Electrical energy storage technologies and the built environment

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Introduction

Considering the large introduction of renewable energy sources in the built environment in the following years, electricity storage will play a double role. On one hand, it will enable renewable energy to be captured and stored for later use, without wasting extra amounts of resources for electricity generation. On the other hand, it can also serve as a valuable tool that will provide the needed flexibility in energy supply, by blurring the gap between supply and demand [1-3]. Given the attempts currently being made towards the reduction of CO_2 emissions around the globe, electrical energy storage (EES) technologies, along with renewable energy technologies, are expected to be a necessary element of the built environment in the future [1, 3, 4-8].

With growing concerns about the environmental impacts of the electricity sector, the EES market is developing quite rapidly and the performance characteristics of the technologies are constantly improving. Hence, the aim of this study is to gather the most recent findings in the field and analyse their relation to the integration of EES systems in the built environment.

The currently available types of EES technologies exhibit a broad range of performances and capacities to match different application environments and EES scales. The requirements concerning power, energy and discharge times are very different and are presented on the right.

Power, energy and discharge time of EES systems in the future

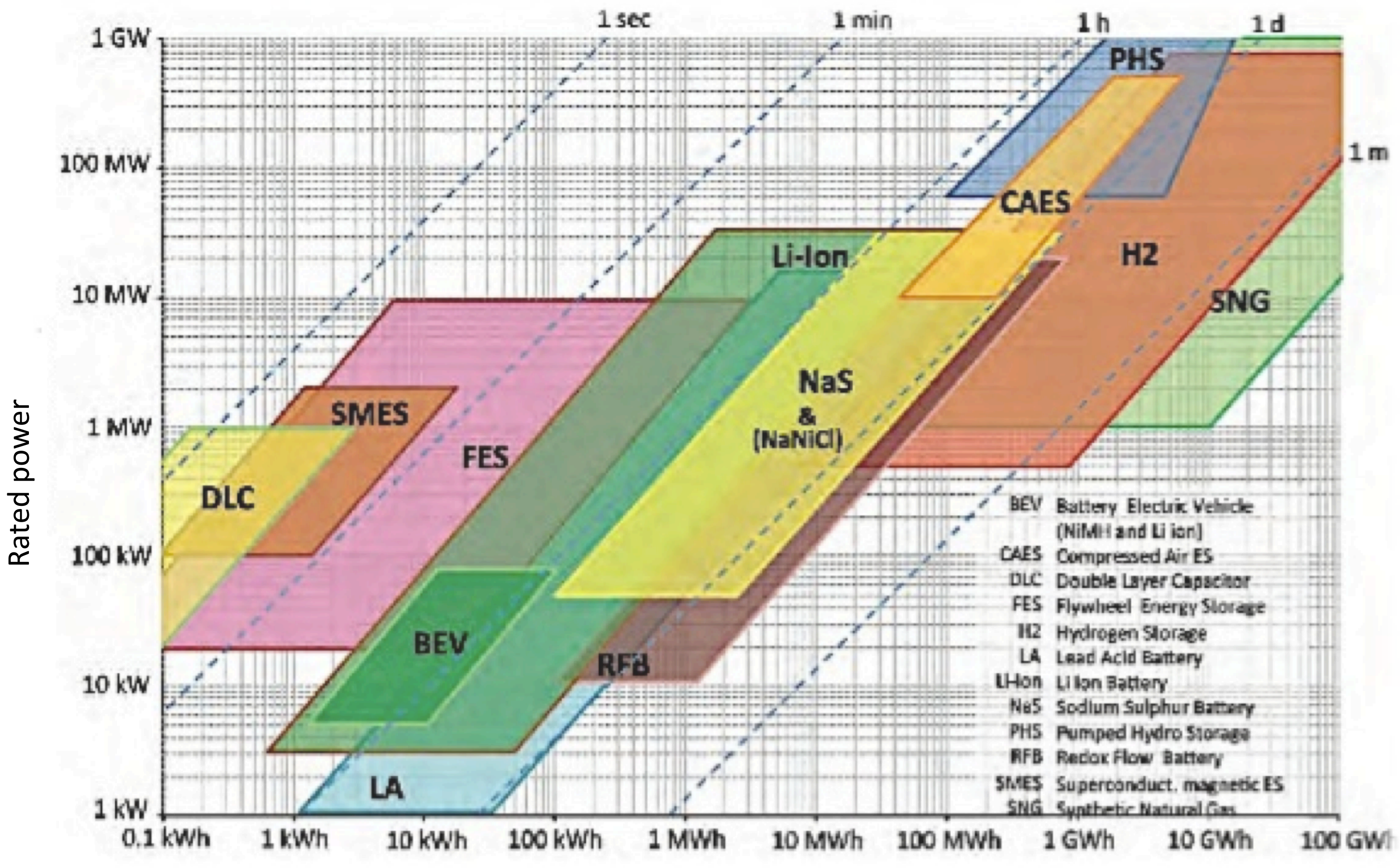

Figure 1: Rated power, energy content and discharge time of EES technologies [8]. The predicted range in future applications is also comprised.

