Stiesdal Storage Technologies

GridScale Battery

Electric Energy Storage System

Henrik Stiesdal, September 1, 2018

Framework

Company Structure

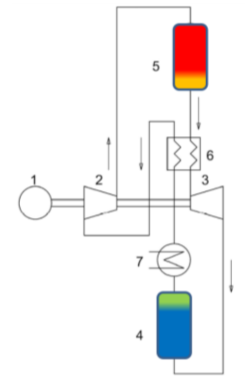
- Climate technology company with focused subsidiaries

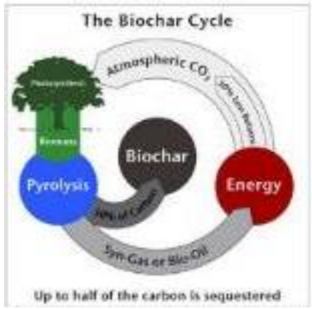
Purpose

- Combat climate change by developing and commercializing solutions to key challenges

Stiesdal A/S

	Stiesdal Offshore Technologies A/S	Stiesdal Storage Technologies A/S	Stiesdal Fuel Technologies A/S
Project	**Tetra**	**GridScale**	**SkyClean**
Target	Low-cost offshore wind energy	Firm power from renewables	Carbon capture and sequestration
Means	Industrialized fixed & floating foundations	Storage system w. 10h – 10d capacity	Carbon-negative jet fuel





Stiesdal GridScale Battery technology addresses the growing need for reliable, cost-effective bulk energy storage

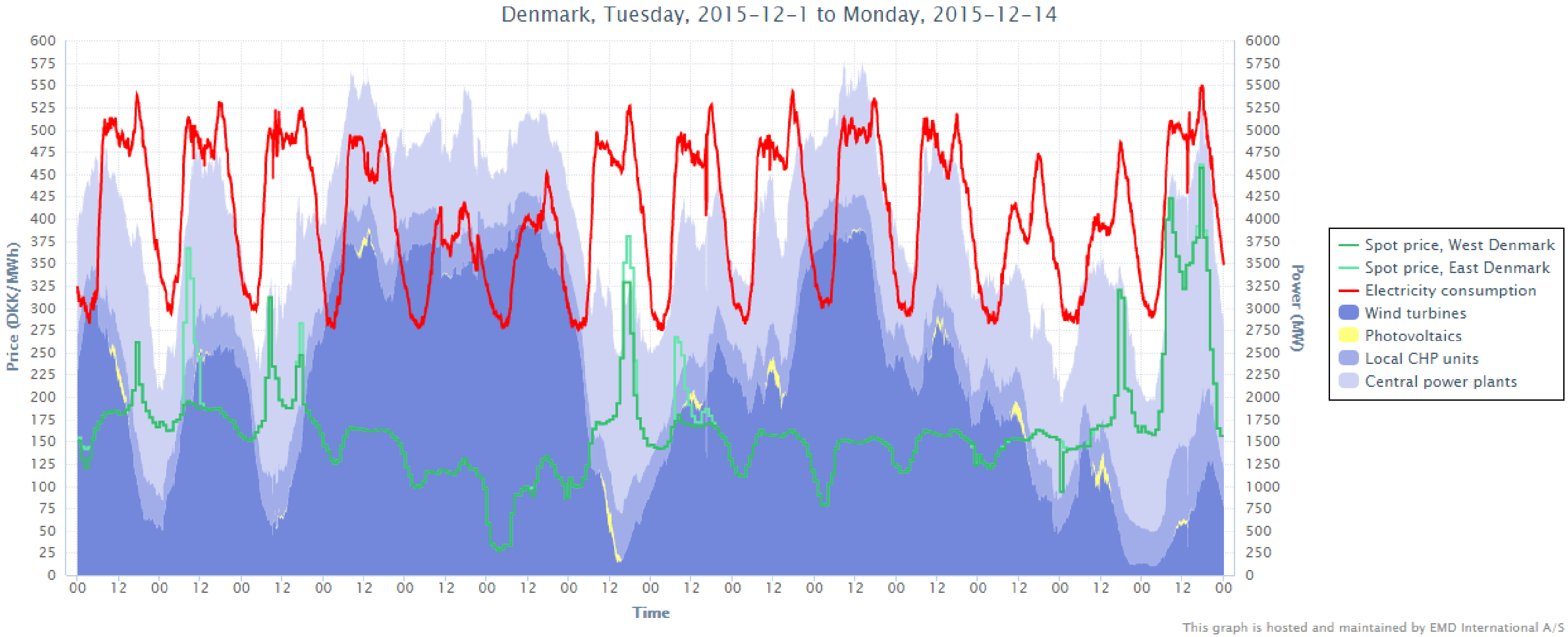
A GridScale Battery is a cost-efficient, long-duration, and low carbon thermal energy storage system that

