Fuel Cells and Hydrogen in Finland 2012
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Summary

This report, the first in a series of five on the Nordic countries, looks at the energy context in Finland and examines where fuel cells might fit within this. It then describes the current fuel cell research, development and demonstration activities in the country and the commercial products that could arise from this.

Like the other Nordic countries, Finland is at a relatively advanced stage in the development of renewable energy sources to meet a sizeable portion of its energy needs, for reasons of both energy security and action on climate change. Its particular strength is in the use of wood-based biomass, and the country has maximised the value of this domestic resource by using it in highly efficient combined heat and power generation. The emergence of biomass gasification, a technology receiving much attention in Finland, is of significance for fuel cells as it opens the way for efficient use of renewable wood-based material as a source of fuel.

Technology industry is of great importance to Finland, which has developed strong export markets in a number of areas, notably energy technology. The Finnish government has identified continued innovation in clean technology as necessary for both a healthy economic and environmental future for the country and government spending on energy R&D has been growing rapidly since 2006.

Tekes, the Finnish Funding Agency for Technology and Innovation, coordinates much of the fuel cell and hydrogen RD&D in Finland under the Fuel Cell Programme, which runs from 2007 to 2013. In this it is supported particularly by VTT, the Technical Research Centre of Finland, and the Fuel Cell Finland Industry Group, which has a number of corporate members who serve both the domestic Finnish and international markets. The Programme will culminate in a major, cross-discipline demonstration at a port facility, Helsinki’s new Vuosaari Harbour. ‘Demo2013’ will run for six months and international fuel cell and hydrogen development partners are invited to participate.

The specific fuel cell and hydrogen developments discussed in this report are:

- the targeting by industrial gas supplier Woikoski of existing hydrogen infrastructure and industrial surplus for use in fuel cell vehicles, plus the company’s diversification into hydrogen refuelling stations;
- the delivery of a hydrogen refuelling station to the Arctic Driving Center where fuel cell vehicle testing by major automotive OEMs is underway;
- the opportunity for a megawatt-scale fuel cell power plant running on by-product hydrogen from sodium chlorate production;
- the investment in SOFC systems by Wärtsilä to expand its existing power plant product portfolio into the sub-megawatt range, with systems tested so far on landfill gas and in ship auxiliary power using methanol;
- the development of hybrid electric drivetrains for non-road mobile machinery, such as Cargotec’s cargo- and load-handling equipment, with the use of fuel cells as the final goal;
- the development of an electric snowmobile which will also incorporate a fuel cell, primarily for use in clean and quiet snow safaris in Lapland;
- the unique innovation of a bio-fuel cell as a thin, flexible power source manufactured using printing techniques for a growing global market in disposable electronics.
1. Introduction

Fuel cell developments in Finland, interesting in their own right, have wider significance. Like the other Nordic countries, Finland is at a relatively advanced stage in the development of renewable energy sources to meet a sizeable portion of its energy needs. Fuel cells as an energy technology will not be applied in isolation but will form part of an integrated sustainable energy solution, and therefore it makes sense to look to countries such as Finland to see how fuel cells could interconnect with other clean energy and energy efficient technologies.

Over a fifth of Finland’s total primary energy consumption is met by bioenergy, one of the highest proportions among the OECD member countries. It has the highest share of biomass in electricity generation in the world and much of this biomass is used in highly efficient combined heat and power generation (CHP). Finland is a world leader in CHP, and has been generating a third of its electricity and most of its district and industrial heat in this way for decades.

This report describes the energy context in Finland, with particular attention to bioenergy and CHP, and examines the potential for fuel cells to fit within this. It then reviews the latest developments in Finnish fuel cell research and development, and the on-going demonstration and commercialisation activities in the country.

2. Energy Supply and Demand in Finland

2.1 Energy Challenges and Policy

One of the motivations behind Finland’s long-term interest in bioenergy is the security of its energy supply. Currently, almost half of Finland’s energy consumption is reliant on fossil fuels (Figure 1); the country lacks domestic fossil fuel resources and is dependent on imported gas, oil and coal, mainly from Russia. It is also a net importer of electricity, again primarily from Russia. Improving energy security is thus an important issue in Finland and is being addressed on a number of fronts.

The situation is not helped by the fact that, in European terms, Finland’s per capita consumption of energy is relatively high: almost double the European Union (EU-27) average and approaching the consumption levels of the USA and Canada. This is due to the combined effect of the cold climate and low light levels, the low population density, and the high level of energy-intensive industry (industry accounted for 47% of...
electricity consumption in 2010\(^2\), Figure 2). As a result, despite the high proportion of renewable energy in Finland, its carbon dioxide emissions from fuel combustion per capita are the highest of the five Nordic countries and among the highest in the EU\(^4\).

Finland intends to remedy these issues. It is a signatory to EU Directive 2009/28/EC on renewable energy, which sets a target for the EU of an average of 20% of its energy consumption to be met from renewable sources by 2020; Finland’s target for 2020 is 38%\(^5\). The Finnish government has also set an objective for energy consumption in 2020 of 310 TWh, more than 10% below the baseline scenario\(^6\).

There is political commitment behind this and government spending on energy R&D has accelerated since 2006\(^7\) (Figure 3). The intention is to ensure an adequate and flexible supply of moderately priced energy from domestic sources, which also supports climate policy. The strategy is two-fold: efforts focus on improving energy efficiency and developing renewable energy resources.

Much of the government’s energy R&D budget (around €220 million in 2011) is dedicated to improving energy efficiency in buildings and industry. Finland’s spending here is high in absolute terms: a comparison of spending by the IEA member countries from 2005 to 2010 places it fourth on this metric, behind only the US, Japan and Italy\(^8\) – all much more populous countries.

It has achieved some decoupling of economic growth from energy consumption and both energy intensity and carbon dioxide intensity have been in decline since the mid-1990s\(^9\). On the energy production side, the widespread adoption of cogenerated heat and power has been particularly helpful in this regard; CHP is discussed in more detail in Section 2.2.

In end-use, the national building code requiring 30% energy efficiency improvements for new buildings came into force at the start of 2010 and in 2012 this will require a further 20% increase in energy efficiency. Energy certification is compulsory for all new buildings and many existing buildings\(^10\).

Public spending on renewable energy is lower than on energy efficiency but still generous. With over 70% of this budget in 2010 dedicated to biomass, liquid biofuels and biogas\(^8\), it could be said to show limited diversification, but this reflects a realistic assessment of the available resources and the country’s strengths. Below is a brief overview of the renewable energy resources and other alternatives to fossil fuels being exploited in Finland; policy support measures are summarised in Table 1\(^11\). The use of wood and wood-derived biomass is discussed more comprehensively in Section 2.3.

**Wood**

Over a fifth of Finland’s total energy consumption is from wood-based biomass\(^1\) (Figure 1) and 13% of the electricity generated in the country is from wood\(^2\) (Figure 4).
Following its commitment to the EU’s 2020 targets, the Finnish government is offering more overt support for the increased use of biomass in electricity generation. A feed-in tariff scheme for electricity from biogas and wood-based fuel was introduced on the 1st January 2011 and will support electricity producers for twelve years (Table I). In particular it is intended to go some way to achieving a target of 25 TWh annually from forest chips, considered to be an underdeveloped source of energy. Small-scale, wood-fuelled CHP plants are also included and will receive a subsidy for cogenerated heat.

