RWE`s former, current and possible future energy storage applications

Jan Bernholz
Project Engineer, RWE Technology International GmbH

VGB KONGRESS & IERE WORKSHOP
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Agenda

- Introduction
- Pumped Hydro
- Power-to-Hydrogen
- Power-to-Heat
- Compressed air energy storage
- Battery storage
- Future applications

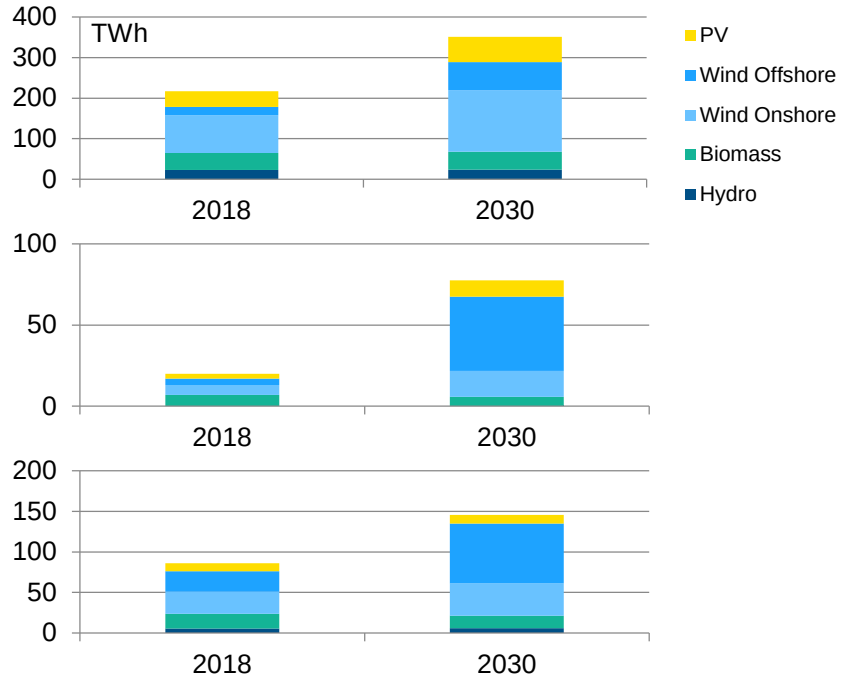
RWE with clear focus on storage perspectives in core markets Germany, Netherlands and UK

Share of renewables expected to grow significantly in the next decade

- Political target is 65% share of renewables by 2030
- Regulatory environment not storage-friendly

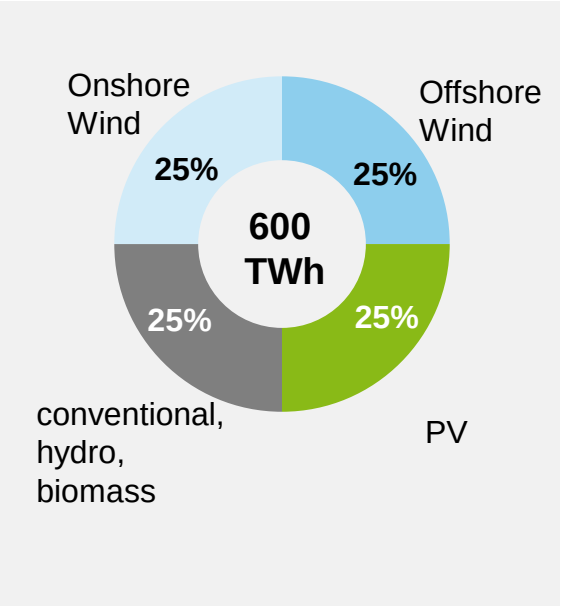
- Political target is 49% emission reduction in 2030 (compared with 1990)
- Flexibility options including storage on the agenda of Energie-akkoord; process just started

- Political target is 40% reduction in emissions vs. 1990 but by 2030
- The regulatory framework for storage is on the agenda, but no concrete details yet



