

# Biomass Technology Roadmap

European Technology Platform  
on Renewable Heating and Cooling







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Heating and Cooling



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# 1

## Background, scope and objectives



# 1 BACKGROUND, SCOPE AND OBJECTIVES

Responsible for roughly half of the final energy demand in Europe, the heating and cooling sector is a cornerstone of the EU's energy and climate strategy. As 92% of all renewable heat is produced from biomass, bioenergy will play a key role in reducing the greenhouse gas footprint of the heating and cooling sector. Technological innovation is vital in ensuring that reliable, cost-competitive and environmentally-friendly biomass-based heating and cooling solutions are delivered to different types of consumers in Europe.

In this context, the European Technology Platform on Renewable Heating and Cooling (RHC-Platform), an initiative officially endorsed by the European Commission since October 2008, gathers over 700 research and industry stakeholders to define a common strategy to increase research and innovation for renewable heating and cooling. The Biomass Panel of the RHC-Platform published the **Strategic Research Priorities for Biomass Technology** in April 2012. This publication identifies the R&D activities needed to achieve the RHC-Platform 2020 objectives:

- Increase the biomass heat market share in Europe from 11% in 2007 to about 25% in 2020, taking into account the reduction in heat demand
- Double the biomass fuel supply in comparison with 2008 by developing standardised and sector oriented sustainable biomass fuels at competitive production costs
- 50% reduction for real life emissions (particles and volatile organic compounds) from fire wood stoves and a 20% increase of real life efficiency of small scale biomass central heating systems
- Substantial improvement of the fuel flexibility of biomass technologies, with a particular focus on increasing the use of residues and wastes
- Increase in load flexibility of industrial scale boilers
- 50% reduction of emissions for industrial scale boilers
- Substantial increase in electrical efficiency of large combined heat and power plants through the increased steam parameters of the steam cycles

The Biomass Technology Roadmap<sup>1</sup> outlines a number of actions and investments needed in the short-term (up to 2020) to implement the biomass strategic research priorities, with a specific focus on ensuring the commercial availability of reliable, cost-competitive and environmentally-friendly bioenergy heating and cooling solutions for different types of consumers. The implementation actions described in this document have been selected with the key principles listed below taken into account. These principles will be described for each implementation action in section 2.

- Industrial leadership
- Maturity of the technology (short-term commercial deployment)
- EU added value
- Benefits for society and end-consumers
- Resource-efficiency

<sup>1</sup> A number of organisations have declared their support for the Biomass Technology Roadmap. These organisations are listed here: <http://www.rhc-platform.org/structure/biomass-technology-panel/biomass-technology-roadmap/supporting-organisations/>

Biomass conversion technologies cannot be developed at large-scale on a stand-alone basis; the entire value chain - from feedstock to end products – needs to be taken into account for successful implementation. This document therefore adopts a value chain approach, integrating different research priorities throughout the entire supply chain: from the sourcing of the biomass resources - with a particular focus on waste and residue streams 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 (Figure 1).

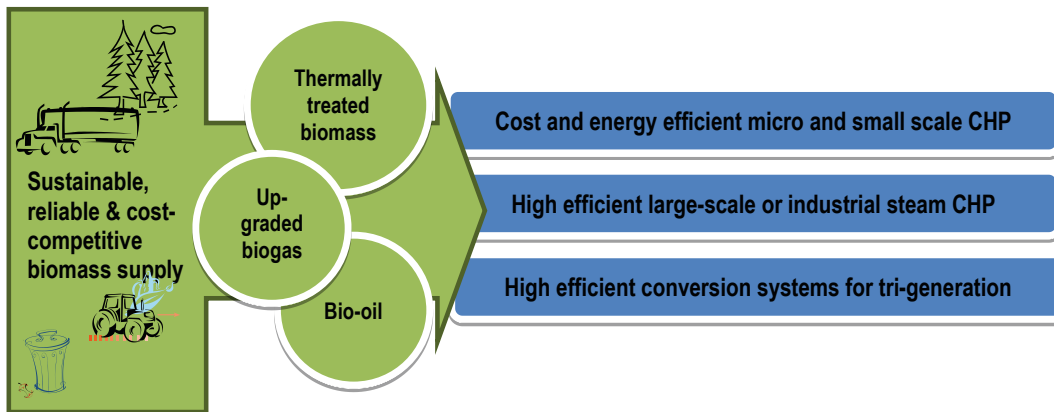


Figure 1 - Value chain approach

Different types of RD&D projects are required to implement the strategic research priorities for biomass technology: applied research and development activities are needed to develop and optimize specific elements for the demonstration of the different value chains (Figure 2). This document provides an indication of the R&D budgets needed to implement the individual research, development and demonstration activities described in the document, as well as relevant key performance indicators to monitor their technological and economic success.

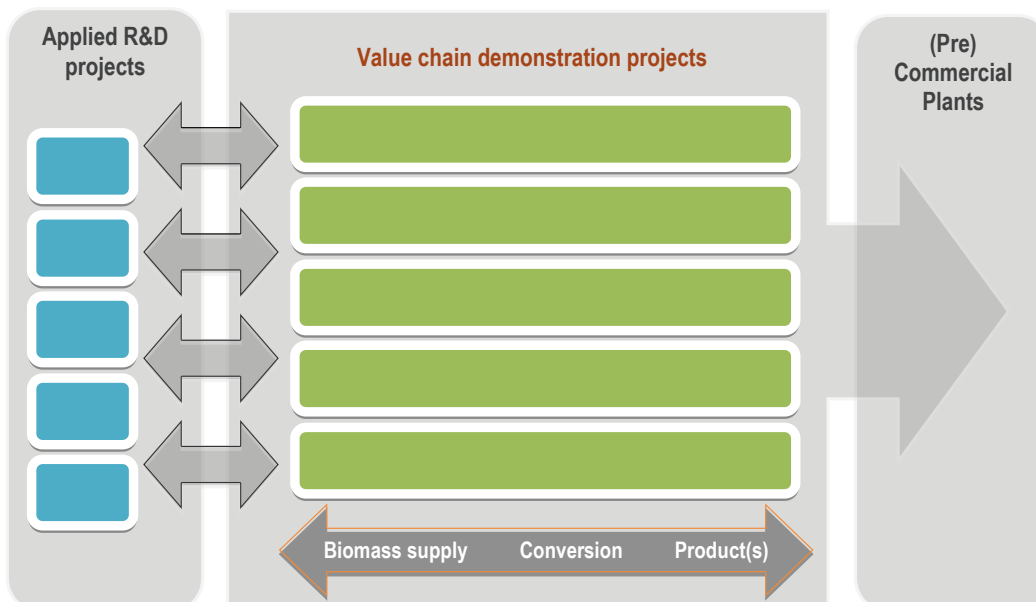


Figure 2 - Different types of research activities



# 2

## Implementation actions for 2014-2020



## 2 IMPLEMENTATION ACTIONS FOR 2014-2020

### 2.1. ADVANCED FUELS REPLACING COAL, FOSSIL OIL AND NATURAL GAS IN HEAT AND CHP PRODUCTION

Ensuring the security of the biomass fuel supply constitutes a key challenge in the provision of reliable and environmentally friendly biomass technologies. By 2020, the biomass fuel supply should double compared to its current use (~100 Mtoe in 2008) through the development of standardised and sector-oriented, sustainable advanced biomass fuels (new biocommodities, thermally treated biomass fuels, fast pyrolysis bio-oil and upgraded biomethane) including the provision of adequate feedstock at competitive production costs (cfr. research priorities BIO.8 and BIO.11 in RHC-SRA). The development of advanced standardised biomass fuels should focus on ensuring an enlarged raw material portfolio for bioenergy inside Europe, with a particular focus on the use of agricultural and forestry residues as well as biodegradable waste (Figure 3). Waste and residue streams result from harvesting practises (agriculture, forestry, landscape), feedstock processing, conversion processes (industry), and from end use (definitions in Appendix III).

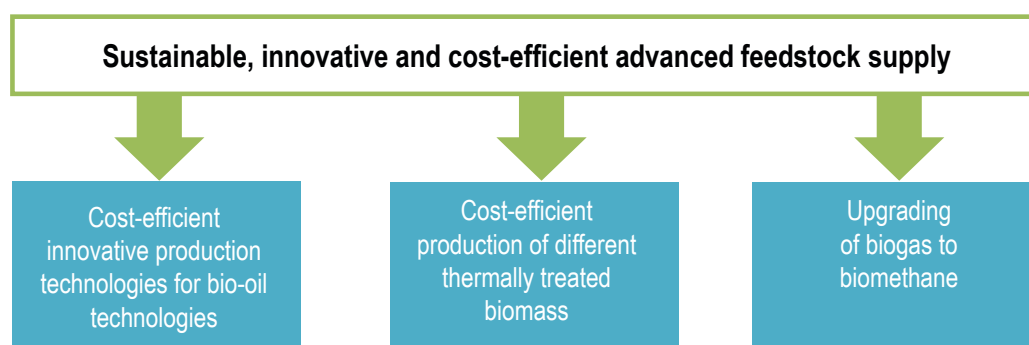


Figure 3: Full demonstration of different standardised advanced biomass fuel commodities value chains, taking into account flexibility in raw material

#### 2.1.1. SUSTAINABLE, INNOVATIVE AND COST-EFFICIENT ADVANCED FUEL FEEDSTOCK SUPPLY

Sustainable, innovative and cost-efficient advanced feedstock production, handling, pre-treatment and storing technologies for different biomass sources need to be developed to meet the quality requirements for thermally treated biomass, bio-oil and biomethane production. The feedstock span of bioenergy supply chains should be broadened through the mobilisation of alternative biomass feedstock resources, such as forest and agricultural residues and wastes. The harvesting, pre-treatment and transport fleet needs to grow considerably if the European Union aims to mobilize its industrial and energy wood potentials.