**Biogas**

Finland currently makes limited use of biogas in heat and power production. Biogas, a mixture of methane and carbon dioxide, is produced by anaerobic digestion of wet biomass, typically sewage sludge, animal manure and landfill. In 2010, well over half of the biogas produced in Finland was from landfill, as collection of landfill gas is compulsory. A third of the collected gas was flared and total energy from the remainder was just 0.42 TWh, 25% as electricity and 75% as heat12.

The country has a biogas potential from non-forestry sources of 7 TWh to 18 TWh13, considered to be technically feasible by 2015, but to date much lower numbers have been projected. These are likely to be revised now that a feed-in tariff and heat subsidy have been introduced (Table I), but the present legislation on the feed-in tariff includes a very low cap on the total capacity. There is no fuel tax on biogas for heat and power production, but biogas incurs taxes in the transportation sector.

**Biofuel**

Just over 2 TWh of energy consumption was met by liquid biofuel in 20101. In its 2008 Climate and Energy Strategy, Finland committed to 10% renewable energy in transportation by 2020, but on the 1st January 2011 an Act increasing this target to 20% entered into force, with a consumption target of 7 TWh by 202011. This target has been calculated by making allowance for double-counted biofuels, i.e. those derived from waste and renewable residues.

Neste Oil produces NExBTL renewable diesel in Finland from vegetable oil and waste fat from food manufacturers and is undertaking R&D work to broaden the raw material base to support larger volumes14. Similarly, energy company St1 produces ethanol from food waste using a proprietary process. It has seven bioethanol plants in Finland, and is building up a manufacturing base to supply up to 300,000 cubic metres of bioethanol for transportation use by 202015.

UPM announced in February 2012 that it will invest €150 million in a biorefinery producing wood-based advanced biofuels, mainly biodiesel, using hydrotreatment technology. The plant will have a production capacity of 100,000 tonnes a year and production will start in 201416. There are also plans for biofuel plants under consideration by several other operators.

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**Table I: Examples of Feed-In Tariffs for Renewable Energy**

<table>
<thead>
<tr>
<th>Source</th>
<th>Feed-in tariff (from 2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest chips</td>
<td>Electricity: €18/MWh⁴b</td>
</tr>
<tr>
<td>Wood (small CHP)</td>
<td>Electricity: (€83.5/MWh – MP)⁷b</td>
</tr>
<tr>
<td></td>
<td>Heat: €20/MWh</td>
</tr>
<tr>
<td>Biogas (small)</td>
<td>Electricity: (€83.5/MWh – MP)⁷b</td>
</tr>
<tr>
<td></td>
<td>CHP Heat: €50/MWh</td>
</tr>
<tr>
<td>Hydropower</td>
<td>None</td>
</tr>
<tr>
<td>Wind</td>
<td>(€105.3/MWh – MP)¹⁶c</td>
</tr>
</tbody>
</table>

**Table notes:**

MP = market price

⁴At carbon dioxide emission permit cost of €10/t

⁷New plants only

¹⁶For wind, target price is €105.30/MWh until the end of 2015 and €83.5/MWh thereafter

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![Figure 4: Domestic electricity production by source in 2010, percentage of 77.2 TWh; non-wood renewable is predominantly hydropower.](image)
As such, by 2020 it is likely more use will be made of liquid biofuel (bioethanol and biodiesel) than of gaseous biofuel in Finland. However, as in much of Europe, biomethane is receiving increasing attention as a prospective vehicle fuel and there are several projects promoting its use. There are already sixteen compressed natural gas (CNG) filling stations servicing a growing number of CNG vehicles (currently around 1,000) and Finland’s natural gas supplier Gasum has plans to expand this network. It has started producing upgraded methane from water treatment for use in vehicles and plans to use its existing grid for distribution of biomethane.

**Peat**

Peat is strictly neither biomass nor a fossil fuel, being regarded as a slowly renewing energy source but with an emission factor similar to those of the fossil fuels. Finland’s lack of domestic fossil fuel led it to exploit its considerable peat reserves to supplement coal supplies and it is now the largest producer and consumer of peat for fuel in the world, supplying 7% of its energy from this source. The country’s national energy and climate strategy aims to maintain the use of peat as a competitive alternative in energy production, most importantly in CHP and district heating applications.

**Hydropower**

With 187,888 lakes, 65 rivers and 5,100 rapids, a tenth of Finland’s land surface is under water. However, apart from the far north of the country, its topography is fairly flat and it has a much lower theoretical hydropower potential than Sweden or Norway: 31 TWh per year compared to 200 TWh and 600 TWh, respectively. Compounding this, many of the natural flows suitable for hydropower production are located in preservation areas.

Despite these constraints, Finland produces about 13 TWh of electricity from hydropower in an average year (16.5% of its electricity in 2010). This figure is close to the maximum that is considered economically exploitable and will not increase much: the government is targeting just 14 TWh by 2020. As such, little new capacity for domestic load balancing using pumped storage will become available and other methods will be needed.

**Wind Power**

There has been relatively little deployment of wind power in Finland to date, despite its high theoretical potential (particularly in offshore generation), and wind accounted for just 0.4% of electricity production in 2010. However, installed capacity is increasing and growth is set to accelerate as a very favourable feed-in tariff for wind power was introduced for the first time in Finland on the 1st of January 2011. The aim is to generate 6 TWh of electricity from wind power per year by 2020, from 0.3 TWh at present.

**Heat Pumps**

Heat pumps contribute 5% of overall space heating in Finland, both ground-source and air-source heat pumps with many more of the latter. The number of heat pumps in Finland is growing rapidly: from 20,000 heat pumps in 1997, the country had over 240,000 by the end of 2009. The government target for annual renewable energy production by heat pumps is 8 TWh by 2020.
Nuclear Power

Finland expects to rely to a large extent on a substantial increase in nuclear power to meet its emission reduction targets from the energy generation side. Its reactors have some of the highest capacity factors in the world and already make a significant contribution to the electricity supply (Figure 4).

At the time of writing, Finland has as yet given no clear indication that it will revise its position on the safety of nuclear power following Japan's Fukushima nuclear accident in March 2011 and it is unlikely that the nuclear strategy will be revisited in the absence of significant clean energy innovation. It currently has one new reactor under construction and plans for two more plants previously given the green light have not changed; these would almost triple installed capacity by 2020.

Carbon Capture and Storage

The targets for carbon capture and storage (CCS) are longer-term, as one might expect. In 2011, CLEEN (Cluster for Energy and Environment companies and research institutes) launched a CCS research programme, with natural gas in CHP being one focus area. Finnish Energy Industries is aiming for urban CHP to be carbon dioxide neutral by 2050, with CCS contributing part of the emissions reduction.

The integration of steam methane reforming (SMR) with carbon capture is already being practiced on a large scale at one of Finland’s two major oil refineries, both owned by Neste Oil. Carbon capture is taking place at the larger of these, at Porvoo, which produces 12.5 million tonnes of petroleum products a year. The hydrotreating process requires hydrogen and at Porvoo Neste Oil has constructed one of the largest single-line SMR hydrogen production plants in the world, with a capacity of 14 t/h of pure hydrogen (~108,000 t/a). Natural gas is the feedstock for this process but very little carbon dioxide is emitted: most of it is captured and used in industry or for greenhouses.

2.2 Combined Heat and Power

Motivating Factors in Finland

In 2008, the IEA undertook an assessment of CHP implementation in various countries under the International CHP/District Heating and Cooling (DHC) Collaborative. Finland was one of only two countries to be awarded a maximum rating of five stars on its scorecard, the other being Denmark. The rating was awarded in recognition of the high share of CHP in both heat and electricity generation in Finland but, in contrast to Denmark, direct government incentives have played little part in bringing this about. Instead the use of cogeneration has been driven largely by market forces.

