4th Energy Wave

The Fuel Cell and Hydrogen Annual Review, 2017

About 4th Energy Wave

4th Energy Wave was founded in 2014 by the ex-head of Fuel Cell Today and FCT Consulting and Director of the Navigant Energy Smart Energy team.

Focused on delivering strategy and analysis on the fuel cell, hydrogen and increasingly energy storage sectors, 4th Energy Wave is trusted as the voice of authority on the rapidly evolving markets. 4th works directly with SMEs, corporates, investors and governments to ensure cost effective results, which are focused and results driven. The company has developed a range of tools and methodologies with which it analyses markets and geographies of interest to clients.

Each year, 4th engages with a maximum of five clients on a long-term basis and works with them to develop their corporate plans. This one-to-one attention enables clients to develop a much more robust position in the market and leverage the knowledge and contacts that 4th holds. 4th also produces a range of standalone reports, including in 2017, a major report on China and the start of a range of company briefing notes.

The Fuel Cell and Hydrogen Annual Review is the continuation of the Fuel Cell Annual Review report from Fuel Cell Today, started by Dr Kerry-Ann Adamson and her team in 2007. The dataset combines both historical data from FCT and fresh data, collected and collated by 4th Energy Wave. This special 10th Anniversary Edition presents for the first time one of a range of scenarios developed by 4th on the emerging fuel cell and hydrogen sectors.

Any questions, orders and requests for the chart book, should be directed to Kerry-Ann at;

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2050 - Hydrogen and Fuel Cells mature in the Global Decarbonised Economy

"Under the The H_2°C Scenario by 2050 the majority of the world's transport market is over 85% decarbonised. The freight sector, including shipping, relies on the use of fuel cells and transport for the movement of goods around the world. The public transport sector is a local mix of battery and fuel cells, with a number of countries predominantly fuel cells. LDVs are increasingly all electric, with fuel cell vehicle penetration high in countries where travel is increasingly extra urban. China has the world's largest fleet of fuel cell vehicles.

The biggest shifts in the hydrogen market came from Norway, Argentina, Australia and increasingly Saudi Arabi setting themselves up as major hydrogen export markets. This created a maritime hydrogen market in the late 2020s which has burgeoned since then. Policies enacted in the 2020s have ensured that green hydrogen is taxed at a much lower rate than brown hydrogen, pushing the rapid development of a green hydrogen market.

Hydrogen arbitrage is now a growth industry, with the power to gas sector playing a key role in countries such as Germany, the UK, Japan and China."

UK
"Teaming agreement with India and South Africa leads to high penetration of off grid rural communities powered by hydrogen and fuel cells. Transport fleet 80% electrified with fuel cells deployed in trains, freight, buses and cars"

Germany
"Economy 100% renewable with high penetration of power to gas, and hydrogen imports from the Nordic region. Largest hydrogen consumption market in Europe. GHG budget down 90% from 1990"

Norway
"First nation to reach full decarbonisation. Hydrogen and fuel cells play a pivotal role in this in both the transport and power sectors. GDP growth linked to the development of a hydrogen export market."

France
"Hydrogen innovation based economy. 90% of global nuclear hydrogen produced in France. Largest fleet of fuel cell trains."

China
"4 millions fcv's on the road, 85% road transport electrified, largest power to gas economy in the world"

South Korea
"World's largest hydrogen plant now 10 years old. Water use from energy production down 60%"

Canada
"Liquid green hydrogen significant export market by 2050. Major cities well on the way to full decarbonisation."

Japan
"Hydrogen Economy Realised. 2 million tonnes of CO_2 avoided, oil dependency 2%, 1 million jobs created."

USA
"Long decarbonisation path, with hydrogen and fuel cells playing major role in the greening on the fossil fuel and steel industries. 25 States with over 70% electrified transport fleet. 10 States with fully electric transport fleet."

Australia
"World's largest green hydrogen export market, with primary supply to Asia. Long term off take agreement from Japan and South Korea. 1.5 million jobs created. Hydrogen created 2% GDP growth from 2020."

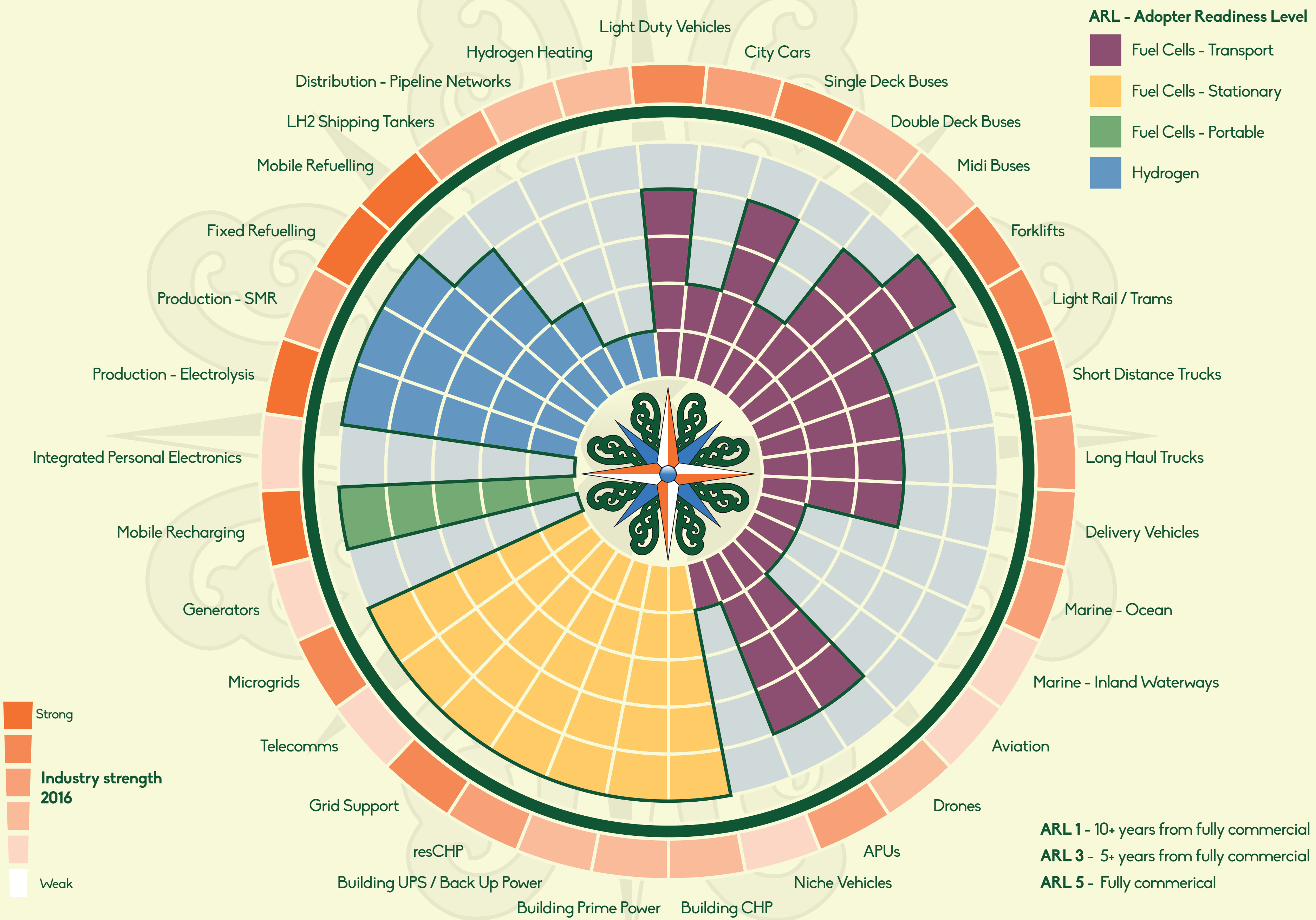
Argentina
"Second largest green hydrogen export market"

Saudi Arabia
"Rapidly moving to a hydrogen arbitration market. Large scale production of green hydrogen. Development of hydrogen gas pipeline from Saudi to Europe underway. Local use focused on transport."

South Africa
"Universal energy access for all achieved in the 2030s. 3D printed fuel cells and electrolysers play a key role in stimulating the South African economy. Central node for export of locally made systems into Sub Saharan Africa. Largest Hydrogen port in Africa. 1.2 million new jobs created from €5 billion in leveraged investments."

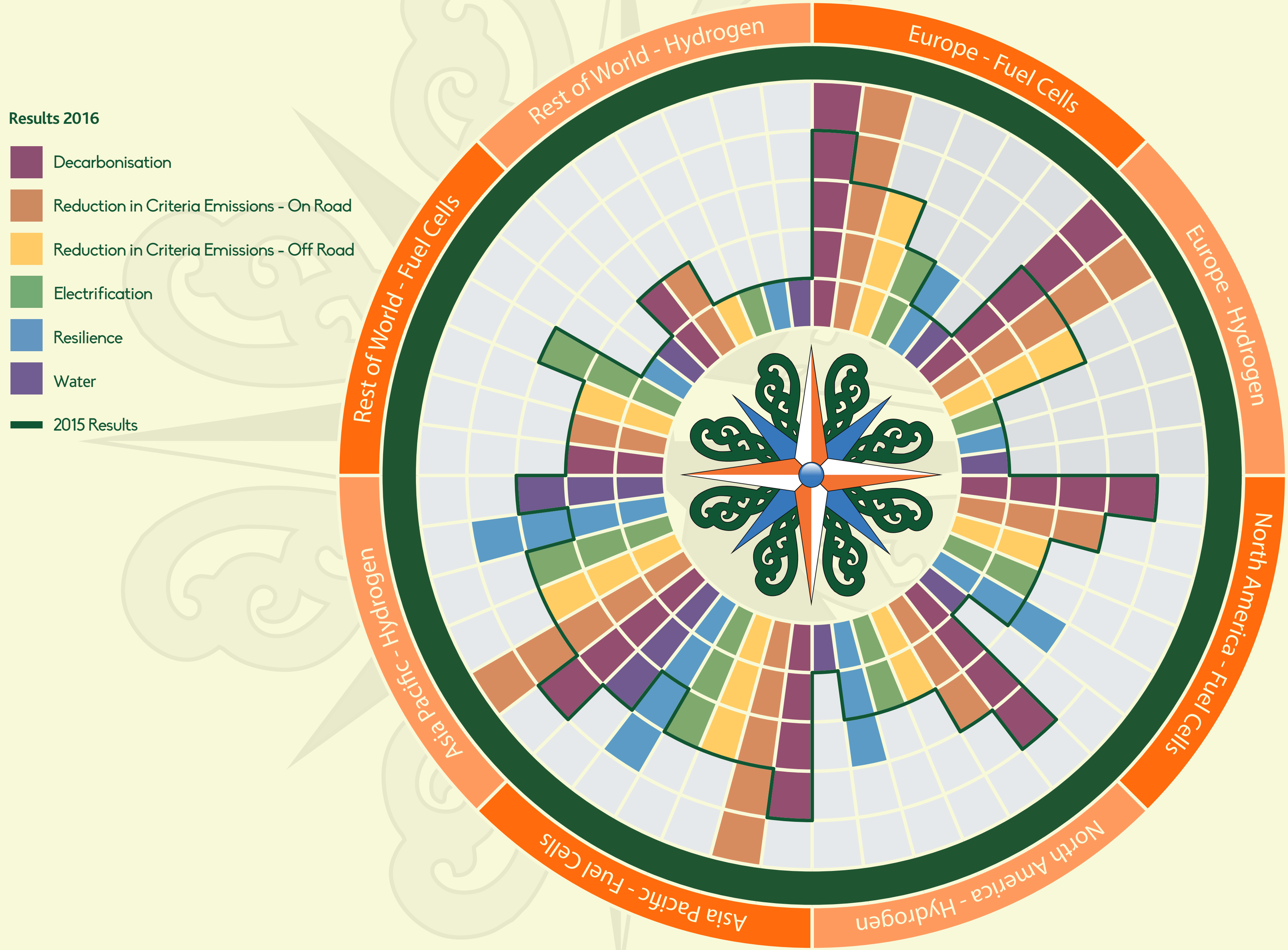
India
"Transport fleet fully electrified, with fuel cells and hydrogen making up 75% of freight transport, 80% of buses, and 30% of LDV fleet. Universal energy access across the country"

Table 3.2: Drivers for Change and Adoption of Increased Use of Fuel Cells and Hydrogen

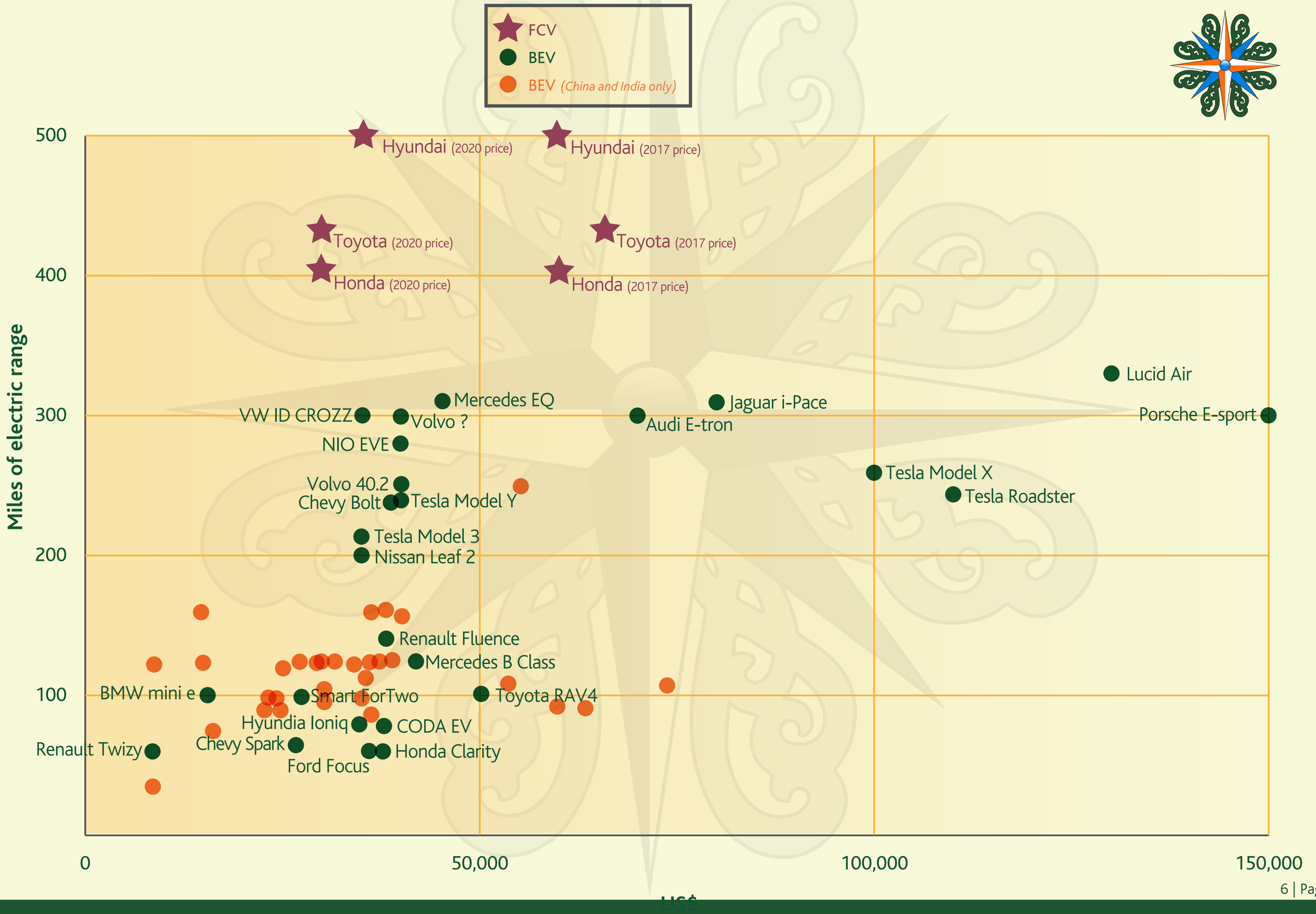


Source: 4th Energy Wave, 2017

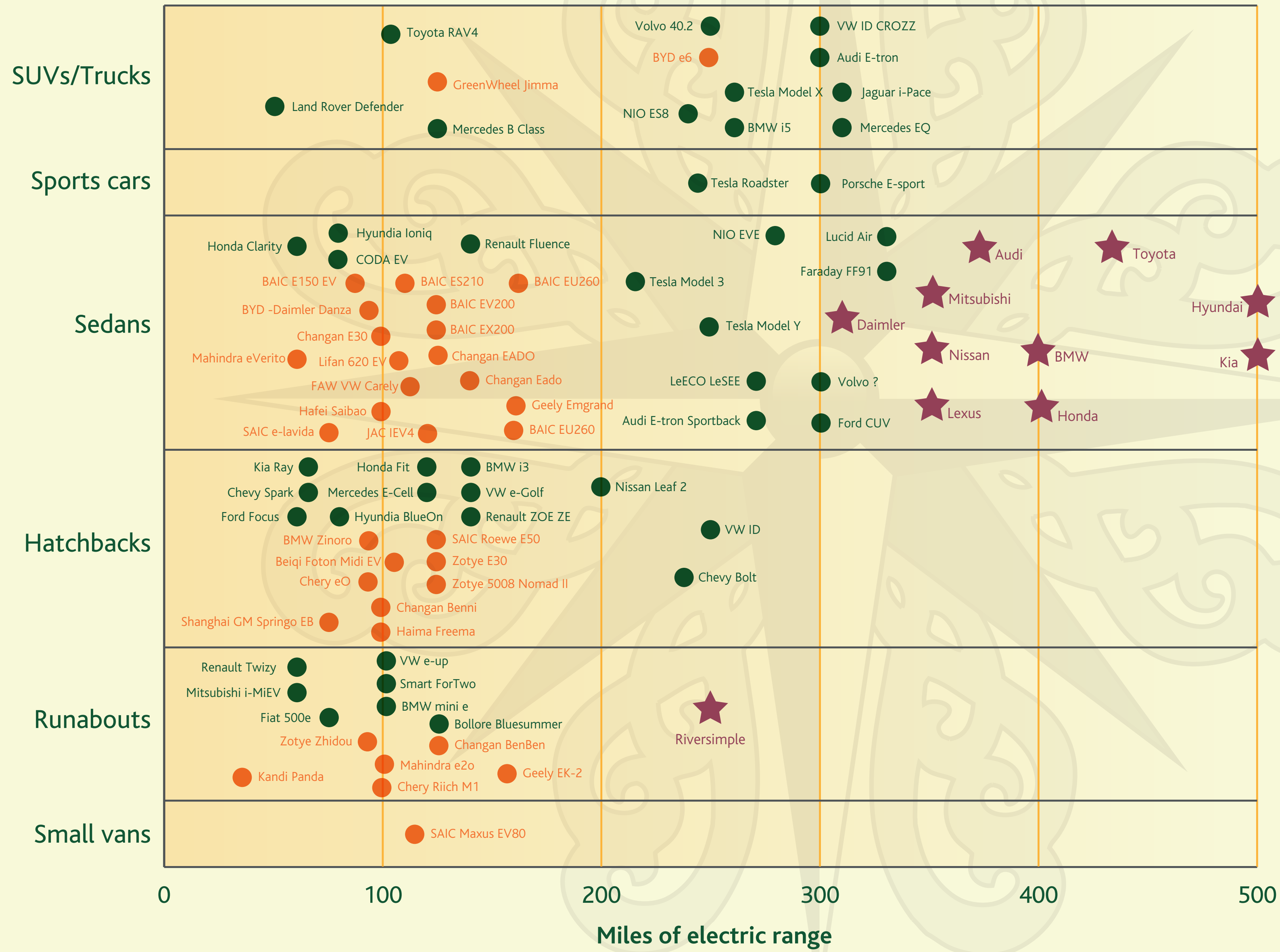
Table 2.1: Shifting Importance of Drivers for Fuel Cell and Hydrogen Adoption 2015 and 2016

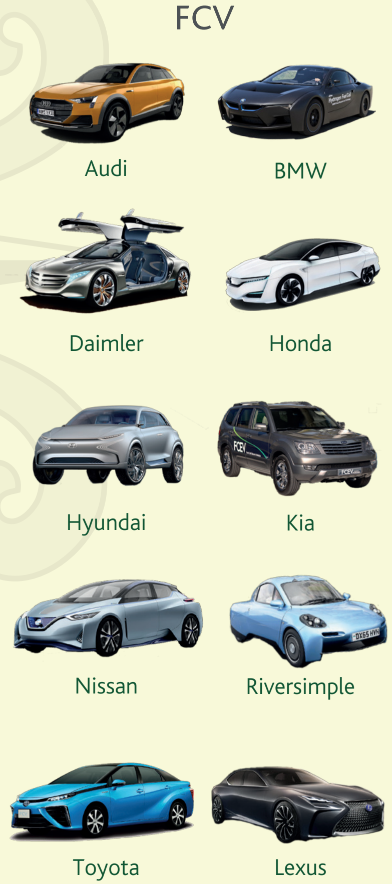


Electric Car Boom - Models by price and range through 2020



2020 LDV Electric Revolution - Models by style and range through 2020





1. The Fuel Cell and Hydrogen Annual Review Definitions

The Annual Review covers all markets for stationary, portable and transport fuel cells. It does not cover the fuel cell toy market, or the drone market.
The stationary sector has been updated since the last

Categories

Annual Review and the split is now categorised into:

- Prime Power
- Residential CHP
- CHP
- UPS and Remote Power

Transport

The transport sector is now classed as:

- Cars
- Heavy Duty Vehicles
  (Buses, trucks, trains, marine, etc.)
- Logistic vehicles and Others

Portable

The portable sector is split into:

- Skid Mounted Systems
- Systems for Personal Electronics

What is not covered in this report is the civilian / military split. The report also does not break out the sectors into the myriad of subsectors that are emerging. Whilst these are being tracked for the sake of providing an overview, not in-depth analysis, this report is kept primarily at the sector level.

Tracking of the hydrogen sector is kept this year at electrolysis and does not include any developments in the market for steam methane reformers (SMR). The numbers provided are our estimates of electrolyser units ordered and do not place any emphasis on the use of the hydrogen produced.

As the hydrogen market is much bigger than just fuel cells, users need to be careful not to equate the numbers in this report with developments in the fuel cell sector, unless specifically noted otherwise.

The report divides the world into 4 regions:

- Europe – For this report, Europe covers the European Union, Switzerland, Norway, Iceland and Russia. Unless otherwise clearly stated, references in the document to Europe are for the entire continent, and only when tagged as such do they refer to the European Union (EU).

- North America – For this document, this refers to Canada and the US only.

- Asia Pacific – Refers to the Asian subcontinent and includes India.

- Rest of the world – Everywhere else.
- South Korea second and Germany third.

