חידושים באגירת חשמל רבת היקף בשיטות אלקטרוכימיות

פרופ' עמנואל פלד

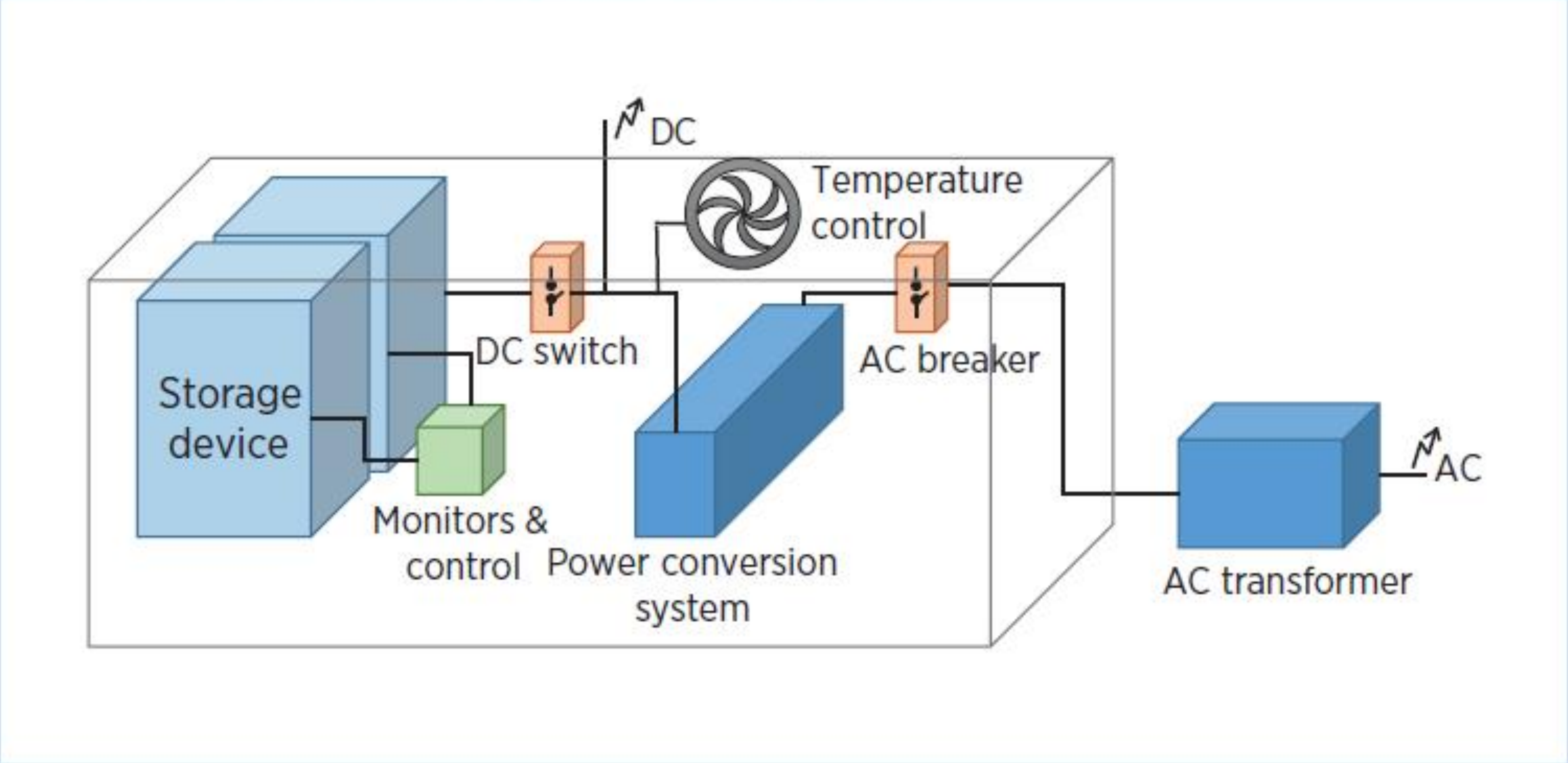
בה"ס לכימיה

אוניברסיטת תל אביב

Potential applications – why storage?

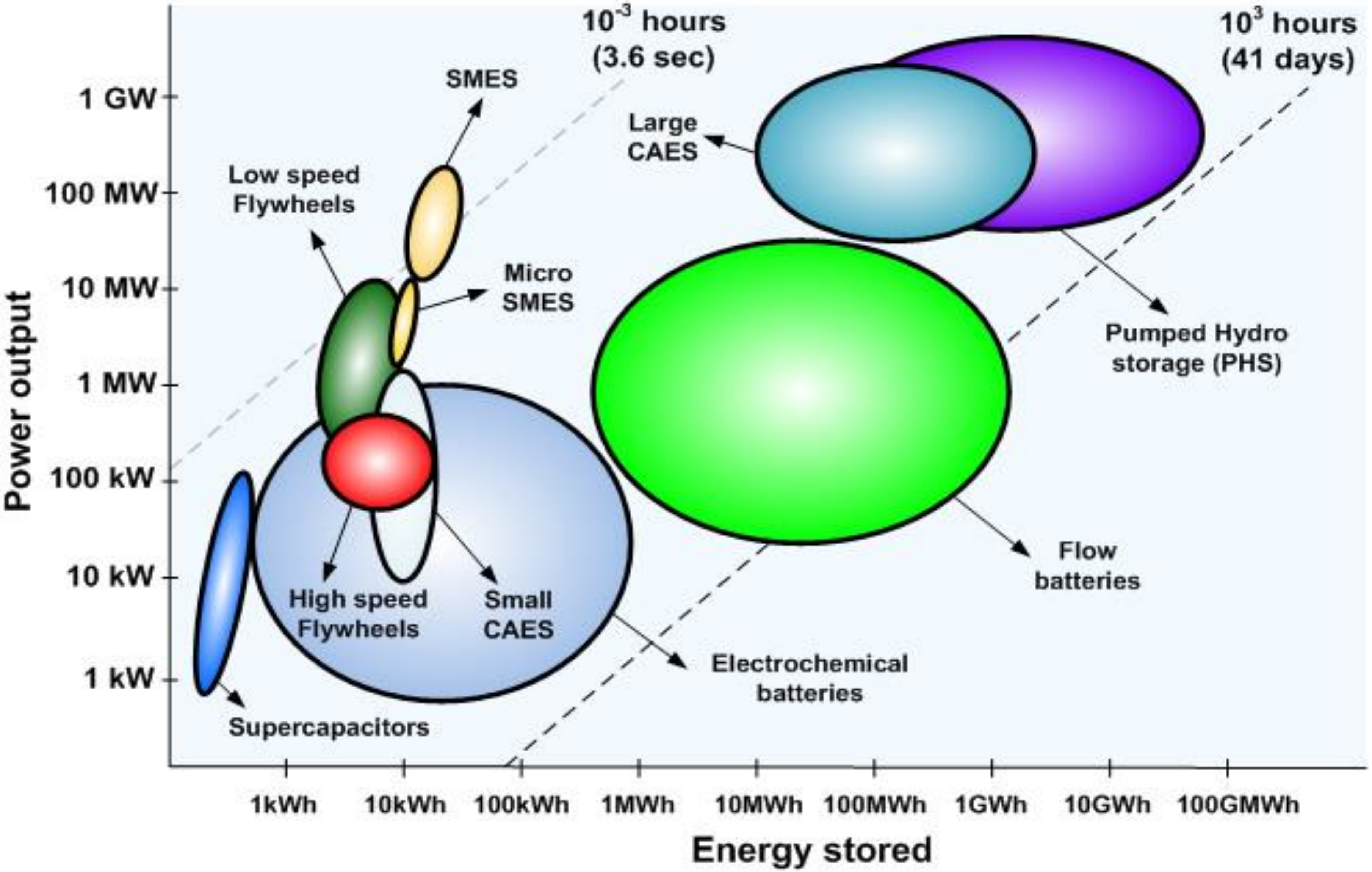
- **<u>Renewable energy applications (Wind & Solar):</u>**
  - **Capacity firming**
  - **Time shifting**
- **<u>Grid Applications:</u>**
  - **Load management / Leveling / peak shaving / Capital deferral & price arbitrage**
  - **Spinning reserve (fast response)**
  - **System stability and voltage regulation**
- **<u>End use applications - Industrial & Telecom:</u>**
  - **UPS & emergency power back-up**
  - **Peak shaving**
  - **Remote Area Power Supply (RAPS)**

