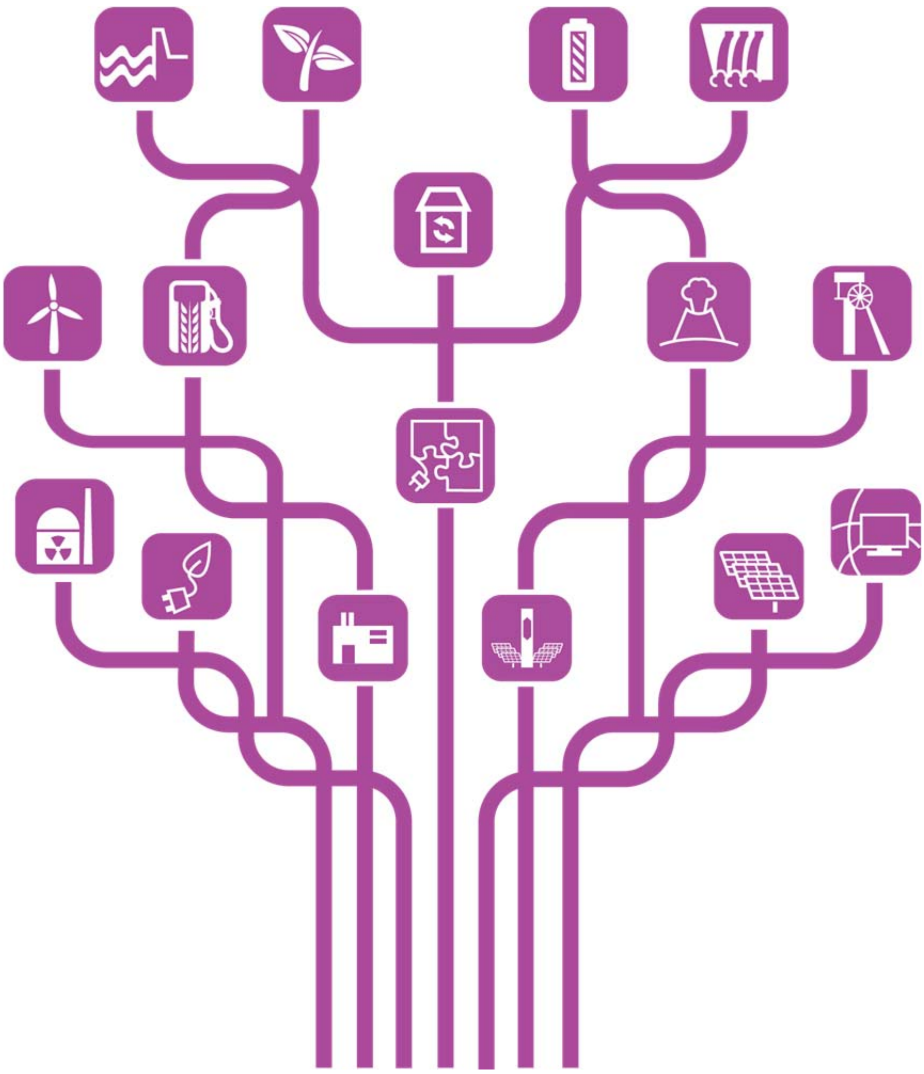
SET-Plan: The Integrated Roadmap

ANNEX I: Research and innovation actions

Part II – Competitive, Efficient, Secure, Sustainable and Flexible Energy System



Acknowledgements to Drafters and Contributors

in alphabetical order

European Industrial Initiative on Carbon Capture and Storage (EII CCS)

European Association for Storage of Energy (EASE)

European Electricity Grid Initiative (EEGI/DSO)

European Energy Research Alliance (EERA): Joint Programme Geothermal Energy

European Energy Research Alliance (EERA): Joint Programme Carbon Capture and Storage

European Geothermal Energy Council (EGEC)

European Heat Pump Association (EHPA)

European Investment Bank (EIB)

European Industrial Bioenergy Initiative (EIBI)

European Electricity Grid Initiative (EEGI)

Energy Materials Industrial Research Initiative (EMIRI)

European Photovoltaic Industry Association (EPIA)

European Power Plant Suppliers Association (EPPSA)

European Sustainable Nuclear Industrial Initiative (ESNII)

European Photovoltaic Technology Platform: Solar Europe Industry Initiative (EU PV TP - SEII Team)

European Association for Coal and Lignite (EURACOAL)

European Energy Research Alliance (EERA)

European Solar Thermal Electricity Association (ESTELA)

European Association of Gas and Steam Turbines Manufacturers (EuTurbines)

European Wind Energy Association (EWEA)

European Fuel Cells and Hydrogen Joint Technology Initiative (FCH JU)

Hydro Equipment Association (HEA)

European Energy Research Alliance (EERA): Joint Programme Concentrated Solar Power/Solar Thermal Electricity

KIC InnoEnergy SE

Ocean Energy Europe Association (OEEA)

European Technology Platform on Renewable Heating and Cooling (RHC Platform)

Sustainable Nuclear Energy Technology Platform (SNETP)

Sustainable Process Industry through Resource and Energy Efficiency (SPIRE)

European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP)

<table>
<tr><th colspan="2"></th><th>Number</th><th>Investments (M Euro) (when available)</th></tr>
<tr><th colspan="2">Headings</th><td>8</td><td rowspan="2">39 953,5</td></tr>
<tr><th colspan="2">Challenges</th><td>26</td></tr>
<tr><th rowspan="3">Proposed R&I Actions/Programmes</th><th>ARP</th><td>92</td><td>6 138</td></tr>
<tr><th>IRDP</th><td>88</td><td>12 640</td></tr>
<tr><th>IMUP</th><td>64</td><td>21 175</td></tr>
</table>

TABLE OF CONTENTS

HEADING 1: Making Renewable Electricity and Heating/Cooling Technologies Competitive by 2020 and beyond

Challenge 1: Wind Energy

Wind energy is the renewable energy (RE) technology expected to provide the largest contribution to the RE targets. In 2013 there were 117 GW of installed wind energy capacity, enough to cover 8% of the EU's electricity consumption. By 2020 these figures could reach 216 GW and 14% of electricity demand and by 2030 350 GW installed could cover between 21 and 24% of demand[1].

KEY ISSUES

Production value chain performance/cost competitiveness

- Offshore wind needs to reduce its levelised cost of energy (LCoE) to 50% of 2010[2] levels by 2030, by increasing reliability and availability, by reducing costs from component to power production including through improved materials and advanced manufacturing capabilities, and by optimising logistics, installation, operation and maintenance. These improvements should enable an offshore capacity factor of 50% already by 2020.
- Onshore wind aims to reduce its LCoE by 20% in 2020 and by 30% in 2030, again with reference to the 2010 levels, and to enlarging the deployment possibilities. Focus will be on:
  - Developing innovative technologies adapted for complex terrains and with significantly reduced mass of turbine.
  - Turbine upgrade processes requiring new, increasingly sophisticated condition monitoring techniques to maximise the yields from existing wind farms.
  - Developing new foundation designs that are more suited for repowering.

Supply chain

- Achieve standardisation of component design, develop standards and create supply chains to produce turbines and components in grand volumes to generate economies of scale.
- Develop the infrastructure for the offshore sector, with the design and construction of dedicated ports and offshore logistic hubs.
- Develop effective methods for repowering and recycling.
- Develop lighter, stronger, cheaper materials which will extend the lifetime of wind turbine structures; these new materials should be suitable for appropriate recycling.
- There are certain turbine components or subcomponents, such as control and power electronics, which fail more often than it is desirable. More research is needed in why these components fail which findings should be applied into new, improved components.

System integration

[1] 2013 Technology Map of the European Strategic Energy Technology Plan. doi:10.2790/99812

[2] The LCoE and reference year should be understood as the year of the final investment decision in a wind farm and its resulting LCoE

- Electricity systems should allow higher wind power levels, up to 70% of the electricity demand, in an economic and safe manner.
- Ensure reliability of the grid at very high levels of wind power penetration by further improving system integration. Develop smart interfaces, new equipment capabilities, new or improved services to network operators (grid support services). Research in this area is a prerequisite for achieving high penetration for wind energy and will contribute to improved competitiveness. Standardised solutions will enable faster procurement for projects and therefore will reduce CAPEX.
- Optimise coordination with network builders/operators to ensure timely connection to the grid.
- Wind power forecasting for power system operation should offer improved accuracy. For trading, a reduction of the day-ahead forecast error of 35%-45% by 2020 should be reached.

Wind conditions

- Improve the efficiency and accuracy of wind design conditions, siting, resource assessment and forecasting for onshore and offshore wind, taking into account different conditions, such as complex terrains and extreme climates.
- Developing an effective and standardised evaluation of uncertainty within each stage of the lifecycle of a wind project is a priority.

Non technological aspects

- Investigate and develop new market designs and optimal business models for a power system with high shares of non-dispatchable renewables (such as wind) generation, including efficient link to other energy markets, such as heat, coal, gas or transport fuels, also taking into account regulatory changes in public support schemes.
- Develop efficient market structures that enable high levels of wind deployment, by optimising e.g. energy market policy and administrative procedures.
- Develop a new model for the evaluation of wind energy vis-à-vis other energy technologies focused on the current and future impacts of the different technologies. An analysis that is based on scientific principles and that values the strategic, environmental, social and economic aspects of those technologies will help evaluating energy investments and illustrate clearly how wind energy contributes to a safe, secure, affordable, sustainable and environmentally friendly energy supply.
- Improved financing conditions for wind energy projects, especially reducing the cost of capital for offshore wind.
- Minimise the gap of qualified staff needed in STEM topics (science, technology, engineering and maths), related to wind energy.

Environmental and societal issues

- Develop knowledge on potential impacts of wind energy on the environment and develop techniques to minimise it. Compare the potential impact with other energy and non-energy technologies.
- Increase social acceptance and support for wind energy, especially onshore wind farms and repowering of old wind farms by investigating the motivation behind public opinion, reviewing case studies and best practices, improving public awareness of wind energy and environmental impacts and involving local communities.

ADVANCED RESEARCH PROGRAMME

Action 1: New turbines, materials and components

Scope: Developing cost-effective and reliable large turbines will contribute to making wind power fully competitive. This embraces from the development of cost-effective manufacturing processes for more performing materials to the scaling up of research projects, which often leads to the development of better or less expensive applications for smaller turbines in a cascading effect. Supporting these actions, therefore, contributes to the overall competitiveness of wind power.

To create the conditions for designing, producing and installing larger turbines. As a result, a number of prototypes of turbines between 10 and 12 MW should be installed and tested between 2017 and 2020.

Deliverables:

- Higher-performance steels, blade materials, permanent magnets etc.
- Low-maintenance power electronics and other components.
- Tested prototypes of 10-, 12- and 15-MW generators and drive trains.
- Tested prototype blades of up to 110m in length.

Expected impact:

- Significant reduction in cost of energy from wind farms using these machines.
- Increasing the efficiency of energy capture and the capacity factors of new turbines.
- Significant reduction in the number of wind turbines for a given wind farm capacity.
- Reduction in downtime from unplanned maintenance.
- Increase in the world market share of European wind turbine manufacturers.
- Development of a high-technology supply base in Europe.

KPIs:

- Prototype 10 MW generator and drive train by 2016; 12 MW by 2018; 15 MW by 2021.
- Prototype 100m blade by 2016 and 110m by 2018.
- 10 MW wind turbine in the market by 2018.

Costs: EUR 160 million.

Timeline: from 2015 - 5 years projects' duration.

Modality of implementation: Both European and national funding are necessary.

Action 2: Resource assessment – (Key issue: wind conditions)

Scope: One of the most important drivers for reducing the cost of energy is minimising uncertainty and improving the predictability and availability of wind energy production. A detailed knowledge of the climatic conditions (specially wind but also waves, ice, temperatures and so on) is fundamental for minimising investment risks; reducing financing costs from a reduction in resource assessment uncertainty; reducing cost of energy through lean turbine designs with less allowance for the uncertainty in climatic conditions; mitigating technical constraints and improving understanding of environmental constraints interacting with climatic conditions. An effective and standardised evaluation of uncertainty within each stage of the life cycle of a wind project is a priority. Cost competiveness of wind energy is closely linked to accurately quantifying uncertainty. It has an impact on the cost of finance and is therefore as important as the annual energy production (AEP) estimates.

Deliverables:

- Interaction flow on wind turbine generators (WTG) (single and in wind farms), comprising: Experimental campaigns.
- Ad-hoc models tailored to large rotors and large wind farms.
- Updated synthetic data for wind turbine codes.
- New standards, certification procedures and methodologies.
- Improved wake models both onshore and offshore quantifying loads and wake losses.
- Open platform for design condition models.
- Quantification of other extreme condition risks, comprising: Mapping of such conditions.
- Load measurements campaigns.
- Development of extreme condition standards.
- Mitigation strategies for extreme conditions.
- Uncertainty of yield and load prediction.

Expected impact:

- Improved standards and software for wind resource prediction and site assessment, including uncertainty evaluation, coupling both atmosphere-ocean and sea-land interactions.
- New knowledge in meteorological issues, applicable as well to other fields of science.
- Leaner, lighted wind turbines and components.
- Significant reduction in wake losses in wind farms.
- Increasing efficiency of energy capture and transformation.
- Reduction in downtime from ice and unplanned maintenance in particular in cold climate wind farms.

KPIs:

- Improve wind energy forecasts and understanding of wind conditions to develop predictions with an uncertainty of less than 3% by 2030.

Costs: EUR 70 million.

Timeline: from 2015 - 5 years project duration.

Modality of implementation: Both European and national funding would be suitable.

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Offshore technology – (Key issue: production value chain performance/cost competitiveness)

Scope: Short-to medium term research actions need to be addressed to allow the rapid deployment of offshore wind in Europe's waters. Focus should be on increasing reliability and availability of offshore wind turbines and their components; reducing cost of offshore wind from components to power production including through advanced manufacturing capabilities and developing infrastructure for the sector.

Make offshore wind power costs competitive with conventional electricity generation by 2030, develop technology in sites with a water depth beyond 50m and at any distance from shore.

Deliverables:

- Improved sensors and measurement technologies e.g. for extreme conditions.
- New bottom fixed substructures to minimise lifecycle costs.
- Improved offshore wind farm modelling techniques.
- Development and demonstration of WTG floating platforms.
- Development and validation of improved systemic WTG and substructure design models and practices.

Expected impact: -

KPIs:

- Cost of foundation EUR/MW/ water depth (m).
- Weight (mT)/ structure /MW installed.
- Quantification of operations costs and times for different floating structures concepts.

Costs: EUR 750 million.

Timeline: from 2016 - 4 years project duration.

Modality of implementation: Both European and national funding would be suitable.

Action 2: Logistics, assembly, testing, installation and decommissioning – (Key issue: supply chain)

Scope: Latest developments in onshore and offshore turbines with larger rotor diameters and new foundations required dedicated logistics infrastructures (ports, vessels, testing facilities).

The objective by 2020 is to achieve a serial large scale implementation of offshore wind with known technologies and achieve cost reductions by improving current methods.

Deliverables:

- New offshore installation processes.
- Definition of methods and standards for testing 10-15 MW wind turbine components.
- Improvement of size and capabilities of system-lab testing facilities for 10-15 MW turbines.
- Field testing facilities for 10-15 MW turbines aimed at increasing reliability.
- Development of five large scale manufacturing and logistics processes, both size and numbers for in and out-of-factory and site erection.
- Facilities, infrastructures and logistics for offshore wind:
    - New and better ports management strategies;
    - New and better vessels management strategies;
    - Improved installation methods and logistics
- Recycling and end-of-life scenarios.
- Turbine life-time extension and decommissioning.

KPIs:

- Installation of a 5MW-level offshore WTG and substructure at 230 EUR/kW by 2020.
- Speed of installation of offshore turbines and foundations reduced to 2 hours per MW-equivalent by 2018 (transport to site not included).
- EU methods and standards for testing large components (other than turbine components, which is treated in Action 1 of the Advanced Research Programme) available in 2015.

Costs: EUR 583 million.

Timeline: from 2015 - 5 years project duration.

Modality of implementation: Both European and national funding would be suitable.

INNOVATION AND MARKET-UPTAKE PROGRAMME

Action 1: Grid integration – (Key issue: system integration)

Scope: The successful transformation of the power system requires R&D and demonstration projects on connection technologies for offshore and onshore wind power plants to AC and DC networks (including multi-terminal HVDC grids); wind power capabilities for system support and virtual power plant (VPP) operation; and a better fit of wind energy in the power market.

To develop grid integration techniques enabling secure and cost-effective integration of high penetration levels of wind power; to develop and demonstrate optimal solutions for connecting offshore wind farms and clusters to future offshore networks; to develop and demonstrate methods for wind power management providing system support services with regard to market integration and combined operation with other power plants.

Deliverables:

- Demonstration of a multi-terminal offshore connection.

- The experience from existing HVDC-connected wind power plants is shared among the industry.
- Better wind plant modelling within electricity system models.
- Grid support services design and provision/VPPs.
- Testing of wind power plant capabilities (methods and facilities).
- Better knowledge of impact and operation of wind power on electricity markets.
- Improved wind power forecasting techniques and utilisation.
- Understanding of interaction between existing offshore wind farms and a future North Sea grid, including the definition of standards e.g. for connection.

Expected impact:

- Wind power will cover anywhere between 30% and 70% of electricity demand in an economic and safe manner.
- Better integration of existing offshore wind farms into a future North Sea grid.

KPIs:

- Multi-terminal offshore grids: efficiency of power collection (%); investment cost of power collection (EUR/MW); curtailment (% of yearly production); reliability (% availability); load factor of offshore grid (%).
- Grid support services: reliability of service (%); cost of service (EUR/MW or EUR/MWh); economic cost and benefit from ancillary services (EUR/MW and EUR/MWh); possible penetration (% on annual basis).
- Availability of data on HVDC connected wind power plants (%).

Costs: EUR 235 million.

Timeline: From 2015 - 2/3 years project duration.

Modality of implementation: Both European and national funding would be suitable.

Action 2: Spatial planning, social acceptance and end-of-life policies – (Key issue: non technological aspects)

Scope: to develop spatial planning methodologies and tools taking into account environmental and social aspects; to analyse and address social acceptance issues of wind energy projects including promotion of best practices; and to better define end-of-life options and policies including recycling.

Deliverables:

- EU offshore atlas capturing wind, wave, soil and bathymetry.
- Increased knowledge on noise issues (underwater, atmospheric propagation, monitoring and control, human perception of wind turbine noise).
- Assessment of the possible impact of wind turbine on health (noise, flickering/shadow, etc.).
- Development and validation of more accurate and robust noise propagation models.
- New passive and active aerial markings.
- Reduced local environmental impacts and increased environmental benefits (e.g. regarding birds, bats, fisheries, or the treatment of cumulative impacts).
- Improved siting and spatial planning techniques.
- Better offshore planning.
- Increased social acceptance.
- By 2018 a scheme will be consented to quantify/evaluate levels of acceptance/perception.

- Clearer guidance, methodologies and tools to assess the cumulative impact of wind farms in Europe.

Expected impact:

- Improvement of the social acceptance of wind energy in those areas (countries/regions/municipalities) where this was an issue.
- Improvement spatial planning regulations so that they do not limit technological developments, e.g. by imposing height limitations.
- Better knowledge of environmental and health impact of wind by individual and groups of wind farms.

KPIs:

- Consented guidance, methodologies and tools on assessment of cumulative impacts of wind farms in Europe should be developed by 2016.
- Rate of approval of new wind farm proposals reaching ten percentage points above current levels.
- Evaluation of offshore wind development costs.
- Cost optimisation measures identified.

Costs: EUR 15 million.

Timeline: from 2015 - 2 years projects duration.

Modality of implementation: Both European and national funding would be suitable.

Challenge 2: Photovoltaics

KEY ISSUES

- All major future important energy scenarios foresee key role for photovoltaic solar energy (PV). PV is renewable and has a huge global and European potential, making it an important building block for a secure and sustainable energy system. Even in the short term, i.e. by 2020, PV could cover as much as 10% of the EU electricity demand. This ambition provides the context for the RDI objectives:
  - Broadening cost-competitiveness of PV by RDI-driven technology improvements, enabling self-sustained growth under a suitable electricity market design.
  - Identification and development of solutions for large-scale integration of PV in energy grids and markets (see also Heading 2: Energy and System Integration).
  - Further improvements in quality, reliability and lifetime of PV components and systems.

  The RDI actions defined in this challenge address large-scale deployment of PV as well as seizing the related economic opportunities. The availability of world-class technology and advanced deployment solutions made possible through an ambitious innovation process is essential for the success of PV as a sustainable energy source, but also for the success of the European PV industry sector.
- Advanced manufacturing and competitive cost:
  The essential goal is to make PV cost competitive under suitable electricity market conditions. This is done by improving cost and performance of PV systems, in particular by reducing the CAPEX for large PV systems to 0.8-1.0 in 2020 EUR/Wp (while restoring profit

margins that vanished in recent years), enabling reduction of the Levelised Cost of Electricity (LCoE)[3].

- Increase the efficiency of commercial solar modules (i.e. not laboratory or prototype record values) to the following values.

Module technology	**2014 level[4]**	**2020 target[4]**
Wafer-silicon technologies (cSi)	15-22%	21-25%
Thin-film technologies (TF)	9-14%	14-20%
High Concentration PV (HCPV)	28-33%	38-40%
Low Concentration PV (LCPV)	17-22%	>24%

- Reduction of manufacturing and application costs by improvement of industrial processes, reduction of materials and energy consumption and introduction of new materials, enhancement of lifetime and reliability of photovoltaic components (see also next point) and increase of system power conversion efficiency.
- Development of processes and tools for very high throughput manufacturing; demonstration with flexible pilot production lines.

- Supply chain management and operational excellence.
- The first goal is to further increase lifetime and long-term operational reliability and to implement total quality assurance of PV technology, thus reducing lifecycle cost of electricity production. The second goal is to improve yield forecasting and assessment, to increase the value of PV electricity.
  - Further improve materials efficiency and introduce new materials where appropriate. For example, reduce silicon feedstock consumption cells to <3g/Wp.
  - Increase the guaranteed power output time (≥80% of initial) of modules to >35 years and Increase inverter lifetime to 30 years by 2020.
  - Increase the average new system performance ratio to >85% for residential PV and 90% for utility scale PV by 2020.
  - Adopt total quality control over the value chain of all system components (modules and Balance of System) and the system at large. Analyse and increase the statistical reliability to predict ageing and failures and allow for preventive maintenance.
  - Design PV systems and their components for increased reliability, operational monitoring and sustainability (e.g. by allowing for efficient recycling).
- System integration:
  - Enable the effective and efficient integration of growing shares of PV into the grids, electricity markets and the environment, along with other renewable energy sources and new types of electricity demand. This subject is linked to Heading 2: Energy and System Integration.
  - Identify and develop control strategies for PV inverters linked to manageable demand and electricity storage.

[3] Typical LCoE values in 2020 would then be 0.04-0.06 EUR/kWh in S-EU and 0.07-0.10 EUR/kWh in NW-EU (note that LCoE values depend critically on calculation parameters used)

[4] Ranges correspond to different options in the respective technology subcategories

- Adopt distributed energy management, as well as the provision for, and fair remuneration of ancillary services at distribution and transmission level.
- Enable to achieve benefits of scale in the electricity system by adopting adequate levels and methods of aggregation of PV plants.
- Further improve PV power operational forecasts in the context of both grid and market integration.
- Develop flexible solutions for physical and multifunctional integration of PV systems.

- Frameworks for large-scale deployment:
  Develop PV-specific and general regulatory and financial frameworks that will allow for commercially viable and sustainable business models for PV electricity, both at retail and wholesale level. This should be done considering both self-consumption and aggregation of electricity from PV.
  - Develop or modify PV standards to reflect field rather than standard conditions, including the corresponding test procedures.
  - Develop and adopt open interface and communication standards to facilitate integrated operation of energy devices within buildings and the power system.
  - Improve the existing framework for training and education, to guarantee the availability of the right skills for PV jobs across the whole value chain.
- Societal issues:
  - Develop programmes to address the potential societal and regulatory barriers that may occur upon very large-scale deployment of PV, related to, among others, financing instruments and public acceptance.

ADVANCED RESEARCH PROGRAMME

Action 1: Novel PV technologies for low costs and/or high efficiencies

Scope: Increasingly advanced versions of existing PV technologies (and combinations thereof) need to be developed to maintain technology competitiveness in a rapidly innovating global sector. Emerging (i.e. pre-industrial) technologies need to demonstrate their added value in terms of cost, performance or unique application options and their viability in terms of manufacturability and stability. Novel, potentially very high efficiency PV technologies with new device architectures and advanced materials need to be developed. Low cost PV technologies and processes should be explored for technical and economic viability and developed to readiness for pilot manufacturing.

Deliverables and KPIs:

- Demonstration of device designs and fabrication processes for at least two high efficiency technologies (defined as ≥3% above relevant values for commercial products; see Table in next Action).
- Demonstration of pilot production readiness of at least two emerging and/or novel low cost technologies (potential module costs at large scale ≤ 0.3 EUR/Wp).

Expected impact:

- Europe is prepared to face global competition beyond 2020, i.e. for large-scale PV deployment at system cost levels of 0.5-0.8 EUR/Wp.

Costs: EUR 120 million.

Timeline: 2015 - 2020 (and beyond).

Modality of implementation: Action to be implemented both at the EU and at the national level.

Action 2: Enhanced PV conversion efficiencies and lifetimes

Scope: Increasing module and system electricity production (i.e. efficiency under standard and actual operating conditions) is a key driver to bring down the cost of PV electricity, enhance the sustainability and lower the energy payback time. R&D along the value chain, i.e. materials, cells, modules and power converters is necessary to increase the efficiency of modules and systems towards significantly higher values. Further R&D on high-quality and long lifetime products and balance of system components are essential.

Deliverables and KPIs:

- Module efficiencies:

Module technology	**2014 level[5]**	**2020 target[3]**
Wafer-silicon technologies (cSi)	15-22%	21-25%
Thin-film technologies (TF)	9-14%	14-20%
High Concentration PV (HCPV)	28-33%	38-40%

[5] Ranges correspond to different options in the respective technology subcategories

Low Concentration PV (LCPV)	17-22%	>24%

- Module lifetime: Guaranteed power output time (80% of initial power) > 35 years.

Expected impact: Increasing competiveness of European PV sector in the timeframe 2015-2020 and large-scale deployment of PV at steadily increasing performance and decreasing costs.

Costs: EUR 600 million.

Timeline: 2015 - 2020.

Modality of implementation: Action to be implemented both at the EU and at the national level.

Action 3: Cost reduction through lower materials consumption and use of low-cost materials

Scope: As total costs of PV cells, modules and systems decrease, materials generally represent an increasing fraction of them. Therefore reduction of materials consumption and the introduction of new (low-cost) materials are crucial. This requires more efficient materials and component production processes and new device and system designs. Moreover, new materials are required to enable design-for-sustainability and to facilitate new PV applications, such as those requiring very low weight and/or flexibility.

Deliverables and KPIs:

- Silicon feedstock: consumption <3g/Wp at cell level (<100 µm wafer thickness or kerfless cutting).
- Module materials: options for low-weight and/or flexible modules available at competitive costs.
- Cell metallisation: low-cost, sustainable options available (e.g. copper-based).

Expected impact:

- Improved cost competitiveness of the technology; improved sustainability by more efficient use of resources (materials) and business opportunities for the European material industry sector.

Costs: EUR 240 million.

Timeline: 2015 - 2020.

Modality of implementation: Action to be implemented both at the EU and at the national level.

Action 4: Reduction of LCoE by enhanced PV system energy yield and lifetime

Scope: The costs, specific energy yield (kWh/Wp/yr) and lifetime of a PV system are determined by the modules (see Actions 1 and 2) and by the Balance of System (BoS) components, including inverters, and system design and engineering (this Action). The aim is to reduce LCoE by lowering the latter costs and enhancing BoS (and hence, system) efficiency, reliability, and lifetime. Particularly for the power electronic components (inverters, power optimizers, etc.), the focus is on the production process, the introduction of new materials for power electronic devices, integration and reduction of the number of parts, design for reliability and design for low lifecycle costs. In addition, inverters need to be smart-grid-ready, i.e. suitable for multifunctional and interactive operation. Finally, low-cost, high-accuracy sun tracking systems (single and double axis) are required for different applications.

Deliverables and KPIs:

- Inverter lifetime: >30 years.
- BoS costs: CAPEX excl. PV modules for large systems <0.4 EUR/Wp.

Expected impact:

- Improved cost competitiveness of the technology, PV systems smart-grid-ready, business opportunities for the European (power electronics) industry.

Costs: EUR 240 million.

Timeline: 2015 - 2020.

Modality of implementation: Action to be implemented both at the EU and at the national level.

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Pilot production lines

Scope: This action aims to bridge the gap between research and large-scale application, in other words: between LAB and FAB. By testing and demonstrating new material production processes and improved PV technologies on pilot level, their viability for industrial production can be proven and risks can be minimized. This Action complements those in the Advanced Research Programme. It covers the whole value chain from materials, via cells and modules up to power electronics and addresses manufacturing processes as well as corresponding equipment. Key aspects are: throughput, yield, statistical quality control and large scale manufacturability.

Deliverables and KPIs: Pilot lines established for each of the following sectors:

- At least one for material processing.
- At least one for a very low cost concept.
- At least one for an enhanced high efficiency concepts.
- At least one long-lifetime power electronics concept.

Expected impact:

- Increasing cost competitiveness of the technology; triggering investments; enhancing bankability; increasing potential for industrial growth and jobs.

Costs: EUR 240 million.

Timeline: 2017 - 2020.

Modality of implementation: Action to be implemented at the EU level.

Action 2: Demonstration of new PV solutions

Scope: In order to allow new approaches to enter the market, demonstration projects are essential. In particular, proof-of-concept demonstration projects for new PV system types (i.e. new PV elements and new Balance of System components and designs) and new types of system integration. These projects concerns both large PV power plants and significant numbers of (basically identical) smaller systems and aim to enhance confidence of potential system operators as well the financial sector.

Deliverables and KPIs: Demonstration plants established for each of the following categories:

- At least two of >1 MWp size using new PV technologies
- At least two of >1 MWp including new BoS components or designs or grid integration concepts
- At least two of significant numbers of smaller systems (total power typically 1 MWp) including new integration concepts for the built environment.

Expected impact:

- Triggering investments, enhancing bankability, increasing confidence of systems owners and operators, paving the way for market entry of new PV technologies and solutions.

Costs: EUR 60 million.

Timeline: 2018 - 2020.

Modality of implementation: Action to be implemented both at the EU and at the national level.

Action 3: Making PV mainstream source of power

Scope: Making PV a mainstream source of power requires inclusion of ancillary services from PV, distributed and supervisory control strategies for PV inverters integrated with controllable demand and storage, methods for aggregation of these resources into large portfolios, improved PV generation forecasting, and integrated tools for forecasting, optimisation and control of generation and demand on local (prosumer) and global (power system/market) level. These features need to be demonstrated in a market-compatible demonstration set up and on a sufficient scale that can be replicated or scaled up to the regional, national or European level.

Deliverables and KPIs:

- Readiness to offer active and reactive power control to ancillary service markets.
- Off-the-shelf control systems for PV inverters for local energy and storage management.
- Single-site power forecast RMSE <8% of installed power (intra-day, in NW-Europe).

Expected impact:

- Contribution to generation adequacy and security of supply of a decarbonised power system; reduction of cost of power generation as compared to scenarios relying on full fossil backup generation and extensive capacity mechanisms.

Costs: EUR 480 million.

Timeline: 2015 - 2020.

Modality of implementation: Action to be implemented both at the EU and at the national level.

Action 4: Industrial RTD for and demonstration of higher Performance Ratios

Scope: The Performance Ration (PR) of actual to ideal energy output is an important measure for a PV system. If this is increased the cost per generated kWh can be lower. The PR is determined during operation of a PV system but is influenced by the whole value chain. Therefore, the challenge to increase its value must be addressed at the level of conversion devices (cells and modules), Balance-of-System components and systems. Key aspects are total quality control over the value chain, introduction of new materials, and integrated design for reliability, operational monitoring and adequate maintenance; see also Action 2 and 4 of Advanced Research Programme.

Deliverables and KPIs:

- System Performance Ratios: >85% for residential systems and 90% for utility scale systems.

Expected impact:

- Increasing cost competitiveness of the technology; reducing energy costs.

Costs: EUR 240 million.

Timeline: 2017 - 2020.

Modality of implementation: Action to be implemented both at the EU and at the national level.

Action 5: Long-Term reliability of PV modules and systems

Scope: Improving the lifetime of PV modules and systems has a great impact on the levelised cost of electricity and sustainability; see also Action 4 of Advanced Research Programme. Therefore it is of vital interest to increase the guaranteed lifetime of PV installations. This goal is achievable via research, development and innovation at product (i.e. system component component) and system level, as well as at the level of materials (e.g. encapsulation materials, glass, antireflective layers, etc.) and electronic components. Moreover, total quality management, improvement and/or application of in-line low-energy production processes, production control techniques and recycling processes shall be implemented.

Deliverables and KPIs in 2020:

- Warranted service life for PV modules > 35 years.
- Design service life of inverters > 30 years.
- Recycling of PV modules established.

Expected impact:

- Increasing cost competitiveness of the technology; reducing energy costs; increasing bankability; increasing further overall environmental sustainability; facilitate the implementation of the Waste Electrical and Electronic Equipment (WEEE) Directive.

Costs: EUR 240 million.

Timeline: 2017 - 2020.

Modality of implementation: Action to be implemented both at the EU and at the national level.

Action 6: Building-Integrated Photovoltaic (BIPV)

Scope: BIPV is a special application of PV technology. Its multifunctional role makes this an important market segment to develop, especially taking into consideration future targets on near zero energy buildings and smart cities (see Heading I: energy efficiency in buildings). Specific topics to be addressed are: certification as building construction materials, flexibility in design, variety of products, availability at different scales and on different substrates, and improved aesthetics.

Deliverables and KPIs:

- Certified BIPV products available as integral components for buildings.
- Norms and standard for BIPV established.
- Various BIPV-installations and demonstration applications summing up to > 1 GWp.

Expected impact:

- Increasing cost competitiveness of the technology; improved efficiency in the use of resources (materials); testing and improving industrial potential of technologies; increasing potential for manufacturing growth and jobs.

Costs: EUR 180 million.

Timeline: 2015 - 2020.

Modality of implementation: Action to be implemented both at the EU and at the national level.

INNOVATION AND MARKET-UPTAKE PROGRAMME

Action 1: Financing and risk of large-scale manufacturing

Scope: Mitigation of risk and financing for large scale multi-gigawatt manufacturing is a key aspect to provide a sound and competitive basis for the European PV industry. Schemes for different segments of the value chain that are ready to move from pilot production into large scale industrialisation must be developed and specific support action for technology transfer are needed. This action is also linked to Heading V: Innovative financing for energy efficiency.

Deliverables and KPIs:

Investment decision and financial closure achieved for at least three manufacturing plants in Europe for different segments of the value chain at multi-gigawatt scale.

Expected impact:

- Re-confirmed European technology leadership by investments into innovative multi-gigawatt manufacturing of materials, solar cells, and power electronics in Europe at competitive costs; lower risk for private investors.

Costs: EUR 120 million.

Timeline: 2015 - 2020.

Modality of implementation: Action to be implemented at the EU level.

Action 2: Implementing regulatory, financial and societal solutions for large-scale, market-based exploitation of PV investments

Scope: The action addresses the development of regulatory and financial solutions that allow commercially viable business models for PV power generation. Strategically, the objective is to enable a long-term sustainable business with manageable and understandable risk for professional and non-professional investors when PV electricity is commercialized at market conditions. Especially, new models for financing and operating PV plants in the built environment have to be established. Moreover, the action addresses the potential societal and regulatory barriers that may arise with high levels of PV deployment, related to non-suitable and ineffective electricity market design and financing instruments, as well as public acceptance of PV in built environment and landscape. This action is also linked to Heading 2: Energy and System Integration.

Deliverables and KPIs:

- In markets with retail or wholesale price parity based on LCoE, annual installation rates in the respective market segments are growing at a sustainable pace without operational aid.
- Adjusted market instruments and rules fit for PV electricity are developed.
- PV accepted by society as a mainstream contributor to the energy supply in Europe.

Expected impact:

- PV remains a viable business for a broad range of investors: households, non-energy sector enterprises, real estate developers, independent power producers, financial investors and utilities; civil society welcomes PV in public spaces.

Costs: EUR 60 million.

Timeline: 2015 - 2020 and beyond.

Modality of implementation: Action to be implemented both at the EU and at the national level.

Action 3: Improved yield assessment for reduction of risk

Scope: Today's long term yield assessment for large PV plants is still associated with a large uncertainty. This increases the spread between the so-called P50 and P90 values and, hence, the risk for the financers of a PV project. The uncertainty of long-term yield assessment and the quality assessment of PV modules and inverters are the decisive parameters for the financing costs. The action aims to reduce risk by reducing the uncertainty of the long-term yield assessment. This should be achieved by reviewing the assumptions made for the long-term yield assessment and adapting them based on operational experience from existing plants.

The uncertainty of long term yield assessment world-wide needs to be reduced by reducing the uncertainty of resource assessment but also better methods for PV system modelling and component operational parameters, all including an estimate of their specific uncertainties.

Deliverables and KPIs:

- Standard deviation of the modelling chain below 4% based on real operational experience (excluding local climatic variability but including uncertainty of the expected value of solar irradiation).
- Good practices of how to quantify and account for uncertainty within the financial model of a commercial PV plant investment.

Expected impact:

- Increasing cost competitiveness of the technology; reducing energy costs; increasing bankability.

Costs: EUR 120 million.

Timeline: 2015 - 2020.

Modality of implementation: Action to be implemented both at the EU and at the national level.

Action 4: Market uptake of new PV products

Scope: New, sometimes multifunctional PV products often lack trust of investors. The action focusses on enabling and facilitating deployment of innovative PV products in all fields of application. For such products, the action comprises innovative product specifications, market uptake studies, quality management, testing and contributions to standardisation.

Deliverables and KPIs:

- New PV elements for standard application in buildings available.
- Innovative PV products for (flat-plate and CPV) power applications available.
- New PV-powered stand-alone products available.

Expected impact:

- Broadening of the range of commercial PV applications; bringing current and new niches with big potential to mainstream. Further, enabling market penetration of emerging and new PV technologies through innovative products and applications.

Costs: EUR 120 million.

Timeline: 2015 - 2020.

Modality of implementation: Action to be implemented on EU-level and world-wide.

Action 5: Standards and European PV data collection

Scope: This action focuses on data collection and the development and updating of standards (for PV-technologies and applications, for measurements, for grid, for electronics, etc.), in order to reflect as much as possible the field conditions. The final goal is to ensure performance and reliability by standardizing adequate testing on component level. For this purpose, statistically significant amounts of data of consistently high quality are required covering resources, performance and reliability and market data. These data should be made publicly available.

Deliverables and KPIs:

- Standards for all PV applications and market segments updated/developed and published.
- Resource, performance and reliability, and market data are publicly available.

Expected impact:

- Increasing cost competitiveness of the technology; reducing energy costs; increasing bankability; increasing further overall environmental sustainability; support international standard committees (like IEC, CENELEC, SEMI, ISO). Providing interested stakeholders (industry, research, civil society, policy makers, etc.) with first-hand, reliable and harmonised data on PV.

Costs: EUR 120 million.

Timeline: 2015 - 2020.

Modality of implementation: Action to be implemented on European level and World-Wide.

Action 6: Training and education for photovoltaics

Scope: This action addresses the framework conditions for training and education. Further improvements in the existing training and education programmes should aim at providing the right skills for PV-related jobs, across the whole value chain. Particular focus should be put on the aspects linked with the identified key issues: manufacturing, performance / cost competitiveness, supply chains and system integration.

Deliverables and KPIs:

- Courses of covering new challenges of PV at different universities established.
- Professional education and training schemes for craftsmen established.

Expected impact:

- Horizontal, accelerating the completion of the overall challenge.

Costs: EUR 60 million.

Timeline: 2015 - 2020.

Modality of implementation: Action to be implemented on National and European level.

Challenge 3: Solar Thermal Electricity

KEY ISSUES

Achieve 12 c€/kWh for a radiation of 2050 kWh/m2/y and 10 c€/kWh for a radiation of 2600 kWh/m2/y for a 25-year Power Purchase Agreement (PPA) by 2020 through increased efficiency, costs reduction, increased dispatchability and reduced need of water for cooling and cleaning purposes.

The KPIs referring to a number (i.e KP1, KPI2, etc.) are related to the KPI table in the STE Implementation Plan 2013-2015 and in the ESTELA Strategic Research Agenda. The percentage variations stated in the KPIs take 2010 as reference year.

There are four configurations/technologies for a STE plant: parabolic troughs, tower (or central receiver), linear Fresnel reflectors, and parabolic dishes (or dish Stirling). The actions below can refer either to one of these configurations or to cross-cutting issues.

The actions described below are essential steps to achieve flexibility of supply and competitiveness compared to other conventional sources. Indeed STE is the most viable alternative to fossil fuels when taking into account the crucial need for dispatchable energy. If well combined with other renewables, STE will allow a high penetration of carbon-free electricity to be achieved in Europe, while at the same time contributing to the reliability of the transmission grid.

Beyond the above mentioned flexibility of dispatch, STE will allow demand to be met with firm supply offers, providing a clean and sustainable solution - replacing fossil fuel imports in particular.

In addition to the development of innovative components, the improvement of reliability and storage technologies, the integration or hybridization with other sources, the reduction of water consumption, it is important to promote R&D activities and services in order to keep knowledge, technological leadership and workforce in Europe and to provide to potential European STE investors a stable investment framework.

This does not exclude to build plants in third countries, where the solar radiation allows for better electricity output efficiency. The STE community will also deploy efforts and initiatives in order to demonstrate the validity of the cooperation mechanisms foreseen in the existing European legislation.

A concrete outcome of this roadmap should be the construction and operation of large scale facilities to validate innovative STE concepts at system level, also reducing the risk factors affecting the financing mechanisms.

ADVANCED RESEARCH PROGRAMME

Action 1: Development of more efficient STE components

Scope: To develop relevant innovations in order to reduce the costs of solar components and to identify the heat transfer fluids (HTF) that allow for advanced system designs with higher conversion efficiency. This is the basis for developing industrial products in the framework of the industrial research and demonstration programme.

Deliverables:

- New optical solutions: Both linear (parabolic trough collectors and Fresnel reflectors) and point focus (Tower, Dish) systems can benefit from increased concentration factors, reducing thermal losses at high temperatures and, thus, increasing the solar-to-electricity conversion efficiency.
  This can be achieved, in all cases, by an evolution of the present conventional optical focussing solutions towards new primary-secondary concentrating solutions, reaping thus the benefits offered by the use of non-imaging optics. These new configurations can be obtained with essentially the same type of manufacturing capacities and similar mirror shapes, which will result in no increase of the current manufacturing costs; they constitute a significant step towards achieving goals such as expressed in KPI_2 and KPI_3:
  - Larger parabolic troughs with second stage concentration.
  - Parabolic troughs with fixed receivers.
  - Linear Fresnel designs.
  - Other concepts.
- Receivers: Development of selective coatings with better optical and thermal properties at high temperatures and under oxidizing conditions:
  - Of new receiver designs for high temperatures, including the combination of tubular receivers and second stage concentrators.
  - Of solar receiver-reactors for solar fuel production.
  - Of improved and new model for durability prediction of receivers.
  - Of procedures for accelerated aging and durability testing.
  - Of new receiver materials.
- Heat Transfer Fluids (HTF): Synthetic oil with new chemical formulation, new solar salt compositions with lower melting point and higher working temperatures, advanced HTF solutions (higher temperature HTF, more environmentally friendly, better stability…), pressurized gases, thermal properties and corrosion tests.

Expected impact:

- The development of receivers and HTFs that operate at higher temperature is a key development (>500°C for trough and Fresnel and more than 900°C for dish and tower). Depending on the selected technologies annual system efficiencies can be increased until 2020 by more than 50% compared to 2010 values making electricity costs of less than 10 €cents/kWh feasible.

KPIs:

- Solar-to-electric conversion efficiency > 18 % for parabolic trough, >14% for linear Fresnel reflectors, >20% for towers.
- HTF Temperature >500°C trough / Fresnel / > 900°C dish and tower.

Costs: EUR 75 million invest out of which EUR 30 million grants.

Timeline: Research performed until 2020 should be the basis for IRDP to be ready for commercial implementation by 2025.

Modality of implementation: A 50:50 mix of national and EU wide activities would ensure best alignment of the programs with the commercial development of the industry.

Action 2: Improvements for the reliability and availability of STE plants

Scope: Very efficient quality control procedures are implemented during the assembling of STE plants. A few companies are already offering services for measuring mirror reflection and trough receiver reflectivity, but this needs to be further developed in order to allow a more systematic evaluation of their optical, geometrical and thermal quality after their installation in the solar field. Also, an overall optimization of the plant design needs to be achieved to guarantee a reduction of the operation and maintenance costs.

Deliverables:

- Control, monitoring and operation tools: Systems for on-site checking, inspection, characterization of performance analysis and diagnostic (optical quality of concentrators, thermal quality of receivers, HTF leakage).
- Overall optimization of the plant design: Components modelling for design and optimization, software development for simulation of global dynamic analysis of solar thermal power plants.

Expected impact:

- The development of faster, cheaper tools and management procedures will contribute to improve the overall efficiency and reduce the PPA. It will also increase electricity production thanks to better operational procedures and allow for a better use of the installation (better use of land, better efficiency, and larger plants).

KPIs:

- KPI-4 O&M costs reduced by 20%.
- KPI-2: Plant efficiency increased by 5%.

Costs: EUR 20 million invest out of which EUR 6 million grants.

Timeline: Research performed until 2020 should be the basis for IRDP to be ready for commercial implementation by 2025.

Modality of implementation: A 50:50 mix of national and EU wide activities would ensure the best alignment of the activities of the programs with the commercial development of the industry.

Action 3: Integration and Hybridization of STE plants

Scope: Hybridized and integrated plant concepts allow using several resources (such as solar, biomass or fossil fuels) and can provide one or several products, including electricity, solar fuel and clean water. Some technologies have already reached TRL7 but further investigations on new concepts are needed to address future needs for desalination plants, for the production of solar fuels through thermochemical processes, for new integration concepts with fossil fuels and for new hybrid plant concepts.

Deliverables:

- Integration with desalination plants (Optimization and integration with thermal desalination technologies): Multi-Effect Distillation (MED), Humidification-DeHumidification (HDH), and Membrane Distillation (MD).
- Integration for the thermochemical production of solar fuels: Improved existing and innovating routes.

- New integration and hybrid plan concepts: New integration concepts increasing solar share, cost-effective power and desalination plant design, several resources (biomass or fossil fuels).

Expected impact:

- The hybridisation with other power plants will lead to an increased operation, i.e. generation time or may even provide additional marketable products which would directly impact the overall plant performance and its economics. Coupling to desalination plant, particularly in arid coastal areas, offers possibilities not only generating electricity but also delivering drinking water that is often scarce in these areas. The sustainable production of fuels through the solar heat process could also pave the way to reinforce the environmental profile and support clean technologies in the field of transport.

KPIs:

- KPI 1: 12 c€/kWh for a radiation of 2050 kWh/m^2/y and 10 c€/kWh for a radiation of 2600 kWh/m^2/y.
- KPI 10: Improvement of environmental profile; water consumption: no net consumption of water in hybrid desalination plants.

Costs: EUR 10 million invest out of which EUR 5 million grants.

Timeline: Research performed until 2020 should be the basis for IRDP to be ready for commercial implementation by 2025.

Modality of implementation: A 50:50 mix of national and EU wide activities would ensure best alignment of the programs with the industrial sector.

Action 4: Improvement of Storage Systems

Scope: The potential to store thermal energy and use it to follow the demand is one of the most important advantages of STE compared to other renewables. Enhancing this feature at the lowest possible cost is essential to enable a high penetration of renewable energy in the electricity system.

Deliverables:

- Storage design: Storage system with gas as heat transfer fluid.
- New storage concepts: Advanced high temperature thermal storage systems, new molten salt formulations, thermochemical storage systems and phase-change storage systems suitable for direct steam generation plants.
- Storage optimization: Development of improved simulation tools.

Expected impact:

- In the future, all STE plants will have storage capability since storage allows for delivering the key added value of STE: dispatchability and consistency of supply. Without storage, STE plants cannot compete with conventional energy systems. Concepts with storage are therefore competitive particularly for markets which assign extra value to dispatchability and grid stability. Research actions on the improvement of storage systems are key drivers that can further help reduce the electricity costs while providing dispatchable electricity. Higher subsystem efficiencies and advanced designs with lower manufacturing costs will greatly contribute to cost reduction after 2020.

