HCSS Geo-economics

Coal's Paradox: A Source for Renewable Technology

Dylan Browne-Wilkinson, Assistant Analyst

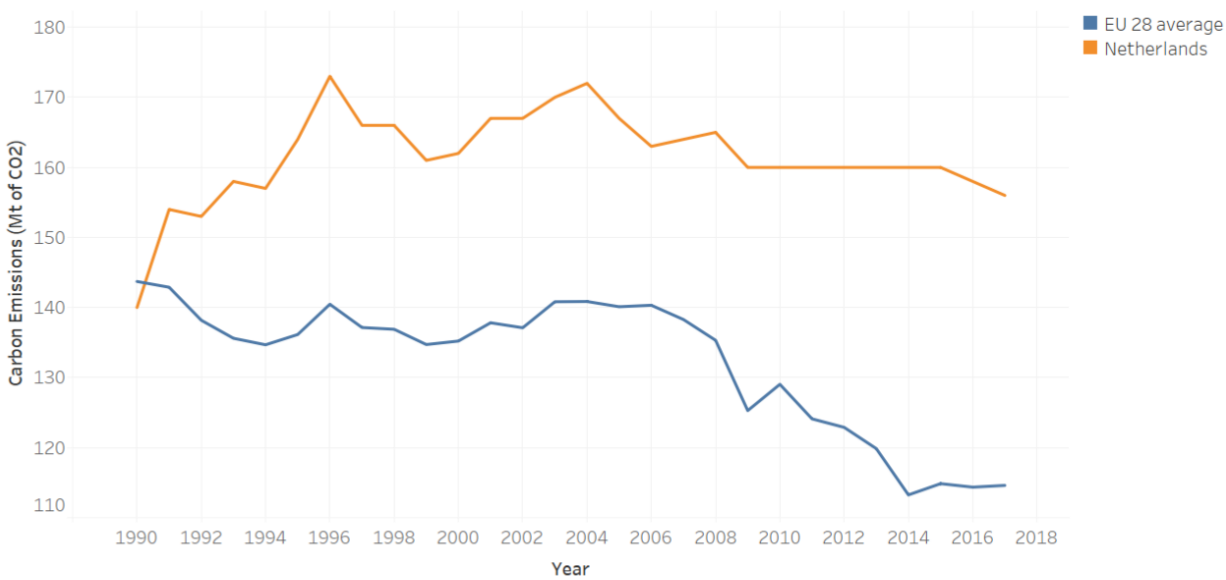
Patrick Bolder, Strategic Analyst

The Carbon Footprint of The Netherlands

This paper will discuss how the Netherlands' continuous production of coal fire ash (CFA) from the combustion of coal can be utilized in the production of Vanadium Flow Batteries (VFBs) and its relevance for the urban renewable energy transition.

From 1990 to 2014, an approximate two-million increase in population of the Netherlands has subsequently contributed to a significantly higher energy consumption (45%) and, therefore, an increase in carbon emissions (2.6%).[1] This is in stark contrast to the rest of the member states of the European Union which have combined to reduce carbon emissions on average by 23% over the same time period *(see Fig. 1)*.[2] Aware of the projected environmental footprint, the Urgenda Foundation successfully sued the Dutch government on behalf of 900 citizens in 2015.[3] Ruling that the Dutch government has a constitutional duty to protect its citizens from the impacts of climate change, it pledged a 25% reduction in greenhouse gas emissions (GHG) by 2020 compared to 1990 levels.

Carbon Dioxide Emissions in the Netherlands compared to the average of the European Union's 28 countries between 1990-2017



Source: International Environmental Agency (IEA)

However, with the addition of three new coal-fired power stations in 2015—Maasvlakte 2, Rotterdam and Eemshaven—strong pressure is being exerted on politicians to close

[1] "StatLine - Population," December 12, 2019, https://opendata.cbs.nl/statline/#/CBS/en/dataset/37296eng/table?fromstatweb; "The Netherlands - Countries & Regions," International Energy Agency (IEA), accessed February 20, 2020, https://www.iea.org/countries/the-netherlands; "Greenhouse Gas Emissions, 1990-2016," Environmental Data Compendium, September 6, 2017, https://www.clo.nl/en/indicators/en0165-greenhouse-gas-emissions.

