Advent Technologies
(ADN US)

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11 May 2021
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Price ($)	10.9
Shares in issue (m)	46
Mkt Cap ($m)	501
Net debt ($m)	-1
EV ($m)	500
BVPS (c)	-1.8

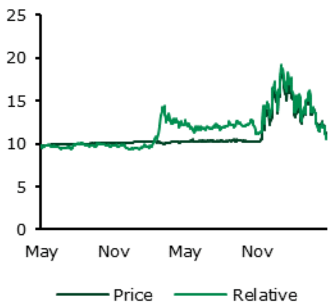
Share price performance	
1m	-20.7%
3m	-30.7%
12m	6.8%
12 m high/low	19.2/10.1
Ave daily vol (30D)	560,365

Shareholders	
Gregoriou Vasilis	11.9%
Kaskavelis Christos	8.0%
Invesco Ltd	5.2%
De Castro Emory	4.6%
BNP Paribas	4.0%
Neptune Intl Ag	3.9%
Vanguard Group	3.4%
Davidson Kempner	2.8%
Shaolin Capital	2.4%
A Charalampos	2.2%
Total for top 10	48.3%
Free float	67.9%

Next news Ints Q3

Business description

Membranes and MEAs for fuel cells, electrolysers, flow batteries and sensors.



Unlocking the Hydrogen Economy

Advent Technologies offers exposure to the next generation of hydrogen technology and is already selling a viable product today. The NASDAQ listing brings fresh capital giving it firepower to develop new sales opportunities and the signing of a development agreement with the US Department of Energy puts it at the forefront of fuel cell development globally. We initiate coverage with a central valuation of $20 per share.

A better hydrogen technology

Advent makes core technology for proton exchange membrane (PEM) fuel cells. PEM fuel cells are the go-to technology for hydrogen vehicles which are the leading option to decarbonise long-range heavy-duty travel. Unlike other PEMs, the Advent product operates at a high temperature. This allows it to run on any fuel and to operate in any environment. Additionally, with no water management issues, Advent cells can last longer than other PEMs.

Multiple markets creates diversity

These benefits are also available for other membrane-based applications including PEM electrolysers, flow batteries and gas sensors. The company is already selling viable products to a number of strong clients with sales in portable power, off grid power, aviation, automotive, flow batteries and IoT markets. Clients include the Department of Defense, Nissan and Safran.

Leading the learning curve

Advent is the chosen partner of the Los Alamos, Brookhaven and NREL National laboratories to develop the next generation of membranes which have the potential to deliver a PEM fuel cell with 90% less platinum. With applications in both PEM fuel cells and PEM electrolysers, Advent is leading the hydrogen learning curve downwards. By leading on both technology and on costs Advent can put itself at the forefront of the industry and build share from the competition.

Central case valuation at $20 per share

Our central case valuation of Advent puts the shares at $20/share. Even a low case, assuming limited progress beyond niche applications delivers $13/share and a case assuming market dominance with the second-generation product sees a value of $52/share. The key risks to our valuations are failure to gain commercial traction, development setbacks on the next generation product, competition, and any stalling of the hydrogen economy.

$,000 Dec	2019a	2020pf	2021e	2022e	2023e	2024e
Sales	1,222	1,089	14,709	27,077	60,000	122,800
EBITDA	-159	-4,139	-17,158	-16,265	-3,500	21,800
PBT	-270	-4,193	-17,410	-17,403	-5,518	17,700
EPS	-0.8	-9.1	-37.8	-37.7	-12.0	28.0
CFPS	-0.6	-5.7	-79.0	-64.6	-42.0	-48.0
DPS	0.0	0.0	0.0	0.0	0.0	0.0
Net Debt (Cash)	-699	-134,310	-98,385	-68,963	-49,852	-27,915
Debt/EBITDA	4.4	32.5	5.7	4.2	14.2	-1.3
P/E	-14.0	-1.2	-0.3	-0.3	-0.9	0.4
EV/EBITDA	-3149.3	-88.6	-21.4	-22.5	-104.8	16.8
EV/sales	409.3	336.5	24.9	13.5	6.1	3.0
FCF yield	-5.3%	-52.3%	-727.5%	-595.0%	-386.8%	-441.8%
Div yield	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

INVESTMENT SUMMARY

A materials science company unlocking the hydrogen economy

Advent Technologies is a materials science company which develops and produces proton exchange membranes (PEMs) and membrane electrode assemblies (MEAs). These are key components in fuel cells, electrolysers, and flow batteries. The membranes also have applications in gas sensing.

A working HTPEM and MEAs for fuel cells and more

Advent has successfully developed a high temperature proton exchange membrane (HTPEM). PEMs are the key building block for fuel cells for transport applications as well as use in off grid and backup power supply. Advent's HTPEM improves on low temperature PEMs by being able to take any fuel and to operate in any conditions. It also has a major cost advantage.

Already shipping product

Advent is already selling membranes and MEAs to developers of applications from portable power supplies to automobiles. Clients include the Department of Defense, Nissan and Safran. Advent HTPEMs have applications in fuel cells, electrolysers, flow batteries and gas sensors. The company is now selling into three out of these four areas.

A seat at the top table of fuel cell development

Advent is the chosen partner of the Los Alamos, Brookhaven and NREL National Laboratories to develop the next generation of PEMs. This work will build on the existing technology and the technology roadmap is already very advanced. The agreement formalises a long working history between Advent with the company formally partnering with the Los Alamos L'Innovator programme in 2019.

Leading the learning curve

The development work is targeting a reduction in the platinum catalyst of 90% and as a result Advent is targeting an MEA cost of $80/MW down from over $500/MW today. The company is confident of being able to commercialise the technology, bringing products to the market in 2022 and scaling up to mass production in 2023. The development of the hydrogen economy depends on such cost reductions and by leading these, Advent can be seen as a genuine disruptor of this market.

Substantial market opportunities

Increasingly governments are committing to a Paris aligned net zero outcome by 2050. To meet these goals, we estimate a total addressable market in fuel cells alone of 2TW. While adoption will be slow and Advent will face competition, even a 5% market share of the PEM MEA market should value the company at $20 per share in our view. If the company can use its technology to deliver an eventual 20% share our valuation rises to $52. Even if only niche opportunities can be found we think the shares are still worth $13.

Bull points

- A better hydrogen technology
- Partnered with the top national laboratories
- Next generation product in market by 2023
- Resourced to develop the full business potential

Bear points

- Next generation product not commercial yet
- Traction may take time to build
- Competing technologies

Catalysts

- Product development success
- Evolution of sales pipeline

Valuation

Given the early stage nature of most companies in the hydrogen space, it is difficult to draw too much conclusion from comparative multiples. We have used a DCF methodology to value the company with a central case assuming that the company can retain a 5% market share of its addressable market across fuel cells, sensors with some electrolyser and flow battery sales. This suggests a valuation of $20 per share putting the company on a FY 23 EV/Sales ratio of 13x, in line with a group of PEM based peers. A more cautious case which assumes no real growth beyond a niche provider gives a value of $13 per share. If the company can use its technology to build a leading market position, we can see a valuation of $52 per share.

DCF Scenarios

	Markets	Long term market share	DCF
Low case	Fuel cells and sensors	5%	13
Central case	Fuel cells, sensors, electrolysers and flow batteries	5%	20
High case	Fuel cells, sensors, electrolysers and flow batteries	20%	52

Source: Longspur Research

Risks

The key risks to our valuations are failure to gain commercial traction, development setbacks on the next generation product, competition, and any stalling of the hydrogen economy. Failure of commercial traction is often driven by a lack of marketing effort making this less of a risk and more of a performance issue. In the case of Advent, a CMO at board level and the fact that commercial sales are already evident suggests any risk here is manageable in our view. Development setbacks for the next generation of the technology remain a risk but given that the current role Advent is playing here is the final commercial development stage, the technology itself appears to be in a good place. Competition from existing LT PEM providers will continue but we see Advent's technology as conferring competitive advantage. Finally, policy is always a risk but there does appear to be a clear momentum in support of the hydrogen economy.

ADVENT - COMPANY INTRODUCTION

Advent Technologies is a materials science company which develops and produces proton exchange membranes (PEMs) and membrane electrode assemblies (MEAs). These are key components in fuel cells, electrolysers, and flow batteries. The membranes also have applications in gas sensing.

Advent's proprietary membranes are high temperature PEMs (HTPEMs) which give them significant advantages over alternatives. PEMs are based on a polymeric electrolyte which is proton conducting with the most common available being Nafion from Chemours (formerly DuPont). Conventional PEMs use water containing polymers as the electrolyte which allows the proton conduction. Because water boils, PEMs cannot be used above about 80°C. Advent's HTPEM is based on polymers doped with phosphoric acid which allows operation at temperatures of up to 200°C. This allows faster chemical reactions, higher efficiencies, and better tolerance to fuel impurities. Rapid reactions also mean faster starts and shutdowns making them ideal for transport and other applications requiring rapid changes in supply.

HTPEMs were originally developed by chemical major BASF. Original designs suffered from migration of the phosphoric acid leading to decreased performance and corrosion issues. Advent has solved these issues and the current offering has a life of 20,000 hours without significant degradation.

STRONGLY EXPERIENCED

The Advent team includes highly experienced materials scientists with both the CEO and CTO showing strong CVs in this area. CEO Vasilis Gregoriou has degrees from Duke and Princeton as well as having worked for Polaroid and at MIT. Emory de Castro has degrees from Duke and Cincinnati and is a recipient of the Department of Energy Award for Manufacturing R&D for his work on fuel cell components. His professional experience includes roles with electrode developer De Nora and with BASF. The team began developing fuel cell technology in 2003 and incorporated the business in 2012.

Key developments

Date	Announcement
2003	Development of initial fuel cells
2011	Advent TPS Introduced
2012	Incorporate in USA Seed Round
	Projects with NASA, ESA, DoE
	Consolidate membrane technology; BASF license
2013-2016	UltraCell renews multi-year supply contract
	License advanced stack technology from EnerFuel
2018-2019	US Navy purchases stacks
	Stealth IoT company begins program with Advent
	SAFRAN expands program
	Collaboration with US DoE Los Alamos, Brookhaven labs
	Palcan signs MEA supply agreement
	ESS signs component supply agreement
2020	EV manufacturer engagement, scale up fundraising.

Source: Advent Technologies

The company now has over 120 patents and considerable manufacturing know-how with manufacturing sites in the US and in Europe. This is a developed technology with the company already making commercial sales to a number of high-profile customers. The team is not just scientists with CFO Bill Hunter and CMO Chris Kaskavelis bringing financial, industrial and marketing experience to the business.

WELL RESOURCED

Advent develops, manufactures, and sells HTPEMs and MEAs. It also develops and licences high temperature fuel cells and complete systems, licencing to system integrators, tier one suppliers, and OEMs. It develops, manufactures, and sells the key proton exchange membranes themselves and also membrane electrode assemblies which are the key building blocks of fuel cells. The company also works with fuel cell developers to develop cells and complete systems, taking a licence fee in addition to membrane and MEA revenues.

Advent developed, manufactured and sold

High-Temp PEM Membranes	Membrane & Electrode Assembly ("MEA")
• Next generation electricity conducting plastics that can operate at 160+oC	• MEA is the "heart of the fuel cell"
• Significantly enhances capabilities and performance of fuel cells and other clean technology systems	• Analogous to Li-ion cell for the battery industry

Source: Advent Technologies

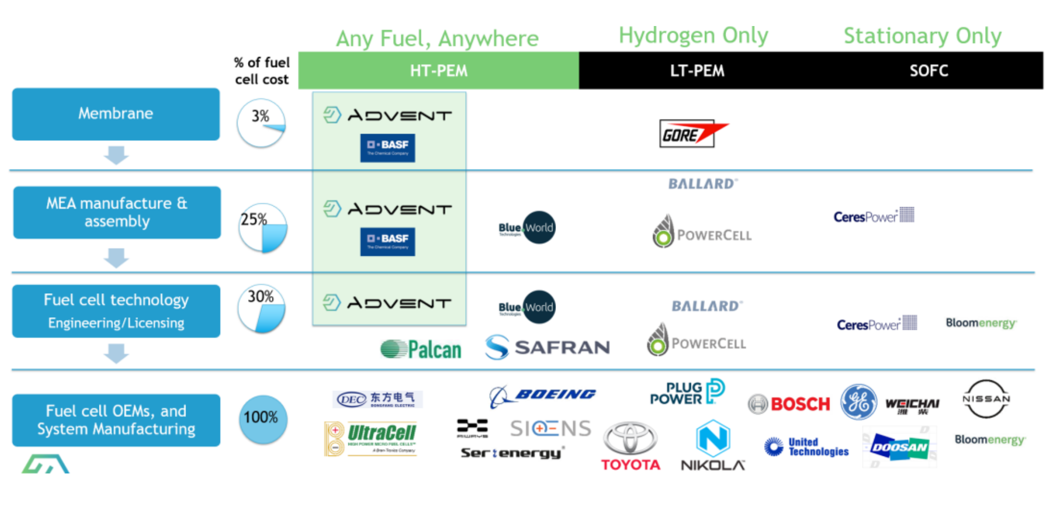
Advent developed and licenced

High-Temp Fuel Cell	Complete Systems
• Fuel-flexible fuel cells that significantly reduce need for hydrogen infrastructure	• Leverage MEA technology with a matched fuel cell and license to system integrators, Tier 1s and OEMs
• Enter into joint development programs with partners	• IP in design, cooling, testing and optimization
• Intend to scale-up production for mobility (auto, aviation) and stationary (off-grid, portable, security, charging station) markets	

Source: Advent Technologies

The company aims to forge strategic alliances with OEMs and Tier 1 manufactures to build solutions specific to the clients' needs. In this way it can build strong relationships which in time are likely to build sustainable earnings streams. Within the fuel cell value chain, Advent dominates the upstream end of the HTPEM chain.