KPIs:

- KPI 8: Investment cost storage: 15,000€/MWh$_{th.}$

- KPI 9: Storage efficiency >96%.

Costs: EUR 60 million invest out of which EUR 20 million grants.

Timeline: Research performed up to 2020 should be the basis for IRDP actions on concepts to be ready for commercial implementation by 2025.

Modality of implementation: A 50:50 mix of national and EU wide activities would ensure best alignment of the programs with the commercial development.

Action 5: Water consumption

Scope: Any improvement that reduces the number of washings of reflector and collector systems would also reduce not only the maintenance costs but also the overall water consumption of the plant, which is a critical factor for the commercial deployment of STE plants in desert areas. Auto-cleaning methods should also be developed. This advanced research program addresses the water consumption related to the cleaning. The improvement of dry cooling technology is addressed in the IRDP.

Deliverables:

- Soiling issues: Standardized measurements of soiling rates, soiling mechanisms as function of dust composition, wind, humidity, temperature, surface properties, predictions of soiling rates based on environmental data and, glass reflectors with anti-soiling coating.
- Cleaning methods: Develop auto-cleaning methods.

Expected impact:

- Understanding the soiling mechanisms and lower the water consumption used for cleaning systems will improve sustainability and reduce the environmental impact of STE plants. Auto-cleaning solutions will also help to reach this goal.

KPIs:

- Reduce O&M cost by >5%.
- KPI 10 reduce water consumption < 15 litre/year/m^2 of solar reflectors.

Costs: EUR 10 million Invest out of which EUR 5 million grants.

Timeline: Research performed until 2020 should be the basis for IRDP to be ready for commercial implementation by 2025.

Modality of implementation: A 50:50 mix of national and EU wide activities would ensure best the alignment of the activities of the programs with the commercial development of the industry.

Action 6: Weather Forecasting

Scope: Good forecasts are essential for reliable estimates of the costs of a plant in a given site, as well as for optimizing plant operation and management. Before a STE project is started, it is critically important to have the best possible information regarding the quality and reliability of the energy source. This means that project developers need to have reliable data on the solar resource available at specific locations, including historic trends with seasonal, daily, hourly, and (preferably) sub-hourly variability, in order to predict the daily and annual electricity output.

Deliverables:

- Operational strategy: Studies on the use of solar irradiance for very short term forecast.
- Solar Resource assessment: Improved numerical weather prediction models for STE plants, analysis of the inter-annual variability of the DNI.

Expected impact:

- Accurate weather predictions during the life-time of the plant will increase its electricity production and thus its profitability.

KPIs:

- Increase solar to electricity conversion efficiency by 3%. Indeed, a better knowledge of cloud passing could result in a more efficient operational mode of the plant, and therefore increase the annual energy yield. A wrong forecast may negatively impact plant operation.

Costs: EUR 10 million Invest out of which EUR 5 million grants.

Timeline: Research performed until 2020 should be basis for IRDP to be ready for commercial implementation by 2025.

Modality of implementation: A 50:50 mix of national and EU wide activities would ensure best the alignment of the activities of the programs with the commercial development of the industry.

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Development of more efficient STE components

Scope: The European industry in cooperation with the research centres contributing to the Advanced Research Programme should focus on making the solar components cheaper and on finding new fluids which increase the working temperature and allow for advanced system designs with higher conversion efficiency. The research topics below, considered as cross-cutting issues between the four current STE technologies (parabolic trough collectors, central receivers, linear Fresnel collectors and parabolic dishes) need to be addressed in order to propose innovative solutions.

Deliverables:

- Concentrators: Development of light reflective surfaces with higher specular reflectivity, Mirror glass with higher solar transmissivity, development of new structures and new tracking systems.
- Receivers: Development of new receiver designs for high temperatures and better durability (lower maintenance cost due to replacements), reduction of parasitic power requirements.
- HTF: Direct steam generation as HTF, degradation of the HTF (in situ monitoring and measuring devices), new synthetic oil formulations with additives allowing higher pressure and temperature.
- Sub-components: Design and optimization of high reliability and low cost sub-components for STE plants (valves, instruments, heating systems, special piping devices), materials, components durability (accelerated aging procedures) and corrosion testing (Life-time prediction).

Expected impact:

- Increasing efficiency and reducing the construction costs of STE plants for cost competitiveness and energy efficiency will largely contribute to the reduction on the costs of the generated electricity. The cost evolution of the technologies can lead to electricity cost savings of up to 30% by 2015 and 50% by 2025, thus reaching competitive levels with conventional sources.

KPIs:

- KPI: PPA costs: 12 c€/kWh for a radiation of 2050 kWh/m^2/y and 10 c€/kWh for a radiation of 2600 kWh/m^2/yr.

Costs:

- A 50:50 mix of private and public fund would ensure best the alignment of the programmes. For the investments in innovative concepts: EUR 750 million: 40% from EU (EUR 300 million), 20% from MS (EUR 150 million), and 40% from industry (EUR 300 million).
- Additionally, soft loans and risk sharing instruments might be put at the disposal of the companies for implementing these innovative solutions in the new commercial plants in order to compensate the usual bank reluctance and the higher interests.

Timeline: This action should be performed in close cooperation with research centres and implemented in new plants starting construction in 2020.

Modality of implementation: Most of the plants will be constructed outside EU with the EU technology. Nevertheless, important support from EU programmes is necessary to guaranty a competitive position of the European industry and for incorporating all necessary innovation in order to reach the cost reduction goals.

Action 2: Improvement reliability and availability of STE plants

Scope: Better systems and management procedures to improve the reliability and availability of STE plants are needed. An overall optimization of the plant design needs to be achieved to guarantee a reduction of the operation and maintenance costs. Also, the ability to achieve accurate forecasts of insolation (number of sunny hours/clouds passing) is of paramount importance for the efficiency of STE plants and new tools need to be set up for this.

Deliverables:

- Control, monitoring operation tools: Overall optimisation of control and operation procedures.
- Overall optimization of the plant design: Components modelling for design and optimization, improvement and optimization of procedures for STE management systems.
- Improved mechanical and process design: Dynamic simulation with flux application during transients, Start-up, shutdown.
- Operation strategy: Electricity production forecasting system.
- Solar resource assessment: Improving DNI measurement ground base data network, deriving the global and beam irradiance components from meteorological satellite images, DNI nowcasting/forecasting system with improved methodologies and instruments.

Expected impact:

- The development of faster and cheaper tools and management procedures will help to improve the overall efficiency and PPA. It will also increase the electricity production thanks to better operational procedures (ie. reduction of O&M costs) and allow for a better use of the installation (better use of land, larger plants).

KPIs:

- KPI-4: O&M Costs reduced by 20%.
- KPI-2: Plant efficiency increased by 5%.

Costs: EUR 60 million of which 50% private sector and 30% grants (grants distributed between 20% from EU and 10% from Private funding).

Timeline: From now to 2020.

Modality of implementation: A 50:50 mix of national and EU wide activities would ensure best the alignment of the activities of the programs with the commercial development of the industry.

Action 3: Integration and Hybridization of STE plants

Scope: Hybridized and integrated plant systems with fossil or biofuels are an attractive option to improve the competitiveness of STE plants. Further improvements are needed for those technologies that have already reached a TRL of 4/5/6.

Deliverables:

- With large steam plants: HTF/Steam cycle heat exchangers, boiler design, and boiler control system.
- With gas turbine and combined cycle plants: Design of HTF/Steam cycle heat exchangers, materials for high temperature heat exchangers, solarised gas turbine.
- With biomass plants: Integration of low cost solar fields with biomass steam boiler.
- With desalination plants: Multi-effect distillation and reverse osmosis concepts.
- Hybridization: For the direct systems using the same molten salt mixture as HTF and HSM (Heat Storage Medium), overall system design optimization, other concepts beyond simply substitution of the solar field by the gas heater.

Expected impact:

- The hybridisation with other power plants will lead to an increase in operation, i.e. generation time and have a direct impact on the overall plant performance and economics: it will make possible to convert the collected solar power with higher efficiency and to ensure dispatchability to cover demand peaks as well as delivering energy on demand. This

means that the variability of the solar radiation is no longer an issue. The reduction of start-up time will also decrease the generation cost.
- The coupling to desalination plants, particularly in arid coastal areas offers the possibility not only to generate electricity but to produce drinking water that is often scarce in these areasl, thus contributing to improving the environmental profile of STE plants and reinforcing cooperation with the MENA countries.

KPIs:

- Advanced hybridisation concepts available at commercial scale.

Costs:

- Independently of the implementation cost of the project which will be mostly constructed outside EU, the research and innovation costs will be in the range of EUR 100 million: 50% public (of which 30% EU grants and 20% from countries) and 50% private.
- Additionally, soft loans and risk sharing instruments might be made available to companies for implementing these innovative solutions in new commercial plants in order to compensate the usual bank risk aversion and consequent higher interest rates.

Timeline: This action should be performed in close cooperation with research centres and implemented in new plants starting construction in 2020.

Modality of implementation: Most of the plants will be constructed outside the EU with EU technology. Nevertheless, significant support from EU programmes is necessary to bring the European industry in a competitive position and to incorporate necessary innovations in order to achieve the cost reduction objectives.

Action 4: Improvement of Storage systems

Scope: Although many plants are already built with a storage system, more efforts are needed by European industry to improve the competiveness of these systems and in particular system design, system optimization and new storage concepts.

At present it is not clear which of the different STE technologies (characterised by the different HTF) will be the most effective, so it is necessary to pursue several concepts in parallel (see also Action 4 in the Advanced Research Programme).

Deliverables:

- Storage design: Storage system for molten salt as HTF, Storage system for water/steam (direct steam generation) as HTF, Storage system for gas as HTF, Storage systems for thermal oil as HTF.
- Storage operation optimization: optimized charging and discharging strategies, development of simulation tools.

Expected impact:

- All STE plants to have a substantial storage capability (providing the real added value of STE: dispatchability and consistency of supply). The improvement of the thermal energy storage systems will lead to an increase in the hours of production and have a direct impact on the overall plant performance and economics. Research actions on the improvement of storage systems are key drivers that can further help reduce the electricity costs while providing dispatchable electricity.

KPIs:

- KPI 8 Investment cost storage < 15,000€/$MWh_{th;}$ KPI Storage efficiency >96%.

Costs: The costs for the storage in innovative plants will be EUR 200 million (of which 70% from private funds and 30% from public funds (of which 20% from the EU and 10% from countries). Additionally, soft loans and risk sharing instruments might be put at the disposal of the companies for implementing these innovative solutions in the new commercial plants in order to compensate the usual bank reluctance and the higher interests.

Timeline: This action should be performed in close cooperation with research centres and implemented in new plants starting construction in 2020.

Modality of implementation: Most of the plants will be constructed outside EU with EU technology. Nevertheless, a substantial important support from EU programmes is necessary to ensure a competitive position for the European industry and to integrate innovations in order to reach the cost reduction objectives.

Action 5: Water consumption

Scope: Development of new approaches with water consumption lower than for current wet-cooling systems and with similar cost and efficiency. This is also strongly related to the development of new cleaning systems with lower water consumption. The technical feasibility of natural cooling solutions in desert areas with low ambient temperatures overnight must be evaluated in order to replace current wet-cooling systems.

Deliverables:

- Development of new cooling systems, optimization of cleaning systems.

Expected impact:

- Lower water consumption in order to achieve a better sustainability and reduce the environmental impact of STE plants by avoiding an excessive use of water resource and allow for lower O&M and implementation costs in desert areas.

KPIs:

- KPI 10: reduce water consumption < 1 litre/kWh.

Costs: EUR 50 million of which 70% from private funds and 30% from public funds (20% from the EU and 10% from MS countries).

Timeline: This action should be performed in close cooperation with research centres and implemented in new plants starting construction in 2020.

Modality of implementation: Most of the plants will be constructed outside EU with the EU technology. Nevertheless, important support from EU programmes is necessary to guarantee a competitive position of the European industry and for incorporating all necessary innovation in order to reach the cost reduction goals.

INNOVATIVE AND MARKET-UPTAKE PROGRAMME

Action 1: Establish contractual formula with third countries and support innovation in the bids that European companies will submit under the tendering processes

Scope: The STE market is undergoing a shift from established regions (USA; Spain) towards emerging markets in MENA, South Africa, India, Chile and China. The competitive environment in the new target regions requires the timely achievement of all possible cost reductions for STE power plant projects in these regions. The highest cost reduction potential arises from the implementation of the advanced STE technologies described above. However, the financing environment in emerging markets does not yet support the introduction of innovative STE approaches, since investors and owners are hesitant to invest in non-commercialized technologies. In order to create confidence among local investors, advanced technologies need to be demonstrated and commercialized in the respective countries. Moreover, the demonstration of the viability of the cooperation mechanisms foreseen in the European Renewable Energy Directive, i.e. in Article 6 "Statistical Transfers", in article 7 "Joint Projects" and in article 11 "Joint Support Schemes" is urgently needed and can be achieved through this action.

Deliverables:

- Build an innovative plant, for instance in Spain, and sell the electricity, for instance to Germany, with participation of stakeholders from different countries including the TSOs of intermediate countries, the research centres for the grid aspects, the components manufacturers, etc. Such a plant should be defined as KET deployment project, and would contribute to achieving the related policy goals described in the RES Directive.
- Constitution of the necessary legal and/or organisational entity to make it happen. This entity could for example act as off-taker for the electricity generated in the MENA region that would be exported to Europe. It could be constituted by public agencies promoting renewable energy in the different countries, for instance, Germany, France, Italy, Spain, Morocco, Algeria, etc. and remain open to any other country that would support the initiative, as a producer, receiver or transporter. It could also count on financial back-stopping by the EIB. Other alternatives might be possible.

  As a KET deployment project: the number and type of agents will cover the whole value chain from innovation suppliers, plant constructors and promoters to TSOs and off takers. The institutional support at single country and at European levels according to the codes developed so far by the European Network of Transmission System Operators for Electricity will be an essential part of the project as well.

Expected impact:

- Once the first project is launched, the existing barriers to further projects will be removed and the viability be demonstrated so that the replication effect will follow automatically. Such a first-of- kind project would demonstrate the feasibility of Article 9 of the RES Directive.

KPIs:

- First of its kind plant on the basis of the RES directive joint mechanisms.

Costs: EUR 500 million (of which 90% from private funds – 10% from EU funds). Additionally, soft loans and risk sharing instruments might be put at the disposal of the companies for implementing these innovative solutions in the new commercial plants in order to compensate the usual bank reluctance and the higher interests.

Timeline: This plant should be started before 2020.

Modality of implementation: Pan-European project involving different countries and EU institutions.

- Support to specific technologies to be applied in projects outside Europe could provide important advantages. If contractual formulas with sufficient guarantees are established, many foreign investors will be attracted, resulting in a boost of the economy in these countries.

Action 2: Set up of European Standards

Scope: Setting up European standards as a contributor to further cost reductions and reliability increase.

On the one hand, existing standards relating to solar collectors are mainly intended for factory-made collectors that are of small size (up to a few m^2 in size); these are either flat or with relatively low concentrations. On the other hand, STE technologies require large size concentrators, on-site field assembled with high concentration and with a variety of 2 D or 3D geometries, resulting in new challenges and requests to the industry. STE technologies will therefore benefit form specific standards that are not yet available.

Standards will not only apply to components but to systems as well, setting up clear terms to address specific efficiency figures.

Deliverables:

- Qualification/certification and testing procedures.
- Components/system durability testing.
- Commissioning procedures.
- Solar field modelling procedures.

Expected impact:

- A common framework of standards and procedures can increase the chances of the European industry to get high quality products penetrating growing markets in those regions. The development of a common framework for quality standards and modelling procedures is of paramount importance for obtaining reliable and comparable solar field performance which is needed for both plant design and project finance.

KPIs:

- Production of at least 3 standards.

Costs: This would not represent a significant amount of funding but rather request the in kind contributions of companies and research centres.

Timeline: 2020.

Modality of implementation: National and International.

Challenge 4: Solar Thermal Heating and Cooling

KEY ISSUES

- Production value chain performance/cost competitiveness: Reduce the solar heat costs by 50% by 2020 by highly integrated compact hybrid heating systems, increase the solar fraction per building from about 25% to about 60% (single family house in Central Europe) up to 80% (in South Europe) by staying at the same heat costs, reduce the solar heat costs by 50% for industrial processes to 3-6 EURct/kWh for low temperature applications up to 100°C and 4-7 EURct/kWh for medium temperature applications up to 250°C.
- Supply chains (industrial logistics, maintenance, materials and manufacturing, recycling): optimize the energetic design of the nearly zero-energy buildings with high solar fraction ("Solar-Active-Houses") and develop new design tools. Adapt industry machinery (breweries, laundries, textile, food, automotive, etc.) to allow the use of solar heat. Improve hydraulic and safety system technology with simplified overheating protection. Increase the reliability of components and systems; develop improved function controls and monitoring concepts as well as self-optimizing systems.
- System integration (smart interfaces, new capabilities of equipment, new or improved services to system, forecast): develop compact heating systems integrating solar and backup-heater; develop simplified system design to reduce costs and failures in installation and operation; develop improved control and monitoring concepts by using new ICT technologies (self-learning and self-adapting, using weather forecasts,…) to increase performance and reliability and optimized cooperation of solar, backup-heater and building components; develop standardized hydraulic and electrical inter-connections between all solar thermal and HVAC-systems of the building.
- Non technological aspects (market framework, business model, spatial planning, standards, financing, skills and capacities): provide transparency and comparability on the system yield of solar heating and cooling (SHC) systems (before and during operation); improve bankability of SHC projects (especially for industrial applications); facilitate integration of SHC projects into ESCO´s portfolio; develop new financing and business models for SHC projects and provide the legal framework (e.g. solve the landlord-tenant dilemma).
- Societal issues (environment impact, safety, health, social acceptance): Raise the awareness about lower ecological footprints of SHC systems; simplify the handling and increase the user-friendliness of SHC systems; improve the architectural design of solar collectors to increase the acceptance of SHC installations.

ADVANCED RESEARCH PROGRAMME

Action 1: Development of Solar Compact Hybrid Systems (SCOHYS) for single family homes (DHW and combi systems) and multifamily homes (DHW)

Scope: SCOHYS are compact heat supply systems including a solar and a backup heating source (based on bio energy, heat pumps or fossil fuels) with:

- A solar fraction of at least 50% in the case of DHW SCOHYS systems, which deliver only domestic hot water.
- A solar fraction of at least 25% in typical Central European applications in the case of combi SCOHYS systems, which deliver both, domestic hot water and space heating.

The objective of this action is to develop solar-based hybrid systems, which provide a full heat supply for small and multifamily residential buildings by combining the solar thermal components with a backup heater in one compact unit including a smart controller. This will enable cost reduction of these "plug and function" systems for material and installation labour time significantly, since the complexity of the system is limited to the prefabricated inner part of the hybrid unit. The performance will be increased and trouble-free operation of the hybrid heating unit will be achieved.

Deliverables:

- Cost-reduced collector inclusive mounting structure with high reliability and simplified mounting solutions.
- Simplified water storage technology with improved cost-performance ratio and reduced failsafe connection concepts.
- Improved hydraulic and safety system technology with improved overheating protection and hydraulic connections to reduce costs, number of pieces, installation time and error-rate.
- Smart controller and monitoring technology with an optimized operation strategy using self-adapting control concepts for different buildings and operation states, improved sensors, extended function control, and improved performance monitoring.
- Compact, simplified and robust system design with high compactness of solar thermal and back-up heater, error-rate reduced concept with high pre-fabrication, simplified and robust initial operation procedure and flexible utilization.

Expected impact and KPIs:

- Prototype for single family homes (DHW and combi systems) and for multifamily homes (DHW) with solar heat costs reduced by 35% in comparison to 2013, leading to fossil fuel parity in Southern Europe (< 10 EURct/kWh).

Costs: EUR 15 million / public: 70%, private: 30% / development of 6 different prototypes for different applications/regions.

Timeline: 2014-2017.

Modality of implementation: European projects focused on development from TRL 3 to 5.

Action 2: Applied research and prototypes on new built single family Solar Active Houses (SAH)

Scope: Solar Active House, the solar based solution for Nearly Zero Energy Buildings, will become a cost-competitive solution for new built single and multi-family homes as well as for refurbished homes in Central Europe in comparison to other nearly zero-energy buildings. Applied research will lead to performance improvements and cost reduction on component and on system level including smart control technologies and optimized design tools. Cost reduction will also be achieved by the development of standardized solutions.

Deliverables:

- Improved collector & collector array design (design, hydraulics, mounting concepts and structures, etc.) to reduce costs, improve reliability (avoid stagnation), ease installation and improve integration into the roof.
- Improved water storage technologies (charging/discharging structures, vacuum insulation, storage wall material, on-site-mounting concepts, etc.) to reduce costs, improve performance, reduce size, and ease integration.
- Improved hydraulic and system technology (simplified hydraulic, overheating protection concepts, etc.) to reduce costs and failure vulnerability, ease installation, increase reliability and performance.
- Improved controller and monitoring technology (self-adapting control concepts, improved sensors, extended function control, etc.) to avoid malfunction and increase reliability
- Improved system design (flexible simulation tool to design the SAH (building insulation and ventilation concept, heating system and solar system) for different climates and construction types, etc.) to optimize the SAH with minimized costs and optimized performance.

Expected impact and KPIs:

- SAH with 60% solar fraction for new built single family homes will be ready for the market as a standardized solution, which can be applied by all professional planners and construction companies based on sophisticated design tool.

Costs: EUR 7 million / public - 70%, private - 30% / R&D activities.

Timeline: 2014 - 2017.

Modality of implementation: European and national actions focused on development from TRL 3 to 6.

Action 3: Applied research and technical development of the next generation of medium temperature collectors (100°C to 250°C)

Scope: The development of a next generation of medium temperature collectors will become more relevant for further developments on SHIP (solar heat for industrial processes) and to allow improved solutions for higher temperature processes. Hence the development of a next generation of medium temperature collectors will focus on improved performance and durability with reduction of O&M costs.

Deliverables:

- Improved medium temperature collectors with new materials and production processes for high vacuum, non-tracking flat plate collectors, stagnation proof flat-plate and evacuated tube collectors, next generation air collectors and solutions for façade integration, simplified tracking concepts and performance optimized tracking collectors with reduced material demand.
- Improved reflectors for concentrating collectors with very high reflection, dirt-proof or self-cleaning, and high durability to reduce costs for production, cleaning and maintenance, and increase performance.

Expected impact and KPIs:

- By 2020, the solar heat costs will be further reduced to 3-6 c/kWh for low temperature applications below 100°C and 4-7c/kWh for medium temperature applications below 250°C.

Costs: EUR 40 million / public: 70%, private: 30% / R&D activities.

Timescale: 2014 - 2020.

Modality of implementation: European and national actions focused on development from TRL 3 to 6.

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Prototype development and demonstration of Solar Compact Hybrid Systems (SCOHYS) for single family homes (DHW and combi systems) and multifamily homes (DHW)

Scope: The development of SCOHYS prototypes shall address two main market segments within building sector, for small and medium scale systems. Focus shall be placed on compact solutions at reduced costs due to simplified design, only one controller, and high grade of prefabrication and reduced installation effort. Due to optimized combination of components and prefabrication the performance and reliability will improve. Demonstration shall test the solutions in multiple contexts with different requirements and conditions in terms of energy demand, solar irradiation, building patterns. For system targeting multifamily homes, the demonstration will be both for Combi systems (DHW + space heating) and DHW systems.

Deliverables:

- Optimized integration of large water storage into the building and cost reduced large collector and mounting structures.
- Optimized system design with reduced cost, improved stagnation protection solutions and smart controller.

Expected impact and KPIs:

- Availability of SCOHYS systems for multifamily homes and ready for broad market deployment with solar heat costs reduced by 50% in comparison to 2013 (accomplishing the fossil fuel parity target for central Europe).

Costs: EUR 30 million EUR / public: 50%, private: 50% / demonstration of 30 SCOHYS systems for single family homes for different applications in Europe / Development of two prototypes and demonstration of 10 systems for multifamily homes.

Timeline: 2016 - 2020.

Modality of implementation: European projects focused on development from TRL 6 to 8.

Action 2: Demonstration of new built single family Solar Active Houses (SAH)

Scope: New solutions regarding Solar Active Houses, the solar based solution for Nearly Zero Energy Buildings, applied to single family houses require demonstration of the different options (in terms of design, equipment in different building typologies) under different conditions (climate, radiation levels, DHW and space heating and cooling demand).

Deliverables:

- Optimized integration of large water storage into the building and cost reduced large collector and mounting structures.
- Optimized system design with reduced cost, improved stagnation protection solutions and smart controller.

Expected impact and KPIs:

- By 2017, SAH60 for new built single-family homes will be ready for the market as a standardized solution, which can be applied by all professional planners and construction companies based on sophisticated design tool.

Costs: EUR 10 million / public - 50%, private - 50% / 10 demonstration buildings for new built single family SAH.

Timeline: 2018 - 2020.

Modality of implementation: European projects focused on development from TRL 7 to 8.

Action 3: Prototype development and demonstration of new built multifamily Solar Active Houses (SAH)

Scope: Solar Active House concepts for multifamily houses shall benefit from developments on the solutions for SAH for single family houses, as well as for refurbishing solutions and updates coming from existing demonstration projects. Therefore a new demonstration stage is required, based also on improved insulation standards for buildings and improved solar heating technology.

Deliverables:

- Adapted storage and system technology to optimize the system and the storage integration to minimize costs.
- Adapted system design taking into account the specific conditions of MFHs and develop cost-optimal solutions.

Expected impact and KPIs:

- SAH with 60% solar fraction for small multifamily homes will be a standardized solution. The SAH60 will be cost-competitive with other nearly zero-energy buildings and will provide solar heat at costs comparable to today's combi systems in central Europe (between 15 and 20 EURct/kWh).

Costs: EUR 16 million / public - 50%, private - 50% / R&D activities and 10 demonstration buildings for new built multifamily.

Timeline: 2018 - 2020.

Modality of implementation: European projects focused on development from TRL 6 to 8.

Action 4: Prototype development and demonstration of refurbishment solutions for existing buildings to Solar Active Houses (SAH)

Scope: The Solar Active House concept can also be adapted to existing buildings and this is clearly the largest market for such solutions. The experience already in place for SAH solutions will provide the base for prototype development and demonstration of SAH solutions on the refurbishment of existing buildings.

Deliverables:

- Improved integration of the collector array (mounting concepts and structures to integrate large collector arrays in existing roofs) to optimize architectural and technical quality of integration at minimized costs.
- Large water storage for existing buildings (design, geometry, on-site-mounting concepts, separated volumes, underground installation, new storage wall and insulation materials, etc.) to reduce the space for storage installation, ease the integration into existing buildings, maximize performance and reduce costs.
- Improved system technology and system design (adapted simulation and design tools to refurbish existing buildings taking into account sub-optimal orientation and improvements of existing construction, integration into existing system technology, etc.) to maximize solar fraction + performance at minimized costs.

Expected impact and KPIs:

- SAH with 60% solar fraction for refurbished buildings will be a standardized solution. The SAH60 will be cost-competitive with other nearly zero-energy buildings and will provide solar heat at costs comparable to today's combi systems in central Europe (between 15 and 20 c/kWh).

Costs: EUR 21 million / public: 50%, private: 50% / R&D activities and 10 demonstration buildings for refurbished SAH with 60% solar fraction.

Timeline: 2016 - 2020.

Modality of implementation: European projects focused on development from TRL 5 to 7.

Action 5: Technical development and demonstration of cost optimal SHIP solutions for all relevant industrial processes

Scope: Solar Heat for Industrial Processes (SHIP) can provide a large part of the heat demand for industrial processes. In order to do so, it is important to demonstrate its advantages in different industries, for different industrial processes. This is the way to gain improve and reduce costs (design and simulation, improved configurations and hydraulics) and also to gain confidence from industry, regarding operation and economical factors. Hence, a large demonstration programme is needed.

Deliverables:

- Self-carrying and modular collector structures for installation on industrial buildings to reduce costs, ease installation, and reduce load on industrial roofs.
- Improved large-scale solar collector arrays with optimised hydraulic designs for uniform flow distribution and low pumping power for direct steam generation, and hot water and thermal oil heating.
- Improved planning guidelines and innovative design tools for solar heat in industrial processes with identification of the ideal feed in point of solar heat in industrial processes and optimal solar system design, simulation of heat flows with real-time profiles to optimize the solar system performance via optimal heat integration into industrial processes, optimized storage management + plant operation strategy.
- Improved highly performing dirt-proof or self-cleaning, durable reflectors.
- Optimize large-scale solar collector arrays for uniform flow distribution and low pumping power.
- Cost-efficient and energy and material optimised solutions for hydraulic designs for large-scale collector fields. Design tools (calculation and simulation programs for planners available).

Expected impact and KPIs:

- SHIP (solar heat for industrial process) cost in the range of 5-9ct/kWh for systems with 10-20% solar fraction, by reducing the investment costs to 350 EUR/m2 for low temperature SHIP systems including storage and 400 EUR/m2 for medium temperature SHIP systems without storage.

Costs: EUR 380 million / public - 50%, private - 50% / 700 demonstration projects.

Timeline: 2014 - 2017.

Modality of implementation: European projects focused on development from TRL 5 to 7.

INNOVATION AND MARKET-UPTAKE PROGRAMME

Action 1: Market uptake of innovative Solar Compact Hybrid Systems (SCOHYS) for single family homes (DHW and combi systems) and multifamily homes (DHW)

Scope: Market uptake of SCOHYS (Solar Compact Hybrid Systems) require diversified actions in the field of enabling technologies, standards and quality, socio-economic framework and legal and administrative aspects. There are other barriers than merely technical ones to the integration of solar thermal with other technologies. Besides the use of how water from RES-H&C should be incentivised also on “white” house appliances.

Deliverables:

- Requirements to monitor system performance of all types of heating systems (solar, biomass, fossil fuel, heat pumps, etc.) to increase system performance and enable guarantee of performances concepts for medium to large systems.
- Requirements allowing that hot water consuming appliances are able to use pre-heated water (can be combined with solar thermal systems).
- Extension of standards for testing and certification of system performance of solar thermal systems to SCOHYS systems (inclusive back-up heater).

- Standardized hydraulic and electrical interconnections between all components of solar thermal and HVAC-systems in buildings.

Expected impact and KPIs:

- New and improved business models for solar thermal system deployment like leasing, guarantee of performance, and contracting (e.g. financing by solar kWh payments of the customers).
- Standardized methodology for design, installation, commissioning, operation, maintenance, and monitoring of solar thermal systems.

Costs: EUR 20 million / public - 30%, private - 70% / initiatives assisting standardisation process, promoting regulatory requirements, promoting system monitoring concepts, promoting new/effective business models.

Timeline: 2016 - 2020.

Modality of implementation: European projects focused on development from TRL 9.

Action 2: Market uptake of new built single family Solar Active Houses (SAH)

Scope: Solar Active Houses, the solar based concept for Nearly Zero Energy Buildings, become a cost-competitive solution for new built single and multi-family homes as well as for refurbished homes. Still, action is required to address some barriers in terms of market uptake, such as the development of adequate standards and the integration of SAH in nZEB standards.

Deliverables:

- Standards for testing and certification of Solar-Active-Houses ensuring harmonization with European building efficiency standards.
- Standardized hydraulic and electrical interconnections of all components of the solar thermal and the other HVAC-system in buildings.
- Standardized calculation scheme of overall heating costs in energy efficient buildings including SAH taking into account all types of costs (investment, operation and maintenance, electricity and fuel costs) and the security of supply aspect.

Expected impact and KPIs:

- Certification scheme for all types of Nearly-Zero-Energy Buildings including Solar-Active-Houses oriented on primary energy demand including the assessment of the temporal electricity demand dependency (e.g. for pumping and heat pumps).
- Support policy for Solar-Active-Houses (subsidy programs, interest reduced loans, increased efficiency standards, renewable energy obligations, etc.) for new constructions and refurbishment of buildings.

Costs: EUR 20 million / public: 30%, private: 70% / initiatives assisting standardisation process, promoting regulatory requirements, promoting system monitoring concepts, promoting new/effective business models.

Timeline: 2014 - 2020.

Modality of implementation: European projects focused on development from TRL 9.

Action 3: Market uptake of solar heat for industrial processes (SHIP)

Scope: Solar Heat for Industrial Processes (SHIP) is currently at a very early stage of development. Market uptake requires that business models are developed based on existing demonstration projects, to gain investor confidence and to make projects more “bankable”. In order to improve simulation of long time performance, standardisation is also required for accelerated ageing tests for medium temperature collectors. Furthermore, SHIP solutions need to be regarded as a serious competitive and reliable option for industry and adequately supported.

Deliverables:

- Standards and certification schemes as well as accelerated ageing tests for medium-temperature collectors and collector systems; test procedures for different concentrating collectors, high vacuum flat plate collectors, components and systems in order to achieve long term operation with high efficiency.
- Financial sector requirements for SHIP systems to become "bankable" for the financing sector and integrated into ESCO's portfolios; development of other financing and business models for SHIP technology dissemination.

Expected impact and KPIs:

- Integration of SHIP systems in industry energy audits by setting the preparation of a feasibility assessment of SHIP systems as an obligation in energy audits for industries with heat demand up to 250 °C.
- Effective public support policy for SHIP systems with first phase for low temperature and second phase for medium and high temperature SHIP systems (subsidy programs, interest reduced loans, renewable energy obligations, etc.).

Costs: EUR 30 million / public - 30%, private - 70% / initiatives assisting standardisation process, promoting regulatory requirements, promoting system monitoring concepts, promoting new/effective business models.

Timeline: 2014 - 2020.

Modality of implementation: European projects focused on development from TRL 9.

Challenge 5: Ocean Energy

KEY ISSUES

Production value chain performance/cost competitiveness:

Deliver technologies that: 1) generate effectively and reliably and 2) meet or exceed project investment criteria within supported markets. Achieve a LCOE target of <15-20EURc/kWh through the deployment of the first GW of wave or tidal stream technologies and associated cost reduction through volume, economies of scale and continued innovation. Continue on path to full competiveness with other low carbon options (<10EURc/kWh).

Supply chains:

Ensure a sufficient pipeline of project sites (>3-5GW in development by 2020) to encourage supply chain investment. Develop standards and standardise operating procedures, vessels, components and subsystems. Increase system lifetime, maintainability, reliability and accessibility offshore. Improve logistics and create supply chains for progressively larger projects. Make anticipatory investments in infrastructure such that grid links, ports and harbours are built in advance of projects.

System integration:

Ensure that the development of European grid infrastructure anticipates the use of large scale ocean energy. Ensure benefits from reduced system costs of integrating temporally diverse ocean energies with other renewables such as wind and solar are recognised and captured in decisions made about the energy mix and energy system investments. Investigate fuel production and energy storage options.

Non technological aspects:

Achieve a sustainable business model through technology advancement and market enablement measures for projects to generate a return on investment comparable with other investment opportunities (>8%-15%). Ensure the availability of finance to match market demand and support for global uptake of European ocean technologies. Engage banking and insurance sectors to accelerate market uptake. Remove uncertainties from the potential environmental impact of ocean energy technologies to accelerate consenting.

Societal issues:

Ensure that the increase in knowledge and economic benefits associated with the advancement of ocean energies are recognised and factored into decision making. (eg benefits to remote communities, potential for skills transfer from fishing and other maritime activities, manufacturing benefits, potential for technology transfer to other sectors). Increase public awareness of ocean energy and share knowledge of impacts (or lack of impacts) on the environment to reduce consenting timelines.

Introduction to the Programmes:

While wave and tidal are at different stages of development, it is the opinion of the stakeholders that a common program for both should be maintained, as most issues are similar for both. The timelines are slightly different, as the Advance Research and the Industrial Research and Development programmes are more relevant to wave energy, given its TRLs; whilst the Industrial Research and Development and Market Uptake programmes are more relevant to tidal energy. That said, this is a general rule, but should not be applied systematically but rather on a project by project basis.

Additionally wave and tidal are only two of the existing ocean technology and splitting actions according to respective issues concerning OTEC and Salinity Gradient would add complexity.

ADVANCED RESEARCH PROGRAMME

Action 1: Site Characterisation

Scope: The aim of this action is to develop tools and know-how to the characterisation of:

- Resource: correct assessment of energy available, modelling of the capacity factor and uncertainties associated, and modelling of local phenomena (as turbulence) likely to drive the sizing of devices.
- Physical conditions: sea bed investigation, local current confines, site accessibility.
- Environment: seabed, wildlife and plant life characterisation and impact measurement.

Deliverables:

- Innovative hardware or methodologies; Improved modelling techniques; Best practices for data collection; Joint technological and environmental data collection; Data quality increase; Dissemination; Identification and suitability of resource types per technology.

Expected impact:

- Reduced time and cost for development applications, installation, operation, maintenance, reduced production uncertainty by 10 %; Cross-fertilisation with other sectors for universally valuable data and knowledge gathering.

KPIs:

- Increase towards 90-95% predictability of resources.
- Decreasing of development cost by identifying multi-scale sites confines.

Costs: EUR 10 million.

Timeline: 2014 - 2017.

Modality of implementation: -

Action 2: Technological Research – Devices, components, materials

Scope: Projects in this action should address the designs of basic components and subcomponents and realisation of a first demonstrator for primary technologies of marine energy devices:

- Power take-off.
- Prime-mover, electrical conversion, marine connectors and wires.
- Pooring technologies, drilling, anchoring.
- Installation procedures, vessels and marine technologies.
- Projects should also address fundamental topics, strongly related to marine industry issues, as:
  - Material sciences.
  - Chemistry (corrosion).
  - Hydrodynamics and fluid dynamics, including tank testing.
  - Electromagnetism.
- Projects should study the transfer of existing technologies to marine applications. Development of new technologies also requires relevant protocols for testing, prediction and analysis of load cases.

Deliverables:

- New component functionalities; transfer of existing technology to marine applications; Innovative materials for reduced weight, cost, improved strength and suitability for marine applications; supply chain standardisation.

Expected impact:

- Reduce costs towards the 15-20 c/kWh target (%); Increase yield and life-cycle reliability toward the 15-20 year lifetime target; reduce environmental impact; achieve design consensus on different technologies to unlock mass manufacturing.

KPIs:

- Reliability of the concept tested.
- Measurable cost reduction.
- Component standardisation.
- Environmental impact.
- Compared to similar existing technologies.

Costs: EUR 140 million.

Timeline: 2014 - 2017.

Modality of implementation: local project gathering technologies developers, utilities, and industrial partner.

Action 3: Grid services and inter-array interactions

Scope: Address the specific issues associated with the efficient, reliable transmission of electricity /energy produced by marine energy devices, alone or in arrays; analysis and design of a dedicated electrical distribution system valid for most devices/arrays; development of cost effective transformers, switch gear, dynamic cabling, connectors and static cabling suitable for the highly dynamic marine environment and on platforms that are most appropriate (e.g. floating, fixed, subsea). Test and evaluation of such components and systems, potentially integrated with action 1 of IR&D Programme and or with other complimentary technologies such as offshore wind.

Deliverables:

- Control algorithms for ocean energy array; smoothing of energy output over time; new electrical distribution systems; standardisation of connectors; umbilical inter-array cabling.

Expected impact:

- Reduce CAPEX linked to cabling; Grid stability services; Industry wide solutions; cable-laying in high energetic zones.

KPIs:

- Measurable reduced CAPEX in the complete chain.
- Standard connectors for 440V, 3KV and 11kV. DC cables.

Costs: EUR 50 million.

Timeline: 2014 - 2017.

Modality of implementation: -

Action 4: Array design and modelling tools

Scope: Creation of design tools to optimise array layout and understanding of device performance in arrays, independently of device used. Take advantage of the first prototypes of devices and small farms for validation of numerical models. Evaluate uncertainties in modelling. Develop models to determine balance between cost of array, its efficiency and the complexity of the proposed layout. Determine balance of plant for array control algorithms.

Deliverables:

- Design tools and initial analysis report on array design and performance.

Expected impact:

- Improved array performance, reduced cost of energy, industry-wide solutions.

KPIs:

- Decrease uncertainties by less than 10%.
- High array performances.
- Reduce array costs.

Costs: EUR 10 million.

Timeline: 2014 - 2017.

Modality of implementation: -

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Actions under this programme are derived to encourage technology collaboration on subsystems and components to increase reliability and drive down capital costs of technologies. They have the following impacts:

- Ensure EU industrial leadership is maintained; technical learning.
- Cost of energy reduction; public and private investments triggered.
- Increased market confidence.
- Reduced project risk.
- Blue Growth through supply chain opportunities.
- Increased socio-economic benefits.

Some additional specific impacts are listed for each action below.

Action 1: Technology System Testing and Demonstration

Scope: System-level and device testing, at scale and full-scale operation (typically individual ocean energy converters in real sea test environment – novel concepts and iterations of existing, promising concepts). Focus on: materials and techniques to reduce capital costs, automated machine operation to increase yield; failure prediction and preventative maintenance; reduction in operational costs from wear, fatigue and bio-fouling; increased system reliability; efficient space utilisation, maximising site potential for ocean technologies.

Deliverables:

- Progress of ocean energy devices to TRL 6/7 and beyond; system-level demonstration for TRL progression, deployable within devices.

Expected impact:

- Reliable technology, Technical learning;
- Reduced cost of energy;
- Increased market confidence.

KPIs: Number of devices progressing through TRLs, assessed through benchmarking performance across the sector and against standards as these is developed:

- PTO efficiency and capacity factor to reach at least 25% by 2020.
- Increased operational hours.

- Availability >85%.

Costs: EUR 150 million.

Timeline: 2014 - 2017.

Modality of implementation: European wide cross-country collaboration.

Action 2: Demonstration of Marine Technology Access and Logistics

Scope: Vessels adaptation, innovative vessel design, as well as methodologies for efficient offshore operations, covering construction, operation and decommissioning and innovations to reduce infrastructure bottlenecks (eg ports and harbours). Reduction in time and cost in installation, connection and disconnection of machines; improved accessibility for maintenance; reduction in time and cost for maintenance activities.

Deliverables:

- Demonstration of cross-sector utilisation of existing assets, using innovation for adaptation to Ocean Energy; Demonstration of novel vessels (or supporting solutions) in ocean energy marine operations in period to 2020; integration with other maritime users, eg tracking and navigation.

Expected impact:

- Understand and reduce installation and O&M costs, time to devices; increase days of operability at sea.

KPIs:

- Installation and O&M costs.
- Time to devices.
- Increase days of operability at sea.

Costs: EUR 70 million.

Timeline: 2017 - 2020.

Modality of implementation: -

Action 3: Monitoring and Analysis of Technology Demonstrations

Scope: Ensuring technical, environmental and socio-economic results from technology demonstrations are captured and disseminated, in order to inform future technology design as well as address environmental considerations feed back into consenting and minimise uncertainties on ocean energy project impacts.

Deliverables:

- Measurement and analysis of key technical parameters across regions and projects in order to consolidate certification procedures and impact assessment knowledge. Establish database of parameterised ocean energy projects, incl. access for diverse stakeholder. Supporting a science based approach to baseline data gathering, avoiding unnecessary work and reducing costs.

Expected impact:

- Comparability of projects; optimised environmental and socio-economic impacts; Consolidate and reduce consenting time.

KPIs:

- Creation of Database.
- N° of projects analysed.
- Formal engagement and contribution from MS / projects.
- Validation and evolution of assessment criteria for certification bodies and authorities.

Costs: EUR 10 million.

Timeline: 2014 - 2020.

Modality of implementation: -

Action 4: Pilot Project Support** - **up to 10 MW, or 3-5 units

Scope: Moving from single device prototype technologies, to multi-device small-scale pilot projects; prove deployment, operability and generation of devices beyond single unit tests. CAPEX assistance required to continue foster innovation, otherwise early arrays will reduce innovation in order to reduce risk.

Deliverables: -

Expected impact:

- Technology deployment and market confidence.

KPIs:

- Number of projects including MW installed deployed using this scheme across Europe and corresponding investment by the private sector.
- Operational hours.
- Installed capacity.
- Inwards investment.
- Technology progression (TRL).

Costs: EUR 150 million.

Timeline: 2017 - 2020.

Modality of implementation: -

Action 5: Pre-normative research for developing Industry Standards

Scope: Develop industry standards for both the testing and manufacturing of devices, components and subcomponents, taking account of existing IEC/IEA work on standards. Ensure the use of manufacturing readiness level for the engagement of supply chain and OEM at broader scale and reduce CAPEX.

Deliverables:

- Standards and guidance for device and component manufacturing, engagement, consolidation and wider acceptance of standardised procedure for testing of ocean energy technologies.

Expected impact:

- Trigger investments through increased confidence from standard implementation, consistency and safety.

KPIs:

- Number of standards developed, number of standardised components.

Costs: EUR 5 million.

Timeline: 2017 - 2020.

Modality of implementation: -

INNOVATIVE AND MARKET-UPTAKE PROGRAMME

Actions under this programme have the following impacts: Ensure EU industrial leadership; socio-economic benefits and blue growth; private investments triggered; reduced LCOE; increased technological and environmental learning; market confidence and therefore uptake.

Some additional specific impacts are listed for each action below.

Action 1: Early Commercial Array Deployment Assistance Scheme

Scope: Deployment of 10+MW Scale Projects; This Action is focused on moving beyond the earliest "Pilot Projects" (addressed in Action within Industrial Research and Demonstration), reduce risk of multi-device deployment through grant schemes building upon innovation (CAPEX assistance). This addresses new, scale of deployment issues and therefore innovation and additional enabling actions are required as projects move towards greater scale.

Deliverables:

- In the region of 5 – 15 Individual projects deployed with the generating capacity of 10 – 50MW in each case.

Expected impact:

- Technology deployment leading to reduced Cost of Energy; Greater volumes creating supply chain opportunities, economic growth.

KPIs:

- MW installed.
- N° of individual projects achieving Final Investment Decisions.

Costs: EUR 500 million.

Timeline: 2017 - 2020.

Modality of implementation: -

Action 2: Grid Integration Assistance, on- and offshore

Scope: Financing electrical studies, focusing on the Integration of ocean energy technologies alongside other RES and non-RES, considering the unique aspects of ocean energy production characteristics concurrently with other forms of generation, from resource through to power take-off systems; Projects demonstrating this integration intention and capability should be supported through CapEx in line with innovation risk. Standardisation of grid access point for offshore RES (including offshore wind) and contribution to the development of smart grid.

Deliverables:

- Increased grid access options for ocean energy projects; understanding of grid services provided by ocean energy, through more efficient use of existing grid infrastructure, etc. Ocean energy-specific electrical system models. Stable grid-connected ocean devices.

Expected impact:

- Access to a wider range of sites; optimisation of EU integrated grid system.

KPIs:

- Number of MWs available in periphery of grid systems.
- Ocean Energy MWs able to connect through existing / shared connections with other generators.

Costs: EUR 15 million.

Timeline: 2014 - 2020.

Modality of implementation: -

Action 3: Establish consistent Consenting, Environmental and Socio-economic Assessment Baseline Frameworks

Scope: Determine a standard baseline state for several environmental areas impacted by ocean energy: benthos, marine life, sediments, etc. Develop scenarios for impacts at project level, as well as for the overall EU installed capacity. Streamline socio-economic impact assessments of ocean energy projects for consistent evaluation across at national and EU level.

Deliverables:

- Demonstrate co-ordination and consolidated output along with existing working groups and initiatives; National- and EU-wide consistent framework and regulations; Consistent analysis method for environmental impacts and associated uncertainties; Identification and increase of positive environmental Impacts: Established national- and EU-wide assessment method for socio-economic evaluation.

Expected impact:

- Optimised environmental impacts, increased level of social acceptance, and increased ocean energy contribution to economic growth. Improved mitigation measure to reduce potential impacts, increased level of social acceptance. Reduced conflict of use with other marine sectors.

KPIs:

- Number of MS systems subscribed to a given procedural system.
- Number of uncertainties reduced.
- Reduced time and cost of EIAs / consenting.
- Quantification of ecosystem values, quantification of ocean energy project economic value in MS and EU context.

Costs: EUR 15 million.

Timeline: 2014 - 2020.

Modality of implementation: European, MS and Regional level.

Action 4: Manufacturing and Production Advances/ Supply Chain - Est. Cost: EUR 100m

Scope: Enabling the move from early production requirements (< 5 units) to large-scale manufacturing through automation, mass-production techniques, optimised logistics, etc. in order to facilitate volume capability. This should focus on progression from bespoke practices to incorporation of reduced time and cost of automated processes where possible (e.g. material forming, assembly lines of drive-train, electrical or mechanical load testing, transportation of multiple devices, etc.).

Deliverables:

- Demonstrable migration to automated processes; improved quality control and supply chain opportunities; Evaluation of supply chain value; Training and skills.

Expected impact:

- Reduced cost and time of manufacturing and delivery per MW, increased economic opportunity for supply chain, ensure EU Leadership in the sector.