[2] "Total Greenhouse Gas Emission Trends and Projections in Europe," European Environment Agency, December 19, 2019, https://www.eea.europa.eu/data-and-maps/indicators/greenhouse-gas-emission-trends-6/assessment-3.

[3] "Climate Case," *Urgenda* (blog), accessed January 10, 2020, https://www.urgenda.nl/en/themas/climate-case/.

older, less efficient power stations.[4] The new plants have translated into 35% of Dutch electricity being generated from coal during 2018.[5] Importantly, although there has been a 13% reduction of overall GHG in 2017 from 1990, compared to 2016, carbon emissions have increased 1.1 ton per capita.

Acknowledging that the 2020 promise of reducing carbon emissions by 25% is unrealistic, the Dutch government responded with the release of the Klimaatakkoord 2018 detailing policies which aim for a 49% reduction in carbon emissions by 2030.[6] This includes the phasing out coal-fired power station entirely by 2030, with 70% of total Dutch electricity generated by renewables.[7] The government further acknowledges that a new energy system will be optimized by as much locally generated energy supplying neighboring urban environments.

Since around three-quarters of the Dutch population live in densely populated urban areas of towns and cities, ensuring electricity supply to these areas whilst meeting environmental targets will require better infrastructure by harnessing data, information and technology to form smart cities in the urban renewable energy transition.[8] The fifth mission drive innovation program (MMIPs) of the Klimaatakkoord identifies how electricity storage in district batteries can offer an opportunity integrate the Dutch companies and citizens located in built environments into the new energy system.[9]

Extending Coal's Lifetime

Redesigning the life cycle of coal and its residual of CFA has become a pressing topic in alleviating the economic pressures of raw material extraction and the environmental footprint of CFA's disposal. In the process of burning one ton of coal, one hundred and eighty kilograms of coal ash (composed of CFA and coal boiler ash (CBA)) is produced, representing the second-largest waste product in the world after household waste.[10]

CFA has been identified as a source of rare-earth elements (REE) which are crucial for clean technologies. With the gap between their global demand and supply increasing due to China controlling 95% of the global market supply, efforts to identify novel methods in

4 "Vattenfall's Last Coal Power Plant in the Netherlands Is Closing," Vattenfall, n.d., https://group.vattenfall.com/press-and-media/news--press-releases/newsroom/2019/vattenfalls-last-coal-power-plant-in-the-netherlands-is-closing.

5 "Energy Report - Transition to Sustainable Energy" (Ministry of Economic Affairs of the Netherlands, April 28, 2016), https://www.government.nl/documents/reports/2016/04/28/energy-report-transition-tot-sustainable-energy.

6 Karel Beckman and Jilles van den Beukel, "The Great Dutch Energy Transition" (The Oxford Institute for Energy Studies, July 2019), https://www.oxfordenergy.org/wpcms/wp-content/uploads/2019/07/The-great-Dutch-gas-transition-54.pdf?v=796834e7a283.

7 "Klimaatakoord" (Rijksoverheid, June 28, 2019), https://www.rijksoverheid.nl/documenten/rapporten/2019/06/28/klimaatakkoord.

8 Kersten Nabielek, David Hamers, and David Evers, "Cities in the Netherlands" (PBL Netherlands Environmental Assessment Agency, 2016).

9 "Klimaatakoord."

10 "Coal Ash Waste | Beyond Coal," accessed November 27, 2019, https://content.sierraclub.org/coal/disposal-ash-waste.

sourcing REE has become prevalent.[11] Furthermore, recognizing its significant leverage over REE global supply whilst wanting to protect their domestic industries, China has been increasing their export taxes as well as restricting export rates.[12]

CFA presents itself as a viable alternative as not only does REE extraction have less environmental impact than mining mineral ores, CFA also contains a full range of trace elements rather than a select few. Governments and companies, therefore, are exploring whether REE extraction from CFA is economically viable.[13] Massachusetts-based Physical Sciences Inc. and Colorado-based Neumann Systems, both advanced engineering and manufacturing companies, have been developing technologies to recover REEs from fly ash.[14] The latter reported a 60% retrieval of the available metals in CFA obtained from Colorado Springs Utilities power plant, calculating that $600 worth of rare elements can be obtained from each ton of fly ash, which translates to approximately $49 million worth of elements per year from one power plant alone.[15] Applying these figures to the context of the Netherlands, which produced 2 million tons of CFA in 2019, the valuation of metals that can be potentially reclaimed amounts $1.2 billion.[16]

Recently, an element which has gained growing interest due to its use in flow batteries is Vanadium, of which China controls most of the global market's supply (*See Figure 2*).[17] As such, coal's lifetime cycle is extended by using its rest products for much-needed battery materials, reducing its waste footprint.