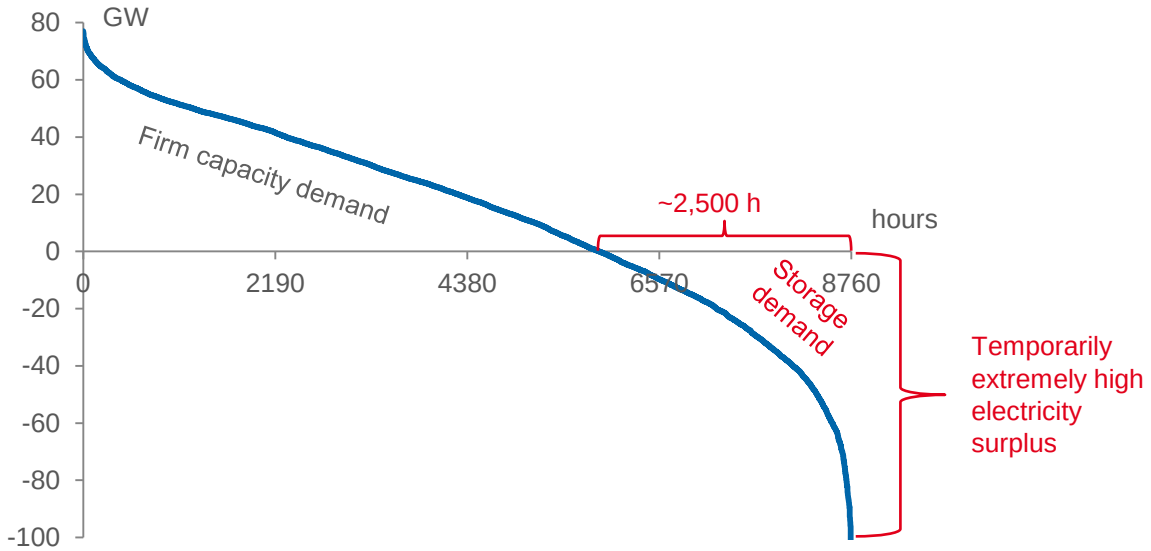
2,500 hours with electricity surplus over the year on national level at 75% renewables

Generation of electricity in a balanced scenario (generic)



Source: Simulation of hourly residual load without export. RWE AG

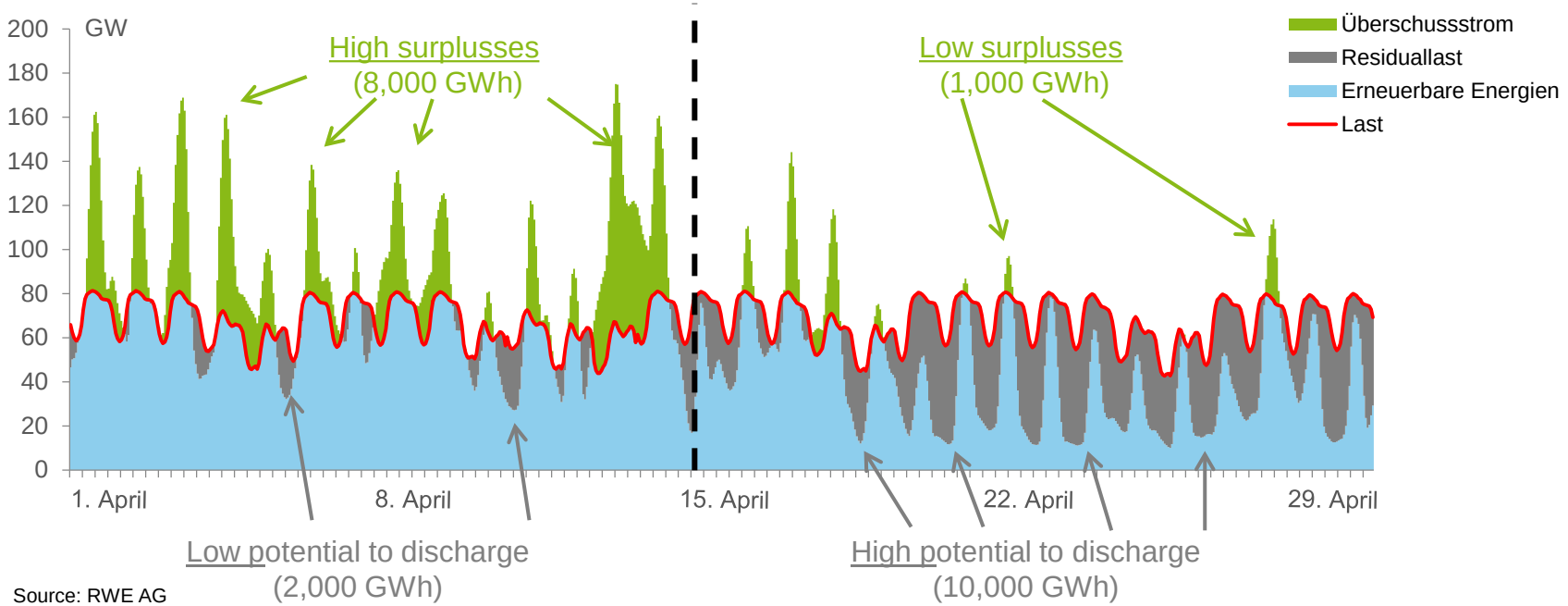
Duration curve of residual load[1)] for German electricity market at a 75% share of PV and Wind in GW



