IEA Bioenergy

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TASK 33

Gasification of Biomass and Waste

Final Proposal for Task Prolongation for the new triennium 2016-2018

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and
Task 33 National Team Leaders

Triennium 2016-2018
Task / Strategic Project (SP)* Proposal Summary Sheet – Second draft for ExCo75

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Objective

To promote commercialisation of biomass gasification (BMG), including gasification of waste, to produce fuel and synthesis gases that can be subsequently converted to substitutes for fossil fuel based energy products and chemicals, and lay the foundation for secure and sustainable energy supply; to assist IEA Bioenergy Executive Committee activities in developing sustainable bioenergy strategies and policy recommendations by providing technical, economic, and sustainability information for BMG systems.

Work scope

The proposed task Gasification of Biomass and Waste is a continuation of Task 33 with emphasis on coordination with complimentary Tasks, e.g., combustion and cofiring (Task 32), pyrolysis (Task 34), integrating energy into solid waste management (Task 36) and climate change aspects of biomass and bioenergy (Task 38), and The International Energy Agency (IEA) Implementing Agreement for Cooperation in the Field of Fluidized Bed Conversion (FBC) of Fuels Applied to Clean Energy Production (IEA-FBC). The continuation of the Task will build on a number of years of activities that have concentrated primarily on technical barriers to development and commercialisation of BMG for diverse markets, e.g., small scale combined heat and power systems (CHP), utility scale CHP systems, and emerging liquid fuels and chemicals markets.

Work programme

The proposed work program was developed jointly by current Task 33 members and in cooperation with some of the other task leaders of IEA Bioenergy. It includes several special projects focused on technical and commercialization aspects of BMG and delivers reports targeted towards policy makers, technology developers, industrial end users, researchers and the general public. Semi-annual workshops organized by the Task will target researchers and industrial end users will help promote information dissemination and discussion amongst BMG experts. Significant interaction with other tasks, annexes and associated international bodies is planned, and will include joint studies and workshops targeting common interest areas and barriers to successful commercialization of BMG and associated bioenergy technologies. General activities to facilitate information exchange within and outside IEA Bioenergy will continue through the triennium, including semi-annual Task meetings to exchange and review country and global RD&D programmes and projects, updates of the BMG database, publication of Task newsletters and interaction with and support of ExCo.

Deliverables and Target Groups

- Special projects
  - Gasification of waste (joint with Task 36)
  - Protocol for tar sampling using the SPA method
  - Gasification for hydrogen production
  - Potential of biomass gasification to contribute to BECCS (joint with Task 38)
  - Gasification-based renewable energy hybrid systems
  - Pretreatment of biomass for thermal conversion (joint with Tasks 32, 34, 36, 40 and 43)
- Workshops (five during triennium)
  - Gasification of waste (joint with Task 38)
  - Fluidized bed biomass and waste gasification systems (joint with IEA-FBC)
  - Analytical methods and online measurements for gasification systems
  - (fourth and fifth workshop topics yet to be decided)
- Continued updates of Task website and BMG Database.
- Publication of semi-annual Task newsletter.
- Updated Country reports from member countries, as well as a final comprehensive report, summarising the status of BMG, and providing detailed information on projects for inclusion into the BMG database

Management Qualifications

Task Leader: Dr. Kevin Whitty, Professor of Chemical Engineering, The University of Utah, USA.
Task Co-Leader: Dr. Reinhard Rauch, Professor, Vienna University of Technology, Vienna, Austria.

Annual Budget US$150,000; **Budget per participant**; US$15,000, assuming 10 countries participate.

Table of Contents

1. INTRODUCTION

Gasification of solid fuels such as coals and petroleum refinery residual hydrocarbons is a proven energy conversion technology to produce clean fuels, electricity, and chemicals. At present, around the world in roughly 30 countries, more than 230 plants are operating more than 600 gasifiers to produce over 100 GWth capacity of synthesis gas (equivalent to roughly 1.5 million barrels of oil per day). With clear economic and environmental advantage over the then prevailing energy practices, it has taken over 60 years of worldwide effort to reach this level of fossil fuel gasification production capacity. In contrast, the first commercial exploitation of biomass gasification (BMG) was attempted about 30 years back, in Scandinavian countries, at a time when there was uncertainty about the rising cost and accessibility to oil. Although technical viability of BMG and the related environmental benefits are widely acknowledged, the extent of its commercial utility has been mostly limited to CHP and district heating and a handful of co-firing applications, driven primarily by regional or local environmental or economic considerations. Until recently, the development of advanced processes and broader application of BMG has been impeded by competition from low-cost fossil fuels and inadequate market pull. Other contributing factors are the lack of an infrastructure for sustainable supply of quality controlled biomass and the lack of adequate incentive-driven policies and partnerships with industry to develop and scale-up bioenergy conversion technologies, in particular the high efficiency processes. Recent years have witnessed significant fluctuations in oil and gas prices and raised concerns about security of energy supply. Further, the need to attain several environmental targets is fast approaching. Against this backdrop many of the national renewable energy plans are constantly reviewed and revised to implement measures conducive to commercialization of biomass energy technologies. Biomass gasification should play a central role in producing heat and power, biofuels, substitute natural gas (SNG), and value-added chemicals.

