Energy storage

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NTVA- meetingTrondheim 18 /5/17

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Energy storage is as old as our civilization

collecting wood for maintaining fire

- ✓can be stored for practically an indefinite amount of time without losing its energy content
- ✓it is reasonably safe
- ✓it can easily be converted to the useful forms of energy (i.e. heat and/or light)

Energy storage for different time and sizes scales

- Capacitors in electronic devices store small amounts of energy for short times
- batteries provide the energy for cell phones, laptops, or the propulsion of cars
- gasoline, diesel fuel, and jet fuel provide the high storage density required for cars, trucks, or planes
- big subterranean caverns store grid-scale amounts of energy in the form of oil and natural gas

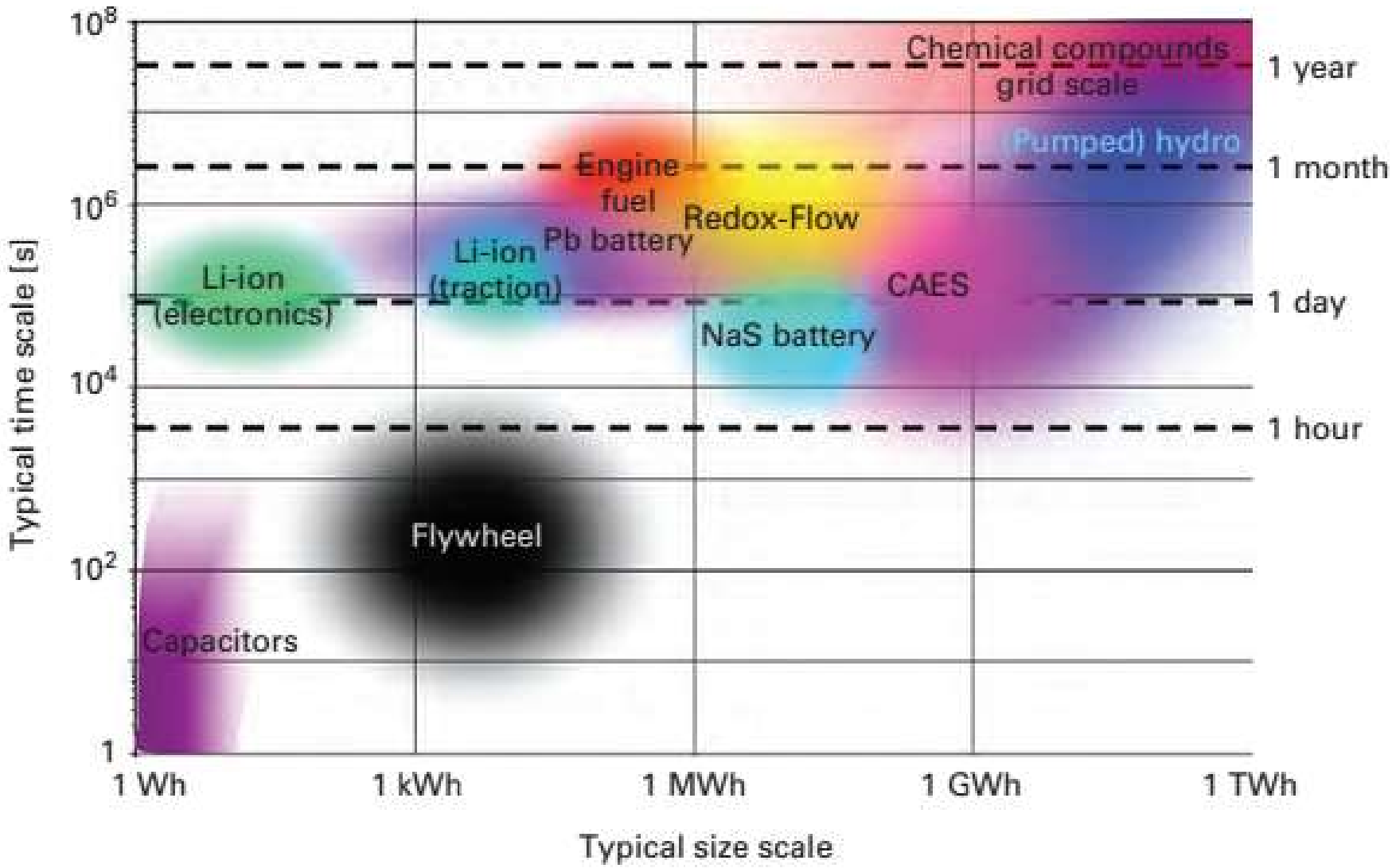
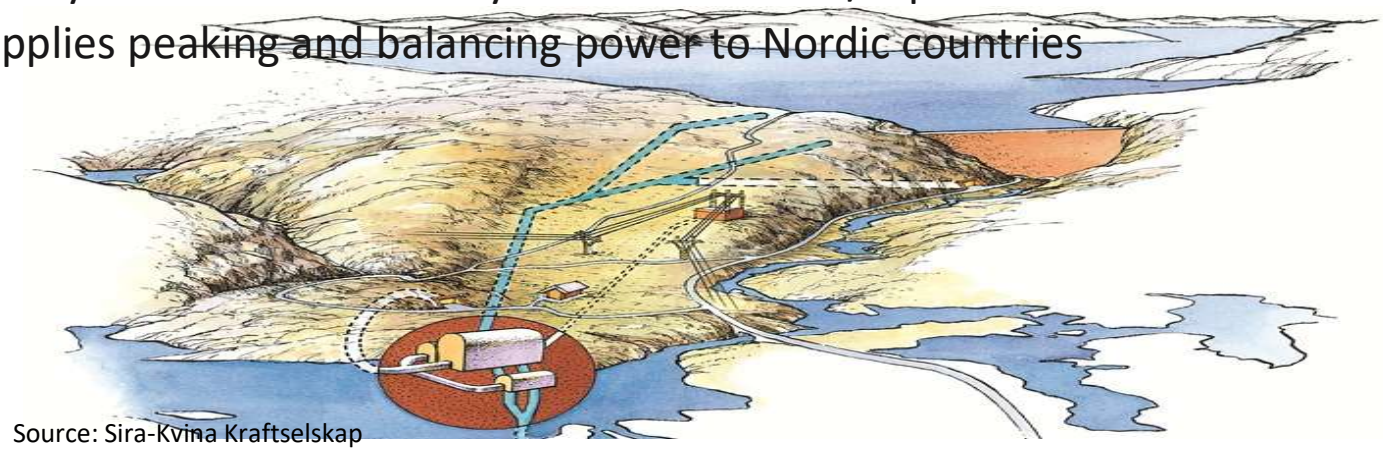