Figure 3: Battery storage system and primary power components



Source: Based on EPRI and DOE, 2013

Storage Technologies by Application



Techno-Economic Analysis of Different Energy Storage Technologies

By Hussein Ibrahim and Adrian Ilinca

J. Cho et al. / Progress in Energy and Combustion Science 48 (2015) 84–101

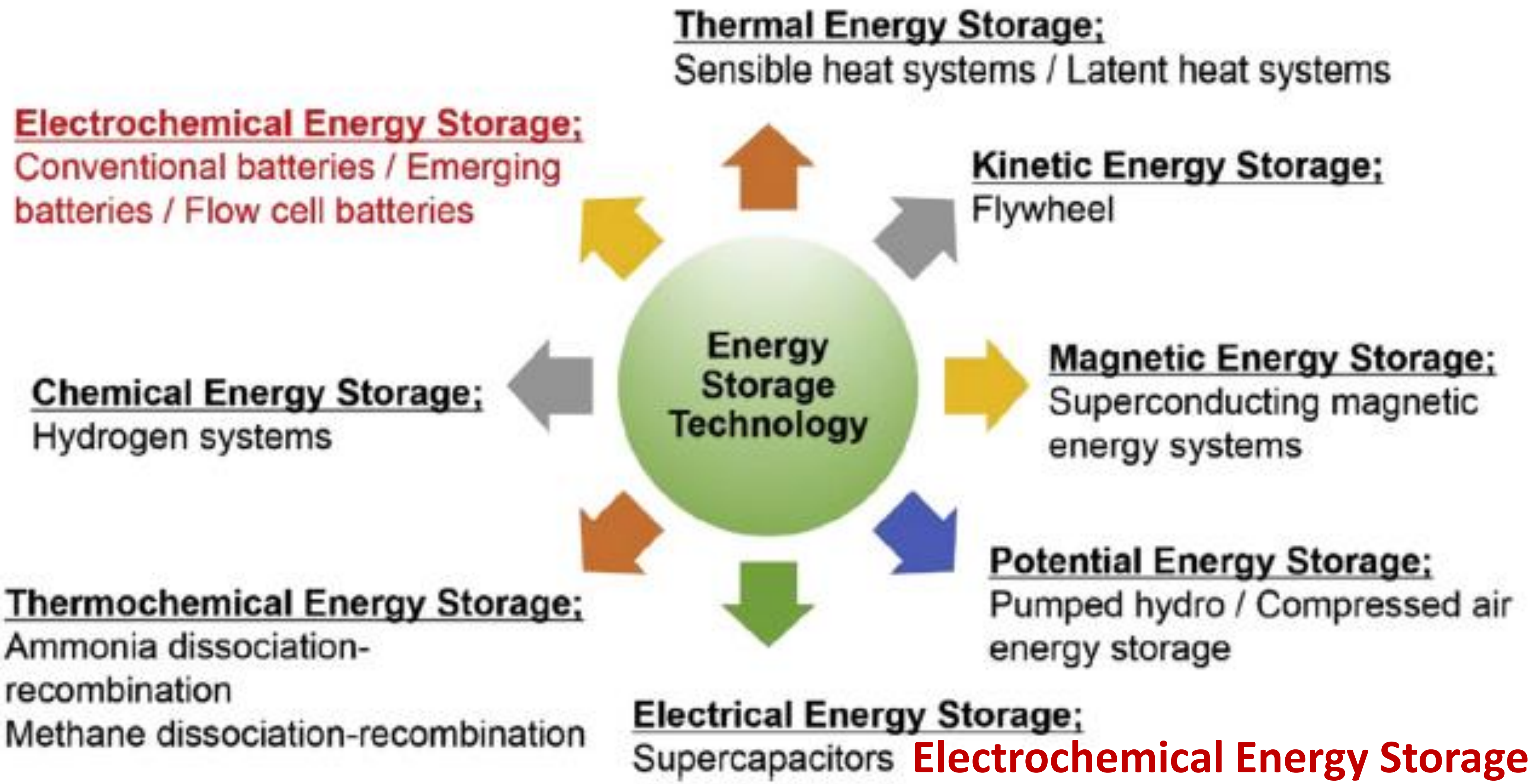


Fig. 2. Classification of electrical energy storage for large scale stationary applications.

פרויקטי מו"פ אגירת אנרגיה ובטריות לרכב חשמלי (בקבוצת המחקר שלי באוניברסיטת תל אביב)

- תא דלק רגנרטיבי (Enstorage)
- בטרית ליתיום גופרית , פרויקט אירופאי (HELIS, HORIZON 2020)
- בטריות ליתיום ונתרן – אויר (לטווח הארוך)
- סופר קבלים מימיים ואל מימיים (מגנט TEPS עם אלביט)
- אנודת ננו חלקיקי סיליקון , מגנט TEPS עם תדיראן) ופרויקט אירופאי (MARS)
- זרזים לתאי דלק (מפא"ת)