Applications	Thermally treated biomass fuels, bio-oil and biomethane production
Main products	Improved quality of biomass feedstock produced in a cost-efficient and sustainable way
Main feedstock	Forestry biomass especially residues from harvesting and forest industry, increasing use of agricultural and agroindustry residues and wastes
Technologies covered	Intelligent machinery for feedstock production, handling, drying, logistics and storing technologies

## European added value and the services to society

- Mobilisation of European endogenous biomass, reduced dependency on imported resources
- Enlarged raw material portfolio for biomass fuel production (including wastes and residues) inside Europe addressing challenges related to competition between uses
- Maintenance of Europe's leadership in the field of forestry machinery manufacturing: in 2030 the forest sector will need annually 30,000 to 40,000 harvesting and transportation machines for the energy wood sector, creating a 3-4 € billion forest machinery market in Europe
- Forest machinery production will employ more than 5,000 man-years, and an overall 40,000 man-years in the wood fuel supply chain in 2030<sup>2</sup>
- Substantial job creation also in agricultural fuels supply chains

## Technological challenges

- Reduction of fossil fuel consumption in driving and chipping with efficient diesel hybrid technology
- Reduction of energy consumption in material handling by using pneumatic accumulation of braking energy in cranes
- Improving local pre-treatment (mechanical or thermal) in order to optimize transport chains
- Increased net payloads by larger load spaces and fast loading and unloading of vehicles with advanced terminal concepts
- Virtual on the job tutoring and feedback systems for machine and vehicle operators that support economic and efficient driving and new harvesting
- Fleet management systems for high capacity utilization of harvesting and transportation fleet
- Optimization of feedstock selection, pre-treatment and quality (blended raw material use, reduction of impurities and residues) for the requirements of advanced biomass fuels production
- Optimisation of value chain logistics

## Key Performance Indicators

	2013	2020
Biomass supply costs for forest biomass <sup>3</sup>	20-25 €/MWh=5.6 – 6.9 €/GJ (Nordic countries, Eastern EU) 25-35 €/MWh = 6.9 – 9.7 €/GJ (Central and Southern EU)	30% reduction through the use of intelligent machinery and optimized supply chain concepts and logistical optimization
Biomass supply costs for agrobiomass residues like prunings and straw	5 – 21€/MWh=1.2 – 5.9 €/GJ <sup>4</sup>	20-30% reduction through the use of intelligent machinery and optimized supply chain concepts and logistical optimization
CO <sub>2</sub> emissions in the biomass supply chain (forest biomass) <sup>5</sup>	5 – 7 kgCO <sub>2</sub> /MWh = 1.4 – 1.9 gCO <sub>2</sub> /MJ	30% reduction of CO <sub>2</sub> emissions
Share of agricultural and industrial biomass residues used in energetic value chains	< 10 %	30% of agricultural and industrial biomass residues used in energetic value chains
Share of forest machinery based on diesel hybrid technology	0%	30% of forest machinery based on diesel hybrid technology
Decrease in production losses and improvement of biomass from forestry and agriculture	10 – 30 % of the yield	10-20% decrease in production losses (e.g. dried fuel, better pre-treatment of biomass, decrease of storage losses)
Reduction of fossil fuel consumption in biomass supply chain	2 – 4 % of energy value of biomass fuel (about 3 – 4 litres/MWh)	30% reduction of fossil fuel consumption in biomass supply chain e.g. by using biofuels

<sup>2</sup> Asikainen, A et al.2011, Development of forest machinery and labour in the EU in 2010-2030, Formec, Austria

<sup>3</sup> From biomass production up to plant, including harvesting, transport and biomass processing

<sup>4</sup> Biofutures project 2012

<sup>5</sup> From biomass production up to plant, including harvesting, transport and biomass processing

## Supporting Organisations

Supporting Organisations can be found here:

<http://www.rhc-platform.org/structure/biomass-technology-panel/biomass-technology-roadmap/supporting-organisations/advanced-fuels-replacing-coal-fossil-oil-and-natural-gas-in-heat-and-chp-production/sustainable-innovative-and-cost-efficient-advanced-fuel-feedstock-supply/>

## 2.1.2 INNOVATIVE PRODUCTION AND UPGRADING TECHNOLOGIES FOR BIO-OIL

Fast pyrolysis bio-oils (later bio-oil) are ecological low-cost liquid biofuel which can replace fossil fuels such as heavy fuel oil or natural gas for example, in district heating plants or in lime kilns in the pulp and paper industry. Industrial kilns and heavy fuel oil boilers are typically larger and more robust and thus less demanding as regards the quality of the fuel used. In addition to replacing heavy fuel oil and natural gas, higher value applications such as gas turbine, diesel engine and mineral oil refinery co-feeding usages are also very attractive future considerations. However, significant bio-oil quality improvement is needed in order to make these alternatives possible.

### Innovative production technologies for bio-oil

Applications	CHP including small-scale heating sector, gas turbine and stationary engine usages for example in electricity, district heating, and process steam production <sup>6</sup> .
Main products	Bio-oil suitable for CHP and stationary engine applications including small-scale heating
Main feedstock	Improved quality of biomass feedstock (ash <2 w-% on dry basis, volatiles > 75 w-%) (cfr. section 2.1.1)
Technologies covered	Fast pyrolysis <sup>7</sup>
covered	

### European added value and the services to society

- Contribution to the production of renewable energy in Europe: the estimated fast pyrolysis-oil output in 2020 could reach 3 Mtoe in Europe which represents about 10% of the mineral oil currently used for heating (approximately 30 Mtoe/year) and corresponds to a greenhouse gas reduction of almost 2 million tons CO<sub>2</sub> equivalent compared to natural gas<sup>8</sup>.
- Decreased dependency on imported mineral oil and increased security of the energy supply: bio-oil can be produced from local feedstock such as forest residues and other woody residues
- Fast contribution to the decarbonisation targets in Europe: by utilizing bio-oil in heating applications, CO<sub>2</sub> emission reductions up to 90% can be achieved when compared to the life cycle emissions of fossil fuel firing.
- Bio-oil is a good bioenergy carrier or intermediate (increased energy density of a factor 4 – 5<sup>9</sup> compared to the initial feedstock) which is easy to store and to transport and which could be upgraded to higher value products and chemicals.
- High fuel flexibility: a wide variety of different feedstock can be processed in the pyrolysis process, and more than 45 different types have already been tested at pilot scales, including wheat straw, rice husk and other food industry residues, bagasse, sludge, tobacco, energy crops, prunings and many more. However, the type of biomass used influences the bio-oil yield and quality. Woody biomass is typically the type of biomass that gives the highest bio-oil yields<sup>10</sup>.

- Job creation in the bio-oil production value chain for example in the forms of feedstock harvesting, transportation, and facility management. In Europe and North America, nearly 200 CHP plants within

<sup>6</sup> Lehto, J.; Oasmaa, A.; Solantausta, Y.; Kytö, M.; Chiaramonti, D.. 2013. Fuel oil quality and combustion of fast pyrolysis bio-oils. Espoo, VTT. 79 p. VTT Technology; 87, (<http://www.vtt.fi/publications/index.jsp>) <http://www.vtt.fi/inf/pdf/technology/2013/T87.pdf>

<sup>7</sup> Meier, D., van de Beld, B., Bridgwater, A.V., Elliott, D.C., Oasmaa, Anja, Preto, F. 2013. State-of-the-art of fast pyrolysis in IEA bioenergy member countries: Elsevier. Renewable and Sustainable Energy Reviews, Vol. 20, Pp. 619 – 641 doi:10.1016/j.rser.2012.11.061

<sup>8</sup> Based on the greenhouse gas reduction estimations of the Bioliquids-CHP project: pyrolysis oil produced from 100% forest residues and used in a 1000 kWe piston internal combustion engine in CHP mode

<sup>9</sup> EMPYRO project

<sup>10</sup> EMPYRO project

the pulp and paper and mechanical wood industries have been identified as suitable candidates for integrated bio-oil production by VTT and Pöyry. As estimates indicate that one such integrated production unit generates the need for the order of 60-70 man years, there is potential to generate at least 14,000 jobs in these regions. If CHP plants outside these industries and stand-alone bio-oil production units are included, the investment and job creation potential is significantly increased.

### Technological challenges

- 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.
  - The specifications to be defined for bio-oils in the standard are under development by CEN (EC mandate M/525 accepted 10/2013); important properties include water content, heating value, acidity, homogeneity, stability, viscosity, solids and ash content; additionally the nitrogen content should be considered as it may lead to increased NO<sub>x</sub> upon combustion (in boilers, engines, turbines etc.).
  - For example, innovative process integrations and fractionation of the produced bio-oil into different products (polygeneration) - some of them with a higher value - could reduce the production costs of the fuel products and thus increase the competitiveness of bio-oils. Chemical upgrading to a mix of fuels (light fuel oil, diesel for stationary engines, and heavy fuel oil) may also be considered.
  - In order to broaden the feedstock pool, blending of batches to optimize the bio-oil for certain purposes or climates (as is done with biodiesel) is needed and instructions shall be developed.
  - Development of cost-efficient bio-oil upgrading methods so that the quality would be suitable to, for example, CHP and stationary engine usage and to replace light fuel oil including in the small-scale heating sector. Chemical upgrading will most probably be required, but the objective should be to limit the upgrading effort to physical methods (like solids removal, control of water content, blending) for economic reasons. This might be very case-specific but also country depending.
- Use of alternative feedstock, in particular agricultural residues like verge grass, straw, reed, but also lower quality wood/wood residues/used wood. This requires the introduction of specific treatments in the plant itself or post-treatment. The oil produced from these resources should comply with the specifications defined in the new EN-standards.
- Bio-oils are completely different from petroleum fuels and other bio-oils in the market, like biodiesels, as regards both their physical properties and chemical composition. Due to these unique properties, bio-oil as such is not infrastructure-ready fuel, which means that the whole fuel chain from transportation, storage and piping to the gaskets, burner and combustion chamber must be developed to meet its special characteristics
- Development of suitable, standardised transportation and storage concepts (i.e. suitable coatings and materials) that guarantee the product quality, handling instructions and bio-oil combustion and emission control system development