Figure 1.2.1 Typical time and size scales associated with sufficient storage technologies.

Norwegian Hydropower

- ~ 96 % of electricity is supplied by hydropower in Norway
- Connected to Sweden, Denmark, Finland, Russia and Netherland
- Largest hydropower producer in Europe and number 7 in the world
- Mainly consumed in Norway – Ca 26 000 kWh/capita
- Supplies peaking and balancing power to Nordic countries



Source: Sira-Kvina Kraftselskap

	Size	Number of plants	Total Power	Annual production
	[MW]	[-]	[MW]	[GWh/år]
Mini hydro	0 - 1	554	175	800
Small hydro	1 - 10	587	1.989	8.300
Large hydro	10 -100	255	9.523	43.000
Large hydro	> 100	80	19.273	79.500
	SUM	**1476**	**30.960**	**131.600**
Storage capacity in the Norwegian reservoirs				~ 86.000
Remaining energy potential (not protected)				~ 33.000

Current Technology

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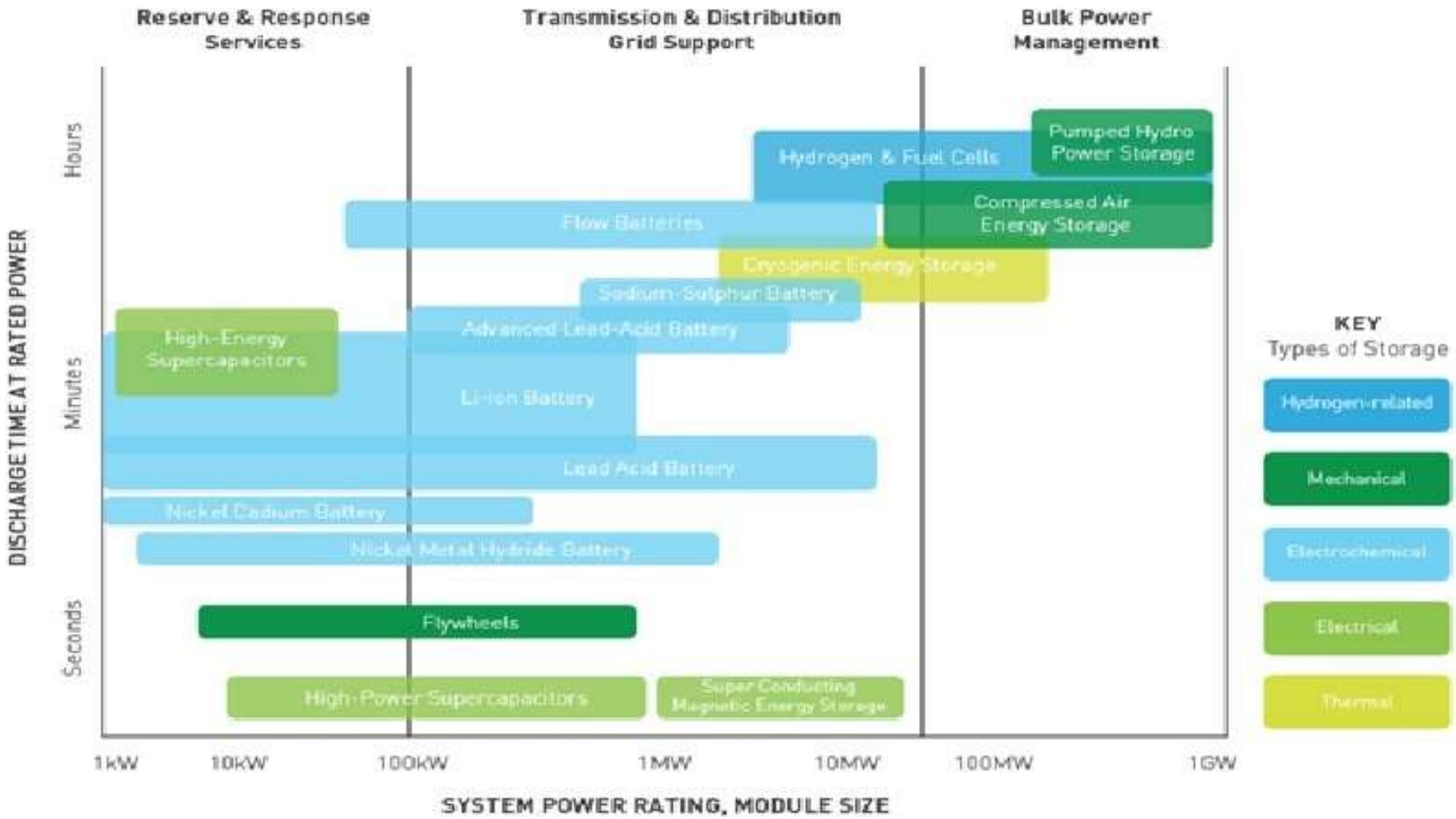
A familiar graphic showing "The Grid"

