ESS (Energy Storage System)

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Topics

I. What is ESS?

II. Why ESS?

III. Types & Characteristics

IV. How to Choose?

V. Grid Applications

VI. Application Examples

VII. Recommendations

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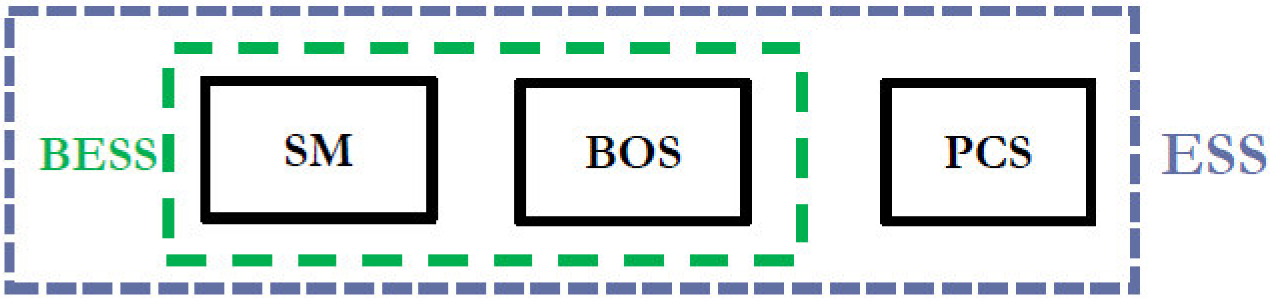
What is ESS? (Schematic)



SM	Storage Module Rack Level System (DC)
BESS	Battery Energy Storage System Containerized System (DC)
ESS	Energy Storage System Complete System

Unit : (PCS) MW/(BESS) MWh

From: **LAZARD'S LEVELIZED COST OF STORAGE - VERSION2.0, 2016**

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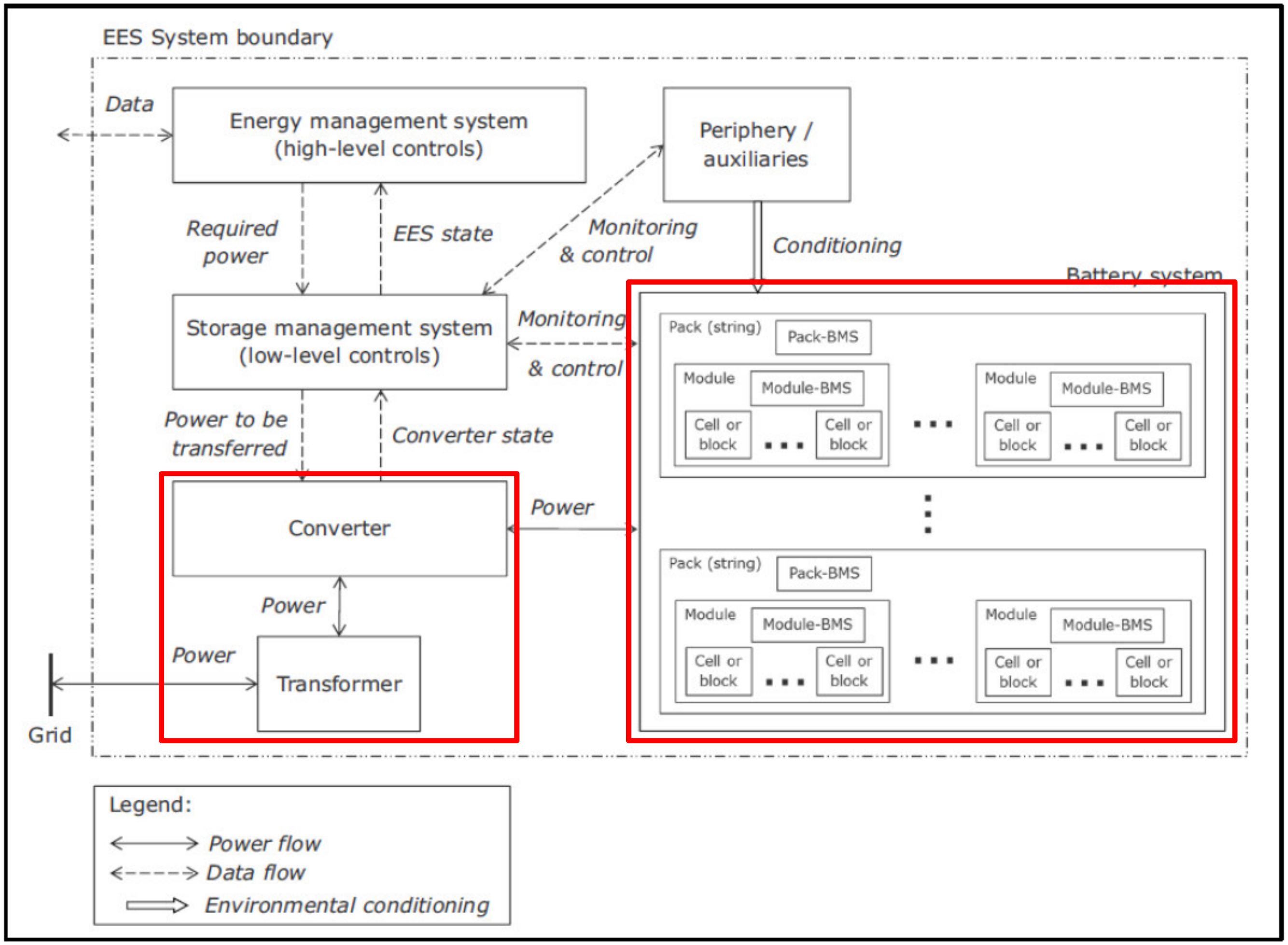
What is ESS? (Architecture)



From: Battery Energy Storage Study for the 2017 IRP, PacifiCorp, 2016

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Why ESS?

1) Power System Transition

Item	Centralized Power System	Distributed Power System
Generation	Baseload Plant + Intermediate Load Plant + Peak Load Plant	Gas (Co-Gen and Tri-Gen) + RE + DER (ESS, EV, DR etc.)
Keyword	Reliability	Flexibility
	Stability	
Core Facilities	Generators T&D Facilities	RE DER (ESS, EV, DR etc.)

Why ESS?

