European Metrology Research Programme

Energy impact report

A summary of the outputs and impact of the finished EMRP joint research projects in Energy.

The aim of this theme is to establish the measurement infrastructure necessary to support Europe's sustainable energy goals. The research is focused on technologies that support reduced greenhouse gas emissions and the security of Europe's energy supply.

EURAMET e.V. - the European Association of National Metrology Institutes

Measurement matters

Measurement underpins virtually every aspect of our daily lives, helping to ensure quality and safety, support technological innovation and keep our economy competitive.

Supported by the European Commission, EURAMET's **European Metrology Research Programme (EMRP)** brings together National Measurement Institutes in 23 countries to pool scientific and financial resources to address key measurement challenges at a European level.

The programme is designed to ensure that measurement science meets the future needs of industry and wider society. Research is structured around four themes – Energy, Environment, Health and Industry – as well as the measurement needs of emerging technologies and the fundamentals of the SI measurement units that form the basis of Europe's measurement infrastructure.

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Metrology for energy

The first group of projects under the EMRP Energy theme was finished in 2013. The aim of this theme is to establish the measurement infrastructure necessary to support Europe's sustainable energy goals. Focus was placed on technologies that support reduced greenhouse gas emissions and the security of Europe's energy supply.

The Energy theme supported nine EMRP projects involving 39 research groups from European National Metrology Institutes (NMIs) and Designated Institutes (DIs) alongside researchers from academia and public research organisations. The project researchers also worked with the energy industry – with energy generators and distributors, large scale users and key process equipment and instrumentation suppliers – to ensure the new measurement capabilities met their needs and to transfer the new knowledge and skills generated to end users.

Research was conducted to develop the measurement infrastructure needed to support the introduction of sustainable energy into Europe's energy mix, accelerate uptake of low carbon technologies and improve the efficiency and security of the existing energy infrastructure.

Sustainable energy

The increased use of energy from renewable sources is a key feature of European energy policy. The Renewable Energy Directive (2009/28/EC) sets a target of at least 20 % of Europe's total energy needs fulfilled by renewables by 2020 including at least 10 % of transport fuels from renewable sources by the same date. In addition, non-conventional lower carbon energy sources, such as liquefied natural gas (LNG), not only play a role in lowering our carbon footprint but also play an important part in securing Europe's energy supply.

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Three EMRP projects focused on the development of measurement infrastructures required for biogas, liquid biofuels and LNG to ensure they can be traded fairly and efficiently and can be incorporated safely into existing distribution networks and infrastructures.

Measurement challenges

Incorporating renewables and non-conventional fuels into the energy mix creates a range of measurement challenges. Fuels are bought and sold based on their energy content. This requires accurate knowledge of a range of their physical and chemical properties. While traditional natural gas has very well-known properties, fuels from renewable sources are more varied in terms of chemical composition and behaviour. In order to assess the amount of fuel and its energy content at the point of trade, its properties in terms of volume, density and chemical composition need to be known.

In addition, the behaviour of the fuels with varying environmental parameters such as temperature and pressure needs to be understood to ensure safe and efficient processing, transportation and distribution. This requires new measurement infrastructures that can provide reliable and robust measurements to identify and quantify a range of new energy gases and the ability to measure their physical parameters and behaviour under conditions typical of their production and distribution processes.

Low carbon technologies

Reducing carbon emissions also requires increased use of low carbon technologies. Two EMRP projects focused on energy harvesting technologies and energy efficient lighting.

Harvesting energy from waste heat, movement and vibration can provide energy at the point of use for a wide range of portable electronic devices, decreasing the demand for energy from the grid and batteries. It also offers opportunities for increasing the efficiency of vehicles via recycling energy lost to heat.

One-fifth of global electricity consumption is for lighting and a considerable reduction in energy consumption could be obtained by replacing conventional lighting products with low energy technologies such as LEDs.


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Measurement challenges

The development and successful commercialisation of energy harvesting techniques requires appropriate measurement capabilities to accurately quantify and assess the performance of materials, technologies and devices. This requires the development of measurements to assess properties of candidate materials and to assess the very small and variable electrical signals (and other parameters) generated from micro and nanoscale harvesting technologies.

Widespread implementation of LED (solid-state) lighting is hampered by user concern over lighting performance, in particular differences between manufacturers' claims and perceived performance. LEDs generate light in an entirely different way to traditional incandescent and fluorescent lighting and the existing measurement infrastructure was not designed with LEDs in mind. Not only do measurement capabilities need to be widened but the performance of these new lighting sources in terms of human perception needs to be better understood.

Modernising the electricity infrastructure


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Upgrades to the existing electricity generation and transmission infrastructure are required to ensure a reliable electricity supply and contribute to carbon reductions. Europe's energy mix will include fossil fuel powered plants, nuclear power and renewables. Current fossil fuel powered energy plants will remain in service for many years and will be upgraded not only to extend their lifetimes but also to improve their efficiency and reduce their carbon emissions. Next generation nuclear power plants are planned based on new reactor designs and fuels.

Increasing levels of electricity generated from renewables such as solar and wind need to be incorporated into Europe's electricity grids. This brings the dual challenge of managing intermittent electricity inputs and geographical remoteness. Solutions include long distance high-voltage direct current (HVDC) transmission and 'smart grids' that can accommodate variable and intermittent incoming power.

Four EMRP projects focused on the measurements required to help improve the efficiency of existing power plants, support the development of next generation nuclear plants and HVDC connections, and manage smart grids.

Measurement challenges

More efficient conventional and next generation nuclear power plants will operate at significantly higher temperatures than current plants and so require new measurement methods and instrumentation to assess both the temperature during operation but also to characterise and test the materials used in their construction and operation. Improved measurement capabilities are also required for key performance parameters that determine energy and heat generation and transport such as flow and nuclear decay processes.