Table 1: Characteristics of EES technologies

		Power rating MW	Energy rating kWh	Specific power W/kg	Specific energy Wh/kg	Power density kW/m³	Energy density kWh/m³	Round-trip eff. %	Critical voltage V	Discharge time	Response time	Lifetime (years)	Lifetime (cycles)	Operating temp. °C	Self-discharge %/day	Spatial requirement m²/kWh [f]	Recharge time [l]	Investment power cost €/kW	Investment energy cost €/kWh	Commercial use since	Technical maturity	Envir. impact [e]	Recyclability [e,f]	Maintenance [e]	Memory effect	Transportability	Cumulative en. demand MJ/kWh [k]
	PHS	**100-5000**	**$2x10^5$-$5x10^6$**	Not appl.	*0.5-1.5*	0.1-0.2	*0.2-2*	75-85	Not appl.	**h-days**	s-min	**50-100**	>$5x10^5$	Ambient	0	0.02	min-h	*500-3,600*	60-150	1929	**mature**	*1*	Not appl.	3	N/A	no	N/A
	CAES	***100-300***	***$2x10^5$-10^6***	Not appl.	30-60	0.2-0.6	12	≤55	Not appl.	**h-days**	*1-15min*	***25-40***	**No limit**	Ambient	0	0.10-0.28 [g]	min-h	400-1,150	***10-40***	N/A	medium [j]	*1*	Not appl.	3	N/A	no	N/A
	Hydrogen	<50	>10^5	>500	33,330	0.2-20	600 [b]	*29-49*	Not appl.	**s-days**	ms-min	5-15	>10^3	+80 to +100 [a]	0.5-2	***0.005-0.06*** [g]	**Instant.**	550-1,600 [d]	**1-15**	2010	*early*	3	2-3?	*1*	N/A	yes	5,501
	Flywheel	<20	10-$5x10^3$	***400-1600***	5-130	***5,000***	20-80	85-95	Not appl.	15s-15min	ms-s	≥20	***10^5-10^7***	-20 to +40	*20-100*	0.28-0.61 [g]	<15min	***100-300***	1,000-3,500	2008	mature	**5**	4	3	no	yes	*30,449*
	SMES	0.01-10	10^{-1}-10^2	**500-2000**	0.5-5	2,600	6	**≥95**	Not appl.	ms-5min	ms	≥20	10^4	*-270 to -140*	10-15	*0.93-26* [g]	min	100-400	*700-7,000*	2000's	*early*	3	N/A	2	N/A	yes	N/A
	EDLC	0.01-1	10^{-3}-10	*0.1-10*	0.1-15	**40,000-120,000**	10-20	85-98	0.5	ms-1h	ms	≥20	>$5x10^5$	**-40 to +85**	2-40	0.43	***s-min***	100-400	300-4,000	1980's	medium	3	4	***4***	no	yes	N/A