2) System Efficiency Increase

- Any system without storage has very bad system efficiency

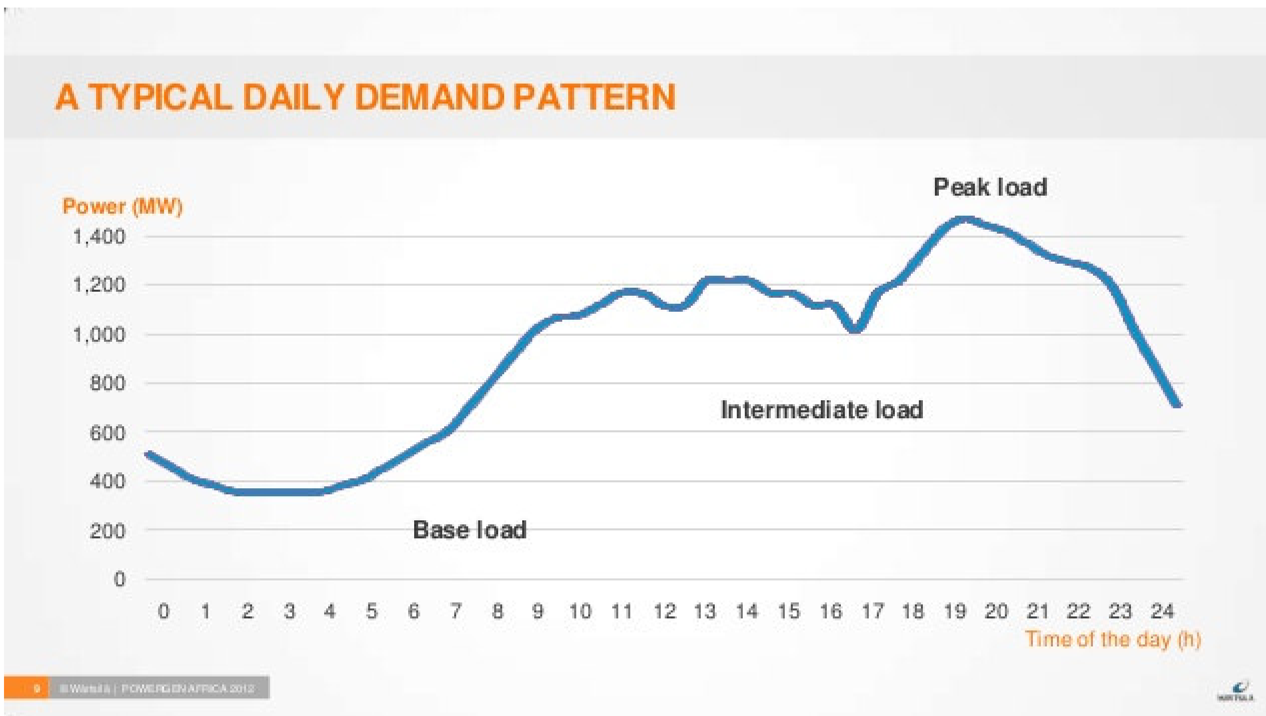
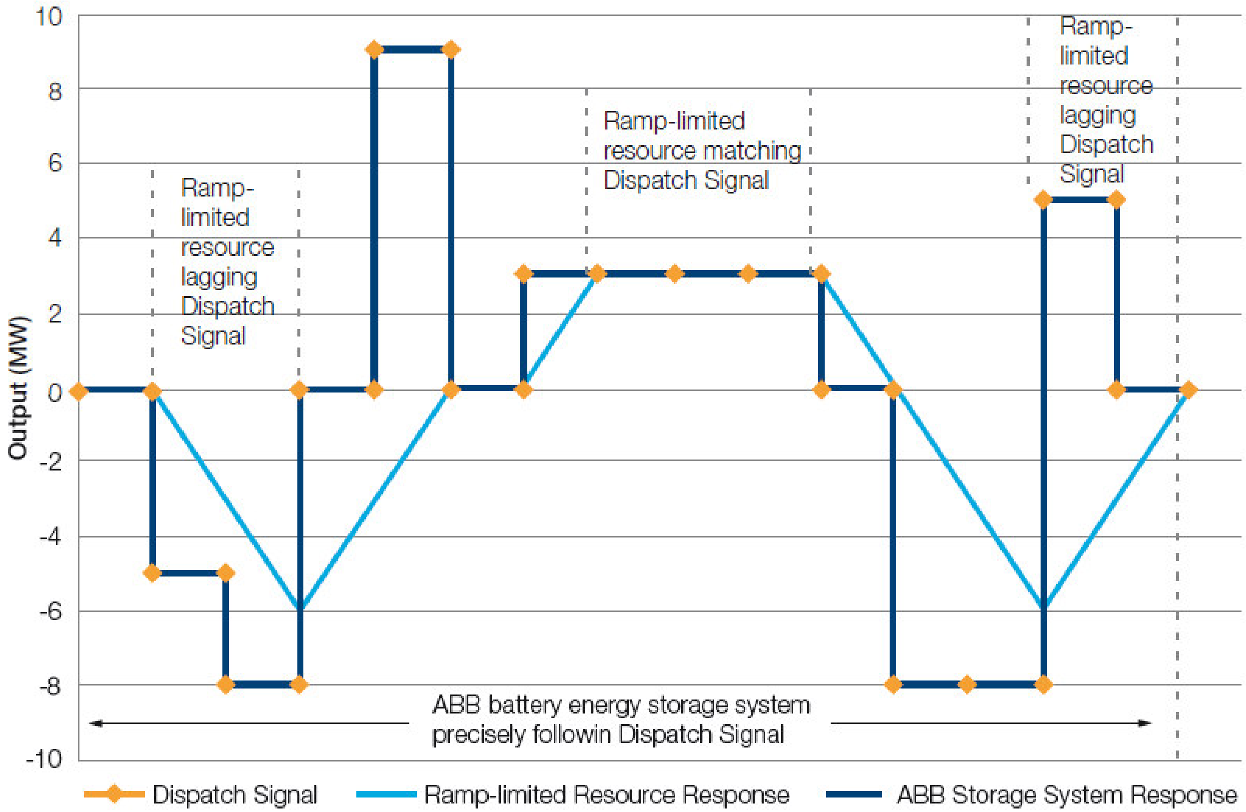


Image from www.google.com

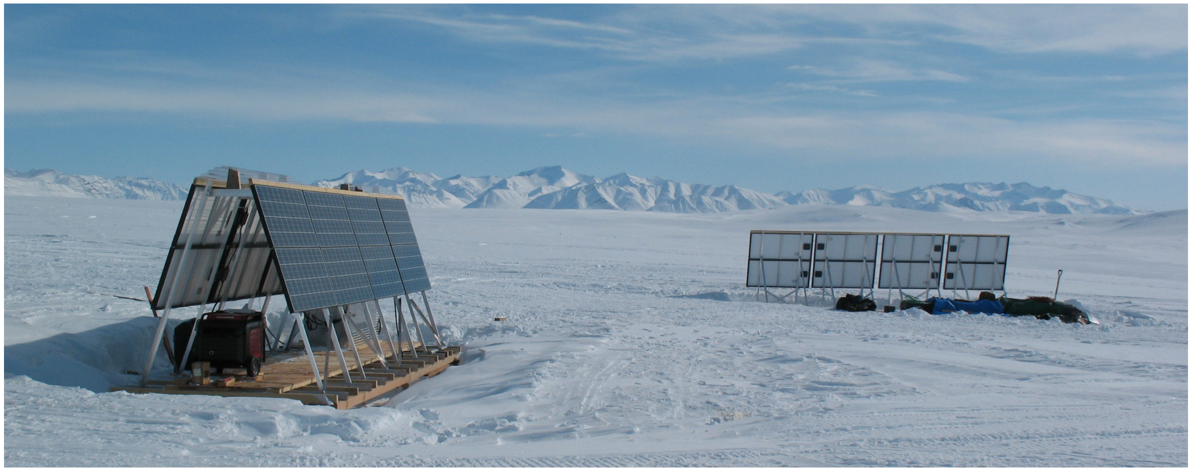
Why ESS?

3) Digitized Output



Why ESS?

4) Good Solution for DMCs



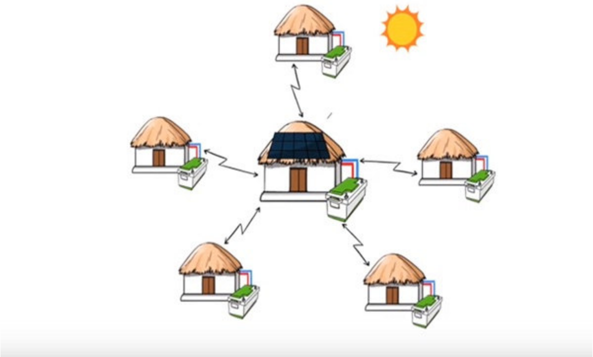


Image from www.google.com

Why ESS?

