Energy Storage Technologies
Battery Storage for Grid Stabilization

IEA EGRD Conference on Energy Storage

BMWi, Berlin, October 23rd 2014

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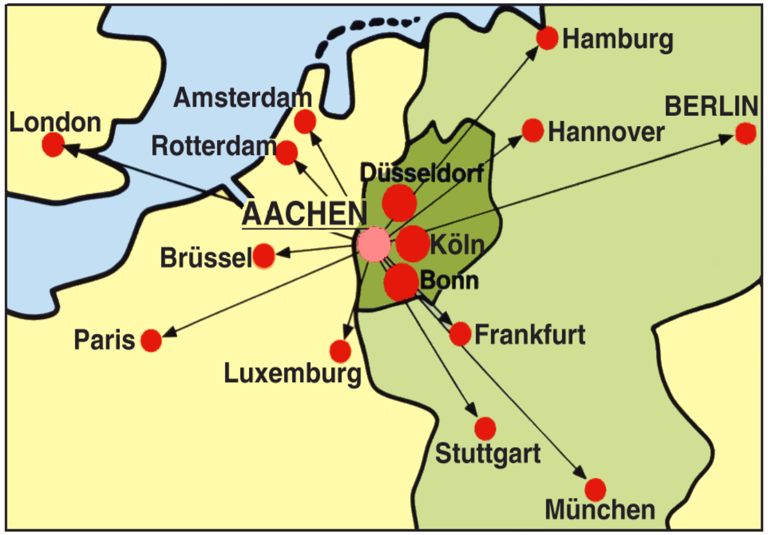
RWTH Aachen
Institute for Power Generation & Storage Systems (PGS)
Electrochemical Energy Conversion and Storage Systems (ISEA)

Who we are



Cathedral of Aix-la-Chapelle
Charlemagne 800 a.d.

- RWTH Aachen University
  - Major technical university in Germany, >30.000 students
  - Electrical Power Engineering: 5 institutes / 6 professors, >250 PhD candidates
  - Biggest research cluster on electrical energy technology in Germany
- Storage @ Aachen University
  - Electrical Engineering: from cell - to system - to application - to techno-economics

Storage @ RWTH Aachen

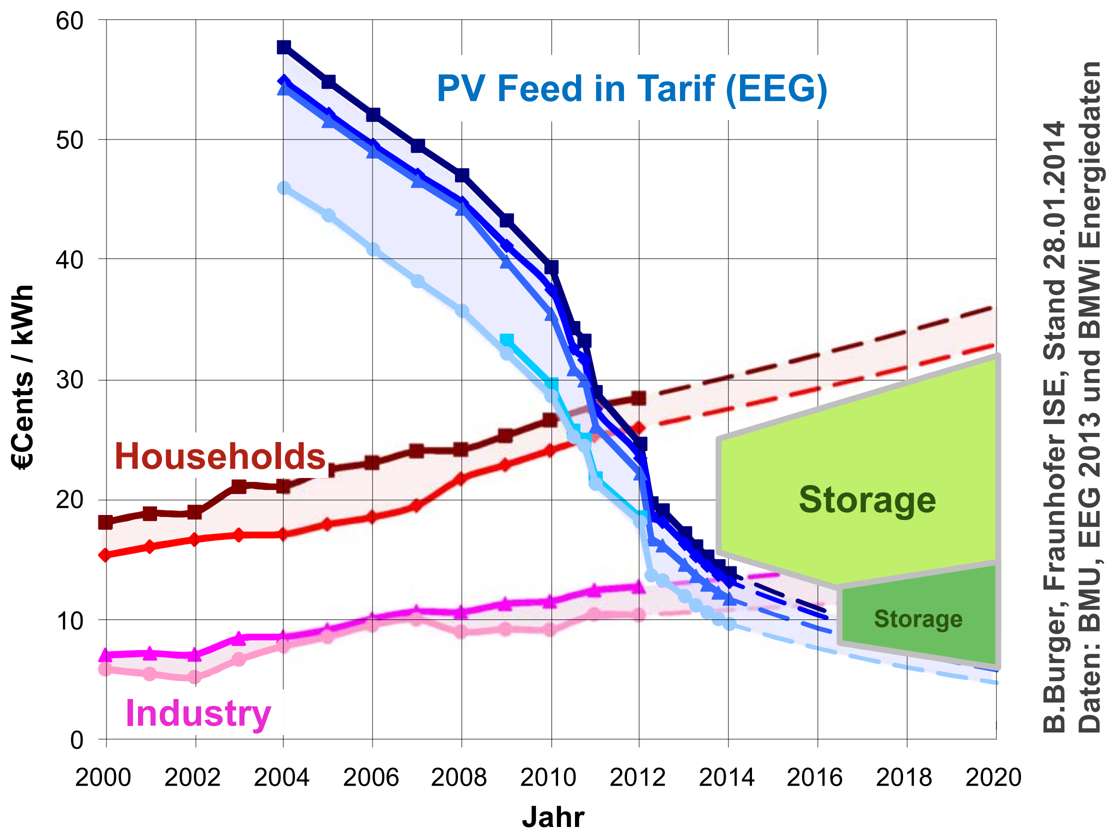
Electrical storage systems

Chair for Electrical storage systems

1 Professor
3 Senior scientists / heads of section
65 Scientist and engineers
5 Research fellows
60+ Students (full and part time)

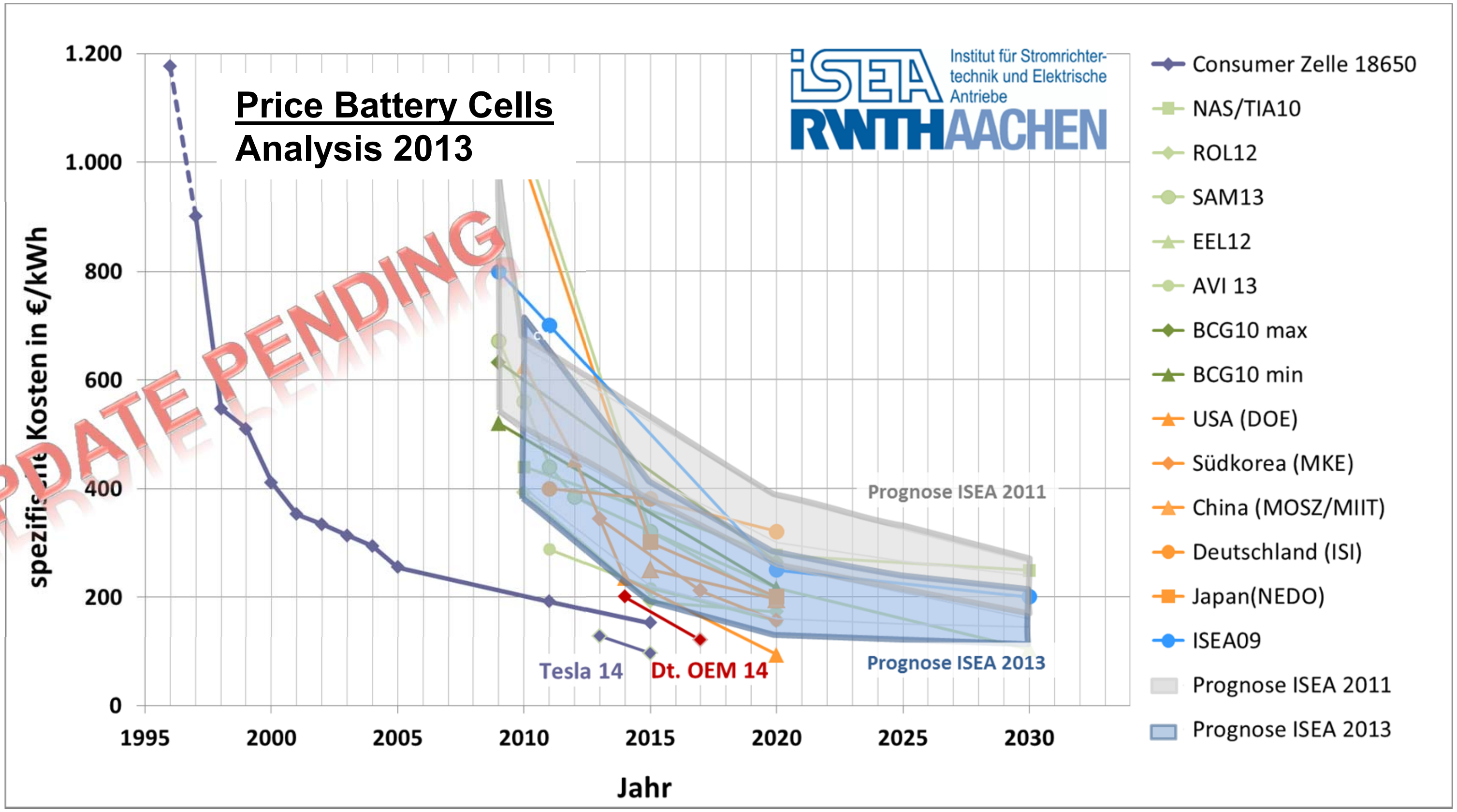
- **Lead Acid, Li-Ion, NiMH, NiCd, SuperCaps, Fuel Cells, Redox-Flow and others …**
- **Energy- und Battery Management Systems**
- **Thermal and electrical modelling**
- **Battery pack design**
- **Characterization and** durability tests
- **System integration renewable energy**
- **Hybrid, plug-in und electric vehicles**
- **Vehicle power net**
- **Micro grids / Autonomous power systems**
- **Uninteruptible power supply** (UPS)