2. GASIFICATION OVERVIEW

The basic principles of biomass gasification are presented below. Applications discussed include heat and power generation, as well as synthesis gas production. As received, biomass can range from very clean wood chips at 50% moisture, to urban wood residues that are dry but contaminated with ferrous and other materials, to agricultural residues, to animal residues, sludges, and the organic component of municipal solid waste (MSW). The process of gasification can convert these materials into carbon- and hydrogen-rich fuel gases that can be more easily utilized, often with a gain in efficiency and environmental performance compared to direct combustion of the biomass.

Gasifier systems incorporate a biomass fuel handling and feeding system, which is normally coupled by means of airlocks to the gasifier. The gasifier is usually a refractory lined vessel and fixed bed or fluid-bed gasification is carried at temperatures of 750-850ºC at either atmospheric or elevated pressures. The product gas has to be treated so it matches the end-use application. For close-coupled gasifier-combustor systems there is no cleanup of the gases. For gas engine and turbine applications the gas has to be free of particulates, tars, sulphur, chlorine compounds and alkali metals to ensure the integrity of the engine or turbine. Fuel cell applications require the gas to be mainly hydrogen without any significant sulphur or chloride contamination to protect the electrodes. For synthesis operations such as methanol and hydrogen production, particulates and other contaminants (H_2S, etc.) must be removed to prevent poisoning of downstream catalysts.

The process efficiency is high; gasification can be as much as 80-85% thermodynamically efficient in converting the organic content of the feed into a fuel gas mixture. Because biomass gasification results in a clean fuel gas, the efficiency is further enhanced by the use of combined cycles to generate electricity; biomass-to-electricity efficiencies greater than 45% are conceivable. If the gases are converted to hydrogen, the biomass-to-electricity efficiency with fuel cells may be over 55%. The environmental advantage is that the fuel gas (syngas) is a much smaller volume to be processed than the combustion stream from a boiler; this and the generally lower treatment temperature of the biomass results in retention of metals (including alkali) in the ash as salts that can be disposed. The gas can usually easily be cleaned of acid gas components, including hydrogen chloride, before combustion in e.g. an engine or turbine.

The gas can also be used for a number of chemical or biological synthesises to other liquid and gaseous energy carriers such as e.g. methanol, ethanol, DME Fischer Tropsch hydrocarbons, SNG and hydrogen as a product in its own right.

2.1 Gasifier Medium

Gasification involves the thermal destruction of biomass in a reducing atmosphere of steam, air, pure oxygen or a combination of theses gases to produce a medium- or low-calorific value gas. If air is present, the ratio of oxygen to biomass is typically around 0.3. Air-blown, or directly heated gasifiers, use the exothermic reaction between oxygen and organics to provide the heat necessary to devolatilize biomass and to convert residual carbon-rich chars. For directly heated gasifiers, the heat to drive the process is generated inside within the gasifier. When air is used, the product gas (known as producer gas) is diluted with nitrogen and typically has a dry-basis calorific value of 5-7 MJ/Nm^3, then also including tar hydrocarbons retained in the hot fuel gas. The dry-basis calorific value of the product gas can be increased to 13-14 MJ/Nm^3 using oxygen instead of air. Oxygen production is expensive, however, and its use has been proposed only for applications involving the production of synthesis gas where nitrogen dilution is not permitted in downstream synthesis conversion operations. Indirectly heated gasifiers heat and gasify biomass, usually with steam, through heat transfer from a hot solid or through a heat transfer surface. Because air is not introduced into the gasifier, little nitrogen is present and a medium-calorific gas is produced; dry-basis values of 10-12 MJ/Nm^3 are typical.

2.2 Gasifier Type

Four primary types of biomass gasification reactor systems have been developed: fixed-bed reactors, bubbling fluidized bed reactors, circulating fluidized bed reactors, and entrained-flow reactors. These are described below.