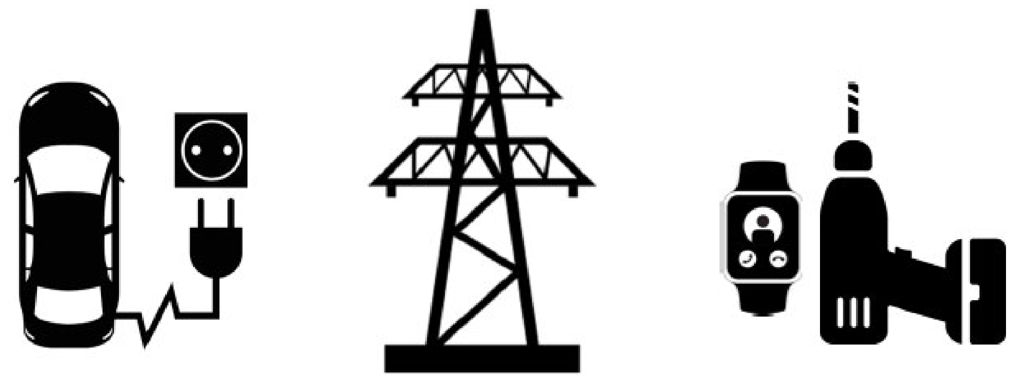
5) Business Opportunity

Previously, there was one major industry investing in batteries....

Consumer Electronics

8 - 10% CAGR

Replicating Success



Transportation	Energy Storage	Consumer Devices
20 - 30% CAGR	>30% CAGR	>15% CAGR

From: Global Lithium Market Outlook, ALBEMARLE, 2016

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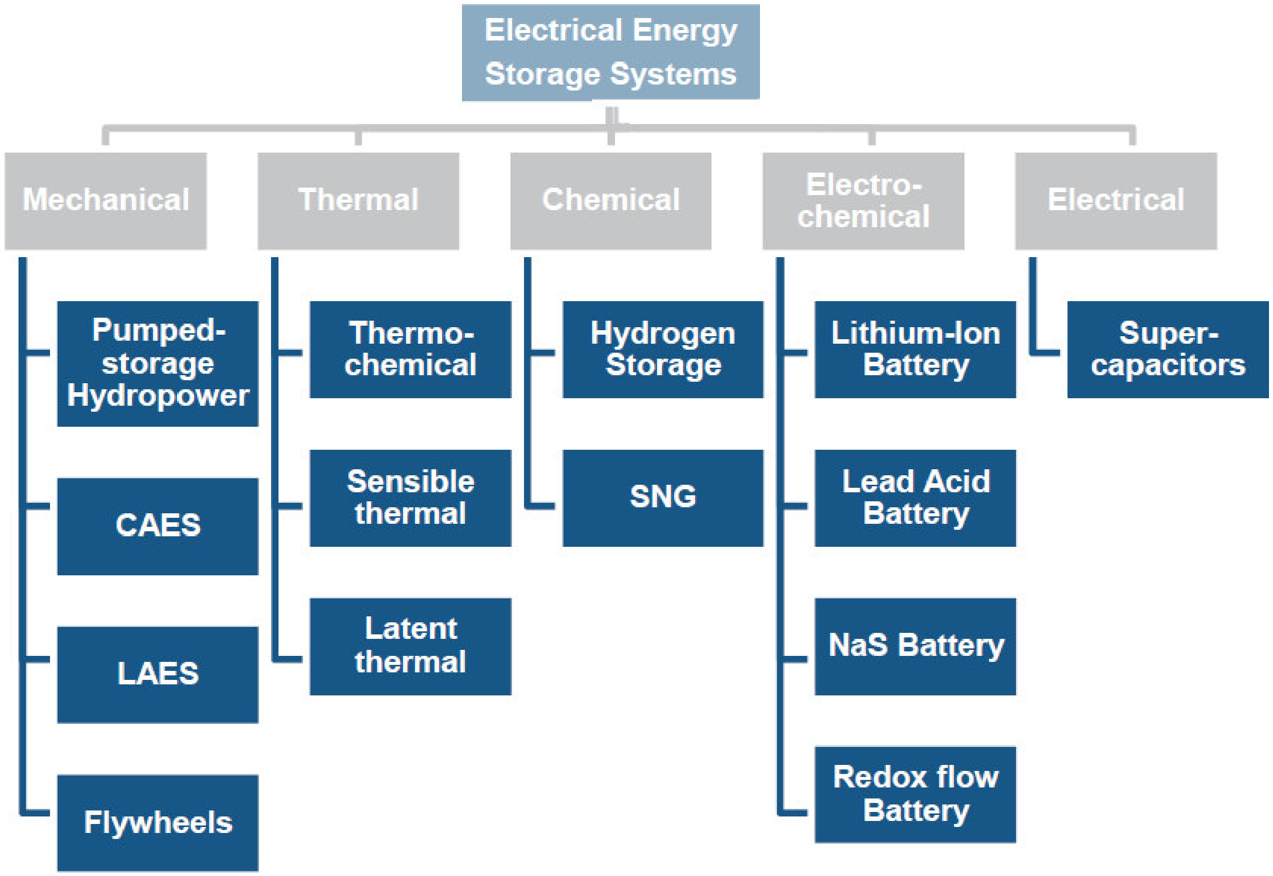
Types & Characteristics

Source: PwC, 2015.

CAES is Compressed Air Energy Storage; LAES is Liquid Air Energy Storage; SNG is Synthetic Natural Gas.



From: **World Energy Resources, WEC, 2016**

Types & Characteristics

Sources for technical parameters: ISEA Aachen (2012), Fraunhofer IWES, IAEW Aachen, Stiftung Umweltenergierecht (2014)[24]; Sources for Economics parameters: Agora Energiewende (2014)[25], ISEA Aachen (2012), Fraunhofer IWES, IAEW Aachen, Stiftung Umweltenergierecht (2014), PwC research.

Technology		Pumped hydropower storage*	Compressed air*	Liquid air*	Lithium battery*	NaS battery*
Parameter	**Unit**					
Main applications		Frequency control (secondary reserve, minute reserve), voltage control, peak shaving, load levelling, standing reserve, black start. Note that pumped hydropower storage can also provide long term storage subject to suitable topography.	Frequency control, peak shaving, load levelling, island grids, residential storage systems, uninterruptible power supply	Frequency control (negative secondary reserve, positive and negative minute reserve), peak shaving, load levelling, standing reserve, black start, island grids, residential storage systems, uninterruptible power supply.	Frequency control, voltage control, peak shaving, load levelling, electro mobility, residential storage systems	Frequency control, peak shaving, load levelling, island grids, electro mobility, uninterruptible power supply
Technical parameters						
Technology maturity	(-)	Well developed technology	Developed technology	Demonstration phase	Developed technology	Developed technology
Rated power	(kW)	Up to > 1 000 000	Up to 320 000	Up to 600 000	Up to 10 000	Up to 34 000
E2P Ratio	(h)	1-10	1-10	1-10	1-10	1 - 10
Efficiency	(%)	75 – 80	60 – 70	50 – 70	80 – 92	75 – 80
Maximum depth of discharge	(%)	80 - 100	80 - 100	80 – 100	up to 100	up to 90
Technical lifetime	(a)	40 - 80	20 – 30	20 – 30	5 – 20	15 – 25
Response time	(min)	3	3 – 10	5 – 15	0.003 – 0.005	0.003 – 0.005
Economics parameters						
Specific investment costs	(€/kW)	700 – 1 500	900 – 1 800	1 100 – 3 000	800 – 3 700	2 900 – 3 900
Operation costs	(%*Invests)	1,5 - 2	1,5 – 2	1 – 2	1,5 – 2	1,5 – 2

*Assumption: Pumped hydropower storage with E2P Ratio of 4; Compressed air with E2P Ratio of 6; Liquid air with E2P Ratio of 6; Lithium battery with E2P Ratio of 1-4; for both application cases: 4; NaS battery with E2P Ratio of 6.

From: **World Energy Resources, WEC, 2016**

Types & Characteristics

Sources for technical parameters: ISEA Aachen (2012), Fraunhofer IWES, IAEW Aachen, Stiftung Umweltenergierecht (2014).

Sources for economics parameters: Agora Energiewende (2014); IEA-ETSAP; IRENA (2013);ISEA Aachen (2012); Fraunhofer IWES; IAEW Aachen; Stiftung Umweltenergierecht (2014), PwC research.