Different types of storage



Energy Storage Technologies

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1. **Solid State Batteries** - a range of electrochemical storage solutions, including advanced chemistry batteries and capacitors

2. **Flow Batteries** - batteries where the energy is stored directly in the electrolyte solution for longer cycle life, and quick response times

3. **Flywheels** - mechanical devices that harness rotational energy to deliver instantaneous electricity

4. **Compressed Air Energy Storage** - utilizing compressed air to create a potent energy reserve

5. **Thermal** - capturing heat and cold to create energy on demand

6. **Pumped Hydro-Power** - creating large-scale reservoirs of energy with water

What is a ”good” battery?

- Long cycling – do not need to be replaced
- Fast recharge
- Safety – no side-reactions
- Small weight and volume
- Low self-discharge
- No memory effect
- Non-toxic materials
- Low-cost materials
- High voltage
- High capacity
- High energy density
- High power density

- High voltage: difference in electrode potential anode *vs.* cathode
- High capacity: $Q = I*t$

Where we need to go!

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Gap of x10 !

1 liter petrol
2000Wh/kg

1 kg Li-ion battery
225Wh/kg

The need for natural resources for batteries

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Vehicles

1.10^9 cars 10% electric

➔ 20.10^6 tons batteries

World reserves $30x10^6$ tonnes Li_2CO_3

Load-levelling

World electricity production = 2.10^{13} kWh 10% stored/day

➔ 60.10^6 tons batteries!

Mandatory use of Sodium (SIBs)

Batteries

1. **Solid State Batteries**

- Electrochemical capacitors (ECs)
- Lithium Ion (LI-ION) Batteries
- Nickel-Cadmium (NI-CD) Batteries
- Sodium Sulfur (NAS) Batteries

2. **Flow Batteries**

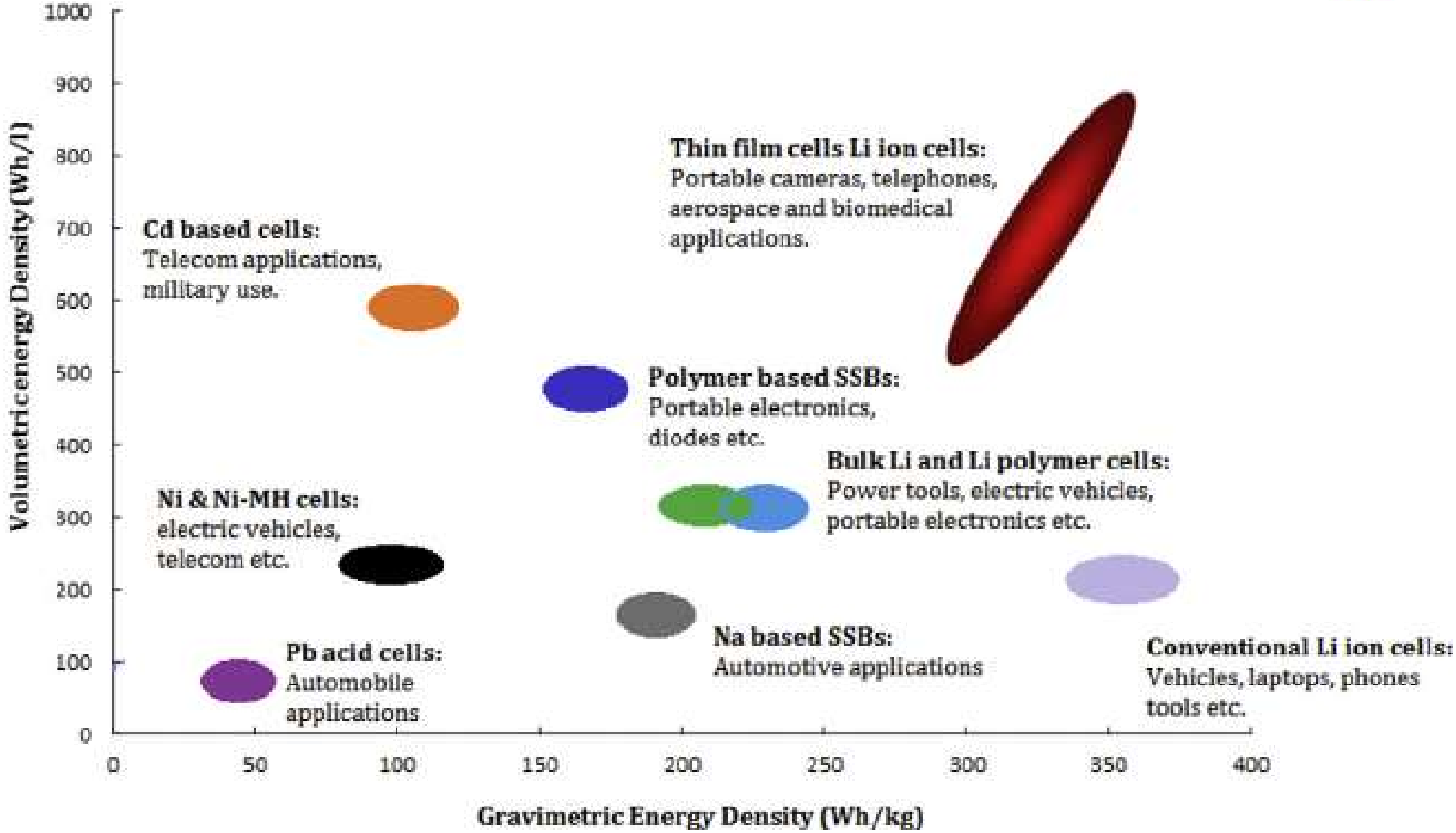
- Redox Flow Batteries
- Iron- Chromium (ICB) Flow Batteries
- Vanadium Redox (VRB) Flow Batteries
- Zinc-Bromine (ZNBR) Flow Batteries

Why LIB for ESS?