Where Advent sits in the fuel cell value chain



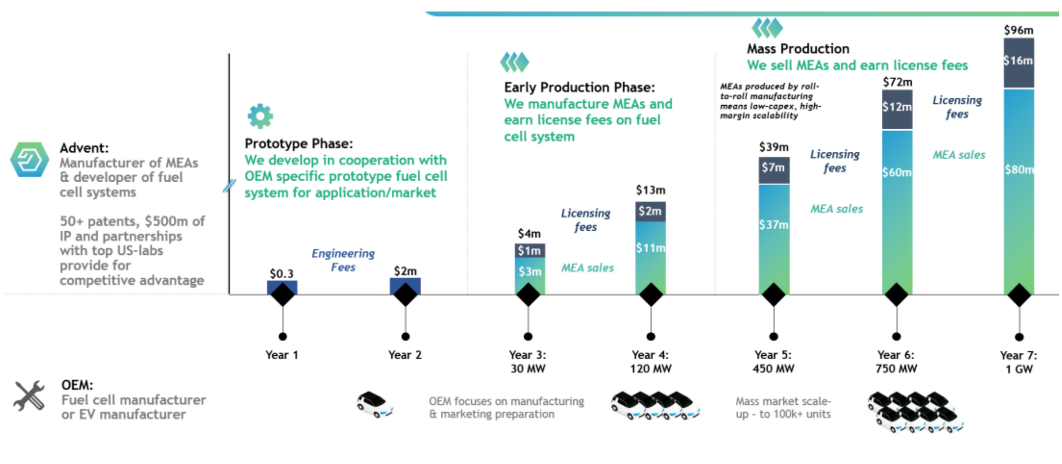
Source: Advent

BUSINESS MODEL ALLOWS MAXIMUM GROWTH FOR LIMITED CAPEX

As a provider of core technology, Advent enters into long term partnerships with its customers. It essentially has two roles; as a developer and as a manufacturer. As a developer the company receives engineering fees and licence income. As a manufacturer it receives income from the sale of MEAs. Of course, these sales are symbiotic with the development role which drives business to MEA manufacturing.

A typical relationship will start with a protype phase where Advent works with an OEM to specify a fuel cell system for a particular application and market. The company will monetise this relationship through engineering fees. Once the final product enters production, Advent will manufacture and sell MEAs and also take a licence fee for providing the technology. At a point, production will reach a level where mass manufacturing becomes appropriate. Advent will continue to supply MEAs but will move to high volume roll-to-roll processes with low capex implications and high margin scalability. Advent will also continue to earn licence fees.

The Advent business model



Source: Advent Technologies

BEYOND FUEL CELLS

Advent membranes and MEAs are used in fuel cells, flow batteries, electrolysers and gas sensors. Fuel cells, flow batteries and electrolysers are all electrochemical devices making use of reduction-oxidation (redox) reactions. All have a cell design with electrodes and electrolytes, and separate proton and electron flows, either consuming electricity in the case of an electrolyser, producing it in the case of a fuel cell or both in the case of a flow battery.

The use of proton exchange membranes is one of the most efficient designs for all of these devices and allows flexible and responsive products well placed to meet the needs of their various applications. The limitations of PEMs is also an issue for all of these and therefore the Advent HTPEM which overcomes these limitations has clear potential in all these areas.

Flow Batteries

Advent is already supplying ESS Inc with material for its iron flow batteries. These have the potential to offer a lower cost flow battery than the incumbent vanadium based technology. Early issues have been overcome and in 2019, ESS secured insurance cover for its products from Munich Re supporting the system performance of its flow battery. Advent MEAs can also be used with other flow battery technologies bringing performance improvements and lowering costs.

Electrolysers

Electrolysers are the key to producing low carbon "green2 hydrogen and the demand for this is potentially greater than for fuel cells given the wider application of hydrogen beyond transport and power. PEM electrolysers have a higher capital cost than the rival alkaline technology but are faster acting and therefore more suitable for combining with intermittent renewable energy. Electrolyser manufacturer NEL (NEL NO) predicts cost parity by 2030 but because balance of plant costs for alkaline are greater than PEM we see this point being reached sooner. With Advent technology this could be much sooner. Advent is also currently working with partners on electrolyser technology that can directly use salt water for hydrogen production.

Gas sensors

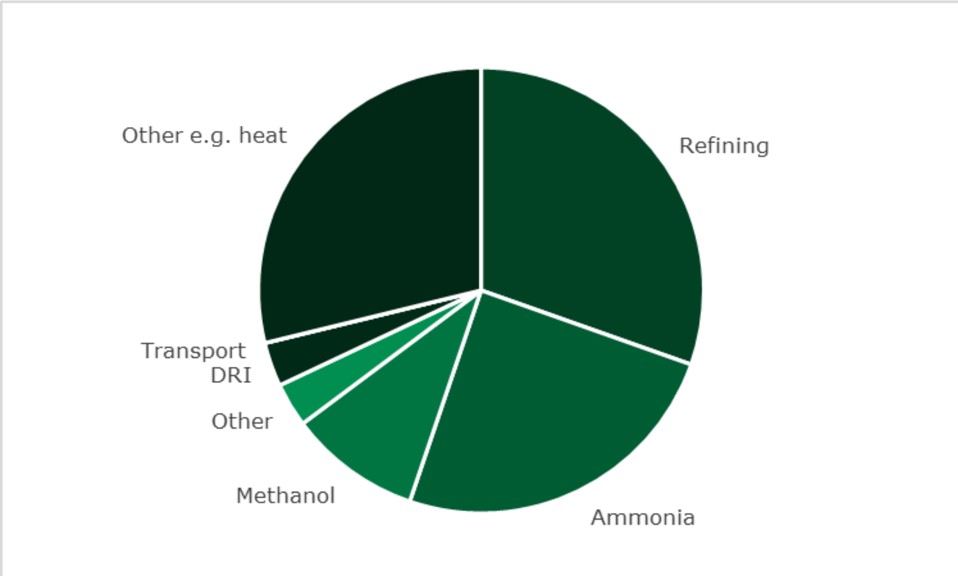
Advent membranes can be used to create miniature gas sensors with applications in pollution detection, health screening and wider IoT uses. Advent's high temperature product means it can be surface mounted making it ideal for inclusion in smart phones and Korean and Chinese phone OEMs are looking to implement the technology in the current year.

By having multiple products and markets, Advent diversifies its risk. For example, early progress on sensor sales has brought useful revenue while key fuel cell customers are developed.

WHY HYDROGEN?

A hydrogen economy already exists. The world currently produces 50Mt of annually, primarily used in the refining industry and for the production of ammonia and methanol.

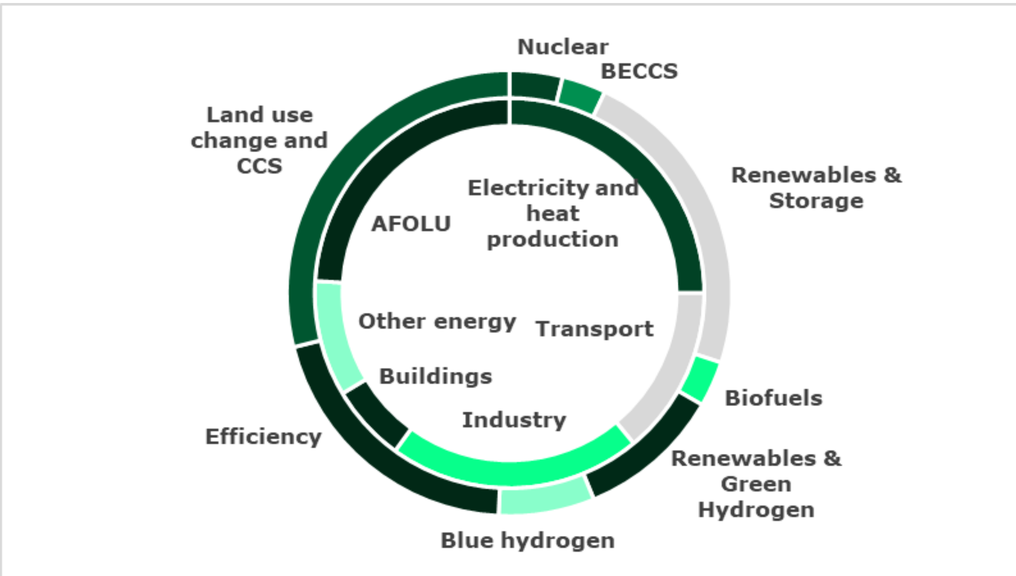
Current uses of hydrogen



Source: Hydrogen Council

Hydrogen is also a key tool in cutting greenhouse gas emissions. It can help decarbonise industries such as steel and cement production. It provides a transport fuel for heavier transport solutions where lithium-ion batteries lack power and range. It can be used to provide power and also as an electricity storage solution. In this regard it can offer solutions including frequency management and balancing nuclear. Finally, it can be used for heating. Our analysis of the IPCC's 1.5ºC pathways suggest that hydrogen can be a major part of the decarbonisation toolkit, potentially removing 17% of current greenhouse gas emissions.

Global Emissions and Solutions

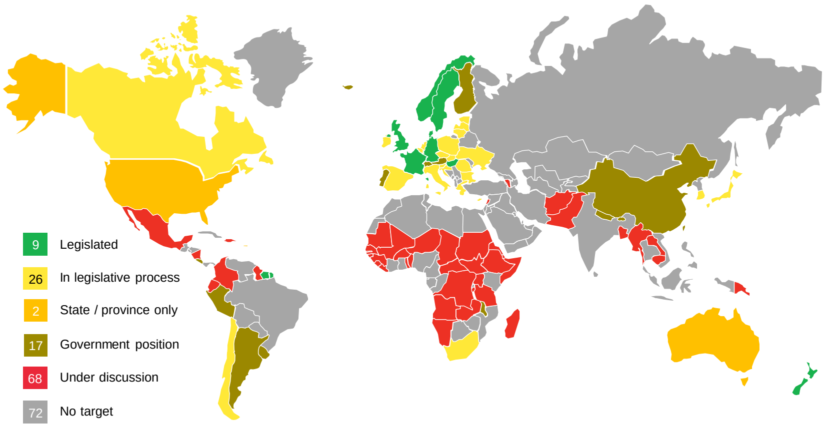


Source: IPCC, Longspur Research

POLICY DRIVING HYDROGEN

Policy is now driving the hydrogen economy, and this is itself being driven by the realisation that hydrogen is essential to achieving net zero emissions and prevent the worst damage from climate change. 28 countries now have climate neutrality targets representing over 60% of global CO_2 emissions.

Countries with net zero emission targets

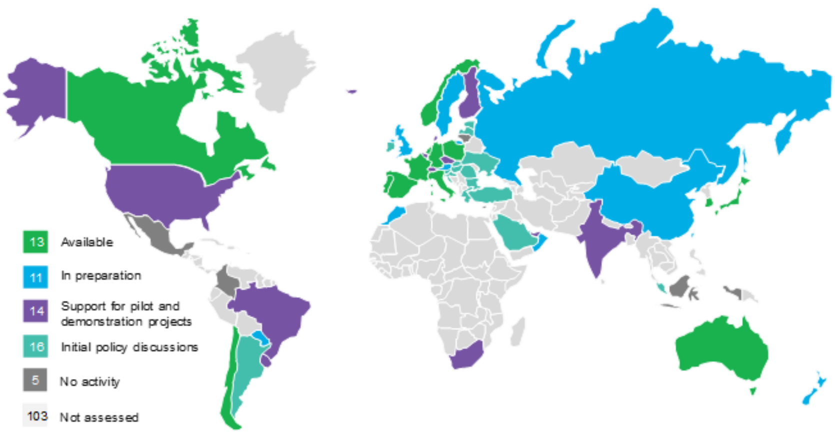


Source: Bloomberg New Energy Finance

There are a number of key industries where hydrogen is the most viable solution to decarbonisation. Once adopted as a solution in one such area, other uses become more viable expanding the potential market. The ubiquity of hydrogen has seen it described as a Swiss army knife of emission reductions.

Eleven countries now have hydrogen policies in place. The US has recently signalled that it will set a goal to reduce the cost of renewable hydrogen by 80% by 2030.

Countries with hydrogen policies



Source: Bloomberg New Energy Finance

Also notable here is China which sees a major role for hydrogen mobility. The country is currently drafting proposals said to cover the period of the 14th five-year plan to 2025 and with a strong focus on the fuel cell industry.

The EU's hydrogen roadmap is calling for 40GW of electrolyser capacity by 2030 with Chile looking for 25GW and Australia 8GW in the same timeframe.

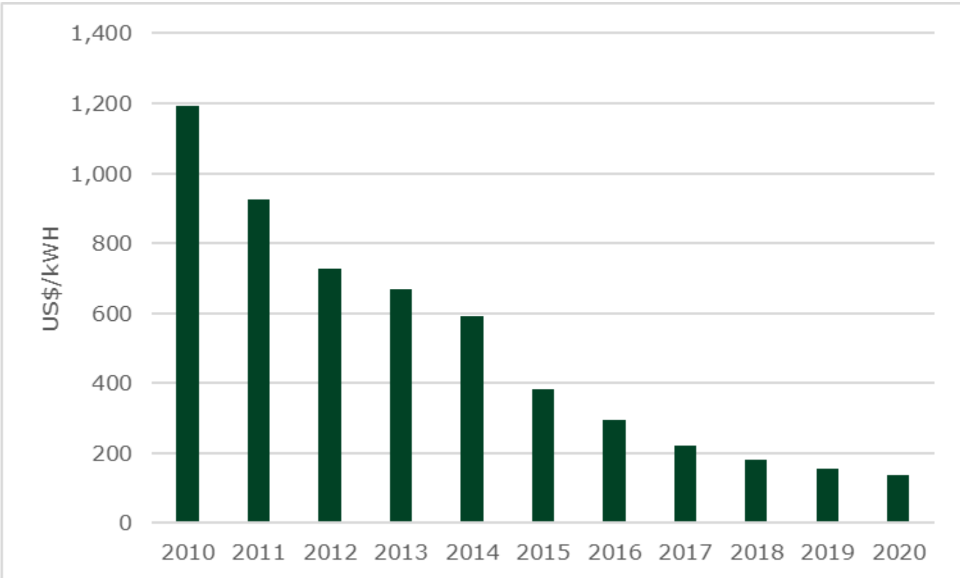
WHY FUEL CELLS?