2.2.1 Fixed Bed

Fixed-bed gasifiers are classified primarily as updraft and downdraft. Updraft gasifiers represent the oldest and simplest gasifiers. The updraft gasifier is a counterflow reactor in which fuel is introduced into the top of a refractory-lined chamber by means of a lock hopper or rotary valve and flows downward through the reactor to a grate where ash is removed. The gasifying medium is introduced below the grate and flows upward through the reactor. At the bottom of the reactor (combustion zone) char burns to form carbon dioxide (CO_2) and steam (H_2O), which then flow upward through the bed countercurrently to the downwards-flowing solids. The exothermic combustion reactions supply the energy to drive gasification, pyrolysis and drying. The maximum temperature in the combustion zone is typically higher than 1,200ºC. In the reduction zone CO_2 and H_2O are partially reduced to carbon monoxide (CO) and hydrogen (H_2) through reaction with carbon in the char at temperatures of 800 to 1,200ºC. In the pyrolysis zone these gases contact dry biomass in the temperature range of 400-800ºC and devolatilize the biomass to produce pyrolysis products and residual char. Above this zone the gases and pyrolytic vapors dry the wet biomass. Typical product exit temperatures are 80-100ºC. A wide range of tars and oils, which can condense in product lines, are produced in the pyrolysis zone. For this reason updraft gasifiers are usually operated in a close-coupled mode to a furnace or boiler to produce steam or hot water

In downdraft gasification the gasifying medium (e.g., air) and product gas both flow in the same direction as the solid bed. Downdraft gasifiers are specifically designed to minimize tar and oil production. The fuel and pyrolytic gases/vapors move co-currently downward through the bed. The pyrolysis products pass through a hot char (about 15% of the original feed) combustion zone, where they are contacted with air and the tars are thermally cracked and partially oxidized. Typical tar conversion is greater than 99%, and is a function of temperature, combustion efficiency and the degree of gas channeling. The combustion zone temperature is typically 800-1,200ºC. The hot char in the reduction zone reduces CO_2 and H_2O, to CO and H_2. The exit gas temperature in a downdraft fixed bed gasifier is typically around 700ºC.

2.2.2 Bubbling Fluidized Bed

In a gas-solid fluidized bed a stream of gas passes upward through a bed of free-flowing granular materials in which the gas velocity is strong enough that the solid particles are widely separated and flow freely throughout the bed. The bed of solids in this state is called a fluidized bed. When a bed of solids is behaving as a *bubbling* fluidized bed, transient streams of gas flow upward in channels or bubbles containing few solids, and clumps or masses of solids flow downward[1]. The fluidized bed looks like a boiling liquid and has the physical properties of a fluid. In fluidized bed gasification of biomass the gas is air, oxygen, or steam, and the bed usually comprises particles of sand, olivine, limestone, dolomite, or alumina in the range of 0.1-1 mm particle size. The gas acts as the fluidizing medium, and if air/oxygen is used, is the oxidant for biomass partial oxidation. A fluidized bed gasifier is a vessel with dimensions such that the superficial velocity of the gas maintains the bed in a fluidized condition at the bottom of the vessel, and an increase in cross-sectional area above the bed lowers the superficial gas velocity below the fluidization velocity to maintain bed inventory and act as a disengaging zone. To obtain the total desired gas-phase residence time for complete devolatilization, the larger cross-sectional-area zone (usually referred to as the freeboard) is extended. A cyclone is used to either return fines to the bed or to remove ash-rich fines from the system. A gas distribution manifold or series of sparge tubes is used to fluidize the bed[2]. Biomass is introduced either through a feed chute to the top of the bed or through an auger directly into the bed. Fluidized-bed gasifiers have the advantage of extremely good mixing and high heat transfer, resulting in very uniform bed conditions. Gasification is very efficient, and 95%-99% carbon conversion is typical. Bubbling fluidized-bed gasifiers are normally designed for complete ash carryover, necessitating the addition of cyclones for particulate control.

2.2.3 Circulating Fluid Bed

If the gas flow of a bubbling fluid bed is increased, the gas bubbles become larger, forming large voids in the bed and entraining substantial amounts of solids. This type of bed is referred to as a turbulent fluid bed[3]. In a circulating fluid bed the turbulent bed solids are carried up in the reactor and overflow the reactor, are separated from the gas in a cyclone, and are returned to the bottom of the bed, forming a solids circulation loop. In addition, there is also an even larger internal circulation in the reactor as radial movement of the solids causes clusters to from in the wall layer which are partially re-entrained and partially slides along the wall to the reactor bottom. A circulating fluid bed can be differentiated from a bubbling fluid bed in that there is no distinct separation between the dense solids zone and the dilute solids zone. Circulating fluidized-bed densities are about Approach 500-700 kg/m^3 in the bottom section and a density profile which drops buy over one magnitude along the reactor height of several meters, compared to a bubbling-bed density of approach 700 kg/m^3 in the bed of a 1-2 meters height, and then very little material above the bed in the freeboard zone. To achieve the lower bed density and induce circulation, gas velocities are increased from the 0.3-2.0 m/s of bubbling beds to 4-12 m/s, while possibly also using a finer bed material cut.