Motivation 1



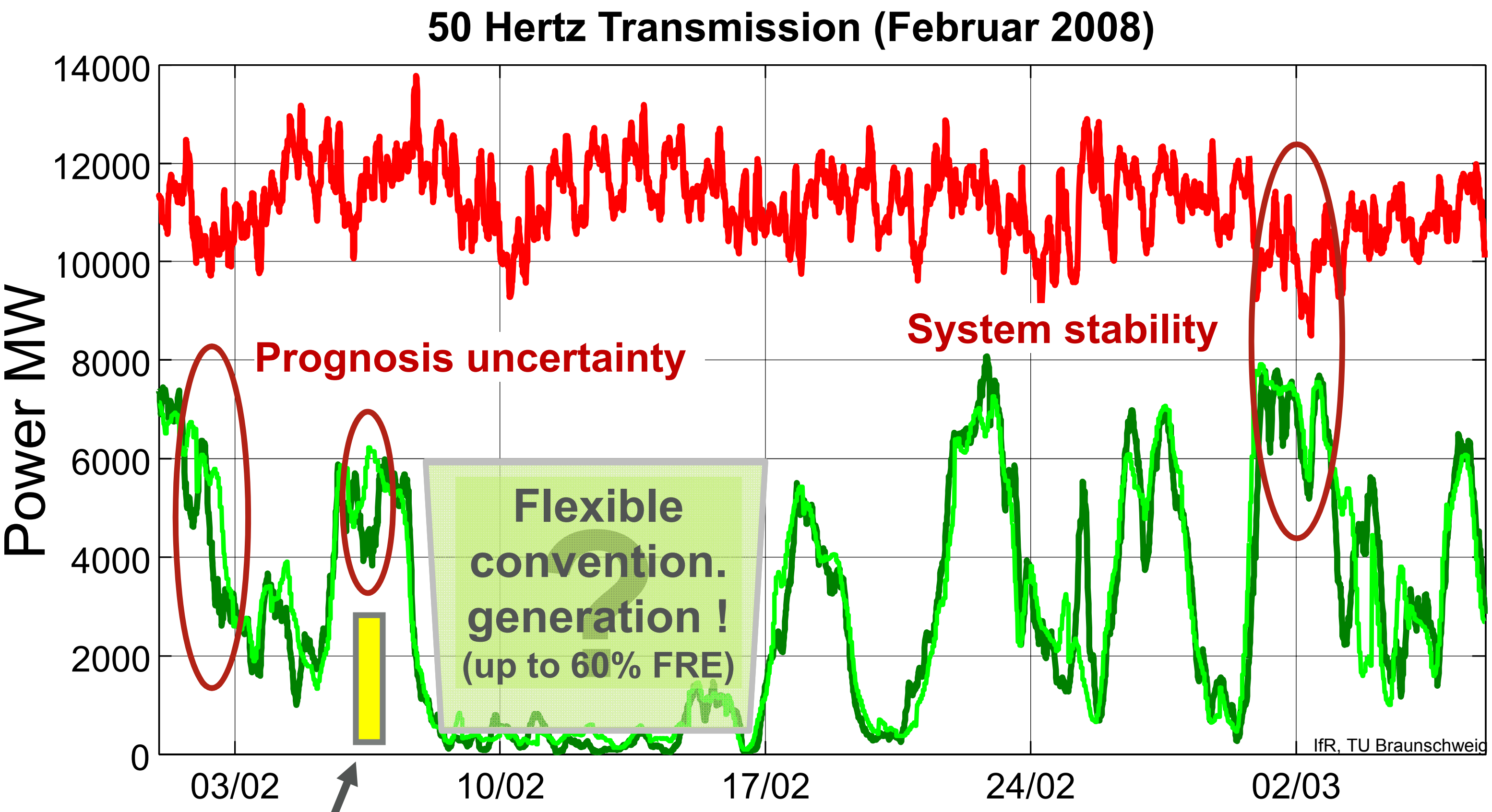
- Electricity price / PV-cost opens window for storage
- Depends on cost of generation, electricity and storage (and regulation!)
- Sizing + energy management determine viability

Motivation 2



- Massive decay of prices for lithium-ion-cells
- Electric mobility dominates development (> ten-fold market size of stationary)
- Drives also stationary storage system costs down (in part)

Motivation 3
Renewables: Where do we need storage?