If the heat is harnessed, CHP plants can have an efficiency double that of conventional condensing power plants producing only electricity, and thus allow for much better use of limited energy resources. However, thermal output from CHP typically exceeds electrical output and its use is most advantageous where heat demand is high. Finland uses energy at a relatively high heat-to-power ratio: the cold climate creates a need for nearly year-round heating and domestic industry requires process heat in large quantities.

Crucially, the country made early use of centralised production in urban heating, establishing district heating (DH) networks that are served from a single source of energy, which in turn made it possible to cogenerate electricity in these plants. Similarly,
industrial heat production is often of sufficient scale to allow for electricity production. Electricity generated in this way is almost a by-product of heat, and can be profitably sold to the grid or used at the industrial site itself. As shown in Figure 5, in 2010 CHP constituted 32% of Finland’s electricity supply, 19% from DH plants and 13% from industry².

**Industrial CHP**

As stated above, in 2010 Finland’s industrial sector accounted for 47% of electricity consumption. The forestry and paper industry was responsible for more than half of that, 25% of the total². There is thus a strong business case for near-site CHP plants that use the waste and by-products from pulp and paper manufacturing to generate heat and electricity. In 2010, fully 85% of industrial heat was from CHP and over 60% was produced from wood biomass²⁶ (Figure 6).

**District Heating**

District heating supplies almost half of Finland’s space heating needs²⁷: most public, communal and commercial buildings and many homes are heated by hot water circulating through local DH networks. Around three quarters of DH derives from CHP, but the proportion of renewables here is much lower than in industry²⁶ (Figure 7); Helsinki’s CHP plants, for instance, are largely fuelled by natural gas and coal²⁸. Although these plants are highly energy efficient, their carbon dioxide emissions remain a concern. Substitution by renewable sources is possible and, as mentioned above, the future application of carbon capture and storage in these plants is being considered.

**2.3 Wood-Derived Biomass**

**Motivating Factors in Finland**

Forestry used to be the economic backbone of Finland and is still one of its dominant industries; ‘forestry’ in this context denotes the management of forests and plantations, associated wood processing and manufacturing industries such as pulp and paper. Finland has capitalised on the by-products of this industry to an impressive extent: among the OECD countries, Finland and Sweden have the highest proportion of bioenergy in their total primary energy supply, both over a fifth²⁹. But where Sweden uses much of its biomass in pure heat production, Finland has the highest share of bioenergy in electricity generation (13% in 2010). This high proportion of ‘bio-electricity’ derives particularly from Finland’s intensive use of biomass in CHP.

Wood-based biomass appears to be not only a renewable but also a sustainable source of energy in Finland, as its forests are growing. The Finnish Forest Association estimates the rate of increase in the growing stock of trees at around 100 million cubic metres a year³⁰. In 2008, Finland also adopted a National Forest Programme which seeks to maximise the economic and energy-related benefits of the country’s forests while ensuring that they are protected, both as carbon sinks and to conserve biodiversity³¹. However, the picture is complicated by the fact that Finland also imports some wood from Russia, but Finland is working
with Russia to formulate a common understanding of the ‘efficient and sustainable use of the boreal forest resources’ of both countries\textsuperscript{32}.

Feedstock

In industrial CHP, biomass is often in the form of by-product black liquor from papermaking\textsuperscript{26} (right), offsetting some of the energy intensity of this process. Woody biomass (comprising woodchips, bark, sawdust and other by-products of mechanical wood processing, plus logging residues and directly harvested wood) is also used in significant quantities in both industrial and district heat production\textsuperscript{26}, and is a considerable source of fuel in domestic combustion. The wood used in log boilers, stoves, fireplaces and saunas in homes and recreational buildings across Finland adds up to around 5\% of total primary energy consumption\textsuperscript{1}.

Processing

While small-scale combustion of wood to produce heat is the simplest form of energy generation known to man, the use of woody biomass to fuel industrial-scale electricity production or transportation is much less straightforward.

Conventional combustion power plants may be able to handle limited quantities of biomass if it is co-fired with the standard feedstock. In Finland, woody biomass is often introduced into power plants that use peat as fuel, as co-firing reduces the sulphur dioxide emissions resulting from peat combustion\textsuperscript{33}, and it can similarly be co-fired with coal – but without process and equipment changes this is usually only practicable at fairly low proportions (up to ~10\% coal replacement)\textsuperscript{34}.

Since the 1980s, power plants with more flexible fluidised bed combustion technology have been able to handle much higher proportions of biomass\textsuperscript{35,36} and recently large plants that are capable of using a feedstock of 100\% biomass have been commissioned in Finland, using some of the largest wood-fired fluidised bed boilers in the world\textsuperscript{37,38,39}.

There are still drawbacks, however. For efficient steam turbine power generation, steam at high temperatures and pressures is needed. Restrictions on the amount of biomass locally available often place limits on the size of biomass fuelled plants and they tend to be smaller than fossil fuelled power stations\textsuperscript{40}. As a result, some economy of scale is lost and power generation efficiency may be affected. Typical power-to-heat ratios tend to be lower than with fossil fuels (although the total efficiency of CHP plants would still be high, over 85\%). In principle, the most efficient and economic use of biomass for energy when heat production is not the primary consideration is through gasification rather than combustion\textsuperscript{41,42}.

Gasification

Gasification is the thermochemical conversion of a carbonaceous material into a (partly) combustible gaseous mixture; biomass gasification typically yields a combination of carbon monoxide, hydrogen and methane with smaller quantities of other hydrocarbons, plus carbon dioxide, water vapour and nitrogen (if air instead of oxygen is used). The composition varies and is dependent on the process parameters.

Gasification product gas can be combusted in gas turbines or boilers to generate heat and electricity, or used as a feedstock to synthesise other products – opening the way for conversion of solid biomass into syngas, hydrogen, methane or fuel for transportation\textsuperscript{44}. There is much work being done in Finland on biomass gasification technologies and associated gas processing, and a range of applications for the technology is being explored\textsuperscript{43}.
A number of small biomass gasification plants and one 60 MW unit have already come on-line in Finland\textsuperscript{43} and a 160 MW unit with two gasifiers using waste-derived fuels will start its operation in Lahti in 2012. In 2011 it was announced that a 140 MW woody biomass gasification plant for the production of heat and power will be constructed in Vaasa, on the west coast of Finland. This will be commissioned in December 2012 and will be the largest plant of its kind in the world. The product gas will be co-fired with coal in an existing 565 MW power plant, replacing 25–40\% coal\textsuperscript{44,45}.

The conversion of biomass to synthetic fuels for transportation (biomass to liquids, BtL) is seeing increasing interest. For example, in 2009 NSE Biofuels, a joint venture between Neste Oil and Stora Enso, opened a BtL demonstration plant at Stora Enso’s Varkaus Mill which uses a 12 MW gasifier. The plant is intended to pilot a process for commercial production of synfuels from wood with a potential launch in 2016\textsuperscript{46}. As mentioned in Section 2.1, UPM is investing in a large-scale, wood-based BtL plant\textsuperscript{16} and the Metsäliitto/Vapo Consortium has also publicised plans for a plant producing biodiesel from forestry biomass on a similar scale\textsuperscript{47}.