Fuel cells are the most efficient way to convert hydrogen into electricity and have a form factor that makes them the only valid solution for hydrogen-fuelled transport other than shipping. Hydrogen-fuelled transport should not be seen as being in competition with lithium ion but rather augmenting it and taking off where lithium ion falls short.

Lithium ion and transportation

Lithium-ion batteries have allowed battery electric vehicles to emerge as a valid solution to low carbon transport. Costs have fallen and energy density (which drives vehicle range) has risen. Battery electric vehicles (BEVs) are likely to be the go-to decarbonisation solution for passenger cars and light duty commercial vehicles especially for urban duty cycles.

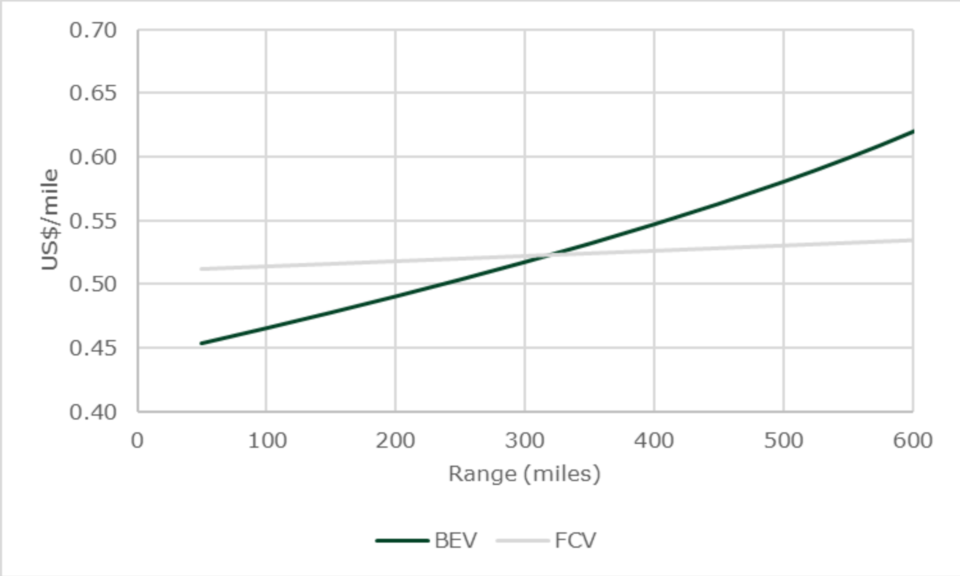
Lithium ion battery pack prices



Source: BNEF

Batteries are already making strong inroads towards decarbonising transport but are limited by the way they scale with range. Physically the only way to get greater range with a battery is to add weight in a linear manner. As a result, efficiency falls off by comparison with traditional fossil fuelling or hydrogen fuel cell vehicles. The graph below from Bloomberg New Energy Finance shows their estimates of the cross over point for a heavy-duty truck in a supportive policy environment for hydrogen. This suggests that at ranges over 300 miles a fuel cell is a better option.

Total cost of ownership class 8 heavy duty truck (strong policy)



Source: BNEF

This is worsened for heavier, more powerful applications. We are already seeing a move by Chinese bus OEMs to make use of fuel cells notably for longer distance buses. There is also interest in trucking, including mining, and in areas such as forklift trucks and logistics vehicles, including airport or port service vehicles. All of these benefit from the fact that they can be fuelled at their depots without the need for a hydrogen infrastructure.

Commercial vehicle energy sources compared

Vehicle Type	Distance	Weight	Charge/Refuel Time
Diesel	500 mile	45,000lb Payload 35,000lb Unloaded	5 Minutes
Battery	125 mile	44,000lb Payload 36,000lb Unloaded	3 Hours
	500 mile	34,600lb Payload 45,400lb Unloaded	11 Hours
Fuel Cell	150 mile	45,000lb Payload 35,000lb Unloaded	5 Minutes
	500 mile	42,600lb Payload 37,400lb Unloaded	15 Minutes

Source: Plug Power

We think lithium ion is already testing its limits for transportation. The new Porsche Taycan was originally promoted with a 350kW charger but following feedback from battery supplier LG Chem have downgraded this to 270kW. For Porsche, performance over the life of the vehicle is important and battery degradation due to overly rapid charging is an issue.

New battery technologies can overcome issues but not quickly or completely.

New battery technology can push these limits out in time, with silicon anodes and solid-state electrolytes the most likely areas of progress. However, electrochemistry is a difficult area and we do not expect new technologies in mainstream applications overnight. As a result, we see alternative solutions, notably those based on hydrogen, gaining ground especially in long range and high-power applications.

There is debate about the extent to which fuel cell vehicles will from part of the energy transition, but we note that Chinese policy in particular is supportive, focusing on the fuel cell supply chain and developing hydrogen powered trucks and buses with a target of 1m fuel cell vehicles on the road by 2030.

We see the debate between batteries and hydrogen as rather simplistic with its assumption that there can be only one solution. This is not a VHS/Betamax analogy. A better guide would be fossil fuel propulsion where the automobile industry has lived with two competing technologies co-existing side by side for about a hundred years; the spark ignition petrol engine and the compression ignition diesel engine.

In fact, this type of false dilemma is even true of VHS/Betamax where after losing out to VHS in the consumer market, Betamax developed into Betacam and went on to dominate the profession broadcast market until the arrival of digital technologies.

TRANSPORTATION SPLITS BETWEEN SHORT HAUL AND LONG HAUL

As a result of lithium-ion limitations, we see most transport markets being split between long-range heavy-duty applications and short-range light duty ones. For almost all short-range applications battery electric vehicles are the obvious answer. This will of course need to be matched by an increase in renewable generation to provide the low carbon electricity to charge these batteries and for a significant investment in charging infrastructure including grid reinforcement.

This makes lithium-ion batteries the go-to solution for most domestic vehicles and light goods vehicles. For longer range applications we think hydrogen is the most suitable solution with the exception of long-haul aviation where we think biofuels are really the only viable option.

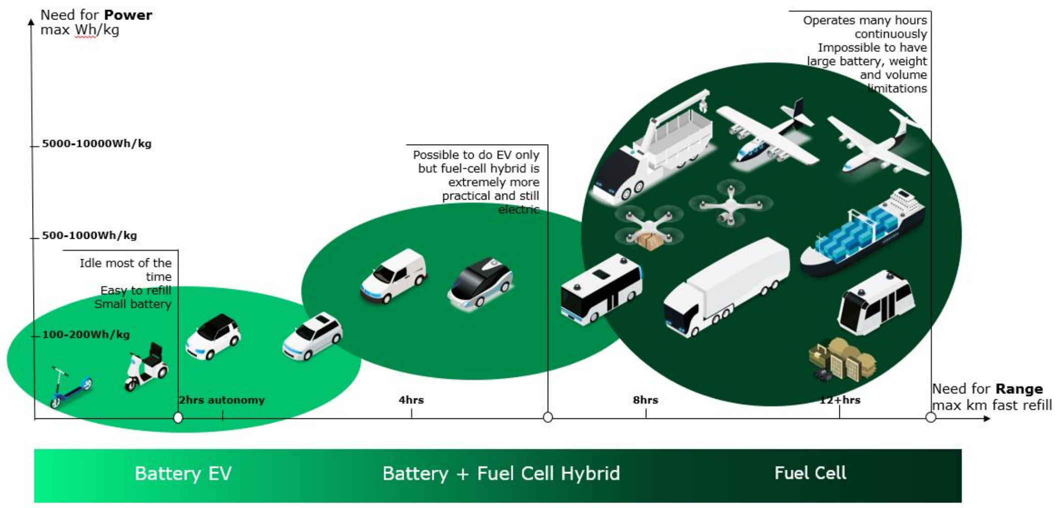
Passenger cars, delivery vans and urban buses already have viable EV solutions. Charging can be an issue especially where grids require reinforcement, but this can be overcome by a mixture of grid reinforcement, storage, and distributed generation. Longer distance travel such as intercity buses and haulage are likely to see hydrogen solutions. Rail is already heavily electrified and there is scope to do more. However, some locations are unsuitable for electrification and here we see hydrogen solutions being applicable.

Near shore marine such as OSVs and ferries are very suitable for battery power and progress has already been made in this area. In fact, we think a ferry is perhaps one of the best applications for a battery given the dwell time at either port and the known duty cycle. Deep sea shipping is most likely to be a hydrogen solution with many industry commentators looking at ammonia as a carrier. Green ammonia can be produced from natural gas by the Haber Bosch process which captures the CO_2 produced in the reactions.

Short haul light aviation can be electrified using hydrogen fuel cells and airborne freight in the form of autonomous drones is a very low emission form of delivery. However, much of aviation is more challenging. Private company Zero Avia is making real progress with potential to use hydrogen fuel cell powered aircraft in the commuter and regional segments with eventual potential in the short haul space.

An element of efficiency is required here but real progress has also been made on zero carbon and negative carbon aviation biofuel. Airbus SE (AIR FP) is also developing hydrogen solutions. Longer range and larger aircraft are likely to be decarbonised by a combination of efficiency and sustainable aviation fuel (SAF). As with automobiles we should avoid a false dichotomy between these viable solutions. Guillaume Faury of Airbus was recently quoted as saying *"We're not saying it's hydrogen and it's not sustainable fuels. It's both, and on the contrary, in the very short term, sustainable aviation fuels will definitely play a very important role."*

Low carbon vehicle market segments



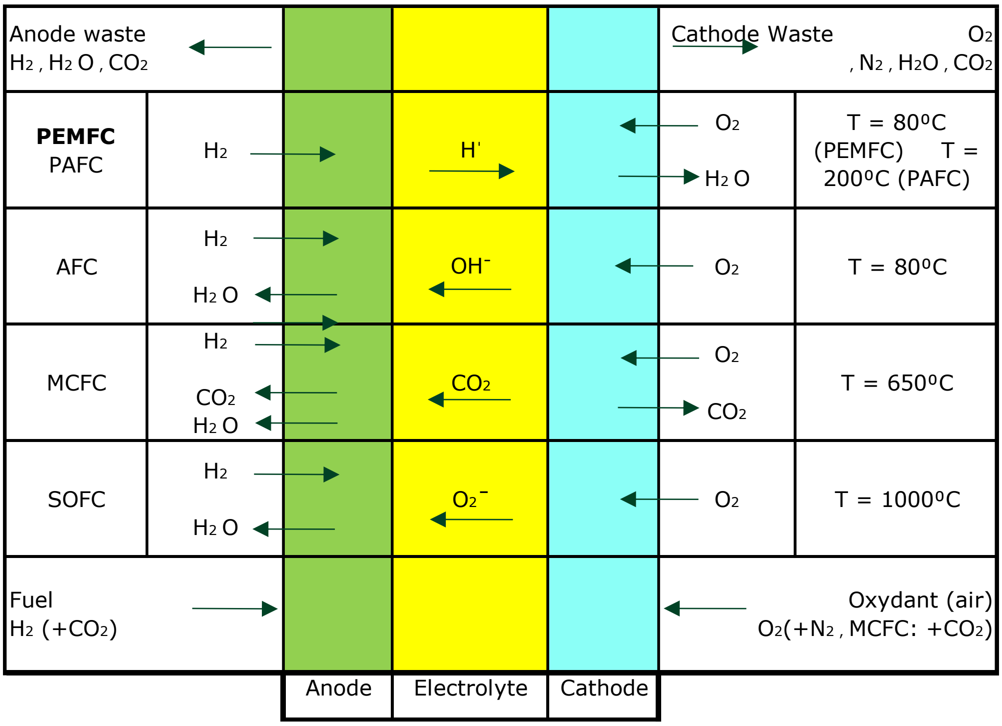
Source: Advent Technology

Increasingly therefore hydrogen is seen as the go to solution for longer range and high-power transport with motors powered by fuel cells as the key prime movers.

WHY PEMS?

Fuel cells work by oxidising hydrogen and reducing oxygen so that $2H_2 + O_2 \rightarrow 2H_2O$ and the resulting water is a cleaner output than the CO_2 that results from burning natural gas ($CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$). The actual reactions will differ with fuel cell design and different approaches to design result in cells with different properties. The main types of fuel cell are PEM, phosphoric acid, alkaline, molten carbonate and solid oxide and their key reactions are shown below.

Main fuel cell reactions



Source: University of Cambridge

While hydrogen is the most abundant element on earth it is normally found combined with other elements most notably oxygen in the form of water (H2o). Hydrogen is mainly produced for fuel cells from the industrial reformation of natural gas using steam methane reformation or from the hydrolysis of water ideally using renewable energy. Once produced the hydrogen gas can be expensive to transport.

As a result, many fuel cell solutions look to reform natural gas or other fluids containing hydrogen directly at the fuel cell site. Other fluids include ammonia and methanol. The hotter temperature at which a fuel cell runs the more reformation can be undertaken within the cell itself. The cooler the temperature, the more expensive external reformation equipment is required. Additionally, some fuel cell types are more easily damaged by impurities in the fuel, including low purity hydrogen.

