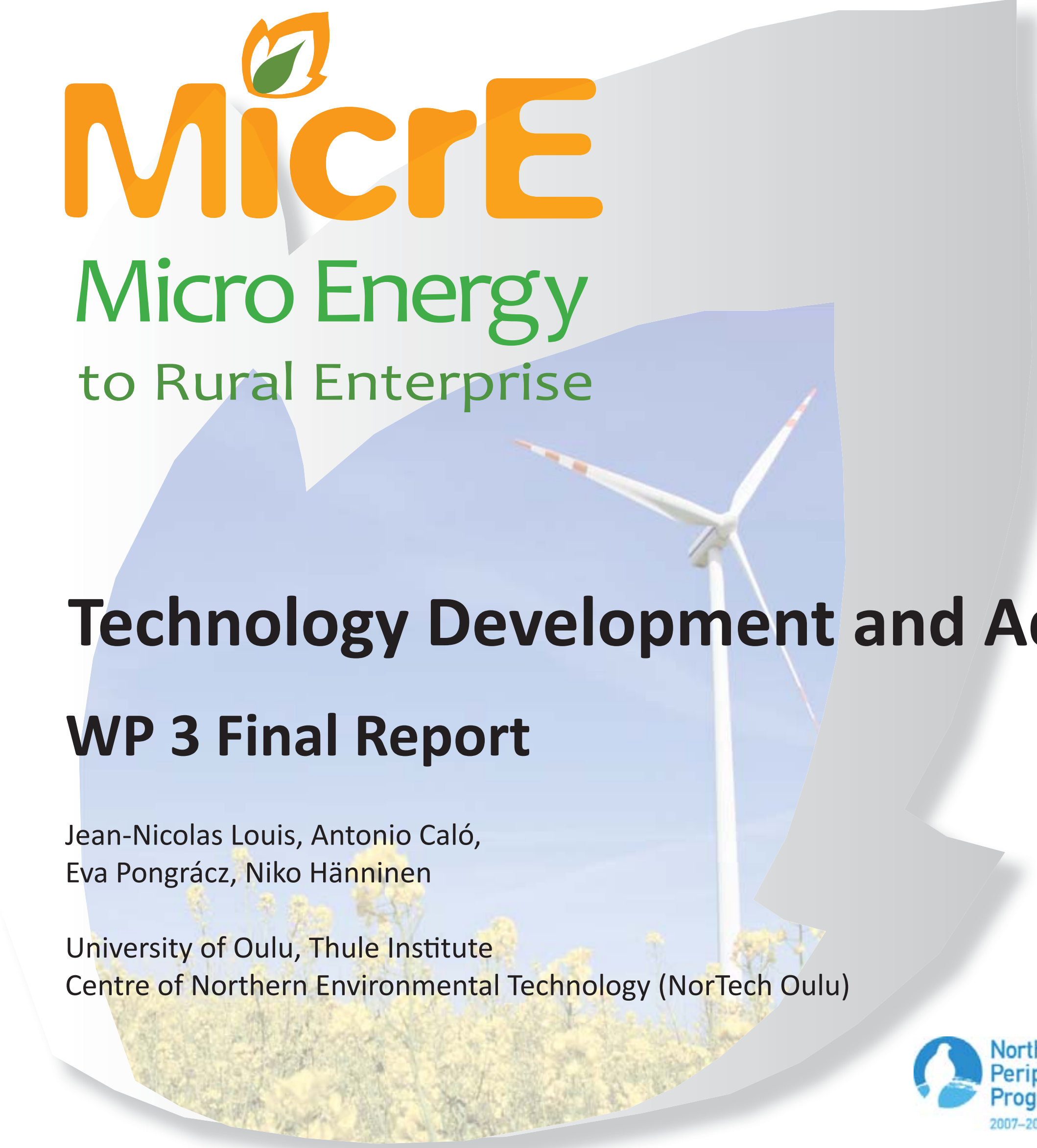

MicrE

Micro Energy

to Rural Enterprise

UNIVERSITY of OULU

OULUN YLIOPISTO

Technology Development and Adaptation

WP 3 Final Report

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Northern Periphery Programme 2007–2013
Innovatively investing in Europe's Northern Periphery for a sustainable and prosperous future
European Union
European Regional Development Fund

Providing a research base for micro- and small-scale waste-to-energy technologies

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The MicrE project

The aim of the Micro Energy to Rural Business (MicrE) project was to develop and promote innovative small scale renewable energy solutions for rural SME's in the Northern Periphery (NP). The idea was to utilise new and existing technologies which have not been tried in a rural environment before, such as gasification, pyrolysis and anaerobic digestion. Targeted were especially SMEs which generate organic by-products and waste, such as of food and biotechnology industries.

MicrE aimed to provide a service to develop small scale renewable energy solutions, some of which will use waste as a resource. These solutions would use new technologies available for generating energy from waste, and adapt them to suit SME's and local organisations of the size and character that typify NP rural regions. The overall goal of MicrE was to enhance the capacity for self-sustaining business in rural NP regions. The objectives were to make new small-scale renewable energy technologies, especially energy from waste available to SME's and organisations in rural NP regions on a scale that is viable and economically feasible; and to embed them within specific organisations within the partner regions to demonstrate the benefits they can deliver.

MicrE developed a service that can offer the skills required to promote and embed the technologies in rural areas throughout the partner regions, using the combined skills base, technology access and financial strength to make the technologies accessible. The MicrE project will work through a programme to establish and activate the service, so that, during the lifetime of the project, it achieves its goals of delivering new small-scale renewable energy solutions in the partner regions.