11 Wojciech Franus, Małgorzata M. Wiatros-Motyka, and Magdalena Wdowin, "Coal Fly Ash as a Resource for Rare Earth Elements," *Environmental Science and Pollution Research*, January 2015, https://doi.org/DOI: 10.1007/s11356-015-4111-9.

12 Nabeel A. Mancheri et al., "Effect of Chinese Policies on Rare Earth Supply Chain Resilience," *Resources, Conservation and Recyling* 142 (March 2019): 101–12, https://doi.org/10.1016/j.resconrec.2018.11.017.

13 "Pu Neng Wins Contract for the Largest Vanadium Flow Battery in China as the China National Development and Reform Commission Initiates a Major Push for Energy Storage in Support of Renewable Energy," accessed February 6, 2020, https://www.globenewswire.com/news-release/2017/11/01/1172376/0/en/Pu-Neng-Wins-Contract-for-the-Largest-Vanadium-Flow-Battery-in-China-as-the-China-National-Development-and-Reform-Commission-Initiates-a-Major-Push-for-Energy-Storage-in-Support-of.html; Franus, Wiatros-Motyka, and Wdowin, "Coal Fly Ash as a Resource for Rare Earth Elements."

14 "Report on Rare Earth Elements from Coal and Coal Byproducts" (US Department of Energy, January 2017), https://www.energy.gov/sites/prod/files/2018/01/f47/EXEC-2014-000442%20-%20for%20Conrad%20Regis%202.2.17.pdf; Adam Currie, "Rare Earth from Fly Ash: A Method Explored," Business Insider, June 25, 2012, https://www.businessinsider.com/rare-earth-from-fly-ash-a-method-explored-2012-6.

15 Franus, Wiatros-Motyka, and Wdowin, "Coal Fly Ash as a Resource for Rare Earth Elements."

16 Arpita Bhatt et al., "Physical, Chemical, and Geotechnical Properties of Coal Fly Ash: A Global Review," *Case Study in Construction Metals* 11 (December 2019), https://doi.org/10.1016/j.cscm.2019.e00263.

17 "Circular Economy," European Parliamentary Research Service, 2019, https://www.europarl.europa.eu/thinktank/infographics/circulareconomy/public/index.html.

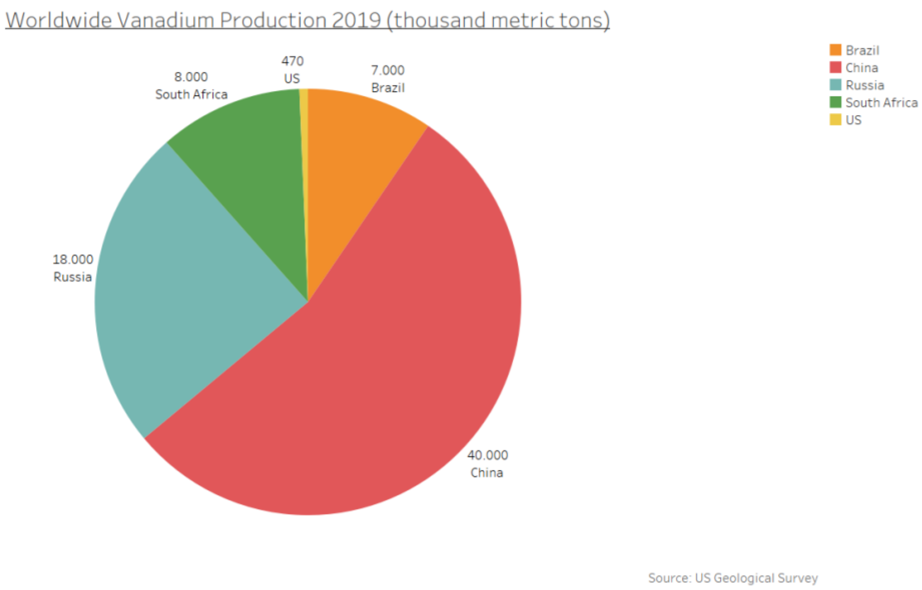


Figure 1 - The largest producers of Vanadium worldwide.

