BIOMASS AND WASTE-TO-ENERGY TECHNOLOGIES:

ENVIRONMENTAL IMPACT ASSESSMENT

Report based on the activities of WP3 (Technology Development and Adaptation) of the Micro Energy to Waste (MicrE) Northern Periphery Programme project

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Introduction

Biomass and waste –based renewable energy technologies can take a key role in combating global warming and other problems associated with fossil fuels. All renewable energy technologies are not appropriate to all applications or locations. In earlier tasks of this project, the most appropriate biomass and waste-to-energy (W2E) technologies for Northern Periphery areas have been selected.

Anaerobic digestion and gasification were found the most suitable technologies for Northern Periphery conditions. Anaerobic digestion is an excellent technology to produce energy from wastes also in very small scale while gasification is maybe a slightly more demanding technology in small-scale with special feedstock requirements. Anaerobic digestion is a fully commercial technology and is suited well to energy production from biomass-based wastes. The produced biogas can be utilised as transportation fuel or via heat and power production. Combustion is an ancient and very common technology for heat production purposes. Pyrolysis is expected to be commercial in large-scale, but the product, pyrolysis oil, is demanding to upgrade to transport fuel. The oil can be used for combined heat and power production but the overall efficiency of the pyrolysis process is rather low. Fermentation from first-generation raw materials is a commercial technology but competes with food production. Second-generation fermentation from wood and herbaceous raw material starts to be commercial technology in large-scale. The produced alcohol can be used for heat and power production and preferably as transportation fuel. Pelletization is a technology viable on small scale to convert forest industry and agricultural residues to solid fuel.

As with conventional energy production, there are environmental issues to be considered also with W2E technologies. Ultimately, all these W2E technologies are based on burning the carbon content of the biomass, and thus will result in carbon dioxide emissions. Inevitably, biomass derived energy generation will produce also other pollutants, including carbon monoxide, nitrogen oxides, and particulates such as ash. The major benefit of substituting biomass for fossil fuels is that, if done in a sustainable fashion, it would greatly reduce emissions of greenhouses gases. The amount of CO_2 released when biomass is burned is very nearly the same as the amount required to replenish the plants grown to produce the biomass. However, fossil-fuel inputs may be required for planting, harvesting, transporting, and processing the biomass. Some of the above mentioned W2E technologies have a rather high energy requirement and thus contribute to indirect CO_2 emissions, through the potential CO_2 emissions of energy generation. Many of the main products of these W2E technologies require down-stream processing, which, as well, may be energy, resource and capital intensive. Yet, if efficient cultivation and conversion processes are used, the resulting emissions should be small (around 20 percent of the emissions created by fossil fuels alone). If the energy needed to produce and process biomass came from renewable sources in the first place, the net contribution to global warming would be zero. It is argued that if biomass wastes such as crop residues or municipal solid wastes are used for energy, there would be a slight greenhouse benefit of avoided emissions, since, when landfill wastes are not burned, the potent greenhouse gas methane may be released by anaerobic decay. (Brower, 1992)

Beyond this, there are concerns about the impacts of using land to grow biomass for energy. Increasing the amount of forest wood harvested for energy could have both positive and negative effects. On one hand, it could provide an incentive for the forest-products industry to manage its resources more efficiently, and thus improve forest health. But it could also provide an excuse, to exploit forests in an unsustainable fashion. (Brower, 1992)

Environmental impacts in relation to biomass-based energy production include direct and indirect land-use changes (LUC and ILUC), water footprint and other natural distraction. LUC and ILUC can have significant impacts on greenhouse gas balances and eutrophication (Searchinger et al., 2008). The risks of nutrients removal, soil erosion and water run-off, as well as loss of natural biota, habitats and wildlife also have to be considered (Abbasi & Abbasi 2010). "Energy farming" could affect biodiversity through the destruction of species habitats, especially if forests are more intensively managed. If agricultural or forestry wastes and residues were used for fuel, then soils could be depleted of organic content and nutrients unless care was taken to leave enough wastes behind. Although energy crops could be grown with less pesticide and fertilizer than conventional food crops, large-scale energy farming could nevertheless lead to increases in chemical use simply because more land would be under cultivation. (Brower, 1992)

If sustainable forestry principles are applied, it should be possible to extract energy from forests indefinitely. Growing trees and other plants for energy could benefit soil quality and farm economies. Energy crops could provide a steady supplemental income for farmers in off-seasons or allow them to work unused land without requiring much additional equipment. Moreover, energy crops could be used to stabilize cropland or rangeland prone to erosion and flooding. Trees would be grown for several years before being harvested, and their roots and leaf litter could help stabilize the soil.