Another key consideration is operational and in this regard PEM fuel cells are generally seen as the key choice for transport applications. Their fast start-up time and flexible operation works well given the varying duty cycle demanded by transport and their power to weight ratio allows a working form factor in vehicle design.

Fuel cells compared

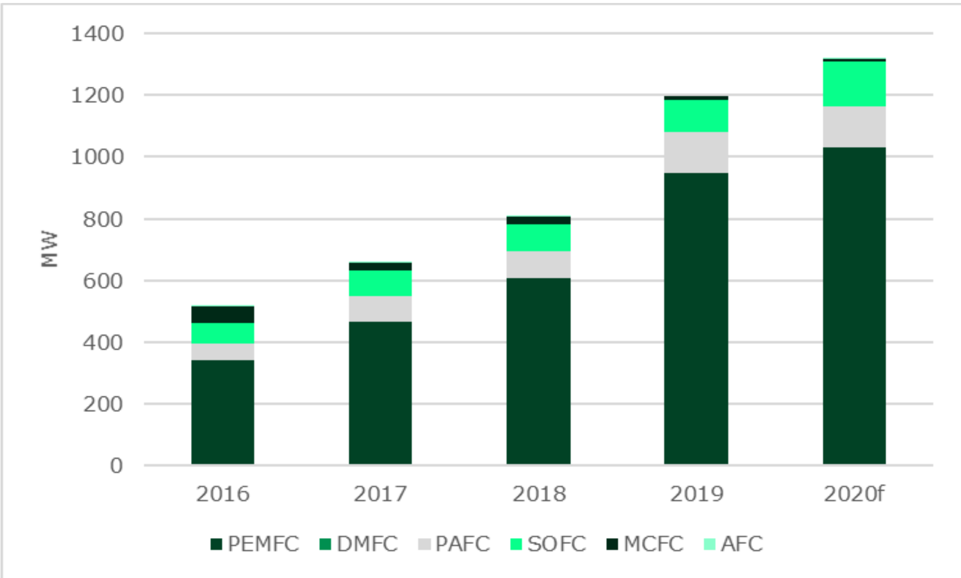
Fuel Cell Type	Polymer electrolyte membrane (LTPEM)	Alkaline (AFC)	Phosphoric acid (PAFC)	Molten carbonate (MCFC)	Solid oxide (SOFC)
Operating Temperature	<120°C	<100°C	150°–200°C	600°–700°C	500°–1,000°C
Typical Stack Size	<1kW–100kW	1–100kW	5–400kW	300kW–3MW	1kW–2MW
Efficiency	60%	60%	40%	50%	60%
Applications	Backup power	Military	Distributed generation	Electric utility	Auxiliary power
	Portable power	Space		Distributed generation	Electric utility
	Distributed generation	Backup power			Distributed generation
	Transportation	Transportation			
	Specialty vehicles				

Source: Department of Energy

Every other fuel cell type is compromised in some regards for a transport application. Ceres Power (CWR LN) does offer its low temperature SOFC as a range extender for battery electric buses with powertrain manufacturer Weichai Power but Weichai are also working with PEM provider Ballard (BLDP CN) for PEM cells for buses.

As a result, PEMFCs are the main choice for automotive and other transport applications. PEMs are already building a market and represent 75% of all fuel cell sales to date.

Fuel cell sales by type



Source: E4Tech

WHY ADVENT?

Advent's HTPEM technology takes the benefits of PEM technology and removes many of the drawbacks. Because the Advent membrane is not water based it can operation at higher temperatures from 120ºC to 200ºC. This makes reactions more efficient and in the case of fuel cells allows more reformation of hydrogen carrying fuels within the cell.

As a result, PEM fuel cells using Advent's membranes and MEAs will be longer lasting, resilient and fuel flexible. Manufacturing is based on standard roll to roll processes and, without the need for complex cooling and water management, Advent can offer cells with low total costs of ownership.

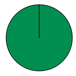
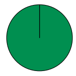
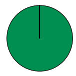
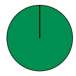
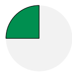
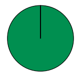
Key benefits of Advent's technology

Long lasting	• Degradation is still a problem for fuel cells • Advent can more than triple lifetime (~10,000 hrs to 10% power loss vs 3,500)
Fuel-Flexible	• Hydrogen infrastructure can be delivered quickly and efficiently with methanol or other hydrogen sources such as biogas • Impurities in regular hydrogen such as 10 ppm CO (carbon monoxide) kill a low temperature fuel cell – our materials withstand > 2 % CO • The same holds true for air purity; air pollution decreases power in low temperature fuel cells
Resilient	• Reducing humidity and temperature issues increases life and reduces cost, and these units work anywhere in the world • Low temperature cannot run hot and dry – no less than 50% Relative Humidity (RH) and not hotter than 70 °C while our technology runs from 0% RH (Nevada) to 100% (Florida in the summer)
High Power	• At least as powerful as current tech (1,100 mW/cm2 peak power) without the extra weight and volume of complex cooling and water management
Cost Competitive	• Roll-to-roll processing mated to catalyst technology that reduces platinum 8-10 fold • Simpler system design and fuel flexibility drop TCO massively

Source: Advent Technologies

We can quantify the extent of these benefits in more detail.

Technology benefits versus competing PEM solutions

	LT-Pem (Competitors)	HT-PEM (Competitors)	Advent HT-PEM
Fuel Flexibility			
Fit for Mobility			
Resilience, Durability, Lifetime			
Affordability			

 Most Benefits to End User

 Least Benefits to End User

Source: Advent Technology

ANY FUEL

Being able to use different fuels is important for hydrogen transport solutions especially early in the energy transition. Fuelling infrastructure is a critical consideration for all forms of low carbon transportation. While early adoption of hydrogen has been based around transportation segments that can benefit from depot fuelling, a full hydrogen solution for all transport has been estimated to cost up to $15tr. This compares with the estimated cost of battery charging infrastructure of $5tr. Of course, as we have already said solutions will be mixed and hydrogen refuelling can be economically implemented in the right locations especially for depot-based transportation. However, an even more economical solution is available through the use of hydrogen carrying fuels with can be distributed using similar infrastructure to fossil fuelled solutions. Here the total cost could be just $50bn and the ability of Advent's technology to work with these fuels is a key advantage.

Low carbon refuelling infrastructure costs

Source: Advent Technology

ANYWHERE

Battery electric vehicles have well known issues when recharging in extreme cold or hot conditions. Traditional fuel cell vehicles also have issues around temperature and humidity, especially when used in high power applications. Traditional PEM fuel cells have an operating ceiling of 70ºC and a relative humidity (RH) floor of 50%. All these issues have solutions but usually these entail a cost with additional balance of plant required to maintain a working operating temperature and humidity. By contrast, Advent membranes will be able to run in relative humidities from 0% to 100% a range which can be just about experienced within the contiguous US by driving from Nevada to Florida in summer.

ACTIVELY SELLING PRODUCT NOW

Advent is already shipping product. While initial quantities are small there is clearly interest from a growing number of high-quality customers. Advent's current HTPEM does not yet deliver all the benefits of the next generation product in development with the DoE but is already fully fuel flexible with very high resilience giving the cells a longer lifetime than their low temperature equivalents. These are finding real commercial applications with a number of customers. Additionally, major clients are buying test samples for evaluation and looking to move towards a HTPEM solution in a number of major application areas.

Portable power

Advent has been supplying UltraCell with MEAs under licence since 2016 for their portable lightweight fuel cells. The relationship was clearly strong as Advent has now purchased UltraCell, giving it a direct route to this key market. We examine the deal in more detail further in this note.

Off grid power

Advent supplies MEAs and key components to two companies working in the off-gird power market. Siqens has developed a PEM fuel cell using methanol as the hydrogen carrier. The Munich-based fuel cell manufacturer has recently secured EU Horizon 2020 funding. Advent also works with Vancouver based fuel cell developer Palcan supplying fuel cells to the Chinese market for off-gird, stationary and automotive applications.

Energy storage

ESS Inc has developed a iron flow battery. Advent supplies key components enabling the company to overcome some of the limitations seen in early iron flow batteries.

Aviation

Safran is an international technology group serving aviation, defence and space markets. Advent is supplying MEAs and collaborating on innovation in the aviation market.

Gas sensors

Advent is working with a Silicon Valley based IoT company which is developing specialised sensors. Advent has a multi-year collaboration agreement. There is also interest from a Korean and a Chinese phone OEM for the implementation of sensors in the current year.

Automotive

Automotive major, Nissan is currently testing Advent MEAs for its next generation of hydrogen vehicles.

Power Generation

Fuel Cell Energy is a leading fuel cell manufacturer, mainly using molten carbonate cells. It is taking Advent MEAs for its trigeneration (combined cooling, heat and power) sytems.

MOVING QUICKLY

The SPAC transaction has allowed Advent to raise $158m in new capital which it will use for product development including talent acquisition, capex on production facilities, sales and marketing and finally to provide working capital. The scale of the raise is healthy and should allow good progress in all these areas.

The Ultracell acquisition

One of Advent's first acts post listing was to acquire UltraCell, the fuel cell division of private company Bren-Tronics Inc. The company has not disclosed the acquisition price. We have assumed $6m in our modelling together with an assumed $1.8m of annual sales.

UltraCell has been a client of Advent since 2016. It produces battery charging solutions for the military and other users who require resilient, lightweight, off grid power charging. It's battery chargers are the only NATO approved fuel cell products produced in the USA and thus eligible for a Made in USA country of origin label. For accessing the substantial US defence budget this is important as the Buy America Act of 1933 still stands and mandates a preference for US made products.

UltraCell is one of only two approved fuel cell products across NATO. It has fuel cell-based batter chargers already deployed in the field with US military and security agencies and three additional NATO countries including the UK are currently testing UltraCell systems.

The key UltraCell products are battery chargers ranging from 55W to 1kW fuelled with methanol. This provides in-field autonomy allowing full off grid charging. A typical deployed system uses 3 gallons of methanol weighing 9kg and replaces batteries weighing 55kg.

Honey Badger selected by DoD

Following the acquisition, it was announced that UltraCell's "Honey Badger" 50W wearable fuel cell power system has been selected by the Department of Defense's National Defense Center for Energy and Environment (NDCEE) to take part in a demonstration and validation programme this year. The UltraCell product is the only fuel cell participating in the programme which is supporting the US Army's goal of having a technology enabled force by 2028. The Honey Badger is actually fuelled by an existing windshield cleaning compound already proven in the US Army supply chain and containing c.70% methanol. It is very quiet at 40db which is similar to the hum from a refrigerator and far quieter than the 90db+ of a generator.

UltraCell also opens up opportunities for Advent's technology to be deployed in other off-grid situations including solutions for wellhead methane reduction where fugitive emissions can be capture and converted into electricity using an Advent cell. In the wider portable power generator space, UltraCell fuel cells with Advent MEAs offer significant performance improvements on diesel generators being far quieter and relatively vibration free, and of course with no emissions.

New offices and facilities

The company has wasted no time in deploying its new capital, immediately announcing a new product development and manufacturing facility at the new Hood Park development in Charlestown, Mass. This site is targeting innovation companies and is well connected with downtown Boston and the university campuses in Cambridge ("the most innovative square mile on the planet"). It is thus extremely well located for recruitment from a wide pool of intellectual talent. The facility will include state of the art coating machines allowing seamless transition from protypes to full production runs. Full analytical and testing facilities will be included including a lab targeting production improvements.

THE NEXT GENERATION HYDROGEN ENABLER

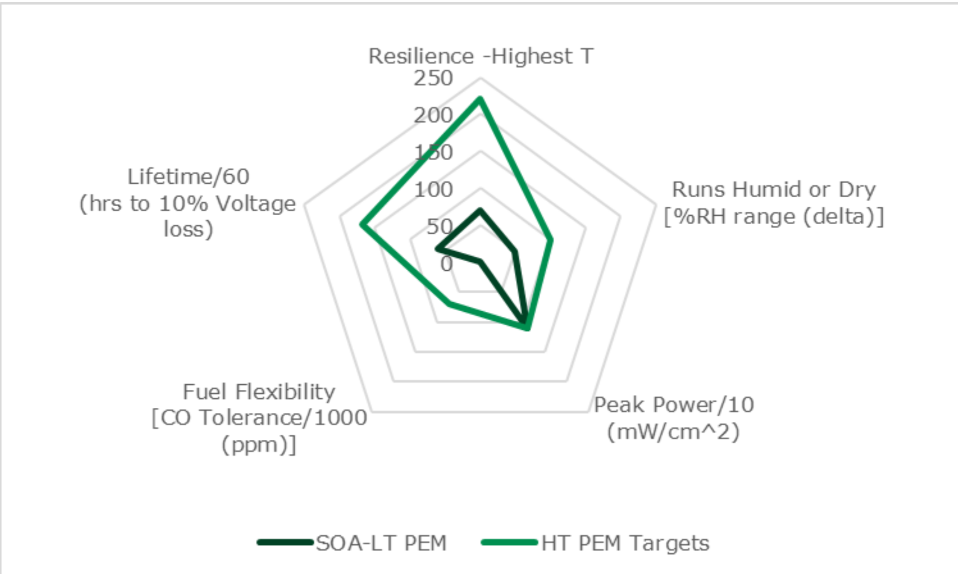
Advent has a strong competitive product in the market right now. But it is continuously developing, and the next generation looks set to be a true disruptor in the hydrogen space. Advent has signed a joint collaboration agreement with the US Department of Energy (DoE) for the development of the next generation fuel cell technology which will be based on Advent's HTPEM technology. The agreement will see Advent work with the DoE's Los Alamos National Laboratory, Brookhaven National Laboratory and the National Renewable Energy Laboratory. This is a seat at the top table of fundamental fuel cell research and in our view differentiates Advent from the competition as well as highlighting the leading expertise the company has in this area.

