European Metrology Research Programme

Towards secure, sustainable energy

A summary of the outputs and impact of the EMRP joint research projects in the energy theme.

The aim of this theme was to develop the metrological infrastructure to support Europe's sustainable energy goals. The research focused on technologies and metrological research that supports reduced greenhouse gasses and a secure, sustainable and affordable energy system whilst increasing the competitiveness of Europe's industries.

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

The programme was designed to ensure that measurement science meets the future needs of industry as well as wider societal challenges. Research was structured around 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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Introduction: Metrology for Energy

The European Union aims to produce over 32 % of its energy needs from renewable sources by 2030 and to reduce associated carbon dioxide emissions to help mitigate climate change. The introduction of the Energy Union strategy, supported by directives and regulations that address all aspects of the energy supply chain, along with measures to reduce energy consumption at point of use, has made Europe a world leader in this field. This strategy focuses efforts on sustainable and secure energy supplies, methods to reduce greenhouse gas emissions and increasing the competitiveness of European industries.

Maintaining Europe's leading position requires the continuous development of new technologies and ensuring a uninterrupted, secure energy supply requires the ongoing use of conventional energy generation. Both must be underpinned by the science of measurement - metrology. EURAMET research has contributed to advances in measurements that support the introduction of new energy sources as well the efficient operation of conventional power plants and potential next generation nuclear power.

EURAMET's European Metrology Research Programme (EMRP) supported a coordinated approach to research in energy measurement. This provided Europe's research and innovation base, as well as policy-makers, public agencies and instrument manufacturers with access to the combined experience and capability of Europe's National Measurement Institutes (NMIs).

EURAMET's two EMRP Energy themes provided the funding to support 21 collaborative research projects that brought together 42 NMIs and Designated Institutes (DI) with energy generators, distributors, instrument manufacturers and academia to address some of the associated measurement challenges across the entire energy supply chain.

This report presents the key technical achievements of these research projects and highlights examples of the impact generated within the energy community. Projects are grouped into three sub-themes:

- Better measurements for sustainable and secure energy supplies
- Better ways to improve and monitor the electrical infra-structure
- More efficient ways to use energy produced

Research continues in the European Metrology Programme for Innovation and Research (EMPIR) Energy theme projects.


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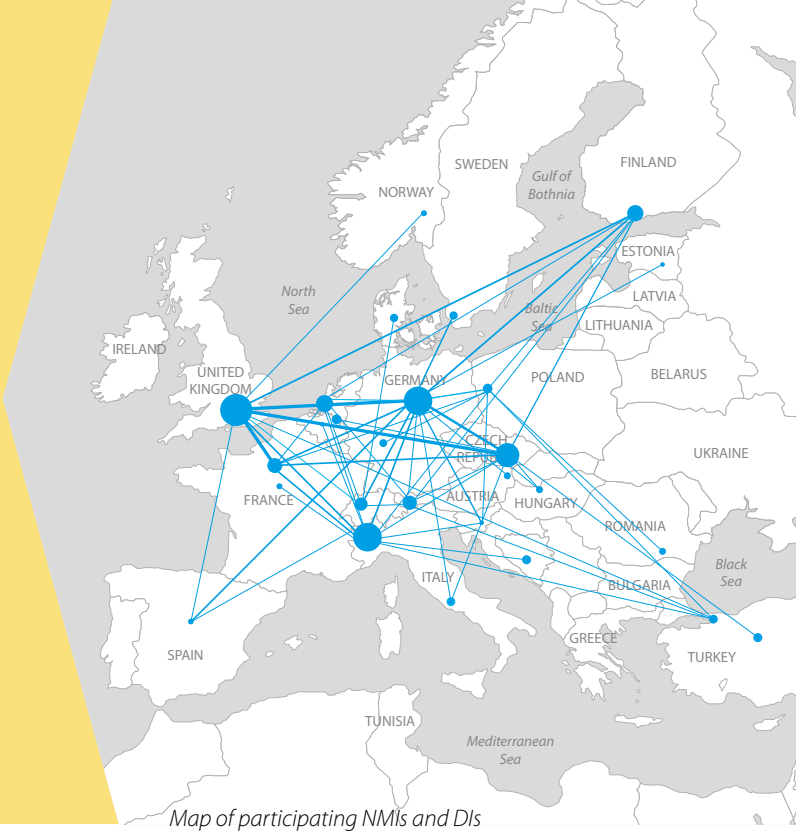
Highlights

The EURAMET Metrology Research Programmes (EMRP), which ran from 2010 to 2017, brought together metrology experts and organisations within the energy field to address some of the biggest challenges facing Europe in the 21st century.

Through this collaborative work improved measurement methods, new instrumentation and international standards were developed – important to help us improve and encourage the use of energy from sustainable sources and to better manage the energy we do produce. The European Commission and national governments invested €77.8 M in collaborative energy-related research projects involving research groups in 42 European National Measurement Institutes (NMIs) and Designated Institutes (DIs), along with 22 academic groups, and 8 businesses.



Map of participating NMIs and DIs

Integrating renewable fuel into European pipelines

Europe is the world leader in the production of biogas, a form of renewable energy generated from carbon neutral sources. However sustainable development policies require that these types of fuels have 'trackability' in terms of their biological and geographical origin. Furthermore, to enable access to the existing transportation and storage infrastructure used by natural gas – and reassure purchasers of the quality and calorific value - requires the precise characterisation of these gases. Biofuels often have a more varied and heterogenous composition than conventional ones and to make these measurements is challenging. EMRP research developed new techniques, measurement instruments and certified reference materials for the analysis of these complex mixtures. The research enabled the precise characterisation of contaminants, such as water, ammonia and particulates that have the potential to damage the transportation infra-structure. The research also demonstrated the applicability of using the existing 'energy density equations' currently used for natural gas – which is important for calculating the density of the gas during transportation and storage.

This information is vital for Europe to foster the growth in the production of non-conventional energy gases from renewable sources and to help develop more diversified and secure energy supplies.

Improved methods for measuring the efficiency of solar cells

Since the 1980s the energy expected from solar cells has been determined based on three fixed measurements termed Standard Test Conditions (STC). However, STC does not take into consideration the real-world operating conditions where cells are installed, which can lead to a discrepancy between the predicted and actual energy output - with financial consequences.

EMRP research developed a more realistic way of determining performance by combining a wider range of measurements with climactic data from around Europe. The results have now been incorporated into new international standards for testing solar cells, which will better inform investors and help stimulate the uptake of new and existing solar technologies.

Reliable measurement of wind turbine drivetrains

Europe's impressive recent growth in wind energy generation capacity may need to continue for EU Renewable Energy Directive targets to be met. Yet the all-too-common sight of stationary wind turbine blades highlights a reliability issue limiting sector competitiveness. Income is reduced and maintenance costs accumulate due to insufficient standards for ensuring component quality, and an absence of direct traceability for the instruments large enough to check production quality.

The EMRP DriveTrain project developed techniques and standards so manufacturers can improve component reliability. For both Zeiss and Hexagon, participation led to upgrades of their measuring instruments, to offer direct traceability and heightened confidence for their customers.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Solving measurement challenges for smarter grids

Incorporating renewables into Europe's energy mix along with evolving demands will lead to transformational change for Europe's electricity distribution and supply infrastructures. Supporting industry efforts to address this challenge, EMRP research developed the measurement infrastructure required for the introduction of 'smart' grids. Low-carbon electricity generation output is variable and often localised, requiring distributed networks, rather than existing, centralised, grids. Consumers will also expect networks to power transportation and for their meters to be accurate and secure. Smart grids are a proposed solution to changing patterns of supply and demand, designed to be more flexible and responsive, and ensure reliable connectivity.

Five EMRP projects developed solutions to the measurement challenges presented by this transformation. Advances made by projects in the 2009 Energy call – *Metrology for high voltage direct current (HVDC) and Measurements for smart electrical grids (SmartGrid)* – were built on in 2013 projects, that focused on overcoming barriers to realisation. SmartGrid II delivered a deeper understanding of stability issues; GridSens developed cheaper, secure ways to monitor and control smart grids; while *FutureGrid* investigated technologies for monitoring smart grid 'health'.

Outputs were exploited in further collaborative research projects and testbeds, supporting efforts to vastly expand the use of sustainable energy in Europe.


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Lighting the path to lower energy use

European household energy consumption has fallen over 1% almost every year since 2005 – largely driven by EU ecodesign regulations regarding the use of energy efficient appliances. Light emitting diodes (LEDs) use less power than traditional filament or incandescent lighting, but newer types often have large or curved areas making the properties of these difficult to assess. Through EMRP research new instrumentation and reference standards were developed to help validate manufacturer's performance, reliability and lifetime claims. This new set of tools will aid in the uptake of this technology and allow it to demonstrate adherence with current European regulations.

EMRP Energy theme projects at a glance

Total investment €77.8 M

Pooling expertise of **42** NMIs and DIs from European countries

plus **1** NMI from Outside Europe

18 businesses

and **8** other organisations from the energy and instrumentation sectors

22 academic research groups

76 published newsletters and press releases

73 presentations at workshops and seminars, reaching an audience of **4,837** people

367
articles in peer-reviewed journals

205
training courses delivered to over
13,243
people

578
presentations at conferences

289
contributions to
48
technical committees and working groups of standards organisations

Supported the development of improved instrumentation with projected sales of
€6.9 M

48
articles in trade and popular press

Energy generation and security

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Measurement challenges

The European Union imports over half of its energy, with most of our electricity production coming from fossil fuels. As well as the environmental and financial issues that this creates, there is a potential that disruption could impact supply security. The EU's **Energy Union strategy** supported by EU directives, such as the Renewable Energy Directive, addresses these challenges.