Vanadium Flow Batteries

CFA contains the element Vanadium which is becoming an increasingly more attractive material when used in redox flow batteries. Named Vanadium Flow Batteries (VFBs), the technology is challenging the most popular battery on the market at the time of writing - Lithium Batteries (LiBs).[18] Both have their advantages and disadvantages resulting in their optimization in contrasting contexts. This can be best understood through assessing their on-going, annual costs:

	Units	LiBs	VFBs
Calendar Life	Years	3-10	20-25
Number of cycles	#	6,000-12,000	20,000-30,000
Depth of discharge	%	80-95%	100%
Battery Power	mW	0.1-100	0.5-200
Battery Density	Whr / kg	80-200	20-40
Energy efficiency	%	92-99%	75-90%

Figure 2 - Comparing the ongoing costs of Lithium Batteries against Vanadium Flow Batteries. Source: Bushveld Minerals.

Figure 3 presents how VFBs' greater calendar life, number of cycles, depth of discharge and battery power make them better purposed as a utility-scale battery. One of the key advantages of VFBs is the potential of the Vanadium electrolyte being easily regenerated and reused. Conversely, Lithium Batteries (LiBs) are irreversible and resource exhaustive. Yet, their higher efficiency of 92-99%, combined with a higher power density, make LiBs

18 Adam Z. Weber et al., "Redox Flow Batteries: A Review," *J Appl Electrochem* 41 (2011): 1137, https://doi.org/10.1007/s10800-011-0348-2.

better suited for smaller applications such as automobiles and households. Nevertheless, these two characteristics highlight areas to improve the competitiveness of VFBs.[19]

VFBs provide an ingenuitive approach in recycling the materials within CFA. The battery's longer service life, less maintenance, and larger modularity in capacity all combine to make it optimized for utility-scale use. The extent of its potential can be realized in smart cities.

Urban Renewable Energy

VFBs can be used as utility-scale batteries to efficiently distribute electricity within dense urban areas. As a renewable technology, they can facilitate the storing and supply of electricity where the roles of injecting energy and of absorbing and consuming energy overlap. This is in juxtaposition to the existing electricity distribution framework which is geared around a grid system designed to balance supply and demand from power plants.

In this manner, the batteries are an instance of how smart cities can function. Enabled by software, VFBs can be embedded into the fabric of cities to provide a real-time system that enables the more efficient management of electricity distribution.[20] This can be achieved through bidirectional charging. For example, VFBs can facilitate the discharge of idle electrical vehicles that are connected to the grid (V2G) to power homes/buildings in need of electricity (V2H/B) and vice versa. Consequently, the peak load of electricity demand is reduced since electricity can be redistributed locally.[21]

In addition, the implementation of localized VFBs into the fabric of cities enables higher shares of low-cost various-renewable energy (VRE) to penetrate the grid. In considering both structural advantages, IRENA calculates that in the long-term software enabled utility-scale batteries which facilitate urban management could reduce costs by 42% with a 62% reduction in carbon emissions compared to the current business-as-usual model.[22]

19 Fortune Mojapelo and Mikhail Nikamarov, "Energy Storage & Vanadium Redox Flow Batteries 101"; Garg Bhaskar, "Introduction to Flow Batteries: Theory and Applications," March 22, 2012, http://large.stanford.edu/courses/2011/ph240/garg1/.
20 Rob Kitchin, "The Real-Time City? Big Data and Smart Urbanism," *GeoJournal* 79, no. 1–14 (November 23, 2013).
21 Peter Bach Anderson, "Innovation Outlook: Smart Charging for Electric Vehicles" (IRENA, 2019), www.irena.org/Publications.
22 Anderson.