סוגים ומחירים של בטריות לאגירת אנרגיה

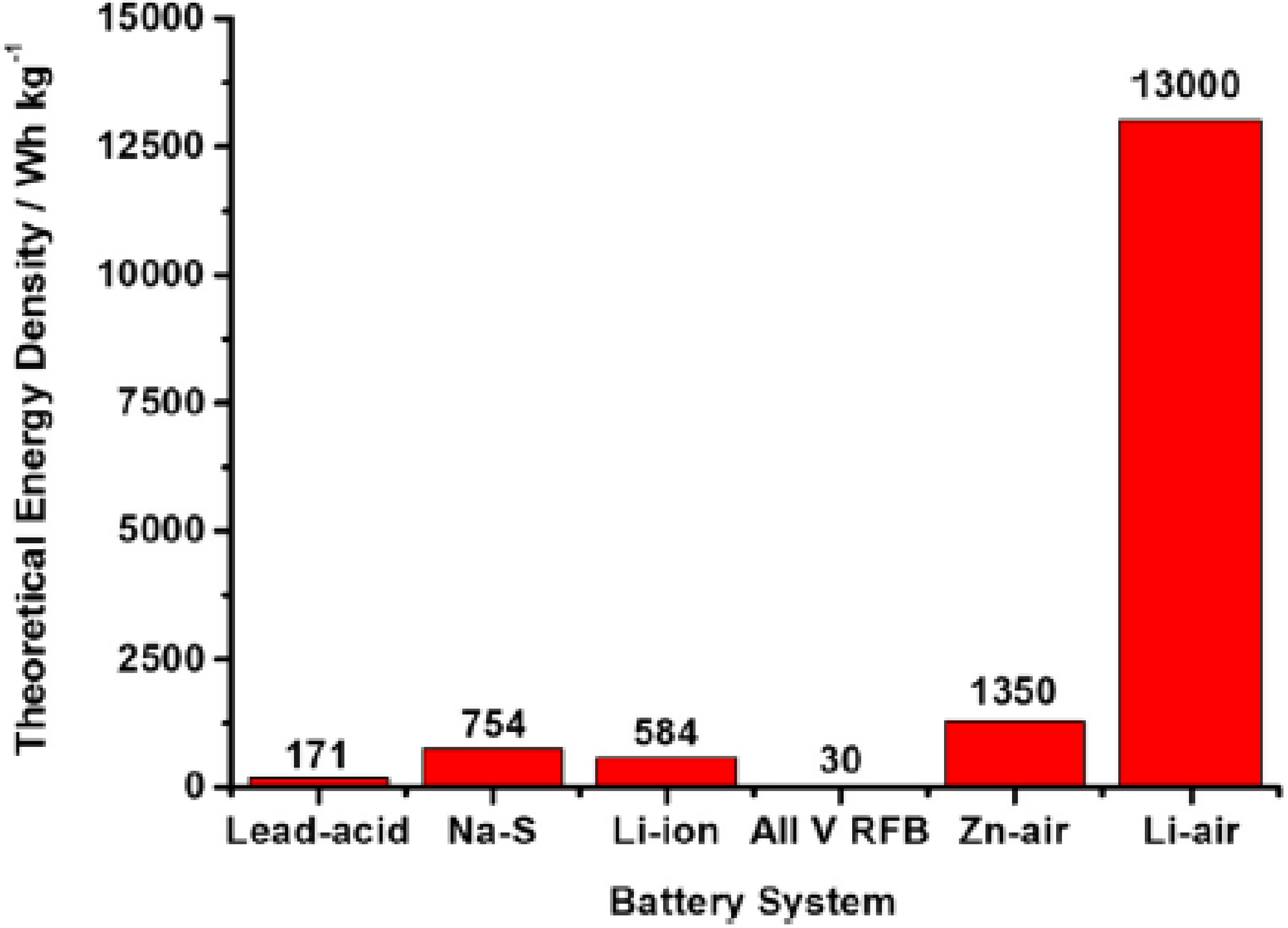
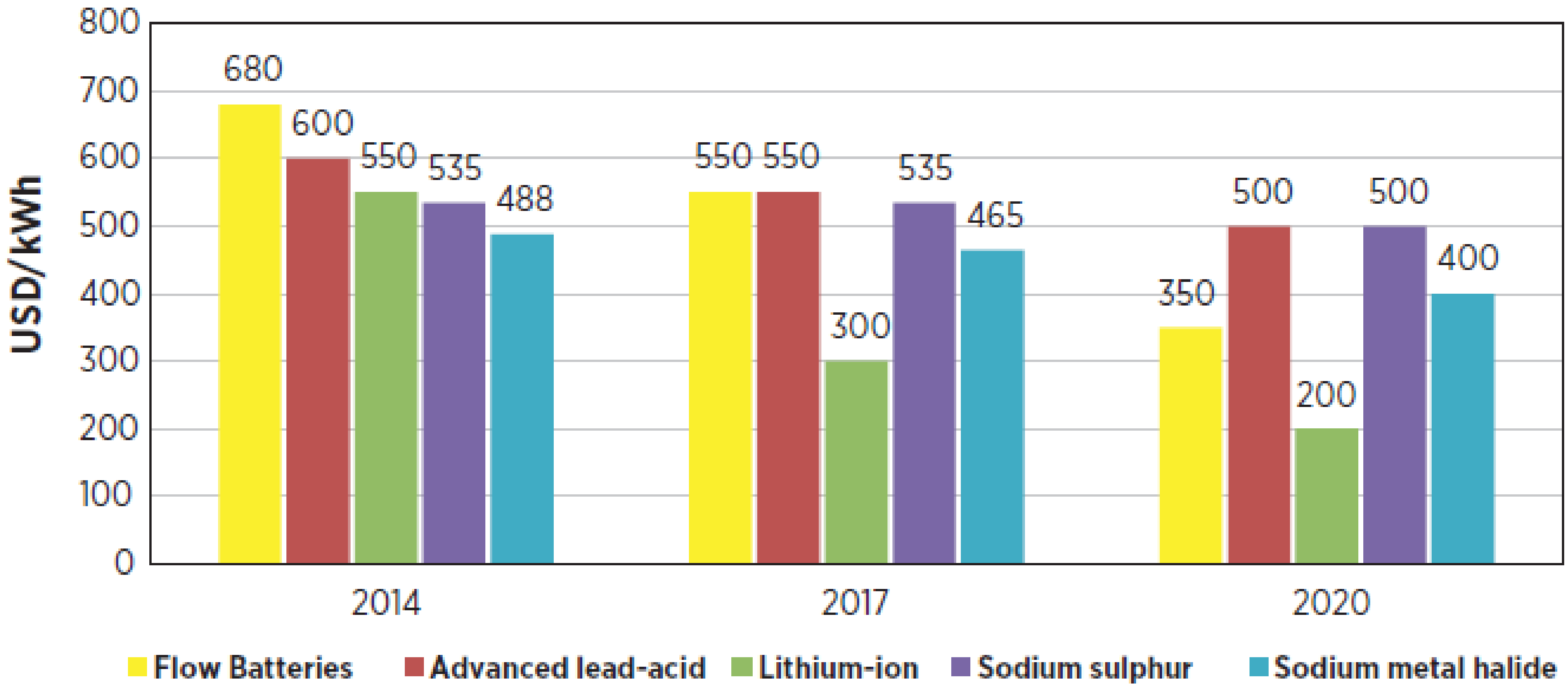


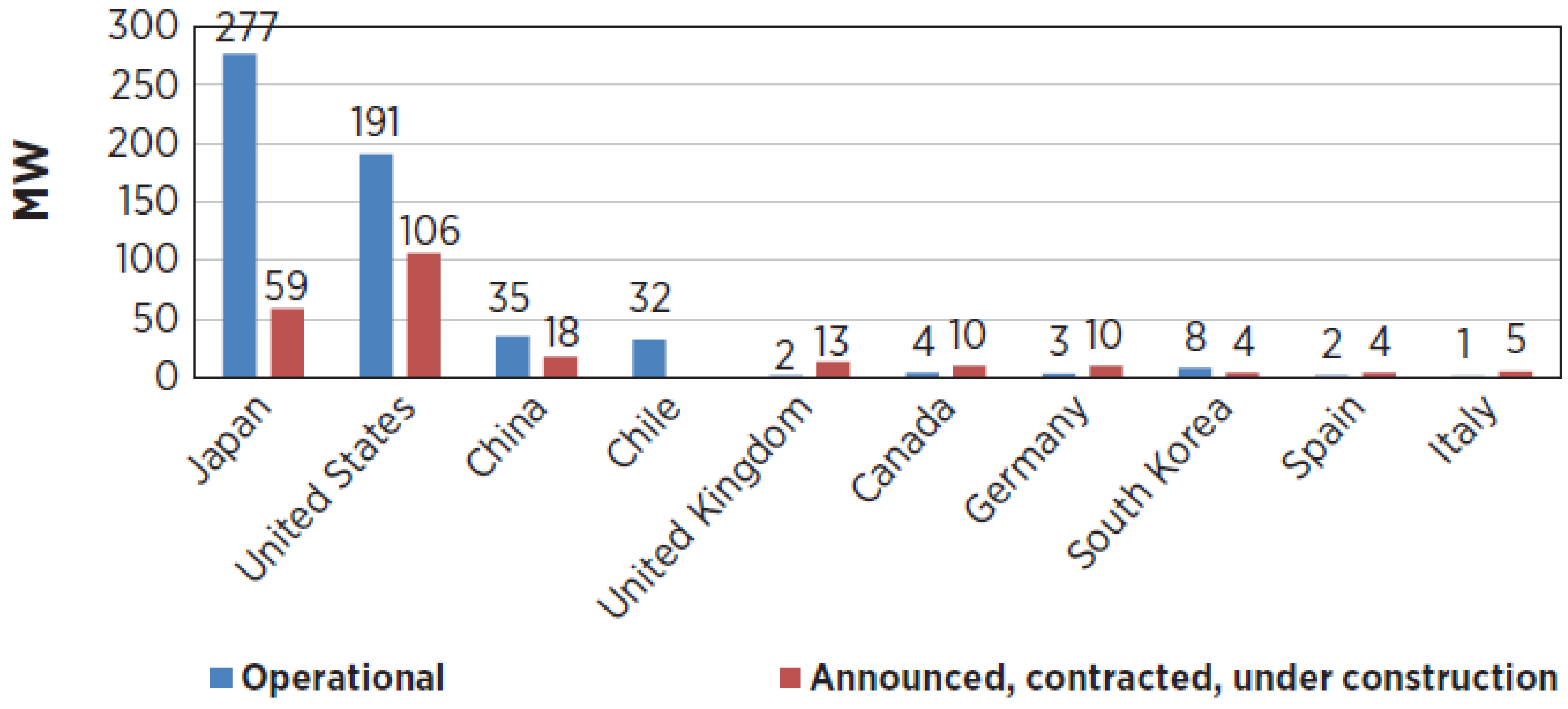
Fig. 10. The comparison of theoretical specific energy density of electrochemical energy storage system [71,156,157].