HVDC electricity transmission systems require improved measurement capabilities to enable the quantity and quality of electricity to be assessed for trade purposes and efficient operation.

Smart grids need to be able to manage the variable energy inputs from renewable sources while distributing a consistent, reliable and high quality output to users. This requires the development of measurement methods and instrumentation to assess the quantity and quality of inputs for trade purposes and to monitor the stability of the grid as a whole on an on-going basis.

Research outputs:
Sustainable energy

Three EMRP projects addressed the measurement requirements for biogas and other non-conventional gases, liquid biofuels and liquefied natural gas (LNG) to ensure that they can be traded fairly and transported and transmitted safely. They developed new highly accurate composition and calorific measurement capabilities at NMIs, traceable to the SI, where none had previously existed as well as reference materials and measurement techniques to disseminate these measurements to commercial users and for use in the field. NMI capabilities that provide traceable measurements of physical parameters such as volume, temperature and pressure in conditions appropriate for processing, storage and transportation, and distribution of these fuels were also developed.

Characterisation of energy gases

This EMRP project brought together the expertise of scientists at 17 NMIs to develop the metrological infrastructure for the assessment of the physical and chemical parameters of a wide range of gas based fuels.

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The project developed:

- **New accurate chemical analysis methods to determine the composition of a range of biogas and other non-conventional gases, and trace levels of impurities and deliberately added odorants, plus a suite of certified traceable reference materials to transfer accurate measurements to other users.** These new measurement capabilities provide confidence in the verification of non-conventional gases before they enter the distribution network and the cost-effective use of environmentally friendly gas odorants.
- **A primary reference calorimeter (at a European NMI) capable of measuring the energy content (calorific value) of reference gas mixtures of methane and carbon dioxide that correspond to non-conventional gases.** During the project the reference instrument was used to validate modified commercial field calorimeters to demonstrate that, when used in line with structured guidance (developed by the NMI researchers), they are able to accurately measure calorific content of such gases. This provides equipment manufacturers with the opportunity and the confidence to produce commercial instruments for measuring energy content for trade and billing purposes.
- **New national facilities that define and measure humidity at the highest levels of accuracy for a range of energy gases, gas mixtures and at the high pressures used in gas distribution networks.** Humidity measurement is key to ensuring there is no build-up of potentially damaging liquid water or ice in high pressure gas distribution networks. The new facilities are not only available for calibrating commercial humidity sensors with non-conventional gases but also for validating performance of novel sensors and systems. Two innovative approaches to humidity measurement – tuneable diode laser absorption spectroscopy (TDLAS) hygrometers and quasi-spherical microwave resonator (QSR) based hygrometers – were also developed and tested which, with further R&D, may be suitable for commercialisation.

Delivering impact

A number of industrial companies worked closely with the NMI project partners, providing measurement equipment, access to gas processing and distribution facilities, and participating in measurement

intercomparisons – providing the project with knowledge of practical real-world conditions and gaining insight and know-how into best practice measurement methods and potential improvements. One company has been able to validate and gain valuable insight into the performance of a new product recently launched into the market. The NMI in Sweden is exploiting the advances made in impurity analysis in their support of the Swedish biogas industry. The project team has contributed to, and continues to contribute to, the CEN Technical Committee (TC408) developing standards for natural gas and biomethane for use in transport and biomethane for injection in the natural gas grid.

The research outputs are being developed further in the EMRP project: **Metrology for Biogas (Biogas).**

More information	Short name: Biofuels Project number: ENG01 www.euramet.org/project-ENG01
	Details of the related project: www.euramet.org/project-ENG54
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Metrology for biofuels

The EU's Fuel Quality Directive (2009/30/EC) sets out the quality and sustainability criteria for biofuels. Therefore liquid biofuels from a range of sources with different characteristics need to be accurately measured and monitored during production, storage, transportation and distribution. In addition, sustainable development policies also require 'trackability' of biofuels in terms of their biological and geographical origin.

This EMRP project focused on liquid biofuels used in the automotive sector. It developed a measurement infrastructure that not only provides reliable data but can rapidly adapt to different types and origins of biofuels.

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The project developed:

- **Reference methods for chemical parameters at NMIs to identify and quantify methanol, glycerol, glycerides and selected Fatty Acid Methyl Esters (FAME) content of biodiesel in line with the requirements of European standards.** These reference methods ensure that measurements made in testing labs are traceable to national standards and therefore reliable and comparable.
- **Accurate data, traceable to the SI, for key physical parameters of a range of typical biofuels** (density, viscosity, calorific value and state behaviour at high temperatures and pressures). These data enable accurate determination of the volume and energy content for biofuel trade in line with legal requirements and support process control in biofuel production and optimised design of engines using biofuels.
- **Reference measurement methods and reference data for two important biofuel quality indicators** – the pH value of bioethanol and electrolytic conductivity. These indicators are used to assess the risk of corrosion and potential damage to engines using biodiesel. The methods developed have provided data traceable to the SI for the first time.
- **A successful feasibility study of analytical methods for origin discrimination of biofuels** including geographical origin, production method and source materials.

Delivering impact

The project has put in place the metrology infrastructure to enable European and international harmonisation of the measurement methods of biofuels and their blends with fossil fuels. Internationally comparable quality standards and a wider knowledge of properties of biofuels is enabling further technical developments in their use as an automotive fuel and facilitates greater acceptance from customers and

vehicle manufacturers. More generally the development of references for chemical and physical parameters provides confidence in international quality assurance of biofuels and facilitates global trade.

The project's results have been shared with the relevant ISO and CEN Technical Committees (TCs) – CEN TC 19 Gaseous and liquid fuels, lubricants and related products of petroleum, synthetic and biological origin and ISO TC28 Petroleum products and related products of synthetic or biological origin – and have contributed to the draft of a new standard on ethanol test methods under ISO TC28/SC7/WG4.