KPIs:

- Unit cost per MW.
- Manufacturing lead time.
- Production capacity of the entire supply chain.

Costs: EUR 100 million.

Timeline: 2017 - 2020.

Modality of implementation: -

Challenge 6: Geothermal Energy

KEY ISSUES

Geothermal power production has a substantial potential in Europe. Technology includes the geothermal steam plants in Iceland, Italy and Turkey, as well as the use of hot water in binary systems (also applied in Austria, Germany, France, and Portugal). The next generation geothermal technology enhanced geothermal systems - EGS, aims at overcoming the geological limits for current geothermal power sites and strives to make geothermal power an option almost anywhere in Europe. The potential towards 2050 is stated in the SRA of the Geothermal Technology Platform (2012) as 320 GW installed capacity world-wide, with about 90-100 GW in Europe. Considering the high load factor of geothermal power plants with an average of about 70-80 %, geothermal energy could provide 550-700 TWh of electricity per year.

Most geothermal power plants are capable (or can be made capable, by tuning the flow rate of the in-well production pumps) of responding to command from system operators to ramp output up and down on demand and thereby can provide the necessary flexibility to the electricity system.

Geothermal energy offers vast resources to cover demand for **heating and cooling**, with numerous technical options, ranging from supply to individual buildings using geothermal heat pumps to providing heat (and cold) for whole cities or city quarters through large district heating networks.

Key Issue 1: Deploy EGS technology and make competitive this technology. The short-term targets of this challenge should be to achieve an installed geothermal power capacity in Europe of >3 GW (of which 1.5 GW in EU27) by 2020, and aiming at >10 GW by 2030.

Key Issue 2: Keep production cost for electricity from geothermal resources low, by decreasing installation and operation cost of the power plants, by increasing longevity of installations, by optimising efficiency and power output.

Key Issue 3: Include geothermal power in grid-optimisation schemes, and use its advantages as a base load, flexible, sizable, controllable, and local resource (one of the few among renewables).

Key Issue 4: Enhance the current use of geothermal energy for heating and cooling by reducing cost of exploration, drilling and installation, by improving longevity of material and efficiency of operation. In particular with geothermal heating and cooling, non-technical issues like investor awareness, city planning, regulations concerning the resource, etc. can create substantial barriers against further deployment, and thus need to be addressed in priority. Also activities outside the realm of geothermal energy sensu strictu, like development in thermal storage and in (smart) thermal grids, are crucial to make full use of the geothermal heat resources.

ADVANCED RESEARCH PROGRAMME

Action 1: Improving deep geothermal well design and completion

Scope: The cost of drilling usually increases exponentially with depth. Well design has to target longer operative well life, optimisation of well delivery and productive/injective capacities, prevention of particle invasion and well/formation impairment, mitigation of corrosion and scaling problems, reduction of well maintenance and work-over cost. The well completion technology needs to be improved in order to fulfil these design goals.

Deliverables:

- Optimisation of well geometry, side-tracks, multilaterals, horizontal legs and its technologies including directional and horizontal drilling in general.
- Design of optimised production well completion for European geothermal reservoirs including casing while drilling.
- Specific solutions related to accessing very hot reservoirs and to materials to withstand the often corrosive environments.
- Improving measuring while drilling and monitoring while drilling technologies.
- High temperature (>150°C) directional drilling (DD) and measurement while drilling (MWD).
- Continuous, flexible hose, drill lines, coiled tubing developments, application of composite thermoplastics below 3 km depths.
- Design of suitable injection wells for sensitive (sand, sandstone) reservoir settings (e.g., in the Pannonian Basin and the North German - Polish Basin).

Expected impact:

- Novel production technologies to improve efficiency, reliability and cost of reservoir access (including well design and completion, definition of suitable materials, prevention of formation-damage, high temperature-high pressure tools, etc.). Geothermal well design will become more has reached a good standardised. Reduction in the time (and costs) of geothermal drilling projects while minimising the damage to the geothermal reservoir around the well.

KPIs:

- Reduction of operation and maintenance cost or drilling technology by at least 25 % compared to current estimated cost of around EUR 10 million for a 5 km deep well, improved system reliability and energy efficiency of operation.

Costs: EUR 10 million (see Geothermal roadmap – RHC platform, May 2014).

Timeline: 2016 - 2020.

Modality of implementation: EU required with national contribution.

Action 2: Improving deep geothermal production technologies: reservoir stimulation and management

Scope: Natural permeability of reservoirs is one of the key factors to determine the energy output of geothermal systems by controlling the productivity of a well. Existing stimulation methods need to be refined to increase rate of success, to improve predictability of results, to remove well and formation damage, to develop and prop fracture networks, and to reduce environmental hazard (pollution of aquifer, induced seismicity). Research should focus on understanding the underlying processes leading to improved permeability and develop concepts to minimise unwanted side effects. These concepts include the use of non-hazardous materials and soft stimulation approaches.

Deliverables:

- Design and field implementation of hydraulic, chemical, thermal stimulation techniques in selected rock and structural settings (sedimentary/stratified, volcano/tectonic, crystalline/metamorphic).

- Improved prediction and monitoring of chemical and hydraulic developments.
- Field testing of candidate fluid handling processes/facilities, well completion, water sand control protocols and removal/remedial procedures.
- Development of thermally activated/deactivated reagents.

Expected impact:

- Novel stimulation technologies to improve efficiency, reliability and cost of reservoir stimulation and monitoring of stimulation treatments tools.

KPIs:

- Reduce stimulation cost by at least 25 % compared to current estimated cost of EUR 4-8 million for a doublet system, improve system reliability and energy efficiency of operation: well productivity increased by a factor >3, sustainable for >5 years.

Costs: EUR 10 million (see Geothermal roadmap – RHC platform, May 2014).

Timeline: 2014 - 2018.

Modality of implementation: EU required with national contribution.

Action 3: Improving deep geothermal production technologies: New materials

Scope: Corrosion and scaling are among the main problems during operation of deep geothermal plants, jeopardising plant efficiency and longevity. Corrosion and scaling are not stand alone processes but a matter of the system. Therefore, the interaction of technical materials with terrestrial fluids has to be systematically investigated by basic research to prevent design shortcomings and secure well/equipment integrities.

Deliverables:

- Design and testing of low cost high temperature, high pressure mechanically resistant metal, alloys, and composite materials.
- Study of interaction of geothermal fluids from different geological environments with standard and newly developed specific alloys and composite materials as technical system components of the thermal cycle (e.g. Tubing, cements, sealing, well head, heat exchanger).

Expected impact:

- Novel materials withstanding hostile geothermal fluids (high salinity, gas bearing, etc.) with the mechanical stability to fulfil all requirements of a reliable operation of a geothermal plant.

KPIs: improve systems lifetime by 20 years minimum.

Costs: EUR 15 million (see Geothermal roadmap – RHC platform, May 2014).

Timeline: 2016 - 2020.

Modality of implementation: EU required with national contribution.

Action 4: Costs reduction of deep geothermal drilling technologies: develop novel drilling technologies

Scope: Novel drilling concepts at the technological frontier are expected to allow for dramatic drilling time/cost breakthroughs in an unforeseeable future. The concepts should be investigated today (2014-2016), and basic (and later applied: 2016-2020) research supported in order to have these techniques available for geothermal drilling in the medium/long term timeframe. A non-exhaustive list of concepts comprises: millimetre wave deep drilling, hydrothermal and instant steam spallation drilling, robotic, ultra-deep, high temperature/pressure drilling technologies. Other technologies as laser drilling and fusion drilling should first be analysed by reliable assessment studies to prove their basic viability.

Deliverables:

- Set up an (ad-hoc) evaluation panel.
- Basic research and subsequent R&D for selected prospective technologies.
- Low-cost, exploration only drilling technology.
- High temperature (>150°C) directional drilling (DD) and measurement while drilling (MWD).
- Improved drilling and installation technology for deep borehole heat exchangers (BHE).
- Deep air/foam balanced drilling.
- High temperature, high pressure cement slurries; high temperature, high pressure inflatable/metal packers for open hole and casing.

Expected impact:

- Reductions in drilling cost by developing new technologies.

KPIs:

- The target is to reduce cost for drilling per well and underground installations by at least 25 % compared to current estimated cost of around EUR 10 million for a 5 km deep well.

Costs: EUR 80 million (see Geothermal roadmap – RHC platform, May 2014).

Timeline: 2014 – 2020; Develop novel drilling technologies by 2020 - in laboratories (by 2015), on site (by 2017), on a demonstration plant (by 2020).

Modality of implementation: European required with National contribution.

Action 5: Improve exploration technologies

Scope: Exploration technologies for subsurface imaging are crucial prior to locating drilling targets. The goals are delineation of the geologic structure and characterization of bulk properties of the reservoir. Heat transfer processes, the stress field and fracture patterns related to fluid flow in the reservoir are important. Full-scale investigations of the basic hydraulic, mechanical and chemical processes are required, for example in observatories, because they are relevant for the development of petrothermal and hydrothermal systems.

Deliverables:

- Development of innovative, cost-effective, subsurface imaging tools capable of investigating down to reservoir depth incl. application of new geological and geophysical methods.
- Creation of a European geothermal resource data base, Update of European Geothermal Atlas and evaluation of the EU EGS potential.
- In-situ analysis of reservoir properties, modelling of geothermal reservoir behaviour and management and optimisation and further development of numerical tools for thermal, chemical, hydraulic and mechanical behaviour of geothermal facilities.
- Scale relevant experimental investigations of the principal processes dominating the geothermal reservoir behaviour under energy extraction in terms of optimisation of available resources.
- Deep Underground Observatory installed at a safe distance from urban areas in boreholes at different depths to allow for full-scale investigation of the basic hydraulic, mechanical and chemical processes relevant to the development of petrothermal and hydrothermal systems. The drilling needs to be preceded and accompanied by a comprehensive range of other

geophysical surface measurements and monitoring, such as 2D and 3D active and passive seismic experiments, magnetotelluric, gravimetric surveys, as well as an extensive borehole measurement programme for characterizing the reservoir.

Expected impact:

- Improved exploration of geothermal resources and creation of a European geothermal resource database. By 2020, not a single project should need to be abandoned after the decision to go ahead with drilling.

KPIs:

- Reduction of exploration cost by at least 25% in 2020, and 50% in a longer term compared to current estimated cost of EUR 2-6 million. Decrease geological risk to 2020 by 25% (expressed by reduced number of abandoned projects due to low temperature or flow).

Costs: EUR 40 million (see Geothermal roadmap – RHC platform, May 2014).

Timeline: 2014 - 2018.

Modality of implementation: European with strong National support for the chosen site.

Action 6: New concepts and materials for Shallow Geothermal ground-coupling

Scope: The efficiency of heat exchange with the geological strata can be increased by R&D for optimization of components such as borehole heat exchangers (design, pipe material, and grouting material), well completion materials, compressors, and pumps.

One more concern is about the identification/development of an environmentally benign, low viscosity antifreeze ("thermal transfer fluid") fluid for closed loop GSHP systems in order to have thermal characteristics that are equal to, or better than, mono-ethylene glycol. The objective is to produce with long term stability - at least as good as mono-ethylene glycol; and preferably derived from a sustainable source. Such antifreeze could contribute to system efficiency by reducing power demand of circulation pumps, and to acceptance with authorities by imposing no threat to the groundwater.

Deliverables:

- Materials research on heat exchanger materials (PE, PEX, etc.).
- Loops could be made of alternative materials with similar lifespan and lower resistance to energy transfer.
- New antifreeze fluid.

Expected impact:

- Improved pipe materials for borehole heat exchangers (BHE) and horizontal ground loops. New pipes for higher temperatures. Better thermal transfer fluid.

KPIs:

- Increase of heat exchange efficiency to 2020 by 25% (by reduced borehole thermal resistance compared to current estimate of 0.07-0.08 K/Wm), allowing for higher efficiency (for boreholes, expressed as increase in Hellström-efficiency from current value of 75%).

Costs: EUR 15 million (see Geothermal roadmap – RHC platform, May 2014).

Timeline: some research in particular on materials might lead to new solutions only in a medium term.2015 - 2019.

Modality of implementation: European required with National contribution.

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: European geothermal drilling programme

Scope: The major boost for EGS commercialisation could be generated by a European Drilling Programme, which would provide support for pilot projects in various regions of Europe. Such a programme would close gaps in the knowledge base and accelerate the development leading to a steeply rising learning curve. This kind of development will ultimately trigger investments in follow-up projects at much larger scale than the initial investment in the programme.

Improve current drilling technologies: Investigation of those topics likely to improve rates of penetration, cutting recovery, equipment/borehole integrities, prevent formation damage and reduce/mitigate technological risks, safety requirements and therefore ultimately save rig time, reduce costs and environmental impacts.

Deliverables:

- Low-cost, exploration drilling technology.
- Directional and horizontal drilling in general, casing while drilling, seismic and logging while drilling.
- Continuous, flexible hose, drill lines, coiled tubing developments, application of composite thermoplastics below 3 km depths.
- Improved drilling and installation technology for deep borehole heat exchangers (BHE).
- Mud jets with PDC (polycrystalline diamond compact) drill bits.
- Mud logging/processing.
- Improvement of drilling engineering design, crew/staff training.

Expected impact:

- Optimisation and development of measurement-while-drilling (MWD) technologies, development of data interpretation methodologies.
- Improved drilling for reservoir development and exploitation.
- Drilling and installation for deep borehole heat exchangers (BHE) in low-/medium enthalpy, low permeability reservoirs to improve techniques and reduce costs.
- Swift progress (and continuous improvement) will be pooled with coordinated international R&D efforts, with a view to successful demonstration and implementation.

KPIs:

- Progress in drilling technology can help reducing the cost by 25 %.

Costs: EUR 50 million (see Geothermal roadmap – RHC platform, May 2014).

Timeline: 2017 - 2020.

Modality of implementation: European with strong National support for the chosen site.

Action 2: Improving deep geothermal production technologies: innovation in monitoring and operation

Scope: Downhole instrumentation is required to improve performance, reduce environmental impact and increase public acceptance. A reliable and expanded monitoring system should be developed and installed at geothermal sites under development and in operation. That way, hazards of induced seismicity, of radioactivity from the deep thermal waters and the protection of drinking water can be better controlled and measures to mitigate unwanted side effects of geothermal development and operations can be defined.

For the successful operation of most geothermal projects in non-volcanic environments, there is a need to improve pump efficiency and longevity, to secure production reliability, to develop tools for avoiding two-phase flow in wells, etc., in order to upgrade exploitation economics. The harsh geological environment of geothermal installations can lead to corrosion and precipitation from thermal waters, processes accelerating the decline in productivity.

Deliverables:

- Application of new monitoring networks including surface installations to measure seismic and other physical properties of the subsurface, downhole imaging tools and distributed vertical measurements (with fibre-optic cables) of temperature, flow rates, and acoustic emissions (seismic activity).
- Improvements to high temperature, high pressure downhole gauges for temperature, pressure and yield, fluid samplers and cables, and resident bottom-hole recording devices.
- In situ / continuous well monitoring (e.g. using fibre optics): temperature, conductivity, flow, pressure, seismicity, fractures propagation, etc.
- Development of high temperature resistant, high efficiency electrical submersible pumps (ESP). Improvements in line-shaft and submersible pump technology to increase flow and efficiency, and to enhance resistance against high temperature and pressure.
- Measures to reduce corrosion and scaling in operating geothermal plants inclusive new developed inhibitors.

Expected impact:

- Environmentally safe operation of geothermal plants.
- Improved reliability of the plant operation.
- Life cycle cost reductions.
- Optimised efficiency of the whole chain.

KPIs:

- There is room to reduce operation and maintenance cost by at least 25 % compared to current estimated OPEX/CAPEX ratio of 0.55 for EGS systems, and to improve system reliability and energy efficiency of operation, in particular by decreasing energy consumption of production pumps by at least 50 %.

Costs: EUR 20 million (see Geothermal roadmap – RHC platform, May 2014).

Timeline: 2014 - 2020.

Modality of implementation: EU with local application.

Action 3: Launch an EGS FLAGSHIP PROGRAM

Scope: EGS is a technology for accessing the heat in hot but impermeable basement rock. Once fully developed it will provide a major increase in the geothermal resource base, both for heat and electric power.

At each stage of EGS development, proven methodologies can be applied and bottlenecks identified. The expected outcome will be the development of cost-effective and reliable large EGS plants to make geothermal power fully competitive. Upscaling projects often lead to the development of better or less expensive applications (cascading effect for drilling).

Deliverables:

- Establish network of complementary 5-10 European EGS test laboratories.

- Demonstration sites in different geological settings (3 plants of 5 MWe-10MWth) and upscale (1 plant=10 MWe-20MWth and 1 plant=20 MWe-40MWth).

Expected impact:

- Development and demonstration of energy efficient, environmentally sound and economically viable electricity and heat and cold production from Enhanced Geothermal Systems (EGS).

KPIs:

- Reduction of capital cost for a 5 MWe EGS plant with 5 km wells by at least 25% compared to current estimate of 8000-10000 EUR/kWe capacity in 2020, and 50% in a longer term. Reduction of production costs below 10 EURct/kWh by 2020, in increasing of conversion efficiency to 2020 by 25%, allowing for either higher efficiency (for production, turbine, etc.).

Costs: EUR 315 million (see Geothermal roadmap – RHC platform, May 2014).

Timeline: 2014 - 2020.

Modality of implementation: European with strong National support for the chosen site.

Action 4: Deep geothermal resources assessment

Scope: Improved exploration of geothermal resources and creation of a European geothermal resource database. Presently, technology is mainly based on extrapolation of products tailored for hydrocarbon industry (e.g., geophysical software, logging tools, etc.) into the geothermal sector. A drilling campaign of slimholes should be launched in Europe for getting more geological data.

The two principal goals are to promote basic research and a European drilling campaign. To decrease the cost of exploration, a framework for pre-drilling basic research on geothermal resources and geochemistry, in addition to geophysical campaigns, will be proposed. The aim of the drilling campaign is to further reduce risk, and thereby promote commercial initiatives, by supporting secondary exploration through drilling of characterization wells in prospective regions based on commercial initiatives. Data will be collected in high-quality public databases.

Deliverables:

- European campaign of slimholes: new technologies & drilling campaign.
- Creation of a European geothermal resource data base.
- Update of European Geothermal Atlas.
- Evaluation of the EU EGS potential.
- Reinterpretation of existing geophysical, geological, geochemical data, and acquisition of new data.
- Methodological and technological developments.

Expected impact:

- Decrease geological risk to 2020 by 25% (expressed by reduced number of abandoned projects due to low temperature or flow).

KPIs:

- Decrease the number of project abandoned after the decision to go ahead with drilling at a rate below 5%.

Costs: EUR 35 million (see Geothermal roadmap – RHC platform, May 2014).

Timeline: 2014 - 2020.

Modality of implementation: Resource assessment (productivity when related to the injectivity) at different scales: European, National, Regional, and Local.

Action 5: Improvement in Shallow Geothermal Ground-Coupling technologies

Scope: A lot can be expected also from further reducing manual work in drilling and installation, by automation and robotics. R&D in specific shallow geothermal drilling technology is also required to further reduce the impact on the surroundings (e.g. sensitive clays, groundwater), to provide techniques to control borehole deviation, etc. The use of geothermal activated structures (geothermal piles, diaphragm walls provided with embedded heat exchanges, etc.) may also lead to substantial cost reductions. Some key items can be listed as:

- Improved vertical borehole drilling technologies to enhance safety and reduce cost of BHE installations.
- Improved installation technologies and geometries for ground Heat Exchange technology.
- European-wide Geoactive Structures Alliance, including development of a network of laboratories to create 4 testing sites.

Deliverables:

- Further work is needed towards long-term reliability, adaptation to ground parameters, optimisation of working media, etc.
- There is a significant potential for the development of dedicated drilling rigs capable of reliable, predictable, fast production with low maintenance requirements, constant process quality and acceptable working conditions.
- Often geothermal sites are in urban areas where traffic management is already an issue. Therefore, additional movement by trucks moving material off site is unwanted. On site processing and storage of excavated materials would benefit the installation process. Also noise reduction, low emissions and relatively clean construction sites are desired.

Expected impact:

- Improved vertical borehole drilling technologies to enhance safety and reduce cost of BHE installations.
- Improved installation technologies and geometries for ground Heat Exchange technology; Development a network of laboratories to create 4 testing sites.
- Improved pipe materials for borehole heat exchangers (BHE) and horizontal ground loops. New pipes for higher temperatures. Better thermal transfer fluid.

KPIs:

- The borehole thermal resistance (Rb) Performance Indicator has been reduced by more than 40 % over the last ten years. The overall impact of this value to a defined shallow geothermal system is given by the Hellström-efficiency, which increased from below 60 % to about 75 % in state-of-the-art installations over the past 10 years. There is still room for improvement, so provided the technology progress is continued, efficiencies of about 80% in 2020 seem achievable. Reduction of average installation cost by at least 25% in 2020, and 50% in a longer term. Increase of heat exchange efficiency to 2020 by 25% (expressed by reduced borehole thermal resistance or similar), allowing for either higher efficiency (for boreholes, expressed as increase in Hellström-efficiency) or reduced cost.

Costs: EUR 45 million (see Geothermal roadmap – RHC platform, May 2014).

Timeline: 2014 - 2020.

Modality of implementation: European and National.

Action 6: Flexible generation from geothermal power

Scope: The largest source of flexibility in power systems is the ability of dispatchable power plants such as geothermal plants to ramp output up and down on demand. Geothermal plants are dispatchable as they are able to respond to commands from a system operator, at any time, within certain availability parameters, and to increase or decrease output over a defined period. Geothermal plants are ‘base load’, designed for operating 24 h per day throughout the year. It is also flexible because plants should be ready to respond with at least 6 hours' notice. In a CHP plant electricity generation can be seasonally tuned, accordingly to the peak heat demand in winter, and increased during summer period.

Deliverables:

- Test on dispatchability: able to respond to commands from a system operator, at any time, within certain availability parameters, and to increase or decrease output over a defined period.
- Test on flexible combined heat and power plants.
- Define the range of operability of the thermodynamic processes (Binary: ORC, Kalina, Engines, etc.) used for geothermal power generation through a parametric study using system-scale modelling.
- Review of technical and field experience data available for flexibility of geothermal. Assessing and improving the technical capability of binary geothermal power plants to respond to command from system operators to ramp output up and down demand, and thereby provide valuable flexibility to the electricity system.

Expected impact:

- Grid flexibility: Flexible and base load electricity production from geothermal plants.
- The aim should be to have a step between centralised and completely decentralised systems with regional security of supply. In this aspect, geothermal CHP production is a key. A high penetration of geothermal CHP-plants could play a positive role on the operation of distribution networks and the ancillary services these units could provide to the electricity system, under consideration of the different operating modes e.g. heat/ power driven, with/without storage, afforded by their operational flexibility.

KPIs:

- Minimum load reduced by 30%; Provide significant flexible response: ramp output up and down with a 4 hours’ notice, Mitigation of negative price situations in the electricity market.

Costs: EUR 10 million (see Geothermal roadmap – RHC platform, May 2014).

Timeline: 2014/2020 – 2030.

Modality of implementation: European, National and Regional.

INNOVATION AND MARKET-UPTAKE PROGRAMME

Action 1: Public acceptance of geothermal technologies

Scope: Increasing the information (via Internet, social tools, communication materials) about the useful geothermal potential and its advantages, among the various stake holders (end-users, advisers, authorities, etc.). It can concern microseismicity, stimulation, environmental impact, (sound, landscape, emissions).

- Socio-political acceptance: of technologies and policies by the public, by key stakeholders, by policy makers and market acceptance: Consumers, Investors, Intra-firm.
- Community acceptance: communication and information, Integration and involvement, balance of interests and conflict resolution, NIMBY effect.
- Development of methodology and strategies with regard to system interaction is a requirement for acceptance and sustainability.

Deliverables:

- Impact guidelines for social participation in geothermal installations.
- Information and communication strategy (via Internet, social tools, communication materials) about the useful geothermal potential and its advantages, among the various stake holders (end-users, advisers, authorities, etc.).

Expected impact:

- Wider acceptance: Accepted as standard feature by general public and governing bodies.

KPIs:

- Standardized communication concept for geothermal installations. Less than 1% of projects abandoned due to not in my backyard syndrome.

Costs: EUR 5 million (see Geothermal roadmap – RHC platform, May 2014).

Timeline: 2014 - 2018.

Modality of implementation: European, National, Regional and Local.

Action 2: GSHP Systems, integration and environment

Scope: The objectives are to Improving the understanding of the shallow geothermal reservoir as an entity and as a process) involves the characterization of the important parameters (thermal, hydrogeological, environmental) as well as engineering.

As most of the buildings existing in 2020 are already built, the development and testing of underground coupling systems suitable for retrofitting or adaptable into old buildings/historical buildings is crucial to substantially increase GSHP technologies penetration.

Deliverables:

- The online availability of relevant information through databases and GIS systems would be beneficial, especially if information on underground infrastructure and the position of other geothermal systems is included. Borehole characterization by geophysical logging will be relevant for design but allows for establishing compliancy of borehole design and construction with environmental legislation. In more complex situations with varied geology or hydrogeological influence more advanced TRT testing should be developed to characterize the thermal behaviour of the ground and groundwater effects.
- The potential for hydraulic and thermal interaction between adjacent well based systems or thermal interaction with nearby systems using BHE needs special attention. To date little research has been carried out on integrated ground-source systems, and virtually none on integrated control strategies. Integrated control of ground source heat pump systems to include ground side, heat pump, building circuits and building characteristics; multiple input - multiple output control approaches.

Expected impact:

- Avoid of negative effects of shallow geothermal systems to ground and groundwater. General coverage of GIS soil thermal properties databases. Improve technology awareness.

KPIs:

- Increase of efficiency by at least 25% through better overall system design and operation.

Costs: EUR 70 million (see Geothermal roadmap – RHC platform, May 2014).

Timeline: 2014 - 2020.

Modality of implementation: EU, National, Regional and Local.

Action 3: Mitigate geological risk associated with geothermal

Scope: Several risk factors (e.g. technical, financial, and environmental) need to be carefully evaluated during the exploration phase while the subsurface model is not well understood, the resource not completely proven and the development scenarios not yet clearly defined. In particular, seismic risks associated with EGS projects and ground deformation associated with exploitation of shallow reservoirs should be addressed and mitigation actions identified accordingly in stimulation planning.

It is assumed that in early exploratory stages a framework insurance policy would be promoted to mitigate the exploration risk. It should act as a stimulus until, after the initial high level risk be mastered, developers carry out exploration/development issues under their own responsibility and resources.

Deliverables:

- Development of advanced approaches, guidelines and tools addressing exploration risk assessment and mitigation easing the decision making process.
- A European Geothermal Risk Insurance Fund (EGRIF) is seen as an appealing public support measure for reducing the geological risk.

Expected impact:

- Reduced number of abandoned projects due to low temperature or flow.

KPIs:

- Decrease number of projects abandoned due to low temperature or flow rate below 10%, from current percentage of 20%.

Costs: EUR 80 million (see Geothermal roadmap – RHC platform, May 2014).

Timeline: 2014 - 2020.

Modality of implementation: European and National.

Challenge 7: Bioenergy (Heat and Power)

Bioenergy represents two-thirds of the total renewables sector and so will continue to play a key role in helping Europe to reach its 20-20-20 targets. The actions outlined in this challenge will facilitate the replacement of fossil fuels with RES with great potential for reduction in greenhouse gas emissions by replacing fossil fuels with Biomass. Assuming a current GHG emission intensity of 3 tons GHG/toe, or 71.3g/MJ, implementation of these actions for biomass heating can ensure the saving of 370 million tons of GHG in 2020. Biomass supply is crucial to achieving the 2020 goals with biomass supply expected to double by 2020 bringing 124Mtoe, and 231Mtoe by 2050. By offering a sustainable indigenous resource, Bioenergy will greatly increase the security of energy supply in Europe. Implementing these actions will help us see

share in the biomass heat market grow from 11% in 2007 to 25% in 2020, brining significant contribution to the renewables targets.
This challenge will greatly assist the EC in the achievement of the SET-Plan objective of further lowering the costs of low-carbon energy. This challenge addresses how bioenergy can help to achieve this goal. It is necessary to consider the entire *value chain* - from feedstock to end products. This challenge therefore adopts a ***value chain*** **approach**, integrating different research priorities throughout the entire supply chain: from the sourcing of the biomass, to the transformation of the biomass and its conversion into heat (and electricity), including the logistical aspects needed to transport the biomass or the energy carrier. These value chains include topics that are included across different programmes.

KEY ISSUES

Feedstock:

- Mobilisation of alternative biomass feedstock resources such as forest and agricultural residues to widen the feedstock base of bioenergy supply chains including low ILUC biomass.
- Upgrading of conventional and alternative feedstock through thermal treatment, the production of bio-oil, and the conversion of biogas to biomethane with the potential to deliver GHG savings over 700 million tons of CO2 (assuming the replacement of 300 million tons coal with torrefied biomass).
- Development of standardised and sector oriented (up-graded) sustainable biomass fuels at competitive production costs doubling the potential biomass fuel supply.

Technology:

Technologies for the implementation of cost and resource efficient value chains for biomass based heat/cool and power production address harvesting and logistics, biomass up-grading, micro and small-scale CHP, large-scale industrial CHP, and trigeneration/polygeneration. Challenges include:

- Secure supply of high quality biomass fuels to the end consumer.
- Enhance availability and mobilisation of sustainable biomass resources.
- Integration of Small Scale CHP systems contributing to the distributed electrification of the EU energy system further reducing emission levels that are already in compliance with EN303-5[6], to 1/10 of these levels.
- Large scale CHP bringing emissions levels (SOx, NOx and PM emissions) into compliance with the IED and significantly contributing to renewable heat and electricity supply.
- Polygeneration systems integrating other intermittent renewables, facilitating a 100% renewable electricity market. Total energy production efficiency is doubled, fulfilling the requirements of the EED.

Market Uptake:

Commercialisation of innovative technologies and value chains for biomass based heat/cool and power production depends on political leadership and an adequate legislative framework. Only by actively stimulating investment will Europe benefit from the benefits with respect to energy security, reduction of import dependence, job creation, growth, rural development and GHG emission reductions.

Challenges include:

- Guarantee adequate public and private funding and risk sharing mechanisms.
- Develop sustainability criteria for solid and gaseous biomass.
- Guarantee a stable and long term policy framework facilitating the market up-take of micro and small-scale CHP for decentralised biomass based heat/cool and power production as well as of large-scale industrial CHP (e.g. through co-firing of biomass with fossil fuels).
- Create positive awareness amongst consumers.

Aggregated Costs: EUR 785.50 million - public funding, EUR 1,519.50 million - private funding.

[6] EN 303-5:2012, Heating boilers - Part 5: Heating boilers for solid fuels, manually and automatically stoked, nominal heat output of up to 500 kW - Terminology, requirements, testing and marking

ADVANCED RESEARCH PROGRAMME

Action 1: Upgrading bio-oil quality to be suitable for CHP and stationary engine usage

Scope: This action aims at significantly improving bio-oil quality to enable it to replace heavy fuel oil and natural gas in the small-scale heating and CHP sector, such as the use in gas turbines and stationary engines for electricity, district heating, and process steam production.

Deliverables:

- Physical upgraded bio-oil for use in small-scale CHP and stationary engines.
- Chemically upgraded bio-oil for use in micro-CHP and engines.
- Broadening feedstock base for upgraded bio-oil.

Expected impact:

- Development of cost-efficient bio-oil production methods and upgrading methods to decrease the production costs and to satisfy the quality criteria to be set for bio-oil in standards.
- Enhanced bio-oil quality allowing for higher value applications such as gas turbines, diesel engine and mineral oil refinery co-feeding usages.
- Broadening of feedstock base for the production of bio-oil for cost-efficient production of electricity and heat/cool.
- High fuel flexibility.

KPIs:

- 20% reduction in bio-oil costs through process integration and logistical optimization.
- Full scale bio-oil production with plant availability of greater than 6.500 hours per annum.
- Bio-oil satisfies specifications of the EN standards (for boilers and engines) under development by CEN (mandate accepted 10/2013).

Costs: EUR 20 million (50% public, 50% private funding).

Timeline: 2014 - 2020.

Modality of implementation: European level.

Action 2: Materials research for micro and small scale CHP

Scope: This action addresses advanced material research on thermoelectric materials, working fluids, working machine materials, and heat exchanger materials in order to improve performance and reduce costs of micro and small scale CHP applications.

Deliverables:

- Development of high temperature- and high corrosion-resistant heat exchangers including reliable cleaning mechanisms or technological solutions to avoid deposit formation.
- Development of advanced materials for seals, heat exchangers, electrodes, etc.

Expected impact:

- Reduction in electricity production costs through decreasing investment and maintenance costs, increasing electricity efficiency and availability and the development of energy efficient and cost effective storage systems.

- Reliable and cost efficient decentralized renewable energy production for the end consumers.

KPIs:

- Electric System efficiencies based on solid state technologies of 2%.
- Electric System efficiencies based on thermodynamic cycles of 7% (<5 kW_{el}), <10% -12% (5 - 50 kW_{el}), 12-15 (<250 kW_{el}).

Costs: EUR 30 million (50% public, 50% private funding).

Timescale: 2014 - 2016.

Modality of implementation: National and European level.

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Sustainable, innovative and cost-efficient advanced biomass feedstock supply

Scope: This action focuses on the optimization of logistics, feedstock selection and quality, and machinery improvements to meet the quality requirements for the production of standardised, sector-oriented and sustainable advanced biomass fuels (e.g. new biocommodities, thermally treated biomass fuels, fast pyrolysis bio-oil and upgraded biomethane).

Deliverables:

- Reduction of both fossil fuel consumption and overall energy consumption through smarter and more efficient harvesting and logistics technologies.
- Reduction of costs and enhanced value chain efficiencies by greatly improving transport and logistic processes.
- Demonstration of new types of sustainable feedstock supply chains in different climatic conditions.

Expected impact:

- Mobilisation of European endogenous biomass, reduced dependency on imported resources with enlarged raw material portfolio.
- Decreased supply costs, decreased production losses.
- A substantial increase in employment in the wood fuel supply chain with an overall employment of around 40.000 man-years by 2030.

KPIs:

- Biomass supply costs reduction of 30% for forest biomass and agrobiomass residues
- Decrease in production losses by 10-20% (through dried fuels, better pre-treatment of biomass, and decrease in storage losses).
- Reduction in fossil fuel consumption in biomass supply chain by 30% through the use of biofuels.

Costs: EUR 60 million (50% public, 50% private funding).

Timeline: 2014 - 2016 (demonstrations by 2017).

Modality of implementation: National and European level (cooperation RHC TP and EBTP).

Action 2: Biogas production and up-grading to biomethane

Scope: The aim of this action is to improve biogas production and up-grading to biomethane from indigenous resources in order to contribute to enhanced energy security and reduce dependency of imported natural gas. Up-grading of biogas to biomethane offers a solution to the problem of unused heat and helps to increase the overall efficiency of biogas utilisation.

Deliverables:

- Improved feedstock selection methods, pre-treatment technologies, and determination of techno economic criteria to increase efficiency of biogas production.
- Development of technologies for measurement and control systems.
- Technological improvements on the upgrading step of biogas to biomethane. Down-sized applications are delivered, power consumption is reduced, and flexibility of CHP units to contribute to load management is enhanced.

Expected impact:

- Reduction of import dependency of natural gas through enhanced cost efficient production of biogas and biomethane from indigenous feedstock.
- Enhanced overall efficiencies due to the reduction of unused heat. The ability to treat wet materials also brings the potential to decrease organic waste.
- Increased gas yield and production of a high quality digestate as a by-product which can be suitable as a substitute for chemical fertilizers.
- Full use of the energy content of biogas upgraded to biomethane to be demonstrated between 2014-2016 and market ready beginning 2017.

KPIs:

- Increase of biogas yield of alternative energy crops by 20-30%.
- Increase in the efficiency of biogas up-grading to a power consumption of Ø 0.15 kWh/Nm^3.
- Cost reduction of biogas upgrading by 10-20%.
- Part load operability of biogas CHP units greater than 40%.
- Use of 'waste heat' from CHP units at 80% of all European biogas plants bringing almost 14 million tons in GHG savings by 2020.

Costs: EUR 40 million (50% public, 50% private funding).

Timeline: 2014 - 2020.

Modality of implementation: National and European level.

Action 3: Development of cost and energy efficient, environmentally friendly micro and small scale CHP

Scope: This action addresses component and system development for micro and small scale CHP technologies in order to improve efficiency and performance and to reduce maintenance costs, prepare for serial production and integrate the use of a wider range of biomass feedstock.

Deliverables:

- Cost reduction (including maintenance) by technical optimization with consideration of serial production.
- Integration in smart houses and smart grids.
- Development of efficient storage systems (electricity, heat) to avoid grid losses.
- Use of a wider range of biomass feedstock.

Expected impact:

- Flexible bio-electricity and thermal energy supply with high electric system efficiencies.
- Contribution to electrification of the EU energy system and decentralized electricity production in smart grids.
- Reduction of electricity production costs by decreasing investment and maintenance costs, increasing electric efficiency and availability, and energy efficient and cost effective storage systems.
- High contribution to the reduction of emissions.

KPIs:

- 50% reduction of electricity production costs by 2020 through a technology specific mix of decreased investment and maintenance costs, increased efficiency and availability, energy and cost efficient storage, and reduced price for end consumer with instantaneous use.
- Reduction in investment costs to 10 EUR/W on solid state technologies and 3,5 EUR/W on thermodynamic cycle technologies.
- Reduction of emissions to 10% of emissions specified in EN303-5 (except for NOx).

Costs: EUR 125 million (50% public, 50% private funding).

Timeline: 2014 - 2017.

Modality of implementation: Member State, European level.

Action 4: Development of high efficient large-scale or industrial steam CHP with enhanced availability and increased high temperature heat potential (up to 600°C)

Scope: This action focuses on maintaining high operational electrical efficiency - close to nominal - for variable feedstock and/or variable load in large scale industrial CHP units. The steam parameters and/or heat medium temperature should be increased, new ash utilization options identified and catalyst deactivation issues and PM emissions in flue gas cleaning systems addressed.

Deliverables:

- The development of materials, corrosion control processes, novel ash utilization options, improving the knowledge of components and corrosion.
- Increase the fuel flexibility for large-scale combustion / co-firing / gasification processes to be able to use more complex and low cost biomass fuel (e.g. agrobiomass and waste recovered fuels/sludges).
- Optimization of boiler design / placement of heat exchange surfaces / cleaning techniques.
- Lab-scale and pilot testing of co-firing matrices and material solutions for biofuels for example steam coil in SH at elevated admission data in existing plants.

Expected impact:

- Reduction of bioenergy production and investment costs through the use of cheaper fuels and high-efficient conversion to bioenergy, plus implementation of simple concepts.
- Increased energy generation from (scarce/limited) renewable fuels and more efficient utilization of renewable sources.
- Minimization of environmental impact of large-scale CHP units through reduction of emissions and identification of ash utilization pathways.

KPIs:

- Retrofit of existing CHP boilers:
  - Increase ash utilisation to 30%.
  - Emissions conformity with IED and increase in catalyst operating times.
  - A maximum of 10% reduction from the nominal level of operational electric efficiency.
  - Greater than 50% Agrofuels thermal share of fuel mixture of wood fired units.
- New CHP boilers:
  - Net nominal electric efficiency of 34% for clean wood boilers and 32% for wide fuel mix boilers.
  - Steam characteristics of 600°C / 175 bar (clean wood boilers) and 563°C / 160 bar (wide fuel mix boilers).
  - Increase of not more than 10% total capital expenditure over current state of the art for new technologies.
  - Increase ash utilisation to 30%.

Costs: EUR 130 million (50% public, 50% private funding).

Timeline: 2014 - 2017.

Modality of implementation: National and European level (cooperation RHC TP and EBTP).

Action 5: Development of high efficient biomass conversion systems for trigeneration/polygeneration

Scope: This action focuses on system development for trigeneration/polygenertation. The focus is on the operation of a hybrid electric/heating/cooling grid with the integration of cooling systems and distribution to CHP plants. It addresses the optimisation of plant design, and the identification of business models for two-way tri-generation and poly-generation energy networks. Polygeneration technologies balance daily and seasonal changes in solar and wind electricity and loads of boilers, increasing plant availability, peak load duration and economic performance.

Deliverables:

- Elaboration of cooling grid techniques/concepts: Distribution of heat and absorption cooling, and of cold media and direct cooling.
- Development of concepts for the operation of a hybrid electric/heating/cooling grid.
- Development of test beds for on-line monitoring and measurement techniques.
- Development of specific technologies to increase the flexibility of multi-fuel units.

Expected impact:

- Increase potential for CHP in particular in Middle and Southern Europe.
- High flexibility allowing change from electricity, heating, cooling, and bio-oil production (depending on conditions).
- Facilitation of a 100% renewable electricity market.
- Increased efficiency and reduced emissions.

KPIs:

- Achievement of an annual average efficiency of >90%Emissions (CO2, CO, NOx and SOx) reduced by half compared to condensing power production.
- Electricity production efficiencies of >30% (<10MWe) and >40% (<200MWe).

Costs: EUR 65 million (50% public, 50% private funding).

Timeline: 2014 - 2016.

Modality of implementation: Groups of Member States, EU level (cooperation RHC TP and EBTP).

INNOVATION AND MARKET-UPTAKE PROGRAMME

Action 1: Full-Scale Commercial Demonstrations of Bio-Oil in the heating sector

Scope: This action addresses the demonstration of bio-oil in the heating sector to replace heavy fuel oils and natural gas with good availability and safe operation for technical optimisation and economic evaluations.

Deliverables:

- Demonstration of fully commercial bio-oil production in heating appliances.
- Demonstration of pyrolysis oil quality control integrated with production plant.
- Demonstration of oil fractionation at pilot and pre-commercial scale (~10 – 1000 kg/h).
- Use of forest and agriculture residues and their blends to increase the fuel feedstock flexibility.

Expected impact:

- Decreased dependency on imported mineral oil and increased security of the energy supply.
- Emissions reductions of up to 90% compared to fossil fuels in heating appliances.
- High fuel flexibility allowing a wide variety of feedstocks to be processed in the pyrolysis phase. This brings reduced costs, enhanced storage and transportation properties and the possibility of better storage, transportation and emission control standards.
- Potential to create 14.000 jobs in Europe and North America by 2020.

KPIs:

- Full scale bio-oil production with plant availability > 6,500 h per annum.
- Physical upgraded bio-oil usage in small scale CHP and stationary engines demonstrated.
- Chemically upgraded bio-oil usage in micro-CHP and engines demonstrated (including small scale heating sector).

Costs: EUR 40 million (30% public, 70% private funding).

Timeline: 2016 - 2020.

Modality of implementation: EU level (cooperation RHC TP and EBTP).

Action 2: Demonstration of thermally treated biomass fuel to replace coal and other fossil fuels in CHP

Scope: This action addresses the full-scale semi-commercial demonstration of thermally treated biomass fuel to replace coal and other fossil fuels in CHP with good availability and safe operation. The action aims to optimize the feedstock selection (including increased flexibility), exploit possible by-product uses, ensure thermal energy efficiency, and handle health and safety risks.

Deliverables:

- Full-scale semi-commercial demonstration of thermally treated biomass fuels in large-scale heating and CHP applications.
- Development of specific blends for thermally treated biomass suitable for different raw materials and conversion technologies of different scales.
- Pelletizing or briquetting of thermally treated feedstock.
- Introduction of standardised safety procedures.

Expected impact:

- Higher cofiring percentages due to high energy density and compatibility leading to decreased dependency on fossil fuels and greater security of energy supply.
- Improved behaviour in transport and storage, as well as more energy efficient upgrading processes leading to improved cost efficiencies in fuel and energy production.
- Enlarged raw material portfolio for bioenergy production in Europe.

KPIs:

- Increased co-firing potential of >50% commercial operation of biomass co-firing in coal CHP plants.
- Reduction of production costs by 5-10 €/MWh (1.4 – 2.8 €/GJ).
- 8.000 operational hours per year at full load.
- Overall efficiencies of >90% (based on net calorific value).
- Minimum share of 10% agrobiomass to increase raw material flexibility.
- 10-15% of annual production will fulfil quality requirements for large-scale outdoor storage.

- Trading volume of 1 to 2 million tons for thermally treated biomass in the EU.

Costs: EUR 40 million (30% public, 70% private funding).

Timeline: 2016 - 2020.

Modality of implementation: Member State, EU level (cooperation RHC TP and EBTP).

Action 3: Industrial demonstration and market up-take of cost and energy efficient, environmentally friendly micro and small scale CHP

Scope: This action addresses the demonstration of the long-term performance of operational prototypes of engines and turbines (20-50 kWe) to proof reliability and techno-economic performance in field operation of micro and small scale CHP technologies in order to reduce costs and prepare for serial production.

Deliverables:

- 10 demonstration units of cost and energy efficient, environmentally friendly micro and small scale CHP solutions utilising different technologies (e.g. thermoelectrics, Stirling engines, steam cycles, organic Rankine cycles (ORC), internal combustion engines (IC), micro gas turbines (MGT), and fuel cells (FC)), and using a wide range of biomass feedstock.
- Development of efficient storage systems (electricity, heat) to avoid grid losses.
- Integration in smart houses and smart grids.

Expected impact:

- Contribution to electrification of the EU energy system and decentralized electricity production in smart grids.
- Reduction of electricity production and end consumer costs by decreasing investment and maintenance costs, increasing electric efficiency and availability, energy efficient and cost effective storage systems.

KPIs:

- Reduction of electricity production costs by 50%.
- Proven lifetime of 20.000 h (<5 kWel) / 35.000 h / 50.000 h (>50 kWel).
- Reduction of investment costs to 10 EUR/W for solid state technologies.
- Reduction of investment costs to 3,5 EUR/W for thermodynamic cycle technologies.

Costs: EUR 225 million (30% public funding, 70% private funding).

Timeline: 2016 - 2020.

Modality of implementation: National and European level.

Action 4: Industrial demonstration and market up-take of high efficient large-scale or industrial steam CHP with enhanced availability and increased high temperature heat potential (up to 600°C)

Scope: This action addresses the need to maintain high operational efficiency by demonstrating retrofitting (in existing plants), long-term testing of fuels and materials for increased electrical efficiency, monitoring of efficiency and emissions behaviour, and development of control concepts (for both new and existing plants).

Deliverables:

- 3-4 demonstration units in existing CHP and/or co-firing plants.
- 3-4 demonstration units in new CHP and/or co-firing plants.

Expected impact:

- Significant contribution to renewable heat and electricity supply through large single units with reduced production costs through increased efficiencies and reduced fuel costs.
- Reduced consumer costs through cheaper fuels, high-efficient conversion to bioenergy, and simple concepts thus allowing for limited additional investment and short-term effectiveness to decrease GHG emissions.
- High reliability and flexibility for consumers through increased energy generation from (scarce/limited) renewable fuels and more efficient utilization of renewable sources.

KPIs:

- New CHP boilers:
  - Reduction of electricity production costs by at least 5% (clean wood boilers) and 9% (wide fuel mix boilers).
  - Emissions conformity with IED (with regards to PM emissions and increase in catalyst operating times for SCR.
  - Increase ash utilisation to 30%.
  - Increase of not more than 10% total capital expenditure over current state of the art for new technologies.
- Retrofit of existing CHP boilers:

- Increase ash utilisation to 30%.
- Emissions conformity with IED (with regards to PM emissions and increase in catalyst operating times for SCR.
- A maximum of 10% reduction from the nominal level of operational electric efficiency.
- Greater than 50% Agrofuels thermal share of fuel mixture of wood fired units.

Costs: EUR 30 million (existing units), EUR 600 million (new units) (30% public, 70% private funding).

Timeline: 2016 - 2020.

Modality of implementation: Member State, European level (cooperation RHC TP and EBTP).

Action 5: Demonstration and market up-take of high efficient biomass conversion systems for trigeneration/polygeneration at Medium to Large Scale

Scope: This action addresses trigeneration/polygeneration demonstration at medium scale (10 – 30 MW), municipal scale (concept demonstrations 51 – 100 MW with extended multifuel operational capability) and large scale (concepts for different climactic conditions reaching >80% operation capability) demonstration.

Deliverables:

- 2-4 medium-scale trigeneration/polygeneration demonstrations (utilising different feedstock, optimised for different climatic conditions in European countries).
- 2-4 municipal scale tri-generation concept demonstrations (utilising different feedstock, optimised for different climatic conditions in European countries).
- 2-3 large scale trigeneration/polygeneration demonstrations (utilising different feedstock, optimised for different climatic conditions in European countries).

Expected impact:

- Increase potential for CHP by increasing the heat and cold load of power plants.
- Facilitating 100% renewable electricity market.
- Fulfilling the requirements of the energy efficiency directive by doubling the total energy production efficiency (> 90% overall efficiency) compared to the dominant electricity generation based on condensing power production (around 40 %).