Whilst most countries' government agencies are still embedded in the high-level discourse of the opportunities that a fuel cell, or hydrogen, sector represents to them, and are not focusing on the long, complex and exceedingly detail-orientated nitty gritty of identifying and removing local barriers to adoption,

2. Drivers and Influencers

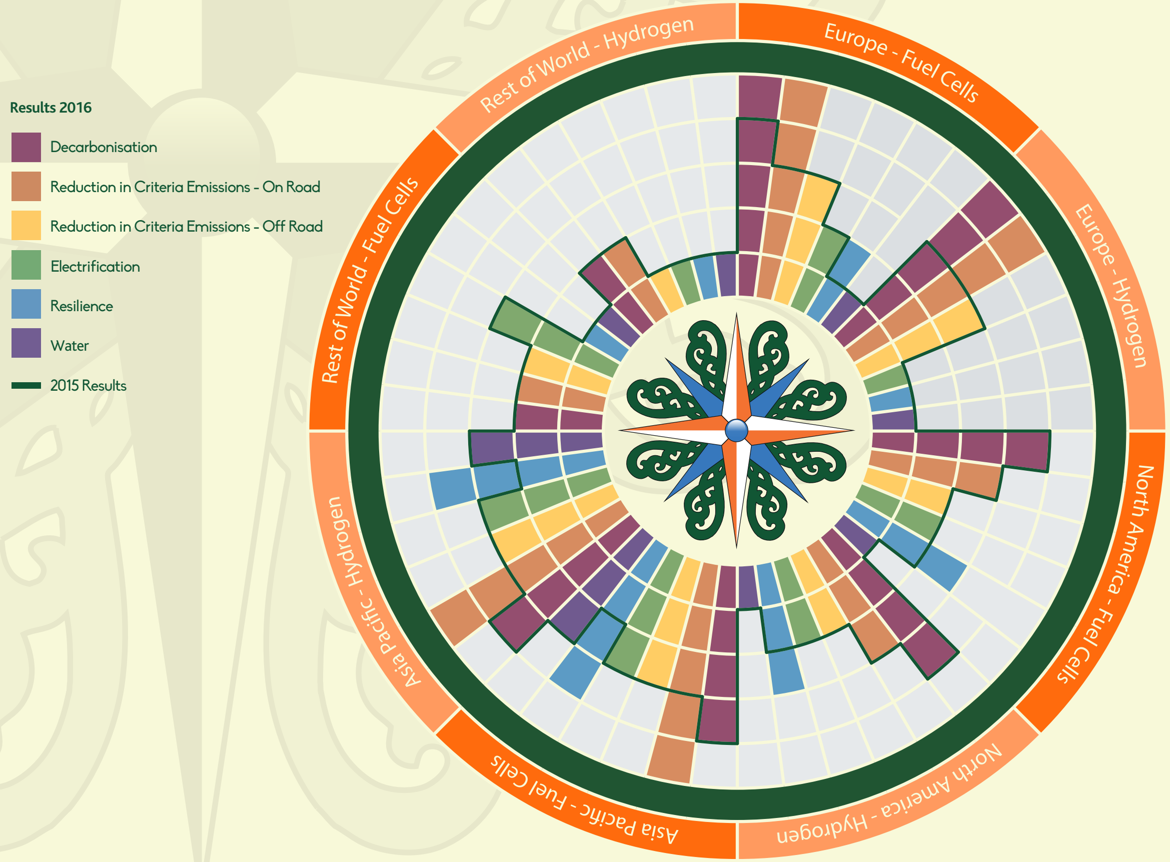
The main drivers for the switch to, and adoption of, fuel cell technology and hydrogen fuel remain the same at:

- Decarbonisation
- Criteria Emission Reduction
- Electrification
- Resilience
- Reduced Water Consumption

The main difference from the 2016 Review is the importance that is now placed on criteria emission reduction in the urban environment.

If we look at these as a basket of drivers, what is clear is that none of these drivers are just for fuel cells or hydrogen. They are the societal level drivers for change in the energy and transport system. They are not for pushing the adoption of one technology, or fuel, over another. Also, outside of Japan, governments are very keen on keeping markets open for multiple solutions. Although the light duty automotive sector is the most talked about for this, this in reality also includes building technology and residential solutions.

Table 2.1: Shifting Importance of Drivers for Fuel Cell and Hydrogen Adoption 2015 and 2016



2.1 Criteria Emission Reduction

n the light duty vehicle sector, so-called "Dieselgate" has directly led to a number of car companies jump-starting battery programmes, or reinvigorating fuel cell programmes. VW, at the centre of the scandal, has at the time of writing of this report, incurred damages of € 25 billion and launched an EV intensive programme. Whether this will be a success in part depends on issues surrounding any blowback on the ethics of cobalt, something that the company is fastidiously ignoring whilst promoting the environmental benefits of its new range of vehicles. More on this in the second special section in this report.

Indirectly, it can be argued that the emissions scandal helped tip the lens of interest on urban pollution from diesel vehicles, which in Europe at least, has led to multiple cities and regions banning the sale of petrol and diesel cars by 2040. The gradation of focus is very different in different countries, something we go into in the second special section of this report. But in essence, most analysts and industry watchers now concur that by 2040, the market will be very different in terms of vehicle mix sold, and any ban by 2040 is something of a safe bet from governments.

2.2 Decarbonisation

Decarbonisation is still very much on the agenda.

Even though the current Federal government in the US seems to be moving into a different direction, at the time of writing, 11 US states, plus Washington, DC and Puerto Rico, have joined the **United States Climate Alliance**, which is a growing, bipartisan group with the single aim of seeking to reduce greenhouse-gas emissions nationwide. For fuel cells and hydrogen, what this practically means is that the power to change markets seems, during the current administration, to be being decentralised back down to State level. So instead of focusing the lens of attention of US DOE, each of the key adopter States should be worked with.

Resilience, or creating systems that are capable of withstanding severe climate change shocks, is bouncing back up the agenda, primarily due to the increased level of severe storms to hit the US and Caribbean.

2.3 Resilience

A recent study by the American think tank The Universal Ecological Fund forecast that in the US alone, within the next decade, economic losses from extreme weather combined with the health costs of air pollution could reach at least $360 billion annually. When combined with increased insurance premiums, to cover the increased pay outs, we are looking at the system that will reaching a tipping point where without inbuilt resilience, insurance against climate-related weather events could be impossible to purchase. Again, this push towards resilience is technology, and system design, agnostic. Meaning that fuel cells and hydrogen, if they want to leverage this opportunity, need to have their ducks in a row.

2.4 Water

Water may be a topic that is still bubbling under in terms of impact when compared with decarbonisation, air pollution and resilience, but it has the potential to fundamentally shift the way we produce, and consume, energy. Coca-Cola, for example, has had to close down a number of its bottling plants due to reduced water availability. Now, granted, in this example, Coke use water as their primary ingredient, but if we see this company as a canary in the mine, then we can say that it has started to show extreme signs of illness.

As early as 2014, the International Energy Agency (IEA) showed data highlighting that the global energy sector's water usage accounted for 15% of the world's overall consumption. To reword, this is freshwater consumption.

In terms of scale, the following was taken from IEA data:

- Coal power plants consume 100 - 1,100 gallons of water per MWh of energy produced
- Nuclear 600 - 800 gallons of water per MWh
- Natural gas - 20 - 300 gallons of water per MWh
- Solar - 0 gallons of water per MWh

The big question though, which we need to produce reliable data on, is how much water does the electrolysis of electricity consume? Per electrolyte type.

If we are entering a time where the available freshwater is an increasing political tool, or measurable risk, depending on how you measure the metrics, then without a clear understanding of the level of resource consumption, and its knock-on impacts on adoption, from hydrogen production, we are operating blind. And in terms of investment, operating blind is not something companies will invest in.

3. 2016 Fuel Cell and Hydrogen Market Overview Adopter Readiness Level

The 4th Energy Wave metric, Adopter Readiness Level (ARL), was devised as an assessment of market readiness for a new product. Covering a number of different factors and pain points the ARL analysis focuses fully on market pull.

The reason for this is that both of the well-known metrics of Technology Readiness Level (TRL) and Manufacturing Readiness Level (MRL) are both pure technology push metrics.

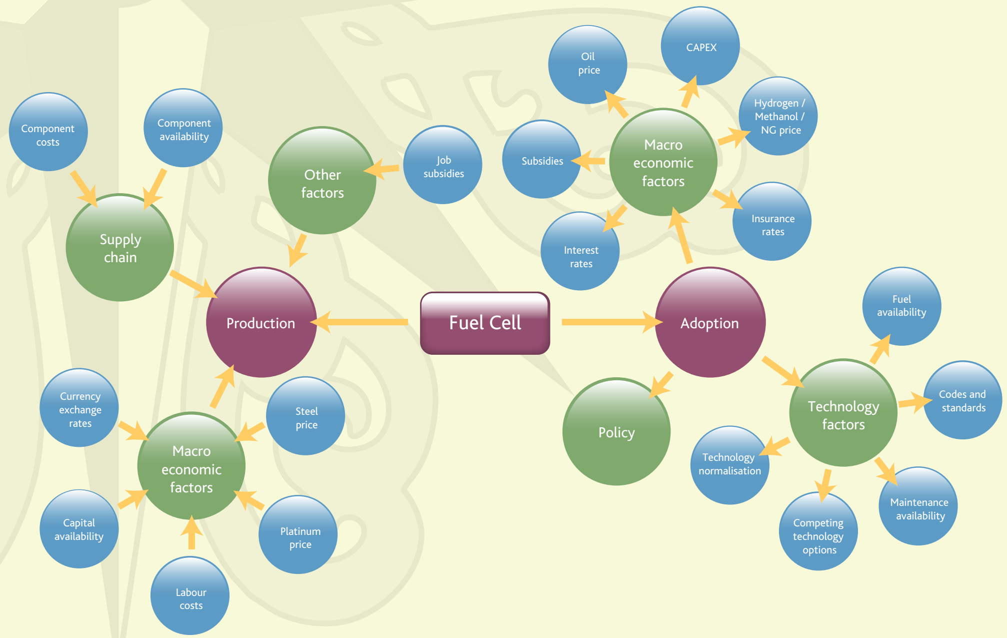
They both measure how ready the technology is for market. But neither measure how ready the market is for the technology, or how much market pull there is. Because of this, and the focus on funding is on developing technology, we have seen a number of companies come to market with a technology, but no customer, and worse, no idea of where to look for one. The prevalence of this, especially in the fuel cell sector, has been one of the key reasons, we posit, for the slow take-off of fuel cells.

What the sector needs is a much more holistic view of solution development, not technology development, and this is where ARL, combined with TRL and MRL, comes into play.

Note that ARL is the new name for CRL. 4th has been using the term Commercial Readiness Levels (CRL) for the last three years, but we have been made aware that this term was trademarked in 2016 and we have been informed that we cannot continue to use this term.

The ARL metric combines information in some twenty plus areas to assess where a market is in terms of readiness for potential adoption of new solutions. This includes the development of codes and standards (C&S), relevant infrastructure, customer awareness, etc. The scale goes from ARL 1 – at least 10 years away from being fully commercially ready, to ARL 5 – market fully ready.

Chart 3.1: Influencing Factors and Pain Points



When working with commercial clients, we suggest that the ideal point at which to start looking at, and incorporating thinking of ARLs, in fuel cell development, is at TRL 4 or 5. Whilst this is still very early for some, the flip side of having a technology with no market entry point is very costly.

The radial chart on the next page incorporates two metrics for assessment of where the fuel cell and hydrogen industries were in 2016. For 35 of the end use sectors that 4th Energy Wave tracks developments in, we have measured the current ARL. ARL 5 is fully commercial now, with no show-stoppers in the market. This is not to say that customers are beating down a path to adopt, but that there is nothing in commercial space that would prevent adoption. ARL 1, as already mentioned, highlights a market where there is still significant non-technical work to be done before it can be classed as fully commercial.

As can be seen from the radial chart, the stationary sector is by far the most developed in commercial and market readiness.

Note that there is no measure of economics in ARL. The economics of fuel cells is still somewhat of a pejorative issue. There is no clear consensus on what price is acceptable, or good enough. What CAPEX level is low enough, or in what circumstances lifetime costs are acceptable. Instead of therefore creating what could end up being another stick to beat the sector with, we have not included economics in the assessment.

The other assessment used in the chart is that of industry strength. How deep and broad is the sector? If one company fails with supplies, say fuel cells to the telecoms sector, how much does this weaken the overall footing of that sector? Also, how strong are the companies supplying into that sector. Our models at 4th are bottom-up models, in that we model company by company performance for the long term. We use our own, internal only, assessment tool on company performance and ability to grow, and we grade each company based on a ramp-up rate. The model still sees the overall industry, fuel cells at least, in constraint, in that we still have too few, unstable companies, for the long term to create a sustainable, high volume, high growth industry. In the radial chart, the darker the orange in the outer ring, the higher our assessment of the strength of the industry in that area.

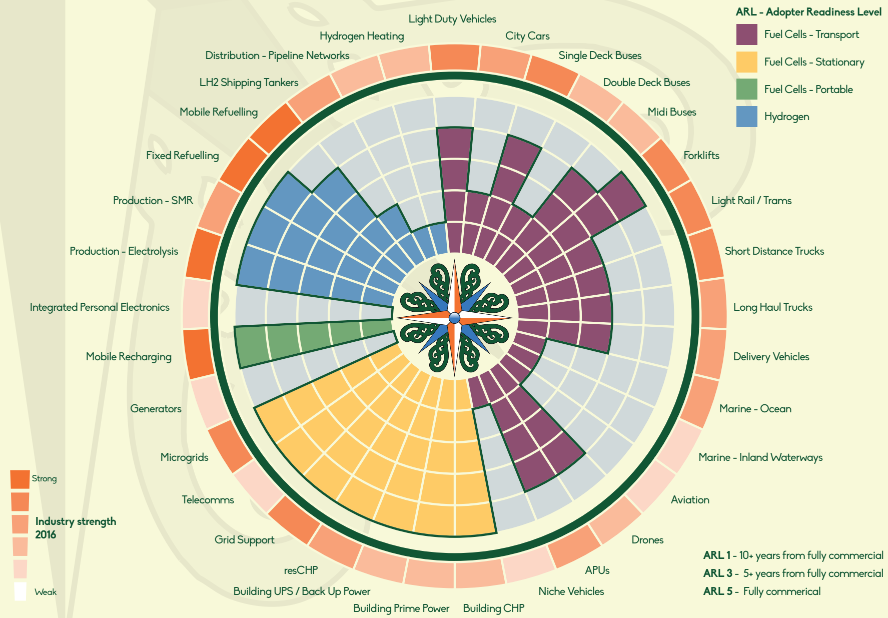
As can be seen from the chart, there are very few market areas where in 2016, we assess the strength of the industry to be high. Very few. There are some that are acceptable and many that are far too low to create profitable sectors. So although we are seeing signs of growth in over 40 areas, 35 shown here, any of these still have the potential to collapse and never see profitability.

Unlike say solar, or even batteries, there remains a job of work to do to create an industry that is strong enough to grow, supply, and reach profitability, and markets that are open enough to adopt into them new fuel cell based solutions.

Using ARL and an assessment of the strength of interest and company involvement in 2016, the following chart was developed for 33 separate fuel cell and hydrogen sectors. These are broken out from the usual stationary, portable and transport fuel cells and hydrogen, into more detailed sectors. If a company's focus and developments in 2016 was strong then the colour in the outer ring is deeper. When this is combined with a market that is ARL 5 then these markets are likely to see strong adoption in the near term.

Markets with a lower ARL but high developer interest are likely to see companies needing to play a much longer game, as they will need to focus on removing market barriers as much as developing the technology. This, as we now know, can be highly expensive, suggesting that these companies' cash burn could be high.

Table 3.2: Drivers for Change and Adoption of Increased Use of Fuel Cells and Hydrogen



Source: 4th Energy Wave, 2017

4. 2016 in Numbers
Fuel Cells

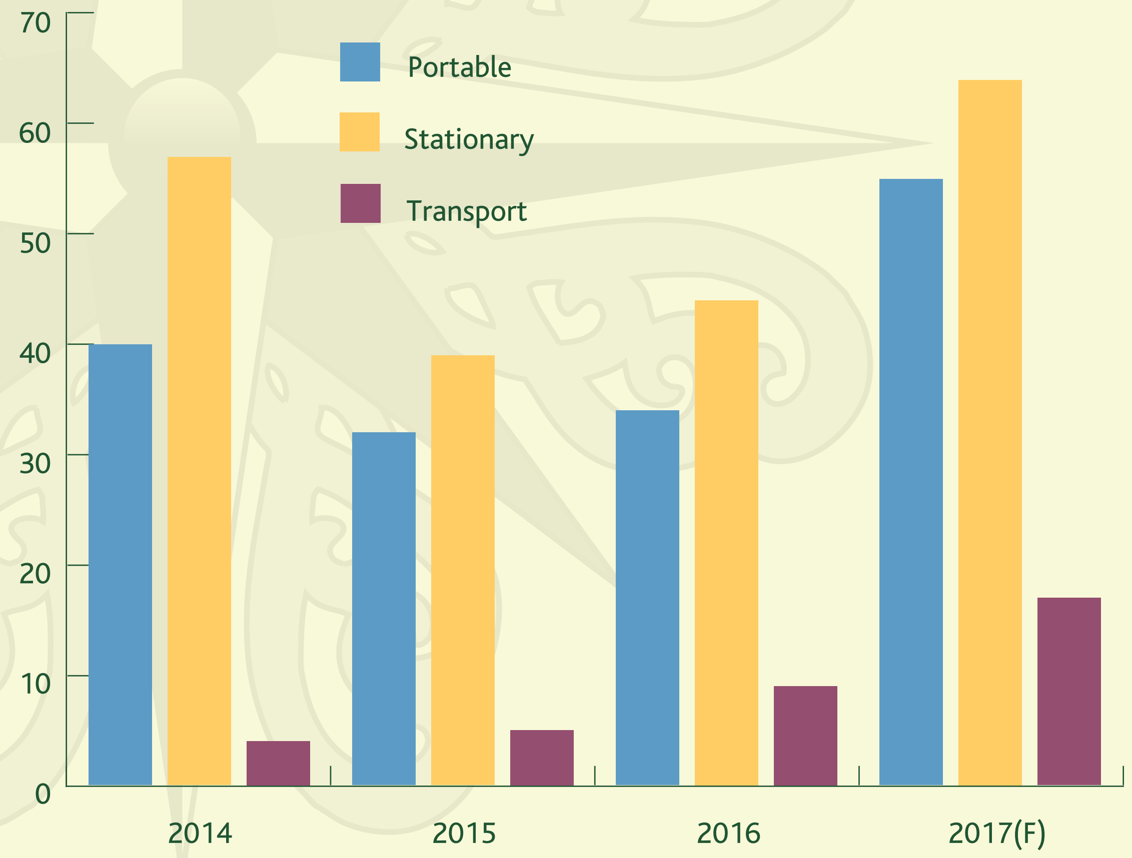
Overall, 2016 was a difficult year for a number of fuel cell companies. At the start of the year, there was the promise of large-scale orders, both in terms of actual systems, but also megawatts of installed power. In the end though, market intractability in a number of areas pushed back, and orders were either dropped, or in some cases, moth balled.

In terms of actual deployments though, due to the emergence of the heavy duty vehicle sector, and the start of the long-term roll out of light duty vehicles, overall, numbers were bolstered from 2015 to 2016.

4.1 Shipments and MWs

The global fuel cell industry grew to 88,000 units shipped in 2016. This was up from 76,000 in 2015. Between 2014 and the end of 2016 though, the industry contracted 8%. This continued wobbly nature very much points to the industry still being immature, with growth heavily predicated on a range of uncontrollable factors. For example, the oil price and customer attitudes to fossil fuels.

Chart 4.1: Systems shipped by Sector: 2014 - 2017 (F)



If we turn to 2017, we are forecasting that the impact of China will be increasingly visible by the end of the year, with an increase in units shipped jumping to 146,000. This is a combination of heavy duty transport deals with fuel cell developers **Ballard Power Systems**, **Hydrogenics** and **Palcan**, but also the mobile recharger deal announced in December 2016 between **myFC** and **Nanjing Tianningjun Communication Technology**, a subsidiary of **Telling Communication**. If completed, this deal will be the largest fuel cell deployment, globally, to date, with an overall potential order of 1.4 million fuel cell JAQs deployed in China by the end of 2018.

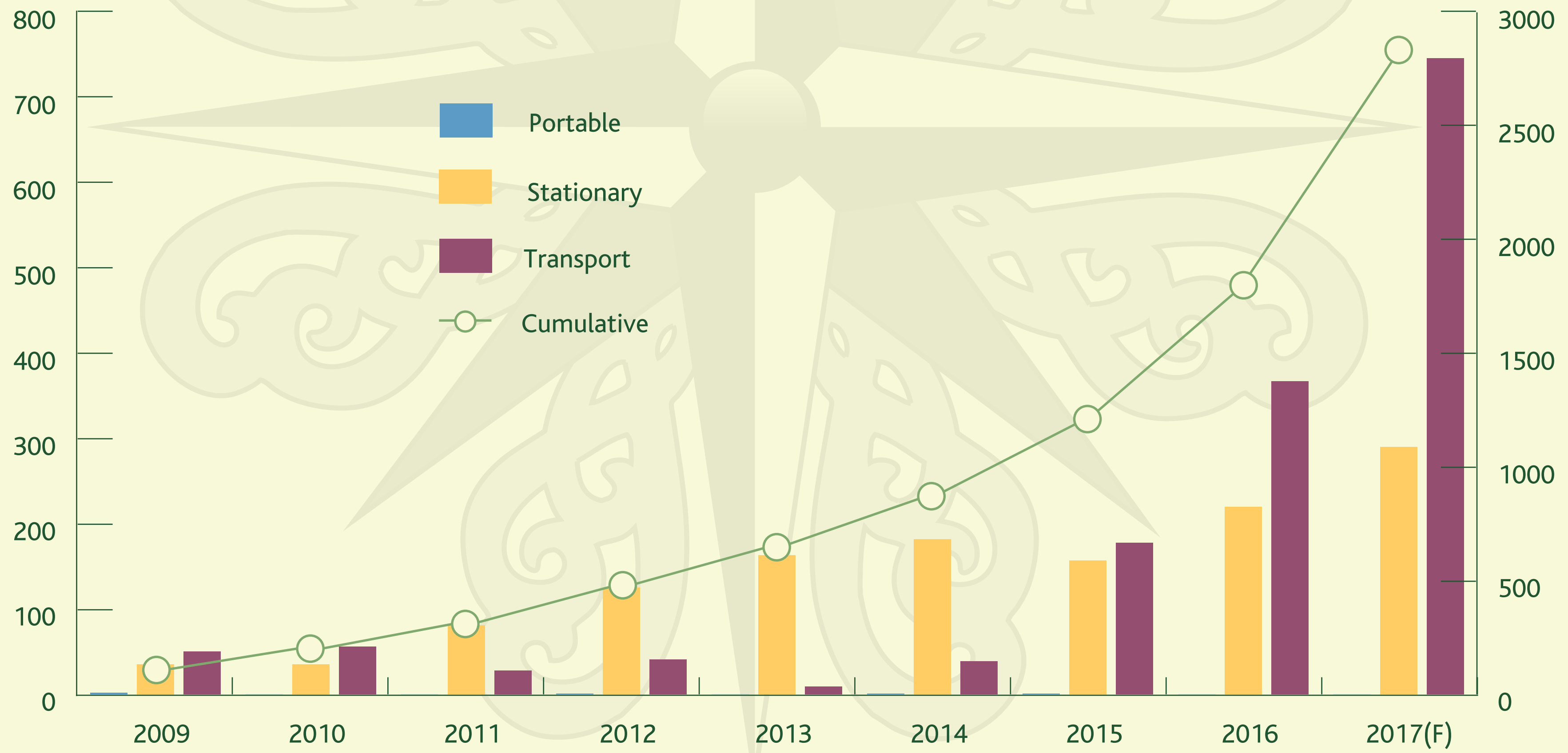
If we move to MWs of fuel cell systems shipped, we see that in 2016, globally, some 1.8 GWs of fuel cell power, and fuel cell drivetrains, were shipped.

Note that as we see a shift to MWs becoming the de facto unit of measurement for the sector, away from number of systems shipped, we have extended this chart back to 2009.

It is no surprise with the tail off in 2016 of the stationary sector, and the tsunami of interest from China in the transport sector, that between 2015, 2016 and 2017, there is an obvious flipping of importance between the two sectors.

In 2016, the transport sector jumped to shipping of 467 MWs, up from 178 in 2015, whilst the stationary sector increased from 157 MWs to 220 MWs. This gap is forecast to exacerbate in 2017, with the transport sector forecast to ship 456 MWs more of fuel cell power than the stationary sector. This shift of increase in market pull for fuel cells in transport is having direct knock-on impacts in terms of costs of PEM fuel cells, steeper learning curve, platinum demand in the fuel cell sector, and the increase in use in direct hydrogen.