In another recent development, Gasum, the Finnish importer and marketer of natural gas, is collaborating with energy utility Helsingin Energia and paper and pulp producer Metsä-Botnia to assess the feasibility of constructing a biorefinery using wood-based biomass as raw material for the production of bio-SNG (synthetic natural gas). It will be sited in Joutseno, in the south-east of Finland. The bio-SNG will be injected into the existing natural gas grid; production could potentially cover the consumption of over 50,000 homes\textsuperscript{17,48}.

\section*{2.4 Potential for Fuel Cells}

The evolution of energy in Finland has been driven by the need to maximise the potential of alternative domestic energy sources by using these in the most efficient and environmentally sound way, and energy technologies that cater to this need are likely to flourish. The use of biomass for energy and the use of industrial by-products in CHP are both established practices and this helps prepare the way for fuel cells.

\textbf{Moving Away from Centralised Energy Production}

Further growth of CHP in Finland needs new technology, for two main reasons. Firstly, the demand for heat is stabilising while power demand continues to grow, and as such the use of conventional cogeneration technologies with fractional power-to-heat ratios is constrained. Technologies offering ratios close to or greater than one are needed. Secondly, the use of CHP grew from large, centralised heat production but potential for growth lies in distributed generation and technologies which are efficient at smaller sizes (<10 MW)\textsuperscript{49}. Fuel cells can fulfil both these requirements.

Finland is a large country but is sparsely populated; most of the population is clustered in the south west. Outside of this region there is a very real need for distributed generation and remote, off-grid power which can be served by fuel cell systems.

Even within the south west, the tightening regulations on the energy efficiency of buildings are likely to drive fuel cell deployment, particularly in micro-CHP. Certification applies to both new buildings and existing...
buildings when sold or rented. Hot water and space heating/cooling systems of both new and renovated buildings come under particular scrutiny, and in small residential buildings electricity consumption is also included in the energy efficiency calculations.10,50

Efficient Use of Biomass

CHP using biogas and landfill gas should be a relatively easy market for fuel cells to access in Finland and, with annual generation of up to 17 TWh considered technically possible, not an insignificant one. An early Wärtsilä SOFC system has been successfully demonstrated with landfill gas in Vaasa municipality and the company is looking to capitalise on the opportunity; more detail on this is given in Section 4.1.

The transition from combustion to gasification of wood-based biomass is significant, as it makes it possible for fuel cells to be used as a means of generating energy from this fuel. Regardless of the abundance of wood in Finland generally, as a fuel it is not well suited to transportation in large quantities over significant distances. Any installation using wood-based biomass is likely to be limited to local supplies and would therefore want to use these in the most efficient way possible. As such, the production of bio-hydrogen via gasification for use in fuel cells will merit consideration.

Capitalising on Industrial By-Products

Finnish industry has used its by-product biomass for energy for many decades, but hydrogen is also formed in various chemical processes. Sodium chlorate, for example, is produced in large quantities for the pulp and paper industry where it is used for on-site production of chlorine dioxide, a key bleaching agent for the elemental chlorine free (ECF) chemical pulping process. Production is via electrolysis of brine and hydrogen is evolved as a by-product. Much of this is vented, but some facilities have been combusting it for power. This is an ideal application for fuel cells, which would offer greater flexibility and efficiency, and this was investigated recently for a Kemira plant in Äetsä (see Section 4.1).

Transportation

The options available to Finland for decarbonising road transport are the same as for other countries: battery electric vehicles, fuel cell electric vehicles and internal combustion engines used in combination with improved drivetrains and renewable fuels. The conditions of the Finnish winter do not favour BEVs, given the negative effect of low ambient temperatures on battery performance – which is exacerbated by the fact that ancillary load tends to increase under the same conditions, due to the need for heating and light. Although Finnish electricity has a high renewable content already, as yet there is little spare capacity for transportation, for the reasons discussed above.

There are several plans to produce liquid biofuels in large quantities in Finland and there is also some scope for use of biomethane in transportation. This could be burned in vehicle engines, but would arguably be more efficiently used in fuel cells, either directly or reformed to produce hydrogen – with hydrogen offering the additional advantage of keeping carbon emissions at the point source (even renewable carbon is a candidate for sequestration).

As described in more detail in Section 4 below, Finland’s well-established industrial machine and hydrogen industries are working to exploit opportunities for the development and introduction of hydrogen fuel cell vehicles and machines.
3. Fuel Cell Research and Development

3.1 Government Support

Technology industry is of great importance to Finland. The sector accounts for 60% of total exports, 80% of private sector R&D investment and employs, directly and indirectly, over a quarter of the workforce. In energy technology specifically, Finland exports more than it imports and can therefore be said to be a net innovator. Much of this innovation stems from the early and extensive use of CHP and bioenergy in the country.

Continued development in clean energy is necessary to strengthen this position and, along with emissions reduction, the prospect of export revenues is a strong motivator for investment in technologies such as fuel cells. Finnish government policy recognises that innovation is necessary for sustainable economic growth and it is strongly backing development in clean technology, with the stated aim to grow this into a significant economic sector in Finland.

Innovation in Finland is characterised by a highly structured approach. The Research and Innovation Council advises the government on the coordination, evaluation and implementation of innovation policy, which the Council of State then executes. Fundamental research takes place at universities and the Academy of Finland, while applied research and technical development generally falls under the Ministry of Employment and the Economy. Sitra (the Finnish Innovation Fund), Finnvera, Finpro and Finnish Industry Investment Ltd all provide finance, expertise and support for commercial development.

Within this framework, development of any new technology for the market is likely to see significant collaboration between government agencies, universities, research organisations and industry. In fuel cells this principally occurs through the following bodies, together with a number of participating universities.

3.2 Tekes Funding Agency

Function and Strategy

Tekes, the Finnish Funding Agency for Technology and Innovation, is the largest publicly financed R&D organisation in Finland with a significant budget allocation of €600 million annually. It supports wide-ranging innovation activities in research communities, public service sectors and industry (both Finnish and international companies located in Finland). The agency provides a funding bridge for risk-intensive projects that could struggle to find investment through conventional channels. Its focus is true innovation and it is less interested in ‘business-as-usual’ technology, making it a natural fit for fuel cell development.

This funding model requires a long-term approach and many projects run for several years. However, the choice of projects is strategic as the agency aims to accelerate development of technologies that have demonstrated commercial potential while winnowing out those that are unlikely to deliver. Progress towards commercialisation is assessed annually and projects which have stalled are shut down.
Tekes falls under the Ministry of Employment and the Economy, which also administers the country’s energy policy. It is tasked with facilitating growth in business productivity, creating new growth areas and strengthening existing competencies to capitalise on domestic and international opportunities in the energy sector. It must also support the Ministry’s energy and environmental targets. Combining these two objectives creates the framework for sustainable development as a competitive factor.

Tekes’ funding allocation to energy production technologies from 2006 to 2010 is shown in Figure 9. Fuel cells fall under ‘Other energy technology’ and most activity in this area is coordinated under the Finnish Fuel Cell Programme.

The Finnish Fuel Cell Programme

In 2006, Tekes created an umbrella fuel cell programme based on agreed Finnish fuel cell strategy and this forms Finland’s contribution to the European Fuel Cell and Hydrogen Joint Undertaking (FCH-JU). It runs from 2007 to 2013 and has a total budget of €140 million over the seven years; €50 million each from Tekes and industry and the rest from international funding and other sources. It comprises some 61 projects at universities, at VTT Technical Research Centre of Finland, and in industry.

