NPL National Physical Laboratory | Centre for Carbon Measurement

Centre for Carbon Measurement

The Impact of Our Work

National Measurement System

TECHNOLOGIA

The authors of this report

A spin-out from a Cambridge product development consultancy, Technologia has developed its own skill base in policy consulting, innovation support, business case development, appraisal of R&D propositions in technology, and due diligence. It has unique and privileged access to numerous individual subject experts in its extensive network of associates – with expertise ranging from medical devices to domestic showers, and from drug delivery to free-space optics. Technologia's clients can truly have the best of both worlds.

http://technologia.co.uk

Centre for Carbon Measurement

The Centre for Carbon Measurement reduces uncertainties in climate data, provides the robust measurement that is required to account for, price and trade carbon emissions and helps develop and accelerate the take up of low carbon technologies.

www.npl.co.uk/carbon-measurement

National Physical Laboratory

The National Physical Laboratory is a world-leading centre for the development and exploitation of measurement science, technology, related standards, and best practice in a diverse range of technical areas and market sectors. As the UK's National Measurement Institute, our capabilities underpin the UK National Measurement System (NMS), ensuring consistency and traceability of measurements in support of UK and overseas customer interests. We aim to provide world-class science and engineering with economic, social and environmental benefits to the UK.

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For more information

For more information about this set of case studies, or the work of the Centre for Carbon Measurement, please view the website above or contact us on ***carbon-measurement@npl.co.uk***.

Executive Summary

The National Physical Laboratory Centre for Carbon Measurement reduces uncertainties in climate data, provides the robust measurement that is required to account for, price and trade carbon emissions, and helps develop and accelerate the take up of low carbon technologies.

The Centre for Carbon Measurement was set up in March 2012 and is an example of how the National Physical Laboratory (NPL) seeks to further its economic and environmental impact. Its formation also recognises the importance of applied measurement and value added services, in addition to the traditional pure measurement capabilities that still underpin NPL's international reputation.

The Centre for Carbon Measurement at NPL creates new technology, develops knowledge, and enables and enhances regulation. Its strong stakeholder network, including industry bodies, policy-makers, universities and NPL scientists, ensures that a critical mass of expertise develops in areas that will benefit the UK economy and climate change.

Climate Data

Carbon Markets & Accounting

Low Carbon Technologies

The Centre was launched in early 2012, but NPL's portfolio of low carbon and climate science work stretches further back. We commissioned Technologia, a science and technology consultancy, to undertake an independent study on the impact of a number of these projects, including current projects and those that have been completed over the last 18 months. The analysis covers both the impact that has already been delivered, and anticipated impact over the lifetime of knowledge and innovations worked on.

We looked at project areas ranging from smart grid innovations and testing the thermal performance of reflective insulation, to measuring the amount of methane produced by plants and reducing uncertainties in climate data.

The benefits of this work are impressive.

Our portfolio is calculated to be responsible for 8 million tonnes of emissions reductions. This is equivalent to approximately 2% of the UK's total annual carbon dioxide emissions.[1]

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Economic benefits, for example from increased sales, cost savings or a quicker time to market, are calculated to be over half a billion pounds.

[1] Estimated to be 456 million tonnes (DECC, Statistical Release: 2011 UK Greenhouse Gas Emissions)

The information below summarises the headlines from the projects reviewed. Further details on selected case studies can be found in the subsequent pages.

Climate Data

TRUTHS

- Reducing uncertainties in climate data from satellites.
- Reduction in uncertainties of climate data by up to 0.5%.

CONTROLS

- Creating reference standards for calibration and inter-comparison of satellites.
- Improvement in data consistency to at least 2% (compared to 20% or more at present).

Carbon markets and accounting

Measuring plant methane production

- Experiment measuring methane gas production from plants and leaf litter relevant to an emerging controversy.
- If accepted, an incorrect hypothesis could have led to looser international agreements on carbon reduction. The University of Sheffield/NPL paper published on the project has received 37 citations.

Greening power stations

- Helping power station operators understand the corrosion effects of using biomass in coal power stations.
- Accelerated biomass energy generation and enabled savings of 726k tonnes of carbon emissions and £1.4 million.

Low Carbon Technologies

More efficient solid state lighting

- Design and patent of an energy-saving lighting control circuit for LEDs.
- Increases efficiency of LEDs by ~1%, creating carbon savings of 2.37k tonnes, economic efficiencies of £870k and enhanced competitiveness of EU manufacturers of LED lighting.

Low energy lighting models

- Sophisticated computer modelling to design and simulate industrial lighting schemes.
- Six existing projects (to date) average annual energy saving of 119MWh or 59 tonnes of carbon emissions and have led to an additional turnover of £300k generated in the UK lighting sector.