Activities in WP3

Within the MicrE project, the University of Oulu was responsible for WP 3: Technology Development and Adaptation. The strategic focus of this WP is to provide the research base for the MicrE service to be effective, especially in terms of technology development and adaptation. The following acitivites were conducted in this WP:

1. Technology review - Identifying technologies suitable for selected SME's and feedstock to be tested

2. Experimental design/adaptation - Examining selected technologies for their performance capabilities in the environment of an SME in rural regions, to assess the capacity and efficiency of the technologies. This activity also aided in plannig the experiments for technology tests, selecting feedstock, scale-up/down when necessary, to take account of the development and adaptation demands and constraints

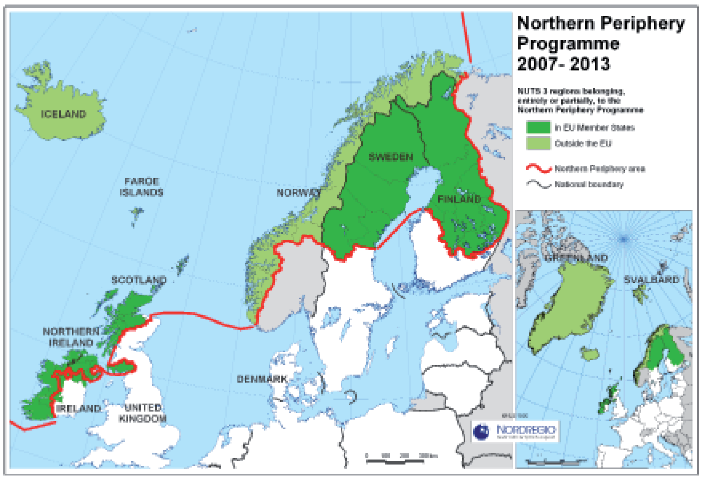
3. Lab Test Experiments - The selected technologies tested in a controlled laboratory environment

4. Installation protocol - Guides to be prepared detailing the installation steps and protocols for the selected technologies

5. Environmental impact assessment - The emissions related to selected technologies evaluated and suitable measurement and abatement methodologies suggested. The performance of these methodologies reviewed and ested.

6. Troubleshooting - Advising to be provided for SMEs implementing the selected technologies

7. Reporting - Reports and publications prepared all through the project duration



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Introduction

A growing concern in relation to the impacts of global warming and the decrease in conventional fossil fuel sources is the enhancing interest toward renewable energy sources. Also the EU Waste Framework Directive (2008/98/EC) has created challenges in the handling of waste e.g. by requiring energy recovery from waste when recycling and reuse of materials are not applicable. The European Union is aiming to diversify its energy supply, reduce the reliance on imported energy and decrease greenhouse gas emissions across Europe by promoting renewable energy production for transport, electricity and heating purposes.

In this framework, there has been growing interest in waste to energy technologies, which, for the northern periphery areas, include conversion technologies that produce energy commercially, also in a small scale, are inexpensive and simple to maintain.

Waste can be divided into several categories including municipal solid waste, construction and demolition waste, commercial and industrial waste, medical waste, hazardous, radioactive or electronic waste, and biodegradable waste. Waste can be converted to energy by thermochemical, biochemical, mechanical, chemical and electrochemical processes, depending on the original material. Thermochemical conversion processes include gasification, pyrolysis and combustion, biochemical processes include fermentation and anaerobic digestion, and mechanical conversion processes include pelletization. Thermochemical and biochemical conversion technologies are well suited to a wide range of feedstock, while the others have more limitations. Thermochemical conversion methods are best suited for relatively dry woody or herbaceous feedstock whereas biochemical technologies can also handle material with high moisture content. Material properties can vary widely depending on the original material, but generally the following properties are important with regard to energy production: moisture content, calorific value, proportions of fixed carbon and volatiles, ash/residue content, alkali metal content, cellulose/lignin ratio, carbohydrate/sugar content, lipid/fat content, protein content, and pH.

1. Technology Review

Small scale biomass- and waste-based energy solutions have the potential to answer the need for resource availability while systematically reducing the human impact on the environment. This, in turn, empower SMEs and local organization in rural areas to generate energy on site from their own wastes and by-products, at the scale that is economically viable.

The technologies suitable for selected SMEs strongly depend on the locally available feedstocks and its characteristics (i.e. moisture content, calorific values, ash/

Table 1. Selection Matrix

	ALCOHOL FERMENTATION	ANAEROBIC DIGESTION	GASIFICATION	PELLETIZATION	PYROLYSIS	COMBUSTION
Scale	Ethanol yield 102-106 m3 annually	Reactor size 50-10.000 m^3	1 kWe – 150 MWe depending on the technology used	Pellet yield 102-105 t annually	Pilot plant of 200kg/h, with 66% energy yield	Small-to large scale
Temperature	15-60 °C	Optimum 35°C or 55°C	650-1200°C 650-1200°C	150 °C	400-800°C	>800°C
Input (prefereable)	Food crops and by products, forest residues, energy crops, biowaste	Biowaste &waste waters, by-products, energy crops	Forest products, energy crops, biowaste	Woody, herbaceous and fruit biomass, blends & mixtures	Forest products, energy crops, mill wood waste, agriculture and urban organic wastes	Pellets, Biomass, wood wastes,
Requirements for input	Homogenous input, sufficient, sugar content, nutrients	Total solids up to 40 %	Moisture 6-45 % ash< 15 %	Moisture 10-25 % particle size < 20 mm	Moisture <45 % Ash <25 %	Moisture <50 %
Inhibitors	Ash; Furfurals, levulinic acid, aromatic compounds (arising during the process)	Antibiotics & other organic compounds, ammonia, sulphide, ions, heavy metals	alkali metals, trace impurities, (S, Cl, N), particulates (inorganics, fly ash)	Inorganic impurities, insufficient lignin content, lack or excess of moisture	Alkali metals, trace impurities (suplhur, chlorine, nitrogen), particulates (inorganic, fly ash)	Manure, organic domestic wastes, fish industries wastes
Output (Useful)	Ethanol, butane & other alcohols	Methane	Product gas (syngas)	Pellets	Pyrolysis oils	Heat
Output (others)	Liquid & solid residues, gases	CO_2, digestate	Gaseous impurities, char, tars	Dust	Gases, char	Ash
Post-treatment	Purification & distillation	Depends on the usage	Particulates & tars removal	Dust removal	Oxygen removal	No
Applications & uses	Transportation, fuel, CHP; digestate as fertilizer or animal feed	Transportation, fuel, CHP; digestate as fertilizer or soil conditioner	CHP, synthetic fuel production	Small scale combustion, CHP, fuel for gasifiers, animal bedding	CHP and fuel for engines	Electricity and heat production, liquid or gaseous fuels

residue content, etc.) (McKendry 2002, Kelleher et al. 2002). Based on the criteria a selection of the most suitable technologies has been made (Table 1).

