
Wind	13.7 GW	19.06., 18:45 (+2:00)	2.47 TWh
Conventional > 100 MW	50.3 GW	11.06., 08:00 (+2:00)	27.4 TWh

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX Transparency Platform /

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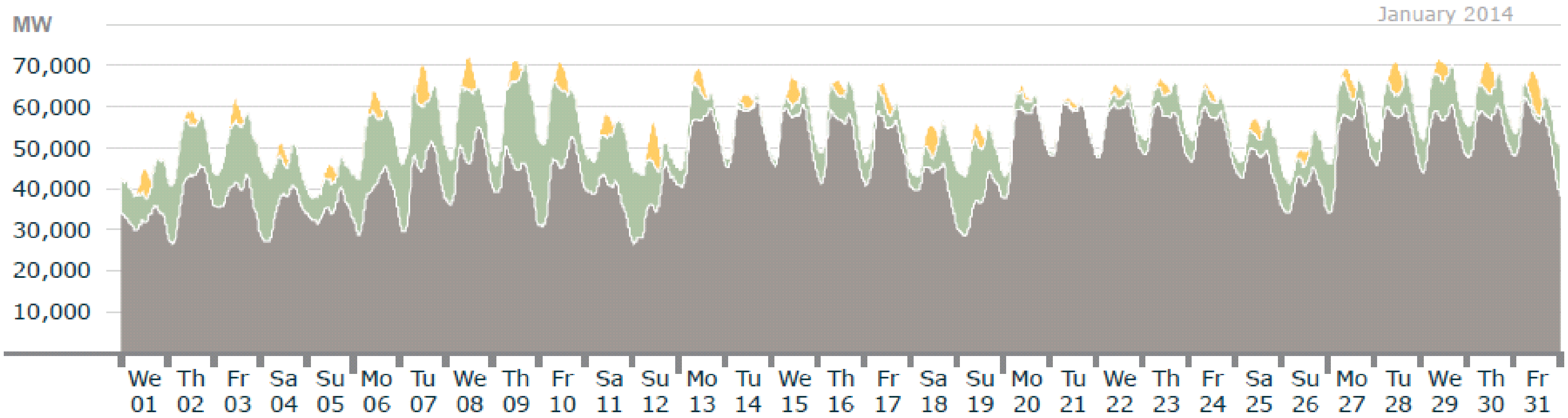
Motivation
Power production: January 2014

Actual production



	max. power	date max. power	monthly energy
Solar	10.1 GW	07.01., 12:30 (+1:00)	0.75 TWh
Wind	25.0 GW	09.01., 18:30 (+1:00)	6.2 TWh
Conventional > 100 MW	62.2 GW	31.01., 08:00 (+1:00)	34.7 TWh

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX Transparency Platform /

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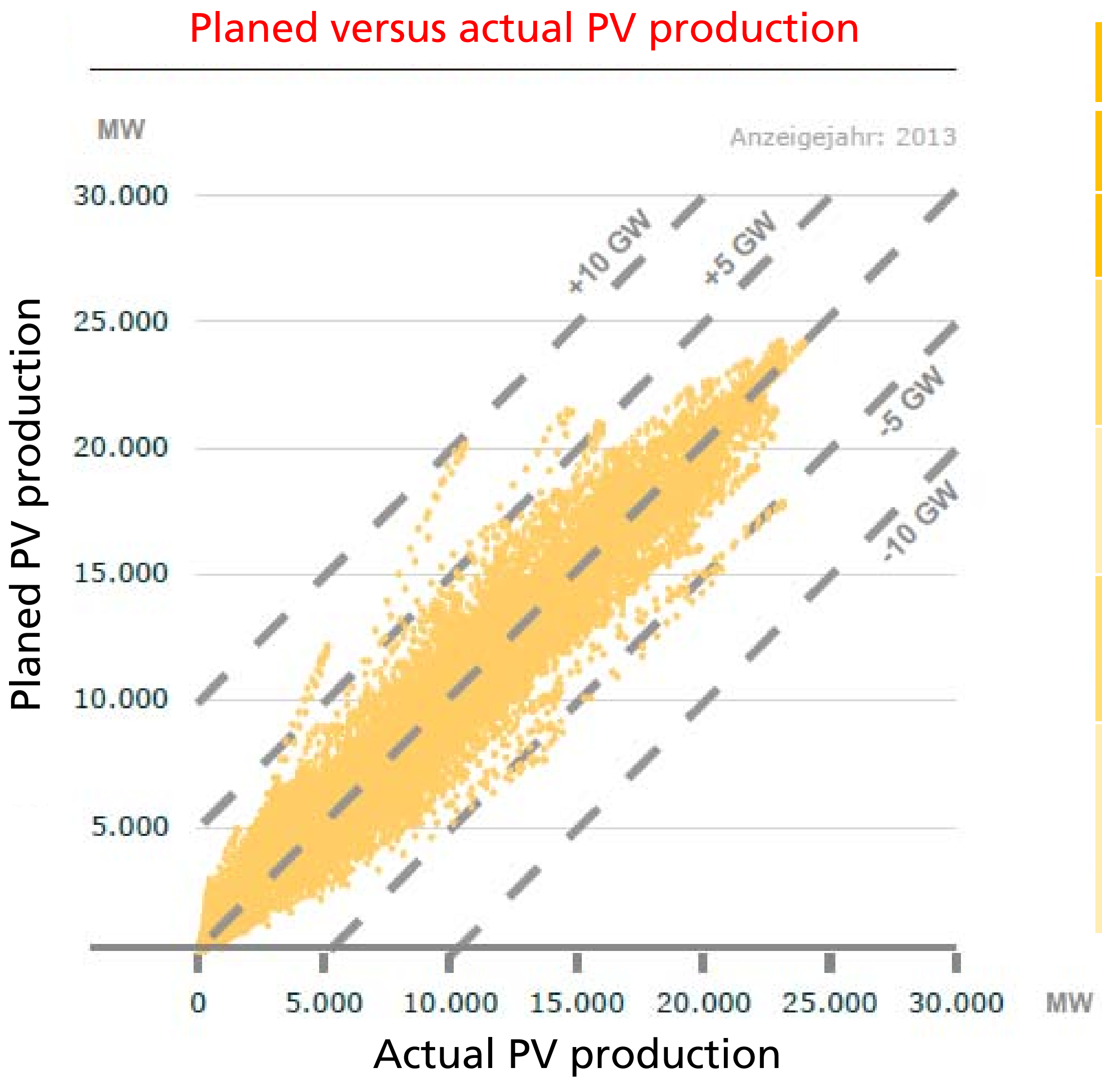
Motivation
PV power production: Planed versus actual



Date	03.03.	03.04.
Time	13:15	12:30
GMT	+1:00	+1:00
Planed production	7.5 GW	19.7 GW
Actual production	13.7 GW	10.1 GW
Forecast error	-6.1 GW	+9.6 GW
Relative forecast error	-44.7 %	+94.8 %

Source: B. Burger, Fraunhofer ISE; Data: EEX Transparency Platform

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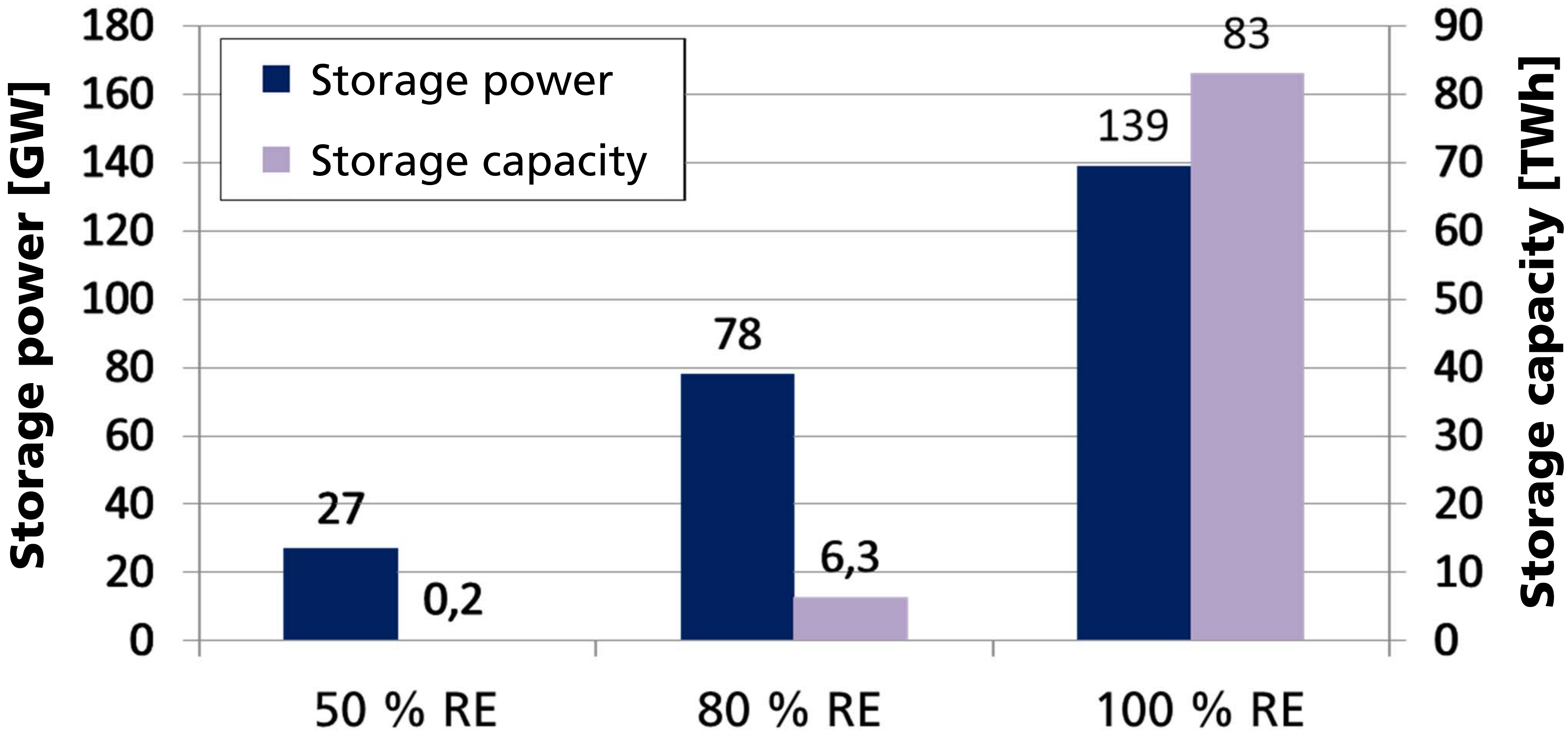
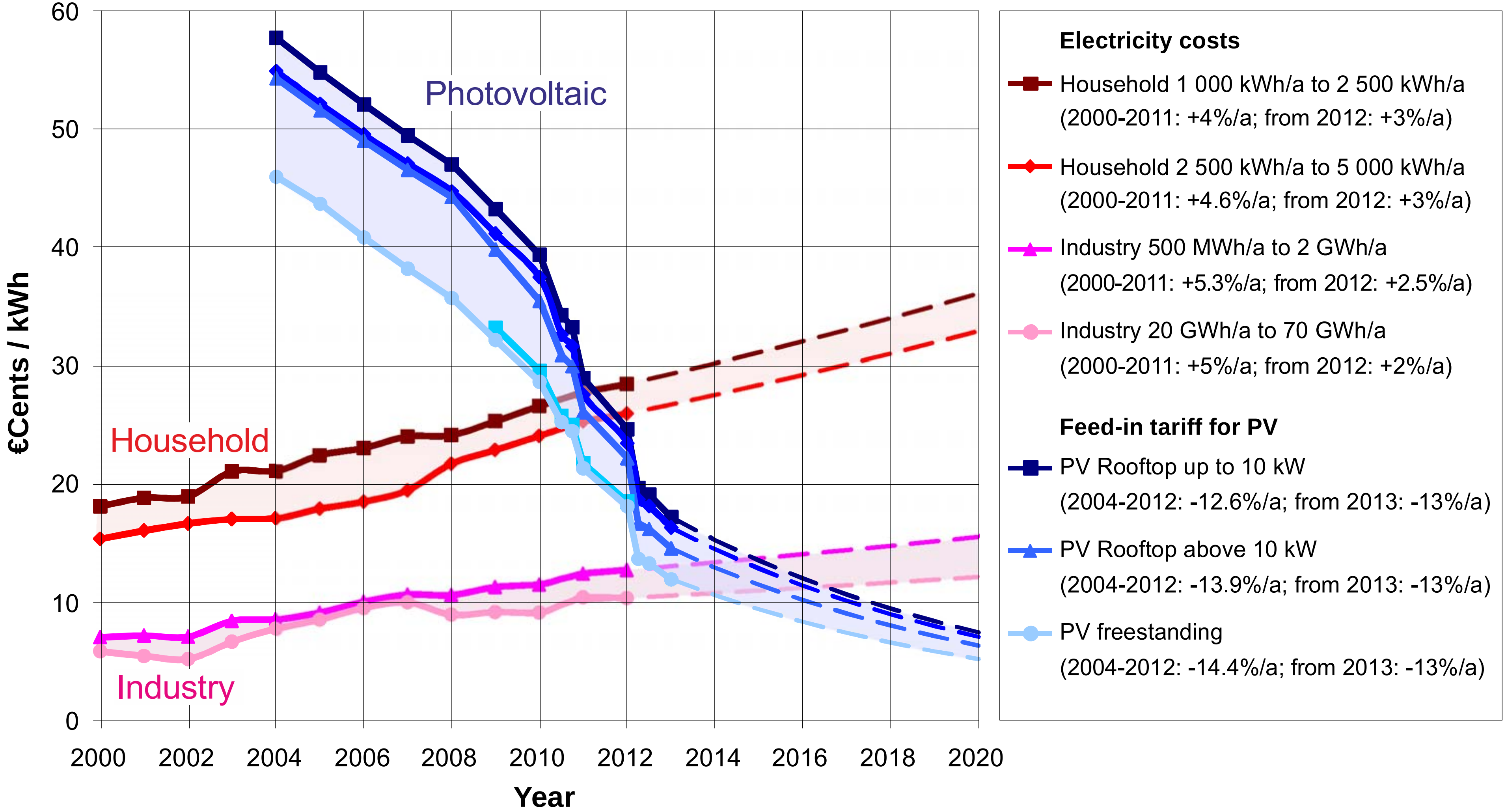
Motivation
Storage demand in Germany