Chart 4.2: Global Fuel Cell Shipments, by MWs Shipped and Sector: 2009 – 2017 (F)



In fact, apart from a handful of vehicles, over 98% of the fuel cell transport sector uses direct hydrogen. Our forecasted increase in interest in using methanol as a transport fuel can be seen at the edges of the industry, but so far, at least, it is not having the in-roads of interest that it did in the late 1990s. Currently, **SerEnergy** and **Palcan** are leading the way with methanol vehicles, though in April 2017, Li Shufu, the chairman of **Geely** and **Volvo Cars**, submitted a formal proposal to the Chinese central government for the mass launch of methanol-fuelled vehicles in China. So far, there has been no formal reaction to this.

The stationary sector was hit somewhat during 2016 and 2017, with the call off of a number of large-scale orders, including the telecoms deal between **Intelligent Energy** and **GTL**, and the fall out of the **FuelCell Energy** and Beacons Fall project. These two deals alone represented potential fuel cell capacity of over 115 MWs.

Various reasons are behind each order's collapse, but what is clear is that the business case for fuel cells very much still needs to be built on a case by case basis. This, in some ways, feeds into the continuation of a lack of a common metric against which "stationary fuel cells" are measured. A number of companies and organisations are starting to heavily pitch for a single metric against which "stationary fuel cells" can be measured against a range of competing technologies.

In terms of cumulative MWs shipped, since 2009, the industry has shipped 1.6 GWs of new power producing units and new drivetrains. Annually, it has jumped from 87 MWs per annum in 2009 to 587 MWs in 2016, and is forecast to jump again in 2017, breaking the GW per annum barrier for the first time.

In many ways, any exercise in creating a common metric for measuring "stationary fuel cells", we would strongly argue, is one of utter fallacy. For a start, "stationary fuel cells" now covers at least nine discreet markets sectors and six technologies, each with their own cost points, learning curves, points of profitability, available subsidy, etc. So if we were to adopt a common metric, it would at the very least, need to go down to sector level, telecoms back up, prime power for the grid, etc.

To be of any real value, it would then also need to be region specific, making it even less easy to have a single number to answer everything.

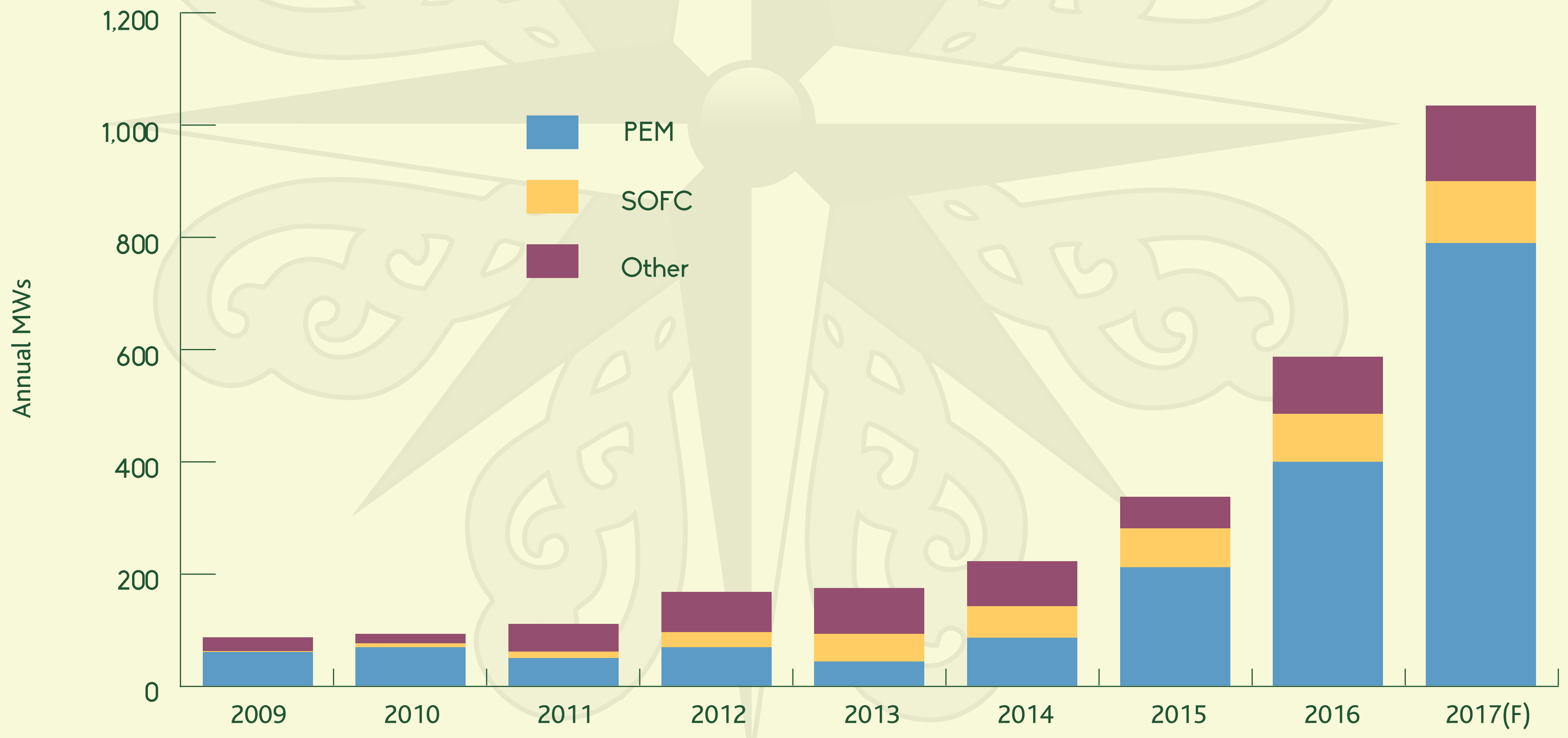
Note that in many respects, the Lazard report "Lazard Levelized Cost of Energy Analysis" is light years ahead of most, and is clearly the best of a bad bunch, in that at least the analysis appears to be comparable year on year. But to be useful as a working business analysis metric, the level of information needs to increase dramatically on fuel cells, and expanded out of the US-based subsidy structure and away from simply "fuel cell".

4.2 Electrolyte Mix

One of the big improvements we are finally seeing in the sector is the long overdue death of the question "but which electrolyte will win". As the markets and technologies continue to develop, the opportunity for all electrolytes continues to present itself. There are now clearly markets where one, or two, electrolyte types are leading, but there is no market where only one electrolyte type is working. Even in the light duty vehicle sector, **Nissan** are working with **Ceres Power**, using its SOFC stack.

Chart 4.3 below clearly shows that although PEM remain dominant, with the lion's share of deployment, there is also clear growth in the other electrolytes. In 2017 (F), this also included, for the first time in many years, commercial deployments of an alkaline unit. **GenCell** are deploying in-house developed alkaline fuel cells (AFC) units in a number of countries worldwide, including Israel, the company's home market, France, and the USA.

Chart 4.3: Development of Fuel Cell Electrolyte Mix, by MWs Deployed Global: 2009 – 2017 (F)



4.3 Shifting Sector Mix

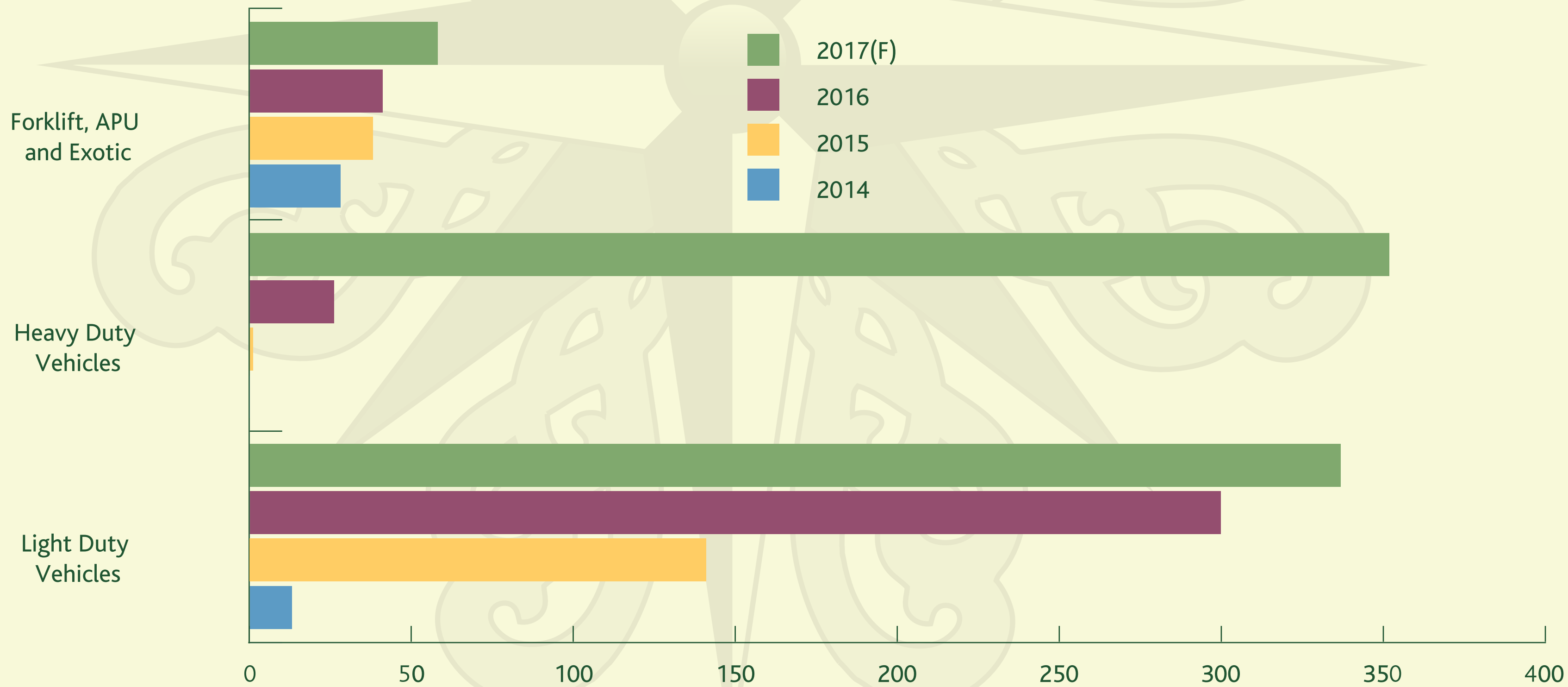
As mentioned in section two of this report, the 4th Energy Wave dataset tracks market sector development at a granular scale. For transport, the sector is split into light duty vehicles, heavy duty vehicles, and forklifts, APUs and exotics. As the market continues to grow and splinter, we can further develop the classifications, but at present, these three categories cover all the major areas.

Chart 4.4 clearly shows the arrival of the heavy duty vehicle sector. From imperceptible in 2015 to the projected leading transport sector in 2017, the transformation is forecast to continue, with China leading. Also though, we are forecasting the global marine market starting to see deployments by 2020 and the fuel cell bus market normalising also around 2020, all adding to the weight of the heavy duty sector. The logistics market continues to be classed by 4th Energy Wave as high risk medium potential. Dominated by one player, namely **Plug Power**, which we forecast will focus the majority of its efforts on serving its current anchor clients in the US, the sector is directly pegged to the growth or not of Plug. Toyota have announced plans to deploy over 400 units in Japan, and **Hyster Yale** have hinted at sales by **Nuvera** in Q4 of 2017, but we are still in a phase where over 98% of the logistics market is controlled by one company.

Note that Plug Power's deal in China is carefully worded at "fuel cell electric vehicles", leaving, we would suggest, the deal open to produce vehicles such as small delivery vans and other types of vehicles. Not logistics vehicles. The reason for this is that Chinese forklift companies continue to develop cheap ICE forklifts or battery vehicles.

For reference, Table 4.1 shows the top 10 forklift companies and notes on current, and past, interest in fuel cells.

Chart 4.4: MWs of Transport Fuel Cell Systems Shipped, by Market Sector: 2014 - 2017 (F)



Auxiliary Power Units (APUs) have for a long time been a much derided market. Nothing more than a trickle charge for a battery. But now, as we see the emergence of a number of range extender fuel cell vehicles, which in the 4th Energy Wave dataset, are counted in the APU sector, the attitude is changing. This is certainly one the areas we are expecting to see a number of significant developments and we would pin as watch with interest.

For reference, other breakout sectors we see in the near future are trains and marine.

If we turn to the stationary market and break this into the separate sectors we are tracking, we see that prime power still dominates, but then combined heat and power (CHP) continues to be up and down. Although the number of companies developing CHP systems continues to grow, and continues to manage to create a genuinely high level of press coverage, the number of available commercial systems remains steady, and low.

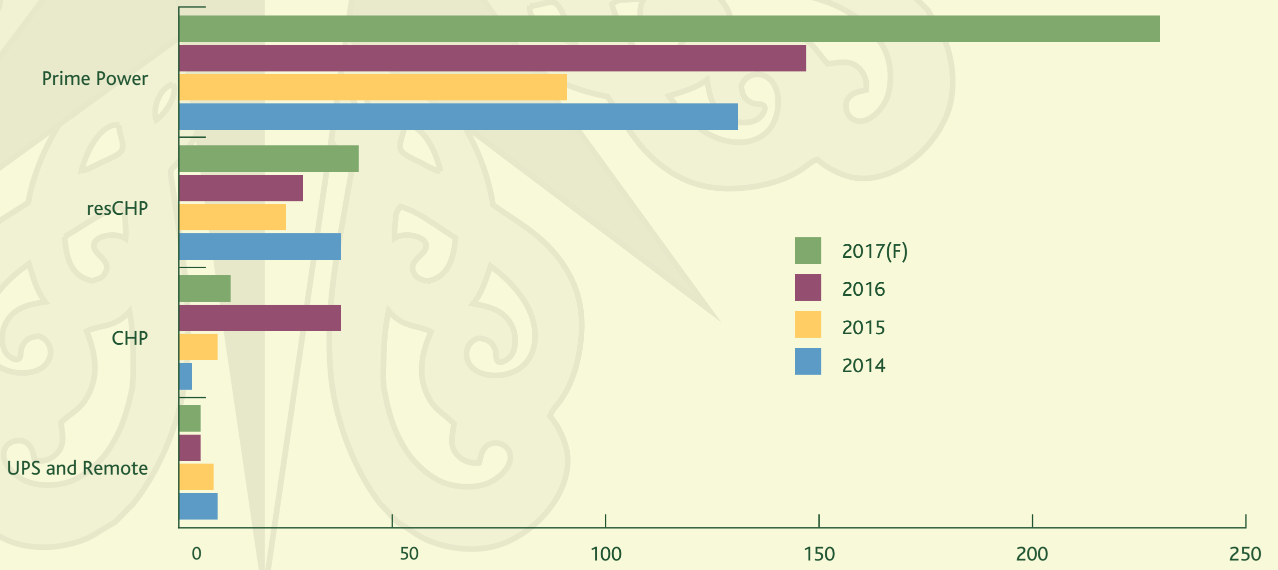
Once, or more accurately, if, companies such as **Versa Power** (now part of FuelCell Energy), **GE**, **TMI**, **Convion**, **LG Fuel Cell Systems**, **Redox Power**, **Dominovas Energy** and **Mitsubishi** actually commercialise their units, all of which interestingly are SOFC systems, then we could see the CHP market bounce back.

At the minute, the pressure on **Atrex Energy**, **Doosan Fuel Cell America**, **Fuji Electric**, and **FuelCell Energy** to demonstrate, create and promote the options into new adopter markets is too high to create sustainable, profitable global markets.

Chart 4.4: MWs of Transport Fuel Cell Systems Shipped, by Market Sector: 2014 - 2017 (F)

COMPANY	GLOBAL POSITION	INVOLVED WITH FUEL CELLS?
Toyota Industries	1	Own fuel cell forklift brand.
KION Group	2	STILL (a Kion brand) has its own fuel cell forklift. Stacks from Plug (with support from Linde).
Mitsubishi (Nichiyu Forklift Co)	4	Developed fuel cell forklift with Plug Power.
Jungheinrich	4	Involved since mid-2000s. Used methanol and hydrogen fuel cells. Current supplier: Plug Power
Crown Equipment	5	Producing fuel cell forklifts with Plug Power stacks.
Hyster-Yale	6	Owns own fuel cell brand Nuvera. No shipments.
Anhui Forklift Truck Group	7	Developing fuel cell forklift. Stack company not known.
Doosan Industrial Vehicle	8	No development but parent company owns a PEM stack company.
Hangcha Group	9	To date, appears to be purely battery focused.
Clark Material Handling	10	To date, no posted involvement in fuel cell product development

Chart 4.5: MWs of Stationary Fuel Cell Systems Shipped, by Market Sector: 2014 - 2017 (F)



The residential CHP (resCHP) market remains Japanese centric. With official figures from NEDO stating that at the end of 2016 (fy), 194,710 systems had been installed since the start of the Ene Farm programme, with on average, around 40,000 new units currently deployed per annum. This number will likely change somewhat in 2017, as **Toshiba Fuel Cell Power Systems Corporation (TFCP)** has halted production of its residential unit to focus on large, direct hydrogen, prime power units.

What could counter this somewhat is the projected introduction of a **Kyocera** system. Kyocera are expected to come back to the small fuel cell market during 2017, with a 4 kW unit for both the Japanese and European market. The size of the unit breaks from the norm of the ENE FARM project, which has systems of around the 1 kW size, but is a size much better suited for the European residential market. It is expected that in Japan, the initial 4 kW unit will be targeted at light commercial, with a smaller residential unit to come later. Kyocera have placed an ambitious 500 unit sales target on year one, with projected sales of low thousands by 2021.

Panasonic, in direct counter point to TFCP, are expanding their resCHP system focus to include the UK and Austria during 2017. The units, deployed though the Viessmann Group, are currently only available in Germany within Europe.

The speed of deployments of resCHP systems in Europe continues to remain very heavily predicated on demonstration projects from the Fuel Cell and Hydrogen Joint Undertaking (FCH JU). The current FCH JU funded projects, ENE FIELD and PACE, together would see the deployment of just over 4,600 resCHP in Europe. Compare this with the average deployments in Japan of over 40,000 per annum and you see the scale of the difference.

In terms of overall market size for resCHP systems in Europe, this remains a highly debated area, but as the interest in hydrogen towns grows, in the UK at least, we could well see the market segmenting in hydrogen towns, with no use for a resCHP fuel cell system, and cities with a distributed energy grid, including resCHP systems. Whilst it is highly unlikely that we will see the same levels of deployment of residential fuel cells in Europe as there is in Japan, we will see pockets of market development. Germany, through the KFW444, otherwise known as the Technology Rollout Programme (TEP), which has a strong subsidy of up to 40% of eligible costs for a resCHP system, will clearly continue to lead, but some of the Nordic state, and some areas of the UK, with high heat needs, could still break out with higher than anticipated levels of deployment.

Finally in this section, 4th has rolled the telecoms sector into Uninterruptible Power Systems (UPS), along with sub markets such as UPS for railroads. Whilst we are seeing increased interest for the product from areas such as railroads, the backup, or prime power, for telecom sites remains a highly elusive market. Both **Intelligent Energy** and (what was) **Heliocentris**, now part of the **ODASCO** group, tried to break the market open with power management contracts for telecoms sites, but both have failed. Also, a handful of companies that had aimed to break into this market have now pulled back and either retrenched, or exited completely. Of the companies that are left, **CHEM**, which secured the rights to the methanol fuel cells from **Ballard**, and are the parent company of **First Element Energy**, seem to be positioning themselves for growth, potentially in China, though again, this market has been notorious for positive signals followed by nothing.

A note on drones – at present, we do not include the drone market in our data analysis. The reason for this is that when this report was started 10 years ago, the decision was taken not to include toys. To date, the majority of drone sales have been into the toy market. And the majority of fuel cell powered drones have been demonstration units.

The commercial drone market, which would be of interest to our analysis, will, according to market research firm Tractica (https://www.tractica.com/), see sales of commercial drones increase from 80,000 units to nearly 2.7 million units in 2025. This jump in interest is predicated on interest from applications such as filmmaking, mapping, prospecting and disaster relief.

If the commercial drone market does see this uptake of interest, and alongside, there is a commercially-based uptake of fuel cells into this, we will look to develop data sets in this area.

At the minute though, this is a market that has potential.

4.4 Revenue

Turning to revenue, first, we need to be clear what we are measuring when we report out revenue numbers. This figure is the amount of revenue generated from the sales of fuel cells systems or drivetrains for use within the range of products. For transport, the measurement is the revenue generated from the sales of the fuel cell drivetrains, not the overall vehicles.

For portable, it is the sale of the fuel cell power pack.

For stationary, it is sale of the power-producing unit. For example, a Bloom Box, or a resCHP system.

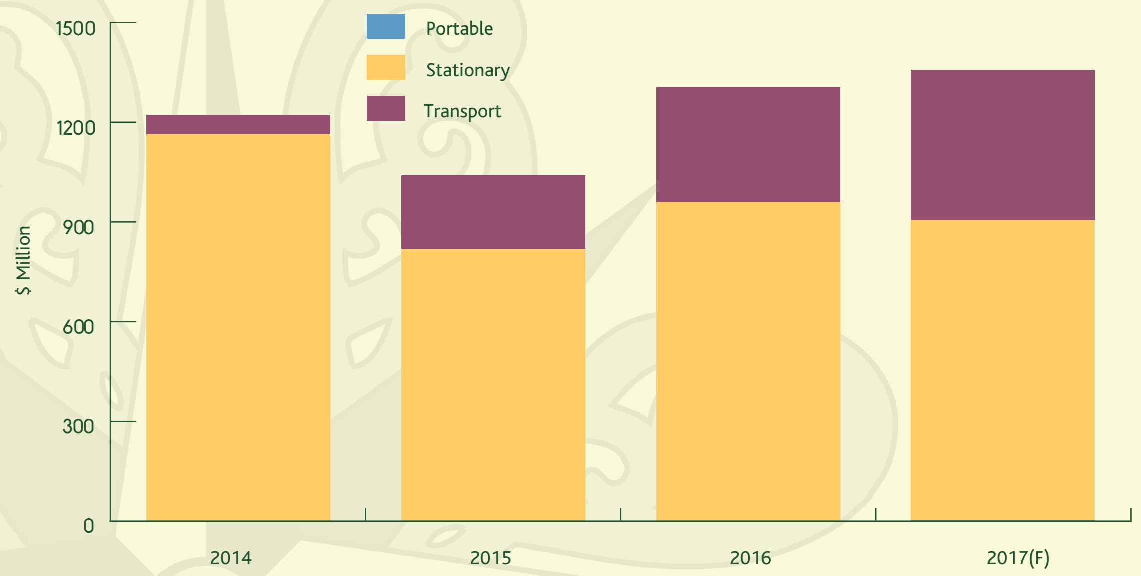
With the shift to leasing and PPAs of fuel cell systems, this figure has become increasingly complex, as revenue is therefore generated on an annual lease basis, not upfront CAPEX. At present, we attribute this annual revenue on a straightforward annual basis for the lifetime of the PPA, but are looking at other accounting options.

Also, to avoid potential for double counting, we have stopped reporting out revenue from stack sales. Although this in itself is a sub set of system sales, we often see this conflated together, creating a much higher number.

In 2016, revenue from the sales of fuel cells, globally, from all electrolyte types, was $1.4 billion, a small increase over 2015. In 2017, this is forecast to increase only less than half a per cent, due to the prevailing market conditions.

Stationary still dominates in terms of revenue, and within this, less than 10 companies comprise over 95% of revenue. When broken out by revenue generated by region of manufacture, we see that North America still dominates.

Chart 4.6: Revenue Generated from the Sales of Fuel Cell Systems by Market: 2014 - 2017 (F)



4.5 Region of Manufacture

In terms of region of manufacture, we do not break out of the revenue by component part and region. This would be a very long-term exercise in supply chain mapping, which although would be highly interesting, would require significant commercial funding to undertake.

