Custom Research Report

PEM Fuel Cell Technology Cost & Diffusion

Analyzing the Potential Impact of a Cost Reduction in PEM Fuel Cell System Technology

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Section 1

INTRODUCTION AND BACKGROUND

1.1 PEM Fuel Cell Cost Overview

The fuel cell technology market grew at a compound annual growth rate (CAGR) of 27% between 2008 and 2010, according to data in Pike Research's *Fuel Cells Annual Report 2011*. This market view includes the stationary, transport, and portable sectors, and includes all electrolyte types. Additionally, Pike Research's data revealed that a number of key companies are taking steps to scale up their manufacturing capabilities in advance of a mass-market rollout in the medium term.

Realistically, fuel cell technology is just out of the gate in terms of its diffusion and adoption in the marketplace; as such, it is still in the phase of high-cost, low-volume manufacturing. Even with this caveat, we have seen impressive cost reductions posted by a number of companies.

In 2002, the U.S. Department of Energy (DOE) launched a concerted cost reduction program for low-temperature polymer electrolyte membrane (LT PEM) fuel cells. For manufacturing levels of 500,000 PEM[1] fuel cell systems per year, the DOE now estimates that costs have declined from more than $270/kW in 2002 to $51/kW in 2010. The program's goal is to further reduce this amount to $30/kW.

Table 1.1 Cost Summary of PEM Fuel Cell System: 2010

Annual Production Rate	Units	1,000	80,000	500,000
System Net Electric Power (Output)	(kW_{net})	80kW	80kW	80kW
System Gross Electric Power (Output)	(kW_{gross})	87.91kW	87.91kW	87.91kW
Fuel Cell Stacks	($)	$11,617.8	$2,873.61	$2,030.92
Balance of Plant	($)	$6,480.71	$2,725.93	$1,968.52
System Assembly & Testing	($)	$157.17	$110.91	$110.67
Total System Cost	**($)**	**$18,255.7**	**$5,710.44**	**$4,110.11**
Total System Cost	**($/$kW_{net}$)**	**$228.20**	**$71.38**	**$51.38**
Total System Cost	**($/$kW_{gross}$)**	**$270.67**	**$64.96**	**$46.75**

(Source: DTI)

[1] In this report, PEM refers to LT PEM only. HT PEM is always explicitly labelled as such.

Table 1.2 Projected Cost Summary of PEM Fuel Cell System: 2015

Annual Production Rate	Units	1,000	80,000	500,000
System Net Electric Power (Output)	(kW_{net})	80kW	80kW	80kW
System Gross Electric Power (Output)	(kW_{gross})	87.27kW	87.27kW	87.27kW
Fuel Cell Stacks	($)	$10,552.3	$2,435.24	$1,711.47
Balance of Plant	($)	$2,634.34	$1,505.11	$1,352.76
System Assembly & Testing	($)	$135.55	$92.12	$91.92
Total System Cost	**($)**	**$13,371.2**	**$4,032.47**	**$3,156.16**
Total System Cost	**($/$kW_{net}$)**	**$166.47**	**$50.41**	**$39.45**
Total System Cost	**($/$kW_{gross}$)**	**$152.59**	**$46.20**	**$36.16**

(Source: DTI)

As shown in Table 1.1, the PEM fuel cell system cost realistically lies somewhere between $71.38 and $228.20. No single company even comes close to producing the half-million units per year that would be required to bring costs down further. Consequently, fuel cells are multiple times higher in cost than the incumbent technology. Until these costs come down significantly, mass market adoption will not occur.

This high initial cost is not unique to fuel cell technology as all new technologies go through a similar phase; however, the cost issue must be addressed for the industry to grow more rapidly.

The aim of this report is to look at the cost issue from the standpoint of "What if the DOE's 2015 target of fuel cell systems of $30/kW was achievable today? What impact would this have on the rate of adoption of fuel cells across a number of key applications?"

Table 1.3 takes the 2010 data from the "1,000 Units" column in Table 1.1 and re-runs it to highlight the impacts of a 20% and 40% cost reduction as well as the $30/kW target. The 1,000-unit level was chosen for the fact that it most closely represents the industry's annual output per company. While the industry itself currently posts unit shipments of more than 15,000 per year, this total reflects a number of companies each making a small number of systems. At present, fewer than 10 companies worldwide exceed 1,000 systems per year.

Table 1.3 Cost Summary of PEM Fuel Cell System: 2010

LT PEM Cost Breakdown	Units	1,000 Units	20% cost down	40% cost down	$30/$kW_{net}$
System Net Electric Power	(kW_{net})	80kW	80kW	80kW	80kW
Fuel Cell Stacks	($)	$11,618	$14,448	$10,796	$2,242.83
Balance of Plant	($)	$6,480.71	-	-	-
System Assembly and Testing	($)	$157.17	$157.17	157.17	157.17
Total System Cost	**($)**	**$18,255.75**	**$14,604.8**	**$10,953.6**	**$2,400**
Total System Cost	**($/$kW_{net}$)**	**$228.20**	**$182.56**	**$136.92**	**$30**

(Source: Pike Research)

This point – that the industry is composed of a number of companies, each constrained in their manufacturing capacity – is important to remember going forward. Even with a significant cost reduction from $228.20 down to $30, the companies are unlikely to be able to meet full market demand in the short to medium term. If it takes on average 1 to 2 years to commission and build new manufacturing facilities, there will still be a time lag in the system.

Section 2

OVERVIEW OF MODEL ASSUMPTIONS

2.1 Introduction

Pike Research was retained by PowerDisc to develop and run a model that looked at the potential impact on diffusion rates of PEM and HT PEM in the following markets:

- Fuel cell light-duty vehicles
- Micro combined heat and power (mCHP) systems
- Forklifts
- Prime power for commercial buildings
- Uninterruptible power supplies for telecoms

For each application, Pike Research has created a model that includes a revised payback period based on the cost decrease.

Pike Research knows that when a consumer makes a choice on a product purchase they take into account many factors, including price, styling, environmental impact, relevance, and a perception of need. The relative merits and importance of each of these to the consumer is outside the scope of this report; however, it is fair to say that cost is a high priority. Cost involves both the upfront, capital expenditure and the expenses across the product's lifecycle. Increasingly, as consumers become aware of and take into account issues such as fuel bills, the lifetime costs and payback periods become a more prominent part of the equation. For this reason, we have chosen a payback period model rather than a more straightforward capital cost model, where adoption is based purely on the technology with the cheapest initial outlay.

To aid transparency and prevent any accusation of fuel cell technology bias, the key assumptions in the Pike Research model are outlined here.

2.2 Key Model Assumptions

2.2.1 Payback Period

The payback period below which a consumer will adopt a fuel cell-based product is 5 years. Although there is evidence that early adopters will accept up to a 12-to-14 year payback for renewable energy sources, specifically wind and solar photovoltaics (PV), our model focuses on the *mass market*, where paybacks are required to be much shorter. The mass market was assumed to be below a 5-year payback period, which is lower than most of the incumbent market technologies.

In the model when the payback period is greater than 5 years, the Pike Research baseline forecast was used for diffusion rates; it is only when the payback period equals or drops below the 5-year threshold that the rate of diffusion rises.

2.2.2 Fossil Fuel Costs Do Not Go Up Between 2011 and 2020

The base costs of using petroleum-based products and grid energy are held constant over the forecast period. Although this is highly unlikely to be the case, forecasting the price at the pump and wire to 2020 ends up masking the impact of the price drop through improved technology. As it is expected that prices of oil and electricity will increase somewhat between now and 2020, the savings from the use of more efficient technology will increase over time, shortening the payback. This model is focused on the potential reduced payback from the improved technology and the shortened switch, in terms of time, of the move to mass manufacturing. By holding the cost savings steady, we remove any secondary bias toward the fuel cell.

In reality, the market will see a combination of both increased fuel savings and decreased capital cost.

