Energy Storage

Beyond Batteries

Henrik Stiesdal, November 4, 2019

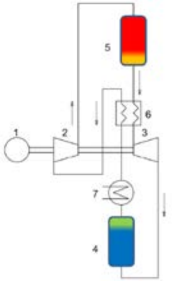
Framework

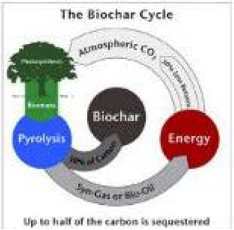
Company Structure
- Climate technology company with focused subsidiaries

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

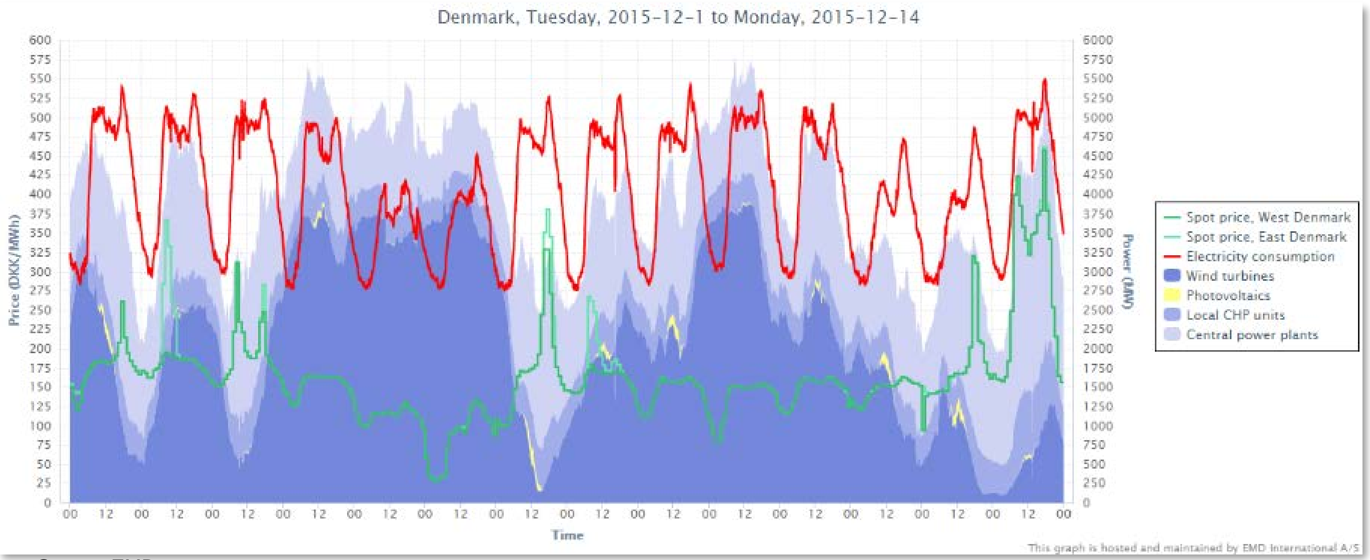