Instead, we assign revenue at point of unit assembly. So, for example, we know that **Bloom Energy** has components manufactured in Asia, but the stack and housing is manufactured in the US, and therefore, the overall revenue is assigned to the North America.

Continuing with regional analysis, chart 4.7 shows that in terms of region of fuel cell systems manufactured, Europe and Rest of the World are microscopic, as compared with North America and Asia. Remember that this is for systems. This is not a supply chain analysis.

The race between North America and Asia for manufacturing dominance is clearly forecast in 2017 to heat up, but we see manufacturing shift from Canada to China, for example; longer term out to 2020, we are likely to see Asia increase again.

The push for local manufacturing for local adoption is really at the minute only being seen in China. This in itself is interesting, as a number of countries are lining up with ambitions to be centres of manufacturing. If we see China as a case study in how to attract manufacturing, we are back to the theory that we posited many years ago that strong local adoption can be tied to local manufacturing.

If we move one step down the supply chain to stack level, the influence of Asia on the global fuel cell industry is clearer. The chart below, which is measured in thousands of stacks produced, only counts new stacks produced, and does not include a measurement of replacement stacks. We have entered the phase in the market where a number of the earlier deployments will be having new stacks retrofitted in the systems. At present, these replacement stacks are not included.

We are hoping to include this data in future versions of the report once the rate of turnover per manufacturer is locked in.

Chart 4.7: MWs of Fuel Cell Systems Manufactured by Region of Manufacture: 2014 – 2017 (F)

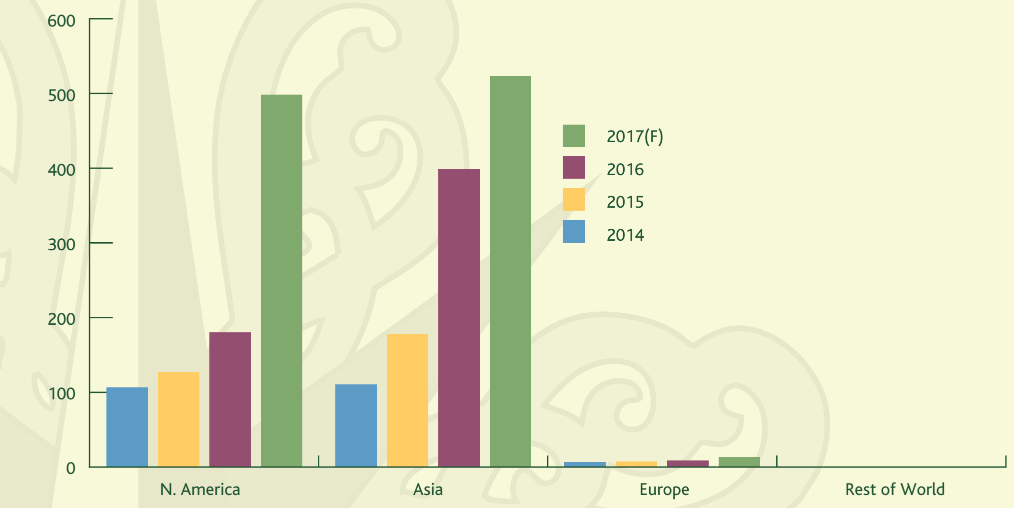
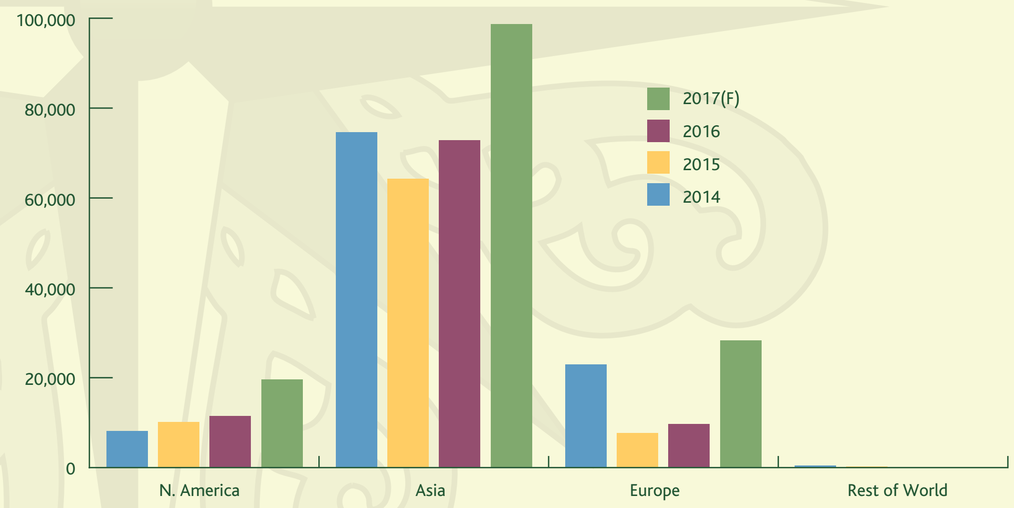


Chart 4.8: Fuel Cell Stacks, All Electrolytes, By Region of Manufacture: 2014 - 2017 (F)

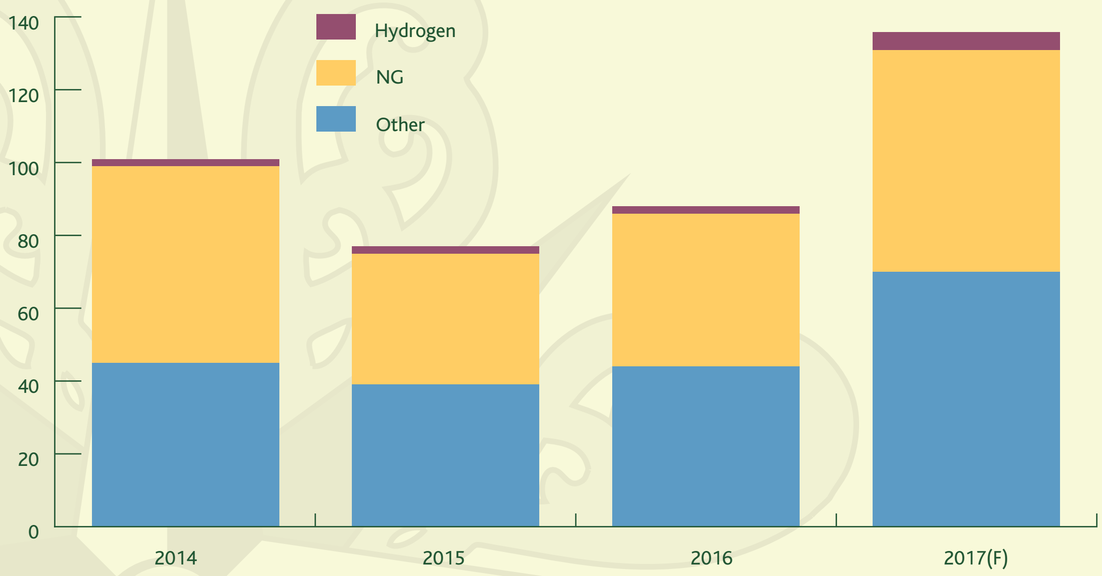


4.5 Fuel

The fuel split is a metric that has somewhat dropped off in recent years, but with the continued push away from fossil fuel use, and the renewed interest, globally, in the use of direct hydrogen, we have taken the decision to start reporting this data out again.

Chart 4.9 clearly shows the renewed interest in hydrogen, with now over 51% of all systems shipped employing direct hydrogen. Some 45% of the units use natural gas and less than 4% use “other”. The other is predominately methanol and propane, with biogas being less than half a per cent.

Chart 4.9: Number of Systems Shipped by Fuel Type, Global, 2014 - 2017 (F)

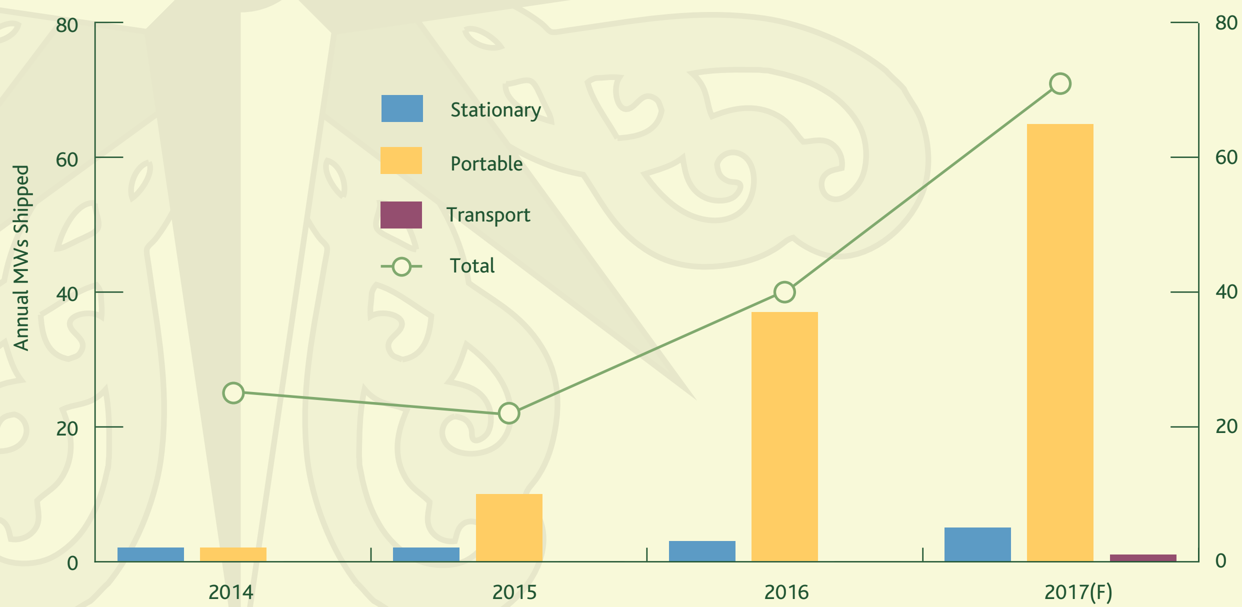


4.6 Platinum

In 2016, global demand from platinum in fuel cells increased to 80,000 ounces and is forecast to increase again to 142,000 ounces in 2017. This represents a 69% CAGR between 2014 to the end of 2017.

Whilst this is a healthy growth rate, it should be noted that according to the (publicly available) PGM Market Report from Johnson Matthey, total demand in 2016 was 8,227 ounces. Within this, fuel cells remain a tiny fraction of demand.

Chart 4.10: Global Platinum Demand from Fuel Cell Shipments: 2014 – 2017 (F)



5. 2016 in Numbers Hydrogen Electrolysers

As hydrogen is already a large, commercial market, the level of investment in terms of time needed to gather information on the overall size, and scope of the hydrogen market, including Steam Methane Reforming (SMR) units, and the overall use patterns of the produced hydrogen, is well outside the remit of this free report. 4th Energy Wave is therefore tracking the development of the electrolyser market. A subset of the overall hydrogen market.

The hydrogen market continues to ramp up. With increased interest in electrolysis, especially using renewable energy, to produce zero carbon fuel, deployments of electrolysers are jumping year on year.

Note that unlike the fuel cell market, we are not tracking units shipped, but just MWs of electrolyser shipped. What we can see from 2014 to 2017 (forecast) is already is a ramp up in shipments. This can be evidenced in the annual reports of the top companies.

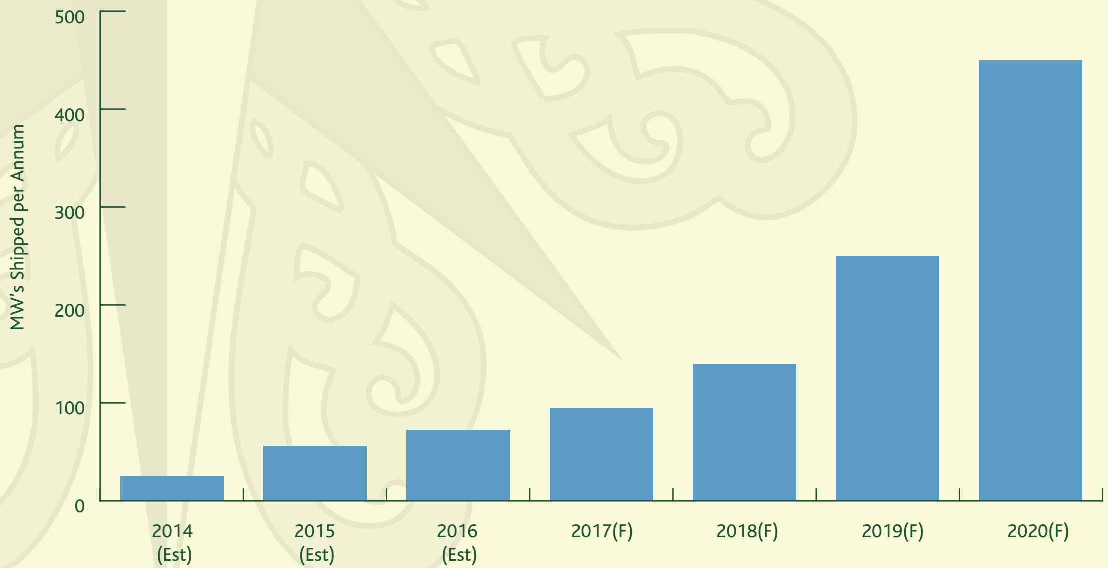
In terms of the market, the clear leading electrolyser companies are (in alphabetical order):

- Hydrogenics
- ITM Power
- McPhy
- NEL Hydrogen
- Siemens

Between them, these companies deploy over the majority of global electrolysers.
In terms of market developments, both PEM and AFC electrolyser continue to see market traction. Solid Oxide Electrolysers (SOEC) remain on the fringes, with only a small handful of companies developing the technology.

Compared with the global demand for hydrogen, the cleantech economy, including fuel cells, currently consumes less than 3% of demand.

Table 6.1 Electrolyser Market Deployments and Forecast



Source: 4th Energy Wave

6. Special Section 1
A Review of Reviews

Fuel Cells: Commercialisation" was the very first Industry Review from the now defunct Fuel Cell Today. Started by Dr. Kerry-Ann Adamson, CEO of 4th Energy Wave, and her team, the report has been publishing data on the fuel cell industry from 2016 onwards.

Looking back on the first three Reviews Commercialisation, Emerging Markets and Sustainability, it is clear now that they were predicated on a very technology centric optimism. A build it and they will come approach. At the time, the levels of understanding of the non-technology based challenges to broad spread market adoption of fuel cell technology were limited.

This led to analysis that was centred around technology development, and then consumer adoption once a value add was identified. Barriers including codes and standards, consumer preference, distribution models, and to some degree, economics, were not rated as highly as they are now. In short, the first Reviews very much speak to the then juvenile nature of the industry.

Table 6.1: Electrolyser Market Deployments and Forecast

	Fuel Cell: Commercialisation	10th Anniversary Edition
Climate Change	*"GHG emissions come from a range of sectors with current data from the EU showing nearly one third from the production of energy and a fifth from transport. Due to their efficiency gains and use of less carbon intensive fuel, the commercialisation of fuel cells could provide significant cuts in GHGs emissions from energy production, buildings and transport, making them a key target for government support."*	By 2050, the EU should cut greenhouse gas emissions to 80% below 1990 levels.
Energy Security	*"The geopolitics of oil has come under intense scrutiny over the last decade. With oil prices reaching $100 a barrel, an unthinkable level even three years ago, and with the cost of exploration and extraction rising, diversification of energy supplies is high on the agenda."*	With the rise of shale gas in the US and decarbonisation in Europe, the focused concerns over energy security now are focused in Asia. Japan, South Korea, and to a certain extent, China, are looking at ways of reducing importing fuel.
Urban Pollution	*"Transport is one of the most important sources of anthropogenic precursors of atmospheric urban pollution. Although some cities are tackling this issue with policies such as low emissions zones, or even banning the use of the internal combustion engines in certain applications, increasing legalisation is driving the development of clean vehicle technologies including battery hybrids, and in the longer term, fuel cell vehicles"*	At the time of production of the report, an increasing number of cities, regions and countries are moving to place an outright ban the sale of new petrol and diesel cars. Also, we are seeing a number of cities move to ban the use of all petrol and diesel cars on their roads
Resilience	Not on the agenda	With the rise of power outages, and the financial and human costs associated with them, resilience has become of the one of the most impactful areas for change.
Water	Not on the agenda	Still at the edges of the drivers for change, water is starting to become a real concern in terms of energy production.
Limitations of Existing Technology	*"The power density of lithium-ion and nickel ion batteries, whilst increasing, is not keeping pace with the growing demand for energy from the products that they power."*	This focus on the failure of current technologies has been replaced with a high level of faith that battery technology, especially, will continue to evolve and meet customer wants. Also, the drive for longer lasting batteries in mobile phones has been somewhat supplanted by a new market for mobile phone portable rechargers.

6.1 Then and Now

Going back into the data and analysis, what we do see is:

1. The drivers have shifted from somewhat nebulous levels to much more concrete certainty.

So what can be seen from this is that for the three of the five core current drivers, 10 years ago, these were there but at a much more unfocused level.

2. What goes around comes around

At the time, markets that were seen to be close to commercial levels of adoption included integrated fuel cells into portable electronics, trains and fuel cell generators for the high end off grid sector. Marine was very much being discussed, but more of a longer term (10 years) market.

The residential CHP was tipped for rapid take off in Europe. In terms of regions, the reports were very much focused on China and India as near term volume markets, after the obvious Japan, South Korea and North America. Also, adoption in Latin America was seen as high potential.

Overall, for a lot of markets, the focus was right, but the timing was very wrong. The maturation cycle of the industry has simply been much, much longer than we understood at the time. This is shown in the adoption forecasts.

3. Adoption has not taken off at the rate that was forecast.

As mentioned above, the forecasts of adoption can now be said to have been optimistic. The model results from the 2008 report are shown right as an example.

Table 6.2: Fuel Cell: Commercialisation – Fuel Cell Shipments by Application and Region Forecast, 2005 – 2009 (rounded to the nearest thousand units)

		2005	2006	2007	2008	2009
Stationary						
	North America	1,000	1,000	<1,000	5,000	11,000
	Europe	0	0	<1,000	3,000	7,000
	Asia	0	1,000	2,000	3,000	10,000
	Rest of World	0	0	0	1,000	2,000
	Total	1,000	2,000	3,000	12,000	30,000
Transport						
	North America	0	0	2,000	3,000	4,000
	Europe	0	1,000	1,000	6,000	8,000
	Asia	0	0	1,000	1,000	2,000
	Rest of World	0	0	0	0	0
	Total	<1,000	1,000	4,000	10,000	14,000
Portable						
	North America	1,000	1,000	2,000	3,000	4,000
	Europe	1,000	1,000	2,000	4,000	6,000
	Asia	1,000	6,000	11,000	180,000	700,000
	Rest of World	0	0	1,000	1,000	2,000
	Total	3,000	8,000	16,000	188,000	712,000
Total		~5,000	11,000	23,000	210,000	756,000

Source: Fuel Cell Today

Note that the ramp up in numbers in the portable forecast was based on what seemed at the time to be the very rapid move to integrated fuel cells into laptops and mobile phones.

4. Cars

Finally, it is now fairly clear that back at the start of the Review, we were still feeling the tail end of the impact of a fuel cell car hype cycle. In 2008, **Daimler** had just bought a controlling share in **Ballard's** automotive fuel cell business, and some 800 vehicles were known to be on the road.

Roll out plans per manufacture were still fairly punchy, as shown in Table 6.3, taken from the original Review.

What we now know is that market readiness for fuel cell vehicles, as well as a number of technical challenges, was still high, and that at the time, the 2017(ish) forecast for the first quasi commercial vehicles was more realistic.

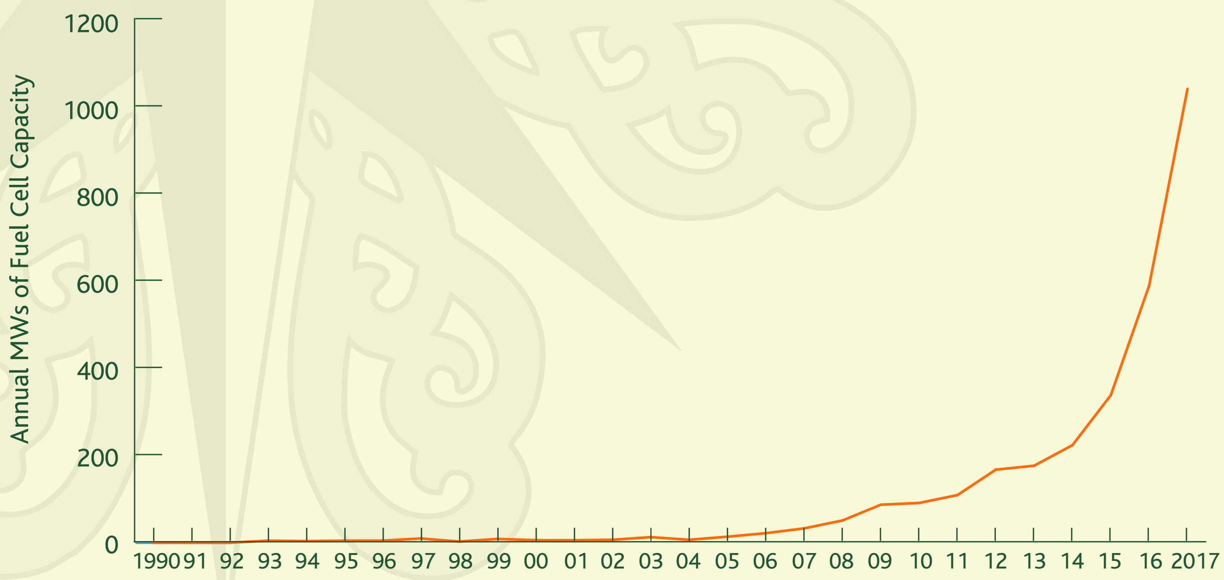
In terms of mass-market roll out, we are currently forecasting that mid 2020s we will see price parity, between fuel cell vehicles, pure battery EVs and ICE vehicles. At this point, the market issues will dominate as customer preferences will the driving factor on adoption. More on this in the second Special Section of this report.

Table 6.3 Fuel Cell: Commercialisation – Current Fuel Cell Vehicle Commercialisation Plans by Major Automotive Companies

Manufacturer	Numbers	Year	Notes
Daimler (Germany)	10,000	2012 2015	Initial Launch Mass Market
Ford (USA)	No public info	2015	"commercial readiness"
GM (USA)	No public info	2010 – 2015 2025	Commercial viability Mass Market
Honda (Japan)	12,000 (in the USA) 50,000 (in the USA)	2010 2020	Start Production
Hyundai (Korea)	10,000 per annum	2012	Commercialisation
Toyota (Japan)	No public info	2015	Will cost $50,000

Source: Fuel Cell Today

Chart 6.1: Annual MWs of Fuel Cell Power Shipped, Global, All Electrolyte Types: 1990 - 2017 (F)



6.2 So What Did Happen?

If we look back at the actual actuals since 1990, of all electrolyte types, we can see that the long tail has been, well, long. The first annual MW of fuel cell power shipped was reached in 1994, 100 MWs per annum in 2011, and we are forecast the first 1,000 MWs per annum in 2017.

Eighteen years to go from 1 to 100 MWs per annum and only 6 years to go from 100 to 1,000 MWs per annum.

From 2006 to 2016, we see an overall (cumulative) increase in 1.86 GWs shipped.

Finally, on this first chart, what is clear is that even for annual MWs of fuel cell power shipped, it really is looking like an S-Curve. S-Curve economics and forecasting have somewhat fallen out of favour.

Next, if we look at shipments by electrolyte type, we see the continued domination of PEM fuel cells. Also, what is clear is that SOFC, whilst having great potential, have so far fundamentally failed to deliver on that potential.

Note the peak in 2008 was the launch of the Toshiba Dynario. The limited edition unit of 3,000 systems was an initial portable recharging fuel cell. The peak in 2014 was based on the shipped on another set of portable recharging fuel cells.