LIB has its strengths in the ESS industry because of its high energy density, efficiency, long lifespan and eco-friendliness.

	1st	2nd	3rd	4th	5th
ENERGY DENSITY (Wh / kg)	LIB 150-250	NaS 125-150	Flow 60-80	Ni-Cd 40-60	Lead-Acid 30-50
ROUND TRIP EFFICENCY (%)	LIB 95	NaS 75-85	Flow 70-75	Ni-Cd 60-80	Lead-Acid 50-70
LIFE TIME (yrs)	LIB 10-15	NaS 10-15	Ni-Cd 10-15	Flow 5-10	Lead-Acid 3-6
ECO-FRIENDLY ASPECT	LIB ○	NaS ×	Ni-Cd ×	Flow ×	Lead-Acid ×

Batteries for different applications



Flywheels

- Flywheel energy storage systems (FESS)

Compressed Air Energy Storage (CAES)

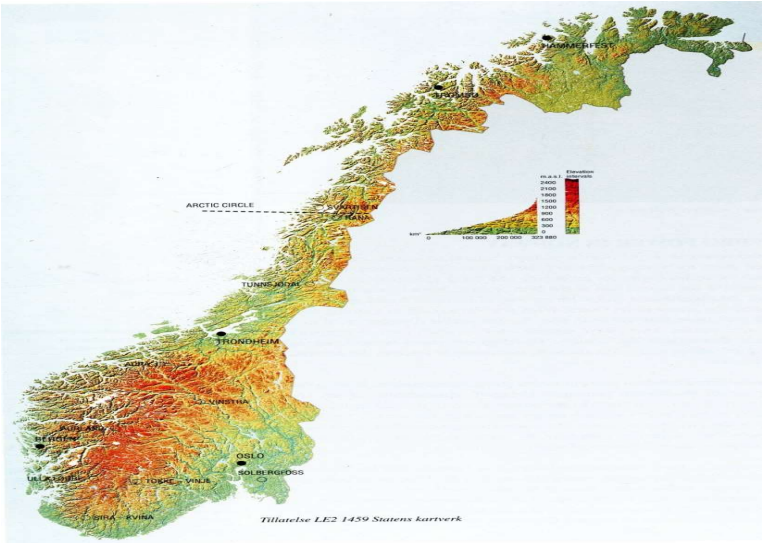
- Compressed Air Energy Storage (CAES)
- Advanced Adiabatic Compressed Air Energy Storage (AA-CAES)
- Isothermal CAES

Thermal

- Pumped Heat Electrical Storage (PHES)
- Hydrogen Energy Storage
- Liquid Air Energy Storage (LAES)