Key motivation for storage – renewable power integration

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

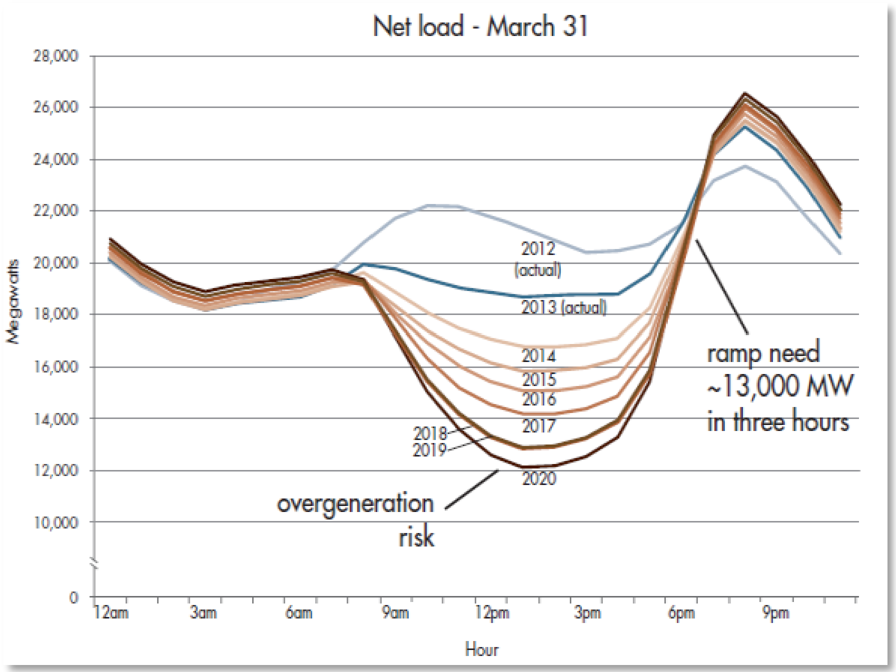


Source: EMD

Key motivation for storage – eliminating gas peaker plants

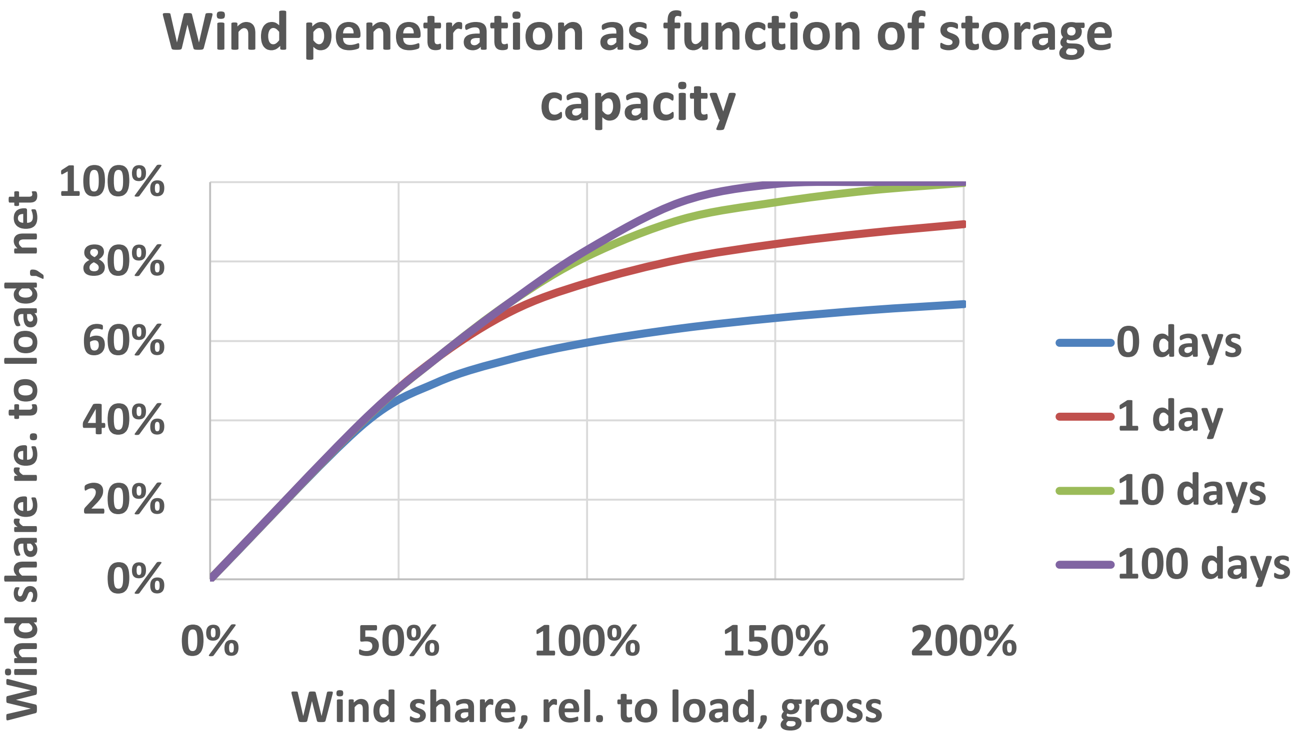
The California "Duck Curve"