2.2.3 Cost of Hydrogen and Hydrogen Tax

In addition to holding fossil fuel costs steady, the model maintains the cost of hydrogen at today's rate of $10/kg. Although this cost varies between regions, Pike Research has found the variation to be less than $1/kg. In 2011, the key variations relate to the classification of hydrogen. In California, for example, hydrogen has already been adopted as an official motor fuel, but cannot be sold. Therefore, the price of hydrogen for the growing fleet of FCVs in California is zero. Additionally, no region in the world presently imposes a tax on hydrogen that will be used in a fuel cell or internal combustion engine. Taking into account the levels of tax that do exist on more standard fuels, it is a fairly safe assumption that hydrogen will also be taxed[2] at some point in the future.

Taxation of hydrogen is unlikely to happen while the use of the fuel is still low, as an artificial price increase could easily slow, or stop, the market from expanding. Since many governments want to encourage the use of hydrogen within fuel cells, our model assumes a hydrogen tax of 0%.

Unlike the cost of gasoline, which is expected to increase, the cost of hydrogen is expected to decrease over time. The U.S. DOE cost projections, for example, place hydrogen from electrolysis in the range of $4/kg to $5/kg before 2020.

2.2.4 Regions

The regions chosen for this report were North America, Europe, and Asia Pacific. This is a very broad brush approach to the geographical spread; it is known, for example, that Germany will exhibit a very different adoption rate than Spain, and that the diffusion pattern in California will differ from that of Texas. However, at this point in the development of the technology at PowerDisc, this first report is aimed at illuminating the impact of potential strategies rather than specific geographies; thus, the broader regional approach.

The Rest of the World (ROW) region has not been included; even a drop in costs to $30/kW is unlikely to lead to a system that can be employed en masse outside of the traditional big three regions. The only caveat to this *may* be South Africa, Kenya, Argentina, Chile, and Russia as there is an increasing policy and market pull.

2.2.5 Experience Curve

For any new technology there is an experience curve by which for every doubling of

[2] An interesting hypothesis here would be to test if the rate of adoption through the cost drop in the fuel cell cost was at a level that was high enough to see legislators bring forward the time when hydrogen is taxed. This would need to be done in conjunction with policy makers in different regions and could certainly be seen as an unintended consequence of the speeded up rate of adoption of fuel cell technology.

manufacturing, or shipments, per year the cost drops by a repeatable amount.

This is represented by the equation:

$$C_{cum} = C_o . CUM^b$$

Where:

C_{cum} = cost per unit

C_o = cost of first unit

CUM = cumulative production

b = experience index

Technologies experience different experience curves at different stages of development and diffusion.

2.2.5.1 Fuel Cell System Experience Curve

From information gathered to date and from interviews with the limited number of fuel cell companies making the shift to low rate mass manufacturing, the fuel cell experience curve appears to be very similar to that of solar. This implies that for every doubling of manufacturing, the cost per unit drops 20%.

When an industry begins to mature, the experience curve clearly starts to drop off as the initial high gains in cost reduction from the switch to mass manufacturing begin to slow. Due to the current level of the fuel cell industry, with annual unit shipments in the low tens of thousands, we have left the experience curve at 20% per doubling of shipments throughout this forecast period.

Ideally, a full economic costing would see the experience curve being modeled for each industry player, as experience and impacts are gained at the company level not the industry level. Yet, the use of an experience curve for an industry is accepted practice given that staff move between companies, taking experience with them, and companies often help each other out with non-confidential, non-business-critical information.

In this Pike Research model, we have used a fuel cell system 20% industry experience curve with the option at a later date to modify the curve over time and unpack the information to the company level.

2.2.5.2 Balance of Plant Experience Curve

It is unrealistic to assume that the balance of plant (BoP) in the product, outside of the fuel cell system, will not exhibit an experience curve; however, this is one area that remains undocumented. What we know is that companies are moving away from bespoke components in favor of off-the-shelf components as the over-engineered systems are being readied for everyday mass use. This in itself will rapidly drive down the cost of the BoP for the unit.

To prevent any overshadowing of this separate cost reduction with the 20% reduction, 40% reduction, and DOE target option, we have modeled the BoP experience curve at 0.5%. In reality, we suspect that this is a lot lower than what the industry is experiencing, but companies have been reticent to provide information in this area. The model is set up so that this can be altered as and when more defensible information is provided.

2.2.6 Time to Reach 50% Market Penetration

When the 5-year payback threshold is achieved, we project that the rate of diffusion of the fuel cell system will begin to rise.

To calculate this new diffusion rate, we use the standard S-Curve equation of:

$$X(t) = a.b_T^t$$

Where:

X(t) = value of X at time t

a = value of x at time 0

b = growth rate

t = time

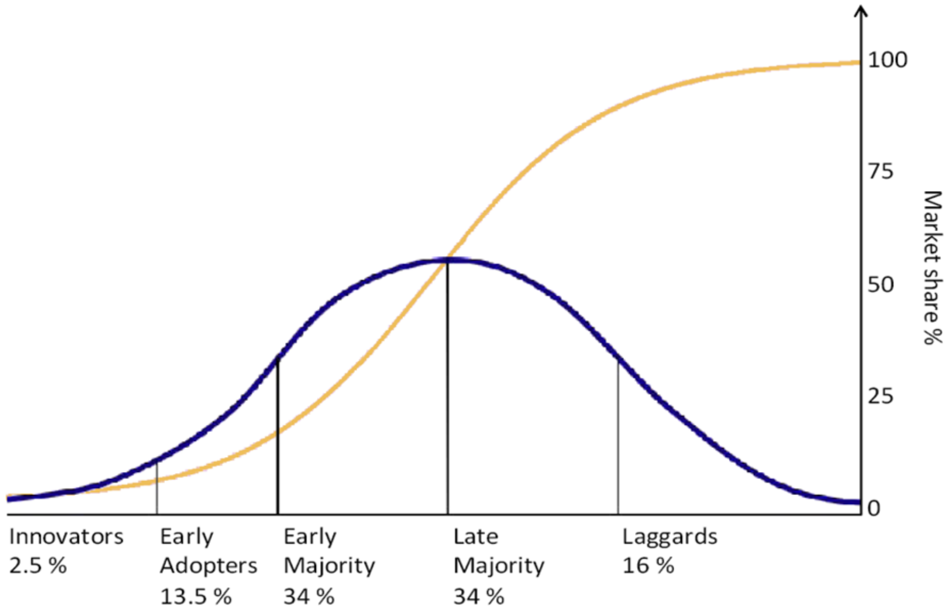
T = time required for x to increase by a factor of b

The base question behind the calculation is this: How would *b*, the growth rate, be affected by the cost reduction?

Given the time period in question (2011-2020), we are really only looking at the first three adopter sectors: innovators, early adopters, and early majority.

- Innovators – This group adopts based not on economics but on the “first to have” factor. This group wants to be first to have the latest gadget and tends to have sufficient personal wealth to absorb the very high cost of initial product generations.
- Early Adopters – This group adopts on the additional functionality (or usefulness) gained from the technology. Although cost is not the primary driver, it does play a role. Consequently, for early adopters to enter the market, costs will have to come down somewhat from those considered acceptable to the innovators group.
- Early Majority – This is the first group for which economics plays the critical swing factor. Here, the cost cannot be more than the incumbent or competing technologies.

Figure 2.1 Standard S-Curve Diffusion Pattern



(Source: Rogers)

The time period we are looking at, 2011 to 2020, combined with the current state of the fuel cell industry, implies that our model is really looking at the Early Adopters and Early Majority groups.

The present business-as-usual (BAU) model has in general a 25-year rate of diffusion. In other words, it would take 25 years from commercialization for the application to reach a 50% market share. This is in line with data from other technologies, exempting those with government interventionist policies that aim to help the market proliferate.

Section 3

MODEL RESULTS

3.1 Introduction

This section of the report outlines first the business-as-usual Pike Research 2011-2020 forecast for fuel cell adoption. Note that this represents a previously unpublished forecast; Pike Research's published forecasts only extend out to 2017. The second part of this section highlights the results from the Pike Research model and the impact of cost reductions of 20% and 40%, as well as the DOE targets of $30/kW.