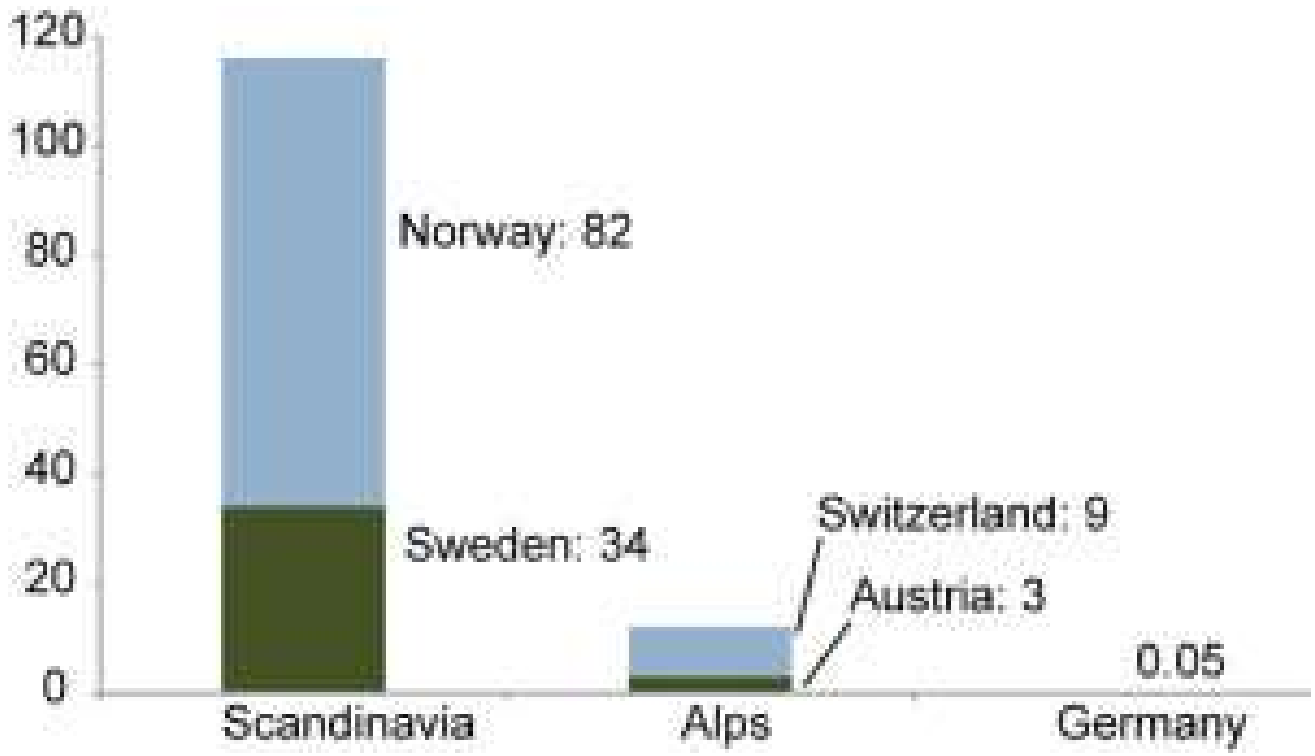
Pumped Hydro-Power

- Pumped Hydroelectric Storage
- Sub-Surface Pumped Hydroelectric Storage
- Surface Reservoir Pumped Hydroelectric Storage
- Variable Speed Pumped Hydroelectric Storage



High precipitation	**400-6000 mm/year**
Low evaporation	100 – 400 mm/year
High runoff	15 to > 100 l/s*km^2
Steep topography	30% at 0-300 masl 30% at 300-600 masl 40% at higher than 600 masl
1st Norwegian hydropower plants	Senjens Nikkelverk 1882 Laugstol Bruk 1885
Tunnels in Norwegian hydropower plants	~ 4300 km
Average age of Norwegian hydropower plants	~ 45 years
Largest reservoir	Blåsjø – 7.8 TWh

Blåsjø reservoir
source: Statkraft



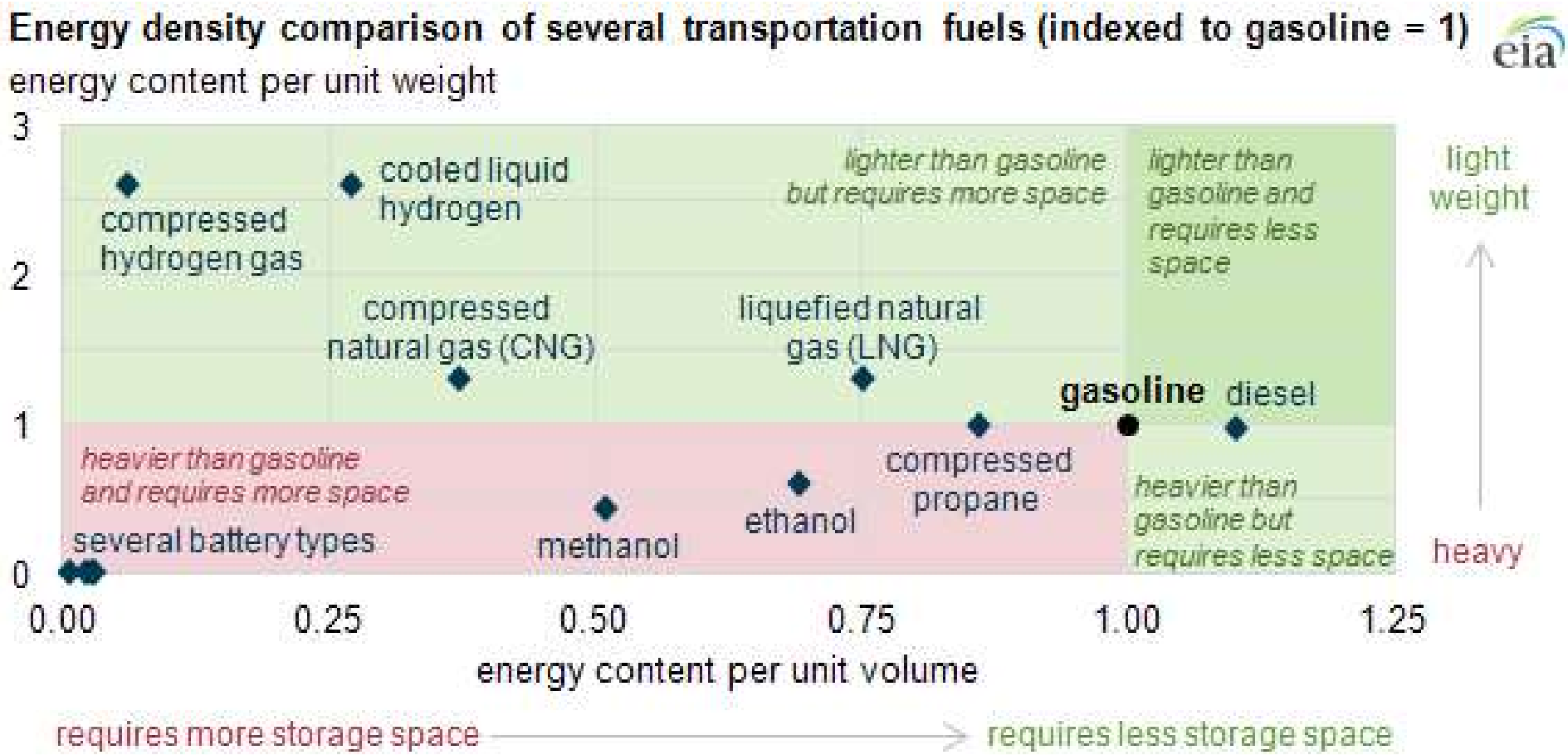
	Germany	Austria	Sweden	Norway
Store capacity (TWh)	0.05	4.5	33.8	81.7
pumped Hydro (GW)				20
Electricity consumption (TWh)	600	70	130	129
% percentage of Energy covered by Hydro	0%	6%	26%	63%