- Can store huge amounts of electric energy for hours, days or weeks at much lower cost than any other comparable technology
- Addresses all relevant storage requirements – renewable energy integration, “Duck Curve” of high PV systems, provision of ancillary services and energy security
- Can be implemented in greenfield applications, facilitating higher renewables penetration and 24h solar PV

Key motivation for storage – renewable power integration

Production and load curves for Denmark illustrate the issue

- Even in a high-wind period such as the first two weeks of December 2015, there are periods with essentially no renewables production

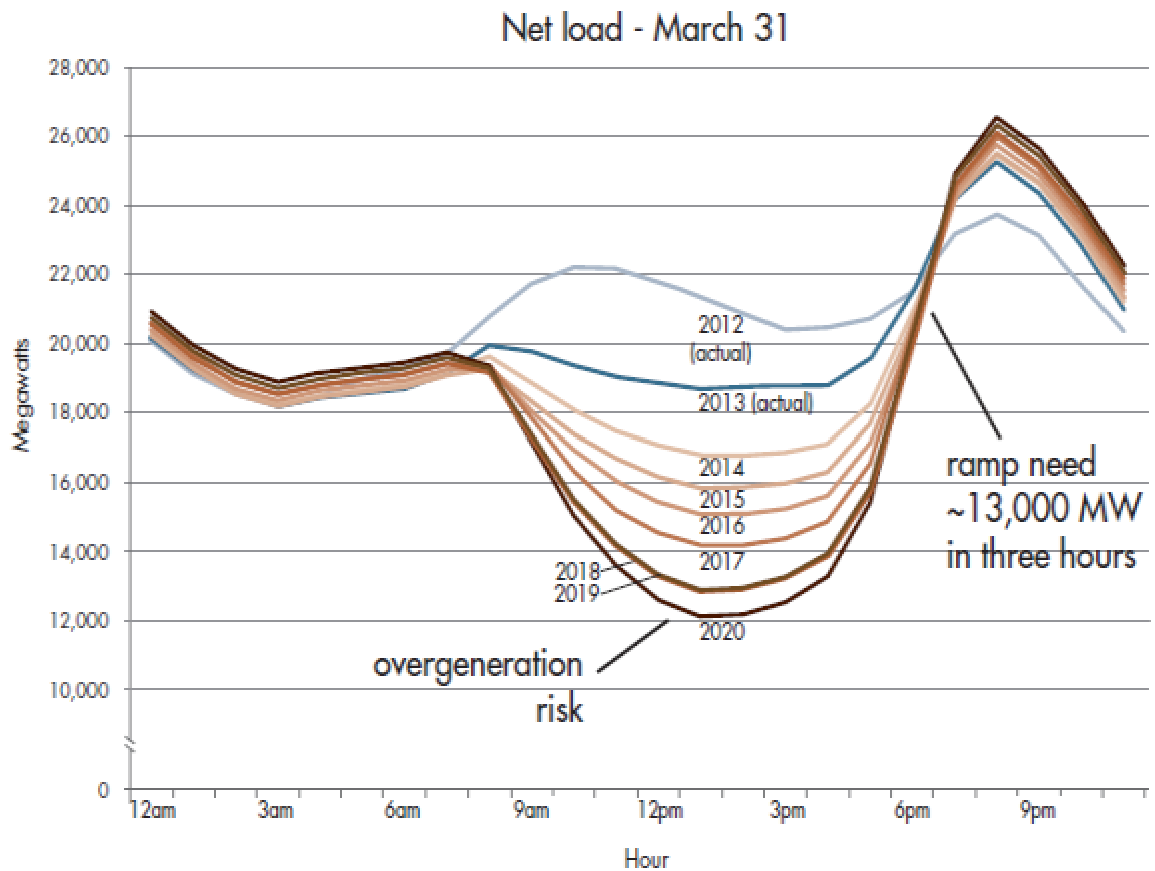


Source: EMD

Key motivation for storage – enabling increased PV production

The California "Duck Curve"

- Large-scale PV build out without storage leads to costly evening ramping needs
- Within a few years CAISO expects ramp rates to reach 13,000 MW over three hours, above current thermal peaker capacity
- High-capacity storage systems with fast ramp rates offer a low-carbon solution