The expected positive impacts by using biomass based raw material are reduced need of fossil fuels, potential GHG savings and improved carbon economy. Positive impacts also include enhanced energy security due to reduced dependency on imported crude oil, and increased employment. Security of jobs and development of rural areas are enhanced as labour force is needed to produce raw materials in agricultural and forest sectors.

The Renewable Energy Directive (RED) includes three relevant articles in respect to sustainability: Sustainability criteria for biofuels and bioliquids (Article 17), Verification and compliance with the sustainability criteria (Article 18) and Calculations of the greenhouse gas impact of biofuels and bioliquids (Article 19) Article 17 sets sustainability criteria (both qualitative and quantitative) for all biofuels produced either inside or outside European Union. These include for example feedstocks and indirect land use: Areas with high stocks of carbon, highly biodiverse grassland, peatlands, primary forests and protected areas are not allowed to be used. The European Commission (EC) should report to the European Parliament and the Council every second year about the measures taken to follow the sustainability criteria and the protection of soil, water and air when producing biofuels in the Member States or in third countries. There are no compulsory criteria for economic and social sustainability for Member States, but the EC should also report the impact of the biofuel policy on the availability of foodstuffs at affordable prices, and respect of land-use rights and wider development issues. (2009/28/EC)

Based on Article 18, economic operators (e.g. farmers, biofuel producers, distributors and vendors) of each Member State need to show that given sustainability criteria are carried out. By the end of 2012, the EC should also report to the European Parliament and to the Council on how effective the system for information on sustainability criteria is. At this time, the feasibility and applicability of mandatory requirements in relation to air, soil or water protection will be assessed, taking into account the latest scientific evidence and the Community's international obligations. (Biograce 2011)

This report identifies some of the key environmental impacts associated with the technologies mapped in this MicrE project. Key attention is paid to potential environmental impacts during processing technologies, pointing out especially potential emissions, and also associated safety concerns. Steps requiring high energy consumption, especially pre-processing or downstream processes are also highlighted, due to their resource intensive nature.

Anaerobic digestion

Anaerobic digestion (AD) is a biochemical process in which biogas is produced from organic matter by micro-organisms in the absence of oxygen. Anaerobic digestion occurs in a bioreactor. The operating temperatures are divided to mesophilic (35 °C) and thermophilic (55 °C) temperatures. The advantage of thermophilic reactors is shorter retention time, but maintaining a higher temperature requires higher energy input. (EUBIA 2011)

There are also potential health risks related to the raw material and the by-product. The feedstock, which may include pathogenic bacteria need to be sterilized. Moreover, the digestate from the reactor is post-treated to fulfill the regulations of the fertilizer legislation. Fertilizer consisting pathogenic bacteria is not allowed to be used as a fertilizer. Pathogenic bacteria can cause diseases for livestock, for instance. (Tavitsainen 2006) Sterilization kills pathogenic bacteria and, conventionally, this is done by using high temperature in the sterilization chamber. In addition, the sludge that comes out of the bioreactor need to be post-treated by composting. (Erjava 2009)

Biogas consists mainly of methane and carbon dioxide. The desired final product, methane, is a highly flammable gas and it can explode when meeting a spark and reacting with oxygen. (OSHA 2005, Tavitsainen 2006)

The main contaminants in biogas are hydrogen sulphide, ammonia, carbon monoxide, siloxanes, water, and particulates. In addition to odour, hydrogen sulphide can cause corrosion problems in gas engines because the SO_2 produced in combustion of the biogas containing can create an acidic environment in the presence of moisture. The ventilation must work on the floor level because hydrogen sulfide is heavier than air. In a reactor, H_2S has also corrosive effects. There are numerous proven and commercially available technologies for H_2S abatement including chemicals-based systems using ferric chloride as an additive and systems using biological techniques. Ammonia can be removed by catalytic destruction or wet scrubbing techniques if necessary. (Austerman et al. 2007, Austerman & Whiting 2007)