KPIs:

- Achievement of an annual average efficiency of >90%.
- Emissions (CO_2, CO, NO_x and SO_x) reduced by half compared to condensing power production.
- Electricity production efficiencies of >30% (<10MWe) and >40% (<200MWe).

Costs: Large Scale: EUR 360 million, Municipal Scale: EUR 360 million, Medium Scale: EUR 180 million (30% public, 70% private funding).

Timeline: 2016 - 2020.

Modality of implementation: Group of Member States and European level (cooperation RHC TP and EBTP).

Challenge 8: Hydropower

The sustainable, i.e. taking account of technical, economic, ecological and social constraints contribution of hydroelectricity to the EU-27's was estimated at 630 TWh, an 80% increase on the current annual generation (350 TWh). This new potential stems from new, greenfield installations; refurbishing existing power stations; and exploiting unconventional sites such as multipurpose projects, low-head sites, and sites with low potential.

KEY ISSUES

- There is room to increase the availability and productivity of hydropower equipment, for example by designs that tackle the following issues:
  - Large sediment loads, resulting in greater resistance in the materials in contact with the flowing water, reduce the availability of electromechanical equipment
  - Very variable hydrology, due to increasing variation in precipitation, discharge and head in run-of-river stations, make equipment to work at inefficient load level points.
  - The power density and efficiency of the generation unit can be improved by new designs that enable upgrades of plants without major new civil works.
- A significant, unexploited potential exists in small, non-conventional or multipurpose hydro plants such as irrigation dams or canal locks.
- The business case is not always clear, in particular for unconventional sites, and research is needed on the relevant environmental constraints and the resource potential.
- There is a need for solutions for local small size, low cost hydro for communities and towns.
- The time that it takes to obtain approval for a new project is too long, thus increasing development costs.

ADVANCED RESEARCH PROGRAMME

Action 1: Virtual Test Rig

Scope: A virtual test rig is a computer running software that exposes different designs of electromechanical equipment (which may exist only as computer models) to simulated flows, stresses or other steady-state or transient conditions. In-depth studies of the flow phenomena most relevant for instability, pressure pulsations and cavitation, which impede operation at low loads must be carried out and the results applied in designs. Computational Fluid Dynamics (CFD) should be used to improve the hydraulic design process by exploring the effects of changes on efficiency, performance and output with particular regard to flow-induced vibrations and hydraulic and mechanic stability limits (especially of single-regulated Francis turbines and pump-turbines). New, validated or perfected Computer Aided Engineering (CAE) methods should be the result of this work.

Deliverables and KPIs:

- By 2020: CFD, Finite Element Methods, and models of the interactions between water and the turbine structure should yield reliable lifetime predictions for any load.
- By 2030: CFD successfully predicts flow (in)stability for any design (today: it makes errors having serious consequences in 30% of design cases where the design is thought to be close to creating instability).

Expected impact: -

Costs: 4 projects, EUR 3-5 million each, with public funding covering two thirds.

Timeline: 2014 - 2020.

Modality of implementation: national or regional, as there is little scope for collaboration between manufacturers, implying that each will develop its own virtual test rig possibly in collaboration with the aerospace or automotive industries and turbo-machinery industry.

Action 2: Ventilation optimisation and electromagnetic design of generators

The aim is to increase the power per unit volume of power generators, for example to enable existing plants to be upgraded without civil works.

Scope:

- Create fast and accurate models, calculation and design methods for higher power density with emphasis on precision in ventilation, thermo-mechanical and electromagnetic modelling.
- Validate and fine-tune the models by comparing with experimental data.
- Identify relevant design parameters and test them. Develop new design rules for high-performance generators to achieve higher efficiency.

Deliverables and KPIs: CFD for generator ventilation (heat dissipation) and 3D Finite Element analysis for electromagnetic calculation with higher accuracy and with half of today's computer power or time by 2020 (10% by 2030). The benchmark to monitor is the number of differential equations solved per second which can increase with hardware or software improvements.

Expected impact: -

Costs: 2 projects, EUR 5-10 million each with public funding covering two thirds.

Timeline: 2014 - 2020.

Modality of implementation: indicatively, two projects would be necessary in the EU, funded with EU money. The consortia would be pan-European, including manufacturers, software developers, universities and plant operators.

Action 3: Achieving the most environment-friendly hydro plant deployment possible for maximal social acceptance

Scope: Improvements addressable by the hydro equipment industry are:

- Water quality: use of biodegradable oils and avoiding use of oil and grease altogether.
- Fish survival: establish correlation between design parameters and fish survival for use in predictive modelling.

Deliverables and KPIs:

- 2020: 60% of new turbines will by 2020 be lubricated by water only (by 2030, 100%).
- Perfect control of oxygen content in tail water by 2020.
- 90% or better fish survival: build a European test rig for fish friendliness.

Expected impact: -

Costs:

- EUR 0.5-1 million per year to 2020 for materials identification and 1-2 per water-lubrication demo project (3 demo project).
- By 2018 the fish test rig should be built to check the effectiveness of turbine designs against computer models. The test rig should measure hydro equipment for fish friendliness at 1:20 scale. The likely cost is EUR 10 million and the capital costs should be covered entirely by the public sector, via, for example, the department of a university.

Timeline: 2014 - 2020.

Modality of implementation: National and European. funding is preferred for the fish friendliness test rig as it should be a piece of research infrastructure hosted at a neutral site accessible to all manufacturers.

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Systems for optimised maintenance intervals

Scope: Apply new lifetime prediction methods to assess the impact of operation mode on the lifetime of the core components of a hydro plant, like the turbine runner or regulation elements.

- Develop new online monitoring and diagnostic systems which predict the optimal maintenance interval based on the way of operation. Similar systems are used in the aerospace and automotive industries and in the turbo machinery field (e.g. gas turbines, compressors). The aim is to enhance these systems towards better predictability of operational impact on equipment condition and equipment life.
- Collaborate with utilities to build prototype monitoring systems and install them at plants.
- Integrate into plant SCADA.
- Maintenance intervals and lifetime are also affected by the choice of material (like coating) used for different hydro equipment components. Improvements in the properties of materials are possible (see, for example, above – sediment loads) and require research.
- Monitoring techniques that isolate the effect of materials on lifetime need to be developed.

Deliverables and KPIs:

- Monitoring systems for optimised maintenance intervals have reduced outage time by 10% (2020), (20% in 2025).

Expected impact: -

Costs: EUR 2-5 million per project/year, with public funding covering half (4 projects).

Timeline: 2014 - 2020.

Modality of implementation: This action could involve a great many different actors from different parts of the value chain quite possibly from in different countries. The optimisation of maintenance intervals is very complex and also requires the knowledge and experience of operators, combined with the core proprietary knowledge of hydro equipment manufacturers. This shall be done for different types of power stations (storage, run-of-river, high/low heads). Four projects are necessary in the EU.

INNOVATIVE AND MARKET-UPTAKE PROGRAMME

The expected budget for each of these Actions is of the order of a few hundred thousand euros.

Action 1: Establish business case for balancing services from hydro

Scope: Modelling and analysis to develop relevant business models. The main objective of the activity should be to investigate the potential of storage and how the service of large-scale balancing by hydropower may be valorised.

Deliverables and KPIs:

- A recommendation from the sector on hydropower's treatment in aid schemes for generation adequacy, and more generally on the features needed of ancillary services markets to optimally extract value from hydropower projects.

Expected impact: -

Costs: -

Timeline: 2014 - 2016.

Modality of implementation: Collaborative between hydro equipment customers (utilities); European-level funding.

Action 2: Environmental impact assessment

Scope: Methods and models for environmental impact assessments. New hydropower operations will lead to changes in the yearly, seasonal, and daily fluctuations in reservoir water levels, and may also affect downstream water bodies. But the extent to which they do affect the bodies is poorly understood, therefore the safe limits of impact may also be over-cautious or insufficiently cautious.

Deliverables and KPIs:

- New guidance on the relevant quantities to measure when performing an EIA on hydropower projects and on safety limits.

Expected impact: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: Collaborative between manufacturers and NGOs; European-level funding.

Action 3: Confirmation of the resource

Scope: The ICOLD database, covering dams of heights >15 m has been used to estimate that 23% of dams in the range 100 to 1 000 billion m have not been equipped with hydropower generation capability[7], but this data is from 2007 and may need to be revised, or at least analysed in greater detail. DG JRC has assessed the European potential for pumped hydropower energy storage[8]. Similar work for the hydropower resource would be welcome.

Compilation of best practice examples in dam construction to enable more greenfield sites to be utilized.

Deliverables and KPIs:

- Precise understanding of the potential of existing dams in EU and outside, followed by marketing campaign to utilise that potential based on a clear understanding of the views of all competent authorities (spatial planning, permit granting bodies, …) and other stakeholders.

Expected impact: -

Costs: -

Timeline: 2014 - 2016.

Modality of implementation: Collaborative between manufacturers and utilities; European-level funding.

---

[7] HEA Technology Roadmap 2013

[8] Report: https://setis.ec.europa.eu/newsroom-items-folder/jrc-report-european-potential-pumped-hydropower-energy-storage

HEADING 2: Ensuring Energy System Integration

Challenge 1: Energy Grids

KEY ISSUES:

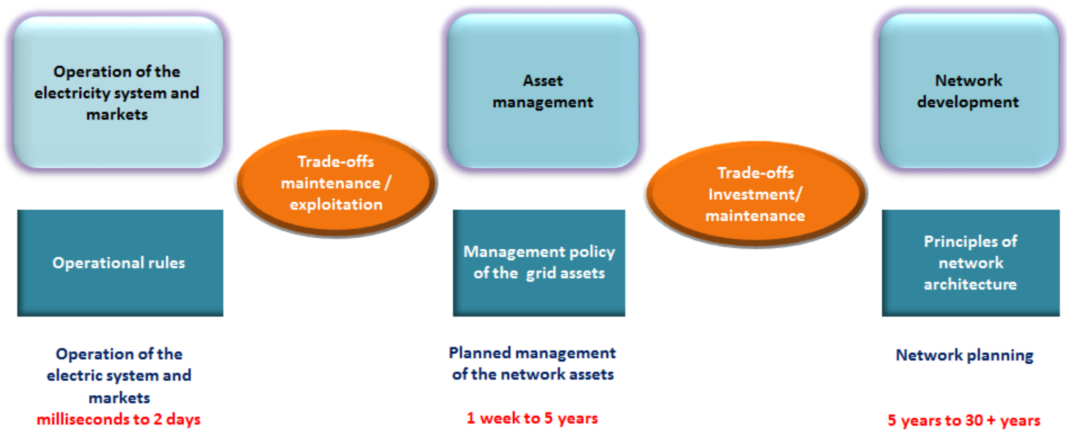
- To increase the overall competitiveness of the electricity market, delivering efficient business cases for market players (generator, supplier, consumer, aggregator, storage operator, etc.), exploiting new services emerging from a more efficient coordination between DSO and TSO grid based services, and maintaining security of supply and high power quality for customers, thanks to a combination of:
  - **Technology-based solutions** which enable system integration of an increasing amount of local and remote renewable sources in combination with appropriate deployment of EV/PHEV, storage solutions, flexible back-up generation and virtual power plants.
  - **Market-based solutions** (electricity market frameworks, designs and products like ancillary services, balancing or demand side response) which enable the full exploitation of the flexibility potential provided by a wider range of energy options.
- To further optimise the whole energy system by enabling appropriate energy networks interplay at European level[9] (electric and gas, electric and transportation), thus covering grid planning, development and operation with the help of appropriate architecture developments, innovative planning methods and tools, and the massive use of Information and Communication Technologies.
- To improve the network capacity, controllability, interoperability, reliability and flexibility using demonstrated innovative network solutions along the whole electricity value chain (network expansion, refurbishment, maintenance and operations, including the establishment of system services at distribution level).
- To respond to network investment needs by the development and integration of novel technologies into electricity grids (ICT, power electronics, new conductors, superconducting cables, etc. and their associated supply chains viz. industrial logistics, maintenance, materials and manufacturing, recycling) in cooperation with European technology manufacturers, thus strengthening their cost competitiveness and industrial leadership.
- To speed-up the network innovation deployment across Europe by properly addressing non-technological issues such as skill development, sustainability of financing schemes, standardisation, environmental impacts, and public acceptance of grid infrastructures and ICT solutions, thus making the cost-benefits analysis coming from the scaling-up and replication studies of innovative solutions both attractive and reliable.
- harmonized energy use for fluctuating inputs (e.g. wind, converter gas) and variable (batch) process demand, on-site energy flow management (smart grids) represents added value information to be incorporated in the Energy Management System.

[9] The interlink issues of different energy networks is covered at local level in Part I of the roadmap (building) and in Part III (smart cities and districts)

- With a view to fully integrated technical solutions, the improvement of the grid infrastructure and the optimal connection should to be tackled in order to avoid instabilities that may affect to the processes.

Grid operators (transmission and distribution) must address R&D activities which simultaneously cover three very different time scales, typical of their three main functions (planning, maintenance and operations of the networks), thus leading sometimes to highly interacting objectives, with trade-offs which may impact all three time scales together.

GRID OPERATOR FUNCTIONS



The activities below are therefore highly interacting in terms of impact onto the whole electricity system. The table below describes each of the KPI impacted by the ARP activities.

Expected network improvement/ KPI$_i$		**Activity**	**Compliance with EU policy goals**			**TSO/DSO**	
			Sustain-ability	Market Competitive-ness	Security of supply	TSO	DSO
1	*Extended asset life time*	3,6,7			X	X	X
2	*Increased RES and DER hosting capacity*	2, 4, 5, 6	X	X	X	X	X
3	*Reduced energy curtailment of RES and DER*		X	X	X	X	X
4	*Increased flexibility from energy players*	1, 2, 4, 5, 6	X	X	X	X	X
5	*Increased quality of service and supply*			X	X	X	X
6	*Improved competitiveness of the electricity market*	5, 6		X		X	X
7	*Decreased network congestions*	1, 3, 4, 5, 6	X	X	X	X	

8	*Increased hosting capacity for Electric Vehicles and other new loads*	1, 2, 4, 6	X	X	X		X

Action 1: New methodologies to design grid architectures and plan transmission and distribution networks

Scope: Improved network planning tools are needed at transmission and distribution levels to account for new generation technologies based on renewables, new power technologies including electricity and thermal storage and network monitoring/control techniques, and active demand approaches. The novel planning methodologies combine:

- Incremental improvement of existing approaches dealing with regional clusters chosen by TSOs to address pan European issues in a tractable way, or complex districts as operated by DSOs. Cost benefit optimization of grid architectures involve appropriate network models and numerical simulations which cover production and consumption scenarios, different transmission/distribution technologies and, possibly, interactions with gas or heat networks as well as with distributed heating systems (heat pumps). In particular for distribution, technologies such as fast-reacting tap-change transformers, advanced breakers, synchronising re-closers (to reconnect islanded micro-grids) need to be considered in detail (the choices should then be selected by DSO's and their suppliers).
- Breakthrough planning approaches able to account for uncertainties affecting generation (spatial correlations affecting wind and solar generation as critical design variables which make architecture optimization becoming more stochastic), the increased use of power electronics (AC/DC converters, electronic interfaces of wind turbines, etc. reducing the inertia of the Pan-European Network and pushes to address its dynamic behaviour at planning level), and including defence plans to ensure an acceptable level of reliability for the electric system: it uses dynamic programming which aims at identifying a schedule for transmission or distribution additions along an extended planning horizon.
- Increasing public acceptance methodologies to develop transmission and distribution grid infrastructures, which involve new multidisciplinary approaches for the management of relationships and the consultation of stakeholders taking into account social dimensions (i.e. non technological or economical).

Deliverables:

- A concise, scientific approach to construct meaningful long term energy scenarios constraining the electricity networks in Europe, and leading to clear and reliable long-term goals to implement network development plans.
- Joint optimization techniques for network development able to identify the most cost-effective grid architectures, including the optimization of grid locations which take into account regulatory constraints to support cross-border system development.
- Electricity networks with reduced environmental impacts (EMF, visual impact, during construction)
- Acceleration of the permission and construction processes required to build new and/or refurbish existing network infrastructures.
- Innovative tower designs and conductors based on new materials (e.g., nano materials and composites).

Expected impact:

- A better and more effective utilisation of the growing infrastructures will be realised while increasing security of supply.
- Faster integration of RES will be possible as well.

KPIs: see table above.

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European and National.

Action 2: Research for electric grid compatible renewable and new user integration

Scope: Novel network topologies and interface conditions under which renewable electricity generation, power technologies, electricity storage and new electricity usages must be network-connected at high, medium and voltages:

- New transmission network topologies and interoperable power technologies optimizing the capacity and flexibility of both transmission and distribution networks.
  - For electricity transmission networks: AC and DC configurations, superconducting cables to integrate massive amount of distant renewable generation.
  - For electricity distribution networks: hosting increasing amounts of Distributed Energy Resources combined with the deployment of demand side management, EV/PHEV, heat pumps/thermal storage and Smart Homes/smart districts/smart cities, DC grids, Smart Power Electronics and control, industrial needs as final users for electricity transmission networks: AC and DC configurations, superconducting cables to integrate massive amount of distant renewable generation.
- Integration of power electronic controllable interfaces to serve the optimization of the electricity system in the presence of intermittent generation and controllable loads, (viz. load/generation/storage management, voltage control, active demand, etc.), thus paving the way for regulatory schemes showing a fair reward to the different stakeholders of the electric system.
- Interoperable power technologies to allow for new services at DSO level provided to TSO operations (local balancing, local markets, self-regulating and mostly self-organizing micro-grids).
- Smarter power system electronics using local grid intelligence and controllers to achieve wider regional/global system goals.

Deliverables:

- A flexible network integrating RES and helping to cope with demand.
- Increased overall system reliability and quality of service.
- Technical and economic feasibility of novel grid architectures.
- Load control provided by distributed resources allowing TSOs to improve on network planning and operations.

Expected impact:

- The integration of RES and new users will be facilitated.

KPIs: see table above.

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European and National.

Action 3: Research and development of novel tools for grid asset management in order to increase network flexibility and continuity of power supply

Scope: Current maintenance practices by grid operators involve periodic preventive actions, based on the average values of reliability performances for homogeneous families of components. This avoids taking into account either the real solicitations on the concerned equipment (which are more and more impacted by variable in-feeds coming from renewable generation), or the impact of an equipment failure which depends upon its geographical location in the network. Accounting for such parameters is another way to improve the overall electric system flexibility in order to host more intermittent electricity generation and/or controllable loads. Moreover, operation and network planners manage the network risk using a statistical approach of a full line. New tools are therefore needed to perform economic arbitrages between the three time horizons typical of any network operator. This in turn requires, amongst others:

- The development of a single framework to describe and simulate the aging laws of power components.
- the implementation of predictive maintenance approaches for both transmission and distribution networks.
- the validation of formal links between reliability levels of each electric network component and the reliability level of a full line.
- The coupling of such approaches with probabilistic security rules involving recent progresses in information science (data bases and data mining), applied mathematics (notably optimisation techniques) and technological component monitoring.
- Developing predictive analytic technics, dedicated to improve grid maintenance, in order to take advantage of new big data incoming from smart grid system.

Deliverables:

- Local health monitoring of power components involving wide coverage of climate/working conditions.
- Life span prediction models of existing power components using real-life data of existing equipment.
- Lifetime prediction models for new components.
- Methods and tools to optimize asset management using a risk-based approach at the system level, including interactions between equipment, impacts on security and quality of supply and also environmental and safety constraints.
- Tools for dynamic management of outage planning and maintenance schedules.
- Revisited maintenance rules with standards and interoperability of health monitoring system
- Fault predictive algorithms and models.

Expected impact:

- Optimisation of the operation and maintenance costs of the infrastructures.

KPIs: see table above.

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 4: Development of innovative tools for grid operations

Scope: Optimizing further the electric system capacity and flexibility can lean on improved operations from both TSOs and DSOS. TSOs deal every minute with the operational uncertainties of the pan-European transmission grid which requires TSOs to cope, among others, with balancing challenges, keeping voltages and frequency at appropriate levels, guaranteeing system security, restoration planning, and minimizing transmission losses. The pan European transmission network requires novel and shared tools in order to:

- Observe and control the pan-European network.
- Ensure coordinated operations at pan European level with stability margin evaluation, including risk-analysis based transmission system operation.
- Train operators in view of ensuring coordination at regional and pan-European levels
- Assess the pan-European network reliability.
- Develop further ICT tools e.g. sensors, controllers, telecommunication systems, real-time simulation, decision support tools, big data analysis systems, etc.

Distribution networks will benefit from joint development of novel tools in order to:

- Monitor and control low voltage networks by WAMS (Wide Area Measurement Systems), PMU (Phasor Measurement Units) towards distributed self-organized systems vs centrally controlled systems.
- Automate and control medium voltage networks, including the dynamic rating of lines, cables and components.
- Tools to manage the medium and low voltage networks including demand side approaches, under all possible system states (normal, critical, emergency, blackout) considering pre- and post-contingency actions, including risk-analysis based distribution system operation.
- Process Smart metering data and equipment.

Joint research and development of transmission and distribution operators are also supposed to:

- Increase the distribution grid observability for transmission network management and control.
- Help DSOs providing TSOs with ancillary services.
- Improve existing defence and restoration plans, Black start by distribution (Micro Grid) system capabilities and services in cooperation with connected users; with and without (temporary) connection to Medium-, High- and Extra-high voltage grid based systems.
- Support cross border approaches to operate power systems.
- Manage data as integral component of the entire process chain around Smart Power and Energy Systems which involves the capture of relevant data in real-time to make it available as a "big data".
- Integrate data semantically (information modelling) and adapt data/information exchange management techniques for this task.
- Place information in the "energy data cloud" and to develop analysis tools which offer dedicated support for the evaluation of such data.
- Handle big real-time data in the communication-constrained cloud and at the same time handling grid congestion constraints and market requirements.

Deliverables:

- Tools to provide improved potential for effective monitoring of the electricity system to take appropriate decisions regarding system operational planning and real-time operation.
- Validation of the role of corrective actions in network operations.

- Increased coordinated operations to maintain system stability and high-quality supply of energy to consumers.
- Coordinated defence and restoration plans based on methods which accounting for uncertainties.
- Common training tools and methods for network operators to facilitate system restoration.
- Increased network observability thanks to more accurate production and load analysis.
- Deployment of DER control centres, responding both to TSO and DSO constraints.
- Percentage reduction in time needed for awareness, localisation and isolation of grid fault (%).
- Reduction in energy not supplied from distributed energy resources in distribution network due to improved network conditions (MW).
- Potential for increased network hosting capacity for distributed energy resources in MV and LV distribution network (MW).
- Potential for increase in hosting capacity of EVs in MV and LV distribution network (MW).

Expected impact:

- Improvements of the grid operation; higher degrees of its utilisation, easier integration of distributed generation.

KPIs: see table above.

- Increased hosting capacity for electric vehicles (EVs) and other new loads.

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 5: Research and development of tools development to support new market designs at Pan-European and regional levels

Scope: A progressive harmonization of electricity market rules to provide increased market efficiency, with increased benefits to electricity customers and more business opportunities to generators and energy traders. TSO must therefore ensure that the objectives of the Third Internal Energy Market package are reached. Novel pan-European market solutions must be designed and developed in order to support:

- Ancillary/balancing services with active demand management and cross border trading *taking into account the intensive industry needs and demand.*
- Capacity allocation and congestion management.
- System adequacy and efficiency when integrating very large amounts of local energy sources, including RES generation.

Distribution System Operators need to develop market simulation tools to design proper recommendations in view of answering the following questions:

- How to trade electricity at energy and capacity (power) prices leading to minimum total energy cost for variable electricity production and capital costs for electric capacity investments.
- How to charge electricity grid use at regulated tariffs integrated with the capacity costs for reserve generation and the capacity flexibility of grid users including consumers.
- How to couple electricity and transport regulations (plug-in hybrid cars)?
- What are the types of Reliability- and quality of supply- based regulations to be deployed while harmonizing over European DSOs and TSOs?

- What are the safety, quality and market impacts induced by the large scale use of local energy sources (RES, DER)?
- What are the regulatory options able to best encourage the development of electricity energy storage and of distributed energy resources?
- What are the options for DER network interconnection standards (distributed generation and storage systems) and telecommunication system standards for DER control?
- Elaborating new model for network telecommunication infrastructure dedicated to DSO control system to fasten smart grid evolution.

Deliverables:

- Business models and frameworks for the pan-European grid improving the real-time market for balancing services.
- New congestion management rules that do not impact system reliability using flow-based market coupling and improving capacity calculations/risk assessment.
- Simulation toolbox to quantify the economic impact of multiple renewable integration routes based on the results of large-scale experiments.

Expected impact:

- Regional exchange will be improved significantly.

KPIs: see table above.

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 6: Research for methodologies and development of tools which enable scaling up and replicating the results of innovative demonstrations

Scope: Preparing for the market uptake of innovative grid solutions paradoxically raises several scientific and technical challenges to address the following issues when considering the results of innovative demonstrations designed to validate integration:

- What type of evolving network simulation tools are needed to be developed to support scaling-up studies of experimental demonstrations?
- What type of network simulation tools are needed to support replication studies of experimental demonstrations, once scaling-up results prove promising?
- Which are the studies related to minimum experimental data to be collected during demonstrations in order to point out the critical KPIs which will drive the scalability and replication potentials of demonstrations?
- Which are the studies related to numerical experiments can be designed and run in order to extract the critical relevant KPIs which drive scalability and replication performances?
- Which are the studies related to the acceptable level of uncertainty to be reached when using the tool box in order to claim that an innovative solution is scalable and/or replicable?
- Which are the studies related to sharing the resulting tools box and results while preserving confidentiality constraints of the involved stakeholders, with an emphasis on investigations related to the technology solutions involved in the demonstrations?

The above answers will come from research and development studies linked with existing or future large scale demonstrations. They are needed to specify costs and benefit studies as requested by regulatory authorities to validate the full scale deployment of innovative solutions tested or not in the control zone of interest for such regulators, including coverage of technical, economical and regulatory barriers.

Deliverables:

- Solutions to remove barriers against scaling up and replication of large scale demonstrations.
- Options to make the studied functionalities in large scale demonstrations evolve in view of improving their future scaling and replication potential.
- Cost/benefit methodologies able to appraise the scaling and replication issues of successful demonstrations.

Expected impact: -

KPIs:

- Increased network flexibility at affordable cost.
- Increased RES and DER hosting capacity.

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 7: Research and development of new materials for grid applications

Scope: A cross cutting approach to develop advanced materials for low carbon energy and energy efficiency applications has been underlined at EU level by EMIRI[i]. Grids technologies are indeed impacted with short term applications dealing with cables, lines and sensors, while medium-term priorities may cover areas such as high-temperature semiconductors, materials for high-power semiconductor-based systems. Specifications from grid operators are needed very early in the development of such advanced material solutions in order to anticipate grid integration constraints right from the early development stages but to cover grid environments over the next thirty years because of the very long lead time for novel material solutions to reach a reliable integration stage:

- New materials to extend asset life, durability and reduce total cost of ownership.
- New materials for extreme conditions to provide improvements in noise reduction, surface modification, performance, safety, sustainability.
- Surface treatment of existing materials to protect and improve performances.

These solutions will extend the life and performance of cables and electrical accessories.

Deliverables: -

Expected impact:

- Deploying new innovative materials solution will allow higher degree of performance of the infrastructures.

KPIs: see table above.

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

The table below describes each of the KPI impacted by the IRDP activities.

Expected network capacity improvement/KPI		Related R&I cluster(s)	Compliance with EU policy goals			TSO/DSO	
			Sustainability	Market competitiveness	Security of supply	TSO	DSO
1	*Extended asset life time*	3			X	X	X
2	*Increased RES and DER hosting capacity*	1, 2, 4, 5,6	X	X	X	X	X
3	*Reduced energy curtailment of RES and DER*		X	X	X	X	X
4	*Increased flexibility from energ players*	1, 2, 4, 5,6	X	X	X	X	X
5	*Increased quality of service an supply*			X	X	X	X
6	*Improved competitiveness of th electricity market*	5, 6		X		X	X
7	*Decreased network congestion*	3, 4, 5	X	X	X	X	
8	*Increased hosting capacity for Electric Vehicles and other new loads*	2, 4	X	X	X		X

Action 1: Demonstration of novel interoperable power technologies integrated into Electricity Grids

Scope: Current advances in power technologies provide transmission and distribution system operators with opportunities to implement new solutions to cope with future network development and operating challenges, including capacity, generation units and flexibility re-optimization. Yet, innovative technologies must be properly integrated into the existing infrastructure since offering a lot of often contradictory options:

- Power transfer capacity: HVDC and AC cable, AC/DC converter, multi-terminal and vendor-independent HVDC VSC, super-conducting cables, GIL and "low sag" conductors, HVDC circuit breakers, High capacity, new material cables (using superconductors, high capacity metal cables, HV cables and accessories to 1000kV, Materials for medium voltage smart electrical accessories).
- Equipment and methodologies to monitor conductor temperatures using nanotechnologies.
- Power control devices: FACTS, phase-shifting transformers (PST), flexible generating units, HVDC back-to-back.
- Network monitoring technologies (PMU, WAMS, RTTR, Smart Meter, RTTR, etc.).
- Network control technologies (PDC, WACS, WAPS, smart substations, etc.).

- Novel grid architectures (HVDC meshed grids, mixed AC/DC grids, etc.).

These technologies have their own learning curves and innovation cycles. Their performance when network integrated can be predicted using simulation tools and network models requiring network-connected demonstrations in order to validate their performance and to specify real-life implementation procedures. This leads to final product specifications and product implementation plans as well as new network management rules, thanks to a close cooperation between network operators and manufacturers. Benefits of interest encompass the definition of a reliable and stable backbone to support the internal European electricity markets, the interoperability of power technologies with the existing power systems, new operating practices, reliable and cost-effective cross-border connections leading to increased security of supply in the pan-European power energy system, data validation for future scaling-up and replication studies of innovative network configurations at EU level.

Deliverables:

- Conclusions and lessons learned from demonstration project.
- Evaluated project KPIs.
- Identification of barriers to scaling-up and replication of the solutions being demonstrated.
- Disseminate and share knowledge gained.

Expected impact:

- Better utilisation of the energy infrastructures; allowing further smartisation of the grid and energy unit cost reduction.

KPIs: see table above.

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European and National.

Action 2: Demonstration of the grid integration of renewable generation, electricity storage and new users

Scope: RES integration challenges security of supply and the economic efficiency of the whole electricity value chain: increasing wind and PV gradients require increased reserves to maintain system stability, high system margins on power reserves and standby production, or curtailment of wind or PV production and ultimately higher costs for the security of supply as well as for the end-users. This is why integration demonstration requires grid operator management since requiring innovation at grid level as well.

New approaches include frequency and voltage control with RES using virtual power plant (VPP), electricity storage or Active Demand (AD) measures providing domestic, commercial and industrial consumers with information on their consumption and the ability to modify their consumption in response to time-based prices or other types of incentives (this relates also to Citizen engagement, capacity building, governance and communication for energy efficiency described in Part 1, Heading 6). The use of thermal storage in heat pump systems must be included for its demand side management potential. For this to work, information from the grid must be provided via standardized interfaces. Any of such approaches will require affordable ICT-based infrastructures, using the large scale integrated demonstrations of the above solutions, possibly coupled at both transmission and distribution levels, in order to validate on real networks and within several regulatory regimes how to optimize the electricity system across the value chain - from renewable power generation to new users and distributed demand side action. For instance, electricity storage systems, connected to the grid through power electronic controllable interfaces (that, inter alia, give the possibility to control active and reactive power flows) can facilitate the integration of highly variable renewable energy sources and diffuse demand response, easing network operations and energy management. Yet, the economic value of storage, the use of thermal storage /heat pumps, the hosting of EV/PHEV and the integration of highly variable renewable energy sources combined with flexible generation from RES (hydropower, biomass, geothermal, CSP) has to be demonstrated by comparison with available alternatives and subsequently embedded in the framework of new regulatory schemes allowing fair reward to the different stakeholders of the electric system.

Deliverables:

- Conclusions and lessons learned from demonstration project.
- Evaluated project KPIs.
- Identification of barriers to scaling-up and replication of the solutions being demonstrated.
- Disseminate and share knowledge gained.

Expected impact:

- Solutions to overcome barriers for up-scaling will be developed; best practices will be disseminated faster.

KPIs: see table above.

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European and National.

Action 3: Demonstration of novel grid asset management techniques

Scope: The implementation of novel integrated asset management approaches coming from the research activities must be demonstrated, first using a few types of critical pieces of equipment, for instance at substation level, and leading to scaling-up and replication of the results to be performed in several control zones. This will allow showing how to progressively move away from the past "normalized" implementation of power components, to design network components based on local future expected constraints coming from highly variable power flows, while validating new asset condition monitoring concepts of such primary and secondary components (using scheduled and conditional maintenance, embedded ICT to monitor individual assets, robotics for problem detection as well as to intervene in hostile environments and avoid the need for human maintenance, UAV to inspect overhead lines are tested to implement maintenance activities while having the network "on"). The quantified benefits include a further increase of network flexibility (implementing novel maintenance methodologies for new power technologies like HVDC links, AC/DC converters, underground cables, substations), a further understanding of the network working conditions which impacts most the ageing of critical components (using ex-post analysis of assets that have been removed from the grid), analysing the impacts of connecting storage, EV, DER and other devices to the distribution systems, and testing the role of corrective actions in network management (with a specific attention to islanding modes of operation). Demonstrating the scaling up and a replication potential of the demonstrated results will deliver:

- Approaches to determine and maximize the lifetime of critical power components for existing and future transmission networks while optimizing asset maintenance.
- Increased system flexibility coupling load control with asset management and operation.

- Reduced uncertainties in asset management strategies thanks to tools allowing for long-term (>20 years) asset management simulations.
- Mitigation strategies of climate change risks which clearly impacts the grid.

Deliverables:

- Conclusions and lessons learned from demonstration project.
- Evaluated project KPIs.
- Identification of barriers to scaling-up and replication of the solutions being demonstrated.
- Disseminate and share knowledge gained.

Expected impact: -

KPIs: see table above.

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European and National.

Action 4: Demonstration of tools for improved Grid operations

Scope: The existing electricity system capacity reserves are impacted today (and even more in the future) by variable energy sources, in particular the daily (inaccurate) forecasts of wind and sun electricity production: some TSOs have already adapted their reserve management approach. Yet, early research indicates that the current definition of primary, secondary and tertiary sources should be revisited. On the other hand, monitoring devices such as PMUs provide TSOs with new information and hence opportunities for very accurate online monitoring. The power energy system should then be operated using real-time measurements where look-ahead technologies enhance historical data currently in use. This requires the demonstration of new algorithms and methodologies developed in the research activities in order to handle and process huge amounts of data, as well as the implementation of human-machine interfaces to support decision-making in control centres in real time. Such demonstrations encompass:

- Innovative tools and methods:
  - to observe and control the pan-European multi-networks.
  - For coordinated operation with stability margin evaluation.
  - To ensure better coordination at the regional and pan-European levels.
  - To ensure better integration of different energy systems.
- Move towards partial balancing at regional (or even local) levels for pan-European multi-networks reliability assessment monitoring, automation and control of Low Voltage network and Medium Voltage network and distribution network management tools.
- Smart metering data processing, combining data from all energy networks.
- Increased observability of the distribution system for transmission network management and control, ancillary services provided through DSOs multi-networks and improved defence and restoration plans.

Deliverables:

- Conclusions and lessons learned from application of tools in demonstration project.
- Evaluated project KPIs.
- Disseminate and share knowledge gained.
- Pilot demonstration project on real subset of distribution network.

Expected impact:

- Best practices will be disseminated faster.

KPIs: see table above.

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European and National.

Action 5: Demonstration of novel tools to prepare recommendations for novel market designs

Scope: Market designs are needed to propose fair remunerations for the use of transmission or distribution capacity. They are also essential to fully integrate and exploit the benefits brought by RES, active demand or electricity storage to the electricity system. Moreover, regulations must make sure that transmission and distribution tariffs provide regulated companies with revenues that cover their operation and maintenance costs, yielding appropriate returns on investment to guarantee that electricity networks are able to reach a negotiated level of reliability. Market models and parent simulation tools are therefore needed to provide recommendations on specific rules for integrating local energy resources, including renewables, in power/energy systems, balancing and system services and therefore allow massive integration of local energy sources, including RES. Using the market simulation tools developed in the research activities, demonstrations encompass:

- Tools and market mechanisms for ensuring system adequacy and efficiency in electric energy systems integrating very large amounts of energy generation using local energy sources involving RES generation and incorporating the intensive industry demand (industrial parks design).
- Advanced pan-European multi-network market designs (and the associated tools) for ancillary services and balancing, including active demand management.
- Advanced tools for multi-network capacity allocation and electrical congestion management.
- New market designs for the secure, sustainable and cost effective integration of distribution multi-network users including:
  - Charging electricity costs with tariffs reflecting the marginal cost of electricity.
  - Reliability- and quality of supply- based regulations with an impact on DER deployment with harmonization over EU-27 for DSOs and TSOs.
  - Quality and safety market impacts induced by the large scale deployment of DER.
  - Regulation options for electricity storage and distributed energy resources.
  - Management of costs of ownership for DER units when contributing to system services.
  - Coupling of electricity and transport regulations (plug-in hybrid cars).
  - Development of standards for DER (distributed generation and storage systems) interconnection to the network and telecommunication systems for DER control.

Deliverables:

- Conclusions and lessons learned from application of tools and market mechanisms in demonstration project.
- Evaluated project KPIs.
- Disseminate and share knowledge gained.

Expected impact: -

KPIs: see table above.

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European and National.

Action 6: Demonstration of small generators upgraded for Network Code compliance

Scope: System operators require to establish evidence that generators are compatible with the requirements of their Grid Codes in order to be connected to the grid. Various types of generators can show Grid Code Compliance by defining assumptions which have to be implemented at generator level. Showing compliance with Grid Codes can be done by certification (GCC). As an example, the ENTSO-E Network Code due to be adopted in 2014 will change to demand fault ride-through capability from small generators like run-off river hydro plants, small wind turbines (expected to increase in the near future) in which low inertia bulb turbines are in operation. The consequences of non-fulfilment are at present unknown: yet, it could make it hard for plants to have their licences renewed or, worst-case scenario, that plants have to be taken offline. Solutions involving controlled power electronics must be developed both for existing and new generators. Full scale demonstrations of the resulting innovative solutions implemented on existing generators must be performed.

Deliverables:

- Conclusions and lessons learned from application of solutions in demonstration project.
- Evaluated project KPIs.
- Disseminate and share knowledge gained.

Expected impact:

- Minimise issues of connection for new distributed generation.

KPIs: see table above.

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European and National.

INNOVATION AND MARKET-UPTAKE PROGRAMME

Transmission and Distribution operators are regulated companies for which the value chain of services involves similar skills used in similar activities, even though their detailed legal obligations may differ from Member State to Member State. Market uptake of innovative solutions has therefore a special meaning for regulated grid operators: it is the large scale deployment of successfully demonstrated grid innovations involving scaling-up and replication studies of the outputs coming from research and demonstration projects. Such studies result in cost/benefit analysis which are debated with the regulators since addressing:

- The economic risk of deployment is not under control, even though the technical risk appears mastered (lack of economic scaling).
- The regulatory environment, which may be favourable to deploy innovations in one regulation area (economic scaling is then managed), but may no longer be favourable in another regulation area (lack of replication potential).

The scaling-up and replication studies thus appraise the economic risk of deployment which should remain acceptable both for regulated and free-market players.

Action 1: Modular development plans of the pan European transmission system based on new planning and grid architectures

Scope: ENTSO-E releases the Ten-Year Network Development Plan (TYNDP) intended as an input for the NREAPs (National Renewable Energy Action Plans) energy targets set by the Member States for 2020. On 19 October 2011, the European Commission (EC) unveiled its proposal for a Regulation on "Guidelines for trans-European energy infrastructure". Overall, it can be assumed that, by early 2015, ENTSO-E will be in a position to comply with the decisions of the European Council of February 4th 2011, viz. completing the internal electricity market, proposing the development of transmission infrastructures to achieve the 2020 energy targets and developing critical network codes. The new simulation methods developed in the research activities allow proposing pan-European grids expansion long term (2050) scenarios in line with the post-2020 targets. They are aligned with the scenarios in the System Outlook and Adequacy Forecast[10], Ten Year Network Development Plans[11], e-Highway2050[12], and Energy Roadmap 2050[13]. The modular long term planning roadmap, following up the ARP Action 1, then implements the following steps:

- Approaches to generate different energy generation and consumption scenarios, set on the basis of macro-economic data, the energy adequacy between generation and consumption being ensured whatever the scenario studied.
- Power localization scenarios, using the assumptions about the generation mix and consumption for each Member State and the account of stochastic inputs (like renewable generation, uncontrollable consumption or failure modes of generation units) with their temporal and spatial correlations, whereas power adequacy between generation and consumption should be ensured probabilistically.
- Market and network simulation techniques to identify feasible Pan European grid architectures under each of the above chosen scenarios.
- Network implementation routes proposed on the basis of cost/benefit analyses, of appropriate wider socio-economic considerations and of grid governance models able to address cross border power flows.
- A verification that the selected grid architecture options alleviate all critical issues (overloads, voltage and/or stability problems) while ensuring an acceptable level of system reliability , which in turn allows the studied architecture to become part of the final modular deployment plan over 2020 to 2050.

Deliverables:

- A concise and scientific approach is available to construct meaningful long term energy scenarios in Europe.
- Pan-European energy scenarios available for all stakeholders.
- Investment signals for energy generation and load centres.

---

[10] www.entsoe.eu

[11] www.entsoe.eu

[12] e-Highway2050 project website

[13] http://ec.europa.eu/energy/energy2020/roadmap/index_en.htm

Expected impact: -

KPIs:

- Increased network capacity at affordable cost.
- Improved competitiveness of the electricity market.

Costs: -

Timeline: 2016 - 2019.

Modality of implementation: European.

Action 2: Scaling up and replication platform to support the market uptake on innovative grid operation and electricity market solutions

Scope: Scaling up and replication of innovative grid operation and electricity market solutions are investigated extensively to reach an acceptable level of confidence within manageable risks. It uses undisputable simulation tools located on a platform validated in the research activities with the help of large scale experiments under several regulatory regimes in order to deliver cost benefits analysis of innovative smart network solutions to regulatory authorities. This simulation platform must be able:

- To investigate the risk levels of proposed demonstration studies.
- To assess the experimental data requirements needed to investigate the scaling-up and replication potentials of solutions.
- To mimic the network behaviour using the demonstrated innovative solutions.
- To provide detailed cost/benefit analysis of the power and IT solutions needed to deploy the demonstration results at large scale.

Deliverables:

- Barriers of scaling-up and replication.
- Simulation software tool for scaling up and replication studies including cost/benefit analysis.

Expected impact:

- Boost competitiveness.

KPIs:

- Improved competitiveness of the electricity market.

Costs: -

Timeline: 2015 - 2018.

Modality of implementation: European.

Action 3: Interoperability of standards for data and knowledge exchange

Scope: The exchange of data and knowledge about demonstration results for grids requires tools, processes and guidelines to ensure that such exchange is scalable and can be replicated. A common framework for interoperability (communication protocols, information models, semantic models, connection requirements, etc.) in the field of Smart Grids has been requested by the European Commission on 1st of March 2011, through the Mandate M/490. In this respect, interoperability between various standard protocols (e.g. IEC 61968 DMS; IEC 61850-7-420 DER, IEC 61970 EMS, IEC TS 62351 Security) requires further study. The efforts in this action should be focussed on:

- To define open standard data models that ensure interoperability between different data exchange protocols for smart grid applications and to increase competitiveness.
- To analyse data exchange protocols that reinforce interoperability constraints at the pan-European level with an adequate level of security.
- To strengthen knowledge sharing in the domain of data management and data exchange between different actors of the power system (transmission system operators, distribution system operators, generation companies, thermal storage/heat pumps, etc.).

Deliverables:

- Gaps in standards to accelerate validation phase of innovation technologies and solutions.
- open standard data models that ensure interoperability between different data exchange protocols for smart grid applications and to increase competitiveness.

Expected impact:

- Boost standardisation for interoperability standards.

KPIs:

- Reduced development costs for manufacturers.

Costs: -

Timeline: 2015 - 2020.

Modality of implementation: European.

Action 4: Improved awareness and acceptance by the public of new grid infrastructures and electricity metering use

Scope: Current public consultation processes must be revisited both to better appraise and to understand the reasons why the general public is reluctant to accept electricity infrastructure investments. Using the results of research activities, new ways and means are needed to address such concerns while increasing public awareness about future long-term energy challenges. New approaches must be implemented in order to develop and/or to update European guidelines on good practices in transparency, public engagement and permitting process (including new construction guidelines of overhead power lines with reduced visual, audible noise, electromagnetic field, sag and environmental impact across the whole Europe).

Deliverables:

- Toolkit to obtain public acceptance for building grid infrastructures.
- Lessons learnt how to involve public and stakeholders in realising grid infrastructures.

Expected impact:

- Improved public perception and facilitation of acceptance for energy infrastructures.

KPIs:

- Reduced negative environmental impacts of infrastructure (EMF, visual impact, during construction).
- Acceleration of the permission and construction processes required to build new infrastructure. and/or refurbish existing infrastructure.

Costs: -

Timeline: 2015 - 2018.

Modality of implementation: European.

Action 5: Increasing stakeholder acceptance of novel energy market designs and products

Scope: it is necessary to investigate how to involve different customers and stakeholders in deploying smart grid solution, actively participating in market and providing services for system operations. Best practices to increase stakeholder awareness and engagement, overcome the privacy issue is investigated to fasten full-scale rollout of smart grids and the use of new electricity metering (smart meters) or new market products such as active demand. The deployment of new technologies involves some level of risk which must be minimized, analysed and addressed jointly by stakeholders; technology risks can be best addressed by the technology providers and system operators, while policy and market risks must be considered with the support of regulators and with the help of customer involvement.

Deliverables:

- Toolkit to increase stakeholder acceptance of novel energy market designs and products.

Expected impact:

- Improve information sharing.

KPIs:

- Increased awareness and acceptance of customers and stakeholders towards new energy market products.

Costs: -

Timeline: 2016 - 2019.

Modality of implementation: European.

Action 6: Training tools and workforce certification at EU level

Scope: Simulator/training facilities for network operators of the pan European transmission must evolve with several options induced by the electricity system evolutions. First, the power system is operated closer to its physical limits than today. Secondly, in case of contingencies, interactions between operators and the various control systems become critical and new competence is needed. System simulators must then train operators at gaining knowledge on the operation of disturbed interconnected systems in general. Overall, such a training must be able to deliver pre-defined levels of new knowledge to address pan-European power system issues. Dispatching training becomes a mature technology where transient, mid and long term phenomena can be simulated in real time for training purposes, while being extended for testing purposes such as the design and optimization of restoration procedures, management procedures to address emergency conditions and scenarios. Future common training activities must enable at a pan European level which is also available to other operators such as the power plant operators and the distribution network operators to improve grid/plant and grid/distribution network interfaces.

Deliverables:

- Training facilities for grid operators and power plant operators.
- Certification system for grid operators.

Expected impact:

- Improve training schemes at EU level and develop a more dedicated certification framework.

KPIs:

- Increased expertise and skills of the network operating workforce.

- Minimized human risks in handling complex network operations.

Costs: -

Timeline: 2016 - 2018.

Modality of implementation: European.

Challenge 2: Storage (Heat and Cold, Electricity, Power to Gas or other energy Vectors)

The storage challenge considers the diversity of energy storage in the most neutral way possible. It shall be applicable to all energy storage technology classes: Chemical, Electrical, Electrochemical, Mechanical and Thermal.

KEY ISSUES

- Solution value chain performance/cost competitiveness demonstrating the full benefits of cost competitive storage solutions. These are able to address small/dispersed, fixed and movable needs connected to local energy distribution networks (heat, cold, electricity) and large/centralised needs connected to pan European electricity and gas transmission networks (via a full life cycle optimisation taking into account environmental impacts of the innovative solutions explicitly), thus including power to gas options as well as the use of heat pumps.
- System integration (smart interfaces, management modes, new or improved services to system) to integrate storage solutions into the European energy (heat, electricity, gas) grids, using interfaces which allow energy management, and thus increase the overall flexibility of the energy systems at local or global levels.
- Supply chains (industrial logistics, maintenance, materials and manufacturing, recycling to reinforce the storage technology supply chains (key material provision, manufacturing, industrial logistics to install and maintain, recycling at end of life) in response to network investments in order to improve the technology cost competitiveness and strengthen the European industrial leadership.
- Non technological aspects (market framework, business model, spatial planning, harmonisation of standards, financing, skills and capacities) to develop promising regulatory schemes, market frameworks and commercial products for storage solutions which maximise their flexibility potential and, in turn, increase the overall competitiveness of energy markets by recommending efficient business cases for all market players (generators, aggregators, storage operators, network operators, etc.).
- Societal issues (environment impact, safety, health, social acceptance) to address the non-technological aspects of storage development by taking care of the operational safety, health and environmental impacts, public acceptance of storage solutions thus making the cost-benefits analysis coming from the scaling-up and replication studies of validated storage solutions reliable enough to speed up their deployment process across Europe.