2.2.4 Entrained Flow

In entrained-flow gasifiers, pulverized fuel or liquid fuels are continuously fed dry or in a slurry into a pneumatic-flow reactor, or as a fine droplet spray, respectively along with oxygen or air, and possibly steam. A high temperature flame (typically 1,200-1,400°C) results, which nearly completely destroys oils and tars. The high temperature also means that the ash is typically removed as a liquid slag. Today several companies including Shell, GE, Siemens, CBI, Thyssen Krupp, Lurgi and Chinese universities ECUST and Tsinghua offer entrained-flow reactors, and entrained-flow gasification is today the most common technology for gasification of coal and petroleum coke. Nearly all entrained-flow gasifiers operate at high pressure (to 80 atm) and provide syngas for production of chemicals or electric power through a so-called integrated

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[1] Perry, R and C. Chilton (1973). *Chemical Engineer's Handbook*, 5th ed., McGraw-Hill, New York, NY.
[2] Hansen, J. (1992). "Fluidized bed combustion of biomass; an overview," in *Biomass Combustion Conference*, Reno Nevada, USDOE Western Regional Biomass energy Program, January 28-30.
[3] Babcock and Wilcox (1992). "Atmospheric pressure boilers," in *Steam: Its Generation and Use* (ed. S. Stulz and J. Kitto), 40th ed., Babcock and Wilcox, Barberton, Ohio, Chapter 16.

gasification combined-cycle (IGCC) configuration. Despite the success of entrained-flow gasification for coal, and only limited development of entrained-flow biomass gasification has taken place.

There are a number of reasons for the lack of application of these reactors to biomass, such as the relatively low heat content the biomass, the high economic/energetic cost of feed preparation to reduce moisture content to low levels, and in particular to arrive at the small and consistent particle size of approx 1 mm by milling of the biomass, or the use of additional pre-treatment such as by torrefaction or pyrolysis, , are the primary concern[4]. Limited refractory life is also a concern for biomass feeds with high potassium content[5]. Nonetheless, advantages such as excellent carbon conversion and nearly tar-free syngas will sustain interest in entrained-flow biomass gasification. However, for black liquor gasification in the paper and pulp industry, the technology has been successfully piloted by Chemrec in Sweden.

3. STATUS OF GASIFICATION TECHNOLOGY

The early biomass gasifiers were developed based on the principles of moving bed (or fixed bed) coal gasifiers and deployed essentially for CHP applications. These include the eight, 4 to 5 MWth capacity, automated Bioneer biomass gasifiers that were built in Finland and Sweden during mid-1980s for heating, and are still in operation. The most developed and known moving bed biomass gasifiers are the Babcock Borsig Vølund gasifier developed in Harboore, Denmark and replicated in Japan, the Biomass Engineering Ltd gasifiers in UK, XYLOWATT AB systems in Belgium, the Pyroforce gasifier in Stans in Switzerland and Austria and the Nexterra gasifiers installed in the U.S. and Canada.

The successful high throughput circulating fluidized bed combustors (CFBC) designs, developed during the 1970's, were later modified to operate effectively as circulating fluidized bed gasifiers (CFBG). The early CFBGs in Scandinavia produced a fuel gas that could readily replace fuel oil in industrial burners. Since there was little or no gas cleaning involved in these applications, these plants were successfully scaled-up to 100 MWth capacity, processing about 600 tonnes per day of biomass materials. Since the early 1980s, Andritz fka as Ahlström in this field)) has succeeded in building seven, 3 to 70 MWth CFBGs in Finland, Sweden and Portugal.

Lurgi (prior changes to its organization and the acquisition by Air Liquide) has built three CFBG units of which the 100 MWth Rüdersdorf, Germany plant is successfully gasifying waste to produce fuel gas for pre-firing a cement kiln. In Amersfort, Lurgi also installed a 75 MW co-firing unit based on demolition wood, but then developed further by the owner RWE.

In 1988, Valmet fka as Götaverken built a 25 MWth CFBG in Sweden. The same year, TPS has designed two, 15 MWth capacity CFBGs for RDF pellets at Greve-in Chianti in Italy. which have been shut-down due to non-technical reasons.

The recent additions to successful Foster Wheeler, also with origins from Ahslström, WE biomass CFBG plants for co-firing include the 60 MWth plant in Lahti, Finland and the 50 MWth Ruien co-firing gasifiers. The Lahti coal-fired power plant has been converted to a gasification plant where treated MSW is gasified and the resulting gas is burned in the existing boilers to produce a nominal 60 MW of electricity.

In recent years, Valmet Power has constructed several large gasifiers for biomass and waste. The Kymijärvi II project in Lahti, Finland, started up in 2012 and involves two 80 MW_{th} CFB gasifiers processing household and wood waste to form a syngas that is burned in a boiler to produce 50 MW electricity and 90 MW of district heating. The largest biomass gasifier in the world, a 140 MW_{th} Valmet Power CFB gasifier, is located in Vaasa, Finland, started up in 2013 and had 97% availability in its first year. The syngas generated from biomass is co-fired in an existing coal-fired boiler.

Both Valmet and Andritz have recently supplied 2*100 MW and 60 MW, respectively, CFB gasifiers to paper and pulp industries in China and Indonesia.

