FORESIGHTING REPORT

Non-Grid Connected Micro-Generation

A foresighting study to better understand the market and potential for non-grid micro-generation products sized 10 kW and below.

For Members only

28th February 2007

V1.0

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Non-Grid Connected Micro-Generation

FINAL REPORT

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1. Introduction

After analysing the grid connected microgeneration technologies and markets last year, ITI Energy wished to better understand the market and potential for non-grid micro-generation products sized 10 kW and below. ITI's interest is in individual market segments with potential for tens of thousands of units a year. The following report is the result of Delta's analysis of this market and does not necessarily reflect ITI Energy's points of view. ITI nevertheless believes that it will provide interesting reading for its members.

Delta addresses this issue in two parts. The first part, a screening study, identifies (potential) market sectors/applications, or at least as comprehensive a list as possible, and which of these have realistic potential for tens of thousands of systems a year. This includes recommendations as to whether each sector is examined in more detail.

Sectors covered are:

- APUs for trucks
- Military (tactical generators and APUs)
- Telecommunications
- Leisure (boats and caravans/motorhomes)
- Off-grid homes (rural electrification in developing economies and off-grid homes in developed economies)
- Remote monitoring
- Aircraft
- Temporary power
- Cathodic Protection

A table summarising the applicability of different technologies to each of these sectors is shown below.

Table 1: Micro-generation Technologies and Market Opportunities

Sector	Fuel cells	PV	Micro-wind	Stirling engine	Rankine cycle	Pico-turbine
Auxiliary Power Units for Trucks[1]	✓✓	✗	✗	✓	✓	✓
Telecoms[2]	✓✓	✓	✓	✓	(✓)	(✓)
Military[3]	✓	(✓)	✗	(✓)	(✓)	(✓)
Off-Grid Homes[4]	✓	✓✓	✓✓	✓	✓	✓
Leisure[5]	✓	✓✓	✓✓	✓	✓	✓
Low Power Prime Power[6]	(✓)	✓✓	✓✓	(✓)	(✓)	(✓)
Temporary Power[7]	✓	✗	✗	(✓)	(✓)	(✓)
Aircraft[8]	(✓)	✗	✗	✗	✗	✗
Cathodic Protection[9]	(✗)	(✓)	(✓)	✓	✓	(✗)
Forklift Trucks[10]	✓✓	✗	✗	(✗)	(✗)	(✗)
Railways[11]	✓	✓	(✓)	(✓)	(✓)	(✓)

Source: Delta Energy & Envrionment

Notes:

1. The higher electrical efficiency of fuel cells gives them advantages over other technologies. However the fuel flexibility of the other three technologies gives them an advantage over fuel cells, which require diesel to be reformed into hydrogen (or a hydrogen carbon monoxide mixture for solid oxide fuel cells). It could be possible to recover the heat from the other three technologies and use them as a combined parking heater/APU – however parking heaters are available at very low cost, so the value in displacing them is not so high.
2. Fuel cells, given their high electrical efficiency and – for this application – the ability to run of stored hydrogen (rather than having to reform natural gas) and low running hour requirements are well placed for backup power telecoms applications. Wind and PV are suitable for sites without grid access, although are resource dependent. The lower electrical efficiency of the other technologies reduces their potential as the fuel storage requirements increase. If Stirling engines can increase efficiency >20% then they may be well placed to compete with current diesel/gas engine technology.
3. Some PV applications for the military sector; low power generation efficiency of Stirling engines, Rankine cycle engines and pico-turbines limits their potential.
4. PV and micro-wind are highly applicable for off-grid homes as they do not require any fuel. They do, however, require good resources and battery banks. If fuels are used, all technologies offer the potential to compete with diesel generators, but meeting the full electrical needs of a home (and the need to minimise fuel transportation) places a premium on electrical efficiency (unless heat is continually required), giving fuel cells and advantage.
5. There are possible niches for all technologies in this diverse sector. PV and micro-wind are particularly suitable for certain marine applications; Stirling engines are securing a niche in this market, and so pico-turbines and Rankine cycle engines could also offer potential. Fuel cells are being sold to the recreational vehicle market, and there is some interest from the marine market.
6. This is a very diverse sector, but a general requirement to avoid fuel transportation opens up opportunities for micro-wind and PV. Where backup power is required there are opportunities for other technologies, although a premium on electrical efficiency points towards fuel cells ahead of other technologies.

7. A preference for electrical efficiency points towards fuel cells.
8. A requirement for high electrical efficiency (minimising fuel consumption) and high power density points towards fuel cells, although the stringent product requirements mean competing with gas turbines will be extremely challenging.
9. Maintenance requirements of fuel cells and pico-turbines will likely limit their potential for cathodic protection. PV and micro-wind are used for these applications, but suffer from intermittency.
10. Low electrical efficiency of Stirling engines, Rankine cycle engines and pico-turbines limits their potential for forklift truck applications. Fuel cells can, for these applications, run directly on hydrogen and avoid the requirement for an inverter.
11. Intermittency of micro-wind limits potential for railway applications; low power generation efficiency of Stirling engines, Rankine cycle engines and pico-turbines limits their potential for this sector.

Following review of this analysis with ITI Energy, three sectors were selected for further investigation in the second part of this work – *APUs for trucks*, *leisure (recreational vehicles and boats)* and *telecommunications* - in greater depth to better understand the potential for micro-generation technologies within these sector.

2. Sector Screening

2.1 Auxiliary Power Units for Trucks

Sector Requirement

Many trucks require power to run on-board electronics or air conditioning systems when parked.

How is the Need Currently Met?

Periodic idling of the main truck engine in order to charge batteries.

The Opportunity

Truck idling is an extremely inefficient way to meet power needs, with electricity generation efficiency of around 3%. As fuel prices have risen (particular in the U.S) this is leading to a greater focus on efforts to reduce idling. Secondly, idling engines causes additional wear and tear on truck engines. And finally, emissions from truck idling have come under increased scrutiny, with some U.S. States and countries banning idling of truck engines.

This has led to a market for internal combustion engine based APU systems. However these systems have not been widely accepted by the trucking industry. To Delta's knowledge, Volvo North America is the only company to be offering such systems with new trucks. There is a market for retrofitting these units, but this appears to be relatively small and fragmented.

This problem has led to a number of new technology developers focussing on this market, including MTT with their pico-turbine and a number of fuel cell developers including Webasto, Delphi, TMI/Ricardo and Cummins/SOFCo.

There are, however, competing solutions – primarily larger batteries.

Potential Market Scale

Some 650,000 trucks are delivered per year in Western Europe, North America, and Japan. These markets are likely to the major focus on idling reduction as they will have the greatest focus on reducing NOx emissions. However not all of these will be trucks that regularly travel long distances and therefore have a need for power when parked.

One organisation estimates that there are just 400,000 trucks in North America that have such a need (regularly requiring overnight stops away from base). If Europe and Japan are assumed to be equal in size in terms of the trucking market, but involve less long-distance transport requiring overnight stops, then the total market in North America, Europe and Japan is likely to be in the 600,000 to 700,000 range.

Truck manufacturer Scania does not currently incorporate APU systems in its vehicles but estimates that between 10% and 40% of new trucks it manufacturers may have a requirement for APU systems.

Conservatively taking market demand at 10% of new trucks would give a market size of some 65,000 APUs a year incorporated into new trucks. The retrofit market is likely to be to be good for another 10,000 units (assuming 2.5% penetration per year) or more.

Recommendation

We recommend this sector for further examination. Although there is not a large existing market and the size of a future market is uncertain, there is a clear need to be solved, a cost effective APU system that is efficient, reliable, clean, quiet and has low maintenance requirements.

2.2 Telecoms

Sector Requirement

There are two requirements for the telecoms sector:

- Prime power for off-grid sites
- Backup power for grid-connected sites.

The sites of interest for the <10 kWe market are primarily (but not exclusively) transmitter stations for mobile telephone applications (wireless applications). These typically have about 5 kWe power requirements (requiring DC power). The vast majority are grid-connected. Most of these require backup power for the grid outages. However sites that are deemed relatively low value by telecoms providers are not backed up.