Pike Research fuel cell forecasts combine a top-down and bottom-up approach to produce a medium term business-as-usual (BAU) forecast, some results of which are outlined in this section. The model takes a short, medium, and long term position on all companies working in the fuel cell sector at present, considering a host of factors, including the following:

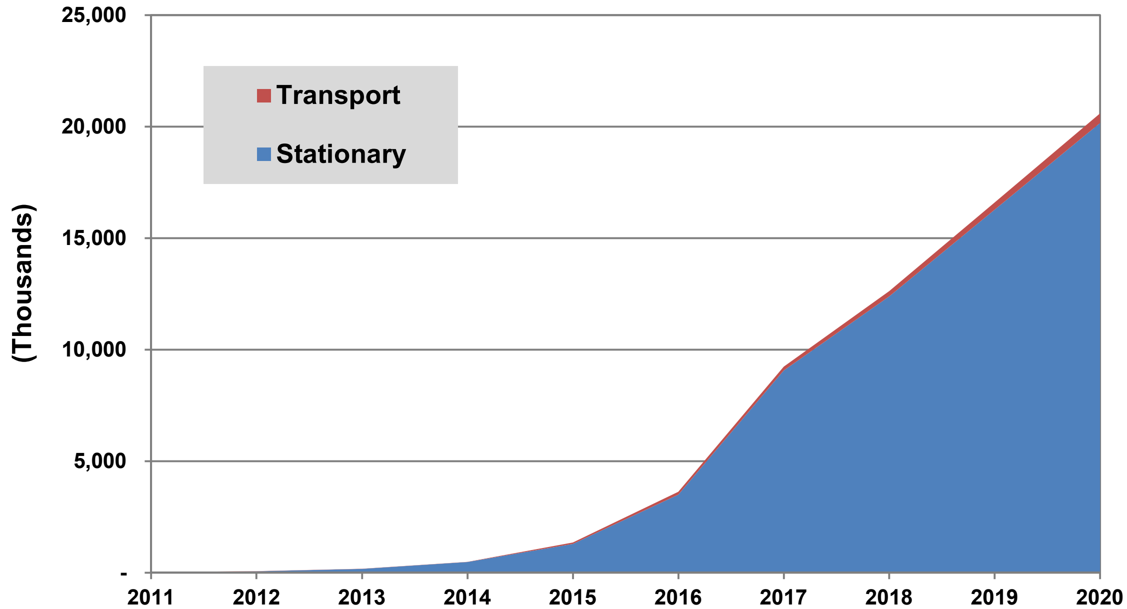
- Location (base of operations)
- Potential to move its manufacturing operations
- Financing structure

Subsequently, we produced an overall map of where the fuel cell industry could by 2020. Note that the forecasts are based on no new interventionist government policy and/or major flexing in the energy industry. For these forecasts, Pike Research assumed that business will continue "as usual."

3.2 Pike Research Baseline Forecast: 2011-2020

According to the Pike Research baseline forecast, the stationary and transport fuel cell sectors will reach shipment levels of just over 20 million systems per year by 2020. This represents a global total and covers all electrolyte types.

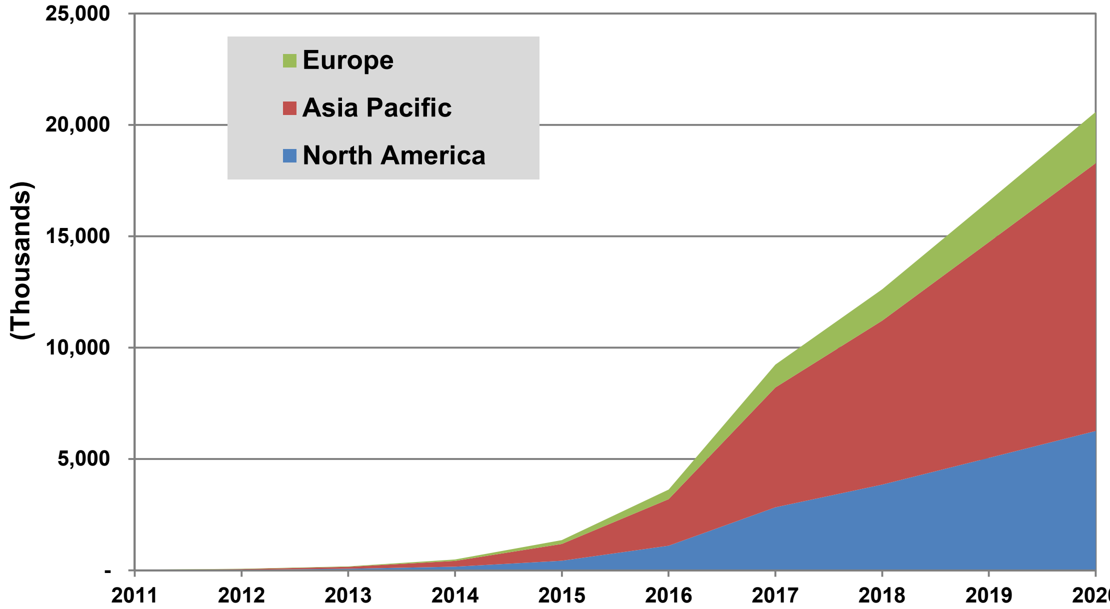
Chart 3.1 Transport and Stationary System Shipments by Sector, World Markets: 2011-2020



(Source: Pike Research)

As shown in Chart 3.1, the overwhelming majority of shipments will come from the stationary sector, which is significantly more commercial in 2011 than the transport sector (Note that the transport sector, for these purposes, covers only light-duty vehicles, trucks, and buses). Also depicted in the chart is the 2014/2015 inflection point, when shipments will begin to increase. Before this point, the industry will continue to languish in the low tens of thousands of shipments per year – and at a level where economies of scale are difficult to obtain.

Chart 3.2 Stationary and Transport Shipments by Region, World Markets: 2011-2020



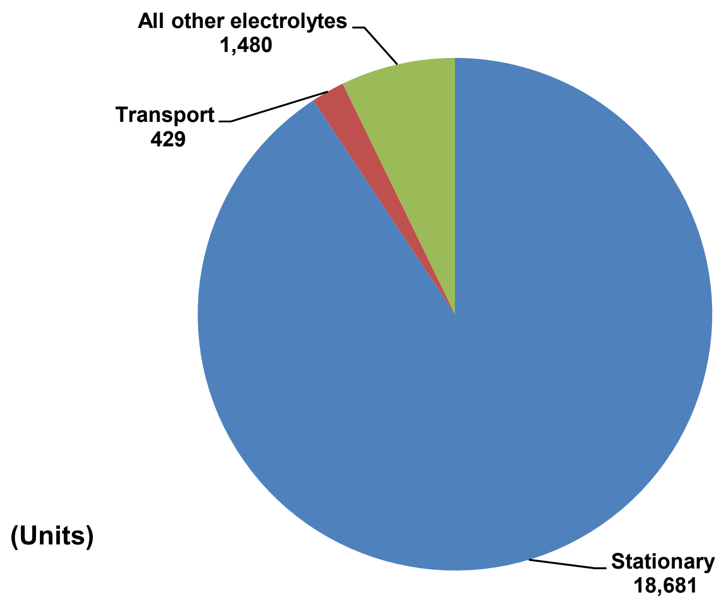
(Source: Pike Research)

The regions depicted in Chart 3.2 are Europe, including Turkey and the 27 member countries of the European Union (EU27); Asia Pacific, including Australia and New Zealand; and North America (the United States and Canada). As previously mentioned, the Rest of World region is not represented in this report. Even with cost reductions to $30/kW, diffusion in the ROW region will be limited to a few high-growth countries. If PowerDisc decides to focus its development activities in these countries[3], it is highly recommended that these be modeled within a separate report that breaks out the pros and cons.

As this report focuses only on PEM fuel cells, it is of value here to highlight here how important the PEM electrolyte is to the growing fuel cell industry.