Source: N. Hartmann, University of Stuttgart, Dissertation, 2013

Motivation

Electricity cost and feed-in tariffs in Germany



Source: B. Burger, “Energiekonzept 2050”, June 2010, FVEE, www.fvee.de, Update of 14.11.2012

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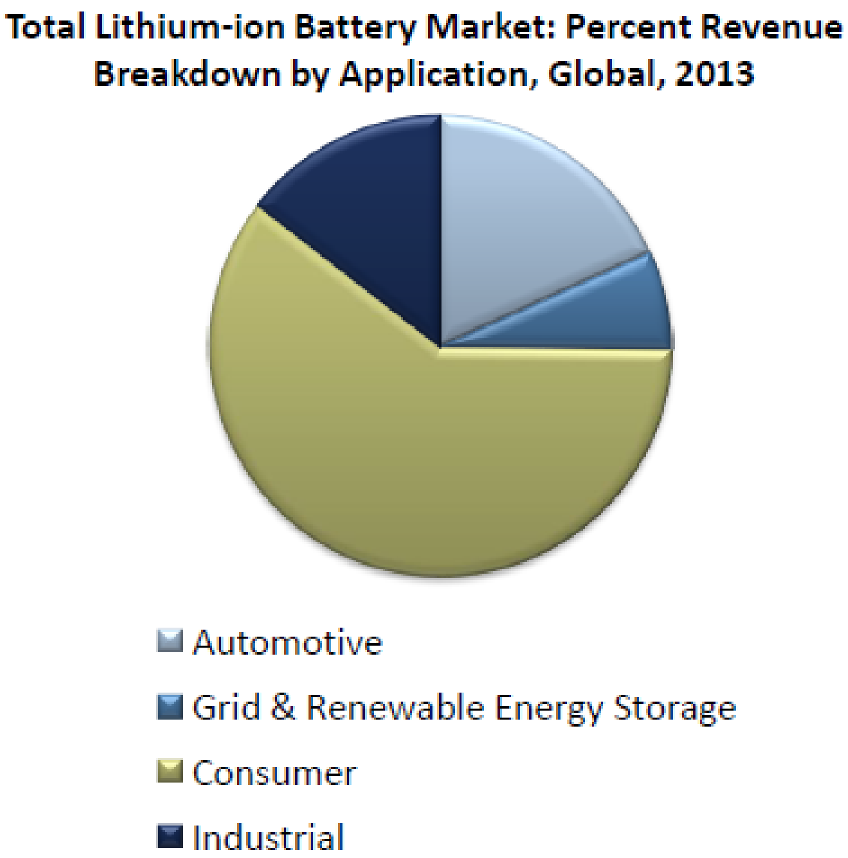
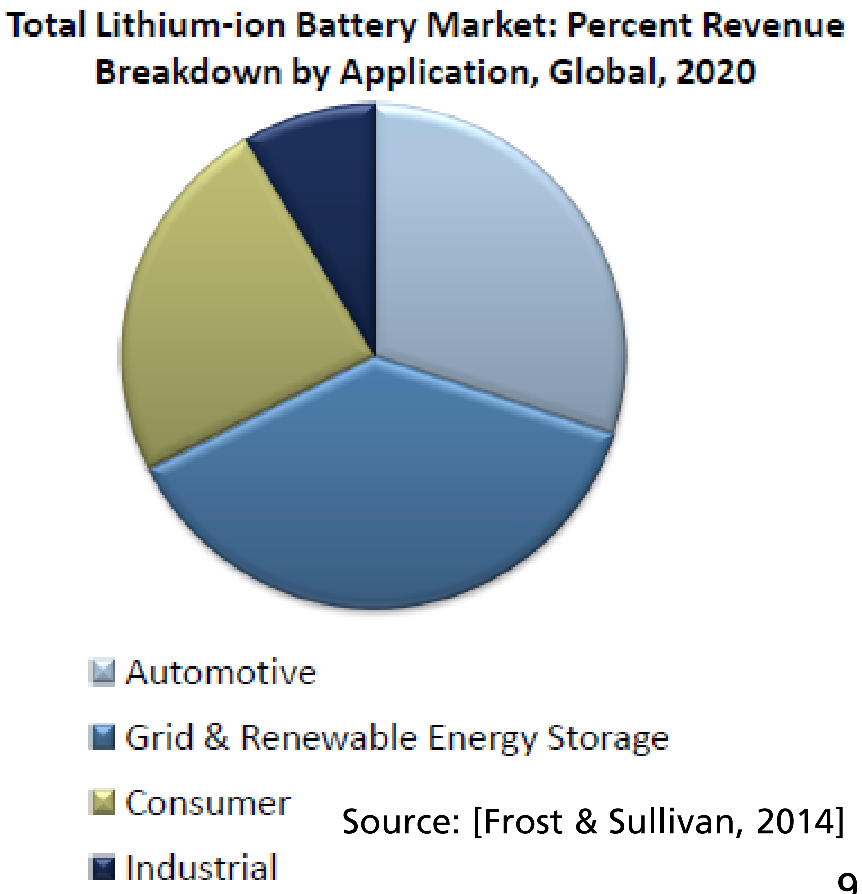
Market for stationary storages
Forecast for lithium-ion batteries

Turnover 2013: 17.58 Bill. US$ → Forecast: More than four times until 2020





Source: [Frost & Sullivan, 2014]

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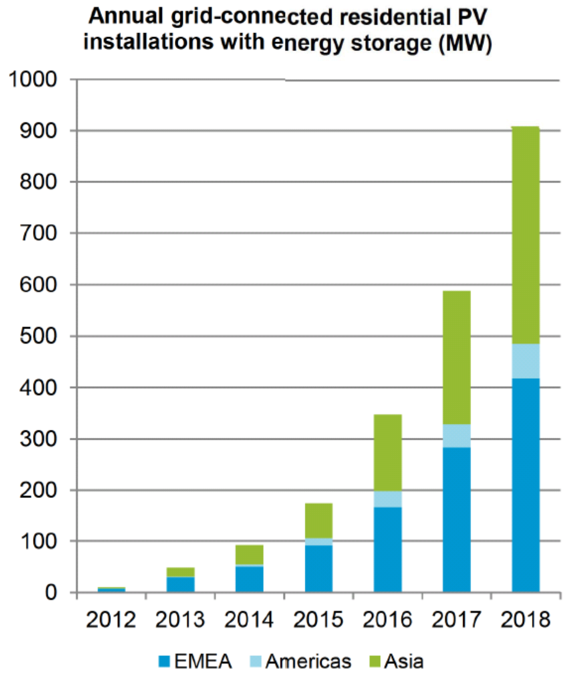
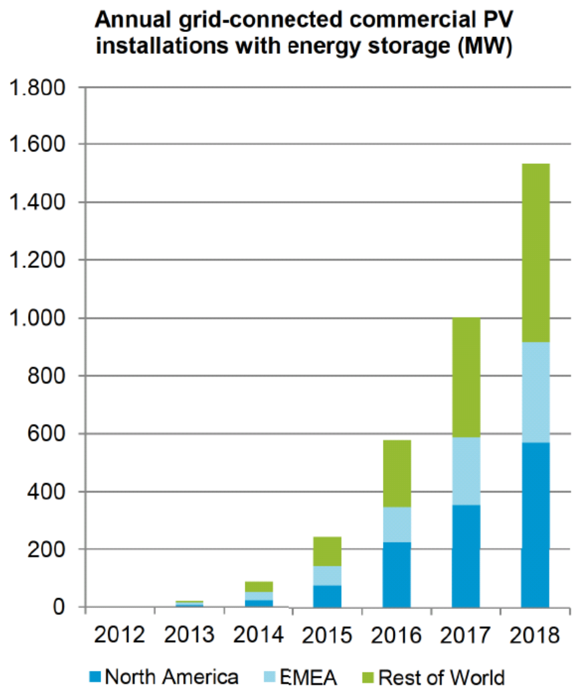
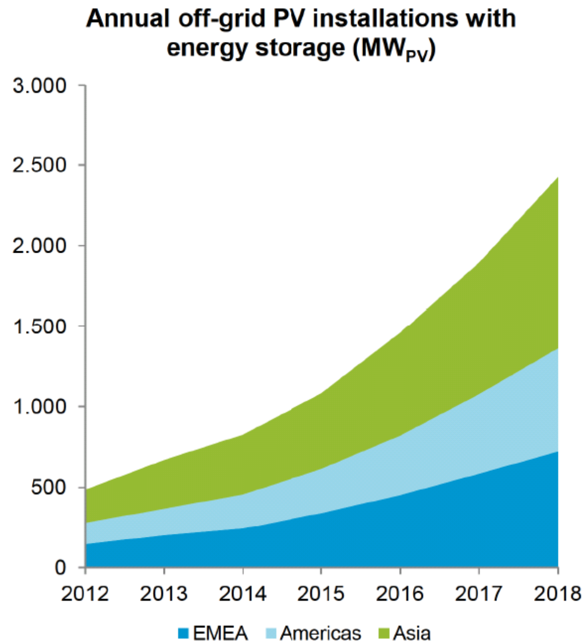
International Markets for PV Storage Systems

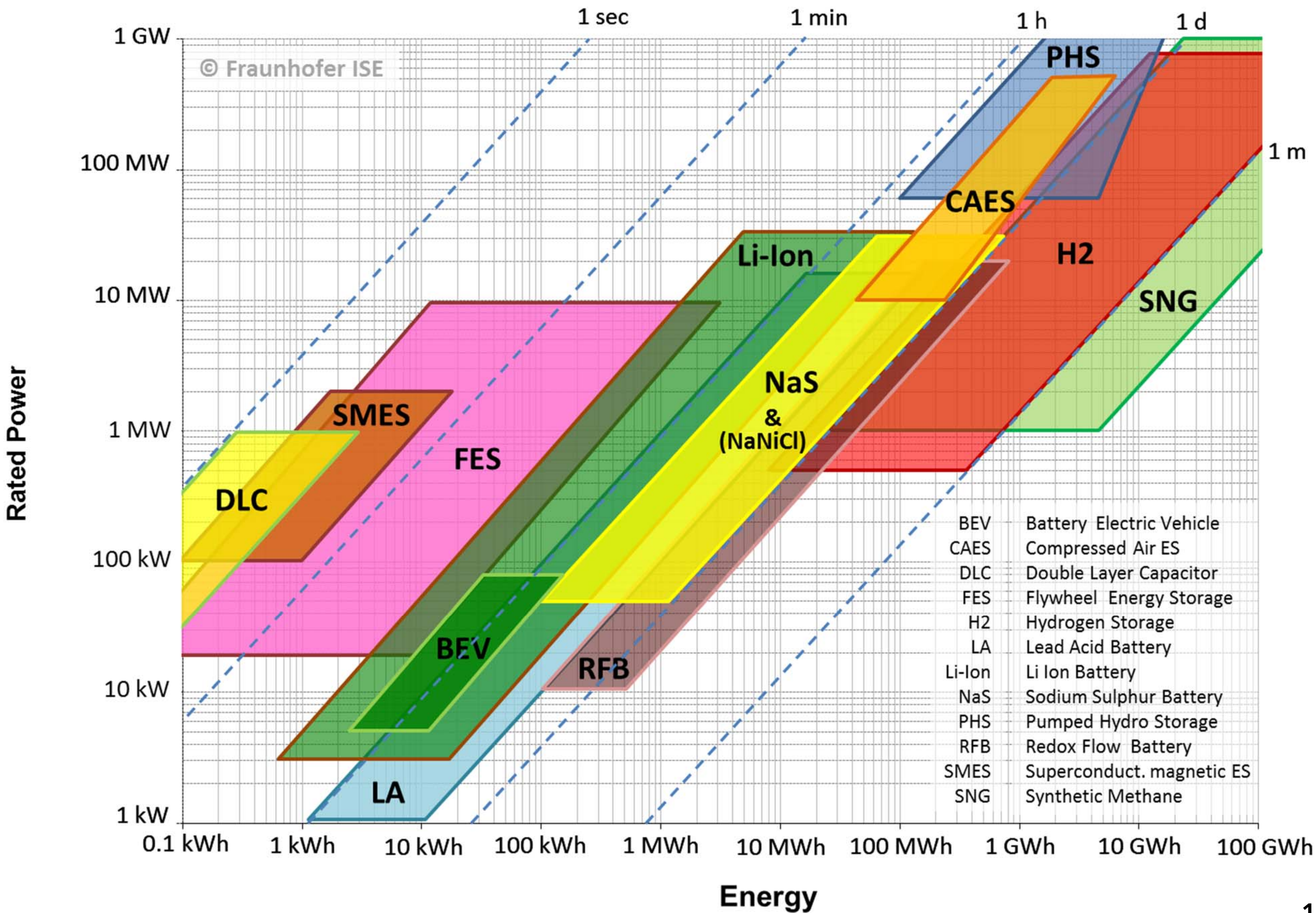






Source: S. Wilkinson, IHS: Opportunities and Challenges for Energy Storage in PV – On and Off the Grid. Energy Storage – VDE Financial Dialogue, 10.03.2015.