Other applications include wireline applications. Many of these, for example switching stations, require more (typically much more) than 10 kWe. Some applications fall within the <10 kWe segment, but according to a report carried out by Battelle for the U.S. DoE, these applications typically require more than 50 kWe.

How is the Need Currently Met?

For the backup power market VRLAs (valve regulated lead acid) batteries are the default technology. While they have their limitations, these are known and understood by the telecoms industry.

For off-grid prime-power applications, a variety of solutions are used. These include LPG generators and renewable-based solutions such as small wind turbines or photovoltaics coupled with battery storage.

The Opportunity

Backup

The main limitations of batteries are their maintenance requirements and relatively short lifetimes. Lifetimes appear to typically be in the 4-7 year range. Maintenance is required periodically, and towards the end of their lifetimes the amount of energy stored in the battery decreases, resulting in less backup time available. Fuel cell developers currently targeting these applications include Plug Power, IdaTech, Ballard, ReliON and Acumentrics.

Prime power

If a site if off-grid, then it is likely to be remote. Providing fuel on a regular basis to such a site is costly, whereas systems based on renewable energy obviously do not require fuel.

Potential Market Scale

Backup

The market for backup power for the telecoms industry is large. For countries that have developed networks and that have already moved to 3G, the market is primarily a replacement market. For countries that have still to move from 2.5G to 3G, there is a "new build" market as additional transmitter stations will be required, since 3G requires about three times the density of transmitter stations compared to 2.5G. Finally countries with still expanding networks will clearly require new build.

There are approximately 25,000 mobile phone transmitter stations in the UK. Making assumptions on the numbers of transmitter stations per population, coverage and 2.5G or 3G networks gives a global total of some 700,000 stations. Assuming half of these are backed up, and a battery replacement time of five years gives a market of 70,000 units a year. This crude estimate is based on current mobile phone stations, and ignores both expanding networks and upgrades from 2.5G to 3G (or similar).

The only other global estimate available is one from Plug Power, which estimates there are about "500,000 outside plant backup power systems" for the telecoms and utility market.

Prime power

We have not been able to quantify these markets. Indicators on market size include:

"No more than 100 sites in the UK", according to one interviewee.

Wind turbine generators typically sell less than 100 units a year to this segment.

Taking an estimate of 100 sites per 50,000,000 population would, for North America, Europe and Eastern Asia (2.5 billion), give a market of 5,000 sites in these markets. Assuming a generator lifetime of 10 years gives a replacement rate of 500 units a year (ignoring new build).

However expanding mobile telephone networks in developing economies with poor electric grid coverage or unreliable grids may mean this is a more attractive market. A telecoms company in Nigeria, for example, is reported to be spending US$24 million to install renewables at grid-connected telecom sites.

Recommendation

Backup power markets are certainly worth of more consideration given the sheer scale of the market and the weakness of batteries.

Pursuing prime power applications is more questionable – without considering new build, the market is likely to be less than 10,000 units a year. And opportunities are likely to be limited to PV and wind. A plus for this market is expanding mobile telephone networks in developing economies.

2.3 Military

Sector Requirements

Whilst there are likely to be a number of niche applications within the whole military market, we focus upon the two key requirements of land based forces:

- Small tactical generators
- Vehicle APUs

Land forces need small tactical generators in the 5 – 10kW range to power increasingly sophisticated communications and reconnaissance equipment. These generators must be man-portable, quiet and reliable.

APUs with 5-10kW capacity are used in certain vehicle classes enabling electronics to be operated without use of the main engine – this allows the vehicle to operate with greater stealth and fuel efficiency. Other vehicles idle engines to recharge batteries as necessary.

How are the Needs Currently Met?

Diesel reciprocating engines are used to power tactical generators.

APUs are typically small reciprocating engines that are fuelled by the same source as the main engine.

The Opportunity

The majority of tactical generators used by the U.S. army date from the 1980's. These units are reaching the end of their operational lives and will have to be replaced. A tactical generator with greater efficiency would be of benefit to the military as less fuel would need to be transported. DRS Technologies offer a 1kW fuel cell tactical generator, marketed as having greater efficiency and a lower IR (infra-red) signature than a typical tactical generator.

Bulk transport of fuel reportedly accounts for 60% of logistic tonnage transported by the US Army. The army is keen to reduce this figure by improving vehicle efficiency. Installing APUs in more land vehicles would go some way to achieving this whilst providing the additional benefit of a lower IR signature. GM Motors have designed a truck that incorporates a 5kW fuel cell APU – they hope the U.S. Army will replace their current fleet of 30,000 general-purpose trucks with this model. Radian have developed a PEM fuel cell based APU specifically for use in military vehicles.

Potential Market Scale

Tactical Generators

A significant if not mass market for small tactical generators already exists. The U.S. army had around 40,000 tactical generators in the 2kW to 10kW range in 2003, but said they need an additional 10,000 units. Tactical generators are typically replaced after 20 years of operation. Based on the figures it can be assumed that a market for approximately 2,500 units per year or more exists in the U.S.

Assuming European forces have similar requirements and replacement rates to the US Army then this market can be scaled up. The combined US and European market is approximately 6,000 tactical generators per year.

Vehicle APUs

The U.S. Army has a fleet of some 246,000 vehicles – the majority of which do not have APUs.

Based upon a crude assumption that only 25% of the current fleet of U.S. Army vehicles are fitted with APUs this leaves 184,500 vehicles without APUs. Assuming that the US Army decides to fit APUs to all these over a 30 year period gives a market size of 6,150 units per year.

Based upon the same methodology and assumptions as used for tactical generators, the combined US and European market size is roughly estimated to be 13,000 units per year.

Recommendation

Both markets are recommended for further examination.

Tactical Generators

Although possibly not tens of thousands of units per year this market could be very profitable as military organisations will pay handsomely for products designed exactly for their needs. The potential also exists for lucrative lifetime servicing contracts – whereby the manufacturer will maintain and upgrade the product over its lifetime, which could be up to 30 years. The market exists today and is likely to increase in size as the tactical generation requirement of land forces increases.

Vehicle APUs

There is and existing market for new tanks and other military vehicles that require APUs. There is also potential for a sizeable market if the US Army and others decide to fit a greater number of vehicles with APUs.

2.4 Off-Grid Homes

This section is divided into rural electrification (in developing economies) and off-grid homes in developed economies.

2.4.1 Rural Electrification

Sector Requirement

Households that do not have access to grid-electricity of other forms of electricity generation.

How is the Need Currently Met?

Households without access to the grid or micro-generation meet their energy services needs in a variety of ways. These include:

- Candles for lighting
- Biomass or kerosene fuel for cooking
- Dry cell batteries for torches, radios etc.
- Car batteries, which are recharged in grid-connected towns or at charging points with generators

The Opportunity

Micro-generation can, and indeed is being used to supply households that do not have access to the grid with electricity. There are a number of programme supporting provision of electricity using decentralised energy. These typically focus on renewable technologies such as PV, small scale wind, micro-hydro and even biomass.

There is typically substantial grant funding behind such solutions, although in a few areas self-sustaining markets have developed (e.g. small wind in China, PV in Kenya). In 2003 some 70 MW of PV capacity was installed for rural electrification. Translating this into number of units is difficult – in some programmes modules as small as 20 W have been installed. If 50 W is assumed as the average size, this translates to over 1 million units a year.

In China well over one hundred thousand small wind turbines have been installed for rural electrification at a rate certainly over 10,000 units per year. In Sri Lanka alone NGO ITDG estimate the market for small wind turbines to be over 60,000 households in costal fishing villages.

While grid electricity continues to expand (in some cases at rapid rates), there will still be substantial numbers of off-grid homes seeking for non-grid electricity provision solutions due to both the sheer scale of off-grid households and population growth.

Efforts by governments, development banks and others to support such solutions have, according to the leading wind turbine manufacturer active in this market, reduced in scale in recent years. Governments have tended to focus on grid-extension, while donor organisations such as the World Bank have not been as active in this area as they were 10-15 years ago. Without funding to subsidise product costs, the market shrinks dramatically as it is highly dependent on such funding.