More information	Short name: GAS Project number: ENG09 www.euramet.org/project-ENG09
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Metrology for liquefied natural gas

This EMRP project brought together the expertise of scientists at 12 NMIs and four universities to make a significant reduction in the measurement uncertainty of transferred energy in liquefied natural gas (LNG) for trading purposes. This required improvements in the measurements for LNG quantity and calorific value. The project developed improved national capabilities and improved techniques for field measurements for: flow measurements, as a method to accurately assess LNG quantity; and composition and density in order to determine the LNG calorific value. The project supported both traditional and innovative measurement methods by developing a metrological framework consisting of test and calibration standards together with the written standards and guidelines.

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The project developed:

- **The world's first primary standards for flow measurement at -163 °C – the temperature of LNG.** This is the first step in developing traceability for LNG flow meters. The system currently handles flow rates up to 25 m^3 per hour and a scaled up facility has been designed for 200 m^3 per hour. Commercial flow meters were evaluated against the new standards and against static measurement methods (ship tank gauging, weighbridge methods) to demonstrate the potential of flow based methods in the field. These evaluations and the metrological framework will make it possible for LNG flow metering to become an accepted method with a clear potential to reduce overall measurement uncertainties and simplify operations.
- **Improved understanding of LNG composition assessment.** The performance of different sampling systems to assess LNG composition was assessed via a review of design principles and analysis of real data provided by industry. The published findings will enable industry to review and improve their measurement installations.
- **Improved LNG density measurements.** An advanced primary LNG densitometer system is now available providing reference data with very low uncertainty and covering densities from 10 kg per m^3 to 1000 kg per m^3 in a temperature range from 90 K to 290 K and at pressures up to 8 MPa. Applying the accurate reference data to existing equations of state used to calculate LNG density and calorific value revealed considerable variation with different physical conditions (temperature and pressure) that, in commercial terms, equates to significant financial impact for buyers and sellers. The project partners are developing improved density modelling and equations of state in another EMRP project.

Delivering impact

The measurement of LNG for trading purposes is regulated and heavily influenced by the directives, standards and guidance of the legal metrology community, ISO, CEN and the industry association GIIGNL (International Group of Liquefied Natural Gas Importers). The project outputs have been widely shared with

these communities. As a result dynamic flow measurements have been incorporated in the ISO standard for LNG process control ISO10976 and ISO TC 28 (Petroleum products and related products of synthetic or biological origin) has adopted a resolution to form a new and joint working group for the creation of a dedicated ISO standard for LNG flow metering systems. The new edition of the GIIGNL LNG custody transfer handbook, a key guidance document used by industry, will incorporate the knowledge created in the project.

The project partners are continuing to work with the regulatory, standards and industrial communities, and the research outputs are being developed further in the EMRP project: **Metrological support for LNG custody transfer and transport fuel applications.**

More information	Short name: LNG Project number: ENG03 www.euramet.org/project-ENG03
	Details of the related EMRP project: www.euramet.org/project-ENG60
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Research outputs:
Low carbon technologies

Two EMRP projects addressed the need to accurately assess the performance of low carbon technologies for energy harvesting and solid-state lighting. They developed measurement facilities, traceable methods and reference materials to reliably and robustly assess performance parameters to support both the design and development of effective low carbon technologies and their adoption by manufacturers and consumers.

Metrology for energy harvesting

Mass market adoption of energy harvesting technologies is dependent, in part, on reliable information about their performance. Both developers and users of energy harvesting technologies require reliable performance information in order to design and implement suitable devices. This EMRP project developed measurement capabilities for two approaches to energy harvesting: waste heat and movement and vibration i.e. technologies that perform thermo-electric and electro-mechanical energy conversion.

The project developed:

- **New facilities, reduced uncertainties and new reference materials for the assessment of the performance of thermo-electrical converters.** New facilities have been constructed for measuring the thermal conductivity of thermoelectric materials from room temperature to 725 K with reduced uncertainties (between 5 % and 8 %). High temperature reference materials were developed for the Seebeck coefficient (a key performance parameter) at a range of temperatures. These are particularly important for improving engine efficiency in the automotive industry and it is the first time that reliable reference materials for Seebeck coefficients with low uncertainties above about 400 K have been made available.
- **New facilities to assess the properties and performance of vibrational energy harvesters** such as piezoelectric converters. These included capabilities to conduct performance mapping of vibrational energy harvesters with varying inputs in terms of vibration frequency, amplitude, acceleration and load resistance. This performance mapping provides important input into the development of standardised test methods and performance metrics.
- **Unique facilities for the measurement of efficiency for electro-mechanical conversion** and models to predict efficiency in technologies of commercial interest such as the piezoelectric cantilever. These facilities enabled the identification of new sources of internal loss in piezoelectric converters, and demonstrated that efficiency can be significantly improved by reducing the amount of piezoelectric material, potentially saving cost as well as improving performance.
- **Traceable measurement of electrical quantities in energy harvesting devices.** New techniques were developed for power measurement for the low level and complex signals typically encountered in energy harvesting power measurements. These techniques enable a wide range of measurement equipment to be tested and calibrated.
- **Novel approaches to assess micro and nano scale energy harvesting devices.** Energy harvesting is in its infancy and a suite of measurement facilities has been developed to support the development of MEMS (micro-electromechanical systems) as energy harvesters and emerging approaches based on nanostructured thermoelectric and piezoelectric devices.

Delivering impact

Documentary standards play a key role in the uptake of energy harvesting technologies. Input from the project team was requested by the International Society of Automation for the development of energy harvesting performance metrics for their Power Sources Working Group (ISA100.18). Broader standards participation by the NMI community has been discussed and is expected with IEC Technical Committee 113 (Nanotechnology standardization for electrical and electronic products and systems) and IEC Technical Committee 47 (Semi-conductor devices).