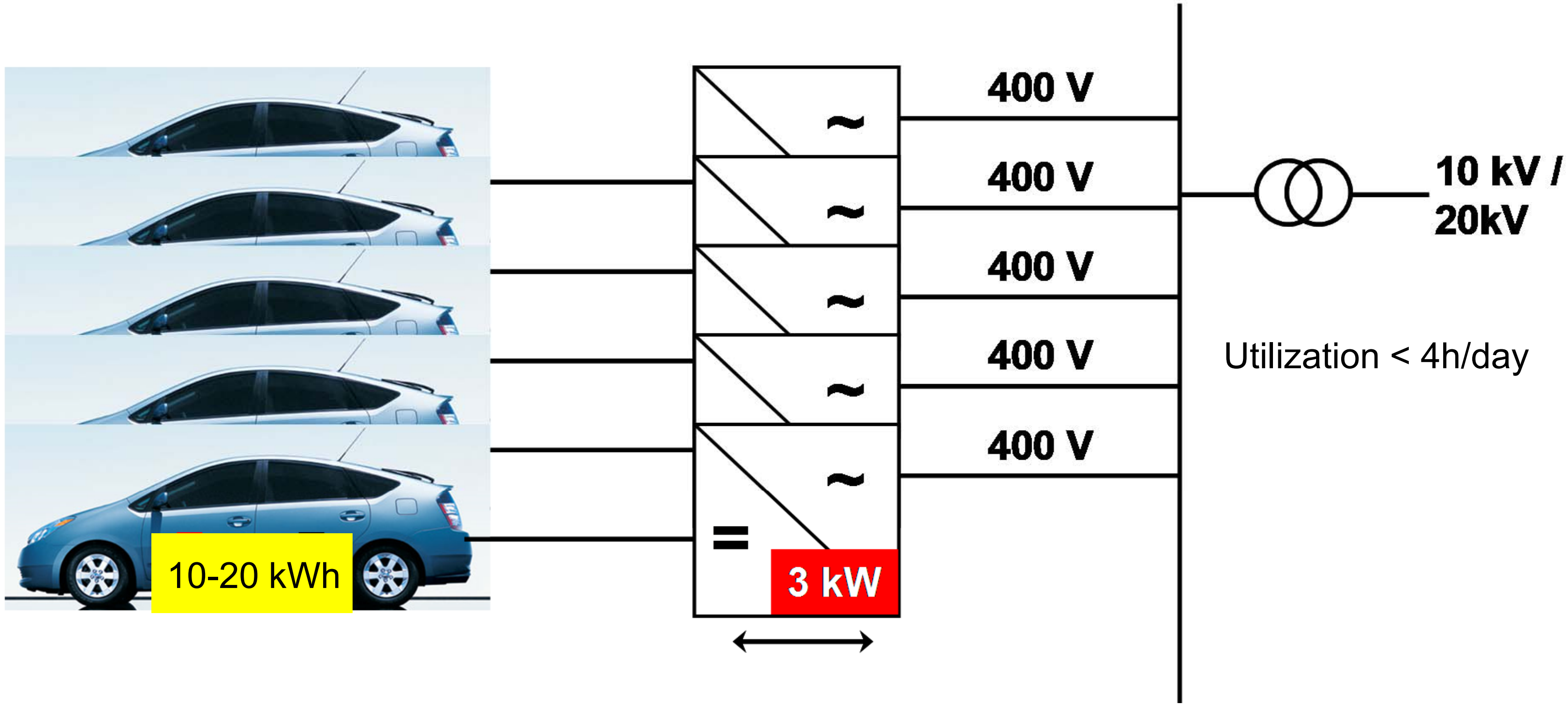


Source: IfR / TU Braunschweig

Pumped Hydro Capacity in Germany
40 GWh, 5GW

Load **Wind generation (real)**
Wind generation (prognosis)
Storage Applications

Motivation 4
Batteries in Electric Vehicles



Total power rating and storage capacity
2020: 1 million EV = 3 GW / 10-20 GWh

Selected Projects

Institut für Stromrichtertechnik und Elektrische Antriebe
RWTH AACHEN
E.ON Energy Research Center

- WMEP
  - Scientific Monitoring and Evaluation Program of the Market Incentive Program for PV-Storage Systems

Supported by:
Federal Ministry of Economics and Technology
on the basis of a decision by the German Bundestag

- GENESYS
  - Genetic Optimization of the European Energy System

STROMNETZE Forschungsinitiative der Bundesregierung
ENERGIESPEICHER Forschungsinitiative der Bundesregierung

Supported by:
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- Battery Storage for Grid Stabilizatio
  - M5Bat: Modular Multi-Megawatt Multi-Technology Medium Voltage Battery

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RWTH AACHEN UNIVERSITY

GENESYS

100% Renewable Electricity Supply is possible

Goal: Determination of the cost optimal European Energy System with 100% Renewable Energy

Optimization for minimal cost

Simulation of 100% renewables for entire Europe, 7 years of data, 1h resolution

Estimate of required capacities of generators (PV and wind) different storage types and grid

Simplified model for fast analysis of multiple years of data. General picture plus sensitivities. 30 regions plus interconnections

Institut für Stromrichtertechnik und Elektrische Antriebe RWTH AACHEN

E.ON Energy Research Center

IAEW Institut für Elektrische Anla und Energiewirtschaft

Gefördert durch: Bundesministerium für Wirtschaft und Energie aufgrund eines Beschlusses des Deutschen Bundestages

open source

GENESYS Result 1:

Genetic Optimization of the European Energy Systems)

Institut für Stromrichtertechnik und Elektrische Antriebe
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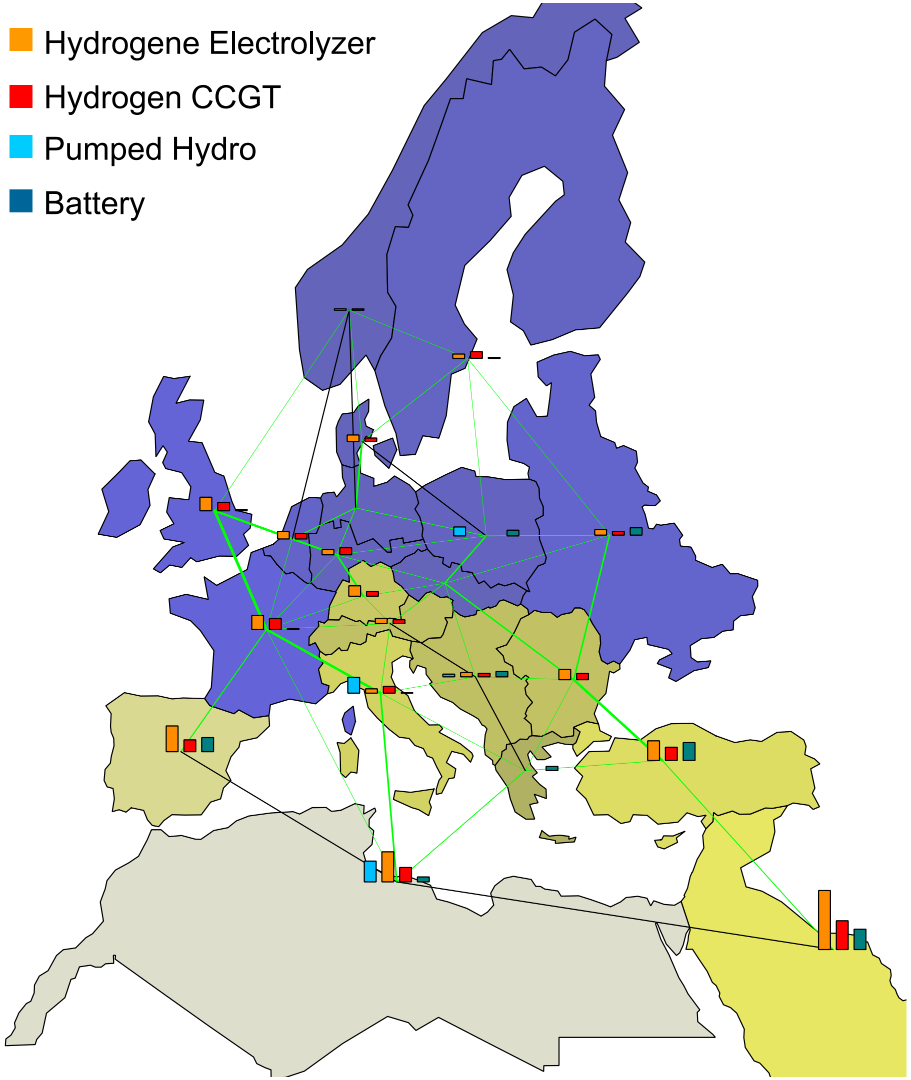
E.ON Energy Research Center

- **Long Term Storage** 802.000 GWh
  - Technology: Power to Gas
  - Charge/Discharge: 880 / 540 GW
  - Energy/Power Ratio: Ø1270 h
- **Medium Term Storage** 2.730 GWh
  - Technology: Pumped hydro
  - Charge/Discharge: 190 GW
  - Energy/Power Ratio: Ø 15 h
- **Short Term Storage** 1.550 GWh
  - Technology: Battery Storage
  - Charge/Discharge: 320 GW
  - Energy/Power Ratio: Ø 6 h