Moisture reduces the calorific value of biogas and affects adversely the gas engine performance. Simple condensers are commonly used for moisture removal, especially in anaerobic digestion plants which are used to generate electricity. Particulates from the anaerobic digestion process and more notable from combustion air accelerate engine wear. Simple filters can be used to reduce the particle load to gas engines. (Austerman et al. 2007)

Siloxanes are a subgroup of compounds containing Si-O with organic radicals bound to silicon. Feedstocks containing silicon can generate siloxanes which have a negative influence on gas engines. Siloxanes are a problem mainly in anaerobic digestion plants processing municipal solid waste. Siloxanes abatement techniques are less development and available than H_2S abatement techniques and seldom used in small-scale plants processing only biomass. (Austerman et al. 2007)

The percentage of CO_2 in bio gas can be as high as 40. Therefore, biogas needs to be purified to be used e.g. as transport fuel. Removal of carbon dioxide is important also because of the ability to form carbonic acid in wet conditions, which causes corrosion in pipelines. CO_2 can be separated and captured in many ways, but the problem is, what to do with the redundant CO_2. Many of the methods for biogas purification are originated from flue gas purification. The composition of flue gas is not very far from the composition of biogas in a matter of carbon dioxide removal. Both of them have CO_2 as a major constituent and nitrogen and methane are unsolvable to adsorbent. Industrial methods for CO_2 removal from flue gas are e.g. scrubbing, adsorption and membranes. The increase need for trapping CO_2 drives research and development efforts to seek new sequestration methods. In the work of Ritamäki (2011), the process to sequestrate CO_2 into adsorbent was examined. Oil shale ash was studied as absorbent and was found a promising material for gas purification.

Gasification

Gasification is a thermochemical process, which uses biomass as a feedstock in order to produce syngas and other outputs. Possible feedstock for gasification includes wood, wood residues, bark, shrubs, sawdust, energy crops and other wood-based raw materials. Wastes, such as agricultural wastes and crop residues, are also suitable raw materials. (MicrE 2011, Basu 2010) The final product, syngas (a mixture of hydrogen and carbon monoxide) can be utilized as a fuel in the internal combustion engine or to run a gas turbine. (MicrE 2011)

A conventional gasification process consists of biomass drying, pyrolysis, oxidation and reduction steps. Firstly, high moisture content is essential to be removed, by drying the raw material input in a specific drying chamber. The temperature in the pyrolysis chamber varies between 400–650°C. Endothermic pyrolysis and gasification reactions occur in the oxidation chamber at temperatures between 900–1200°C. Syngas is formed in the reduction chamber through several reactions. (Basu 2010, MicrE 2011)

Biomass gasification is ready for commercialisation but large-scale introduction is hampered by safety and environmental issue. Apart from the high energy needs, the possible impacts to the environment are emissions to the atmosphere, noise pollution, soil protection, waste generation and possible waste water discharges. (Gasification guide 2009) During the processing of biomass in gasification plant and the production of gases also several unwanted by-products will be produced. The most significant impurities, such as tars and particulates are separated from the final product. Conventional separation processes for tar and particulate removal are usually cyclones, filters, electrostatic precipitators and scrubbers. (Basu 2010)

The gasification process is inwardly related to production, utilization and handling of toxic and flammable compounds. Carbon monoxide (CO) is a very poisonous compound, which can be dangerous to handle. Explosion hazard can occur, if there is spark available for ignition and the concentrations of CO_2, H_2 and O_2 are suitable. Moreover specific concentration of dust and source of ignition can cause a dust explosion. Product gas can also auto-ignite in temperatures of 600-650 °C. Glowing particles, gases and explosions can also start the fire in the plant. (Gasification guide 2009)

In addition to CO, also other compounds from the process can be hazardous. For example Polycyclic aromatic hydrocarbon (PAH) compounds are toxic and carcinogenic, and can leak from the process. (Gasification guide 2009) The best way to avoid these safety hazards is to follow the ATEX Directive.