Classification of storages



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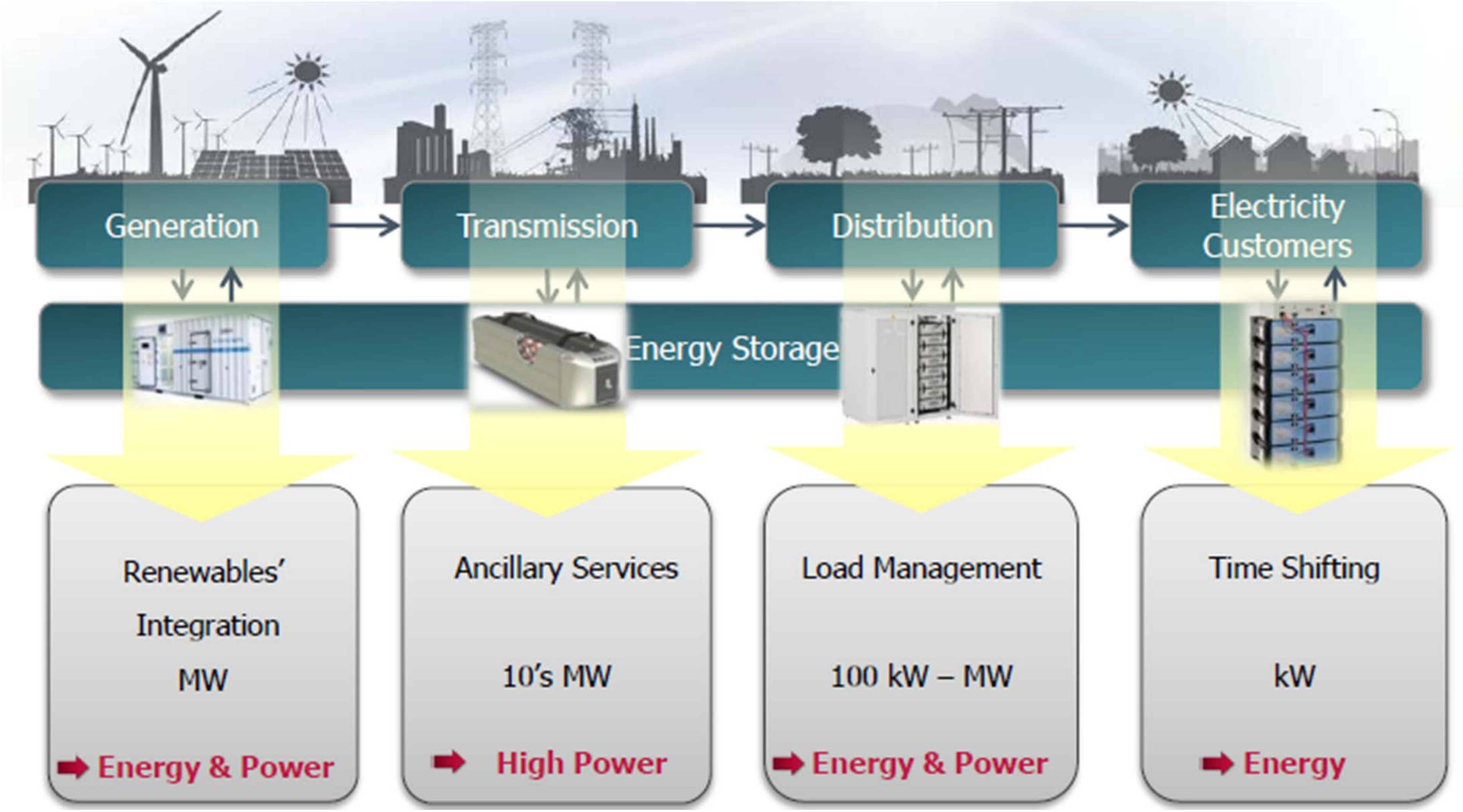
Classification of storages
Grid connected systems along the electricity value chain



Source: Michael Lippert, Li-ion battery storage and renewables, Intersolar Munich, 2014

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Battery technologies

Redox-flow

NiMh

Source: www.saftbatteries.com

Lithium-ion

NaS / NaNiCl

Source: www.ngk.co.jp

Lead-acid

Sodium-ion

Source: www.aquionenergy.com

Battery technologies - Parameters

	Lead acid	NiMH	Li NMC / Graphite	LiFePO4 / Graphite	LMO / Graphite	LMO / Titanat	Vanadium-Redox-Flow	NaNiCl	NaS
Energy density (Wh / kg)	40	75	160	110	130	75	45	100	110
Power density (W / kg)	350	600	1300	4000	1500	4000	120	120	100
Cycle life time	600	900	2500	5000	3000	8000	12000	2500	4500
Calendar life time (years)	7	5	7	14	8	12	15	12	11
Efficiency (%)	85	75	93	94	94	94	80	85	80
Self discharge (% / month)	8	20	3	3	2	2	5	10 pro Tag	12 pro Tag

Battery technologies – Investment cost

Speicherkennwerte | Characteristic Storage Values

Speicherart | Type of Storage	Preis pro | Price per kWh	Zyklenzahl | No. of Cycle	Wirkungsgrad | Efficiency
Elektrochemische Speicher | Electrochemical Storage			
Natrium-Schwefel (NaS) | Sodium Sulfur	300–600 €	4.500	65–75 %
Natrium-Nickelchlorid (NaNiCl) | Sodium NiCl	450 €	2.500	85 %
Lithium-Ionen | Lithium Ion	200–2.000 €	200–7.000	94 %
Bleibatterien (Pb) | Lead Acid Battery	60–300 €	600	80–86 %
Alkalische Speicher | Alkaline Storage			
Nickelmetallhybrid (NiMH) Nickelcadmium (NiCd)	400–600 €	900	75 %
SuperCaps (Doppelschichtkondensatoren) | Double Layer Capacitors	>2.000 €	100.000	96 %
Vanadium-Redox-Flow	150–800 €	13.000	> 80 %
Mechanische Speicher | Mechanical Storage			
Schwungräder | Flywheels	20 €	1 Mio.	85 %
Pumpspeicher | Pumped Storage	20 €	50 Jahre	75 %
Druckluftspeicher | Compressed Air Storage			
Druckluftspeicher | Compressed Air Storage	600–800 €		50–70 %
Chemische Speicher | Chemical Storage			
Wasserstoff | Hydrogen		30.000*	21–43 %
Synthetisches Methan | Synthetic Methane			ca. 30 %

*Zyklenzahl der Brennstoffzelle | Fuel Cell Cycle
Quelle | Source: BMWi 2009, IER 2007, BMU 2009, VDE 2009, Krause 2009

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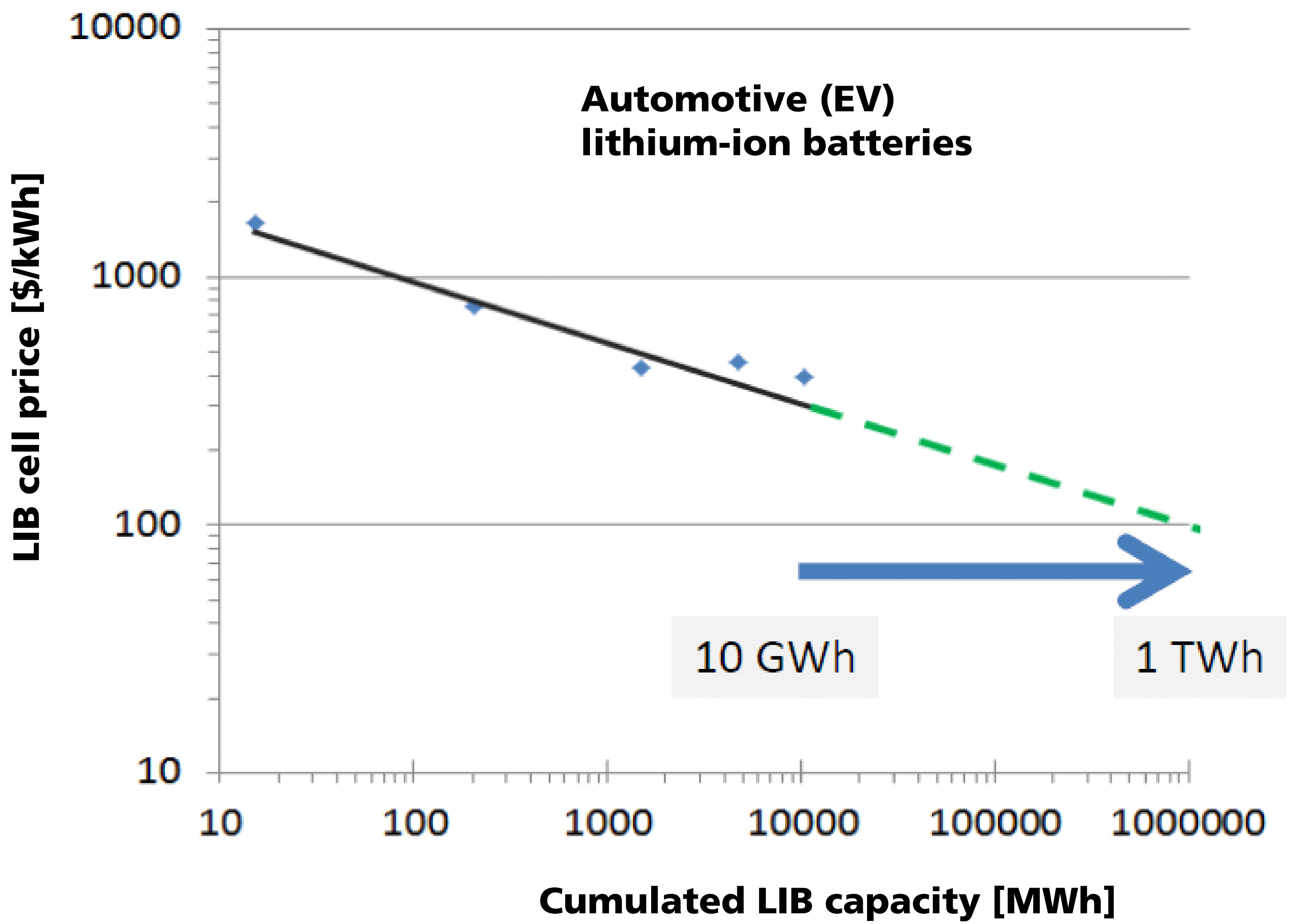
Battery technologies – Investment cost
Price experience curve for automotive applications



Source: Winfried Hoffmann, Importance and Evidence for Cost Effective Electricity Storage, PVSEC, 2014

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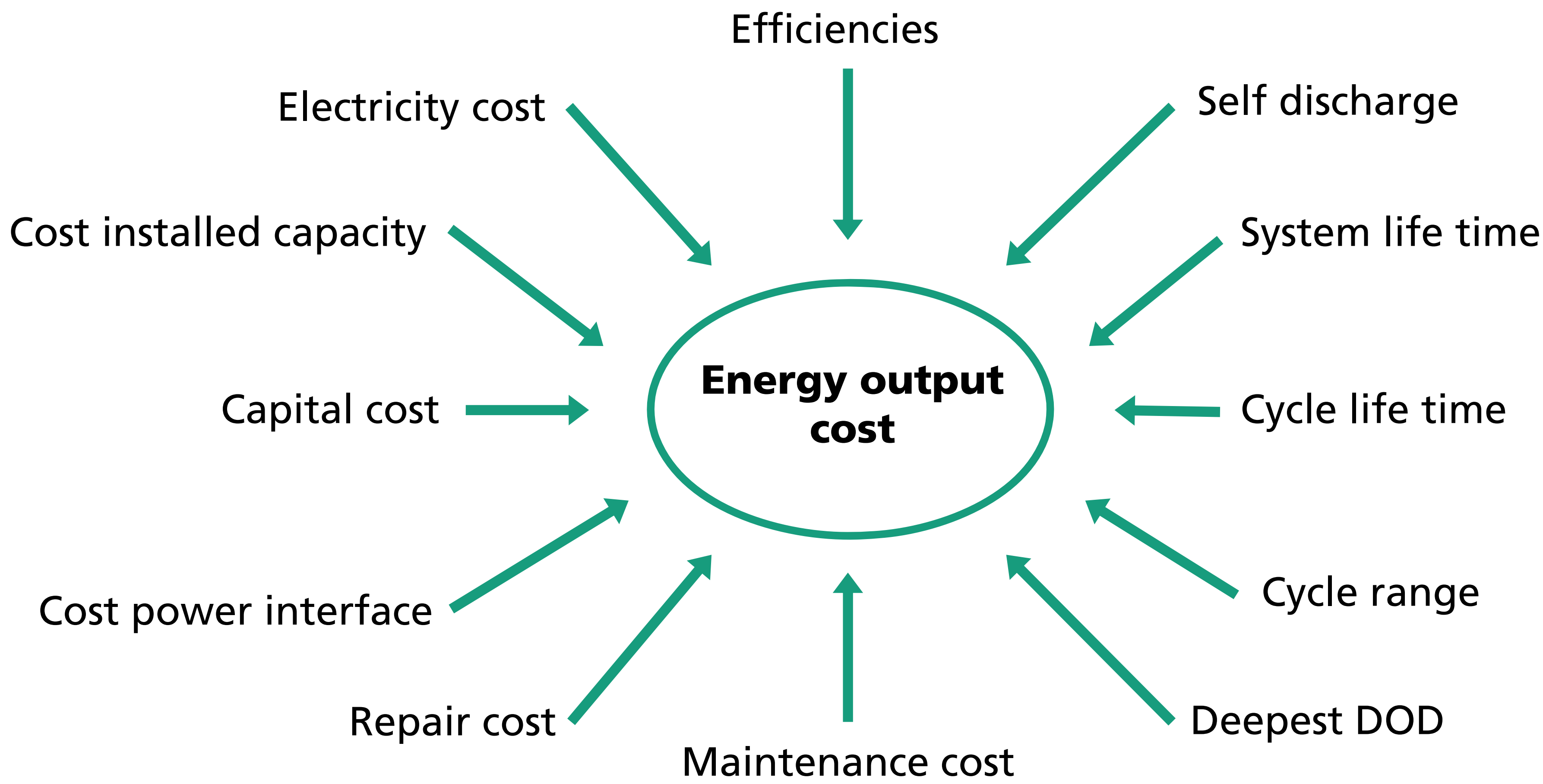
Cost analyses – Levelized cost of electricity storage



Lithium-ion batteries

Pouch bag

Prismatic

Cylindrical

Advantages:

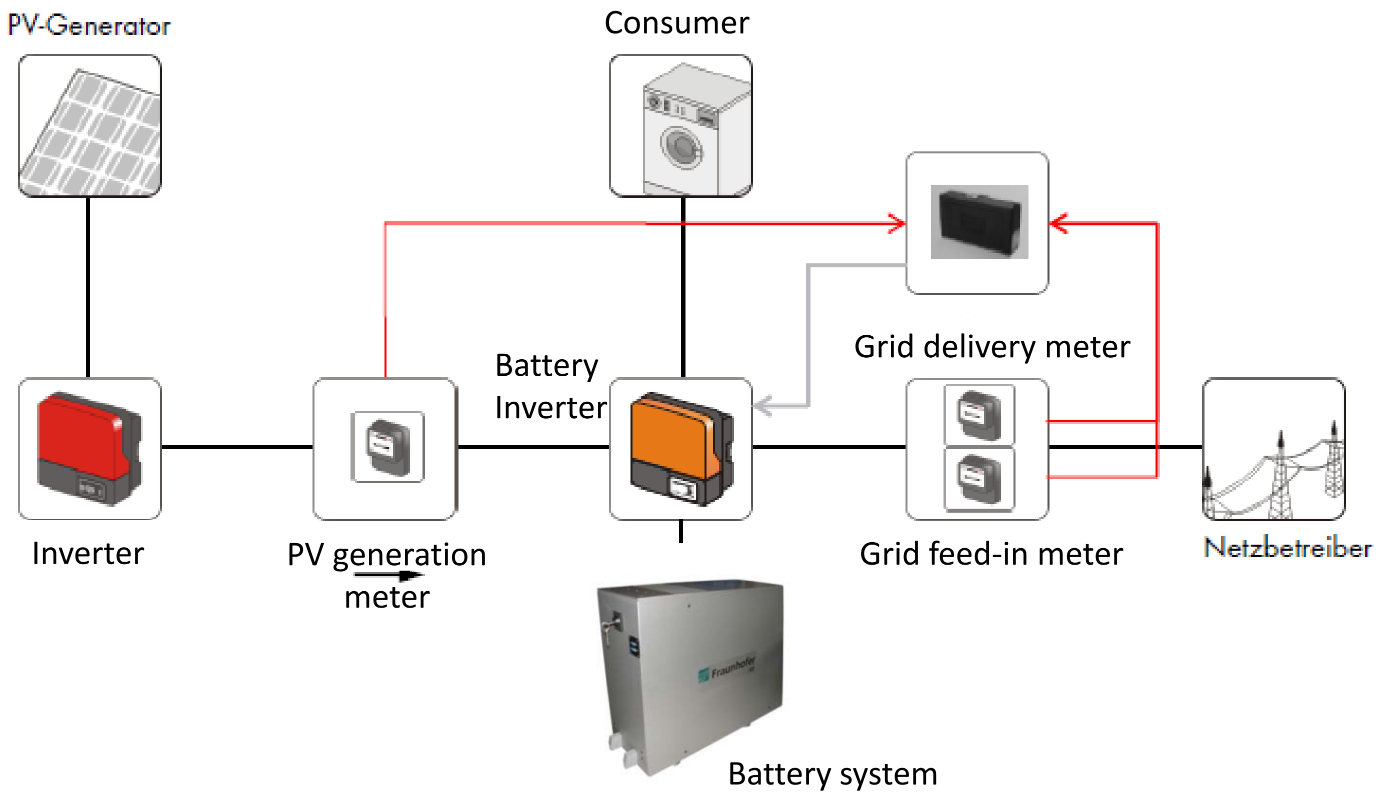
- High energy density
- High power to capacity ratio
- Little or no maintenance
- Low self discharge
- High energy efficiency
- Long calendar life times
- Large number of cycles

Disadvantages:

- Safety – need for protective circuit
- High initial cost
- Thermal runaway possible when overcharged or crushed

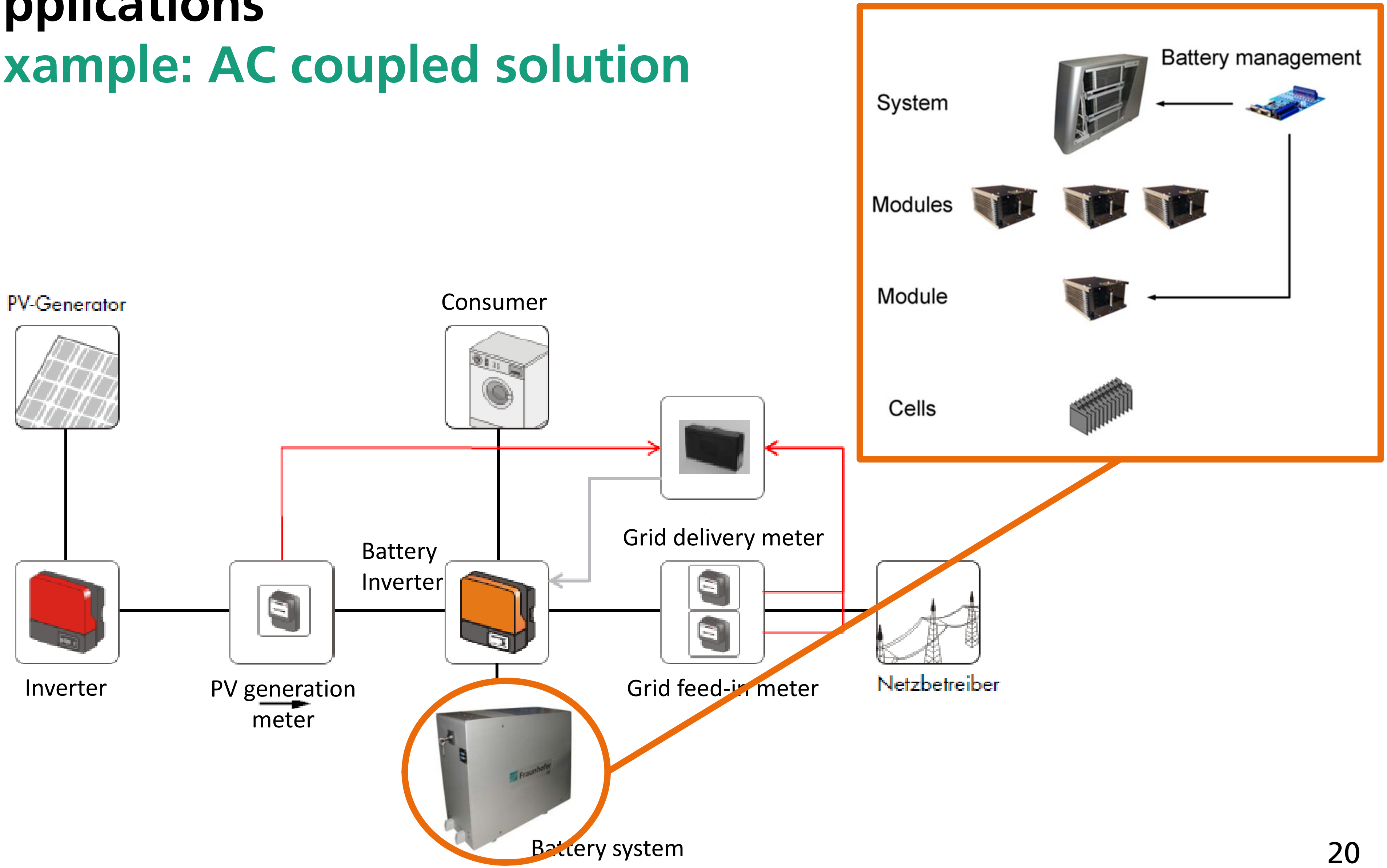
System design – Lithium-ion batteries for residential PV applications

Example: AC coupled solution



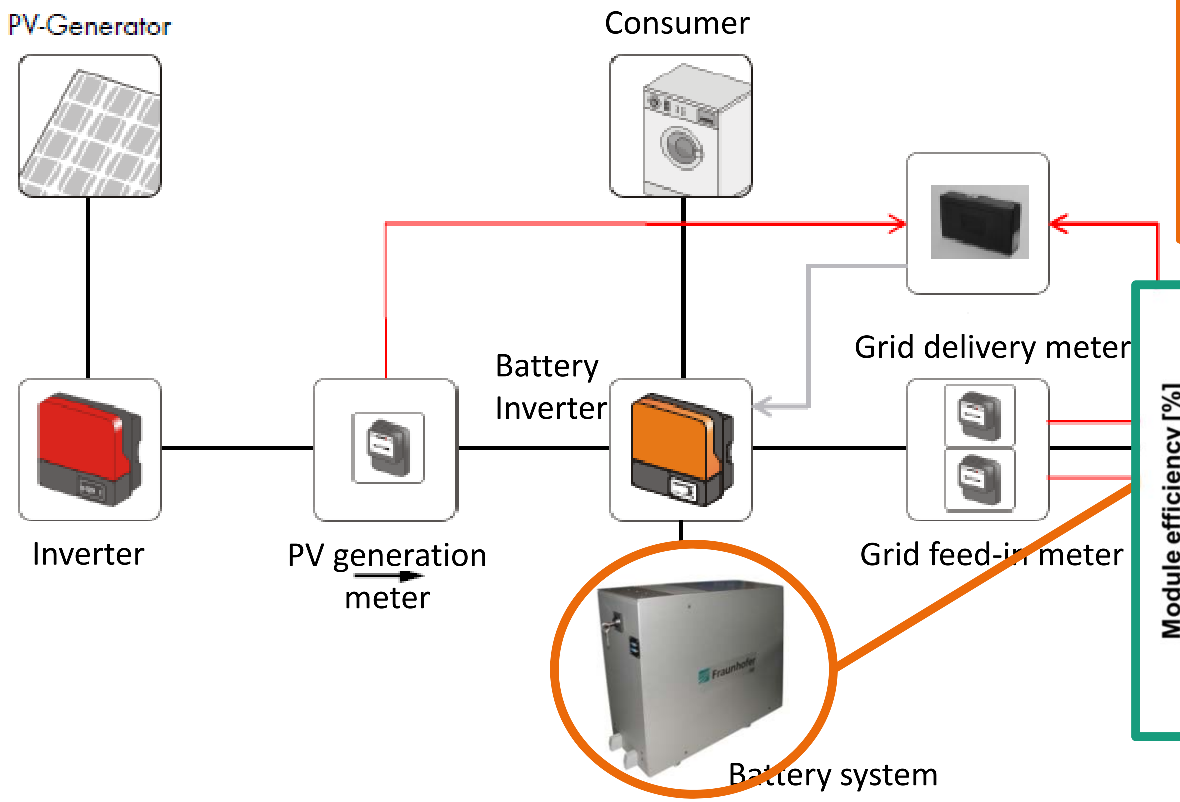
System design – Lithium-ion batteries for residential PV applications