Binding targets are in place requiring that at least of 32 % of energy consumption to be from renewable sources and that at least 14 % of transportation comes from biofuel by 2030. To meet these targets requires that the energy generation from solar power, wind power and biofuels increase whilst conventional energy sources are wound down. However, to support greater diversity in the supply chain requires the development of the energy measurement infrastructure.

Diversifying European energy supplies has many challenges specific to each source type. Solar power generation has grown significantly since the 1990s but discrepancies between predicted energy outputs and those achieved have large financial implications that are hampering its increased adoption. Off-shore or remote wind turbines suffer damage to their gear mechanisms which can be accelerated by minor measurement inaccuracies or surface imperfections that necessitates expensive and laborious repairs, yet no traceable measurement standards to measure surface quality existed. Biofuels, such as biomethane, need improved measurement methods to demonstrate conformity to EU directives before they can enter the existing gas grid. Similar quality concerns are also slowing the uptake of Liquefied Natural Gas (LNG) – a cleaner, alternative fossil fuel to diesel for heavy duty transportation fleets.

EMRP research has supported projects that address:

- Improved classifications for solar cells to allow real world performance to more closely match predictions.
- Measurements to increase the lifespans of wind energy systems.
- Improved characterisation of biofuels and liquified energy gases to the same level as that for conventional fuels.
- Better instrumentation to measure the composition of conventional fuels.

Key technical achievements

New energy classifications for solar cells

The International Energy Agency has projected that power generated from photovoltaics (PVs) will be the world's major source of electricity by 2050. Traditionally, solar modules were sold based on 'peak power' output calculated under Standard Test Conditions using fixed values for solar angle, irradiance and module temperature. Across European geographies, these parameters vary considerably. The reference standards used to calibrate these technologies were based solely on crystalline silicon, resulting in discrepancies in calibrating PV devices made from other materials. The resulting lack of certainty between predicted and actual energy outputs has been estimated to have added tens of billions of Euros per year of uncertainties to estimates of profitability, therefore reducing investor confidence in solar plants.

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The EMRP project **Towards an energy-based parameter for photovoltaic classification** developed and ratified a more realistic and accurate energy classification scheme for a range of solar cell technologies.

The project:

- **Introduced a new measurement classification system for PV devices based on energy output** for different climate zones across Europe.
- **Published three new international standards in IEC 61853** as well as three good practice guides for PV measurements.
- **Developed and validated new SI traceable calibration reference devices** capable of measuring a greater range of light levels for different types of solar cell technology.
- **Developed four new facilities** to provide measurement services for PV modules over a range of operating conditions.

Delivering impact

The new classification system and the standards enabled producers to rate PV modules in terms of actual energy output (in watts per hour) for a range of irradiances tailored to specific climatic zones, meaning that local light levels, temperatures and angle of the sun can each be taken into account.

As a result the international standard for calibrating reference cells, the World PV Scale (WPVS), was improved. New stable reference devices incorporating these advancements were then commercialised by Fraunhofer ISE, the largest solar research institute in Europe.

For the first time producers and purchasers have a standardised way to accurately estimate and specify PV modules for specific geographical and climatic conditions. This allows a more accurate determination of which types of solar cell to install at any one site and greater certainty for projections of return on investments, so increasing confidence in solar energy.

More information is available at	ENG55 Towards an energy-based parameter for photovoltaic classification (Photoclass) https://www.euramet.org/project-ENG53 Follow on project: 16ENG02 (PV-Enerate)
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Improving wind turbine reliability


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The wind is a plentiful source of renewable energy, and turbines produce no greenhouse gases in operation. In 2017, wind power became the largest source of renewable electricity, contributing 17.5 % of energy and 30.7 % of electricity consumed in EU states. The target set for the proportion of total energy sourced from renewables in the EU is 32 % by 2030, but continued growth prospects could be compromised by mechanical failures of Wind Energy Systems (WES). Measurement inaccuracies can lead to excess wear to turbine drivetrains, while surface imperfections also reduce gear reliability. Traceable measurement standards and accurate techniques for measuring surface quality were needed to improve the reliability of large WES components and enhance competitiveness.

The EMRP project **Traceable measurement of drivetrain components for renewable energy systems** developed measurement techniques for WES components and traceable measurement standards to enable component manufacturers to increase the reliability of drivetrains.

The project:

- **Developed the first measurement standards and calibration procedures** capable of establishing traceability and measurement uncertainty for WES gears and bearings.
- **Established traceability and uncertainty estimations** for WES drivetrain components.
- **Developed design modules and numerical models** to simulate sources of error in measuring large components.
- **Developed and tested Good Practice Guides** for measuring dimensional and surface properties of WES drivetrain components.

Delivering impact

The availability of measurement standards means, for the first time, that the wind energy industry can reliably measure dimensions of drivetrain components.

During the project, both Zeiss and Hexagon incorporated the new knowledge of measurement uncertainty sources to make their measuring machines more accurate and provide traceability to customers in the wind industry.

Having developed its software and invested in a Zeiss Xenos coordinate measuring machine, in 2019, CMI launched an accredited gear calibration service. The first customer was Solar Turbines EAME sro, based in Žatec, Czech Republic, a subsidiary of Caterpillar Inc. and one of the world's leading manufacturers of industrial gas turbines.

Traceable measurements will enable the manufacture of more reliable WES components, enabling increased reliability and therefore more attractive returns from wind energy investments, while helping EU states to meet renewable energy targets and reduce carbon dioxide emissions.

More information is available at	ENG56 Traceable measurement of drivetrain components for renewable energy systems (DriveTrain) https://www.euramet.org/project-ENG56
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Characterising energy gases

The EMRP project **Characterisation of Energy Gases** brought together the scientists at 17 NMIs to develop a metrological infrastructure to assess physical and chemical parameters of a wide range of gas-based fuels.

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The project developed:

- **Accurate chemical analysis methods to determine composition of a range of biogas and other non-conventional gases, trace-levels of impurities and added odorants, plus a suite of certified traceable reference materials to transfer accurate measurements to other users.** The developed measurement capabilities provided confidence in the verification of non-conventional gases prior to entry into distribution networks and more cost- effective use of environmentally-friendly gas odorants.
- **A primary reference calorimeter (at a European NMI) capable of measuring 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 used to validate modified commercial field calorimeters demonstrated that, when used in line with guidance (developed by the NMI researchers), that calorific content of such gases could be accurately measured. Equipment manufacturers then had the opportunity and confidence to produce commercial instruments to measure energy content for trade and billing purposes.
- **New national facilities to define and accurately measure humidity for a range of energy gases, gas mixtures and at the high pressures used in gas distribution networks.** Humidity measurement is key to preventing build-up of potentially damaging liquid water or ice in high-pressure gas distribution networks. The new facilities were available for calibrating commercial humidity sensors with non-conventional gases and 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, could 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 inter-comparisons. One company validated and gained valuable insight into the performance of a new product, that was commercialised as a result.

The Swedish NMI, RISE, exploited advances made in impurity analysis to support the Swedish biogas industry. The project team contributed to CEN Technical Committee (TC408) that develop standards for natural gas and biomethane for use in transport and biomethane for injection in natural gas grids.

The research outputs were developed further in the EMRP project *Metrology for biogas* (Biogas).

More information is available at	ENG01 Characterisation of Energy Gases (Gas) https://www.euramet.org/project-ENG01 Follow on project ENG54 Metrology for biogas (Biogas)
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Measurements for Biogas

Biofuels have an important role in enabling EU states to meet Renewable Energy Directive targets and supporting a transition from fossil fuels to renewables for powering transport. Europe is the world leader in the production of biogas, a 100 % renewable energy source, but cost-effective distribution will require access to existing natural gas infrastructure. This requires conformity of biogas to existing standards, such as EN 16723, to ensure safety, prevent damage to gas networks from impurities or particulates, and build confidence with agents in the supply chain about gas quality. However, the characteristics of biogas are sufficiently different from natural gas that it is necessary to develop new measurement methods to enable demonstration that these new energy sources comply with existing regulations.

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The EMRP project **Metrology for biogas** provided a metrological framework for assessing biogas quality and enabling characterisation to the same level as for natural gas.

The project:

- **Developed novel traceable methods and certified reference materials** to measure specific impurities in biogas and biomethane at trace-levels.
- **Developed capabilities for measuring particulate concentration,** essential for demonstrating that biogas meets specifications required for injection into the gas network.
- **Developed robust analytical tools to measure water content and the dew point of biogas and biomethane,** so purchasers can be assured they will be accurately billed for gas calorific value.
- **Refined infra-red spectroscopy techniques to measure ammonia levels in biogas** allowing detection down to parts per million levels.
- **Confirmed the suitability of existing energy density equations for biogas.**

Delivering impact

The new reference materials, methods and calibration services for the detection of impurities developed in this project, are being considered by a newly formed ISO standardisation working group for biomethane ISO/TC193 'Natural gas'. As a result, tailored normative standards for biogases are planned at the equivalent level as those for fossil-fuel based gases.

The projects confirmation of the suitability of existing energy gas density equations, important during transportation and storage, enables the fuel industry to rely on measurement results, as they will be able to benefit from similar accuracies as obtained for conventional gases. This will enable biogas to be used in the existing gas infrastructure, foster growth in the production of non-conventional energy gases from renewable sources, and encourage development of more diversified and secure sources of energy.