1.1 Thermochemical conversion

Thermochemical conversion processes take place at high temperatures and occur in environment characterized by very different concentration of oxygen. Selected technologies that fall in this categories are combustion, pyrolysis and gasification.

1.1.1 Combustion

Combustion is the oldest and still the most used way to convert biomass to energy. Utilized for heat and power production, the useful scale of this technology is very large in heat production, while for power production the smallest commercial technologies start from 50 kW. Combustion, however, is a rather inefficient power generation method when compared with other methods like, for example, gasification (Lampinen and Jokinen 2006).

1.1.2 Pyrolysis

Pyrolysis is a process in which organic material is heated at high temperatures in an oxygen free environment. The products are gases, oils and char (Ahmed and Gupta 2009). Gasses are usually utilized for drying and pyrolysis reactions, oils are utilized for heating or, if refined, as secondary fuels. The product ratio may differ, depending on the method used: slow pyrolysis produces mainly char, while fast pyrolysis produces higher oil yield (Lampinen and Jokinen 2006).

1.1.3 Gasification

In gasification biomass is converted by partial oxidation at high temperature into gas mixture called product gas or syngas. The product gas can be used for heat and power production and it is suitable for micro-scale application (Lampinen and Jokinen 2006).

The gasification process is strongly dependent on a number of factors such as the feedstock particle size range, moisture content, gass-solid contacting mode, pressure, heating rate, temperature and residence time. The taking into account of these factors brought to the development of different design and configuration of reactor types; however, only few models are fully commercialized , particularly the fixed bed (updraft and downdraft) and fluidised be design (Austerman and Whitng 2007).

1.2 Biochemical conversion

In biochemical conversion, micro-organisms convert biomass into biofuels. These processing techniques are “wet” processing techniques as they are more economical and efficient that thermochemical conversion processes for high moisture materials (McKendry 2002).

1.2.1 Fermentation

In the fermentation process, microbes (usually yeast or bacteria), or less frequently fungi, split organic matter producing typically alcohol as a final product (Lampinen and Jokinen 2006). This process is particularly suitable for crops and plants with high content of sugar or starch (e.g. sugar beet, corn, potatoes, etc.). As the first-generation biofuel from agricultural crops is commercially available thanks to a mature technology and a growing industry, second generation biofuels are still more expensive providing only marginal contribution. Nevertheless, extensive research is currently occurring in both fields (COM(2005) 628).

Ethanol is the most common fuel produced through commercial fermentation thanks to its versatility as transportation fuel and fuel additive. Beside ethanol, butanol is being developed as fuel substitute.

1.2.2 Anaerobic digestion

Anaerobic digestion occurs in an oxygen free environment and it is based on the decomposing of organic matter by anaerobic bacteria. The main product of this process is biogas which mainly consists of methane and carbon dioxide. The produced biogas can be used for heat and power generation, or it can be purified in order to be used as transportation fuel in vehicles. Anaerobic digestion can be also used to produce hydrogen, but this technology is not yet commercially available. (Kelleher et al. 2002, Lampinen and Jokinen 2006)

1.3 Mechanical conversion

Biofuels can be produced by mechanical conversion. Splitting and pressing of solid bioenergy sources are much used conversion methods. The energy density increases while, however, densification of solid biomass is a fairly expensive process and its cost addition to fuel is significant and needs to be taken into consideration during the technology selection.

1.3.1 Pelletisation

Pelletisation is a process in which biomass is dried and compressed under high pressure into cylindrical extruded pieces with a diameter of 6–10 mm and height

of 10–20 mm. Pellets have a higher energy density (approximately 1,100–1,500 kg/m^3), representing therefore a more efficient fuel to store and transport, especially in long distances. In pelletisation, the amount of dust produced is minimised and pellets offer a uniform and stable fuel. (Uslu et al. 2008, Kuokkanen 2009).

2. Experimental Design

2.1 Meat industry wastewater RO and AD

In the last decade, tertiary biomass has become a prime source of interest in bioenergy generation, and efforts are extended to utilising the energy content of organic waste and effluents.

Compared to other agro-industrial sectors, food processing generates a great amount of wastewater due to the high water content of raw materials and the high water demand of flushing and cleaning procedures. Food processing companies face the demand for efficient wastewater purification and biowaste handling systems. At the same time, because of the low average temperature in the northern regions, the efficiency of traditional biological wastewater treatment technology is low.

Beside this, the high volume of wastewaters and their fluctuating composition, the high volumes and the periodic operating nature of small- and medium-sized meat processing plants make it difficult to plan and to optimise the biological purification processes, and to achieve a profitable biogas production regime.

Membrane operations are suitable for efficient wastewater purification and concentration in one stage process. Furthermore, membranes techniques are known to be easily adaptable for different flow rates and for fluids with diverse chemical compositions.

In the designed experimental work, the optimization of reverse osmosis (RO) operation was investigate in order to find optimal process parameters for the purification and concentration of meat industry wastewaters. The main aim of this research was to find technology for treatment of food industrial wastewater in Northern Periphery which appropriate to produce recyclable process water with efficient removal of organic matters and on the other hand is suitable in local energy supply systems based on anaerobic digestion. A unique feature of this work was that the tests were conducted on actual wastewaters delivered from a local meat processing company. Further, AD tests were conducted on the obtained wastewater concentrate, and the biogas production was determined with mesophilic anaerobic digestion tests. To examine the possible interactions between the operating conditions and to optimizing the influential parameters for membrane purification central composite face centered (CCF) experimental design and response surface methodology (RSM) was performed using MODDE 8.0 statistical experimental design software (Umetrics, Sweden). RSM is an adequate method to fit a model by least square technique when a combination of independent variables and their interactions affect the desired response.