## Key Performance Indicators

	2013	2020
Production cost of bio-oil	Estimation depending on feedstock price; approximately 50 – 70 €/MWh, 13.9 – 19.4 €/GJ	Commercial bio-oil production for heating applications, 20% reduced bio-oil costs through process integration and logistical optimization
Plant availability	No data	Full scale bio-oil production with plant availability > 6,500 hrs. per annum
Bio-oil upgrading	Upgrading technologies under development	Bio-oil upgrading to higher value products demonstrated at industrial scale.
Feedstock flexibility target	Woody biomass	Forest and agricultural residues and their blends
Bio-oil quality improvement to be suitable for CHP and stationary use and light fuel oil replacement including small-scale heating sector, using different types of feedstock	Moisture content: 20-30 w% Net calorific value: 14-18 MJ/kg Kinematic viscosity at 40°C: 10-20 cSt Solids content: < 0.5 w% Ash content: <0.05 w% <sup>11</sup>	Bio-oil satisfying specifications of new EN standard (for boilers and engines) under development by CEN (mandate accepted 10/2013). New bio-oil grades having improved quality – higher LHV, no solids, good stability, pH > 4. 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)

## Supporting Organisations

Supporting Organisations can be found here:

<http://www.rhc-platform.org/structure/biomass-technology-panel/biomass-technology-roadmap/supporting-organisations/advanced-fuels-replacing-coal-fossil-oil-and-natural-gas-in-heat-and-chp-production/innovative-production-and-upgrading-technologies-for-bio-oil/>

### 2.1.3. Thermally treated biomass fuels production

Different biomass thermal treatment processes are considered in this section. **Torrefaction** involves heating biomass in the absence of oxygen in the temperature range between 200-320°C. At these temperatures, a dry, brittle and nearly water resistant product is obtained, which makes it much easier to grind and store than the parent biomass material and reduces biological degradation in storage. **Steam Explosion (SE)** is a process in which biomass is heated with steam in a pressure vessel and then blown to atmospheric pressure breaking the material structure. **Hydrothermal carbonisation (HTC)** refers to “torrefaction in liquid phase” or “wet torrefaction” at moderate temperatures (< 260°C) in a pressurized reactor<sup>12</sup>. HTC is a suitable densification technology for wet biomass which has a very high potential<sup>13</sup>.

<sup>11</sup> Feedstock used pine wood and straw (Bioliquids-CHP project: <http://www.bioliquids-chp.eu>), Oasmaa, Anja; Peacocke, Cordner. 2010. A guide to physical property characterisation of biomass-derived fast pyrolysis liquids. A guide. Espoo, VTT. p. 79 + app. 46 p. VTT Publications; 731 <http://www.vtt.fi/inf/pdf/publications/2010/P731.pdf>

<sup>12</sup> VGB PowerTech White Paper on Torrefaction/Refined Pellets for Biomass Co-Firing

<sup>13</sup> Source: EUBIONET project, <http://dx.doi.org/10.1021/ef401295w>

## Thermally treated biomass fuels production

Applications	CHP production in utilities and industry
Main products	Thermally treated biomass suitable for fossil fuels substitution in CHP, co-firing or other conversion process (e.g. gasification)
Main feedstock	Improved quality of biomass feedstock (cfr. section 2.1.1), increasing use of agrobiomass
Technologies covered	Torrefaction, hydrothermal carbonisation, steam explosion

### European added value and the services to society

- Promising technologies for the promotion of the large-scale implementation of bioenergy: production of a high-energy-density biomass fuel commodity (when combined with pelletisation or briquetting) offering compatible properties with coal and enabling higher co-firing percentages
- Improved behaviour in transport and storage as well as in many major end-use applications (enhanced reliability to consumers): better water resistance, slower biodegradation, good grindability, good “flow ability”, homogenized material properties
- Energy-efficient biomass upgrading process: overall biomass-to-thermally treated-pellets energy efficiencies exceeding 90% (based on net calorific value) can be reached, provided that the thermal treatment process is conducted in an energy-efficient way (with heat recovery and integration)
- Significant contribution to the renewable energy and decarbonisation targets in Europe: if 100 coal fired CHP plants would use 5% torrefied biomass in co-firing, this would enable the substitution of 33 Mtons<sup>14</sup> coal which corresponds to a greenhouse gas emission saving of 79 Mtons CO<sub>2</sub><sup>14</sup>. VTT estimated that co-firing rates with coal<sup>15</sup> can reach up to 50%, enabling the substitution of 300 Mtons coal and greenhouse gas emission savings of 695 MCO<sub>2</sub> tons<sup>16</sup>.
- Decreased dependency on imported fossil fuels and increased security of the energy supply
- Enlarged raw material portfolio for bioenergy production in Europe, including both agricultural and forestry residues as well as wet biomass (through Hydrothermal Carbonisation), tackling issues related to competition between different biomass uses but also improving the cost-effectiveness (raw material costs are almost 50% of thermal treatment process)
- Job creation in the European agricultural industry
- Lead the path toward further conversion of biomass (e.g. through gasification) and end-products (2nd generation biofuels, biochemicals)

### Main technological challenges

- Successful full-scale commercial demonstration of thermally treated biomass fuels in small-scale heating and CHP applications (co-firing percentages) and in peak load, start-up and partial load installations
- Improving overall cost-efficiency of thermally treated biomass fuels production
- Development of specific blends for thermally treated biomass suitable for different raw materials and conversion technologies of different scales
- Exploiting possibilities of by-product use e.g. production of biobased pesticides, additives for glues
- Ensuring standardized product quality (ISO international product standard developed in 2016) and sustainable production and processing
- Ensuring high thermal energy efficiency.
- Handling of health and safety risks (e.g. existing Material safety data sheet, MSDS, REACH registration)
- Ensuring high feedstock flexibility with a blend of wood, agricultural residues, and biodegradable waste material (food industry, shaving, pruning, roadside greenery)
- Pelletizing or briquetting of thermally treated feedstock

<sup>14</sup> 33 Mtons coal\*23.8 TJ/ton\*93.3 MCO<sub>2</sub>/TJ

<sup>15</sup> Wilén, C., Jukola, P., Järvinen, T., Sipilä, K. Verhoeff, F. & Kiel, J. 2013. Wood torrefaction – pilot tests and utilisation prospects, VTT Technology 122. p. 73

<sup>16</sup> 300 Mtons coal\*23.8\*93.3=695 MCO<sub>2</sub> tons

## Key Performance Indicators

	2013	2020
Increased co-firing percentages	5-10% biomass co-firing of torrefied or other thermally treated biomass	Commercial operation of thermally treated biomass co-firing >50% of coal CHP plants using torrefied biomass
Production costs	32 – 41 <sup>17</sup> €/MWh (8.8 – 11.4 €/GJ)	Costs reduction by 5 - 10 €/MWh (1.4 – 2.8 €/GJ)
Operational hours per year	Technology is under demonstration, data not available	Full load 8 000 hours/year
Overall biomass-to-thermal treatment-pellets/briquettes energy efficiencies (based on net calorific value as received)	Technology is under demonstration, data not available	>90%
Flexibility of raw material input	At present, thermal treatment processes are mainly based on woody biomass resources.	Minimum share of agrobiomass 10%
Health and safety risk of thermally treated biomass fuels	Investigations self-heating/off-gassing, self-explosion started	Risk avoiding guidelines and MSDS as a standardised procedure
Intermediate and long-term storage capacities	Outdoor storage is yet not verified for tested qualities	10 to 15% of annual production to have a verified in large scale a quality that can be stored outdoors
Availability of thermally treated biomass	No commercial plant available	In EU the trading volume of thermally treated biomass about 1 – 2 million tons.

## Supporting Organisations

Supporting Organisations can be found here:

<http://www.rhc-platform.org/structure/biomass-technology-panel/biomass-technology-roadmap/supporting-organisations/advanced-fuels-replacing-coal-fossil-oil-and-natural-gas-in-heat-and-chp-production/thermally-treated-biomass-fuels-production/>

### 2.1.4 Upgrading of biogas to biomethane

Biogas typically refers to a gas produced by the anaerobic digestion or fermentation of organic matter including manure, sewage sludge, municipal solid waste, biodegradable waste, energy crops, agricultural residues (straw, catch crops, etc.) or any other biodegradable feedstock.

In many CHP units located in remote areas with no potential heat user, the heat produced is only partly used, or wasted. This inefficiency in energy use is a bottleneck in current biogas production, causing macroeconomic and microeconomic losses and challenges in the context of overall increasing land use competition. There are many different solutions to use this “unused heat”, including micro district heating networks, injection of the heat into the district heating network, installation of biogas-pipelines to satellite-CHP units, heat use in nearby greenhouses, cooling, drying, etc.

A further solution to overcome this problem of “unused heat” of biogas plants is to promote the upgrading of biogas to biomethane with adjacent injection of the biomethane in the natural gas grid. Once the biomethane has entered the natural gas grid, it can be easily stored and consumed at any place with natural gas grid access

<sup>17</sup> SECTOR project (2013), [www.sector-project.eu](http://www.sector-project.eu)

thereby utilising its full energy content can be utilised. Finally, biomethane can also be used as fuel for transport applications (cars, heavy duty trucks, etc.).

Through an upgrading process, biogas is cleaned of impurities such as hydrogen sulphide, water, nitrogen ammonia, siloxanes, particles and oxygen and CO<sub>2</sub>, whereas the methane content is increased from 45-70% CH<sub>4</sub> to >95% CH<sub>4</sub> - thereby increasing the energy density. After the upgrading process, biomethane is conditioned (fine-tuning of the gas composition and the heating value), odorised and pressurised in order to be injected into the natural gas grid.