Novel electrodes for organic PV

- Improved design of organic photovoltaic electrodes.
- Emissions reductions of 257k tonnes of carbon emissions.

Real time metrology for fuel cells

- Voltage mapping for design improvements of fuel cells.
- Potential carbon saving of 0.8 million tonnes. Innovation leading to investments would be of particular benefit to the UK economy due to high fuel cell research capacity.

Energy gases

- Establishing measurement standards for methane and biogas.
- Enables disagreements to be resolved in the course of trade, and for interested parties to test compliance with regulatory standards, thus increasing transparency in a growing market and saving transaction costs for buyers and sellers.

Smart grids

Impact of Renewables on the Smart Grid

- Measuring the impact of solar PV on the grid.
- Potential annual carbon savings of 16.7k tonnes.

Smart Grid Digitizer

- Developing an on-site measurement instrument to enable Smart Grid design.
- Total benefit of 839kt of carbon savings.

Climate Data: TRUTHS

Reducing uncertainties in climate data from satellites. Reduction in uncertainties of climate data by up to 0.5%.

The Earth's climate is undoubtedly changing, but the speed of this change and its exact implications are still unclear.

NPL is working with the international community to establish a globally useable, internationally harmonised, operational calibration system for satellite sensors. The system aims to facilitate interoperability between sensors and identify any 'normalisation factors' that may need to be applied to harmonise data from different sensors and/or observing environments for the user community.

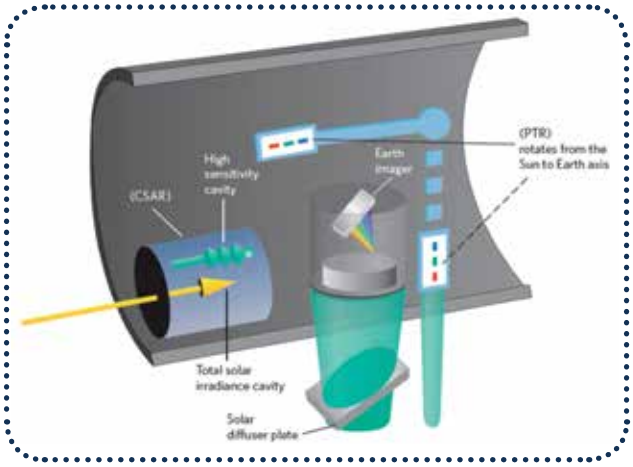
NPL is working with Imperial College London, the Rutherford Appleton Laboratory and Surrey Satellite Technology Ltd on a UK Space Agency-funded study – the TRUTHS (Traceable Radiometry Underpinning Terrestrial and Helio - Studies) mission – to develop and deploy a space-based SI-traceable benchmark sensor to underpin this international calibration system.

Such a benchmark would transform the measurements made by the system from being relative to being absolute. If launched, this will enable inter-comparisons of instruments in orbit and reduce uncertainties by up to 0.5%.

The TRUTHS satellite would be equipped with a black cavity radiometer cooled to -250 °C. This increases absorption in the cavity, making it more sensitive than the radiometers used in existing satellites. TRUTHS would use this cavity as a primary standard in orbit to provide a high-accuracy calibration of its on-board instrument measuring solar and Earth-reflected solar radiation. Whenever another satellite flies over the same point as TRUTHS, it would adjust its instruments to match the TRUTHS reading. With the same standard for all satellites, the data they send back will be directly comparable and the uncertainty will be reduced drastically.

Joanna Haigh, professor of atmospheric physics at Imperial College London, says: "Two current instruments give measurements that are adrift by about a third of a per cent — and that allows for a substantial amount of doubt. Without some sort of reference point we can't really tell if a data shift is due to faulty instruments or trends in the sun."

Nigel Fox, lead scientist on the project at NPL, says: "TRUTHS improves measurements of the earth and current accuracy levels of satellites 10 fold. This reduces the time we [scientists] need to discriminate between variability in climate forecast model predictions from 30 - 40 years to 12 – the lowest possible due to natural variability."



The economic benefits of Earth observation satellites are not yet easy to assess. However, since TRUTHS allows a cost effective way of harmonisation and maximising the compatibility of the total set of space-based observation programmes, it will drastically reduce the need for new Earth observation spacecraft. If just one less satellite were needed to provide a comprehensive Earth observation data set, the saving would amount to around £125 million.

Climate Data: CONTROLS

Creating reference standards for calibration and inter-comparison of satellites. Improvement in data consistency to at least 2% (compared to 20% or more at present).