ADVANCED RESEARCH PROGRAMME

Action 1: Enhanced Storage materials

Scope: Energy storage involves a whole range of materials, ranging from high temperature steel for thermal or compressed air storage, electrolytes for flow batteries and new nanostructured materials, such as graphene, to main stream pairs or next generation Lithium Ion electrodes. Currently only a very limited set of the possible materials has been applied in specific technologies, while others remain subject of basic research. Any promising storage material identified here shall be further researched in actions 2/3 for targeted storage development.

In this regard two actions are required:

- Scan the set of available storage material for use in novel technologies of any kind.
- Stimulate research in materials with improved performance / features in comparison to the ones currently used for existing storage technologies.

Deliverables and KPIs:

- List of materials to be considered for next generation storage technologies.

Expected impact:

- Research storage materials for improved new storage technologies including all variants such as electrical, thermal, electrochemical, chemical or mechanical storage.

Costs: 3%.

Timeline: 2014 - 2020.

Modality of implementation: -

Technology Readiness: TRL 0-2.

Action 2: New Technologies for Next Generation Central and De-central Storage Technologies of any scale

Scope: Especially for electrochemical storage new materials have emerged over the past years. In spite of their advantageous characteristics for next generation storage concepts, only lab scale experience has been gained with these materials so far. Consequently the findings of basic research need to be transformed into novel storage concepts, which have to be further developed and ultimately brought to industries and markets.

Deliverables and KPIs:

- Reliably completed technology data sheet defining the technical and economic target data for this particular technology such as efficiency, gravimetric/volumetric density of power/energy, expected CAPEX.

Expected impact:

Develop new technologies up to being able to realistically determine possible ranges for KPIs CAPEX, OPEX, efficiency, lifetime, etc. This applies for novel technologies such as LiS, ZnAir, new energy storage concepts using hydraulic equipment to convert energy into potential energy, etc.

Costs: 11.5%.

Timeline: 2014 - 2020.

Modality of implementation: -

Technology Readiness: TRL 2-4.

Action 3: Improved second generation technologies for Next Generation Central and Decentral Storage Technologies of any scale

Scope: Some already been deployed storage technologies are not fully developed according to their technical potentials. This is the case for the widely applied pumped hydro power plants, which are only rarely equipped with variable speed drives in Europe. Similarly Compressed Air Storage Technology (adiabatic as well as diabatic) can be further developed and also Lithium Ion Batteries have potential could be further improved at cell level. Also new technical features shall be considered such as hiding a sensible thermal storage unit underground or the development of very low-head turbines or the deployment of small to large pumped hydro in unconventional sites (e.g. lagoon plants).

Deliverables and KPIs:

- Provide a certain improvement >5% for a selected cost or technical parameter of the technology key data (e.g. Li Ion at costs < 150€/kWh and capacities of 300-400 Wh/kg, sensible thermal storage at lower costs or prolonged life of Pumped Hydroelectric Storage (PHS) pump turbines due to reduced cavitation).

Expected impact:

- Better economic features (e.g. lower CAPEX) and improved technical performance (e.g. higher lifetime, or higher flexibility) compared to the state of the art.

Costs: 11.5%.

Timeline: 2014 - 2020.

Modality of implementation: -

Technology Readiness: TRL 2-6[14] .

Action 4: Storage System interfaces

Scope: As storage will rarely be operated as standalone device it must be properly connected to and fit into the energy system. This comprises local control of residential storage, proper integration into a smart energy environment and if aggregation is possible also to the Supervisory Control and Data Acquisition (SCADA) system of the grid operator. All comprises Information and Communication Technologies (ICT), which need proper handling.

Deliverables and KPIs:

- Exhaustive and verified set of preferable ICT-channels and parameter set for Smart Energy interfacing as a list of chores for standardisation.

Expected impact:

- Determine the common set of technical features and parameters of storage, which must be controlled by an overarching control system. This includes aggregation processes as well as ICT standards.

Costs: 3%.

Timeline: 2014 - 2020.

Modality of implementation: -

Technical Readiness: TRL 2-7.

[14] In spite of the preceding technology generation may have considerably higher TRL-levels

Energy Storage Technology KPIs:

	Technology	KPI	Unit	2014	2020
Electrical	Super Caps incl. LV Connection	CAPEX Converter	[€/kW]	1100-2000	300
		CAPEX Reservoir	[€/kWh]		3000
		Efficiency	[%]	95	95
		Standby loss			
		Lifetime	[a]/[cycles]	5/10000 - 15/ 500000	
	SMES	CAPEX Converter	[€/kW]	600	300
		CAPEX Reservoir	[€/kWh]	2500	
		Efficiency	[%]	80-98	
		Standby loss	[% p. hour]	0.4-0.6	
		Lifetime	[a]/[cycles]	20-40 /500000	
Electro Chemical	DC Connected Lithium Ion (E-Mobility)	CAPEX Converter	[€/kW]		20
		CAPEX Reservoir	[€/kWh]		150
		Efficiency	[%]	90-95	95
		Standby loss	[% p. month]	2-5	better
		Lifetime	[a]/[cycles]	3-20 / 5000-10000	20 / 10000
		Gravimetric Energy Density	[Wh/kg]		300-400
	MV connected Lithium Ion	CAPEX Converter	[€/kW]	175	170
		CAPEX Reservoir	[€/kWh]	700-1300	277
		Efficiency	[%]	87-93	95
		Standby loss	[% p. month]	2-5	better
		Lifetime	[a]/[cycles]	3-20 / 5000-10000	20 / 10000
	LV Connected Lithium Ion	CAPEX Converter	[€/kW]	100	95
		CAPEX Reservoir	[€/kWh]	700-1300	277
		Efficiency	[%]	87-93	95
		Standby loss	[% p. month]	2-5	better
		Lifetime	[a]/[cycles]	3-20 / 5000-10000	20 / 10000
	Resdential Lithium Ion	CAPEX Converter	[€/kW]	200	180
		CAPEX Reservoir	[€/kWh]	1800	550

		Efficiency	[%]	87-93	95
		Standby loss	[% p. month]	2-5	better
		Lifetime	[a]/[cycles]	3-20 / 5000-10000	20 / 10000
	LV Connected Lead Acid	CAPEX Converter	[€/kW]	135	130
		CAPEX Reservoir	[€/kWh]	90	90
		Efficiency	[%]	80	90
		Standby loss		0.01 %/d	0.07% /d
		Lifetime	[a]/[cycles]	1 / 1250	2 / 2700
	LV Connected Flow Batteries	CAPEX Converter	[€/kW]	150-1000	<250
		CAPEX Reservoir	[€/kWh]	550-650	120
		Efficiency	[%]	60	80
		Standby loss		n/a	n/a
		Lifetime	[a]/[cycles]	5 / 4500 - 20 / 10000	20 / >10000
	DC Conneceted Post Li-Ion (e.g. NaIon, NaS, LiS, ZnAir, Na–NiCl2)	CAPEX Converter	[€/kW]		
		CAPEX Reservoir	[€/kWh]		Cell: <350
		Efficiency	[%]		
		Standby loss			
		Lifetime	[a]/[cycles]		- / 3000
		Gravimetric Energy Density	[Wh/kg]		>500
Mechanical	Flywheel	CAPEX Converter	[€/kW]	1400	300
		CAPEX Reservoir	[€/kWh]	n.a.	n.a.
		Efficiency	[%]	70-95	95
		Standby loss	[% p.h]	7.5-20	7.5
		Lifetime	[a]/[cycles]	10-25 / 500000	
	Pumped Hydro	CAPEX Converter (Range over all sizes. incl civil cost, E&M (without financing costs). One reservoir existing, the other new.)	[€/kW]	650-1500	600-1400
		CAPEX Reservoir	[€/kWh]	150	130
		Efficiency	[%]	75	80
		Standby loss		n/a	n/a
		Lifetime	[a]/[cycles]	80 / -	80/ -

	A-CAES, cavern	CAPEX Converter and 4-h-Reservoir	[€/kW]	2000	1300
		CAPEX Reservoir	[€/kWh]	6	6
		Efficiency	[%]	65%	70%
		Standby loss		1% /d	0.5 %/d
		Lifetime	[a]/[cycles]	35 /-	35 / -
	D-CAES	CAPEX Converter and 4-h-Reservoir	[€/kW]	700	650
		CAPEX Reservoir	[€/kWh]	6	6
		Efficiency	[%]	52%	54%
		Standby loss		n/a	n/a
		Lifetime	[a]/[cycles]	30/ -	35/ -
Thermal	Sensible Heat Water Storage	CAPEX Converter	[€/kW]	n/a	n/a
		CAPEX 1000 l tank	[€]	400-900	300-700
		Efficiency	[%]		
		Standby loss	[W] acc. EN12897	150-200	56
		Cost to customer (excl VAT) of high performance insulation Thermal Resistance (Rc) = 7 m2•K/W)	[€/m^2]	300	<100
		Lifetime	[a]/[cycles]		
	PCM/TCM	CAPEX Converter	[€/kW]	n/a	n/a
		CAPEX Reservoir	[€/kg]	8	<2 (value for 2030)
		Efficiency	[%]		
		Standby loss			
		Lifetime	[a]/[cycles]		
	Underground TES	CAPEX Converter	[€/kW]		
		CAPEX Reservoir	[€/kg]		
		Efficiency	[%]	60	75
		Standby loss			
		Lifetime	[a]	10-25	20 -30
		Maintenance share of OPEX		4-8%	2-4%
	Common	Volumetric energy density		n/a	20% reduction

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Storage System Integration and Benefit Assessment via Simulation of System Embedding

Scope: The planning of complex energy systems requires state of the art models for grid flow, power generation and other energy subsectors.. It must be ensured that the European R&D community has a common understanding of how to describe the different storage technologies and to implement these into their standard models (e.g. oversimplification should be avoided in the description of Power to Gas and Pumped Hydro storage technologies in Pan-European scenarios).

Deliverables and KPIs:

- Number of relevant applications (e.g. time shift, reserve power, grid congestion relief) covered.

Expected impact:

- Availability of easy usable simulation and generally accepted tools to assess storage in an energy system (power, heat, natural gas) context.

Costs: 3%.

Timeline: 2014 - 2017.

Modality of implementation: -

Technical Readiness: TRL 7-8.

Action 2: Central and De-central Storage Technology Demonstration of any scale

Scope: Any theoretically derived storage concept from the advanced research and development programme must be cross checked for validity of technical and commercial parameters before entering mass deployment. This requires a number of demonstration actions.

Deliverables and KPIs:

- Verified technical and economical key data.

Expected impact:

- Availability of technologies ready for market uptake.

Costs: 17.5%.

Timeline: 2014 - 2020.

Modality of implementation: National and European.

Technical Readiness: TRL 6-7.

Action 3: Storage System integration Demonstration

Scope: In addition to being technically feasible and having a proof of concept, a storage system needs to be integrated into, e.g. a smart energy system, a home automation system or a SCADA system. This implies that also the supporting ICT concepts derived in the advanced R&D concept are demonstrated for the respective storage technologies in their final development stages and in real life applications.

Deliverables and KPIs:

- Number of successful projects.

Expected impact:

- Proven concept of integration into a hierarchical energy system, e.g. a smart grid environment for different storage technologies[15].

Costs: 17.5%.

Timeline: 2014 - 2020.

Modality of implementation: National and European.

Technical Readiness: TRL 7-8.

Action 4: Storage Manufacturing Processes

Scope: Many energy storage technologies are currently suffering from high CAPEX, which constitutes one of the economic barriers to wider deployment. This barrier can be overcome by improving both the technology as such and the manufacturing process. A specific technology must be produced as efficiently as possible. Once the market takes up, production processes can be switched from small lot manufactory assembly to large lot automated industrial production. The complexity involved in setting up a large scale industrial production process requires R&D actions.

Deliverables and KPIs:

- Percentage of reduced production cost due to new processes.

Expected impact:

Affordable energy storage, especially smaller storage devices allowing mass deployment.

Costs: 3%.

Timeline: 2015 - 2020.

Modality of implementation: -

Technical Readiness: TRL 6-8.

Action 5: Storage Recycling

Scope: In Germany some lead acid battery manufacturers recycle their products to a high percentage. European industry has also a scheme for recycle Lithium Ion Batteries at hand. Yet, recycling is not widely applied as the raw materials used by the technology are rather cheap. Other storage technologies are less far advanced with respect to recycling. Assuming a future mass deployment of these, there would be a case for recycling, in particular for the rare earth electrode material in batteries. This implies a need for R&I with respect to the following issues:

- Determine, when a recycling will be needed for a specific technology.
- Provide an applicable and verified recycling method.

Deliverables and KPIs:

- % Share of storage technology in current and future mass deployment, which are recyclable.

Expected impact:

- Design and prove feasibility of proper storage technology recycling[16].

[15] This means that e.g. a decentralised battery may be aggregated with other batteries in order to participate in the electricity whole sale market in the very same way as intelligent household appliances would be aggregated

[16] For Lead Acid and standard Li-Ion this rather is in the market uptake programme

Costs: 3%.

Timeline: 2014 - 2020.

Modality of implementation: -

Technical Readiness: For storage to be recycled: TRL 9, for the recycling technology TRL 1-4.

INNOVATION AND MARKET-UPTAKE PROGRAMME

Action 1: Storage Standardisation

Scope: In order to make a storage technology suitable for mass deployment it has to be covered by a standard. Especially for smaller scale and largely applied ES systems proper standards are needed through elaboration and description of common technological aspects and assessment schemes. Ideally the corresponding application is standardized, too. The coordinating action is thus a crucial prerequisite for market uptake.

Deliverables and KPIs:

- Number of standards derived / Ration of Storage Technologies and Applications covered by standards.

Expected impact:

- Existence of generally accepted standards enabling market uptake.

Costs: 3%.

Timeline: 2014 - 2017.

Modality of implementation: European/CENELEC.

Technical Readiness: TRL7-9.

Action 2: Storage Business Case Evaluation in global market environment/systems

Scope: Storage is a multi-application asset. Generating income streams from different applications is needed if the high CAPEX market entry barrier is to be overcome. From a system point of view, reaching an optimum means maximising social welfare. Hence it is important to determine to what extent the different storage applications can generate benefits in future European scenarios. The past literature on storage valuation shows a lack of understanding the stacking of possible storage revenues. Practically there is a need for system and storage models validated against real deployment or large scale demonstrators and in respective regulatory regimes. These models can then be used for cost benefits analysis to be presented to regulatory authorities. The main goal of this research project is to design and develop a Web-based European platform supporting validated numerical tools that bring a rigorous and thorough assessment of all the benefits of electric energy storage services involved in the sustainable evolution of energy systems.

Deliverables and KPIs:

- Provide a market and business case evaluation for the applications demonstrated in the industrial programme. Verified market volume outlook and prospective IRR in a given scenario context.

Expected impact:

- Availability of a generally accepted market and business case evaluation tool suited for storage cost benefit analysis.

Costs: 9%.

Timeline: 2014 - 2020.

Modality of implementation: National under European umbrella/framework.

Technical Readiness: TRL 7-8.

Action 3: Storage Business Cases in local market environment/systems

Scope: Complementarity to the deployment in the energy system, storage can also be used in a local environment. This could be an industrial site as well as an urban energy supplier or a contractor optimising his portfolio or firming RES generation as required by regulation (The basic idea is similar to the CONCERTO Projects of FP6) Assuming that the storage devices will be operated behind the fence of the supported equipment, the assessment of the storage value requires a cost benefit approach as a market based evaluation is not possible.

Deliverables and KPIs:

- Study determining the market volume outlook and prospective IRR in a given scenario context.

Expected impact:

- Proof of storage benefits in local and "behind the fence" environments.

Costs: 9%.

Timeline: 2014-2020.

Modality of implementation: European in order to serve the predominant system types in Europe.

Technical Readiness: TRL 7-8.

Action 4: Soft Aspects and Society Acceptance

Scope: Public acceptance is crucial for ensuring the deployment of any promising technology.. This applies e.g. to the alternation of landscapes for pumped hydro storage, depositing brine produced during salt cavern excavation and potential fire hazards caused by batteries.. Clearly economic considerations will be a factor in the choices faced by potential owners of energy storage – and this work will compare this to other factors. If storage is to be deployed in on a large scale– an evidence based understanding of the choices of potential owners will be a solid platform to base future policy decisions.

Deliverables and KPIs:

- Pan-European framework to provide a greater understanding of the choices faced by potential owners of energy storage: comparing the differing choices made by different groups of customers in different member states when choosing to own energy storage. Also a comparison on how this compares to their experience after ownership and in use.
- Number of awareness campaigns and degree of changed public perception before and after e.g. verified by surveys.

Expected impact:

- Provide a proper view on storage among the European citizens. This particularly addresses the concern e.g. against new pumped hydro, poisonous lead acid and potentially inflammable Lithium batteries. Citizens need to be able to understand pros and cons of the technology and its potential if "rather not because somehow/potentially hazardous" attitudes are to be avoided.
- Energy storage technologies (both electrical and heat) also face potential owners with a complex set of choices. The balance of economic to non-economic factors may even change after ownership of energy storage, and this action would explore this.

Costs: 3% for promotion campaigns and EUR 0.9 million per annum for the Pan-European framework and dataset on ownership.

Timeline: 2014 - 2020.

Modality of implementation: European level.

Technical Readiness: TRL4-8.

Action 5: Closed storage material loop

Scope: The elaborated recycling concepts from the industrial programme must be implemented into everyday business. For this reason it has to be investigated how much "storage-waste" is actually produced and how to minimize the amount of the equipment, which will be subject to incineration or land fill depositing. The basic driver is not only the recycling rate, which is rather national but also the scarcity of resources, just like it has been an issue for indium in LCD colour displays. This latter issue is a rather global one, which should be tackled on European level. This applies for a wide variety of technologies.

Deliverables and KPIs:

- Rate of material recycling of critical materials, which are needed for large scale deployed storage technologies.

Expected impact:

- Especially at potential mass deployment material resource constraints of storage may occur. It must be ensured that storage material is recycled. Bases on technologies potential scarcities not yet reflected in the material markets (just like indium at LCD colour displays) must be identified.

Costs: 3%.

Timeline: 2018 - 2020.

Modality of implementation: Balanced National and European.

Technical readiness: TRL 8-9 (for recycling technology).

Challenge 3: Demand Response

KEY ISSUES:

- Enable the participation of all relevant actors to ensure the full exploitation of demand response across Europe and demonstrate the full value chain performance of cost competitiveness and system integration capability.
- Develop integrated solutions including a range of consumer demand, distributed generation, storage and market players such as aggregators, TSOs, DSOs and retailers to support a secure, stable and fast reacting system response. Demonstrate the system integration capability of demand through smart interfaces, management modes and new and improved services.
- Address standardisation needs and develop business models, involving all relevant parties (system operators/utilities/aggregators/service providers) including non-technological aspects such as market framework, business model, standards, spatial planning, standards, financing, skills and capacities.

- Address solution acceptance by end-users (appliance/smart meters) in all sectors (residential, commercial and industrial), and social issues such as environment impact, safety, security, health, social acceptance.
- Develop holistic communication to provide security, oversight and participation opportunities between DSO, TSO, Aggregators and BRPs.

ADVANCED RESEARCH PROGRAMME

Action 1: Tool development to support new electricity energy market designs that support Demand Response

Scope:

- Development of a new tool for detailed analyses of various balancing market and products designs to identify best practices and to perform large-scale experiments with metered customers that illustrate the costs and benefits of demand Response at local and European level. This will include computer based studies and analysis of new market products that will enable the participation of all relevant actors and clarify their roles.
- To design grid tariff mechanisms for demand response to correlate the load curve and RES integration.

Deliverables:

- New balancing market design(s) and new market products suitable for Demand Response.
- Large scale experiment(s) to test new market and products designs (as above).
- New grid tariff mechanism(s).

Expected impact: -

KPIs: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 2: Develop mechanisms to enable the participation to the electricity market of all relevant actors and to ensure the full exploitation of Demand Response

Scope:

- Enable the participation of all relevant actors to ensure the full exploitation of demand response across Europe.
- Address solution acceptance by end-users (appliance/smart meters) in all sectors (residential, commercial and industrial) and wider issues such as environment impact, safety, security, health, social acceptance.
- To model aggregated RES/DER generation, flexible conventional generation, demand and storage systems; to use such models for market design, market mechanisms and simulation tools for planning and operation purposes.
- To design market mechanisms for incentivizing both the maximization of the provision of ancillary services by new actors (including aggregated RES, cogeneration and high-efficiency production, demand, storage, etc.) and the minimization of the use at system level of ancillary services. The aim is to harmonize the requirements of license provider and to help the supervision, control and recording of the services provided.

Deliverables:

- Plans for the full exploitation of DR in Europe.
- Plans for the acceptance by end-users of solutions for the full exploitation of DR.
- Model(s) for the full integration of DR and generation in the electricity system.
- Application of these models to devise market mechanisms for the full integration of DR in the electricity system.
- Market mechanism(s) for the optimization of the provision of ancillary services including with DR.

Expected impact: -

KPIs: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 3: Develop integrated solutions to maximise value chain performance and cost competitiveness of Demand Response

Scope:

- Develop integrated solutions including a range of system and and market players (in demand, distributed generation, storage and aggregators, TSOs, DSOs, retailers) to support a secure, stable and fast reacting system response.
- Develop processes for commercial actors (e.g., VPP, aggregators, retail companies) to generate local offers that could be activated by the relevant DSO, TSO, or market operators.
- Define demand requirements and data required by TSOs for the pan-European planning tool.
- Demonstrate that active customer involvement[17] and suitable operations can achieve a reduction in peak demand (10–15 %).
- Model customer/load behaviour and segmentation and quantify the degree of flexibility provided by distribution networks, e.g., through reconfiguration or other methods.

Deliverables and KPIs:

- Proposal of integrated solutions for all system and market actors the competitiveness and the value chain of DR.
- Local commercial offers that activate DR.
- Demand requirements for pan-European transmission planning tool.
- Study demonstrating that active customers and system optimization can achieve 10-15% reduction in peak demand.
- Study quantifying the flexibility of distribution networks with activated demand.

Expected impact: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

[17] with "indirect" feedback (provided post-consumption) and "direct" feedback (real-time)

Action 4: Develop holistic communication systems to provide security, oversight and participation opportunities between DSO, TSO, Aggregators

Scope: Develop holistic communication concepts and systems to provide security, oversight and participation opportunities between DSO, TSO, Aggregators. The complete characterisation of the communication systems shall include:

- The specification of the services to be provided by the load.
- ICT system architectures to allow for virtual power plant approaches.
- Telecommunications protocols.
- Development of interfaces with smart meter and data collection and processing.

Deliverables and KPIs:

- New, holistic communication concept(s) and system(s) for the safe participation of all actors in the optimization of the electricity system.

Expected impact: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 5: Develop load forecast tool with full integration of Demand Response

Scope:

- Develop forecasting tools, load activation tools and control tools, as well as management tools that fully include DR.
- The tools need to correlate local generation and demand patterns, by improving the for short-term (15', 1h, 3h) and long-term (5-day) forecast engines for PV, wind, CHP and loads.
- The tools need to include new functions to improve generation and load observability (such as scaling-up techniques, solutions for the (technical) aggregation of DER and load data acquisition capabilities.

Deliverables and KPIs:

- New forecasting tools with full integration of DR.

Expected impact: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 6: Functional and Virtual Power Storage

Scope: This action aims at determining to what extent generation or demand side management may provide virtual storage capacity simply through intelligent control of existing system components. It relates to and should be cross-referenced with the Smart Grids and Demand side management actions. The primary question to be answered is: can storage be emulated by intelligent control of electrical loads and generators? Storage cycles (Load and discharge) must be considered and consequently, beside for the power involved, also for the short, medium and long-term storage must be regarded in a regional context.

Deliverables and KPIs:

- Potential estimation a Virtual Power Storage for the EC-28 countries.
- Standard procedure for comparison with physical storage.

Expected impact:

- Determine to what extent management of generation or demand side management may provide a virtual storage device simply via using and intelligently controlling existing system components. This is closely related to Smart Energy and potentially only including a cross reference.

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: National and European.

Technical Readiness: TRL 6-8.

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Demonstration of the integration of Demand Response in electricity energy grids

Scope: Demonstration of power technology to increase transmission network flexibility and operation means: The affordability and technical performance of emerging technologies can significantly improve transmission systems and facilitate energy market, while reducing extra costs associated with variable generation and load demand volatility linked to renewable resources and Demand Response and management. Benefits of interest encompass:

  - The interoperability of new power technologies with the existing power system.
  - Deriving operating practices that affect all other aspects of the TSO business.
  - Cross-border connections that are cost-effective and offer increased security of supply in the pan-European power system.
  - Providing field data validation for scaling-up and replication studies of innovative network configurations at EU level.

- Demonstration of infrastructures to host active Demand Response: Large scale integrated demonstration projects, possibly coupled, are needed to validate on real networks and within several regulatory regimes how to optimize across the value chain the benefits of active Demand Response.

Deliverables and KPIs:

- Demonstration project(s) for power transmission technology to increase the integration of DR as well as RES.
- Large scale demonstration project(s) for power transmission technology to increase the integration of DR as well as RES.

Expected impact: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: National and Cross-border.

Action 2: Demonstrate the full value chain performance, the cost competitiveness and the system integration capability of Demand Response

Scope: To perform large-scale experiments involving metered customers that show the costs and benefits of demand-side management approaches and Demand Response potential at the pan-European level.

Deliverables and KPIs:

- Large scale demonstration project(s) involving metered customers proving the benefits of DR integration at pan-European level.

Expected impact: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 3: Demonstrate system services from Demand Response

Scope:

- To demonstrate how system services, e.g. ancillary and balancing services, can be provided by Demand Response, including in combination with RES and storage.
- To demonstrate the future need for ancillary services with a high penetration level of RES and Demand Response.
- To demonstrate that loads are more flexibility and can provide novel solutions for grid operators.

Deliverables and KPIs:

- Large scale project(s) demonstrating the potential of DR in providing system services, including ancillary and balancing services, also with large scale penetration of RES.

Expected impact: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 4: Demonstrate the capability of smart interfaces, management modes and new services to increase the integration of Demand Response in the energy system

Scope:

- The potential benefits of demand response for load control (such as peak shaving and energy savings) that involves customers on a large scale must be drawn up before assessing its impact on grid planning and operations.
- Technologies such as smart meters and energy boxes are included in the demonstration and help raising awareness about consumption patterns and fostering active customer participation in the energy market. Demonstration projects will help defining specifications for:
  - The data needed by grid operators for the pan-European planning tool.
  - Grid operations designed to achieve a reduction in peak demand (10 – 15 %) through active customer participation.
  - The requirement to planning tools in case using metering data.
  - Models to describe customer behaviour and segmentation.

Deliverables and KPIs:

- Large scale project(s) demonstrating the benefit of smart interfaces for the integration of DR in the energy system.

Expected impact: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 5: Control of distributed energy resources for demand response

Scope:

- Application and demonstration of methods and tools for the control of flexible distributed energy resources at the distribution system level.
- Development and demonstration of tools for the control and aggregation of distributed energy resources (generation and load).
- Development and demonstration of tools for the optimisation of distributed energy resources (generation and load)systems.

Deliverables and KPIs:

- Project for the demonstration of control and optimization tools for the integration of distributed energy sources, including DR, at the distribution level

Expected impact: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: Distribution Systems, Local and National level.

INNOVATION AND MARKET-UPTAKE PROGRAMME

Action 1: Demand Response and new users integration: scaling up and replication

Scope: This action supports scaling up and replication programmes to allow the deployment of demonstrated solutions for:

- Active Demand Response.
- Increased market accessibility for private customers and SME.
- Increased Energy Efficiency through the wider integration with Smart Homes and smart cities.
- Demand side management at Distribution System level, that feed into TSO operations in a multi-networks level approach.

Deliverables and KPIs:

- Programme(s) for the scale up of demonstrated solutions for the integration of Demand Response and new users.

Expected impact: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European and National.

Action 2: Standardisation needs.

Scope:

- To support the development of a set of standards for data exchange at the European level involving all relevant parties (smart meters/aggregators/ICT systems).
- To develop a set of data exchange templates and ICT infrastructures to enable ancillary and balancing services at the EU level.
- Assessment of Open interfaces and protocols allowing to integrate control systems from different manufacturers into aggregation.

Deliverables and KPIs:

- Providing recommendations to and/or participation in standardization committee for data exchange in the energy system.

Expected impact: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 3: Market framework and business models for demand response

Scope:

- The specification of a pan-European system for demand response integration based on experimentally validated business models and business cases.
- Definition of Business models in support of virtual power plants at the DSO level.
- Cost-benefit analysis for all market players and for different business cases in the various regulatory contexts.

Deliverables and KPIs:

- Cost-benefit analyses for all market player in various business cases and in different regulatory contexts.
- Business models and frameworks will be delivered for the pan-European grid that improves the real-time market for demand response.

Expected impact: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 4: Regulatory aspects to enable Demand Response

Scope:

- The evolution of the electricity sector and the birth of new players like aggregators will affect the roles of the TSOs and distribution network operators: specific attention is to be paid by TSOs and DSOs, taking into account legal, contractual and market aspects.
- This action aims at identifying the legal, contractual and regulatory aspects related to ancillary services provided by demand and distributed generation, in order to allow for more/new aggregated business models
- New market rules and products enable the active participation of demand in the energy system. At the same time, new arrangements among system actors (e.g. TSOs, DSOs, aggregators, suppliers and retailers) are necessary to ensure that demand side participation is optimised both from an economic and a systemic point of view. An energy system where demand and supply are appropriately and more actively linked will be more efficient and will integrate more cost-effectively variable RES. In order to do so, it will be necessary to:
    - Define a set of market rules, measures and products aimed at favouring the participation and optimising of demand response in the energy system and its remuneration in the energy market. The rules, measures and products should be defined to increase the overall efficiency of the energy system, where variability coming from demand and supply, with increasing levels of variable RES, will have to be matched.
    - Demonstrate these market rules, measures and products in various settings, and to run CBAs.
    - Support with appropriate regulations these market rules and products.

Deliverables and KPIs:

- New market rules and products to enable Demand Response.
- Demonstration projects of these market rules and products in different contexts.

Expected impact: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 5: Demonstration of and regulatory development support for demand response aggregation

Scope: Aggregation is key in order to provide market access for the products that demand response can offer. Scaling up can contribute to overcome transactions costs, which currently act as one of the entry barriers to the energy market. The scope of this action is to:

- Promote pilot projects:
  - Demonstrating that aggregation is a market enabler for demand response in various settings (various electricity systems conditions, e.g. in various member states and portfolios).
  - Running cost benefit analysis at the demonstration level.
- Support the introduction of new demonstrated system features in the regulation, where appropriate, remove administrative barriers and adapte pre-qualification rules to access different markets; point out benefits in terms of integration of variable renewable energy sources, including economic gains and improved security of supply should be taken into account here.

Deliverables and KPIs:

- Pilot project(s) to demonstrate that aggregation is a market enabler for Demand Response with an improved regulatory framework.

Expected impact: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 6: Demonstration of and regulatory development support for further visibility and manageability of demand

Scope: Network operators should be able to increase their visibility and manageability of demand through communication and control infrastructure, in order for the system to be able to maximise the flexibility provided by demand response. This action aims at:

- Demonstrating the effective use of rolled-out communication and control infrastructure to allow for communication between system operators and active demand units directly and via aggregators.
- Running cost benefit analysis in various settings.
- Support regulation favouring the introduction of these new system features where appropriate.

Deliverables and KPIs:

- Pilot project(s) to demonstrate that an effective use of communication and control infrastructure along with an updated regulatory framework positively supports the deployment of demand response.

Expected impact: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Challenge 4: Flexible /Back-up Energy Generation

KEY ISSUES

- **Solution value chain performance/cost competitiveness** to address increased flexibility required from power plants to provide stable, economical and clean back up power for RES. Topics to be addressed are development of technologies at the feature and system levels to enable stable and low emission low load, increased efficiency at both low and base loads, and faster ramp up times.
- **Non technological aspects** (market framework, business model, standards, spatial planning, financing, skills and capacities) that enable the full exploitation of flexible /back-up energy generation with the support of network operators; including the ability to respond rapidly on different short timescales in capacity market designs.
- **System integration capability** to develop solutions for highly dynamic operation of the existing units delivering frequency control, adaptation and modernisation of existing technologies to meet the ever-changing requirements of the electrical grid, i.e. improve the flexibility for plants (increase amount of start/stop cycles per day), address efficiency at part loads, demonstrate the full value chain performance of cost competitiveness. Thermodynamic processes and architectures can be compared to each other and a baseline should be developed to determine the best economical solution for flexibility.
- **Societal issues** to improve environmental impacts and social issues such as safety, security, health, social acceptance by ensuring lowest emissions and a most reliable, stable and economical flexible back up power.

ADVANCED RESEARCH PROGRAMME

Action 1: Innovative Tools to support new grid market designs and mechanisms at EU level

Scope: New market tools are to be delivered that go beyond those currently used in member states.

Deliverables and KPIs:

- Improve the flexibility of the power energy system.
- Increased range of energy options (e.g. RES involvement, active demand and storage systems) to contribute to system balancing and to provide ancillary services.

Expected impact: -

KPIs: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Improve flexibility of the production from RES flexible technologies

Scope:

- Define the range of operability of the thermodynamic processes used for flexible RES power generation through a parametric study using system-scale modelling to evaluate reference configuration efficiency variation, especially in off-design situations, and to compare, technically and economically, architectures to enable better flexibility.

- Review of technical and field experience data available for flexibility of biomass (gasification, anaerobic digestion), CSP, hydro and geothermal.

Deliverables and KPIs:

- Evaluation of reference configuration efficiency variation, especially in off-design situations, and comparison both technically and economically of architectures to enable better flexibility.
- New generation and robust component designs for hydropower turbine and generator designs.
- Improved biomass, CSP, hydro and geothermal ramp response, efficiency, operational and grid balancing capabilities to provide back-up power for renewable power generation.

Expected impact: -

Costs: EUR 2 - 10 million per year until 2020.

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 2: Programme in design and demonstration of new generation of turbine and generator: Hydro plant upgraded for better grid-balancing

Scope: Hydro plant upgrading projects to improve their capability to deliver ancillary services.

Deliverables and KPIs:

Successful implementation of a number of projects of:

- Turbine (>40 MW) optimised for a full-size converter in use from zero to peak discharge rates.
- Class 180 hydropower generator (>50 MW) demonstrating high temperature capability of new insulations and winding operation.

Expected impact: -

Costs: -

Timeline: Implementation by 2020, monitoring until 2025.

Modality of implementation: Two to three projects will be needed in Europe.

Action 3: Efficient and Responsive Thermal Power Plants

Scope:

- Increase coal and gas power plant efficiency:
  - Optimize combustion/water-Steam/auxiliary systems in particular for minimum and part load operation
  - Increase fuel flexibility towards low-carbon fuels and improve gas cleaning.
- Increased power plant ramp and start up times:
  - Advance stress calculation and life prediction methods, design features, simulation tools and materials, non-destructive inspection methods, sensor systems.
- Reduced power plant minimum load:
  - Adapt boiler operation to lower steam throughput.
  - Improve combustion stability at low loads.

Deliverables and KPIs:

- Reduce the minimum load of coal fired power plants below 20%.
- Reduce the minimum load of gas fired power plants below 30%.
- Increase the number of possible starts by 100%.
- Meet future emission limit requirements.

Expected impact: -

Costs: EUR 12 million.

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 4: Flexible and Efficient Gas and Steam Turbines

Scope: Reduced minimum load of gas and steam turbines by improvements in flow path design, aeromechanical and combustion stability, design and lifing methods, and auxiliary systems.

- Increased efficiency and environmental performance for future load regimes of gas and steam turbines by design and demonstration of new turbine cycles, sealing and bearing systems, low emission combustion systems, advanced hot gas path concepts, and analysis techniques.
- Reduced gas and steam turbine ramp up and start up times through development of life prediction methods, advanced materials and coatings, cooling concepts, combustion robustness under unsteady operation conditions, advanced monitoring and sensor systems, and transient operation design features and simulation tools.

Deliverables and KPIs:

- Turbomachinery minimum load reduced by 30%; enabling additional 50 GW (+5% of total capacity) RES without a loss of security of supply.
- Reducing specific part load CO_2 emissions by 1/3 (while improving full load efficiency as well), will reduce the power sector CO_2 emission an estimated EUR 60 million tons in 2030.
- Complementary generation profile to RES profile, enabling a potential of 20GW extra RES.

Expected impact: -

Costs: EUR 140 million.

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 5: Programme in design and demonstration of new generation of turbine and generator: New generation of hydropower turbine and generator design

Scope: Develop robust hydropower turbine and generator designs, using simulations and addressing insulation systems and materials of hydro plant components to allow:

- Electricity production between 0-100% of peak power.
- Frequent stop-starts for both variable- and fixed-speed operation.
- Rapid and stable change of mode of operation for pump-turbines.

Deliverables and KPIs:

- Increase max. possible operating temperature of the high-voltage insulation system to 180°C.

- Increase number of thermal cycles of the high voltage insulation system according to IEEE standards by factor of 2.5 (from 1 000 to 2 500 in the case of pure-generation hydropower plants).
- Robust design (turbines and generators):
  - Lifetime prediction reliable for all operating conditions including increased stop-starts (today: only for 70% to 100% load).
  - Increased lifetime of turbine runners and critical rotor parts (generator) by a factor of 10.
  - Turbines can be operated at 0 to 100% load without risk of damage (today: 70% to 100% load).

Expected impact: -

KPIs: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European and National.

Action 6: Programme in improving power converters to permit variable-speed operation: Power electronics and converter technology for hydro projects

Scope: Develop power electronics and large scale power converters for hydro plants. Future converter technology should enable the integration of variable-speed generators or pumps into the grid, so that turbines or pumps may be operated at optimal efficiencies and provide millisecond regulation services. For instance, multiphase machines associated with adapted converters would allow emergency operation after single phase.

Deliverables and KPIs:

- Increase voltage range from 6.6 kV today to 20 kV in 2020.
- Reduce size by 40% by 2020 (from 2-3 m3/MVA to 1.5 m3 /MVA).
- Increase efficiency from 98% today to 99% in 2030.
- Reduced costs.

Expected impact: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Challenge 5: Cross-technology Options

KEY ISSUES

- Develop solutions that integrate fluctuating demand and fluctuating sources: space and time scale imbrication, resilience, regulation by demand (e.g. thermal solar coupled with biomass, remote and quasi-autonomous districts, coupling heat, electricity, gas, and water management in arid environments, photovoltaic with heat pumps).

- Develop non technological aspects (market framework, business models, spatial planning, standards, financing, skills and capacities) and ensure that market designs enables the full exploitation of cross-technology options.
- Cyber security issue for grid infrastructures, data flow from demand, storage and generation.

ADVANCED RESEARCH PROGRAMME

Action 1: Cross Sector Chemical Storage Technologies

Scope: Focus should be on electricity as energy source , since this system will experience the most critical imbalances in future. As many cross-sectorial technologies are rather new concepts a separation into novel and improved technologies has been omitted for the timeframe 2014-2020.

The prime goal of the action is to provide flexibility to the power system and, at the same time, provide valuable energy commodities, like chemical fuels. The scope predominantly comprises:

- Power to Gas: Power to Gas offers two unique features: On the one hand it is providing a good long term storage feature. On the other one it offers solutions to transportation issues since once having a natural gas equivalent also gas grids can be used rather than power grids. However, the technology needs substantial improvement at efficiency and costs. This majorly addresses two tasks:
    - Technically improve power to gas technologies, especially innovative and affordable electrolysers are needed to pave the road for any kind of long term storage.
    - Develop one step electrochemical synthesis process by-passing the hydrogen production stage through electrolysis.
    - Develop ways to efficiently use the gas produced (injection in the natural gas network, mobility, etc.).
- Power to Fuel: Given the low efficiency of power to gas and the high cost of the technology a fairly good usage of the equipment is needed. Especially at the early phases of RES penetration this is rarely given. Consequently it may make sense to set up these sites with a base load production, providing e.g. fuel for CNG vehicles or raw material for industries. On top of that flexibility features for the power system can be offered. This implies a siting close to RES generation centres. Power to Fuel comprises the electrolyser relevant items, too.
- Power to chemical feedstock. Renewable electricity can be used for electrochemical synthesis of valuable chemical feedstock such as ammonia, methanol, ethanol and formic acid. Ammonia industry, as an example, consumes 1% of world energy generated, leasing 0.7% of world CO_2 emission and for power to ammonia, CO_2 capture, storage and transportation is not required.
- Power to Heat. Similar to the gas sector the district heating sector or smaller heat networks with some heat storage capacity can be served. This is especially useful if green spill over energy will occur. For this purpose electrical heaters can be installed at comparably low costs.

Deliverables and KPIs:

Technology	KPI	Unit	2014	2020
Power to Hydrogen (Electrolyser) + Methanation + Re-electrification in OCGT	CAPEX Converter	[€/kW$_{el}$]	2400	1400
	CAPEX Reservoir	[€/kWh]	*Existing Gas Grid*	
	Efficiency	[%]	21	25
	Standby loss			
	Lifetime	[a]/[cycles]	5-10/>10000	10-20/>50000
Power to Hydrogen (Electrolyser) + Methanation + Re-electrification in CCGT	CAPEX Converter	[€/kW$_{el}$]	2400	1400
	CAPEX Reservoir	[€/kWh]	*Existing Gas Grid*	
	Efficiency	[%]	31	39
	Standby loss			
	Lifetime	[a]/[cycles]	5-10/>10000	10-20/>50000
Power to Hydrogen (Electrolyser) + H2-cavern storage + Re-electrification in Open cycle H2-Gas turbine	CAPEX Converter	[€/kW$_{el}$]	1400	900
	CAPEX Reservoir	[€/kWh]	0.2-10	0.2-10
	Efficiency	[%]	26	29
	Standby loss	[% / month]	0.01-0.001	0.005
	Lifetime	[a]/[cycles]	5-10/>10000	10-20/>50000
Power to Hydrogen (Electrolyser) + H2-cavern storage + Re-electrification in Fuel Cell System turbine	CAPEX Converter	[€/kW$_{el}$]	2000	1000
	CAPEX Reservoir	[€/kWh]	0.2-10	0.2-10
	Efficiency	[%]	39	46
	Standby loss	[% / month]	0.01-0.001	0.005
	Lifetime	[a]/[cycles]	5-10/>10000	10-20/>50000

Expected impact:

- Capability to exchange electrical energy with other vectors in the energy system (e.g. gas or other fuels).

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: -

Action 2: Small hydro power plant as active component in a VPP

Scope:

- Technologies will be developed that efficiently perform dynamic regulation with short response time such that by 2020 small hydro power plants can provide a variety of ancillary services to the grid.
- In parallel, and continuing to 2030, a variety of actors (including owners of generating capacity, distribution system operators and aggregators) should be brought together to create a VPP where small hydropower plants play a major role. Interfaces will translate signals sent from the VPP manager into changes in the operation of the small hydropower plant. The plant, equipped with instrumentation to allow its performance to be analysed, should demonstrate rapid regulation of frequency, voltage and active or reactive power, while keeping downstream water flows within acceptable environmental limits.

Deliverables:

- Small hydro power plants to provide a variety of ancillary services to the grid. Demonstration of rapid regulation of frequency, voltage and active or reactive power.

Expected impact:

- Combining small power producers and make them acting like one plant. In addition this VPP is able to accept set points for active and reactive power from almost 0 to 100 % due to the granularity of the individual plants. In addition a significant resource is established with the VPP to work on voltage and frequency stability in the grid.

KPIs:

- Number of VPP's established to provide Services comparable to large size plants.
- Number of Small Hydro projects providing ancillary services.
- Number of Small Hydro projects ready to enter in a VPP concept.

Costs: No more than four projects are needed to develop and test the interfacing of a small hydropower plant with a VPP, each requiring maximum 1 M EUR per year, with public funding covering half. Four VPP demonstration projects making heavy use of hydro generation assets are needed, costing EUR 3 - 5 million per project per year in setting up and monitoring, also half funded with public grants.

Timeline: by 2020 small Hydro power plants can provide a variety of ancillary services; by 2030 demonstration of rapid regulation of frequency, voltage and active or reactive power.

Modality of implementation: Hydro Equipment manufacturers will work with utilities, academia and ICT Specialists.

Action 3: Research for high cyber security

Scope: Research and development related to:

- Keeping a high level of security of supply of electricity even if telecommunication net-works fail or are attacked (redundancy of information, degraded modes).
- Protect all IT systems involved in a secure grid based electricity system linked to the operation, metering, end-use of electricity.

Deliverables: -

Expected impact: -

KPIs: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 4: Research for "big data" in the cloud, in real-time

Scope: Research and development related to:

- Manage data as integral component of the entire process chain around Smart Power and Energy Systems.
- Capture relevant data in real-time and make it available as a "big data".
- Integrate data semantically (information modelling) and adapt data/information exchange management techniques for this task.
- Place information in the "energy data cloud" and to develop analysis tools which offer dedicated support for the evaluation of such data.
- Handle big real-time data in the communication-constrained cloud and at the same time handling grid congestion constraints and market requirements.

Deliverables: -

Expected impact: -

KPIs: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 5: Enhancing Network Interaction and synergies – Gas and Electric networks

Scope: The optimisation of the cost of renewable energy integration into the future energy system will depend on the continued innovative use our existing energy networks. The gas network will continue to play an extensive role in the energy system having a capacity for energy transportation greatly in excess of existing European electricity networks and orders of magnitude greater storage capacity. The utilization of gas at the ends of the distribution network is already highly efficient with substantial gains in efficiency still being made, through hybridization with renewables and distribution generation of heat and power. The R&I requirements will therefore cover both innovative uses of the network (including storage of renewable energy as hydrogen or synthetic natural gas), introduction of renewable energy directly into the gas system as biomethane, and the development of flexible heat and power generation which will support the variable nature of other renewable sources and ensure energy security without unnecessary extra capital expenditure on renewable electricity generation and network upgrading.

Deliverables:

- Make Power to Gas energy storage technologies market ready.
- Develop SMART gas network approaches to ensure integrity, compliance and operation of the gas grid as it becomes increasingly decarbonized and linked to other energy networks through demand and supply management.
- Develop flexible smarter back up power generation, which will maintain efficiency while accepting a wider range of gas qualities including renewable gases and hydrogen.

- Incorporate the use of a new range of highly efficient end use gas and gas hybrid technologies into SMART system models and ensure the technologies are developed to meet requirements. The increased use of distributed small scale CHP units running on gas, renewable gas, and hybridized with renewable sources, will contribute significantly to optimization of investment requirements at the transmission scale, and to overall efficiencies of the energy system.

Expected impact: -

KPIs: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 6: Energy Systems Integration – Testing and Evaluation of Integrated Energy Systems

Scope: Testing and evaluation of integrated energy systems will be key for de-risking investments by validating their value prior to wide-scale deployment. Across Europe, there are a number of test laboratories and facilities (e.g. DERLab) that focus on validating the performance of individual energy technologies. Much more is needed to validate how these new technologies (e.g. renewables, electric vehicles, controllable loads, energy storage) can work in an integrated system (across electricity, thermal, and fuel systems) at a variety of scales (homes to regional areas). These facilities can be used to help evaluate the variety of open standards for interoperability between devices that are currently being developed to enable control systems from homes, to distribution systems, to regional levels. The United States recently opened the Energy Systems Integration Facility (ESIF) at the National Renewable Energy Laboratory (NREL) in Golden, Colorado, which serves as a hub for integrated system experimentation and grid integration R&D. This facility allows evaluations of a variety of energy systems via hardware-in the-loop to integrate capabilities between multiple labs. As systems get larger, there is also the opportunity to create linkages between laboratories in Europe and the U.S. using this testing capability.

Deliverables:

- Create an integrated platform that allows experimentation of integrated energy systems across multiple laboratories.
- Facilitate collaborations between Europe and the U.S. on the integrated platform.

Expected Impact: -

KPIs:

- Improve integration of testing capability for a range of systems (distribution to bulk-system) that includes multiple energy systems (electricity, thermal, and fuels).
- Extend analysis to a variety of system operations and economic market scenarios.

Cost: EUR 20 million.

Timeline: 2016 – 2019.

Implementation: European and International (particularly US).

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Demonstration of high cyber security

Scope: Demonstration related to:

- Keeping a high level of security of supply of electricity even if telecommunication net-works fail or are attacked (redundancy of information, degraded modes).
- Protect all IT systems involved in a secure grid based electricity system linked to the operation, metering, end-use of electricity.