Conventional batteries	**Pb-acid**	<70	10^2-10^5	75-300	30-50	90-700	75	80-90	1.75	s-3h	ms	*3-15*	$2x10^3$	+25	0.1-0.3	0.06	*8h-16h*	200-650	50-300	1870	**mature**	2	5	3	no	yes	**652**
	NiCd	<40	10^{-2}-$1.5x10^3$	150-300	45-80	75-700	<200	70-75	1.0	s-h	ms	15-20	$1.5x10^3$	***-40 to +45***	0.2-0.6	0.03	1h	350-1,000	200-1,000	1915	mature (portable)	2	4-5	*1*	*yes*	yes	1,372
	NiMH	*10^{-6}-0.2*	*10^{-2}-500*	700-756	60-120	500-3,000	<350	70-75	1.0	h	ms	*5-10*	*$3x10^2$-$5x10^2$*	-20 to +45	0.4-1.2	0.02?	2h-4h	120%xNiCd	120%xNiCd	1995	mature (mobile)	3	4-5?	*1*	*yes*	yes	N/A
Advanced batteries	**Li-ion**	0.1-5	10^{-2}-10^5	230-340	***100-250***	***1,300-10,000***	***250-620***	**90-98**	*3.0*	min-h	ms-s	8-15	>$4x10^3$	-10 to +50	0.1-0.3	0.01? [h]	min-h	*700-3,000*	200-1,800	1991	mature (mobile)	***4***	4	**5**	no	yes	1,156
	NaS	0.5-50	$6x10^3$-$6x10^5$	90-230	***150-240***	120-160	<400	85-90	1.75-1.9	s-h	ms	12-20	$2x10^3$-$4.5x10^3$	*+300*	20	0.019	*9h*	700-2,000	200-900	1998	Medium	***4***	5	3	no	yes	N/A
	NaNiCl	<1	120-$5x10^3$	130-160	125	250-270	150-200	90	1.8-2.5	min-h	ms	12-20	10^3-$2.5x10^3$	*+270 to +350*	15	0.03?	6h-8h	**100-200**	70-150	1995	mature (mobile)	N/A	5	**5**	no	yes	N/A
Flow batteries	**V-Redox**	0.03-7	10-10^4	N/A	75	0.5-2	20-35	75	***0.7-0.8***	s-10h	**< 1ms**	10-20	>$13x10^3$	0 to +40	0-10	0.04	min	2,500	100-1,000	1998	medium	3	5	3	no	no	774
	ZnBr	0.05-2	50-$4x10^3$	50-150	60-80	1-25	20-35	70-75	**0.17-0.3**	s-10h	**< 1ms**	*5-10*	>$2x10^3$	+20 to +50	0-1	0.02	3h-4h	500-1,800	100-700	2009	medium	3	5	*1*	no	yes	N/A
	Zn-air [c]	several	$x10^3$	1350	**400**	50-100	**800**	60	0.9	6h	ms	***30***	>$2x10^3$ (>10^4)	0 to +50	N/A	**<0.005?**	N/A	785	126	2013/14	*early*	3	3	3	no	yes	***710***

