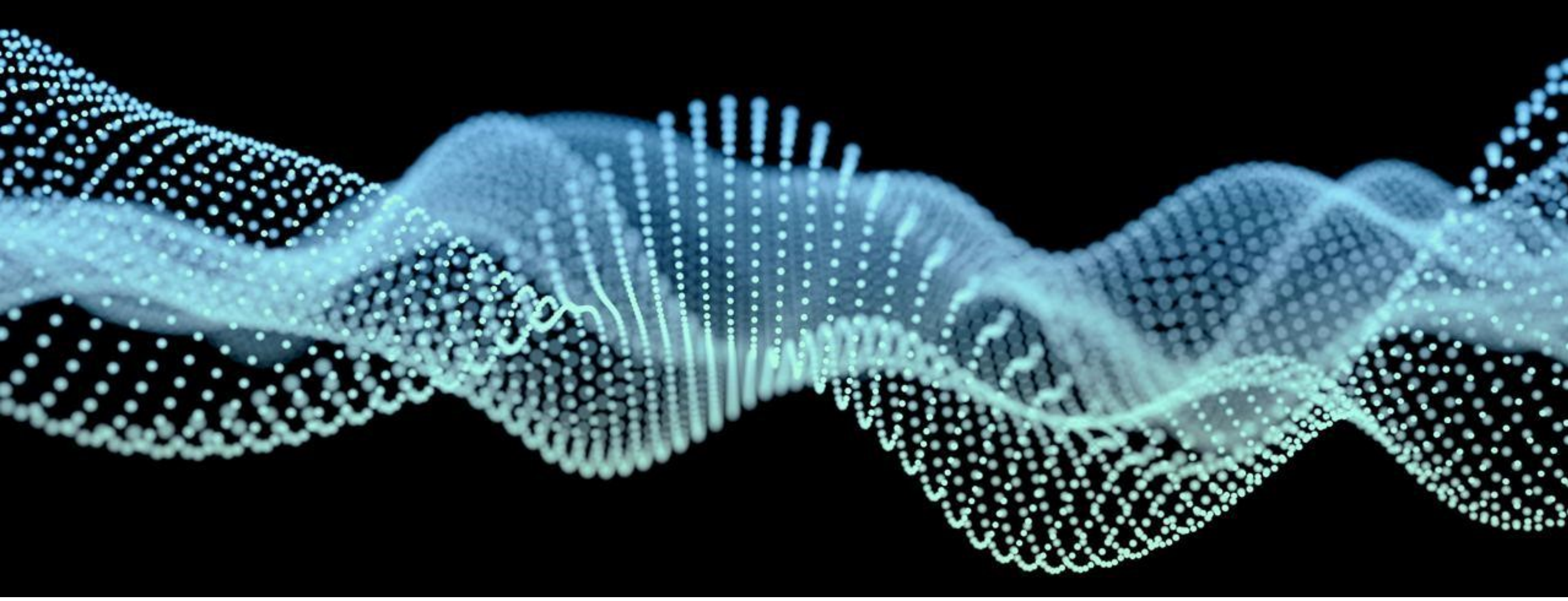


The Age of Electrochemical Power: Energy Storage, Hydrogen & Carbon Capture

Marcus Clover, Grant Gischen and Harry Michael

Powering the

Energy Revolution.

Electrochemistry – the elixir of clean energy

Energy
Revolution
Ventures

Executive Summary

Addressing climate change is the most important work of our lifetime. We believe electrochemistry will have the most outsized impact on climate technology in the coming decade and become the hub technology for a sustainable energy system. At Energy Revolution Ventures, we invest in companies leveraging electrochemistry to accelerate this energy transition. Conservative estimates put the global market for electrochemical technologies at $1.5Tn by 2050.

A core premise of our thesis is that electrochemistry allows us to economically store, distribute and use renewable electricity to power society and industry. It is the fundamental technology unpinning hydrogen, carbon capture and energy storage sectors. The exponential growth in these nascent sectors required to meet COP27 goals this decade will require similar growth in the enabling electrochemical technologies. Electrochemistry can also economically decarbonise industry with applications from steel to cement and plastics to chemicals.

Electrochemistry offers potential for outsized returns due to: (1) ubiquity of applications across hydrogen, carbon capture and energy storage, (2) opportunity for applications in adjacent hard-to-decarbonise sectors, (3) electrochemical technologies are primed for scale, (4) increasing volume of research and talent in the field.

In this piece we breakdown our thinking, provide context on why there is a unique opportunity for electrochemistry now and detail the exciting breadth of applications.