Potential Market Scale

Some 1.6 billion people, just over one quarter of the world population do not have access to electricity. About 50% of these are in South Asia, 14% in East Asia and 32% in Africa. By 2030 the IEA estimates that electrification rates will 96% or above in all regions except for South Asia (66%) and sub-Saharan Africa (51%).

Whilst grid access grows there will remain, therefore, a very large number of households without access to electricity for tens of years to come. These households will generally be in rural areas and have extremely low income.

Recommendation

The scale of the market (existing and future) is certainly of interest. However development of new technology is likely to be based around incremental improvements in renewable, non-fuel dependent technology already used to provide solutions to off-grid homes (such as PV and wind) and is highly dependent upon funding programmes.

We suggest this sector is not a top priority for ITI Energy.

2.4.2 Off-Grid Homes in Developed Economies

Sector Requirement

Home are off-grid in developed countries because it is cheaper to install and operate generating equipment than to connect to the grid system – a new connection typically costs between US$10,000 and US$30,000 per mile. Off-grid homes range from rustic log cabins to large top-end homes.

How is the Need Currently Met?

Solutions include reciprocating engines (likely to be mainly diesel or propane fuelled) and renewable technologies such as PV and small wind turbines coupled with battery storage.

The Opportunity

Internal combustion engines used for prime power require regular servicing to remain reliable, as well as requiring fuel delivery – which in some cases could be problematic.

Photovoltaics already has established a firm foothold in this market. Some 30 MW a year is sold into the U.S. residential off-grid market (up from 5 MW in 1993). Assuming an average system size of 2 kW peak gives a market of 15,000 systems a year.

Wind, according to one of the U.S' leading wind turbine manufacturers, falls a long way behind this in the U.S, however their main competitor says they have sold 50,000 units to remote homes and cabins around the world, a market perhaps around 5,000 units a year.

Potential Market Scale

There are a reported 200,000 or so off-grid homes in the U.S. (the American Wind Energy Association estimates 150,000 of these are suitable for small scale wind turbines). A rural electricity co-operative we spoke with believe that this number would likely increase if a cheap and reliable source of off-grid power were to become available. The other major concentration of off-grid homes appears to be the Scandinavian market, with a reported 300,000 off-grid holiday homes. The total market size is estimated to be in the 700,000 to 800,00 region. Assuming generating equipment is replaced every 10 years gives a replacement market of some 70,000 to 80,000 homes a year.

A secondary market consists of remote communities in Canada who rely on diesel generators; however these are much larger than 10 kW.

Recommendation

This market could be investigated further to yield a better understanding of current market trends, but should not be a priority.

2.5 Leisure

Sector Requirement

The leisure market, as defined here, is made up of two main sectors:

- Caravans and motor homes
- Yachts and other small marine leisure craft

Electrical appliances and lighting used in these craft/vehicles are typically supplied using a battery powered 12 V DC supply. It is commonplace in the US and Europe for owners to hook up to a mains supply when staying over night at a caravan park or marina to power onboard equipment and recharge batteries. Otherwise, batteries are recharged when the boat/ motor home/car engine is running.

How is the Need Currently Met?

Wind turbines and, to a lesser degree PV systems are relatively commonplace in a segment of the marine market – described by the leading manufacturer of small wind turbines as "blue water" cruisers in the 10m to 20m range that regularly overnight away from marinas.

Wind and solar chargers do have a presence in the U.S. and European caravan and motor home markets but to a lesser extent, as more nights are typically spent at locations with a grid connection, the main engine is used more and installation can be difficult – particularly in the case of wind chargers.

The needs of the caravan and motor home market in Australia (a very small market) are quite different. The majority of owners appear to spend many nights at locations without grid access so there is a much greater need for battery charging; as such, the majority of owners reportedly have some form of equipment to do this.

The Opportunity

Power requirements of leisure vehicles are increasing rapidly as owners demand higher levels of home comfort. And an increasing number of yachts have an increasing number of electrical appliances such as televisions and even dishwashers.

PV and wind turbines cannot always reliably meet the demands placed upon them whilst small reciprocating engines are relatively noisy and require regular maintenance and adequate ventilation.

Several companies are making efforts to develop products for these markets. German company SMART fuel cell is developing a 50 W APU for use in caravans. The caravan manufacturer Hymer announced that it intended to integrate the APU into its high-end model.

U.S. caravan manufacturer Airstream said that they were interested in fuel cell APUs and that they would consider them for inclusion in future models – probably sold as an optional extra.

Fuel Cell developer MAX POWER is developing a 50 W fuel cell product for marine battery charging.

Potential Market Scale

The leisure vehicle market is huge – there are over 1,000,000 motor homes and caravans in the UK alone. There are over 20 million marine leisure craft in three largest international markets.

Caravans and Motor Homes

The market for caravan and motor homes in Europe and the U.S. is theoretically very large; over 30,000 are sold annually in the UK, 22,000 in Germany and 231,200 in North America. However, the majority of owners will continue to use grid hook ups. Part of this market does appear to demand an off-grid solution – which at this stage, is difficult to quantify.

The Australian market, although much smaller, is much more promising as there is a clear need for an alternative solution to those available at present. There are approximately 400,000 caravans and motor homes in Australia of which around 70% have some form of auxiliary generating capacity usually in the form of PV panels or a small reciprocating engine. It is difficult to quantify the number of sales per year, however this is likely to be in the 10,000 to 20,000 units per year range.

Yachts and other marine leisure craft

The theoretical market for "blue water" cruisers is large, but according to the leading manufacturer of wind turbines relatively static – they sell between 50 and 500 units a month to this market. Assuming a 25% market share gives a market of around 10,000 systems a year. A conversation with a manufacturer of marine electronics suggested that if a suitable product became available sales of tens of thousands of units per year could easily be achieved.

Recommendation

ITI Energy should look further at the caravan and motor home APU market. The advantage of this market is that there are a relatively small number of large manufacturers and using wind turbines is difficult. The disadvantage is that much of the market generally has access to grid power.

The need to look further at the marine leisure APU market is more questionable. The pluses of this market is the relative affluence of boat owners and their need for a battery charging solution. The disadvantage is that PV, and in particular wind appear to provide acceptable solutions to much of the market.

2.6 Low Power Prime Power

Sector Requirements

This is a broad and diverse sector and includes applications such as remote monitoring of water quality; power for traffic signs; and power for parking meters. Such applications typically require just tens or hundreds of watts to charge batteries. Another (very niche) sector is street/security lighting.

How is the Need Currently Met?

For water companies, lead acid batteries powered by renewable power, typically PV, appears to be the most popular solution (at least in the UK).

Parking meters and traffic signs can either be grid connected or incorporate PV systems to trickle charge batteries.

Street/security lighting is almost always powered by the grid, but in Japan there is a niche for PV/wind systems charging batteries for such lighting applications.

The Opportunity

Where the grid is not easily accessible the main limitation of renewable/battery systems is the short lifetime of the battery. Scottish Water replace batteries at their remote monitoring sights every 1 or 2 years. This short battery lifetime is due to both a harsh operating environment (temperature extremes) and the unreliable nature of renewable power generation leading to irregular battery discharge patterns.

There are, therefore, opportunities for technology that can either extend battery lifetime, or alternatively a fuel-powered solution (such as fuel cells) that has very low maintenance requirements.

Potential Market Scale

There are at least 500 off-grid remote monitoring sites maintained by water authorities in the UK. The global size of this market can be crudely estimated using GDP statistics and the assumption that number of remote monitoring stations in a country is proportion to those in the UK. As UK GDP is 3% of the global total, the 500 off-grid remote monitoring sites in the UK can be taken as 3% of the global total, giving an estimated global market of over 15,000 sites. Assuming an average replace rate of once every 1-2 years gives a annual market of 7,500 to 15,000 units.

There are a reported 130,000 PV powered parking meters globally. As this market is probably growing quite rapidly, the annual market may be as high as 15,000 to 30,000 units a year.

We have a number of calls in to companies supply PV systems for traffic sign applications but have not yet had the required conversations to better understand the potential size of this market.

Recommendation

Whilst the market size for this whole sector is certainly above 10,000 units, the low power outputs mean it is a low value market. Better technology that extends battery life will be well received by this market, but fuel-powered solutions may struggle to penetrate the market due to fuel delivery/storage issues.