Figure 20: Lowest current and projected battery cell price by type for utility-scale applications



Source: Navigant Research (Jaffe and Adamson, 2014)

Figure 22: Estimate of operational and planned battery storage (MW) in the power sector by country[14]



Source: Abe, H. (2013), and DOE (2012)

Table 3: Overview of battery storage projects in South Korea

Storage Type	Program/Owner	Capacity	Funding Source
Li-ion Battery ESS	2012 Smartgrid program	0.5	KSGI and End user
Li-ion Battery ESS	2013 Smartgrid program	5	KSGI and End user
Li-ion Battery ESS	2014 Smartgrid program	5	KSGI and End user
Li-ion Battery ESS	KEPCO Frequency regulation	52	KEPCO
Li-ion Battery ESS	Island projects	3	KETEP, KEMCO, Provincial Gov.
Li-ion Battery ESS	Samsung SDI	5.5	Samsung SDI
Li-ion Battery ESS	LG Chem	5	LG Chem
Li-ion Battery ESS	HHI	1	KETEP, HHI, Kokam
Li-ion Battery ESS	LSIS	2	LSIS
Li-ion Battery ESS	KPX FR	8	KETEP, KPX, Hyosung
Li-ion Battery ESS	KEPCO Jochun S/S	4	KETEP, KEPCO, Hyosung, Samsung SDI
Lead-acid	Woojin IS	0.5	Woojin IS
Lead-acid	KERI	0.5	
ETC(Li-ion, Lead-acid)	Jeju Smartgrid Demonstration	5	KSGI and Private
Total battery storage projects		97.0	

Source: ESS Committee of KSGA and Hyosung Corporation

California – storage targets

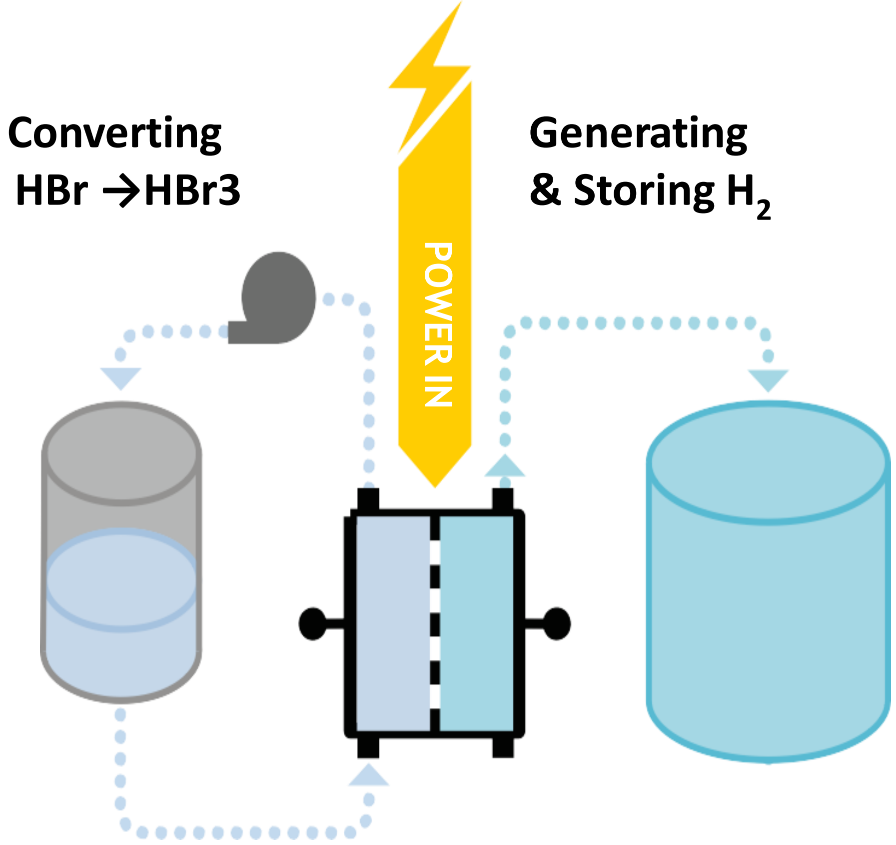
Table 1 – Initial Proposed Energy Storage Procurement Targets (in MW)

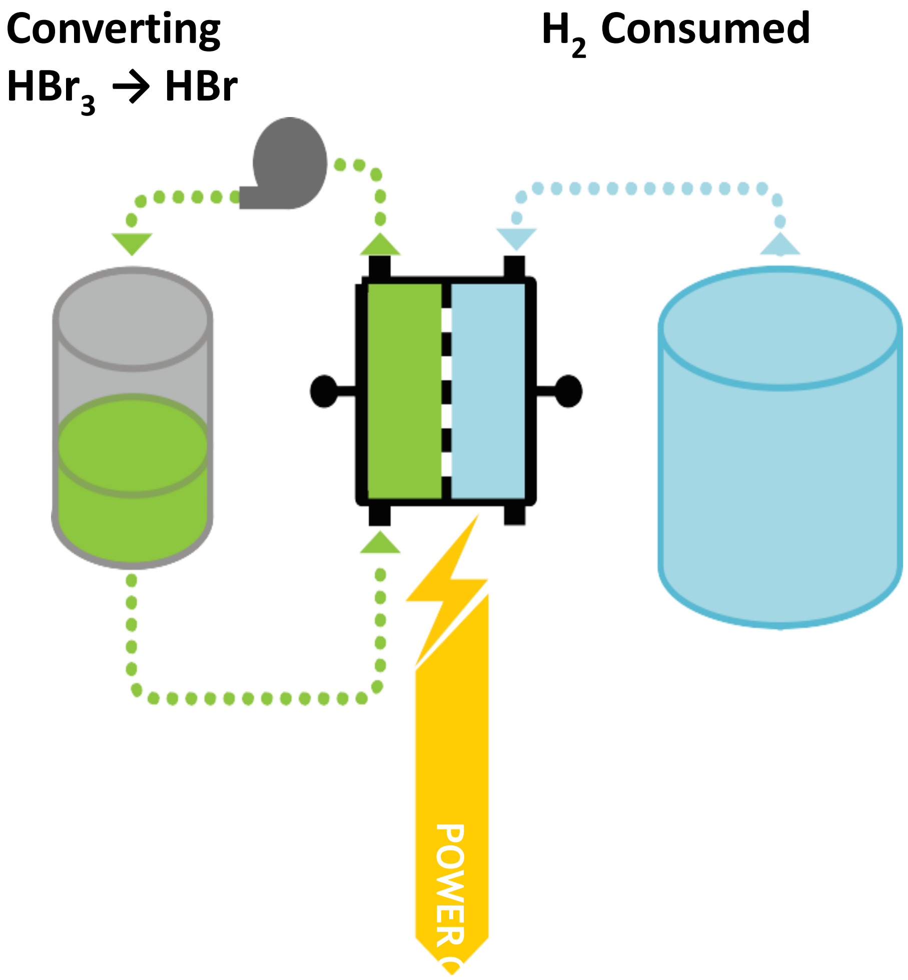
Use case category, by utility	2014	2016	2018	2020	Total
Southern California Edison					
Transmission	50	65	85	110	310
Distribution	30	40	50	65	185
Customer	10	15	25	35	85
Subtotal SCE	**90**	**120**	**160**	**210**	**580**
Pacific Gas and Electric					
Transmission	50	65	85	110	310
Distribution	30	40	50	65	185
Customer	10	15	25	35	85
Subtotal PG&E	**90**	**120**	**160**	**210**	**580**
San Diego Gas & Electric					
Transmission	10	15	22	33	80
Distribution	7	10	15	23	55
Customer	3	5	8	14	30
Subtotal SDG&E	**20**	**30**	**45**	**70**	**165**
Total - all 3 utilities	**200**	**270**	**365**	**490**	**1,325**

EnStorage

EnStorage ESS system

- **Totally sealed system**
- **No emissions or solid waste**
- **Infinite electrolyte life**





Systems in construction (150 kW for four to six hours)

- EU: EnStorage is developing and deploying its system with AREVA and Schneider Electric – The FlowBox Project
- US: EnStorage has partnered with O'Brien & Gere to manufacture and scale up its system

תודה על ההקשבה

In 2050, wind generation variation ratios between 10 and 30% correspond to necessary storage capacities from 40 to 100GW. Because 33GW of energy storage capacity already exists in WEU, mainly in the form of pumped hydro capacity, new storage capacity of 7–67GW will be required to mitigate net power variations due to variable renewables through 2050.