This Energy Transition

Climate change is the greatest threat facing humanity this century. To achieve COP27 goals by 2050 and transition to a low-carbon society we'll need to develop clean ways of producing and utilizing energy which will affect every part of the global economy. This provides a significant market opportunity in electrochemistry and advanced materials technologies which will lower the economic barriers to this energy transition. All stakeholders are well incentivised to shift to clean energy driven by four main factors:

A. **Growing governmental support for decarbonisation** - Most governments have set targets, some in law, to achieve net zero carbon emissions by 2050 with some targeting before 2035 such as Uruguay and Finland. The EU Green Deal and Climate Law set binding targets to cut emissions by 55% by 2030 (from 1990 levels) and to reach climate neutrality by 2050.
B. **Shifting investor behaviour** - According to Blackrock, investors have moved their money into sustainable investments at 6 times the growth rate of traditional investments, with assets now totalling $4T globally across all ESG categories[1].
C. **Corporates proactively developing more sustainable products** - In the UK alone, over half of the largest businesses have committed to eliminating their contribution to carbon emissions by 2050, representing a total market capital of over £1.2T.
D. **Sharply declining renewable energy costs** - According to Bloomberg New Energy Finance (BNEF), the global levelized cost of electricity (LCOE) for utility-scale solar PV has decreased by c.85% since 2010, with both offshore and onshore wind costs decreasing by c.50% during the same period[2].

---

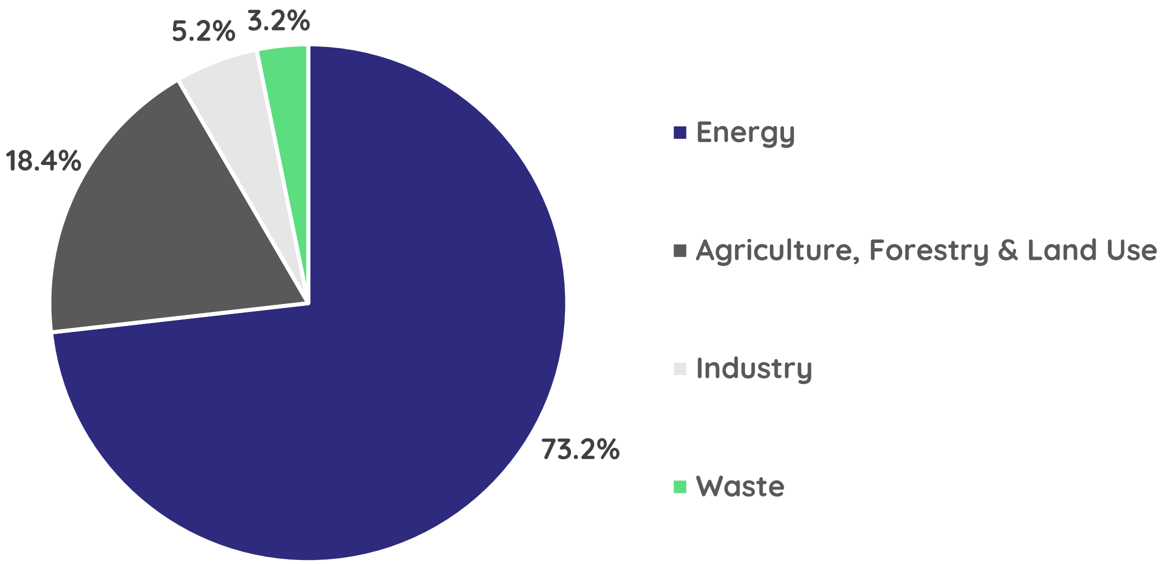
[1] https://www.blackrock.com/corporate/investor-relations/transition-investing

[2] https://about.bnef.com/blog/cost-of-new-renewables-temporarily-rises-as-inflation-starts-to-bite/

The Clean Energy Challenge

For the world to achieve its decarbonization targets, it is critical we transition to zero carbon ways of producing and consuming energy. Energy usage from fossil fuels contributes to c.73% of global greenhouse gas emissions, as shown in Figure 1. Furthermore, CO_2 emissions are on the rise. According to the IEA, global energy-related CO_2 emissions increased by more than 2 billion tonnes in 2021, their largest-ever annual rise in absolute terms, a 6% increase from 2020.

Figure 1: Share of global CO_2 emissions by sector in 2016. Global GHG emissions were 49.4 billion tonnes of CO_2eq[3].