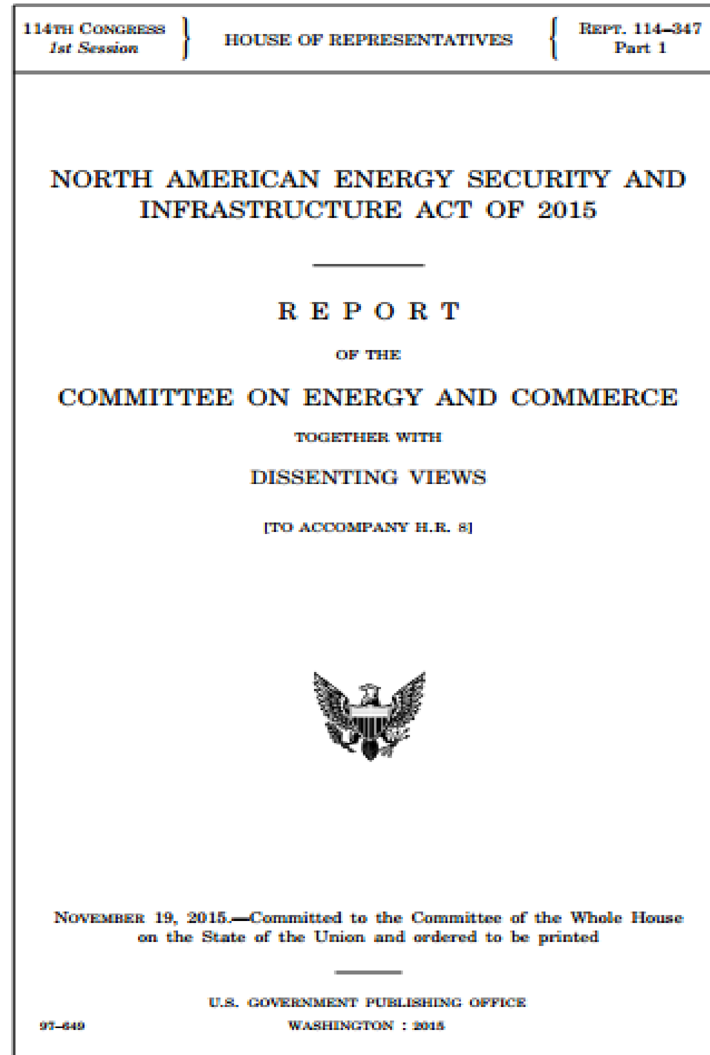


Source: CAISO

Key motivation for storage – strengthening energy security

The grid is increasingly vulnerable to disruption by hacking and terrorist attack

- Storage plants can be located in urban areas, providing on-the-spot backup to improve grid resilience against service interruption from cybercrimes or terrorism



114TH CONGRESS
1st Session

HOUSE OF REPRESENTATIVES

REPT. 114–347
Part 1

NORTH AMERICAN ENERGY SECURITY AND INFRASTRUCTURE ACT OF 2015

R E P O R T

OF THE

COMMITTEE ON ENERGY AND COMMERCE

TOGETHER WITH

DISSENTING VIEWS

[TO ACCOMPANY H.R. 8]

NOVEMBER 19, 2015.—Committed to the Committee of the Whole House on the State of the Union and ordered to be printed

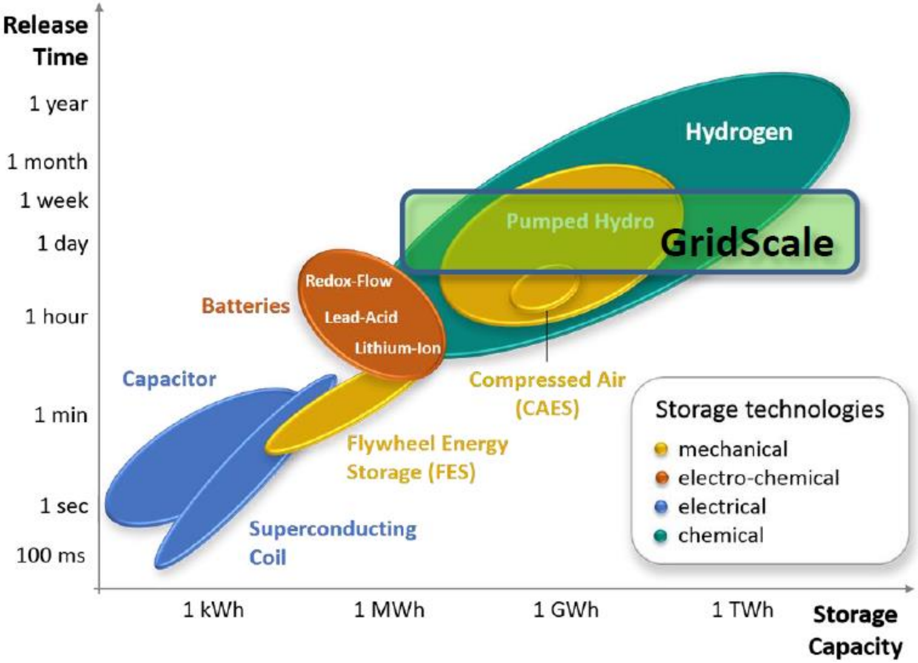
U.S. GOVERNMENT PUBLISHING OFFICE
97–649 WASHINGTON : 2015

Source: US Congress

Energy storage technologies

GridScale can deliver cost-effectively in the crucial capacity range

- An energy storage system has to have 10 h to 10 days capacity to manage variability of renewables
- At this capacity, batteries will remain prohibitively expensive for decades
- Pumped hydro can deliver the desired capacity, but is constrained by topographical requirements. Other non-battery storage technologies have similar issues.
- GridScale can deliver cost-effectively in the desired time range and is unconstrained by topographical or geological requirements