[3] Example countries here would be: South Africa, Kenya, Argentina, Chile, and Russia

Chart 3.3 Stationary and Transport PEM Shipments by Sector, World Markets: 2020

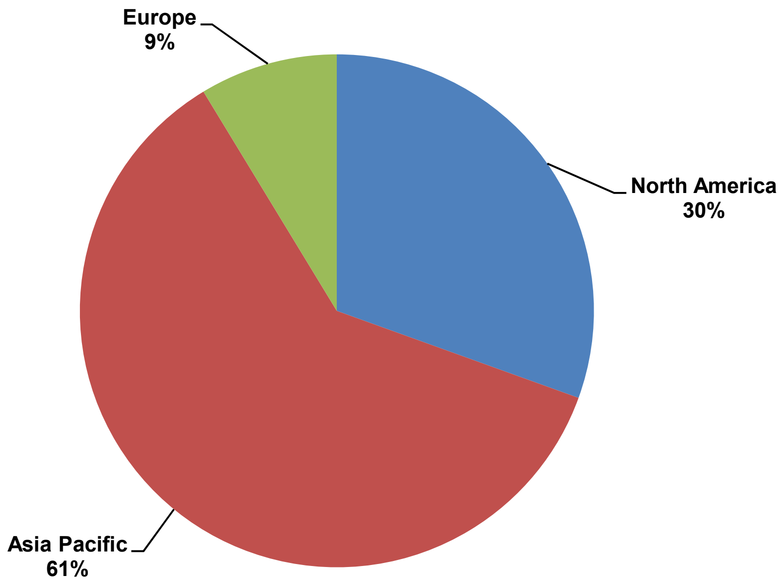


(Source: Pike Research)

In terms of becoming the bedrock of the industry, the PEM system is forecast to comprise more than 95% of all shipments in the stationary and transport sector, with all other electrolytes, under the BAU model, forecast to take less than 5% of the market by 2020[4].

[4] Note that this does not cover the portable sector, where the development of solid oxide fuel cells (SOFCs) in particular is more likely to be fast tracked for military applications. If development of SOFCs is escalated, we may see an increasing penetration in the civilian sector; however, given current levels of interest in and the potential represented by HT PEMs, there are a lot of questions around this.

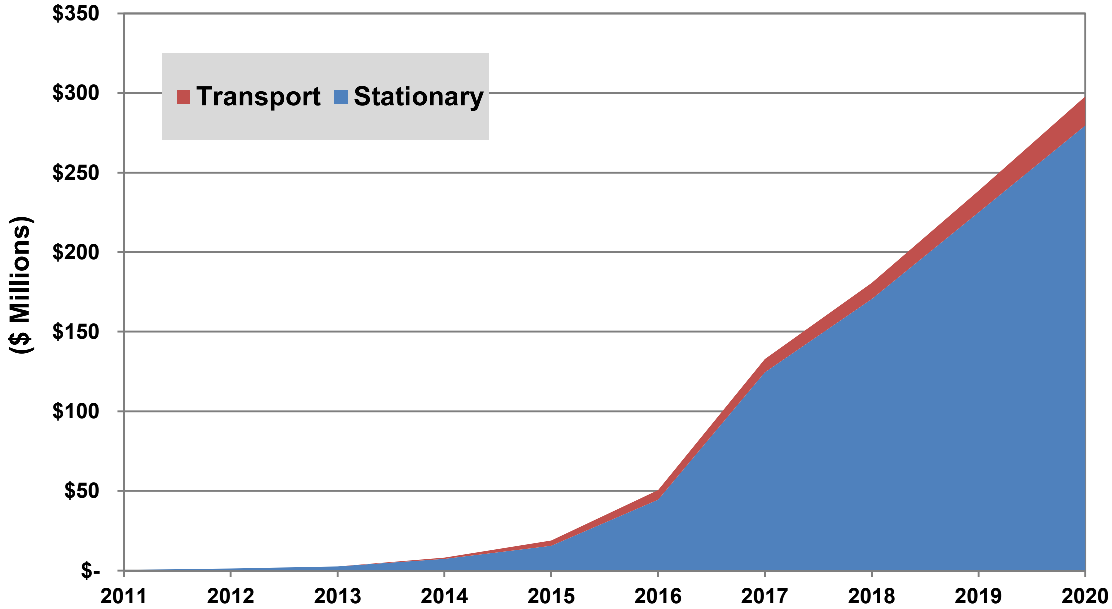
Chart 3.4 Stationary and Transport PEM Shipments by Region, World Markets: 2020



(Source: Pike Research)

Chart 3.4 clearly shows that under the Pike Research BAU forecast, the Asia Pacific region is the largest adopter of PEM technology in 2020. It has to be noted that in terms of potential, North America far outstrips Asia Pacific; however, North America requires some strong modifications in the market to break through the barriers to adoption.

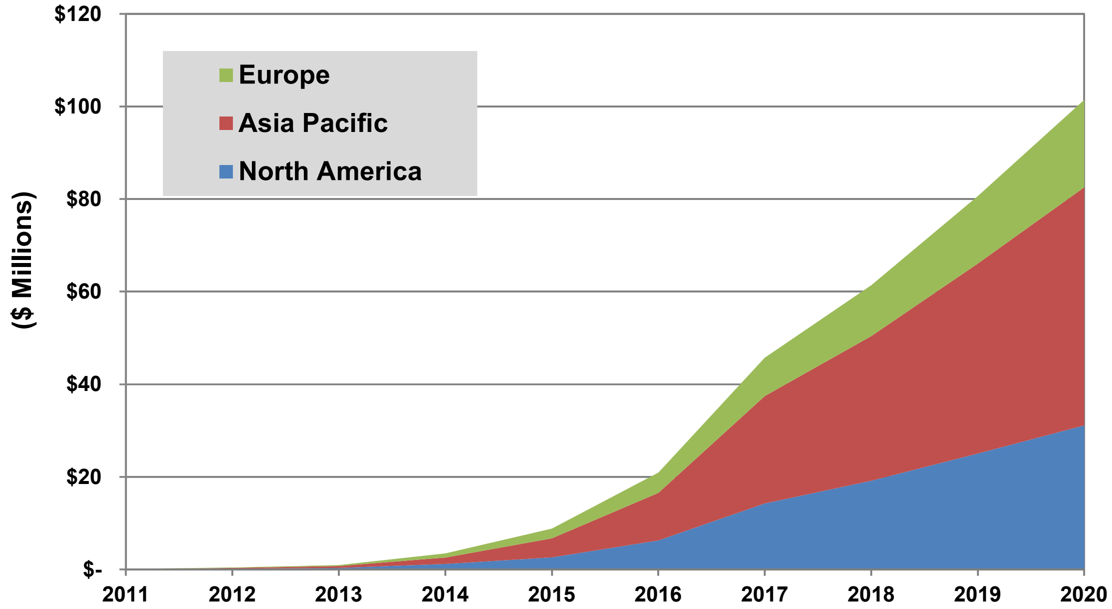
Chart 3.5 Stationary and Transport Revenue by Sector, World Markets: 2011–2020



(Source: Pike Research)

If we take a step back to look at the full transport and stationary markets, we can see that the stationary sector dominates the value chain in terms of revenue (shown in Chart 3.5). One of the main reasons for this is that the light-duty vehicle market, with its projected high-value income stream, is still very limited at this point in terms of shipments and income. This is unpacked further in Section 3.3.2.1 of this report.

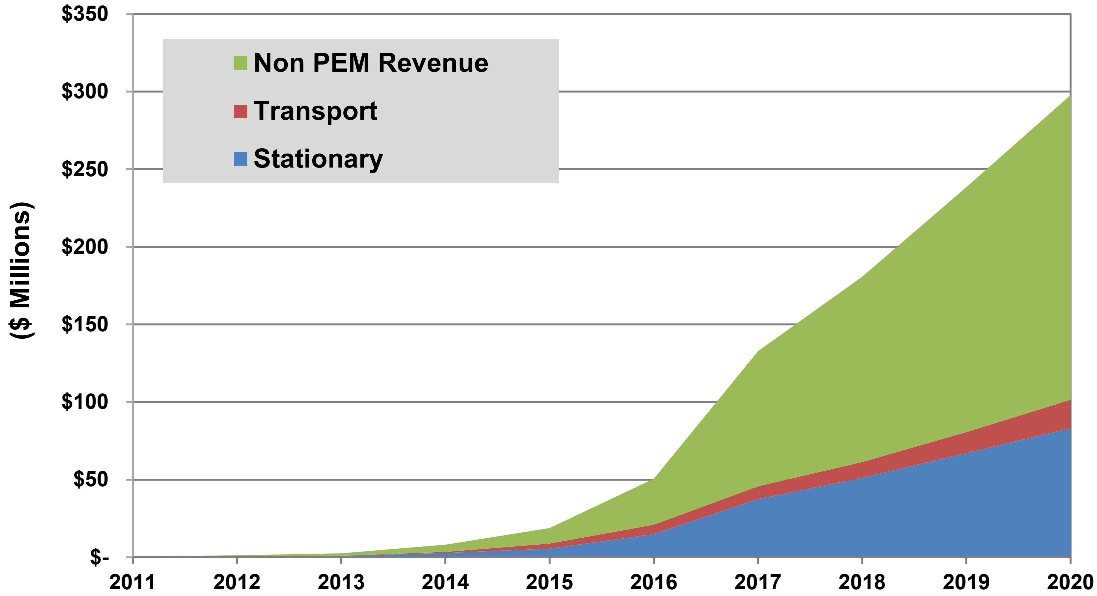
Chart 3.6 Stationary and Transport Revenue by Region, World Markets: 2011–2020