More information is available at	ENG54 Metrology for biogas (Biogas) https://www.euramet.org/project-ENG54 Follow on project 16ENG05 Metrology for biomethane (Biomethane)
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Measurements for biofuels

The EU's Fuel Quality Directive (2009/30/EC) sets out quality and sustainability criteria for biofuels, requiring liquid biofuels – vegetable oil, biodiesel and bioethanol - from a range of sources with different characteristics to be accurately measured and monitored during production, storage, transportation and distribution. In addition, sustainable development policies require 'trackability' of biofuels in respect of biological and geographical origins. The EMRP project **Metrology for Biofuels** focused on liquid biofuels used in the automotive sector, to develop a measurement infrastructure to provide reliable data and enable adaption 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 ensured that measurements made in testing labs can be 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** (including density, viscosity, calorific value and state behaviour at high temperatures and pressures). This data enabled accurate determination of volumes and energy content for biofuel trades, in line with legal requirements. This also supported process control of biofuel production and optimised engines designs suitable for 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 put in place a metrology infrastructure that enabled harmonisation of European and international measurement methods for biofuels and fossil fuel blends. Internationally comparable quality standards and a wider knowledge of the properties of biofuels enables its confident usage as an automotive fuel and facilitates greater acceptance from customers and vehicle manufacturers. More generally, development of references for chemical and physical parameters provide confidence in biofuels quality assurance and facilitate global trade.

The project's results were shared with the relevant CEN Technical Committees on gaseous and liquid fuels, lubricants and related products of petroleum, synthetic and biological origin and with the ISO technical committee on Petroleum products and related products of synthetic or biological origin. The interaction with the ISO committee has enabled the contribution of project outcomes to be incorporated into a draft normative standard on ethanol test methods.

More information is available at	ENG09 Metrology for Biofuels (Biofuels) https://www.euramet.org/project-ENG09
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Measurements for liquefied natural gas

The EMRP project **Metrology for liquefied natural gas** significantly reduced measurement uncertainty of transferred energies in liquefied natural gas (LNG) trades, as a result of improvements in the measurements of LNG quantity and calorific value.

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Improved national capabilities and techniques for field measurements for flow measurements as a method to accurately assess LNG quantity were developed, as well as improved field measurements of composition and density to determine the LNG calorific value. The project supported both traditional and innovative measurement methods by developing a metrological framework made up of test and calibration standards, written standards and guidelines.

The project developed:

- **The world's first primary standards for flow measurement at -163 °C, the temperature of LNG**, a first step in development of traceability for LNG flow meters. The system handled flow rates of up to 25 m^3 per hour and a scaled-up facility was 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 were intended to make it possible for LNG flow metering to become an accepted method for reducing overall measurement uncertainties and to simplify operations.
- **Improved understanding of LNG composition assessments.** The performance of different sampling systems to assess LNG composition was assessed via a review of design principles and analysis of data provided by industry.
- **Improved LNG density measurements**. An advanced primary LNG densitometer system was developed providing reference data with very low uncertainty that addressed densities from 10 kg/m^3 to 1000 kg/m^3 in a temperature range from 90 K to 290 K and at pressures up to 8 MPa. Applying accurate reference data to existing equations of state used to calculate LNG density and calorific value revealed variation with different physical conditions (temperature and pressure) that, commercially, equates to significant financial impacts for buyers and sellers.

Delivering impact

Measurement of LNG for trading purposes is regulated and heavily influenced by directives, standards and guidance of the legal metrology community, through ISO, CEN and the industry association GIIGNL (International Group of Liquefied Natural Gas Importers). The project outputs were shared with these communities. As a result, dynamic flow measurements were incorporated in the ISO standard for LNG process control ISO10976. The ISO TC 28 (Petroleum products and related products of synthetic or biological origin) resolved to form a joint working group to create an ISO standard for LNG flow metering systems. The new edition of the GIIGNL LNG custody transfer handbook, the key guidance document, was expected to incorporate knowledge created in the project.

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

More information is available at	ENG03 Metrology for liquefied natural gas (LNG) https://www.euramet.org/project-ENG03 Follow on project ENG60 Metrological support for LNG custody transfer and transport fuel applications (LNGII)
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Building trust in LNG as a transport fuel

The EMRP project **Metrological support for LNG custody transfer and transport fuel applications** developed new LNG calibration facilities and standards for flow and composition measurement. The project also developed and validated methods to calculate LNG density and provided a new approach to correlate methane number, a measure of fuel quality, with LNG composition.

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The project:

- **Developed an improved model for evaluating LNG density via an improved equation of state for characterising LNG properties**, subsequently included in the International Group of Liquefied Natural Gas Importers handbook, the leading guide for LNG measurements.
- **Developed a prototype sensor to simultaneously measure density and speed of sound**, key parameters for ultrasonic flowmeters, providing in-field metrological traceability.
- **Developed and validated a new algorithm to determine the methane number**, a parameter needed to fine tune efficient operation of LNG-fuelled engines.
- **Developed a new sampling and vaporising method** that provides representative LNG samples for accurate composition measurements.
- **Validated a laser-based method to measure LNG flow in cryogenic conditions**, developed in LNG I. This has subsequently been accredited for operation under explosive atmosphere conditions.

Delivering impact

A research facility was constructed to calibrate flow meters for LNG vehicle and ship fuel dispensing. Validation continued in the follow-on project LNG III *Metrological support for LNG and LBG as transport fuel.*

LNG II delivered the first algorithm to determine the methane number that incorporates measurement uncertainty, enabling LNG users to fine-tune ship or truck engines for optimal performance, cost efficiency, and reduced CO_2 emissions.

The cryogenic Laser Doppler Velocimetry system for flow measurement validated in LNG II is planned for commercial exploitation by Cesame, the French national test laboratory for gas flow measurement. A field test has been done, and another is planned for installation by Reganosa, the Spanish natural gas transmission and regasification company. The project also led to the establishment of an ISO Working Group for the *Dynamic measurement of LNG*, that has produced a draft standard for dynamic flow measurements of LNG that incorporates project outcomes.

More information is available at	ENG60 Metrological support for LNG custody transfer and transport fuel applications (LNGII) https://www.euramet.org/project-ENG60 Follow on project 16ENG09 Metrological support for LNG and LBG as transport fuel (LNG III)
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LNG is regarded as the cleanest fossil fuel, that, as part of the EU's clean fuel strategy, could support a transition to a lower carbon economy. In addition, an effective LNG infrastructure would ease the introduction Liquified Bio Gas, a renewable fuel.

Improving oil and gas production flow measurements

Over 50% of global energy demand is currently met by oil and gas production, but as reserves dwindle, new sources tend to be smaller, remote and in deeper water. Oil is typically extracted as multiphase flow, a mixture of oil, water and gas. Where production profitability is marginal, knowing flow rates of each of these components becomes critical, yet typical multiphase flow measurement systems have uncertainties of 20 % or more.

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The intrinsic complexities and the absence of a traceable reference network capable of independently evaluating multiphase meters hindered industry efforts to reduce these uncertainties. To overcome this barrier, a test methodology and reliable reference measurements needed to be developed.

The EMRP project **Multiphase flow metrology in oil and gas production** developed a harmonised approach to measuring flow with multi-flow meters. For the first time, an inter-comparison of a test method demonstrated very good agreement in test data at two multiphase flow laboratories.

The project:

- **Developed a comparison procedure**, independent of the type of multiphase flow meter.
- **Developed a transfer standard**, based on mass flow measurement, feeder pipe length and observation of flow pattern.
- **Established and implemented a standard testing protocol**, concluding that a 10-minute sampling time is sufficient.
- **Developed a data comparison method**, that combined facility and multiphase flow meter uncertainties, so facilities can be compared without explicit reference to the performance of the flowmeter deployed.
- **Performed a successful inter-comparison between two test laboratories**, in different countries, across a range of parameters.

Delivering impact

The findings of the inter-comparison procedure were used as the foundation of the first standard guidelines for multiphase flow measurement. The methodology was submitted as an ISO technical report on multiphase measurements (ISO/TR21354), resulting in the ISO/AWI 21354 standard *Measurement of multiphase fluid flow,* due to be published in January 2020.

This will expand the laboratory harmonisation network and provide confidence in the robustness and relevance of the methods deployed.

This approach to multiphase flow measurements is being applied to an enlarged network of laboratories, covering a wider range of flow conditions and multiphase meter types, in the follow-on EURAMET project *Multiphase flow reference metrology.*

More information is available at	ENG58 Metrology for liquefied natural gas (MultiFlowMet) https://www.euramet.org/project-ENG58 Follow on project 16ENG07 Multiphase flow reference metrology (MultiFlowMet II)
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Energy distribution

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Measurement challenges

To support the Energy Union strategy, the EU has set ambitious targets on the amount of energy to be produced from renewable sources by 2030. However, these sources are more decentralised than conventional power plants and may cause power surges which can destabilise the electricity grid due to reductions in power quality. Upgrading the energy distribution and transmission systems requires power quality monitoring at more points and over larger distances than previously necessary.

Using new technology designed to assess power flow, such as phasor measurement units (PMUs), and novel current and voltages sensors, 'smart' grids can monitor network status in real-time and automatically respond to counter any destabilisation issues. Significant challenges to upgrading the grid system are a lack of calibration standards to validate PMU performance and a poor understanding of where best to site these instruments to optimise grid security. Furthermore, as these new devices must be able to communicate over the internet with centralised control devices, this could leave the system vulnerable to cyber-attacks.