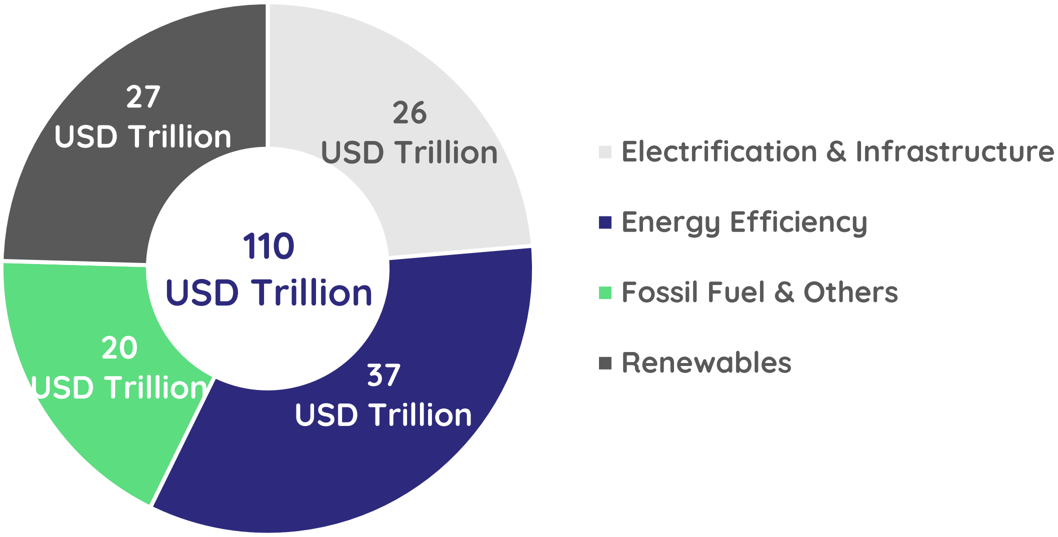


---

[3] https://ourworldindata.org/ghg-emissions-by-sector

Focusing on clean energy technologies offers an outsized opportunity to achieve both carbon reduction impact as well as economic upside from an investment standpoint. Countries are driving towards renewable sources in search of more resilient and reliable energy systems for which renewables offer an attractive prospect. The Ukraine war has also put the spotlight on countries becoming energy self-sufficient. The scale of the investment opportunity to fulfil global decarbonisation targets is immense. IRENA estimate investments of $100T are required by 2050 to achieve a climate neutral energy system[4].

Figure 2: Cumulative investments in the energy sector between 2015 to 2050 (USD Trillion).



The scale of this challenge is staggering. However, it also represents an unprecedented commercial opportunity for technology companies in emerging sectors. Virtually all decarbonisation scenarios see energy storage, hydrogen, and carbon capture sectors as essential to achieving a cost-effective energy transition. In the next section we describe why these nascent sectors are critical to accelerating this energy transition and thus will experience exponential growth.

---

[4] https://irena.org/media/Files/IRENA/Agency/Publication/2020/Apr/IRENA_GRO_Summary_2020.pdf?la=en&hash=1F18E445B56228AF8C4893CAEF147ED0163A0E47

The Need for Energy Storage, Hydrogen and Carbon Capture

Energy storage

Energy storage is a critical component of the entire electricity infrastructure as it enables decoupling of energy supply and demand. Wind and solar energy both have inherent intermittency and resilience challenges. As higher levels of these renewables are integrated into the grid, energy storage capacity will also need to scale accordingly to balance energy supply and demand – for example, when the wind isn't blowing and the sun isn't shining. If energy storage is deployed properly it improves electricity grid stability, flexibility, reliability, and resilience.

Energy storage is also a critical component for electric vehicles, which are at an inflection point for mass adoption. Electric vehicle sales grew globally from 0.4 million in 2013 to 16.4 million in 2021, at a 41.4% CAGR[5]. According to BNEF, this growth is only expected to continue, with electric vehicles projected to account for 61% of sales by 2030[6]. This growth is expected to drive increased energy storage demand as batteries are fundamental to the scale-up of electric vehicles. The Faraday Institution expects electric vehicles to account for c.70% of additional energy storage demand between 2020 and 2030[7].

Furthermore, BNEF estimates that an 83-fold increase in energy storage capacity is required, increasing from 20 GW in 2020 to 1,650 GW in 2050[8].