https://www.worldenergy.org/data/resources/country/norway/hydropower/

Blåsjø

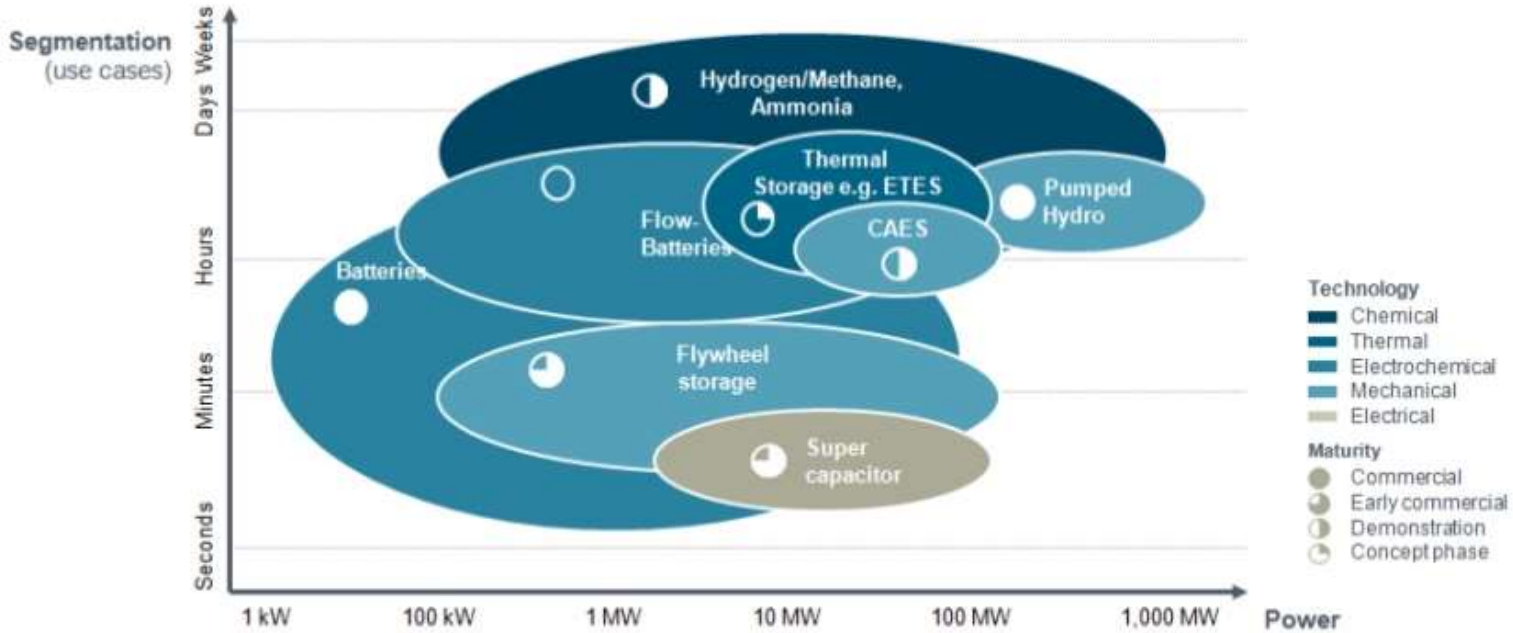
- Tilsvarer 1,24 milliarder Tesla batterier

Energy storage for transport



Commercial readiness

Siemens is developing a wide range of storage technologies to meet the expected need for a portfolio of solutions



Unrestricted © Siemens AG 2016

PILOT-E

PILOT-E er en ny støtteordning skal sette fart på utviklingen av miljøvennlig energiteknologi. 70 millioner kroner skal gå til klimavennlige skip.

Ampere er verdens første batteridrevne bilferge. Den ble bygget av Fjellstrand verft for rederiet Norled

Ampere ferry

Lengde o.a……. 80,00 m
Bredde mld. ……20,80 m
Bilkap. …….. 120 pbe
Passasjekap. ……. 360
Passasjerstoler …. 140
Mannskapslugarer …7

Siemens batteriproduksjon i Trondheim

Siemens satser nå på batteriproduksjon i Trondheim.

Selskapet skal levere elektrisk fremdriftsystem og egenproduserte batterier til Kleven som skal bygge ferje til FosenNamsos Sjø

Selskapets ambisjoner er å revolusjonere norsk og internasjonal skipsfart.

PBES sammen med ABB skal levere fire batteripakker på til sammen 4,16 MWh til to H-borg-H-ør ferger som skal bli helelektriske.