Currently, two European standards for natural gas and biomethane for use in transport and biomethane for injection in the natural gas grid are under development by CEN/PC408.

### Upgrading of biogas to biomethane, also for smaller biogas plants

Applications	As a natural gas substitute in the heating sector including also small-scale heating systems
Main products	Biomethane to replace natural gas in CHP
Main feedstock	Improved quality of biomass (cfr. section 2.1.1) such as agricultural residues (straw, catch crops, manure etc.), energy crops and biogenic wastes (sewage sludge, separated household waste and organic industrial waste) mass
Technologies covered	Anaerobic digestion or fermentation and biogas upgrading. Upgrading technology include adsorption technologies, absorption technologies, permeation technologies, and cryogenic upgrading technologies.

#### European added value and the services to society

- Contribution to the renewable energy production and decarbonisation targets in Europe: 4.5 Mtoe (52.3 TWh, 188.3 PJ) heat is expected to be produced from biogas in 2020 and GHG savings will be almost 14 million tons.
- Organic waste reduction potential: ability to treat wet materials which is difficult for thermo-chemical processes, including manure, sewage sludge, municipal solid waste or any other biodegradable feedstock.
- Crops grown for biogas can be integrated into a crop rotation or a catch crop system which improves the overall productivity of the farm, including subsequent food crops
- Production of high-quality digestate which can substitute chemical fertilizers
- Reduction of unused heat from (remote and nearby located) CHP units: the upgrading of biogas to biomethane with adjacent injection of the biomethane in the natural gas grid offers a solution to tackle the problem of “unused heat” of biogas CHP plants thereby increasing the energy efficiency of the process. By 2020, 80% of all European biogas plants will have implemented the use of “waste heat” in their CHP units which means almost 14 million tons of GHG savings

#### Main technological challenges

- Diversification of input material - Increase the flexibility of biomass feedstock in the fermentation process (e.g. sustainable energy crops with potential on soils not suitable for food crops, intercropping, agricultural residues, roadside maintenance biomass, grass silage, biodegradable waste, food residues)
- Reduction of specific investment (fermenter and post-fermenter)
- Downscaling of biomethane upgrading plants
- Automation of the control system for biogas production and feeding
- Increase the efficiency of biogas and biomethane compression
- Increase the safety of handling and delivering by the use of standardized and certified concepts
- Enhance the agricultural use by quality improvement of digestate as substitute for fertilizer
- Reduce the costs for biogas cleaning and upgrading of biogas to biomethane (especially for smaller systems)
- Reduce the power consumption of biogas up-grading
- Increase of the flexibility of CHP units to contribute to load management
- Increase the heat use of biogas systems

## Key Performance Indicators

	2013	2020
Diversification of raw material for biogas production	Biogas yield per ha of alternative energy crops is significantly lower than yield for maize <sup>18</sup>	Increase of biogas yield of alternative energy crops by 20-30%
Increase of efficiency of biogas up-grading	Up-grading power consumption: Ø 0.25 kWh/Nm <sup>3</sup>	Up-grading power consumption: Ø 0.15 kWh/Nm <sup>3</sup>
Cost reduction of biogas upgrading	A 500 Nm <sup>3</sup> /h upgrading plant costs about 7.500 €/Nm <sup>3</sup> h	Cost reduction by 10-20%
Improvement of load flexibility of biogas CHP systems	Part load operability of biogas CHP units > 60%	Part load operability of biogas CHP units > 40%
Increase of efficiency of biogas CHP systems	Electrical efficiency of biogas systems is 33-45%	Efficiency improvements by 10-20%
GHG emission reduction by the use of waste heat of biogas CHP units	About 50% of European biogas plants have implemented appropriate use of "waste heat".	80% of all European biogas plants have implemented the use of "waste heat" from their CHP units with GHG savings almost 14 million tons.

## Supporting Organisations

Supporting Organisations can be found here:

<http://www.rhc-platform.org/structure/biomass-technology-panel/biomass-technology-roadmap/supporting-organisations/advanced-fuels-replacing-coal-fossil-oil-and-natural-gas-in-heat-and-chp-production/upgrading-of-biogas-to-biomethane/>

<sup>18</sup> Silo maize - methane yield - 4000 - 6000 m<sup>3</sup>/ha, sudan grass - methane yield - 2200 - 4500 m<sup>3</sup>/ha, mixed grass - methane yield - 2000 - 3500 m<sup>3</sup>/ha (Provided by VGB PowerTech e.V., all figures from KTBL Faustzahlen Biogas)

<sup>19</sup> Technology Readiness Level (cfr. Annex II)

## 2.1.5. REQUIRED RD&amp;D ACTIVITIES AND BUDGET FOR ADVANCED FUELS

Type of research	TRL <sup>19</sup>	Research activities	Estimated number of projects	Overall required budget [€ million]
Applied research	2,3	<ul style="list-style-type: none"> <li>- Optimized feedstock selection and quality, better understanding of the process conditions for thermally treated biomass and its behaviour in later consumption processes</li> <li>- Development of stabilization, quality improvement and upgrading methods to upgrade bio-oil to suitable quality for CHP and stationary engine usage and for the replacement of light fuel oil (including small-scale heating sector)</li> </ul>	5-10	20
Development	4	<ul style="list-style-type: none"> <li>- Optimized feedstock selection and quality (blended raw material use, reduction of impurities and residues), proof of concepts, enlargement of raw material base for thermally treated biomass</li> <li>- Development of innovative forestry and agrobiomass residues harvesting machinery</li> <li>- Selection and development of appropriate and sustainable energy crops and agricultural residues for biogas, improve of pre-treatment technologies to ensure high availability and digestibility of feedstock, reduce the costs for the biomethane upgrading step, determination of technoeconomic criteria to facilitate the choice between biologically based and thermochemically based conversion technologies, development of disintegration technologies (mechanical, biological, thermally), increase of the specific gas yield, time reduction for a given degradation rate, development of alternative input material for anaerobic digestion and verification of specific gas yield, development of biogas specific measurement technology (e.g. flow measurement for biogas), volume measurement for floating domes/carrying air roofs, condition monitoring of the microbiological process</li> <li>- Bio-oil CHP and stationary engine usage development, enlarging raw material base for bio-oil production, reduction of production costs, detailed market implementation analysis</li> </ul>	10-20	100
Demonstration	7	<ul style="list-style-type: none"> <li>- 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, technical optimisation, economical evaluations</li> <li>- Full-scale commercial demonstrations of bio-oil in heating sector to replace heavy fuel oils and natural gas with good availability and safe operation for technical optimisation and economical evaluations, pyrolysis oil quality control integrated with production plant, demonstration of oil fractionation at pilot and pre-commercial scale (~10 – 1000 kg/hr)</li> <li>- Demonstration of new types of sustainable feedstock supply chains in different climatic conditions</li> <li>- Down-size applications for the biomethane upgrading step</li> </ul>	5-10	80
<b>TOTAL</b>				<b>200</b>
Of which public funding				100
Of which private funding				100

	2014-2016	2017-2020
Commercial plants for thermally treated biomass <sup>20</sup>	BR	Demo
	AR	
Sustainable and cost efficient feedstock	AR	Demo
Full use of the energy content of biogas	AR	M
	Demo	M
Commercial plant for bio-oil	BR	Demo
	AR	

**BR:** basic research

**AR:** applied research & experimental development

**Demo:** demonstration

**M:** market-ready

<sup>20</sup> HTC is expected to be at demonstration stage in the period between 2014-2016

## 2.2. COST AND ENERGY EFFICIENT, ENVIRONMENTALLY FRIENDLY MICRO AND SMALL SCALE CHP

Small and micro-scale CHP constitute a high energy efficient solution (total sum of thermal and electrical efficiency > 85%) for flexible bio-electricity and thermal energy supply (cfr. research priorities **BIO.3** Cost-effective micro-CHP systems and **BIO.7** Cogeneration technologies and small scale biomass gasification technologies in **RHC- SRA**). Small and micro-CHP are developed for various applications. Micro-scale CHP are serial products developed for residential scale heating with electricity production (possibly grid independent, typical P < 5 kWe) or as cogeneration systems for small industries, the service sector or in micro grids (base heat for >2.000 hours/year, typical P < 50 kWe). Small scale CHPs are plants rather than products for cogeneration in industries, the service sector or DHC (base heat for >5.000 hours/year, typical P < 250 kWe).

	Micro scale CHP <5 kWe	Micro scale CHP 5-50 kWe	Small scale CHP 50-250 kWe
<b>Applications</b>	Residential market	Small industries, services, micro grids etc.	Industry, services, DHC etc.
<b>Main products</b>	Heat, by-product electricity	Heat, electricity	Heat, electricity
<b>Main feedstock</b>	High quality solid biomass (woody sources), biogas, bio-oil <sup>21</sup> , preferably standardised quality fuel	Solid biomass (mostly woody sources), syngas, biomethane, biogas, bio-oil	Solid biomass (wood chips), biogas, syngas, bio-oil tolerating a wider quality range. Applicable fuels range from wood pellets to lower grade wood chips or even locally available non-wood or pre-treated biomass fuels derived from waste streams
<b>Technologies covered</b>	Thermoelectrics, Stirling engine, steam cycles, organic Rankine cycle (ORC), internal combustion engine (IC), micro gas turbine (MGT), fuel cell (FC)	Stirling engine, steam cycles, ORC, gasification + IC, IC, externally fired micro gas turbine (EF-MGT)	Stirling engine, steam cycles, ORC, gasification + IC, IC, EF-MGT

### European added value and the services to society

- Reliable and decentralised renewable energy production for the end consumers: 5% of new installations (residential and small commercial applications) will be CHPs in 2020
- Contribution to electrification of the EU energy system and decentralized electricity production in smart grids
- Reduction of electricity production costs of biomass based systems through a technology specific mix of decreasing investment and maintenance costs, increasing electric efficiency and availability, energy efficient and cost effective storage systems, reduced electricity price for the end-consumer compared to electricity from the grid due to instantaneous use

### Main technological challenges

- Cost reduction by technical optimization with consideration of serial production
- Reduction of maintenance costs
- Development of high temperature- and high corrosion-resistant heat exchanger including reliable cleaning mechanisms or technological solutions to avoid deposit formation
- Material development (seals, heat exchangers, etc.)
- 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
- Increase the reliability of the technology in order to continuously achieve more than 7000 operational hours per year.