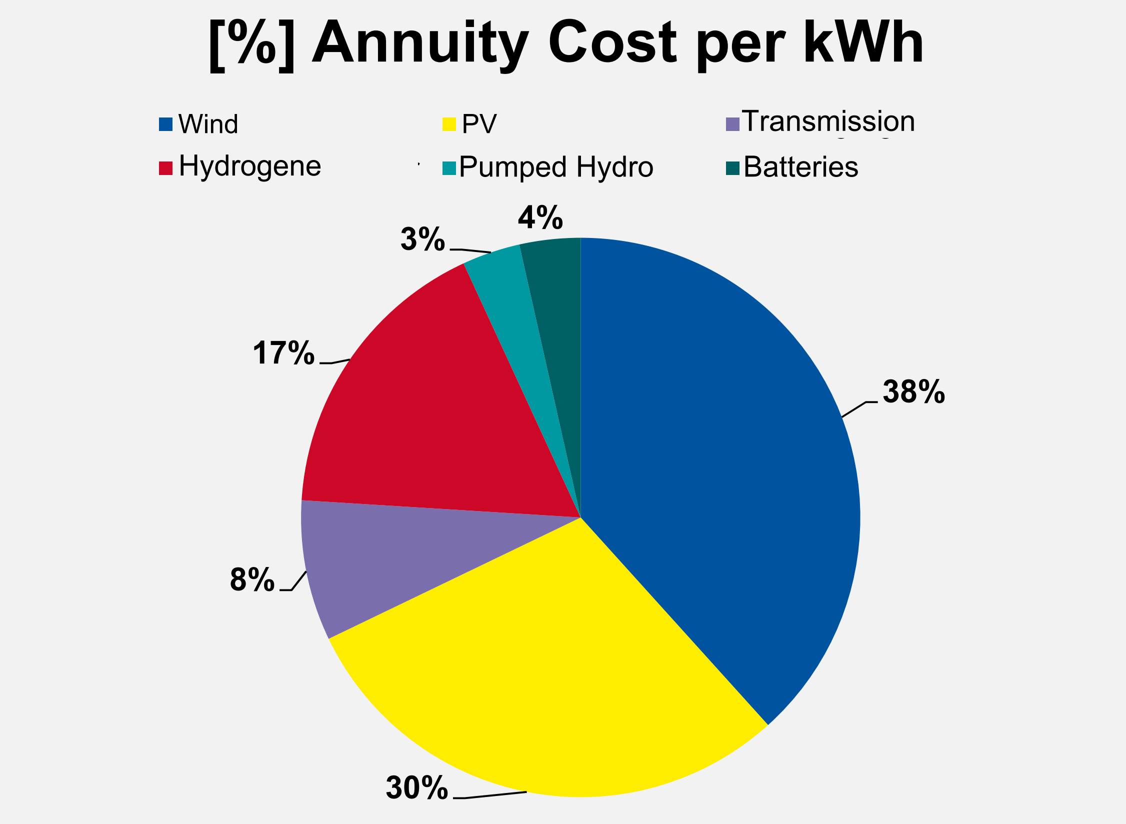
Total Discharge Power ~ Peak Demand



GENESYS Result 2:
System Cost dominated by Generation

System Costs are dominated by Invest for Generation Capacity

- At 100% RE only fixed costs i.e. CAPEX plus maintainance
- Cost per kWh dominated by CAPEX of generation capacity (wind and photovoltaics)
- Fraction of storage systems about 25% of total system cost
- Transmission grid contributing just below 10%



Institut für Elektrische Anlagen und Energiewirtschaft
Univ.-Prof. Dr.-Ing. Albert Moser
E.ON Energy Research Center
PGS | Institute for Power Generation and Storage Systems
RWTH AACHEN UNIVERSITY

The M5BAT Project

Modular Multi-Megawatt Multi-Technology Medium Voltage Battery

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages
ENERGIESPEICHER Forschungsinitiative der Bundesregierung

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Partners

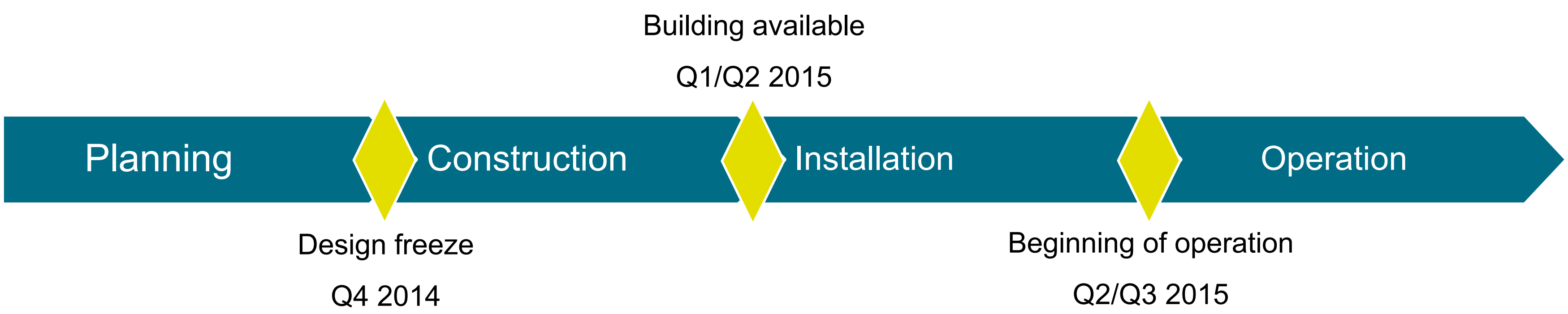
- RWTH Aachen University (Project Lead)
  - PGS (Batterie research)
  - EBC (Building monitoring)
  - IAEW (Energy Economics)
- beta-motion GmbH (Li-Ion Battery)
- E.ON SE (Building, Marketing)
- GNB Industrial Power – Exide Technologies (Lead Acid Battery)
- SMA Solar Technology AG (Inverter)

M5BAT – Projekt Overview

- Projekt duration: 4 years (07/2013-06/2017)
- Planing and construction: 2 years
- Operation: 2 years
- Total Budget: 12,5 Mio. Euro
- Funding BMWi: 6,5 Mio. Euro
- Projekt goals:
  - Construction of a pilot hybrid battery storage system
  - Realistic operation and market participation in several applications
    - E.g. Primary Control Reserve, SRL, MR, Arbitrage, Ramping support …
  - Evaluation of technical and economical results and development of recommendations for design and operation of hybrid battery systems
  - Development of several components for Battery Storage Systems
    - System Control and Monitoring System (Leittechnik,Anlagensteuerung)
    - Optimized design for stationary lead acid batteries
    - Optimized control for inverters