Deliverables: -

Expected impact: -

KPIs: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 2: Demonstration of "big data" in the cloud, in real-time

Scope: Demonstration of:

- Managing data as integral component of the entire process chain around Smart Power and Energy Systems.
- Mapturing relevant data in real-time and make it available as a "big data".
- Integrate data semantically (information modelling) and adapt data/information exchange management techniques for this task.
- Placing information in the "energy data cloud" and to develop analysis tools which offer dedicated support for the evaluation of such data.
- Handling big real-time data in the communication-constrained cloud and at the same time handling grid congestion constraints and market requirements.

Deliverables: -

Expected impact: -

KPIs: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: European.

Action 3: Demonstrate the flexibility of PEM electrolysers at large scale

Scope: In the aim of offering valuable services to the grid operator, dealing with high penetration of intermittent production, two main features of electrolysis performances should be addressed:

- Capability to overrun the water electrolysis helping the TSO/DSO to cope with excess of renewable electricity in the grid (situation expected to occur more frequently):
    - To bring to the TSO/DSO down-regulation services and not only up-regulation.
    - To produce additional hydrogen when electricity is cheap and without over-sizing the stacks in that purpose.
- Reactivity of the system from nominal power to standby or to maximum overrun power within 1 or 2 seconds to offer to the TSO up- and (or) down-regulation for system services: typically, primary or secondary reserve, which represents highly valuable services.

PEM technology is particularly well suited to fulfil such grid services requirements, thanks, in particular, to its ability to increase the current density for a given lapse of time. However, additional qualifications in such behaviour patterns, are needed to demonstrate on one hand the reliability and durability of operations and on the other hand, acceptable degradation of the efficiency. Alkaline technology could also partly comply to such market requirements.

Deliverables:

- Demonstrate the functioning of a PEM electrolyser (1-2MW) at different points of use (from 0 to 150% of its nominal capacity).
- Demonstrate the availability of this electrolyser to follow power command variation with a characteristic time <2s.

KPIs:

- H2 production electrolysis, energy consumption (kWh/kg) @ rated power: Ref. 57-60 @100kg/d - 2017: 55@500kg/d – 2020: 52 @1000+kg/d – 2023: 50 @1000+kg/d.
- H2 production electrolysis, flexibility with a degradation < 2% year: Ref: 5% - 100% of nominal power – 2017: 5% - 150% of nominal power – 2020: 0% - 200% of nominal power – 2023: 0% - 300% of nominal power.
- H2 production electrolysis, hot start from min to max power: Ref. 1 minute – 2017: 10 sec – 2020: 2 sec – 2023: < 1 sec.
- H2 production electrolysis, cold start: Ref. 5 minutes – 2017: 2 minutes – 2020: 30 sec – 2023: 10 sec.

Expected impact:

- Stabilisation of the electricity grid.
- A reduced need for ever-greater quantities of renewable electricity, bio-fuels and bio-energy necessary to create a sustainable low carbon energy system after 2030.

Costs: EUR 60 million.

Timeline: 2014 - 2020.

Modality of implementation: Regional scale (semi-centralized).

Action 4: Optimised integration of renewable energy sources and surplus heat in DHC and enhancement of thermal energy storage at system level

Scope: Further research activities are needed to allow DHC networks to efficiently integrate all types of RES without jeopardising the quality of the service provided to the consumers. In the same way, it is important to explore new synergies between various customer groups with different thermal needs. The DHC sector must be able to exploit and upgrade all available renewable energy, as well as any surplus recovery heat.

- Reaching high penetration of RES in DHC requires applied research to develop smart thermal networks connecting diverse types of buildings and industrial processes, including prosumers where appropriate.
- Energy storage is a central component for enhancing the flexibility of district and heating systems, matching variable renewable energy sources with a fluctuating thermal demand. TES solutions already exist for district heating systems but they mainly suit short term storage. There is a need to develop flexible, efficient, multifunctional and cost-effective TES and to integrate these solutions in smart thermal networks.

Deliverables:

- Increase by 20% by 2030 the energy efficiency of DHC systems (maximise the energy output (heat delivered) for each unit of the energy input) by integration of thermal energy storage.
- The activities of research, development, demonstration and integration of TES solutions should result in a 30% reduction of heat costs
- Increase the efficiency and performance of thermal energy storage technology, in particular seasonal storage.

KPIs:

- Reference heat cost - 2012: 200-50EUR/MWh; 2020: 90-40EUR/MWh; 2030: 70-35EUR/MWh
- Reference energy efficiency of DHC systems (index using baseline = 100) - 2012: 100; 2020: 110; 2030: 120.

Costs: EUR 50 million.

Timeline: 2018 - 2020.

Modality of implementation: European and National actions.

Action 5: Demonstration of large Smart Thermal Grids

Scope: Large Smart Thermal Grids have to adapt fast to changes in energy supply and demand, they should be intelligently planned and operated as well as enable the end-user to interact with the heating and cooling system; they need to be integrated in the whole urban energy system from a spatial point of view and from an energy system point of view; and they need to be attractive for the citizens and investors by increasing the cost efficiency, creating possibilities for the customers to participate and developing new business models.

- Advanced district heating and cooling systems must be developed that are able to deal with both centralised and decentralised hybrid sources (e.g. solar thermal, biomass, geothermal, heat pumps, waste heat, waste-to-energy, excess renewable electricity, storage). In addition, smart metering and load management systems are needed for the integration of thermal and electrical grids into a liberalised energy market. Such smart thermal grids have an important potential to meet the load balancing needs of combined heat and power production in a liberalised market for electricity.
- In terms of components, specific decentralised cooling and air-conditioning units for district heating systems are needed, as well as new cost-optimized forms of long-term heat storages. Integration and standardisation of thermal components are required to decrease their price and increase their efficiency. For existing heating grids the integration of heat pumps for active flue gas condensation may be a viable concept, which should be demonstrated. The development and demonstration of bi-directional grids may be an interesting system option for new grids.

Deliverables:

- Large scale demonstration of the technical feasibility and economical competitiveness of Smart Thermal Grids combining the above described smart aspects.
- At least 50% share of renewable energy or industrial surplus heat in Smart Thermal Grids and overall efficiency gain of 30 % (including impact on heat generation efficiency) compared with state-of-the-art thermal grids.
- Large scale demonstration of above described smart non-technical characteristic (end-user participation, integration of heat prosumers, new business models).

Expected impact: -

KPIs:

- Number of smart thermal grids demonstrated with cost of delivered heat less than 90 EUR/MWh: 2012: none, only single smart grid aspects demonstrated - 2016: 5 demonstration projects started - 2020: 5 large scale demonstration projects (> 20 GWh/a) realized demonstrating 30 % efficiency improvement compared to state-of-the-art thermal grids and 50 % RES or industrial surplus heat
- Cost of delivered heat (this average value must be adjusted on the basis of national indexes): 2012: 200 EUR/MWh - 2016: 130 EUR/MWh - 2020: 85 EUR/MWh that is a price competitive with conventional DHC
- Average share of RES and surplus heat from industrial processes in Smart Thermal Grids: 2012: 11%- 2016: 20% - 2020: >50 %
- Efficiency Indicator (primary energy factor): 2012: 0.8 - 2016: +10% - 2020: +30%

Costs: EUR 100 million.

Timeline: 2014 - 2016.

Modality of implementation: European and National actions.

Action 6: Take into account the electrical network needs to Optimize centralized Hydrogen production (spot price, load curtailments (on peak), over consumption (off peak))

Scope: Study the needs of the network.

- Monitor and optimize the functioning of the PEM electrolyser to take into account demand/response constrains and spot price spread of the electrical network and decrease the price of hydrogen.

Deliverables and KPIs:

- PEM PtoH2 system, to validate the conditions of feasibility and profitable business model (2015 – 2018).
- Define with the local electricity network operator the optimized operating modes in function of the geographies.(2015 – 2018).
- Supply with Green-H2, local H2 potential mobility projects (for 10 to 15 years).

Expected impact: -

Costs: -

Timeline: -

Modality of implementation: Region scale, preferentially in locations where there is a market for green hydrogen.

INNOVATION AND MARKET-UPTAKE PROGRAMME

Action 1: Improved, highly efficient substations for both present and future lower temperature networks

Scope: Substations should become smarter, softer, and cheaper. The following priorities are identified:

- Improving in the manufacturing process.
- Costs reduction.
- Efficiency gains.
- Capacity to adapt to changes in the energy demand profile.

To reach these objectives, R&D must also look at ways to harmonise substations' standards, to reduce materials' cost, to invest in the automation of manufacturing methods and to achieve good performances also at temperatures below 70° C.

Deliverables:

- Reducing energy consumption for the customer by 8% through the use of eco-efficient substations.
- Reduce manufacturing cost by 15% compared to current standards.

Expected impact: -

KPIs:

- Specific KPIs Substations' reference manufacturing cost (in EU, residential buildings): 2012: 5.000 to 10.000 EUR - 2016: 5.000 to 8.000 EUR - 2020: 4.000 to 6.000 EUR

- Average electricity consumption of substations for residential building: 2012: 4.380 kWh/year - 2016: 3.400 kWh/year - 2020: 2.600 kWh/year
- N. of “smart substations” (efficient pumping systems and intelligent control system) installed as a proportion of all new substations: 2012: 15% to 20% - 2016: 50% - 2020: 80%

Costs: EUR 40 million.

Timeline: 2016 - 2018.

Modality of implementation: European and National actions.

HEADING 3: Developing Sustainable Biofuels and Alternative Fuels for the European Transport Fuel Mix

Challenge 1: Advanced (Second and Third Generation) Biofuels

KEY ISSUES:

- The overarching goal of this challenge is to develop technologies and to create market access to enable commercial availability of advanced biofuels technologies to cover at least 0.5% (1.8 Mtoe) of EU transportation energy needs by 2020. This target supports the EU objective to promote the deployment of advanced biofuels within the proposed revision of the RED/FQD.
- Biofuels are playing a significant role in reducing greenhouse gases. Beyond 2020, an IEA roadmap estimates that by 2050, biofuels will provide 27% of total world transport fuel and avoid around 2.1 Gt CO_2 emissions per year (accounting for 20% of total emissions in transport) when produced sustainably[18]. Estimating a share of only 8 % in the EU transport energy demand 2030 and 2050[19], advanced biofuels could avoid around 54 MT CO_2 per year. This is only 2.5 % of the EU target to reduce GHG emissions by 40 % until 2030 or 1.25 % of the 2050 target of 80 % (in comparison to 1990), but a significant reduction to the GHG emission of the transport sector, increasing from 778 MT in 1990 to 926 MT in 2011.[20] The IEA scenario applied to the EU, would lead to 185 MT avoided CO_2 emissions per year.
- In order to reach the 0.5 % target by 2020, around 20 new production plants for advanced biofuels will have to be built in the next few years. Apart from a stable, long-term policy framework for biofuels to increase investor confidence, which includes binding targets for 2020 and beyond, the deployment of advanced biofuels will require further substantial research, development and demonstration activities with accompanying funding measures. Process optimisation, valorisation of side-streams into higher value products and new financing mechanisms for large biofuels projects are key elements to reach this goal by 2020 and thereby effectively contribute to the de-carbonization of the transport sector and increase energy security.
- ***Technology.*** EIBI has defined 7 generic bioenergy pathways, from which 6 are relevant to biofuels - 3 thermochemical and 3 biochemical - that include different feedstocks and conversion methods for advanced biofuels. Challenges include:
- Improve economy of advanced biofuel production by:
  - Processing of lower priced raw materials.
  - Better process efficiency.
  - Production of products with higher value.
- Enhance conversion efficiency for current technologies as well as disruptive advanced technologies.

---

[18] Biofuels for Transport Roadmap, IEA 2011; Blue Map Scenario

[19] EU Energy, transport and GHG emission trends to 2050 ; reference scenario 2013, EU 2014

[20] Energy, transport and environment indicators, Eurostat 2013

- Develop conversion technologies to provide the largest possible feedstock flexibility and/or higher added-value end products.
- Increase in economic valorisation of biorefinery side-products streams in order to optimise the business model of the future plants.
- Demonstrate and evaluate sustainability in the EU context for implementation of second generation technologies at industrial scale from several biomass types including energy crops, agro-residues, waste, forestry and marine biomass, as well as residue, waste and landscape management material.
- Develop biofuel processing and production for maximum yield of diesel and middle distillates, to enable balancing of fuel supply and demand.
- ***Feedstock.*** Many sectors are competing for biomass feedstocks. Additionally, many EU countries have limited experience with large-scale collection and storage of biomass. As a consequence, there is a need to help establish cost-effective agriculture and forestry biomass supply-chains and reduce raw material uncertainty. Challenges here include:
    - Ensure standardised and sector oriented sustainable and reliable supply of feedstocks in long-term commercial perspective taking into account logistics and other competing uses.
    - Enhance innovations on creation of new biomass sources.
    - Increase mobilisation to widen the feedstock base and to deal with the competition between different uses.
    - Technology transfer and legal framework across energy, agriculture, forestry and environment should be developed accounting for sustainability and higher biomass conversion efficiency.
- ***Policy, Market and Financing.*** Commercialization of advanced biofuels technology depends on political leadership and an adequate legislative framework. Only by stimulating investment in scale-up, supply of relevant feedstocks and valorisation of innovative biobased co-products, will Europe enjoy the benefits of advanced biofuels production in terms of job creation, growth, rural development and GHG emissions reduction. Challenges here include:
    - Encourage valorisation of co-products, while still concentrating on advanced biofuels. This is important for the creation of a process basis for integrated energy-driven biorefineries, creating value chains leveraging on industrial synergies.
    - Guarantee adequate public and private funding and risk sharing mechanisms.
    - Financing instruments should include improved access to risk finance via equity and debt alongside with the combination of public structural funds and the development of public-private partnerships in order to share the risks and prepare the ground for a successful market entry of next generation biofuels.
    - Guarantee a stable and long term policy framework for the deployment of sustainable advanced biofuels technologies.
    - Create positive awareness amongst consumers.

ADVANCED RESEARCH PROGRAMME

Action 1: Develop low-cost integrated process concepts to reduce the investment needed for the production of biofuels and bioproducts

Scope:

- Develop processes for the valorisation of second generation co-products –e.g. lignin and hemicellulose- into high(er) value products.
- Develop biofuel pathways using marine biomass.
- Develop new fermentation pathways with engineered microbes.
- Develop more effective catalysts for thermal processes with greater tolerance to contaminants likely to be present in biomass based processes.
- Develop downstream technologies (e.g. separation and purification) for high quality and low cost streams for biofuels and bioproducts.

Deliverables:

- Process concepts able to cope with "difficult" feedstocks at acceptable costs.
- Process concepts with a larger range of marketable products.

Expected impact:

- Broader range of conversion technologies tackling all kind of biomass feedstocks and lowering the hurdle for new investments.

KPIs:

- Cost reduction: reaching 1st generation cost level by 2030.
- Net efficiency (based on LHV) of conversion of biomass feedstock from plant gate to commercially marketable bioenergy product Target: 75% (less than half of which is heat).
- Improved sustainability (20% of water use reduction by 2020 compared to current processes, preserved biodiversity and lower GHG emissions beyond the requirements of the RED and FQD.

Costs: EUR 100 million.

Timeline: 2014 - 2020.

Modality of implementation: European, National, Regional and Local.

Action 2: Develop innovative biological, chemical and thermochemical routes for biomass conversion to obtain biofuels and bioproducts from all fractions of biomass

Scope:

- Develop and test robust biocatalysts (enzymes) for ligno-cellulosic biomass conversion into sugars, to improve performance and achieve cost reduction.
- Develop engineered yeasts to obtain building blocks like long chain alkanes and alkenes from C5&C6 sugars.
- Develop new catalysts for novel catalytic routes, such as catalysis to obtain higher alcohols for biofuel applications.
- Improve catalysts for production of valuable products from synthesis gas.
- Catalyst development for deoxygenation and upgrades of bio oils.

Deliverables:

- New/improved processes with better performance and lower costs.
- Innovative routes covering enhanced feedstock basis.

Expected impact:

- Broadening the range of processes ready for scale up in 2020.

KPIs:

- Net efficiency (based on LHV) of conversion of biomass feedstock from plant gate to commercially marketable bioenergy product. Target: 75% (less than half of which is heat).
- Absolute cost target: Price before taxes of bioenergy products in 2020 (€/MWh) per value chain at point of sale to customer. Targets for primary products:
  - Synthetic liquid fuels by gasification: < 80 €/MWh (equates to 0,75 €/litre).
  - Biomethane (≤ price as for natural gas) and other synthetic gaseous fuels by gasification: (depends on product, e.g. – DME <60 €/MWh), Hydrogen compressed (<80 €/MWh), CO (<30 €/MWh).
  - Intermediate bioenergy carriers: pyrolysis oil <50 €/MWh (to compete with Heavy Fuel Oil , but this depends on actual product), torrefied product <30 €/MWh.
  - Ethanol and higher alcohols from ligno-cellulosic biomass by biological processes: <80 €/MWh (Note: equates to <0,50 €/litre).
  - Hydrocarbons by biological processes and/or chemical synthesis: < 80 €/MWh.
  - Bioenergy carriers by micro-organisms (algae) from CO2 and sunlight: < 70 €/MWh for lipids (to be competitive with vegetable oils and animal fats). Biomethane (≤ price as for natural gas).
- Cost reduction: reaching 1st generation cost level by 2020.

Costs: EUR 100 million.

Timeline: 2014 - 2020.

Modality of implementation: European, National, Regional and Local.

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Demonstrate processes at TRL6-7 that decrease Capex and/or Opex and increase the overall sustainability of advanced biofuels processes to various end-use applications (road transport, aviation, etc.)

Scope:

- Demonstrate fermentation and relevant down-stream processes for industrial production of advanced biofuels and co- bioproducts by engineered microorganisms. Validate at pilot and demonstration scale.
- Demonstrate efficient gasification and upgrading concepts at relevant scale, for the industrial production of synthetic fuels/hydrocarbons and gaseous fuels.
- Demonstrate other thermochemical concepts (e.g. based on pyrolysis or torrefaction) for the industrial production and upgrading of industry-relevant bioenergy carriers.
- Valorise biorefinery streams and co-products for advanced biofuels at demonstration scale.
- Demonstrate processes for transforming constituents such as hemicelluloses and lignin into high(er) value products in combination with advanced biofuel production.

Deliverables:

- Processes with better performance than the ones currently available on the market: Quantity and quality of products, energy efficiency, GHG balance.

Expected impact:

- Range of advanced, environmentally sound, socially acceptable and economically viable biofuel processes able to use a variety of different feedstocks that can compete with fossil fuels.

KPIs:

- Capex reduction by 15% by 2020 compared to 2014 estimates.
- Opex reduction by 10% by 2020 compared to 2014 estimates.
- Process efficiency: Net efficiency (based on LHV) of conversion of biomass feedstock from plant gate to commercially marketable bioenergy product; target: 75% (less than half of which is heat).
- GHG balance: Reduction by 60 % in 2020.

Costs: EUR 250 million.

Timeline: 2014 - 2020.

Modality of implementation: European and National.

Action 2: Evaluate feedstock chain and process flexibility for relevant biomass sources at demonstration scale (TRL 6-7)

Scope:

- Evaluate feedstock flexibility of pre-treatment and conversion processes for relevant cellulosic biomasses (available agricultural residues, energy crops and forest residues), marine biomass, the organic fraction of waste/industrial residues and other non-exploited sustainable low ILUC biomass at demonstration scale.
- Evaluate the availability of sustainable biomass, including non-exploited biomass.
- Demonstrate the potential of the organic fraction of waste as an alternative feedstock for advanced biofuels production.
- Demonstration of advanced microbial conversion processes.
- Demonstrate the sustainability of the production of biomass, for example, non-food crops in a variety of ecosystem profiles and lands (including dry, low quality soil, non-profitable agricultural lands) as a cost effective feedstock additional source.
- Demonstrate advanced cost effective marine biomass sources with a higher production efficiency (including cultivation technology, Integrated Multi-Trophic Aquaculture, logistics, use of organic wastes).
- Scale-up and evaluate by technical and sustainability criteria (including energy, cost, and environment) the demonstrated processes. Estimate the potential of their application in an EU context and the necessary requirements to improve the viability of their industrial implementation.
- Demonstrate the validation of reliable tools for determination of sustainable feedstocks resources availability based on cost supply curves at regional level.

Deliverables:

- New biomass supply and processing chains unlocking biomass potentials not used so far (agriculture, forestry, marine biomass), increasing the exploitable potential by 10-to 25 % in relation to 2014).
- Cost supply curves for relevant biomass chains at regional level.

Expected impact:

- Unlocking significant additional biomass potentials for advanced biofuels and higher value co-products at competitive cost levels. 50 million tons agricultural residues per year in EU27 (Biomass Futures); 80 million tons forest biomass per year in EU27 (EUWOOD); in addition 15 million tons of marine biomass.

KPIs:

- Quantity of biomass which has been or can be additionally mobilised by 2020 directly via these processes: 0,5-1 million tonnes.
- Proven sustainability of these processing chains according to RED.
- Cost competitiveness compared to existing chains.

Costs: EUR 120 million.

Timeline: 2014 - 2020.

Modality of implementation: European, National, Regional and Local.

INNOVATION AND MARKET-UPTAKE PROGRAMME

Action 1: Implement advanced conversion technologies at large scale energy-driven biorefineries and implement sustainable, reliable and efficient value chains at large scale (TRL=8)

Scope:

- Convert lignocellulosic feedstock, the organic fraction of waste/residues and marine biomass into cost-competitive advanced biofuels and co-bioproducts at large scale, by using biological or thermochemical production routes.
- Demonstrate at large scale the conversion of lignin and hemicelluloses into added-value products.
- Demonstrate process integration and cost-competitiveness technologies deployed at large scale plants and, in the longer-term, an industrial ecosystem. Technical and sustainability evaluations of their integration in the EU context, including feedstock production and logistics.
- Demonstrate improved methodologies for industrial production of enzymes.
- Demonstrate industrial production of catalysts for thermochemical routes.

Deliverables:

- Larger availability of industrial thermochemical catalysts and industrial enzymes.
- Significant number of developed integrated value chains at large scale (at least 1-3 per value chain).

Expected impact:

- Creation of a new bioenergy industry typically in rural regions.
- Decarbonisation of transport sector contributing to the 10 % target of the Fuel Quality Directive 2009/30/EC for 2020.

KPIs:

- Number of economically viable/sustainable large scale energy-driven biorefineries: 20-30 biorefineries with capacity of 50.000-100.000 tons advanced biofuels per year.
- Capex reduction by 30% by 2020 compared to 2014 estimates.
- Opex reduction by 20% by 2020 compared to 2014 estimates.

Costs: EUR 1200 - 1800 million.

Timeline: 2014 - 2020/2025.

Modality of implementation: 'Access to Risk Finance' (Horizon 2020) to provide a range of financial instruments and risk sharing mechanisms at EU level.

Action 2: Improve large scale logistics and storage of feedstock to provide a continuous supply (TRL=8)

Scope:

- Mobilize at pre-commercial scale an increasing biomass supply by sustainably increased productivity and mobilization of currently unexploited biomass, residues and the organic fraction of waste. Cost-efficient preparation of harvested material at farm level including for example, suitable packaging and water removal from biomass to reduce transport volume and improved storage capability.
- Cost-efficient preparation of heterogeneous waste-based feedstock to convert the organic matter into biofuels and bioproducts at pre-commercial scale.
- Integrate advanced lignocellulosic feedstock (e.g. agricultural residues and energy crops) supply, transportation and storage into a complete biorefinery logistics concept to demonstrate economics of year-round operation at an appropriate scale (up to 1.000.000 tonnes /year of biomass supply).
- Demonstrate at pre-commercial scale TRL 8 a portfolio of biomass supply chains, based on Best Practice, (subject to regional ecology and climate) with high potential for feedstock supply in relation to availability, infrastructure and supportive policy framework.
- Develop feedstock quality and monitoring systems both for wet and for dry storage at pre-commercial scale in order to have reliable predictions of feedstock availability and quality at commercial scale.
- Validation of large equipment to minimise logistics chain costs and to meet conversion requirements.

Deliverables:

- Range of competitive and energy efficient supply systems for different biomass feedstocks.
- Additional biomass mobilised.
- Cost-supply curves for biomass on regional level.
- Clear picture of available biomass potential at regional level.

Expected impact:

- Optimised large scale logistics and storage of feedstocks, thus reducing costs by 30 % while improving energy efficiency and usable biomass quantities.
- Improved sustainability.

KPIs:

- 30 % reduction in supply costs for forest biomass and agrobiomass residues compared to 2014 levels.
- 10-20 % decrease in production losses in relation to 2014 levels.
- Increase Energy efficiency of supply systems by 20% compared to 2014 levels.
- Quantity of biomass mobilised 20 million tons by 2020.
- At least 60% GHG emissions reduction by 2020 in accordance with EU legislation or voluntary agreements.

Costs: EUR 120 million.

Timeline: 2014 - 2020.

Modality of implementation: EU projects focussed on the development from TRL6-7 to TRL8.

Action 3: For innovative biofuel technologies, ensure continued R&D support through the development of innovative EU and national instruments, and relevant investment schemes to allow funding of more risky demonstration and flagship units, including integrated process concepts, also via public/private partnerships

Scope: Propose measures to harmonise incentive and taxation schemes for biofuels in transport by EC and MS:

- Sharing experiences of MS biofuels implementation programmes and incentives.
- Continuous improvement of distribution and end use system performance, and optimisation of value chains.
- Address challenges posed by higher blends, e.g. fuel distribution and end use.
- Matching fuel quality with fuel requirements of future low-emission high performance engines.
- Demonstrate effects of fuel composition and quality on the performance (emissions, power, and durability) of future advanced internal combustion engines.
- Develop and improve technical and sustainability standards and certification schemes for biomass quality (moisture, ash content, heating value, etc.) after pre-treatment.
- Increase consumer awareness on biofuels benefits and other bio-based products by documenting and communicating the environmental and economic benefits.

Deliverables:

- Consistent and harmonised incentive scheme for advanced biofuels in the EU.
- New fuel standards accommodating higher biofuel blends.
- Consumer awareness campaign based on sound information.

Expected impact:

- This action will show that advanced biofuels and bioproducts can be introduced in the market.

KPIs:

- Number of flagship units: 20-30 (capacity 50.000-100.000 tonnes biofuels per year).
- Share of infrastructure/filling stations able to distribute new fuel qualities such as E20/E25/.
- Number of vehicles fleets with new low-emission high performance engines.
- Percentage of consumer stating a positive image of biofuels/bioproducts.

Costs: EUR 96 million.

Timeline: 2014 - 2020.

Modality of implementation: European Coordination and Support actions.

Challenge 2: Hydrogen and Fuel Cells

KEY ISSUES

- Improve performance and reduce costs of the next generation of Fuel Cells Electric vehicles by a factor of 10 (compared to cost of small fleet FCEVs in 2010), whilst increasing lifetime towards 6000 operational hours.
- Improve modularity, refuelling time, reliability, safety and availability of hydrogen refuelling infrastructure, while reducing investment intensity and operational cost.

- Demonstrate competitive Fuel Cell Electric Vehicle (FCEV) and infrastructure solutions, by targeting around 100,000 FCEVs and around 1000 publically accessible hydrogen refuelling stations to transition the transport sector to sustainable renewable fuels.
- Contribute to the integration of intermittent renewable energies (wind, solar) by providing Multi-MW cumulative hydrogen conversion capacity for use in transport and stationary applications, including chemical feedstock or injection into the natural gas grid.
- Develop a portfolio of cost-competitive, energy efficient and sustainable hydrogen production, storage and distribution processes, with 50% of hydrogen used for H2 energy applications produced from renewable sources or from near zero-CO2 -emission sources.
- Develop and demonstrate APU applications for road, aircraft, rail and maritime applications by 2020.
- Assure development and production of competitive hydrogen and fuel cell technologies in Europe.

ADVANCED RESEARCH PROGRAMME

Action 1: Novel materials and components for Fuel Cell and Hydrogen technologies

Scope:

- In the field of transport applications fuel cells still need to fully reach the main targets of efficiency, (service) lifetime and costs. This requires strong research programs devoted not only to short term basic and applied research but also to medium long term breakthrough research. Research programs will have to contribute to the improvement of all components of a typical fuel cell system: from one side cell and stack components and from the other side balance of plant components. For example novel materials for advanced electrolytes (ionic conductors), for electrodes (anodes and cathodes), for "robust" stacks (metallic components, sealing, coatings), new concepts for heat exchangers, diagnostics and control tools, inverters, etc. catalysts and reformers, and reduction of sensitivity to fuel purity. Fuel cell system components and sub systems are still to be improved, especially air supply, anode loop components, and humidifiers. Additionally, low cost high storage density hydrogen storage systems on the basis of compressed hydrogen still need to be improved beyond the current status.
- Furthermore, research for electrolysis is needed on improved materials advanced Interconnectors, cells and sealings, coatings and catalysts, as well as for scalable stack technology. Advanced H2 production based on hydrocarbons and biofuels requires materials research for Ceramic and metal supported Pd- and next-generation membranes.

Deliverables: -

Expected impact: -

KPIs: -

Costs: EUR 15 million.

Timeline: -

Modality of implementation: European, National, Regional.

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Develop the capabilities necessary to initiate a European-wide refuelling infrastructure and FCEV deployment including road and non road vehicles and APUs (Auxiliary power units)

Scope: Within the road transport sector, find ways to increase demand for, and to develop the capabilities necessary to produce cost-efficient FCEVs (mainly passenger cars but also two wheelers or commercial vehicles) and to initiate a Europe-wide refuelling infrastructure. The objective is to:

- Improve and validate hydrogen vehicle and refuelling technologies to the level required for commercialization decisions by 2015 and a mass market roll-out as from 2020.
- Demonstrate competitive FCEVs and infrastructure solutions, by contributing a significant proportion of FCEVs and publically accessible hydrogen refuelling stations to the transition of the transport sector into drive train electrification.
- Develop production technologies for mass production of FCEVs in order to meet the goal of mass production readiness in 2020.
- Develop a safe, competitive and efficient H2 refuelling infrastructure in terms of refuelling time, capacity, availability and cost.

* Develop and demonstrate APU applications in particular for road, but also aircraft, rail and maritime applications.
* Adapt and demonstrate FCH technologies for propulsion in maritime, rail and aviation applications provided that there is sufficient industry commitment and engagement in these market segments.
* Further increase the performance of non-road fuel cell vehicles like forklifts to increase their competitiveness.

Deliverables:

* Next generation FCEVs with a ten-fold (compared to 2010) reduction in production cost of the fuel cell systems and with lifetimes of 6,000 operational hours and maintained (or even increased) driving performances.
* Volume based production technologies that reduce by a factor of 10 passenger vehicle production costs (including all powertrain components).
* APU demonstrated for road, aircraft, rail and maritime applications by 2020.
* Modular, turnkey HRSs (Hydrogen Refuelling Stations) scalable capacity that is competitive and efficient in terms of refuelling time, capacity, availability and cost.
* A series of demonstration projects with around 1000HRS and 100 000 FCEV by 2020 as part of nationwide roll-out experiences with HRSs and vehicles. These demonstrations will be embedded in a wider European refuelling infrastructure in a number of Member States to support the introduction of FCEVs in the EU by 2020.
* Technologies for competitive materials handling applications (e.g. forklifts and other material handling systems at warehouses, airports, docks, etc.) implemented at an economic scale 50+ per site.
* Pilot production lines for PEM-FC systems and FCEVs.

Expected impact:

* Reduction of the CO2 emissions and of particles emissions.
* Decrease in fossil fuel consumption with a positive impact on Europe energy security.
* A substantial growth in the hydrogen vehicles and hydrogen refuelling stations sector with direct job creation and indirectly in associated supply chain.

- This impact will only be reached if the whole chain from H2 production to utilisation is developed and implemented (actions 2).

KPIs:

Application	Parameter	Unit	2012	FCH-JU target		
				2017	2020	2023
Fuel cell electric passenger cars	Specific FC system cost Assumed number of units (per year) as cost calculation basis	€/kW	>500	150 20 000	100 50 000	75 100 000
	FC Vehicle cost (C-segment)	k€	200	70	50	30
	Tank-to-wheel efficiency (vehicle in New European Drive Cycle)	%	40	42	45	48
	Availability	%	95	98	98	99
	FC system Lifetime	hours	2500	5000	6000	7000
Fuel cell electric buses	Specific FC system cost	€/kW	< 3500	< 1800 750	1000 500	800 400
	FC Bus System Lifetime	hours	10000	15000 2 x 8000	20000 2 x 10000	25000 2 x 12500
	FC Bus cost	k€	1300	700	650	500
	Fuel consumption (vehicle, average of SORT1 and SORT2 cycle)	kgH2/100km	9	8.51	8	7.59
	Availability	%	85	90	95	99
	Assumed number of units (per year) as cost calculation basis			< 50	200	> 500
Hydrogen Storage	Hydrogen storage system cost	€/kg H2	>3000	800	600	500
	Volumetric capacity (H2 tank system)	Kg/l	0.02	0.022	0.023	0.025
	Gravimetric capacity	%	< 4	4	5	6

	(H2 tank system)					
Material handling vehicles FC system	Specific FC system cost	€/kW @10 kW	4 000	< 1500	< 1200	< 1000
	Hydrogen storage system cost	€/kg H2	> 3000	< 1000	< 750	< 500
	Lifetime	h	<5000	<10000	>10000	<15000
	Efficiency	%	>45%	>50%	>52%	>55%
	Availability	%	>90%	>95%	>98%	>99%
Hydrogen Supply	Hydrogen refuelling stations cost[21]	M€	1.5 -3.5	1.0-2.5	0.8–2.1	0.6 - 1.6
APU for truck applications (3 kW)	Specific FC system cost	€/kW	> 10,000	< 5,000	< 3000	< 1500
	Lifetime	hours	2000	5000	8000	12000
	Efficiency	%	25[1]/35[2]	30[1]/40[2]	32[1]/44[2]	35[1]/50[2]
	Availability	%	60	80	90	95

Costs: EUR 3 200 million.

Timeline: 2014 - 2023.

Modality of implementation: European, National, Regional.

Action 2: Produce and distribute hydrogen with a low carbon foot print at a competitive cost for transportation and other applications

Scope: This action will address:

- Hydrogen production from renewable electricity including system integration, large scale hydrogen storage, blending into the natural gas grid and the business model development.
- The challenge for 2020 is to develop hydrogen production and storage solutions that are competitive and adapted to offer relevant services to the grid while taking advantage of a higher volatility in electricity prices and develop potentially profitable business cases. Compared to single-digit MW in 2014, the typical scale for those systems in 2020 shall reach 10 MWs per unit at least.
- Hydrogen production with low carbon footprint from other resources (grid electricity, gas, solar energy, biogas, waste streams) and waste hydrogen recovery.
- Fuel cell vehicles using low cost hydrogen produced centrally by natural gas reforming already considerably reduce carbon emissions compared with vehicles powered by current state of the art gasoline or diesel engines. However, the objective and challenge is to further reduce the carbon footprint of hydrogen production (e.g. reforming of carbonaceous feedstock, high temperature water splitting, photoelectrochemical and biological, with innovative purification technologies) while assuring a reliable and low cost fuel.

---

[21] 700 bar HRS with 200 to 1000 kg/day capacity including on-site storage

- Emphasis is on improving efficiency and reduces costs of hydrogen production, increase yield and reduce costs of purification methods, and improve carbon dioxide removal from production pathways.
- Hydrogen storage, handling and distribution: compressed gas, cryogenic liquid, solid or liquid carriers, pipelines:
  - Industrial scale storage to deal with imbalances between supply and use of hydrogen, in particular caused by fluctuations of renewable electricity.
  - Innovative large scale hydrogen compression technologies with improved efficiency and cost effectiveness.
  - Improved delivery concepts to increase customer base around central facilities.

Deliverables:

- A number of on-site electrolysis systems with reduced operational and capital costs and electrical efficiency of up to 77%.
- Electrolysers with reduced TCO (in EUR/kg H2) from both lower CAPEX and increased reliability and lifetime, able to exploit opportunity costs of electricity and flexible in terms of start-up time, ramp rates, etc. to provide of ancillary grid services.
- Multi-MW electrolysers for power to gas and large-scale consumers, enabling integration of renewable energy sources, based on novel electrolysis concepts: high temperature, co-electrolysis, as well as other power-to-hydrogen processes with alternative feedstocks.
- A report on the requirements of Transmission and Distribution System Operators (TSO/DSO) for the design of suitable hydrogen production systems that take account of both technical and economic needs.
- One large single or several MWh scale storage systems for smart Grids, and 10s-100s kWh capacity for stationary applications.
- A minimum 10 tonne industrial scale hydrogen storage system with an investment cost at or below EUR 400 000/tonne.
- For the injection of renewable hydrogen in the natural gas grid:
  - A number of electrolyser systems integrating GWH of renewable power mainly from intermittent sources into the natural gas distribution systems in the range of 2-5%.
  - Studies and tests that demonstrate the feasibility of 20% vol of hydrogen in the natural gas grid.
- High pressure truck trailers with increased capacity of 1000 kg/truck at an investment cost of 500 EUR/kg H2 capacity. Validated and pertinent permitting processes for Europe. The trucks will have an unloading time below 60 minutes, including the time needed to connect to the customer facility.
- A transport and storage system for liquid hydrogen for truck transport as well as shipping and/or rail transport, with a capacity of 3500kg of hydrogen or more and cost below 200 EUR/kg H2.
- Co-electrolysis of CO2 and Hydrogen developed and demonstrated.
- Small scale, on-site hydrogen production systems from renewable fuels (biogas, bio-(m)ethanol) for decentralized hydrogen production with Capex reduced by 40% and Opex by 10% when compared to current state-of-the-art.
- Catalysts and materials with increased life-time for direct solar pathways such as high temperature water splitting and photoelectrolysis to produce low cost and low carbon footprint hydrogen. Pre-commercial demonstrator powered by sunlight.

- Biological reactors with increased volumetric productivity 50 times and scale 200 times the current state-of-the-art while maintaining or increasing (by 10%) the carbon yield of biomass input.
- New adsorbent materials (e.g. Metallic Organic Frameworks, enzymatic adsorbents) plus improved and optimized designs and cycle times that, together, improve yield and reduce costs of PSA systems.
- Low cost systems for hydrogen recovery of waste streams and other hydrogen containing streams. Many new biological and current waste streams contain low concentrations of hydrogen. New system designs will need to be developed to economically and efficiently (energy) purify such streams.
- Membranes with new alloys or other materials for membrane separation systems to reduce minimum operation temperatures (from 300 down to 180°C), reduce of costs and increase of hydrogen flux (100%).

Expected impact:

- A reduced need for ever-greater quantities of renewable electricity, bio-fuels and bio-energy necessary to create a sustainable low carbon energy system after 2030 (as mentioned in a recent IEA report[22]).
- A substantial growth in the hydrogen and fuel cell technology sector with direct job creation and indirectly in associated supply-chains.

KPIs:

These KPIs are consented between FCH2JU members and included in the MAWP.

Electrolysis:

		2012	2017	2020	2023
KPI 1	H2 production electrolysis, energy consumption (kWh/kg) @ rated power	57-60 @100kg/d	55 @500kg/d	52 @1000+kg/d	50 @1000+kg/d
KPI 2	H2 production electrolysis, CAPEX @ rated power including ancillary equipment and commissioning	8.0 M€/(t/d)	3,7 M€/(t/d)	2.0 M€/(t/d)	1.5 M€/(t/d)
KPI 3	H2 production electrolysis, efficiency degradation @ rated power and considering 8000 H operations / year	2% - 4% / year	2% / year	1,5% / year	<1% / year
KPI 4	H2 production electrolysis, flexibility with a degradation < 2% year (refer to KPI 3)	5% - 100% of nominal power	5% - 150% of nominal power	0% - 200% of nominal power	0% - 300% of nominal power
KPI 5	H2 production electrolysis, hot start from min to max power (refer to KPI 4)	1 minute	10 sec	2 sec	< 1 sec
KPI6	H2 production electrolysis, cold start	5 minutes	2 minutes	30 sec	10 sec

[22] Energy Technology Perspectives 2012: Pathways to a Clean Energy System (ISBN: 978-92-64-17488-7)

Notes: (*) KPI 4 and KPI 5 shall be considered as optional targets to be fulfilled according to the profitability of the services brought to the grid thanks to the addition of flexibility and (or) reactivity (considering also potential degradation of the efficiency and lifetime duration).

"H2 Production . . . @ rated power *"- * corrected for 30 bar hydrogen output pressure.

Other production pathways:

Key performance indicator (KPI)	2012	2017 target	2020 target	2023 target
Distributed H2 production from biogas, CAPEX	4.2 M€/(t/d)	3.8 M€/(t/d)	3.1 M€/(t/d)	2.5 M€/(t/d)
Distributed H2 production from biogas, efficiency (HHV)	64%	70%	70%	72%

Hydrogen storage, handling and distribution:

Topic	Parameter	Unit	2012	FCH-JU target		
				2017	2020	2023
Tube trailer transport	Trailer Capex	M€/t capacity	0.55 (@400 kg)	-	0.55 (@ 800kg)	0.45 (@1000kg)
Liquid H2 storage	Container Capex	M€/t	0.30		0.25	0.20
Gaseous Hydrogen storage	System Capex	M€/t	0.5		0.45	0.40

Costs: EUR 1 300 million.

Timeline: 2014 - 2023.

Modality of implementation: European, National, Regional.

INNOVATION AND MARKET-UPTAKE PROGRAMME

Action 1: Facilitate the transition to the market of Fuel Cell and Hydrogen technologies in transport and other applications

Scope: This includes the following activities:

- Safety is of paramount for public acceptance of FCH technologies and special attention will be paid to technology transfer from the professional community to the general public.
- Pre-Normative Research. This will among other actions include harmonisation of testing procedures and of reporting templates, as well as establishment of commonly agreed representative loading profiles (stressors) for different applications of FCH technologies, such as automotive and stationary fuel cells. Particular emphasis will be placed on aligning with international efforts in this area eg USA and Japan.
- Regulations, Codes and Standards (RCS) observatory and coordination of strategy definition.
- Education and training, targeting scientists, engineers, technicians and decision/policy makers outside the FCH sector. These activities will be coordinated with education activities identified in the SET Plan and combined where additional funding can be leveraged and will

target consolidation of European technical training through networks between academia, industry and research with a particular emphasis establishing pan-European education activities on safety and RCS to provide knowledge and transfer safety technology to all interested stakeholders.

- Identification and development of financial mechanisms to support market introduction. Participation to the Death Valley financing.
- Activities to increase social acceptance and public awareness: general public conferences and workshops, brochures, public 'show rooms', e.g. museum displays; addressing and informing local authorities, certification bodies, first responders, etc.
- Support portable applications and other niche market fuel cell solutions for market dissemination to prepare the introduction into the market of other FCH transport technologies and build a competitive European supply chain of necessary components.
- Conduct socio-economic research to determine the environmental and societal impact of FCH technologies in transports, their effect on European GHG emissions and primary energy use, and their effect on the economy. This will be done in order to identify and/or support new business cases and feasible models.
- Conduct projects on recycling and dismantling of FCH technologies such as fuel cell components (stacks and system components), composite tanks, etc.
- Maintain international connections in order to monitor hydrogen energy evolution outside Europe and be able to suitably interact with relevant developments.
- Information exchange and networking regarding European and national/regional/international FCH associations, industrial groupings and municipalities; hosting a web site dedicated to general technical and deployment information.

Deliverables:

- An RCS framework compatible with the deployment of FCH technologies, in particular for transportation.
- Up-to-date safety rules and standards
- Financing tools adapted to the specificities of the deployment of Fuel Cell Electric Vehicles and the Hydrogen Refuelling Station infrastructure.
- Acceptance of the FCEV by the public.

Expected impact:

- FCH technologies ready for full commercial uptake in a number of applications, including transport and the related infrastructure.
- A substantial growth in the hydrogen and fuel cell technology sector with direct job creation and indirectly in associated supply-chains.

KPIs:

- 100 000 FCEVs on the road in 2020.
- 1000 HRS in Europe in 2020.

Costs: EUR 11 100 million.

Timeline: 2014 - 2023.

Modality of implementation: European, National and Regional.

Challenge 3: Alternative Fuels

Liquid hydrocarbons, and to a lesser extent liquefied or compressed gaseous hydrocarbons, are expected to continue playing a key role in the medium term for a number of transport applications (e.g. long haul road freight, shipping, aviation) requiring energy carriers with high energy density per unit volume and mass to enable a large driving range. The infrastructure for distribution and storage of such fuels is already available.

KEY ISSUES

- Most production routes yield high quality / high purity fuels. Diesel, kerosene and gasoline from power-to-liquid routes can be used in existing engines. The premium fuel qualities of synthetic fuels may be utilised for improved efficiency and emission performance in advanced engine concepts.
- There is no clear vision on the energetic, ecologic and economic feasibility of this option, nor on the role that power-to-liquid technology can play in the transition to sustainable mobility.
- Key issues include:
  - In terms of energetic efficiency the multi-step production processes need to be simplified by **new catalytic routes**.
  - **New reactor concepts** need to be developed enabling better heat and mass transfer and higher yield.
  - Processes need to be analysed in terms of adjusting the dynamics of fluctuating renewable power supply to the chemical conversion by **integration of storage or increased dynamic operation** of the various process steps.
  - **Thermal integration and utilization of all material streams** are inevitable for increasing the overall efficiency of the process.
  - Focusing on the later use as transportation fuel for heavy transport, shipping or aviation, the processes need to be adjusted for production of a **specifically tailored hydrocarbon product range**.
  - Process development and techno-economic evaluation of innovative process concepts needs to provide a basis for technological development.

ADVANCED RESEARCH PROGRAMME

Action 1: Development of sustainable catalysts and process technologies for CO2 to methanol and fuels

Scope: Development of sustainable catalysts and process technologies for CO2 to methanol and fuels for advanced methanol production from CO2 for fuels production.

Deliverables:

- Development of unconventional routes to methanol, including selective methane oxidation, methane pyrolysis, reduction of formic acid, or low temperature synthesis in liquid phase.
- Development of efficient catalysts, coupling water permeoselective membranes with catalysts for rWGS and methanol synthesis to reduce process steps and improve productivity, development of novel catalysts less sensitive to inhibition by high concentration of CO2 and H2O or impurities from CO2 capture and purification step to improve catalyst productivity and stability.
- Optimization of purification and energy integration schemes to increase energy efficiency, recycle unconverted reactants and adapt product composition to next stages process.
- Identification of BAT for low carbon hydrogen production that can reach production prices needed for CO2 to fuels process to be economically competitive at the time CO2 to fuel technology reach commercial scale.
- Solar-assisted CO2 conversion into liquid hydrocarbons.

Expected impact:

- Proof of concept for cost-competitive production of methanol and other CO2 to fuel routes.

KPIs:

- Productivities > 0.8 (kg MeOH/kg cat·h).
- Catalyst stability 300-500 h.
- 10 - 50 L alcohol/day production.

Costs: EUR 20 million/5year project.

Timeline: 5 years.

Modality of implementation: Requires European , MS, and industry support coordinated at European level.

TRL range: 2 - 4.

Action 2: Development of electrodes and membranes for direct selective conversion of CO2 to methanol, ethanol, or other fuel molecules using renewable energy

Scope: This approach tries to give an answer on rather unconventional ways of producing fuels as methanol and ethanol. Electrochemistry offers a way of minimal energy input to get optimal catalytic conversion of CO2 into fuels as ethanol and methanol. Selecting the right potential will optimise the energy transfer in the electrochemical system and trigger the catalyst to the highest efficiency. As catalyst as well chemical catalysts as biocatalysts as enzymes and microoarganisms can be used. Aim of the approach is to see if less purified and concentrated CO2 streams can also be processes. Especially in the case of microorganisms, immobilized on the cathode, water content and small sulphur concentrations will not influence the conversion.

Deliverables:

- Development of electrode and membrane-electrode assemblies for optimal electrochemical catalyst immobilization and electrochemical processes.
- Development of a robust system allowing less purified CO2-streams.
- Selection of optimized electrochemical catalysts.
- Selection of optimized biocatalysts with special emphasis on robustness.
- Combination with renewable energy peaks (up and own in process).
- In situ product recovery of alcohols from the cathode system.

Expected Impact:

- Possibility to convert less pure CO2 into methanol and ethanol will lead to strong purification costs of the CO2-stream reduction.
- If the upscaling via a cassette-based system is not exaggerating in costs, a cheaper production method can be achieved.
- A process that can handle electricity peaks and will not be killed by down time (no excess of energy).

KPIs (for monitoring):

- 10L alcohol/day production.
- With electricity price at zero (peak shaving) costs must compete with bioethanol price.

Costs: Minimum EUR 6 to 9 million/project with timeline of 3 years (TRL 4 - 5).