There is also a need for downstream processes to purify the end-product. Particulates and tars are the most significant contaminants which have to be removed. Tar content varies from about 0.5 to 100 g/m^3 when most applications of syngas require tar content of 0.05 g/m^3 or less. Also alkali compounds, nitrogen-containing compounds and sulphur may cause problems. (Austerman & Whiting 2007, Han & Kim 2008)

Solid phase materials in syngas, called particulates, consist typically of inorganic ash which is derived from mineral matter in the feed material. Cyclones, filters (ceramic, baffle, fabric), electrostatic precipitators (ESPs), and scrubbers (water, venturi) remove particulates effectively from syngas and are widely used. (Han & Kim 2008) Vaporised tars will condense either onto cool surfaces or as aerosols, which could lead to fouling or blockage in the fuel lines, filters, turbines, and engines. Therefore, tar removal is needed in systems where syngas is compressed prior to use, such as gas turbines. ESPs and wet scrubbers have been used widely for tar removal from gas streams in coal and coke processing plants. Also catalytic tar destruction, thermal cracking and plasma (Pyroarc, Corona, Glidarc) techniques are being developed. (Austerman & Whiting 2007, Han & Kim 2008)

Though scrubbers, filters, cyclones, and ESPs remove tars effectively and quite inexpensively, they can only remove or capture the tar from syngas and the energy in tar is lost. Some of these systems also produce a lot of contaminated water which creates a disposal problem. Thermal cracking systems decompose tar very effectively but operation costs are high due to high temperature. Catalytic cracking can operate at very low temperature. However, there are still shortcomings. The commercial Ni-based catalysts, which are extensively applied in the petrochemical industry, and dolomite are deactivated significantly by carbon deposition, while alkali metal catalysts are easily sintered. (Han & Kim 2008)

Mineral matter in feedstock contains generally high levels of alkali salts, which can vaporise when temperature is above 800°C and further deposit on cooler downstream surfaces. These alkali vapours condense to form sticky particulates (<5 µm) or aerosols. High temperature removal of alkali compounds is possible using ceramic filters or packed bed filters employing activated bauxite. (Austerman & Whiting 2007)

Removal of ammonia from syngas can be done to avoid conversion to NO_x when the syngas is combusted. Catalytic destruction or wet scrubbing techniques can be used to ammonia removal. Sulphur compounds, typically H_2S but sometimes also COS (carbonyl sulphide), can be formed in the gasifier and this poses technical challenges. H_2S could be oxidised to SO_2 in a thermal device downstream. (Austerman & Whiting 2007)

Combustion

Combustion is one of the oldest ways to convert fuel to produce heat energy. Combustion of biomass is a process in which oxygen reacts with carbon in the fuel and produces carbon dioxide, water and heat. Gaseous combustion products include also nitrogen oxidants, carbon monoxide and aromatic compounds. Solid products include charcoal and ash, for example. (Loo & Koppejan 2008)

Air emissions, such as CO_2 as well as output ash amounts of combustion are significant. Combustion plants also fall under the IPPC Directive; therefore, best available technologies will have to be adopted in order to protect theenvironment. (Ministry of Environment 2011a, FINLEX 2011)

The amount of pollution emitted per unit of energy generated varies widely by technology, with wood-burning stoves and fireplaces generally the worst offenders. Modern, enclosed fireplaces and wood stoves pollute much less than traditional, open fireplaces for the simple reason that they are more efficient. To remove particulates, electrostatic precipitators are available. (Brower, 1992)

In small-scale applications, the main safety-related issues originate from the spillage or backdraft of exhaust gas, which should be led outside. Carbon monoxide (CO) is one of the most hazardous compounds from the combustion process. CO forms when combustion temperature is low and available oxygen levels are low. CO is an odorless, tasteless and initially non-irritating and, therefore, difficult to detect. Yet even at relatively low concentrations, CO can cause lightheadedness and confusion. A CO detector, adequate ventilation and appropriate combustion conditions are essential to avoid problems with CO. (EREC 2008, DeKieffer 1995)

Emissions from conventional biomass-fueled power plants are generally similar to emissions from coal-fired power plants, with the notable difference that biomass facilities produce very little sulfur dioxide or toxic metals (cadmium, mercury, and others). The most serious problem is their particulate emissions, which must be controlled with special devices. More advanced technologies, such as the whole-tree burner (which has three successive combustion stages) and the gasifier/combustion turbine combination, should generate much lower emissions, perhaps comparable to those of power plants fueled by natural gas. (Brower, 1992) Properties of raw material have a great impact on the environmental impacts of combustion. High moisture content leads to incomplete combustion and high amounts emissions. (Loo & Koppejan 2008)