Nuclear energy generates almost 30 % of EU electricity and this is likely to continue for the foreseeable future. Next generation nuclear power plants will be considerably different from those operating today, with different fuel mixes, reactor designs and will operate at far higher temperatures. New measurement methods and sensors will be needed for their safe and effective operation.

EMRP research has supported projects that address:

- The introduction of standards and traceable measurements for PMUs.
- Optimisation of PMU positioning within transmission networks.
- New, traceable current and sensing technologies for extended network monitoring.
- New or improved measurement methods for next generation power plant.

Key technical achievements

Measurements for smart electrical grids

The EMRP project **Metrology for smart electrical grids** advanced the metrology infrastructure for monitoring the stability and quality of supplies delivered by smart electrical grids.


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To support development and implementation of smart grids, the project developed:

- **Tools for designing metrological strategies to cost-effectively optimise the measurement and control of smart grids.** Algorithms to model, simulate, and analyse smart grids that were developed enabled operators to devise effective measurement strategies, optimise sensor placement plans and provide cryptographic infrastructures for grid security.
- **A measurement framework for reliable and accurate Phasor Measurement Units (PMUs)** to monitor stability of smart grids. The project developed 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 data on the effect of renewable energy on power quality. This enabled grid operators to predict impacts of planned large-scale installations and provide for network reinforcements to mitigate detrimental effects on power quality or network reliability.
- **Traceable on-site energy measurement systems to ensure fair energy trades.** The project developed techniques and devices to support the cost-effective implementation of accurate smart meters.

Delivering impact

As a result of working closely with utility companies and instrumentation manufacturers, project outputs were adopted by a number of companies. The developed PMU calibration service was used to evaluate commercial PMUs, helping the manufacturer identify improvements to its design. Secondly, a commercial smart meter was tested using the system developed in the project. Third, an NMI worked with an operator to help install PMUs in a grid in the Netherlands to monitor stability and quality. Lastly, smart meter data collected in Sweden was evaluated with the analysis tool developed in the project.

Important contributions were made to industrial documentary standards, including a Technical Brochure of the CIGRE (Council of Large Electric Systems) committee on PMU applications for electrical grids, and the 2014 revision of the IEEE standard for PMU testing.

Further research on metrology for smart grids was 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) and *Non-conventional voltage and current sensors for future power grids* (FutureGrids).

More information is available at	ENG04 Metrology for smart electrical grids (SmartGrid) https://www.euramet.org/project-ENG04 Follow on projects ENG52 Measurement tools for smart grid stability and quality (SmartGrid II) ENG61 Non-conventional voltage and current sensor for future power grids (FutureGrid) ENG63 Sensor network metrology for the determination of electrical grid characteristics (Gridsens)
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Measuring smart grid stability and quality


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To help meet European emission reduction goals, vastly increased renewable power generation capacity will be needed, necessitating considerable changes to electricity supply network instrumentation and control systems. Much of this generation will be intermittent, bi-directional and will require 'smart' management of supply and demand to maintain grid stability, and avoid blackouts due to poor power quality (PQ) issues. Phasor measurement units (PMUs) are a technology designed to monitor energy flows related to power demand and generation and enable improved grid management. However, improved calibration and traceability of PMUs will be needed for network operators to be confident that these complex instruments perform reliably.

The EMRP project **Measurement tools for smart grid stability and quality** developed technologies and standards to monitor the stability and quality of electricity supplies. Building on outcomes from the EMRP project *Metrology for smart electrical grids,* SmartGrid II delivered a new understanding on how PQ issues spread across a working electricity network.

The Project:

- **Developed and implemented a prototype PQ location method using new PMU algorithms in a transmission grid**, that determined the source of large disturbances in PQ.
- **Designed and implemented a fully operational, standards-compliant, automated PMU calibrator,** with uncertainties 10 times lower than existing commercial products.
- **Characterised the voltage transformers used by PMUs and PQ instruments using a new technique for on-site measurement of voltage transformers**, that reduced measurement uncertainty by two orders of magnitude.
- **Developed three new ways to measure grid impedance**, a metric important for Smart Grid state estimation models and PQ relating to high-frequency interference on grids.

Delivering impact

On a renewable-rich smart grid on Bornholm Island, Denmark, measurements were made using six installed bespoke PMUs with PQ capabilities, applying new algorithms, that located issues for network operator Østkraft. Data was presented on network operating conditions, that combined with weather data, was able to estimate renewable generation levels.

A method for calibrating PMU reporting signal delay, important for power system protection and control was enhanced after the end of the project by Strathclyde University, enabling passive real-time operation, with any PMU, and without changes to PMU hardware or software. This method offers very high accuracy while requiring only low-cost additional hardware and open-source software.

The new methods for measuring grid stability and power represent breakthroughs for removing causes of power loss, grid control malfunctions, interference, shortened asset life and malfunctions of connected products. The measurement infrastructure now exists for incorporating reliable and accurate PMUs, capable of advancing the development of Smart Grids, and helping to meet carbon emission reduction targets.

The EMPIR project, *Standard tests and requirements for rate of change of frequency measurements in smart grids* addresses the need for greater standardisation in these measurements for power quality in electrical grids.

More information is available at	ENG52 Measurement tools for smart grid stability and quality (SmartGrid II) https://www.euramet.org/project-ENG52 Follow on project 15NRM04 Standard tests and requirements for rate of change of frequency measurements in smart grids (ROCOF)
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Sensor networks for managing smart grids


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Smart Grids could unlock further expansion of renewable generation capacity, enabling the control of what will be more distributed and complex networks. Localised generation demands two-way flows of current, necessitating careful management to maintain grid stability. Billing data and network control will also be expected to be handled in new 'smart' ways. Sensors are used to measure network current, voltage and frequency, with this data aggregated to form a view of the overall network 'state'. However, distributed generation will need distributed sensor deployments. Methods to decide on the best places to site sensors are needed for accurate estimations of grid state, and interoperability with pan-European smart grids is expected to add further cyber-security requirements.

The EMRP project **Sensor network metrology for the determination of electrical grid characteristics** applied mathematical and measurement methods to develop cost-effective and secure ways to apply sensors to monitoring and control of smart grids. Methods for optimising sensor placement, a measurement framework for Phasor Measurement Units (PMUs), state estimation using smart meter data, and strong cyber-security measures were each investigated to improve network management.

The Project:

- **Developed algorithms that provided improved network state estimation and sensor placement**, tested on simulated and actual distribution networks, enabling effective grid monitoring and control.
- **Developed a sensor placement algorithm to optimise PMUs for grid monitoring**, providing significantly reduced uncertainty, and cost-effective state estimation.
- **Refined and tested algorithms to provide network structure estimations**, found effective at recovering unknown connections in networks.
- **Demonstrated cost-effective determination of grid power flows** using smart meter data.
- **Tested a secure communication system**, designed to protect grid measurement systems from cyber threats.

Delivering impact

The open-source software developed for secure data exchange has been published for re-use and inspection to an open repository, that has received regular visits and downloads. This and other secure data exchange outputs of the project led to the creation of the European Metrology Cloud, a PTB initiative promoting a pan-European IT infrastructure for Legal Metrology.

The expertise built in the project and connections made with industry also helped pave the way to the formation of EURAMET's European Metrology Network on Smart Grids. This network of NMIs and stakeholders will enable high-level coordination of impacts from Research and Development activities.

As a result of this project, grid operators will be able to apply sensor networks for improved visibility of their grids performance enabling the planning of strategies for Smart Grid operation. This will help integrate renewable energy generation into existing networks while maintaining stable, high-quality power supplies, thus removing a barrier to investments in renewable electricity generation capacity.

More information is available at	ENG63 Sensor network metrology for the determination of electrical grid characteristics (Gridsens) https://www.euramet.org/project-ENG63
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Novel sensors for smarter power grids


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Integrating power from renewable energy sources into existing distribution grids will become an essential requirement for reducing CO_2 emissions. However, the flow of electricity from non-conventional sources can cause harmonics or surges of power, leading to outages and failures. One way to address this problem is to introduce smarter grids that use digital control technologies to monitor electricity use in real-time, making automatic changes to reduce energy wastage, and allowing networks to operate at higher capacities. Accurate and traceable measurements will be needed but many of the existing measurement instrument types are approaching end of life and are not designed to be effective in distributed networks, where power sometimes flows in two directions.

The EMRP project **Non-conventional voltage and current sensor for future power grids** examined emerging measurement technologies potentially suited to monitoring the state of grids, from the high-voltage transmission grid to the medium and low-voltages of the distribution grid.

The Project:

- **Developed a current sensing device for calibrating high and medium voltage transformers**, offering a 100-fold improvement in shielding from environmental interference.
- **Developed optical current and voltage sensors that show potential for fault detection in networks over larger distances** than conventional instruments.
- **Produced two Good Practice Guides** on calibrating and installing non-conventional sensors.

Delivering impact

Following the project, the European measurement institutes PTB, METAS and VSL initiated novel calibration services for non-conventional sensors.

The University of Strathclyde, in Scotland, further developed the optical sensors that were subsequently validated at the Power Network Demonstration Centre (PNDC) in Cumbernauld, also in Scotland. Six devices were installed for testing on medium voltage networks as part of an electrical distribution grid.

Synaptec, a company that makes high-performance instrumentation for network operators, took on the commercialisation of these sensors, working closely with energy suppliers Statnett in Norway and SSE in the UK.