M5BAT – Timeline

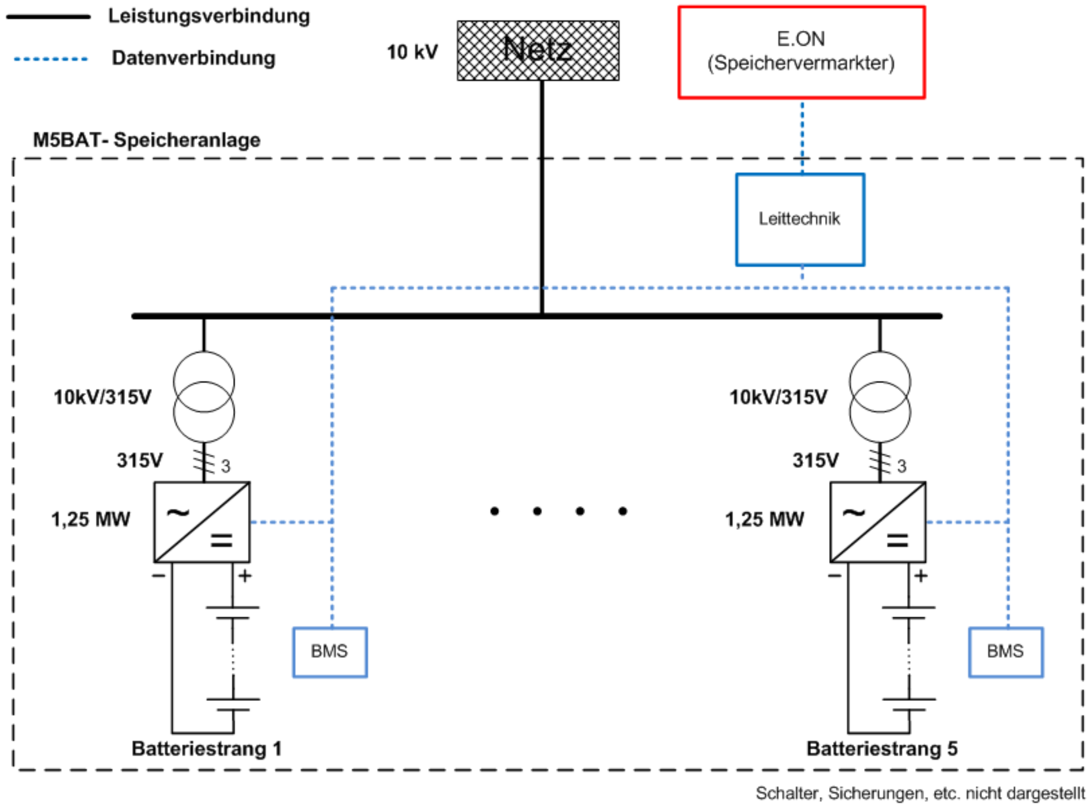
- Project duration: 4 years (07/2013 –06/2017)
  - Planing, permissions, detail planning, tenders
  - Retrofit of existing building
  - Installation of components (batteries, inverter, TGA, electrical system, protection and control system)
  - Operation and evaluation



TGA = Technische Gebäude-Ausrüstung

M5BAT – Technical Data

- 5 parallel strings (voltage level between 450-820 V DC)
- Nominal power rating: 5 MW (AC) / overall capacity: 4,2 MWh
- 2 parallel inverters per string à 630 kVA nominal power



Batterien – Technical Data

- Each string connected with two inverters (2-4 parallel inverters à 630 kVA)
- Seperate control für each string possible

Battery type	Power / Capacity	Manufacturer
Lead-Acid(OCSM)	1,25 MW / 1,48 MWh	GNB Industrial Power (Partner)
VRLA Lead-Acid(OPzV)	0,85 MW / 0,85 MWh	GNB Industrial Power (Partner)
Lithium-Ion (NMC)	2,50 MW / 0,77 MWh	beta-motion (Partner)
Lithium-Ion (LFP, LTO or LMO)	1,25 MW / 0,6 MWh	Tendered
NaNiCl	0,25 MW / 0,5 MWh	Tendered

Capacity at 1h discharge (C1)
Usable capacity of lead acid batteries is larger at slower discharge
VRLA = Valve Regulated Lead Acid

M5Bat - Goals

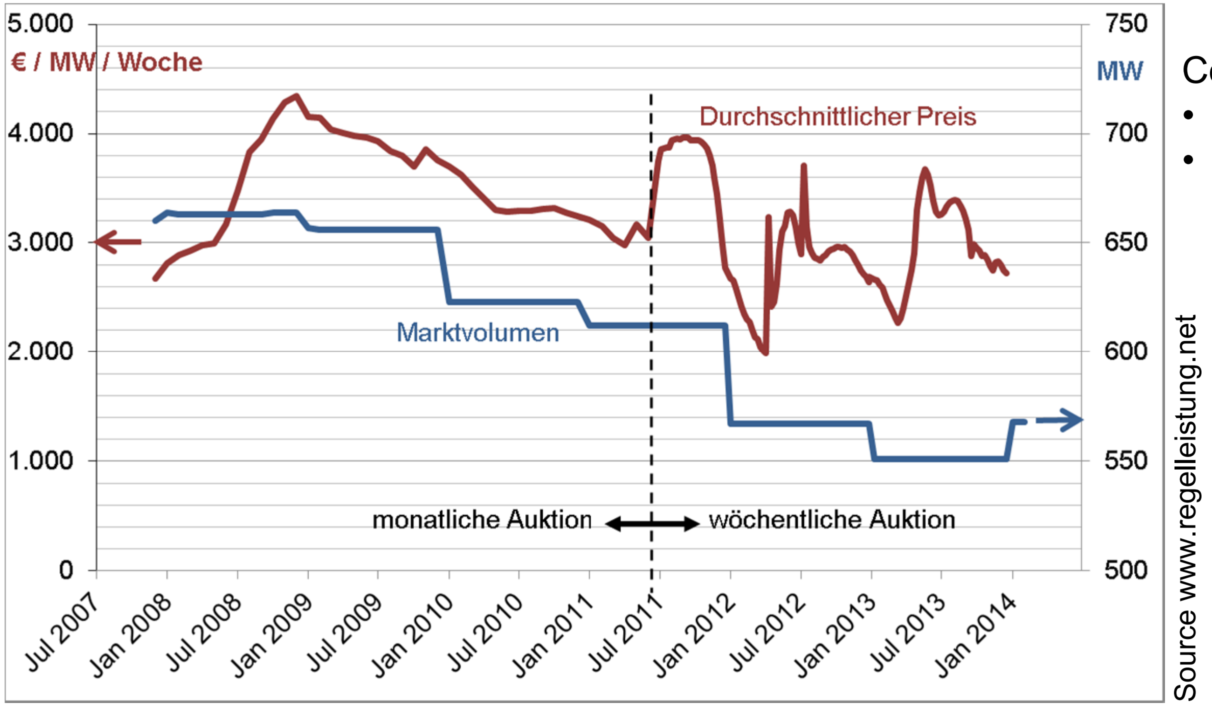
Deliverables

+ Handbook for design and operation of MW-Battery Systems in MV-grid
+ Technology comparison, single and combined operation
+ Delivery of multiple services (revenue stacking)
+ Grid planning and operation implications