- 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

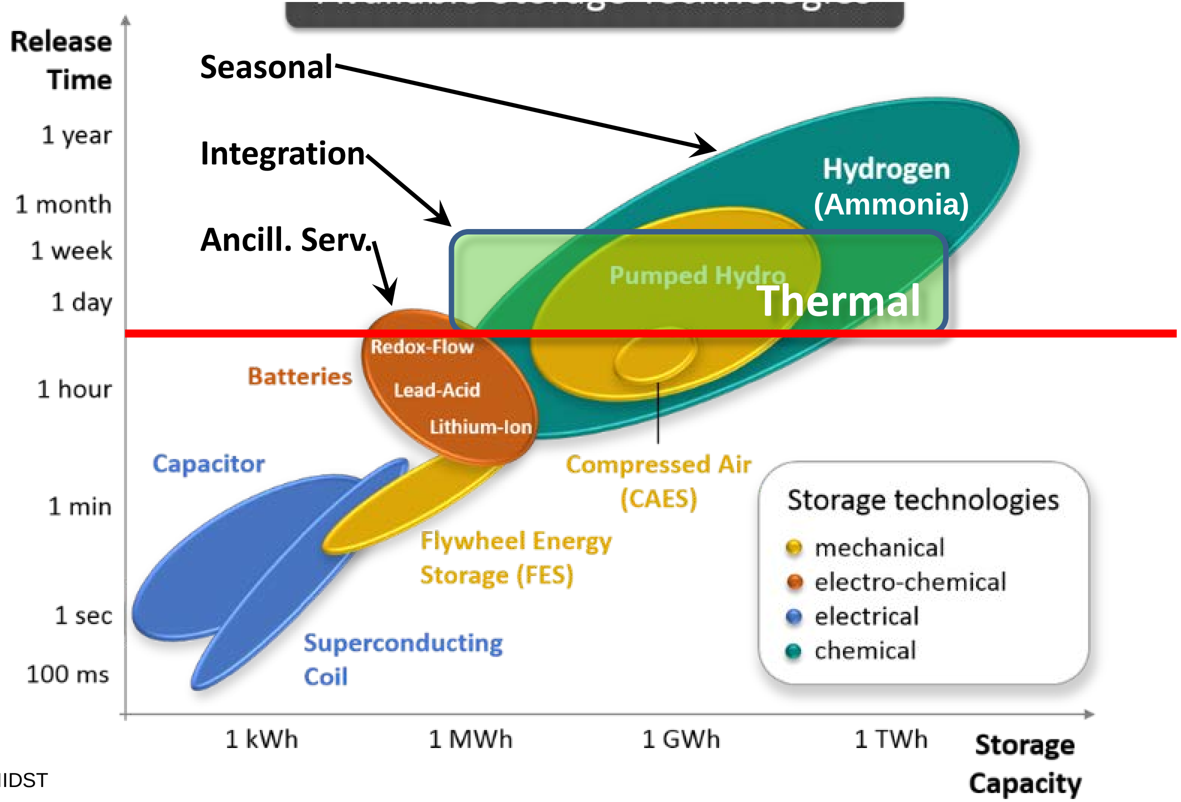


Source: CAISO

So – how much storage do we need?