The new measurement capabilities and knowledge generated are being taken up by industry in a number of ways. A large materials engineering company is using the project's research to help them develop standardised energy harvesting metrics, to provide their customers with a clear understanding of the output of a device in specific environments. A global engineering company is applying the measurement capabilities to energy harvesters currently under development. The project partners are also working with an industrial consortium, including a world-leading provider of aerospace systems, an international software company and four SMEs, which is developing vibration energy harvesters for autonomous sensors for aircraft monitoring.

More information	Short name: Harvesting Project number: ENG02 www.euramet.org/project-ENG02
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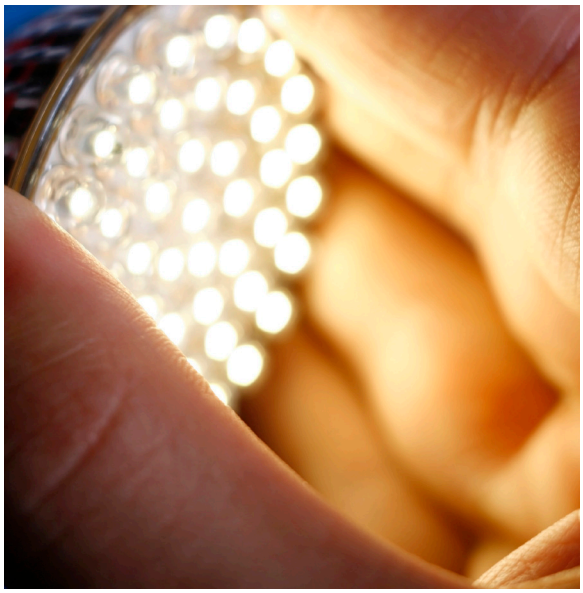
Metrology for solid-state lighting



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European NMI experts in photometry came together to extend their capabilities in the measurement of incandescent and fluorescent lighting to solid-state lighting (i.e. LEDs). Solid-state light sources not only generate light in an entirely different way to traditional sources but produce light with different properties, such as spectral output and angular distribution of the light produced. Therefore accurate measurements of electrical, optical and visual performance are required for the design, manufacture and quality control of solid-state lighting devices.

This EMRP project developed:

- **New facilities to measure the optical parameters of solid-state lighting devices.** Facilities are now available to assess the spectral and dynamic features of solid-state lighting devices. Studies were conducted of the effect of the fast-pulsed electrical inputs to solid-state devices on the colour of their output.
- **New facilities to measure the key electrical parameters of solid-state lighting devices.** Traceable measurement facilities are now available to measure the electrical power and power factor of solid-state lighting devices. These measurements are essential to determine the energy efficiency of solid-state lighting devices and to assess how large-scale implementation of these sources may impact on the electrical power grid.
- **Improved methods to assess luminous efficacy.** This is the most important performance parameter when it comes to assessing and generating energy savings. Access to traceable measurement services is essential for manufacturers and customers for establishing confidence in product claims. The project has demonstrated that NMI facilities can reliably determine this parameter for solid-sate devices.
- **Important developments towards establishing reliable life-time estimation for solid-state lighting devices.** The life-time is an important economic and environmental factor in the adoption of solid-state lighting. The project developed and tested a process for accelerated aging of these long-lasting light sources.

- **New facilities to measure the visual properties of solid-state lighting devices in real-world contexts.** These were used to develop methods to assess key qualities of solid-state sources including colour rendition, visual comfort, and mesopic (low light) vision that are critical to consumer acceptance of solid-state lighting.

Delivering impact

Consumer confidence in the product claims for solid-state lighting is essential to increased uptake. This requires that performance assessments are based on appropriate and traceable measurement methods. This will largely be achieved via the specification of measurement methods in documentary standards. The project has made contributions to the key standards making bodies – the CIE (recognized by ISO as an international standardisation body) and CEN – including the CIE Test Standard (S-025:2015): Test Method for LED Lamps, Luminaires and LED Modules, CEN standard EN13032 published in June 2015 and a revision of EN13021 expected to be published in 2016.

Industrial uptake of improved methodologies and traceability is already underway. A manufacturer of luminance and illuminance meters participated in the project and is marketing commercial instruments for solid-state lighting that can now be made traceable to national standards at NMIs, and a calibration laboratory is aiming for accreditation in the measurement of solid-state lighting devices. Together the availability of commercial measurement instrumentation and calibration facilities increases the use of accurate measurements in the solid-state lighting supply chain.

Project partners worked with Autostrade per l'Italia (that manages Italy's highways) to investigate the use of solid-state lighting in tunnels. The work will contribute to safety critical design parameters for tunnel lighting.

The project has also generated two patent applications in methods to assess LED efficiency and colour mix.

The research outputs are being developed further in the EMRP project: **Metrology for efficient and safe innovative lighting.**

More information	Short name: Lighting Project number: ENG05 www.euramet.org/project-ENG05	
	Details of the related EMRP project: www.euramet.org/project-ENG62	
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Research outputs:
Modernising the electricity infrastructure

Four EMRP projects addressed measurement requirements to improve the performance of existing power plants and support the development of an electricity generation infrastructure for the future. Existing measurement capabilities were extended and improved – for example to higher temperature ranges and voltages required for greater efficiency in existing power plants, next generation nuclear reactors and long-distance HVDC transmission systems, and new measurement capabilities were developed to ensure the stability of electricity grids taking electricity from a wide range of traditional and sustainable sources.