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[4] Larson, E. and R. Katofsky (1992). "Production of hydrogen and methanol from biomass," Princeton, NJ, Report No, PU/CES 271, July.

[5] Higman, C. and van der Burgt (2003). *Gasification*, Elsevier Science, New York, NY (ISBN 0-7506-7707-4).

Sydkraft and Ahlstrom were involved in the development of a second generation pressurized CFBG process for IGCC application, at Värnamo, Sweden. The 18 MWth capacity plant was operated at 18 bar pressure, raw gases were cleaned without condensation employing high temperature filters, and the low heating value fuel gas was successfully combusted in a closely integrated Typhoon gas turbine to generate 6 MW electricity and 9 MW of district heat. The Värnamo plant was mothballed in 2000, after more than 8,000 hours of gasifier and 3,600 hours of integrated operation with the gas turbine. In 2005 efforts began to reactivate the Värnamo plant for demonstration under a multinational EU CHRISGAS project, but that project has since also been cancelled. Also the Arbre plant was built as an IGCC plant but did not come to pass commissioning stage for non-technical and technical reasons.

The Technical University of Vienna has developed a fast internal circulating fluidized bed (FICFB) biomass gasification process, which incorporates a bubbling bed gasifier and a CFBC unit that has been scaled-up in cooperation with REPOTEC. In 2002 an 8 MWth CHP plant producing 2 MW electricity started up in Güssing, Austria and remains in continuous operation. Additional plants based on this technology have been built in Ulm, Germany and Burgeis, Italy. Most recently, the technology developed at TU Vienna has been the heart of a biomass-to-SNG project in Gothenburg, Sweden, which has since December 2014 been feeding 20 MWth of bio-SNG to the Swedish natural gas grid. Indirect gasifiers are also being developed by others including ECN's Milena process in the Netherlands, and the TRI process in the USA.

Ahlstrom/FWE has also built a 40 MWth, Corenso bubbling fluidized bed gasifier in Finland. This plant has been operating successfully for about five years, producing energy while recovering metals from the waste feedstock. Carbona/Andritz is now operating a 30 MWth capacity (6 MWe), fluidized bed gasifier for CHP in Skive, Denmark.

Other biomass gasification concepts include plasma air/oxygen gasifiers originally developed for hazardous waste destruction applied to biomass feedstocks. Developers include Alter NRG and InEnTec.

4. BARRIERS TO DEVELOPMENT

The main technical barriers to commercialize BMG include reliable handling and feeding of mixed feedstocks, in particular low-density herbaceous biomass, ash withdrawal, and also including pressurized operation, as well as gas cleaning. This latter barrier include reduction of tar formation in gasification reactors, particulate entrainment and removal, managing carbon, tar, alkali, chlorides and ammonia in product gases, , Reliable scale-up and successful demonstration of high-efficiency advanced BMG processes for IGCC and synthesis gas application would remove such barriers. Gasification processes employ in-situ tar decomposition materials and thermal oxidation techniques to minimize tar formation with varying degrees of success. In addition to conventional gas scrubbing with liquids, high-temperature ceramic and sintered metal barrier filters have been developed to successfully remove entrained particulate matter. It has been repeatedly observed that improvements made in the reliability of individual process steps do not necessarily guarantee successful scale-up and integrated operation of the overall process. Therefore, system integration remains an important issue in process scale-up, demonstration, and commercialization.

At present, limited but significant research is continuing in Europe and USA to address many of the technical hurdles listed above. These include basic research in understanding and modeling tar formation and its destruction in the BMG reactor as well as on catalytic surfaces. Studies conducted at VTT in Finland, TU Vienna in Austria, the National Renewable Energy Laboratories (NREL) in USA and at several other research organizations, including catalyst major Haldor Topsoe AS have evaluated several catalysts and concluded that the best option for tar destruction is to employ calcined dolomite or olivine in the gasifier as the primary tar decomposition agent followed by a secondary or polishing tar destruction step with Ni or Zr based catalysts. Although Ni has the capability to reform or crack condensable hydrocarbons and even ammonia at about 800°C, Ni catalysts are also vulnerable to poisoning by sulphur, chlorine, and alkali metals. Research is continuing to find robust tar decomposition catalysts and to explore breakthroughs in quantitative gasification of biomass to produce synthesis gas essentially free of condensable hydrocarbons. Meanwhile, there is merit in investigating the tolerable limits of raw gas contaminants and the types of condensable hydrocarbons allowable in selected gas processing or energy conversion devices (i.e. risk management). This requires collaboration between gasification technology developers and manufactures of energy conversion devices.

5. DRIVERS

The increasing global concern for climate change and the search for ‘green’ energy should provide major market drivers to promote renewable energy technologies in many countries. Increased use of biomass should reduce dependence on imported fossil fuels and stimulate economic growth in rural communities, which could take an active role in providing the much needed sustainable supply of biomass feedstock and in the utilization of biomass derived products.