RWTH Aachen-IAEW und RWTH Aachen-PGS

M5Bat - Impressions

Primary Control Reserve

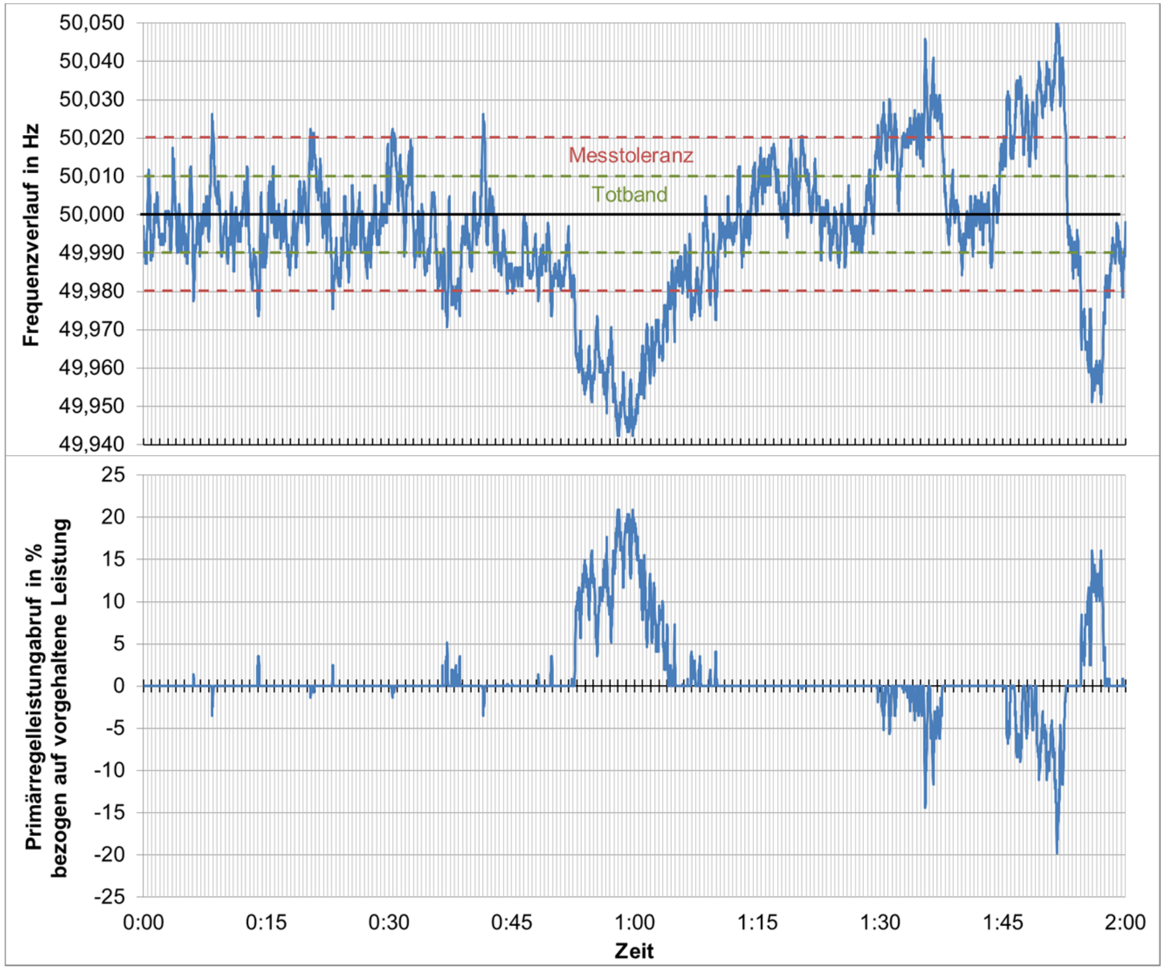


Coupled Markets:

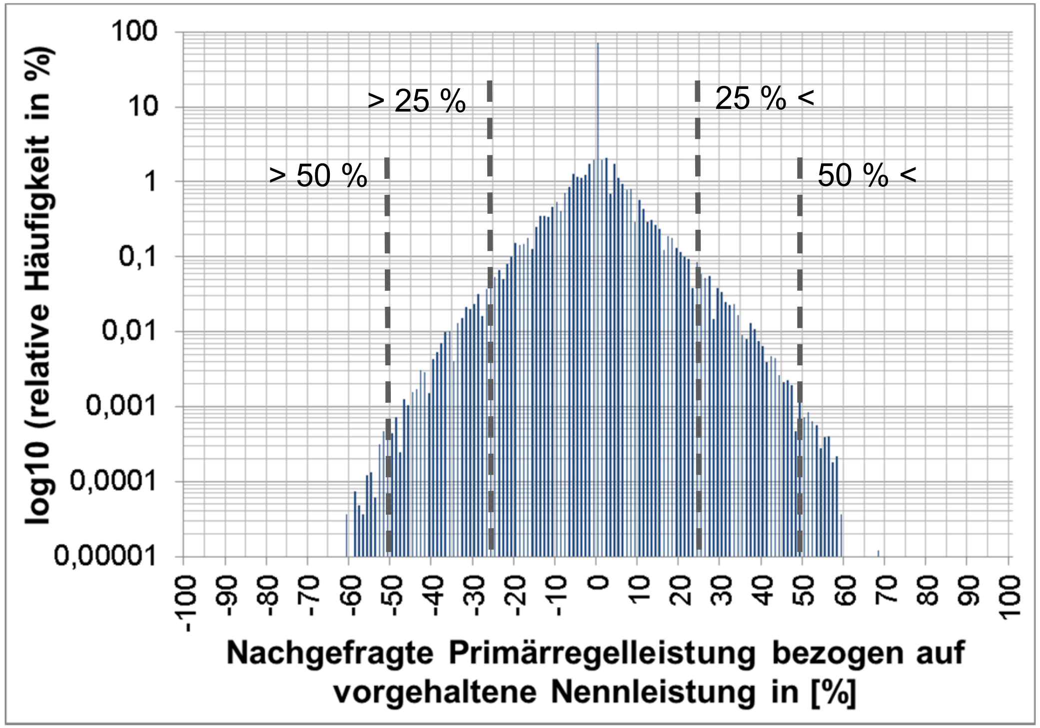
- 25 MW CH
- 35 MW NL

+ Pay as bid auction by TSO: weekly, min bid 1 MW
+ Participation requires prequalification
+ Activation fully automatic based on grid frequency (static)
+ Market volume 570 MW in Germany (100 M€/a), 3.000MW in Europe

Primary Control Reserve (PCR) – Load Profile



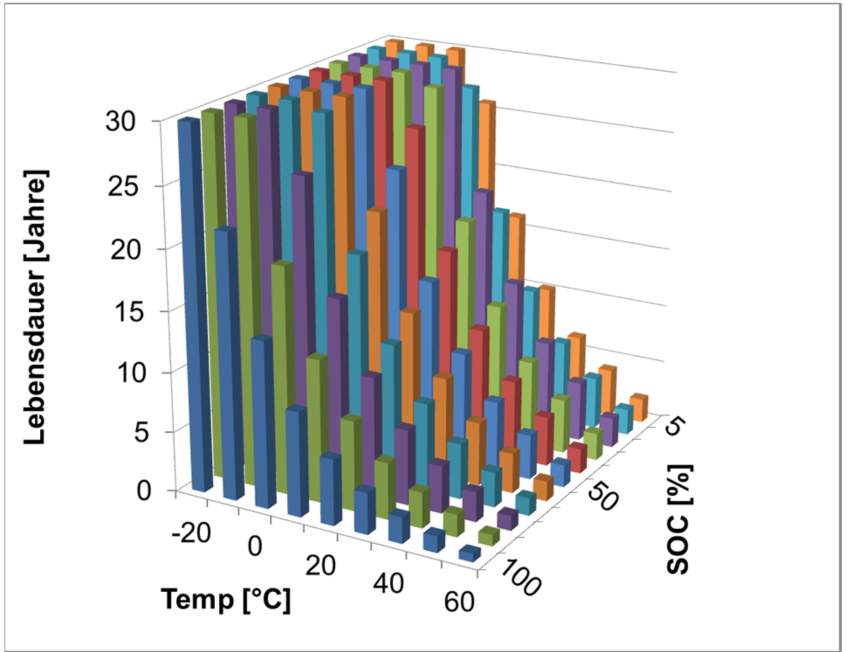
Primary Control Reserve (PCR) – Load Profile



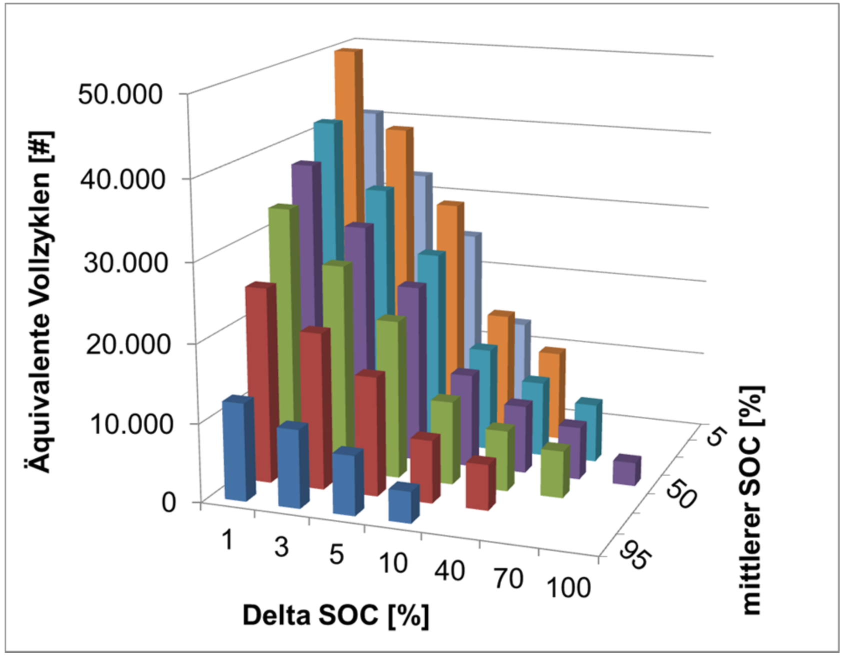
Data 3,5 months cleaned data

- 72 % of the time no load (dead band)
- Activation nearly symmetrical pos. and neg. reserve – not quite
- Maximim demand in 3 months 70 % of nominal power rating
  - Activation of > 25 % of nominal power in 0,36 % of the time → 15,4 hours per year
  - Activation of > 50 % of nominal power in 0,0036 % of the time → 8,5 minutes per year