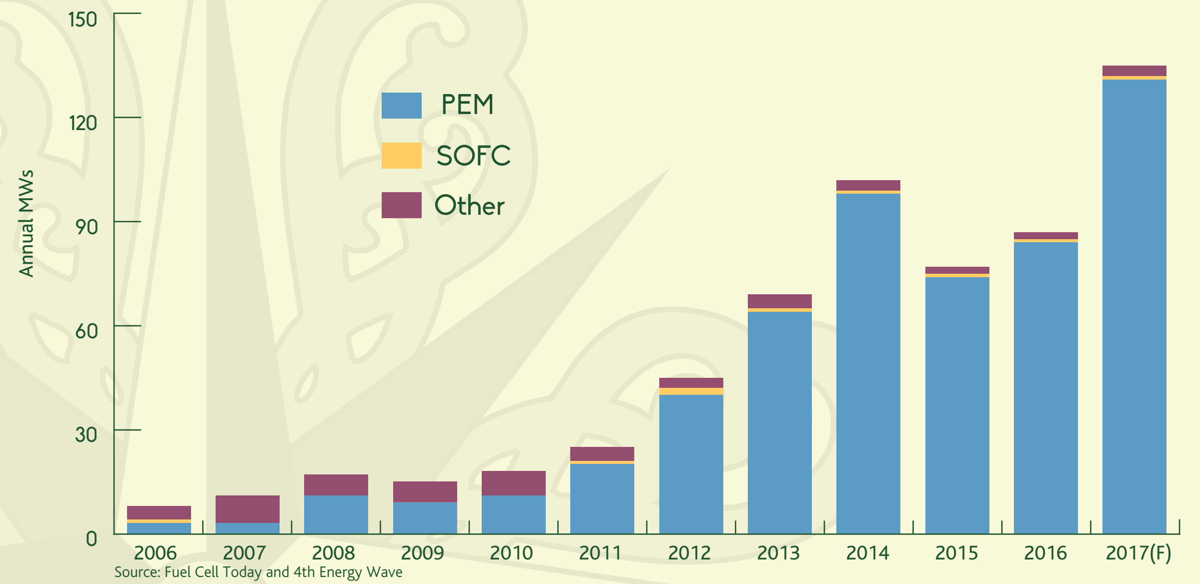
Finally, in this section, we look at the political hot potato of region of manufacture. Political in that there is an increasing pressure to show a return on government investment. Return is often measured in terms of revenue generated, or jobs created.

In terms of jobs, this is simply impossible to quantify, as the boundaries are so fuzzy. So any actual study on this would need to be so clear on the terms of reference as to be almost hide bound by its own rules.

If we use MWs of fuel cell power manufactured, we can use this as a proxy for (manufacturing and often management) jobs, as it shows the region of manufacturing plant, and therefore a source of employment. In the chart below, we see that North America and Asia continue to play chase with each other, whilst Europe and the Rest of the World are simply lines at the bottom of the chart.

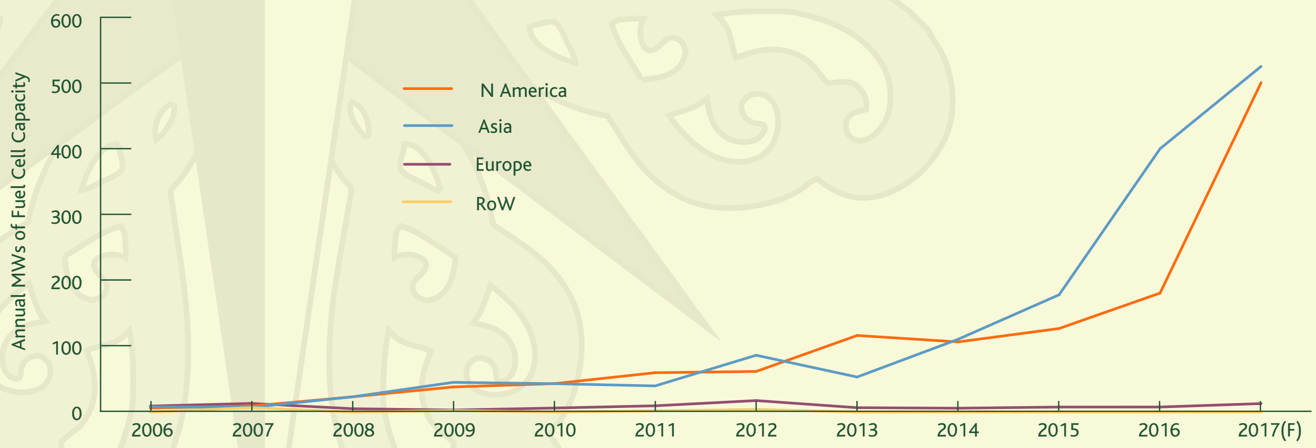
As regions North America, Asia and Europe continue to draw down significant levels of government support. We are forecasting that as the need to show an outcome for this investment increases metrics such as these will increase in importance. It also would suggest that in Europe at least, any Fuel Cell and Joint Undertaking 3 will need some hard reality checks on whether to fund imported technology, with the benefits being gained from adoption, or whether to encourage the development of locally developed and manufactured systems.

Chart 6.2 Fuel Cells Shipped by Electrolyte Type, 2006 – 2017(F)



Source: Fuel Cell Today and 4th Energy Wave

Chart 6.3: Annual MWs of Fuel Cell Power by Region of Manufacture, Global, All Electrolyte Types: 2006 - 2017 (F)



7. Special Section 2 Fuel Cell Cars and Battery Electric Cars

This second special section provides an overview of some of the developments in the electric vehicle market, both FCVs and BEVs. The pros and cons of each. The aim is not to provide an exhaustive analysis, but information that can be used for a much more educated discussion.

The presupposed "war" between the EV and the FCV has never been more prominent. There are headlines daily, proclaiming one side has won and the other has lost. Nicely black and white and binary. The reality is much more complex and that for a long time the market will have, and will need, both types of drivetrains. If the barriers and challenges can be overcome. Add to this, from at least one car company, vehicle price parity is forecast to be reached by the mid-2020s, so the reality is that the market has never been more open.

Both EVs and FCVs have pros and cons, both have their backers and supporters, and both face infrastructure challenges.

At the minute, the one key difference between the two is that the number of BEV models due to be released between now and 2020 far, far outstrips the number of FCVs.

A Bloomberg New Energy Finance chart doing the rounds during the summer of 2017 purported to show the "EV Boom", charting BEV models due for release by 2020. Fuel cell vehicles were not included.

7.1 2020 – Current Market Plans

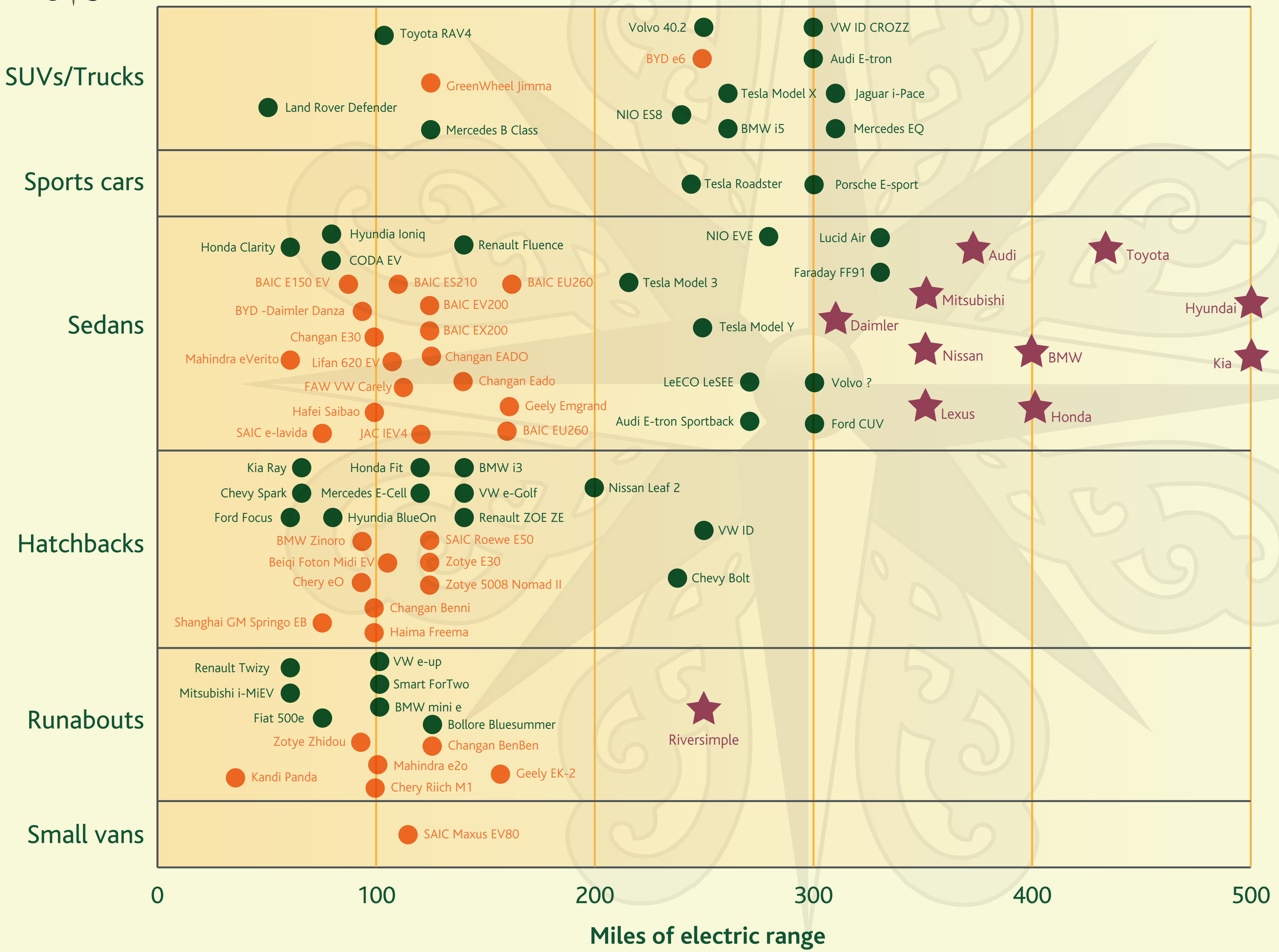
The first of the infographics in this section was produced by interrogating the information in the Bloomberg chart and including information on FCVs due to be released by 2020. The chart shows all of the BEV and FCVs we know are planned to be released between now and 2020, and miles of pure electric range. The information in the chart is taken from public databases, press releases, and company presentations only. Any vehicle that we could not find range information on was not included.

In the chart, dots represent BEVs and stars represent FCEVs. It was clear from the start that when we assembled the data that although the overall number of BEVs to be released far, far outstrips the number of FCVs, in reality, around half of these vehicles were due for release in China, or India, only. To reword this, unless you lived in China or India, you would be unable to purchase one of these vehicles. This is not too say that this is not interesting or important, especially as China will likely be the largest market for BEVs for next few decades, but that in terms of the overall marketplace, it could be seen to be giving off a somewhat skewed picture.

Secondly, when you look at the range, it is clear that the majority of the vehicles are in a cluster well under 200 miles of range. Interestingly, all Chinese BEV vehicles projected out to 2020, apart from one, had a range under 200 miles, and the majority of them are under 150 miles.

2020 LDV Electric Revolution

Models by style and range through 2020



FCV

Table 7.1: BEV and FCV Vehicles to be Released by 2020, with Range

Manufacturer	BEV or FCEV	Name	Vehicle Range (miles)
Hyundai	FCEV		500
Kia	FCEV		500
Toyota	FCEV		435
Honda	FCEV	Clarity	403
BMW	FCEV		400
Audi	FCEV		373
Mitsubishi	FCEV		350
Nissan	FCEV		350
Lexus	FCEV		350
Mercedes	FCEV		310
Mercedes	BEV	M-B EQ	310
Jaguar	BEV	i-Pace	310
Riversimple	FCEV	Rasa	300
VW	BEV	ID CROZZ	300
Audi	BEV	E-tron	300
Volvo	BEV		300
Ford	BEV	CUV	300
NIO	BEV	EVE	280
LeECO	BEV	LeSEE	270
Audi	BEV	E-tron Sportback	270
BMW	BEV	I5	260
Volvo	BEV	40.2	250
VW	BEV	ID	250
Tesla	BEV	Model Y	250
BYD	BEV	e6	249
NIO	BEV	ES8	240
Chevy	BEV	Bolt	238
Tesla	BEV	Model 3	215
Nissan	BEV	Leaf 2	200

7.2 Range and is it Important?

Taking the data from the chart, the table left, lists all BEVs and FCEVs with a projected range of over 200 miles, and a list price under $100,000. The reason for the price cut off is that we are looking at mass-market cars, not high end luxury vehicles.

What is clear from the table is that in terms of range, some of the BEVs are starting to creep up to the range of FCVs, but in the same breath, the FCEV range continues to increase. Also, there is no analysis here on the reality, or not, of any of vehicle in the table actually coming to market.

Whilst we can say for some certainty that a number of the FCVs are being readied for commercial launch, we cannot say so about, for example, the Mercedes M-B EQ, which is listed on the company's own website as being a concept vehicle. One of the other vehicles, the Jaguar i-pace, is also listed as a concept car, but a concept car with a supposed launch date of 2018.

So the only thing we can say with some certainty is that the table below will continue to evolve. But what is also clear is that the 18 BEVs and the 11 FCEVs are facing a brave new world of electric mobility.

But the range...

The reason we are focusing on 200 miles is that many BEVs supporters see this is as the cut-off point above which range anxiety is not an issue for adopters. One comment from 4th is that for city-based cars this makes sense, but for adoption in the rural community, 200 miles is likely still to be considered far too short a distance for any meaningful adoption.

It can be argued though that BEVs are still seen as short range city cars, or second cars, and that fuel cell cars are targeted at the primary car market, or long range car. With over 43% of households in the UK, for example, having only one car, and less than 25% having two cars, the mass-market still lies in replacing the primary household vehicle.

7.3 Cost

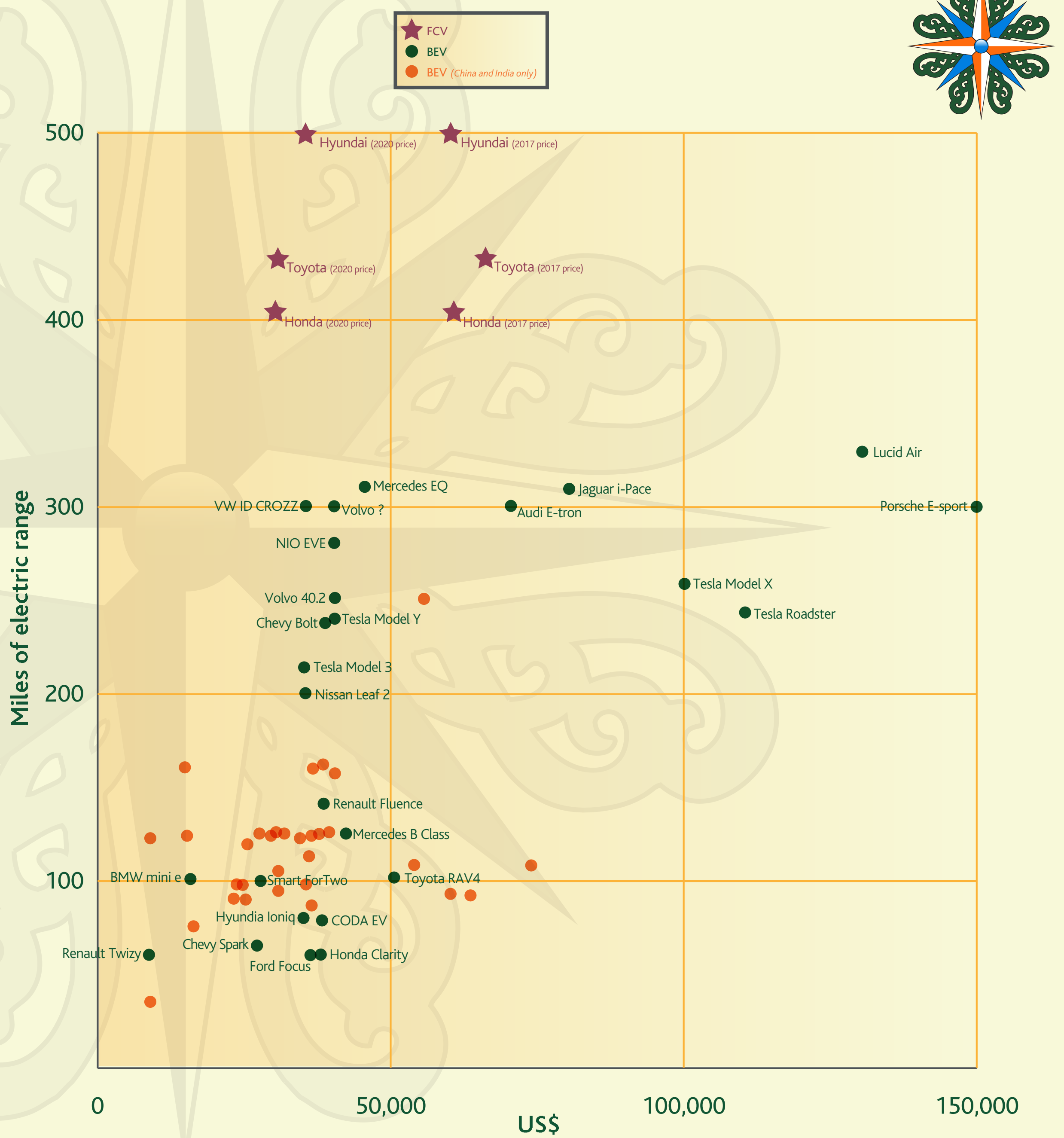
Over the next few years, and at least one generation of fuel cell vehicle release, the fuel cell car will remain more expensive than the majority of BEVs. This statement, of course, does not take into account the high end luxury end of the market.

To highlight the impact of this, the data from the first chart was replotted against list price. This does not take into account any available government subsidy. Note that again, the list price was taken from public databases. Any vehicle where we could not secure a publicly available list price was removed from the dataset. Also, the X axis was capped at $150,000. This captured most, but not all, of the BEV market.

What can clearly be seen is there a cluster of BEVs at around the $40,000. As the projected price at 2020 of the next generation of FCVs is around $40,000, this is a really interesting space to look at.

It seems, at the minute at least, that by 2020, if you have $40,000 to spend on a car, and are not based in China or India, you realistically have a choice of a very low range BEV, such as the EV Ford Focus, or at around 200 – 240 miles a Chevy Bolt, Nissan Leaf or Tesla Model 3 BEV vehicle. Or, for FCVs, a Toyota, Honda or Hyundai FCV with a minimum range of 400 miles. At this point, issues of refuelling availability, customer opinion on hydrogen and utilities, vehicle design etc. really come into play.

Electric Car Boom - Models by price and range through 2020



7.4 Infrastructure

Infrastructure for both BEVs and FCVs remains a major bottleneck to vehicle roll out. To be clear, there are challenges to rolling out the infrastructure for both vehicle types.

For EVs, one of the key challenges is the deployment of city centre recharging. And the challenge of developing enough recharging for high density cities with many multi-unit residences (blocks of flats). For FCVs, the key challenge is currently the upfront cost of refuelling stations. That said, cost effective refuelling stations are being talked about by a handful of developers, which are quoting costs much lower than currently seen in the market.

What is clear from the table is that again, there is no clear winner. And that unless a government stipulates one particular drivetrain over the other, there will be very different models of roll out of the infrastructure.

Table 7.2: Pros and Cons of Rolling out of FCV and BEV Refuelling and Recharging Infrastructure

	FCV	Battery EV
Infrastructure	Plus: Roll out of refuelling network can be rapid after planning permissions are gained Plus: refuelling can be centralised to refuel many cars at one location Plus: hydrogen can be made on site (electrolysis and potentially small SMR) Plus: All refuel times similar to a conventional ICE car Plus: Home refuelling being developed Plus: Refuelling can be put close to, or alongside, rural petrol stations, allowing the rural community to be served. Negative: Refuelling stations are currently costly to install Negative: costly to ship in hydrogen Negative: price of hydrogen at refuelling stations currently variable Negative: If hydrogen has to be brought on to the refuelling site entire station has to be closed down whilst off-loading of hydrogen	Positive: Home recharging Positive: Potential for new business models to sell back excess power to the grid Negative: Lack of interoperability between recharge points (no common design) Negative: Decentralised. No solution for apartment blocks. No solution for city centres. Number of home recharge points limited. Negative: No clear plans to ensure acceptable levels of recharging points in rural communities. Focus is on cities and high density corridors. Negative: faster recharger times = higher power needed from recharge units. Tesla Supercharger 135kW. Very real potential for grid instability in terms of brown and black outs. Negative: Need for grid upgrades to cope with new demand. Location dependent. Who pays for this? And how critical is it? No clear vision. Negative: Grid black outs = no recharging = no car. Negative: Current lack of clear pricing structure for recharging.

Source: 4th Energy Wave

7.5 Critical Minerals

Both BEVs and FCVs contain critical, or strategic, minerals. As defined by an EU expert group working on mineral criticality in Europe, a raw material is defined as critical *"if it is important to the economy of the EU and if there is an associated major risk to its access according to current knowledge. A critical raw material cannot usually be replaced by another material."*

The critical raw materials identified in terms of a shift to cleantech, low carbon, economy have been identified as antimony, beryllium, **cobalt**, fluorspar, gallium, germanium, graphite, indium, magnesium, niobium, **platinum group metals**, **rare earths**, tantalum, and tungsten.

The minerals underlined are used in either fuel cells or batteries. Cobalt, graphite and rare earths are needed for Lithium Ion based EV batteries and platinum group metals (PGMs) for PEM based fuel cells, which is the overwhelming majority of fuel cells used in cars.

7.5.1 Cobalt

A typical nickel cobalt aluminium oxide battery (NCA), such as the ones used by Tesla and VW, use around 200 grams of refined cobalt per kWh of battery capacity. If we take the data supplied to financial analysts that the Tesla Model 3 will have two versions, at 50 kWh and 75 kWh, we can calculate out that a Model 3 will require 10 kgs of cobalt for the base version and 15 kgs for the long range car.

Using this as a baseline, we can say with some certainty that with the projected continued expansion of BEV then market demand for cobalt will rapidly increase.

Why is this a problem?

1. Price

VW, which are currently making a heavy push for BEV market share, but have been unable to lock in a 5-year fixed price cobalt deal, due apparently to requiring the tender price to be much lower than the market price.

This is just one example of the current push back in the market by the much higher cobalt price, which in the main is already being driven by the expansion of the BEV market.

Data from the London Metals Exchange (LME) shows the increasing price of cobalt, measured in $ per tonne, from January 2015 to the start of October 2017. What it shows is a stark upward trend in pricing.

For future pricing, the two key risks to the BEV market are the fluctuations in the price, as well as the overall rapid increase in price.

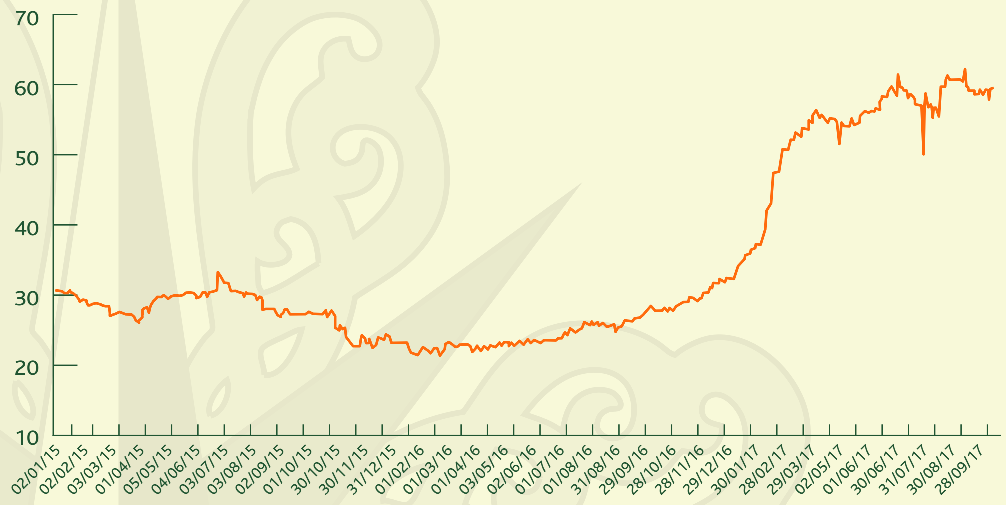
2. Supply

98 per cent of cobalt is produced as a by-product of copper and nickel mining.