<sup>21</sup>Bio-oil for micro-scale will probably, whereas small-scale utilization might be based on bio-oil as it is produced or on physically treated bio-oil.

## Required RD&D activities and budget

Type of research	TRL <sup>22</sup>	Research activities	Estimated number of projects	Overall required budget [€ million ]
Basic research	3	Material research: thermoelectric materials, working fluids, working machine materials	8-10	50
Applied research	4	Component and system development, performance and efficiency improvement, cost reduction	15	225
Demonstration	7-8	Demonstrate long-term performance to assess reliability and techno-economics in field operation. Cost reduction, preparation for serial production. Demonstration of bio-oil engines and turbines prototypes operational (20 -50 kWe).	10	225
<b>TOTAL</b>				<b>500</b>
Of which public funding				250
Of which private funding				250

	2014-2016	2017-2019	2020
Thermoelectrics	BR	AR	
Stirling engine	AR	Demo	M
Steam cycle	AR	Demo	
ORC		Demo	M
Fuel cell		Demo	M
Micro gas turbine	AR	Demo	
Gasification +IC		Demo	

**BR: basic research**

**AR: applied research & experimental development**

**Demo: demonstration**

**M: market-ready**

<sup>22</sup> Technology Readiness Level (cfr. Annex II)

## Key Performance Indicators

	2013	2020
Electricity production costs		Reduction of 50%
Minimum lifetime suitable components for bio-oil engines and turbines		2,000 operational hours
Proven lifetime	No data	20.000 h (<5 kWel) / 35.000 h / 50.000 h (>50 kWel)
Electric system efficiencies based on solid state technologies	1%	2%
Electric system efficiencies based on thermodynamic cycles	No data	7% (<5 kWel) <10% -12% (5 - 50 kWel) 12-15 (<250 kWel)
Investment costs solid state technologies	20-30 EUR/W (depending on materials and suppliers)	10 EUR/W
Investment costs thermodynamic cycle technologies	4-25 EUR/W (depending on technology and fuel)	3.5 EUR/W
Reduction of emissions	In compliance with EN303-5	1/10 of the specifications in EN303-5 (except for NOx)

## Supporting Organisations

Supporting Organisations can be found here:

<http://www.rhc-platform.org/structure/biomass-technology-panel/biomass-technology-roadmap/supporting-organisations/cost-and-energy-efficient-environmentally-friendly-micro-and-small-scale-chp/>

## 2.3. HIGH EFFICIENT LARGE-SCALE OR INDUSTRIAL STEAM CHP WITH ENHANCED AVAILABILITY AND INCREASED HIGH TEMPERATURE HEAT POTENTIAL (up to 600°C)

In 2010, about 54% of the gross inland consumption of biomass was fed into electricity and/or heating plants, or used in industrial processes. Considering the European Union's climate and energy targets for 2020, biomass use in industrial power plants and DHC is expected to roughly double in 2020<sup>23</sup> through retrofitting of previous fossil-fuelled as well as new biomass plants. Taking into account the increasing strictness of air quality requirements (in e.g. the IED) and the limited availability of high quality wood resources in Europe, significant R&D efforts are required to develop high-efficient large-scale and industrial multi-fuel systems (cfr. research priority BIO.11 in RHC-SRA).

Applications	Industry, DHC
Main products	Heat, Power, Cooling
Main feedstock	Woody biomass, e.g. wood pellets, wood chips, recycled wood etc. Thermally treated biomass e.g. torrefied biomass Agrobiomass, e.g. agricultural residues, energy crops Waste recovered fuels, e.g. RDF/SRF
Other feedstock	Sulphur containing fuels, peat for co-firing applications, digested sewage sludge as additive
Technologies covered	Grate firing Bubbling/Circulating Fluidised bed Pulverised Fuel Gasification Corrosion reducing additives or the use of co-combustion, with focus on furnace wall and super heater corrosion Development of coating technology for critical areas of the furnaces in order to avoid corrosion Material technology development for critical areas of super heater surfaces Flue gas cleaning systems

<sup>23</sup>Strategic Research Priorities for Biomass Technology

### European added value and the services to society

- Significant contribution to renewable heat and electricity supply through large single units
- Commercial deployment of cost-effective bioenergy technology providing moderate costs for the consumers through the use of cheaper fuels, high-efficient conversion to bioenergy, and simple concepts, thus allowing for limited additional investment and short-term effectiveness to decrease GHG emissions
- Commercial deployment of feedstock-effective and sustainable bioenergy technology, providing high reliability and flexibility for consumers through increased energy generation from (scarce/limited) renewable fuels and more efficient utilization of renewable sources
- Reduce electricity production costs from biomass through increased efficiency and reduced fuel costs
- Contribute to the mobilization of new biomass feedstocks, which can be used in large-scale CHP units
- Minimize environmental impact of large-scale CHP units through reduction of emissions and identification of ash utilization pathways

### Main technological challenges

- Increase the fuel flexibility for large-scale combustion / co-firing / gasification processes, especially to be able to use more complex and low cost biomass fuels (e.g. agrobiomass and waste recovered fuels/sludges)
- Maintain high operational electrical efficiency<sup>24</sup>, close to nominal, for variable feedstock and/or variable load
- Increase steam parameters and/or heat medium temperature
- Address catalyst deactivation issues and PM emissions in flue gas cleaning systems with increasing share of biomass
- Identify new ash utilization options

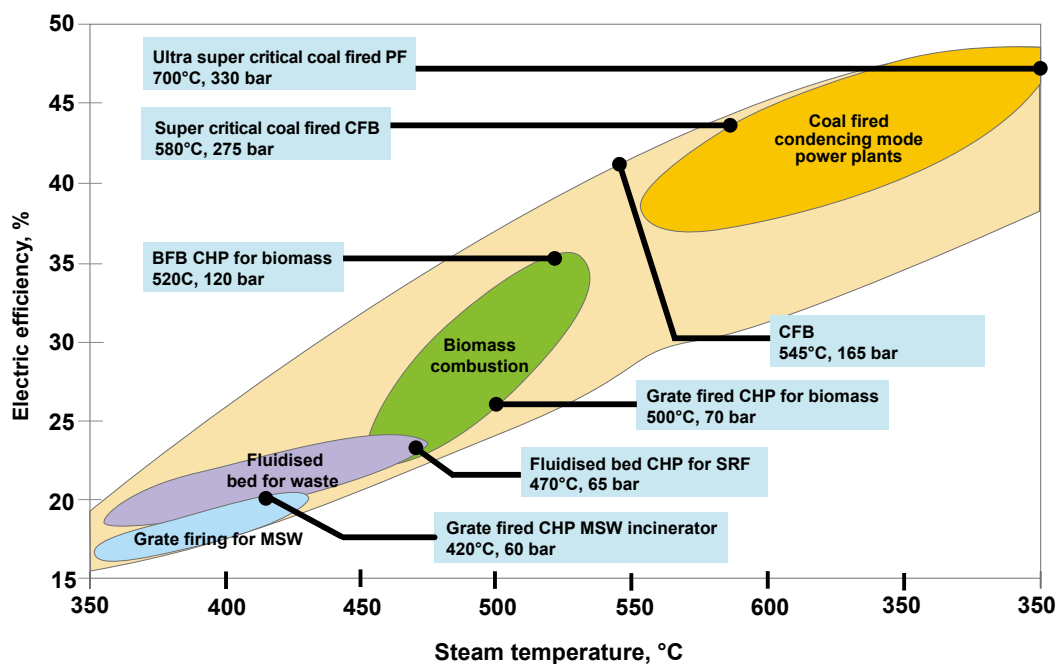


Figure 4: Indicative range of electric efficiency vs. steam temperature for different fuel and plant types (Adapted from: Remondis)

<sup>24</sup>Definition of operational efficiency from Bio-CHP best practice guide: actual efficiency based on monthly operational data

## Required RD&D activities and budget

Type of research	TRL <sup>25</sup>	Research activities	Estimated number of projects	Budget per project / unit [€ million]
Applied research	4	<ul style="list-style-type: none"> <li>Material science (new coatings, new SH tube materials)</li> <li>Corrosion control (corrosion memory, development and testing of new additives, development of sensors)</li> <li>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</li> <li>Optimization of boiler design / placement of heat exchange surfaces / cleaning techniques</li> <li>Increased fuel flexibility and utilisation of more complex biofuels</li> <li>Improved knowledge on the correspondence with fuel properties, flue gas components and corrosion</li> <li>Novel ash utilization options</li> </ul>	6-7	2-5 per project <sup>26</sup>
Demonstration	7-8	<b>Existing CHP and/or co-firing plants:</b> <ul style="list-style-type: none"> <li>Boiler retrofitting</li> <li>Long-term testing of fuel mixtures / new materials with increased agrobiomass, recycled wood and other low quality biofuels share</li> <li>Long-term testing of SH material solutions at elevated admission data for increased electrical efficiency</li> <li>Monitoring of plant efficiency and emissions behaviour</li> <li>Development of control concepts and strategies for optimal efficiency under variable loads</li> </ul>	3-4	10 per demonstration unit <sup>27</sup>
		<b>New CHP and/or co-firing plants:</b> <ul style="list-style-type: none"> <li>Long-term testing of fuel mixtures / new materials with increased agrobiomass, recycled wood and other low quality biofuels share</li> <li>Monitoring of plant efficiency and emissions behaviour</li> <li>Development of control concepts and strategies for optimal efficiency under variable loads</li> </ul>	3-4	100 – 300 per demonstration unit <sup>28</sup>