Facilities that burn raw municipal waste present a unique pollution-control problem. This waste often contains toxic metals, chlorinated compounds, and plastics, which generate harmful emissions. Since this problem is much less severe in facilities burning refuse-derived fuel (RDF)-pelletized or shredded paper and other waste with most inorganic material removed-most waste-to-energy plants built in the future are likely to use this fuel. Co-firing RDF in coal-fired power plants may provide an inexpensive way to reduce coal emissions without having to build new power plants. (Brower, 1992)

Ash from biomass combustion process can contain high alkali and heavy metal concentrations, causing corrosive effects to a boiler. Moreover, ash and slag can foul surfaces, causing harm especially for heat exchange systems. Agglomeration of ash particles can also inhibit the combustion equipment and lead to poor combustion conditions, but high ash levels can affect also downstream processes. These conditions will lead to inefficient combustion productivity, therefore, process equipment must be cleaned at times, and adequate combustion conditions are important to maintain. (Loo & Koppejan 2008)

Pyrolysis

In pyrolysis, large hydrocarbon molecules (cellulose, hemicelluloses and part of the lignin) break down into smaller and lighter molecules. Unlike combustion and gasification, pyrolysis occurs in total absence of oxygen. (Basu 2010)

Condensable pyrolysis gases can be condensed into bio-oil, which can be utilized for vehicles or in CHP-units. Other lighter gases (CO_2, CO, CH_4) can be combusted and thus heat can be produced. Tar from the process can be also treated to improve bio-oil yield. Solid residues, especially charcoal, can be sold or utilized in heat production or barbeques. (Basu 2010)

Safety issues are one of the fundamentals of the pyrolysis plant because of several fire and explosion hazards (Ministry of Environment 2011). The pyrolysis process is producing and handling hazardous compounds, such as CO, H_2 and hydrocarbons. Carbon monoxide is very toxic compound; it can cause dizziness and even in low concentrations. (Gasification guide 2009) Hydrogen can also be a source of safety hazard in the pyrolysis plant. For humans, hydrogen is an undetectable compound and, at high concentrations, hydrogen can ignite very easily, causing fires and explosions. Also hydrocarbons can cause fire and explosion hazard, if there is source for ignition. (DOE 2006, Basu 2010)

Pyrolysis process conditions have significant influence on the composition of the produced oils. Pyrolysis oils typically suffer from poor thermal stability and cause corrosion to engines. Generally, bio-oil is a difficult product to be used or upgraded directly. (Soltes 1988, McKendry 2002b)

Pyrolysis oils can primary be phenolic; therefore, hydrotreating is necessary to remove oxygen. Single ring phenolics and cyclic ketones present in the oils can be upgraded through deoxygenation to hydrocarbon fuels. Heavier, higher molecular weight products such as the polycyclic aromatics need also to be hydrocracked. A number of catalysts have been tested. Initially, typical petroleum hydrotreating or hydrocracking catalysts at high pressures have been used but more recently acidic zeolites at lower pressures have gained interest. (Soltes 1988, McKendry 2002b)

Alcohol fermentation

Alcohol fermentation is a process in which sugar containing biomass is converted to alcohol, by the metabolism of microorganisms. The fermentation process is usually anaerobic, but also aerobic conditions can be feasible. Raw materials with high sugar content, such as corn and sugar beet, are the most suitable for the fermentation process. In addition, lignocellulosic raw materials, like wood and straw can be also utilized in order to produce alcohols. The conventional fermentation process consists of hydrolysis, fermentation, separation and purification steps. If the process uses lignocellulosic raw materials, milling and acid or enzymatic hydrolysis is required. After pre-treatment, sugars go through the fermentation process. The produced alcohol is removed from the process and enriched to 99%. (Nag 2007, MicrE 2011)

A major environmental impact of fermentation is the wastewater of the fermentation process. Depending on BOD and COD content, treating the wastewater can be very energy intensive. The high content of nitrates and phosphates in the wastewater might influence the development of certain species such as algae.