2.7 Temporary Power

Sector

This is a large and varied sector, three important applications are:

- Construction work – a suitable grid connection is often unavailable on building sites and in homes that have yet to be grid connected.
- Temporary lighting – often temporary floodlights must be erected in locations without suitable grid access.
- Temporary road signs – mobile illuminated diversion signs are typically positioned far from a suitable grid connection.

Sector Requirement

The general requirement is a source of cheap, reliable, readily available power delivered from an easily transportable unit. As well as the major sectors, certain niche markets place additional constraints upon product suitability, for example, film crews require especially quiet generators.

How is the Need Currently Met?

This sector is dominated by diesel and petrol powered generators manufactured by a handful of companies, namely – Honda, Kawasaki, Briggs & Stratton, Kohler Co and Tecumseh Products. Units are typically purchased from the manufacturer by rental companies, who hire out the products to end users, as they are required.

The Opportunity

Diesel and petrol generators are a very mature technology, they can be purchased cheaply, are reliable, relatively cheap to run and can be easily transported. It is also relatively straightforward to attenuate noise produced by diesel and petrol generators for applications that require low operating noise levels. Fuelling the unit is left to the end user; therefore efficiency is not a prime consideration of leasing companies when making purchasing decisions.

Given these conditions, it is difficult to see how an emerging energy technology would be able to gain a foothold in this market.

Potential Market Scale

This market is very large; Honda sells, according to our estimates, around 10,000 general-purpose electric generators in the 1-10kW range every year in Japan alone. Assuming a 25% market share for Honda and scaling up using GDP figures would give a global market of 750,000 units a year.

Of the sub-sectors, the mobile lighting unit market is estimated at 5,000 to 10,000 mobile lighting units in the UK. Scaling up by GDP gives a total market of between 165,000 and 330,000 units. If a 5 year lifetime is assumed (generators have a lifetime

typically around 5,000 hours), this gives an annual global replacement market of some 30,000 to 60,000 units a year.

Recommendation

This would be a very difficult market to penetrate due to the dominance of low cost petrol and diesel generators, which adequately meet the needs of the sector, and calcified market channels. It is not recommended that ITI Energy investigate this sector in more depth.

2.8 Aircraft

Sector Requirement

Aircraft use auxiliary power units (APUs) to provide on-ground power when the main aircraft engines are not in use. There are also needs for electrical power when the aircraft is airborne.

How is the Need Currently Met?

For commercial-scale planes, APUs range from ~100 kW to 550 kW and possibly more.

Aircraft typically have three other sources of electrical power. According to Airbus, these are:

- Main engines (1,000 kW)
- RAM air turbine (25 kW) – this is from the main engines, and is used for emergency hydraulic and electrical power
- Batteries (3 kW)

The Opportunity

Gas turbine APU systems are relatively inefficient (about 15-20% electrical efficiency) and produce NOx emissions. This presents an opportunity for new technology. According to NASA APUs currently account for 50% of maintenance delays.

Boeing is working on a 440 kW solid oxide fuel cell APU system.

Airbus/EADS has a different approach, first looking to develop a 25 kW fuel cell system to replace the RAM air turbine. They plan to initially test fuel cells in the 10 kW size range.

Potential Market Scale

In the last few years Boeing has delivered ~290 commercial aircraft a year. Airbus delivered some 378 aircraft in 2005. This gives, say, around 1,000 aircraft a year in the commercial/freight sector.

Recommendation

This sector is not recommended for further examination.

There may be opportunities in the short term for products sized at ~10 kW or below, but the longer term opportunity is for larger products.

The market volume is relatively low compared to other sectors, although the market value may be attractive.

There are major challenges to penetrating this sector, in particular reaching the power/mass ratios required for this market.

2.9 Cathodic Protection

Sector Requirement

Pipelines (for example those used for oil and gas) require cathodic protection. This is used to inhibit corrosion in metal structures. There are two cathodic protection solutions: attachment of "sacrificial anodes" such as a magnesium, used in buried structures, re-enforced concrete, ship hulls etc..; and "impressed current", whereby an external power source impresses a dc current onto pipelines.

How is the Need Currently Met?

Where grid power is available, this is used to power cathodic protection. For low power (hundreds of watts) requirements, PV, wind or thermo-electric generators are used. When a few kilowatts of power are required, natural gas (from the pipeline) powered organic Rankine cycle engines are used.

The Opportunity

Existing technology appears to provide adequate solutions. The organic Rankine cycle engines appear to have long lifetime and low maintenance requirements. Renewable based solutions and thermoelectric generators appear to be acceptable solutions for low power requirements. And in many cases grid power is available.

Potential Market Scale

This is a small market. Ormat, a manufacture of small organic Rankine cycle engines, typically sells just tens or several tens of units a year, or possibly over 100 units in a good year (when there is significant new pipeline construction). They say they dominate the market in the 1 kW to 5 kW range for remote locations.

Even taking into account smaller capacity systems (thermoelectric generators, PV and wind systems), the market is unlikely to be more than 1,000 units a year at best.

Recommendation

We do not recommend further examination of this market due to the small scale.

2.10 Forklift Trucks

Sector Requirement

Forklift trucks require electric or mechanical power.

How is the Need Currently Met?

Forklift trucks are typically powered by internal combustion engines (diesel or LPG fuelled) or electric batteries (recharged at charging stations).

The Opportunity

Concern over emissions, particularly when forklift trucks are used indoors, has seen increased growth of electric-powered trucks. However the drawback of electric-powered trucks is that these have to be returned to charging stations for significant periods of time where their batteries are recharged. These batteries also have limited lifetimes.

A number of fuel cell developers are targeting this market.

Potential Market Scale

About 25,000 trucks are sold each year in the UK, which has an installed base of around 350,000 trucks. This encompasses a large variety of truck sizes. Approximately one half of these are powered by internal combustion engines, and half are electric powered.

Using a GDP scaler gives a global market of around 800,000 trucks a year, or more conservatively at least a few hundred thousand trucks a year. The proportion of electric trucks worldwide may be lower than the UK, but the potential market is certainly tens of thousands of units a year.

Recommendation

This market should be further examined, primarily in relation to opportunities for fuel cells.

2.11 Railways

Sector Requirement

Railway operators' backup power suppliers to telecoms, signalling and other critical equipment. In some cases, where grid supply is not available, micro-generation is used for prime-power.

How is the Need Currently Met?

Lead acid batteries are understood to be typically used for backup power suppliers. Both PV and internal combustion engines are known to supply prime-power sites.

The Opportunity

Lead acid batteries have to be replaced at regular intervals. Prime power solutions using internal combustion engines require regular fuel supplies.

Potential Market Scale

There approximately 2,000 sites backed up by lead acid batteries in the UK. The global size of this market can be crudely estimated using GDP statistics and the assumption that number of remote monitoring stations in a country is directly related to its GDP. This gives a global estimate of 65,000 sites. Assuming 2-4 year replacement cycles gives an annual market of 16,000 to 32,000 units.

Recommendation

This is a mature, stable market that places an emphasis on reliability. As such, and due to the risk-adverse nature of the rail industry, it should not be a top priority for ITI Energy.

3. Detailed Sector Analysis

3.1 Auxiliary Power Units for Trucks

3.1.1 Current State-of-the-Art Technology

Trucks require power when parked. This is typically provided by the truck battery which can cope with low levels of power requirement for several hours. However they cannot provide high levels of power for several hours – for example when the truck cabin needs to be cooled when the truck is parked.

Internal combustion engine (ICE) diesel fuelled auxiliary power units are sold (as after market sales), primarily in the U.S. These small diesel engines – typically about 5 kWe in size – operate independently of the main truck engine. They are typically sold by relatively small companies which package diesel engines from established manufacturers such as Kubota and Cummins.

3.1.2 Need for Next Generation Technology

Diesel fuelled ICE APUs have not been widely accepted by the trucking industry. In the words of a major North American truck manufacturer, they are "stinky, loud, heavy, and cost too much" and "require maintenance outside of the 'normal' service interval of the vehicle". This manufacturer also cites the lack of a widespread servicing network as a hindrance to this technology.