Li-Ionen Batteries - Aging



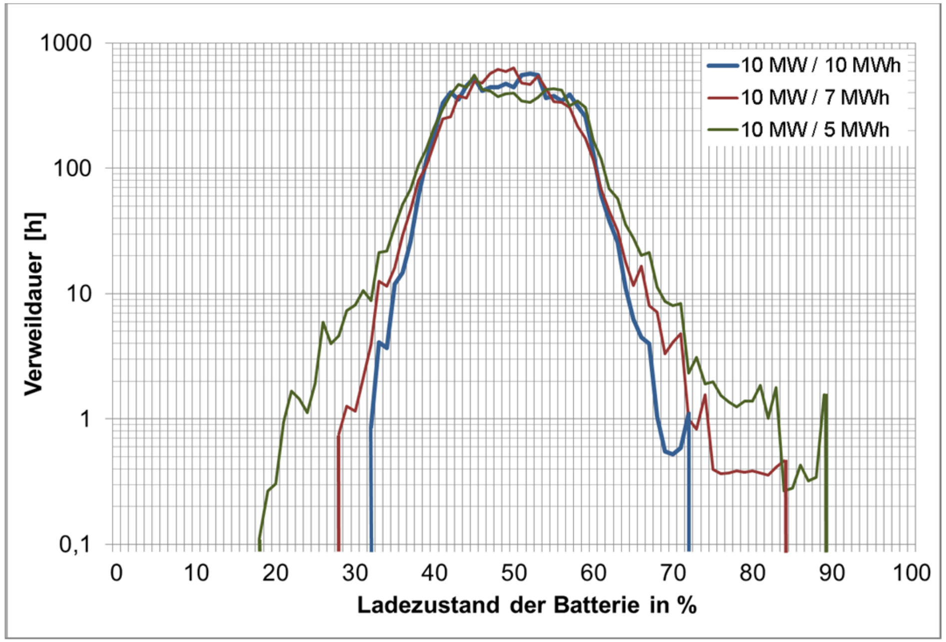
SOC - State of Charge (Ladezustand)



Delta SOC - Entladetiefe

- Lifetime: superposition of calendaric and cyclic aging
- To first order
  - Low SOC → longer life / high SOC → shorter life
  - Low delta SOC → longer life / high delta SOC→ shorter life.

Primary Control Reserve (PCR) – SOC Profile



- Operational strategy for compensation of losses necessary (slow and low power)
- Time share at given SOC depends on size of battery – influence on aging
- Smaller capacity results in larger variation of SOC i.e. increased aging
- String influence on invest (capex)
- Prequalification requires 2 x 15 min full load, ENTSOE pushing towards 2 x 30 min
- Technically 0.5 MWh/MW sufficient – only prequalification requires 1MWh/MW

M5Bat – Lessons learned so far

- Safety standards for LIB-systems missing – no reference cases
  - ➔ permissions difficult (fire, hazard, explosion, earthquake)
  - ➔ safety levels of car industry not applicable
    (e.g.controlled burn down not feasible)
  - ➔ explosion of single cell less critical than explosion of aerosols
- Grid connection fees even though system operated exclusively for grid services: 60 T€ per MW = 6 % of invest
- Tender very complex - without references no established warranty schemes
- Time line very slow due to lack of experience at many stakeholders (administration, municipality, fire department, …)
- No standard for prequalification, back up, penalties
  - ➔ individual negotiations with TSO necessary

Questions

- Which energy storage technologies are currently used?
- What is the status of these technologies? Can they be scaled?
- Which primary technological limitations and barriers need to be overcome to make Energy Storage more beneficial to power utilities?
- Which technological research needs to be done?

Questions / Answers

- Which energy storage technologies are currently used?
  - Lead-Acid, Lithium-Ion, NaS/NaNiCl, VRFB
  - Most dynamic Lithium-Ion
  - New Candidates: Metal-air, Lithium-Sulfur, Anodes with Silicon, Sodium-Ion (Aquion), Liquid Air, …
  - Requirements: safe, cheap, abundant, cyclic and calendaric stability, energy dense, power dense, non toxic
  - Candidates fail at least one requirement, usually more
  - Time to market min. 5 years rather 10
  - Hard to beat Lithium Ion
  - However, different applications have different requirements:
    - e.g. UPS matched best by Lead-Acid
    - E2P > 2-4h NaS/NaNiCl + Flow Batteries

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Questions / Answers

- What is the status of these technologies? Can they be scaled?
  - In principle …

Scaling up Battery Storage

- Cells cost 1 MWh: 200 T€ - 250 T€

  (Life time today up to 10 years, in 2020 up to 20 years probably realistic)
- Converter cost 1 MW: 100 T€
- System integration 1MW: 100 T€ (BMS, BOP etc.)

➔ Cost target

- ➔ 1 MW / 1 MWh ~ 450 €/kW
- ➔ 1 MW / 2 MWh ~ 750 €/kW
- ➔ 1 MW / 3 MWh ~ 1.050 €/kW
- ➔ 1 MW / 4 MWh ~ 1.300 €/kW

➔ Construction: anywhere within < 6 months

Scaling up Battery Storage

- Modern container vessels carry 15.000 Containers (ca. 400 m x 56 m, 157 kt)

Scaling up Battery Storage

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≡

Energy

- = 15 GWh (all German PHES together have 40 GWh)

Scaling up Battery Storage

- Modern container vessels carry 15.000 Containers (ca. 400 m x 56 m, 157 kt)