---

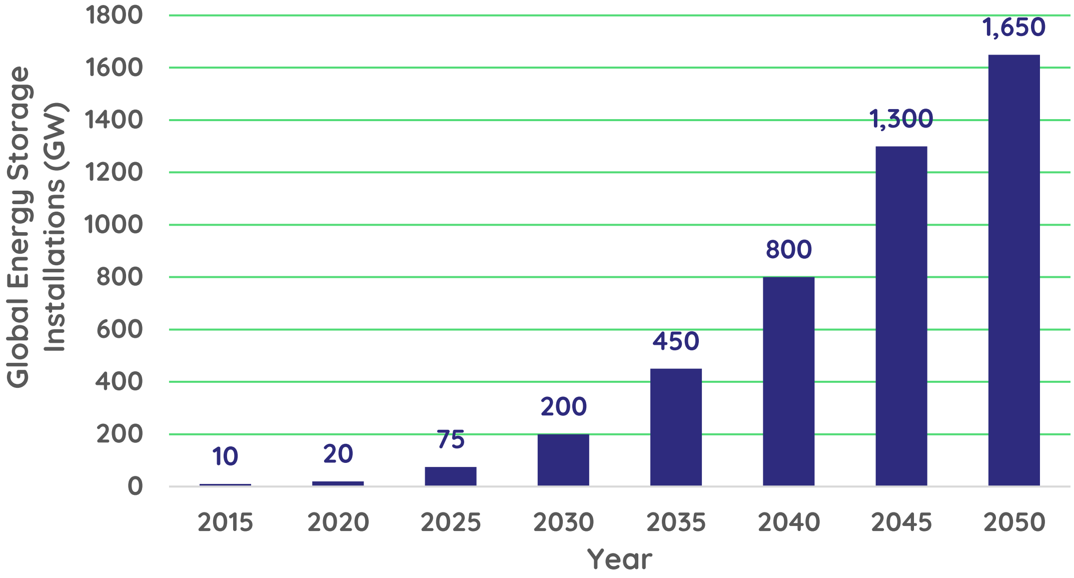
[5] https://faraday.ac.uk/wp-content/uploads/2019/10/191025_Rapid_market_assessment_of_storage_in_developing_countries.pdf

[6] https://about.bnef.com/blog/net-zero-road-transport-by-2050-still-possible-as-electric-vehicles-set-to-quintuple-by-2025/

[7] https://faraday.ac.uk/wp-content/uploads/2019/10/191025-Rapid-market-assessment-of-storage-in-developing-countries.pdf

[8] https://www.energy-storage.news/bloombergnef-predicts-30-annual-growth-for-global-energy-storage-market-to-2030/

Figure 3: Long-term energy storage market outlook 2020[9].



Hydrogen

There are several applications that renewable electricity cannot decarbonise outright – these sectors are commonly referred to as 'hard-to-abate' – where hydrogen offers a commercially viable alternative. Hydrogen is used as a feedstock in industrial processes primarily for fertilizer and methanol production as well as in refineries. In these applications hydrogen cannot be replaced through electrification as electrons do not possess the requisite chemical properties for chemical reactions to work. In 2020, global hydrogen demand stood at 90 megatonnes, equivalent to c.3,000 TWh which is roughly the EU's electricity consumption. The vast majority (>95%) of this is produced from fossil fuels[10].

Hydrogen has also been proposed as a replacement for gas in providing high-temperature industrial heat (>1200 °C) which is challenging to provide electrically. For energy storage up to four hours, lithium-ion batteries have proven themselves as a workable solution, but their application for longer-duration storage becomes uneconomical due to the coupling between power and energy intrinsic to this technology. There is a gap in the market for a long-duration

---

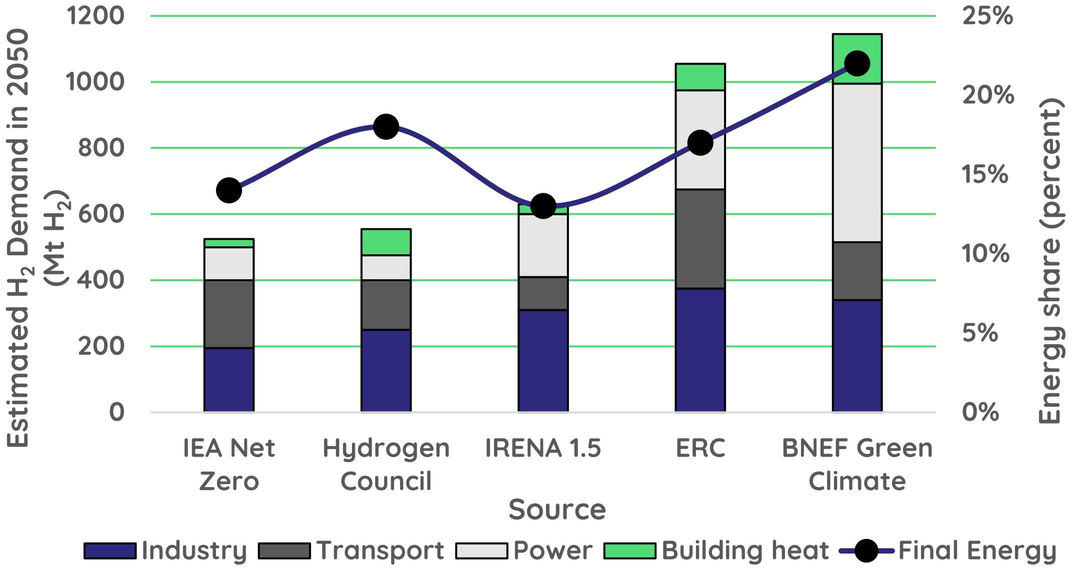
[9] https://content.macquarie.com/macquarie-capital/asia/2021/events/group-call/ess-day/2021-08-11-%20BloombergNEF%20Energy%20Storage_Macquarie%20Securities.pdf