Although a (relatively small) market for ICE APUs exists, and there appears to be a strong market demand for APUs (at least in North America), truck manufacturers do not appear to be interested in integrating such a product into their trucks, and are focusing their efforts on alternative technologies. As an example of ICE APU limitations, one of the leading vendors of these systems recommends oil and filter changes every 150 hours, and boasts that their APU is so quiet that "some drivers even admit they can hear the truck next door over the sound of the Pony Pack [APU]". In California tighter emissions legislation will shortly require expensive exhaust clean up for ICE APUs.

Several alternatives do exist to truck idling or APUs.

- One is based on de-humidifying air. These relatively low cost solutions use the truck battery to power a fan and evaporation of water to de-humidify truck cabin air. This is reportedly used in parts of southern Europe and in the U.S.

- Another solution has been developed for the North American market involving a chilled thermal store which is "charged" when the truck is being driven, and a simple fan then circulates this chilled air into the cab when the truck is parked.

- Some companies offer systems based on larger/additional batteries – basically extending the ability of batteries to provide electric power to the cab.

- An increasing number of truck stops in North America are being electrified. These either provide "shore power" to trucks (basically an electrical connection), and/or have hoses that provide warm or chilled air into the truck cab.

Note that the first three options are still limited in the period of time for which they can cool trucks, and for the first two do not provide any electrical power for the truck.

In terms of market requirements for APUs, again quoting from a major North American truck manufacturer, new technology needs to be:

> "low cost (both acquisition, plus installation cost... both affect payback), fuel efficient, quiet, and light weight. They need to be able to provide power (heating, cooling, and 120V [alternating current] at least 10 hours per day, every day, with occasional extended periods (30~40 hours) of use during extended down-time. They must be reliable and easily serviced at multiple locations."

Fuel cells are the focus of most of the new technology developments for APU applications. This is because they offer the potential to meet the requirements articulated above. In many cases this fuel cell activity in the form of fuel cell developer push. However examples of truck manufacturer engagement include:

- Volvo and their joint venture with Statoil – Powercell
- Daimler Chrysler-owned U.S. truck manufacturer Freightliner has demonstrated fuel cell APUs in the past
- International Truck and Engine Corporation is working with Cummins and SOFCo to develop fuel cell APU systems.

Stirling engine developers have only talked in general terms about, rather than targeted, the truck APU market, although one Stirling engine developer is discussing concrete opportunities with a truck manufacturer. Another pico-turbine / Rankine cycle developer is in initial discussions with a truck manufacturer about APU opportunities. Stirling engines, pico-turbines and Rankine cycle engine have the potential to meet a number of the truck manufacturer's product criteria, although both will struggle compared to both ICEs and fuel cells in terms of efficiency, and Stirling engines may struggle to demonstrate significantly better weight characteristics than ICEs.

3.1.3 The Market for APUs: Delta's View

Truck idling has been banned across much of Europe for many years. While one European truck manufacturer told us they believed that some truck drivers do idle their engines when parked, in general they see very little market pull for APUs in Europe. Most truck drivers appear to accept the limitations of truck batteries when parked (although note some use of evaporative de-humidification technologies in southern Europe as detailed below). We have not seen evidence of any market demand in the Asian markets, where there is likely (outside of Japan) to be much less focus on truck driver comfort and emissions from truck idling.

The situation in North America is very different. While APUs have been available since the 1980s, according to Cummins, "serious market interest is a recent phenomenon", with this being driven by two issues: dramatic increases in fuel prices, and increased interest at state and national level in reducing truck idling (in order to reduce NOx emissions).

APUs based on new technology (fuel cells, Stirling engines or pico-turbines) are, if they do find a home in the truck APU market, sure to first find a home in the North America. If product requirements (as detailed above) can be met, it seems certain that truck manufacturers will offer such APUs.

There is clear market pull, with truck manufacturers actively developing products. For new technology, it is unlikely that APUs will be available to customers within 3 years, and possibly not even within 5 years. After that time, assuming product requirements can be met, a healthy market is likely to develop.

As well as the market demand for APUs, another driver is the possible move to electrically driven air conditioning systems in trucks. Currently trucks use air conditioning systems with the compressor mechanically driven by the engine. APUs installed today power a separate, electrically driven air conditioning system. This is typically installed in the roof space of the truck cab. According to two truck manufacturers, trucks in the future may well utilise such electrically driven compressors, and hybrid (diesel-battery) trucks may also be developed. It therefore appears likely that trucks will become increasingly "electrified" in the future, and this bodes well for APUs. Although incorporations of larger batteries in trucks – as part of diesel-battery hybrids – could limit the potential for APUs as larger capacity batteries will be used in trucks, these larger capacity batteries will still have limitations – particularly in powering air conditioning systems in truck cabs.

In the long term (20 years) we would expect to see APUs to be relatively commonplace in trucks. In the medium term, (5 to 10 years), assuming that products with the required characteristics are developed, we expect to see APUs gaining a toehold in part of the U.S. market.

There are, however, some showstoppers for truck APU systems that may cloud the relatively rosy picture painted above. If, in the long term, fuel cells are used in trucks as the main source of propulsion, this would eliminate the opportunity for APU systems.

Another possible show-stopper for APUs is rapidly reducing levels of emissions from the main truck diesel engine. Volvo NA told us that in California there are moves to re-consider the ban on truck idling in the near future if diesel engine emissions continue to be lowered. While idling would still negatively impact on engine maintenance requirements, engine lifetime and fuel consumption, such a move would remove one of the most important drivers for the truck APU market.

3.1.4 Market Size and Available Market Segment

North America offers by far the most significant opportunity in the short and medium term when compared to Europe. This is because truckers reportedly "live" in their trucks to a much greater degree than in Europe and they have been used to – and in many cases still are – idling their engines to provide power to the truck when parked. ICE APUs are currently sold as after-market sales in North America – typically by small organisations whose sales are unlikely to number more than the hundreds of units a year.

One organisation estimates that there are 400,000 trucks in North America that have such a need (regularly requiring overnight stops away from base), the EPA estimates there are 300,000 "sleeper cabs" in North America, Cummins estimate that 500,000 trucks could have a need for APUs.

In Europe some 650,000 trucks are delivered each year. Identifying the proportion of these that could have requirements for APUs (those that regularly "overnight" away from their base) is difficult. One European truck manufacturer estimates the proportion at 10% to 30%, which sounds high. Delta's research strongly suggests that the market pull in Europe is much lower than in North America.

3.1.5 Barriers to Entry

It is clear that major North American truck manufacturers are interested in including APUs in their trucks, but not those based on diesel engine APUs. This route to market is likely to be the only one that can offer significant market volumes. The after-sales market is too fragmented and cannot offer the required maintenance and servicing networks. Therefore the ability to engage with truck manufacturers is a critical barrier to entry. This is likely to be relatively high in Europe, but low in North America, where truck manufacturers are actively looking for APU solutions.

Other barriers to entry are those that would be expected for any new product – demonstrating the required performance, price, robustness, maintenance requirements etc. Of these, a competitive price is likely to be one of the hardest to achieve.

3.1.6 R & D Timescales to Displace Existing State-of-the-Art Technology

From the delivery of a pre-commercial prototype, products are unlikely to be offered on the market by truck manufacturers within three years, although one manufacturer indicated that, at a push, a product could be brought to market in two years. Trucks are a relatively harsh environment for new technology, especially in the form of vibrations. A pre-commercial prototype needs to be validated, industrialised, field tested, and integrated into the truck design. This timescale is likely to be 3-5 years, according to one fuel cell APU developer.

3.1.7 SWOT Analysis

The SWOT analysis below is primarily constructed for fuel cell APUs. Where strengths and weaknesses do not apply to fuel cells but apply to Stirling engines or pico-turbines (and vice versa), this is noted.