Picture credit: idstch.com

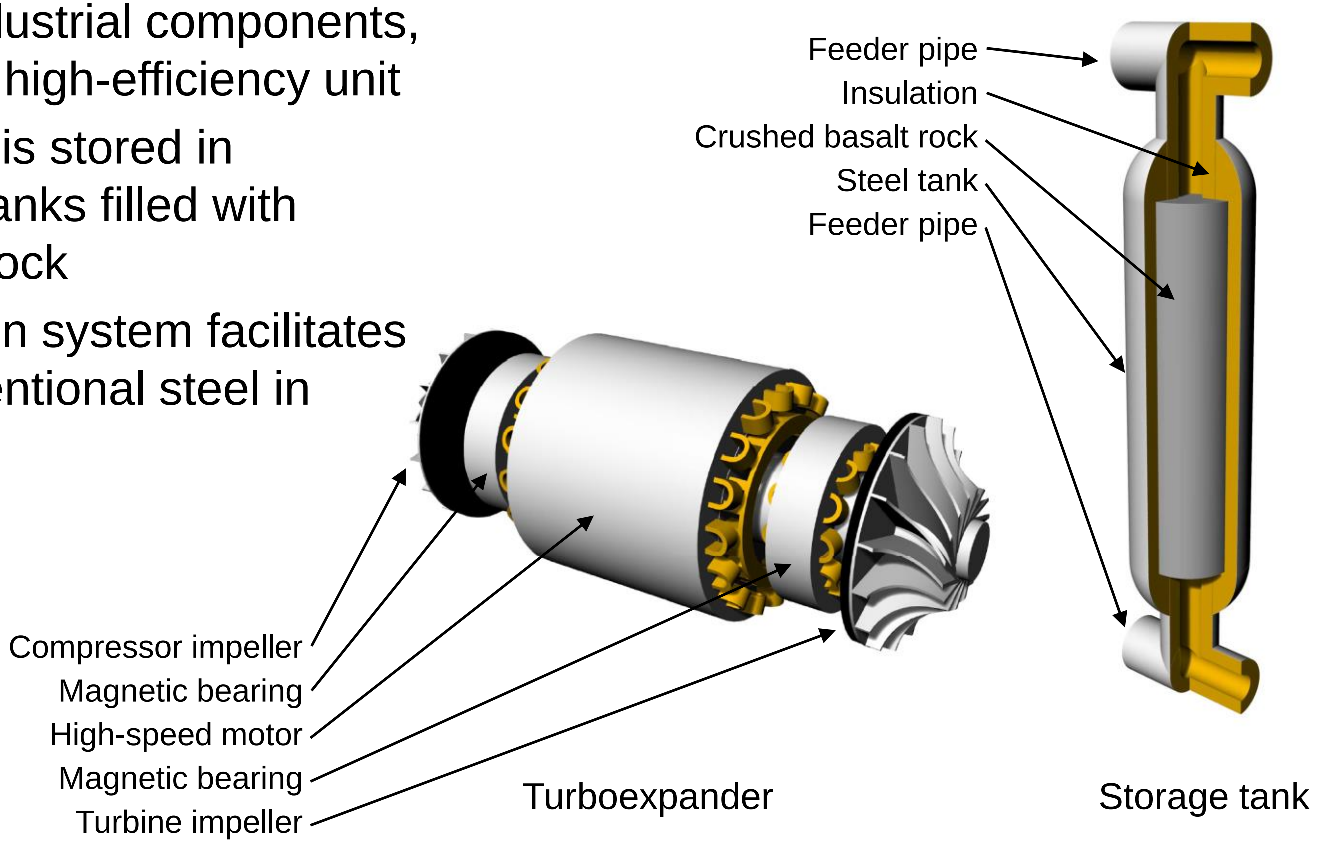
GridScale Battery compared with known storage technologies

Topic	Li-ion	Pump H_2O	CAES	Hydrogen	GridScale
Technology readiness charge-discharge	Mature	Mature	Mature	Development stage	Mature
Technology readiness storage unit	Mature	Mature	Mature	Mature	Development stage
Round-trip efficiency	90%	85%	40-60%	30-50%	35-65+%
Round-trip energy cost	High	Low	Low	Medium	Low
Energy density	High	Low	Low	High	High
Footprint	Small	Large	Small	Small	Small
Scalability, power	0.01-25 MW	50-1000 MW	5-100 MW	1-1000 MW	1-1000+ MW
Scalability, energy	0.01-25 MWh	100-10.000 MWh	10-1000 MWh	1-100.000 MWh	1-100.000 MWh
Location requirement	None	Special topography	Special geology	Special geology	None
Raw material use	High	None	None	Moderate (electrolyzer)	None