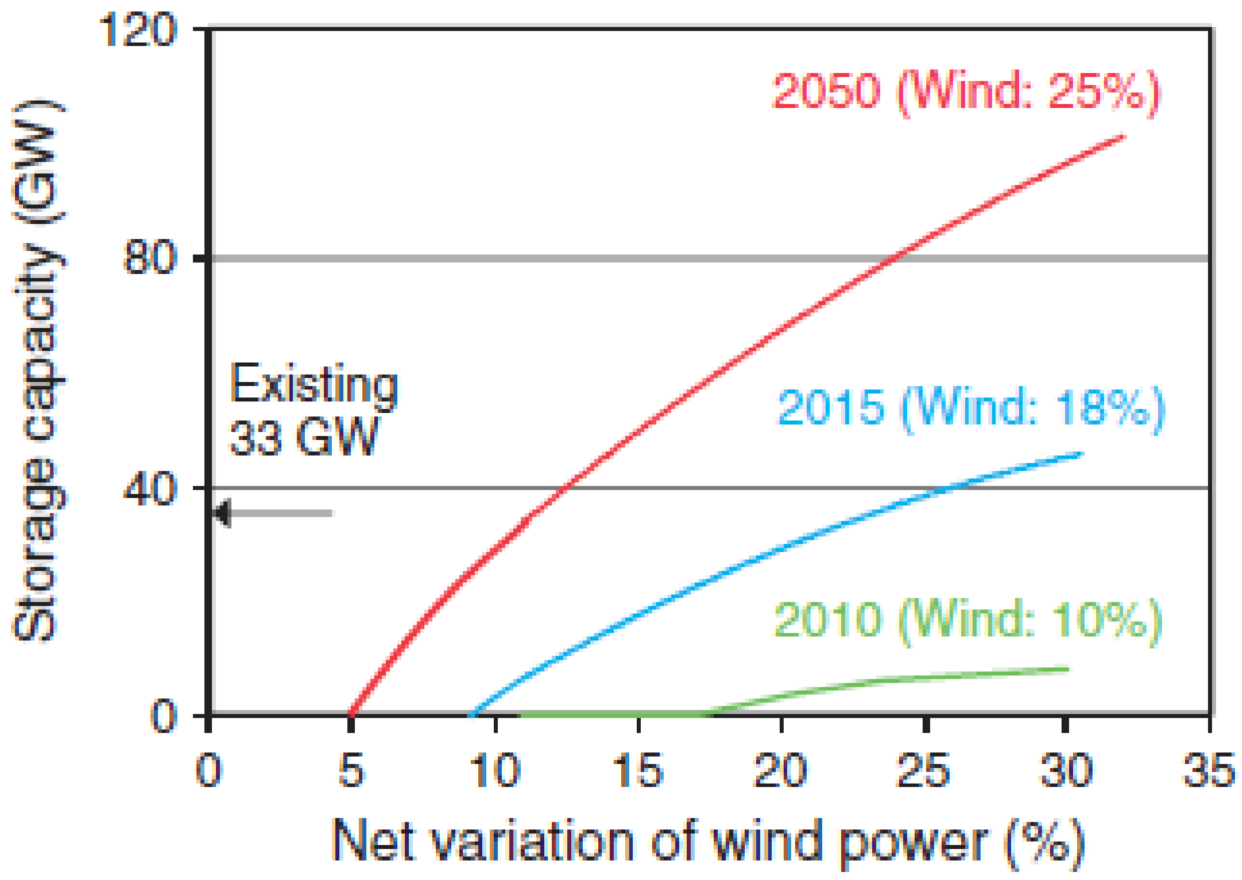


FIGURE 17 | Relationship between net wind power variation and necessary storage capacities.[8] (Reproduced with permission from Ref 8. Copyright 2009, IEA)

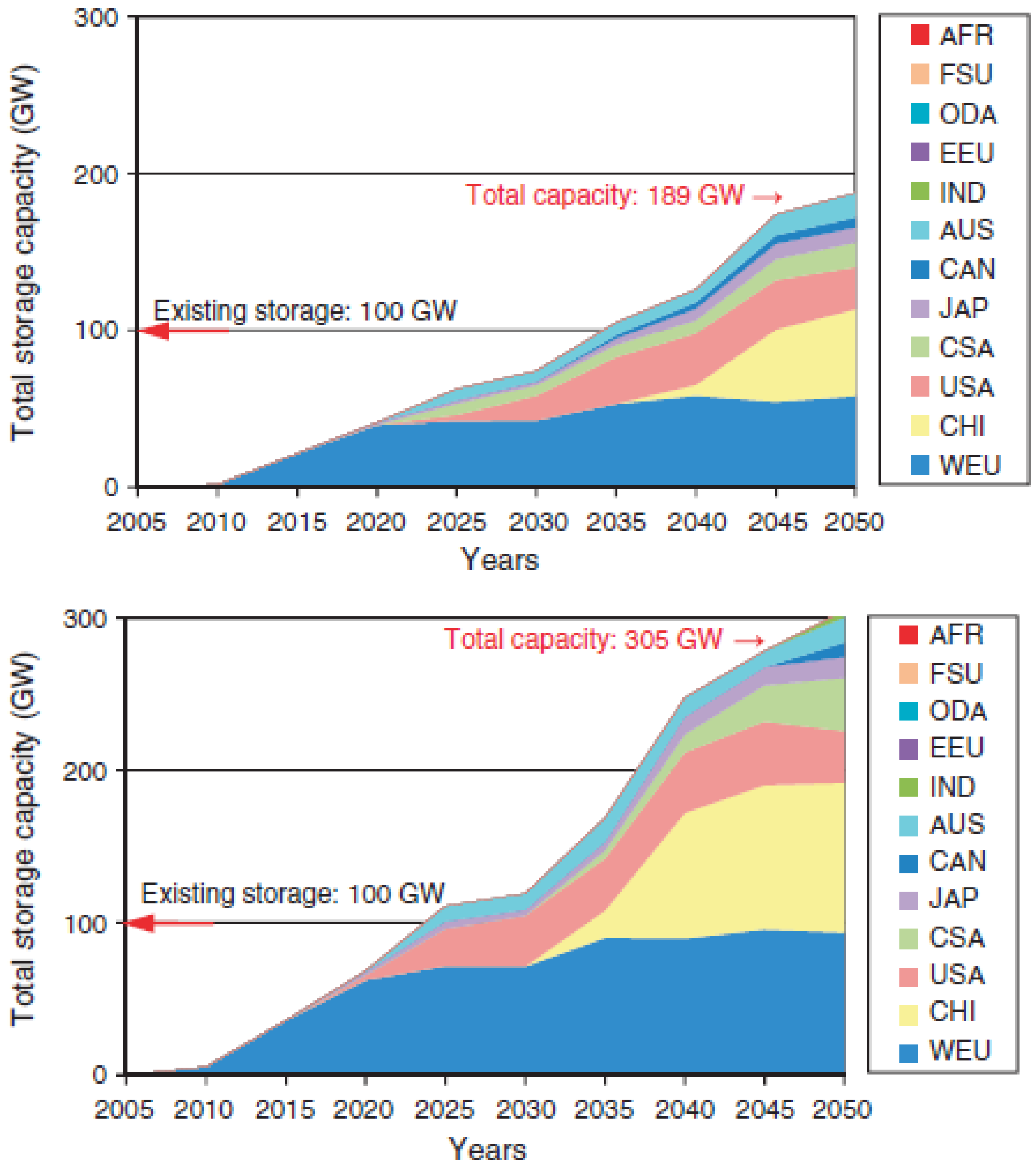


FIGURE 18 | Growth of necessary energy storage capacity worldwide during 2010–2050, with net variation ratios of 15% (top) and 30% (bottom).[8] WEU, Western Europe; CHI, China; USA, United States; CSA, Central and South America; JAP, Japan; CAN, Canada; AUS, Australia; IND, India; EEU, Eastern Europe; ODA, Other Developing Asia; FSU, Former Soviet Union; AFR, Africa. (Reproduced with permission from Ref 8. Copyright 2009, IEA)

Table 2
The chemistry and characteristics of developed electrochemical energy storage system. Ref. [18,156].