The key storage technologies



Source: IIDST

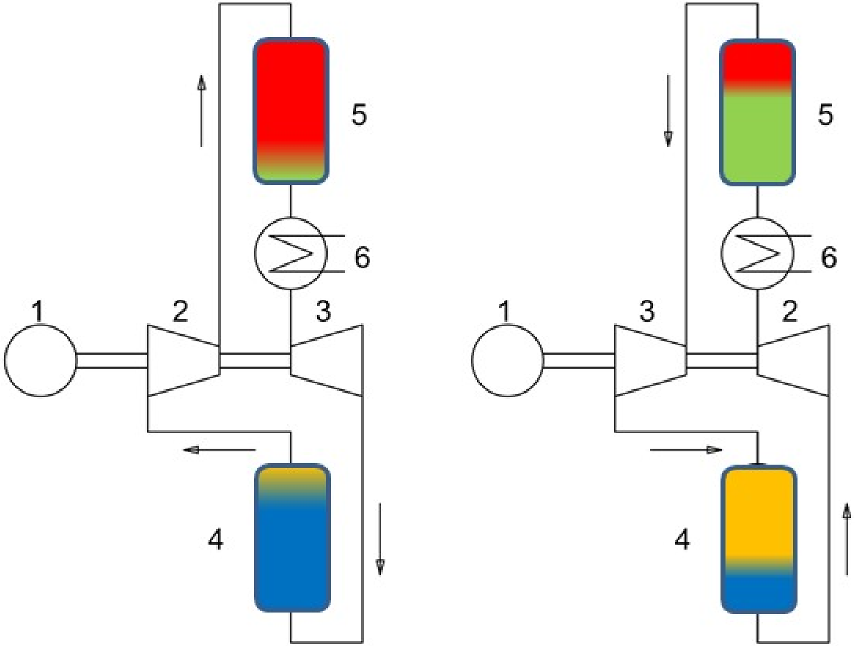
Comparison of technologies

Topic	Li-ion	Pump H_2O	CAES	H_2	NH_3	Thermal
Technology readiness charge-discharge	Mature	Mature	Mature	Mature	Mature	Mature
Technology readiness storage unit	Mature	Mature	Mature	Mature	Mature	Development stage
Round-trip efficiency	90%	85%	40-60%	30-40%	30-40%	35-60+%
Round-trip cost	High	Low	Low	Medium	Medium	Low
Energy density	High	Low	Low	High	High	High
Footprint	Small	Large	Small	Small	Small	Small
Scalability, power	100 MW	1000 MW	100 MW	1000 MW	1000 MW	1000 MW
Scalability, energy	100 MWh	100 GWh	1 GWh	100 GWh	500 GWh	500 GWh
Location requirement	None	Special topo	Special geology	Special geology	None	None
Raw material use	High	None	None	Moderate	Moderate	None