Data that is used both for direct monitoring and as input to climate models is closely scrutinised. Many of the important measurements -- such as ice cover, cloud cover and sea levels -- must be gathered globally and thus by Earth observation satellites in space. Scientists must be able to show that any observed trends in the data are indicative of actual long-term climate change rather than differences between instruments on different satellites and/or drift in the instruments as they gradually age.

In early 2012 there were around 110 Earth observation satellites run by various agencies from different countries. There is great need for these to be calibrated and regularly inter-compared to remove biases for measurements, in order to remain credible.

NPL is deeply involved in the Committee on Earth Observation Satellites (CEOS) and leads the Infrared and Visible Optical Sensors Subgroup (IVOS), while playing a major role in quality assurance in general. NPL scientists recently completed a project called 'CONTROLS' (Comparisons to Maintain Traceability and Equivalence for Post-launch Optical Sensors) for the European Space Agency (ESA). This addressed the growing need to provide a baseline set of calibration sites and methods using Earth scenes imaged in-flight throughout the world.

A key element of the CEOS IVOS strategy is to establish an internationally agreed group of core reference standard test sites virtually linked to form a network. Each site would have a minimal set of instrumentation to measure incoming sunlight and sunlight reflected from the Earth's surface, which would operate autonomously. The instrumentation would still need to be regularly calibrated to an appropriate reference standard but the number of expensive site visits would be dramatically reduced.

Every satellite would thus regularly acquire measurements over these sites and the results would be compared with those measured from instruments on the ground. Together with data collected over other sites, a 'CEOS agreed' correction factor could then be established. The results would be provided to the community via a web-based interface.

The full implementation of this strategy is still under development but when operational it will lead to significant improvements in data consistency; at least 2% should be achievable compared to 20% or more at present.

To put this further into context: a typical tree in a tropical forest is equivalent to about 1 tonne of carbon, one hectare contains around 100 trees and the Sumatran rainforest is around 2.5 million Hectares or 250 million tonnes of carbon – equivalent to around half of UK annual emissions. It is easy to see how a percentage error in determining the number of trees, which can only 'reliably' be done by satellite, translates into uncertainty in the calculation of emissions levels, and lower confidence within the political arena. With the UN REDD (Reducing Emissions through Deforestation and forest Degradation) scheme and rapidly developing carbon markets, the financial consequences of uncertainty are also an issue. The current level of uncertainty on evaluating forest carbon from satellites ranges from 10% to 100% or more.

Historically, the most effective way to try to ensure the comparability of measurements from different satellites across the earth and over long timescales was to launch a series of satellites with identical instrumentation. It is now, however, hoped that the CONTROLS project, and the international coordination and visibility it has stimulated, will allow much more rapid progress towards harmonisation and maximise the compatibility of the total set of space-based observation programmes, drastically reducing the need for new duplicate Earth observation spacecraft to maintain operational integrity. If just one less satellite were needed to provide a comprehensive EO data set, the saving would amount to around £125 million.

Carbon Markets and Accounting: Measuring Plant Methane Production

Experiment measuring methane gas production from plants and leaf litter relevant to an emerging controversy. If accepted, an incorrect hypothesis could have led to looser international agreements on carbon reduction. The University of Sheffield/NPL paper published on the project has received 37 citations.

One of the features of the global response to climate change is the level of debate over the science involved. It is not unusual to find novel scientific hypotheses and findings about global warming mechanisms hitting the headlines. In a recent case, NPL reacted fast to provide measurement data relevant to an emerging controversy.

A paper in Nature, one of the top scientific journals, reported sizeable levels of methane emissions from plants and leaf litter due to a 'hitherto unrecognised process'. Methane is a potent greenhouse gas, trapping over 20 times more atmospheric heat than carbon dioxide. The paper went on to scale up these emissions to a global level, and suggested that a reconsideration of the role of natural methane sources in past climate change would be necessary.

NPL had previously developed expertise in trace gas sensing techniques based on flame ionisation and it was suggested that this expertise might be applied to the detection of methane from plant sources. Through collaboration between NPL and the plant science group at the University of Sheffield a project was formulated to carry out measurements under controlled biological and metrological conditions, and to relate any methane production to photosynthesis or respiration.

In the experiments, the input and output of gases were very carefully controlled and measured. Inputs of the main atmospheric gases - oxygen, nitrogen and carbon dioxide - were controlled via mass flow controllers, yielding accuracies of 0.5% or better. The output of gas was measured by taking automated samples every ten minutes and analysing these samples using a flame ionisation detector. Numerous precautions were taken to ensure that the experimental design did not introduce any biases or other limitations that could affect the validity of the results.

Findings showed that, contrary to the hypothesis proposed in Nature, well-illuminated, actively photosynthesising or respiring leaves did in fact not emit substantial quantities of methane.