It is worth stressing that this work will build on the existing technology and the technology roadmap is already very advanced. The agreement formalises a long working history between Advent and the DoE going back at least before 2015 and with some key staff relationships as far as 1996. The new agreement is aimed at scaling up existing proven components combining a membrane from Los Alamos and Brookhaven catalysts using Advent's expertise in fabrication. As a result, Advent hopes to bring products to the market in early 2022 and start to scale up to mass production in 2023.

The new product will give Advent the leading hydrogen product in the market in our view. The new generation MEAs will lead in five key areas.

- Power density with any fuel close to that of the leading low temperature PEMs using pure hydrogen.
- Catalyst loading will be reduced by 90%.
- Weight reduced by 75%.
- Simple design with no need for reforming stages, water management and a reduced radiator. Also improves resilience and life of product.
- Similar production to existing PEMs leading to reduced production cost.

Key performance characteristics of Advent HT PEM



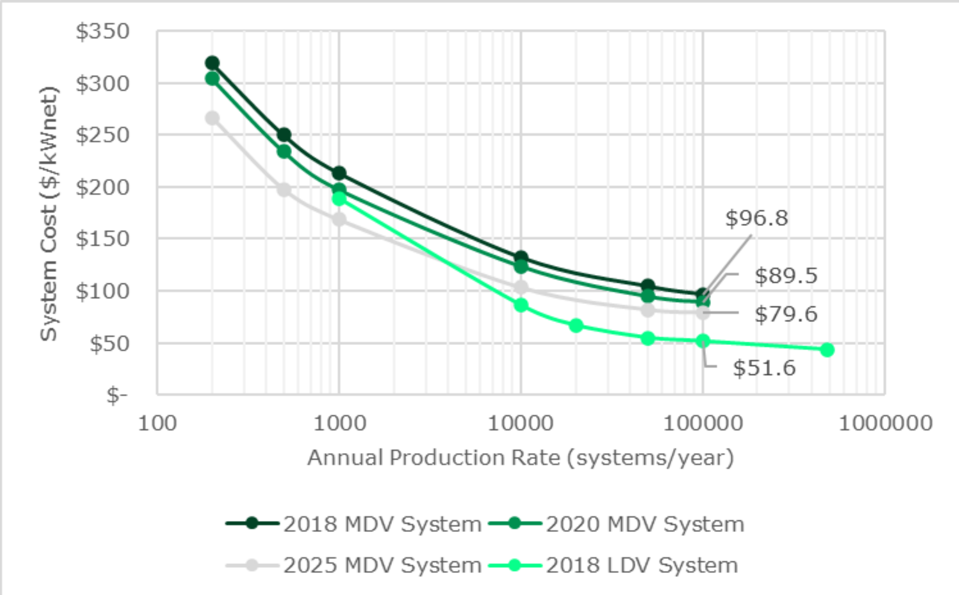
Source: Advent Technology

Mountain bike developer Keith Bontrager famously said of bicycle parts: "Strong. Light. Cheap. Pick two." This maxim can apply across all engineering but for Advent the potential breakthrough with this new work means that they can genuinely offer a stronger (more resilient), lighter, and lower cost product.

LEADING THE LEARNING CURVE

The hydrogen industry needs to bring costs down both for fuel cells and electrolysers. The DoE regularly updates its fuel cell system cost outlook with the latest showing a low temperature PEM fuel cell learning rate as high as 22%. Advent's HTPEM, with much simpler balance of plant, is capable of beating these estimates.

DoE LTPEM Fuel Cell System Cost Estimates



Source: DoE Fuel Cell Technologies Office

However, these cost reductions are not axiomatic. The classic work on learning curves is Abernathy and Wayne, *Limits of the Learning Curve*, Harvard Business Review 1974:

"The frequency with which this cost reduction/ volume increase pattern is found in practice sometimes leads to the incorrect impression that the learning-curve effect just happens. On the contrary, product design, marketing, purchasing, engineering, and manufacturing must be carefully coordinated and managed."

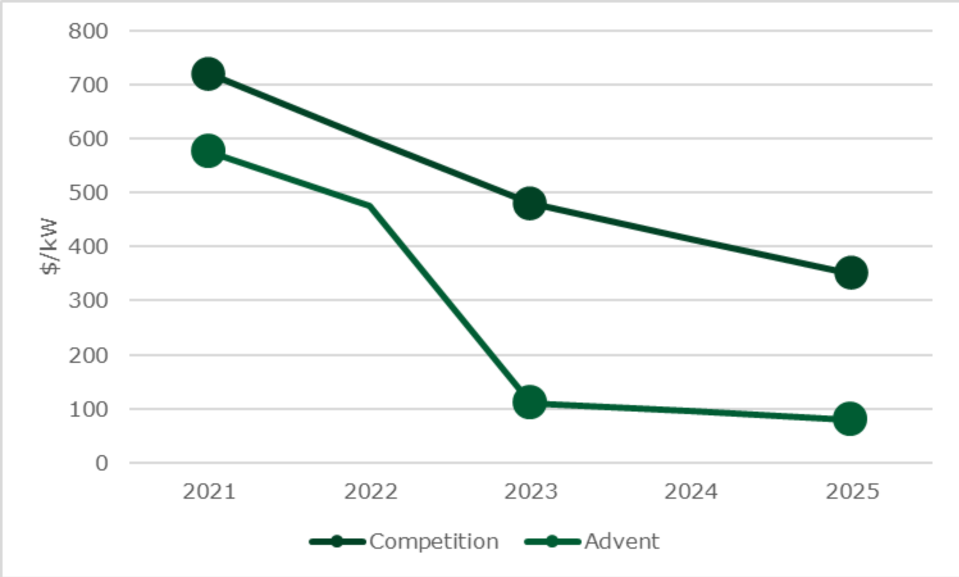
It requires work especially on design to bring costs down. In its work with the DoE we see Advent as leading this process for fuel cells, and by extension electrolysers. Advent is seeking cost reductions both through innovation and by scaling up.

With innovation it sees substantial savings in the automation of assembly line and advanced MEA product development projects. The automation of the assembly line has the potential to deliver a threefold efficiency improvement in direct labour costs. At the product level, the new MEA will provide the same power output as a traditional cell but with just 25% of the raw materials.

On top of these savings, volume scale up will bring unit cost savings and purchasing efficiency. Additionally, with manufacturing in Greece, the company is able to be competitive on procurement, labour and processing costs.

Advent predict that through the introduction of the new MEA together with the other drivers mentioned above, it can reach a target of $80/kW, well ahead of competition in the market.

Advent MEA Cost Estimates

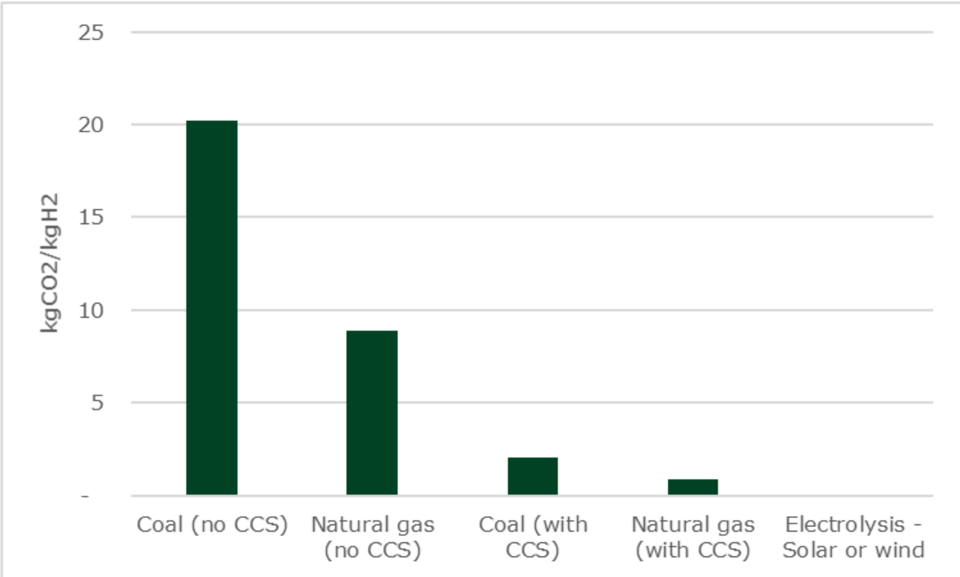


Source: Advent Technology

THE ELECTROLYSER OPPORTUNITY

Currently, hydrogen is mainly produced by steam reformation of natural gas. Steam methane reformation (SMR) is energy intense and a major emitter of CO2. Carbon capture and storage (CCS) is an option to reduce or eliminate the CO2 emissions, creating "blue" hydrogen. There is some debate about the application of blue hydrogen in net zero solutions. While the process can be low emission from the point of delivery of the natural gas, methane losses further upstream can result in a high emission outcome.

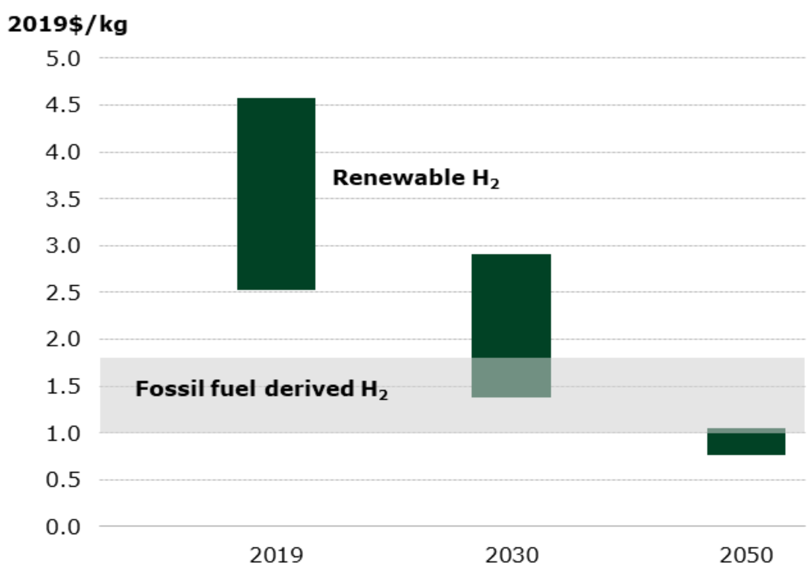
CO2 emissions from hydrogen production



Source: BNEF

Low carbon, or green, hydrogen can be created from the electrolysis of water with renewable energy providing the electricity. Of these technologies, blue hydrogen appears the cheaper. However, costs are likely to fall for electrolysers and by 2030 green hydrogen could begin to compete with blue.

Levelised cost of hydrogen forecasts



Source: BNEF

There are two main types of electrolyser, proton exchange membrane (PEMEC) or alkaline (AEC). Solid oxide electrolysers also exist but are at an earlier stage of development. PEMECs are more responsive but higher cost thanks to the use of expensive catalysts. Alkaline electrolysers are cheaper but less responsive, taking longer to start up when needed. Electrolyser manufacturer NEL (NEL NO) manufactures both types and expects the capital cost of these to converge by 2030.

Alkaline electrolyser technology is well proven with large scale alkaline units being operated since the 1920's. Driven by demand for hydrogen for ammonia production, many projects were completed with output in the 2-3 ton per hour (50 –70tpd) range. However, these were rendered uneconomic by steam methane reforming as plentiful natural gas became available.

As with fuel cells, several factors come into play when choosing between PEM and alkaline electrolysers. A key difference is flexibility with PEM electrolysers offering millisecond response times and flexible operation. This makes them a better choice for pairing with intermittent renewable energy especially if operators are targeting electricity response markets for some of their income. Purity of the hydrogen produced and a higher output pressure are additional benefits of the PEM technology.

Electrolyser technologies compared

	AEC	PEMEC	SOEC
Voltage efficiency (%HHV)	62-82	67-82	<110
Operating Temp. (C)	60-80	50-80	650-1,000
Operating Pressure (bar)	<30	<200	<25
Gas purity (%)	>99.5	99.99	99.9
System Response	Seconds	Milliseconds	Seconds
Cold-start time (min.)	<60	<20	<60
Stack Lifetime (h)	60,000-90,000	20,000-60,000	<10,000
Maturity	Mature	Commercial	Demonstration
Capital Cost (€/kWe)	1,000-1,200	1,860-2,320	>2,000

Source: Imperial College

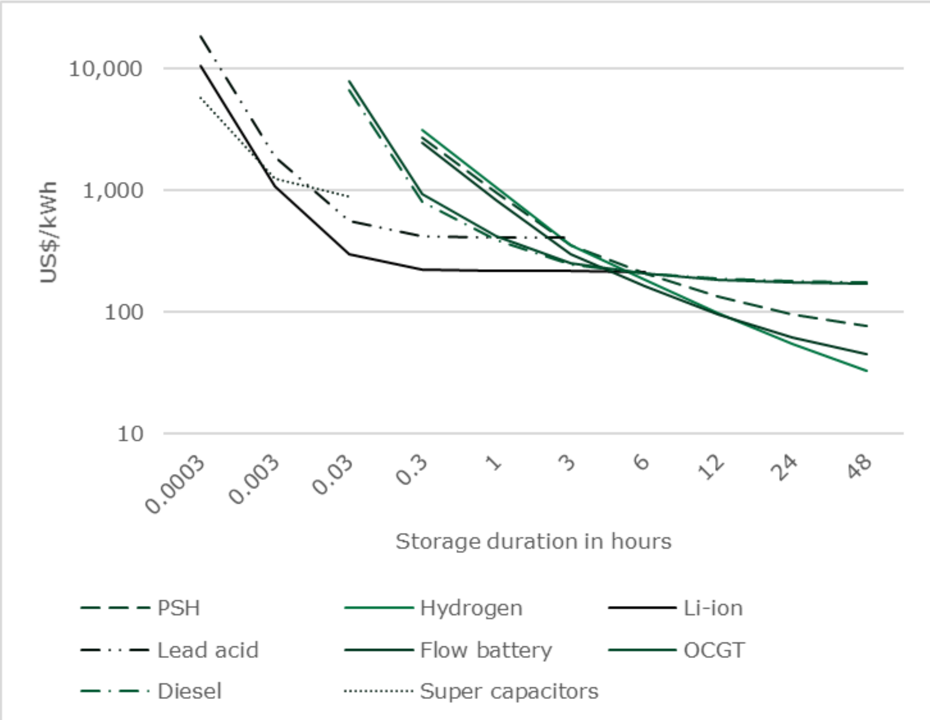
Green hydrogen costs are impacted by the utilisation of the electrolyser. While surplus renewable energy may be available at a low or zero cost due to curtailment, this would suggest low utilisation. However, the growth of intermittent renewable energy means that hydrogen generation becomes a competitive demand source for renewables at times other than just when curtailment would occur. We see electrolysis as especially relevant when paired directly with renewable energy. In this regard PEM technology appears the better solution and this is potentially a major opportunity for Advent.