[10] https://www.irena.org/-/media/files/irena/agency/publication/2018/sep/irena_hydrogen_from_renewable_power_2018.pdf

energy storage solution, where energy can scale independently of the power needed, and we believe hydrogen has strong potential to fulfil this need.

There are also calls to use hydrogen in the transport sector. While batteries are making inroads in ground transportation, particularly in passenger and light-duty vehicle segments, they will struggle to decarbonise weight-sensitive modes, such as freight, marine, and aviation as their energy density is orders of magnitude lower than existing fuels, impacting vehicle range. Here, hydrogen could play a role directly as a fuel, or indirectly, as a building block to synthetic, carbon-neutral hydrocarbons. Agora Energiewende predicts that hydrogen, or hydrogen-based fuels, will provide between c.15-23% of global final energy demand by 2050.

Figure 4: Estimated global hydrogen demand in 2050 in selected Net-Zero scenarios[11].



Carbon Capture

Limiting global warming to below 1.5 °C by 2050 will require both capturing CO_2 produced at source and removal of CO_2 from the atmosphere. All Intergovernmental Panel on Climate Change (IPCC) pathways that limit warming to 1.5 °C by 2050 rely on CO_2 removal at scale followed by a period of net-negative emissions.

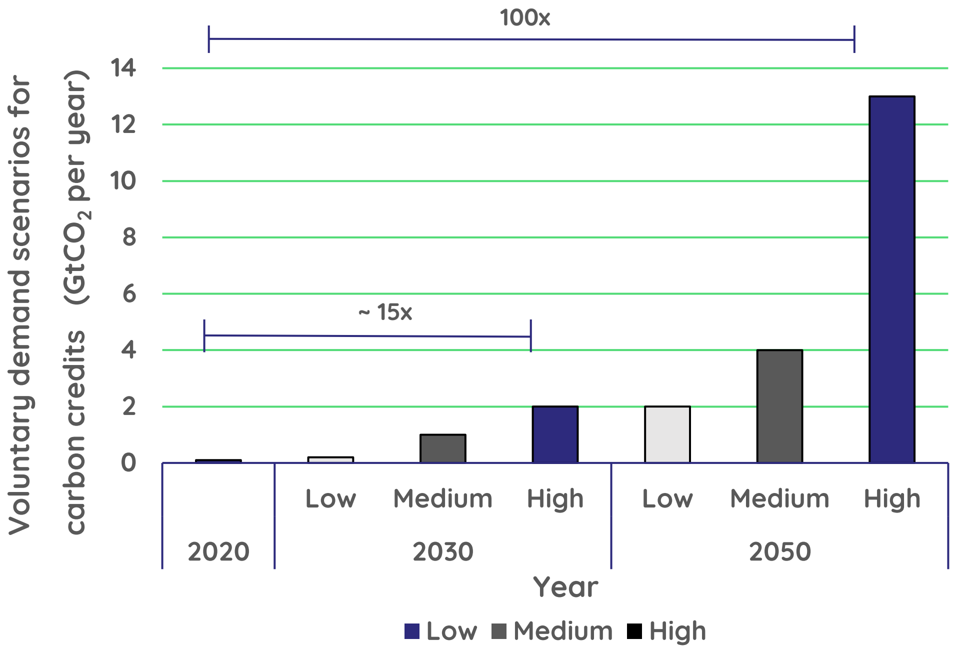
---

[11] https://static.agora-energiewende.de/fileadmin/Projekte/2021/2021_11_H2_Insights/A-EW_245_H2_Insights_WEB.pdf

Carbon capture technologies have several critical applications in decarbonising the energy sector. These technologies can be used to reduce emissions from existing energy infrastructure by being retrofitted to existing power and industrial plants to capture emissions. In addition, they can also remove CO_2 directly from the atmosphere, via direct air capture, to balance emissions that are unavoidable (e.g. fugitive methane emissions). Direct air capture (sucking carbon dioxide directly from the atmosphere) also helps to remove historic emissions and contributes to achieving net negative emissions as demanded by various IPCC scenarios[12].