Strengths	**Weaknesses**
♦ Ability to power air conditioning systems and on board electronics for prolonged periods of time – compared to the limitations of non-APU technologies (batteries, thermal cold stores, and de-humidification technologies). ♦ High electrical efficiency (not so for pico-turbines or Stirling engines) when compared to ICEs. ♦ Quiet ♦ Compact (high power density) – although not for Stirling engines. ♦ Relatively light (not Stirling engines, not clear for fuel cells). ♦ (Potentially) low maintenance requirements.	♦ If maintenance is required, a servicing requirement with these capabilities will need to be developed (Stirling engines and pico-turbines may have very low maintenance requirements). ♦ As truck air conditioning systems are currently mechanically driven, APUs require the installation of a dedicated truck air conditioning system. ♦ For fuel cells, a diesel reformer must be developed. This may involve water management issues depending on the type of reforming employed. ♦ The truck industry is fairly focused on economic benefits of APUs, and reportedly looks for paybacks of two years or below. Truck driver comfort is the weakest driver (compared to increased engine lifetime and reduced fuel costs). These factors lead to aggressive cos targets.
Opportunities	**Threats**
♦ More stringent emissions legislations outlaws truck engine idling across more of North America and in Asia (truck engine idling is already banned in much of Europe). ♦ Development of electrically driven air-conditioning and hybrid diesel-battery vehicle drives gives	♦ Reduced emissions from truck engines means that drives to outlaw truck idling slow down, or are even reversed. ♦ Lower oil prices and lower fuel costs reduce the economic rationale for using APUs. ♦ Development of battery

stronger rationale to develop truck APUs. ♦ Increasing use of on-board electric appliances – in particular demand for air-conditioning - increases the market demand for truck APUs.	technology reduces market size for APUs with batteries better serving power requirements for short periods of time. ♦ Increasing numbers of electrified truck stops reduce need for APUs. ♦ Evaporative cooling technologies and chilled thermal stores prove popular solutions with truck drivers, reducing the need for APUs. ♦ In the long term, battery-ICE hybrids mean that increased battery capacity reduces the requirement for APUs. ♦ In the long term, fuel cell driven trucks eliminate the requirement for truck APUs.

3.2 The Leisure Market: Recreational Vehicles

3.2.1 Current State-of-the-Art Technology

The electricity requirements of recreational vehicles (RVs) is almost universally served by a 12V direct current supply powered by lead acid batteries. Specially designed consumer electronic equipment is available to integrate with this supply and inverters are also available to convert to a mains voltage AC supply if required.

The vast majority of caravan owner stay overnight at caravan sites which are equipped with electric hook-ups that allow caravan owners to run equipment from a mains supply and to recharge batteries. Batteries are also charged by the alternator of the main engine (for motor homes). According to conversations with the industry, in the U.S. an estimated 10% of motor home owners regularly park away from mains electric supplies, and this number is growing. In Australia the number is much higher, up to 70%. In Europe the figure is likely to be less than 10%.

A number of products are available to allow batteries to be recharged without using a vehicle engine or a mains hook-up. They fall into three categories:

- Photo-voltaic (PV) chargers
- Micro-wind turbine chargers
- Petrol/diesel generators. A major U.S. motorhome/caravan manufacturer told Delta that it is becoming increasingly common for their customers to use (Honda) generators to provide sufficient power in "off-grid" sites.

3.2.2 Need for Next Generation Technology

Generators, PV, micro-wind generators and battery banks are used by parts of this segment, but each have their limitations:

- PV and micro-wind chargers provide power only intermittently, but with sufficient battery storage are suitable for low power requirements.
- Petrol and diesel generators are available for use in caravans and motor homes. Diesel generators are noisy, have high emissions and require regular maintenance and adequate ventilation. However relatively quiet generators are available. Honda has developed a range of very quiet, clean LPG and petrol powered 'suitcase' generators marketed to caravan owners (amongst other applications) starting at 700W in size. These units are advertised as having a noise level of 57 dB at 7m. However caravan owners are likely to be very sensitive to noise: given that a residential street at night typically has a background noise of 40dB, many caravan owners will consider diesel engine

generators to be too loud. As such generators are only typically only available as retrofit products, it is unlikely they will benefit from additional noise insulation.

- Battery banks are heavy, take up space, require maintenance and do not cope well with deep discharges.

None of these factors, are, however, showstopper for current technology. The industry does not appear desperate for new technology, but growing power requirements of motor homes and caravans (due to increased use of air conditioning, wide screen TVs, dishwashers and other electrical appliances) and sensitivity to noise are likely to open up opportunities for new clean, low noise, reliable power generation technology.

3.2.3 The Market for New Technology: Delta's View

Fuel cells are already being integrated into German RV manufacturer Hymer's top of the range model: the Hymer Hypermobil S – Class (motor home). This comes as standard with Smart Fuel Cell's SCF A50 (50 W) product. Hymer is also selling the fuel cell product as an optional extra on other models. Discussions with Smart Fuel cell, who are specifically targeting this market, revealed that they have already sold at least 2,000 products to the RV market – the majority of which were to RV owners (i.e. the after-sales market).

Smart Fuel Cells told Delta they are working with half a dozen other caravan and motor home manufacturers and believe that the market for their product is very large, "greatly in excess of 10,000 units per year". They believe that their product will become a standard piece of caravan and motor home equipment.

Smart Fuel Cells appear to have captured the imagination of at least Hymer, and possibly a number of other RV manufacturers. Whilst the product does appear to have limitations (the fuel used by Smart Fuel Cells is not currently widely available and the fuel cell only produces 50 W of power) the concept appears to be generating considerable interest amongst both manufacturers and users. It appears likely that, if the product performs successfully (and Hymer's incorporation of the unit in their top-of-the-range model suggests that it does), increasing numbers of manufacturers will incorporate fuel cells in their products. This in turn is likely to lead to increased penetration in the after-sales market.

Although small internal combustion engines can adequately provide power to RV owners, reduced noise levels are a strong driver in this sector.

Within ten years it is feasible that most manufacturers will be including fuel cells (or possibly other technologies such as Stirling engines) in their products. Initially this will be in their top-of-the-range models and, if successful, this is may be cascaded down to other models. There is also likely to be a strong after-sales market.

3.2.4 Market Size and Available Market Segment

122,000 caravans and 78,000 motor homes were sold into the European market in 2004-5. 231,000 RVs were sold in the North American market in 2005, giving a global total likely to comprise close to 500,000 units.

U.S. manufacturer Airstream estimates that 10% of their customers regularly travel to sites without electric hook-ups, and this number is increasing as motor home owners increasingly take their vehicles to sports events, rock concerts and other similar events.

Applying this 10% proportion globally gives an available market segment of some 50,000 units a year. However it is likely that the ability to provide off-grid power will appeal also to users who commonly use electric hook-ups, but value the ability to have power away from these sites. This is likely the rationale of Hymer and their integration of a fuel cell system. The available market segment may therefore be closer to 100,000 units a year range. This is just for integration into new RVs – any retrofit market would be in addition to this.

3.2.5 Barriers to Entry

There are two distinct markets for fuel cell manufacturers: RV manufacturers, and the after-sales market. The barriers to entry to the manufacturers market appear to be relatively low. There are relatively few major manufacturers, and a proportion of them are likely to be innovators in terms of including new features in their products.

There are likely to be more barriers to entry in the after-sales market, primarily in the form of establishing large numbers of dealerships and authorised sales agents. Smart Fuel Cells has already started developing such an infrastructure, particularly in Germany.

Another significant issue is fuel availability. If a dedicated fuel is required (this is the case for Smart Fuel Cells) fuel supply becomes an issue.

3.2.6 R & D Timescales to Displace Existing State-of-the-Art Technology

The timescale to displace existing technology appears to be relatively short. Smart Fuel Cells received CE certification for their 25 W fuel cell in 2003, and by July 2005 Hymer was incorporating the 50 W fuel cell. Airstream has indicated to Delta that it would test a product for some 30 to 60 days, with a 12 month design cycle for incorporating it in their product.

3.2.7 SWOT Analysis

This SWOT analysis has primarily been developed for fuel cells, but would equally apply to other liquid fuelled technologies such as Stirling engines. For PV and micro-wind there is no significant requirement for new technology (other than lower prices), so these technologies are not included.