<sup>25</sup> Technology Readiness Level (cfr. Annex II)

<sup>26</sup> Share of public funding in line with Horizon 2020 (70%)

<sup>27</sup> Share of public funding in line with Horizon 2020 (70%)

<sup>28</sup> Estimated 100 – 300 total investment per unit of which € 10 – 30 public funding

	2014-2016	2017-2020
High efficient large-scale or industrial steam CHP with enhanced availability and increase high temperature heat potential	AR <i>New materials (e.g. for superheats tubes, catalysts, etc)</i>	Demo <i>Demonstrate fuel flexibility and optimal efficiency under variable load at 3-4 CHP units</i>
	AR <i>Optimization of boiler design / placement of heat exchange surfaces / learning techniques</i>	
	AR <i>Development and testing of suitable co-firing matrices for problematic biofuels</i>	
	AR <i>Corrosion control (additives), ash utilisation</i>	

**BR:** basic research

**AR:** applied research & experimental development

**Demo:** demonstration

## Key Performance Indicators

### New CHP boilers

	2013	2020
Net nominal electric efficiency	32% (clean wood boilers) 29% (wide fuel mix boilers)	34% (clean wood boilers) 32% (wide fuel mix boilers)
Steam characteristics	540°C / 140 bar (clean wood boilers) 500°C / 90 bar (wide fuel mix boilers)	600°C / 175 bar (clean wood boilers) 563°C / 160 bar (wide fuel mix boilers)
Total CAPEX	Between 2500 – 3000 €/kWe	Increase of no more than 10% over current state of the art for new technologies;
Electricity production costs		Reduced by at least 5% (clean wood boilers) Reduced by at least 9% (wide fuel mix boilers)
Emissions	Catalyst deactivation issues for SCR PM emissions due to high alkalis (for wide fuel mix boilers)	Increase catalyst operating times Conformity with IED
Ash utilisation	Mostly landfill	30% utilized

## Existing CHP boilers (retrofit targets)

	2013	2020
Agrofuels thermal share in fuel mixture in wood fired units	Typically limited to 10-20%	> 50%
Operational electric efficiency	Can be as low as 5%	Max. 10% reduction from nominal
Emissions	PM emissions due to high alkalis Catalyst deactivation issues for SCR	Conformity with IED Increase catalyst operating times
Ash utilisation	Mostly landfill	30% utilized

## Supporting Organisations

Supporting Organisations can be found here:

<http://www.rhc-platform.org/structure/biomass-technology-panel/biomass-technology-roadmap/supporting-organisations/high-efficient-large-scale-or-industrial-steam-chp-with-enhanced-availability-and-increased-high-temperature-heat-potential-up-to-600c/>

## 2.4. HIGH EFFICIENT BIOMASS CONVERSION SYSTEMS FOR POLYGENERATION

Bioenergy as a storable energy source presents a real advantage when considering its integration in the overall renewable energy system. Besides the production of heating and cooling, CHP (combined heat and power) and CHP-C (combined heat, power and cooling or polygeneration) technologies are able to provide intermittent electricity, balancing both daily and seasonal changes in solar and wind electricity production and loads of boilers, increasing plant availability, peak load duration and economy (cfr. research priority BIO.12 in RHC-SRA). Depending upon the season, climatic condition and time of day, the primary function of such biomass fuelled units may change from electricity, heating and cooling to even bio-oil production (polygeneration, for example with integrated bio-oil production). Through fractionation, the bio-oil can further be transformed into different products and chemicals (polygeneration) - some of them with a higher value. Polygeneration can be applied at different scales depending on investment conditions and demand of heating, cooling and/or process heat. The most promising areas for polygeneration (CHP-C) generation are:

- Small scale heat network and industrial use at scale of 1-80 MWth (<10MWe)
- Municipal district heat networks and industry at scale of 30-500 MWth (<200 MWe)
- Utility scale boilers at scale over 200 MWth (>100 MWe)

The installation and boundary conditions are different in each option and, therefore, demonstration and R&D activities are needed in each case. There are also several cross cutting issues to be taken into account in order to achieve maximum utilization of biomass and to achieve the high operational flexibility in renewable energy infrastructure.

	1-80 MWth (<10MWe)	30-500 MWth (<200 MWe)	> 200 MWth (>100 MWe)
<b>Applications</b>	Small scale heat network, industry	Municipal district heat networks and industry	Utility scale boilers, regional grid
<b>Main products</b>	Heat, cool, power, process steam. Possibility to produce bioenergy carriers (synthesis gas, bio-oil etc.) in addition	Heat, cool, power, process steam. Possibility to produce bioenergy carriers (synthesis gas, bio-oil etc.) in addition	Heat, cool, power, process steam. Possibility to produce bioenergy carriers (synthesis gas, bio-oil etc.) in addition
<b>Main feedstock</b>	Forest and agricultural residues, sorted wastes	Forest and high quality industrial waste, dedicated energy crops	Forest residues, wood energy crops
<b>Technologies covered</b>	Grate, fluidized bed and, gasification and fast pyrolysis	Fluidized bed and gasification and fast pyrolysis (grate and pulverized combustion)	Grate, fluidized bed and pulverized combustion, gasification (fast pyrolysis)

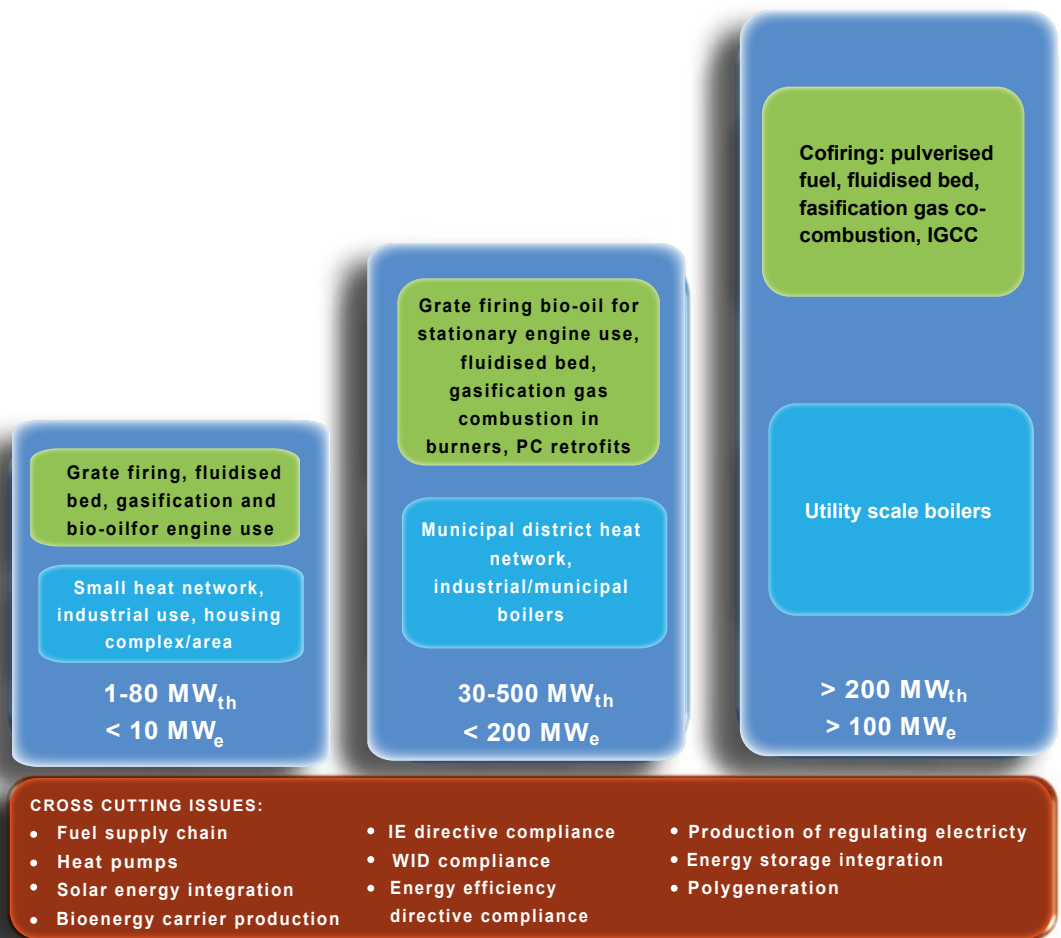


Figure 5: Categorization of the operational scales considered including the cross cutting issues arising from the operating environment and to be taken into account in order to achieve maximum utilization of biomass and to achieve the high operational flexibility in renewable energy infrastructure. Installation and boundary conditions are different in each option and, therefore, specific R&D activities are needed in each case.