The programme aims to facilitate the development of market-ready fuel cell technology. Beyond successful technology demonstrations, this requires the building of complete, robust supply chains and the creation of as much early business as possible. There is a high level of interaction and collaboration within Finland but the programme is also building frameworks for international cooperation. Although the Finnish partners bring much expertise in a number of areas, Tekes recognises that international partners are needed to complete the supply chain and is actively seeking these, stack suppliers in particular.

Core focus areas are:

- **Stationary power**: SOFC and PEMFC technology for micro-CHP, industrial and utility distributed generation (DG), uninterruptible power supply (UPS) and emergency back-up power, remote, off-grid power such as for telecom base stations, and auxiliary power units (APUs) for large ships.

- **Mobile working machines**: low-temperature PEMFC and high-temperature PEMFC with polybenzimidazole (PBI) polymer membranes for use in vehicles in forestry, mining, harbour and military applications.

- **Low-power portable units**: Tekes’ assessment is that improved batteries and better energy efficiency in electronic devices will meet the requirements of the consumer electronic market for some time. The programme has thus for the moment shifted its focus on to fuel cells in other portable applications such as fuel cell power packs and printed fuel cells for disposable electronics.

At this point a number of research projects have been completed and around €35 million has been spent. Much of the expense lies ahead as the focus is now moving on to business development and end users. Further funding rounds will take place in 2012 and 2013 and the programme will culminate in the Demo2013 demonstration.
3.3 VTT Technical Research Centre of Finland

Function and Strategy

VTT, the Technical Research Centre of Finland, also falls under The Ministry of Employment and the Economy. A significant force in technological innovation, it is the largest applied research organisation in Northern Europe. VTT’s purpose is to create business from technology, with a strategic research portfolio that focuses on sustainable development and technology for an ‘intelligent’ digital world.

It primarily undertakes applied research and provides a bridge between fundamental research and commercial development, although its sphere of activity intersects with both universities and industry. Around a third of its revenue is from basic government funding but most of its activity is commissioned by customers (Figure 10), making up an annual turnover of €275 million and creating employment for over 3,000 staff at various locations in Finland and elsewhere53.

The particular strength of VTT is that it can create knowledge clusters that draw on a broad base of expertise, ranging from biotechnology and materials science to construction and mechanical engineering, and there is much inter-departmental cooperation. SMEs that do not have the budget for extensive R&D can outsource work to VTT and draw on this pool of expertise, lowering this particular barrier to market entry.

Fuel Cell Research and Development at VTT

VTT’s strategy is not to produce commercial fuel cell products but to become a centre of excellence in cell, stack, balance of plant (BoP) and system development, modelling and optimisation55. Expertise is gained through experience and, alongside extensive testing of customer technology, VTT has also developed its own in-house stack technology. The IP was acquired by Estonian company Elcogen in March 2011 and it is now collaborating with VTT on development of a commercial product using Elcogen’s own SOFC cells in conjunction with the innovation, which allows temperature gradients in the stack to be minimised56 (Figure 11).

VTT has undertaken much experimental work in cell and stack fundamentals and the data have been used to create bottom-up models for system design and optimisation, which can be licensed to VTT’s partners. The focus at VTT is on SOFC technology, although it is also involved in PEMFC testing systems, as well as PEM electrolyser and some PEMFC materials development.

It is currently undertaking testing and characterisation of stacks from three PEMFC and six SOFC developers from around the world. Testing is fully automated and runs 24/7; various gas stream compositions can be simulated for characterisation.

The ultimate outcome of this work is system design. For example: VTT is currently working on a natural gas fuelled SOFC system for CHP. It uses a single, 10 kW planar SOFC stack module from Versa Power Systems and a BoP module designed and constructed at VTT. Operation is thermally self-sustaining and the system also uses a warm anode gas recycle loop. The design and operational parameters of this unique system have been validated by experimental testing (Figure 12).
3.4 Federation of Finnish Technology Industries

Function and Strategy

The Federation of Finnish Technology Industries states that its mission is to ensure that Finnish technological development meets the preconditions for success in the global marketplace and it offers its 1,600 member companies a suite of services to facilitate this. Central to this is regional and international networking and cooperation in specific technology areas, through a number of branch groups established for this purpose.

Fuel Cell Finland Industry Group

In 2006, the Federation created a branch group for fuel cells, the Fuel Cell Finland Industry Group, which now works closely with Tekes to coordinate demonstrations and other market development activities. Its members include fuel cell developers, companies with interests in the supply chain, and those who wish to use fuel cell technology in their products.

The inclusion of end-users is important as the focus of the group is on growing the market and identifying business opportunities, rather than technological development of fuel cell products as such. It networks nationally and internationally, picking up on developments and market trends and steering its members accordingly.

The members of the Fuel Cell Finland Industry Group are:

- **Bigman:**
  Expert on technology for buildings; HVAC (heating, ventilation and air conditioning) planning and energy efficiency reviews;

- **Cargotec:**
  Global leader in cargo and load handling equipment and services in ports and terminals;

- **Gasum:**
  The Finnish natural gas importer; natural gas grid owner and operator; also handles gas sales, marketing and supply;

- **Konecranes:**
  Leading manufacturer of lifting equipment for shipyards, ports, terminals, factories and plants;

- **MSC Electronics:**
  Designer and manufacturer of power converters in the range 1 kW to 500 kW;

- **Outotec:**
  Global provider of process solutions, technology and services for mining and metallurgy;

- **Patria Land & Armament:**
  Developer of technologically advanced armoured vehicles and mortar systems;
Prizztech:  
Consultancy and project management; creator of Äetsä Hydrogen Village demonstration;

Sandvik Mining and Construction:  
Leading manufacturer of earth-moving machinery, tools and services for mining and construction;

Savox Communications:  
Provider of professional radio accessories and communications equipment for hazardous work;

VTT Technical Research Centre of Finland:  
Technology development for business application.

Wärtsilä:  
Supplier of power plants, engines and propulsion systems to the marine and energy sectors.

4. Fuel Cell Demonstration and Commercialisation

4.1 Stationary Systems

Äetsä: 1 MW PEMFC with By-Product Hydrogen

Chemicals company Kemira has a number of sodium chlorate plants serving the pulp and paper industry in Finland and one of these formed the basis of the FinHydrogen Äetsä Hydrogen Village. The hydrogen village project, which ran to the end of 2011, was financed by a local funding body, Pirkanmaan Liitto (The Council of Tampere Region), and through this body it joined HyRaMP (now HyER). The project was an initiative of the Prizztech consultancy, intended to accelerate the application of hydrogen technology, and the central study assessed the feasibility of a megawatt-scale fuel cell CHP plant running on by-product hydrogen.

The Kemira facility at Äetsä produces around 6,000 t/a. Kemira has, in fact, already been using some by-product hydrogen for power generation at both the Äetsä plant (since 2003) and at Joutseno (since 2006), but through combustion. Sodium chlorate production is highly energy intensive and the benefit of the by-product hydrogen could be maximised by putting it through a fuel cell.