A follow-on project FutureGrid II is continuing to develop calibration methods and the measurement infrastructure for real-time control and monitoring of power grids. This is required to help ensure stability in the challenging electricity supply operating conditions likely to be present in increasingly complex grid systems.

More information is available at	ENG61 Non-conventional voltage and current sensor for future power grids (FutureGrid) https://www.euramet.org/project-ENG61 Follow on project 17IND06 Metrology for the next-generation digital substation instrumentation (FutureGrid II)
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Measurements for next-gen nuclear plants

The next generation of nuclear power plants will be considerably different to those in operation today. Using different fuels,reactor designs and operating at much higher temperatures, the plants will require the development of appropriate and robust measurements to support their development, and safe and effective operation.

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The EMRP project **Metrology for new generation nuclear power plants** developed:

- **Improved temperature measurement suitable for nuclear power plant applications** by a new reference temperature fixed point at 1153.8 °C, as well as new stable temperature sensors and self-validation measurement methods for the nuclear environment.
- **Improved understanding of thermal properties of advanced materials used in nuclear designs** from new reference facilities for measuring 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 relevant nuclear data.** An easy-to-use calibrated neutron fluence transfer standard was developed to reduce uncertainties in measurements crucial to the selection of reactor materials. Similarly, improved nuclear data was developed for fuels and decay products of new reactors. Alpha-particle emission probabilities of 238U were determined with significantly improved uncertainties and a new approach using a cryogenic detector was applied to beta spectra.
- **Improved techniques for on-site radioactivity measurement.** 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

Project outputs were shared with the nuclear industry, researchers and regulators to benefit future plant safety considerations. New temperature monitoring instrumentation suited to the harsh operating conditions of Generation IV power plants was further developed. In addition, the nuclear research organisation (CEA) and the institute for nuclear safety (IRSN) in France showed interest in trials in nuclear research facilities.

A novel thermocouple developed in the project was performance tested against conventional technologies 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 by the project was expected to be included in the International Atomic Energy Agency's nuclear data tables used by the global nuclear community. Digital electronics resulting from research into the prototype miniature TDCR liquid scintillation counter were proposed for incorporation in European and international standards. Work also continued to improve the compatibility of digital electronic outputs using various computer programming formats.

More information is available at	ENG08 Metrology for new generation nuclear power plants (MetroFission) https://www.euramet.org/project-ENG08	
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Energy efficiency

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Measurement challenges

EU member states need to make energy savings each year between 2021 and 2030 to meet energy efficiency targets, and this will require improvements at all stages of the energy supply and consumption chain.

Improved efficiencies resulting from greater control of fossil fuel plants and from the introduction of more efficient solar cells based on new thin-film or multijunction technologies will help to meet these targets. Over 6 % of all electricity generated is lost during its transmission to consumers, this could be reduced by using High Voltage Direct Current power lines that can transport up to three times more electricity, over longer distances, than AC. However, these changes to the supply system require an improved measurement infrastructure to support greater energy efficiency.

Another significant consumer of energy is in the engineering infra-structure, where increased use of light-weight materials, such as fiber reinforced plastic composites, could reduce energy consumption, but new measurement methods to validate material performance are needed.

Much of the energy produced in Europe is used for lighting and the Ecodesign Directive encourages low power consumption technologies such as LEDs. Furthermore, much of the power used by electrical devices is wasted as heat or vibration, re-capturing this would reduce energy consumption. Advances in these areas relies on traceable measurements and standards to support improved performance specifications that will aid significant energy savings.

EMRP research has supported projects that address:

- Important control parameters in power plants to support more efficient operations.
- Traceable and validated methods to characterise new solar technologies.
- The measurement challenges to support a reduction of losses in HVDC transmission.
- The introduction of measurement standards for light-weight fibre reinforced plastic composites.
- New measurements and reference standards to support advances in LED technologies.
- New reference materials for energy harvesting technologies.

Key technical achievements

Improving power plant efficiency

Improving operational efficiency of traditional nuclear, coal and gas plants would significantly contribute to energy-efficiency and emission reduction efforts. The EMRP project **Metrology for improved power plant efficiency** brought together a wide range of measurement 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. It also researched some advanced materials that may be suitable for future turbine designs. These could provide opportunities for an additional energy efficiency benefit of 2 – 3 % for all types of large power plants, and result in a comparable proportional reduction of emissions.

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The project developed:

- **Improved temperature measurements** by reduced uncertainties for measurements at the temperatures and techniques used in power plants. For contact thermometry this enabled a reduction in measurement uncertainty in steam power plants. For non-contact thermometry 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 up to 1500 °C.** Facilities for thermal diffusivity, emissivity and specific heat were developed to assess existing and new high-performance materials and coatings used in turbines of 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 experienced in power plants. These models were proven experimentally to be metrologically valid and reduced 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 power plants, with low uncertainty (better than 0.1 % under laboratory conditions and 0.15 % on-site).

Delivering impact

The improved measurement capabilities developed enabled manufacturers of measurement instrumentation to be able to offer enhanced products to support improved power plant efficiency. A company developed a novel flow meter based on outputs of the project that underwent on-site testing to gain regulatory approval. It was estimated that the efficiencies in plant operation resulting from usage of this device would be equivalent to the amount of electricity required to power 10,000 extra homes.

Furthermore, the operators of two power plants applied project outputs related to flow and temperature measurement, delivering an estimated potential efficiency improvement of 1.5 %.

More information is available at	ENG06 Metrology for new generation nuclear power plants (Powerplants) https://www.euramet.org/project-ENG06 ENG63 Sensor network metrology for the determination of electrical grid characteristics (Gridsens)
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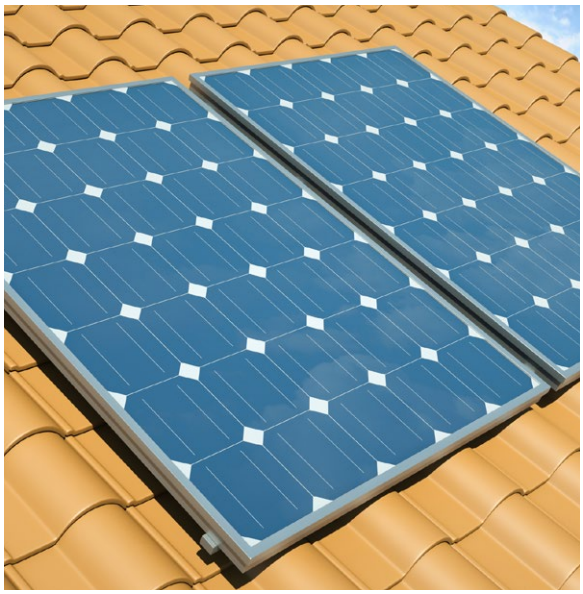
Measurements for more efficient solar cells

Silicon solar photovoltaic (PV) generation capacity has grown rapidly, supported by subsidies that boosted take-up, and cost reductions from competition and manufacturing economies of scale. Another cost reduction strategy is to improve PV module efficiency, that has the added promise of compactness. Multi-junction solar cells (MJSC) are a promising technology, made of several layers of various semiconductors designed to absorb greater proportions of sunlight frequencies than silicon alone. MJSCs already offer much higher efficiencies than silicon PV cells. In time, advances in manufacturing processes and materials may result in even higher efficiencies, perhaps enabling PV to compete directly on cost with more conventional energy sources. However, development breakthroughs will require more reliable methods to measure important parameters, including light conversion efficiency.



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The EMRP project **Metrology for III-V materials based high efficiency multi-junction solar cells** developed a range of measurement techniques that support the development of more efficient MJSC solar cells.

The project:

- **Developed traceable, reliable, cost-effective calibration methods, and measurement standards**, to measure MJSC device efficiency and other parameters to equivalent levels of confidence as for silicon.
- **Produced Good Practice Guides for MJSC calibration procedures.**
- **Designed, fabricated and characterised new types of connectors between cells.**
- **Developed modelling methods to understand the movement of electrons across these connectors**, capable of providing insights for other areas of electronics and photonics.
- **Developed methods to accurately measure electrical properties of MJSCs at the nanoscale**, and developed a gallium arsenide reference sample.

Delivering impact

During the project, the Spanish space agency Instituto Nacional de Técnica Aeroespacial helped the Finnish solar simulator manufacturer Endeas Oy solve measurement issues for its single and multi-source solar simulators used to calibrate component cells and triple junction MJSCs.

Project outputs contributed to the standard IEC 60904-8-1 *Measurement of spectral responsivity of multi-junction photovoltaic devices,* published in May 2017. Applicability for testing to this standard was promoted by a UK-based SME instrument manufacturer in publicity for a photovoltaic characterisation system. This company stated that IEC 60904-8-1 provides important new information on specific test requirements for multi-junction PV devices.

The project established the measurement infrastructure needed to accelerate the development and adoption of more efficient multi-junction solar cells, that could lead to cell modules capable of generating electricity at a cost-competitive basis.

More information is available at	ENG51 Metrology for new generation nuclear power plants (SolCell) https://www.euramet.org/project-ENG51
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Thin-films for energy applications


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The European Union is aiming to generate at least 32 % of all power from renewable sources by 2030, which will require the development of new technologies. Ultra-thin films are a component in many energy-critical applications such as solar panels, energy-efficient windows and power electronics that control the flow of electricity from the grid. Formed of multiple layers of different materials, such films have novel electronic and thermal properties for which correctly-manufactured composition is integral to functionality and reliability. However, a lack of agreement about which measurement parameters are most important for optimising performance, along with quality issues during development, hamper product development and the market competitiveness of thin-films.