Font coding (related to the characteristic described in each column): **bold**=most favourable(s), ***bold and italic***=second most favourable(s), *italic*=least favourable(s)

Spatial requirements for EES technologies

Table 1 is the main outcome of this study and includes the most important characteristics of EES technologies up to date. PHS, CAES and flow batteries have a low energy density and are volume consuming storage systems. On the contrary, Li-ion batteries have both a high energy density and high power density, which is why Li-ion is currently used in a broad range of applications.

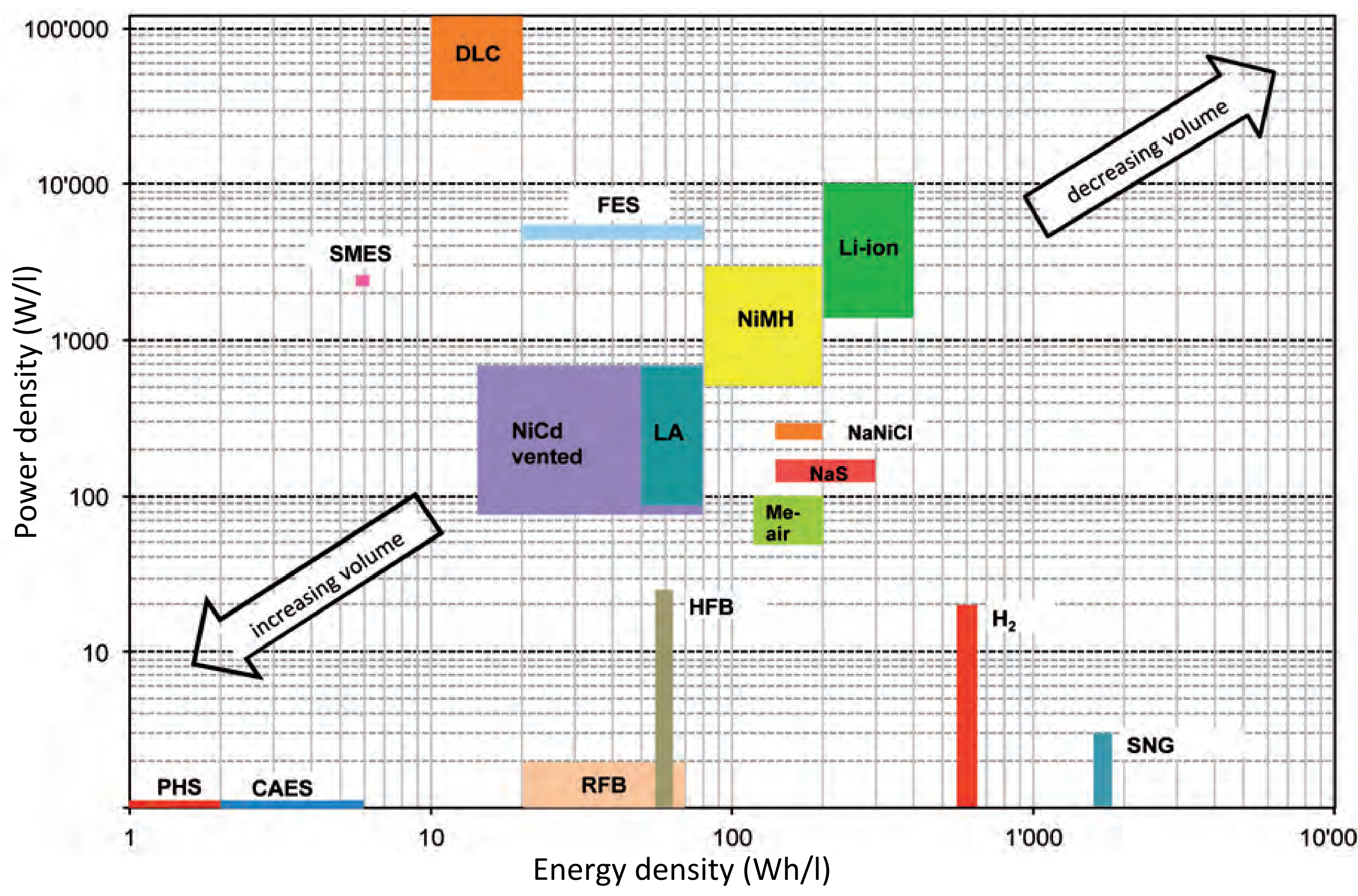

Figure 2: Impact of power and energy density on the volume EES systems require in the built environment [10]. Highly compact EES technologies can be found at the top right. Large area and volume-consuming storage systems are located at the bottom left.

EES deployment potential in the built environment

No single EES technology scores high in all the parameters presented above. Several factors should, therefore, be taken into consideration when planning the integration of a storage system in the built environment. The selection of the most preferable technology for a specific application depends on the size of the system, the specific service, the electricity sources and the marginal cost of peak electricity [11]. In the future, EES in the built environment will be primarily used in combination with renewable energy generation. There will be an increase in distributed generation with active grids, where consumption and generation are typically close together [8]. As regards building applications, the concept of the Smart House, which is designed to use energy more efficiently, economically and reliably, is expected to integrate EES technologies. Currently lead-acid batteries are mainly used in smart houses, but in the future Li-ion or NaNiCl batteries are expected to play an important role [4]. In addition, the growing synergy of the power supply system and the transport sector is an important point to address for a sustainable future [5, 8]. Hence, the use of battery storage system in plug-in electric vehicles is a means for using existing storage systems, providing large-scale decentralised EES.

Conclusions

Li-ion batteries and Zinc-air batteries with energy densities of 620 kWh/m³ and 800 kWh/m³ correspondingly seem to be very promising technologies for advanced EES integration in the built environment. Along with these technologies, NaNiCl batteries are also expected to play an important role in buildings because of their high cycle lifetime and high peak power capability. However, there is still room for improvement of the technologies' properties, so as to increase the systems' efficiencies, lower the costs and extend the lifetimes.

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*For references of each value presented in the table please refer to the paper
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