1) Electricity demand minus infeeds from PV and Wind

High share of renewables requires storage cycles of weeks and months

Exemplary calculation for a month of supply and demand with 75%-share of renewables

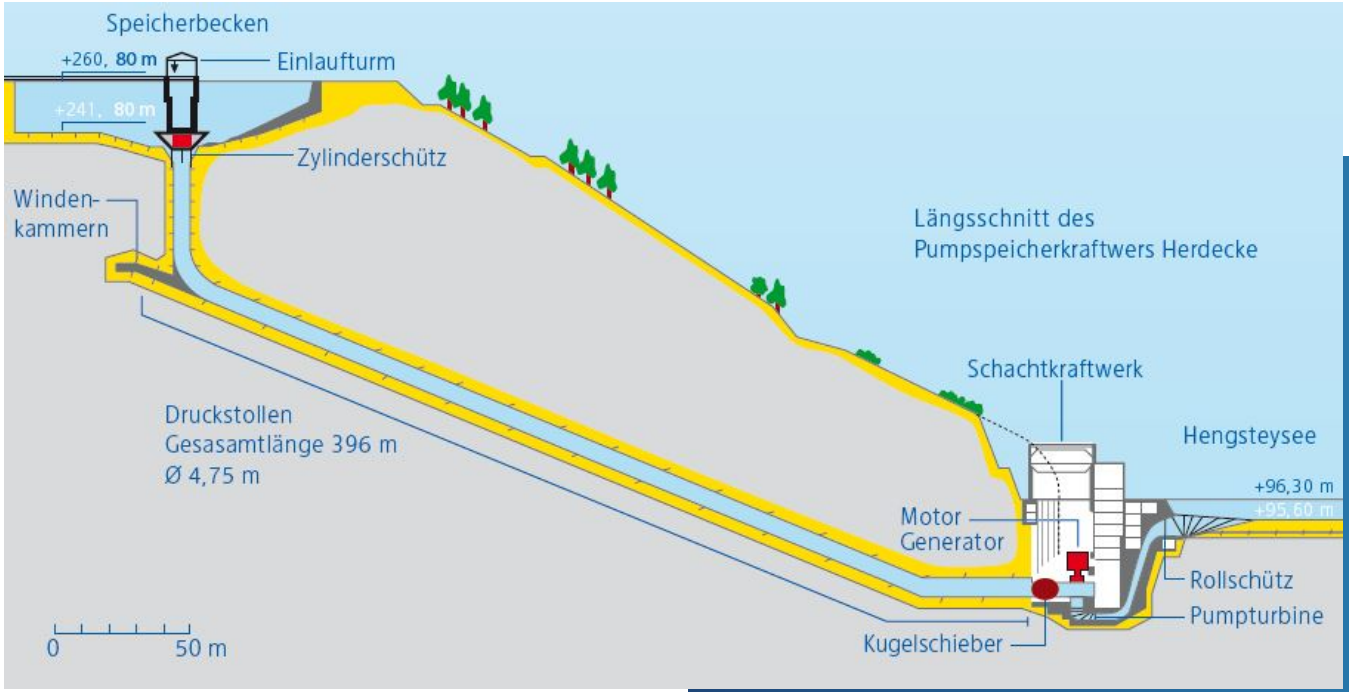


Source: RWE AG

What market potential exists currently for energy storage?