The EMRP project **Traceable characterisation of thin-film materials for energy applications** developed a multi-faceted metrology framework for reliable analysis of these materials and demonstrated improved efficiency and stability in these products.

The project:

- **Developed a new coating method that increased the life-span of thin films or improved efficiency.**
- **Developed new optical and X-ray analysis methods for characterising thin film surfaces, devices and underlying chemistries** to unprecedented levels of accuracy.
- **Published four good practice guides** that describe analytical techniques to best characterise thin-film energy materials.

Delivering impact

The developed protective coating technique enabled the creation of solar cells with increased efficiency that led to the formation of ELFys Inc., manufacturers of high-efficiency photodetectors. The X-ray analysis methods developed in this project, capable of determining the composition, density and thermal diffusivity of thin films over a wide range of temperatures and photon energies have led to the creation of a new measurement facility, important in both power electronics and solar cell applications. These methods are being further developed to enable their use in online process-control during thin film deposition.

Following the project, the measurement institutes PTB, VSL and NPL now offer consultancy services to EU companies in the X-ray, optical and optoelectronic measurement fields, to help improve product performance. Along with the best practice guides, a new German DIN standard was developed scheduled for publication as an international ISO standard.

Cumulatively, these new metrological tools will advance European competitiveness and innovation capability in energy efficiency technologies and, therefore, help meet renewable energy targets. The follow on project *Hybrid metrology for thin films in energy applications* continued research in this field.

More information is available at	ENG53 Traceable characterisation of thin-film materials for energy applications (ThinErgy) https://www.euramet.org/project-ENG53 Follow on project 16ENG03 Hybrid metrology for thin films in energy applications (HyMet)
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Measuring high voltage direct current

High voltage direct current (HVDC) transmission systems offer a means to extend the capacity of electricity grids and integrate sustainable energy generation from remote locations into existing networks.

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The EMRP project **Metrology for high voltage direct current** brought together eight NMIs and DIs to develop a metrological infrastructure to support implementation of HVDC transmission in Europe. The research supported ways to reduce losses in HVDC transmission networks, ease integration of renewable energy sources, enhance electric power grid stability, support low loss, long distance energy transmission and ensure fair trade between operators.

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), as well as techniques to estimate losses at the design stage. 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 %) 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**, tested on-site at HVDC stations. These methods assessed harmonics and inter-harmonics introduced into grids by HVDC converter values. The knowledge generated enabled the design of appropriate filters to improve power quality and prevent component failure.
- **Calibration methods and test systems for DC meters**. 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. Specifications and test methods for DC side electricity meters were identified and suggested for inclusion in 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 refered to methods developed in the project to define verification of losses in its procurement specifications, plus the Swedish NMI, SP, was awarded a contract to perform these measurements.

The long-term measurement campaign in a HVDC system converter station yielded a vast amount of power quality data available for further studies and analysis. In addition, the project's outputs were used in preparations for an IEC standard for loss evaluation of voltage source convertors.

More information is available at	ENG07 Metrology for high voltage direct current (HVDC)) https://www.euramet.org/project-ENG07
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Validated inspection of composite materials

Fibre reinforced plastic (FRP) composites are widely used to enhance the strength, stiffness, fatigue and corrosion resistance of wind turbine blades, gas pipelines, transport and other energy applications. As FRP composites also enable lighter structures, they offer a means by which energy consumption and greenhouse gas emissions can be reduced. However, material defects and damage occurring in production and service compromises structural strength, stiffness and longevity. Non-destructive evaluation (NDE) is essential for characterising material quality but, compared to visual inspection, adoption of more sophisticated NDE techniques is often limited by perceptions in some industries that the techniques are unproven, complex and costly. Few relevant normative standards apply for non-destructive defect detection in FRP, so, new standardised techniques will boost confidence in methods to measure, locate and characterise defects in these materials.

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The EMRP project **Validated inspection techniques for composites in energy applications** addressed the lack of standards by developing validated operational procedures for a range of non-destructive inspection techniques. These NDE techniques and procedures were evaluated and validated using an unprecedented selection of reference samples designed and produced in the project.

The project:

- **Developed and validated the first formalised operational procedures for the use of four main NDE methods for use with FRP**, as precursors to measurement methods for future ISO standards.
- **Developed and characterised thirteen FRP Reference Defect Artefacts**, with well characterised built-in defects.
- **Developed two Natural Defect Artefacts**, designed to replicate typical in-use damage.

Delivering impact

Simulated microwave inspections of reference defect artefacts were provided during the project to a major supplier of microwave inspection equipment, revealing the potential for modifying microwave transducers to reduce or eliminate the formation of unwanted standing waves. As a result, the company implemented similar modelling software to improve the design of its equipment.

The validated inspection techniques informed the work of six relevant standardisation committees, plus, resulting from the project, new measurement services for thermal properties of composite materials are now available from two participating NMIs.

The developed operational procedures for NDE techniques provide new levels of confidence in defect detection techniques for FRP composite applications. Optimised NDE techniques, operational procedures and modelling capability will lead to improved safety, life expectancy, energy efficiency and sustainability of composite structures; while also reducing greenhouse gas emissions and maintenance costs.

More information is available at	ENG57 Validated inspection techniques for composites in energy applications (VITCEA) https://www.euramet.org/project-ENG57
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Measurements for solid-state lighting


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Solid-state light sources operate in an entirely different way to traditional sources, producing light with different properties, including in terms of spectral output and angular distribution. These characteristics impose new requirements for accurately measuring electrical, optical and visual performance for optimal design, manufacture and quality control of solid-state lighting devices.

The EMRP project **Metrology for solid state lighting** developed:

- **New facilities for measuring optical parameters of solid-state lighting devices**, to assess their spectral and dynamic features. Studies were conducted into effects of fast-pulsed electrical inputs to solid-state devices on output colour.
- **New facilities to measure electrical parameters of solid-state lighting devices**. Traceable measurement facilities were made available to measure electrical power and power factors of solid-state lighting devices. These measurements helped determine energy efficiency of solid-state lighting devices and likely impacts of large-scale implementation on electrical power grids.
- **Improved methods to assess luminous efficacy**. This is the most important performance parameter for assessing and generating energy savings. The project demonstrated that NMI facilities can reliably determine this parameter for solid-state devices.
- **Established reliable life-time estimations of solid-state lighting devices**. The project developed and tested a process for accelerated aging of these long-lasting light sources.
- **New facilities to measure visual properties of solid-state lighting devices**, used to develop methods to assess qualities of solid-state sources including colour rendition, visual comfort, and mesopic (low light) vision, each critical to consumer acceptance of solid- state lighting.

Delivering impact

Consumer confidence in product claims made for solid-state lighting is essential for increased uptake, which requires performance assessments based on appropriate and traceable measurement methods, via documentary standards.

The project contributed to standards making, through 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 subsequent revision of EN13021.

As a result of the project, a manufacturer of luminance and illuminance meters that participated in the project commercialised instruments for solid-state lighting traceable to national standards at NMIs, and a calibration laboratory applied for accreditation of measurement of solid-state lighting devices.

The project partners worked with Autostrade per l'Italia (the Italian highways authority) to investigate and implement the use of solid-state lighting in road tunnels.

The project also led to applications for two patent methods, for assessing LED efficiency and colour mix.

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

More information is available at	ENG05 Metrology for solid state lighting (Lighting) https://www.euramet.org/project-ENG05 Follow on project ENG62 Metrology for efficient and safe innovative lighting (MESail)	
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Measurements for efficient lighting

The electricity generation sector is the largest contributor to global CO_2 emissions, and lighting consumes one fifth of produced electricity. Household energy consumption decreased by 1.2 % per dwelling per year in Europe since 2005 driven by ecodesign regulations that promoted the use of more energy efficient systems such as light emitting diodes (LEDs) found in solid state lighting (SSL). However, measurement techniques to assess safety, efficiency, lifetime and illumination are not applicable to the latest generation of SSL products which often have distinct characteristics and large or curved areas. This has restricted the uptake of new technologies by the market and the ability of manufacturers to support performance claims.

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The EMRP project **Metrology for efficient and safe innovative lighting** developed new measurement capabilities and standards applicable to emerging SSL products. This project builds on the outcomes from the EMRP project *Metrology for efficient and safe innovative lighting*.

The project:

- **Developed a multiple transfer standard (MTS) – a single standard device** that mimics the light characteristics of a range of commercial lighting products.
- **Developed an electrical reference standard (eMTS)** that simulates the voltage and current of up to eight different SSL lamps and one incandescent lamp.
- **Developed a unique Impedance Stabilisation Network (ISN)** a test device used to account for measurement 'noise' generated from SSL products and improve measurements of SSL products with a variety of AC sources.
- **Developed new models and methods to determine reliability and lifetimes of LED-based SSL products.**

Delivering impact

Application of the developed measurement standards will enable lighting manufacturers to overcome previous measurement errors caused when the properties of the device under test differ from the transfer standard used. The MTS, used for transferring a single calibration value and characterising test setups for LED measurements, is under consideration for mass production by Osram, a major producer of lighting products. The project also provided input to the development of a new documentary standard EN 13032-4:2015, that specifies the requirements for measurements of electrical, photometric, and colorimetric quantities of LED lamps, LED modules and LED luminaires, for operation with AC or DC supply voltages.

This new set of tools enables lighting producers to validate performance claims for new generations of lighting products, allowing them to demonstrate adherence to European regulations.