Battery system	Redox reaction		Cell voltage (V)	Energy Efficiency (%)	Lifetime (yrs.)	Cycle life (yrs.)	Energy and power density		Energy and power cost		Limitation
	Positive electrode	Negative electrode					Wh/kg	W/kg	$/kWh	S/kW	
Lead-acid	PbO_2	Pb	2.1	>70%	3–12	500–1000	30–50	75–300	200–400	300–600	Limited cycle-life/toxicity of Pb/High cost
Na–S	S	Na	~2	75–90	5–15	2500	150–240	150–230	300–500	1000–3000	Safety/high operating temperature
Li-ion	$LiCoO_2$	C_6	~3.7	85–98	5–15	1000–10,000	75–200	150–315	500–2500	175–4000	High energy cost/safety
Redox flow (all V)	V^{4+}/V^{5+}	V^{2+}/V^{3+}	1.26	75–85	10	12,000	10–30	–	150–1000	600–1500	Low energy density/leak current/corrosion/high cost

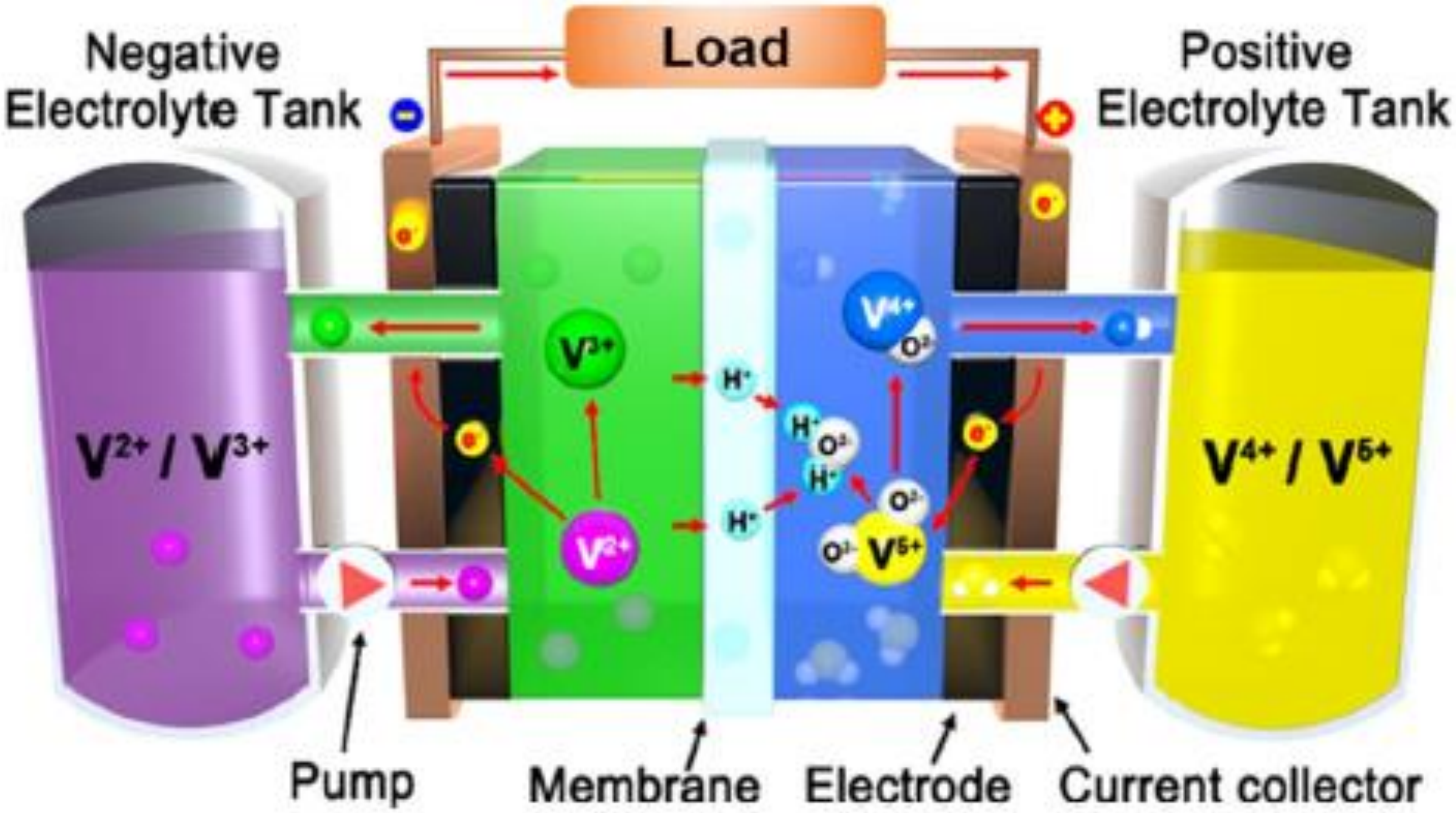


Fig. 9. Schematic view of all vanadium redox flow battery during discharge. Redrawn based on Ref. [83].

Figure 4: Important considerations for battery selection

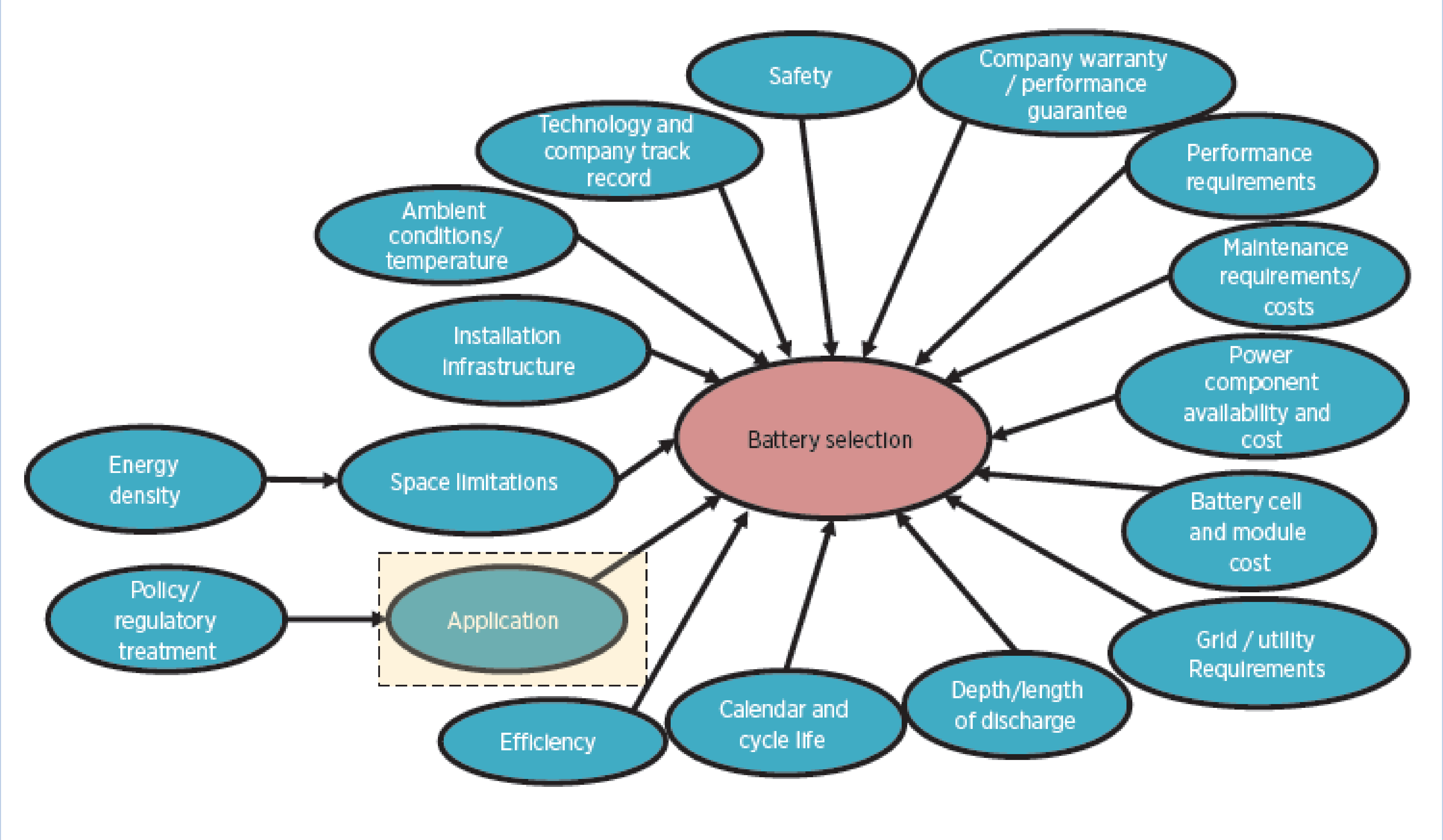
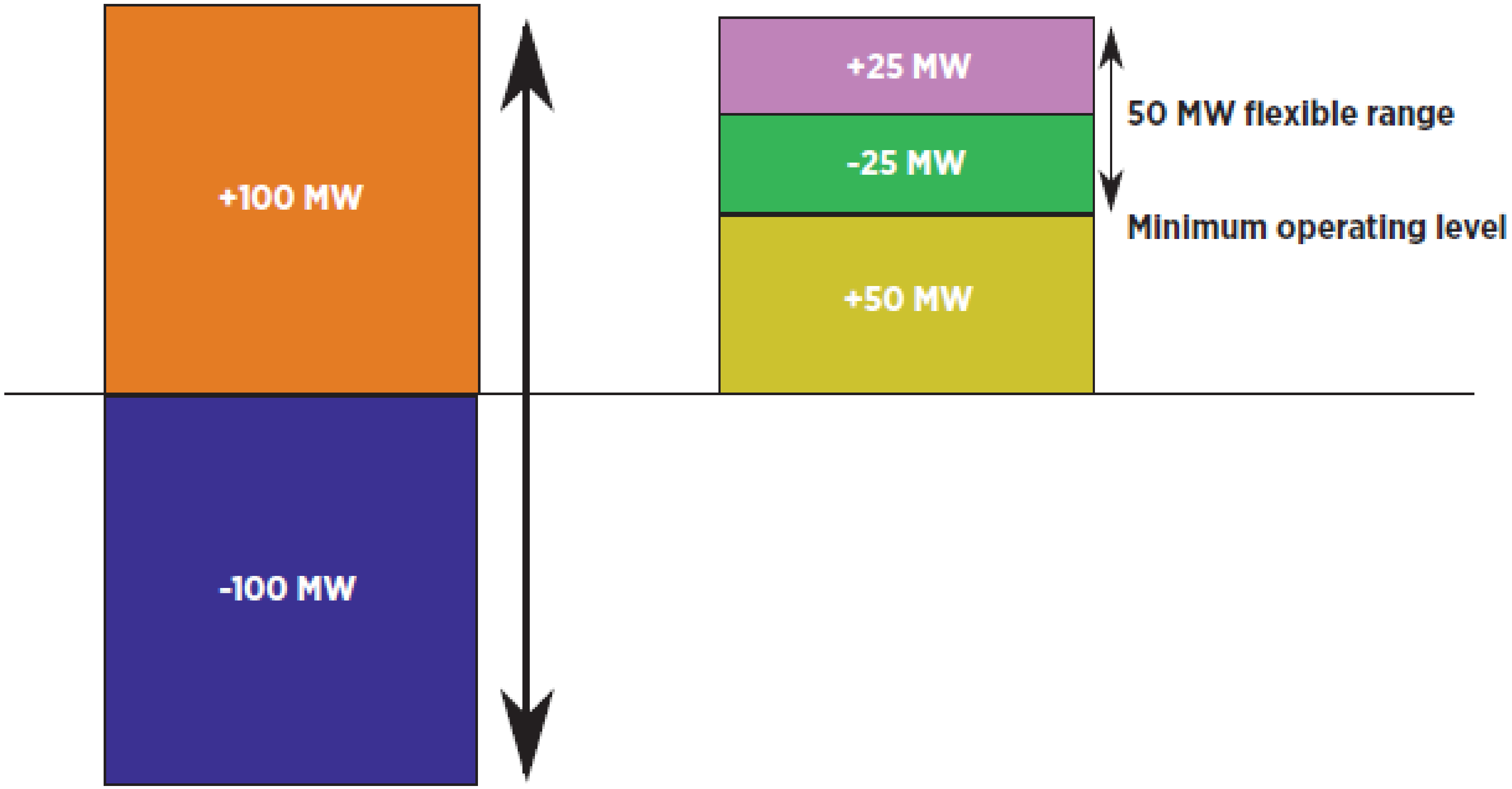