RWE`s former, current and possible future energy storage applications

Pumped Hydro Principals



Source: RWE Power

Pumped Hydro Sites

Source: RWE Power

Power-to-Hydrogen replaces conventional H_2 in chemical industry - existing H_2 infrastructure is used

Hydrogen sector coupling with the chemical industry

Use of hydrogen in Germany

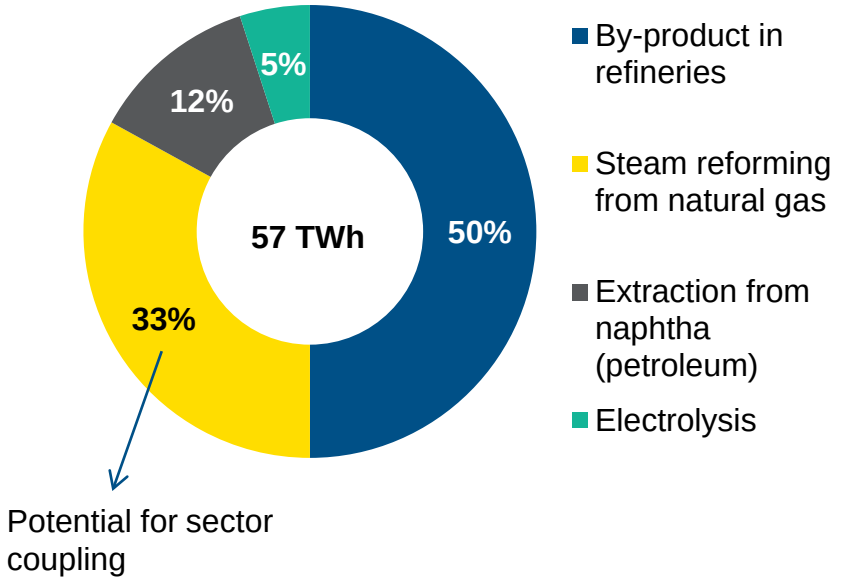
> Hydrogen serves as an important raw material in the **chemical industry**, e.g. production of fuel

Potential for sector coupling

> Natural gas can be stored and later used to generate electricity

> In the long term, around 10-20 TWh can be substituted without hydrogen intermediate storage

Hydrogen production DE by primary energy carrier in TWh



Source: Umweltbundesamt, RWE AG

RWE‘s demonstration project has one of the highest total efficiencies for Power-to-Hydrogen plants worldwide

Key facts

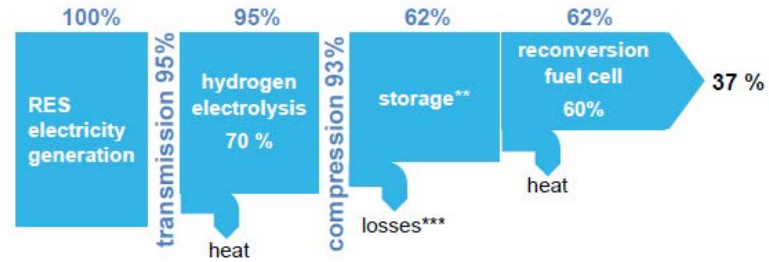
> **Technology:** PEM-Electrolyser

> **Rated:** 150 kW_{el}

> **H_2-Production:** 30 m^3/h

> **Operation:** since 2015

> **Total Efficiency**: 86% (usage of waste heat)



Source: RWE Generation

Power-to-Hydrogen demonstration plant at Ibbenbüren

Source: Westnetz

Power to Heat (PtH) provides the most efficient storage potential with development costs of less than 150 €/kW.