Strengths	**Weaknesses**
♦ Low noise ♦ Low maintenance requirements (in principle) ♦ Low emissions and no odour (as found in diesel or petrol engines).	♦ May require fuels that are not currently widely available (not an issue for Stirling engines). ♦ Need to establish confidence with RV manufacturers. ♦ Limited maintenance and repair infrastructure (currently).
Opportunities	**Threats**
♦ Growing power demands in RV ♦ RV owners reportedly more frequently taking their vehicles away from electric hook-ups ♦ Interest from RV manufacturers in incorporating fuel cells in their top-of-the-range models ♦ Relatively small number of RV manufacturers means relatively straightforward route to market.	♦ Problems with performance lead to loss of confidence in fuel cell technology ♦ RV manufacturers could integrate LPG generators into their products to meet demand – if such generators can be sufficiently acoustically insulated. ♦ Significant improvements in battery performance ♦ Dramatic fall in PV prices.

3.3 The Leisure Market: Boats

3.3.1 Current State-of-the-Art Technology

The electricity requirements of boats depend upon the size of the craft, ranging from 12 and 24V direct current (DC) supplies powered by lead acid batteries to full 3-phase AC supplies powered by a dedicated generator. However, most craft in the leisure market will be fitted with reasonably humble power electronics similar to that of an RV.

The typical setup for an average yacht uses lead acid batteries to supply specially designed 12V or 24V DC equipment. An inverter can be used to generate mains quality AC voltage if required. Batteries will be recharged by an alternator that is part of the yacht's engine and by an electric hook-up when the yacht is moored at shore.

A proportion of boats spend significant time away from shore; many boats used for day-sailing are moored offshore when not in use and so will not be able to use a grid connected hook up point. Blue water cruisers are yachts that spend many days away from shore and so will have no access to an electric hook-up. A proportion of these boats have a source of power in addition to the main boat engine's alternator.

One industry source estimates that, for blue-water cruisers, 10-15% of the market uses PV or micro-wind systems, 20% use (diesel fuelled) internal combustion engine (ICE) generators, with the balance relying on alternators from the main boat engine.

Hanse, a major boat builder, incorporates small diesel engines (~2 kW) for power generation (not propulsion) into around 50% of its boats. They do not see any limitations or drawbacks of such engines, and no requirement for new technology or products.

3.3.2 Need for Next Generation Technology

The limitations of these technologies (PV, micro-wind and ICE generators) are very similar to those described for caravans and motor homes. Essentially PV and micro-wind do not provide reliable power, and ICE generators are noisy, have high emissions and require regular maintenance. However this last issue is unlikely to be a major issue for boat owners who also have to maintain the main boat engine. Noise may be an important issue for some boat owners; however ICE generators can be insulated to reduce noise levels to acceptable levels, and the relatively high background noise around boats means this is less of an issue than for RVs.

Day sailors typically do not have very highly specified boats or additional power requirements for consumer electronics. This particular market is well served by existing technology.

Bluewater cruisers are typically highly specified craft with advanced marine electronics. This particular market would benefit from a more reliable source of power. Boats are

increasingly being fitted with air conditioning systems, dishwashers, washing machines and wide-screen TVs. This is driving an increasing market for ICE generators.

Stirling engine developer Whisper Tech has targeted the marine market for several years. Indeed the name Whisper Tech arose from the quiet operation of their product compared to conventional diesel generators.

3.3.3 The Market for New Technology: Delta's View

The boating industry is typically conservative when examining new technology. Whilst ICE generators do have their limitations, the technical competence of boat owners means their high maintenance requirements are less important than in other sectors. The primary advantage of fuel cells or Stirling engines therefore appears to be noise – however a major boat manufacturer does not believe that the noise of a well insulated ICE is an issue for the vast majority of boat owners.

Reliability is an important concern in this market – introducing a new largely unproven technology could therefore be challenging.

Whisper Tech has demonstrated a small market for their products amongst top end cruisers. It is likely that new technology will find a home amongst innovators in top end cruisers, and perhaps amongst innovative boat manufacturers, although this last market channel has yet to be demonstrated.

Delta believes that small, niche markets may develop within the marine leisure market for fuel cell/Stirling engine APUs, but the relatively weak drivers and familiarity with ICEs makes such developments questionable. In any case the size of the market is likely to be substantially lower than the RV market.

3.3.4 Market Size and Available Market Segment

There are not much more than a dozen manufacturers of cruisers, with most of these based in Europe. These companies manufacture in the region of 8,000 to 10,000 boats a year. No more than a third of these are likely to be blue water cruisers – that is boats that regularly spend time away from their port. For the new build market, the available market segment is therefore only likely to be in the 3,000 or so range.

The number of cruisers on the market is estimated to be in the 150,000 to 200,000 range. Again, no more than one third are likely to be blue water cruisers, giving a potential after-sales market of some 50,000 units in total. Delta understands – from the leading supplier of wind turbines to the marine market – that this market is likely to be relatively stable.

3.3.5 Barriers to Entry

The issues are broadly similar to the barriers for the motor home and caravan markets, although reliability is a greater concern for this market than noise issues.

Fuel availability for fuel cells is likely to be a more significant issue, as cruisers need to be able to purchase fuel in a wide variety of locations around the world.

3.3.6 R & D Timescales to Displace Existing State-of-the-Art Technology

Boat manufacturers are likely to be relatively conservative when it comes to evaluating new technology given the high premium on reliability in the marine industry.

New unproven equipment is tested rigorously for up to 6 months. Testing is especially rigorous if the new equipment has a direct effect upon safety.

So from first discussing a new generator concept to incorporating it into their boats is likely to take a minimum of 2 years, and more likely 3 years or more.

3.3.7 SWOT Analysis

This SWOT analysis has primarily been developed for fuel cells, but would equally apply to other liquid fuelled technologies such as Stirling engines. For PV and micro-wind there is no significant requirement for new technology (other than lower prices), so these technologies are not included.

Strengths	**Weaknesses**
♦ Lower noise compared to running engine and ICE based generators ♦ Low maintenance requirements (in principle) although this less of an issue as boat owners who often enjoy maintaining engines! ♦ Low or no emissions. ♦ No diesel or petrol smell from fuel or vapour	♦ Noise from ICE based generators is deemed to be acceptable by most boat owners. ♦ Some products may require fuels that are not currently widely available. ♦ Maintenance and repairs infrastructure will initially be weak for new technology.
Opportunities	**Threats**
♦ Growing power demands in boats	♦ Problems with performance lead to loss of confidence in fuel cell and other new technology. ♦ Fall in cost of PV systems. ♦ Improved battery technology

3.4 Telecoms

3.4.1 Current State-of-the-Art Technology

Most mobile phone transmitter sites in Europe and North America use valve regulated lead-acid batteries to provide backup power in the event of grid outages. Some sites will not be backed up (if they are classified a "low revenue" site). Others will have battery backup but will rely on a diesel or LPG-fuelled generator as their prime source of power if a grid-connection is not available. And in some cases, solar or wind is used to charge batteries as a backup, or even as a prime source of power (together with a larger capacity of battery storage) in some cases.

In South Africa, a weaker electric grid – particularly in rural areas – leads to more battery storage requirements, or in many cases a higher proportion of diesel or LPG generators used during grid outages. In some cases these generators are even transported to the cell sites in the event of extended grid outages. (South Africa is included in this analysis as it is one of the early adopters of fuel cells for back up power telecom applicaitons).

The situation in the rest of Africa and Asia (excluding Japan, which is likely to have similar characteristics to Europe where the grid is very reliable) is less clear to Delta. Certainly the grid is less reliable than in Europe across much of these regions. Some cell sites are unlikely to have any backup. Others are likely to rely on either batteries or diesel or LPG generators.

4.4.2 Need for Next Generation Technology

Batteries are a well understood technology that can, in many cases, meet the requirements of telecom operators. But they do have a number of limitations. First, they are limited in their ability to store power, and limited in how long a period of time they can provide power. Secondly, exposure to extreme temperatures rapidly decreases their lifetime/storage ability. And thirdly, repeated discharges shorten their lifetime.

Where exposure to high temperatures is limited (perhaps due to intelligent sitting of the batteries) and the grid is reliable (with battery discharges therefore low), batteries can last for several years. However in some cases, for example rural areas of South Africa and North America where the grid is "weak", lifetime can be as little as a few years or less. In parts of South Africa, for example, lifetimes are as low as one year.