Reserves of cobalt are heavily centred in Democratic Republic of Congo, with some 64% of global reserves. North America (US and Canada) has an estimated 291,000 ton reserve capacity. The reason this is of interest is that Tesla have stated that they will secure all cobalt from North America reserves.

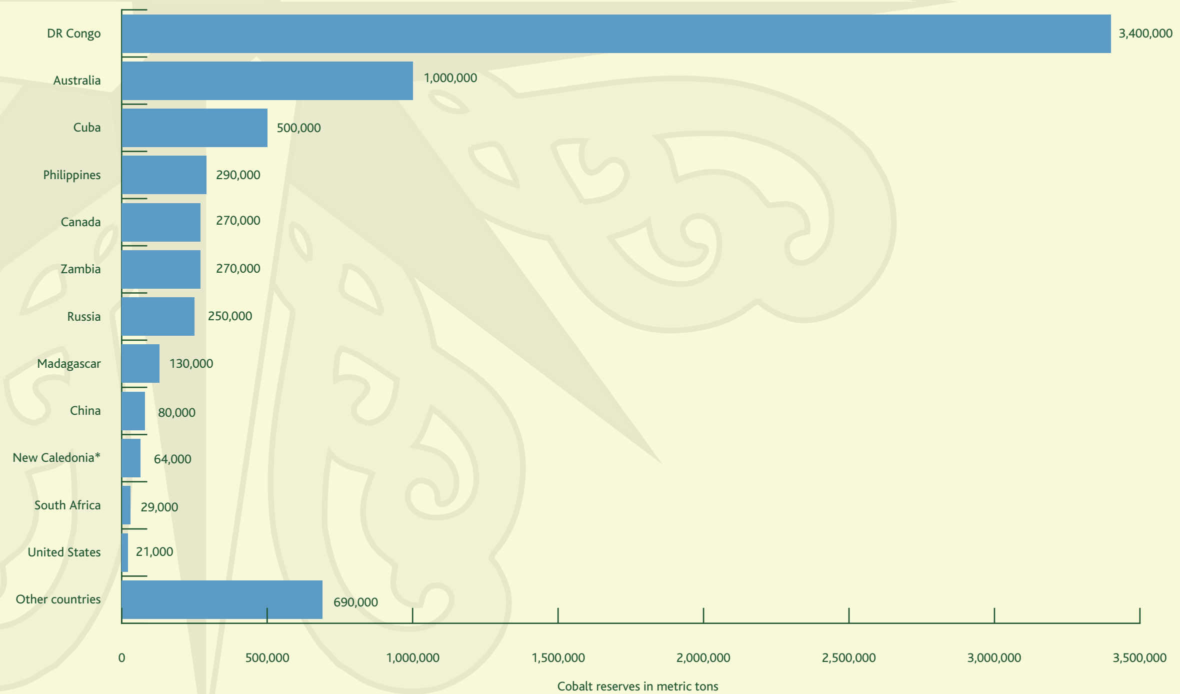
Cobalt needs to be refined before use.

Chart 7.1 Global Cobalt Price for Cash Buyers, $ per tonne



Source: LME, 2017

Chart 7.2 World Cobalt Reserves as of 2016, by Country



Source: Statista, 2017

According to the IEA, in terms of overall demand, BEVs only consumed around 6.5 per cent of refined cobalt in 2016. This will increase to 16.9 per cent in 2021, pushing demand up to nearly 130,000 tonnes, and helping to create an expected market deficit.

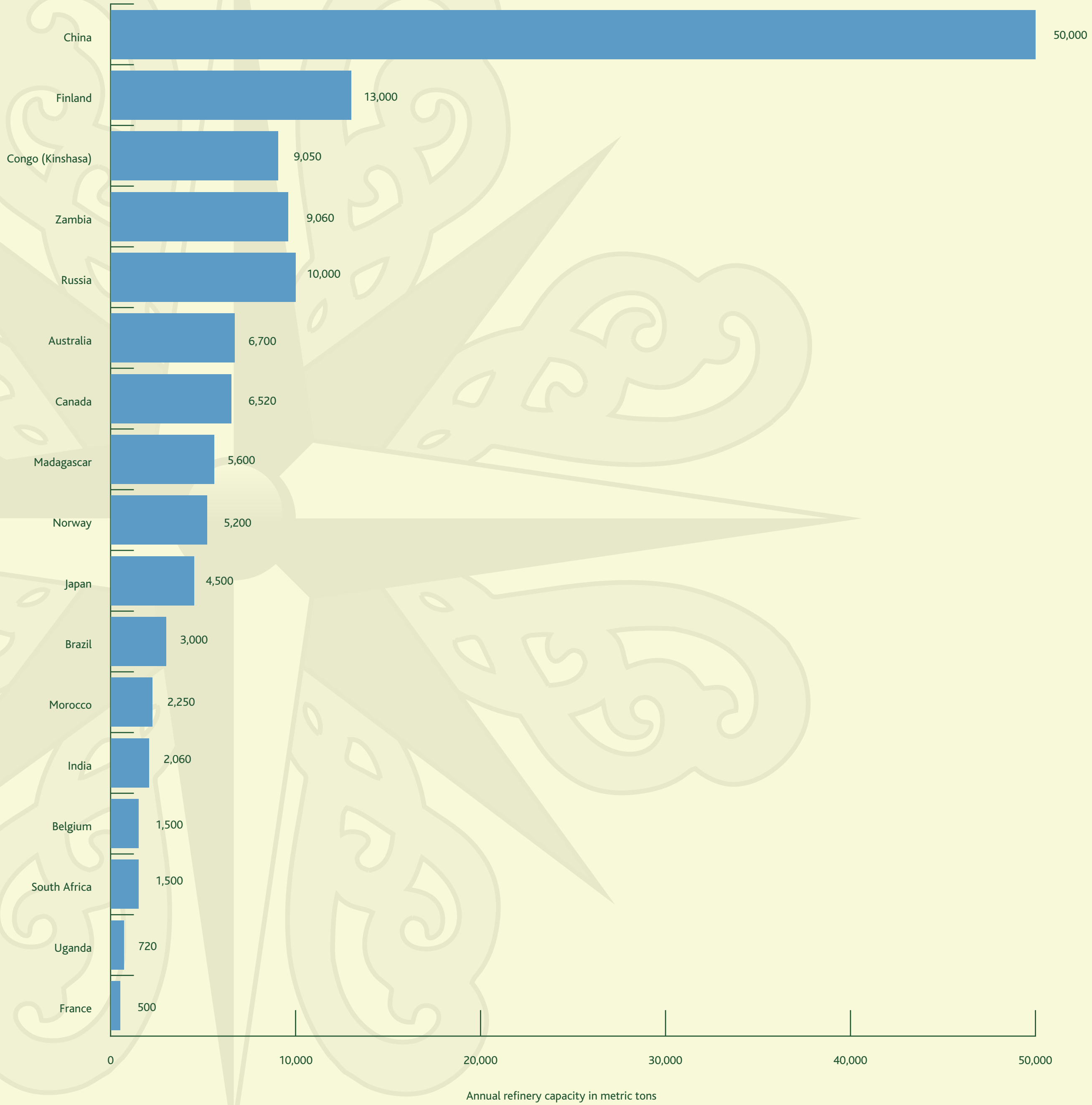
Although also used in mobile phones and laptops, it is the level of demand expected from a future BEV market that is causing concern, with various forecasts seeing market deficit rising as high as a pessimistic 200,000 tonnes per annum delta between demand and refined output by 2025.

In terms of corporate sustainable responsibility, cobalt is (not yet) legally defined as conflict mineral, which would force all companies to declare their supply chains and links to DRC. But as the country is known to be using high levels of child labour to mine cobalt, it has to be said that there is a real risk of potential blowback if the level of child slavery is increasingly publicised.

In summary, the problems for cobalt are:

- Price – fluctuations and overall price level
- Locations of reserves
- Corporate Social Responsibility (CSR) – child labour in mines in DRC
- China – control of majority refining capacity
- Overall market deficit
- No identified substitution for cobalt to extend range of batteries
- No alternative commercially available batteries, with the attendant range

Chart 7.3 Leading Countries Based on Annual Cobalt Refinery Capacity – 2015



Source: Statista, 2017

7.5.2 Platinum

Platinum is used as a catalyst in PEM fuel cells. It is commonly agreed that it is the best catalyst for PEM fuel cells as it does not disassociate over time in the highly acidic environments.

The focus to date has been on reducing platinum loadings, though the core challenge associated with this is the direct link between platinum loading and durability (operating hours). The challenge, therefore, has been to develop techniques to increase catalyst surface area, and therefore be able to reduce overall loadings level. Through development of a number of new catalyst formulations and designs, thrifting of platinum has seen significant success with much reduced loadings on PEM fuel cells. This is evidenced in the trajectory of the automotive stacks developed by AFCC.

The economics of platinum in fuel cells though remain a high concern for many with organisations such as the US Department of Energy (US DOE) and Fuel Cell and Hydrogen Joint Undertaking (FCH JU), funding high levels of research into continued reduction in loadings, or the development of a non PGM based alternative, which is suitable for applications such as cars.

3. Price

Research undertaken by the US DOE have identified that catalyst cost is projected to the largest single component of the cost of the PEM fuel cell manufactured at high volume.

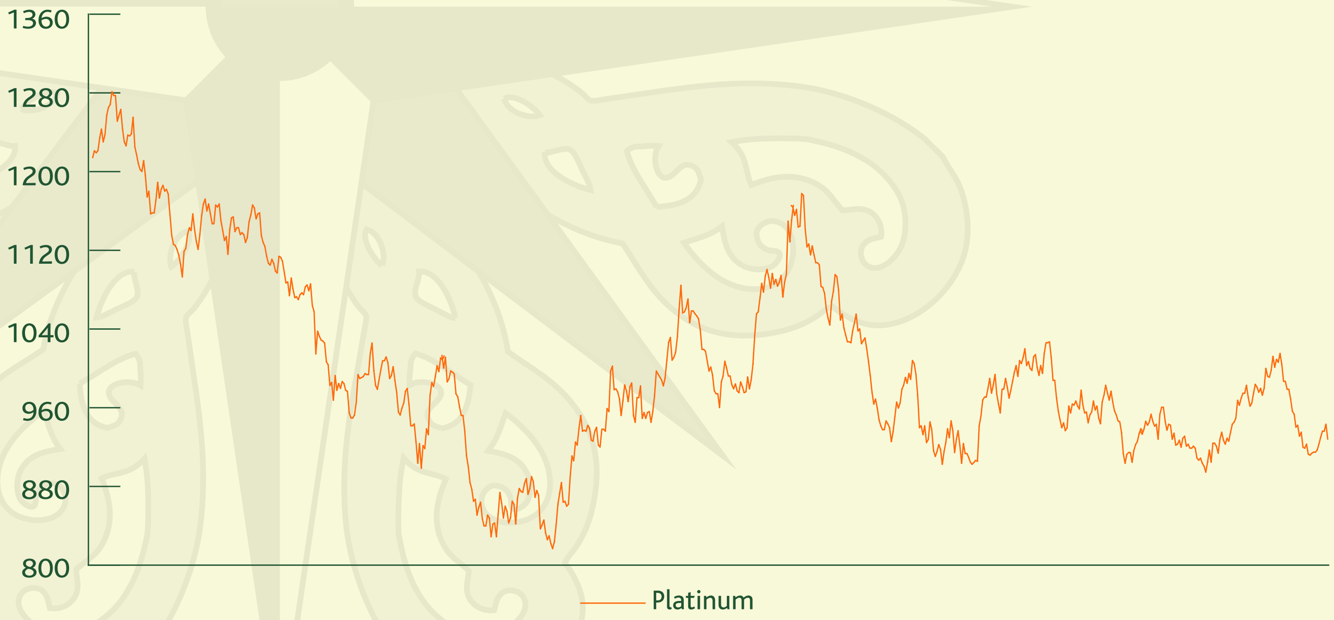
As with cobalt, the major price concerns are both the fluctuations of the price, as well as price spikes. If we go back to 2013, prices were spiking at $1,730 per ounce, where in 2017, the price has somewhat consistently hovered around the $1,000 per ounce and under.

Table 7.3 AFCC Stack Accomplishments

	Gen 1 - 2005	Gen 2 - 2009	Gen 3 – 2014	Gen 4 - 2017
Power (kW)	80	99	75	87
Active Power Density (kW/litre)	2.9	2.6	5.8	10.0
Platinum Loading (grams / kW)	1.6	2.1	0.51	0.22
Durability (km)	80,000	140,000	160,000	200,000
Freeze Start-Up (deg. C)	2	-15.0	-25.0	-25.0

Source: AFCC

Chart 7.4 Platinum Price, $/ounce 2015 – 2017



Source: Johnson Matthey

The importance of this really is to say that depending on which price is used in modelling of future fuel cell costs has a direct impact on the results. There is so far no decoupling of the platinum price from the fuel cell market. This is possible though with shifts to say platinum leasing, and a much increased level of platinum recycling.

4. Supply

Each year, Johnson Matthey produces a Platinum Market Report, which is openly accessible. This is quoted here, as this is the best, consistent, free report on the production and demand for platinum. All numbers here are taken directly from this report.

Recycling is included here to highlight the scale of the return to the availability pipeline at end of life. To put this into the context of fuel cells using the current platinum loading for the AFCC stack, as outlined above, the level of platinum recycling, alone, would be enough for production of 2.83 million fuel cell vehicles.

In summary, the documented concerns for platinum are:

- Price – fluctuations and overall price level
- Current lack of platinum leasing in the market
- Long term concerns over supply pipeline
- Economics of platinum in fuel cells, at volume
- Location of reserves

So in summary, both BEVs and FCEVs have issues surrounding core materials.

Table 7.4 Platinum Supply '000 oz

	2015	2016	2017
South Africa	4,571	4,392	4,383
Russia	670	723	668
Others	868	988	960
Recycling	1,713	1,922	1,897

Source: Johnson Matthey

7.6 Cars v's Mobility

The very clear focus on the types of drive trains that are being developed could well be missing a bigger picture. The shift from car ownership to mobility. Over the last decade, debate has been increasing on "peak cars", in the West at least. The theory is that younger drivers, especially, are not moving to car ownership in the same numbers as older generations had.

Primarily driven by cost, both capital and running costs, and the increasing availability of last mile services, including Uber and car clubs, a number of cities are seeing a decreased number of cars. With statistics suggesting that the average car in a car club services 60 people, instead of the 1 or 2 with private car ownership, we could be seeing in a shift in a large number of cities to reduced vehicle parc.

This is not simply wishful thinking on the part of analysts. Early examples are:

- Oslo plans to permanently ban all cars from its city centre by 2019.
- Madrid plans to ban cars from 500 acres of its city centre by 2020, with urban planners redesigning 24 of the city's busiest streets for walking rather than driving.
- In Hamburg, there will be a large number of areas where cars are banned.
- Brussels is exploring ways in which to expand its car free area, already the largest in Europe.

Whilst there is a long way to go, this could suggest that at some point in the not too distant future, many prominent cities simply ban the use of cars. Like many trends though, this is long term, and at the minute is focused on western economies. With sales of vehicles on Asia and Africa still on the rise, we could be seeing a split of mobility in the West and private transport in the rest of the world. This is of course a very black and white split and the reality will be much, much more nuanced.

But the point of this is by focusing on the vehicle drivetrain, instead of focusing on a fundamental shift in society, we are missing the bigger picture. And if we are facing a shift to mobility, how does this impact the preference calculation between FCVs and EVs?

The $H_2{}^{O}C$ Scenario

8. The $H_2{}^0C$ Scenario

The **10th Anniversary Edition of the Fuel Cell and Hydrogen Annual Review** takes all the information and knowledge built up by the team at 4th Energy Wave and presents an overview of the **$H_2{}^0C$ Scenario**.

The **$H_2{}^0C$ Scenario** is one of a number of scenarios that are being developed internally by the team, which then feeds back into client strategy work. These scenarios allow us to push a range of buttons in terms of policy, public acceptance, economics and development of enabling technologies to see what could happen.

8.1 Overview of $H_2{}^0C$ Scenario

The **$H_2{}^0C$ Scenario**[1], as the name suggests, places hydrogen at the core of future energy markets and transport fuel. Fuel cells play a key supporting role in a range of markets, which vary from country to country.

Investment continues to flow to the hydrogen markets from the venture capital (VC) and corporate sector, with electrolyser companies taking the lion's share out to 2030. As a handful of fuel cell companies continue to push for profitability, and government policies force the market to remain open for all technologies, investors start to take the fuel cell industry seriously again.

In the **$H_2{}^0C$ Scenario**, batteries continue to play a key role. Battery EVs, pure and with range extender fuel cells, take the majority share of the LDV market in China. The BEV market separates in short range neighbourhood EVs, medium range sedans and long-range vehicles with a fuel cell range extender. Self-driving cars do not see the uptake, which was optimistically predicted in the late 2010s. The supposed "war" between batteries and fuel cells end with a fizzle by the mid-2020s, when cost parity is reached in light duty vehicle drivetrains. At this point, customer preference and requirements are the key purchase determinants.

Outside of LDVs, the energy storage market takes an increasingly important role globally. In regions where hydrogen in the gas grid is the norm, residential energy storage is dominated by turnkey solution of batteries and solar. The use of fuel cells as residential generators takes off in North America and Europe, whereas Japan and South Korea remain with fuel cell resCHP systems. At industrial level, the market is a mix of technologies, including supercaps, hydrogen and batteries. This global understanding that markets may develop in one country and not another helps each market implement solutions that are needed for them.

The impact of critical materials such as lithium ion batteries, and in fuel cells platinum, are increasingly built into system design and the global economy shifts to a circular economy model. This model of consumption sees materials and products built, which extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life.

The $H_2{}^0C$ Scenario, critically, sees the development of a number of new business models and new companies leveraging the opportunities that are created. This scenario also sees the exit of a number of large scale, traditional companies who are unable, or uninterested, to innovate to stay relevant. Market makers come forward in the 2020s, opening up a range of markets that have been seen to have potential, but not seen this leveraged.

An overview of the core assumptions, which are backed up by internal data or trend analysis, which are built into the $H_2{}^0C$ Scenario, can be summed up as follows:

1 The full suite of information that has gone into the $H_2{}^0C$ Scenario is not available as a free download and remains the proprietary information of 4th Energy Wave, unless explicitly noted in the text. Data on population, demographics and overall energy demand is taken from OECD and IEA respectively.

Assumptions:

1. Limiting the increase of the global average temperature to 1.5°C is the goal and is achieved by 2050.

2. It is achieved through a strong and focused deployment of a range of options, including fuel cells, hydrogen, methanol, electrolysis, renewable energy, biofuels and batteries.

3. The global political move away from diesel, and petrol, continues apace in the late 2010s with, by 2025, 2040 being the hard deadline in over 30 countries for the cessation of sales of new petrol and diesel light duty vehicles.

4. Lock in and lock out are not seen in the market as there is a growing understanding that every sustainable solution is required.

5. Electrolytic hydrogen reaches fossil fuel parity in 20 countries by 2030.

6. The market for electrolysers continues to take market share away from steam methane reforming (SMR) as the focus on reducing carbon emissions ramps up in the period post 2020.

7. Electricity networks are decentralised, with peer-to-peer trading becoming the norm by the end of the period. The utility business transforms into smart grid managers, instead of energy trading.

8. In a number of areas, gas grids are switched over to hydrogen over a 30-year period. In many areas, pipelines also perform an inter-seasonal storage mechanism;

9. Energy and mobility arbitrage is performed within blockchain, with direct peer-to-peer trading between individuals, companies and communities.

10. The circular economy is the business norm.

11. The top 50 cities, in terms of population, form the largest trading bloc in the world and act on group purchasing to provide market stability for new cleantech product adoption.

12. PEM, DMFC, PAFC, MCFC, and SOFC fuel cells all exhibit cost out, and reach long term CAPEX targets over the period 2020 – 2030, dependent on the electrolyte type.

13. The market for electrolysis of renewables is split into large GW scale markets, often for hydrogen trading and export, and small point of use markets.

14. Mobile electrolysers are key in the period up to 2035 as the markets for hydrogen develop more rapidly that fixed infrastructure can cope with.

15. By 2050, hydrogen refuelling is a mix of forecourt and home refuelling. This mirrors EV recharging, which, by the late-2020s, is common across all EV types.

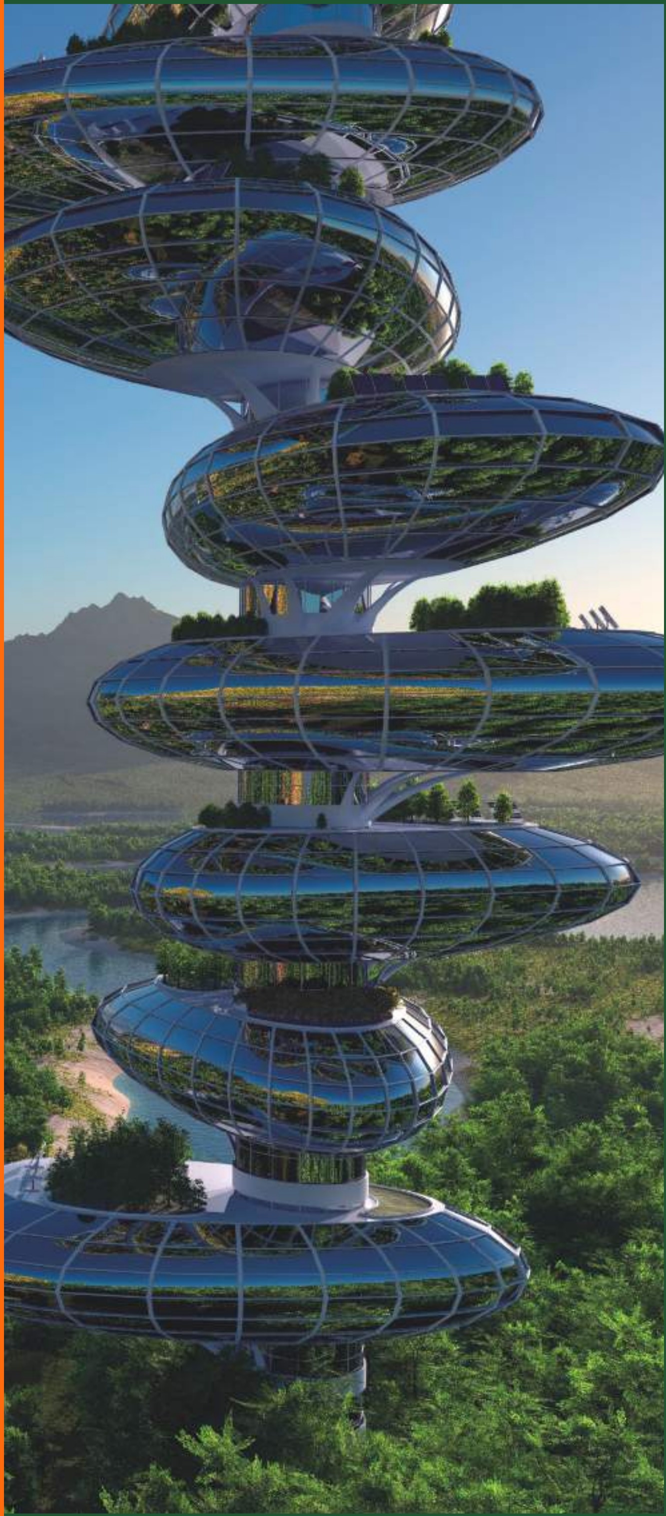
16. Large scale transport companies shift to last mile travelled companies over the period out of 2040. There are a number of large traditional companies that do not make the transition and stop trading in the period 2030 to 2040.