The industrialized concept of the GridScale Battery

Design for industrialization and mass production is a key feature

- The turboexpander design uses standardized industrial components, combined into a high-efficiency unit
- Thermal energy is stored in insulated steel tanks filled with crushed basalt rock
- Internal insulation system facilitates the use of conventional steel in reservoir tanks



The industrialized concept of the GridScale Battery

Modularity for easy scaling

- A storage unit comprises well-defined modules suited for industrialized manufacturing
  - A turboexpander unit with pre-pressure compressor, controls etc.
  - A filter unit with air filters and manifolds
  - Two rows of standardized storage reservoirs
- Storage duration is adjusted with number of storage tanks
- Power rating is adjusted with number of parallel units

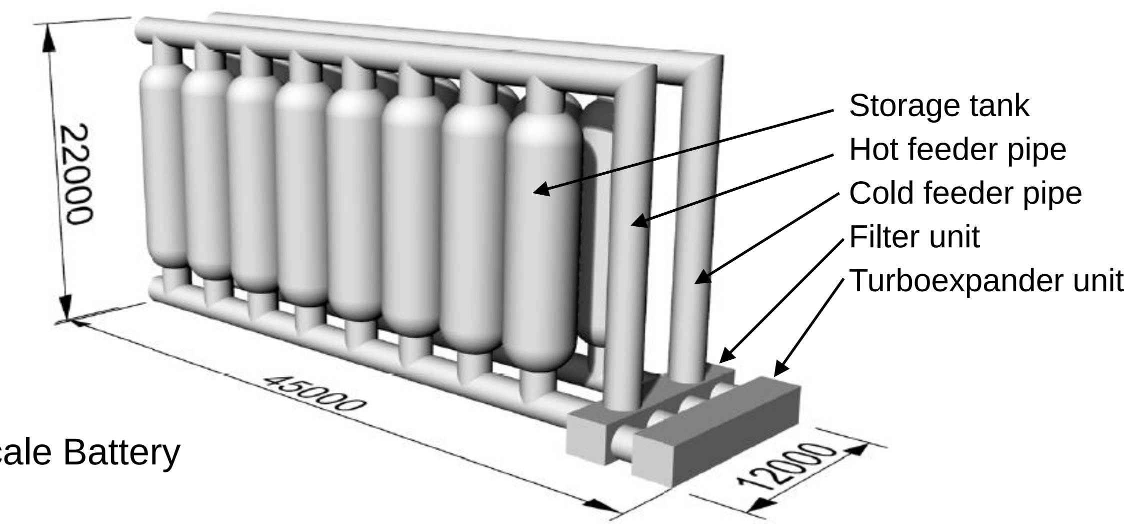
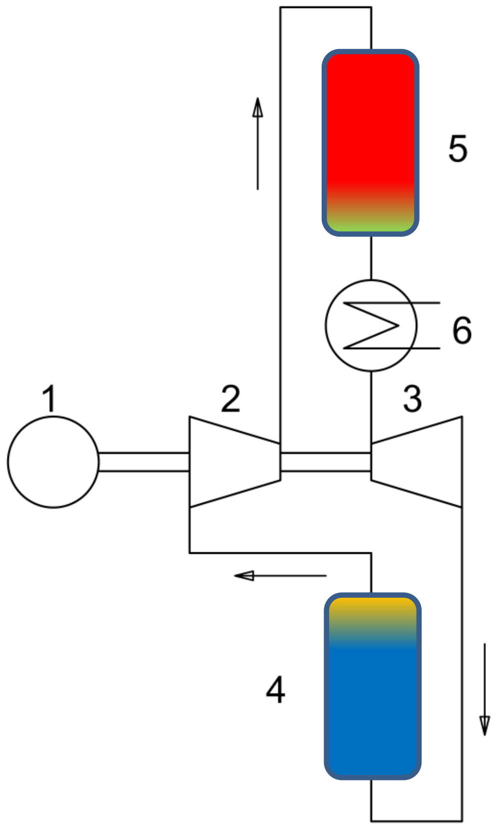


Figure shows 2.5 MW, 60 MWh GridScale Battery

Basic principle of GridScale Battery - charging



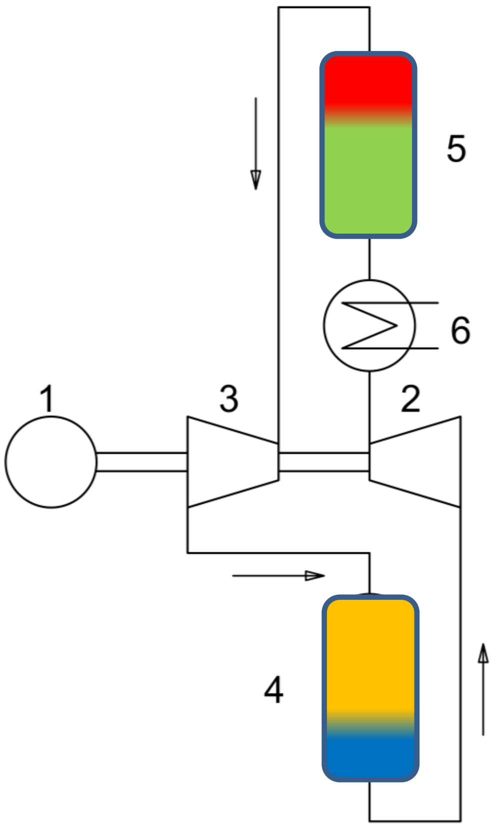
Charge

The charging cycle of the GridScale Battery essentially constitutes a heat pump.