(Source: Pike Research)

Breaking out the revenue projections from the stationary and transport sector, for all electrolytes, we can see from Chart 3.6 that the Asia Pacific region makes up 50% of all revenue, with North America and Europe composing the other half. It is interesting here to split out PEM revenue from stationary and transport, and non-PEM revenue. Here we can now see that the PEM market represents only approximately one-third of total fuel cell revenue.

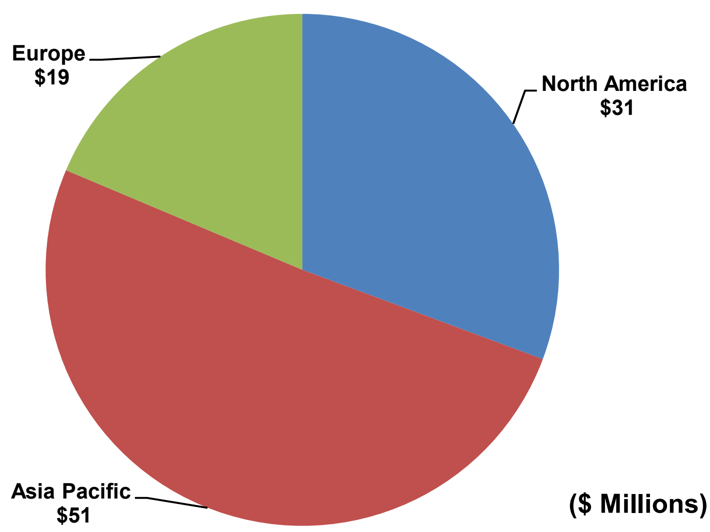
Chart 3.7 PEM Stationary and Transport Revenue by Sector, World Markets: 2011–2020



(Source: Pike Research)

Given the results depicted previously, it is no surprise that Asia Pacific will generate 50% of PEM revenue by 2020, with North America accounting for just over 30%.

Chart 3.8 PEM Stationary and Transport Revenue by Region, World Markets: 2020



(Source: Pike Research)

3.3 Pike Research Cost Reduction Model Forecast: 2011-2020

Under the scope of the project, our model was designed to examine the impact on the rate of diffusion of fuel cells of a 20% and 40% drop in the cost per kW of a fuel cell, as well as what could happen if the DOE $30/kW target were hit in 2012.

3.3.1 Overview

The results clearly show that the adoption of fuel cell technology in the applications covered in this model is critically dependent on a number of factors apart from the base cost of the fuel cell itself. This can be shown in the "back-of-the-envelope" equation below:

$$\frac{dy}{dx} = f(Ca, Cb, R, Z, F)$$

Where:

$\frac{dy}{dx}$ = Rate of diffusion of the fuel cell system

Ca = Initial system cost

Cb = Cost of the fuel savings

R = Resistance to change in the system [5]

Z = Time saved

F = Fear factor (e.g., fear of grid outage)

The assumption in the model is that Ca outweighed all the other factors. What has been shown though is that Cb is critical, and that, realistically, without a decline in the price of hydrogen and a concurrent increase in the price of petroleum, the rate of diffusion of fuel cells will not significantly increase across a number of applications.

That said, we have not attempted to gauge the factors R, Z, and F; for some businesses, and we suspect homes in the United States, F, will be a real tipping point.

Resistance to change (*R*) in any system is a real factor and should be not undervalued. For any new technology, and particularly for one that could potentially alter the prevailing paradigm, resistance to change has been shown to be high up to the first 30% of market penetration. This is one area where government policies can be usefully employed – to begin to force the altering of the status quo.

3.3.2 Transport

The two transport markets modeled in this report were light-duty vehicles (LDVs) and forklifts. Both of these are examples of applications with large growth potential and even larger revenue potential. However, when this is unpacked the reality is much more complex.

[5] The "I bought a Volvo last time and there was nothing wrong with it, so I will buy another Volvo this time" effect.

3.3.2.1 *Fuel Cell Light-Duty Vehicles*

For the automotive sector, the current vehicle cost, as opposed to price, is in the region of $150,000. This is down from well over a million dollars per vehicle just three years ago. The price to the consumer, at present, is only $600 per month, or $7,200 per year, which equates to the automotive industry as a loss per vehicle of some $142,800.

Table 3.1 Closing the Loss Gap for the Automotive Industry per FCV: 2010-2020

System Attributes	Units	2010	2016	2020
Projected annual release rate	(Vehicles)	167	112,508	390,346
Projected cost per vehicle	($)	$150,000	$50,000	$44,700
Projected loss per vehicle	($)	$142,800	$20,000	$14,700

(Source: Pike Research)

The Pike Research PowerDisc model shows that even with a reduction down to the $30/kW DOE target, the overall vehicle cost is still more than $122,000, or a savings of only $28,000 from today's prices. The point here is that the non-fuel-cell components need to come under the microscope so that other costs may be stripped out.

Table 3.2 Cost Reduction Model Results

Cost	Units	2011	2012	2014	2016	2018	2020
Vehicle FC Drivetrain Cost							
20% cost down	($)	$14,614	$14,614	$14,614	$12,914	$12,914	$12,914
40% cost down	($)	$12,489	$12,489	$12,489	$11,214	$11,214	$11,214
$30/kW	($)	$8,664	$,8664	$8,664	$8,154	$8,154	$8,154
Total Vehicle Cost							
20% cost down	($)	$110,772	$110,77	$110,772	$114,172	$114,172	$114,172
40% cost down	($)	$115,022	$115,02	$115,022	$117,572	$117,572	$117,572
$30/kW	($)	$122,672	$122,67	$122,672	$123,692	$123,692	$123,692

(Source: Pike Research)

As we know that the automotive industry is aiming for a per-vehicle cost of $50,000 by 2015, we can only assume there is another non-fuel-cell component that also exhibits the potential for strong cost reductions.

3.3.2.1.1. *Payback Period*

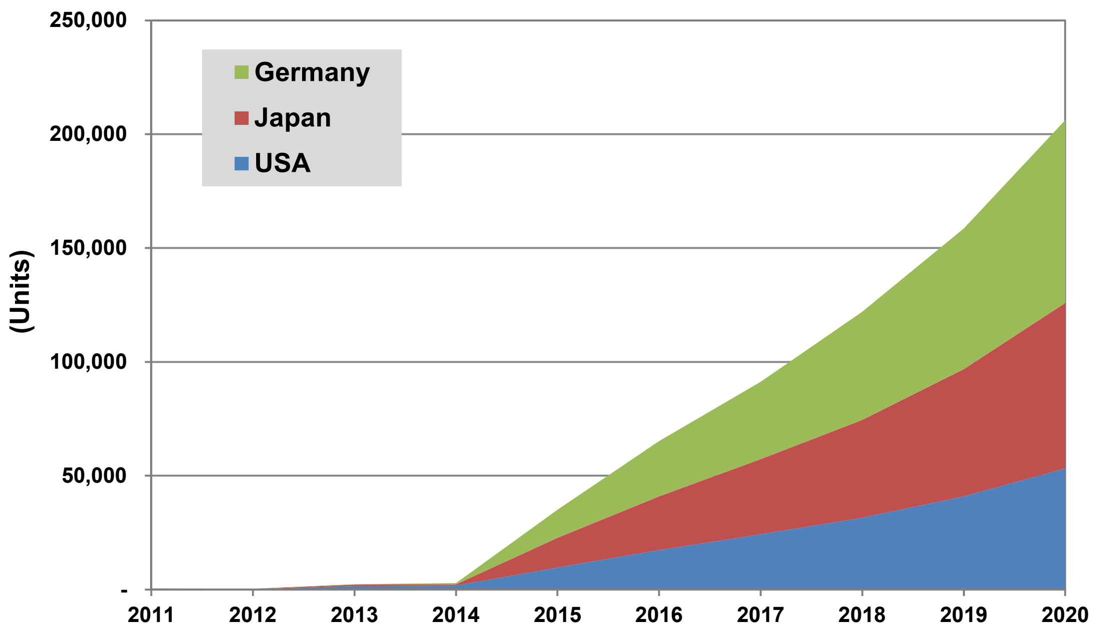
Using the basic payback period, the model shows that, given current hydrogen and gasoline prices, the payback period of an FCV ranges from 107 to 425 years – even at the $30kW DOE target cost. The implication of this is two-fold:

1. Even with a cost reduction that meets the DOE target level, the economics of fuel cell vehicle adoption will still need a lot of work. It is clear that the fuel cell system represents only one component cost of many that will need to come down, in addition to increases in gasoline prices. This includes the price of Hydrogen, which needs to come down dramatically. As hydrogen is a commodity without a spot price, it can be (and is) sold at prices set on a case-by-case basis by hydrogen suppliers. Although $10/kg is the accepted norm, we have heard of cases where the adopter has been charged double this amount. Clearly, this high hydrogen price has a detrimental impact on vehicle savings. This point will be returned to in Section 4.

2. The other impact of the potential cost reduction, as represented by PowerDisc's technology, is that it speeds the automotive industry along toward the point it can start to recoup some of its R&D investment costs. Although the technology itself does not drive the overall vehicle cost to a level where a per-vehicle profit can be made, it does represent the potential to reduce the cost of the fuel cell system to a level where this vehicle component can begin to recoup investment. In terms of go-to-market strategy, therefore, the automotive industry could well be interested in PowerDisc's technology as a means to speed up the recouping of losses.

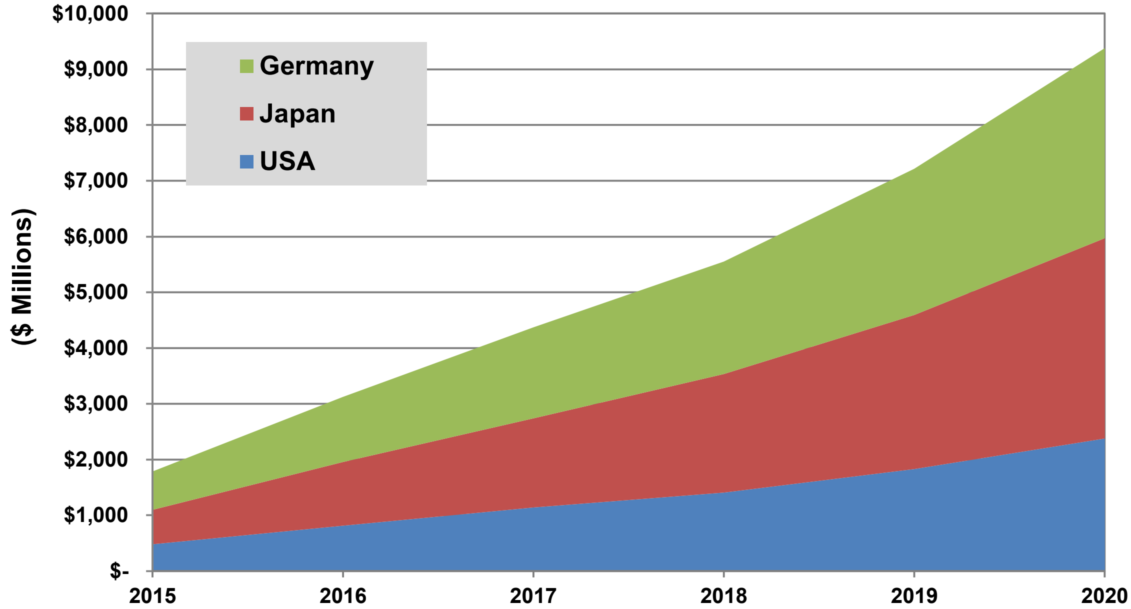
As the payback period of the LDV market was not reduced to under 5 years, the tipping point for increased diffusion, Charts 3.9 and 3.10 show the Pike Research BAU model results for Germany, Japan, and the United States.

Chart 3.9 LDV Adoption, Japan, United States, and Germany: 2010-2020



(Source: Pike Research)

Chart 3.10 Annual FCV Revenue, Japan, United States, and Germany: 2015-2020



(Source: Pike Research)

3.3.2.2 Forklifts

Some are promoting the forklift market as the poster child of early markets for fuel cell technology. In reality, this market is driven and supported by the United States, which to date accounts for more than 98% of all fuel cell forklifts adopted. FC forklifts are touted as reducing time normally lost to battery recharging and as increasing warehouse space by eliminating the need for a dedicated battery room. All told, the benefits of FC forklifts combine to result in a payback period of around 6 years. Yet, this only holds true for North America.

In Europe, where the cost of hydrogen is potentially higher than North America[6] and the change-out time for batteries is in the low minutes, a drop in CAPEX costs is required to offset the much lower savings. If the hydrogen cost issue could be addressed, a drop in CAPEX cost through the adoption of technology such as that being developed by PowerDisc could result in the opening up of the European FC forklift market. One final note, however, is that the size of this market is tiny: The United States is known to have just over 33,000 forklifts suitable for use with fuel cells and it is likely that the EU27 have a similar number. A market of this size cannot support the long-term development of more than a very small handful of companies.

3.3.3 Stationary

3.3.3.1 Residential Fuel Cells

Pike Research views residential fuel cells as the market wherein the PowerDisc model could see with the largest impact. At present, this market is concentrated in Japan and

[6] There is anecdotal evidence for this, but it should be noted that the hydrogen suppliers deny it.

Germany through dedicated programs of RD&D.

Brief Overview of Ene-Farm and Callux. (Excerpt from Stationary Fuel Cells: Fuel Cells for UPS, Residential, and Large Stationary Applications: Market Analysis and Forecasts)

Japan's Ene-Farm program is spearheaded by the New Energy and Industrial Technology Development Organization (NEDO), which is a part of Japan's Ministry of Economy, Trade and Industry (METI). The Ene-Farm program is a commercialization program aimed at achieving widespread initial adoption of PEM-based residential CHP modules in Japan. Nearly two years into the program, 6,000 units had shipped by FY 2009.

The Ene-Farm program includes a subsidy from the program itself. In addition, gas companies, which market and sell the units directly to customers, offer a second subsidy and discounted rates on natural gas for users who adopt the units. The program is expected to continue until 2015, at which point Japanese firms are expressing a cautious interest in beginning to market their resCHP units to overseas markets such as Korea, China, and Europe. However, the products' barriers to entry in the European and North American market are high and the ability to overcome these is questionable.

The German Callux program is a public/private partnership that was set up in 2008 under the auspices of the National Innovation Program (NIP). The aim of the program was to publicly speed up the commercialization of fuel cell-specific resCHP units in Germany and throughout Europe via a medium-term subsidy for specified R&D and demonstration published at the start of the project. By removing the financial risk of new product development, the program was meant to provide a more stable environment for small-to-medium-sized enterprises (SMEs).

In terms of successes, by the end of 2010, the program has seen the introduction and demonstration of approximately 110 fuel cell micro CHP (mCHP) units in German homes. It should be noted that this number is well below the targeted number of 190 units installed by the end of 2010. The two main suppliers active in the program are Baxi Innotech and Hexis.