Metrology for improved power plant efficiency

Improving the efficiency of traditional nuclear, coal and gas plants will make a significant contribution to energy conservation and reduced emissions. This EMRP project brought together a wide range of metrology expertise and disciplines from nine NMIs to reduce the measurement uncertainty of important control parameters (temperature, flow, thermal energy and electrical output) of power plants to support more efficient operations. It also conducted research into the advanced materials used in future turbines. The total results of the research work will provide the opportunity for an overall additional enhancement of energy efficiency of 2–3 % for all types of large power plants, and therefore will result in a comparable amount of reduction of emissions.

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The project developed:

- **Improved temperature measurements** in the form of reduced uncertainties for measurements at the temperatures and techniques used in power plants. For contact thermometry this enables a reduction in measurement uncertainty in steam power plants from 8 K to 3 K at temperatures up to 700 °C. For non-contact thermometry the understanding of the spectral emissivity of turbine materials was improved above 800 °C and dedicated high-temperature fixed points were developed for the calibration laboratory of a manufacturer of radiation thermometers.
- **Improved facilities and methods for thermophysical properties above up to 1500 °C.** The facilities for thermal diffusivity, emissivity and specific heat were developed to assess existing and new high performance materials and coatings used in turbines in gas power plants.
- **Improved flow measurements** via improved extrapolation models for the performance of a range of flow sensors at the high temperatures, flow rates and pressures in power plants. The models were proven experimentally to be metrologically valid and allow for a reduction of the uncertainty of flow rate measurements from approximately 3 % to 0.5 %.
- **Improved electricity measurements.** A complete system was developed to perform fast and reliable electrical output measurements of a power plant with low uncertainty (better than 0.1 % under laboratory conditions and 0.15 % on-site).

Delivering impact

The improved measurement capabilities developed enable manufacturers of measurement instrumentation to offer enhanced products that will support improved power plant efficiency. One company has developed a novel flow meter based on the project's outputs and is currently undergoing on-site testing in order to gain regulatory approval for the device. It is estimated that the efficiencies in plant operation resulting from the device's use would be equivalent to the amount of electricity required to power 10,000 extra homes.

Furthermore the operators of two power plants applied the project's outputs related to flow and temperature measurement and estimated a potential efficiency improvement of 1.5 %.

More information	Short name: Powerplants Project number: ENG06 www.euramet.org/project-ENG06
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Metrology for smart electrical grids

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This EMRP project made significant advances in creating a metrology infrastructure for monitoring stability and quality of supply of smart electrical grids in order to support the effective development and implementation of smart grids.

The project developed:

- **Tools for designing metrological strategies for cost-effective optimized measurement and control of smart grids.** The project's algorithms for modelling, simulation, and network analysis of smart grids enable operators to develop effective measurement strategies, optimal sensor placement plans and cryptographic infrastructures for grid security.
- **A measurement framework for reliable and accurate Phasor Measurement Units (PMUs).** PMUs are a key tool for monitoring stability of smart grids. The project developed a suite of devices to provide traceable measurements and practical methods to assess stability: a reference PMU, relevant reference test signals in line with IEEE standards and a prototype of a commercial PMU.
- **Significant insight into the effect of renewables on power quality.** On-site measurement campaigns in six locations provided important new data on the effect of renewable energy on power quality. This will enable grid operators to predict the impact of planned large-scale installations and make provisions for network reinforcements to mitigate any detrimental effects they have on power quality or network reliability.
- **Traceable on-site energy measurement systems for ensuring fair energy trade.** The project developed techniques and devices to support the cost-effective implementation of accurate smart meters for grid operators and consumers.

Delivering impact

The project partners worked closely with utility companies and instrumentation manufacturers throughout the project. The on-site measurement campaigns deepened relationships with the industrial community. As a result the project's outputs are being adopted by a number of companies. For example: the PMU calibration service has been used for evaluation of commercial PMUs in order to enable the manufacturer to identify weak points in the design and make improvements; a commercial smart meter has been tested using the testing system developed in the project; an NMI is working with an operator to help install PMUs in a grid in the Netherlands to monitor stability and quality; and smart meter data being collected in Sweden is being evaluated with the analysis tool developed in the project. In addition, important contributions have been made to the industrial documentary standards including a Technical Brochure of the CIGRE (Council of Large

Electric Systems) committee on PMU applications for electrical grid and the 2014 revision of the IEEE standard for PMU testing.

Further research on metrology for smart grids is being undertaken in the EMRP projects:

Measurement tools for Smart Grid stability and quality (SmartGrid II)

Sensor network metrology for the determination of electrical grid characteristics (Gridsens)

Non-conventional voltage and current sensors for future power grids (FutureGrids)

More information	Short name: SmartGrid Project number: ENG04 www.euramet.org/project-ENG04
	Details of the related EMRP projects: SmartGrid II www.euramet.org/project-ENG52 Gridsens www.euramet.org/project-ENG63 FutureGrid www.euramet.org/project-ENG61
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Metrology for high voltage direct current

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High voltage direct current (HVDC) transmission systems are a key tool in extending the capacity of electricity grids and integrating sustainable energy from remote locations into the existing network. This EMRP project brought together eight NMIs and DIs to develop the metrological infrastructure to support a wide implementation of HVDC transmission in Europe. The research addressed metrological challenges that support a reduction of losses in HVDC transmission, ease the introduction of renewable energy sources, enhance the stability of electric power grids, support low loss, long distance energy transmission and ensure fair trade between organisations employing the grid.