More information is available at	ENG62 Metrology for efficient and safe innovative lighting (MESail) https://www.euramet.org/project-ENG62
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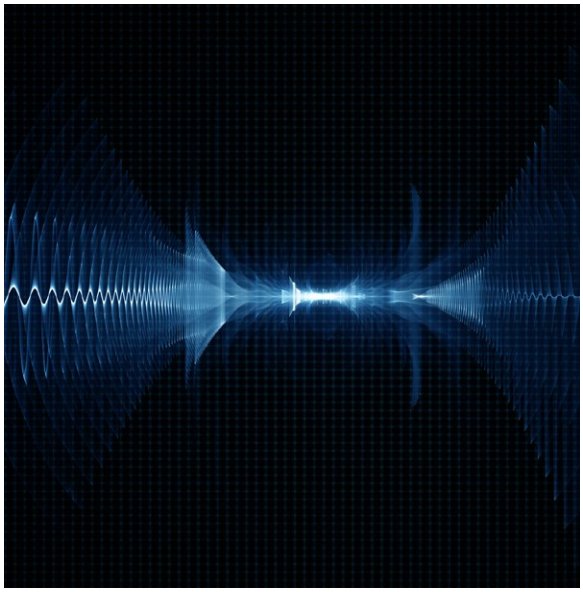
Measurements for energy harvesting

Mass market adoption of energy harvesting technologies is dependent on reliable information about their performance. Both developers and users require reliable information in order to design and implement suitable devices. The EMRP project **Metrology for Energy Harvesting** 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.



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The project developed:

- **New facilities, reduced uncertainties and new reference materials for the assessment of the performance of thermo-electrical converters.** Reduced uncertainties of 5 – 8 % were obtained for the thermal conductivity of thermoelectric materials up to 725 K. For the first time high temperature reference materials for the Seebeck coefficients (a key performance parameter) above 400 K were developed and made available. These coefficients are particularly important for improving engine efficiency in the automotive industry.
- **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 piezoelectric cantilevers. This enabled the identification of new sources of internal loss in converters and significantly improved efficiency by reducing the amount of piezoelectric material, 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

Input from the project team was requested by the International Society of Automation to develop energy harvesting performance metrics for the Power Sources Working Group (ISA100.18). Standards participation by the NMI community was discussed with IEC Technical Committee 113 (Nanotechnology standardization for electrical and electronic products and systems) and IEC Technical Committee 47 (Semi-conductor devices).

A large materials engineering company used project outputs to help develop standardised energy harvesting metrics, providing its customers with a clearer understanding of the output of a device in specific environments. Also, a global engineering company applied the measurement capabilities to energy harvesting development. The project partners also worked with an industrial consortium, including a world-leading provider of aerospace systems, an international software company and four SMEs, that developed vibration energy harvesters for autonomous sensors to monitor aircraft.

More information is available at	ENG02 Metrology for energy harvesting (Harvesting) https://www.euramet.org/project-ENG02
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Focus on Impact

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.

All aspects of the energy supply chain from generation to consumption rely on an advanced measurement infra-structure based on accurate calibrations and robust documentary/normative standards for their use.

Below are highlights of the uptake of project outcomes creating impact in the energy sector.

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Supporting innovation in measurement technology

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Improving wind turbine reliability

Wind energy production capacity increased by 350 % over the last decade. Growth will need to continue but few wind turbines currently reach intended lifetimes without component failures. Stationary blades are an all-too-common sight; such downtimes reduce income and add significant costs. The quality of drivetrain components, and therefore reliability, was limited by the lack of standard processes for ensuring gear quality, plus data provided by measuring machines that could help weren't directly traceable to SI units.

The EMRP project **Traceable measurement of drivetrain components for renewable energy systems** developed new measurement standards, procedures and good practice guides. As a result, Zeiss Industrial Quality Solutions, the leading manufacturer of multidimensional metrology solutions, improved its coordinate measuring machines, and as a result, gained confidence in its capacity to provide traceability for its customers, and sales growth of above 10% in the wind energy systems market.

Hexagon Manufacturing Intelligence, the metrology and manufacturing solutions provider that also participated, enhanced its coordinate measuring machine software as a result of the collaborative efforts of the project. Good Practice Guides developed in the DriveTrain project also improved customer confidence in the reliability and inspection quality provided by its machines.

Future-proofing Europe's gas networks

Michell Instruments, the leading supplier of humidity instrumentation, had developed a novel optical device to measure water content for the gas industry prior to collaborating with the EMRP project **Characterisation of energy gases**. The company was able to make use of a humidity facility developed in the project to evaluate the performance of its instrument at the highest levels of accuracy suitable for its target market. This enhanced Michell Instruments's confidence in the performance of the product, and provided robust evidence to support its marketing and sales plans.

The resulting product was launched in 2014 and has since been installed in locations worldwide, to provide improved confidence to gas network operators about the quality of gas bought and sold, and avoid unnecessary and costly drying processes before gas is injected into their networks. Improving the efficiency and confidence in Europe's gas networks in this way helped pave the way for a range of novel gas mixtures to be incorporated into networks, readying for increased use of renewable gases.

New regulations support stable energy future for Europe

The EMRP project **Metrology for Liquefied Natural Gas** (LNG) developed a new primary flow standard, to provide traceability to a mid-scale LNG calibration facility, as part of the process of enabling flow meters to be used in supporting the transfer and sale of LNG, calibrated accurately in typical operating conditions. Guidance documents issued by the International Organization of Legal Metrology (OIML) were revised to include a section on LNG transfer flow metering developed within the project, plus LNG measurements and flow metering systems knowledge was provided for use in documentary standards for use in the International Group of Liquefied Natural Gas Importers Handbook.

This infrastructure helped develop an approach for fair and open trade of LNG, to reduce financial risks and energy price instability. Adoption of LNG, in place of some of the most polluting heavy-duty fuels, could have a major role in helping diversify Europe's energy supplies.

Standards for biogas

Biogas, biomethane and landfill gases are often contaminated with siloxanes, that are silicon-based materials common to products such as detergents, medical products, cosmetics, paper coatings and textiles. When burned, siloxanes form silica (sand) that can accumulate in gas networks and engines, that can reduce efficiency, increase operating costs and lead to equipment failure. Accurate measurement techniques for siloxanes were needed to demonstrate compliance with impending CEN standards and allow for cost-effective siloxane removal.

The EMRP project **Characterisation of energy gases** worked with instrumentation and standards communities to apply developments of the project for more accurate measurement of siloxanes that were subsequently incorporated into European standards.

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ISO 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 (known as pHe). This best practice for measuring pHe can be used as a quick and simple indicator of bioethanol corrosiveness – a significant concern for engine manufacturers. These practices were incorporated into a new ISO standard, so users can make pHe measurements of the highest accuracy and with global comparability.

Researchers can, as a result, be confident in assessments of the corrosive effects of bioethanol on materials in the process of biofuel-ready engine development. Accelerating development of, and encouraging consumer confidence, is an important step toward more widespread adoption of biofuels and to meeting obligations of the Renewable Energy Directive, that specified that 10 % of transport fuels sold in EU countries be derived from renewable sources such as biofuels.

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Laboratory-based standard for multi-junction solar cells

Multi-junction solar cells (MJSC) are a promising technology, projected to be capable of being developed to, in due course, be able to compete with conventional energy sources directly on cost. However, the development of these advanced cells was slowed by an impractical standard calibration method that needed to be performed at the edge of space.

The EMRP project **Metrology for III-V materials based high efficiency multi-junction solar cells** established a 'synthetic' multi-junction solar cell calibration standard. AZUR SPACE, the German manufacturer of high-performance MJSCs for satellites, signed a contract with project partner PTB for calibration services for developing its four-junction MJSCs, that resulted in the commercialisation of new cell designs. These cells types were purchased by Airbus Defence and Space to power a satellite due for launch by the European Space Agency in 2020 or 2021.

Improved calibrations for solar cells

Solar power will be a major contributor to meeting EU targets on energy from renewable sources and has the potential to be the world's largest source of power by 2050. For this to happen will require multiple approaches, including the adoption of novel photovoltaic (PV) technologies. These advanced cells are likely to have different characteristics to conventional silicon solar cells, which can lead to inaccuracy when reference cells designed for other types of PV are used to calibrate them.

The EMRP project **Towards an energy-based parameter for photovoltaic classification** developed an improved reference standard capable of being 'tuned' to match all solar cell technologies. The advances were incorporated in the World Photovoltaic Scale (WPVS) reference cells sold by Fraunhofer Institute for Solar Energy Systems ISE (Fraunhofer ISE), a project participant. These improved reference cells, with increased stability and greater accuracy, will contribute to the confidence of measurements of a solar cell's performance. This is in turn will encourage the continued uptake of the new and emerging technologies required.

New standards for solar power

The EU has a binding target that at least 32% of energy consumed in Europe comes renewable sources by 2030. Electricity generated from solar cells, or photovoltaics (PV), will have a vital role but will require an increased uptake of new technologies. The energy a solar module generates is assessed using Standard Test Conditions (STC) with fixed values for module temperature, solar irradiance and spectrum. These measurements do not accurately reflect operating conditions in Europe. It has been estimated that each percentage point of uncertainty between the predicted and actual power output equates to a financial uncertainty worth €500 M a year globally.

The EMRP project **Towards an energy-based parameter for photovoltaic classification** developed and validated more accurate measurements for PV modules taking into account a range of temperatures, light intensities and conditions prevalent in Europe. The International Electrotechnical Commission (IEC), responsible for international standards for all electrical and related technologies, incorporated these test conditions into a new set of standards, the IEC 61853 series. These new ratings, applicable to all PV technologies, more closely match a cells performance to the conditions under which it will be deployed which will decrease financial risk for investors and aid in the competitiveness of this technology.