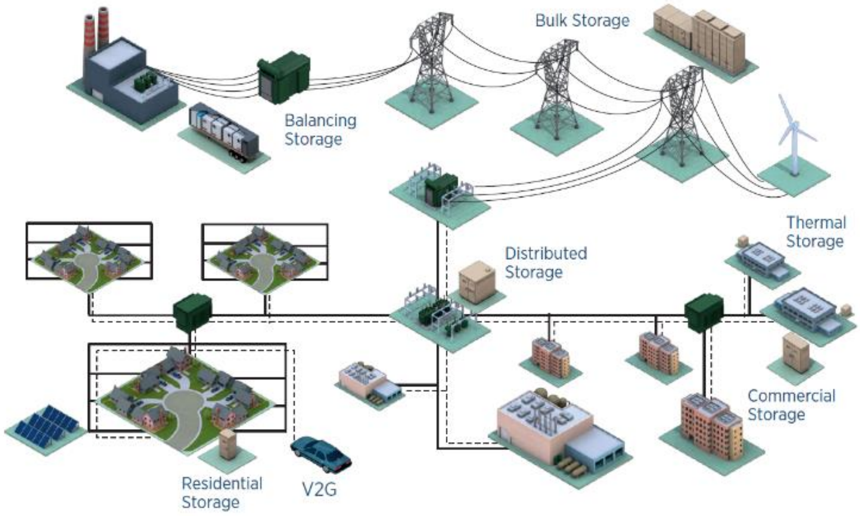


Figure 4 – Potential locations and applications of VFBs as utility-scale batteries in smart cities.

Conclusion

VFBs have the potential to play an instrumental role in the transition to renewable energy within urban areas. Firstly, the features of VFBs compared to LiBs, the most common battery on today's market, make it more favorable for utility-scale use within urban areas. Lastly, VFBs can make the energy consumption of citizens substantially more efficient, reducing both costs and carbon emissions.

Secondly, because the Vanadium required in their production can be harnessed from CFA, a waste product that is in large abundance within the Netherlands. Even though the Klimaatakkoord stated that coal-fired power stations would be phased out entirely by 2030, if cost-effective, the Netherlands could use the buried CFA deposits over the decades. Moreover, since coal is predicted to contribute 32% and 17% to global energy production by the 2030 and 2050 respectively, CFA can be sourced from other European or international countries.[23] An example country is Poland, a member of the European Union which generated 80% of their electricity through coal, lowering to 60% in 2030 and 50% in 2040.[24]

To advance the progress of this technology, calculating the abundance of CFA that can be easily accessed is the first step in realizing the potential opportunity for the Netherlands. From the extent of stock, the abundance of metals that have a market value can be further derived. So far, the extraction process has been successful in extracting REEs and other

23 "Global Energy Transformation: A Roadmap to 2050" (Abu Dhabi: IRENA, 2018), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_Report_GET_2018.pdf.
24 "Poland: Electricity and Heat Generation Source," IEA, n.d., https://www.iea.org/data-and-statistics?country=POLAND&fuel=Electricity%20and%20heat&indicator=Electricity%20generation%20by%20source.; Nina Chestney, "Poland's Power from Coal Seen down at 50 Percent by 2040 - Government Official," October 2, 2018, https://www.reuters.com/article/us-poland-energy/polands-power-from-coal-seen-down-at-50-percent-by-2040-government-official-idUSKCN1MC2FM.

trace elements, however, to make it more cost-effective on an industrial scale requires further investment into R&D. In addition, the sale of non-vanadium metals such as iron and titanium can subsidize the extraction process.

To ensure that the electrical grid in the Netherlands can serve the demands of an increasing urban demographic, it is vital to stimulate further investment to help utility-scale battery manufacturers achieve an economics of scale. Simultaneously, investment can address the weaker features of the batteries such as power efficiency and power density.

Bibliography

Beckman, Karel, and Jilles van den Beukel. "The Great Dutch Energy Transition." The Oxford Institute for Energy Studies, July 2019. https://www.oxfordenergy.org/wpcms/wp-content/uploads/2019/07/The-great-Dutch-gas-transition-54.pdf?v=796834e7a283.

Bhaskar, Garg. "Introduction to Flow Batteries: Theory and Applications," March 22, 2012. http://large.stanford.edu/courses/2011/ph240/garg1/.

Bhatt, Arpita, Sharon Priyadarshini, Aiswarya Acharath Mohanakrishnan, Arash Abri, Melanie Sattler, and Sorakrich Techapaphwait. "Physical, Chemical, and Geotechnical Properties of Coal Fly Ash: A Global Review." *Case Study in Construction Metals* 11 (December 2019). https://doi.org/10.1016/j.cscm.2019.e00263.

Chestney, Nina. "Poland's Power from Coal Seen down at 50 Percent by 2040 - Government Official," October 2, 2018. https://www.reuters.com/article/us-poland-energy/polands-power-from-coal-seen-down-at-50-percent-by-2040-government-official-idUSKCN1MC2FM.