Læringskurver på sol 2

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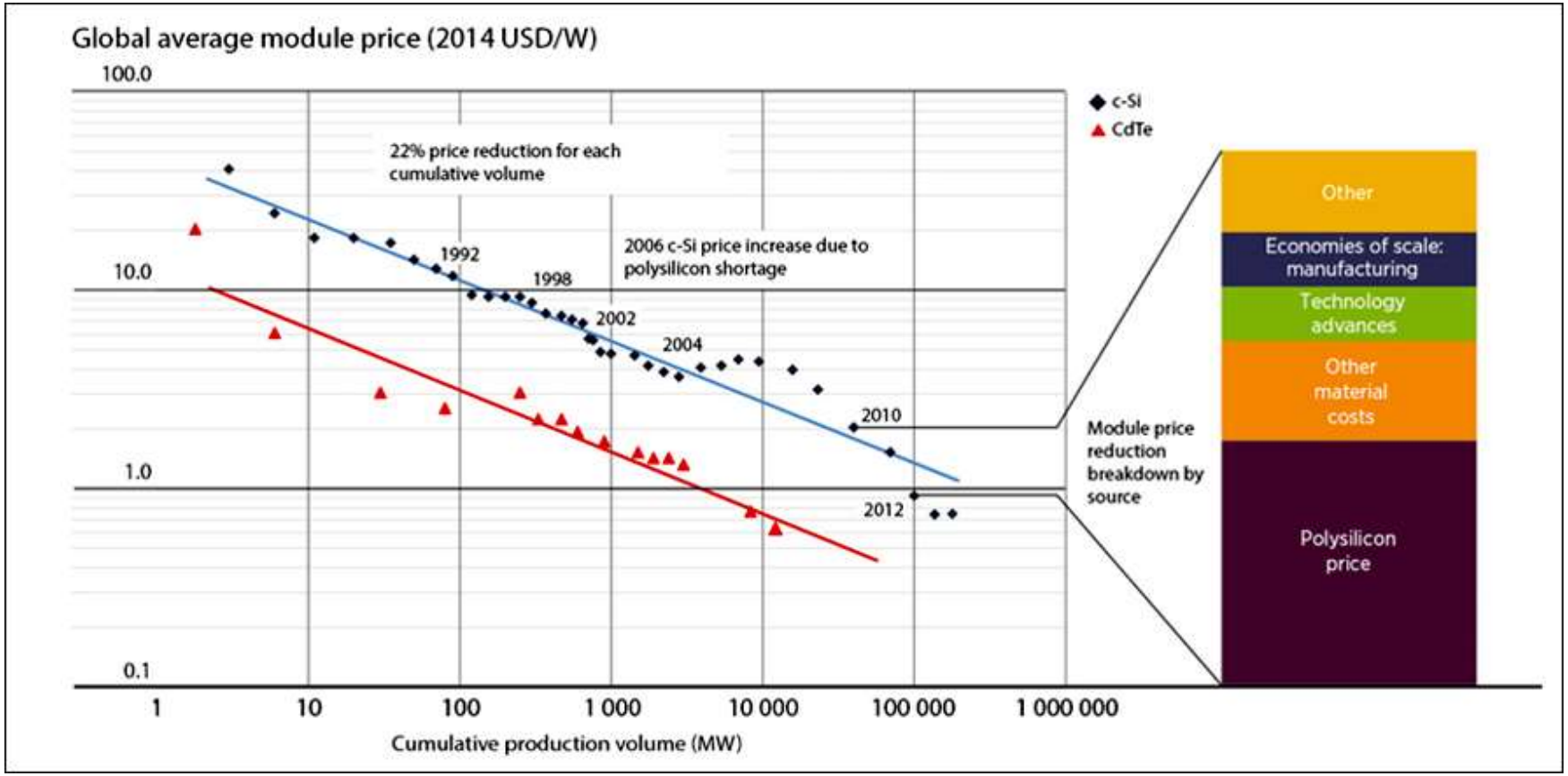

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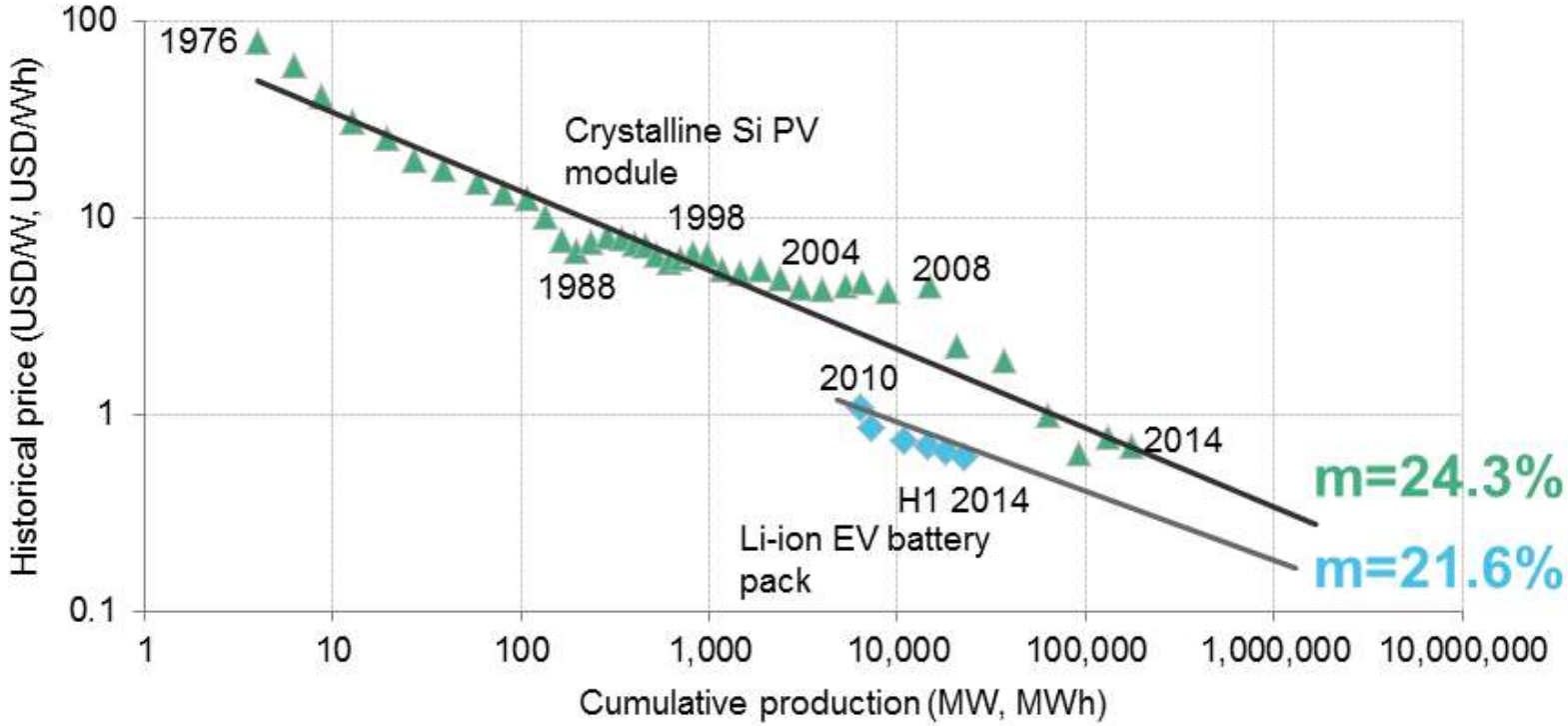
LITHIUM-ION EV BATTERY EXPERIENCE CURVE COMPARED WITH SOLAR PV EXPERIENCE CURVE