The opportunity and need for next generation technology for backup power is therefore particularly strong where the grid is relatively weak and where climatic extremes lead to poor battery performance. For prime power requirements, the opportunity for next generation technologies relates to where there are environmental

concerns (noise or emissions) for operation of diesel or LPG generators and to the high maintenance requirements of these technologies.

Note that micro-generation technology development targeted at this sector is, as far as Delta is aware, exclusively focussed on fuel cells. This is, almost completely, fuel cell developer "push" rather than market "pull". The opportunity to run directly on hydrogen (rather than reforming fossil fuels) is one of the primary reasons that fuel cell developers are drawn to this sector (as well as seeing opportunities in the market due to limitations of batteries). Another advantage is that inverters aren't needed to convert direct current to alternating current output. In principle, there is no reason why Stirling engines, pico-turbines or even Rankine cycle technology could not provide backup power solutions in the same manner in which fuel cells are starting to do. Their primary disadvantage compared to fuel cells would be lower electrical efficiency, and therefore higher fuel storage requirements to provide the same time period of backup power. Some of them also used induction generators to generate alternating current. There is only one company in this second group of technologies that is considering targeting this sector.

4.4.3 The Market for New Technology For Backup and Prime Power: Delta's View

Several telecoms companies in Europe, North America and South Africa are involved in testing or investigating fuel cell solutions for backup power applications. A number are also interested in prime power applications.

We expect fuel cells to gain a foothold in this market (providing they demonstrate acceptable performance, which so far they seem to be doing), and their market penetration to be evolutionary rather than revolutionary. They are, and will continue to be, first installed in the most "battery hostile" environments where frequent grid outages occur. In the U.S, one telecoms operator refers to these as "remote" sites. In South Africa telecom operators have sites in rural areas where battery lifetimes are as low as one year due to regular deep discharging as a result of grid outages.

Fuel cell developers and their distributors will have to develop servicing infrastructures that maintain fuel cells in order to go beyond tens of demonstration projects. Another key challenge is establishing (or utilising) a hydrogen delivery infrastructure.

How quickly they penetrate beyond these battery-hostile sites depends upon how quickly fuel cell developers can bring down their costs. Telecom operators will make decisions – in most cases – on a purely economic basis, comparing the cost of backup power (and potential lost revenue if no backup power is available) between batteries and other solutions. Trends in telecom company focus on either opex or capex will also influence decisions between batteries and fuel cells (fuel cells are likely to offer higher capex and potentially lower opex costs).

Within the next five years we expect some telecom operators in Europe, South Africa and the U.S. to be installing several tens of fuel cell backup power systems a year at their remote/battery hostile sites. One North American telecoms company is a little more bullish, expecting that in 5 to 10 years fuel cells will be providing a "significant

proportion of our backup power needs". Within ten years, it is therefore certainly possible that fuel cells will have gained acceptance within the telecoms industry as an alternative to batteries, if their performance, cost and infrastructure issues are successfully addressed, and will be being used at most of their remote – battery hostile - sites.

Progress in the Asian market is much more difficult to ascertain. Lower grid-reliability does suggest a stronger rationale for fuel cells in these markets. However we expect fuel cell developers to first establish their products in western markets, before then targeting Asian markets. If they are successful in establishing their backup power products in western markets, the opportunities in Asian markets could be extremely large given the generally higher levels of grid unreliability which expose the weakness of batteries.

4.4.4 Market Size and Available Market Segment

The total number of mobile phone transmitter stations is likely to number in the 0.5 million to 1.5 million range worldwide, and is likely to continue to increase as networks continue to be rolled out in developing countries and more networks move from 2G to 3G technology (which requires a higher density of transmitter stations). Somewhere in the region of 10 to 20 percent of this total (50,000 to 300,000) are likely to require new battery backup each year.

The number of remote sites with grid connection, but in areas with weak grids is extremely difficult to estimate (it depends on the definition of "weak"). In South Africa, the number of sites with frequent outages is reported to number in the hundreds. In the U.S. one telecom operator estimates the number in the thousands. In Europe, it is likely to be in the several hundreds range. These are the prime (but by no means the only) candidate sites for fuel cells as they penetrate the market.

Remote, off-grid sites are another obvious target market, if fuel cells can demonstrate the required lifetimes for continuous power generation. Whilst diesel and LPG ICE generators are well understood, in some cases noise is a concern. It can be hard to attenuate the low frequency noise from typical ICE generators used at these sites, and where the site is close to buildings, this can cause annoyance. In other cases, frequent maintenance requirements push up opex costs. These sites likely number a few thousand in each of North America and in Europe.

3.4.5 Barriers to Entry

Fuel cell product developers are partnering with providers of power solutions to the telecoms industry, such as Tyco in the U.S, CEA in Canada, and IST in South Africa. Successfully developing such partnerships is critical to then penetrating the telecoms sector as these companies provide a proven channel to market.

The critical barrier to entry is the conservative nature of telecom operators. In the words of one UK operator, "we're not here to innovate". These companies understand

batteries and diesel and LPG generators, together with their limitations. Moving to a totally different technical solution is not an easy step for these companies to take.

Despite this, operators in countries including South Africa, the UK, Scandinavia, Germany and the U.S have installed fuel cells as backup power solutions – so far mainly as demonstration projects. In many cases government or World Bank funding has been critical to such installations going ahead, with the telecom industry often reluctant to pay the full (in some cases premium) cost of installing products with which they are unfamiliar.

One UK service provider to the telecoms industry expressed frustration with fuel cell companies trying to charge full price for products when "they should be trying like mad to establish confidence [from telecom companies] in their product". A critical barrier to entry is therefore managing to sufficiently engage with telecoms providers to get enough fuel cell products installed for the telecoms industry to gain confidence in them.

It does appear that, particularly in the U.S through Verizon and Tyco, some fuel cell companies are starting to succeed in these efforts. We believe that this is the key to gaining industry acceptance.

3.4.6 R & D Timescales to Displace Existing State-of-the-Art Technology

"We'd want to look at it [fuel cells] for a year or two – in winter and summer conditions – to see how it copes", a UK telecoms company told us. They would also want to have confidence in maintenance costs.

Plug Power first started testing their products with Verizon in July 2003, and is currently still in what are effectively field trials with Verizon over three years later. So from first engagement to roll out of hundreds of fuel cell products is likely to take in the region of three to four years in Delta's view. This process is well underway in some markets (particularly North America), but less so in other markets (such as the UK).

3.4..7 SWOT Analysis

This analysis has primarily been developed for fuel cell micro-generation, as the virtually all efforts to develop micro-generation solutions for the telecoms markets are based on fuel cell technology.

Strengths	**Weaknesses**
♦ Extended back up time – typically 8 to 10 hours or more (depending on the quantity of hydrogen stored at the site) compared to 2 to 4 hours	♦ Need to store hydrogen at the site (as hydrogen is often wrongly perceived as an extremely dangerous fuel to store this can be problematic) and periodically re-

for batteries ♦ Reduced maintenance time compared to batteries (although some telecoms operators do not carry out any maintenance for batteries) ♦ Lower claimed lifetime costs than batteries (although this depends on the reliability of grid supply and the load on the batteries), although it is possible that fuel cell companies are pricing systems according to the market rather than their costs (i.e. loss leaders to establish market presence). ♦ Lower weight than batteries. ♦ Quieter and possibly more reliable than diesel and LPG generators.	supply hydrogen. ♦ Higher capital cost than batteries ♦ Long term fuel cell performance is not yet widely demonstrated.
Opportunities ♦ Increasing competition between telecoms companies' results in increasing pressures to reduce down time of transmitter sties. ♦ If telecoms companies focus increasingly on opex rather than capex once networks have been fully built out, and fuel cells demonstrate lower lifetime costs than batteries, this will present opportunities. ♦ Expanding overall market size.	**Threats** ♦ Initial fuel cell installations do not perform as successfully as hoped, and the telecoms industry "turns away" from fuel cell technology. ♦ Telecoms companies are reluctant to embrace a new technology.