THE FLOW BATTERY OPPORTUNITY

In the past, chemical energy storage was always a major part of the energy mix, for example it represented 76% of UK capacity in 1999. This was energy storage chemically contained in oil tanks, coal stocks and in the gasometers and line stack of natural gas. However, coal being gradually closed down as countries commit to net zero solutions, and it is likely that gas will follow if we are to hit these targets. This represents a significant loss of energy storage from our energy system.

To date, storage in the electricity market has been dominated by pumped hydro. Lithium ion batteries have emerged as a solution to at least some of these storage needs but storage is not a single market. Lithium ion can be an economic solution at shorter durations of up to four hours and, if anything, is displacing open cycle gas turbines and gas or diesel reciprocating engines. But it is not scalable with duration and beyond about 4 hours current lithium-ion technology is uneconomic compared with pumped storage and newer technologies such as compressed air storage and liquified air storage and flow batteries.

Levelised cost of storage against duration



Source: Longspur Research

Flow batteries

Flow batteries have now been successfully installed for a number of stationary storage applications. The first working cell based on a vanadium electrolyte was demonstrated in the late 1980's at the University of New South Wales. A number of early-stage commercial scale batteries are now in operation. They remain expensive but work well at long durations and their cost structure can make them efficient in these situations.

A flow battery has a liquid electrolyte normally based on vanadium, iron or zinc-bromine. The electrolyte does not suffer from degradation so that the stored energy can be retained for long durations with negligible self-discharge over time. Duration itself is created simply by adding more electrolyte and a bigger tank in which to store it. In discharge the battery behaves more like an engine with electrolyte fuel passing through it creating a flow of electrons.

Flow and Lithium Batteries Compared

Flow Battery	Conventional Battery
Industrial-Scale, Medium & Long Duration Stationary Energy Storage Applications	Short Duration, Residential & Small Scale Applications
25 Year Machine Life - Low Levelised Cost of Storage (LCOS)	Deteriorates with Every Cycle, Need to Replace After ~5,000 Cycles (50% Discharge)
100% Depth of Discharge Without Degradation	Discharge Beyond 30-50% Causes Damage, Requiring Systems to be Oversized
Safe - No Risk of Thermal Runaway	Risk of Thermal Runaway, Requiring Safety Systems to be Installed
Charge is Retained Indefinitely With Negligible Self-Discharge Over Time	Fully Charged Systems Will Self-Discharge Over Time
Electrolyte is 100% Recyclable and Can be Reused Over and Over Again	Lithium-Ion Systems are not Widely Recycled & Must be Disposed of Safely
Power and Energy Requirements can be Sized Independently for Best Fit	Power and Energy Components Cannot be Separated
Optimal Performance with Daily Usage, Coupled with Renewables	Most Effective for Occasional Use and Back-up Functions

Source: RedT

Flow batteries tend to have lower volumetric energy densities than lithium batteries. However, this is not a major limiting factor for most long duration stationary applications.

Vanadium based batteries can suffer from transportation of vanadium ions across the central membrane and must use expensive ion-exchange membranes to minimise resulting losses. While there is some risk of fouling of these membranes by vanadium ions resulting in resistive losses, improvements are being made reducing this risk. Lower cost membranes are under development and this is potentially an area of opportunity for Advent.

Zinc bromine flow batteries have higher energy densities than vanadium. However, storage duration is in part dependent on electrode area so that costs will increase more significantly with capacity, reducing some of the benefits when compared to lithium-ion batteries.

Iron flow batteries have less development history but have potentially lower costs thanks to the relative abundance of the materials used. There is a risk of rust although this can be managed, and depth of discharge is limited to 85% without increasing inefficiency. Developer ESS Inc has overcome the key limitations of iron flow technology by using materials provided by Advent. This is potentially a major new opportunity for Advent.

SENSORS

Advent membranes can also be used as sensors for all kinds of atmospheric gases.

Gases sensed by Advent membranes

Pollutant	Medical	Food etc
NOx	Acetone	Aromas
CO	H2S	Formaldehyde
HCNO	Ozone	
NO2	Ethanol	

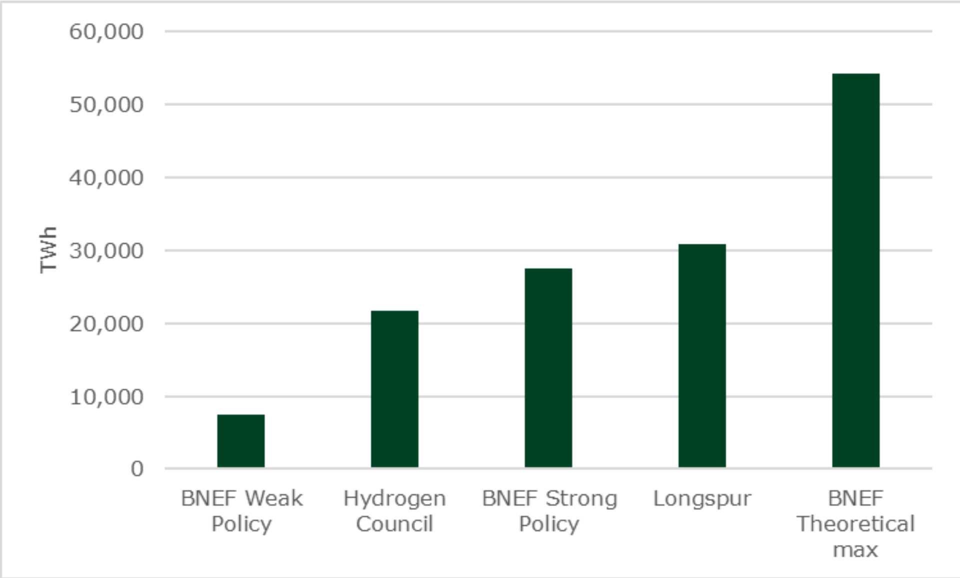
Source: Advent Technologies

Other gas sensors are available including those using sulfuric acid, infra-red and metal oxide semiconductors. However, for reasons of size, power or gas selectivity, none of these can be incorporated into a smart phone. This is where Advent membranes really stand out. They can not only be sized to fit a phone, with sensor sizes down to 4mm square, but as high temperature membranes they are suitable for surface mounting making the fabrication process relatively straightforward and easy to integrate into existing phone manufacturing. Advent is already making sales of membranes for sensors to a Silicon Valley based IoT innovator for incorporation in two well-known smart phone brands.

ADDRESSABLE MARKET

Our analysis of the net zero pathways in the IPCC 1.5-degree report suggests that, in order to meet the more demanding Paris climate change goals, we will need to consume hydrogen fuelled energy equal to 110EJ per annum by 2050. Checking against other forecasts in the market with the Hydrogen Council at 78EJ and BNEF at 99EJ, this seems reasonable for a full net zero solution.

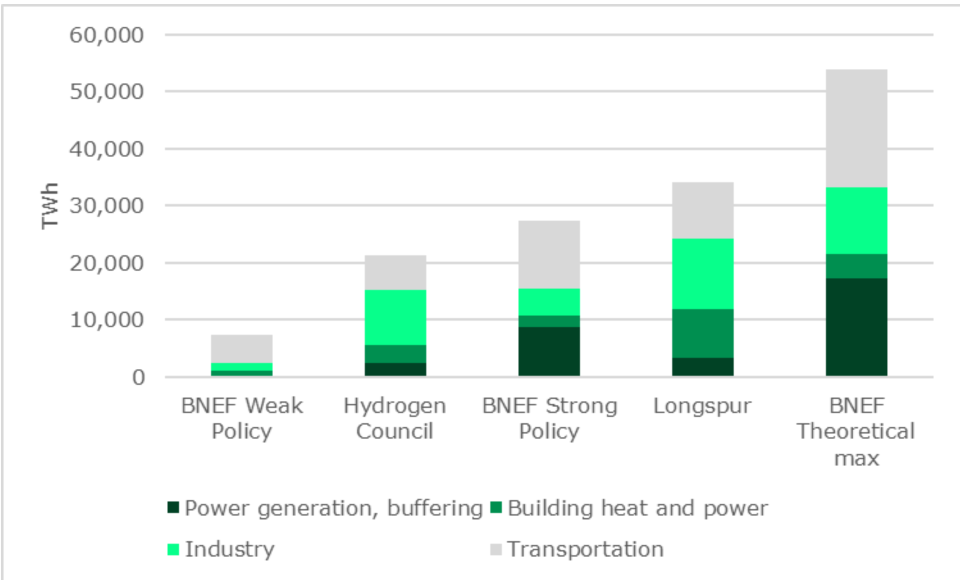
Hydrogen demand forecasts in 2050



Source: Hydrogen Council, BNEF, Longspur Research

This demand splits into the main hydrogen use categories as follows.

Forecast uses of hydrogen in 2050



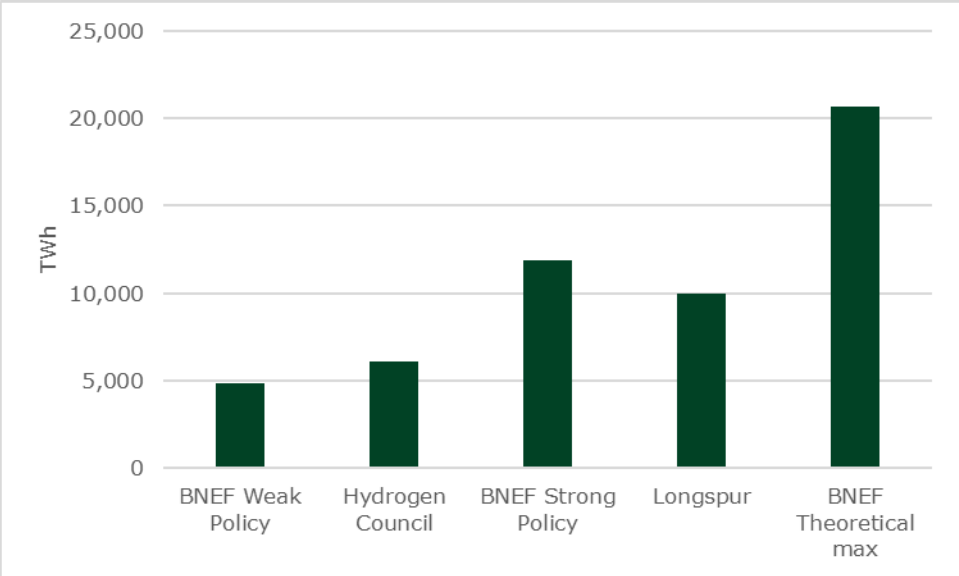
Source: Hydrogen Council, BNEF, Longspur Research

ESTIMATING THE TAM FOR FUEL CELLS

We see fuel cells principally being used in transportation and to a lesser extent for back up generation and off-grid power. Several estimates of how much hydrogen demand will come from transportation are available including from BNEF and the Hydrogen Council. For the net zero cases above these suggest hydrogen for transport will be 43% and 29% respectively.

Our own analysis, based on the amount of energy demand from transport once EVs and biofuels have satisfied initial transport demand shows a total of 10GWh of annual hydrogen transport energy demand or 32% of total hydrogen demand. This is based on our analysis of the IPCC's 1.5°C report decarbonisation pathways.

Transport demand met by hydrogen fuels in 2050



Source:

We now need to estimate how much fuel cell capacity would be needed if this energy was being used. The key issues are utilisation and refuelling cycles. These are broadly offsetting. We can combine the two issues by looking at the average annual mileage and speed of commercial vehicles to estimate the number of hours they are in operation. Using an average mileage of 108,000 miles and a speed of 50mph and dividing the two gives us 2,160 hours. By dividing our energy figure by this number, we get the required total engine/fuel cell capacity which in this case is 4,611GW. This is an effective utilisation rate of 25%. We think that a new technology is probably likely to be used more than the average and we think an overall utilisation rate of 50% is more conservative at this point. That would give a TAM of 2,274GW.

We can do a sense check of this number by looking at the total global commercial vehicle fleet currently on the world's roads. Data from the International Organisation of Motor Vehicle Manufacturers puts this at 335.19m vehicles. Taking the 30kW fuel cell used in a Toyta Mirai, a size which may dominate smaller commercial vehicles, we can multiply by 335m to get 10,000GW. This is a much larger outcome than either number above but then we would not expect every single commercial vehicle to be hydrogen powered. It does however give us some comfort that our figure is the right order of magnitude.