≡

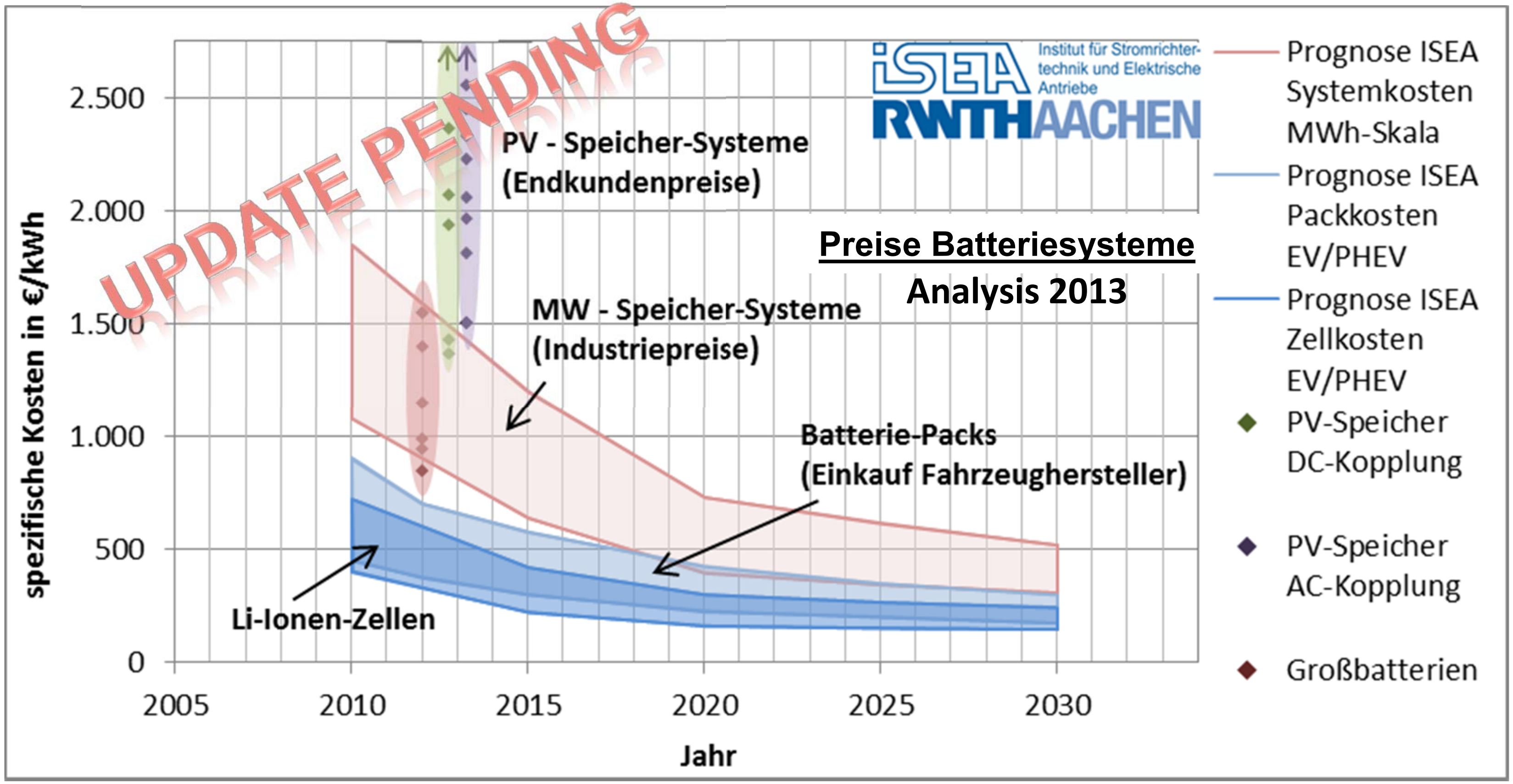
Power

- = 15 GWh /15 GW (all German PHES together have 40 GWh / 5 GWh)

Questions / Answers

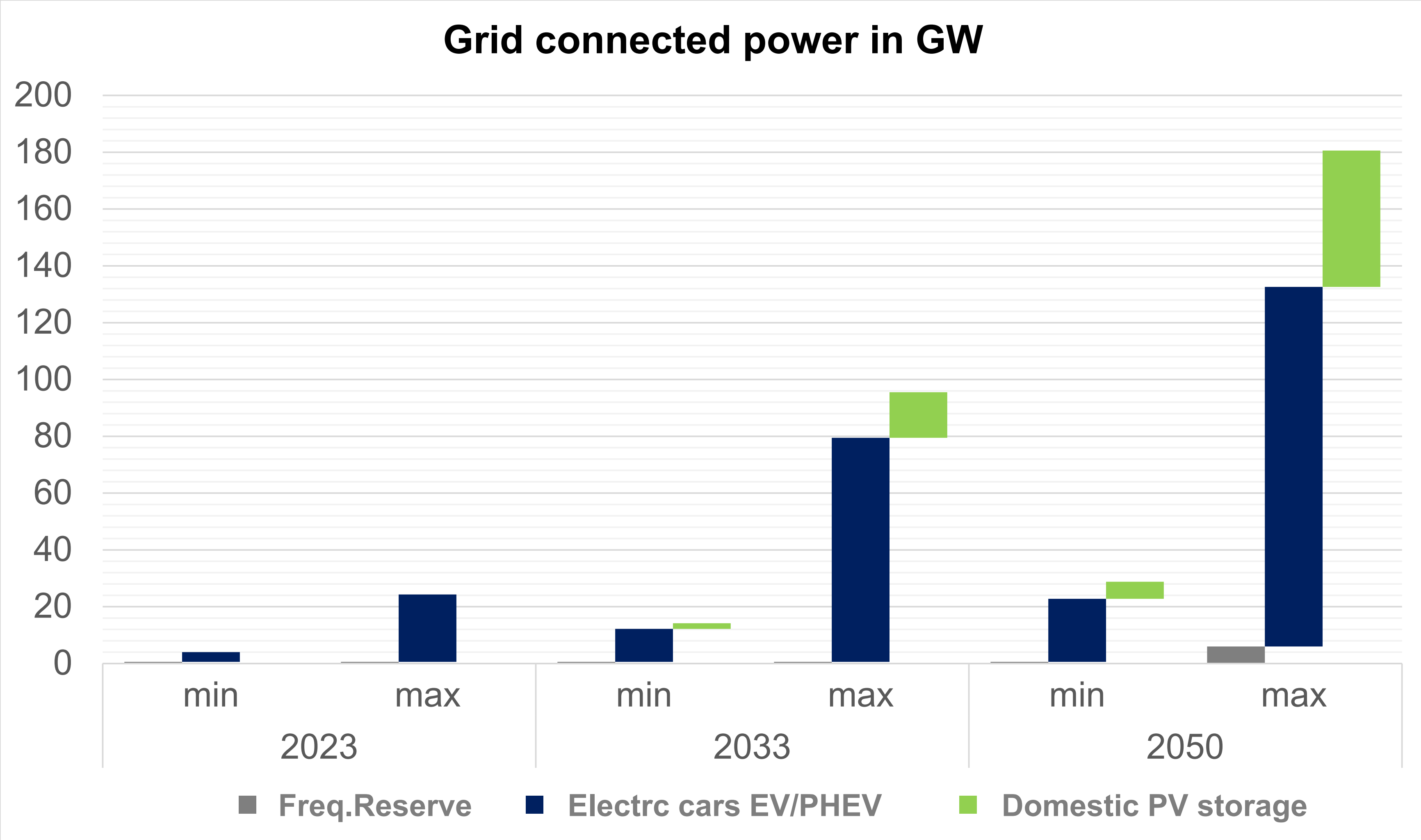
- What is the status of these technologies? Can they be scaled?
  - In principle …but:
  - Safety and standardization: automobile ASIL not applicable
  - Prequalification: PCR capacity requirement still uncertain
  - Interaction of many inverter connected systems to be investigated
    - i.e. how much synchronous generation is required?
  - Regulation/legal: grid connection fees, grid charges applicable?
  - Operational experience needed (e.g. proof of durability at real conditions)
  - As cell prices drop – other components become more cost critical

Lithium-Ionen System Cost
Analysis 2013



- Cost reduction strongly dependent on market volume
- Electric mobility below 500 €/kWh in 2020
- Small stationary systems about 3 x fold cost

Perspektive Storage Markets Germany



Conclusion

- **Electricity storage technologies are available, scaling is technically feasible – the challenge is viability!**
- **Stationary storage systems at the beginning of commercialization**
  - **Ancillary Services (PCR, synthetic Inertia, black start, voltage support, …)**
  - **Domestic PV Storage Systems - plus grid support as secondary use**
  - **Electric Mobility - during grid connection also grid support**
- **Major drop in cost of storage (LIB-cells) since 2011 and continue to do so**
- **Besides research on new chemistries/technologies research on system integration, market introduction and operational experience needed**
- **Major driver is electric mobility**

Institute for Power Electronics and Electrical Drives (ISEA)
Jülich Aachen Research Alliance, JARA-Energy
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2006 RWTH Aachen, Physics Institute 3A

2008 Siemens AG, Renewable Energy, Wind

2010 ISEA, RWTH Aachen, Head of Section

Grid Integration and Storage System Analysis

Energy systems with high shares of renewables
Battery systems for ancillary services
PV-home storage systems
Electric cars in grids

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