Achieving concerted action on climate change is a process which depends partly on science and partly on political will. When the scientific basis is confused or disputed, the likelihood of garnering a political consensus is reduced. The hypothesis has the potential to impact political will and reduce commitment to action. If accepted, it could have led to looser international agreements on carbon reduction.

The University of Sheffield/NPL paper disproved the hypothesis, addressed the potential consequences and received 37 citations, which is a respectable figure for a publication in this field.

Carbon Markets and Accounting: Greening Power Stations

Helping power station operators understand the corrosion effects of using biomass in coal power stations. Accelerated biomass energy generation and enabled savings of 726k tonnes of carbon emissions and £1.4 million.

Burning biomass alongside coal, which is attractive as a method of mitigating carbon emissions from coal power plants, has operational implications for the so-called 'fireside' of a power plant. This is where combustion and heat cause corrosion to the outer surface of key components. Corrosion mechanisms when using biomass were not well understood, as the fuel contains a range of gases that can cause novel types of corrosion.

In a £1.8 million consortium project, co-funded by the Technology Strategy Board and the National Measurement Office between 2007 and 2011, NPL scientists used leading-edge knowledge of materials and advanced software techniques, to create models of materials behaviour in boilers operating with biomass.

The models that were developed enable the use of biomass without compromising the corrosion performance of the boiler. They do this by enabling adequate material wastage allowances to be specified, helping to optimise component lives and plant availability, and minimising costly plant maintenance activities. The results gave operators confidence in using biomass in end-of-life coal power stations, bringing forward reductions in carbon emissions.

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In 2011, the UK operators that took part in the project, E.ON and RWE npower, benefitted from the project outputs when plans were drawn up to accelerate reduction in carbon emissions by converting two coal power stations to 100% biomass. The power stations burned imported wood, which enables a 70% reduction in the impact of carbon emissions compared to coal. Both were of an older type of coal-fired station, required by EU legislation to close by the end of 2015.

In Technologia's view, the fireside corrosion project could be credited with enabling up to 20% of the carbon impact abatement, equivalent to 726k tonnes of carbon emissions. This enables the switch to start sooner and reduces the probability of plant failures (and highly expensive unplanned downtime) which would cut into the available period of biomass operation before the scheduled closure of the plants. It is estimated that reduced outages would save operators £1.4 million when applied across all plants using this knowledge.

"The use of the models in developing maintenance strategies will assist in preventing forced outages of power plants as a result of boiler tube failures. The prevention of even a single tube failure and associated repair outage could save the company in excess of £1 million in lost generation or revenue, this value exceeding the cost to E.ON in participating in the project." Colin Davis, E.ON.

Low Carbon Technologies: More Efficient Solid State Lighting

Design and patent of an energy-saving lighting control circuit for LEDs. Increases efficiency of LEDs by ~1%, creating carbon savings of 2.37k tonnes, economic efficiencies of £870k and enhanced competitiveness of EU manufacturers of LED lighting.

One fifth of global electricity consumption stems from lighting. More efficient LED (light emitting diode) lights are a key solution to lower this impact.

As well as being about five times more efficient than conventional lighting – typically producing 100 lumens per watt compared to 20 lumens per watt for halogen bulbs – solid state (LED) lights have long lifetimes (>50k hours) which can also help justify their relatively high initial costs.

The high costs are partly due to their need for electronic drive circuitry and complex packaging required to dissipate heat. As LEDs get hotter, their efficiency is impaired and their lifetime is reduced. There are strong commercial pressures to develop ways of measuring temperature in situ, and ultimately compensating for, the thermal environment of a solid state lighting fixture.

Using the fact that LEDs can detect light as well as emit it, producing an electrical signal when illuminated, NPL and the University of Surrey devised an ingenious way to measure an LED's temperature in situ.

A signal produced by an LED when lit varies with its temperature. The technique exploits this effect by using light from other LEDs in the array to illuminate the LED whose temperature is to be measured just as it is switched off, so that it has no time to cool. The light causes the LED to generate a current in proportion to its temperature. Using this technique the temperature of an LED can be measured with great accuracy while it is in use and without any extra measuring equipment – just a slightly different drive circuit.

Tests are underway to quantify just how much more efficient the new drive circuit can be in a variety of lighting configurations but the scientists estimate, conservatively, that average energy savings should be in the range of 1 to 2%.

Assuming commercialisation of this technique starts in 2014 and achieves ~20% penetration by 2016, additional annual energy savings of ~600 MWh by 2016 could be expected, generating 2.37k tonnes of carbon dioxide savings.