2.2 CO_2 capture and storage

One of the most successful technologies to produce renewable energy in small scale in the NP conditions is anaerobic digestion (AD), as well as gasification and small scale combustion of biomass (Kauriinoja 2010). The drawback of these technologies is the high content of carbon dioxide in the biogas and flue gases produced. CO_2 needs to be removed from the biogas before it can be used in modern industrial applications and it cannot be released into environment, therefore, it is imperative to determine what to do with it after removal. The surplus CO_2 could be turned into a stable form, a process for which several method are already in place but they do not provide a feasible solution for the growing need of CO_2 sequestration. In this framework though, a promising method is mineral carbonation of carbon dioxide into the formation of calcium carbonate.

Two kinds of fly ashes and green liquor sludge were studied as CO_2 capture and storage materials. Ash samples were collected from the combustor of an Estonian power plant (Narva Power Plants Ltd), from a boiler operating using circulating fluidized bed (CFB) technology. Green liquor sludge was studied as an individual compound and also a mixture with OSA for CO_2 capture.

The goal of the experimental work was to determine how these low cost materials could be utilised in carbon dioxide capture and storage. For that purpose, the reactivity of oil shale ash in carbon dioxide storage was evaluated and a comparative analysis of the actual CO_2 physisorption capacities of green liquor sludge, fresh oil shale ashes, activated oil shale ash and an optimal mixture of all previous materials was conducted.

2.3 Smart energy networks in the North Calotte

The smart energy grid represents a solution that can provide a valuable contribution on matching the need of mitigating the effects of global warming, guarantee energy delivery reliability, and handle scarcity and competing use of resources. A solution where consumers are given the possibility to choose and be directly engaged, smart energy grid indicates a power grid that allows suppliers and consumers to have a two ways communication monitoring in real time the grid condition (i.e. the electricity production, consumption and distribution).

The motivation behind studying the development of smart energy grids can be explained in terms of what a smart grids are expected to do. Using real time monitoring together with smart control system capable to evaluate and improve its performances, the envisioned smart grid based system can anticipate and mitigate power peaks and power quality problems. At the same time, it allows for a more prominent position on the market of those renewable energy resources characterized by a discontinuous and irregular power generation (i.e. wind power).

Within the MicrE project, a study of the potential for smart energy network in the northern calotte was conducted. Furthermore, a hybrid micro-grid simulator was developed from the end-user's point of view. The simulator makes a (smart) use of available renewable energy sources (RES) based on a demand-response logic principle. The hybrid model includes a number of selectable elements: 3 bioenergy based CHP units, a small-scale wind turbine and a photovoltaic system. It also uses a plug-in hybrid electric vehicle (PHEV) as one of the storage elements. The main role of the simulator is to model the communication with the energy grid from the end-user's point of view, i.e. putting energy on the common network in case of excess production and taking energy from it in case the available renewable resources cannot respond to consumer needs.

3. Laboratory tests

3.1 Meat industry wastewater RO and AD

Laboratory tests evaluated the applicability of reverse osmosis (RO) for the pretreatment of meat industry wastewater, to concentrate the waters prior to processing by anaerobic digestion (AD). The selected RO operation produced purified water with low organic matter content and a concentrate suitable for the recovery of valuable organic compounds by AD. For the pilot scale filtration a series flow B1 module of Paterson Candy International (PCI) was used equipped by 18 AFC99 (ITT PCI Membranes Ltd.) tubular polyamide membranes (Nominal retention for NaCl 99%). Each 1.2 m long tubular membranes has 12.5 mm inner diameter, the total effective membrane area was 0.85 m2. The temperature of feed was controlled by a heat exchanger. The recirculation flow rate (Qrec) is varied between 600 and 1000 Lh-1. Considering the nominal pressure range of PCI module and the AFC99 membrane the operating pres-

sure of RO was 25, 35 and 45 bar. In each experiment 30 L wastewater was concentrated to reach a volume reduction ratio (VRR) of 3.75. The AD tests were performed in Mesophilic conditions (35 ± 0.2°C) with a digestion time of 30 days in an Oxitop C 250 mL continuously stirred reactor with barometric measuring heads.
The data obtained showed that the recirculation flow rate, the pressure as well as the temperature have an impact on the efficiency of the RO process. In the considered case, the highest capacity of membrane operation (highest permeate flux) could be reached by 38.5 bar operating pressure with recirculation flow rate of 1000 L h^{-1}. The results of AD tests showed that the preconcentration could increase the overall capacity of digestion with the higher organic matter content of AD feed, moreover the specific biogas yield and the rate of AD process was improved by the applied pretreatment. Comparing to the untreated RO concentrate, the alkaline pretreatment with combination of heating at 70°C could enhance the biogas production by 70%, and the methane content of produced biogas improved.
In conclusion, laboratory results showed how the membrane process is applicable for purification of meat industry wastewater, and concentration of organic matters in one-step. With the application of RO process, low contaminated recyclable process water can be produced, and the biodegradable organic matter content of effluents can be utilizable in local bioenergy generation system for small-sized meat companies in rural areas.

3.2 CO_2 capture and storage

Carbon dioxide capture and storage capability of these materials are studied in two processes; chemisorption and physisorption. Chemisorption process has a goal to turn tobermorites formed in the activation process into calcium carbonate, which is a geologically stable form for carbon storage. Physisorption is a process to adsorb CO2 from gas flows in gas purification. The raw materials need to be pre-treated before they are suitable for carbon dioxide capture and storage.
The pre-treatment used in the experimental work was an alkaline hydrothermal activation process with aqueous sodium hydroxide solution. The activation process was conducted for all raw materials and their derivatives. All silica in oil shale ash was converted into calcium silicate minerals. It was detected that the minerals formed in the activation were mostly tobermorites and katoite. Green liquor sludge was activated as an individual material and as a mixture with oil shale ash.

3.3 Smart energy network in the North Calotte

The obtained results indicated that there is a potential for smart energy grids in the northern calotte area due to a number of favourable characteristics: richness of natural resources, socio-cultural background and financial instruments for the development of an advanced energy market such as the Nord Pool Spot run power market. The system developed in this work is capable of answering to the power and thermal energy needs of the user. Furthermore, it allows monitoring the contribution of the included elements and their combined effect on the common networks, stabilizing the energy consumption profile of the end user. This will, potentially, translate into reduced costs of the transmission and for distribution system operators.