For use in a more industrial context, the biomass available for energy usage is mostly derived from other industrial activities within silvaculture and agriculture Co-production concepts, (e.g. cascading the use of biomass resources) offer the potential to improve the efficiency and economics of biomass utilization.

The current interest in exploring the techno-economic viability of synthesis gas production and co-production of power, liquid fuels, SNG, hydrogen, and chemicals provides impetus to find new and value-added applications for BMG. This is related to policy drivers such as RFS, national and EU targets etc. Further, increasing concerns about instability in oil prices and the importance of securing supply of transportation fuels have brought into focus the importance of BMG for synthesis gas production and its suitability to produce transportation fuels and fuel additives.

In addition, if green certificate systems, renewable portfolio standards (RPS) or carbon dioxide mandates are implemented in regions and countries where such policies do not exist, electric utilities may have to provide large quantities of ‘green’ electricity within a short period of time. In this regard, BMG processes should play a significant role in meeting part of the RPS. When fully developed, advanced BMG processes should have the capability to handle a variety of mixed biomass feedstocks, change the product slate in response to the varying market demands, and offer significant advantages with central bioenergy conversion plants. Furthermore, advanced BMG processes can be designed to co-produce power, fuels, chemicals, and other value-added products, which may offer certain economic benefits.

Therefore, emphasis is given in the proposed work program to review, discuss, and identify mature and near-mature BMG systems that could find immediate application in district heating, cogeneration, co-firing, and dedicated power generation, besides the synthesis gas conversion options mentioned above.

6. OBJECTIVES

The objectives of the task are:

- to provide a non-biased information source for policy makers, the public and professionals to understand the potential, state of technology and challenges associated with commercialization of biomass and waste gasification
- to promote commercialization of biomass gasification (BMG), including gasification of waste, to produce fuel gases and synthesis gases that can be subsequently converted to substitutes for fossil fuel based energy products and chemicals, and lay the foundation for secure and sustainable energy supply
- to assist IEA Bioenergy Executive Committee activities in developing sustainable bioenergy strategies and policy recommendations by providing technical, economic, and sustainability information for BMG systems
- to conduct subtask studies to review and evaluate information from the current world-wide RD&D programs and operating gasification systems to identify and resolve barriers for advancement of economical, efficient, and environmentally preferable BMG processes

- to enable National Team Leaders (NTLS) to develop forward looking strategies and policies to implement programs in their respective countries, and help ‘leapfrog’ resource consuming repetitive and redundant exercises

7. WORK SCOPE, PROGRAMME AND DELIVERABLES

The proposed task Gasification of Biomass and Waste is a continuation of Task 33 with emphasis on coordination with complimentary Tasks, e.g., combustion and cofiring (Task 32), pyrolysis (Task 34), integrating energy into solid waste management (Task 36) and climate change aspects of biomass and bioenergy (Task 38), and The International Energy Agency (IEA) Implementing Agreement for Cooperation in the Field of Fluidized Bed Conversion (FBC) of Fuels Applied to Clean Energy Production (IEA-FBC). The continuation of the Task will build on a number of years of activities that have concentrated primarily on technical barriers to development and commercialization of BMG for diverse markets, e.g., small scale combined heat and power systems (CHP), utility scale CHP systems, and emerging liquid fuels and chemicals markets. A major historical effort has been devoted to dissemination of international status and BMG development through a series of workshops in member countries. Workshop presentations are posted on the Task website. The Task has developed a BMG projects database for member countries that is posted on the Task 33 website and is regularly updated.

7.1 Task Meetings and Communications

Organise semi-annual Task meetings to exchange and review global RD&D programmes and projects to identify barriers to commercialisation of BMG.

Deliverable: Minutes of Task meetings will be prepared and made available on the Task 33 website (http://www.ieaTask33.org)

7.2 Information Exchange

NTLs will prepare and update Country Reports and RD&D needs and make them available for use by other NTLs and Executive Committee members to aid in the development of their respective national BMG and bioenergy plans.

Deliverable: Country reports will be posted to the Task 33 website. One page executive summaries of selected country reports will be published in the Task newsletter

7.3 Workshops

Technical workshops with industrial and academic experts will address the key barriers to advancing BMG on a country and global basis. Workshops will generally be organized to coincide with the semi-annual Task meetings, except for the final task meeting, which is expected to be held in conjunction with the IEA Bioenergy 2018 conference. The themes for four of the five workshops are indicated below.

- Workshop on gasification of solid waste, to be co-organized with Task 36 (integrating energy into solid waste management)
- Workshop on fluidized bed gasification, co-organized with The International Energy Agency (IEA) Implementing Agreement for Cooperation in the Field of Fluidized Bed Conversion (FBC) of Fuels Applied to Clean Energy Production.
- Workshop on analytical methods and online measurements for biomass gasification

The theme for the remaining workshop(s) will be decided jointly by the task members during the triennium.