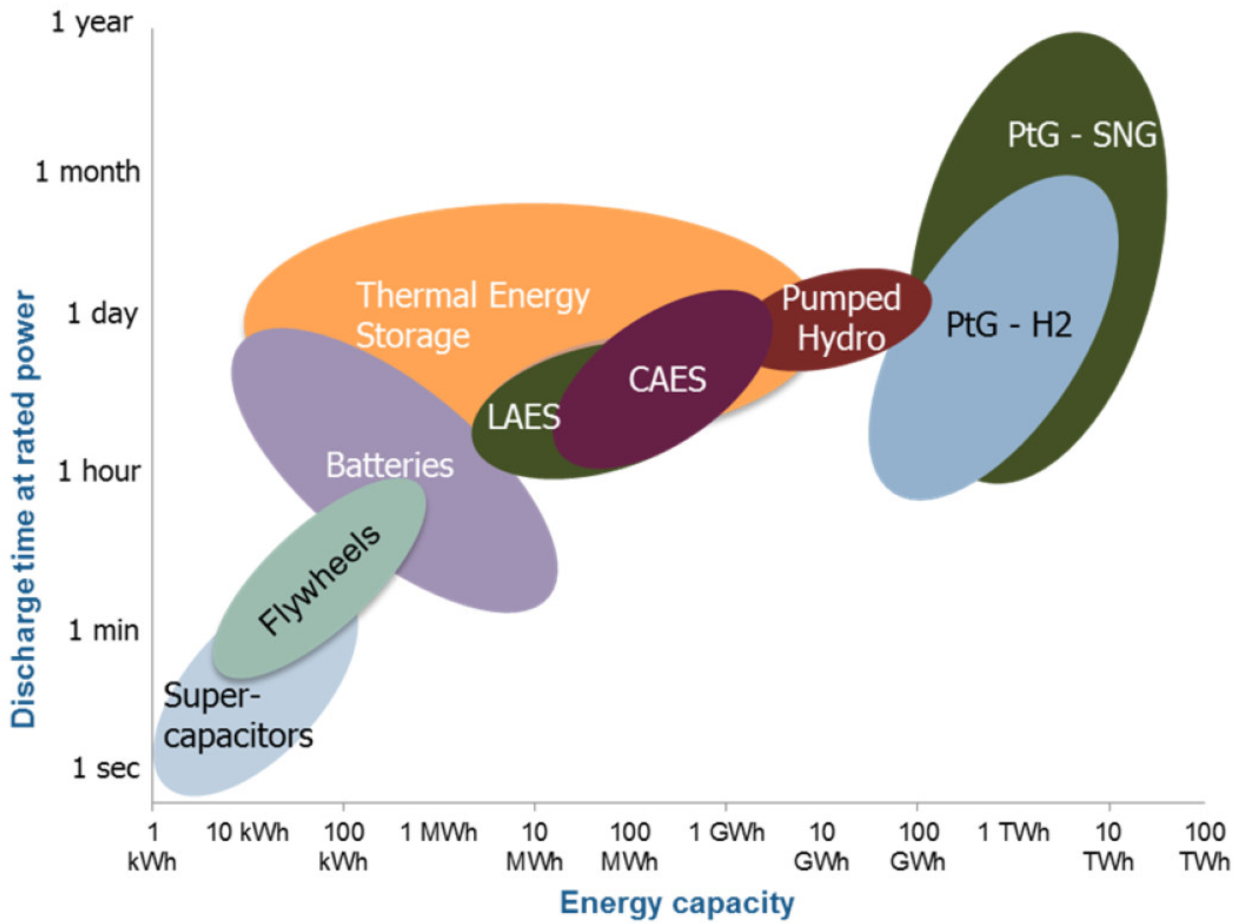
Technology		Lead acid battery	Redox flow battery	Thermochemical	Supercapacitors	Flywheels
Parameter	**Unit**					
Main applications		Frequency control, peak shaving, load levelling, island grids, residential storage systems, uninterruptible power supply.	Secondary / tertiary frequency control, long-term storage, island grids	Frequency control, voltage control, peak shaving, load levelling, standing reserve, black start	Primary frequency control, voltage control, peak shaving	Primary frequency control, voltage control, peak shaving
Technical parameters						
Technology maturity	(-)	Well developed technology	Development phase	Development phase	Development phase	Developed technology
Rated power	(kW)	Up to 70 000	Up to 10 000	Up to 100 000	1	< 500
E2P Ratio	(h)	1 - 10	1 - 10	1 – 10	< 0.25	< 0.25
Efficiency	(%)	65 – 90	70 – 80	75 – 100**	90 – 94**	80 - 95
Maximum depth of discharge	(%)	60 - 70	Up to 100	Up to 100	75	Up to 100
Technical lifetime	(a)	5 – 15	10 – 20	10 – 30	15	15
Response time	(min)	0.003 – 0,005	seconds	-	< 10	10
Economics parameters						
Specific investment costs*	(€/kW)	500 – 1 700	1 000 – 3 500	900 – 3 000	2 100 – 4 200	600 –1 000
Operation costs	(%*Invests)	1.5 – 2	1.5 – 2	1.5 – 2	1.5 – 2	1.5 –2

*Assumption: Lead acid battery with E2P Ratio of 1-4; for both application cases: 4; Redox flow battery with E2P Ratio of 1-4; for both application cases: 4; Thermochemical with E2P Ratio of 6; Supercapacitors with E2P Ratio of 0.25; Flywheels with E2P Ratio of 0.25. **Thermal efficiency