Timeline: 5 years.

Modality of implementation: Requires European , MS, and industry support coordinated at European level.

Action 3: Development of gasoline and Diesel from CO_2

Scope:

- Conversion of CO2 to gasoline via methanol (MTG) using zeolitic (MFI-type) catalysts.
- Conversion of CO2 to diesel: Development of catalysts for Fischer-Tropsch synthesis from CO2 (CO2-FT) with high productivity and stability; development of catalysts coupled with water permeoselective membranes to improve performances in equilibrium-limited rWGS.

Deliverables:

- Successful development of catalyst with improved productivity and stability.
- Successful development of catalysts microreactor technology for distributed production and improved coupling with methanol production from CO2.
- Successful development of catalyst with higher productivity and stability using directly CO2.

Expected impact: Proof of concept.

KPIs (for monitoring):

- Cost effective technology that can be competitive.
- Integrated concept with catalysts and permeoselective membranes.

Costs: 6 million/3 year's project.

Timeline: 3 years.

Modality of implementation: Requires European, MS, and industry support coordinated at European level.

Action 4: Process Development and Techno-Economic Evaluation

Scope: To be able to evaluate the processes for production of alternative fuels from renewable hydrogen by electrolysis and CO_2 flowsheeting simulation tools are needed. These need to include all single process steps being based on experimental data. Themodynamic property methods as well as thermo-physical properties of the multi-component hydrocarbon mixtures have to be taken into account. Based on the desired hydrocarbon product the simulation tool can then be used to identify suitable process routes and increase energetic efficiency by generating a high level of integration of heat and material streams. Adding economic figures to the various process components enables techno-economic evaluation of the overall process.

Deliverables:

- Process simulation tool covering the overall process with all single steps.
- Advanced process concepts and operational strategy for production of tailored liquid fuels from renewable power and CO2.
- Techno-economic evaluation of process concepts.
- Concept for integration and role of this technology in a future energy system.

Expected impact:

- Evaluation of power-to-liquid process routes for supply of alternative fuels that are not based on biological routes.

KPIs:

- Energetic efficiency of the overall process (power to fuel).
- Overall cost for production of power-to-liquid fuels.

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: -

Action 5: Sustainable production of required process heat

Scope: The overall efficiency of the power-to-liquid process can be significantly increased by using high temperature electrolysis SOEC instead of low-temperature polymer or alkaline electrolysis. This is realized by introducing solarthermal process heat for generation of steam for the SOEC process.

Deliverables:

- Development of SOEC in xx kW-scale.
- Concept for integration of SOEC with synthesis steps for liquid hydrocarbons.

Expected impact: -

KPIs: -

Costs: -

Timeline: 2014 - 2020.

Modality of implementation: -

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action1: Pilot plants for CO2-based fuels.

Scope: Demonstration of CO2 to fuels advanced technologies.

Deliverables:

- Large scale integrated demonstration activities including critical steps (H2 electrolysers, or other low carbon footprint technologies, CO2 recovery from real flue gases, CO2 conversion process technology).
- Several demonstration plants with different reactor configurations (e.g Membranes reactors, multitubular reactor) and process schemes (e.g single stage configuration vs two stage configurations (RWGs+ MeOH).
- Define simulation models including kinetics sand thermodynamics, purifications and energy integration schemes and LCA analysis for the whole system.

- Economic and LCA benchmarking with other biofuel competitive routes.
- Establish cooperation and networks between public and private entities to favour knowledge sharing that would help to overcome in a more efficient ways technical barriers to the deployment of CO_2 to fuels technologies.

Expected impact:

- Verify the techno-economic viability of different CO_2 to fuel technologies and demo scale.

KPIs:

- Productivities > 1 (kg MeOH/kg cat·h).
- Catalyst stability 800-1000 h.
- 500-800 L alcohol/day production.

Cost: EUR 25-35 million/project, 4 years.

Timeline: 5 years.

Modality of implementation: Requires European, MS, and industry support coordinated at European level.

Action 2: Demonstration of selective conversion of CO_2 to methanol, ethanol, or other fuel molecules using renewable energy

Scope: Demonstration of Research Action 2 proposed above.

Deliverables: demonstration of

- Electrode and membrane-electrode assemblies for optimal electrochemical catalyst immobilization and electrochemical processes.
- A robust system allowing less purified CO_2-streams.
- Optimized electrochemical catalysts.
- Optimized biocatalysts with special emphasis on robustness.
  Combination with renewable energy peaks (up and own in process).
- In situ product recovery of alcohols from the cathode system.

Expected impact:

- Possibility to convert less pure CO_2 into methanol and ethanol will lead to strong purification costs of the CO_2-stream reduction.
- If the upscaling via a cassette-based system is not exaggerating in costs, a cheaper production method can be achieved.
- A process that can handle electricity peaks and will not be killed by down time (no excess of energy).

KPIs (for monitoring):

- 100 L alcohol/day production.
- With electricity price at zero (peak shaving) costs must compete with bioethanol price.

Costs: EUR 12-15 million / 3 years project.

Timeline: 2017 - 2020.

Modality of implementation: Requires European , MS, and industry support coordinated at EU level.

INNOVATION AND MARKET-UPTAKE PROGRAMME

Action 1: CO2 based fuels should be recognized as renewable fuels and benefit from appropriate regulation (e.g. Renewable Energy Directive)

Scope: Calculation of CO2 reduction in the fuel producing process and leading to credits and definition of appropriate regulation.

Deliverables:

- LCA methodology standardization for CO2 to fuels technologies benchmarking, including WTT and WTW analysis.
- Perform WTW LCA analysis for CO2 based fuels. Benchmarking against biofuels products taking into account ILUC impact.
- Define incentive mechanisms to favour CO2 to fuel integration into the renewable fuel system correlating GHG reduction potential with the incentive or study other different incentive possibilities.
- Perform a detailed study on the forecasted excess renewable energy that would we available for CO2 conversion process in order to define the potential market for this processes.
- Need for regulations and tools that define how CO2 price/tax will be manage within different actors involve in the whole chain (CO2 emitters , CO2 transformers) and how it will be evaluated and quantify.

Expected impact:

- Effective incentive to convert CO2 to renewable fuel.

KPIs (for monitoring):

- Sound and recognized adopted calculation system.

Costs: EUR 2 million.

Timeline: 5 years.

Modality of implementation: Requires European , MS standardisation bodies and industry support coordinated at EU level.

Action 2: Adaptation of current systems (e.g. vehicles) to integrate CO2-based fuels

Scope: cope with technological requirements of the CO2-based fuels and modern engines and promote Flexi Fuel Vehicles development.

Deliverables:

- Define test programs to demonstrate performance viability of different methanol-gasoline mixtures or other CO2 based fuels on conventional, modified existing engines or new configurations.
- Study the impact and modifications needed for the integrations of CO2 fuels in current distribution system.

Expected impact:

- New renewable fuels available for transport.

KPIs (for monitoring):

- Engine efficiently working on CO2-based fuels.

Costs: EUR 10 million.

Timeline: 5 years.

Modality of implementation: Requires European, MS and concerned industry sectors support coordinated at European level.

HEADING 4: Enabling Decarbonisation of the Fossil Fuel-based Power Sector and Energy Intensive Industry through CCS and CCU/CCUS

The critical role of CCS in decarbonising Europe is now indisputable: by accounting for 19-32% of the EU's total emissions reductions by 2050 (EU Energy Roadmap 2050) and by complementing intermittent renewable energy sources with low-carbon, baseload and balancing generation. It also increases independence for the energy supply and is the only tool which can balance increased security of supply, diversification of suppliers and a progressive climate policy. To exploit all its potential, CCS has to be applied at large scale and financial, national regulatory, infrastructure, environmental and social issue could all present barriers to CCS demonstration and deployment.

In addition, the conversion of CO2 from flue gases into chemicals, polymers and materials may contribute to the decarbonisation of Europe through the displacement effect of fossil fuel usage.

The most recent IPCC report (5^{th} assessment report) states that if CCS is not deployed, the cost of keeping to a 2deg warming target will be doubled and that carbon negative solution will be needed.

Challenge 1: CO2 Capture

KEY ISSUES:

- Production value chain performance/cost competitiveness.
- CCS is a key element in a low carbon policy for Europe. The roll-out has been hampered by costs and techno-economic uncertainties of the CCS value chain, where CO_2 capture is a major element. There is thus a need to demonstrate capture technologies for both coal and gas fired power plants in real market conditions by 2020 for CCS and to adapt/optimise/develop capture technologies to the energy-intensive industries, in particular the iron, steel, cement and refinery sectors. The challenge of costs and capture rate has to be addressed to be competitive and to provide lowest acceptable emissions. BioCCS is an option for improved sustainability; this needs to be better understood, explored and framed in a large scale context with the option to be carbon neutral/negative.
- Supply chains (industrial logistics, maintenance, materials and manufacturing, recycling).
- CCS can be employed in 2.5 GW power production by 2025 allowing for large scale commercial deployment of flexible power plants by 2030, achieving 3.5 GW the same year and reaching 200 GW by 2050. This is a major undertaking that will require new sectors to develop with possibilities for the use of new materials, processes and practices. It is a desire to recycle or use CO_2 and avenues for exploring this should be investigated.
- System integration (smart interfaces, new capabilities of equipment, new or improved services to system, forecast).
- The European energy system will be more diversified in the future with flexibility and energy storage being key. Thus, CCS solutions that offer operational flexibility are needed. To address this challenge we need improved approaches and processes for effective integration

of CO2 capture in power plants and relevant energy-intensive industry subject to large variability of load changes. And we need realistic process and economic models that allow cost effective capture technology choices in market conditions with variable demand. **Societal issues (environment impact, safety, health, social acceptance).**

- CO_2 capture must be proved to be feasible and safe with a minimal environmental footprint . It is thus a need to develop technologies with minimal and accepted environmental impact (locally, globally). CCS is potentially a huge market for the CO_2 capture vendor industry in Europe. This needs also to be communicated and understood in the total picture of CCS including the link to a sustainable process industry, the bio economy and low carbon power to Europe.

ADVANCED RESEARCH PROGRAMME

Action 1: Basic R&D for supporting pilots and demonstration actions

Scope: Link insights gained from pilot-scale (and also any commercial-scale) experience with a targeted programme of fundamental work (lab and desktop studies) to ensure that relevant aspects of underpinning science are fully understood in critical areas for CCS. This could for instance be targeted materials and process analysis development and understanding, thermo-physical properties of working mediums and CO_2 mixtures, emissions from capture processes, corrosion in CCS processes, combustion properties and behaviour of fuels used in CCS processes, modelling tools development and experimental work.

Deliverables:

- Extensive databases from pilot-scale campaigns and linked fundamental studies that can be used to support commercial-scale CCS project design and development in general and particularly, to support the design and development of capture plants.

Expected impact:

- Knowledge and understanding developed to ensure minimal 'unintended consequences' associated with CO2 capture deployment (e.g. non-CO2 emissions to environment).
- Provide a sound basis for industrial leadership in this area by a vast pool of data, knowledge and models, prepare the ground for innovation and patents.

KPIs:

- Improved international academic ranking of universities and institutes in Europe.
- 20% increased publication rate within this topic by European R&D institutions compared to 2013.
- Global best practices and databases established.

Costs: EUR 160 million.

Timeline: Continuous - 6 years in this context.

Modality for implementation: Requires European, MS and industry support coordinated at EU level. MS support must provide the backbone of this activity together with European incentives to promote excellence in science.

Action 2: Proof of concept of efficient capture technologies for pan-industrial utilisation

Scope: Develop and experimentally test novel efficient capture technologies that can significantly reduce costs and improve efficiency in power and industrial processes including the subsequent use of CO_2 as a feedstock. Ultimately bio-CCS capabilities can also enable carbon neutral or even carbon negative fossil fuel utilisation. Such breakthrough concepts should have demonstrated a theoretical high potential and their development should be targeted around lab scale prototypes operating under realistic process conditions.

Deliverables:

- Breakthrough CO2 capture concepts with potential for significantly reduced cost of capture and improved efficiency adaptable to industrial and power processes with fuel flexibility including biomass-or biomass derived fuels (not exhaustive).
- Looping technologies (Chemical Looping Combustion, Calcium Looping)
- Oxy-fuel systems with adaptability to energy intensive industries
- Integrated concepts (e.g. liquefaction technologies, membranes, sorbents)
- Novel solvents
- Produce 5 promising concepts based on a long list of 10-15 candidates

Expected impact:

- Improved security of supply by reducing the need for extra fuel (energy) to produce goods and power, increased use of indigenous resources.
- Sustainable process industry including increased use of biomass, bolster against carbon leakage.
- Increased competitiveness by low carbon footprint, preparing for carbon labelling.
- A strengthened European vendor industry in a highly competitive market.

KPIs:

- <5% efficiency loss (% points)- @proof of concept.
- Carbon neutral to negative processes tested in bench scale size.
- >50% operational cost or >25% capital cost reduction based on present status for applications to various processes – proved by tests and calculations.
- List of promising solutions to be further investigated produced within yr. 2 of this activity

Costs: EUR 280 million over 6 yrs.

Timeline: 6+ years for development and testing.

Modality for implementation: Requires European, industry and MS implementation.

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Piloting of promising capture technologies

Scope: Pilot-scale testing of promising CO2 capture options such as looping technologies, oxy-fuel systems with adaptability to energy intensive industries, integrated concepts (e.g. liquefaction technologies, membranes, sorbents) and novel solvents with a focus on proving performance with realistic fuel and flue gas conditions including transient operating conditions.

- Develop improved approaches and processes for effective integration of CO2 capture in power plants and relevant energy-intensive industry subject to large load variability.

Deliverables:

- Knowledge base from extensive pilot plant campaigns, of the actual performance and costs of breakthrough CO2 capture technologies piloted under suitable conditions for scaling up.
- Realistic process and economic models that allow capture technology choices in market conditions with variable demand. Advanced real time predictive models that contribute to

the day-to-day operation of CO2 capture plants (and can be integrated into relevant models including other aspects of the CCS chain).

Expected impact:

- Successful development of efficient and reliable CO2 capture technologies that are tailored to a broad range of applications and can speed up the scale up process to commercial units.
- Safe and cost effective operation of the capture plant in order increase competitiveness and allow integration with storage sites or use of CO2.

KPIs:

- <5% efficiency loss (% points) @pilot scale.
- >50% operational cost or >25% capital cost reduction based on present status for applications to various processes.
- Flexibility gain of 50% less time for ramp-up 0-100% load, quick start enabled.
- Long term operation of test-runs > 6.000 hours.
- Environmental footprint of the various techniques established.

Costs: EUR 370 million, 3 major pilot sites.

Timeline: now to 6+ years for a long-term programme.

Modality for implementation: Requires European, MS and industry support and implementation.

Action 2: Prove options to utilise the full potential of bio-CCS

Scope: Modify current state-of-the-art techniques or develop new techniques suitable for bio-CCS and accelerate its development by demonstration in commercial pilots.

- Correspondingly investigate ways so as to achieve CO2 credits in order to generate a positive business case.
- Stimulate the development of a trading scheme that provides sufficient CO2 credits to allow commercial operation with bio-CCS.

Deliverables:

- Understanding of the modifications required to realize bio-CCS on a technical level for oxy-fuel, post- and pre combustion technologies.
- Explore the possible use of biomass waste or other low cost feed stocks from biomass.

Expected impact:

- Contribute to large scale implementation of Bio-CCS within 2020 and beyond.
- Enable CCS deployment at large by providing a case for more sustainable use of indigenous resources.
- Improved security of supply for Europe within adopted climate targets.

KPIs:

- BioCCS/co-firing BioCCS demonstration plant at more than 50MW power and heat with neutral to 25% negative emissions.
- Enable conversion of several industrial processes to carbon neutral to carbon negative operation by use of biomass- supported by studies, testing and pilots.

Costs: EUR 160 million.

Timeline: 6 years.

Modality for implementation: Requires European, MS and industry support and guidance on the ETS.

Challenge 2: CO2 Storage

KEY ISSUES:

- Cost and Risk reduction. There remain a number of opportunities to further reduce both commissioning and operational costs that result from technical uncertainties and risks associated with the development of a new industry. Policymakers need a detailed comparable assessment of storage capacity to allow planning of post-demonstration CCS implementation, design of storage clusters and supporting transport infrastructures. The availability of suitable storage sites is therefore of critical strategic importance to CCS deployment: yet Europe is falling behind in developing a European Storage Atlas.
- Characterization of storage sites, monitoring, measurements and verification of site performance have been demonstrated to a limited extent but require further improvements to enable wider and safe deployment. Further progresses can be reached, through R&I in pre-competitive characterisation of storage sites, monitoring, enhancing on- and off-shore leakage detection and measurement, safe and efficient storage exploitation, not only in depleted oil/gas fields but mainly in saline aquifers.
- Pilot storage sites are not available to test the full range of storage operations. To validate the envisaged R&I progress in "real-life" geological conditions, up to six new storage pilots are urgently needed. Issues such as storage optimisation, pressure management, plume steering, validation of models against monitored data for untested storage options can be only tackled if these storage pilots are available, which will also enable and support larger demonstration projects in Europe. It is critical that these envisaged storage pilots are "open laboratories".
- Social acceptance is crucial for CO2 storage but some experiences show that publics remain to be convinced. Direct involvement of the local population and the public at large has to be one of the goals of the envisaged actions dealing with pilot and demonstration programmes. Social concerns, now the most important barrier for many geological storage projects, may be turned into social awareness of the benefits of storage, for reducing CO2 emissions, for creating job opportunities and contributing to a the role that CCS might play in the future integrated energy system.

The following proposed programmes and related actions address these issues:

ADVANCED RESEARCH PROGRAMME

Action 1: European ATLAS of potential storage sites

Scope:

- Define methodologies to evaluate storage potentials, by building upon past experiences and projects.
- Undertake a screening study to catalogue and prioritise existing storage options.

- Develop strategies for providing storage infrastructure for storage projects that will follow on from the initial demonstration projects currently underway.

Deliverables:

- Agreed methodology for site characterisation to meet relevant financial, regulatory and reporting standards.
- Online atlas of appraised storage sites at pre-competitive characterisation level.
- Storage development plans on a regional basis integrated between MS and European storage infrastructure.

Expected impact:

- Creation of supply chains to provide storage infrastructure with job creation.
- Cost reductions (~10-20%) and increased efficiencies and safety through cluster development and nationally- and regionally-planned storage development.

KPIs:

- Pre-competitive characterisation to meet 1.8 Gt storage in 2030 and 12.2 Gt storage in 2050 from national atlases in key MS and historic capacity estimates in others.
- 4-5 development strategies for 2020-2030 for post-demonstration deployment.
- Up to 6 regional and national integrated storage development plans by 2020 providing clarity to policymakers and industry.

Costs: EUR 20 million in the period 2015 - 2018.

Timeline: 3 years in the period 2015 - 2018.

Modality for implementation: Requires European, MS and industry support, coordinated at European level.

Action 2: Improved methods for site characterisation

Scope:

- Estimate fault behaviour during CO2 injection at a fault permeability test site.
- Evaluate trapping processes in natural CO2 reservoirs to improve safety cases.
- Improve containment predictions via laboratory experiments on coupling of fluid flow, geochemical and geomechanical processes, at pore- and reservoir-scale.
- Quantify the effects of up-scaling on modelling on predictions of storage performance

Deliverables:

- Test facility for field-scale fault-controlled migration research.
- Improved modelling capabilities for predicting fault-controlled CO2 migration.
- Improved modelling codes for long-term site performance and safety prediction.

Expected impact:

- Increased storage safety, reduced operative costs (-10%) and increased storage implementation (+10%).
- Improved public acceptance of CO2 storage as faults (in addition to wells and brine displacement) are often considered as the most critical issues in storage.

KPIs:

- Reduced development times for site characterisation leading to successful storage permit applications.
- Fault leakage processes included in all storage site risk assessments.

Costs: EUR 60 million in the period 2015 - 2018.

Timeline: 3 years in the period 2015 - 2018.

Modality for implementation: Requires European, MS and industry support.

Action 3: Improved methods for site monitoring

Scope:

- Improved reservoir and over seal monitoring (resolution/sensitivity):
  - long-term, cheap and efficient well integrity monitoring.
  - leakage detection and quantification at surface (especially offshore)
- Permanent geophysical monitoring arrays for geophysical monitoring of storage sites.
- Integrated monitoring packages for cost-effective monitoring including biological monitoring, remote sensing and automated monitoring technologies.

Deliverables:

- Improved technologies for site monitoring for European industry.
- Well monitoring test facility.

Expected impact:

- Reduced storage costs and improved detection, monitoring and measurement.
- Increased confidence in monitoring technologies for CO2 storage.
- New patents, increased jobs and enhanced storage industry.
- Improved public acceptance of CO2 storage, because continuous and effective monitoring is a key element for security assurance.

KPIs:

- Increased detection capabilities which vary depending on technique but better than 0.1% of total injected CO2.
- Wider surveys with increased automation to allow autonomous surveys offshore up to 6 months. Continuous fixed point monitoring for up to 5 years.
- Increased robustness (up to 5 years continuous life) and reduced costs (20% reduction).

Costs: EUR 100 million in the period 2015 - 2020.

Timeline: 5 years in the period 2015 - 2020

Modality for implementation: European and National.

Action 4: Improved methods for safe storage exploitation

Scope:

- Experimental injection in small structures that will respond rapidly to low-volume injection to understand pressure responses and pressure management techniques, especially for deep saline aquifers, to maximise the storage resource.
- Define the key factors that affect the interaction of other resources with CO2 storage/allocation of pore space and resource interaction management.
- Validation of models against data obtained at scale in realistic injection and storage scenarios from demonstrations and pilots.

Deliverables:

- A range of technologies and strategies to optimise the exploitation of the storage space.
- Methodologies to assess impacts of CO2 storage with other uses of the subsurface.
- Experimental pilots for injection optimisation and pressure management.

Expected impact:

- Increased storage efficiency and reduced costs, reduced interruption to injection. Protection of other resources.

KPIs:

- Up to three experimental pilots for injection optimisation and pressure management.
- Reduced costs per stored tonne of CO2 , through better injection strategies and improved storage management procedures.

Costs: EUR 100 million in the period 2016 - 2020.

Timeline: 4 years in the period 2016 - 2020.

Modality for implementation: European and National.

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Start-up and management of up to six new CO_2 storage pilots

Scope:

- Collect knowledge developed in CO2 storage pilots both in Europe and internationally.
- Urgently establish up to six new CO2 storage pilots EU-wide, where the more advanced techniques for site characterisation, monitoring and management can be tested.
- Develop preventative and remediation technologies for the well domain, CO2 plume steering and caprock integrity actions.
- Test techniques for maintaining injectivity during variable injection rates.

Deliverables:

- Six operational storage pilots including saline aquifers and depleted oil and gas fields.
- Portfolio of proven intervention technologies to increase safety and prevent leakage.
- Best-practice manuals for all aspects of the storage operations.

Expected impact:

- Reduced costs and improved demonstration of safety of CO2 storage.
- Increased skills, knowledge and jobs in CO2 storage.
- Increased public awareness and increased social permit to store.

KPIs:

- Patents (up to 10) and market uptake of technologies (up to 10).
- Injectivity maintenance during variable CO_2 supply (± 20%).
- Better match between modelled evolution of the plume of stored CO2 and monitoring data (within ± 10%).

Costs: EUR 270 million in the period 2015 - 2020.

Timeline: 6 years.

Modality for implementation: European, National, variable geometry.

INNOVATION AND MARKET-UPTAKE PROGRAMME

Action 1: Start-up and management of CO2 storage demonstration projects

Scope:

- Large storage sites commissioned to meet expected capture rates in 2030 and 2050.
- Demonstration projects started and further testing of monitoring and site management techniques.
- Integration of multiple storage operations as clusters and regional infrastructure.
- Enable industry to lead in providing development strategies for storage in key regions.
- Develop business models for commercially viable storage.
- Optimise storage in enhanced oil recovery.

Deliverables:

- Commercially viable storage projects.
- Plans for integrated storage hubs.
- Storage of CO2 captured from up to 1 GW by 2020 (ZEP estimate).

Expected impact:

- Potential projects that initiate wider storage deployment.
- Cost-effective CO2 storage, integrated with low carbon energy systems.
- Financially viable storage industry.
- Increased European jobs in CO2 storage.
- Increased public awareness and social acceptance.

KPIs:

- Planning for CCS demonstrations by 2020 and beyond.
- Successful finance structures provided by financial markets.
- Supply of permitted storage capacity to meet future capture rates from Europe which ZEP estimate to be around 240 Mt CO2 per year by 2030.
- Minimum 3-5 demonstrations projects started by 2020 (ZEP estimate).

Costs: EUR 810 million in the period 2015 - 2020.
Timeline: 6 years, for the demonstration sites running also beyond 2030.
Modality for implementation: Requires European and Industry support also.

Challenge 3: Competitive Carbon Capture and Storage (CCS) Value Chains

KEY ISSUES:

- Production value chain performance/cost competitiveness. CCS will be required to operate effectively under real market conditions. This will require substantial flexibility to allow synergies with other energy supply options to be fully exploited, so that overall energy system costs are minimised. Ship transportation could also play a crucial role in facilitating rapid development of CO2 storage resources, by ensuring that large volumes of CO2 are available for initial operations. Development of key underpinning technologies and materials is also crucial to ensure that strong supply chains are available to maximise the value of global CCS rollout for European industry.
- Supply chains (industrial logistics, maintenance, materials and manufacturing, recycling). A substantial up scaling throughout the CCS supply chain will be required to deliver expected CCS deployment trajectories. This includes ensuring that the skills and expertise needed to deliver an integrated transport supply chain to deliver of the order of 3,000 km by 2030 and 20,000 km by 2050, and associated shipping options, is available.
- System integration (smart interfaces, new capabilities of equipment, new or improved services to system, forecast). Integration and flexibility within CCS value chains will be crucial to ensure that CCS deployment is cost effective and complements the development of low carbon technologies. For example, integrated clusters can be used to reduce costs and improve efficiencies and could also play a crucial role in ensuring that CO2 from as broad a range of sources as possible is captured and stored. Effective modelling tools are crucial for effective CCS system integration.
- Non technological aspects (market framework, business model, spatial planning, standards, financing, skills and capacities). Several studies have suggested that pan-European networks for the transport of CO2 to storage sites will be critical for maximising CO2 storage. Successfully delivering this network will require a substantial effort to identify and resolve all relevant non-technological issues. Effective links with relevant European and international activities are also important to ensure that the best concepts are identified and developed.
- Societal issues (environment impact, safety, health, social acceptance). Societal understanding and acceptance of CCS will require public confidence in the health and safety of CCS value chains. Potential positive impacts of the development and eventual deployment of integrated CCS value chains includes boosts to competitiveness of several important European industries (e.g. sectors that deliver underpinning technologies for CCS deployment, such as advanced materials and manufacturing).

ADVANCED RESEARCH PROGRAMME

Action 1: Basic R&D and infrastructure for effective design and operation of CO_2 transport systems

Scope:

- Provide improved understanding of the full CCS chain through development of scientific and transparent CO2 chain assessment methods.

- Undertake essential activities to further improve assessment of relevant variations in CO_2-rich mixtures purity and flow rate and their implications for CO_2 transport and injection (and whole CCS system) design and operation.
- Integrate and test novel solutions for more effective integration of flexible pipeline and ship transport of CO_2 in to CCS value chains.

Deliverables:

- Underpinning knowledge and portfolio of technologies to increase CO2 transport safety and effectiveness (e.g. thermo physical datasets/facilities and multi-fluid, multi-dimensional flow simulators tailored for large-scale CO2 transport systems).
- Next generation transparent value chain methodologies/tools and updated, validated quantitative risk assessment models.

Expected impact:

- Improved technologies allow reduced cost, integrated CCS value chains for a wider range of CO2 sources to be delivered by no later than the mid-2020s.
- Public confidence in CCS increased due to improved transparency, effective risk mitigation and implementing options to manage environmental impacts effectively.

KPIs:

- Successfully tested technologies demonstrated to be cost-effective at scale.
- Patents and market uptake of technologies and value chain/risk assessment tools.

Costs: EUR 67.5 million.

Timeline: 6+ years.

Modality for implementation: Variable geometry, could also be EU or national. Linked to the ESFRI ECCSEL initiative for developing a pan-European research infrastructure for CCS.

Action 2: Developing advanced materials for CCS applications and key enabling technologies

Scope:

- Improving materials for plants where CO2 capture will be deployed and developing advanced cooling systems for high temperature applications.
- Developing options for cost-effective corrosion and fracture control in transport of CO2-rich mixtures that are relevant for CCS applications.
- Other relevant activities to improve other key enabling technologies.

Deliverables:

- Portfolio of cost-effective underpinning technologies that maximise CCS deployment by improving key operating characteristics such as efficiency, operating flexibility, etc. (e.g. steam/gas power cycles with faster ramp rates).
- Robust materials and operating protocols for CO2 transport systems supported by comprehensive datasets and associated research facilities.

Expected impact:

- Improved technologies allow reduced cost, integrated CCS value chains for a wider range of CO2 sources to be delivered by no later than the mid-2020s.
- Improved European competence in advanced materials and manufacturing.

KPIs:

- Patents and market uptake of technologies that facilitate highly efficient performance of integrated CCS solutions (e.g. that facilitate achieving net efficiency of 62% for natural gas, 48% for hard coal base power plant cycles, LHV basis).
- CO2 transport costs reduced by 50% compared to current practice by scale of economy, improved selection of materials and processes and better practices, while ensuring safe and environmentally acceptable transport systems.

Costs: EUR 67.5 million.

Timeline: 6+ years, continuous improvement is needed.

Modality for implementation: Variable geometry, could also be EU or national. Linked to the ESFRI ECCSEL initiative for developing a pan-European research infrastructure for CCS.

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: CO_2 transport pilots for effective design and operation of CO_2 transport systems

Scope:

- Deliver a co-ordinated set of CO2 transport and injection pilot projects with capacity to assess integrity, materials, corrosion, solid formation, seals, etc. for a wide range of CO2-rich mixtures and flow conditions that have not been observed in other applications.
- A supporting programme of underpinning experimental and modelling activities is also expected including round-robin tests and intercomparison studies.

Deliverables:

- World-leading pilot-scale infrastructure for CO2 transport established and regularly used by researchers and companies across Europe to provide data/insights on critical topics such as integrity, materials, corrosion, solid formation, seals, etc.
- Relevant benchmarks agreed drawing on pilot scale insights, results from intercomparison of shared case studies and round-robin testing in multiple labs.
- New technology and operating approaches for effective and flexible operation of CO2 transport systems identified and proved.

Expected impact:

- Strengthened EU supply chains for delivering cost-effective CO2 transport solutions within Europe and internationally due to improved capacity to robustly test products.
- Improved regulatory framework and reduced risk since improved state-of-the-art scientific understanding provides a more solid foundation to design key policies.

KPIs:

- Effective technical solutions for improving CO2 transport validated for scale-up and commercial deployment (e.g. options for managing corrosion and solids formation).

Costs: EUR 150 million.

Timeline: 6 years in this context.

Modality for implementation: EU, national, variable geometry. Requires European and industry support. Linked to the ESFRI ECCSEL initiative for developing a pan-European research infrastructure for CCS.

Action 2: Efficiency improvement and key enabling technology development for CCS

Scope:

- Implement Ultra Supercritical Steam Cycles (USC) with steam temperatures >700°C for CCS specific applications.
- Delivering improved water gas shift (WGS) reactors for CCS applications.
- Other relevant activities to improve other key enabling technologies.

Deliverables:

- Commercial and pilot-scale facilities at scale appropriate to technology maturity.
- Integration of capture process with reduced efficiency loss in new more efficient power and process cycles maximising total efficiency for sustainable utilisation.

Expected impact:

- Integrated processes with minimum losses in efficiency and energy use compared with current state of the art processes without CCS employed facilitate more rapid rollout of CCS in Europe (and internationally).
- Extended use of European competence in advanced materials and manufacturing.

KPIs:

- Deliver base power plants with net efficiency of 62% for natural gas, 48% for hard coal base power plant cycles (LHV basis) that are ready for CO2 capture integration.
- Reduce efficiency loss due to CO2 capture to a minimum of 5% points.

Costs: EUR 150 million.

Timeline: 6+ years, continuous improvement is needed.

Modality for implementation: Variable geometry, could also be European or National.

INNOVATION AND MARKET-UPTAKE PROGRAMME

Action 1: Pan-European transport of CO_2

Scope: Delivering the pre-requisites for a pan-European transport network for CCS projects to be implemented from 2020 onwards (e.g. technical planning, legal framework, etc.).

Deliverables:

- Detailed description of options for legal framework for pan-European CO2 transport.
- Member State role and contributions to a pan-European network clearly identified and detailed discussions within/between relevant States started.
- Assessment of options to deliver effective CCS systems at the cluster/regional level completed to ensure supply rates to available storage sites are feasible to store.

Expected impact:

- Established business model, spatial plans and financing options ensures timely, cost effective delivery of a pan-European CO2 transport network.
- Improved understanding, skills and capacity in relevant regulators, supply chain industries, etc.

KPIs:

- Viable business model(s) for pan-European CO2 transport identified and agreed by key stakeholders, including details such as sharing of costs and liabilities.
- Sufficient confidence in CCS delivery reached to support development of supply chains able to deliver a pan-European CO2 transport infrastructure rapidly.

Costs: EUR 54 million.

Timeline: 6 years in this context.

Modality for implementation: European, National, variable geometry. Requires European and Industry support.

Action 2: Develop tools for understanding integration and cross-cutting issues

Scope:

- Determine changes in operating requirements across the whole CCS chain caused by likely changes in the energy mix (e.g. expansion of European renewable energy use).

- Develop and use enhanced virtual power plant simulation (and/or similar for energy-intensive industry sites) for technology development and operator training.

Deliverables:

- Robust models that inform understanding of requirements for effective contributions from CCS in the electricity/energy system in the future (e.g. costs, ramp rates, etc.).
- Validated virtual power plant simulators (and/or similar for energy-intensive industry sites) that can be used for operator training, assessing operating options, etc.

Expected impact:

- Low carbon energy system is more cost-effective due to improved data for planning and training that optimises technology combinations and refines operating options.
- Timely identification of skills and capabilities needed for CCS supply chains, leading to improved investment needed for competitiveness in the supply chain.
- Potential challenges and effective solutions for CCS system design and operation are regularly being identified by users of the developed tools.

KPIs: Developed tools are used regularly by CCS project developers and energy system analysts, etc.

Costs: EUR 36 million.

Timeline: 6 years in this context.

Modality for implementation: European, National, variable geometry. Requires European and Industry support and/or substantial Member State contributions.

Action 3: Demonstrate Large Scale Integrated CCS plants

Scope: Demonstrate 2 CCS value chains in Europe by 2020 including capture, transport and storage/use. The actions under Heading 4 must be seen as elements in realising this overall target. Demonstrate means in a typical industrial size handling CO_2 on the order of 0.5 Mton/CO_2 per year or above and transporting by ship or pipeline to a suitable storage/utilisation site.

Deliverables:

- Two fully integrated CCS value chains demonstrated in Europe by 2020.
- Includes all the steps in the chain.
- Includes a commercial framework for further deployment post 2020.
- Complete monitoring system and programme in place.
- Business model for CCS pioneered.

Expected impact:

- Europe regaining momentum in deploying CCS.
- Capitalising on targeted R&I actions in Europe – thus releasing the knowledge base and competence pool in Europe providing world class projects.
- Provide the basis for fulfilling the energy and climate targets in Europe.

KPIs:

- > 90% capture rate.
- World class efficiency CCS plants (less than 6% point loss compared to non-CCS plants).
- Both pipelines and ship transport is employed, cross border transport facilitated.

Costs: This is estimated to EUR 3 billion over 6 yrs. (for 2 plants) mainly sourced from the EIB (through NER300 type of instruments), regional funds, MS support mechanisms and industry.

Timeline: 0-6+ years.

Modality for implementation: MS and Industry with support from ETS and the NER300 or similar programmes.

Challenge 4: Conversion of CO2 from Process Flue Gases

KEY ISSUES:

- **Cross-sectorial challenge**: There has been increasing interest in adopting a cross sectorial approach where CO_2 from power plants or process industry is used as a renewable carbon resource for production of chemicals or materials. There may also be opportunities to use hydrogen (which can be produced at plants with pre-combustion CO_2 capture, or water electrolysis) in power to gas (power to methane) and power to liquid (e.g. methanol) schemes, providing another option for storage of energy which is likely to be useful in energy systems that contain large capacities of intermittent renewable electricity generation. It is, therefore, necessary to analyse the energy-intensive industries and relevant associated technologies to assess potential for this cross sectorial vision to be realised. Activities within this challenge should work together with the power industry and the RES. Particular attention should be paid to energy intensity and LCA. The potential of future CO_2 conversion technologies should be evaluated taking into account future energy systems.
- **Stable storage component:** Some processes can convert CO_2 into stable products that have a stable storage component (e.g. materials). Processes that do not have a long term storage component cannot be seen as storage technologies for the part which is ultimately released. However, the potential significant emission reduction resulting from such processes would participate significantly in the decarbonisation of the energy intensive industry and address climate change, by introducing renewable energy in process industry as well, and contributing to replacement of fossil resources by CO_2 as carbon source.
- **Niche development:** In a CO_2 storage context, bearing in mind how large the supply of CO_2 from collectible sources can be, the conversion of CO_2 into chemicals and materials will be niches but important niches in regions with the right framework for development and deployment. They do not possess the ability to process gigatons of CO_2 due to a much lower market demand. It can however provide a bridge to CO_2 management providing feasible business cases
- **Important issues are:**
  - Advanced technology developments for cost-efficient conversion of CO2 into chemicals, polymers and inorganic materials.
  - Production of chemicals from CO2 from less concentrated CO2 streams to reduce investment and processing costs related to concentration and purification steps.
  - Development of a legislative system accepting the CO2-based molecules produced using CO2 from flue gases as renewables.
  - The chemical conversion of CO2 can also play a key role for renewable energy storage (see Part II Heading 2 Challenge2) , and can be used for the production of alternative fuels with a lower carbon footprint (see Part II Heading 3) .

ADVANCED RESEARCH PROGRAMME

Action 1: Advanced olefin production from CO_2

Scope: Develop and demonstrate routes for the conversion of CO_2 to light olefins (in particular ethylene and propylene) as key building blocks for the chemical industry, leading to a variety of large scale products. Two routes are envisaged:

- Direct conversion of CO2 with hydrogen using modified Fischer–Tropsch catalysts.
- Conversion of CO2 into methanol (by reverse water-gas shift, CO2 (dry) reforming, CO2 electrocatalytic reduction, etc.) followed by methanol-to-olefin conversion.

Both processes and related systems need to be developed with less cost and less emissions and including better downstream processing (including their costs). Important is also to integrate the use of renewable energy and its intermittent nature into these systems. This means attention to robustness of the process, possibility to go "on/off" and to reduce investment costs of the developed technology.

Deliverables:

- Successful development of direct and indirect CO2 conversion pathways to olefins.
- Process evaluation and economic assessment providing clear CO2 reduction potentials and framework conditions for economic viability of the investigated process routes.

Expected impact:

- Use CO2 as feedstock for olefin products.
- Fossil fuels replacement, feedstock extension beyond oil.
- Alternative to high CO2 emitting coal-based methanol-to-olefin processes European leadership in CO2-to-olefin technologies.
- Development of a European "Champion" for such processes.

KPIs:

- Technological and economically viable process route from CO2 to olefins.
- 2-3 major industrially driven projects.

Costs: EUR 20 million.

Timeline: 5 years.

Modality for implementation: Requires European, MS and industry support coordinated at EU level.

Action 2: Demonstration of fine chemicals from CO_2

Scope: Fine chemicals are molecules produced at rather limited amounts but with high value for specific applications. Mostly their production is based on a series of conversion reactions needing energy, catalysts, solvents, etc. Value can be added to CO_2 by making specific fine chemicals by using non-conventional routes with higher energy and resource efficiency. This can become the basis for complex polymers, resins, coatings, etc. sold at prices far higher than bulk chemicals. Examples of CO_2-based synthesis routes to fine chemicals which have been validated in lab-scale or already at pilot scale are:

- Cyclic carbonates.
- Reaction of internal epoxides with CO2.
- One-step reaction of alkenes, CO2 and an oxidant.
- Reaction of diols with CO2.
- Linear Carbonates and carbamates.
- Reaction of CO2 and alcohols or amines to give linear carbonates or carbamates.
- CO2 to carboxylic acids.
- Insertion of CO2 into C-H bonds either by traditional organometallic routes, or via electrochemistry.

Deliverables:

- Technical and economically viable process routes for specific fine chemicals.
- Comparative LCA of process routes against commercial reference processes.
- Five projects with their corresponding demonstration activities.

Expected impact:

- More sustainable process designs for fine chemicals production using (partially or completely) CO2 as carbon source instead of fossil feedstock and with lower CO2 footprint than current commercialized pathways.
- Replacement of phosgene in polyurethane synthesis.
- Better techno-economic profile than today's routes to acrylic acids and aromatic and aliphatic diacids and other fine chemicals.

KPIs:

- Establishment of process routes with at least 20% reduced CO2 footprint and reduced energy consumption compared to established fossil routes.
- Reduced number of process steps allowing lower capital investments to build-up corresponding production plant.

Costs: EUR 30 million.

Timeline: 5 years.

Modality for implementation: Requires European, MS and industry support coordinated at EU level.

Action 3: Access to competitive CO_2 for chemical conversion

Scope: Some routes that use CO_2 as raw material can be developed to use gas streams with lower purification level than the purification required for CCS. The chemical conversion of CO_2 using less purified inlet gas at different compositions needs to be explored. Energy efficient and cost effective purification of flue gas, until the appropriate level of purification according to the chemical conversion process, would be a key parameter in the deployment of CO_2 conversion technologies. Therefore, research and development is necessary to define the minimum concentration/maximum impurities of CO_2 streams that the different conversion processes can tolerate, as well as a benchmark of CO_2 capture and purification processes. In addition a profiling and ranking of different industrial CO_2 sources is necessary to achieve a mapping and prioritization of large stationary CO_2 sources according to different CO_2 utilization paths.

Research and development is necessary on improved, robust catalyst systems, which could cope with less pure CO_2 sources, thus improving the overall energy efficiency of corresponding CO_2 conversion processes.

Deliverables:

- Membranes for CO2 separation and purification from flue gases up to a level for direct use in CO2 conversion processes to chemicals.
- New processes and materials for continuous CO2 recovery and purification with low capital intensity and operational cost, and less energy consumption, to develop a competitive solution.
- Catalyst systems for CO2 transformations, less prone to catalyst poisoning and deactivation.
- Process analytical technology (PAT) development for on-line monitoring of CO2 quality.
- CO2 source map of Europe with concentration and impurity profiles including a ranking for different CO2 conversion routes.

Expected impact:

- Sustainable and more efficient process designs for CO2 conversion /utilisation as feedstock.

KPIs:

- Year 0-3: Proof of concept for each process, with estimation of environmental impact, capital and operational costs and CO2 source map.
- Year 2-4: Development of modular skid(s) for test on industrial environment.
- Year 4-5: Dissemination and identification of industrial project(s).

Costs: EUR 30-35million for development of pilot facilities with a modular and containerised approach to allow test on industrial site for final validation.

Timeline: 5 years+.

Modality for implementation: Requires European, MS and industry support coordinated at EU level.

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Demonstration of industrial scale production of polymers from CO_2

Scope:

- Direct carbonation of monomeric building blocks in order to make new polymers.
- Direct CO2 conversion into polyhydroxyalkanoates and other biobased polymers via direct fermentation of syngas (CO +H2) or CO2 +H2.
- Downstream processing of the new made building blocks in an energy efficient way.
- Integration of industry sectors in order to leverage synergies in terms of energy and value streams.

Deliverables:

- New polymeric structures for performing materials.
- New processes leading to more environmentally friendly polymers or more environmental friendly production processes compared to existing production systems.
- Processes that directly produce a biodegradable polymer without need for an extra polymerisation step.

Expected impact:

- Contribute to a robust European process industry.
- New supply chains for CO2 as a renewable raw materials for advanced polymers.
- More environmental friendly products and processes for polymers synthesis.
- Polymers based on CO2 as a renewable feedstock with reduced carbon footprint.
- Direct and indirect use of CO2 for the development of high-value polymers.
- PHA from CO2 as a replacement for PHA coming from sugar.

KPIs:

- New or existing polymers based on CO2 produced at pilot scale.
- 2-3 pilot plants and first small scale production plant by 2020.
- Carbon footprint reduced by at least 20% compared to conventional fossil based products.

Costs: EUR 50 million.

Timeline: 5 years+ starting in 2015.

Modality for implementation: Requires European, MS and industry support coordinated at EU level.

Action 2: Demonstration pilot for mineral production from CO_2

Scope:

- Development of sustainable processes for production of mineral carbonate from CO2 from flue gas.
- Development of upstream processes for CO2 recovery enabling desired quality and cost for valorisation.

Deliverables:

- Demonstration plants producing mineral carbonates, including for construction material. Two or three pilots at useful scale for further scale up.
- Qualification and demonstration of mineral carbonates as additives for cement
- Full demonstration of the use of the new material.

- Estimation of its potential: a) different raw materials that can be used in the production of mineral carbonate from CO2 and b) uses of mineral carbonates.
- LCA analysis to evaluate energy input in these secondary materials compared to primary materials.

Expected impact:

- CO2 conversion to performing materials.
- New processes with less pollution and CO2 emissions.
- Development of a new avenue of activity in Europe- combining the mineral industry with the utility and vendor industry.

KPIs:

- Pilot project completed by 2018.

Costs: EUR 25 million.

Timeline: 4 years starting in 2015.

Modality for implementation: Requires European, MS and Industry support coordinated at EU level.

INNOVATION AND MARKET-UPTAKE PROGRAMME

Action 1: CO_2 based products should be recognized as renewable products and benefit from appropriate support

Scope: A legislative system accepting the CO_2-based molecules produced using CO_2 from flue gases as renewables must be conceived as this is the case for bio-based products, green energy, etc. to attract future investors and to have a positive social impact.

Deliverables:

- Pragmatic and consistent approach to LCA, evaluation and transparent communication of results (to policy makers, value chains, consumers).
- Comprehensive study of the impact of the price of CO2 (as feedstock) and renewable energy on economic viability of CO2 utilization routes and corresponding policy recommendations
- Development of regulations that allow intersectorial use of flue gases, blast gases, etc. and successful business models.
- Development of an appropriate labelling system.

Expected impact:

- Europe leadership in CO2 conversion technologies.
- Production of CO2 based products with significant CO2 emission reduction.

KPIs:

- Clear policy framework on EU level in place enabling investment decisions in CO2 conversion technologies.
- Appropriate labelling system adopted.

Costs: EUR 3-5 million.

Timeline: 3-5 years.

Modality for implementation: -

HEADING 5: Supporting Safe Operation of Nuclear Systems and Development of Sustainable Solutions for the Management of Radioactive Waste

Providing 30% of the electricity generation, nuclear fission is the largest low-carbon energy source in Europe. No CO_2 or other greenhouse gases, GHG, are emitted in the operation of the nuclear reactor, and when the whole cycle of energy generation from the mine to the construction and waste management is included, the level of GHG emissions is similar or smaller than for wind or solar generation. On the other hand, the cost of electricity generation in the existing nuclear plants is one of the lowest in many countries. In addition, the large concentration of energy in the nuclear fuel makes possible to store the fuel for more than one year of generation at the plant, and the diversity of fuel suppliers allows classifying nuclear as a local energy resource, and contribution to providing very strong security of supply. Furthermore, nuclear reactors operate typically more than 7000h/year independently of weather conditions, making nuclear power a very reliable source of electricity which is well adapted to industrial requirements.

In this way, fission nuclear energy provides a very useful contribution to addressing the SET-PLAN and recent EC objectives of GHG emission reduction, energy security and competitive generation. In addition, its low cost and reliability also contribute to make European industry more competitive and, in this way, supports the creation of jobs in Europe. However, citizens require assurances, via the regulatory bodies, that a continuous effort is made to maintain the maximum level of safety. This needs to take into account updated information from existing operation in normal and accident conditions, while maintaining efficiency and competitiveness. In this process, the two paths of research and innovation of both the continuous upgrade of existing plants and the construction of modern designs have to be explored.

The other concern of citizens is the management of the used nuclear fuel. The amount and volume of the waste is very small, in comparison with other industrial wastes, and there are well established storage solutions for a nuclear park which have been safely used for some decades. The solutions are based on interim storage for a number of decades with cooling in monitored conditions, followed by the final disposal; this is described as the open nuclear fuel cycle. This open cycle is considered at present one of the reference solutions in several EC member states. However, no final disposal has been operated yet and some technological options for the interim repositories present challenges to guarantee the safety of the waste for the projected live of the facility. R&D efforts are required to develop the technology and get the necessary proof of concept to assure regulatory bodies and the citizens of the feasibility of safe long term storage of used fuels and other high level nuclear wastes.