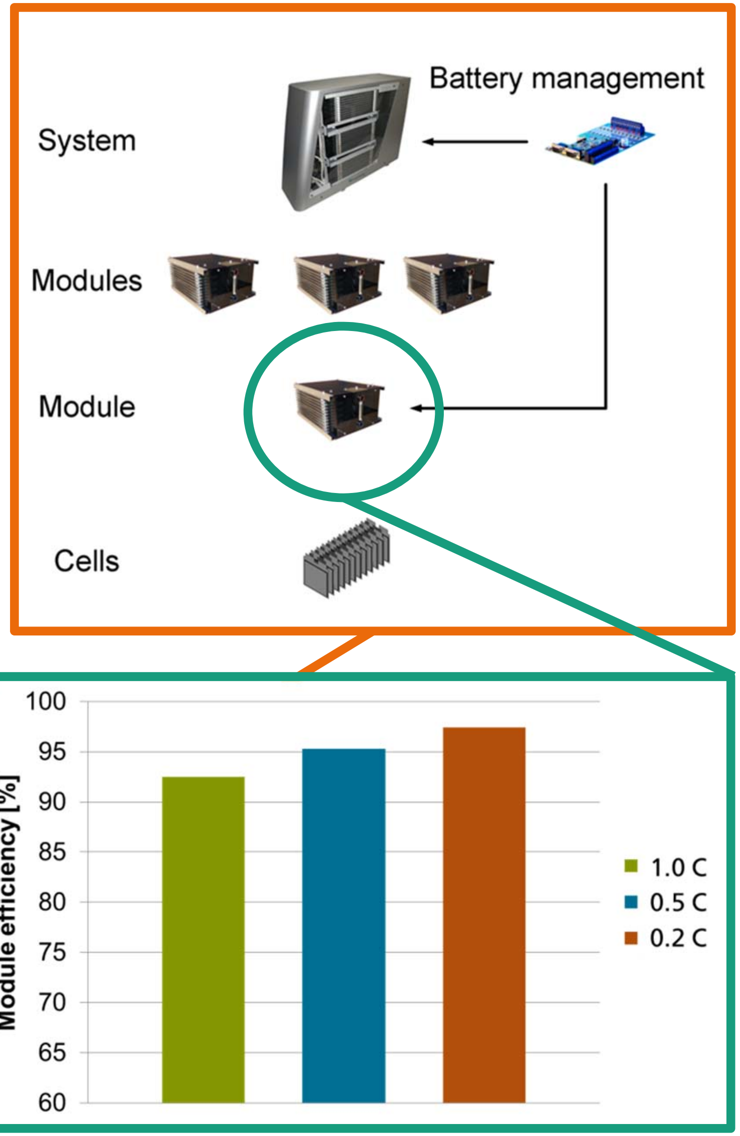
Example: AC coupled solution



System design – Lithium-ion batteries for residential PV applications

Example: AC coupled solution





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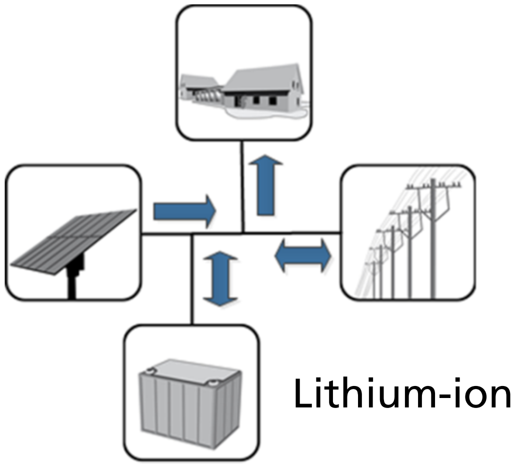
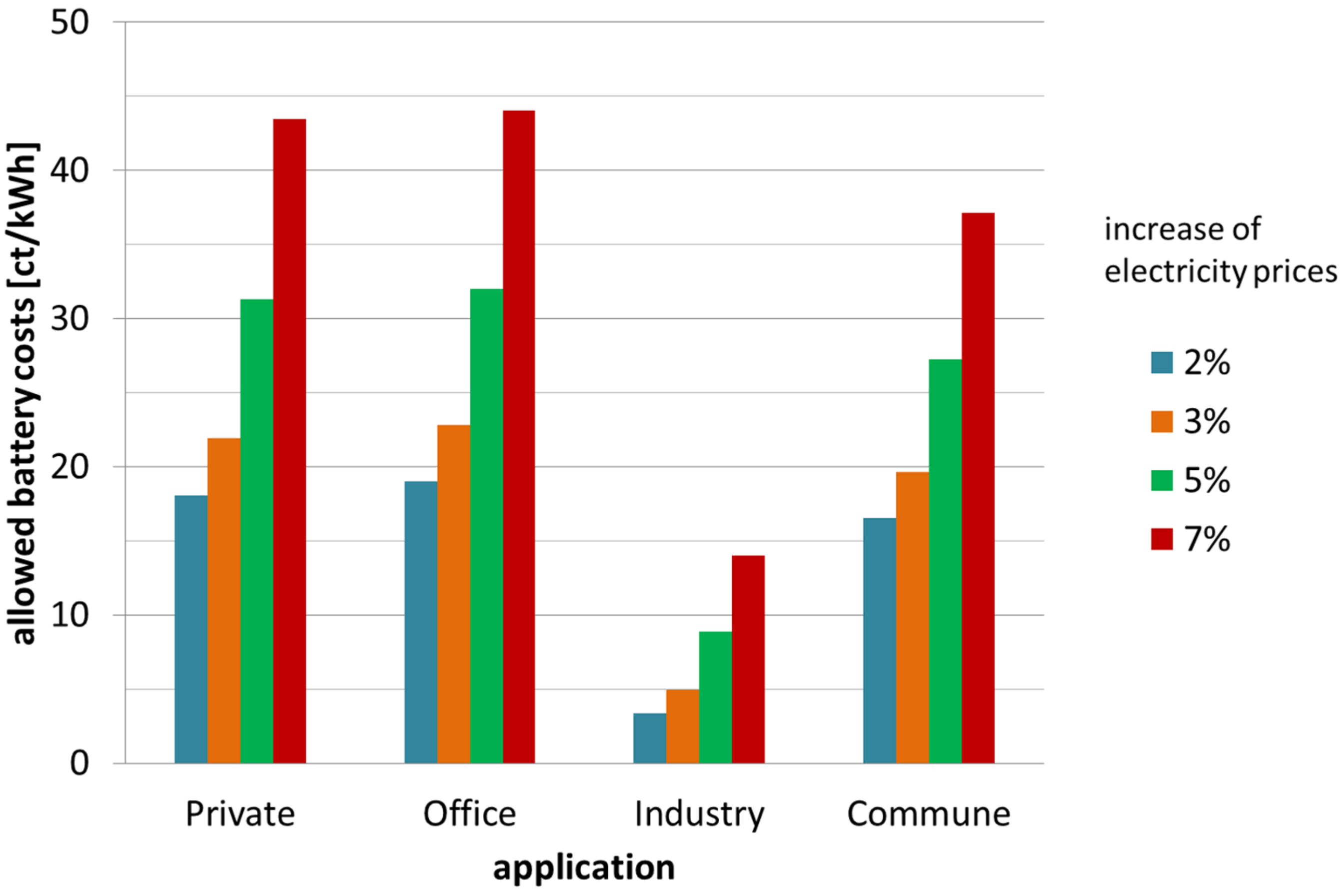
Cost analyses

Example: Optimization of self consumption

Allowed cost for 4 self consumption applications

- Private / residential
- Office
- Industry
- Municipality





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Cost analyses
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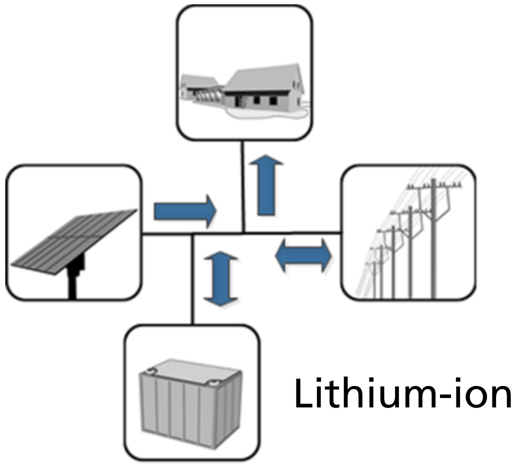
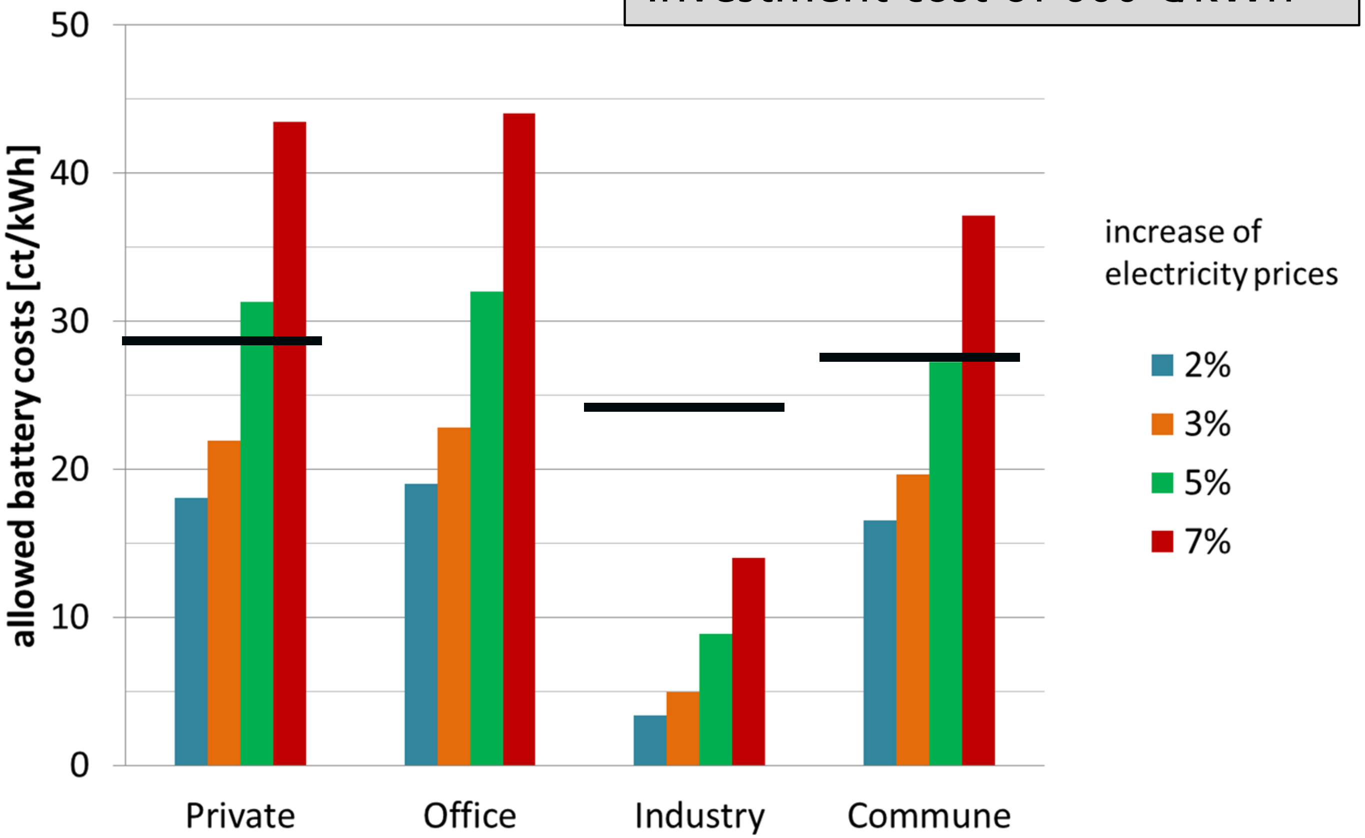


Current cost calculated with Investment cost of 600 €/kWh



Cycles per year	221	75	256	227
Storage cost ct / kWh	28	81	24	27

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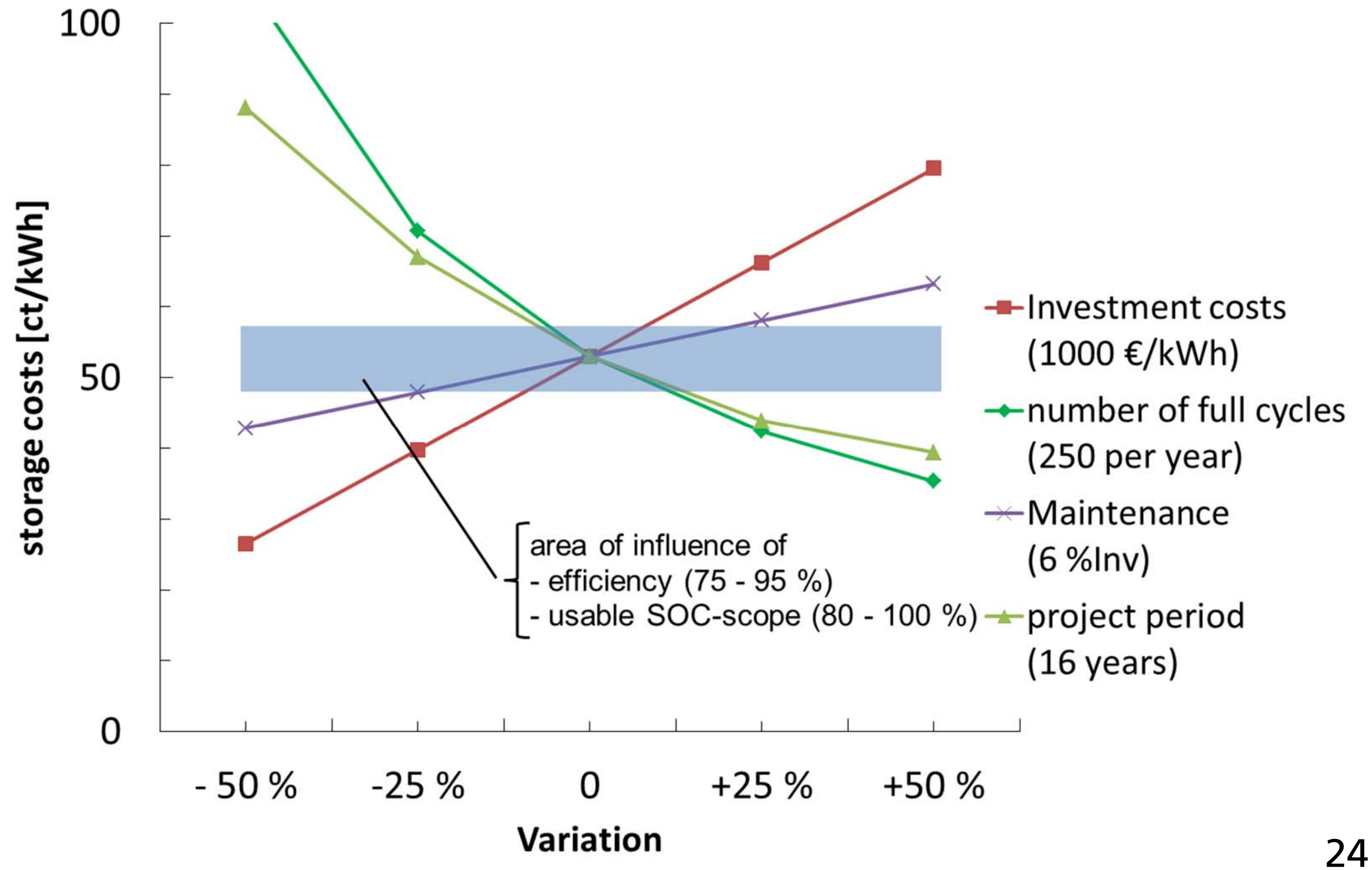
Cost analyses
Lithium-ion battery system