Figure 13: 100 MW Battery storage (left) versus 100 MW gas turbine (right)



Source: Vassallo, A. (2013)

Annex A, Table 1: Lithium-ion subcategory characteristics

	Cathode	Anode	Electrolyte	Energy density	Cycle life	2014 price per kWh	Prominent manufacturers
Lithium iron phosphate	LFP	Graphite	Lithium carbonate	85-105 Wh/kg	200-2000	USD550-USD850	A123 Systems, BYD, Amperex, Lishen
Lithium manganese spinel	LMO	Graphite	Lithium carbonate	140-180 Wh/kg	800-2000	USD450-USD700	LG Chem, AESC, Samsung SDI
Lithium titanate	LMO	LTO	Lithium carbonate	80-95 Wh/kg	2000-25000	USD900-USD2,200	ATL, Toshiba, Le-clanché, Microvast
Lithium cobalt oxide	LCO	Graphite	Lithium polymer	140-200 Wh/kg	300-800	USD250-USD500	Samsung SDI, BYD, LG Chem, Panasonic, ATL, Lishen
Lithium nickel cobalt aluminum	NCA	Graphite	Lithium carbonate	120-160 Wh/kg	800-5000	USD240-USD380	Panasonic, Samsung SDI
Lithium nickel manganese cobalt	NMC	Graph-ite, silicon	Lithium carbonate	120-140 Wh/kg	800-2000	USD550-USD750	Johnson Controls, Saft

Source: Based on Jaffe, S. and Adamson, K.A. (2014)

25 Energy density of about 120 Wh/kg for lithium-ion compared to 35 Wh/kg energy density for lead-acid.

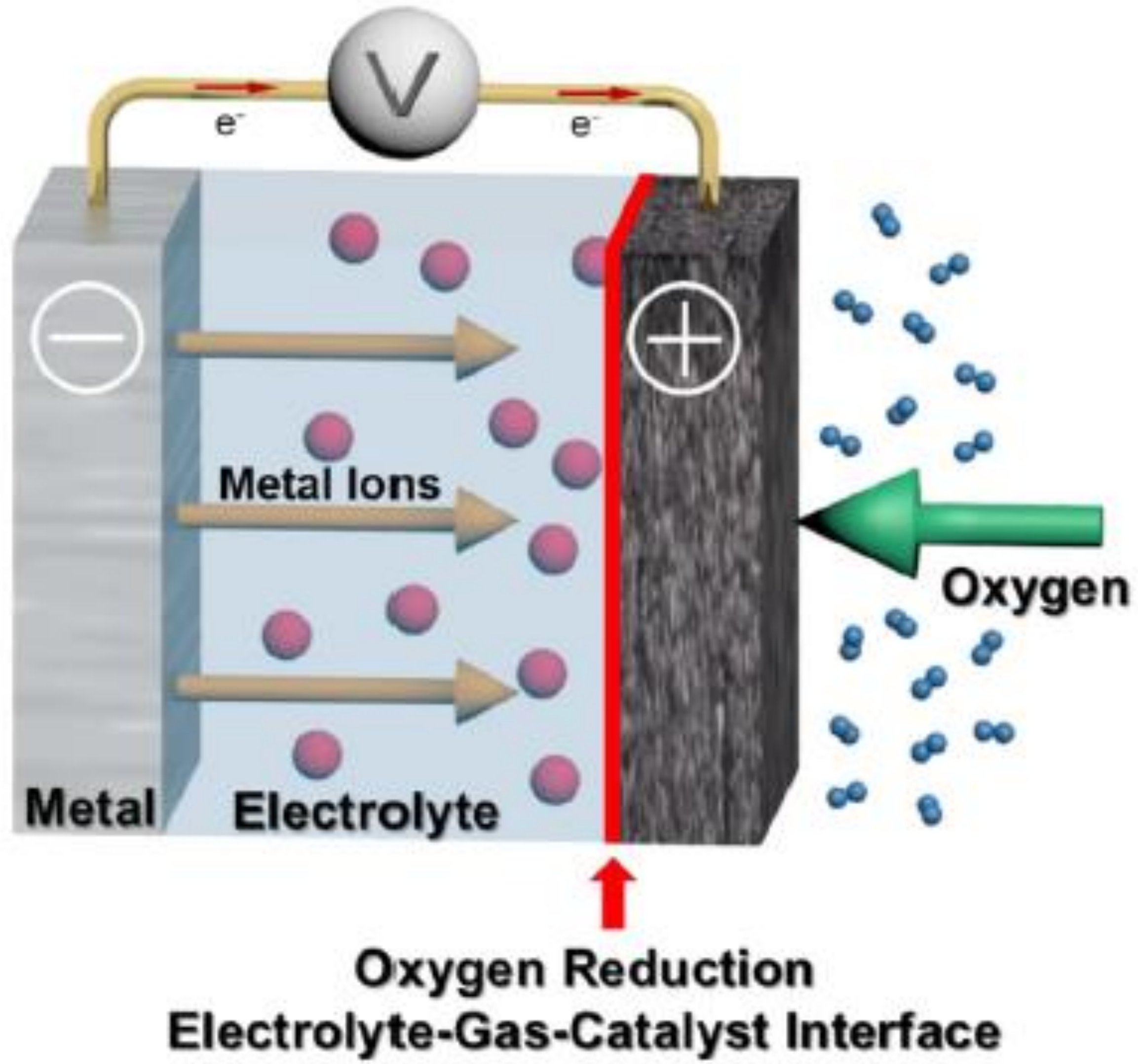


Fig. 11. The general description of metal-air battery system with oxygen reduction reaction phase. Redrawn based on Ref. [158].