The project developed:

- **Improved measurement of power loss.** State-of-the-art methods and instrumentation to evaluate losses in AC DC converter values (the key source of losses) were developed, as well as techniques to estimate the losses at the design stage, in order to support the needs of systems designers. The ability to identify and reduce losses has a direct impact on fuel use and greenhouse gas emissions.
- **Improved capabilities in high voltage measurements.** The measurement range was extended from a few 100 kV to 1000 kV and the uncertainties decreased substantially (to 0.005 %) in order to support accurate electricity metering and loss determination. A system suitable for on-site calibration was developed and tested at HVDC converter stations in Europe and Japan.
- **New methods to assess the causes and effects of poor power quality** were developed and tested on-site at HVDC stations. These methods assessed harmonics and inter-harmonics introduced into the grid system by the HVDC converter values. The knowledge generated will enable the design of appropriate filters to improve power quality and prevent component failure.
- **Development of calibration methods and test systems for DC meters.** Calibration services for primary current and voltage transducers for revenue metering on the DC side of converter stations have been created. Accurate metering is essential for the trading of electricity between commercial partners. A

prototype DC energy meter was developed and demonstrated at the Lindome Scanlink 1 HVDC Station, proving that DC-side metering is feasible. The specifications and test methods for DC side electricity meters have been identified and suggested for future inclusion in publicly available written standards.

Delivering impact

The project worked closely with HVDC operators and equipment manufacturers to understand needs and test solutions on-site in HVDC converter stations. As a result the Swedish electricity transmission system operator now refers to methods developed in the project to define verification of losses in its procurement specifications for a new HVDC intertie, and the Swedish NMI, SP, has been awarded a contract to perform the measurements. The long-term measurement campaign in a HVDC system converter station has yielded a vast amount of power quality that is available for further studies and analysis. Documentary standards are an important route to the use of best practice and the project's outputs have been used in the preparation of an IEC standard for loss evaluation of voltage source convertors.

More information	Short name: HVDC Project number: ENG07 www.euramet.org/project-ENG07
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Metrology for new generation nuclear power plants

The next generation of nuclear power plants will be considerably different from existing plants. They will use different fuels, different reactor designs and operate at much higher temperatures and, as a result, require appropriate and robust measurements to underpin their development and safe and effective operation.

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This EMRP project developed:

- **Improved temperature measurement for nuclear power plant applications** via the development of new reference temperature fixed point at 1153.8 °C and new stable temperature sensors and self-validation measurement methods for the nuclear environment.
- **Improved understanding of the thermal properties of advanced materials for nuclear design** via the development of new reference facilities for the measurement of thermophysical properties of solid materials up to 1500 °C or 2000 °C and improved thermodynamic models for a range of major and minor actinide (nuclear fuel materials) containing systems relevant to nuclear fuels (both in reactors and during reprocessing) and coolants.
- **Improved metrology for neutron cross section measurements and new relevant nuclear data.** An easy-to-use calibrated neutron fluence transfer standard was developed that will reduce uncertainties in measurements crucial to the selection of reactor materials. Similarly improved nuclear data was developed for the fuels and decay products of new reactors. Alpha-particle emission probabilities of 238U were determined with significantly improved uncertainties and a novel approach based on a cryogenic detector was applied to beta spectra.
- **Development of improved techniques for accurate on-site radioactivity measurements.** Prototypes of a portable self-calibrating Triple to Double Coincidence Ratio (TDCR) liquid scintillation counter with innovative digital electronics were built and validated against the international reference system for a range of beta-emitting radionuclides.

Delivering impact

The metrology community is very well connected with nuclear industry, regulators and the wider R&D base. Project outputs have been shared with this community and are expected to be of benefit in future plant safety considerations. New temperature monitoring instrumentation required for the harsher operating conditions of Generation IV power plants is undergoing further development. Interest from the nuclear research organisation (CEA) and the institute for nuclear safety (IRSN) in France will lead to trials in research nuclear facilities. In addition, a novel thermocouple developed within the project has won a rare opportunity for performance testing against conventional technology in the Very High Temperature Gas Reactor fuel trials at the Idaho National Lab in 2016. Furthermore, nuclear decay and neutron cross-section data generated during the project are to be included in the International Atomic Energy Agency's nuclear data tables used throughout the world's nuclear community. Digital electronics resulting from research into the prototype miniature TDCR liquid scintillation counter have been put forward for incorporation in European and international standards and work continues on improving the compatibility of digital electronic outputs into various computer programming formats.

More information	Short name: MetroFission Project number: ENG08 www.euramet.org/project-ENG08
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Further information

More detailed information on the completed projects' outputs and the contact details for each project can be found at:

www.euramet.org/emrp-energy-2009

Ongoing projects in the Energy theme can be found at:

www.euramet.org/emrp-energy-environment-2013

EMRP Energy theme: pooling scientific and financial resources to address key measurement challenges

Total investment €32M

Pooling expertise of 39 NMIs and DIs from 23 European countries plus the NMIs from USA, Japan, Korea, Brazil and Australia

15 academic research groups

20 businesses from the energy and instrumentation sectors

127 contributions into 67 technical committee and working groups of ISO, CEN, IEC, etc.

2 patent applications

28 presentations at workshops and seminars

6 media interviews

164 articles in peer-reviewed journals

504 presentations at conferences

71 articles in the Trade and popular press

43 published newsletters and press releases

€9M of sales of innovative products and services to date

8 contributions to new standards and draft standards

Focus on impact

Extensive engagement

All EMRP projects engage widely with the user communities who will benefit from the research. For the Energy EMRP projects this included energy generators and distributors, large scale users and key process equipment and instrumentation suppliers as well as the relevant technical committees and working groups in the standardisation community.

The projects and their related projects have put, and are putting, in place the metrology infrastructure for a sustainable energy future. The implementation and adoption of these new measurement capabilities takes place over a number of years typically starting with the instrumentation sector and other early adopters in the energy sector and the development of new or revised conformity standards. The instrumentation sector plays a key role in adopting new measurement capabilities (new measurement technologies, devices, methods, techniques, reduced uncertainties etc.) and transferring them into end users in the wider industrial community and public agencies.

A survey of industrial companies that engaged with the Energy EMRP projects demonstrated that early impacts in the form of innovative products and services have generated sales of €9M to date.