Cost drivers

- Investment cost
- Cycle number
- Operation and maintenance
- Project period



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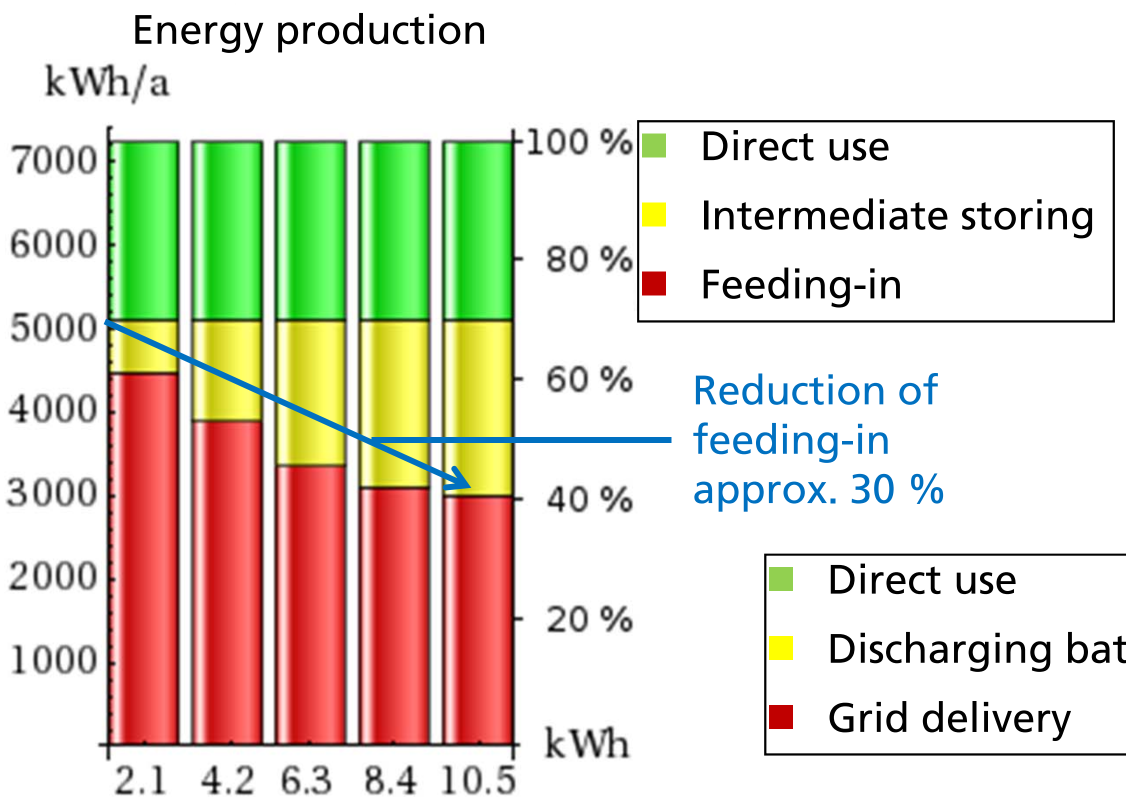
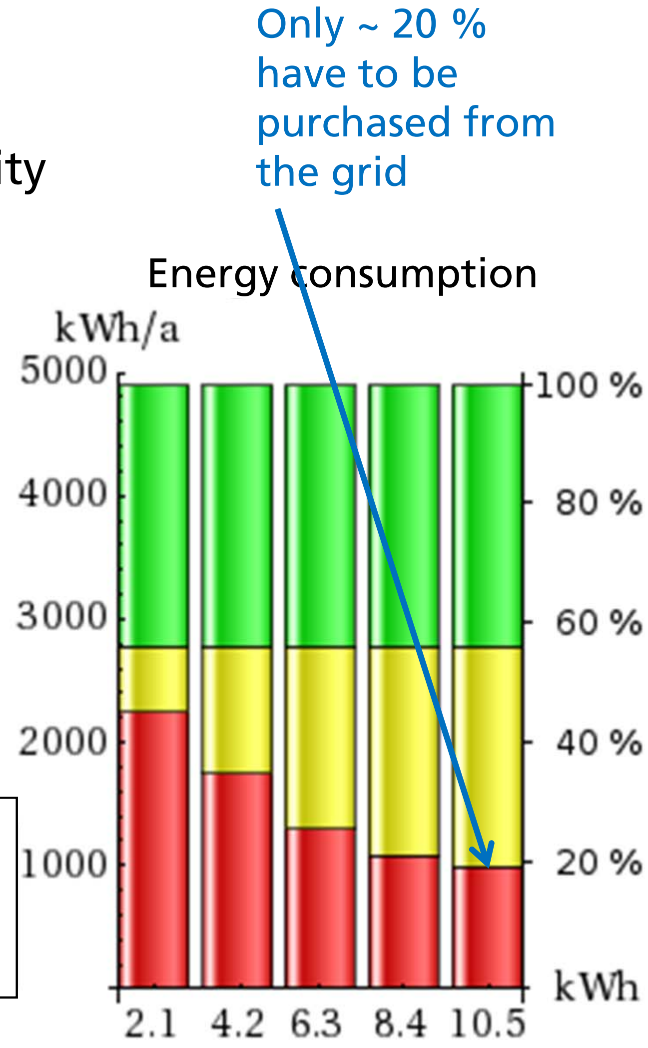
Energy management – Optimization of self-consumption
Analysis of energy fluxes (results of system simulation)

- Load (residential application): 4900 kWh/year
- PV generator size: 6 kWp
- Lithium-ion battery system: Variation of usable capacity





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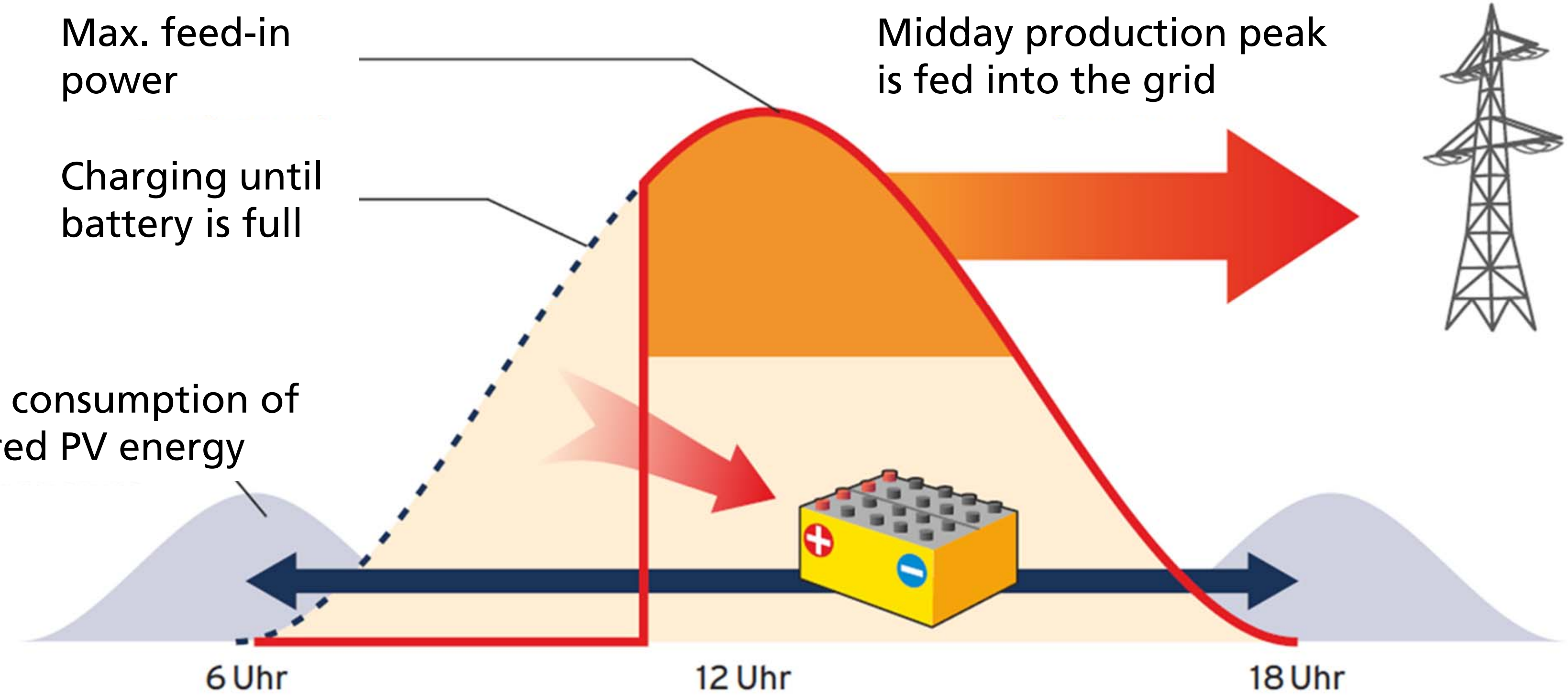
Energy management
Operating control strategies

→ Conventional storage strategies have no significant positive effects for the distribution grid

Conventional storage strategy



Source: J. Mayer (BSW), C. Wittwer (ISE), Batteriespeicher: Ein sinnvolles Element der Energiewende. Berlin, Pressefrühstück 25.1.2013

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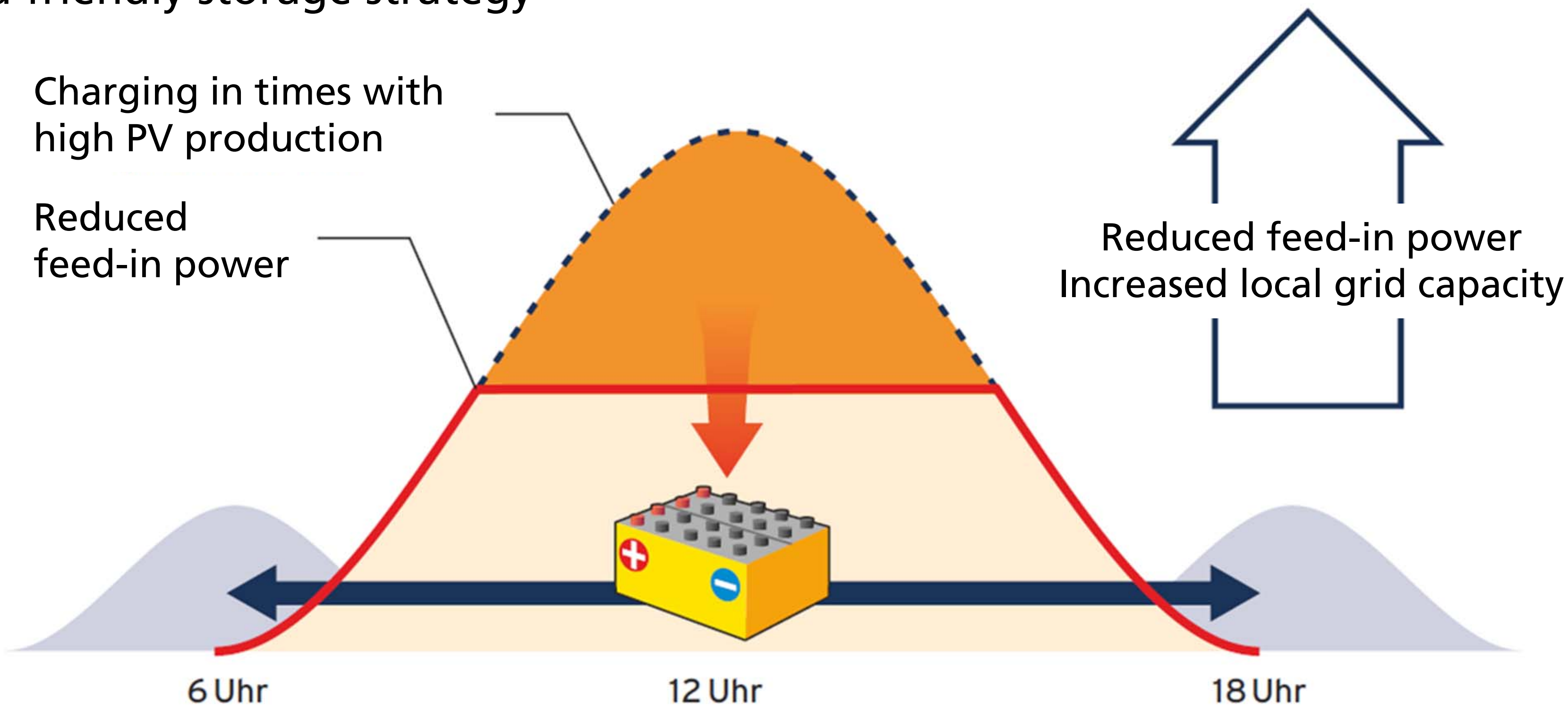
Energy management
Operating control strategies

- → Reduced feed-in peak power decreases problems in the distribution grids
- → Reduced feed-in peak power up to 40 % without yield losses
- → 66 % increase of PV power in local distribution grids possible

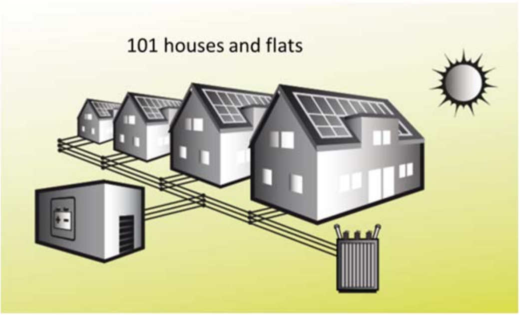
Grid friendly storage strategy

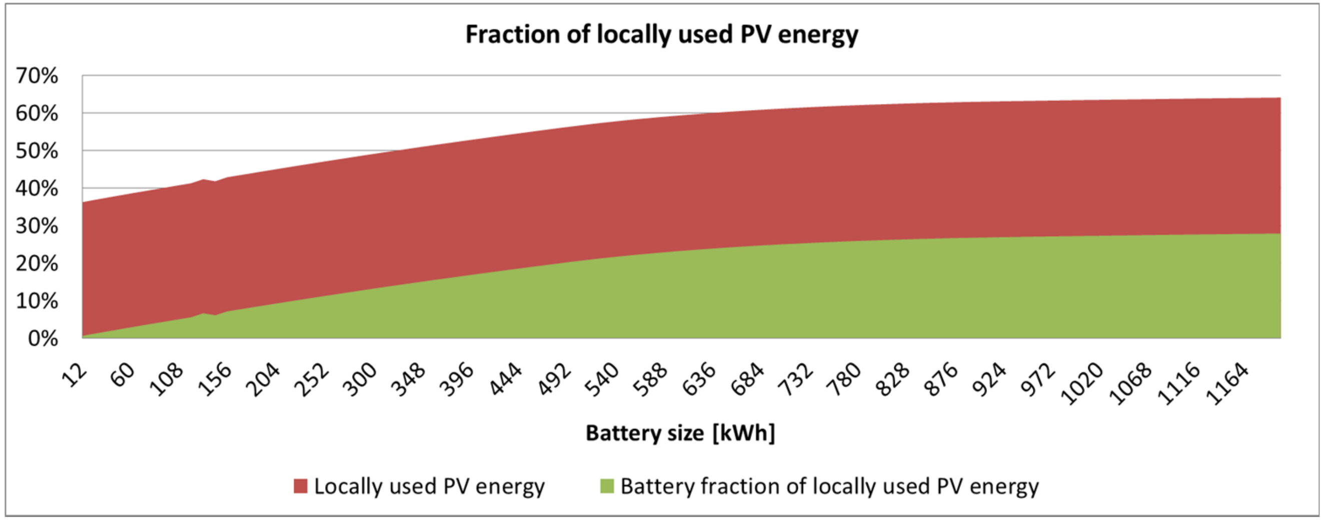


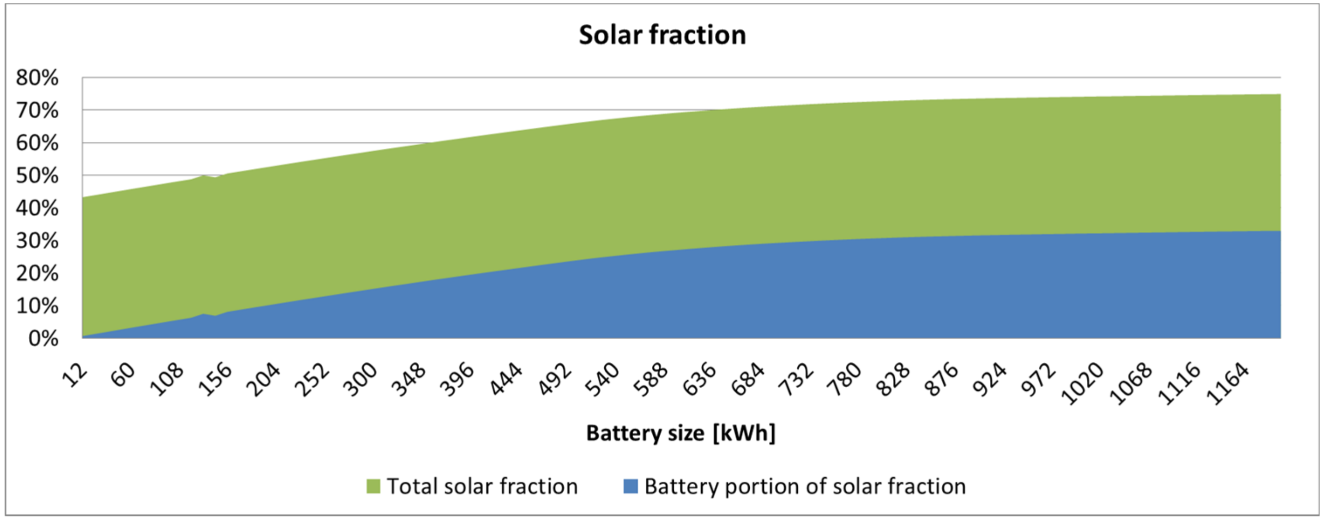
Source: J. Mayer (BSW), C. Wittwer (ISE), Batteriespeicher: Ein sinnvolles Element der Energiewende. Berlin, Pressefrühstück 25.1.2013