Prizztech estimates that Kemira’s production facilities at Äetsä, Joutseno and Kuusankoski produce a combined total of 18,000 t/a of hydrogen which can be harnessed in fuel cell CHP, and it is also looking to develop possible sources of waste hydrogen in the sulphuric acid and fertiliser industries. It will be building a business case for large (>100 kW) fuel cells for industrial and community heat and power plants running on by-product hydrogen. The availability of this hydrogen coupled with existing district heating networks means the barrier to entry for fuel cells in CHP in these locations is low and this could be an ideal early market from which to grow volumes.
Wärtsilä: SOFC Power Plants

Wärtsilä built its first diesel engine in the 1940s and via interests in shipbuilding and other heavy industries evolved to become a market leader in power solutions for ships: globally, it now powers every third ship and services every second one. The propulsion system of a large, ocean-going vessel is more a power station than an engine and Wärtsilä also has a thriving business in products and services for large stationary power applications. These include CHP, industrial self-generation and other distributed generation and it is also targeting grid base-load, peaking and reserve power.

Fuel Cells in the Product Portfolio

Wärtsilä is offering these markets ‘smart power generation’, power plants that maximise energy efficiency while being fuel flexible. The plants are based on engines that can run on a range of gaseous and liquid fuels and are designed such that fuel can be switched during operation. Wärtsilä is also promoting the transition to sustainable fuels and has already delivered a number of liquid (oil-derived) biofuel power plants.

The current product portfolio covers the range from 1 MW to 50 MW, with no sub-megawatt systems as yet. It is in this gap that Wärtsilä is seeking to deploy fuel cell technology, in the belief that it would offer the highest added value to customers in the sub-megawatt range. There is strong commitment behind this: the company intends to be a leading provider of fuel cell power systems for distributed generation, a market that it anticipates being established as early as 2020.

Wärtsilä has high R&D investment and prefers to develop technology in-house but is willing to buy in and adapt where this makes strategic sense, and this is the route it decided to follow for fuel cells when it started work in this area in 2000. It is focusing on planar SOFC technology in atmospheric-pressure operation (to be compatible with gas turbines in hybrid systems) and is using stacks from Topsøe Fuel Cell and Versa Power Systems (VPS) in development.

Early Demonstrations: Landfill Gas and Ship APU

Wärtsilä produced its first systems for internal validation and to establish the suitability of fuel cells for the applications it had in mind. One of the two 20 kW systems (WFC20) was installed in Vaasa municipality in 2008 as a stationary CHP system fuelled with landfill gas. It is still operational, heading towards 5,000 hours, and will be used for further field testing of components and automation.

The second WFC20 was installed on the deck of a Wallenius Wilhelmsen Logistics ship as the basis of the 2009/10 METHAPU project to test the concept of methanol-powered fuel cell APU for ships (below). The successful trial elucidated what is necessary for reliability, safety and RCS compliance of a fuel cell installation on an ocean-going vessel and the use of methanol, specifically renewable methanol, as fuel.

Further Development

The successor to the WFC20 is a 50 kW unit (WFC50) for which VTT’s models are being used to guide system design. Tests of the Wärtsilä-developed integrated power module and key balance-of-plant (BoP) components on the pilot platform have taken place and tests with the VPS and Topsøe stacks are scheduled for 2012. Although some standardisation is possible, the different stacks require different BoP and there are two pilot 50 kW systems being developed side-by-side in the lab. Once completed, a WFC50 will be deployed in Vuosaari Harbour as part of Demo2013 (see Section 4.5).
Beyond this, Wärtsilä’s aims are to develop cost-effective manufacturing processes before commercialisation – significant cost is currently being added by the lack of off-the-shelf BoP and the need to adapt and integrate partly suitable components. Footprint will shrink markedly and improvements to stack efficiency and lifetimes are also expected. The next generation of WFC systems will see power output increased over 100 kW in units which can be used in modular fashion to build up larger systems59.

4.2 Portable Fuel Cells

The BioBattery

A fuel cell product that is nearing commercialisation in Finland is a few square centimetres in area with the thickness of stiff card: an enzymatic bio-fuel cell (BFC) that has been developed for a growing market in disposable electronics (right).

There is rapidly increasing demand for printed, thin-film batteries in radio frequency identification (RFID) tags, smart labels, powered smartcards, sensors, and for cosmetic and medical patches, and these applications all need flexible power sources that are compact and cheap. They must be non-toxic and non-hazardous, and must comply with applicable legislation such as the EU Battery Directive, the EU directive on waste combustion and the Waste Electrical and Electronic Equipment (WEEE) Directive. Ideally, they should be biodegradable or suitable for incineration with household waste. The restrictions on cost and disposal limit the use of many conventional battery materials in these thin-film devices.

Innovative Materials and Manufacturing

This was the starting point for a joint research project by VTT, Åbo Akademi and Aalto Universities, which aimed to create a fully enzymatic power source that could be manufactured using rotary screen printing. The consortium was later joined by Tampere Technical University, which works on prototype medical patch manufacturing. Together they created the ‘BioBattery’.

The BioBattery is a fuel cell that uses enzymes as catalysts and sugar as fuel (Figure 13); the fuel is pre-loaded into the electrode structure during manufacturing, creating a closed package akin to a battery. The applications for which it is designed are single-use and an extended operational life, which would require continuous fuelling, is not necessary. The BioBattery can be stored for up to a year in dry form and activated by adding water, or stored for shorter periods with the wet fuel contained in a capsule which is broken to activate the cell on use.

A significant amount of innovation in the use of reel-to-reel printing techniques, enzymatic/bio-fuel cell technology, inks and materials has been employed in the creation of the cell. The cell is based almost entirely on harmless natural materials: cellulose, carbon, proteins and glucose. A minute quantity (~25 ppm) of mediator remains, but complete removal is considered possible and is being worked on.

Much effort was directed to keeping costs low by harnessing commercially-available, low-cost materials and enzymes with minimal tweaking, rather than making the technology reliant on exotic materials and specialist molecules. The low peak current that is typical of enzymatic fuel cells was boosted through the integration of a printed supercapacitor60.
Commercialisation
Pilot manufacturing runs of the BioBattery are underway. The first areas in which the power sources will be tested are ‘active’ cosmetic and medical patches, and in this application particularly the cell is considered to be ready for commercial demonstration (an example product is a patch that uses a small electric current to accelerate wound healing). The consortium is seeking commercialisation partners, particularly those with specialist knowledge in medical device regulatory and clinical trial compliance.

4.3 Transportation Fuel Cells

Mobile Working Machines
Finland boasts a thriving mobile working machine manufacturing sector, with an annual turnover in excess of €6 billion, 70% of which is accounted for by exports. The motivation for alternative drivetrains in non-road mobile machinery (NRMM) is solid. A study by the Institute for Energy and Environmental Research Heidelberg in Germany – an important export market for Finnish goods – found that NRMM is a significant contributor to diesel particulate and nitrogen oxide emissions from transportation, matching emissions from road transport.

Optimising Drivetrain Design
A multidisciplinary R&D programme for hybrid electric technology for non-road mobile machinery (NRMM) is underway at Aalto University, with partners Lappeenranta University of Technology, Tampere University of Technology and VTT. The objective is to halve the energy consumption of existing NRMM, while improving control and performance. Funding from the Tekes fuel cell programme is allocated to the participating research groups as it is intended that the development path will lead to fuel cell power in these machines – the final goal of the roadmap.

The task is challenging: the great variation of duty cycles across the range of diverse machines classed under NRMM means standardisation is difficult. Heavy mobile working machines tend to be produced in small series, geared towards a specific application in sectors ranging from mining to forestry, cargo handling to construction. Engine outputs vary from 50 kW to 400 kW, and they can be run in anything from constant operation to sporadic use. Detailed design efforts are needed to match the powertrain to the duty cycle in each case, and the development of system control and optimisation strategies is a key outcome of the project. Standardisation can thus be taken up to a certain point, after which optimisation strategies are used to direct further system design and modification most effectively. Using simulations and pilot test facilities, development costs can be minimised.