4. Installation protocol

4.1 Anaerobic Digestor

The design process of a biogas plant starts by defining the properties of raw-materials. Raw-material can include products from a farm, such as manure, sludge and grass but it also includes external raw-material sources. External raw-material sources tend to have stricter requirements than raw-materials straight from the farm. However, additional payments can be required from external inputs.(Tavitsainen2006)
In cases when there are two or more raw-material sources near to each other it may be profitable to build one biogas plant. In this case the post-treatment of process waste has to be agreed between farmers. Business registration and the amounts of raw-materials must be defined and reported. In addition the use of the raw-material can require the permission of a veterinarian.
Requirements for an anaerobic digestion process are strongly depended on biomass feedstock properties. There are no special requirements for a biogas process if it handles only the manure or sludge straight from the farm. External feedstock should be handled properly to guarantee adequate hygienic circumstances (Tavitsainen 2006).
Raw-material may require sterilization as a pre-treatment process. 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, for instance (Erjava 2006).
One important step is determination of the computational biogas potential of a biogas plant. Calculation is done by multiplying the annual solid raw-material production with the methane productivity potential. Determination of heat and power consumption of the plant is

also an essential operation in the beginning. Electricity and heat can be used to run the plant and to heat up households that are nearby. Excess electricity can be leaded to electric grid and sold to a local electric company. (Tavitsainen 2006)

When there is enough background knowledge, the supplier for the process equipment is considered. Some suppliers can perform the energy calculations and preliminary budget offer. In some cases installation costs of a biogas plant can be decreased, if the buyer of a plant helps with construction work (Tavitsainen 2006).

Production of biogas is regulated by several legislation systems related to environment, energy production and agriculture, for instance. At first the construction permission is needed to build an anaerobic digester. A zoning plan may be useful to check also in the beginning. The supplier and agreement for a biogas plant are also necessary.

Environmental legislation (and waste legislation) is also considered, since the possible environmental damage caused by biogas plant. Environmental legislation requires for instance environmental impact assessment. In addition collection, storing and transportation of raw-material and biogas requires separate permissions. For example the requirements for a transportation tank may be strict. Fertilizer legislation is considered in the case when fertilizer is produced by biogas plant and then sold forward (Erjava 2006).

Installation of a biogas plant usually needs an agreement with a local or regional energy company, especially if the purpose is to sell electricity. During the high productivity seasons electricity can be sold and other way around. Electricity companies can be put out to tender to get good price for electricity, when selling and buying it.

Rescue plan and risk evaluation are also necessary to compose. Also the installation of a biogas plant can be reported to a local rescue authority. Furthermore the documents related to an ATEX directive are essential because at least methane is highly flammable gas in normal temperature and pressure conditions.

Permissions and legislative systems behind the installation and maintenance of gas pipes are also considered as well as the legislative related to maintenance of the whole anaerobic digestion process. However the legislation systems and regulations related to biogas plants can vary from country to country substantially (Tavitsainen 2006).

4.2 Combustion plant

Permissions for the installation of a combustion plant vary due to different scale of plant. In small scale applications, such as stoves, there are no significant requirements needed. Small-scale combustion stove usually need only construction permission. After construction, stove is necessary to verify by rescue authority. (15.5.2003/362)

In the case of larger biomass combustion plants, raw-material input is necessary to define to understand what kind of process is suitable. Also the possibility to generate electricity among heat is considered. Thinking also possible raw-material suppliers and more exact scale for the plant is essential. In addition raw-material may require some pre-treatment in order to reach as good combustion circumstances as possible, since there may be some requirements to amounts of emissions and bottom ash (15.5.2003/362).

Larger scale combustion plants require construction plant and land use plan. City plan can be taken into account also. In addition storages, pipes and other process equipment ask construction permission. Stability and fire safety regulations are compulsory to follow here (Ministry of Environment 2011a).

Environmental permission is compulsory for larger combustion plants. Especially air emissions from combustion plants, such as CO2 and ash, are significant. The overall emissions and impacts to environment are done by composing environmental impact assessment. Moreover waste streams from the plant are evaluated by environmental authority. Combustion plant must work also under IPPC directive, using best available techniques to protect environment (Ministry of Environment 2011a).

Combustion process products mainly heat, but if an engine generating energy exists, excess electricity can be then sold to electricity companies. Before distributing electricity or heat, agreements and permits have to be done with companies. Standards and regulations related to possible boilers, turbines and CHP-unit are compulsory to follow (15.5.2003/362).

In larger combustion plants rescue plan, hazard identification and risk evaluation are necessary to compose, since there are hazardous chemical compounds and high temperature present in the process. Safe working environment is also ensured by following these safety requirements.

In the case that heat production of the combustion plant is 20 MW or more, emission trade directive is taken into account. However, legislation and regulations behind a combustion process is largely depended on the scale of the process. Co-combustion may require stricter requirements for combustion circumstances, for instance. Legislation and regulations for the combustion process may also have national varieties (Ministry of Environment 2011b).

4.3 Bioethanol plant

The design process of a biogas plant starts by defining the properties of raw materials. Raw material can include products from a farm, such as manure, sludge and grass but it also includes external raw material sources. External raw material sources tend to have stricter requirements than raw materials straight from the farm. However, additional payments can be required from external inputs. (Tavitsainen2006)

In cases when there are two or more raw material

sources near to each other it may be profitable to build one biogas plant as a joint effort. In this case, the post-treatment of process waste has to be agreed between farmers. Business registration and the amounts of raw materials must be defined and reported. In addition, the use of the raw material can require the permission of a veterinarian. (Tavitsainen2006)

Requirements for an anaerobic digestion process are strongly dependent on biomass feedstock properties. There are no special requirements for a biogas process if it handles only the manure or sludge straight from the farm. External feedstock should be handled properly to guarantee adequate hygiene standards. (Tavitsainen2006)

Raw material may require sterilization as a pre-treatment process. 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, for instance. (Erjava 2009)