The United States is increasingly looking to mCHP, though from a very baseline of interest, as a means to address the growing energy demand from homes. According to the IEA, the United States has 113.6 million homes that together consume 268 million barrels of oil equivalent per annum; in contrast, Germany has 40.2 million homes but only consumes 68 million of barrels of oil equivalent per annum.

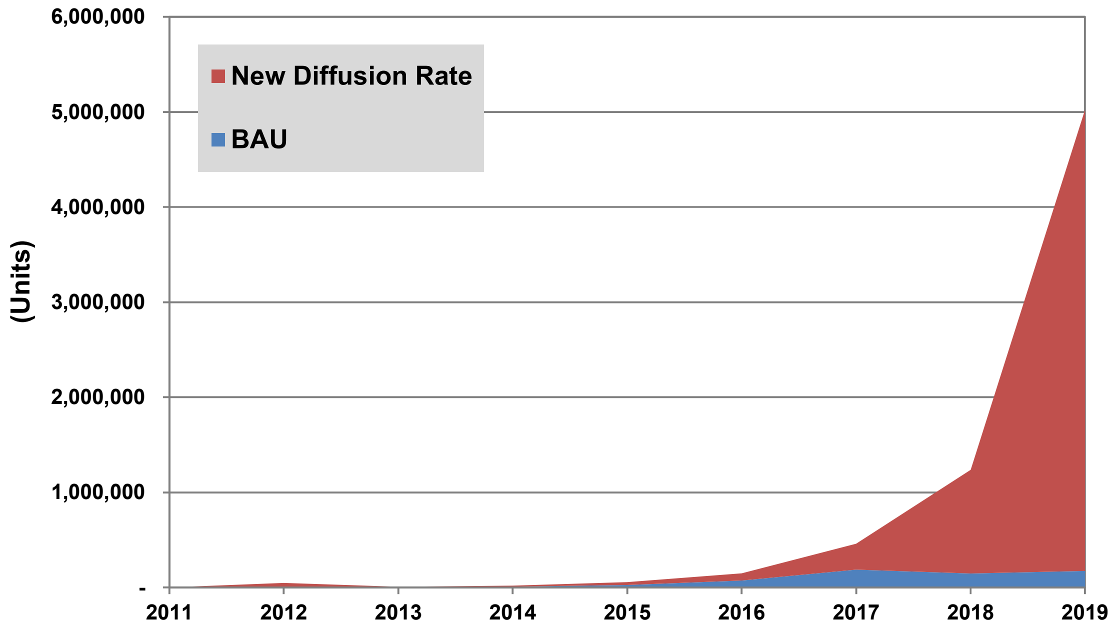
As the U.S. government and companies like ClearEdge Power and Trenergi begin to ship residential fuel cells for the home market, a clear calculation of the payback period in the U.S. is necessary. The current cost of a 5kW HT PEM residential or light commercial fuel cell is greater than $55,000 with the fuel cell system composing approximately 10% of this amount[7]. The model here shows that with a 40% reduction in cost for the fuel cell system, we should see payback periods of 5 years or less in the United States and Germany, given the current level of subsidies (e.g., SGIP in the United States and mikroKWK in Germany). Japan represents a special case as a 5kW system is oversized for the residential market.

The model results show that with the reduced payback period, the potential exists to open up the U.S. market and speed up diffusion in Germany to a small degree. This implies bypassing the Callux program, which may prove a sticking point. Using a model that

[7] Note that here that due to confidential information, some level of detail has been compromised.

projects a 15-year/50% market penetration for the United States and Germany, we could see the diffusion of residential fuel cells nearing the 5 million mark by 2019. This is up from just over 200,000 systems in total for Germany and the United States in Pike Research's BAU scenario.

Chart 3.11 BAU Forecast and New Forecast for Residential Fuel Cells, Japan, United States, and Germany: 2011-2019



(Source: Pike Research)

If we just look at the expanded market for the fuel cell systems here, we see a jump from just over $3.8 billion, in the BAU forecast, to $157 billion in the new model.

The systems in Japan that are under development are 800 W systems that, to date, have been developed using LT PEM technology. This is beginning to change as one company has switched over to HT PEMs. The payback period in Japan was prohibitive; however, given Japan's current economic conditions and a spike in the price of energy, this has changed somewhat.

An important point to note is that adoption in Japan is not based on the desire for power during rolling blackouts. Contrary to some very misleading press material, residential mCHP systems (as opposed to residential UPS systems) must be turned off during power outages. Residential UPS systems operate like any UPS system and kick in when the grid goes down. This is another development track that is focused on the U.S. market and might be of interest to PowerDisc further down the line.

3.3.3.2 UPS

The diffusion of fuel cells to power grid-tied base stations differs greatly from the much more limited diffusion of fuel cells to power off-grid base stations.

Grid-tied base stations use the national grid for baseload power and use a diesel generator for backup when the grid goes down. There is a keen interest in replacing these diesel gensets:

1. Security – Diesel has a secondhand value and is therefore a target for theft. It is also important for the military, as WAS seen during Hurricane Katrina. During the hurricane, cellular base stations stopped working when the military had to requisition diesel fuel from the base stations to power their vehicles. After Hurricane Katrina, it is was mandated that certain base stations would need to have backup power that was not based on diesel, or fuels that were of high tactical value to the military.
2. Carbon emissions – Base station emissions are known to be the "dirty secret" of the electron economy, with emissions in tons per year. Operators are keen not only to reduce energy costs but also to clean up their image and reduce emissions.

The issue with both of these drivers is a lack of monetary value. Increased security and emissions are externalities and are not taken into account within a straightforward payback calculation.

One area that was not included in the scope and has therefore only been given a quick run through in the model is the potential impact on the off-grid base station market. Here, diesel is much more expensive than within the grid-tied market, with some countries logging a 10-fold increase in price due to the remoteness of their stations. The model shows that diesel would only need to increase in price to $1/liter for the savings to result in a significant swing in interest toward fuel cells for off-grid base station applications.

This is a difficult market to model as the number of off-grid stations in the United States, Japan, and Germany is very low. In regions such as India, Russia, and Africa, however, the number is much higher; therefore, if there was an interest in the off-grid base station market, PowerDisc could need to look to developers who are targeting these regions.

3.3.3.3 Commercial

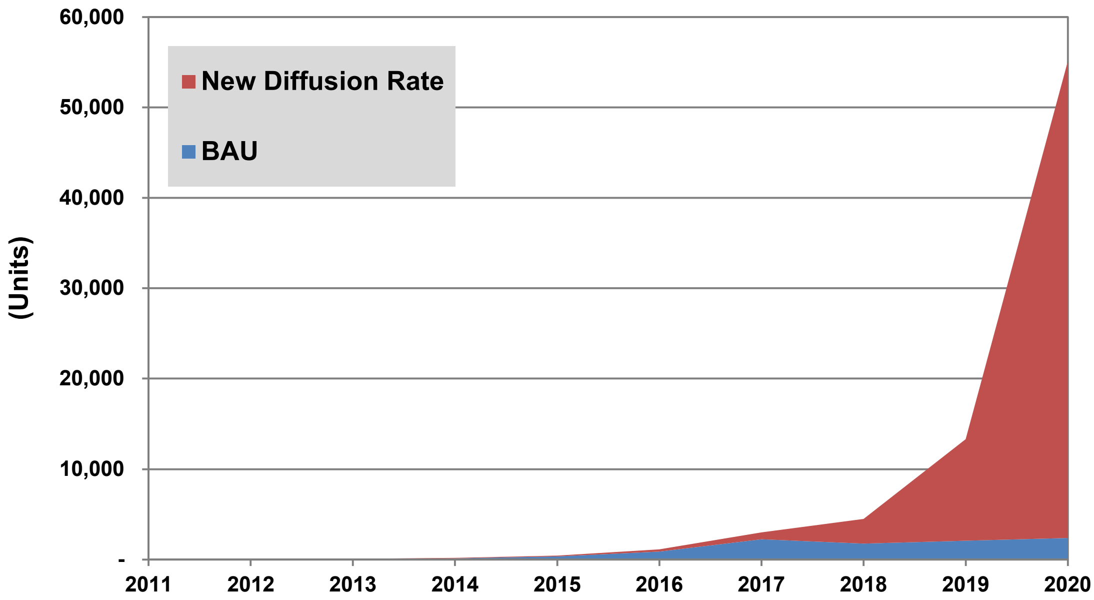
The commercial market is increasingly segregating into light commercial and large commercial applications. For PEM systems, this means 5kWe for light commercial (for example, a typical convenience store), and 1MWe + for large commercial (large office blocks, hospitals, hotels). As the light commercial market is only just beginning to take off, we have only seen shipments in the low hundreds per year – with majority being concentrated in the U.S. market. The market for larger-sized units is comparatively mature but dominated by Phosphoric Acid (PAFC) and Molten Carbonate Fuel Cell (MCFC) units. Now, Ballard and Hydrogenics both offer a product targeted at this market; however, only a handful of sales have been made.