Deliverables: Proceedings in the form of collated presentations will be made available to IEA Bioenergy and other parties on the Task 33 website

7.4 Special Projects

Conduct joint studies/workshops with related Tasks, annexes, and other international activities to pursue mutually beneficial investigation.

- *SP1: Gasification of waste.* Interest in gasification of municipal sold waste is increasing worldwide and several new gasification-based waste-to-energy projects are under development in member countries. A report describing opportunities, waste gasification technologies, energy balances and practical considerations of waste gasification will be developed and disseminated via the website and other channels. A fact sheet on waste gasification will also be developed and made available through the Task website. This task will be conducted jointly with Task 36 (Integrating Energy into Solid Waste Management).
- *SP2: Protocol for tar sampling and analysis using the SPA method.* Solid-phase absorption (SPA) is a relatively new method of sampling tars that is faster and safer than conventional impinger-based sampling. Task 33 will develop a descriptive, detailed protocol for the SPA method of sampling and subsequent quantification and characterization of tars, incorporating experience from research groups within the member countries.
- *SP3: Hydrogen production through biomass gasification.* Hydrogen demand for e.g. oil upgrading and stabilization and industrial hydrotreating continues to increase, and bio-based hydrogen offers an attractive alternative. A report outlining technical options and economics of hydrogen production will be developed.
- *SP4: Potential of biomass gasification to contribute to BECCS.* Gasification is a natural technology for biomass energy carbon capture and sequestration (BECCS), since many of the options for usage of syngas include a CO_2-rich stream at some point in the process. This project, which will be carried out jointly with Task 38, will evaluate the potential impact biomass gasification can have on BECCS. A report will be prepared.
- *SP5: Gasification-based renewable energy hybrid systems.* Gasification is a very flexible system in terms of production and consumption of power, steam, heat, hydrogen and fuel gas, and lends itself well to integration with other renewable energy systems. A vision for biomass or waste gasification would be that it serves as a central processing system accepting and producing renewable energy, including liquid fuels, from and to other systems, such that the entire integrated facility benefits from synergy. This project will explore such options and a report will be developed.
- *SP6: Fuel pretreatment of biomass residues in the supply chain for thermal conversion.* This is a collaborative project that includes tasks 32, 33, 34, 36, 40 and 43, and which is described in detail in a separate proposal for a strategic project. Task 33's scope involves pretreatment in the context of gasification.
- *SP7: Status of biomass gasification report.* This report, which will be delivered at the end of the triennium, will provide an update on the status of biomass gasification development and commercialization in member countries. Input for the report will come from individual member country reports and NTL's, and the report will be managed and compiled by the task secretary.

7.5 Task Website and Gasification Facility Database

The Task will maintain the Task website and regularly update the facility database. The website and database are maintained by the Technical University of Vienna.

Deliverable: Update of website and facility database on a continuing basis. Presentation of website statistics in Task 33 reports for ExCo meetings.

7.6 Task Newsletter

The Task publishes a newsletter on Task activities twice a year.

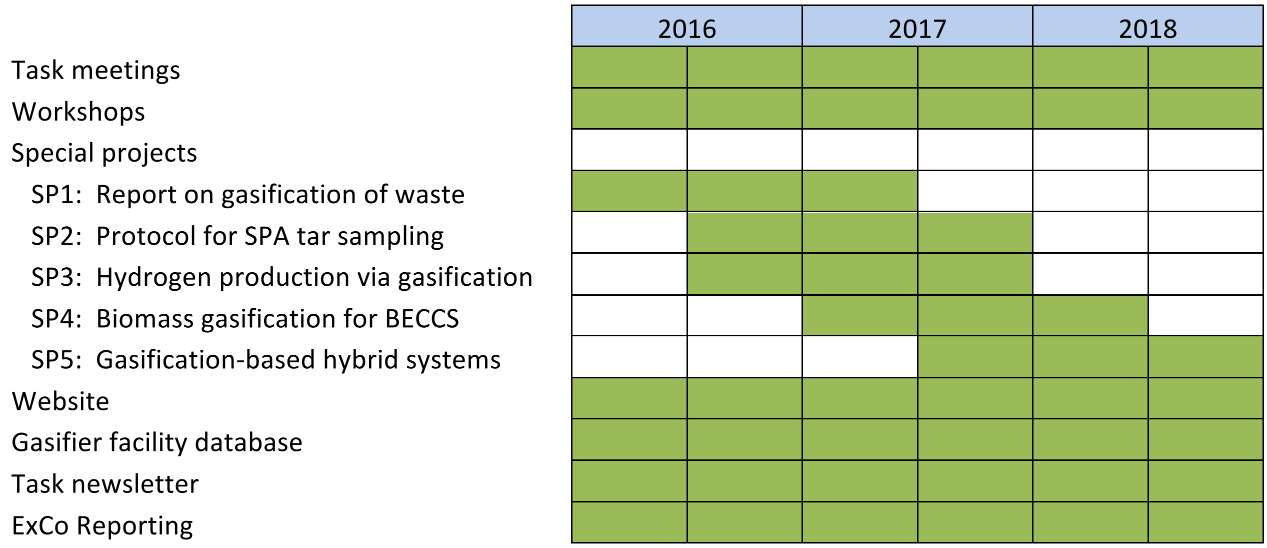
Deliverable: Semi-annual publication and distribution of newsletter.