One important step is the determination of the computational biogas potential of a biogas plant. Calculation is done by multiplying the annual solid raw material production with the methane productivity potential. (Tavitsainen2006)

Determination of heat and power consumption of the plant is also an essential operation in the beginning. Electricity and heat produced by the plant can be used to run the plant and to heat up households that are nearby. Excess electricity can be transferred to the electric grid and sold to a local electric company. (Tavitsainen2006)

When there is enough background knowledge, the supplier for the process equipment is considered. Some suppliers can perform the energy calculations and preliminary budget offer. In some cases installation costs of a biogas plant can be decreased, if the buyer of a plant helps with construction work. (Tavitsainen2006)

4.4 Gasification plant

Construction and operation of a gasification plant is connected to several different requirements and legislative systems. Before making further applications for building a plant, it is necessary to determine a raw-material input (biomass or waste etc.), so the equipment, circumstances and type of the process can be defined. In addition the use of the end product is thought out, so the possible need and regulations of CHP-unit or agreements with biofuel companies can be considered, for instance (Gasification guide 2009).

First of all construction permission is needed for a plant. Regulation of land use planning is taken into account in order to find out appropriate place for the gasification plant. It is also possible that city plan is also taken into consideration here (Ministry of Environmental 2011s).

Environmental permission for the gasification plant is essential. In this case an environmental impact assessment is applied to find out possible impacts to the environment. In this case for example emissions to the atmosphere and noise emissions are prospected and soil protection, waste production and -treatment and possible waste water discharge are taken into account. The need of IPPC directive varies from country to country and can be depended on the size of the gasification plant.

Rescue plan, hazard identification and risk assessment for the plant is also composed and ATEX directive is followed. Health and safety at work must be ensured by following the regulations related to fire and explosion hazards. Moreover the regulations involved to electrical and pressure equipment and machinery are necessary to consider. Adequate handling, transportation and storing of several hazardous substances is essential to avoid accidents. Special monitoring may be required for certain installations. Fire safety and stability regulations of the plant building are essential (Gasification guide 2009, Ministry of Environment 2011a).

The use of energy may ask requirements connected to the feeding of electricity to the power grid. In this case a possible buyer for the electricity is considered and the terms of electricity suppliers and buyers electricity are done (Gasification guide 2009).

Legislative systems and regulations related to installation of pipes and storages are also required. Transportation of waste is also regulated. Produced syngas can be also sold to companies, which must be agreed with the companies. In addition agreements with raw-material suppliers can be made. In this case the possible seasonality of available raw-material is preferable to consider (Tavitsainen 2006).

Differences in national and regional regulations can exist. To avoid the major problems with legislative systems and regulations, it is such an important thing to discuss with local regulator at an early stage of the gasification plant planning process (Ministry of Environment 2011a).

4.5 Pyrolysis plant

Installation of a pyrolysis plant starts with determining the amounts and properties of feedstock, so the circumstances, catalysts, reactor size etc. can be considered.

The end product, which can be gas, charcoal or bio-oil defiens operating temperatures, residence time, product yield and heating rate can be thought out. In addition, raw material suppliers are essential to find and make agreements with them. (Basu 2010)

After determination of raw materials, construction permit is needed to the plant. Land use can also be regulated, and it is possible to consider the city plan to find an appropriate location for the pyrolysis plant. Properties of pipes and storages are regulated and their installation of them may need permission. Installation of liquid and gas devices is done by following appropriate requirements. (Ministry of Environment 2011a)

Environmental permit for the pyrolysis plant is compulsory, due to its potential environmental hazards. Environmental Impact Assessment is necessary to compose, and regulations and legislative systems related to waste streams are taken into account. In addition, it is possible to consider also the IPPC Directive, but the need of this directive varies from country to country and can depend on the size of the pyrolysis plant. Also the collection and transportation of waste is regulated by the EU. These regulations vary also from country to country. (Ministry of Environment 2011a)

Safety issues are one of the fundamentals of the pyrolysis plant because of several fire and explosion hazards. Hazard identification, risk assessment and possible rescue plan is thus necessary to compose. In small-scale applications, at least a notification to the local rescue authority is compulsory. Regulations regarding electrical and pressure equipment and machinery are necessary to follow. Adequate handling, transportation and storing of several hazardous substances is essential to avoid accidents. (Ministry of Environment 2011a, Basu 2010)

Selling bio-oil, heat, electricity and charcoal from the pyrolysis plant requires agreement with companies. Possible buyers and markets are taken into consideration in an early stage of the planning process. (Ministry of Environment 2011a)

Legislative systems and requirements can have national and regional differences. To avoid major problems with legislative systems and regulations, discussions with local authorities at an early stage of the gasification plant planning process is a necessity.

5. Environmental Impact Assessment

The direct and indirect impact of W2E technologies are sumarized in Table 2.

5.1 Anaerobic Digestion

There are 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)

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 SO2 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, H2S has also corrosive effects. There are numerous proven and commercially available technologies for H2S

Table 2. Direct and indirect environmental impacts of W2E technologies

	ANAEROBIC DIGESTION	GASIFICATION	COMBUSTION	PYROLYSIS	FERMENTATION	PELLETIZATION
Direct environmenal impacts	Energy needs, CO2 emissions	CO, PAH, COS, NOx, H2S, particulates	Gaseous emissions, fly and bottom ash, particulates	CO2, CO, CH4	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, potential formation of aldehydes in biofuel run engines	Energy use, emissions associated with combustion of pellets

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.

5.2 Gasification

apart from the high energy needs, the 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/m3 when most applications of syngas require tar content of 0.05 g/m3 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 NOx when the syngas is combusted. Catalytic destruction or wet scrubbing techniques can be used to ammonia removal. Sulphur compounds, typically H2S but sometimes also COS (carbonyl sulphide), can be formed in the gasifier and this poses technical challenges. H2S could be oxidised to SO2 in a thermal device downstream. (Austerman & Whiting 2007)

5.3 Combustion

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 CO2 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)

5.4 Pyrolysis

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, H2 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)

5.5 Alcohol fermentation

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 2004) 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 CO2 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)

5.6 Pelletization

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 incom¬plete 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 reparti¬tion of ash (mostly composed by Calcium, Magnesium, Silicon, Potassium and Phosphorus) will influence the melting behavior and thus the good functioning of the burner.