A minimum 10 year saving of 600 MWh of electricity would save consumers £870k at 2012 prices, but the main economic benefit of the work will be to enhance the competitiveness of EU manufacturers of LED lighting. Having privileged access to this technology will undoubtedly enable them to maintain or even increase market share in the face of fierce competition from the Far East.

Low Carbon Technologies: Low Energy Lighting Models

Sophisticated computer modelling to design and simulate industrial lighting schemes. Six existing projects (to date) average annual energy saving of 119 MWh or 59 tonnes of carbon emissions and have led to an additional turnover of £300k generated in the UK lighting sector.

Solid state LED lights are much more efficient than conventional lighting – typically producing 100 lumens per watt compared to 20 lumens per watt for halogen bulbs – LED lights also last much longer (>50k hours) than other lighting technologies. Solid state lighting is just moving into the mainstream as costs continue to fall but for many years it has been the preferred lighting technology for leading edge commercial applications.

In demanding lighting situations like airports, hotels and car parks, professional lighting designers use sophisticated computer models to design and simulate a lighting scheme. Once the modelling process is completed, the illuminance and luminance produced by each fixture in the space can be calculated. The models then deliver a graphical output of how a proposed design will look.

The success of this process and the confidence that users have in it is crucially dependent on the quality of the model data. "Clients for big lighting projects are increasingly demanding accurate and reliable photometrics, produced by an independent authority, for the proprietary lighting units to be used," says Jago Wickers, technical director of Lumino Ltd, "which is why we looked for help from the scientists at the National Physical Laboratory".

"We work with many fast growing UK companies specialising in solid state lighting to provide validated measurements of the efficiency and quality of their lighting products," says Paul Miller of NPL. To provide this service NPL has recently received UKAS accreditation for its testing of solid state lighting.

The average annual energy saving from these projects is 119 MWh, equivalent to about 59 tonnes of carbon emissions. Given that solid state lighting systems will have a working life of over a decade, a single additional project would enable energy savings of well over a thousand MWh and 590 fewer tonnes of carbon emissions over its lifetime.

These figures in turn need to be scaled up by the number of solid state lighting companies which have been assisted by the NPL team – currently six to date (including Bournemouth Airport and Holiday Inn Express hotels) - making the projected carbon savings 3.53k tonnes. The additional market confidence generated by the NPL work has enabled one 'extra' project per company – thus six extra projects so far worth on average £50k each means that additional turnover of £300k has been generated in the UK lighting sector. Since sector gross margins are ~50% this equates to £150k GVA.

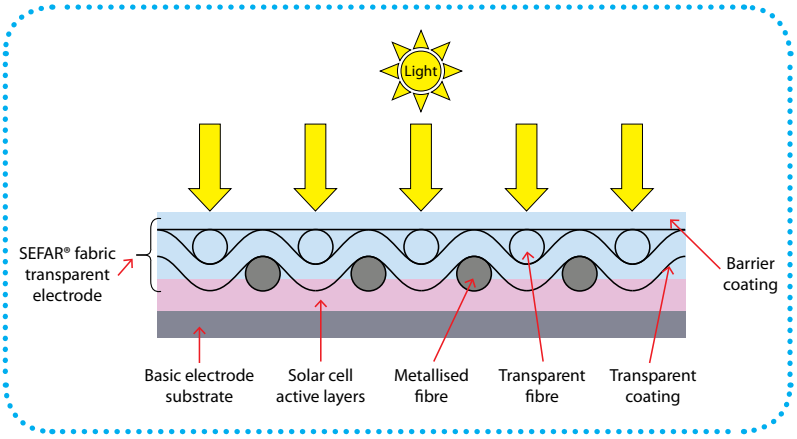
Furthermore, after the payback period of just over three years, seven years of additional energy saving will be enjoyed by the project clients. Projected lifetime net energy savings for clients therefore amount to £725k.

Low Carbon Technologies: Novel Electrodes for Organic PV

Improved design of organic photovoltaic electrodes. Emissions reductions of 257k tonnes of carbon emissions.

In the search for low-carbon energy sources that can match fossil fuels in scale, solar energy has long been one of the favoured candidates.

Commercially available solar panels use a pure semiconductor material such as silicon for the active element. Organic photovoltaic cells (OPV, made from polymer materials) are an alternative and could be much cheaper to produce than silicon in the future. However, cells that use these materials are currently much less efficient than cells based on silicon, at below 12% compared to over 26% for the best silicon cells. Achieving higher efficiencies is therefore an important objective of research.



A key advantage of organic cells is that they can be made flexible – enabling solar panels on apparel, posters and smart labels, for example. For these applications, flexible, transparent electrodes are needed to replace the increasingly expensive but commonly used indium-tin-oxide (ITO), which on flexible plastic substrates has much lower conductivity and cracks easily, and hence works best on rigid glass surfaces.