TAM for PEM electrolysers

We have estimated how much hydrogen would be needed to meet the IPCC's 1.5°C target. We assume that 60% of this will be green hydrogen in line with the Hydrogen Council's green/blue assumed split. We assume that green hydrogen production is based on an electrolyser efficiency of 50kWh/kg and a 54% utilisation factor. This gives a capacity figure of 5.0TW of electrolyser capacity. This is well ahead of the 1.7TW forecast from IRENA but we note that many hydrogen assumptions have tended to be cautious and are not fully reflecting the realistion of the full hydrogen potential to delilver efficient decarbonisation.

TAM for flow batteries

For energy storage systems we have assumed that 50% of renewable capacity used for heating and electricity is matched by a minimum of 1 hour and 20 minutes of storage based on an hour of trading and 20 minutes of response services. We estimate that up to 50% of capacity could be economically matched with storage. This represents capacity of 10.3TWh. This is 14% ahead of forecasts from IRENA at 9TWh and broadly confirms the 10TWh figure given by Tesla at their Battery Day 2020.

It is difficult to gauge the market share which flow batteries might take against competing forms of long duration storage such as compressed air or pumped storage. The latter are highly site specific, and all forms of storage can see their economics impacted by the detail of local grid policies. We think there is a total long duration storage market of 10GWh with three main competing technologies. At this early stage it makes sense to simply assume a TAM of 1/3rd of this market for flow batteries.

From TAM to SAM

The Bass Diffusion model is a well-established model for estimating how a new product diffuses into an existing market. In this case the market is commercial transport fuel, and we want to estimate how hydrogen will diffuse into it. The model uses a coefficient of innovation to represent the propensity of innovators to buy an unknown product and a coefficient of imitation to represent the rest of the market to follow the innovators. We have used coefficients of 0.0037 and 0.3454 respectively based on Park, S. Y., Kim, J. W., & Lee, D. H. (2011), *Development of a market penetration forecasting model for hydrogen fuel cell vehicles considering infrastructure and cost reduction effects*, Energy Policy, 39(6).

Using these with our TAMs above we get market estimates on an annual basis. For the purposes of estimating a valid SAM, we have delayed Advent's material entry into the electrolyser market by two years and the flow battery market by five years. Advent is already working in the flow battery space but it is a newer market and we think for these purposes this assumption is suitably conservative. We can then compare the unit capacity forecasts out to 2025 given by the company in its prospectus and calculate a market share. This rises to 5% of the market which seems credible for a relative new entrant to the market.

Serviceable addressable markets for Advent

GW	2021e	2022e	2023e	2024e	2025e	2026e	2027e	2028e
Fuel cells	8	11	15	20	27	44	58	75
Electrolysers	0	0	6	8	11	15	19	32
Flow batteries	0	0	0	0	6	9	11	15
Sensors	2	2	3	4	6	10	13	17
Total market (GW)	10	14	25	33	50	76	101	139
ADN Sales (MW)	14	29	265	779	2,271			
ADN Market share	0%	0%	1%	2%	5%			

Source: IPCC

FINANCIALS

EARNINGS OUTLOOK

We have based our near terms forecasts on those presented in the prospectus.

Advent prospectus forecasts

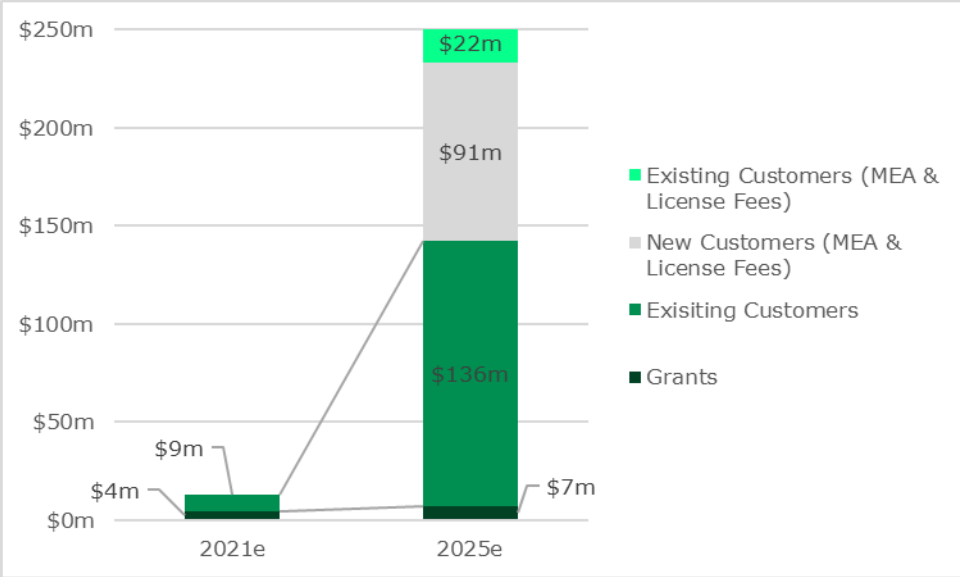
$m	2020	2021	2022	2023	2024	2025
Total Revenue	1.7	13	25.6	60	122.8	254.8
of which:						
MEA sales	0.8	5.9	12.8	30.3	72.5	187.7
Engineering, License Fees and Grant Income	0.9	7.2	12.8	29.7	50.3	67.1
CoGS (ex D&A)	-0.4	-8.8	-19.8	-38.7	-76.1	-174.4
Gross Profit (ex. D&A)	1.3	4.3	5.8	21.3	46.8	80.4
SG&A and other	-2.1	-18.1	-20.4	-22.8	-23	-29.5
EBITDA(1)	-0.8	-13.8	-14.6	-1.5	23.8	51
Capacity sold (MW)	0.1	11	26	265	779	2,271
MEAs sold (000 units)	2	325	788	2,144	6,296	18,354
MEA ASP/MW ($/kW)	*8,000*	*536*	*492*	*114*	*93*	*83*

Source: Advent Technologies

We have calculated the average selling price for a MEA per kW. This falls dramatically from $536/kW in 2021 to $83/kW in 2025 as the company moves costs down the learning curve.

These forecasts are based on a bottom-up assessment of pipeline deals. The pipeline includes a significant proportion of new business from existing customers as well as some wins of new customers.

Advent sales forecast by source



Source: Advent

The new business is based on already identified opportunities. The company has highlighted a selection of these.

Selected opportunities

Customer	Advent Product	Details
Multiple OEMs – Fuel Cell EV trucks	HT-PEM fuel cells	•5,000+ trucks on the road @ 200kW per truck •1GW potential opportunity in 2025
Asian fuel cell manufacturer	MEA	•Existing customer •MoU in place envisages >5m MEAs in 2023 – 2x forecast MEA production
US OEM – portable power	MEA (Durability and Temperature Resilience)	•OEM currently supplies portable power fuel cell units to 4 military units globally, including in the U.S. and U.K. •Existing customer •Projected revenue opportunity $20m in 2025 from single product only
Asia – EV charging stations	HT-PEM fuel cells	•Target 4,500 stations @ 240kW per station = 1.1 GW opportunity
US IoT – gas sensor	Membranes for heat resistivity	•Silicon Valley-based US developer •OEMs – two global cellphone manufacturers •Cellphone market opportunity alone represents $25m in 2025

Source: Advent Technologies

The full year results announced in March showed some differences from the prospectus forecast, principally on the timing of grant income. This is very variable, and we do not have any particular concerns here. The gross margin loss was also higher than the prospectus forecasts, principally due to costs connected with reorganisation ahead of the listing and associated disruption. We have scaled back our gross margin assumptions for FY 21 on the basis that some of this effect will carry on into the current year but we think from FY 22 the gross margin assumptions remain valid.

We have also added in the impact of the UltraCell acquisition. The company has not disclosed any financial details but from our knowledge of the rough size of the opportunity we have assumed that the deal brings additional sales of 3MW of MEA capacity. To be conservative we have assumed this accelerates the growth and so adds sales in FY 21 and FY 22 but beyond we have kept sales in line with the prospectus and see the UltraCell sales as derisking this revenue rather than adding to it.

Forecast summary

	2021e	2022e	2023e	2024e	2025e	2026e	2027e	2028e
Capacity sold (MW)	14	29	265	779	2,271	3,479	4,597	6,312
MEAs sold (000 units)	325	788	2,144	6,296	18,354	28,116	37,155	51,011
ASP/MW ($/MW)	536	492	114	93	83	81	79	77
- MEA fees	7,509	14,277	30,300	72,500	187,700	280,344	361,206	483,520
- Engineering fees	-125	2,570	647	2,416	2,237	-2,883	1,909	2,657
- Licence fees	1,502	4,357	10,417	24,917	62,457	118,526	190,767	287,471
Total revenue	8,886	21,204	41,364	99,833	252,394	395,988	553,882	773,648
Grants & R&D Programs	5,823	5,873	18,636	22,967	2,406	0	0	0
Revenue plus grants	14,709	27,077	60,000	122,800	254,800	395,988	553,882	773,648
CoGs	-11,767	-20,942	-38,700	-76,000	-174,400	-271,037	-379,109	-529,530
Gross profit	2,942	6,135	21,300	46,800	80,400	124,951	174,773	244,118
Gross margin	20%	23%	36%	38%	32%	32%	32%	32%
Business development	-3,024	-3,099	-4,765	-7,327	-15,019	-15,395	-21,533	-30,077
R&D	-8,105	-8,308	-8,515	-4,728	-4,847	-4,968	-5,092	-5,219
G&A	-8,971	-10,993	-11,519	-12,945	-11,634	-11,925	-12,223	-12,529
Total cash op costs	-20,100	-22,400	-24,800	-25,000	-31,500	-32,288	-38,848	-47,825
EBITDA	-17,158	-16,265	-3,500	21,800	48,900	92,663	135,924	196,293

Source: Longspur Research

VALUATION

Hydrogen remains a new technology and most of companies in the sector will be loss making for some time as the market evolves. This makes PE and EV/EBITDA multiples unusable leaving EV/Sales as the main metric on which to make comparisons. These vary widely. As a result, we think a valuation approach should concentrate on a well-constructed DCF valuation and merely use multiples as a sense check.

We have used a weighted average cost of capital of 11.7%. This is based on the high end of the most recent UK's Competition and Markets Authority assessment on cost of capital. We see this as one of the best contemporary estimates based on thorough work that if required must be able to stand the scrutiny of a judicial review. This gives a risk-free rate of -1.0% which with a 2.5% inflation assumption gives 1.5%. The market premium is 8.5% based on historical ex-post market returns going back to 1900. We have used a beta of 1.2 based on the median beta from the comparator group. With no debt this gives us a WACC of 11.7%.

Weighted average cost of capital

Risk free rate	1.5%
Market premium	8.5%
Loan margin	3.0%
Marginal tax rate	35.0%
After tax cost of debt	2.9%
Debt/total capital	0.0%
Beta	1.2
Cost of equity	11.7%
Weighted cost of capital	11.7%

Source: Longspur Research, CMA

We have forecast cashflows to 2030 based on our discussion under earnings outlook above. We then calculate a terminal value in 2030 based on Gordon's growth model and assuming that long term cashflows are flat in nominal terms. The terminal EV/EBITDA on this basis is 6.4x which we do not see as onerous.

DCF Valuation – central case

$'000	2021e	2022e	2023e	2024e	2025e	2026e	2027e
Operating cash inflow	(18,428)	(17,491)	(6,762)	13,189	32,552	72,999	114,653
Cash from associates	0	0	0	0	0	0	0
Tax paid	0	0	0	(2,390)	(8,049)	(16,995)	(28,299)
Interest tax shield	0	0	0	0	0	0	0
Capex & investments	(18,000)	(12,300)	(12,608)	(32,923)	(45,746)	(26,889)	(27,562)
Free cashflow	(36,428)	(29,791)	(19,369)	(22,124)	(21,243)	29,115	58,793
Terminal growth rate	2.5%						
Terminal valuation	2,257,695						
Terminal EV/EBITDA	6.3						
Implied enterprise value	773,620						
Implied market cap.	907,929						
Implied share price	**20**						

Source: Longspur Research, (*explicit forecasts go to 2030)*

This gives a base case valuation of $20 per share. This puts EV/sales in 2023 at 13.1x compares well with a comparator group of PEM fuel cell and electrolyser companies.

Hydrogen economy comparators

Name	Technology	EV/sales 2022	EV/sales 2023
Fuel Cell Companies			
Advent Technologies Holdings	HTPEM	25.1	11.9
Ballard Power Systems Inc	PEM	33.6	23.0
Powercell Sweden Ab	PEM	58.5	43.4
Plug Power Inc	PEM	18.5	12.1
Ceres Power Holdings Plc	SOFC	65.0	63.0
Fuelcell Energy Inc	MCFC	27.1	18.7
Bloom Energy Corp- A	SOFC	4.0	3.1
Afc Energy Plc	AFC	113.8	na
Electrolyser Companies			
Itm Power Plc	PEM	94.1	34.6
Mcphy Energy Sa	AEC	18.9	10.4
Nel Asa	PEM and AEC	19.6	12.8
Enapter Ag	AEM	14.6	7.4
Mean		42.5	22.9
Median		27.1	15.8
Max		113.8	63.0
Min		4.0	3.1

Source: Bloomberg

SCENARIOS

We have also considered scenarios that assumed greater long-term traction is gained. We see this as highly possible given the strengths of Advent's core technology.

Our high case assumes that Advent can grow market share beyond 2025 out to the end of the decade. We have added 2.5% share in every year so that by 2031 the company has 20%.

We also consider a low case where Advent fails to develop share away from fuel cells, with no significant business in flow batteries or electrolysers and limited growth in sensors.