6. Troubleshooting

6.1 Anaerobic Digestor

Appropriate temperature is essential to maintain due to slow methane fermentation process since product yield decreases immediately when temperature decreases. Adequate retention time and moisture content up to 50 % is a base for productive bio reactor. Moreover pH around 7,5 is optimal for microbial growth and metabolism of these microorganisms. For example if pH exceeds the level of 8, the biogas plant is recommended to be stopped. Formic acid can be added in the case of too high pH. (ECOFYS 2004)

Too high organic load can cause troubles for the process. Recommended amount of organic input varies between 0, 5 – 5 kg per m3. In addition, a healthy carbon to nitrogen ratio should be between 20:1 and 40:1. It is also to be considered that too large particle sizes and lack of auxiliary substances can restrict the microbiological process. (ECOFYS 2004)

Mixing is also needed to avoid pressure build-up and improve the substrate diffusion in the whole reactor. Without mixing, the gas bubbles may not reach the surface, which can cause troubles in the reactor. (ECOFYS 2004)

Feedstock containing antibiotics, disinfectants, heavy metals and organic acids can restrict microbial activity in the reactor or even kill them. If there is electronics default, a professional electrician is needed. The CHP unit can also have malfunctions. In this case, the gas supply from the CHP unit is cut. If there is a gas odor, ventilation is done and sparks and open fire ought to be avoided. (ECOFYS 2004)

Blockages are removed immediately, if the pipes malfunction. If there is malfunction in the pumps, be sure that valves are closed and pumps are switched off. There can be also malfunction in the biogas storage. In this case, the storage is to be ventilated, emptied and the gas supply is stopped. (Tavitsainen 2006)

Sterile process equipment are the base of the process, otherwise it might contaminate by unwanted microorganisms. Keeping process equipment sterile and preparing with inoculation storage is the best way to avoid contamination. (Vogel 1983)

6.2 Combustion

Properties of raw material have a great impact on combustion process efficiency. At first, moisture content is significant factor. Increasing moisture content can reduce the maximum temperature of the combustion and increase also retention time. High moisture content leads to incomplete combustion and high amounts emissions. Drying of raw material may be needed to decrease moisture content of raw material. (Loo & Koppejan 2008)

Appropriate temperature (more than 800 °C) is important to maintain due to its significant influence on reaction rates. Temperature is also important to optimize in order to reduce emissions from the combustion process. Higher temperatures can be reached also by improving the insulation of the combustion chamber. (Loo & Koppejan 2008)

The amount of available oxygen can restrict the combustion process. Due to this, excessive air ratio is used, but it is necessary to optimize it. Too high oxygen content can decrease the temperature of combustion. In large-scale applications, it is important to ensure sufficient mixing of excess air and ensure also the amount of forced draught to the combustion process. In small-scale applications, the problem of inefficient combustion can be inefficient natural drought. (Loo & Koppejan 2008)

Fuel type and properties, such as density, porosity, size and surface area, can affect significantly the combustion process. Larger particle sizes requires longer retention times, while more porous and finer materials have better reactivity. It is not recommended to use manure and municipal wet organic wastes in the combustion process because they can inhibit it. Also impregnated and painted woods are not suitable for the combustion process. In addition excessive fuel load can also inhibit a small-scale combustion process. (Loo & Koppejan 2008)

In small-scale combustion systems, too large glass area can cause heat losses, because heat radiates easily through it. Adequate retention time is also necessary to maintain, especially in batch processes. In large-scale applications air preheating may also be needed to raise the temperature of the process. (Loo & Koppejan 2008)

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)

In large-scale systems electrical and machinery malfunctions can have numerous unpredictable consequences to the combustion process. For example malfunction of forced air system in large-scale applications can disturb the system significantly. Boilers, CHP-units and turbines can also foul and corrode. Therefore, a proper maintenance schedule needs to be upheld. (Loo & Koppejan 2008)

6.3 *Fermentation*

It is necessary to know what micro-organisms are working in the process, because they also define the material input for the process. Some micro-organisms cannot use some specific sugar in their metabolism, which can restrict the fermentation process. The length of retention time also affects greatly the ethanol yield. (Nag 2007)

Possible inhibitors for the process are usually ash, furfur, levulinic acids and both aromatic and inorganic compounds. Antibiotics-containing input can restrict or even kill the micro-organisms. (MicrE 2011)

In a fermentation process, the process conditions have to be optimal for microbial growth and action. At first, the temperature should be appropriate for the used microbe. Lack of possible coolant compounds can raise the temperature of the process significantly. In addition, the water content of a growth medium has to be right. (Scragg 2005, 52)

Lack of nutrients can cause inefficient ethanol yield. Micro-organisms need several nutrients and trace elements, such as carbon, hydrogen, phosphorus, sulphur, vitamins, kalium and calcium. Adequate pH-level is also vital for fermentative micro-organisms. Accurate pH-level can be controlled by adding ammonia to the input, for example. (Scragg 2005, 51)

The fermentation process must be free from oxygen. Otherwise the presence of oxygen restricts the production of ethanol considerably. Stirring is usually needed to improve mass and heat transfer in a bio-reactor, especially in continuous reactors. (Scragg 2005 et. al)

Feed conditions can vary from design specifications, which affect the performance of the distillation column, especially the location of a feed tray and the amount of stages needed for the separation. For example changes in upstream input and different process operating conditions can inhibit the profitability of distillation. (Tham 2011)

Incorrect reflux ratio can also impact on the result of distillation. If the reflux ratio is too small, an infinite number of trays are needed to reach the separation result. Moreover the efficiency of trays can decrease by fouling. Vapor flow conditions such as foaming, entrainment and flooding can also disturb the work of distillation. These phenomena can root from too small column diameter or incorrect pressure in the column. (Tham 2011)

Sterile conditions are also essential to maintain. The whole process can be contaminated if an unknown micro-organism enters the process. Therefore, the sterility of all process equipment needs to be ensured regularly. Electrical malfunctions and blockages in the pipes can also happen. (Micre 2011)