From: **World Energy Resources, WEC, 2016**

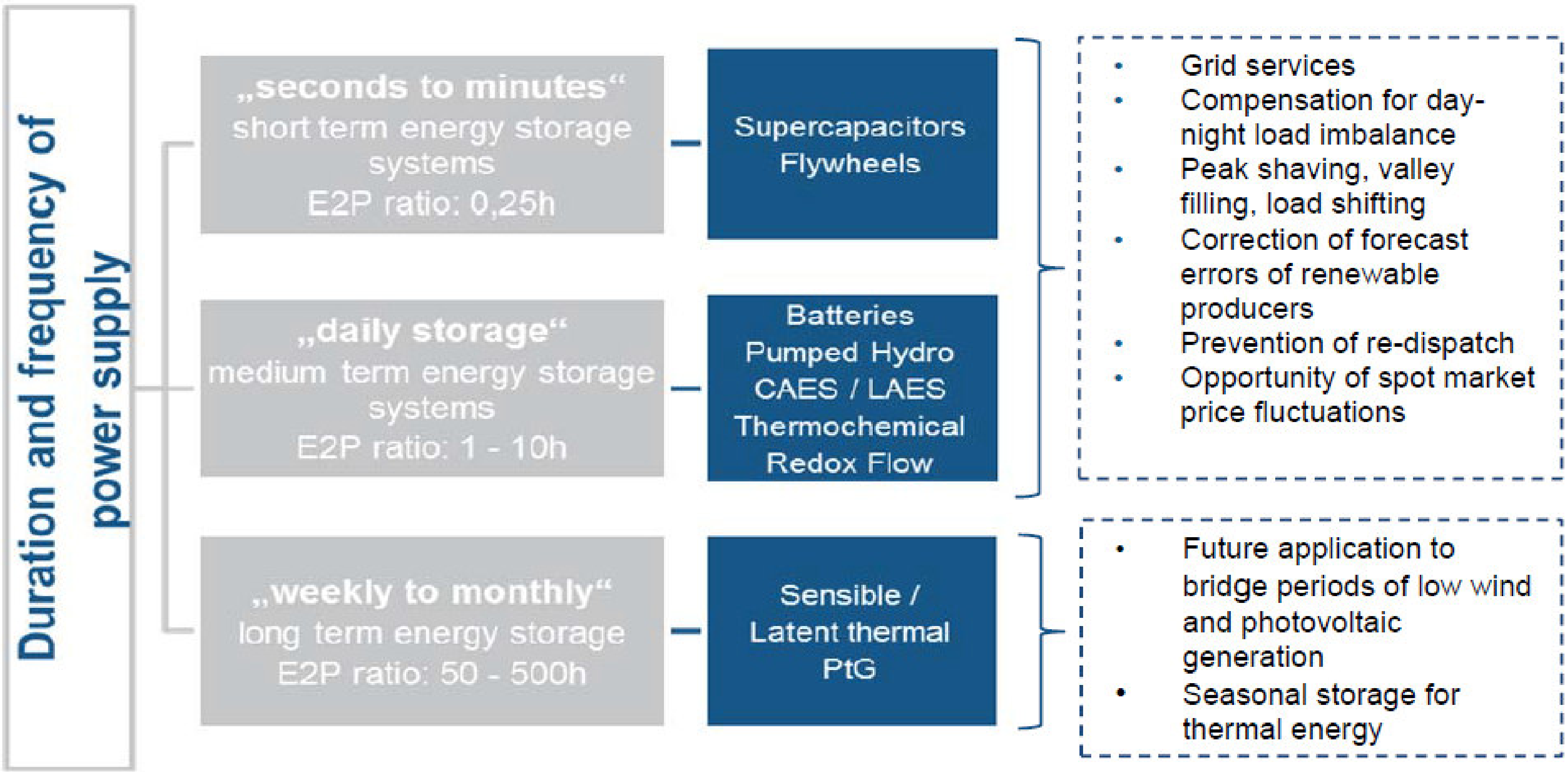
Types & Characteristics

Source: PwC, 2015, following Sterner et al. 2014



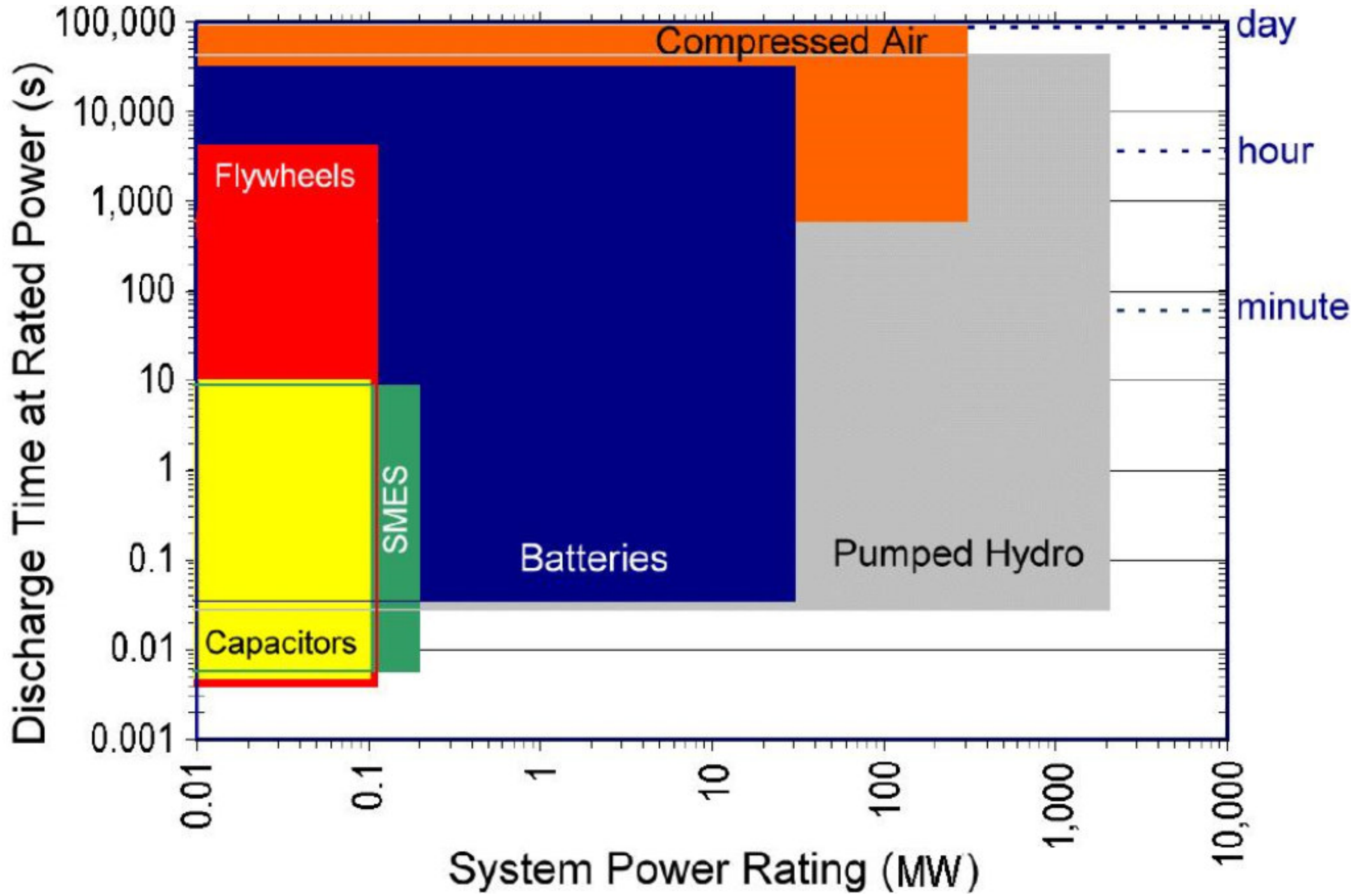
From: **World Energy Resources, WEC, 2016**

Types & Characteristics



From: **World Energy Resources, WEC, 2016**

How to Choose?



From: http://www.climatetechwiki.org/technology/jiqweb-ee

How to Choose?

	SELECTED COMPARATIVE ADVANTAGES	SELECTED COMPARATIVE DISADVANTAGES
COMPRESSED AIR	■ Low cost, flexible sizing, relatively large-scale ■ Mature technology and well-developed design ■ Leverages existing gas turbine technologies	■ Requires suitable geology ■ Relatively difficult to modularize for smaller installations ■ Exposure to natural gas price changes
FLOW BATTERY‡	■ Power and energy profiles highly and independently scalable (for technologies other than zinc-bromine) ■ Designed in fixed modular blocks for system design (for zinc-bromine technology) ■ No degradation in "energy storage capacity"	■ Power and energy rating scaled in a fixed manner for zinc-bromine technology ■ Relatively high balance of system costs ■ Reduced efficiency due to rapid charge/discharge
FLYWHEEL	■ High power density and scalability for short duration technology; low power, higher energy for long-duration technology ■ High depth of discharge capability ■ Compact design with integrated AC motor	■ Relatively low energy capacity ■ High heat generation ■ Sensitive to vibrations
LEAD-ACID‡	■ Mature technology with established recycling infrastructure ■ Advanced lead-acid technologies leverage existing technologies	■ Poor ability to operate in a partially charged state ■ Relatively poor depth of discharge and short lifespan
LITHIUM-ION‡	■ Multiple chemistries available ■ Rapidly expanding manufacturing base leading to cost reductions ■ Efficient power and energy density	■ Remains relatively high cost ■ Safety issues from overheating ■ Requires advanced manufacturing capabilities to achieve high performance
PUMPED HYDRO	■ Mature technology (commercially available; leverages existing hydropower technology) ■ High power capacity solution	■ Relatively low energy density ■ Limited available sites (i.e., water availability required)
SODIUM‡	■ High temperature technology: Relatively mature technology (commercially available); high energy capacity and long duration ■ Low temperature technology: Smaller scale design; emerging technology and low cost potential; safer	■ Although mature, inherently higher costs—low temperature batteries currently have a higher cost with lower efficiency ■ Potential flammability issues for high-temperature batteries
THERMAL	■ Low cost, flexible sizing, relatively large-scale ■ Power and energy ratings independently scalable ■ Leverages mature industrial cryogenic technology base; can utilize waste industrial heat to improve efficiency	■ Technology is pre-commercial ■ Difficult to modularize for smaller installations
ZINC‡	■ Currently quoted as low cost ■ Deep discharge capability	■ Currently unproven commercially ■ Lower efficiency