The heat pump principle of the GridScale Battery

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

600 deg.C
385 deg.C
75 deg.C
-30 deg.C

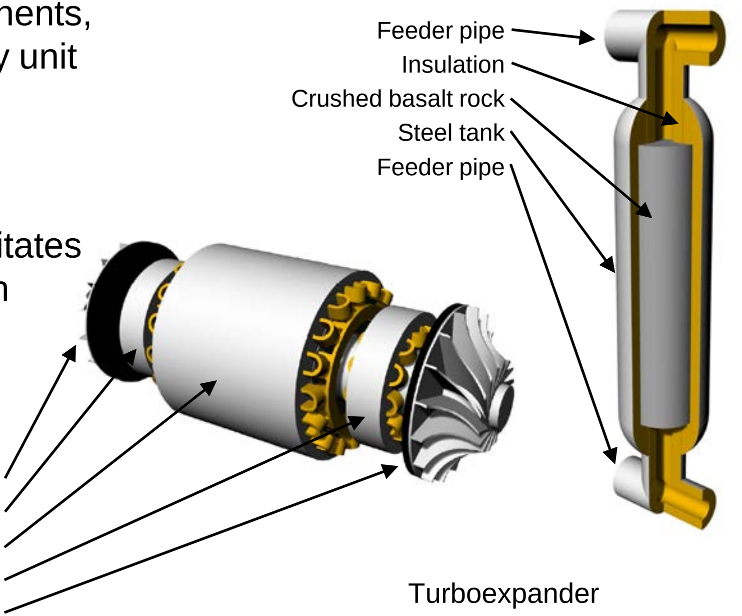


Charge Discharge

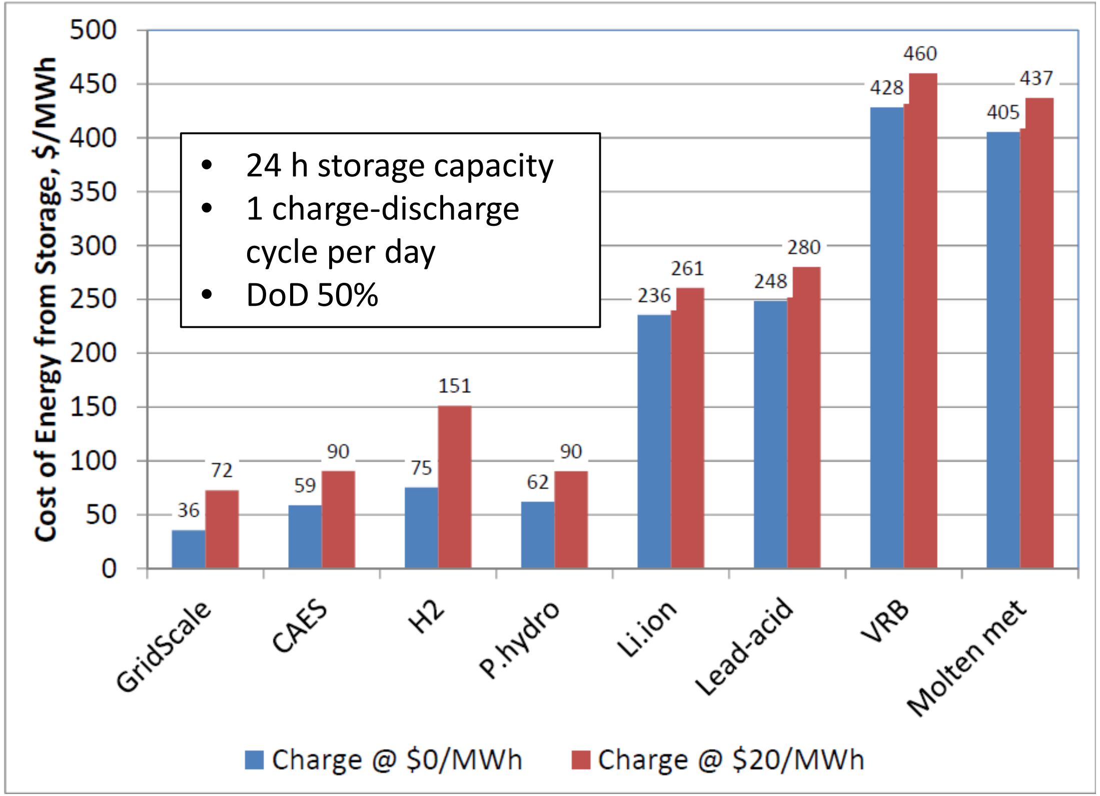
The industrialized concept of the GridScale Battery

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



Storage costs depend on charging costs



Storage is the missing link in global integration of renewables

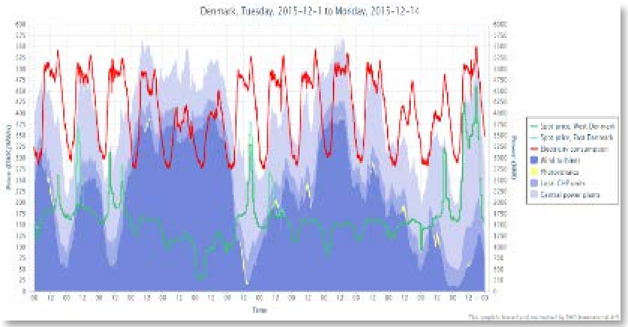
The bad news:

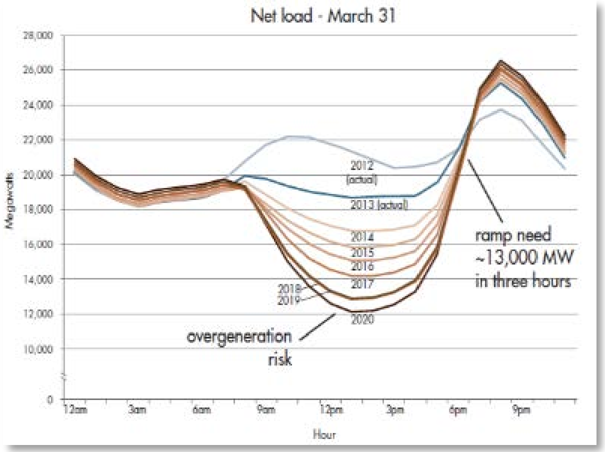
- Without energy storage it is not realistic or economically viable to aim for much above 40-50% share of renewables in the electric power system
- Li-ion battery storage systems are too expensive for large-scale renewable energy integration

The good news:

- Storage technologies exist that can fill the gap
  - Thermal storage for days to weeks
  - Hydrogen storage using amonia as carrier for seasonal storage

We just need to industrialize and implement!





Thanks for your attention

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