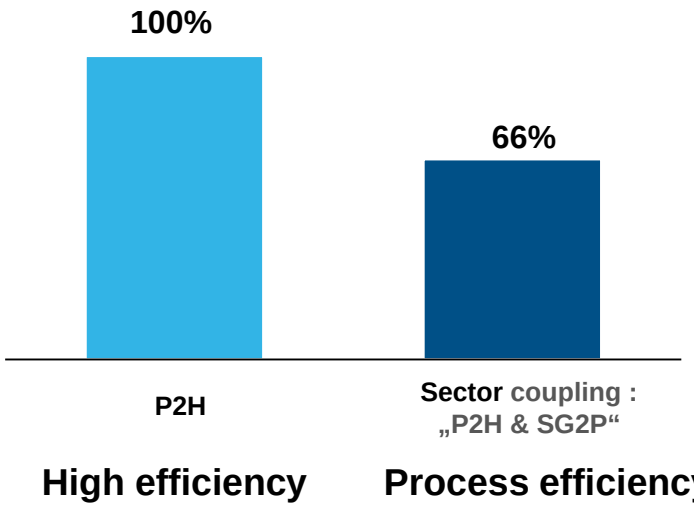
Advantages and applications of PtH

> **Low investment costs** for electric boiler: 100-150 €/kW

> Use of hybrid systems, e.g. PtH + gas, allows **flexible use** of PtH systems in the event of excess electricity

> **Heat can be stored well**, but requires very **high volumes**: at 30-40 kWh/m³

Efficiencies Power-to-Heat vs. total process "PtH & Saved Gas-to-Power"



Source: RWE AG

Case study for an E-boiler at one of the RWE sites

Specification for an E-boiler

- Case study for an E-boiler rated 20 MW_{el}
- Efficiency: ~99 %
- From 0 to full load in less than 30s
- OPEX < 1% CAPEX/a
- Implementation time less than 1 year after FID
- CAPEX is guestimated at 3 million € for a 20 MW boiler including electrical connection

Flow heater and E-boiler

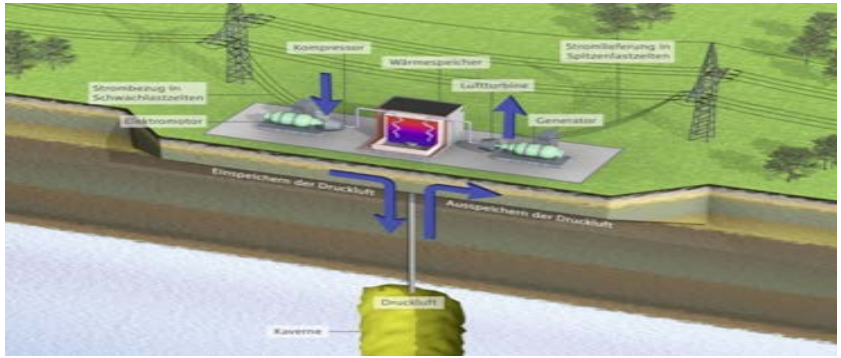
Source: RWE Technology International

Adiabatic compressed air energy storage (ADELE - *Adiabater Druckluftspeicher für die Elektrizitätsversorgung)*

Key facts

- Developing components for an adiabatic compressed-air energy storage facility
- Selecting a concept
- Clarifying all technical, economic and approval-law questions in connection with a demonstration project at Staßfurt
- ADELE (until 06/2013): €12m, including €4.9m by RWE Power; BMWi funding
- Construction of a demonstration plant not implemented due to lack of economic viability
- RWE parties involved, General Electric, DLR, etc.

Storage costs, depending on charge and discharge cycles p.a., in €/MWh[1)]



Source: RWE Power

Large scale battery storage pilot in Herdecke to explore new technologies in existing markets

Specifications

> Technology: Lithium-Ion
> Capacity: 3 x 2.538 kWh
> 552 batteries
> Revenue: mainly PRL
> Investment: approx. 6 million €
> Operation: since Jan. 2018

Battery storage at Herdecke

Source: RWE Generation

Electric vehicle charging stations at the new RWE Campus

Charging stations for electric vehicles

> Electric vehicle charging stations: 22 kW

> Capacity: depending on car battery

> Operation: Q3 2020

Electric Vehicles @ RWE Campus

Source: RWE AG

Thank you very much for your attention