Using the Ballard stack and system costs in the model, we see that by shaving 40% off the system costs alone, we could realize a payback period of fewer than 5 years. Yet, the problem with this market is not the payback but the commitment, and market development of these markets, by the companies for PEM systems. With capacity and sales of 1 or 2 systems a year this really does beg the question: Are the PEM companies really trying to develop this area?

As depicted in Chart 3.12, although payback is low and should generate interest from adopters, diffusion is still limited. To put this into context, the U.S. market alone has nearly 5 million commercial buildings[8], so a diffusion pattern of just over 50,000 in a decade is very low.

[8] Schools, offices, shopping malls, restaurants, etc.

Chart 3.12 BAU Forecast and New Forecast for Large Commercial Fuel Cells, Japan, United States, and Germany: 2011-2020



(Source: Pike Research)

Section 4

DISCUSSION OF RESULTS

4.1 Summary of Key Points

There are four key results from this project, summarized here.

4.1.1 The Importance of the HT PEM Market

It is clear from the model that the HT PEM market is top of the list in terms of impact from a potential fuel cell system cost reduction. The cost reduction could open the way to diffusion of residential fuel cells in the United States – a billion dollar market. With the increasing global attention that HT PEM is receiving for this application and for light commercial applications, positioning the company on the supply chain of HT PEM manufacturers now could be of high value.

4.1.2 The Value-Add to the Off-Grid UPS Market

As the off-grid UPS market is very limited within the United States, Germany, and Japan, the diffusion pattern cannot be altered significantly – even with a cost reduction. Outside of these countries, the model indicates that even with a diesel price as low as $1 per liter, the payback period is such that there would be interest.

The main markets for off-grid base stations are not as easy to target as the EU or North America as they are centered in Africa, India, and Russia. Routes to market would need to be carefully planned if this is an area of interest.

4.1.3 Automotive Interest

The automotive industry is likely to be interested in the technology that PowerDisc is offering if the cost offerings can be met. The model indicates that even though the payback period of the FCV is still ludicrously long, the cost reduction offers the automotive industry a quicker route to recouping investment costs on the fuel cell system.

4.1.4 Altering the Economics of Hydrogen

This is an area that needs to be looked at. The clear implication from the model is that the cost of hydrogen needs to be reduced from its current $10/kg in order to create a sufficient savings and a viable payback period for fuel cell systems. If PowerDisc can use its flowfield plates in electrolyzers, this could be of high value to the company.

4.2 Points for Further Study

Although the model has not provided the clear-cut results that were assumed at the start, it does provide some areas of further interest and research for PowerDisc's go-to-market strategies. Although outside the scope of this initial report, there are a number of areas of suggested investigation that fall out of this model, as outlined below.

4.2.1 Point 1

What is clear is the importance of the cost of hydrogen. At present, the base cost is around $10/kg; however, in smaller quantities this can skyrocket to $18/kg, or even higher in Europe. For reference, the DOE target is $2/kg to $3/kg by 2015.

If PowerDisc's technology can be employed in PEM electrolyzers, this would go a long way toward bringing down the cost of hydrogen. Not only would it help with the diffusion rate of fuel cells, by increasing the savings and reducing the length of the payback period, it would also open up the company to another growing market area: energy storage using hydrogen.

The suggestion here is that the company investigate the possibility of using its technology in electrolyzers. If it can be employed there, the energy storage and fuel cell industry could be explored from a similar perspective.

4.2.2 Point 2

Although this may seem blindingly obvious, the model makes it very clear that there are some short-term exit strategies for the company as well as the longer-term ones.

The suggestion here is that PowerDisc needs to decide on the value-add of developing its technology for a longer-term exit as opposed to a short-term (2-3 year) exit strategy.

4.2.3 Point 3

Some of the applications covered in this report are fundamentally limited by size. Although they could represent a good short-term revenue stream, their longer-term growth potential remains in question.

4.2.4 Point 4

One area of suggested further research for PowerDisc is the potential for its product to have a secondary benefit, impacting the cost of the BoP outside of the fuel cell system. If adoption of PowerDisc technology leads to a reduction in cost for the BoP, this could have a significant impact on the cost of the overall product.

4.2.5 Point 5

The model was limited to Germany, the United States, and Japan. For some applications, such as the off-grid UPS market, the potential of countries such as India and South Africa could be of interest to PowerDisc.

Section 5

ACRONYM AND ABBREVIATION LIST

Business as Usual	BAU
Balance of Plant	BoP
Combined Annual Growth Rate	CAGR
Capital Expenses	CAPEX
Department of Energy (U.S.)	DOE
The European Union of 27 Countries	EU27
High-Temperature Polymer Electrolyte Membrane	HT PEM
Kilowatt	kW
Light-Duty Vehicle	LDV
Low-Temperature Polymer Electrolyte Membrane	LT PEM
micro Combined Heat and Power	mCHP
Molten Carbonate Fuel Cell	MCFC
Ministry Economy, Trade and Industry (Japan)	METI
New Energy and Industrial Technology Development Organization (Japan)	NEDO
National Innovation Program (Germany)	NIP
Operating Expenses	OPEX
Phosphoric Acid Fuel Cell	PAFC
Polymer Electrolyte Membrane	PEM
Photovoltaics	PV
Self Generation Initiative Program (California)	SGIP
Small to Medium Sized Enterprises	SMEs
Solid Oxide Fuel Cell	SOFC
Uninterruptible Power Supply	UPS

Section 6

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SCOPE OF STUDY

The primary objective of the project to be conducted by Pike Research is to undertake an economic modeling exercise to determine the potential impact on rate of diffusion of PEM fuel cell systems if we assume the DOE 2015 cost target of $30/kW is met today.

SOURCES AND METHODOLOGY

Pike Research's industry analysts utilize a variety of research sources in preparing Research Reports. The key component of Pike Research's analysis is primary research gained from phone and in-person interviews with industry leaders including executives, engineers, and marketing professionals. Analysts are diligent in ensuring that they speak with representatives from every part of the value chain, including but not limited to technology companies, utilities and other service providers, industry associations, government agencies, and the investment community.

Additional analysis includes secondary research conducted by Pike Research's analysts and the firm's staff of research assistants. Where applicable, all secondary research sources are appropriately cited within this report.

These primary and secondary research sources, combined with the analyst's industry expertise, are synthesized into the qualitative and quantitative analysis presented in Pike Research's reports. Great care is taken in making sure that all analysis is well-supported by facts, but where the facts are unknown and assumptions must be made, analysts document their assumptions and are prepared to explain their methodology, both within the body of a report and in direct conversations with clients.

Pike Research is an independent market research firm whose goal is to present an objective, unbiased view of market opportunities within its coverage areas. The firm is not beholden to any special interests and is thus able to offer clear, actionable advice to help clients succeed in the industry, unfettered by technology hype, political agendas, or emotional factors that are inherent in cleantech markets.

NOTES

CAGR refers to compound average annual growth rate, using the formula:

CAGR = (End Year Value ÷ Start Year Value)$^{(1/steps)}$ – 1.

CAGRs presented in the tables are for the entire timeframe in the title. Where data for fewer years are given, the CAGR is for the range presented. Where relevant, CAGRs for shorter timeframes may be given as well.

Figures are based on the best estimates available at the time of calculation. Annual revenues, shipments, and sales are based on end-of-year figures unless otherwise noted. All values are expressed in year 2011 U.S. dollars unless otherwise noted. Percentages may not add up to 100 due to rounding.

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