The design of the electrode layers that carry the current is a key part of creating a functional photovoltaic cell. It must conduct the current efficiently, and must be transparent on at least one surface to allow the light to fall on the photovoltaic material. Where a polymer electrode is sufficiently flexible, it does not conduct electricity as well as ITO, so a grid of conducting wires is often used to collect the current generated within the electrode. This approach presents designers with a difficult problem: too many wires block out the light used by the cell, but too few wires result in a loss of current produced by the cell.

Swiss company Sefar AG, together with EMPA, the Swiss Federal Laboratories for Materials Science and Technology, have developed a fabric electrode where evenly spaced metal wires are weaved into a semi-transparent polymer fibre mesh so that the metal wires are only just exposed at one face of the layer. This mesh electrode was designed for cost-effective roll-to-roll fabrication.

NPL scientists measured the current created at different points in the grid with very high resolution, using a method called spatially-resolved photocurrent mapping. Current generation efficiency was observed to be higher where the polymer wires were in comparison to the open areas in the mesh, indicating that there was no need to increase the open area of the meshes by rational design of the metal wire positioning.

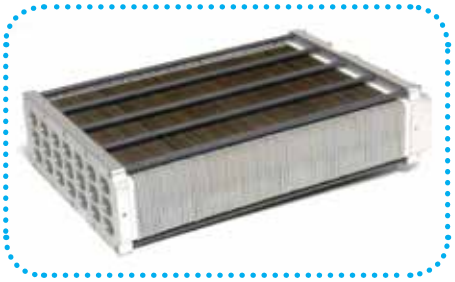
In the UK Department for Energy and Climate Change's central deployment scenario for solar PV, it is expected to reach 11.9 GW by 2020 with around 2.6 million installations completed. Technologia estimates that OPV might achieve 1% penetration of the solar PV market by 2020, and therefore could account for 119 MW in the UK. Assuming that initial OPV applications will mainly be in replacing grid electricity used to charge batteries, Technologia calculates that as much as 257k tonnes of carbon emissions could be saved. McKinsey estimates that global PV capacity by 2020 could be as high as 1kGW. Applying a calculation of direct proportionality from the size of the generation capacity, that is assuming the same levels of penetration in the global market, indicates savings on the scale of 2.3 million tonnes of carbon emissions.

Low Carbon Technologies: Real Time Metrology for Fuel Cells

Voltage mapping and in-stack catalyst area measurements for fuel cells. Potential carbon saving of 0.8 million tonnes. Innovative diagnostic techniques for optimisation of fuel cell performance and durability.

Fuel cells represent a potentially more efficient way to convert chemical energy to electrical energy than most of the current alternatives. Theoretical studies have shown that, if the waste heat from the fuel cell is captured and used, their efficiency can approach 100%. In addition, fuel cells are effectively non-polluting. However, while these advantages have led to fuel cells being used in some applications, they have not become widespread. The main obstacles have been their cost, durability and the lack of a refuelling infrastructure.

Measurement of performance of operating fuel cells is extremely challenging. NPL has recently devised two innovative ways of making such measurements, which are supporting efforts to extend fuel cell durability. Both techniques have been developed for the polymer electrolyte membrane (PEM) fuel cell, widely regarded as the most promising type of fuel cell for electric vehicles.



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The first innovation is a ground-breaking type of reference electrode that can be used to map the variation in potential across the entire active area of the fuel cell.

The durability of fuel cells is highly affected by non-uniformities that can lead to the development of 'hot spots' which can eventually lead to localised failure. The NPL reference electrode enables design of cells with more uniform conditions, resulting in fuel cells that last longer - a key factor affecting whether they are economic to use.

"Voltage mapping is directly relevant to 30% of our R&D. All fuel cell designs are a compromise between different goals so the desire to achieve uniform voltage distribution has to be balanced against cost. But the technique helps us make informed design decisions that in turn should typically yield improvements in our fuel cells." says Dr Simon Foster of Intelligent Energy, the UK's leading PEM fuel cell manufacturer.

The second NPL innovation is a new technique for measurement of the active catalyst area of each cell in a fuel cell stack.

As fuel cells age the active area of platinum catalyst diminishes so measuring this area is an indication of the health of the cell. Using conventional methods, such measurements were only possible at beginning and end of life. The NPL technique makes it possible for the first time to monitor the active area of each cell throughout the lifetime of the stack, creating an invaluable tool for lifetime and durability studies.