Supporting innovation in measurement technology

Future-proofing Europe's gas networks

Michell Instruments, a leading supplier of humidity instrumentation, has developed a novel optical device to measure water content specifically for the gas industry. Working with the EMRP project *Characterisation of energy gases*, Michell Instruments used a new humidity facility developed as part of the project to evaluate the instrument's performance at the highest levels of accuracy relevant to their target market. This not only gave Michell confidence in the product's performance but also provided robust evidence to support their marketing and sales activities.

The product was launched in 2014 and has been installed in a number of locations worldwide. The improved performance of Michell's instrument offers network operators improved confidence in the quality of gas they buy and sell while avoiding unnecessary and costly drying processes before the gas is injected into the network. Besides improving efficiency and confidence across Europe's existing gas networks, the new instrument paves the way for a range of gas mixtures, readying the network for a more renewable, secure gas future.

Paving the way for next-generation nuclear energy

The EMRP project *Metrology for new generation nuclear power plants* developed, tested and patented a new temperature sensor, capable of operating at temperatures up to 1300 °C. Unlike previous instruments, these sensors can be used to ensure the safety and reliability of upcoming Generation IV nuclear reactors, which operate at higher temperatures to offer increased electricity production with reduced waste reprocessing requirements. The Idaho National Laboratory in the US recently held a comparative laboratory test campaign between several conventional thermocouples and a new one developed in the project by the University of Cambridge to select viable temperature sensors for its upcoming Very High Temperature Reactor fuel test validation. Following the lab test campaign Dr Michele Scervini from the University of Cambridge was awarded the opportunity to test the new sensor in Idaho's prototype reactor, one of only a few facilities of its sort in the world.

Testing will assess the new sensor's performance in the high radioactivity and temperature environment of Generation IV reactors. This will provide the validation needed to encourage the sensor's adoption by the conservative nuclear industry, paving the way to next generation nuclear power plants and stable, low carbon energy for Europe.

New in-line flow calibration supports significant energy savings

KROHNE, a leading manufacturer of industrial process instrumentation, has developed a new improved ultrasonic flow meter to monitor power plant processes. Through participation in the EMRP project *Metrology for improved power plant efficiency*, KROHNE used a newly-developed meter design together with a calibration device developed within the EMRP project. This calibration device simulates typical plant operating conditions to demonstrate the meter's accuracy. The validation of the technology using the new calibration device provided KROHNE with the impetus and confidence to start production of the ultrasonic flow meter.

E.ON, another project collaborator, has purchased and installed KROHNE's device in a nuclear power plant in Sweden for evaluation, in part due to the promising results of the project. Preliminary indications are that efficiencies in plant operation resulting from the device's use would be equivalent to around 60 MW, approximately the amount of electricity required to power thousands of extra homes. This is a significant improvement in plant efficiency, and given Europe's dependence on large-scale power plants for the foreseeable future, an important contribution to the efforts to reduce Europe's carbon footprint.

Better measurement for smarter grids

The EMRP project *Metrology for smart electrical grids* developed calibration equipment, software and processes that enable phasor measurement units (PMUs) – the 'life support monitors' of smart grids – to be validated against traceable measurement standards for the first time in Europe. Best practice guidelines for PMU use resulting from the project have also been incorporated into a revised IEEE standard.

Fluke Corporation, a manufacturer of industrial testing equipment, has introduced a unique PMU calibration service based on the methods developed in the project. The service enables operators to demonstrate compliance with the revised IEEE standard, and confidently compare PMU measurements across the grid, safe in the knowledge that all devices produce consistent and robust measurements. Arbiter Systems, a manufacturer of precision timing and power measurement devices, is introducing an improved and cheaper combined PMU and power quality measurement instrument for smart grids following involvement in the project. Grid operators can use Arbiter's new device to demonstrate compliance with the revised IEEE standard, and make reliable grid stability measurements at a price they can afford.

Increased access to cost-effective calibration services and devices, such as these, will help operators ensure the stability of smart grids and accelerate their adoption in Europe, supporting widespread renewable energy generation and a more stable, low-carbon energy future for Europe.

New instrument supports energy harvesting for greener transport

German manufacturer, Netzsch, has developed a precision instrument for measuring electrical conductivity and the Seebeck coefficient – a material property which strongly influences the efficiency and power output of a thermoelectric generator. Netzsch is marketing the instrument with a new reference material developed in the EMRP project *Metrology for energy harvesting*. Together, these products enable automotive manufacturers to reliably assess the performance of thermoelectric materials developed for use in energy harvesting devices.

The reference material will give Netzsch's customers confidence that the thermal efficiency measurements they make agree with national standards in place to ensure accuracy and consistency, enabling potential customers to better compare products. Netzsch's product provides the measurement capability needed to accelerate development and uptake of improved thermoelectric generators within the automotive industry. By making Europe's vehicles more efficient, energy harvesting technology has the potential to reduce one of the most significant contributions to Europe's greenhouse gas emissions.

Supporting smart renewable energy

With support from South Dublin City Council, the International Energy Research Centre (IERV - National Tyndall Institute), Siemens, Intel and Microsoft, the Micro Electricity Generation Association (MEGA) is piloting a 'smart energy cluster' in the outskirts of Dublin, which links small-scale renewable energy generators with local consumers through a smart grid. MEGA's smart cluster distributes locally-generated wind and biogas power using a power stabiliser incorporating a PMU, which links the cluster to the main grid system and allows inflow of power when renewable generation cannot meet local demand.

Through engagement with the EMRP project *Metrology for smart electrical grids*, MEGA received help evaluating the smart cluster's PMU and best practice guidance to enable accurate grid stability monitoring. Support from the project will help to ensure a reliable power supply to users of MEGA's smart cluster and the success of the pilot project. MEGA hopes to eventually interconnect local small-scale smart grids into a citywide system for Dublin. This will be an important step towards widespread renewable energy generation in Ireland and a more stable, low-carbon energy future for Europe.