There is also growing interest in both compliance carbon markets as well as voluntary carbon markets. 83% of national contributions from the 2015 Paris Agreement state the intent to make use of international market mechanisms to reduce greenhouse gas emissions[13]. According to McKinsey & Co, the number of companies with net-zero pledges doubled from 500 in 2019 to over 1,000 in 2020 and expects the carbon market to be worth $50B in 2030.

Figure 5: Projected increase in voluntary demand for carbon credits, gigatons per year for various demand scenarios[14].



---

[12] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_5_Ch5_CCS.pdf

[13] https://www.wri.org/insights/understanding-ndcs-paris-agreement-climate-pledges

[14] https://www.mckinsey.com/business-functions/sustainability/our-insights/a-blueprint-for-scaling-voluntary-carbon-markets-to-meet-the-climate-challenge

Unique Opportunity for Electrochemistry and Advanced Materials

Electrochemistry : the study of the relationship between electricity and chemical reactions.

Advanced materials : those materials that possess novel or unique properties or exhibit greater mechanical, thermal, electrical, optical, and chemical properties, relative to traditional materials.

Today we burn fossil fuels, primarily oil and gas, by reacting them with oxygen to release chemical energy in the form of pressure and heat. These fossil fuel technologies which power our world today (i.e., engines, power plants and furnaces) predominately harness thermodynamics. By burning fossil fuels to release the desired energy, CO_2 is emitted contributing to rising atmospheric CO_2 levels.

With the precipitous decline in the cost of installing and using renewable energy our society is rapidly becoming electrified. Electricity is becoming the carrier of clean energy as all major sources of renewable energy (e.g., solar and wind) produce electricity. Electrochemical technologies use electricity (i.e., moving electrons) to manipulate atoms allowing us to store, distribute and use energy. Effectively these technologies are the key to harnessing renewable energy and doing useful things with it in society. We believe these technologies, which will form the bedrock of a climate neutral energy system, will predominately harness electrochemistry.

New electrochemical technologies are underpinned by synergistic developments in advanced materials. The safe, high-energy lithium-ion battery was created and refined partly due to several advanced material innovations. As another example, the membrane which is present in commercial low temperature fuel cells today, was made possible by the invention of a durable and ionically conductive polymer called Nafion by DuPont in the 1960s[15].

As new energy technologies are fundamentally physical, advanced materials will enable the next wave of economical energy products and services by:

- Making products more durable, energy efficient and lower cost
- Improving product or systems performance and enabling new features
- Enabling regulatory compliance and sustainability without sacrificing performance
- Lessening domestic dependence on imports of critical minerals

Investing in electrochemistry and advanced materials, versus other branches of applied sciences, offers potential for outsized returns for the following reasons:

1. Ubiquity of applications across hydrogen, carbon capture and energy storage
2. Opportunity for applications in adjacent hard-to-decarbonise sectors
3. Electrochemical technologies are primed for scale
4. Increasing volume of research and talent in the field

In the following sections we'll dive into each of these areas.

---

[15] https://www.chemeurope.com/en/encyclopedia/Nafion.html

The ubiquity of applications across hydrogen, carbon capture and energy storage

We are seeing a tidal wave of electrochemical innovations emerging with promising applications across hydrogen, energy storage and carbon capture. In ground transportation the two principal technologies, namely batteries and fuel cells, are both electrochemical technologies. For utility-scale energy storage, 7 of 11 technology pathways for energy storage considered by the IEA require electrochemical technologies[16]. Electrochemistry also offers opportunities to extract key minerals, such as cobalt, nickel and lithium, or to recover these minerals from spent batteries or mine tailings.

Electrochemical technologies are key enablers for the hydrogen value chain. In production, hydrogen can be produced by electrolysis which splits water into hydrogen and oxygen using electricity. Virtually all technology pathways for producing clean hydrogen include electrolysis or carbon capture. Another electrochemical technology called photoelectrochemical water splitting enables hydrogen to be produced spontaneously from water using direct sunlight. Electro fuels (e-fuels) are an emerging class of 'drop-in' replacement fuels that are formed by using electricity to combine the hydrogen molecules in water with the carbon in CO_2. Hydrogen, or hydrogen-derived fuels such as methanol and ammonia, can be converted back into energy using fuel cells to provide power to heavy vehicles or provide stationary power. In carbon capture, there are viable electrochemical pathways to capture and convert CO_2 into synthetic fuels, such as methanol or jet fuel, when combined with water or hydrogen. For example, electrolysis can be used to convert CO_2 emissions into high-purity carbon monoxide as a feedstock chemical or intermediate substance for the chemical industry.