From: **LAZARD'S LEVELIZED COST OF STORAGE - VERSION2.0, 2016**

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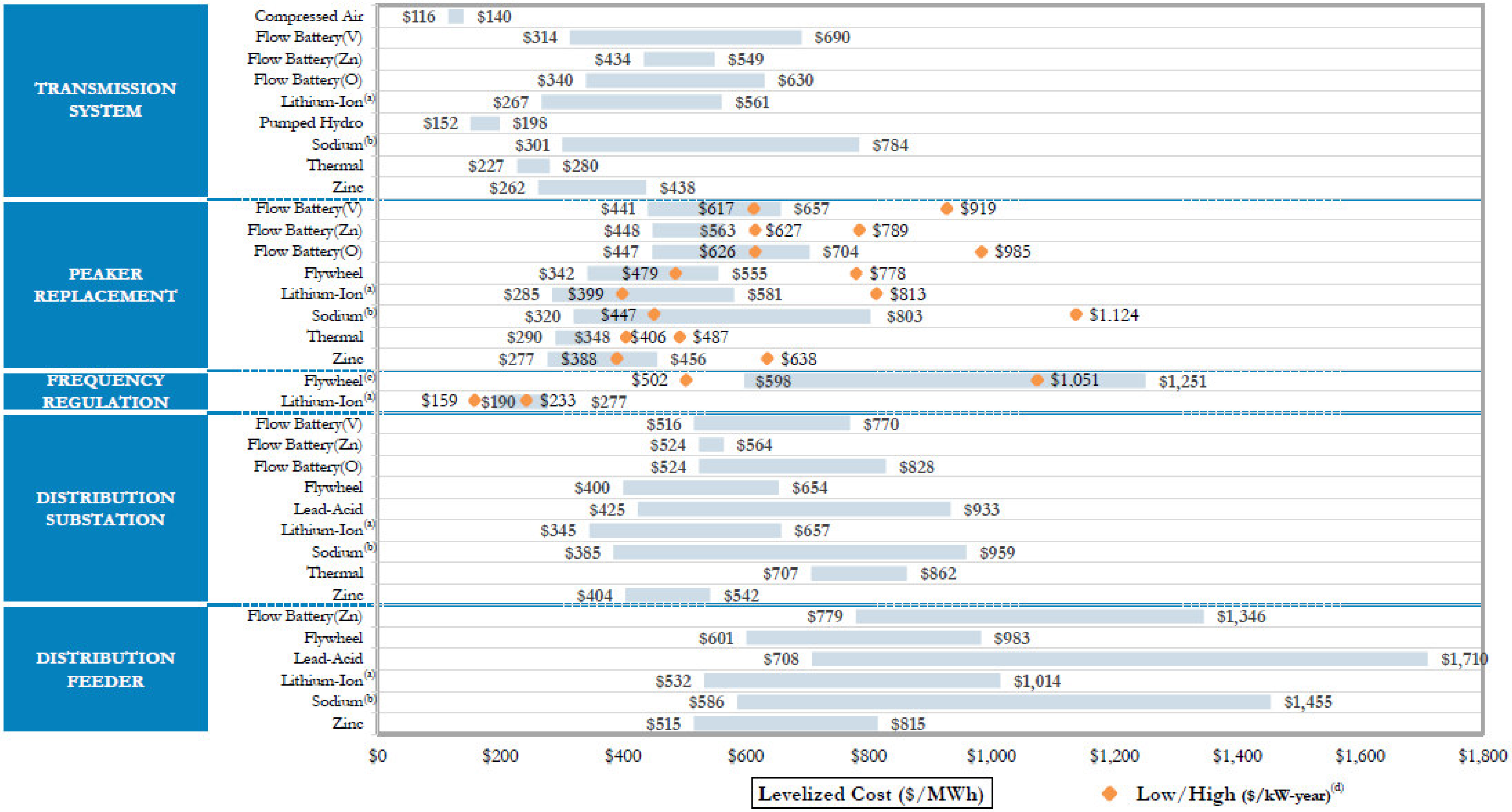
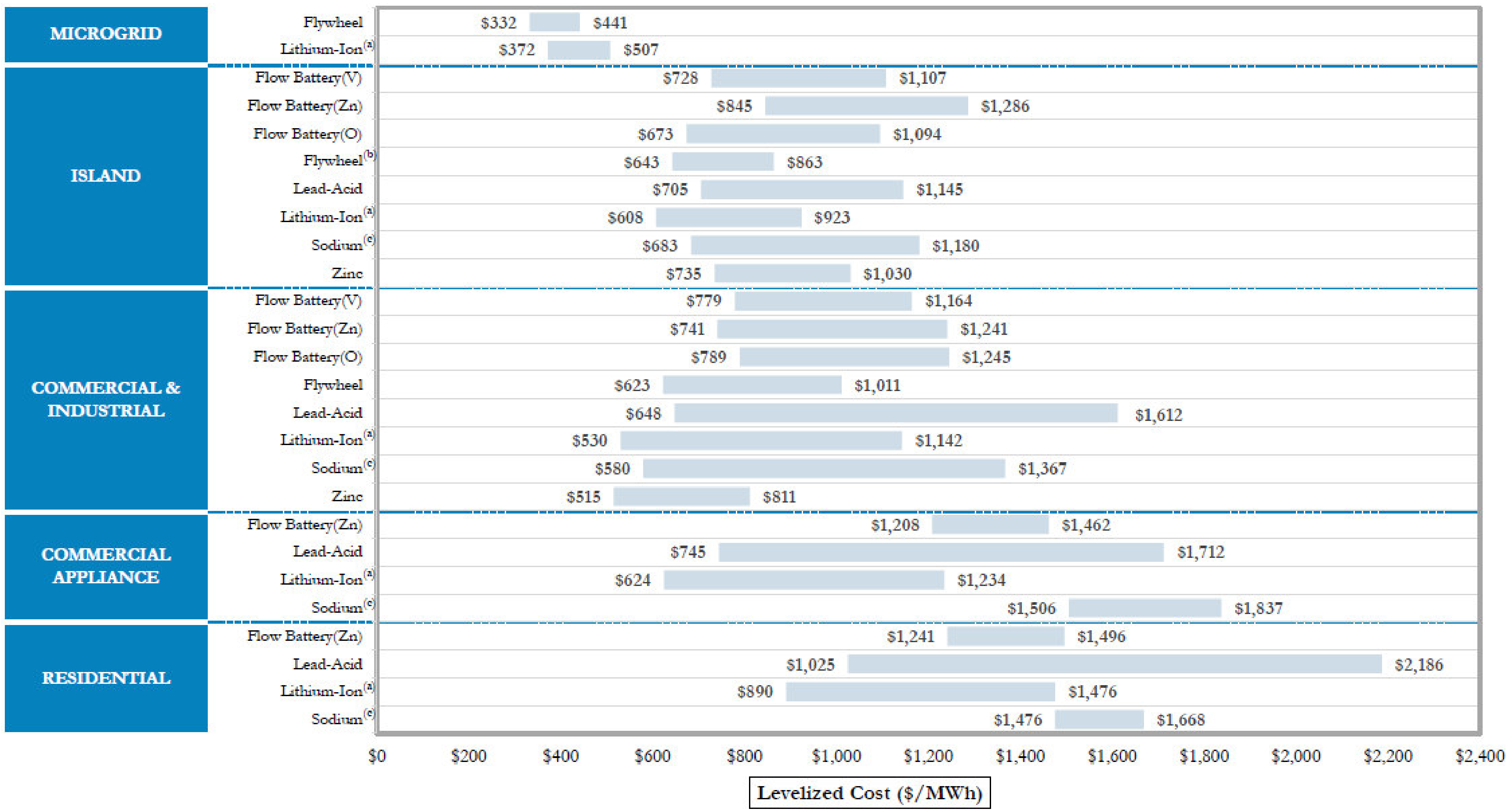
How to Choose?



