TECHNOLOGY FACTSHEET

Vanadium Redox Flow Battery (VRB) for large-scale temporal electricity storage

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Author	Sam Lamboo
Sector	Electricity generation
ETS / Non-ETS	Non-ETS
Type of Technology	Storage
Description	Vanadium Redox Flow batteries (VRB) store electricity through a reversible chemical reaction. In contrast to conventional batteries, chemical energy is stored in external electrolyte tanks (Chen et al., 2009). The active material (i.e. an aqueous liquid electrolyte) is pumped from the tanks into the AC/DC converter where either chemical energy is converted to electrical energy (discharge) or electrical energy is converted to chemical energy (charge). Installations range between 50 kW and 1 MW, with commercial units typically between 5 and 250 kW. VRB are well suited for multiple applications (JRC, 2014). This factsheet focuses on large VRB batteries (utility or distributed systems) for bulk electricity storage, capable of supplying power for longer periods (discharge times of >1h).
TRL level 2020	TRL 7 It represents the most mature flow batteries with multiple demonstration and deployed at MW scale (IRENA, 2015). Mongird et al. (2019) assigned a TRL of 7 to redox flow batteries.

TECHNICAL DIMENSIONS

	Functional Unit		Value and Range		
Capacity	kWh		6,000.00		
			100.00	-	80,000.00

			Current			2030			2050		
Potential	Global	GWh	N/A			-			-		
			-	–	-	*Min*	–	*Max*	*Min*	–	*Max*
Market share	Global utility scale electricity storage	%	See explanation			-			-		
			-	–	-	*Min*	–	*Max*	*Min*	–	*Max*

Capacity utlization factor	1.00
Full-load running hours per year	
Unit of Activity	PJ/year
Technical lifetime (years)	10 years and over 10,000 cycles (IRENA, 2017)
Progress ratio	N/A
Hourly profile	No
Explanation	The potential for all battery types is high as there are no significant space or resource constraints. Instead the demand for storage and costs are usually determining factors when it comes to potential installed capacity. As of 2019, the total global grid-connected redox flow batteries (VRB and other chemistries) capacity is almost 800 MWh, with 75% deployed in 2018 and 2019 and other large projects under construction (USDE, 2020). With an average of 4 hours of storage time this is almost 200 MW, making RFB the second largest battery technology used for stationary applications after Li-ion batteries with 1629 MW installed in 2018 (Mongird et al., 2019). Reports on lifetime vary from 5-15 years (IEA-ETSAP & IRENA, 2012) and cycle lifetime of 10,000+ cycles (IRENA, 2017).

COSTS

Year of Euro	2015

	Euro per Functional Unit	Current			2030			2050		
Investment costs	€ / kWh	735.00			535.00			-		
		420.00	–	1,075.00	455.00	–	780.00	*Min*	–	*Max*
Other costs per year	€ / kWh	-			-			-		
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Fixed operational costs per year (excl. fuel costs)	€ / kWh	8.00			7.00			-		
		6.00	–	14.00	7.00	–	7.00	*Min*	–	*Max*
Variable costs per year	€ / MWh	0.30			0.30			-		
		0.30	–	0.30	0.30	–	0.30	*Min*	–	*Max*

Costs explanation	The main reference for current costs is based on Mongird et al. (2019), who assume a energy-to-power ratio of 4 (4 MWh per MW). The investment costs include the costs of the batteries, balancing of plant and construction costs. As no (recent) cost projections for 2030 were found, the Mongird et al. (2019) cost projections for 2025 have been used for 2030. EPRI (2018) estimate the current costs of a 4 hour, 50-100 MW flow battery energy storage system at 420-720 €/kWh. The costs of 6-8 hour, 30-50 MW systems are estimated to be slightly lower (370-630 €/kWh). Future costs for a 4-hour system are estimated at 360 €/kWh, but no specific year is given for the projection. IRENA (2017) and McKinsey (2015) both have projections for costs in 2030. However, they contain limited elaboration on the cost estimates, which makes it difficult to compare to other sources. IRENA (2017) estimate investment costs at 275-873 €/kWh in 2016 and 94-314 €/kWh in 2030. McKinsey (2015) estimate investmentcosts at 300 €/kWh in 2013 and 70 €/kWh in 2030. McKinsey (2015) also estimate a decrease in fixed O&M costs to 2 €/kW/year in 2030.

ENERGY IN- AND OUTPUTS

	Energy carrier	Unit	Current			2030			2050		
Energy carriers (per unit of main output)	*Main output:* Electricity	PJ	-1.00			-1.00			-		
			-1.00	–	-1.00	-1.00	–	-1.00	*Min*	–	*Max*
	Electricity	PJ	1.47			1.37			-		
			1.25	–	1.47	1.37	–	1.37	*Min*	–	*Max*
		PJ	-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
		PJ	-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*

Energy in- and Outputs explanation	The required amount of electricity input for 1 PJ of electricity output is calculated. A roundtrip efficiency of 68%-80% is assumed in 2020, and 73% in 2030, based on round-trip efficiencies reported by McKinsey (2015) and Mongird et al. (2019).

MATERIAL FLOWS (OPTIONAL)

	Material	Unit	Current			2030			2050		
Material flows			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Material flows explanation											

EMISSIONS (Non-fuel/energy-related emissions or emissions reductions (e.g. CCS)

	Substance	Unit	Current			2030			2050		
Emissions			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Emissions explanation											

OTHER										
Parameter	**Unit**	**Current**			**2030**			**2050**		
Depth of discharge	%	100.00			-			-		
		100.00	–	100.00	*Min*	–	*Max*	*Min*	–	*Max*
Charge time	Hours	N/A			-			-		
		-	–	-	*Min*	–	*Max*	*Min*	–	*Max*
Discharge time	Hours	6.00			-			-		
		2.00	–	8.00	*Min*	–	*Max*	*Min*	–	*Max*
Self discharge	% / month	-			-			-		
		-	–	-	*Min*	–	*Max*	*Min*	–	*Max*
Explanation	JRC (2014) states that the minimum time necessary to charge a unit is approximately 10 seconds.									

REFERENCES AND SOURCES

1	Chen et al (2009). Progress in electrical energy storage system: A critical review
2	JRC (2014). Energy Technology Reference Indicator (ETRI) projections for 2010-2050
3	IRENA (2015). Renewables and Electricity Storage: a technology roadmap for REmap 2030
4	Monogird et al. (2019). Energy storage technology and cost characterization report. PNNL-28866.
5	SANDIA (2019). SANDIA Energy Storage Database accessed on January 18th 2019 (http://energystorageexchange.org/)
6	IEA-ETSAP & IRENA (2012). Electricity storage technology brief
7	Luo et al. (2015). Overview of current development in electrical energy storage technologies and the application potential in power system operation
8	IRENA (2017). Electricity Storage Costs
9	EPRI (2018). Energy storage technology cost assessment: Executive summary
10	Aquino et al. (2017). Battery energy storage technology assessment
Others	McKinsey (2015). Commercialisation of energy storage in Europe