---

[16] https://iea.blob.core.windows.net/assets/80b629ee-597b-4f79-a236-3b9a36aedbe7/TechnologyRoadmapEnergystorage.pdf

Growing opportunity for applications in adjacent hard-to-decarbonise sectors

Electrochemical technologies also have applications across the production of cement, fertilizer, steel, and plastics. In 2019, a low-temperature method was discovered to use electrolysis to produce precursors of cement. Electrochemical routes are now within reach to compete with the industry standard Haber–Bosch reaction to produce ammonia, the key feedstock for fertilizer, as well as offering an alternative production method for precursors used by the plastics industry.

Electrochemical technologies also offer economically viable opportunities to produce green steel. In one pathway the initial production of iron can be enabled by electro generation of both carbon monoxide and hydrogen, rather than current methods which consume vast amounts of energy and are a major contributor to CO_2 in the atmosphere. In another pathway, a high-temperature electrolysis technology can remove the need for coal in steel production.

Electrochemical technologies are primed for scale

Electrochemical technologies are not new. The lithium-ion battery, which forms the building block of electric vehicles and is present in all mobile phones, is intrinsically an electrochemical technology. The accelerated production of sophisticated miniaturised mobile electronic devices has motivated and stimulated the development of advanced batteries with high performance and low cost. Lithium-ion batteries have been the main focus of R&D efforts since the 1980s which we believe has been driven by the demand from the consumer electronics industry where there is no viable alternative. However, lithium-ion battery production today represents just 0.0003% of the global energy consumption at 0.5 TWh in 2020[17]. The plummeting cost of these technologies and increasing performance have now

---

[17] https://www.eia.gov/todayinenergy/detail.php?id=49876

reached a point where they can compete commercially with internal combustion engines in vehicles and are being considered for grid energy storage (i.e. load-levelling applications).

Other electrochemical technologies have already been commercially proven at an industrial scale. Today, established industrial electrochemical processes include the production of sodium hydroxide via the chloralkali process (sodium hydroxide is a feedstock for manufacturing paper, aluminium, and detergents) and the manufacture of aluminium globally via electrowinning. The automotive industry today also uses an electrochemical technology to coat parts. The chloralkali process uses an electrolyser and this process is widespread in industry. In 2010, the European chloralkali industry consumed 35 TWh of energy or 1.2% of the total European energy demand[18]. Thyssenkrupp alone has deployed 600 Chlor-alkali electrolysers worldwide[19].

The technology understanding developed in the lithium-ion battery industry and existing electrochemical processes has cross-pollination to new technologies, which have similar underlying characteristics and engineering challenges. This will speed up new technology developments. Electrochemical technologies are also inherently versatile, have high energy efficiency, are modular and are amenable to automation. This makes them viable for widespread deployment and scale. These technologies are environmentally compatible as they use the electron as a “clean reagent” where the electricity supplements the need for harsh or unsustainable chemicals.

---

[18] https://www.eea.europa.eu/data-and-maps/indicators/overview-of-the-electricity-production-2/assessment-4

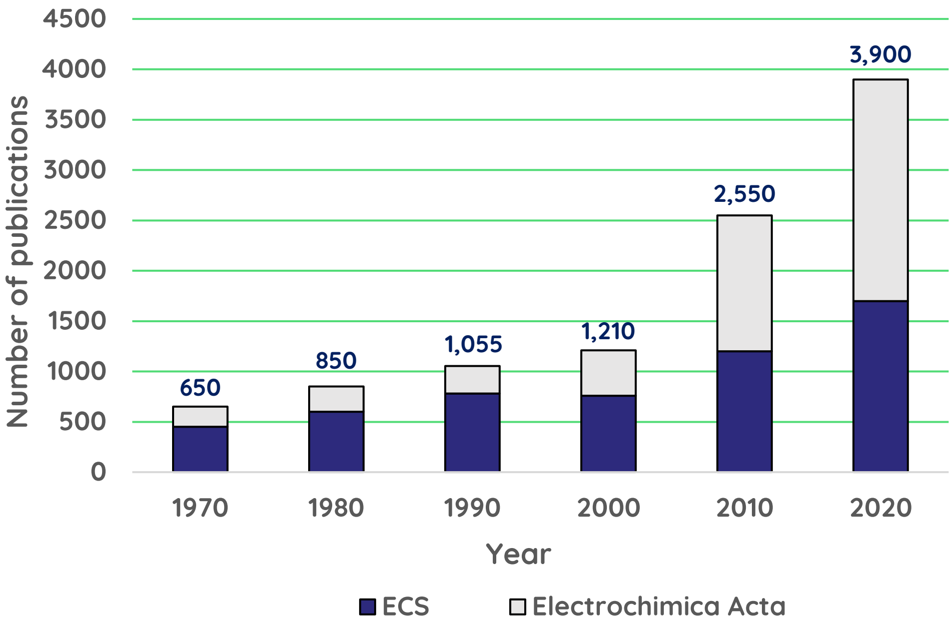
[19] https://ucpcdn.thyssenkrupp.com/_legacy/UCPthyssenkruppBAISUhdeChlorineEngineers/assets.files/products/chlor_alkali_electrolysis/thyssenkrupp_chlor_alkali_brochure_web.pdf

Increasing volume of research and talent in the field

According to the IEA, half of global emissions reduction by 2050 is expected to come from technologies which are still in the early stages of development. Major technology innovations are required this decade to address this challenge. There is significant growth in electrochemical research and development in the past years, as shown in Figure 6. This presents ever growing opportunities to invest in technology breakthroughs yet to be commercialised.