From: **LAZARD'S LEVELIZED COST OF STORAGE - VERSION2.0, 2016**

ADB 50 YEARS

How to Choose?



From: **LAZARD'S LEVELIZED COST OF STORAGE - VERSION2.0, 2016**

How to Choose? (Example of Developed Country)

Application Rankings for CAISO Market Rules Scenario

Application	Current Market Scenario						
	Li-Ion NCM	Li-Ion LiFePO4	Li-Ion LTO	NaS	VRB	ZnBr	Zinc-air
Electric Energy Time Shift	9	8	8	9	8	8	7
Electric Supply Capacity	9	9	9	9	8	8	7
Regulation	9	9	9	9	8	8	7
Spinning, Non-spin, Supplemental reserves	8	8	9	8	8	8	7
Voltage support	7	8	8	7	6	6	6
Load following / ramping support for renewables	8	8	9	8	8	8	7
Frequency response	7	7	8	7	6	6	5
Transmission and distribution congestion relief	9	9	9	9	9	9	8

From: Battery Energy Storage Study for the 2017 IRP, PacifiCorp, 2016

How to Choose? (Example of Emerging Country)

Estimated Fuel Savings and System Costs of Energy Storage Technologies in Remote Microgrids by Battery Type, World Markets: 3Q 2016

Battery Type	Installed Cost ($/kW)	Est. Annual O&M Cost ($/kW)	Avg. Round-Trip Efficiency	Est. Annual Fuel Savings (L/kW)	Est. Annual Fuel Savings ($/kW)
Flow Battery: Utility-Scale	2,300.2	31.1	70%	1,680	1,831.2
Flow Battery: Distributed	2,874.4	34.5	70%	1,680	1,831.2
Advanced Lead-Acid: Utility-Scale	2,903.5	66.2	80%	1,920	2,092.8
Advanced Lead-Acid: Distributed	3,284.5	66.8	80%	1,920	2,092.8
Lithium Ion: Utility-Scale	2,062.0	47.3	90%	2,040	2,223.6
Lithium Ion: Distributed	2,150.3	50.8	90%	2,040	2,223.6

(Source: Navigant Research)

From: Energy Storage Trends and Opportunities in Emerging Markets, IFC, 2017

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Grid Applications

Production	Transmission	Distribution	Consumption
			
Energy & Power	**High Power**	**Energy & Power**	**Energy**
1 - 10MW	10 – 50 MW	100 Kw – 1MW	5 – 50 kW
Renewables Capacity Firming Smoothing, Shaving	Ancillary Services Frequency Control	Load Management Peak Shaving Voltage Control	Time Shifting Local Energy Management

From: **Energy Storage System: Challenges and Opportunities, CEM, 2014**

Grid Applications

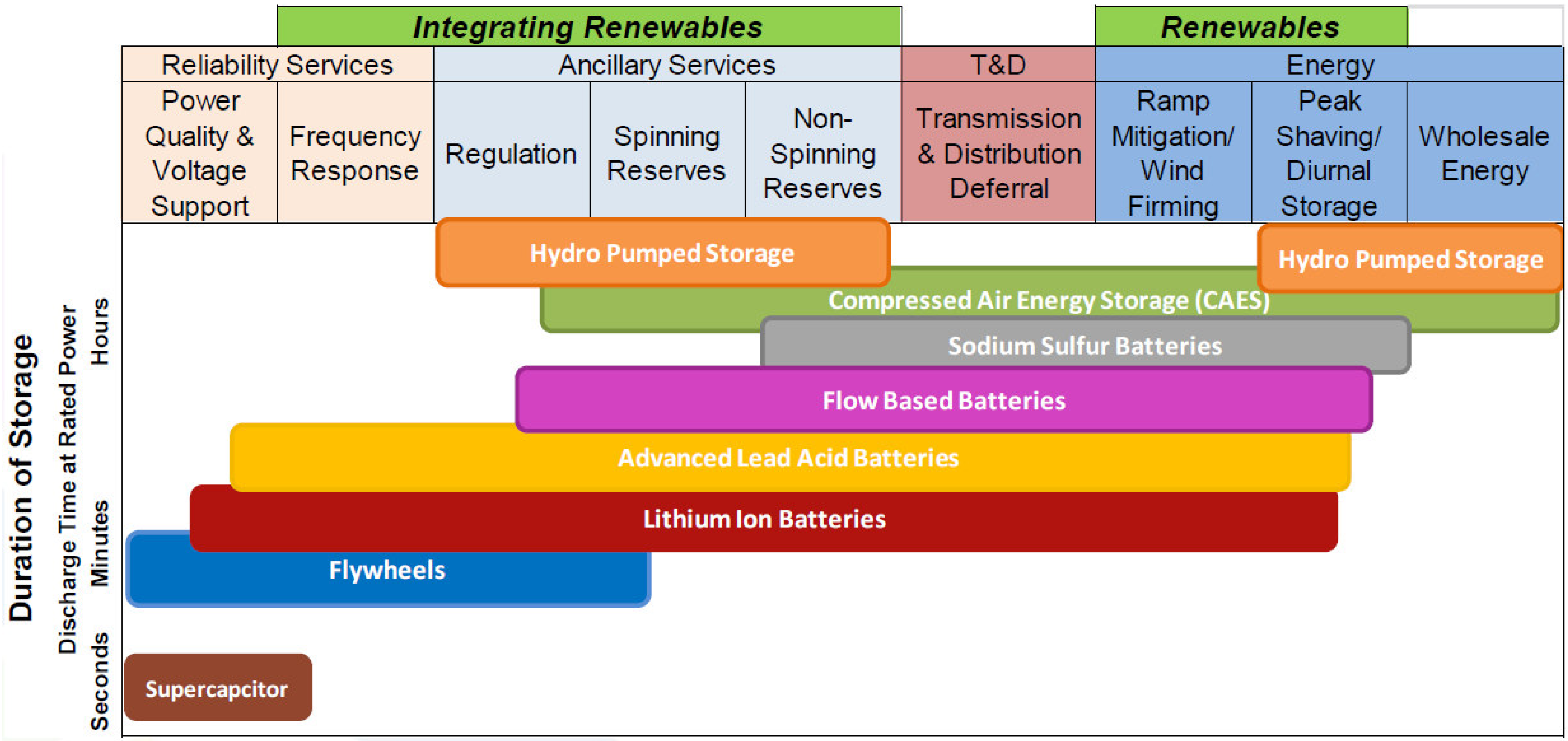


Image from www.google.com

Grid Applications

Characteristics	Use/Duty Cycle	Application
Long Duration/Frequent Discharge	1 cycle/day 250 days/year	Load Levelling Load Following Arbitrage Distribution Deferral
Long Duration/Infrequent Discharge	20 times/year	Capacity Credit
Short Duration/Frequent Discharge	4x15 minutes of cycling 250 days/year	Frequency or Area Regulation
Short Duration/Infrequent Discharge	20 times/year	Power Quality, Monetary Carryover

Application	Storage Support Time
Frequency Regulation	1-5 minutes
Spinning Reserve	15-20 minutes
Distribution Upgrade Deferral	1 - 4 hours
Demand Management	15 minutes – 1 hours
Power Quality	Second to 5 Minutes

Application Examples

❑ Renewable Energy Integration

- **Demonstration for W/T output smoothing**
- **Deployment by ESS specific REC policy for W/T output time shift**