During charging, air is heated by adiabatic compression. After having delivered the heat to a hot storage tank, the air is cooled to ambient temperature and is subsequently cooled to subzero temperatures by adiabatic expansion.

1 Motor
2 Compressor
3 Turbine
4 Cold storage tank
5 Hot storage tank
6 Cooler

Basic principle of GridScale Battery - discharging



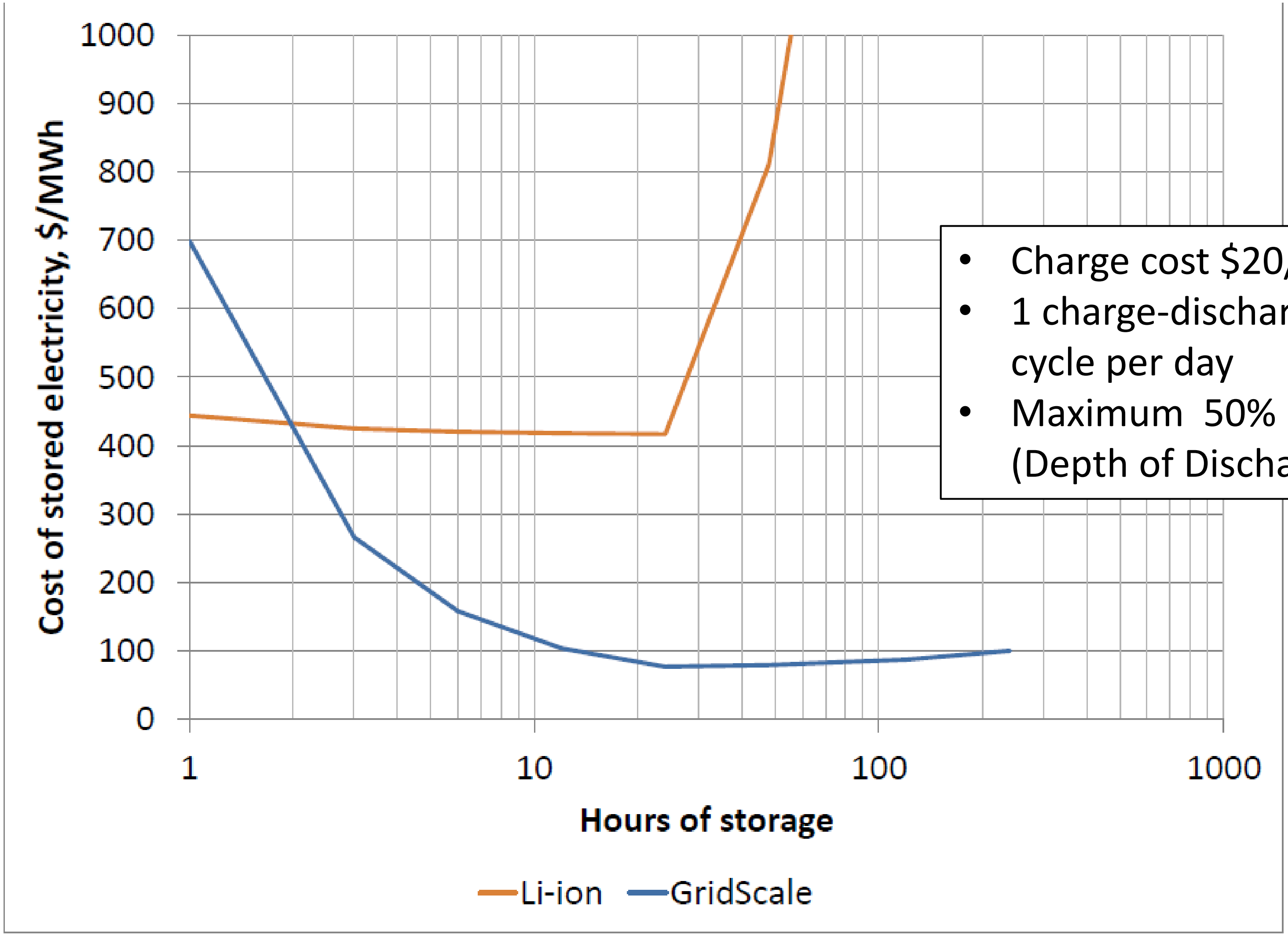
Discharge

During discharging, the compressor-turbine arrangement represents a Brayton cycle (as used in gas turbines)

Air from the cold reservoir is compressed and subsequently heated to a high temperature in the hot reservoir. It is then expanded in the turbine and returns to the cold reservoir.