Simon Foster comments: *"It's like measuring the wear on pistons without taking the engine apart. It helps us understand degradation processes and failure modes. Ultimately it may even lead to an enhanced real-time diagnostic tool….the technique could yield a 5% to 10% improvement in performance."*

Both NPL techniques have already been adopted by leading fuel cell and component manufacturers within the UK, including Intelligent Energy and Johnson Matthey - a global speciality chemicals company and one of the world's largest manufacturers of fuel cell electrodes. NPL has also received many enquiries from within the UK and further afield from companies wishing to apply the new diagnostic tools to their own hardware. Widespread uptake of both techniques is envisaged in the continuing drive towards commercialisation of the technology.

There has been significant private and public investment in fuel cells across the world. The total European Commission contribution between 2014 and 2020 alone could range from €2.5 - €4 billion, in addition to an estimated €2 - €4 billion funding from national/regional programmes. Using the Department for Energy and Climate Change's fuel specific figures for kg of carbon dioxide per kWh abatement and assuming that fuel cells have half the carbon footprint of alternatives, it is estimated that the carbon saving associated with these NPL innovations amounts to 0.8 million tonnes.

Establishing measurement standards for methane and biogas. Enables disagreements to be resolved in the course of trade, and for interested parties to test compliance with regulatory standards, thus increasing transparency in a growing market and saving transaction costs for buyers and sellers.

An important role of measurement standards is in enabling trade and regulating markets. Recent work by NPL as part of an EU collaboration has applied this age-old principle to emerging EU markets for a low-carbon fuel: biogas (methane produced from anaerobic digestion of sewage sludge, or wastes from food production or agriculture).

In its raw state, biogas contains around 60% methane (the fuel gas in natural gas), about 2% hydrogen sulphide and ammonia, together with a variable collection of contaminants at lower concentrations, with the remainder (around 38%) being carbon dioxide. At this stage it is saturated with water vapour.

The gas needs to be cleaned before it can be traded for use as a vehicle fuel or inserted into the grid - a process called 'upgrading'. Carbon dioxide is removed to increase the calorific value (the fundamental attribute that determines market price), sulphur compounds are removed so that sulphur dioxide (SO_2) is not formed on burning, and halogenated compounds are removed to avoid the formation of other corrosive products of combustion. Work at NPL led to the production of reference materials for methane in biogas. These are gas mixtures prepared using specialist techniques and equipment that have a specified composition with known uncertainty. In addition, NPL led the development of measurement methods for impurities in biogas including siloxanes, which can burn to yield inert but abrasive deposits in engine exhausts and convertors.

For natural gas, well established methods exist to calculate calorific value from the chemical composition of the gas – but these cannot be applied to biogas because of the difference in minority components. Other work in the project helped define a corresponding method for biogas that was checked directly by comparing it with accurate measurement of heat produced when samples were burned. The project also led to new methods and standards for measuring the content of water vapour, as this has an important influence on combustion and the safety and corrosion of the distribution equipment.

The project enables disagreements to be resolved in the course of trade, and for interested parties to test compliance with regulatory standards, thus increasing transparency in the market and saving transaction costs for buyers and sellers.

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In assessing the probable impact of advanced metrology on this emerging market, lessons can be drawn from Sweden where biogas is already widely used as a vehicle fuel in a 60:40 mixture with natural gas. In 2010, approximately 32,000 vehicles, including 1,400 buses, were able to use vehicle gas in Sweden. To illustrate the scale of potential impact, Technologia compared potential adoption by the UK with the Swedish exemplar. In 2011, approximately 75 million m^3 of biogas were used in vehicles in Sweden, equating to some 725 GWh. If the existence of measurement standards means that, for example, the UK reaches the 2011 levels of adoption in Sweden a year sooner than it would otherwise have done, there would be a one-off emissions saving of 235k tonnes.

In a wider perspective, increased use of biogas in the EU gas network will occur as other countries adopt and modify the legal and technical framework established in Germany, where 5% of biogas plants feed gas into the grid. In Technologia's opinion, the existence of soundly-based measurement standards will accelerate this development too.

Measuring the impact of solar PV on the grid. Potential annual carbon savings of 16.7k tonnes.

Smart grid technology is a key prospect of moving today's energy industry towards a low carbon future. It will be critical for dealing with the different ways in which we will use energy, and the more local and renewable sources of supply. Network operators need to understand both the impact of such sources of energy on the current grid and how to design and plan for a smart grid.


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In doing so, power quality is an important issue. NPL scientists have designed and built specialised equipment – the Digitizer - to measure power quality in the field with unprecedented accuracy. Using this equipment, a team from NPL carried out a pioneering study of the effects of a large scale photovoltaic array (PV) installation on power quality. The survey was conducted on an estate on the Isle of Anglesey which is characterised by a high proportion of PV systems retrofitted to two-story houses and flats - a so-called 'PV cluster' funded by the Welsh Government.