Generally, as much as 50–70% of the total production cost in first-generation fermentation processes can be due to downstream processing. However, intensive research has improved the efficiencies to usually less than 50% of the total costs. The low final concentration in the water broth, the complex mixture of cellular materials and chemicals in the final broth, and the purity required from the final product are the main reasons for high costs. (Wisbiorefine 2004b, Elander & Putsche 1996)

The most conventional process to separation of water and alcohols is distillation. Distillation is an energy-intensive separation process used to separate two liquids by taking advantage of their difference in boiling point temperatures. Although distillation is conventional and formerly very widely used, it is not effective separation process for fermentation products. (Wisbiorefine 2004b, Elander & Putsche 1996) Other recovery methods include precipitation, other chemicals-based techniques, and diverse types of membrane separation. (Wisbiorefine 2004b) Current research efforts concentrate at low energy separation processes, such as membrane processes, in particular pervaporation. (Nag 2007) Pervaporation is quite a new membrane-based technology. It is used to separate and concentrate volatile compounds from a liquid mixture by selective permeation through a non-porous membrane into a vacuum permeate stream. Pervaporation is a promising technology to dewater liquid biofuels cost-effectively. (Wisbiorefine 2004b)

The fermentation process produces high CO_2 concentrations. In addition, coolant compounds such as ammonia, glycol, propane to cool down the process are considered hazardous. (Liao & Saffron 2008)

Malfunction causing excess pressure and temperature in the distillation column can be a safety hazard. In case of uncontrollable process circumstances, the column can broke and release highly flammable alcohols such as ethanol into air. Ethanol is a dangerous chemical with flammable properties (PÖYRY 2006). This organic compound is also toxic for humans and animals, especially in high concentrations (Safety data 2011).

It is expected that using biomass-derived methanol and ethanol as vehicle fuels, instead of conventional gasoline, could reduce some types of pollution from automobiles. Both methanol and ethanol evaporate more slowly than gasoline, thus helping to reduce evaporative emissions of volatile organic compounds (VOCs), which react with heat and sunlight to generate ground-level ozone (a component of smog). According to Environmental Protection Agency estimates, in cars specifically designed to burn pure methanol or ethanol, VOC emissions from the tailpipe could be reduced 85 to 95 percent, while carbon monoxide emissions could be reduced 30 to 90 percent. However, emissions of nitrogen oxides, a source of acid precipitation, would not change significantly compared to gasoline-powered vehicles. (Brower, 1992)

Some studies have indicated that the use of fuel alcohol increases emissions of formaldehyde and other aldehydes, compounds identified as potential carcinogens. Others counter that these results consider only tailpipe emissions, whereas VOCs, another significant pathway of aldehyde formation, are much lower in alcohol-burning vehicles. On balance, methanol vehicles would therefore decrease ozone levels. Overall, however, alcohol-fueled cars will not solve air pollution problems in dense urban areas, where electric cars or fuel cells represent better solutions. (Brower, 1992)

Growing the feedstock of fermentation requires land and water. Environmental impacts in relation to fermentation therefore include direct and indirect land-use changes (LUC and ILUC), water footprint and other natural distraction. LUC and ILUC can have significant impacts on greenhouse gas balances and eutrophication (Searchinger et al., 2008). This is because farmers respond to higher prices and convert forest and grassland to new cropland to replace the grain or cropland diverted to biofuels. By using a worldwide agricultural model to estimate emissions from LUC, Searchinger et al. (2008) found that corn-based ethanol nearly doubles greenhouse gas (GHG) emissions over 30 years and increases GHG for 167 years. Biofuels from switchgrass, increase emission by 50%. This highlights the value of using waste products or lignocellulosics as a feedstock of alcohol fermentation.

Acidic or chemical hydrolysis as a pre-treatment process for starchy and lingocellulosic material can cause safety hazard depending on the type and concentration of the compounds. Sulfuric acid is a conventional chemical compound to hydrolyze starchy feedstock, and it poses a safety hazard being highly toxic and corrosive. (Nag 2007)

Pelletization

Pellets are a solid biofuel with consistent quality – low moisture content, high energy density and homogenous size and shape. Pellets may be produced from different raw materials. The first and most common raw material is milled wood materials such as cutter shavings, saw dust and grinding dust. Other types of raw material that be used are bark, energy crops (any kind of agricultural crops) and herbaceous plants.