17. Investment in fossil fuel assets reduces as investors continue to view them as poisoned assets.

18. Nuclear hydrogen does not take off, as water consumption from energy production becomes a key concern in policy circles.

19. The insurance industry is a key lever in the switch of companies to more energy efficient and sustainable business practices.

20. The shipping industry joins the emerging global carbon trading scheme by 2025.



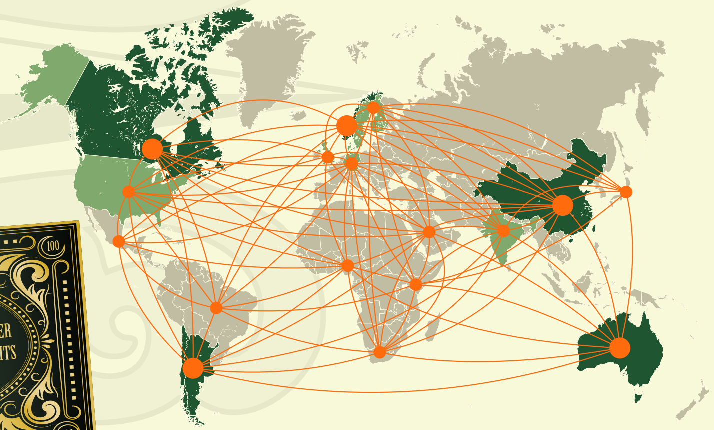
8.2 Blockchain and the $H_2{}^0C$ Scenario

A number of the 4th Energy Wave scenarios are predicated on the development and roll out of enabling innovations. In the $H_2{}^0C$ Scenario, the enabling technology is **blockchain**.

In this scenario, blockchain allows producers, or owners of assets such as green hydrogen certificates and electricity, to set prices, and transactions, at an individual level without the central role of the utility as the arbitrage provider.

In this scenario, the blockchain platform is an enabler of a distributed energy and mobility world. It would increasing be used as a secure peer-to-peer transaction network for the sale from prosumers and community energy projects of electricity, green hydrogen certificates and credits, hydrogen and mobility miles. In short, access to a range of assets that are either not being fully utilised, or the market is moving towards localisation. The ease of use of platform, as well as the accessibility, removes a number of barriers to consumer acceptance of the transition to the prosumer model. Also, the increasing gamification of asset trading is especially is attractive to Millennials, who are the first adopters.

BLOCKCHAIN

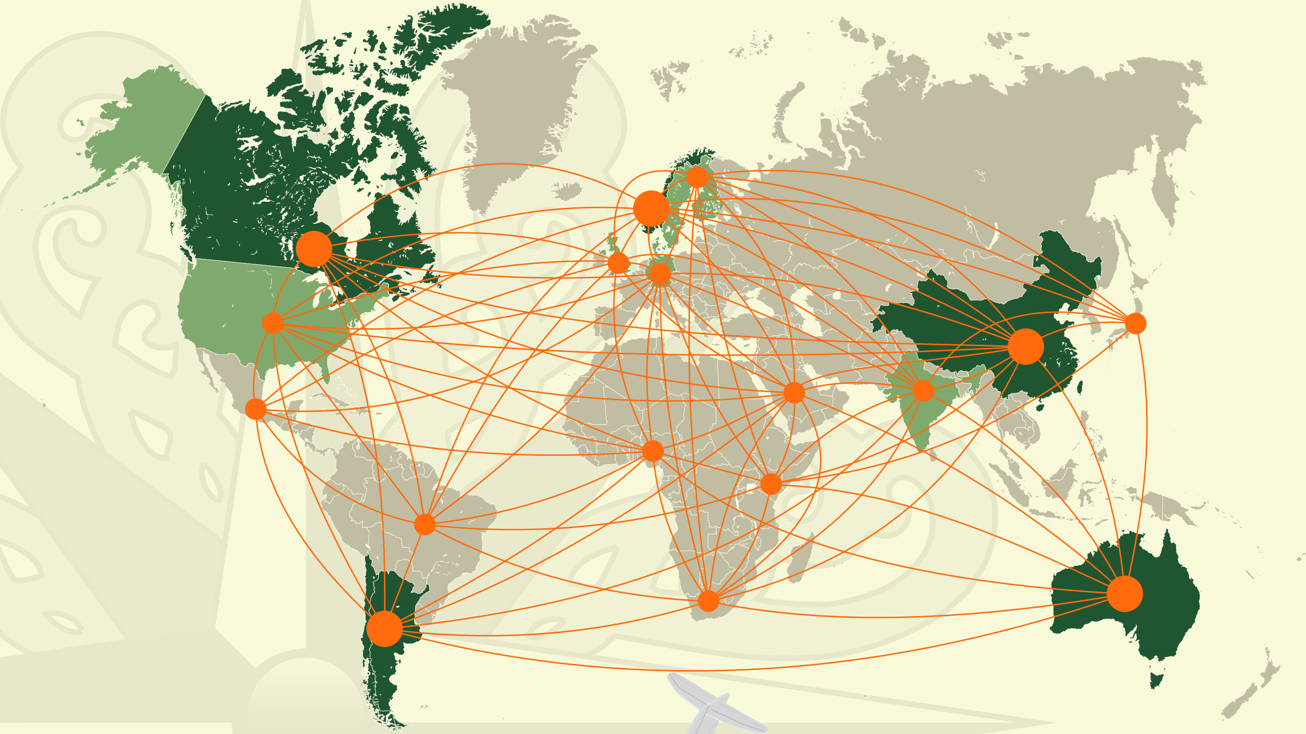


In this model, the role of the utility shifts to owner of transmission networks, and gets paid a percentage fee for each transaction, which utilizes their infrastructure. This fee is, in essence, grid access charges, and are set by an industry watchdog.

New industries open up in collection and delivery of other blockchain traded assets, whether real or virtual.

By 2035, green hydrogen certificate trading is a significant market, in the same vein as carbon trading today. Large scale electrolytic hydrogen producers in Australia, Norway and Patagonia (both Chile and Argentina) are set up as early users of this mechanism, with support from carbon trading houses in China and the Middle East.

Mobility trading includes use of private vehicles, mobility miles and ride sharing. In the H_2^0C Scenario, as transport companies shift to last mile travelled mobility companies, we see the rise of mobility passes and mobility miles. Unused kilometres can be traded on the system in a just in time fashion, with buyers putting a request onto the network to buy a certain number of miles. In this scenario, we see the development of a pricing structure where zero emission mobility, whether it be fuel cells or batteries, allow further kilometres to be travelled on the mobility pass for the set fee. Whereas fossil fuelled transport options, including planes, allows fewer kilometres to be travelled for the fee.



The one side impact of the shift to blockchain trading is the extra datacentre capacity required. As per user represents an individual node in the blockchain ledger, as the number of users, and the level of usership grows, then energy demand from data centres continues to be pushed up. On the back of this distributed energy, water use and cooling of data centres becomes the highest value, in terms of recurring revenue, fuel cell sector by 2040.

The charts on the following pages provide vignettes of some of the high-level country developments. The final map also provides highlights of the socio-economic modelling that has gone into the project. The scenario continues to be developed and refined as more information in gathered on areas such as job growth, both direct and indirect, and supply chain analysis.

What is Blockchain?

Blockchain is a secure online ledger of transactions. Anyone can participate in network, with companies creating platforms for trading of specific goods. To date, the best-known thing trading on blockchain is bitcoin, a digital currency.

Use of blockchain is through **platforms**, which are created by companies. These platforms are created with a set of published rules. This can be, say, only for community energy projects to buy and sell to each other, or say, for example, only residents and companies within the city limits of Berlin.

Users of platform are assigned a **digital key** to access the platform, and each user has a "**node**". A node is a computer with the blockchain platform on it. As the blockchain ledger is continuously synced across all nodes, this computer, or access point, will have fixed internet access, and not therefore be a mobile laptop etc. Each asset to be traded will also have some form of smart metre attached, which measures production, consumption and units available to be sold.

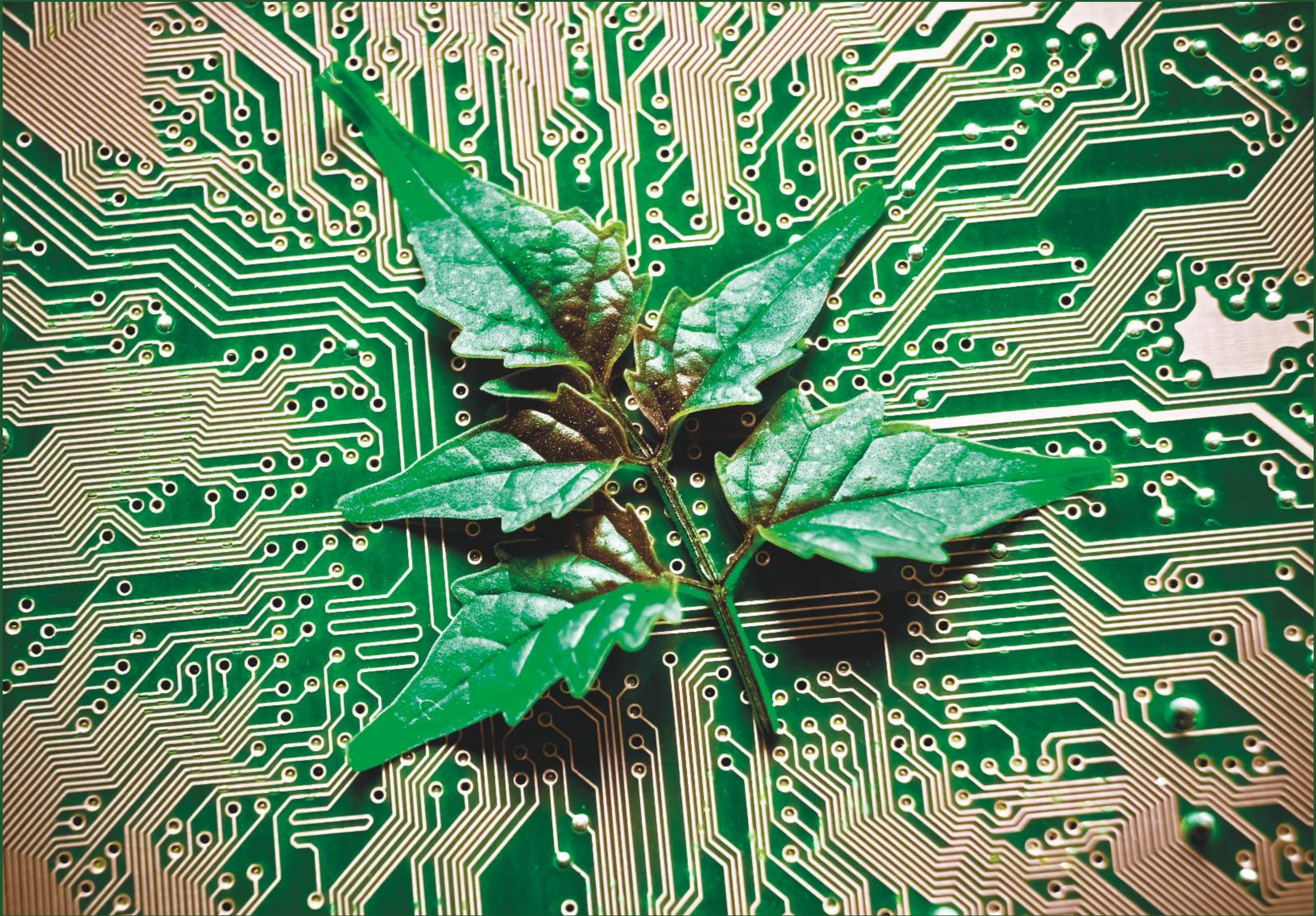
A buyer puts a request to buy onto the platform, which all users within the platform are notified of this buy request. This is request to buy is known as a "**block**". In an advanced platform, an automated system will be set to match the buy and sell offers. This ensures quick, smooth transactions. At the start, and on some platforms, this trading and gamification will likely remain manual. Once a transaction is complete, it is a given a date stamp and cannot be altered. A number of blocks are then collated into a "**chain**" and added to the overall ledger.

In, for example, a neighbourhood electricity trading network, the platform rules would state that users and sellers have to be in a certain geographical area, and also the price set for the trade. This price will be set by the buyers and sellers, not the grid asset owners, as the current model. Each node would be fitted with a smart metre linked to the specific platform. The system would be set up that each buy request would automatically be matched up with available power from the neighbourhood nodes. Each node still requires access to a physical grid and the trade remains virtual. Future developments of the system could see local microgrids set up outside of the current grid infrastructure.

For mobility, the platform would likely be created to sell virtual miles, which upon purchase, would be downloaded to a smartphone for use in payment on a bus or train.

Overall, the ledger is independent of any government, or company, and allows fast balancing of systems. In this scenario, we see the development of a range of platforms for local electricity trading, mobility trading and green hydrogen certificate trading (analogous to bitcoin, in that they would be digital certificates). This relies on a number of things occurring, including companies setting up to create and launch the platforms, as well as in some cases, managing the transaction flow; critically, governments allowing such systems to develop and recognition of the validity of such virtual trades; and the fundamental reorganisation of the utility model.

As one of the megatrends feeding this scenario is globalisation of technology, allowing hyper localisation, this shift towards local trading of assets is deeply embedded in the $H_2{}^0C$ scenario. In this respect, the $H_2{}^0C$ is the most disruptive and transformative of the 4th Energy Wave scenarios.



2020 – Hydrogen from Baby Steps to Rapid Development

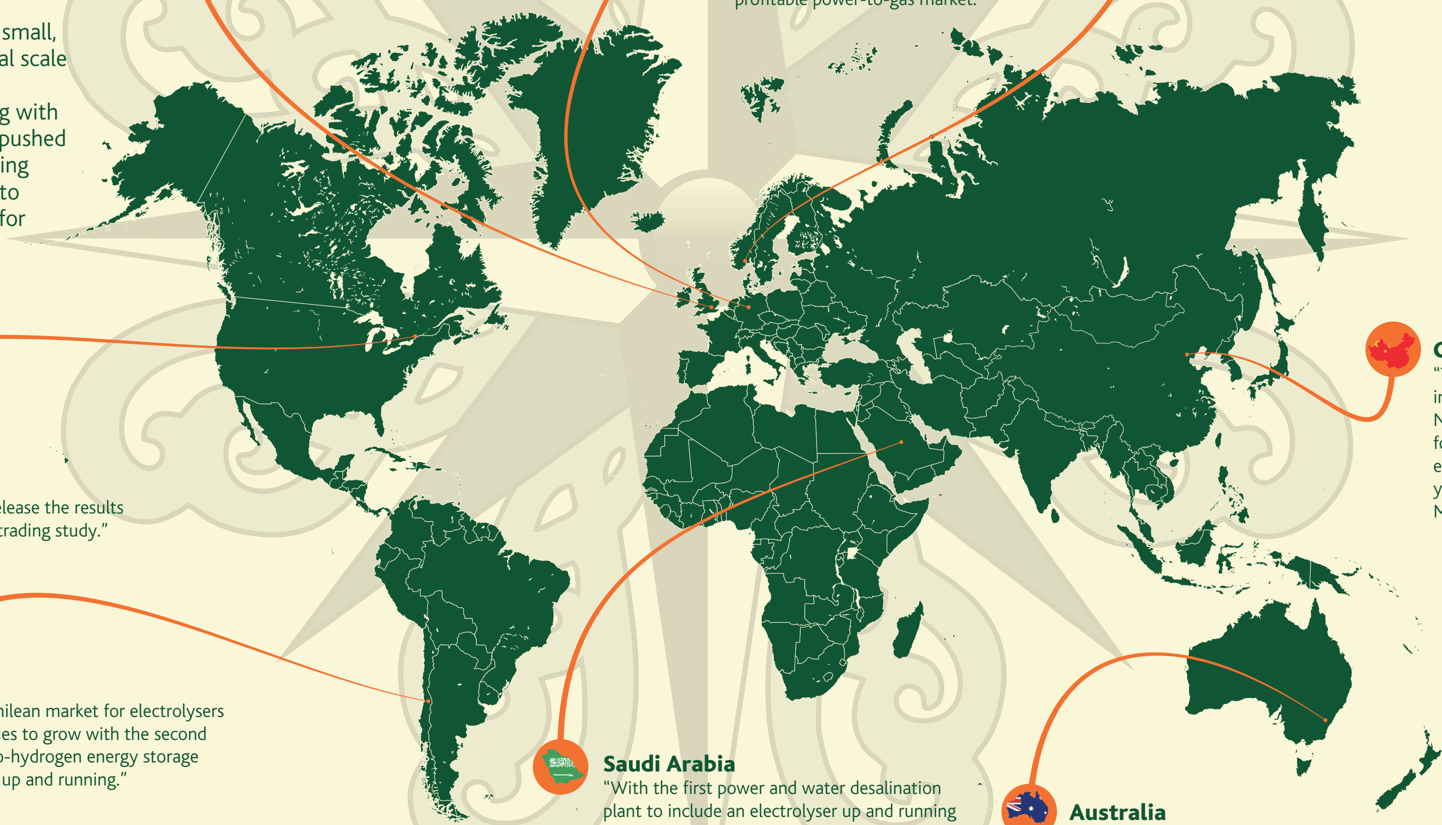
From 25 MW in 2014 to 72 MWs in 2016, now in 2020 to over 200 MWs of electrolysers now being shipped annually. With sales of electrolysers (PEM and AFC) having experienced such an uptick in interest pressure on companies to supply, increase manufacturing ability and reduce cost has seen the electrolyser market compress to just 5 companies supplying to the majority of the market. These companies supply product to both the traditional industrial and new hydrogen industries, enabling a much quicker cost drop than if they were supplying just the new emerging markets.

With CAPEX costs at now under $1,250 / €1,000 per kW for both PEM and AFC electrolysers, the cost of hydrogen produced is now rapidly reaching fossil fuel parity in over 10 countries.

The main new markets of hydrogen refuelling and power to gas continue to see peaks and troughs in terms of market development.

Electrolytic hydrogen still represents less than 5% of the overall global hydrogen market, but is now worth in excess of $100 million in revenue annually.

The market is starting to splinter in small, distributed units, and large, industrial scale units. A standard size for hydrogen refuelling stations is emerging, along with a standard forecourt design. This is pushed by a number of stakeholders, including policy makers, and is being created to encourage quicker price reductions for hydrogen refuelling stations.



UK
"The first wind-to-hydrogen farm is up and running. Producing enough hydrogen to power a fleet of vehicles, the project is set up to include multi day hydrogen storage facilities. Local production for local use is the increasing of the growing number of distributed manufacturers."

Germany
"The power-to-gas market in Germany receives a major boost, with the creation of a specific support scheme within the NOW programme. The scheme sets out a long term roadmap for the development of a sustainable, profitable power-to-gas market."

Norway
"Norway continues to lead the global deployment of electrolysers, the majority for the use in industrial hydrogen. New markets, such as the use in transport fuel, continue to take ground, but remain a minority market."

China
"The first power to gas project is announced in China. Using curtailed renewables in the 3 Norths, the project will produce hydrogen for shipping by pipeline to Beijing. It is expected to be fully operational within 7 years. The demo project order represents 55 MW of PEM electrolysers."

Canada
"Organisations in Canada release the results of a cross border hydrogen trading study."

Chile
"The Chilean market for electrolysers continues to grow with the second wind-to-hydrogen energy storage project up and running."

Saudi Arabia
"With the first power and water desalination plant to include an electrolyser up and running in the mid-2010s, agencies in Saudi have no deployed electrolysers into a number, other than water desalination plant plans."

Australia
"With the launch of the South Australia roadmap in 2017, the federal government launches an all Australia roadmap in 2020. This push forward to join together renewable energy deployment with energy storage sees the potential roll out of both hydrogen and large scale battery deployments. Hydrogen is seen as a local, but primarily, an export market. The export market is designed for economic growth, as well as local job and skills creation."

2020 – Fuel Cells, Increasing Energy Resilience

After year-on-year increases from 2016, annual insurance losses from global and man-made catastrophes topped $175 billion for the first time. This included losses from Atlantic storms, increased flooding in parts of Asia, and global disaster impact of non-resilient transport and energy infrastructure. By 2020, a number of insurance companies now only offer corporate insurance to companies with some form of energy and power resilience plan in place. Primarily, this includes back up power generation, using non-logistics fuels, or not relying on the grid for primary power.

This change in economic levers has seen banks, hotels, data centres, prisons and universities turn to back up power options, including fuel cells. In 2020, in North America, the primary fuel used in these facilities remains natural gas, though in Europe, a significant shift is to the use of direct hydrogen.

At the residential level, the use of fuel cells as backup generators starts to gain ground. These small, modular, 2 – 5 kW units are designed for deployment in basements, or garages.

Remaining issues of codes and standards, and product standardisation, slow down market growth.

Fuel cells powering telecoms remains a “not yet” market, with interest still high but deployment not matching anything like the market potential.

UK
“Scotland becomes one of the first countries in the world to create a rural fuel cell skills centre. Focused on creating and leveraging a joint skills base across multiple regions, the centre, based in the north of the country, opens its doors to much political glad handing.”

Spain
“Spain is starting to emerge from the shadows as a local supply chain and manufacturing centre. A number of regions also express keen interest in working in the off grid project with South African, Canadian and Scottish firms.”

UAE
“An international boat show in Dubai, showcasing the first fuel cell powered superyacht available to purchase. The silent running yacht is targeted directly at high net worth individuals who have a level of eco awareness. Its design is created to showcase a number of the yachts other environmental features.”

South Korea
“An increased push to meet the government set target of replacing the CNG bus fleet with fuel cell buses sees the ordering and deployment of the first 2,000 vehicles. Orders are expected to ramp up over the next 5 years.

Stationary deployments also see an uptick. Large scale projects remain the order of the day, with, on average, five 50 MW projects announced per annum by 2020.”

USA
“The growth of multi MW projects in the US sees companies such as FuelCell Energy, Doosan Fuel Cell and Bloom Energy expand local manufacturing and increase financing. The need for increased financing is based on the trend, first spotted in 2015, of the overall shift to a power purchase agreement (PPA) model. In the USA, by 2020, the average order size is 30 – 50 MW.”

Indonesia
“Leveraging the success of the 2018 Asian games, fuel cells are increasing deployed in multiple areas based on developing a local, resilient emergency network. These include early warning tsunami monitoring sites, shelters, hospitals and police stations.”

Kenya
“Another high end market, the luxury safari business also sees the first deployment of fuel cells. Small units are deployed in safari vehicles for visitors to recharge their phones and cameras. Also, fuel cell vehicle APUs allow the vehicles to continue to provide silent power when the engine is switched off.”

South Africa
“The off grid market receives a major boost with Canada, Scotland, South Africa and Southern Europe signing a product development agreement to work together to create an economic, appropriate product fuel cell product. With funding from a number of international banks, and companies, multiple teams agree to roll out within the decade of the first series of products.”

India
“India sees the launch of its first stationary fuel cell generator. Designed to work on a range of locally available fuels, the unit is targeted at the local market.”