7.7 ExCo Requirements and Deliverables

The Task will submit periodic progress reports, annual reports and financial reports and also participate in other ExCo directed initiatives. Subject to availability of resources, new task deliverables could be added in consultation with the IEA Bioenergy ExCo.

8. SCHEDULE

A schedule for the triennium is indicated below.



9. TASK MEMBERSHIP

Country	Member now	Declared intention to participate	Interested in 2016-18 Triennium	Active R&D
Austria	X	X	X	X
Brazil				X
Canada				X
Denmark	X	X	X	X
Finland	X	X	X	X
France			X	X
Germany	X	X	X	X
Ireland			X	X
Italy	X	X	X	X
Japan				X
New Zealand				X
Norway	X	X	X	X
The Netherlands	X	X	X	X
Spain				X
Sweden	X	X	X	X
Switzerland	X	X	X	X
Turkey				X
United Kingdom				X
United States	X	X	X	X

10. TASK BUDGET

The task budget for the triennium, assuming 10 participating countries each paying $15,000 per year, is presented below. Task administration, including participation in task and ExCo meetings, consumes approximately one-quarter of the budget. Just under half the budget is dedicated to special projects. Web site hosting and administration, including updating the database of facilities, is just 3% of the budget. The other notable expense is the 10% dedicated to ExCo strategic funds.

Category	2016	2017	2018	Total	Fraction
ExCo Strategic Funds	**15,000**	**15,000**	**15,000**	**45,000**	**10%**
Task Management and Administration					
Task leader (240 hr/yr @ $110/hr)	26,500	26,500	26,500	**79,500**	18%
Task co-leader (80 hr/yr @ $68/hr)	5,500	5,500	5,500	**16,500**	4%
Task secretary (180 hr/yr @ $50/hr)	9,000	9,000	9,000	**27,000**	6%
Subtotal for Task Management	**41,000**	**41,000**	**41,000**	**123,000**	**27%**
Task Meetings and Workshops					
Task meetings	4,000	4,000	3,000	**11,000**	2%
Workshops	8,000	8,000	4,000	**20,000**	4%
Subtotal of Task Meetings and Workshops	**12,000**	**12,000**	**7,000**	**31,000**	**7%**
Travel	**12,000**	**12,000**	**12,000**	**36,000**	**8%**
Task website and database management	**5,000**	**5,000**	**5,000**	**15,000**	**3%**
Special Projects					
SP1: Report on gasification of waste	40,000	10,000		**50,000**	11%
SP2: Protocol for SPA tar sampling	10,000	10,000		**20,000**	4%
SP3: Hydrogen production via gasification	15,000	20,000		**35,000**	8%
SP4: Biomass gasification for BECCS		15,000	20,000	**35,000**	8%
SP5: Gasification-based hybrid systems		15,000	25,000	**40,000**	9%
SP6: Fuel pretreatement report	5,000			**5,000**	1%
SP7: Status of biomass gasification report			15,000	**15,000**	3%
Subtotal of Projects	**70,000**	**70,000**	**60,000**	**200,000**	**44%**
Total Task Budget	**155,000**	**155,000**	**140,000**	**450,000**	**100%**

Salaries represent "loaded cost" and include direct salaries and all associated fringe benefits (e.g., health insurance, retirement, worker's compensation). The task website cost represents hosting costs as well as internal and external personnel costs to maintain and update the site and associated database of facilities.

11. TASK MANAGEMENT QUALIFICATIONS

Dr. Kevin Whitty is a professor in the Department of Chemical Engineering at the University of Utah with 25 years' experience in research and development of biomass energy. He received his PhD from Åbo Akademi University in Finland in 1997, spent three years in Sweden working for a biomass gasification development company and joined the University of Utah in 2001. His research focuses on biomass gasification, syngas cleanup and catalytic production of liquid fuels from syngas. Dr. Whitty has been leader of Task 33 for since fall 2013.

Dr. Reinhard Rauch is senior researcher in the field of fluidized bed gasification. He is experienced in operating fluidized bed gasifiers including all necessary measurement and analytical methods. One of his main topics is the usage of producer gas from biomass steam gasification for synthesis gas applications (Fischer Tropsch, methanation). He joined the group in 1996 and obtained his PhD in 2000 with a work on production of synthesis gas from biomass.