  - (Wind Power) REC 1.0 → (Wind Power + ESS) REC 5.5*

  * REC(Renewable Energy Certificate) : (2015) 5.5, (2016) 5.0, (2017) 4.5

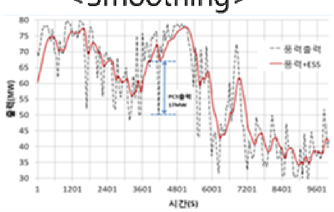
1REC=1MWh

Demonstration

Jochun Substation In Jeju Island

. 4MW/8MWh
. Integration : KEPCO
. PCS : Hyosung
. Battery : Samsung SDI

<Smoothing>

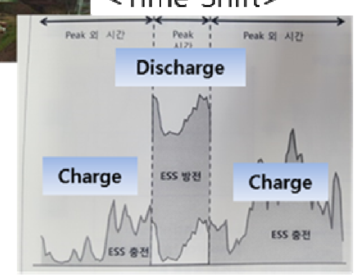


Deployment

- **94MWh installed,**
- **More than 190MWh being planned**

Ex) Youngyang W/T Generation Farm
W/T 60MW, ESS 17MW/51MWh

<Time Shift>



Application Examples

❑ Frequency Regulation

- R&D for Market based FR Service
- KEPCO has been procuring ESS for FR

Demonstration

Demonstration FR Function & Design market structure for FR service

- **KPX**(Korea Power Exchange) - Leading ISO
- **Research Institute** – KERI(Korea Electrotechnology Research Institute)
- **Industry** – LG Chemistry, SK Innovation, LSIS, Hyosung
- **University** – KPU (Korea Polytechnic University)

FR ESS Operation Control Center

8MW 4MWh Li-Ion Battery in Honam Generators

Procurement by KEPCO

Year	2014	2015	2016	2017	Total
MW	52	184	140	124	500
mil USD	570	1,800	1,400	1,240	5,050

Item	Seo-Ansung FR ESS	Shin-Yongin FR ESS
PCS	28MW	24MW
BAT	7MWh(15 Minutes)	12MWh(30 Minutes)
Usage	Primary Frequency Control	Secondary Frequency Control
Panoramic Photograph		

Application Examples

❑ Demand Side Management

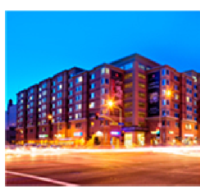
- Demonstration both in domestic and overseas area
- Deployment by Subsidy policy & Self-Promotion among ESS Players

Demonstration	Deployment
✓ 1MW/1MWh for HHI' PV factory	. 55MWh installed by subsidy of 50~75% . More than 50MWh installed at Samsung, LG Group's buildings and factories

Demonstration

✓ 1MW/1MWh for HHI' PV factory

✓ 50kW/110kWh 3sites, commercial building in CA



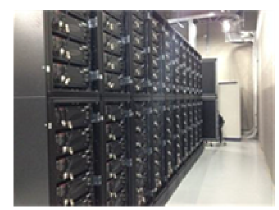
USC

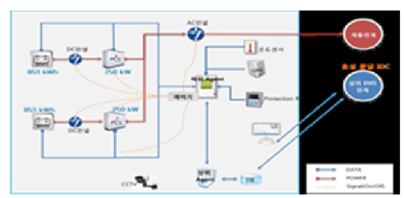
La Kretz Innovation Campus

Deployment

. 55MWh installed by subsidy of 50~75%
. More than 50MWh installed at Samsung, LG Group's buildings and factories

Ex) 0.5MW/1.7MWh for A company's HQ





Application Examples

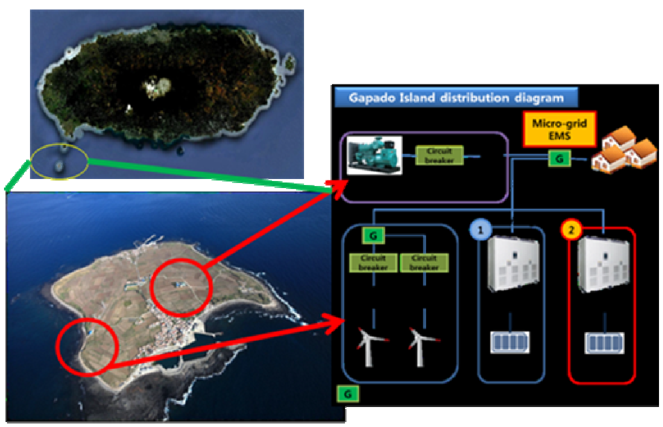
❑ Microgrid

- Demonstration & Deployment for Island Microgrid
- Demonstration for Campus Microgrid

Island Microgrid

- MG : Renewables(W/T and PV) Diesel Gen. + ESS
- 12MWh installed, 40MWh planned

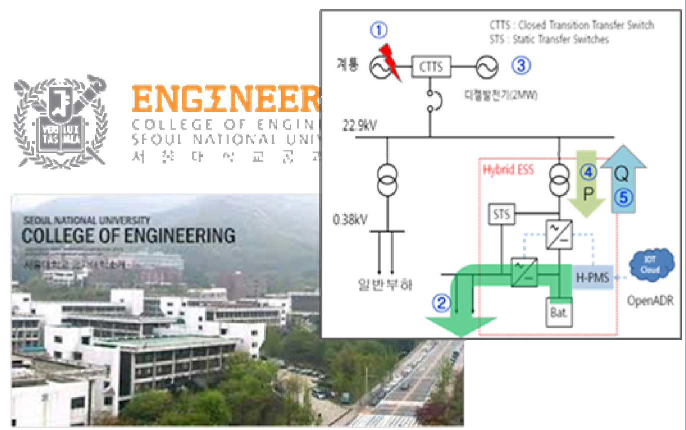
Ex) Gapado 1MW/1MWh ESS included



Campus Microgrid

- Site : Seoul National University Engineering Department Building

ESS : 1MW/1MWh

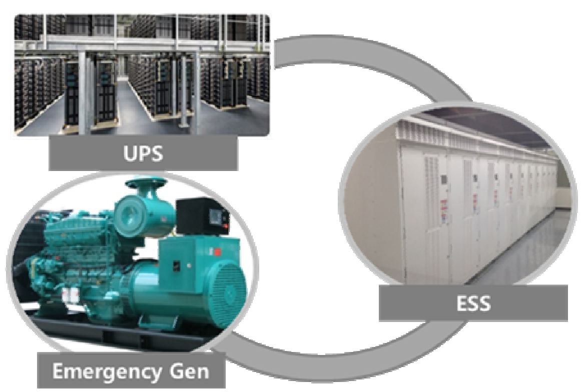


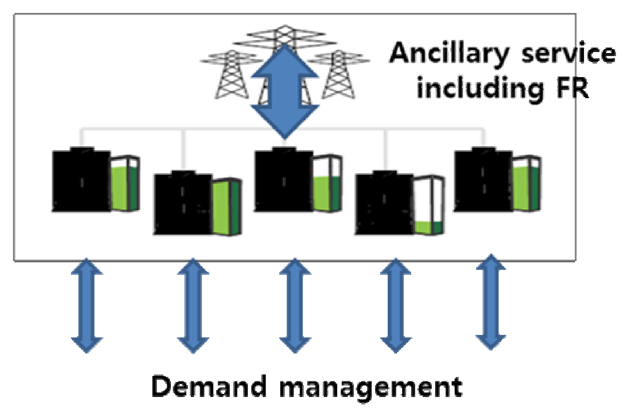
Application Examples

❑ Others

- Demonstration
  . Demand management + UPS or Emergency generator
  . Demand management + Ancillary service

UPS, emergency generator replace by ESS	Ancillary service
. Maximizing revenue stream by multi use . Emergency generation, UPS function . ESS's own function ; demand management ESS : operation power for ESS's own function + reserve for emergency	. Maximizing revenue stream by multi use . Demand management(payback 7years ↑) . FR (payback 3years ↓)





Recommendations

- Develop Policy & Regulation to promote ESS installation in DMCs
  - Valuation and Markets
  - Regulatory Treatment
  - Development Risk
- Consider ESS installation to the Project
  - Generation Project
  - Renewable Energy Project
  - T&D Project
  - Microgrid Project
  - Building EE Project

Thank you