2030 – Maritime Trading of Hydrogen Becomes a Reality

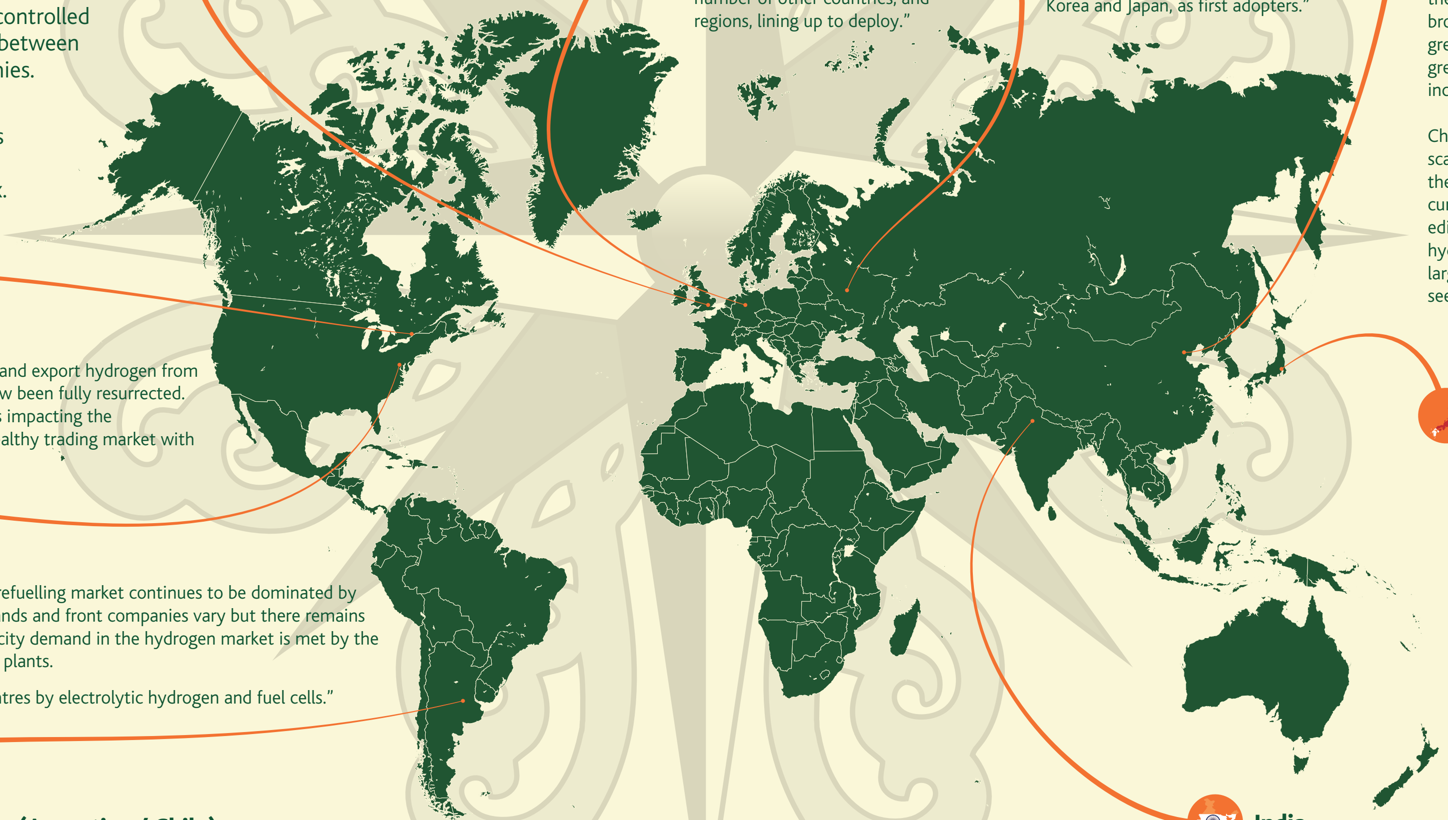
The development and certification of large scale liquid hydrogen tankers sees the development of an international market in hydrogen trading by 2030. Alongside this is the development of the global green hydrogen certification scheme, with green hydrogen traded a higher price than brown. A compact of the major hydrogen consuming nations sign up to move to green hydrogen by 2050, phasing out of the use of natural gas, nuclear and coal to hydrogen before then.

The market for electrolytic hydrogen continues to post double-digit annual growth rates. Over 50% of new hydrogen refuelling stations have electrolysis units to produce local hydrogen.

Hydrogen refuelling stations reach 3,000 stations for LDVs globally, with slightly less for buses and trucks. Issues of common refuelling standards were worked out in the early 2020s, ensuring costs of refuelling stations come down to under $500,000 deployed per station.

Hydrogen for use as a fuel, including in fuel cells, reaches 10% of the global market for hydrogen. Up from less than 2% in 2017. This rapid shift in market dynamics has led to hydrogen being on fossil fuel parity in an increasing number of countries, and pressure on electrolysers companies to expand their manufacturing and operating capabilities. 75% of the global electrolyser market is controlled by three companies, which operate between them a number of daughter companies.

The increased competition between electrolyser and SMR companies has led to the pump price of hydrogen being around $5 - $6 per kg, pre-tax.



UK
"The UK is known to be developing the world's first straw man hydrogen taxation system. It is also at the forefront of the development of rural hydrogen market. Hydrogen farming is subsidised from central government in a continued move of diversified farm income."

Germany
"Germany leads the world in the deployment of power-to-gas projects. It continues to be seen as the global test bed for the concept, with an increasing number of other countries, and regions, lining up to deploy."

Russia
"Russian development of small scale alkaline electrolysers see export of the key technology to Australia, China, South Korea and Japan, as first adopters."

China
"China, in conjunction with Australia, Canada, Patagonia and Norway, are developing a green hydrogen certification scheme, similar to the carbon trading scheme. Companies in the scheme can either buy credits, if using brown hydrogen, from companies with excess green hydrogen, or use a set percentage of green hydrogen. This required percentage increases out to 2050 when it will be 100%.

China is also now moving fast on the large scale deployment of electrolysers to work on the Four Norths problem. With the level of curtailed renewables now under government edict to be reduced, and the demand for hydrogen from transport rapidly increasing large scale hydrogen, manufacture is now seen as an economic route forward."

Canada
"The early 1990s' plans to produce and export hydrogen from excess hydroelectric power have now been fully resurrected. Even with changing rainfall patterns impacting the hydroelectric sector in Canada, a healthy trading market with the US is being built."

Japan
"Japan continues its development programme of treatment of nuclear waste to produce hydrogen. Interest is also seen from France, the USA and the UK. China has its own programme. Japan is also the first receipt of the first tanker of liquid hydrogen. With an initial global maritime fleet of 10 liquid hydrogen tankers, Japanese companies are creating the first long term futures market for hydrogen."

USA
"Supply of hydrogen to the hydrogen refuelling market continues to be dominated by the big three hydrogen companies. Brands and front companies vary but there remains an oligopoly on fuel supply. New capacity demand in the hydrogen market is met by the big three with large scale, 50 MW plus plants.

Google now powers over 70% datacentres by electrolytic hydrogen and fuel cells."

Patagonia (Argentine / Chile)
"The vast wind potential in the Patagonia region of the Argentine and Chile has long been undervalued due to the concerns over land protection, and local land rights. With the development of a green hydrogen certification market, which local developer companies can trade on, the blockchain platform concerns over external exploitation start to be overcome. By 2030, the first four major wind-to-hydro-gen-for-export plants are up and running; each run by local companies. The deep water Port of San Antonio Este is the first port in Latin America to see the docking of a hydrogen tanker."

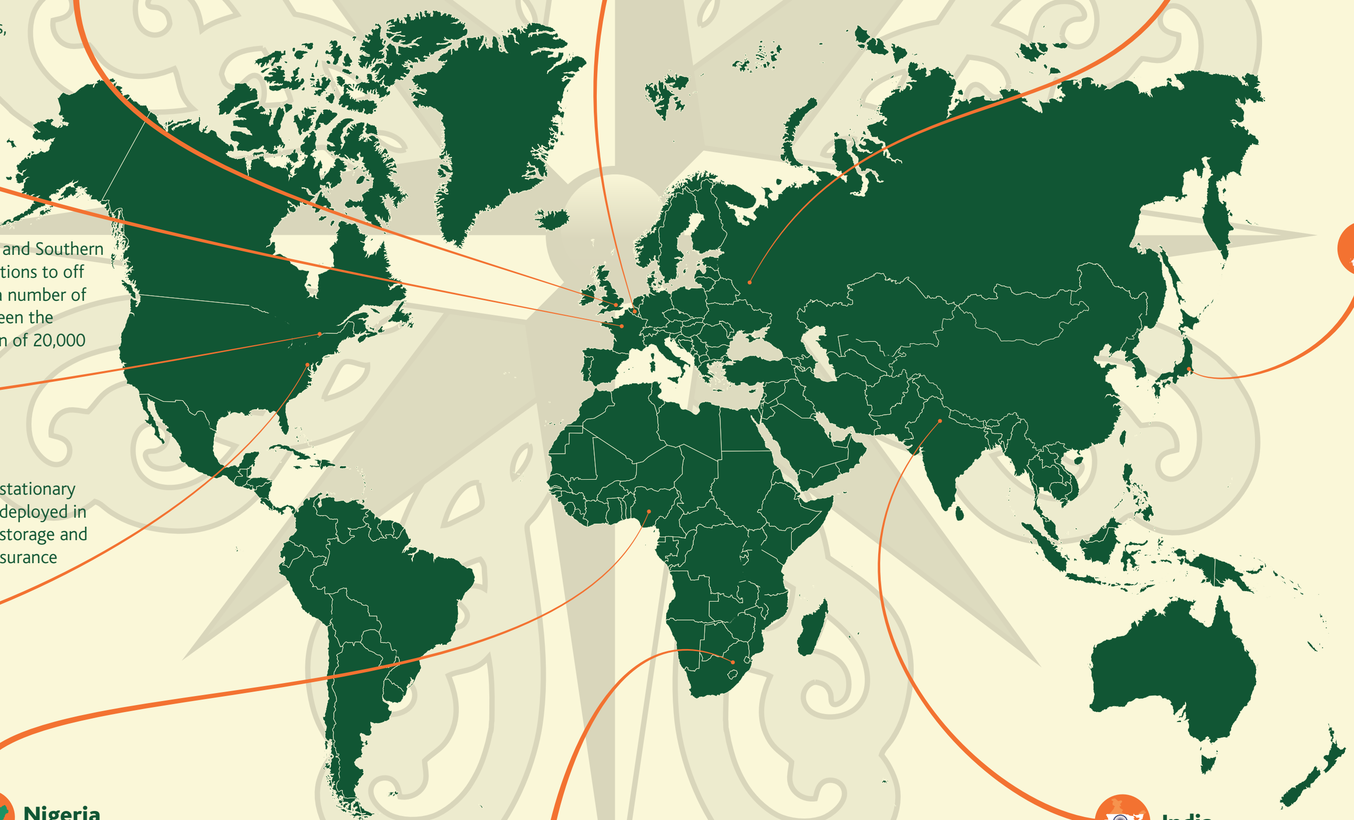
India
"The transport market in India celebrates the deployment of the 350th hydrogen refuelling station. Located in the major urban centres, the government adopted the H2Mobility model of working with companies to create a long term roadmap for change."

2030 – Fuel Cells
10 Million Deployed and Counting

2030 is the tipping point from niche to mass market for the fuel cell sector. Some areas, such as residential fuel cells in Japan, are now the norm for all new builds, and in North America, all new commercial buildings have to have renewables with energy storage, or fuel cells, built into the schemes.

Stationary fuel cells are still second fiddle to transport markets, but the big win is the use of fuel cells in personal electronics, with fuel cell powered laptops and mobiles taking the market share off traditional battery powered units. This market is enabled by the, now, rapidly growing micro hydrogen distribution market, pump primed by a large personal electronics firm.

In the transport markets, the millionth fuel cell car is on the road, but the market share still lags that of BEVs in many regions. Fuel cells trains and buses are now the norm, with an increasing number of countries stipulating that all new infrastructure projects are carbon neutral. Fuel cell powered cold ironing is being rapidly deployed in ports and marinas around the world, with China leading the world. In maritime SECA areas, all new ferries commissioned are either fuel cell or battery powered, with shipyards and maritime designers producing new designs for the market.



France
"France becomes the first nation to require all new commuter rail projects to be fuel cells, with green hydrogen."

UK
"The North of England rail network has now over 50% switched to fuel cells."

Europe
"Refineries across Europe deploy SOFC and MCFC fuel cells to provide base load power as they respond to legislative demands to reduce pollution levels."

Russia
"Oil and gas companies in the high Arctic post deployment of their 50,000 fuel cell. The oil and gas industry remains one of the top five adopter industries of fuel cells."

Canada
"Canada's agreement with Scotland, South Africa and Southern Europe to work together to ensure long term solutions to off grid energy requirements has seen the launch of a number of new start-up companies, with skills transfer between the nations. By 2030, this agreement sees the creation of 20,000 new direct jobs and over 85,000 indirect jobs."

Japan
"4.3 million homes with resCHP installed and 1 million fuel cell cars on the road. SOFC and PEM fuel cells are the biggest winners in Japan. All new office buildings have emergency fuel cell installed and have been the first country to adopt fuel cell laptops. GDP growth from fuel cells and hydrogen is now recognisable."

USA
"New York State holds the title of most MWs of stationary fuel cells deployed. With over 5 GW of fuel cells deployed in distributed power generation, along with energy storage and renewables, the State was officially named by insurance agencies "Storm Resilient" in the late 2020s."

Nigeria
"As Nigeria moves on its commitment to stop routing gas flaring by 2030, high temperature fuel cells deployed at the site of gas flares to capture the waste gas become the norm. Supported initially by investment from the World Bank and the African Investment Bank, this market has quickly become a trend-setter for other nations."

South Africa
"South Africa holds the world leading position in fuel cell stack recycling, with economic gains of 2%. Special economic zones have attracted overseas interest and investment, though the big winners have been local companies and local start-ups."

India
"As grid blackouts still plague the rapidly growing economy, fuel cell generators are now the norm. These units, designed and manufactured in India, are basic on systems designed to run off multiple fuel sources and are rolled out in urban and critically rural areas. "

2040 – Green Hydrogen takes 75% of Global Hydrogen Market

As concerns from environmental groups over covering large areas of desert with solar panels to covert to hydrogen for export are increasingly recognised, localised production of hydrogen for local consumption sees a resurgence. The hydrogen market moves away from majority of centralised production to increasingly decentralised. Working with the new utilities, which are increasingly smaller scale, less monolithic companies, the energy, industry and transport sectors are now increasingly decarbonised.

Europe leads the way in the development of green hydrogen, with Japan still having a small percentage of imported hydrogen produced from brown coal with CCS. A global compact to remove "the last 25%" is signed by a number of countries. The price of green hydrogen certificates has doubled since their launch and this is now traded on the futures markets.

The maritime fleet of hydrogen ships now includes tankers, ferries and yachts. Hydrogen and fuel cells are now seen as a standard option, with reefer vessels and ferries making the majority of adoption. Recycling of electrolyser components are centred in South Africa, the UK and Mexico with high value add job creation enabling rapid upskilling.

UK
"The UK remains the global centre of hydrogen accounting, including hydrogen trading, green hydrogen certificate trading and global maritime logistics."

Norway, Sweden, Finland and Denmark
"The grouping of the Nordic countries is the first to create a cross border green hydrogen trading bloc. Due to the high levels of green hydrogen production in the region the trading bloc rapidly becomes one of the most powerful. Trading is centred on Bergen."

China
"China, very much focused on the 3 Norths Problem, moves to a much more decentralised approach for hydrogen production. Including local production of hydrogen for use on the highly successful reinvention of the Silk Road. The final hydrogen refuelling station to create a pan European – Asian route is opened in China, allowing a continuous driving route of 4,350 miles."

Iceland
"Iceland continues to develop a zero carbon hydrogen industry based on local production and use in its fishing fleet and datacentres."

Japan
"Roll out of residential electrolyser for home refuelling of cars starts to see real commercial traction. "Baby Electrolysers" use electricity from home solar panels and energy storage units, to provide zero carbon hydrogen. The packaging of zero carbon homes, with inbuilt solar, storage, and electrolysers feeds into a step change in adoption of fuel cell vehicles"

South Africa
"South Africa is one of the core areas for electrolyser recycling. As the global industry is based on very high levels of recycling and reuse the high tech approach to recycling pushes forward developments in recycling technologies, which are then leveraged by South African companies into exporting know how to other countries. "

Australia
"The initial focus of large scale exports of green hydrogen now shifts to include a focus on local use. As cross Australia hydrogen pipelines are seen as economically unfeasible the local consumption market is built on a nodal pattern, of a large number of small production facilities delivering to local markets. This leads to the creation of a number of independent hydrogen production and delivery firms generating increasing numbers of high value job growth. "

2040 – Fuel Cells – Planes, Trains, Automobiles and Ferries, Trams, Drones, Buses, Yachts, RVs,Motorbikes, Bikes, Mobility Scooters, Forklifts and Cruise Ships

By 2040, the diversity in the fuel cell sector is staggering. In the transport sector, the PEM fuel cell drivetrain is a standardised unit. Whilst fuel cells continue to share the market with batteries, and to a much lesser degree, the internal combustion engine, the industry is thriving.

The fuel cells in transport supply chain is the most tightly controlled of any fuel cell supply chain.

The standard reference designs for transport companies are created by a handful of companies. Six sigma manufacturing, cost out, rapid prototyping and design, and being able to supply in volume has led to a very heavy shake out of fuel cell stack companies. Stack companies supplying to the transport market is less than ten, globally.

In the stationary sector, the markets are highly segregated by region. There are very few copy and paste markets.

Germany
"Germany is the first country in the world to have no diesel powered trains left in service. The entire network is now either electrified, with overhead catenaries, or powered using fuel cells."

Canada
"Canadian companies continue to dominant in terms of high volume, high quality stack production for the transport sector."

USA
"The world's largest cruise liner company announces its intent to convert its entire fleet to fuel cells, running off where possible green hydrogen. With the company investment in cold ironing at key ports now complete the focus is very much the floating arm of the company.

Whilst Amazon still holds the record for the single largest fleet of fuel cell forklifts, the technology is now the norm in food warehousing, and rapid turnaround distribution locations leading to fuel cells being the highest share of logistics vehicles in the US. "

South Africa
"PEM fuel cell MEA production continues to increase in the number of Special Economic Zones created in country. Focused on utilizing indigenous, as well as imported technologies, South Africa is positioning itself as a critical partner in the supply chain."

India
"India and Germany form a close collaboration to speed up deployment of fuel cell trains into India. This includes cross border investment, as well knowledge sharing."

2050 – Hydrogen and Fuel Cells mature in the Global Decarbonised Economy

"Under the The H_2°C Scenario by 2050 the majority of the world's transport market is over 85% decarbonised. The freight sector, including shipping, relies on the use of fuel cells and transport for the movement of goods around the world. The public transport sector is a local mix of battery and fuel cells, with a number of countries predominantly fuel cells. LDVs are increasingly all electric, with fuel cell vehicle penetration high in countries where travel is increasingly extra urban. China has the world's largest fleet of fuel cell vehicles.

The biggest shifts in the hydrogen market came from Norway, Argentina, Australia and increasingly Saudi Arabi setting themselves up as major hydrogen export markets. This created a maritime hydrogen market in the late 2020s which has burgeoned since then. Policies enacted in the 2020s have ensured that green hydrogen is taxed at a much lower rate than brown hydrogen, pushing the rapid development of a green hydrogen market.

Hydrogen arbitrage is now a growth industry, with the power to gas sector playing a key role in countries such as Germany, the UK, Japan and China."

UK
"Teaming agreement with India and South Africa leads to high penetration of off grid rural communities powered by hydrogen and fuel cells. Transport fleet 80% electrified with fuel cells deployed in trains, freight, buses and cars"

Germany
"Economy 100% renewable with high penetration of power to gas, and hydrogen imports from the Nordic region. Largest hydrogen consumption market in Europe. GHG budget down 90% from 1990"

Norway
"First nation to reach full decarbonisation. Hydrogen and fuel cells play a pivotal role in this in both the transport and power sectors. GDP growth linked to the development of a hydrogen export market."

France
"Hydrogen innovation based economy. 90% of global nuclear hydrogen produced in France. Largest fleet of fuel cell trains."

China
"4 millions fcv's on the road, 85% road transport electrified, largest power to gas economy in the world"

South Korea
"World's largest hydrogen plant now 10 years old. Water use from energy production down 60%"

Canada
"Liquid green hydrogen significant export market by 2050. Major cities well on the way to full decarbonisation."

Japan
"Hydrogen Economy Realised. 2 million tonnes of CO_2 avoided, oil dependency 2%, 1 million jobs created."

USA
"Long decarbonisation path, with hydrogen and fuel cells playing major role in the greening on the fossil fuel and steel industries. 25 States with over 70% electrified transport fleet. 10 States with fully electric transport fleet."

Australia
"World's largest green hydrogen export market, with primary supply to Asia. Long term off take agreement from Japan and South Korea. 1.5 million jobs created. Hydrogen created 2% GDP growth from 2020."

Argentina
"Second largest green hydrogen export market"

Saudi Arabia
"Rapidly moving to a hydrogen arbitration market. Large scale production of green hydrogen. Development of hydrogen gas pipeline from Saudi to Europe underway. Local use focused on transport."

South Africa
"Universal energy access for all achieved in the 2030s. 3D printed fuel cells and electrolysers play a key role in stimulating the South African economy. Central node for export of locally made systems into Sub Saharan Africa. Largest Hydrogen port in Africa. 1.2 million new jobs created from €5 billion in leveraged investments."

India
"Transport fleet fully electrified, with fuel cells and hydrogen making up 75% of freight transport, 80% of buses, and 30% of LDV fleet. Universal energy access across the country"

The $H_2{}^{0}C$ Scenario and the Fuel Cell and Hydrogen Annual Review

Going forward 4th Energy Wave is now actively looking for commercial backing to continue to produce the Annual Review and, separately, to produce a full length, in depth report on the $H_2{}^{0}C$ Scenario.

The Fuel Cell and Hydrogen Annual Review is a free resource for the industry, and interested stakeholders. It is downloaded and accessed annually by over 10,000 users around the world. The Review is regularly quoted and the data reused and leveraged by a range of organisations.

The Review has, too date, had **no** commercial funding or sponsorship. 4th Energy Wave has undertaken all the work to interview and collate all the information, produce the report, and pay for printing, of the last 3 year's Fuel Cell and Hydrogen Annual Review.

The $H_2{}^{0}C$ Scenario is an in-depth scenario covering market, and socio-economic information. Highlights from the Scenario are published for the first time in the 2017 Fuel Cell and Hydrogen Annual Review.

To continue to serve the industry, and produce high quality information, which can be freely accessed we now are looking to move this report, and the scenario, onto a fully commercial footing.

If your organisation is interested in more information on what levels of backing we are seeking please contact

Kerry-Ann@4thenergywave.com

with your contact information and we will be happy to run you through the requirements.

Peace.

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Acronym List

AFC	Alkaline Fuel Cell
APU	Auxiliary Power Unit
ARL	Adopter Readiness Levels
BEV	Battery Electric Vehicle
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
CSR	Corporate Sustainable Responsibility
DMFC	Direct Methanol Fuel Cell
EU	European Union
FCV	Fuel Cell Vehicle
FCEV	Fuel Cell Electric Vehicle (also see FCV)
FCH JU	Fuel Cell and Hydrogen Joint Undertaking
GHG	Greenhouse Gases
GW	Gigawatt
ICE	Internal Combustion Engine
LDV	Light Duty Vehicle
kW	Kilowatt
km	Kilometre
LME	London Metal Exchange
MRL	Manufacturing Readiness Levels
MW	Megawatt
NCA	Nickel Cobalt Aluminium Oxide Battery
Oz	Ounce
PEM	Polymer Electrolyte Membrane Fuel Cell
PGM	Precious Group Metals
PPA	Power Purchasing Agreement
SMR	Steam Methane Reforming
SOEC	Solid Oxide Electrolyser
SOFC	Solid Oxide Fuel Cell
TEP	Technology Rollout Programme
TRL	Technology Readiness Levels
US DOE	(United States) Department of Energy
VC	Venture Capital

Note in the report, we use ton and tonne.
We have not converted data from ton to tonne,
or vice versa. Please be aware of this.