### European added value and the services to society

- Increase potential for CHP in particular in Middle and Southern Europe by increasing the heat and cold load of power plants. Depending upon the season, climatic condition and time of day, the primary function of such biomass fuelled units may change from electricity, heating, cooling to even bio-oil production
- Facilitating 100% renewable electricity market by enabling the integration of other intermittent renewables namely solar and wind power
- Possibility to produce bioenergy carriers (synthesis gas, bio-oil etc.) in addition - for example through fractionation bio-oil can further be transformed into different products and chemicals (polygeneration) - some of them with a higher value
- Chemical upgrading of bio-oil to a mix of different fuels might also be seen as a polygeneration approach (e.g. diesel, light fuel oil and heavy fuel oil); Each of the fuels might be used in different markets
- 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 %)
- Contribution to renewable energy production by replacing condensing power production, with/without energy storage
- Specific emissions (CO<sub>2</sub>, CO, NO<sub>x</sub> and SO<sub>x</sub>) reduced by half compared to condensing power productions

## Main technological challenges

- Development of cost-competitive polygeneration production plants
- Integration of cooling system and distribution to CHP plants (CHP-C)
- Optimisation of plant design:
  - Energy system modelling and identification of the requirements of future biomass CHP-C units as part of solar and wind electricity system. The system analysis requires the development of dynamic models that can simulate the daily and seasonal behaviour of an urban energy system in different climatic conditions.
  - Integration with energy storages
- Eliminating operational problems and improving security of supply:
  - Creating test beds for online monitoring and measurement techniques
  - Specific technologies to increase the flexibility of multi-fuel units must be identified and developed including online fuel quality and process monitoring
- Identifying business models for two-way tri-generation and poly-generation energy networks

## Required RD&D activities

Type of research	TRL <sup>29</sup>	Research activities	Estimated number of projects	Overall required budget [€ million ]
Applied research	2,4	Energy storage	5-10	25
Development	3,4,6	Concepts development for operation hybrid electric/ heating/cooling grid Comparative study on cooling grid techniques/concepts: - Distribution of heat + absorption cooling - Distribution of cold media + direct cooling	10-15	26
Demonstration	7,8	Medium-scale tri-generation demonstrations (10 – 30 MW industrial scale application)	2-4	60
		Municipal scale tri-generation concepts demonstrations (50-100 MW with extended multifuel operation capability)	2-4	120
		Large scale tri-generation demonstrations with concepts for different climatic conditions, reaching > 80% average annual efficiency	2-3	180
TOTAL				450
Of which public funding				225
Of which private funding				225

<sup>29</sup>Technology Readiness Level (cfr. Annex II)

	2014-2016	2017-2020
Energy storage	BR AR	Demo
Concept development	AR	M
3 Demonstrations in different scales	AR	Demo

**BR:** basic research

**AR:** applied research & experimental development

**Demo:** demonstration

**M:** market-ready

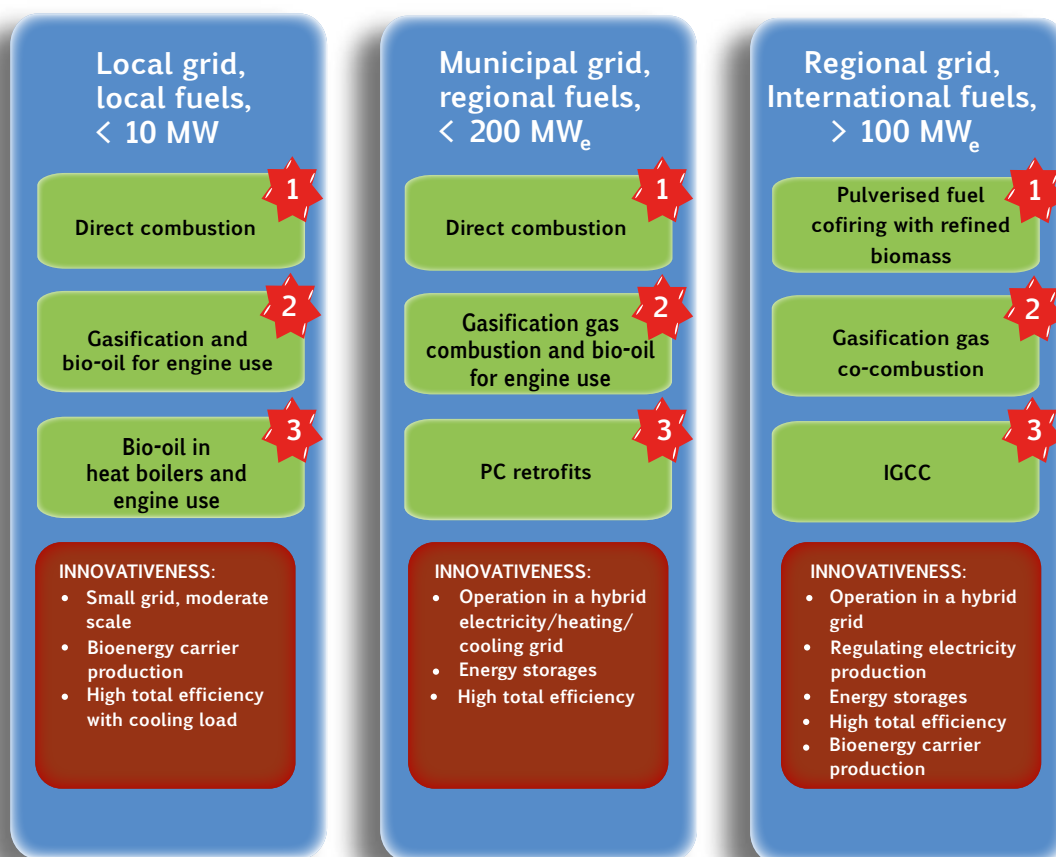


Figure 6: Demonstration plan with RTD component for biomass tri-generation concepts

## Key Performance Indicators

	2013	2020
Average annual efficiency	45% in electricity production, about 65 – 85% in CHP production	>90% overall efficiency
Emissions reduction (CO <sub>2</sub> , CO, NOx and SOx)	Emission levels in fossil condensing plants	Emissions reduced by half compared to condensing power production
Efficiency in electricity production		> 30% (<10MWe) > 40% (<200 MWe)

## Supporting Organisations

Supporting Organisations can be found here:

<http://www.rhc-platform.org/structure/biomass-technology-panel/biomass-technology-roadmap/supporting-organisations/high-efficient-biomass-conversion-systems-for-polygeneration/>



# 3

## Suggested implementation modalities and monitoring



## 3 SUGGESTED IMPLEMENTATION MODALITIES AND MONITORING

### 3.1. PROJECT ELIGIBILITY AND SELECTION PROCEDURES

Eligibility and project selection procedures should take the following aspects into account:

- Quality of the consortium: the project is carried out by a transnational consortium with sufficient operational and financial capacity
- Quality of the technology concept: the project has to ensure a high technological, economic and environmental performance and a reliable working methodology and organisation
- Energy efficiency: the project has to deliver high and verifiable energy efficiency (efficiency calculated as useful final energy/fuel input)
- Economic performance of the commercial concept: the project has to deliver a reasonable economic performance and should be potentially viable in the market
- Innovation: the project should comprise at least one innovative component or focus on the novel integration of known technologies and processes at the appropriate scale for first-of-its-kind demonstration plants
- Feedstock availability: the project has to ensure cost-effective sustainable biomass feedstock is available and overall system efficiency for feedstock sourcing

### 3.2. SUSTAINABILITY

The consideration of sustainability aspects are of crucial importance for the bioenergy sector. This is due to the fact that the sector experienced much criticism due to negative publicity. It is important to ensure the sustainability of biomass in order to gain public acceptance of this type of renewable energy. On the other hand, the small-scale value chains of solid biomass in particular must not be threatened by overly high requirements that could act as a barrier for the use of, for example, log wood or woodchips for small-scale heating systems.

The Renewable Energy Directive (RED, Directive 2009/28/EC on the promotion and use of energy from renewable sources) includes a sustainability scheme (RED Article 17) for (a) biofuels for transport and (b) bioliquids used in other sectors (electricity, heating and cooling). Thereby, Article 17(2) establishes minimum greenhouse gas saving values, whereas Article 17(3), 17(4) and 17(5) require that raw material should not come from high biodiversity value areas, from the conversion of high-carbon stock areas, or from undrained peatland, respectively.

Mandated by Article 17(9) of the RED, the European Commission published a report on sustainability requirements for the use of solid and gaseous biomass in electricity, heating and cooling on 25 February 2010 (COM(2010)11 Final). In July 2013, this topic is still under discussion and Commission guidance and/or a proposal for sustainability requirements have not been published.

On the other hand, on 17 October 2012 the Commission published a proposal for an amendment of the RED (so-called ILUC (Indirect Land Use Change) proposal) to limit global land conversion for biofuel production, and raise the climate benefits of biofuels used in the EU. The aim of this proposal is to limit the use of food-based (conventional) biofuels to meet the 10% renewable energy target in the transport sector to 5%, and to stimulate the development of alternative, so-called second generation biofuels from non-food feedstock, which emit substantially less greenhouse gases than fossil fuels and do not directly interfere with global food production.

For the value chains addressed in this Biomass Technology Roadmap, it needs to be ensured that appropriate sustainability requirements are established and fulfilled for the biomass feedstock used in the heating and cooling sector. Thereby, it is recommended to apply sustainability criteria for solid and gaseous biomass that are comparable to those applied to biofuels and bioliquids (as specified in the RED and its proposed amendment) in order to avoid market distortion for the same raw material used in different sectors. However, specific issues of the agricultural and the forest sector should be adequately recognized especially regarding the implementation of the criteria.

It is recommended to strengthen current efforts in developing a clear legislative framework that takes a further step in the integration of sustainability requirements for biomass used in the heating and cooling sector. In the interim, sustainability can be approached via existing voluntary certification schemes, but there needs to be a goal of tangible progress towards regulatory consensus as we approach 2020.