The study had three significant findings:

1.) Measurements in the middle of the feeder showed a rise of about 4 volts during PV generation. The NPL team noted that the voltage on this network was close to its statutory maximum and signalled that such mid-feeder voltage rises could therefore be of concern to the network operators when planning to add substantial PV to their systems.

2.) On average the PV units were generating only around half of their expected capacity (based on the manufacturer's specification) on the sunniest days during the survey, which was conducted in the summer months. This could be caused by the facing angles of the PV on the roofs not being optimal – more studies and modelling would be needed to confirm this. Further work could improve the PV efficiencies attained in practice, at least in the UK, by up to 50%. The NPL project identified a serious issue and will accelerate the quest for a solution.

3.) The study highlighted the fact that, while the inverters in the PV system generate fundamental active power, the grid is required to supply the harmonics and the reactive power. So the value of the PV power to the grid is significantly reduced.

The three key findings of the study will enable grid planners to anticipate and sidestep several potential pitfalls in the design of the future grid and, as such, should make a highly significant contribution to carbon reduction.

According to a recent report on PV in the EU, most of the capacity in the UK was installed in 2011 (est. 931 MW peak of a total capacity of 1,014 MW). The impact of the smart grid knowledge that emerged from the study can be measured through the capacity potentially affected by the study's findings. Assuming that on average just 5% of the 2011 installations suffered from the same efficiency issues as the Anglesey installation, up to 2.5% of the rated capacity could be at stake.

Technologia calculate that the projected carbon savings from optimising the PV installed in the UK, and assuming that the electricity replaces 'average' grid electricity, could therefore be as much as 16.7k tonnes each year for the 2011 cohort alone. Over the ten year lifetime of the PV installations the carbon savings would amount to 167k tonnes. If the extra capacity is costed at current UK feed in tariff prices (for 4-10kW installations - 14.5p per kWh), it would be valued at nearly £5 million each year – thus additional electricity worth approximately £50 million would be generated over the ten year notional lifetime of the PV panels and this sum would be a net contribution to GDP (gross domestic product).

Smart Grids: Smart Grid Digitizer

Developing an on-site measurement instrument to enable Smart Grid design and saving 839k tonnes of carbon.

Instruments called 'digitizers' have become increasing useful for making alternating current (ac) measurements, particularly of ac power and power quality, which require access to multi-channel sampled data. A popular approach in ac metrology has been to use multiple, synchronised commercial sampling voltmeters or to develop integrated circuit based digitizer systems in order to make sample-based ac measurements.

Scientists at NPL have developed a 'metrology grade' digitizer system suitable for use in the field. Designed for high granularity three phase power levels and quality measurements, the Digitizer's rugged briefcase style design makes it ideal for portable on-site working.

The NPL Digitizer has eight independent highly isolated channels. Software selectable ranges enable low voltage measurements to be made up to 440 V and built-in integrators make it ideal for use with so called 'Rogowski' coils for non-invasive high current measurement.

Field measurements of power quality in the evolving Smart Grid presents a major challenge and requires the use of leading edge instruments like the Digitizer. It allows measurement of power quality in the field with exceptional accuracy and is already being used in Belgium, Denmark and Turkey, helping scientists assess the impact of renewable electricity on the Smart Grid and plan for ambitious energy transmission schemes. The Swedish National Laboratory, SP, and the Swedish transmission grid operator Svenska Kraftnat have used the Digitizer to monitor the power quality of the SwePol system - a 255 kilometre high-voltage direct current (HVDC) submarine cable between Sweden and Poland.

The NPL team which designed the Digitizer, carried out a pioneering study of the effects of one of the most challenging components of the Smart Grid – a large scale photovoltaic array (PV) installation. The findings of this study will enable grid planners to anticipate and sidestep several potential pitfalls in the design of the future grid and thus should make a highly significant contribution to carbon reduction.

Technologia calculated that the projected carbon savings arising from just one result of an early study undertaken by NPL using the Digitizer could be as much as just over 167k tonnes.

This figure serves as a useful guide to the potential magnitude of the value of the five Digitizers in use across Europe. If each instrument were to enable just one advance in knowledge, comparable in carbon saving potential to that made by the NPL team, the total benefits delivered would be 839kt of carbon savings.

In the same early NPL study cited above Technologia estimated economic benefits of up to £50million additional GVA from the retail value of the increased electricity output of solar cells. If each instrument were to enable an advance in knowledge comparable in value to that made by the NPL team then the total commercial benefits delivered would be £250m GVA.

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