Alternative: District battery storage
Simulation study for a low voltage grid

- Decentralized PV systems with a cumulated power of 600 kWp
- “Centralized” battery storage next to the transformer







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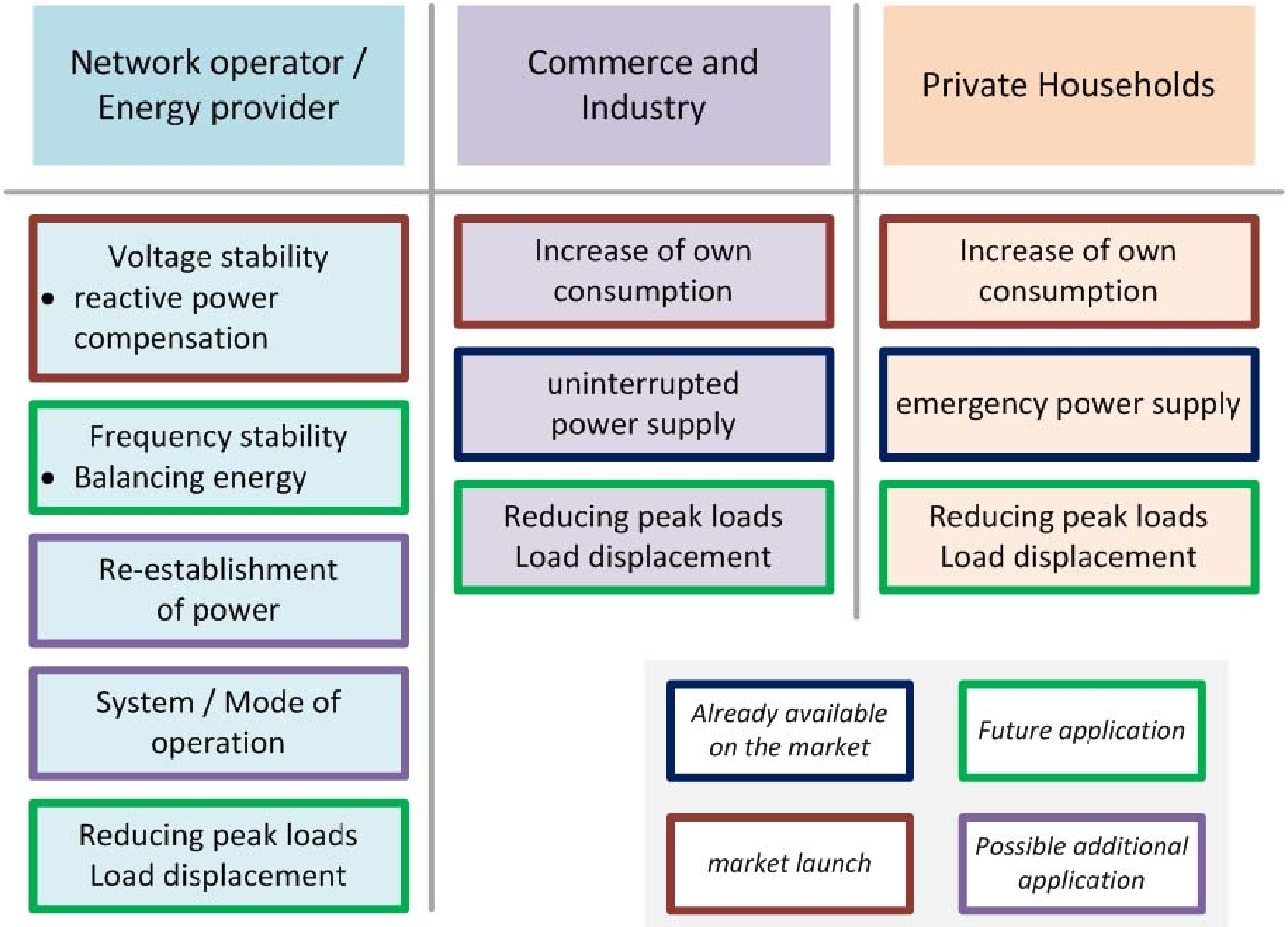
Stationary battery systems
Additional business cases beyond PV self-consumption

- Multiple use of storage device
  - → Additional services, e.g. grid support
  - → Additional revenues

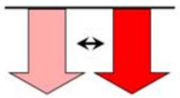


Future distribution grids with various flexibility options
Classification

Additive generation
- Application: rare short-term peak loads
- Technology: e.g. emergency power units (hospitals)

Dispatchable generation
- Application: frequent and high short-term peak loads
- Technology: CHP units

Electric power storage
- Application: daily balancing of power demand and generation
- Technology: e.g. battery systems, decentralized and “centralized”

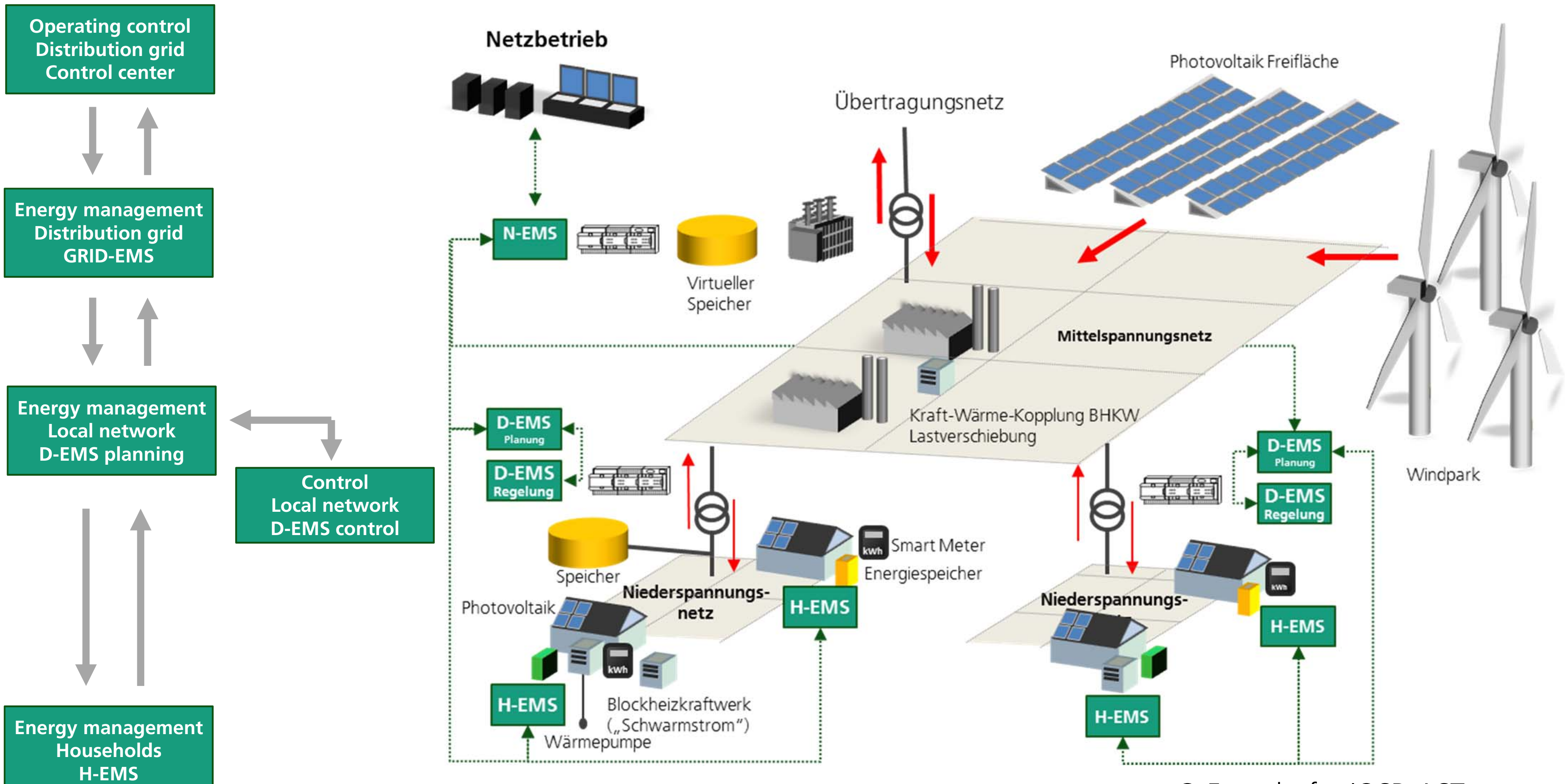


Dispatchable load
- Application: frequent and high short-term generation peaks
- Technology: e.g. heat pumps with thermal storages, *electric cars (!)*

Additive load
- Application: rare generation peaks
- Technology: e.g. electrical heating (domestic hot water, district heating)

Future distribution grids with various flexibility options

Example of an energy management structure



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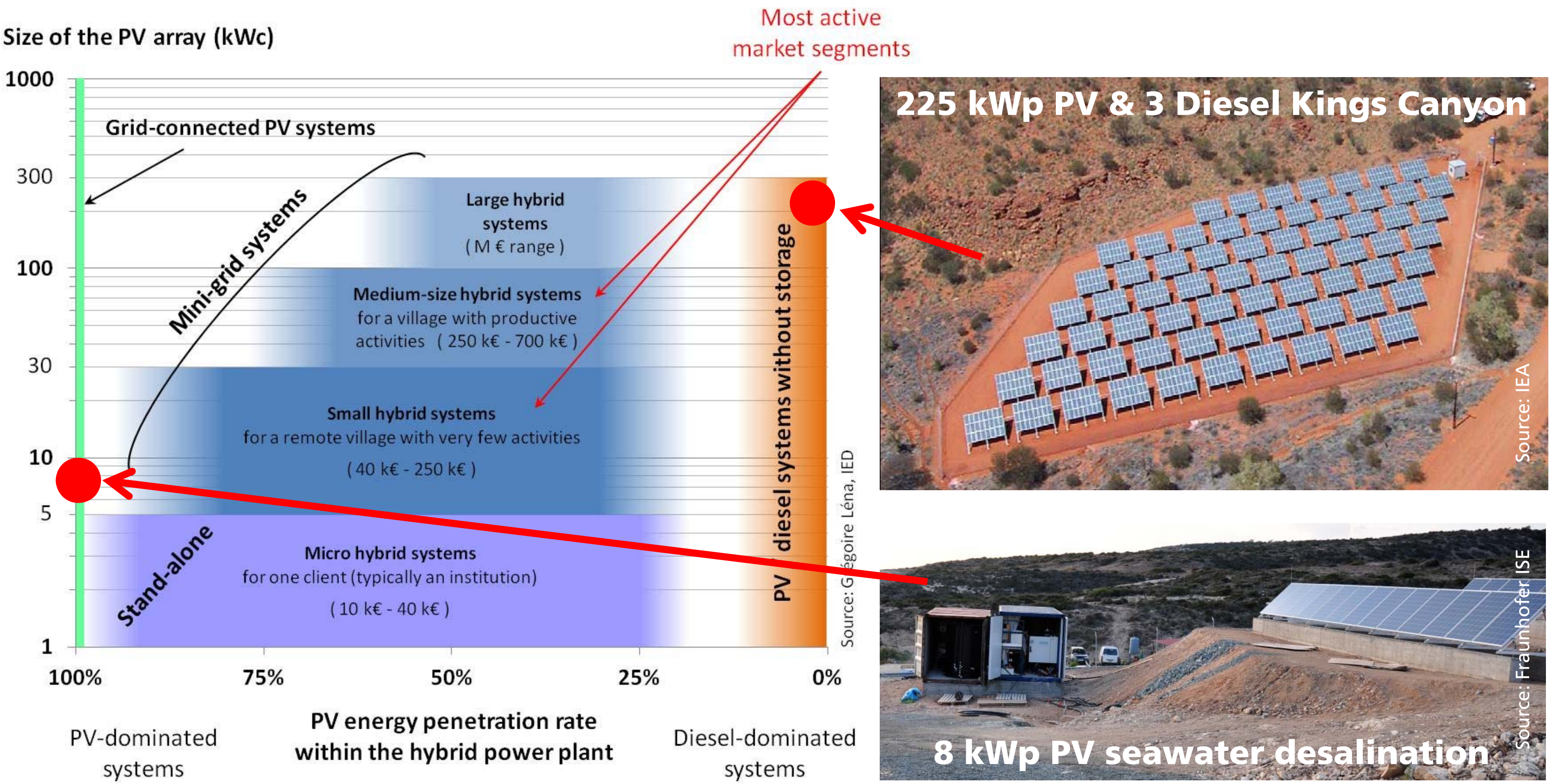
PV battery systems for mini-grids
From Diesel dominated systems to 100 % renewables