In addition, for long term operation (> 100 years) of large parks of nuclear reactors, the sustainability raises additional challenges: avoiding large accumulation of used fuel and guaranteeing the availability of new fuel. The nuclear technology proposes a long-term sustainable solution based on the closed fuel cycle, where the spent fuel of the past, present and future reactors is recycled to recover uranium, plutonium and eventually other materials to fabricate new fuel. It is proposed that this new fuel is reused many times in new, Generation IV, fast spectrum reactors. This is based on the experiences of a once through recycle demonstration. In this way, this closed fuel cycle allows converting the nuclear wastes of the open cycle into new fuel, minimising wastes and extending the existing uranium resources to cover the fuel needs of nuclear reactors for several thousands of years at the level of the present world nuclear energy generation and thereby reducing the production of waste to very low levels. R&D is needed to complete the technological development involved in the closed cycle with the present level of requirements on safety, feasibility and competitiveness, in particular building the already proposed demonstration plants for the more advanced fast nuclear systems.

The contribution to GHG emissions reduction can be further enhanced by directly using the heat from nuclear plants for industrial applications, requiring at present fossil fuel plants. The idea would be to cogenerate simultaneously electricity and process heat. In addition to the reduction in GHG emissions, this application allows the reduction in the dependence on imports of fossil fuels and contributes to the overall security of supply of energy. The R&D should allow selection and optimization of the nuclear plant design for cogeneration and the coupling to the industrial user of the direct heat produced.

Finally, the nuclear industry has to adapt to the energy networks proposed for the future by the EC. These networks will include more renewable energy sources and smart grids for the generation and distribution of electricity and other forms/vectors of energy. Nuclear energy, well suited for base load generation and with large turbine generators, is already today very complementary to renewable energies as a component of the energy mix. However R&D is proposed to develop further synergies between nuclear and renewable energy generation by adapting modes of operation and reactor designs.

Challenge 1: Safe and Efficient Operation of Nuclear Power Plants

KEY ISSUES

- Secure the safe operation of nuclear power plants while maintaining the competitiveness and contribution to the carbon emission reduction of nuclear energy in the mix.
- Provide scientific evidence on the radiation risk lifting uncertainty following low doses due to industrial and medical applications.

ADVANCED RESEARCH PROGRAMME

Action 1: Plant safety, risk assessment and severe accidents

Scope: This includes: probabilistic safety assessment (PSA); improving models and codes for deterministic assessment of plant transients; best estimate simulation methods and assessment of the operational margins; and eventually new reactor safety systems. The highest priority safety challenges for severe accidents are in the following sub-areas: in-vessel and ex-vessel corium/debris coolability and interactions; containment behaviour including hydrogen explosion risk; source term; impact on the environment and scenarios of severe accidents; emergency preparedness and response.

Deliverables:

- Include: more generic and precise risk assessment methods, improvement for the safety systems of present and future reactors, reinforce NPP safety provisions through better understanding of some predominant phenomena, improving Severe Accident Management

Guidelines (SAMGs) and designing new prevention devices or systems for mitigation of severe accident consequences.

Expected impact: -

KPIs: -

Costs: -

Timeline: -

Modality of implementation: -

Action 2: Innovative LWR Generation III design

Scope: New safer reactor designs for the medium term that can reduce the waste generation and improve the natural resources preservation. The R&D work should support existing and new light water reactor concepts, and should be focused on achieving long term operation by design; safety by design; innovative components for reduced maintenance; and enhanced economics.

Deliverables:

- Include: evolutionary technology for mid-term application, breakthrough technology for the longer term advanced LWR designs such as with higher conversion ratio or small modular reactors.

Expected impact: -

KPIs: -

Costs: -

Timeline: -

Modality of implementation: -

Action 3: Effects of low doses of ionising radiation

Scope: The present state and the main R&D priorities can be identified in the MELODI draft of the Strategic Research Agenda (SRA). This topic is particularly relevant for the fraction of the workers of the industrial generation of electricity by nuclear fission that are professionally exposed to these low level doses. It is also relevant for other exposed professionals, particularly in the health sectors, and to the patients receiving doses for diagnosis or treatment. The MELODI SRA includes the following.

Deliverables:

- Dose response relationships for cancer, non-cancer effects, individual radiation sensitivity and hereditary and transgenerational effects. In addition deliverables should include the improvement of the nuclear and radiological emergency response and recovery methodologies, improving the understanding of radiation in the environment and dosimetry methodologies.

Expected impact: -

KPIs: -

Costs: -

Timeline: -

Modality of implementation: -

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Integrity assessment of systems, structures and components

Scope: Integrity assessment of systems, structures and components and in-service inspection and inspection qualification

This sub-point covers integrity, requirements, load quantification, ageing, reliability and components of different systems and different type of materials (metallic, polymer, concrete).

Deliverables:

- Include improving understanding, and development of methods and tools in order to increase the safety and availability of systems, structures and components needed for reliable and safe management of nuclear power plant lifetime, including monitoring, prevention and mitigation of material and components ageing for long term operation.

Expected impact: -

KPIs: -

Costs: -

Timeline: -

Modality of implementation: -

Action 2: Improved reactor operation, fuel, waste management and dismantling

Scope: This includes research for: human and organisational factors for the plant safety and operation, including safe long term operation; safe integration of digital technologies; safe and optimal core management; safety of the water chemistry and the Low Level Waste (LLW) management; and radiation protection.

Deliverables:

- Includes safety improvement of the present fuel concepts, new fuel concepts for present and future reactors, operational wastes minimization and management, efficient and remote dismantling technologies and decommissioning with minimization of generated wastes.

Expected impact: -

KPIs: -

Costs: -

Timeline: -

Modality of implementation: -

INNOVATION AND MARKET-UPTAKE PROGRAMME

Action 1: Harmonization

Scope: Pre-normative research for new design and operating conditions, establishment of shared codes and standards; strategy providing methods to progressively enlarge consensus among stakeholders.

Deliverables:

- Providing the basis for an effective standardisation of reactor component assessments.

- Improving the safety level of the nuclear installation through shared design approaches and licensing processes.
- Several of these actions, using at present high-flux material testing reactors such as the BR2 or HFR, will use the future Jules Horowitz Experimental reactor when available.

Expected impact:

- To maintain the high standards of safe utilization of nuclear systems in Europe, allowing securing the large nuclear fission contribution to a low-carbon energy requirements, and maintaining competitive energy costs and the corresponding impact of moderate cost of electricity into industrial energy intensive applications.
- The safety R&D and improvements should allow Europe to be prepared in advance for any new safety normative following the lessons learned from the Fukushima accident. Life-time extension programmes of the current fleet of nuclear reactors will contribute significantly to the safe operation of nuclear reactors in a cost-effective manner.
- The research should also allow improvements to the competitiveness and industrial leadership of the European nuclear industry, while improving the safety standards.

KPIs:

- Monitoring of the European nuclear plants safety by the national regulators.
- Electricity provided from nuclear fission and corresponding CO_2 emission savings.
- Development of EU nuclear safety normative and adoption by EU members.

Costs: The commission report 'Benefits and limitations of nuclear fission for a low carbon economy' indicates that EUR 1250 million was spent in 2007 on total Nuclear Fission Research (including research undertaken for Gen IV reactors but relevant to Gen II/III) mainly from Member State programme funding and Industrial funding, but also including an EU level contribution. This is not a baseline estimate of the costs of the actions described within this challenge and both SNETP and NUGENIA are updating their Deployment Strategies and preparing a detailed estimation of the timeline and resources needed. However, it is believed that a similar level of total annual spending would allow a level of RD&I to be undertaken to achieve significant improvements and meet the actions identified for the safe and efficient operation of nuclear power plants. The research actions are, and should in the future be, funded using all the modalities described before but the share between the different modalities should depend on the timescales and level of risk associate with each action.

Timeline: -

Modality of implementation:

- Utilities and nuclear manufacturers: Identification of priorities within each challenge according to their operational experience.
- Technical Safety Organizations supporting regulatory bodies: Identification of priorities and R&D orientations according to the national safety regulations and safety culture, as well as from their research and operational experience.
- Some safety networks: SARNET, ENSREG, WENRA, ENIQ, ETSON, etc.: Priorities and R&D orientations according to the international safety regulations, recommendations and best practices.
- National nuclear safety research programs: Alignment of programs in R&D topics where national regulations and strategic priorities can be put in common for several countries.
- The SNETP, mainly via the NUGENIA industry lead association for the R&D on Gen-II and III: To coordinate the R&D research by engineering companies, research centres and

universities, at all levels: advanced research programmes, industrial research and demonstration programmes and innovative and market uptake programmes.

- Research centres and universities: inside EERA, SNETP and other networks for more basic research and medium term topics, mainly for advanced research programmes.
- Large experimental infrastructures: Jules Horowitz Experimental reactor for material test and irradiations, etc.

Challenge 2: Sustainability of Waste Management and Use of Fuel Resources

KEY ISSUES

- Increase sustainability in the long term by making more efficient use of nuclear fuel resources.
- Increase sustainability in the long term by minimising the high level radioactive wastes and optimising their management.
- Ensure availability of suitable materials for sustainable nuclear energy systems, to withstand high temperature and high irradiation, in contact with aggressive coolants, so as to fully guarantee safe and efficient operation.
- All the actions define below will require long implementation times due to the specific nature of nuclear activities. In order to develop new nuclear technologies, detailed screening, qualification and licensing activities are necessary before a technology can be industrialised, resulting in typical lead times of 10 to 15 years.

ADVANCED RESEARCH PROGRAMME

Action 1: Partitioning and Transmutation

Scope: Partitioning and transmutation, are technologies that, by separating and recycling major and some minor actinides in specially designed fast nuclear systems (critical reactors or ADS), can reduce the ultimate nuclear waste by as much as a factor of 50-100 in comparison with the open cycle, currently used in most countries generating electricity from nuclear fission.

Deliverables:

- Partitioning requires further basic research to bring the reprocessing technologies applicable to minor actinides from laboratory scale R&D to industrialization.
- R&D for transmutation, include the specific reactor technologies, the fabrication of fuel targets for transmutation, including a significant content of Plutonium and Minor Actinides, the optimization of national and regional fuel cycle strategies using partitioning and transmutation and the updated nuclear data to optimize those technologies.

Expected impact: -

KPIs: -

Costs: -

Timeline: -

Modality of implementation: -

Action 2: Qualify nuclear materials for operation under Gen IV conditions and develop innovative materials to improve plant safety and efficiency

Scope: The R&D programme on materials is partially performed within the EERA Joint Programme on Nuclear Materials (JPNM) and should include:

- The qualification of structural materials to be used in prototype reactors developed within ESNII and to be able to sustain higher temperatures and irradiation levels.
- The development and qualification for the nuclear environment of advanced steels for high temperature and high burn-up operation.
- The development and characterization of advanced ceramic/metal composites for very high temperature nuclear environments and compatibility with gas or liquid metals.
- The development of physics-based multiscale models for the prediction of the behaviour of structural materials under irradiation and in contact with specific coolants.
- The determination of the high quality data needed for the development of advanced fuels and the improvement of fuel performance codes.
- The development of physics-based models for the understanding of the behaviour of advanced fuels through cross cutting multiscale modelling and separate effect experiments.

Deliverables:

- Qualified structural and fuel materials suitable for the construction of efficient and safe Gen IV reactor systems.
- Pre-normative research recommendations for component design rule modifications in support to ESNII's demonstrators and prototypes.
- Innovative materials for continuously increased safety and efficiency of GenIV reactor systems
- Standardized test procedures to codify and disseminate results of R&D&I activities on advanced materials.
- Robust understanding of the physical mechanisms determining the response of materials to Gen IV reactor operating conditions and relevant predictive models.

Expected impact: -

KPIs: -

Costs: -

Timeline: -

Modality of implementation: -

Action 3: R&D for alternative fast reactor technologies

Scope:

- The lead coolant technology has been identified as the short-term alternative fast reactor technology with ALFRED a demonstration plant for a GEN IV lead cooled fast reactor.
- The gas coolant technology has been identified as the long term alternative technology with ALLEGRO a demonstration plant for a GEN IV gas cooled fast reactor.

Deliverables:

- It will include developing technologies in support of the system design and component development; material qualification and specific coolant technology for those alternative fast reactor technologies.

Expected impact: -

KPIs: -

Costs: -

Timeline: -

Modality of implementation: -

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Support the development, licensing, construction and commissioning of the high priority Demonstration plants for the Gen IV fast reactors (FR)

Scope:

- The priorities have been identified in support of ASTRID, a demonstration plant for a GEN IV sodium cooled fast reactor, and MYRRHA a flexible fast spectrum lead-bismuth cooled irradiation facility able to demonstrate the GEN-IV lead technology, the ADS transmutation technology and to irradiate materials for tests of other technologies.
- This activity also needs access to experimental facilities. A detailed survey of the available and needed facilities was prepared by the EURATOM project ADRIANA. Once available, MYRRHA will be a primary experimental facility for these tests.

Deliverables:

- The main objective of this action is to put into operation both demonstration facilities by 2025.

Expected impact: -

KPIs: -

Costs: -

Timeline: -

Modality of implementation: -

Action 2: Nuclear fuel reprocessing and fabrication of fuel for the demonstration plants

Scope: -

Deliverables:

- Optimization of the reprocessing of fuels to be able to separate when needed minor actinides and too be able to apply these technologies to new forms of fuels with different matrices and chemical form, as expected from advanced reactors.
- In addition, the fabrication of the dedicated fuel for the demonstration plants that will not be suitable for standard fabrication plants and will raise R&D needs to match the demonstration plant requirements.

Expected impact: -

KPIs: -

Costs: -

Timeline: -

Modality of implementation: -

Action 3: Geological Disposal

Scope: The main thematic areas for demonstration include: safety case; waste forms and their behaviour; technical feasibility and long-term performance of repository components; development strategy of the repository; safety of construction and operations; monitoring; governance and stakeholder involvement.

Deliverables:

- Demonstration of the geological disposal technologies at full scale and with realistic load and the operation of prototype installations.

Expected impact: -

KPIs: -

Costs: -

Timeline: -

Modality of implementation: -

Action 4: Interim spent fuel and high level waste storage

Scope: Long-term behaviour of the spent fuel and high level wastes in interim storage conditions; retrievability of the spent fuel and high level wastes from interim storage.

Deliverables:

- The assessment of the retrievability of spent fuel after long term storage and the development of encapsulation and monitoring technologies to improve that retrievability.
- Several of these actions would use the Myrrha experimental reactor when available. Once available, also SUSEN facility will be another of suitable experimental facility for these reactor technologies.

Expected impact:

- To demonstrate the industrial feasibility of Gen-IV fast reactors and of the associated fully closed nuclear fuel cycle. Once deployed, this technology will make the stored depleted Uranium and the available identified natural resources worth more than 5000 years of electricity generation. At the same time, the system might be able to reduce the ultimate nuclear waste by a factor 100, while reducing radiotoxicity half-life from several hundred thousands of years to a few hundreds, and reducing the number of repositories or the aggregated gallery length by a factor between 3 and 40.
- In addition, the combination of interim storage, minimization of waste and geological disposal, provides a complete solution for the high level nuclear wastes that in this way will never leave facilities engineered to maintain the radioactivity inside. This will warrant that the waste will have no chance to get in contact with the population or the environment, and so no damage could be induced by these wastes.

KPIs:

- Demonstration of actinide reprocessing and fuel fabrication.
- Availability of materials for safe design of Gen IV prototypes.
- Progress in the design and licensing of high-priority demonstration plants and the establishment of a consortium gathering the necessary financial resources.
- Progress in the research for alternative fast reactor technologies.
- Progress in the realisation of fuel reprocessing and fabrication facilities for fast reactor prototypes.

- Progress in the Geological disposal technologies at full scale and with realistic load.
- Progress in the interim storage qualification and deployment.

Costs:

To be estimated in detail by the Working Group from evaluations made by the ESNII task force, the IGD-TP and the ongoing national programs. Preliminary cost evaluations were done in 2010 for:

- ASTRID demonstrator: EUR 5 billion.
- MYRRHA multi-purpose research facility: EUR 1 billion.
- ALFRED LFR Demonstrator: EUR 1 billion
- ALLEGRO GFR demonstrator: EUR 1 billion.
- R&D supporting infrastructure for the fast reactor development and infrastructure for fuel reprocessing and manufacturing: EUR 2,65 billion.

Timeline: -

Modality of implementation:

- Research centres and nuclear manufacturers: Defining the objectives and specifications of the demonstration facilities.
- National nuclear safety research programs: Alignment of programs in R&D topics where national regulations and strategic priorities can be put in common for several countries. In addition, the countries proposing to host the demonstration facility had to lead the organization and coordination of the R&D for the corresponding facility (ASTRID-> France and MYRRHA->Belgium).
- The SNETP, mainly via the ESNII, and the associations promoting the different Gen-IV reactors and the reprocessing technologies: to coordinate the R&D research by engineering companies, research centres and universities, at the levels of: advanced research programmes and industrial research and demonstration programmes.
- Universities: inside EERA, SNETP and other networks mainly for advanced research programmes.
- Waste management agencies and research organizations for the interim storage and the geological disposal programme definition and coordination.
- Large facilities for material test and irradiations: MYRRHA, Jules Horowitz Experimental reactor, etc.

Challenge 3: Optimized Integration of Nuclear Reactors in Energy Systems

KEY ISSUES

- Further develop the flexibility of nuclear reactors to integrate in the electricity system of the future.
- Further develop the technology to enable providing nuclear cogenerated heat to applications.

ADVANCED RESEARCH PROGRAMME

Action 1: Cogeneration of heat and electricity from nuclear fission

Scope: Cogeneration technologies could extend the low-carbon contribution from nuclear fission to the energy system by directly providing heat for different applications like process-heat; sea water desalination; contribution to transportation by synthetic fuels or hydrogen production; and district heating.

The range of applications mainly depends on the temperature reachable by the fluid that will transport the heat to the application plant. Most of the market of applications is reachable at temperatures close or smaller than 550ºC. In this sense, the High Temperature Gas cooled Reactor (HTGR), whose designs are today technologically able to deliver process steam close to 600ºC, deserve special attention for cogeneration applications. In addition, HTGR can be designed with the highest level of intrinsic safety improving the flexibility to adapt to many industrial applications. In many senses, the cogeneration with these reactors could be considered as a substitute to natural gas plants with two big advantages: very small CO_2 emissions and improved security of supply including better independence from fuel suppliers from abroad. Recent economical studies show that this type of reactor could start to be attractive at prices around $10/MMBtu that is close to the current price in some European countries.

Nonetheless, other types of reactors like LWR and other SMR, which might be more frequently deployed for electricity generation, are important opportunities to use cogeneration technologies, particularly for applications within the temperature range of their steam.

Deliverables:

- Validation of (V)HTR (including HTGR), LWR and SMR as candidate reactors for cogeneration initiatives.
- Design of the HTGR or other nuclear generation unit in view of standardization and cost reduction;
- Developing tools to adapt those designs for different range of temperatures.
- Design of the coupling of the power generating plant and the process plant.
- Analysis of the coupling of plant transients in the power generating plant and the process plant focused on licensing requirements.
- Development of coupling and buffering technologies.
- The development of cooling and desalination pilot process.

Involved stakeholders for this action should include:

- National governments needing to reduce dependence on fossil fuels while enhancing its security of supply, reducing its GHG emissions, and fostering re-industrialization.

- Industrial companies as potential users for heat and electricity from the plant and utilities that could operate the plant.
- Nuclear research centres, nuclear manufacturers and engineering companies to further develop and provide the required technologies. And the SNETP, mainly via the NC2I, to coordinate the R&D research on nuclear cogeneration.

Expected impact:

- Include: facilitating market deployment, difficult because the long return period on investment, and clarifying the technologies and feasibility of such a coupled installation at industrial scale to reduce the perceived financial risk of such installation.

KPIs:

- Based in the monitoring of the progress on R&D or licensing, design of coupled plants, requirements for the demonstration plant, and identification of potential users for the heat from the nuclear power plant, ready to participate in the design and construction of the demonstration plant for a cogeneration reactor coupled to one industrial application.

Timeline and Cost: for the cogeneration applications is at present being evaluated by SNETP and one ongoing FP7 Project, but a similar project at the USA indicates that to reach and include the demonstration phase more than EUR 1 billion will need.

Modality of implementation: -

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Optimization of nuclear plants for operation as a function of the predicted demand

Scope: Operational and safety flexibility of existing plants, including cost benefit analysis; options for large Gen-III reactors and Small and Medium Reactors (SMR) of different concepts.

Deliverables:

- Assessment of the margins for flexible and still safe operation of nuclear reactors to adapt to predicted demand.
- Assessment of integration of nuclear generation with storage options.
- Technologies to optimize integration of nuclear plants into future energy grids, and smart grids, including cost benefit analysis.

Expected impact: -

KPIs: -

Costs: -

Timeline: -

Modality of implementation: -

Action 2: Specific examples of optimization of integrated production by renewable energies (e.g. wind turbines) and nuclear power plants

Scope: There have been several studies in this sense, proposing something like virtual power plants combining some renewable generation and a nuclear plant (SMR). The virtual plant could provide electricity to the grid with significantly smaller variability. This R&D could be completed and extended to other combinations and with solutions to better utilize the excess generation capacity of the nuclear reactor.

Deliverables:

- Assessment of options to integrate nuclear and variable renewable generation.
- Technologies to optimize integration of nuclear and variable renewable generation.

Expected impact:

Contributing to facilitate the secure and efficient integration of variable renewable energy sources together with nuclear systems into a low-carbon energy system.

Further reducing the CO_2 emissions from the energy system by applying nuclear plants for applications different than electricity generation. In addition this will contribute to reduce the fossil fuels imports and energy dependencies.

KPIs:

- Progress in the definition of Cogeneration projects.
- Progress in the definition of joint projects for nuclear + variable renewable.
- Progress in the definition of joint projects for nuclear in smart grids.

Costs: To be estimated by the Working Group from evaluations made by the SNETP, the Smart Grid EII, R&D prospectives and other initiatives.

Timeline: -

Modality of implementation:

- Research centres with experience in nuclear fission, and nuclear manufacturers and engineering, utilities, and EII for variable renewable generation technologies and Smart Grids: Defining the objectives and specifications and jointly identifying technological possibilities.
- The SNETP, mainly via the NC2I: to coordinate the R&D research on nuclear cogeneration and other applications by engineering companies, research centres and universities, at the levels of: advanced research programmes and industrial research and demonstration programmes.
- Industrial sectors (chemical companies, fuel substitution for transport, countries considering sea water desalination, etc.) that could directly use the nuclear heat for their processes to jointly define target demonstration projects and the required specifications.

HEADING 6: Promoting the Sustainable Development of Indigenous Resources

Challenge 1: Unconventional Fossil Fuel Resources

KEY ISSUES

- Address direct and indirect environmental impact of harvesting unconventional fossil fuel resources.
- Reduce carbon and greenhouse gas emissions from shale gas and other unconventional resources operations.
- Reduce water usage, waste streams and use of chemical additives in hydraulic fracturing and develop alternative technologies to water-based fracturing where sound from an economic, environmental and climate perspective.
- Reduce costs in harvesting unconventional oil and gas resources.
- Abolishing the use of hazardous chemicals in hydraulic fracturing.
- Address the lack of public acceptance.
- Potential use of unconventional oil and gas deposits for CO2 Storage.
- Develop sustainable Underground Coal Gasification.
- Explore the potential gas resources in methane hydrates in Europe.

ADVANCED RESEARCH PROGRAMME

Action 1: Development of improved tools for prediction and monitoring of environmental impacts of unconventional hydrocarbon (e.g. shale gas) extraction

Scope: Better understanding of the environmental impacts and risks caused by hydraulic fracturing operations, and development and validation of improved tools for the prediction and monitoring of such impacts, and in particular the potential effects of hydraulic fracturing on underground aquifers and at the surface, and the induced seismic events. The scope includes the development and validation of numerical models as well as the development of improved geophysical and hydrogeological measuring systems. Monitoring tools should provide a comprehensive assessment of the different potential impacts of the fracturing operations integrating data from different sources. The potential of remote sensing techniques should be also investigated and validated.

Deliverables and KPIs:

- Validated monitoring tools with enhanced capabilities.

Expected impact: -

Costs: EUR 1 million/year.

Timeline: 3 - 4 years.

Modality for implementation: Industry, National and European.

Action 2: Development of improved tools for prediction and monitoring of environmental impacts of underground coal gasification (UCG) operations

Scope: Better understanding of the environmental impacts and risks caused by UCG operations, and development of improved tools for the prediction and monitoring of such impacts, in particular in relation with potential effects on underground aquifers, surface subsidence, and gas emissions. The scope includes both the development and validation of numerical models to simulate and predict the behaviour of the geological formations and hydrogeological systems affected by the UCG operation, and the development of geophysical and other methods and systems for monitoring the evolution of such formations in the short and medium term. The potential role of remote sensing technologies must be investigated and validated.

Deliverables and KPIs:

- Improved tools developed and validated.

Expected impact: -

Costs: EUR 1 million/year.

Timeline: 3 - 4 years.

Modality for implementation: Industry, National and European.

Action 3: Development of exploration and deposit characterization techniques for Methane Hydrates and carrying out an inventory of potential resources in the EU

Scope: Carrying out an inventory of potential Methane Hydrates resources in the EU and associated countries, including both continental and off-shore areas. The scope includes also the refining and further development of geophysical methods for the identification and characterization of Methane Hydrates deposits, and the development of software tools for reservoir assessment and resources evaluation.

Deliverables:

- Pan-European inventory of estimated methane hydrates reserves in continental waters and permafrost areas.

Expected impact: -

KPIs:

- Quantification of the volume and distribution of exploitable methane hydrate resources in European waters and inland.

Costs: EUR 5 million/year.

Timeline: 4 - 6 years.

Modality for implementation: National and European.

TRL: 3 - 6.

Action 4: Research on environmental impacts and risks of Methane Hydrates exploitation

Scope: Investigation on the assessment of potential environmental problems caused by the exploitation of Methane Hydrates, and in particular those which can be a potential barrier for the industrial use of these deposits, such as the risks of mechanical stability in continental platform slopes, and the fugitive gas emissions.

Deliverables: Analysis report, based on field studies.

Expected impact: -

KPIs:

- Environmental monitoring strategy, legal framework adapted to Methane Hydrate exploration.

Costs: EUR 5 million/year.

Timeline: 3 - 4 years.

Modality for implementation: European and National.

TRL: 1 - 4.

INDUSTRIAL RESEARCH AND DEMONSTRATION PROGRAMME

Action 1: Reduction of the environmental impact of high volume hydraulic fracturing operations

Scope: The objective is to reduce in a significant amount the impact of hydraulic fracturing operations: Reduction of water requirements and effluents. Reuse of water. Increase the recycling and reuse of water. Reduction of hazardous additives and development of alternatives to hazardous chemicals. Substitution of potentially harmful additives. Improvement of shallow aquifer protection technologies. Development and assessment of alternative fracturing or formation stimulation methods (e.g. pure gas fracturing, thermal, electrical). In association with this, the potential storage of CO_2 in shale gas operation should also be investigated and demonstrated.

The scope of the action is focused to those operations which are specific of high volume hydraulic fracturing, and not to other operations which are similar as in conventional gas production.

Deliverables and KPIs:

- Reduction of fresh water usage by 40 %. Substitution of 100 % of potentially harmful additives. Alternatives to hydraulic fracturing developed and tested.

Expected impact: -

Costs: EUR 10 million/year.

Timeline: 4 - 6 years.

Modality for implementation: Industry and National.

TRL: 4 - 7.

Action 2: Improving the economical and environmental sustainability of Underground Coal Gasification

Scope: The objective is to improve the medium and long term sustainability of Underground Coal Gasification both from the environmental and the economic point of view. The scope on the economic aspect is on cost reduction both in drilling and syngas processing or utilisation. From the environmental point of view, the focus in on reduction of potential affections to underground aquifers, and reduction of effluents at the surface processing plants. In particular, the potential storage of CO_2 in underground gasification voids should be investigated and demonstrated.

Deliverables and KPIs:

- At least one demonstration project, including the underground storage of CO_2.

Expected impact: -

Costs: EUR 10 million/year.

Timeline: 4 - 6 years.

Modality for implementation: Industry, National and European.

TRL: 4 - 7.

Action 3: Inventory of Coal Mine Methane (CMM) sources at European level

Scope: Carrying out an inventory of the Coal Mine Methane resources in the European coal mines, considering both closed and operating mines, and including all capture technologies for Coal Mine Methane (CMM), and especially Ventilation Air Methane (VAM).

Deliverables and KPIs: Pan-European inventory of CMM sources.

Expected impact: -

Costs: EUR 1 million/year.

Timeline: 2 - 3 years.

Modality for implementation: European.

Action 4: Safe, cost effective and environmental friendly extraction of Methane Hydrates

Scope: Development and demonstration at a pilot scale of cost effective and environmentally friendly gas extraction techniques applicable to Methane Hydrates deposits. The scope covers the definition, development and demonstration of the most adequate extraction technique, and considering as an alternative the substitution of methane by CO2.

Deliverables:

- At least one production test in Europe. The substitution of methane by CO2 should be demonstrated at least at a pilot scale.

Expected impact: -

KPIs:

- Definition of appropriate site-specific production strategies; adaptation of cost-competitive, safe and sustainable technologies. Pilot scale demonstration of substitution of methane by CO2.

Costs: EUR 30 million/year.

Timeline: 4 - 6 years.

Modality for implementation: Industry and National.

TRL: 4 - 7.

INNOVATION AND MARKET-UPTAKE PROGRAMME

Action 1: Development of an European protocol for certifying shale gas operations

Scope: Developing a specific European protocol for the certification of shale gas projects, taking into account all applicable Directives and regulations, and including the development of an specific European standard that enables a third-part certification of the project, in order to simplify the permitting process and also for improving the public acceptance of this type of operations. The protocol should include provisions for communication transparency and stakeholder's involvement, and should also take into account the post-closure monitoring and responsibilities. The scope should also include dissemination and exchange of information of experiences among public authorities.

Deliverables and KPIs:

- European protocol developed and accepted; long-term monitoring of the effects of selected demonstration projects.

Expected impact: -

Costs: EUR 0,5 million/year.

Timeline: 2 - 3 years.

Modality for implementation: European.

TRL: 5 - 8.

Action 2: Supporting Unconventional Coal Gasification (UCG) demonstration projects in Europe

Scope: Providing technical, financial, and regulatory support to the industry for carry out demonstration projects of UCG in the conditions of European deposits.

Deliverables and KPIs:

- At least two UCG demonstration projects in Europe, in different geological conditions.

Expected impact: -

Costs (yearly): EUR 15 million/year.

Timeline: 2 - 3 years.

Modality for implementation: Industry and National.

Potential integration with other challenges In some cases there may be common areas with Heading 4 (CCS).

TRL: 4 - 7.

Action 3: Supporting Coal Mine Methane (CMM) and Coal Bed Methane (CBM) demonstration projects in Europe

Scope: Providing technical, financial, and regulatory support to the industry to carry out demonstration projects of Coal Mine Methane (CMM) and Coal Bed Methane (CBM) projects in the conditions of European deposits.

Deliverables and KPIs:

- At least one large scale CBM demonstration project, and three CMM projects in Europe, including the use of Ventilation Air Methane (VAM).

Expected impact: -

Costs (yearly): EUR 5 million/year.

Timeline: 2 - 3 years.

Modality for implementation: Industry, national, and European.

TRL: 4 - 7.

HEADING 7: Keeping Technology Options Open

Challenge 1: Improve Mechanisms to pick up Promising Scientific Results for Innovation in the Energy Sector and to channel them into Innovation Processes

KEY ISSUES

- The emergence of new technologies, required for the overall transition of the energy sector towards decarbonisation, requires breakthroughs which have to be based on fundamental and generic knowledge at the international state of art. The main goals to achieve are:
  - To prepare technological breakthroughs of the future at the horizon 2030, required to implement the perspectives of evolution of the energy sector and to reach the factor 4 on the greenhouse gases emission reductions.
  - To improve the efficiency of the present energy systems, their sustainability and environmental impact.
- Fundamental and generic knowledge are by nature widespread in scientific disciplines which are generally not targeted to the energy sector. The main challenge is to foster the mobilization of the researchers of these disciplines to applications related to the energy sector, but by keeping the excellence of these disciplines. Moreover, if the basic concepts of quality exist and could potentially generate breakthroughs, the disciplinary compartmentalization makes it difficult to mobilize these concepts in the field of energy, requiring a more systemic approach, usually multidisciplinary.
- Actions to be done are:
  - Implement an efficient watch of the basic sciences and emerging novel concepts that could have applications in the energy field; and consolidating this vision at the European scale, by fostering the diffusion and potential application of basic sciences.
  - Foster interdisciplinary research and encourage the reach of proofs of concepts (i.e. TRL 3-4). This requires the creation of European networks (or wall-less laboratories) that can be supported for long term objectives, in order to be able to handle challenging projects of high scientific level on emerging concepts..
  - Ensure a proper fast-track between successful proofs of concept with high potential for applications. This could lead to the development of programs which target applications keeping in view a systemic approach.
  - Prepare technological breakthroughs by teaching high level European fellows in the energy sector.
- Keeping technology options open requires the development of a strategic implementation plan based on targeted generic scientific fields that must be permanently monitored and periodically updated. These scientific fields should consider in particular:
  - Quantum phenomena for energy applications.
  - Advanced numerical schemes and high performance computing.
  - Modelling and simulation of multistage, multiphysics of materials and systems for energy applications.
  - Modelling and simulation processes of energy transfers.

- Bio-inspired systems.
- Catalysis.
- Modelling of dynamics of complex systems for application to energy.

ADVANCED RESEARCH PROGRAMME

The advanced research programme comprises two main subjects of research, namely:

- *Artificial photosynthesis* i.e. production of solar fuels from solar energy and water or CO2 in direct processes in order to convert solar energy under a chemical form, the solar fuel (actions 1 and 2 of the advanced research programme).
  This programme thus proposes to address the area of production of solar fuels from solar energy and water or CO2 in direct processes in order to convert solar energy under a chemical form, the solar fuel. Such conversion can be obtained through direct photo-electrochemical processes in homogeneous or heterogeneous systems (molecular, bio-inspired or bulk semiconductor platforms), the so-called artificial photosynthesis, and an emerging and challenging area in the field of low carbon energy (present TRL level 1-2).
  Priority research should focus on the design of molecules, advanced solid state materials and hybrid systems together with specific processes for artificial photosynthesis energy conversion and production of solar fuels exhibiting: flexibility of solar fuel device designs, energy transformation and fuel production efficiency, long-term stability and affordability.
- *Materials/nano-science*, such as in catalysis, membrane technology, solar energy, structural materials, energy storage, nuclear materials, etc. (actions 3 to 6).
  Emerging energy technologies call for the development of suitable innovative materials and surfaces: new innovative materials based on abundant elements, the process to manufacture the materials and the integrated energy system are required, as well as the characterization and modelling of the materials and systems in situ and in operando (e.g. heat, chemical species, electrical charges transport, (electro) chemical reactions, radiation effects, etc.).

KPIs: Joint publications in high impact journals, joint collaborative projects, joint PhD and joint post-doctoral programs.

Costs: EUR 120 million per year.

Timeline: 6 years [TRL 1 - 2 to TRL 4 - 5 in 6 years].

Modality for implementation: European.

Action 1: Development of efficient molecules and materials for direct production of solar fuels

Scope: For artificial photosynthesis, the most critical hurdle to overcome is design and synthesis of catalysts for the oxidation of water at sufficient rates. A central research goal is also the assembly and optimization of different parts to construct half cells and thereafter functional integrated systems. The catalysts for water-oxidation and fuel production can be molecular and/or solid-state or nanomaterials. They should also be made from abundant and environmentally benign elements.

Deliverables:

- Durable light-driven or electro-catalysts and light harvesting systems based on abundant, non-toxic and cheap elements.
- Broadband spectrum light-harvesting systems made from abundant, cheap and non-toxic elements.
- Highly conductive, transparent and nanostructured p-type or quasi-metallic metal oxides able to function as photo-electrode materials.
- Immobilization strategies for catalysts and light harvesting systems.

- Control of proton and electron transfer.
- Catalysts for fuel production from water and potentially using CO2 or N2.

Expected impact: -

KPIs:

- For electro-catalysts after immobilization:
    - Catalytic current density >10 mA.cm-2 and stability over 109 turnovers allowing for implementation in a device with 10% Solar-to-fuel efficiency and 20 year lifetime.
- For light-harvesting systems after immobilization:
    - 10 % overall incident photon to current efficiency and stability over 109 photon absorption events allowing for implementation in a device with 10% Solar-to-fuel efficiency and 20 year lifetime.

Costs: EUR 30 million/year.

Timeline: 6 years .

Modality for implementation: European.

From TRL 1 -2 to TRL 4 - 5 in 6 years.

Action 2: Development of processes and devices relevant to artificial photosynthesis

Scope and Deliverables: The aim is to connect photosensitizers to catalysts and surfaces or semi-conductor materials and to study entire device systems using chemical, physical and theoretical methods as well as implementing advanced engineering knowledge. Also biological and bio-inspired approaches are viable. There are many different components to choose from, therefore many concepts should be followed and explored in parallel.

- Light-driven fuel production devices comparing design concepts involving biosourced, molecular bio-inspired or bulk semiconductor materials or any combination thereof.
- Scalability of device design and engineering at all relevant levels.
- Light management at a higher level for improved performances (e.g. integration of solar light concentrators or texturation of the materials).
- Development of smart-responsive matrices (adapted to the working environment) and relevant characterization techniques for improved efficiencies and lifetimes.
- An over-arching deliverable is to have a significant number of laboratory scale pilot devices in operation at the end of the advanced research programme.

Expected impact: -

KPIs: -

Costs: EUR 30 million/year.

Timeline: 6 years.

Modality for implementation: European.

From TRL 1 - 2 to TRL 4 - 5 in 6 years.

Action 3: Materials for the exploitation of heat at low temperature

Scope and Deliverables: Low grade heat wastes are generally abundant, but their exploitation to increase the efficiency of the processes remains generally challenging. Heat wastes can be converted either to power or either be exploited as heat. Development of low cost and robust materials is essential in these fields. The main topics are:

- Material for heat to power conversion.
- Thermoelectrical and thermoionic heat conversion.
- Thermophotovoltaic heat conversion.
- Hybrid thin film materials, made of shape memory alloys and ferroelectrics.
- Material for heat management.
- Nano-composites or graphene/multilayer graphene to enhance thermal properties, mechanical properties and increase processability.
- Polymers conducting heat to design low temperature heat exchangers (e.g. using nano-composite).
- Nanofluids (application to solar energy harvesting, cooling, waste heat collection, etc.).
- Phase-change materials for energy storage.

Expected impact: -

KPIs: -

Costs: EUR 20 million/year.

Timeline: 6 years.

Modality for implementation: European.

From TRL 1 - 2 to TRL 4 - 5 in 6 years.

Action 4: Materials operating under extreme conditions

Scope and Deliverables: Material research under this action includes high strength steels/alloys, oxide dispersion strengthened alloys, ceramic matrix composites, coatings and refractories/ceramics for high temperature and highly corrosive conditions. High-performing, reliable and cost-effective materials and components are key issues in this topic. Materials resistance against several kinds of combustion and irradiation conditions is also a challenge. To successfully meet those challenges, material research must also include the development of combustion additives to increase the flexibility of power plants. Attention will also be paid to different surface treatments, the possibility to fabricate and to joint these materials in order to increase their chemical resistance to slags as well as their mechanical resistance to erosion. Design and manufacturing guidelines for those new materials to ensure mechanical properties and corrosion resistance will be developed. Finally, for nuclear applications the changes undergone by materials under irradiation will have to be explicitly taken into account for the development of advanced radiation-resistant materials. The present action will thus focus on aspects such as:

- Steel and alloys:
    - Ferritic/martensitic/austenitic steels and nickel base alloys for high temperature (HT) applications (T > 500°C) in boilers, steam/gas turbines, heat exchangers, gas clean up devices as well as in-core components of nuclear reactors and for low temperature (LT) applications (T < 200°C) in pipelines and heat exchangers.
- Ceramics:
    - Ceramics for high temperature aggressive environments. Applications in solar receivers and thermochemical, nuclear fusion and fission gas turbine and burners;
    - Ceramic gas separation membranes for high temperature fuels cells;

  - Redox materials for chemical looping, solar water splitting and chemical storage;
  - Cheap refractory linings for e.g. waste incineration.
- Coatings:
  - Metal, ceramic and composites coatings as protective systems, overlays, environmental and thermal barriers.
  - Applications: boiler and turbine coatings, advanced tribological applications, integrated sensors.

Expected impact: -

KPIs: -

Costs: EUR 20 million/year.

Timeline: 6 years.

Modality for implementation: European.

From TRL 1 - 2 to TRL 4 - 5 in 6 years.

Action 5: Multiscale and multiphysics modelling for materials and processes relevant to energy applications

Scope and Deliverables: Integrate different simulation tools that are effective at the different scales, i.e. from atomic scale, nanoscale to reach modelling of transfers (heat, matter, electricity) in macroscopic interfaces and energy systems. This may include modelling of physical, chemical, and mechanical properties, including response of materials to irradiation, as well as mechanical and biological modelling by using integrated simulation tools such as:

- Ab-initio.
- Tight binding (TB model).
- Molecular dynamics.
- Kinetic Monte Carlo.
- Dislocation dynamics.
- Cellular automata.
- Finite element for transfers at the macroscale modelling (fluid dynamics, heat and mass transfer, etc.).

Expected impact: -

KPIs: -

Costs: EUR 20 million/year.

Timeline: 6 years.

Modality for implementation: European.

From TRL 1 - 2 to TRL 4 - 5 in 6 years.

Action 6: Advanced characterization for emerging novel concepts in the energy field

Scope: Numerous breakthroughs in emerging energy technologies are possible only when new advanced characterization techniques become accessible. The needs for further development in this sense are:

- Techniques to study the dynamic processes on relevant time scales, develop model systems and follow catalyst performance; for materials and individual molecules.
- Testing facilities for devices, standardization and definition of specifications.

- Develop a European network of advanced characterization platforms dedicated to studying materials and processes for energy.
- Develop in situ and in operando characterization methods at laboratory scale facilities and large scale instrument facilities (e.g. synchrotron and neutron reactor facilities).

Deliverables: -

Expected impact: -

KPIs: -

Costs: -

Timeline: 6 years.

Modality for implementation: European.

From TRL 1 - 2 to TRL 4 - 5 in 6 years.

HEADING 8: Innovative financing for energy supply

Challenge 1: Financing of technology development

KEY ISSUES

- Establish networks, dialogue, and best practice exchange/cooperation structures between finance, energy industry and technology providers to enable a better understanding of the high risk nature related to the financing of first-of-a-kind commercial demonstration projects in the field of energy supply.
- Address the lack of track record, knowledge and understanding of sustainable energy investments by e.g. banks, financial institutions or investors; foster training and capacity buildings for financial institutions and investors to increase the motivation to finance first-of-a-kind commercial demonstration projects and develop appropriate financing products and practices.
- Develop a supportive market framework for SET-Plan technologies for large scale first-of-a-kind demonstration projects, enabling stability of returns and bankability of projects, thereby reducing the risk level for investors.
- Improve coordination between existing risk sharing instruments at EU level and decentralised financial resources at national/regional level, to enable combined financing solutions of first-of-a-kind projects, necessary along the whole innovation chain and development stages.
- Develop adequate business models to allow deployment of SET-Plan technologies facing insufficient market demand; facilitate coordination and mobilisation of private sector resources towards first-of-a-kind demonstration projects.

ADVANCED RESEARCH PROGRAMME

Action 1: Risk-assessment methodology

Scope: Development of a risk-assessment framework for first-of-a-kind (FOAK) projects at EU level. This would allow better transparency what concerns the investment risks for lenders and project promoters.

Deliverables:

- Tool box for risk assessment;
- Workshops with relevant stakeholders at EU level.

Expected impact:

- Increased market information and transparency related to FOAK projects: greater visibility of investments in FOAK projects on the financial market, enabling to attract more money at more affordable conditions.
- Reduced perceived investment risk for lenders, debt and equity investors of FOAK projects due to a better understanding of the underlying business and financial risks of the respective SET-Plan technologies sectors.
- Better understanding of financial risk issues among technology developers and project promoters.

KPIs:

- Applicability to the key technology sectors of the SET-Plan Integrated Roadmap.
- Risk assessment tools adopted by at least 20% of EU banks.

Costs: -

Timeline: 2014 - 2020.

Modality for implementation: Action to be implemented at the EU level; relevant stakeholders: technology providers, industry associations & corporates, public and private financial institutions (banks, equity investors), public utilities, project developers, member states and regional/local authorities.

Action 2: Financial Instruments

Scope: Review of the need for specific financial structures for first-of-a-kind (FOAK) projects, taking into account the outcome of previous studies or analysis on this topic.

Development of adequate financing for FOAK projects, based on collaboration with relevant stakeholders at EU and/or national/regional level, as to enable risk sharing of long term projects.

Availability of credit-enhancement mechanism in order to improve risk-profile of the project to make it attractive for institutional investors having a low-risk tolerance. Thereby, higher-risk projects could be levelled out with lower risk projects within a portfolio approach supported by risk-taking capacity, allowing also financing of higher risk projects.

Deliverables:

- Studies.
- Workshops.

Expected impact:

- Adequate financing facilities for FOAK projects.
- Closing of financing gaps (where applicable).

KPIs

- Applicability to the key technology sectors of the SET-Plan Integrated Roadmap.

Costs: -

Timeline: 2014 - 2020.

Modality for implementation: Action to be implemented at the EU level; relevant stakeholders: technology providers, industry associations & corporates, public and private financial institutions (banks, equity investors), public utilities, project developers, member states and regional/local authorities.

INNOVATION AND MARKET-UPTAKE PROGRAMME

Action 1: Financial and technical advisory services

Scope: Design and demonstrate targeted financial and technical advisory services to project promoters, corporates (notably SMEs, Midcaps), public authorities and the financial community, respectively.

Deliverables:

- Reports about new services, successfully demonstrated in concrete projects.

- Workshops.

Expected impact:

- Improved investment readiness for FOAK projects.

KPIs:

- Applicability of the services to the key technology sectors of the SET-Plan Integrated Roadmap.

Costs: -

Timeline: 2014 - 2020.

Modality for implementation: Action to be implemented at both national and EU level; relevant stakeholders: technology providers, industry associations & corporates, public and private financial institutions (banks, equity investors), public utilities, project developers, member states and regional/local authorities.

Action 2: Coordination between existing risk sharing instruments

Scope: Develop initiatives for an increased coordination between existing risk sharing instruments at EU level and decentralised financial resources (e.g. ESIF for innovation activities). These shall cover the whole innovation chain and development stages that currently fall between existing funding support offerings, typically FOAK.

Deliverables:

- Reports about new initiatives, successfully demonstrated in concrete projects.
- Workshops and conferences.

Expected impact:

- Increased coordination between existing risk sharing instruments at EU level and decentralised financial resources (e.g. ESIF for innovation activities).
- Appropriate funding support availability for FOAK projects and innovative SMEs/Mid-Caps with short time-constants. It is especially important to provide timely and accessible funding support for innovative SMEs and Mid-Caps.
- Enhanced risk sharing for financing at at EU level through a dedicated facility providing risk finance for the SET-Plan technologies.

KPIs:

- Applicability of the services to the key technology sectors of the SET-Plan Integrated Roadmap.

Costs: -

Timeline: 2014 - 2020

Modality for implementation: Action to be implemented at both national and EU level; relevant stakeholders: technology providers, industry associations & corporates, public and private financial institutions (banks, equity investors), public utilities, project developers, member states and regional/local authorities.

Action 3: Industry co-ordination and mobilisation of industry-wide resources

Scope:

- Support best practice exchange/cooperation structures between finance, energy industry, energy service providers and technology providers as regards the financing of FOAK projects and innovative SMEs/Mid-Caps respectively.
- Promote greater industry co-ordination and mobilisation of industry-wide resources.

Expected impact:

- Increased exchange of best practice between stakeholders as regards financing of FOAK projects and innovative SMEs/Mid-Caps respectively.
- FOAK projects to get the financial and industry resources to succeed.
- Shared knowledge of successful funding mechanisms within and between industry networks.

KPIs:

- Representation of the key stakeholder groups and Member States in the networks and exchange/cooperation structures.
- Coverage of the key technology sectors of the SET-Plan Integrated Roadmap.

Costs: -

Timeline: 2014 - 2020.

Modality for implementation: Action to be implemented at the EU level; relevant stakeholders: technology providers, industry associations & corporates, public and private financial institutions (banks, equity investors), public utilities, project developers, member states and regional/local authorities.