Supporting standardisation to promote sustainable energy

New regulations support stable energy future for Europe

The EMRP project *Metrology for Liquefied Natural Gas (LNG)* developed a new primary flow standard. This will be used to provide traceability to the mid-scale LNG calibration facility, enabling flow meters used in the transfer and sale of LNG to be calibrated with top-class accuracy under typical operating conditions. Guidance documents issued by the International Organization of Legal Metrology (OIML) are currently undergoing revision to include a new section on LNG transfer flow metering developed within the project. Project interactions with ISO standard committees is enabling the inclusion of LNG measurements and flow metering systems into the documentary standards that underpin the International Group of Liquefied Natural Gas Importers Handbook used throughout the LNG industry.

This infrastructure will help to ensure fair and open trade of LNG, reducing financial risks and resulting in more stable energy prices. Increased adoption of LNG, which is more economical to transport over large distances and facilitates the supply of natural gas from new sources, could play a major role in diversifying Europe's energy supply.

New standard for safer, greener roads

The Italian standards organisation (UNI) has incorporated research performed within the EMRP project *Metrology for solid-state lighting* into a new standard for the illumination of road tunnels, optimizing the lighting requirements in the tunnel internal zone and at night.

The new UNI standard enables the safe introduction of LED lighting into Italian road tunnels and has enabled a significant reduction in the consumption of electrical power for tunnel lighting. LEDs operating at the new safe lighting levels identified within the project have contributed a further 33 % saving in electricity consumption. With LED lighting already introduced into approximately 95 % of Italy's 1,500 km of highway road tunnel network, this standard will lead to safer roads with significantly reduced power consumption and associated CO_2 emissions.

New standard supports development of biofuel-ready vehicles

The EMRP project *Metrology for biofuels* developed a reference method for determining the pH value of the most commonly used biofuel, bioethanol (pHe). This serves as a best practice example for measuring pHe, which can be used as a quick and simple indicator of bioethanol's corrosiveness - a property of crucial concern for engine manufacturers. These practices have since been incorporated into a new ISO standard, enabling users to make pHe measurements of the highest accuracy and reliably compare them across the world.

This will enable researchers to confidently assess the corrosive effects of bioethanol on materials being developed for use in next-generation engines, built to withstand biofuel blends. Accelerating the development of biofuel-ready engines, and encouraging consumer confidence, is an important step towards widespread adoption of biofuels and meeting the obligations of the Renewable Energy Directive, which requires 10 % of the transport fuel of every EU country to come from renewable sources such as biofuels.

Lighting the way to a greener Europe

The EMRP project *Metrology for solid-state lighting* has developed improved measurement practices and quality metrics to support reliable, accurate performance testing of LED lighting - the most energy-efficient lighting technology available - which meets the needs of end-users. The methods developed have contributed to an International Commission on Illumination standard and equivalent European Committee for Standardization (CEN) standard, which have recently been revised to include the testing of LED lighting.

This will enable manufacturers to make confident claims about product performance and demonstrate the quality of their products, both of which are critical to encouraging consumer acceptance. By accelerating adoption of energy saving lighting across Europe in accordance with the aims of the Ecodesign Directive, this will make a significant contribution to reducing CO_2 emissions and the use of mercury within the lighting industry, helping Europe meet crucial climate and energy targets.

Standards for biogas

The EMRP project *Characterisation of energy gases* is working with the instrumentation and standards communities to ensure the project's developments in the accurate measurement of siloxanes are adopted in practice and incorporated in forthcoming European standards.

Biogas, biomethane and landfill gas are often contaminated with siloxanes – the silicon-based materials found in everyday products such as detergents, medical products, cosmetics, paper coatings and textiles.

Upon combustion, siloxanes form silica (sand) that builds up in gas networks and engines, eventually causing reduced efficiency, increased operating costs and equipment failure. Accurate measurement techniques for siloxanes are needed to demonstrate compliance with the levels specified in forthcoming CEN standards, and ensure cost-effective siloxane removal and avoid unnecessary operational costs.

Digital standards for the nuclear industry

The EMRP project *Metrology for new generation nuclear power plants* is working with the standards community to develop a compatibility standard for digital data used in the nuclear industry. The increased use of digital data acquisition has led to a range of different digital data formats that hinders interoperability and comparison of important nuclear measurement data between users, across borders and disciplines. These measurements ensure the safe and efficient operation of nuclear power plants, underpin nuclear medicine and provide nuclear security.

The European and international standards communities (CEN and IEC) and the European Thematic Group on the Protection of Critical Infrastructure from Radiological and Nuclear Threats have identified the urgent need for digital data standards and the project team is working with them to develop such an international standard.

Europe's National Measurement Institutes working together

The majority of European countries have a National Measurement Institute (NMI) that ensures national measurement standards are consistent and comparable to international standards. They also investigate new and improved ways to measure, in response to the changing demands of the world. It makes sense for these NMIs to collaborate with one another, and the European Association of National Metrology Institutes (EURAMET) is the body that coordinates collaborative activities in Europe.

The successful European Metrology Research Programme (EMRP) will be followed by the European Metrology Programme for Innovation and Research (EMPIR), both implemented by EURAMET. The programmes are jointly funded by the participating countries and the European Union and have a joint budget of over €1bn for calls between 2009 and 2020. The programmes facilitate the formation of joint research projects between different NMIs and other organisations, including businesses, industry and universities. This accelerates innovation in areas where shared resources and decision-making processes are desirable because of economic factors and the distribution of expertise across countries or industrial sectors.

EURAMET wants to involve European industry and universities at all stages of the programme, from proposing Potential Research Topics to hosting researchers funded by grants to accelerate the adoption of the outputs of the projects.

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