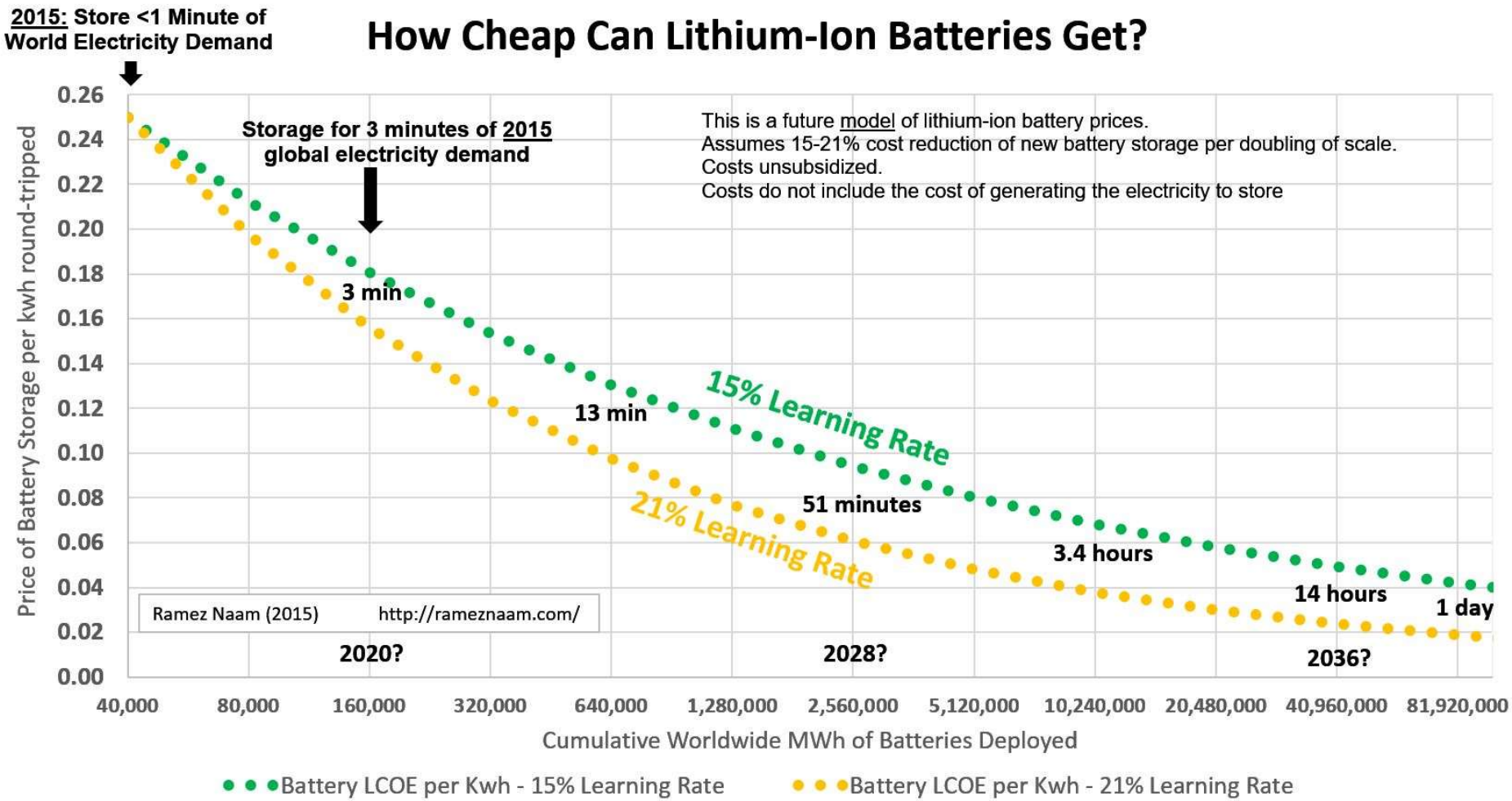
Bloomberg NEW ENERGY FINANCE



Note: Prices are in real (2014) USD.

Source: Bloomberg New Energy Finance, Maycock, Battery University, MIT

Cost of batteries for future



Conclusions

- Energy storage is as old as our civilization
- Extent use of renewable energy requires increased storage capacities
- Energy storage for different time and sizes scales
- Hydropower in Norway give new pumped storage possibilities
- Batteries have different characteristics and will be used for different applications, transport…
- Investments and diffusion of new technologies give lower costs for batteries