We also expect that the talent developed in the lithium-ion battery industry, primarily driven by electric vehicle growth, will create tailwinds in the space. As the characteristics of electrochemical systems are similar this high-calibre talent will contribute to the next wave of businesses applying electrochemical technologies to solve other energy system problems.

Figure 6: Number of academic publications from major electrochemistry journals: Journal of The Electrochemical Society (ECS) and Electrochimica Acta (20, 21).



---

[20] https://exaly.com/journal/12457/electrochimica-acta/articles

[21] https://exaly.com/journal/12429/journal-of-the-electrochemical-society/articles

Looking Ahead

The way we distribute, use and store energy must change. This task is rivalled in magnitude only by the last industrial revolution. However, we remain optimistic as this next decade will be exciting in the energy sector. Specifically, electrochemistry alters the fundamental rules. It allows us to bend energy to our will in more diverse ways than ever before.

It is with this backdrop, we are pleased to share how we’re thinking about this new era of energy, The Age of Electrochemical Power. While these technologies are by no means a silver bullet, they will form the central technology hub required to deliver climate neutrality. To meet our climate targets, we need to develop and deploy these technologies faster than ever before. To go faster we must build an ecosystem around these technologies. We hope to engage the community, connect with electrochemists, engineers, and investors, and get feedback.

As such, we will continue to share our thinking on specific areas of the electrochemistry landscape from electrolysers to alternative metal ions, as well as unpack mineral supply and solid-state batteries. We encourage you to reach out if you're building or using electrochemical technology and join the broader discussion.

About Energy Revolution Ventures

Energy Revolution Ventures has established itself as one of the premier venture capital investors in pre-Seed, Seed & Series A+ start-ups, developing scalable technologies within the electrochemical ecosystem. ERV leverages years of experience of its shareholders turning energy and battery technologies into successful, publicly traded businesses. ERV has a deep understanding of the fundamental technology behind innovations as well as risks to scale and commercialisation. ERV is an active investor, supporting founders and innovators functionally and at the board level.

Contact

Marcus Clover
14 Old Queen Street
Westminster
London
SW1H 9HP

Published in November 2022

Disclaimer

This document may not be disseminated, distributed or used without the prior written consent of H2E Consulting Limited (100% subsidiary of Energy Revolution Ventures Limited) and Sapia Partners LLP (the “Companies”). This document is a summary and is not an offering or a solicitation of an offer to purchase an interest. Any such offer or solicitation will be made to Professional investors only by means of a confidential private offering memorandum and related offering materials, and only in those jurisdictions where permitted by law. Such offer or solicitation may only be made by means of delivery of that document which contains important information (including investment objective, policies, risk factors, fees, tax implications, and accredited investor qualifications) relating to such investment product or fund. There is no guarantee that the investment objective will be achieved. Moreover, the past performance of the investment team should not be construed as an indicator of future performance. Without limitation, this document does not constitute a recommendation to enter into any proposed transaction or investment. You should not construe the contents of this document as legal, tax, investment or other advice. By accepting this document, you acknowledge that the Companies are not acting as your broker, financial advisor, in any other fiduciary capacity or otherwise as your advisor or agent with respect to transaction or investment. The information contained in this document is based on material that Companies believe to be reliable. Assumptions, estimates and opinions contained in this document constitute information we received from reliable sources as of the date of the document and are subject to change without notice. Neither the Companies or any of their respective officers, directors, employees, agents, controlling persons or affiliates makes any representation or warranty, expressed or implied, as to the accuracy or completeness of the information contained in this document, and nothing contained herein is, or shall be relied upon as, a promise or representation, whether as to past or future facts or results. The market analysis, projections, targeted returns, estimates and similar information, including all statements of opinion and/or belief contained in this document (collectively, “forward-looking information”), are subject to inherent uncertainties, contingencies and qualifications and are based on a number of assumptions. Forward-looking information involves significant elements of subjective judgment and analysis that may or may not be correct. This document is for Professional Investors Only.

H2E Consulting Limited is an Appointed Representative of Sapia Partners LLP, which is authorised and regulated by the Financial Conduct Authority.