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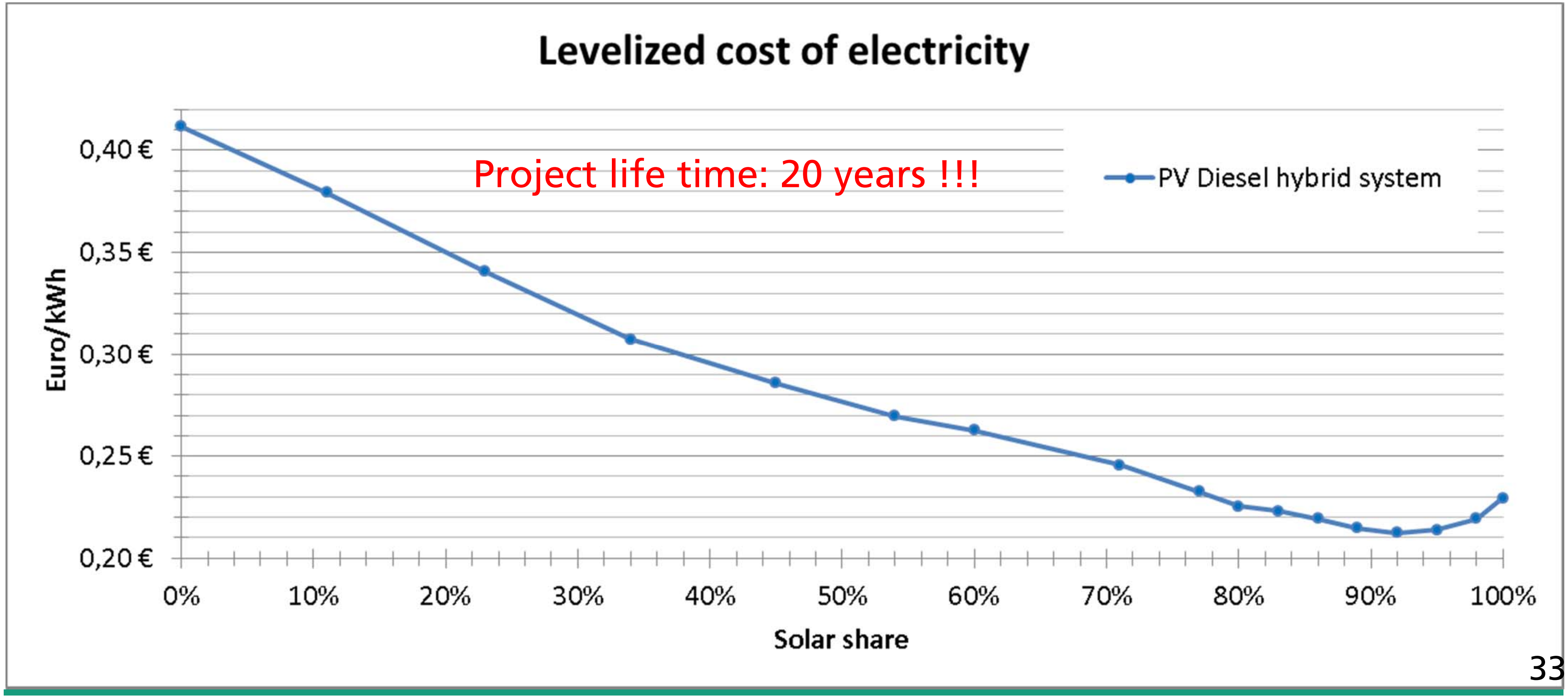
PV battery systems for mini-grids
Levelized cost of electricity – Example Uganda

- Load:
  - Peak load: 200 kW
  - Annual consumption: 574 MWh
- PV Diesel hybrid system:
  - PV system (incl. power electronics): 1.5 Euro/Wp
  - Battery system: 220 Euro/kWh
  - Diesel: Invest 273 $/kW; Fuel 1$/l; Maintenance: 0.7 $/h



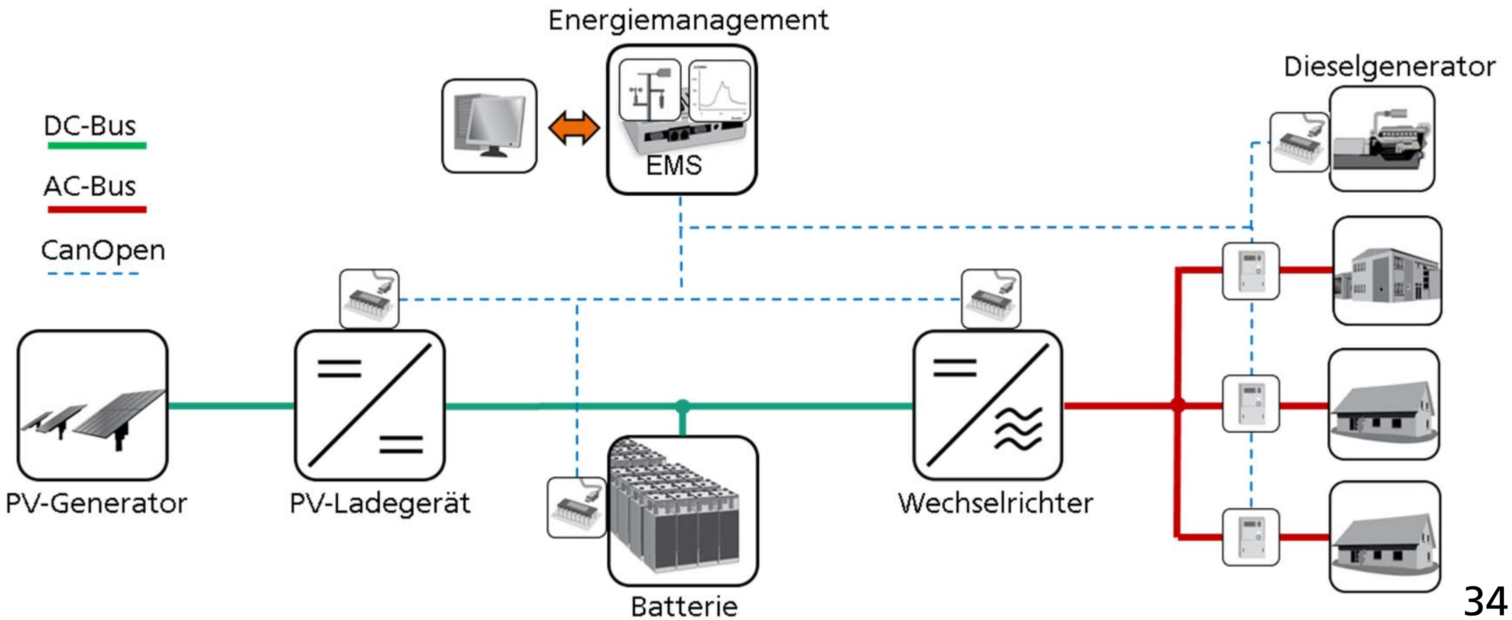
Hybridization of battery system – System simulation

Avoiding to high upfront cost for new technologies

PV generator	110 kWp
DC-DC converter (nominal power)	2 x 51 kW
Inverter (nominal power)	120 kW
Diesel generator	60 kW
Lithium battery system ($LiFePO_4$)	289 kWh
Lead-acid battery system	1.152 kWh
Annual consumption	100.132 kWh

Hybrid generation: PV generator, DC-DC converter, Inverter, Diesel generator

Hybrid storage: Lithium battery system, Lead-acid battery system



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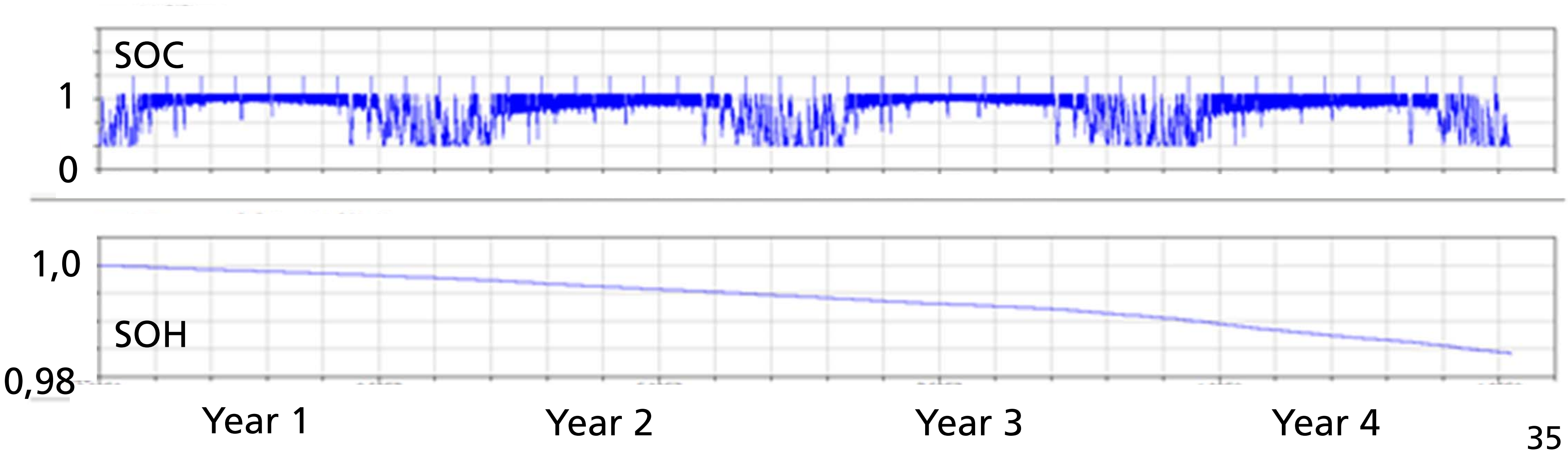
System simulation – Example for a period of four years

- Starting point: Measurement data of a lead-acid battery operated with advantageous boundary conditions (integrated BMS and frequent full charges)
- Loss of capacity of lead-acid battery with simulation period of 4 years: 1.5 % (!)

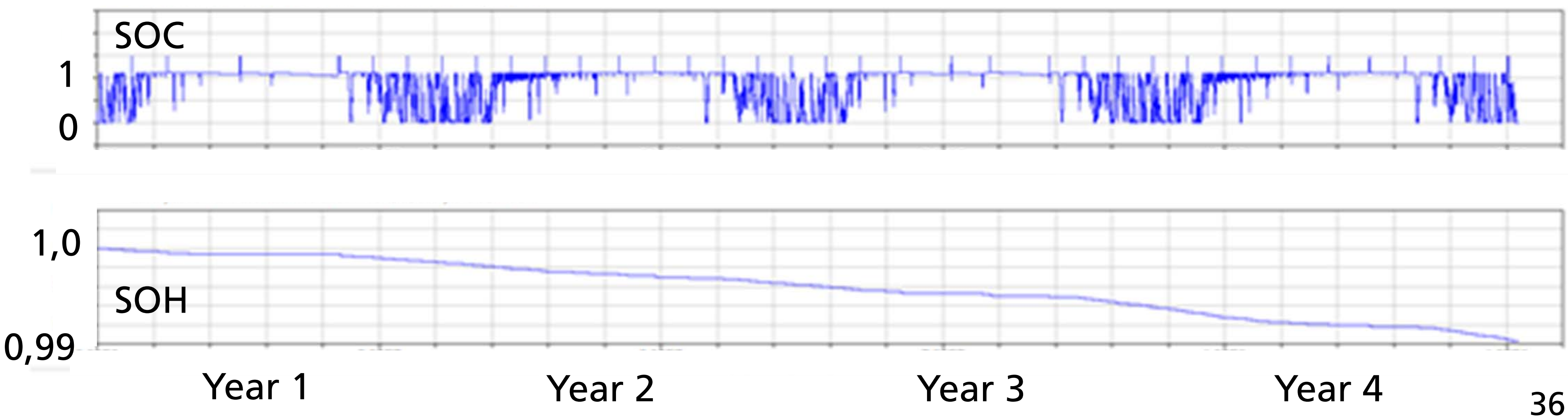
Lead-acid battery



System simulation – Example for a period of four years

- Starting point: Measurement data of a lead-acid battery operated with advantageous boundary conditions (integrated BMS and frequent full charges)
- Loss of capacity of lead-acid battery with simulation period of 4 years: 1.5 % (!)
- Hybridization: Loss of capacity: 0.9 %
  → Reduction of aging: 40 % (within simulation period of 4 years !!!)

Hybrid battery system – Consideration of lead-acid sub-system



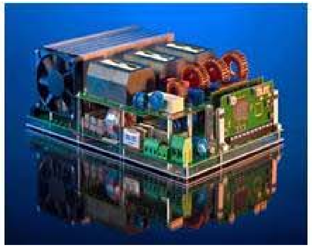
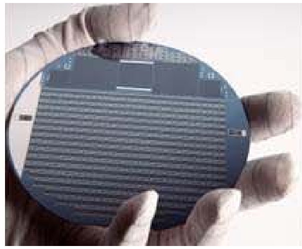
Conclusions

- Storages crucial for **large scale integration** of fluctuating renewables
- Market forecasts for **stationary battery storages** very promising
- Especially **lithium-ion** battery systems very interesting for the use in grid-connected PV applications
- Lithium-ion batteries on the way to be **profitable**, dependent on the specific application and the boundary conditions
  - But: Cost still have to be decreased → Detailed **cost analyses** important
  - **Multiple use** of storage systems may improve the economics
- But: There are more **flexibility options** in the (distribution) grid, which also have to be considered → Smart integrated system solutions necessary
- PV Diesel mini-grids:
  - High solar fractions economic viable in terms of LCOE, but dependent on the considered **project life time**
  - **Hybridization** supports introduction of innovative storage technologies

→ Energy storage: Key for large-scale grid integration of renewable energies

Thanks for your attention !!!




Fraunhofer Institute for Solar Energy Systems ISE

Dr. Matthias Vetter

www.ise.fraunhofer.de
matthias.vetter@ise.fraunhofer.de

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