The development of hybrid electric drivetrains is now underway, fuel cells being one of the possible primary energy sources.

Cargotec Cargo Handling Equipment
Cargotec’s daughter brands Hiab, Kalmar and MacGregor are recognised leaders in cargo- and load-handling solutions. Kalmar ship-to-shore and container handling equipment is used in ports and terminals around the world. In 2008, Cargotec launched the Pro Future trade mark to be applied to environmentally friendly and energy efficient equipment under the Kalmar brand. The intention is to increase the sustainability of using its products while also driving down costs.

Hybrid diesel–electric Kalmar equipment is in commercial production while fuel cell technology is being researched. Cargotec worked with
VTT and Aalto University on a proof-of-concept 5.5 t Kalmar fuel cell forklift truck (FLT), which was created as a collaborative effort in 2009 (above).

In keeping with its strategy, VTT’s focus was on system development rather than cell or stack optimisation (the Nedstack stack is commercially available). Development efforts focused on the anode side and an operating mode with hydrogen recirculation and a periodic purge was implemented in order to maximise hydrogen take-up and maintain anode humidification. For this to be effective, fine-tuned optimisation of the balance of plant and control strategy was necessary to maximise the lifetime of the stack and system efficiency while controlling system cost.

The FLT used two 8 kW Nedstack PEMFC stacks hybridised with a lead–acid battery pack and supercapacitor for total peak power of 50 kWe and was successfully tested in the field65. Further development will be undertaken before product launch.

**Fuel Cell Snowmobile for Tourism**

As the capital of Lapland, Rovaniemi is at the centre of tourist activity in this region and records around half a million tourist visits every year64. The Rovaniemi Regional Development Agency says that fuel cell product development in northern Finland feeds into twin aims: supporting local business and creating sustainable tourism. Snowmobile tours or safaris are very popular in northern Finland, and the development of a fuel cell snowmobile would dovetail with both these aims. Lapland Safaris, the largest provider of safaris in this region, believes there is a business case for clean and quiet snowmobiles: a market survey established that users find the exhaust fumes and noise of ICE snowmobiles highly undesirable.

**eSled**

In response to this, the eSled project was launched in early 2010 to run for two years with a budget of just over €1 million. It is co-funded by industry and Tekes under the European Regional Development Fund. The partners are: Rovaniemi University of Applied Sciences; BRP Finland (snowmobile manufacturer); Lapland Safaris; Fortum (Finnish energy utility company); European Batteries (lithium-ion battery manufacturer) and five local Lapland energy utilities65.

Rovaniemi is the location of the largest snowmobile manufacturing facility in Europe. Originally owned by Finnish brand Lynx Snowmobiles, it was bought out by Canadian company Bombardier Recreational Products, one of the world’s four leading snowmobile manufacturers, and is now operated by its subsidiary BRP Finland. The name was retained and Lynx remains the leading snowmobile brand in Europe. The platform used in the eSled project is the Bombardier Lynx Rave 550 model.

As the name implies, the objective of the eSled project is to develop an electric version of the snowmobile; a battery electric in the first phase, now complete, and a fuel cell electric snowmobile in the second phase. Range must be at least 30 km between fills with performance equal to the current ICE model. A prototype battery electric Lynx Rave was produced in 2010 and went on display at the Rovaniemi Snowmobile Fair in November 2010, where it generated much interest66,67 (above). It was not intended for production but to show that an electric snowmobile meets the necessary performance requirements, which it did very successfully.

**Further Development**

Subsequently, fuel cell heating of the battery during use was added and is in tests with VTT. The project engineers are now working on the integration of a fuel cell range extender, of output around 1 kW to 2 kW, expected to be complete in 2012. The range specified above is sufficient for a typical three-hour safari and
was already achieved in the battery version; the addition of a range extender could make the snowmobile suitable for all day use on one fill. Another common application of snowmobiles in Finland is for reindeer herding where longer ranges are necessary.

A further target for the project is price equivalence with current models and this is likely to prove more of a challenge for which volume production will be necessary. There is a genuine desire on the part of Lapland Safaris to bring the fuel cell snowmobile to market and the involvement of BRP Finland in the eSled project is a hopeful indication that production runs are a real possibility. In recognition of the market potential, the project has just received approval from the funding agencies for extension beyond 2012.

4.4 Fuel and Infrastructure


Finland’s starting point in its strategy for fuel cell vehicles is the recognition that it already has plenty of hydrogen, both as a by-product and from existing industrial production capacity (whether electrolysis or SMR). There is also a degree of hydrogen infrastructure already established in the country and a small quantity of hydrogen can be mixed and distributed with natural gas in the existing network. Where many have seen hydrogen infrastructure as a barrier to FCEV deployment, Finland sees it as an enabler: the country is looking for opportunities to capitalise on its existing industrial infrastructure and hydrogen surplus through the use of fuel cells.

According to the IEA, Finnish public spending on EV and vehicle efficiency RD&D was almost USD20 million in 2010 (approx. €25 million) – and the great majority of Finland’s spending in this category over the last four years has been on fuel cell vehicles. However, the focus is on the deployment of fuel cell electric vehicles (FCEVs) rather than development of fuel cell vehicle technology. The strategy being followed in Finland is for the FCEVs to be supplied by international OEMs once Finnish industry has created the appropriate refuelling infrastructure.

Woikoski Hydrogen Stations

Having identified the opportunity here, Finland’s oldest technical and speciality gas supplier Woikoski is now branching into hydrogen refuelling stations. Established in 1882, it has gas production plans and distribution depots scattered across Finland and a network of 160 vendors. It currently supplies hydrogen to its larger customers in either a gas cylinder container (235 kg per unit) or in a liquid hydrogen tanker (2,000 kg per unit). It is in the process of upgrading its gas cylinders to double their capacity, and is looking to invest in a liquid hydrogen production plant to support growth in this market.

Woikoski says it is in a position to supply 1,500 t of 99.999% purity hydrogen annually to fuel cell applications. Assuming FCEVs in private use doing about 20,000 km a year at a consumption rate of 1 kg hydrogen per 100 km, this translates into enough fuel for 7,500 cars. Woikoski has further calculated the theoretically available amount of hydrogen in Finland overall at 140,000 t annually – enough perhaps for 700,000 cars or 58,000 buses. These figures are rough estimates and likely to be modified downwards in practice, of course, but still indicate a substantial opportunity to establish early infrastructure for FCEVs.

Woikoski is on track to deliver two hydrogen stations in 2012, one for the Arctic Driving Center in northern Finland and the other destined for Vuosaari Harbour.
Testing Fuel Cell Vehicles: Arctic Driving Center

The Arctic Driving Center at Rovaniemi in the Lapland region of northern Finland has been testing cars in arctic conditions for over thirty years. The specialist testing centre is a confidential proving ground for new models and vehicle technologies and, as such, adding the facility for testing of hydrogen fuel cell cars is a natural step forward.

Woikoski is contracted to deliver a 700 bar hydrogen filling station with a capacity of 30 kg per day to the centre in 2012. But demand for fuel cell vehicle testing facilities from the OEMs is high enough that a temporary hydrogen station was delivered to the driving centre so that testing could start in the 2011/2012 winter season. This station was a joint effort by Woikoski with H2 Logic of Denmark and will be replaced by a permanent, fully ‘Finnish brand’ station in due course.