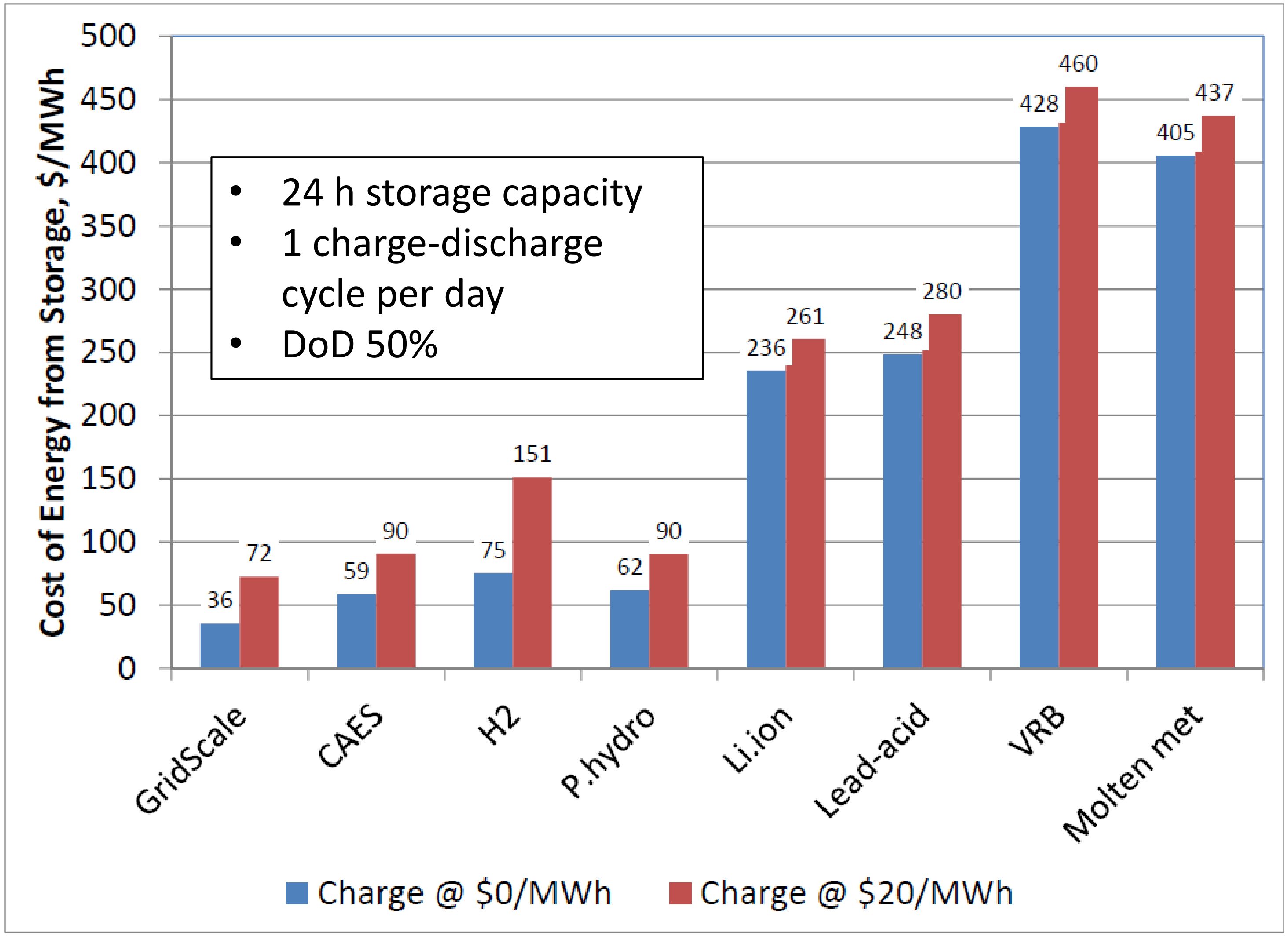
1 Generator
2 Compressor
3 Turbine
4 Cold storage tank
5 Hot storage tank
6 Cooler

GridScale Battery cost advantage for longer-term storage



- Charge cost $20/MWh
- 1 charge-discharge cycle per day
- Maximum 50% DoD (Depth of Discharge)