## APPENDIX I

### EXAMPLES OF PAST AND ONGOING RESEARCH AND INNOVATION ACTIVITIES

#### High efficient large-scale or industrial steam CHP with enhanced availability and increased high temperature heat potential (up to 600°C)

Title of project	Coordinator	Country Coordinator	Duration (months)	Funding Programme
Innovative demonstrations for the next generation of biomass and waste combustion plants for energy recovery and renewable electricity production (NextGenBioWaste)	SINTEF Energy Research	Norway	48	FP6
Demonstration of a 16MW high energy efficient corn stover biomass power plant (ENERCORN)	ACCIONA ENERGIA S.A.	Spain		FP7
Twenty projects ongoing within the Material technology and development research programme KME	Elforsk	Sweden	48	National

#### High efficient biomass conversion systems for tri-generation

Title of project	Coordinator	Country Coordinator	Duration (months)	Funding Programme
DEmonstration of large scale Biomass Co-firing and supply chain integration (DEBCO)	ENEL INGEGNERIA E INNOVAZIONE	Italy	48	FP7
Recovered fuels COMBined with BIOMass (RECOMBIO)	REMONDIS GmbH	Germany	36	FP7

## Advanced fuels replacing coal and fossil oil in CHP

Title of project	Coordinator	Country Coordinator	Duration (months)	Funding Programme
SECTOR: Production of Solid Sustainable Energy Carriers from Biomass by Means of Torrefaction	DBFZ	Germany	42	FP7
Polygeneration through pyrolysis: Simultaneous production of oil, process steam, electricity and organic acids (EMPYRO)	BTG Biomass Technology Group BV	Netherlands	48	FP7
Bioliqids-CHP: Power generation from Biomass	BTG Biomass Technology Group BV	Netherlands	36	FP7

## APPENDIX II

### SCALE OF TECHNOLOGY READINESS LEVELS (TRL) ADOPTED BY THE RHC-PLATFORM<sup>30</sup>

#### TRL 1: Basic principles observed

The initial scientific research has been completed. The basic principles of the idea have been qualitatively postulated and observed. The process outlines have been identified. No experimental proof and detailed analysis are yet available.

#### TRL 2: Technology concept formulated

The technology concept, its application and its implementation have been formulated. The development roadmap is outlined. Studies and small experiments provide a "proof of concept" for the technology concepts.

#### TRL 3: Experimental proof of concept

The first laboratory experiments have been completed. The concept and the processes have been proven at laboratory scale, table-top experiments.

#### TRL 4: Technology validated in lab

A small scale prototype development unit has been built in a laboratory and controlled environment. Operations have provided data to identify potential up scaling and operational issues. Measurements validate analytical predictions of the separate elements of the technology. Simulation of the processes has been validated.

#### TRL 5: Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)

The technology, a large scale prototype development unit, has been qualified through testing in intended environment, simulated or actual. The new hardware is ready for first use. Process modelling (technical and economic) is refined. LCA and economy assessment models have been validated. Where it is relevant for further up scaling the following issues have been identified: health & safety, environmental constraints, regulation, and resources availability.

#### TRL 6: Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)

The components and the process, the prototype system, have been up scaled to prove the industrial potential and its integration within the energy system. Hardware has been modified and up scaled. Most of the issues identified earlier have been resolved. Full commercial scale system has been identified and modelled. LCA and economic assessments have been refined.

#### TRL 7: System prototype demonstration in operational environment

The technology has been proven to work and operate a pre-commercial scale – a demonstration system. Final operational and manufacturing issues have been identified. Minor technology issues have been solved. LCA and economic assessments have been refined.

#### TRL 8: System complete and qualified

The technology has been proven to work at a commercial level through a full scale application. All operational and manufacturing issues have been solved.

#### TRL 9: Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

The technology has been fully developed and is commercially available for any consumers.

<sup>30</sup> The present scale of Technology readiness levels (TRL) is based on HORIZON 2020 – WORK PROGRAMME 2014-2015, General Annexes, G. Technology readiness levels (TRL), available at [http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014\\_2015/annexes/h2020-wp1415-annex-g-tr\\_en.pdf](http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-tr_en.pdf). The description of the TRLs is based on the related FAQs, available at [http://ec.europa.eu/research/participants/portal/doc/call/h2020/h2020-lce-2014-1/1595100-faq\\_1\\_lce\\_call\\_en.pdf](http://ec.europa.eu/research/participants/portal/doc/call/h2020/h2020-lce-2014-1/1595100-faq_1_lce_call_en.pdf). Both webpages were accessed early March 2014.

## APPENDIX III

### ABBREVIATIONS, ACRONYMS AND UNITS OF MEASURE

<b>BFB</b>	Bubbling Fluidized Bed
<b>BIO</b>	Biomass
<b>CAPEX</b>	Capital Expenditure
<b>CCS</b>	Carbon Capture and Storage
<b>CEN</b>	Comité Européen de Normalisation
<b>CFB</b>	Circulating Fluidized Bed
<b>CHP</b>	Combined Heat and Power
<b>CHP-C</b>	Combined Heat, Power and Cooling (tri-generation)
<b>CO</b>	Carbon Monoxide
<b>CO<sub>2</sub></b>	Carbon Dioxide
<b>DHC</b>	District Heating and Cooling
<b>EC</b>	European Commission
<b>EF-MGT</b>	Externally Fired Micro Gas Turbine
<b>EN</b>	European Standard (French: norme, German: Norm)
<b>ETS</b>	Emission Trading Scheme
<b>EU</b>	European Union
<b>FC</b>	Fuel Cell
<b>GHG</b>	Greenhouse gas
<b>HTC</b>	Hydrothermal Carbonisation
<b>IC</b>	Internal Combustion Engine
<b>IED</b>	International Emissions Directive
<b>ILUC</b>	Indirect Land Use Change
<b>ISO</b>	International Organization for Standardization
<b>LHV</b>	Lower Heating Value
<b>MGT</b>	Micro Gas Turbine
<b>MSDS</b>	Material Safety Data Sheet
<b>MSW</b>	Municipal Solid Waste
<b>NO<sub>x</sub></b>	Generic term for mono-nitrogen oxides NO and NO <sub>2</sub>
<b>OGC</b>	Organic Gaseous Carbon
<b>ORC</b>	Organic Rankine Cycle
<b>PF</b>	Power Factor
<b>PM</b>	Particulate matter
<b>R&amp;D</b>	Research and Development
<b>RD&amp;D</b>	Research, Development and Demonstration
<b>RDF</b>	Refuse Derived Fuel
<b>RED</b>	Renewable energy Directive (2009/28/EC)
<b>RES</b>	Renewable energy source
<b>RHC (RH&amp;C)</b>	Renewable Heating and Cooling
<b>RHC-PLATFORM</b>	European Technology Platform on Renewable Heating and Cooling
<b>RHC-SRA</b>	Strategic Research Agenda for Renewable Heating and Cooling
<b>SCR</b>	Silicon Controlled Rectifier
<b>SE</b>	Steam Explosion
<b>SET-PLAN</b>	The European Strategic Energy Technology Plan
<b>SH</b>	Super Heater
<b>SO<sub>x</sub></b>	Sulphur Oxide
<b>SRF</b>	Solid Recovered Fuel
<b>TMF</b>	Thermal Material Fracking
<b>TOE</b>	Ton Oil Equivalent
<b>TRL</b>	Technology Readiness Level

## UNITS OF MEASURE

°C	degrees Celsius
€/EUR	Euro
cSt	Centistokes
g	Grams
GJ	gigajoule = $10^9$ joules
GW <sub>e</sub>	Gigawatt Electrical
GW <sub>th</sub>	Gigawatt of thermal capacity = $10^9$ watts
K	Thousand
J	Joule
KJ/kg	Kilojoules per kilogram
kW <sub>e</sub>	Kilowatt Electrical
kWh	kilowatt-hour = $10^3 \times 1$ hour
kWh/m <sup>3</sup>	Kilowatt hours per meter cubed
kWh/t	Kilowatt hours per tonne
kW <sub>th</sub>	Kilowatt Thermal Capacity
m	Meter
M€/MW	Millions of Euro per Megawatt
m <sup>2</sup>	Square Meter
mg	Milligram
MJ/kg	Megajoules per kilogram
Mt	megatonne = $10^6$ tonnes
Mtoe	Million tonnes of Oil Equivalent = $10^6$ tonne of oil equivalent
MWh	Megawatt hour
MW <sub>e</sub>	Megawatt Electrical
MW <sub>th</sub>	Megawatt Thermal
Nm <sup>3</sup>	Normal cubic meter
P <sub>el</sub>	Power
pH	measure of the acidity or basicity of an aqueous solution
T	Tonne
TWh	terawatt-hour = $10^{12}$ watt x 1 hour
W	watts
W <sub>el</sub>	Watt Electrical

## APPENDIX IV DEFINITIONS

Agricultural residues (EN 14588:2011)

Biomass residues originating from production, harvesting, and processing in farm areas (ex: straw, bagasse, husks, cobs and nut shells and manure)

Agrobiomass (adapted from EN 14588:2011)

Biomass obtained from energy crops and/or agricultural residues

Biomass (EN 16214-1)

Biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste

Biomass residue (EN 16214-1)

Substance or object that is not deliberately produced in a production process and that is neither a co-product nor a waste; includes agricultural, aquaculture, fisheries and forestry residues and processing residues.

Agricultural, aquaculture, fisheries and forestry residues are directly produced by agriculture, fisheries, aquaculture and forestry; they do not include residues from related industries or processing. A processing residue is a substance which is not the end product that a production process directly seeks to produce (ex: crude glycerine, tall oil pitch). It is not a primary aim of the production process and the process has not been deliberately modified to produce it.

**Municipal Waste (Eurostat)**

Portion of waste produced by households, industry, hospitals and the tertiary sector which is biodegradable material collected by local authorities and incinerated at specific installations

**Thinning residues (ISO/CD 16559)**

Woody biomass residues originating from thinning operations

**Waste (EN 16214-1)**

Substance or objects which the holder discards or intends or is required to discard

**Woody biomass (EN 14588:2011)**

Biomass from tress, bushes and shrubs; this definition includes forest and plantation wood and other virgin wood, wood processing industry by-products and residues, and used wood

**Wood processing industry by-products and residues (EN 14588:2011)**

Woody biomass residues originating from the wood processing as well as the pulp and paper industry

## APPENDIX V

### SECRETARIAT OF THE RHC-PLATFORM

This document was prepared by the **Biomass Panel of the European Technology Platform on Renewable Heating and Cooling (RHC-Platform)**, managed by the European Biomass Association (AEBIOM).



The Secretariat of the European Technology Platform on Renewable Heating and Cooling is coordinated by EUREC and jointly managed with:



European Biomass Association (AEBIOM)



European Geothermal Energy Council (EGEC)



European Solar Thermal Industry Federation (ESTIF)

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