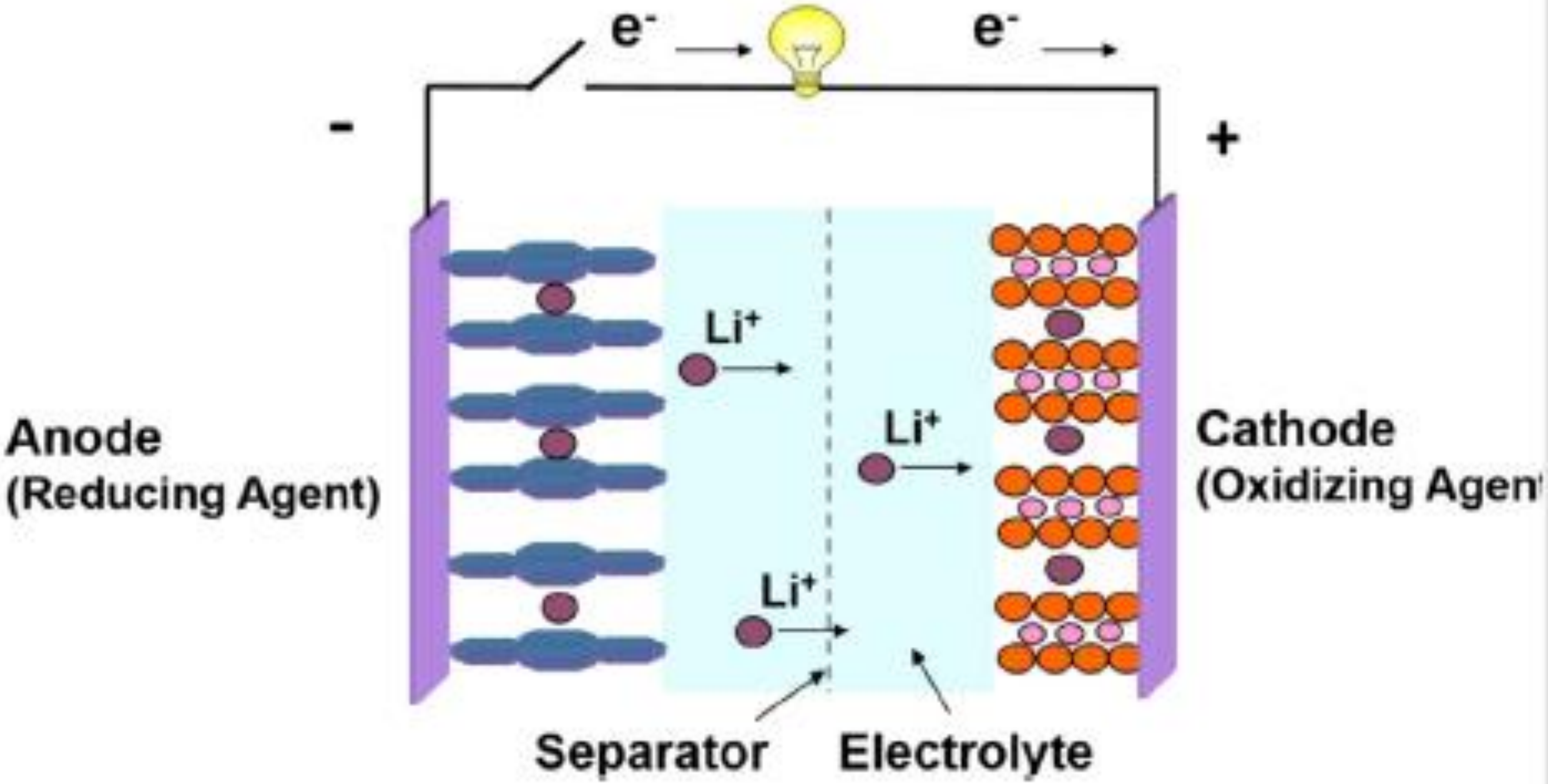


Fig. 8. The schematic view of Li-ion battery consisting of intercalation compoun
during discharge.

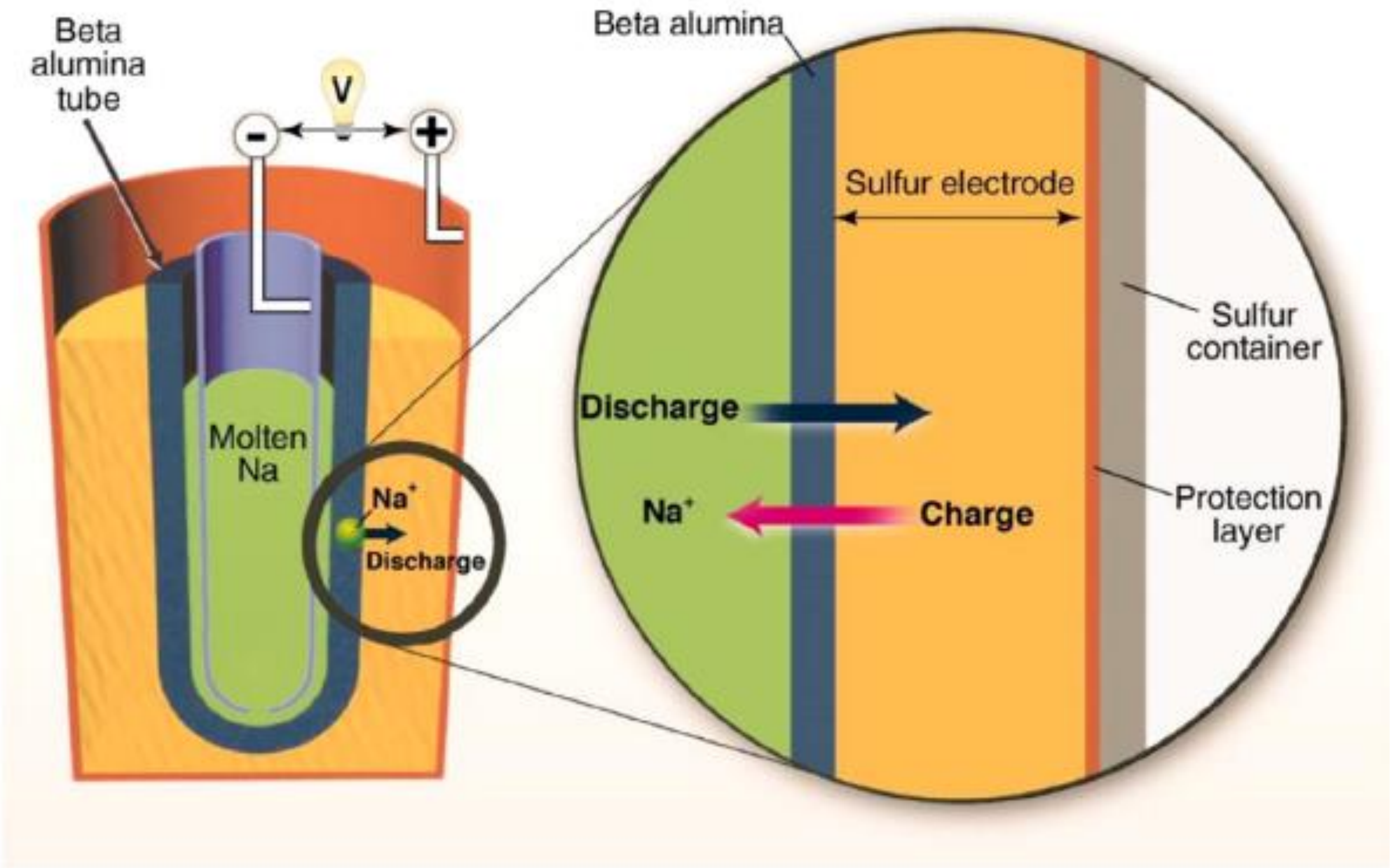


Fig. 7. Schematic illustration of tubular Na–S battery with the detailed structure. Reprinted from Ref. [9] with permiss