These three scenarios are summarised below.

We see the period to 2025 as one where Advent establishes itself in the marketplace, growing market share to 5%. The second half of the decade is where the company can really grow into a major supplier, or alternatively remain a specialist serving a few strong niches. Our scenarios evaluate this longer-term future.

DCF Scenarios

	Markets	**Long term market share**	**DCF**
Low case	Fuel cells and sensors	5%	13
Central case	Fuel cells, sensors, electroysers and flow batteries	5%	20
High case	Fuel cells, sensors, electroysers and flow batteries	20%	52

Source: Longspur Research

MANAGEMENT

EXECUTIVE MANAGEMENT

Chief Executive Officer & Chairman - Vasilis Gregoriou Ph.D.

Chairman and CEO of Advent since inception in 2012. Has held research and managerial positions at Northeastern, MIT, Polaroid, Princeton in the US as well as NHRF and FORTH in Greece. His research activity extends over a wide area of subjects in the renewable energy space. He is co-author of three books and more than 100 scientific papers, as well as co-inventor of 15 patents. Vasilis has more than 25 years of experience in the U.S. market.

President & Chief Financial Officer - William Hunter

Appointed the President and CFO of Advent since the closing of the merger with AMCI Acquisition Corp. Prior to joining Advent, he served as the CEO and CFO of AMCI Acquisition Corp since its inception, a Managing Director of AMCI Group since 2017 and Managing Partner of Hunter Natural Resources LLC, a consulting firm since 2015. Has worked as a Director at Nomura Securities, Jefferies, TD Securities and Dahlman Rose & Co. Currently serves on the board of American Battery Metals Corp. (OTC: ABML) which is a clean energy materials business focused on the recycling of critical minerals from lithium-ion batteries.

Chief Technology Officer - Emory De Castro

Appointed Chief Technology Officer since 2013. Prior to joining Advent, was the Vice President of BASF Fuel Cell Inc and Executive Vice President at the E-TEK Division. Has over 20 patent applications spanning fuel cell materials and catalysts, electrochemical technology, sensors, and a beer bottle cap that extends shelf life. He is the recipient of the 2013 Department of Energy Award for Manufacturing R&D in lowering the cost of gas diffusion electrodes and the 2005 ECS New Technology Award given to E-TEK Division, for introducing and commercializing a new electrolysis technology. Received his Ph.D. from the Department of Chemistry at the University of Cincinnati and a B.S. in Chemistry from Duke University.

Chief Operating Officer - Jim Coffey

Appointed COO and General Counsel of Advent Technologies in 2020. Beginning in 2018, Jim served as Advent's outside legal counsel. Has over 30 years of experience in corporate and securities law, mergers and acquisitions, venture capital and corporate finance, and intellectual property law. From 2013 to 2017, he served as general counsel to another HT PEM fuel cell company that was a customer of Advent.

Chief Marketing Officer - Chris Kaskavelis

Joined Advent as Chief Marketing Officer in 2019. He has served for 13 years as CEO and COO in start-ups that eventually IPOed in Nasdaq and London Stock Exchange and has grown companies from zero to 1,200 people. From 2016 to 2018, he was a research scholar at the MIT Media Lab in Boston, Massachusetts. He has been a seed investor in the company, an angel investor, and has served on its board of directors since the first day.

General Manager, Advent SA - Nora Gourdoupi Ph.D.

Nora Gourdoupi holds a BSc in Chemistry and a PhD from the University of Patras specializing in the synthesis and characterization of polymers for fuel cell applications. She joined Advent Technologies in 2006 as a Senior Scientist and is co-inventor in 18 patents.

Currently overseeing daily operations while also being engaged in product development, government projects and technical sales.

BOARD OF DIRECTORS

Non-Executive Board Member - Katherine E. Fleming Ph.D.

Katherine has over fifteen years' financial and scholastic experience in Higher Education leadership and has been the Provost of New York University since 2016. From 2007-2011 she directed the Institut Remarque at the Ecole Normale Superieure in Paris, and from 2012-2016 she served as the President of the Board of the University of Piraeus. Granted honorary Greek citizenship by the Hellenic Republic in 2015 and in 2019 was named by France to the Legion d'Honneur.

Non-Executive Board Member - Katrina Fritz

Katrina is the Executive Director of the Stationary Fuel Cell Collaborative, advisor to the National Fuel Cell Research Center on state level clean energy policy and market development. Katrina currently serves as an expert to the European Commission on Horizon 2020 programs for research and innovation. As Principal of KM Fritz LLC, Katrina has held leadership positions in numerous trade associations and on advisory boards including: The California Hydrogen Business Council, the International Energy Agency's Fuel Cell Working Group; the U.S. Fuel Cell and Hydrogen Energy Association; the Alliance for Clean Energy New York; the Pacific Clean Energy Application Center at University of California, Berkeley; and the Connecticut Fuel Cell and Hydrogen Coalition. Katrina has held leadership positions at ClearEdge Power (formerly UTC Power), Plug Power and Case Western Reserve University, leading strategic planning, government relations, business development, and corporate communications.

Non-Executive Board Member - Lawrence M. Clark, Jr.

Lawrence served as an independent director of AMCI since November 15, 2018 and is the founder of BalanTrove Management in 2011, a corporate advisory firm to middle market companies, investors and lenders. He is a director of American Consolidated Natural Resources, Inc. From 2019 to 2020 he served as a director of Balackhawk Mining, LLC and from 2015 to 2018, he served as CEO of Accordant Energy, LLC, Prior to that, he served for two years as President and CEO of JW Resources, Inc. Before 2011, he spent eight years at Harbinger Capital Partners LLC. Started his investing career in 1997 in the Corporate Bond Research Department of Salomon Brothers.

Non-Executive Board Member - Anggelos Skutaris

Anggelos is currently a member of the Incorporation Committee and Chief Investment Officer for Power Bank, a Qatar-based financial institution with the aim to provide Islamic financing to the global energy sector. Key positions he held in the past include CIO (Janus Continental Group, JCG), Head of Treasury Operations & Transformation (Qatar Airways), Managing Partner (New Symbol Global Advisors), CEO (Piraeus Capital Management), Founder & CEO (OliveTree Management Associates), Group Treasurer (Titan Cement), Head of Equity Financing (Calyon Securities) and Director of Equity Financing (Credit Suisse).

Chairman of the Advisory Board - Sanjeev Mukerjee Ph.D.

Since 1998, Sanjeev is a Professor of Chemistry and Chemical Biology at Northeastern University. He heads Renewable Energy Technology at Northeastern University and its Laboratory for Electrochemical Advanced Power (LEAP).

RISK

The key risks to our valuations are failure to gain commercial traction, development setbacks on the next generation product, competition, and any stalling of the hydrogen economy.

Commercial traction

Sometime great technologies fail to be taken up by the market. We often see lack of marketing effort as an issue making this less of a risk and more of a performance issue. In the case of Advent, a CMO at board level and the fact that commercial sales are already evident suggests any risk here is well managed in our view.

Development setbacks

While the current technology is saleable, real market dominance is possible with the next generation currently under development with the DoE. Given that the current role Advent is playing here is at the final commercial development stage, the technology itself appears to be in a good place. We see any risk here as being more to do with possible delays rather than any complete failure of the technology.

Competition

Existing LT PEM fuel cell providers already have market share and can claim to offer a viable product which in some cases is actively marketed. They also pursue their own R&D programmes. We believe we have been suitably cautious in our assumptions of the market share which Advent could achieve and see this as addressing this risk.

Hydrogen economy development

The development of a hydrogen economy is driven by policy needs on climate change. All policy can be unpredictable and can face setbacks depending on the politics of the day. That said we do see support building for hydrogen and acceptance in key applications or geographies is likely to create its own momentum.

FINANCIAL MODEL

Profit and Loss Account

$ '000, DEC	2019a	2020pf	2021e	2022e	2023e	2024e
Turnover						
MEAs	620	883	8,886	21,204	41,364	99,833
Grants	602	207	5,823	5,873	18,636	22,967
AMCI	0	0	0	0	0	0
Adjustments	0	0	0	0	0	0
Total	1,222	1,089	14,709	27,077	60,000	122,800
Operating profit						
MEAs	-174	-3,074	-17,913	-17,772	-5,776	17,514
Grants	-2	-16	0	0	0	0
AMCI	0	-1,631	0	0	0	0
Adjustments	0	560	0	0	0	0
Operating profit	-176	-4,161	-17,913	-17,772	-5,776	17,514
P&L Account	**2019a**	**2020pf**	**2021e**	**2022e**	**2023e**	**2024e**
Turnover	1,222	1,089	14,709	27,077	60,000	122,800
Operating Profit	-176	-4,161	-17,913	-17,772	-5,776	17,514
Investment income	0	0	0	0	0	0
Net Interest	-95	-32	503	369	258	187
Pre Tax Profit (UKSIP)	-270	-4,193	-17,410	-17,403	-5,518	17,700
Goodwill amortisation	0	0	0	0	0	0
Exceptional Items	0	0	0	0	0	0
Pre Tax Profit (FRS3)	-270	-4,193	-17,410	-17,403	-5,518	17,700
Tax	-88	0	0	0	0	-4,779
Post tax exceptionals	0	0	0	0	0	0
Minorities	0	0	0	0	0	0
Net Profit	-358	-4,193	-17,410	-17,403	-5,518	12,921
Dividend	0	0	0	0	0	0
Retained	-358	-4,193	-17,410	-17,403	-5,518	12,921
EBITDA	-159	-4,139	-17,158	-16,265	-3,500	21,800
EPS (c) (UKSIP)	-0.78	-9.09	-37.76	-37.75	-11.97	28.03
EPS (c) (FRS3)	-0.78	-9.09	-37.76	-37.75	-11.97	28.03
FCFPS (c)	-0.58	-5.68	-79.01	-64.61	-42.01	-47.98
Dividend (c)	0.00	0.00	0.00	0.00	0.00	0.00

Source: Company data, Longspur Research estimates

KEY POINTS

- FY 21 sees growth in sales from order book start to ramp up
- Investment in production allows significant expansion in FY 23 and FY 24
- FY 24 sees a move into profitability

Balance Sheet

$ '000, DEC	2019a	2020pf	2021e	2022e	2023e	2024e
Fixed Asset Cost	232	369	12,369	24,669	37,276	70,199
Fixed Asset Depreciation	-147	-170	-925	-2,431	-4,707	-8,994
Net Fixed Assets	85	199	11,444	22,237	32,569	61,205
Goodwill	0	0	0	0	0	0
Other intangibles	0	0	0	0	0	0
Investments	0	0	6,000	6,000	6,000	6,000
Stock	32	108	1,457	2,683	5,944	12,166
Trade Debtors	316	421	3,627	6,677	14,795	30,279
Other Debtors	274	1,208	1,208	1,208	1,208	1,208
Trade Creditors	-308	-341	-3,627	-6,677	-14,795	-30,279
Other Creditors <1yr	-1,723	-2,339	-2,339	-2,339	-2,339	-2,339
Creditors >1yr	-209	-259	-259	-259	-259	-259
Provisions	0	0	0	0	0	0
Pension	0	0	0	0	0	0
Capital Employed	-1,533	-1,003	17,511	29,530	43,123	77,982
Cash etc	1,199	134,310	98,391	68,969	49,858	27,921
Borrowing <1yr	500	0	6	6	6	6
Borrowing >1yr	0	0	0	0	0	0
Net Borrowing	-699	-134,310	-98,385	-68,963	-49,852	-27,915
Share Capital	3	5	5	5	5	5
Share Premium	8,812	151,774	151,774	151,774	151,774	151,774
Retained Earnings	-9,649	-18,473	-35,883	-53,286	-58,803	-45,882
Other	0	0	0	0	0	0
Minority interest	0	0	0	0	0	0
Capital Employed	-1,533	-1,003	17,511	29,530	43,123	77,982
Net Assets	-834	133,306	115,896	98,493	92,976	105,897
Total Equity	-834	133,306	115,896	98,493	92,976	105,897

Source: Company data, Longspur Research estimates

KEY POINTS

- Strong cash position following listing in FY 20
- Cash runs down to FY 24 but remains comfortable
- Cash should grow further out as company moves into profitability
- Fixed assets grow strongly with investment in production
- Working capital rises with sales based on historic ratios

Cashflow

$ '000, DEC	2019a	2020pf	2021e	2022e	2023e	2024e
Operating profit	-176	-4,161	-17,913	-17,772	-5,776	17,514
Depreciation	17	23	755	1,506	2,276	4,286
Provisions	0	0	0	0	0	0
Other	-179	840	0	0	0	0
Working capital	17	794	-1,270	-1,225	-3,262	-8,611
Operating cash flow	-321	-2,505	-18,428	-17,491	-6,762	13,189
Tax paid	89	8	0	0	0	-2,390
Capex (less disposals)	-35	-123	-12,000	-12,300	-12,608	-32,923
Investments	0	0	-6,000	0	0	0
Net interest	-95	-32	503	369	258	187
Net dividends	0	0	0	0	0	0
Residual cash flow	-362	-2,651	-35,924	-29,422	-19,111	-21,937
Equity issued	1,351	139,401	0	0	0	0
Change in net borrowing	-3,981	-133,611	35,924	29,422	19,111	21,937
Adjustments	2,991	-3,140	0	0	0	0
Total financing	361	2,651	35,924	29,422	19,111	21,937

Source: Company data, Longspur Research estimates

KEY POINTS

- Working capital remains negative as company experiences continued growth across forecast period
- Capex remains high as company continues to invest
- Pick up in capex on production assumed in FY 24 to support higher sales
- Working capital outflow across period
- Estimated $6m investment in FY 21 represents UltraCell acquisition

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