European Parliamentary Research Service. "Circular Economy," 2019. https://www.europarl.europa.eu/thinktank/infographics/circulareconomy/public/index.html.

Urgenda. "Climate Case." Accessed January 10, 2020. https://www.urgenda.nl/en/themas/climate-case/.

"Coal Ash Waste | Beyond Coal." Accessed November 27, 2019. https://content.sierraclub.org/coal/disposal-ash-waste.

"Energy Report - Transition to Sustainable Energy." Ministry of Economic Affairs of the Netherlands, April 28, 2016. https://www.government.nl/documents/reports/2016/04/28/energy-report-transition-tot-sustainable-energy.

Franus, Wojciech, Małgorzata M. Wiatros-Motyka, and Magdalena Wdowin. "Coal Fly Ash as a Resource for Rare Earth Elements." *Environmental Science and Pollution Research*, January 2015. https://doi.org/DOI: 10.1007/s11356-015-4111-9.

"Global Energy Transformation: A Roadmap to 2050." Abu Dhabi: IRENA, 2018. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_Report_GET_2018.pdf.

Environmental Data Compendium. "Greenhouse Gas Emissions, 1990-2016," September 6, 2017. https://www.clo.nl/en/indicators/en0165-greenhouse-gas-emissions.

Kitchin, Rob. "The Real-Time City? Big Data and Smart Urbanism." *GeoJournal* 79, no. 1–14 (November 23, 2013).

"Klimaatakoord." Rijksoverheid, June 28, 2019. https://www.rijksoverheid.nl/documenten/rapporten/2019/06/28/klimaatakkoord.

Mancheri, Nabeel A., Benjamin Sprecher, Gwendolyn Bailey, Jianping Ge, and Arnold Tukker. “Effect of Chinese Policies on Rare Earth Supply Chain Resilience.” *Resources, Conservation and Recyling* 142 (March 2019): 101–12. https://doi.org/10.1016/j.resconrec.2018.11.017.

Mojapelo, Fortune, and Mikhail Nikamarov. “Energy Storage & Vanadium Redox Flow Batteries 101.” November 13, 2018.

Nabielek, Kersten, David Hamers, and David Evers. “Cities in the Netherlands.” PBL Netherlands Environmental Assessment Agency, 2016.

IEA. “Poland: Electricity and Heat Generation Source,” n.d. https://www.iea.org/data-and-statistics?country=POLAND&fuel=Electricity%20and%20heat&indicator=Electricity%20generation%20by%20source.

“Pu Neng Wins Contract for the Largest Vanadium Flow Battery in China as the China National Development and Reform Commission Initiates a Major Push for Energy Storage in Support of Renewable Energy.” Accessed February 6, 2020. https://www.globenewswire.com/news-release/2017/11/01/1172376/0/en/Pu-Neng-Wins-Contract-for-the-Largest-Vanadium-Flow-Battery-in-China-as-the-China-National-Development-and-Reform-Commission-Initiates-a-Major-Push-for-Energy-Storage-in- Support-of.html.

“StatLine - Population,” December 12, 2019. https://opendata.cbs.nl/statline/#/CBS/en/dataset/37296eng/table?fromstatweb.

International Energy Association (IEA). “The Netherlands - Countries & Regions.” Accessed February 20, 2020. https://www.iea.org/countries/the-netherlands.

European Environment Agency. “Total Greenhouse Gas Emission Trends and Projections in Europe,” December 19, 2019. https://www.eea.europa.eu/data-and-maps/indicators/greenhouse-gas-emission-trends-6/assessment-3.

Vattenfall. “Vattenfall’s Last Coal Power Plant in the Netherlands Is Closing,” n.d. https://group.vattenfall.com/press-and-media/news--press-releases/newsroom/2019/vattenfalls-last-coal-power-plant-in-the-netherlands-is-closing.

Weber, Adam Z., Jeremy P. Meyers, Jeffrey T. Gostick, Matthew M. Mench, and Qinghua Liu. “Redox Flow Batteries: A Review.” *J Appl Electrochem* 41 (2011): 1137. https://doi.org/10.1007/s10800-011-0348-2.

Images & Figures

Figure 4 - Anisie, Arina, and Francisco Boshell. “Renewables and Electrical Storage: A Technology Roadmap for REmap 2030,” n.d.