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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 up to 1300 °C. This development could be applied to help ensure the safety and reliability of future 'Generation IV' nuclear reactors, designed to operate at high temperatures to enable increased power output and reduced waste reprocessing requirements. Idaho National Laboratory conducted a comparative laboratory test campaign of conventional thermocouples and the one developed in the project for its upcoming Very High Temperature Reactor fuel test validation project. Following a lab test campaign by the University of Cambridge that developed the sensor in the project, the new sensor was scheduled to be tested in Idaho's prototype reactor, one of only a few such facilities in the world.

If validated in the high radioactivity and temperature environment of Generation IV reactors, successful testing was expected to encourage adoption of this type of sensor by the nuclear industry, so helping to pave the way to the introduction of a new generation of nuclear power plants that may provide low carbon energy for Europe.

New in-line flow calibration supports significant energy savings

KROHNE, a leading manufacturer of industrial process instrumentation, developed an improved ultrasonic flow meter for monitoring power plant processes. By participating in the EMRP project **Metrology for improved power plant efficiency**, the company gained an early opportunity to test the new meter design and a calibration device developed in the project. The calibration device simulated typical plant operating conditions to demonstrate the meter's accuracy. The successful validation of the technology using the calibration device provided KROHNE with the impetus and confidence to initiate production of its ultrasonic flow meter.

Partly as a result of the promising results of the project, another project collaborator E.ON evaluated KROHNE's device in an actual nuclear power plant in Sweden. Early indications were that efficiencies in plant operation resulting from the device was equivalent to around 60 MW, enough to power thousands of extra homes. Given Europe's reliance on large-scale power plants for the foreseeable future, this significant improvement in plant efficiency could offer an important contribution to efforts to reduce Europe's CO_2 emissions.

Digital standards for the nuclear industry

The EMRP project **Metrology for new generation nuclear power plants** developed a compatibility standard for digital data for use by the nuclear industry. Increased use of digital data acquisition has led to a diversity of digital data formats in the sector, that limited software interoperability, as well as comparisons of important nuclear measurement data between users, across borders and between disciplines.

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 identified an urgent need for digital data standards and the project team responded by working with industry to develop an international standard.

New instruments for new power grids

Existing power grids were not designed to integrate large amounts of renewable generation capacity. Without modernisation, renewable sources can induce harmonics and power surges, risking network outages on such networks. Smart grids, that incorporate digital control technologies, are the proposed solution, but require development of a new generation of instrumentation, to monitor these complex distributed networks.

The EMRP project **Non-conventional voltage and current sensor for future power grids** developed novel optical current and voltage sensors to monitor up to 100 km of grid length in real-time. Synaptec, a company that makes high-performance instrumentation for network monitoring, took up the challenge of commercialising the developed sensor technology and has live-tested instruments embedded in trials with grid operators across Europe. The technology could facilitate the introduction of smart grids and ultimately lead to the development of more stable, diverse, and secure power networks.

Better measurement for smarter grids

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

Fluke Corporation, a manufacturer of industrial testing equipment, introduced a PMU calibration service based on methods developed in the project. This service enabled operators to demonstrate compliance with the revised IEEE standard, and reliably compare PMU measurements across grids. Arbiter Systems, a manufacturer of precision timing and power measurement devices, planned to introduce an improved and cheaper combined PMU and power quality measurement instrument for smart grids following involvement in the project. Grid operators could use the device to demonstrate compliance with the standard and make cost-effective reliable grid stability measurements.

Supporting smart renewable energy

With support from South Dublin City Council, International Energy Research Centre (IERV - National Tyndall Institute), Siemens, Intel and Microsoft, the Micro Electricity Generation Association (MEGA) piloted a 'smart energy cluster' in the outskirts of the city, that linked small-scale renewable energy generators with consumers via a smart grid. This smart cluster distributed locally-generated wind and biogas power that used a power stabiliser incorporating a PMU, that enabled the cluster to be linked to the main local grid and allowed inflow of power when renewable generation couldn't meet local demand.

Engagement with the EMRP project **Metrology for smart electrical grids**, enabled an evaluation of the smart cluster's PMU, plus the developed best practice guidance enabled accurate monitoring of grid stability. The small-scale smart grid was intended to be an important step towards widespread renewable energy generation for Ireland and a testbed for a more stable, low-carbon energy future for Europe.

A new calibration for current sensors

To integrate future renewable energy generation capacity into electricity networks, new types of sensors are required. A Rogowski coil (RC) is a device for measuring current with the potential to be used both as a grid sensor or as a calibration device for other sensors. However, existing designs were sensitive to currents in the grid environment, limiting accuracy.

The EMRP project **Non-conventional voltage and current sensor for future power grids** developed a magnetic shield, that improved resistance to external interference by a factor of 100. TÜBİTAK UME, the National Metrology Institute of Turkey, initiated a calibration service using the improved device, that confirmed, and improved, the performance of a prototype current sensor developed by ALCE Elektrik, a global supplier of instrumentation to the energy sector. This successful use of RCs as a calibration standard for non-conventional current sensors promises to be a significant advancement for validating the types of instruments required for future smart grids.

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New sensors for the high voltage grid

To handle the challenges of efficiently integrating electricity from different renewable sources requires real-time monitoring, allowing electricity grids to instantly adapt to changes that could affect network stability. A new generation of measuring instruments are being introduced to help perform this task these but must demonstrate compliance to international standards, such as IEC 61850-9-2 regarding inter-operability between different device types. However, many of these novel instruments lack traceability to the SI for all their functions.

Through the EMRP project, **Non-conventional voltage and current sensor for future power grids**, METAS, the National Metrology Institute of Switzerland, developed a calibration service for non-conventional voltage and current sensors. This set-up allows the accuracy of a wide range of measurement instrument types to be determined, with robust traceability to the SI.

CONDIS SA, a world leader in medium and high-voltage products and solutions, used this service to validate the performance claims of an advanced IEC 61850-9-2 compliant fiber optic sensor (EFOCT) developed by PROFOTECH JSC and manufactured in partnership with CONDIS SA. The new calibration service for novel, advanced network sensors represents a significant step towards ensuring the operational abilities of the new smart grids.

Helping the development of greener engines

Netzsch, the German-based manufacturer of machinery and instrumentation, developed a precision instrument to measure electrical conductivity and the Seebeck coefficient, a property of materials important for the efficiency and power output of thermoelectric generators. Netzsch markets its instrument alongside a reference material developed in the EMRP project **Metrology for energy harvesting**, to enable automotive manufacturers to quantify the performance of thermoelectric materials used in energy harvesting devices, that is an approach to improving overall engine efficiency.

Netzsch's customers now can have confidence that they have the measurement capability to accelerate the development of improved thermoelectric generators. Should energy harvesting become an effective approach to making internal combustion engines more efficient, it could become one of the most significant contributions to reducing Europe's greenhouse gas emissions.

Lighting the way to a greener Europe

The EMRP project **Metrology for solid-state lighting** developed improved measurement practices and quality metrics to support more reliable and accurate performance testing of LED lighting. The methods developed contributed to an International Commission on Illumination standard and equivalent European Committee for Standardization (CEN) standard, that was revised to include LED lighting testing.

As a result, manufacturers could be confident about claims for product performance and demonstrate product quality, both critical to consumer acceptance. Accelerating adoption of energy-saving lighting across Europe, in line with the aims of the Ecodesign Directive, has significantly contributed to reduced CO_2 emissions, as well as usage of mercury by the lighting industry.

New standard for safer, greener roads

The Italian standards organisation (UNI) incorporated research performed within the EMRP project **Metrology for solid-state lighting** into a standard for road tunnel illumination.

The UNI standard enabled LED lighting to be safely introduced into the many road tunnels of the Italian road network, and also led to significant reductions in electrical power requirements. LEDs operating at the newly designated safe lighting levels identified by the project also contributed a further 33 % saving in electricity than would otherwise have been the case. With LED lighting introduced into approximately 95 % of Italy's 1,500 km of highway road tunnels, this standard led to safer roads and significantly lower power consumption and associated CO_2 emissions.

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Further information

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

https://www.euramet.org/research-innovation/emrp/emrp-calls-and-projects/emrp-call-2013/

Other projects in the EMRP Energy theme can be found at:

https://www.euramet.org/research-innovation/emrp/emrp-calls-and-projects/emrp-call-2009/

Other projects in the EMPIR Energy theme can be found at:

https://www.euramet.org/research-innovation/research-empir/empir-calls-and-projects/

Europe's National Measurement Institutes working together

The majority of European countries have a National Metrology 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.

While traditional metrology stakeholders in manufacturing demand ever-increasing scope and greater accuracy, there is also a greater demand for accurate measurement in areas which support food safety, clinical medicine and environmental quality, as well as emerging areas such as biotechnology and nanotechnology. This requires resources beyond the scope of most national metrology systems and therefore it makes sense for NMIs to significantly increase the level of collaboration with each other. **The European Association of National Metrology Institutes (EURAMET)** is the body that coordinates collaborative activities in Europe.

EURAMET has implemented the European Metrology Research Programme (EMRP), a project programme organised by 23 NMIs and supported by the European Union, with a value of over €400 million. The EMRP facilitates the formation of joint research projects between different NMIs and other organisations, including businesses, industry and universities.

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