In the pelletization process, the biomass is dried and compressed under high pressure into cylindrical shaped fuel products with a diameter of 6-15 mm and a length of 5-50 mm. The main environment al impact of the pelletization process is related to energy consumption. The raw materials needs to comminuted and dried to about 10% moisture content before pelletizing, as woody material with MC over 15% is difficult to pelletize. Pellet formation may also require additives, if e.g. the lignin content of the feed material insufficient. Also dust formation during the pelletizing process can have safety consideration. Wood dust is dangerous to human health, and it can cause spontaneous ignition in storage silos.

The main emissions of pelletization occur during the use phase of the product, namely the combustion. Emissions will be different depending on the adjustment of the burner, thus incomplete combustion or complete combustion would produce different type of emissions. The quality of the pellet is also a very important factor (moisture content, ash content, Cl and S content and so on).

Moisture content will impact on combustion efficacy. The composition and repartition of ash (mostly composed by Calcium, Magnesium, Silicon, Potassium and Phosphorus) will influence the melting behavior and thus the good functioning of the burner.

Conclusions

Thermochemical biomass power and W2E technologies, whether derived from the burning of plant matter or plant-based energy carriers, raises more serious environmental issues than any other renewable resource except hydropower. Combustion of biomass and biomass-derived fuels produces air pollution and particulates. Many of the biofuel production process and especially downstream processes to upgrade the product are energy intensive. The characteristics of biomass-to-energy technologies and their environmental impacts are summarized in Table 1.

Table 1 Characteristics and environmental impacts of biomass-to-energy technologies (Based on Austerman et al. 2007, Austerman & Whiting 2007, Kauriinoja 2010, Kelleher et al. 2002, McKendry 2002, Soltes 1987, Uslu et al. 2008, Ward et al. 2008 & Wisbiorefine 2004)

	Anaerobic digestion	Gasification	Combustion	Pyrolysis	Fermentation	Pelletization
Input materials (preferable)	Biowaste &waste waters, by-products, energy crops	Forest products, energy crops, biowaste	Pellets, Biomass, wood wastes,	Forest products, energy crops, mill wood waste, agriculture and urban organic wastes	Food crops and by products, forest residues, energy crops, biowaste	Woody, herbaceous and fruit biomass, belnds & mixtures
Limiting factors	Total solids 4–40%	Moisture <45% Ash <15%	Moisture <50%	Moisture <45% Ash <25%	Homogenous input, Nutrients, pH, Moisture	Moisture 10-25%, particle size < 20 mm
Product	Biogas	Syngas	Heat	Pyrolysis oils	Alcohol	Pellets
By-products	Reject, water	Char	Ash	Gases, char	Reject, gases, water	Dust
Post-treatment	Moisture removal	Particulates and tars removal	No	Oxygen removal	Water removal	Dust removal
Applications and use	Transportation, fuel, CHP; digestate as fertilizer or soil conditioner	CHP, synthetic fuel production	Electricity and heat production, liquid or gaseous fuels	CHP and fuel for engines	Transportation, fuel, CHP; digestate as fertilizer or animal feed	Small scale combustion, CHP, fuel for gasifiers, animal bedding
Direct environmental impacts	Energy needs, CO_2 emissions	CO, PAH, COS, NO_x, H_2S, particulates	Gaseous emissions, fly and bottom ash, particulates	CO_2, CO, CH_4	Wastewater, COD, BOD, nitrates, phosphates,	Fine particles
Indirect environmental impacts	Potential water impacts of digestate spreading on land	Energy requirement of donwstream processes, catalyst needs	Land use impacts of unsustainable forestry practices	Energy requirement of donwstream processes, catalyst needs	Land use impacts, formation of aldehydes in biofuel run engines	Energy use, emissions and ash from the combustion of pellets

Both environmental and political pressures require increased biofuel production in the future. There are many ongoing attempts for measuring the sustainability aspects of biofuels. Most of them focus on controlling land use impacts and GHG emissions. This is due to the potential long-term adverse impacts of direct and indirect land-use changes on GHG emissions and, in particular, the danger of using productive croplands for biofuel feedstock production. This highlights the value of using wastes and forest-based resources as feedstock for biofuel production. The challenge of using waste materials is in their heterogeneous nature. In the case of lignocellulosics, the challenge lies in developing effective pre-processing technologies. Research needs to intensify to increase the efficiency of W2E technologies and to address the challenges provided by the feedstock.

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