Storage costs depend on charging costs



Use case – Reduced-transmission PV

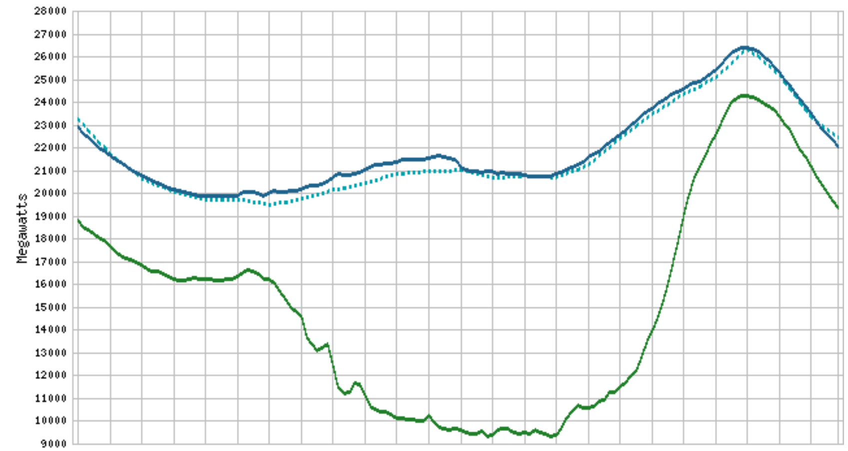
GridScale Battery enables three times more solar electricity on the grid

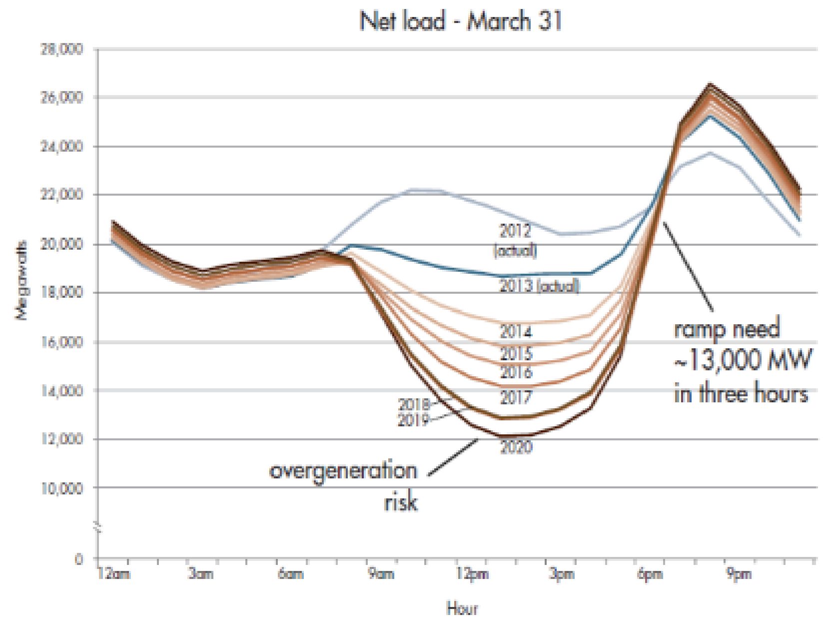
- The development of utility-scale solar PV is often constrained by transmission capacity.
- The transmission grid is only fully utilized during full daylight hours. It is essentially not utilized during nighttime.
- At present-day PV capacity factor levels of ~30%, with storage located at plants three times more solar electricity could be delivered through existing transmission grid.

Use case – Duck curve compensation

GridScale Battery enables load shifting

- The challenge of the duck curve is meeting or exceeding predictions
- Further expansion with solar PV will be severely constrained by grid capacity and stability requirements.
- The GridScale Battery offers an alternative to curtailment and essentially enables 24 h PV





Project status

Main topic	Subtopic	Done	Open
Thermodynamics	• Concept evaluation	✓	
	• Detailed optimization		✓
Storage material	• Selection and testing of rock fill	✓	
	• Development of “coal ash rock”		✓
Storage unit	• Concept design	✓	
	• Detailed design		✓
Charge and discharge systems	• Concept system design	✓	
	• Detailed system design		✓
	• Development of any special solutions		✓
System interaction	• Mapping of use cases	✓	
Validation	• Lab rock bed (kWh range)	✓	
	• Large rock bed (MWh range)		✓
	• Demo system (MW range)		✓
Implementation	• Commercial system (1-10 MW)		✓

Thanks for your attention

Henrik Stiesdal
hst@stiesdal.com

Introduction – Henrik Stiesdal

Former CTO of Siemens Wind Power, retired end 2014

Key Achievements

- Wind power pioneer, built first test turbine 1976, and first commercial turbine 1978; licensed wind turbine design to Vestas 1979, kick-starting modern Danish wind industry
- Served as technical manager of Bonus Energy A/S from 1988, ran company together with CEO until Siemens acquisition 2004, then took position as CTO of Siemens Wind Power
- Installed world's first offshore wind farm (1991) and world's first floating wind turbine (2009)
- Invented and implemented key technologies, including Siemens proprietary blade manufacturing, low-weight direct-drive turbines, variable-speed operation, energy storage, etc.
- Holds more than 800 patents

Post-Siemens activities include work on low-cost floating foundation technology, high-capacity energy storage and carbon-negative fuels