Testing vehicle performance under extreme conditions is necessary for a number of reasons. Electric vehicles, in particular, require thorough testing under cold conditions: early deployments of BEVs in the Nordic countries highlighted that cold temperatures severely curtail effective ranges and without some sort of mitigating strategy these vehicles are impractical for use in cold climates. The development of fuel cells in hybrid electric drivetrains is in the advanced stages by most of the major automotive OEMs and all these models will be thoroughly tested before commercial release.

The Rovaniemi Regional Development Agency is coordinating testing and monitoring of the station, intending to build familiarity with the characteristics of hydrogen refuelling in arctic conditions. By developing refuelling technology alongside the testing of various FCEV models, a seamless fit is ensured. The Arctic Driving Center is thus an ideal starting point from which to grow a network of hydrogen refuelling stations in northern Finland.

4.5 The Finnish Fuel Cell Demonstration: Demo2013

Scope and Outcomes

Demonstrations are important to cement supply chains, attract end-users and raise public awareness, and one of the key outcomes of the Finnish fuel cell programme will be a major, cross-application demonstration in Helsinki in 2013. The Demo2013 project kicked off in August 2011 and will culminate in the demonstration at a port facility, Helsinki’s new Vuosaari Harbour. A joint initiative by Tekes and the Fuel Cell Finland Industry Group, it will present the results of the projects funded by the Tekes Fuel Cell Programme and the FCH-JU as a ‘living laboratory’ of fuel cells in various applications. The demonstration will take place over six months.

Tekes emphasises that the demonstration is an opportunity not just for Finnish fuel cell companies but also for international companies to test and display their products. It has issued an open call for international partners to participate in Demo2013. Organisations with operations in Finland may qualify for funding from Tekes and participants could also benefit from involvement with the FCH-JU and partnerships with Nordic Energy Research. The project further encompasses comprehensive RCS work, a key part in bringing a product to market, and a legislation review (a draft of which is already available on Tekes website). Given the size and scope of the project, media coverage is guaranteed.
The relevant contacts for the project are:

- Fuel Cell Programme Coordinator Anneli Ojapalo: anneli.ojapalo@spinverse.com
- Tekes Programme Manager Heikki Kotila: heikki.kotila@tekes.fi

Vuosaari Harbour

Vuosaari Harbour opened three years ago and is pioneering energy efficiency in a harbour environment. Its location within the city of Helsinki also places strict limitations on emissions and noise pollution. The harbour owner, Port of Helsinki, intends to innovate and maximise sustainability in order to gain a competitive advantage as a port facility. For all these reasons, as well as the scope offered by working harbour operations, Vuosaari is an ideal location for the fuel cell demonstration. Port of Helsinki is collaborating closely with Tekes and the various partners.

The harbour primarily handles cargo but also caters to around 320,000 passengers a year on Finnlines ships to destinations around the Baltic and North Seas. Around 2,000 container trucks and five goods trains are processed in a day, hauling a total of 7.5 million tonnes of cargo annually. The harbour covers 240 hectares in total, with 1.5 km of container quay and 5 km of quay in total.

Fuel Cell UPS for Harbour Operations

Mobile network operator TeliaSonera has a base station in the harbour area and in the demonstration a modular fuel cell UPS system will provide at least 160 hours of back-up power to this station. The system will be supplied by Finnish company T Control using a PEMFC unit from Dantherm Power. Back-up power for communications equipment has received much attention lately with the introduction of the Terrestrial Trunked Radio (TETRA) standard for critical mobile radio communications and there is much interest in testing fuel cells in this application.

In order to minimise emissions from idling trucks, the harbour has an automatic gate system and traffic flow is very smooth with few delays. Light masts at the gates and along the routes can be operated separately with varying light levels to be as efficient as possible. In certain parts of the harbour lighting is critical and cannot fail, so individual back-up power to the control systems of these masts is also needed. The gates and automated security control systems that are vital to the operation of the harbour are another ideal application for fuel cell UPS, as are the various other logistics and IT systems.

Heat and Power Supply to the Harbour

A natural gas fuelled power plant is situated adjacent to the harbour. Under the Demo2013 project, a pipeline is being built from this plant to supply natural gas to a 50 kW Wärtsilä stationary fuel cell housed in a building on the harbour premises. The fuel cell power plant will supply power to the harbour and to the Helsinki electrical grid, and will generate heat for harbour buildings and the local DH system.
Heat from the fuel cell may also be used to warm the harbour water. During winter it is not uncommon for the sea around Helsinki’s coastline to freeze. The harbour operates a small icebreaker and uses warm water from the power plant to warm the seawater in the harbour by a couple of degrees and keep it ice-free.

There are three harbour operators at Vuosaari which lease buildings on-site from the property developers. Multinational real estate investment company Sponda, which states that its vision is to be ‘the environmental responsibility leader in the real estate sector’, has expressed interest in fuel cell energy for the port building. Finns routinely finish their working day with a sauna and the large sauna facility at the top of the building could be an ideal fuel cell application.

**Cargo Handling and Transportation**

Fuel cells will be demonstrated in goods handling in the harbour, an application which requires relatively large working machines. Ideally, Demo2013 will test as many electric, fuel cell or hybrid cargo handling solutions as possible. It must be stressed that there is significant market potential here: Cargotec, a global leader in cargo handling equipment for ports and terminals, and Konecranes, which supplies a sizeable percentage of the world’s cranes in ports and factories, are both part of the Fuel Cell Programme.

Both harbour service vehicles and passenger shuttles are prospective applications for fuel cell vehicles and Demo2013 will include the construction of a hydrogen refuelling station by Woikoski, as a mobile unit initially. The intention is to make use of industrial by-product hydrogen in this station. It will probably be sited midway between the public part of the terminal and the restricted-access area so that it can service both types of vehicle, and will also supply the hydrogen for ship APU and fuel cell UPS units in the harbour. The infrastructure for demonstration of a range of light FCEV will thus be in place and presents a ready-made opportunity for developers to test their products.

It is already clear that the demonstration will not be confined to one location and will involve the whole harbour. There are many other potential applications for fuel cells there and in the nearby residential area and golf course, so during the next preparation phase in 2012, and as new partners join, the demonstration could grow substantially in scope.

### 5. Concluding Remarks

Fuel cell developments in Finland have had a relatively low profile to date. What the above reveals is that this is not due to a lack of activity, but rather to a planned and systematic approach to developing viable commercial products. The view in Finnish innovation is that any new technology takes time to be delivered to the market in a mature enough form to be robust, with as much care needed in establishing the supply chain as the end product, and this is what the fuel cell programme and associated initiatives are steadily working towards.

Finland occupies a unique position in international trade. ‘Cursed’ with a small domestic market it has for many years had to find markets elsewhere for its products. Its consequent strength in external cooperation is of potential benefit to its partners in fuel cell product development. For many, Finland could be a gateway to existing export markets in Europe, and companies wishing to gain a foothold in Russia may similarly find a way in through Finland. For example, the Finnish-Russian Innovation Alliance on Nanotechnology is working towards commercialisation of unexploited Russian R&D for both domestic and international markets. Strategic partnerships may be able to access – for instance – Rusnano’s resources of some €8 billion earmarked for the creation of a whole new industry branch in Russia.

There is no doubt that Finnish companies intend to capitalise on the opportunity presented by fuel cell technology and we should expect to start seeing their products reaching the market by 2015.
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