6.4 *Gasification*

There are several chemical and physical factors affecting the yield of the product gas. Firstly, high moisture content is essential to be removed, by drying the raw material input in a specific drying chamber. If the biomass entering the pyrolysis chamber has too high moisture content (over 30 %), it can inhibit the gasification process and lead to decreased thermal efficiency. In addition, an adequate particle size is important factor to get good yield of gasification. Specific hydrogen-to-carbon ratio of the raw material, among others, affects the gasification yield, especially in the pyrolysis chamber. (Basu 2010)

Tar can cause troubles to the gasification process, when the tar-containing gas is cooled. Tar will condense on cooler surfaces or remaining in small aerosol drops. Tar can condense also on cooler pipeline surfaces, causing blockage, but it can also block engines and filters. Formation of liquid tar can be avoided by keeping the temperature above the dew point of tar before a tar separation unit. Without separation of tar, it will greatly inhibit the subsequent use of syngas, for example in an internal combustion engines. (Basu 2010)

Heavy metals, such as lead, copper and zinc, especially as chlorides, inhibit the gasification process. Most of heavy metals slow down gasification reactions, leading to longer retention time. In addition, some alkali metals can be harmful for the gasification process, because they can foul heat transfer surfaces and react with other inorganic compounds, causing corrosion. (Chartier et al. 1996)

If the gasification chamber is fed by too high oxygen concentration, it can lead to combustion, and thus weaken the yield of product gas. To this effect, an adequate temperature and pressure is necessary to maintain. Appropriate retention time of the process affects greatly on the result. In addition, too high ash content (over 15 %) can inhibit the process. Raw materials possessing low ash content can also minimize disposal issues. (Basu 2010)

Product gas yield can be low due to inefficient catalyst. Catalysts need to be recovered at times and the surface of the catalyst can foul. In case of electrical and machinery malfunctions, a professional mechanic will need to fix the problem. Such malfunctions can cause unknown and diverse consequences in the process, so it is hard to consider them in advance. (Basu 2010).

6.5 *Pelletization*

Pelletization process requires many steps in order to provide good quality pellets. First of all the raw material should be selected. Economically speaking, raw material must come from a waste source of wood industry. Every raw material has different characteristics where the moisture content as well as the chemical composition and the ash content of those raw materials differs.

Having too moist raw material might require a long and nergy intensive drying process in order to reduce the oist content of the pellet which will contribute to improve the combustion process. Having a raw material with high ash content will affect both the combustion and the removal of the ash from the flue gases but also from the combustion chamber. The chemical composition is also a determining factor to evaluate the emissions and the environmental impact of burning wood pellet e.g. sulphur and chlorine emissions.

Depending on the raw material size, different process might be required such as bark separation, chipping or grinding. As mentioned above, different drying process might be used but the most adequate would be to consider the energy recovery from the pellet burner thus using the flue gases to dry up the raw material. In order to have a good and compact pellet product, the lignin content should be evaluated. Indeed, poor lignin content might not make the particles to stick between each other. Thus, additives can be added. There are two types of additives, the natural additives and the artificial additive. Even though it might be cheaper to have the artificial additives, those materials may be forbidden e.g. in Austria because of the increase of harmful emissions. When thinking the conditioning of the pellets product, it is important under what form they have to be conditioned. They may be conditioned in small bags of tenth of kilos or in bigger bags that can be called small bulk or selling it directly to industries in big bulk that can reach the tons of pellets. Thus, a marketing strategy should be set beforehand. Regarding the combustion of wood pellets, it has to be remembered that pellets offer a compact and less dusty solution compare to wood. Also, in the new systems there might be automatic feedings of the fuel in the combustion chamber which actually take away the load of carrying about refilling the machine constantly.

6.6 Pyrolysis

Pyrolysis temperature, heating rate and residence time together affect significantly to product yield. Context between these parameters and those effects on product yield is briefly presented by following list:

- Slow heating rate (< 0,01- 2,0 °C/s), low temperature and long residence time maximize the production of char
- High heating rate, intermediate temperature and (450-600 °C) and short gas residence time maximize the liquid yield
- Slow heating rate, a high final temperature (700-900 °C) and long gas residence time maximize the gas yield.

Gas production can also be controlled mostly by temperature. CO2 yield is high at low temperatures, decreases when temperature increases. Hydrogen production increases, when temperature increases. (Basu 2010)

Particle size is essential to consider, especially because it can affect greatly to the formation of desired end product. In general, smaller particle size leads to increased gas and liquid yield, while larger particle size products more charcoal. Particle size can affect also to required residence time of the process. In many cases, automation systems work properly, when raw-material is as homogenous as possible.

Tar formation can be harmful for the pyrolysis process, because it condenses on cooler surfaces, causing blockages. It also inhibits other process equipment, such as filters. Tar must be separated from the product gas, especially if gas is desired end product. (Basu 2010)

Raw-materials containing large amounts of potassium, other alkali metals and chlorine are not beneficial to a pyrolysis reactor due to their corrosive effect. Those compounds can corrode reactor walls, boilers and other process equipment, causing malfunctions, leaks and structural problems. In addition too high moisture content (up to 30 %) can inhibit the pyrolysis process, and lead to higher consumption of thermal energy. Specific hydrogen-to-carbon ratio of the raw-material, among others, affects also to product yield.

Pyrolysis reactor has to work in total absence of oxygen. If air leak happens, process does not work properly. Certain amount of air or oxygen can be used in a reactor to allow combustion in order to produce thermal energy for the process. Also inefficient action of catalyst can decrease desired product yield (Basu 2010).

In the end, electrical and machinery malfunction can happen, which requires a professional mechanic to fix the problem. These kinds of malfunctions can cause unknown and diverse consequences in the process, so it is hard to consider them beforehand.

7. Project publications

Articles in refereed international journals

Reinik J, Heinmaa I, Kirso U, Kallaste T, Ritamäki J, Boström D, Pongrácz E, Huuhtanen M, Larsson W, Keiski R, Kordás K, Mikkola J-P. (2011) Alkaline modified oil shale fly ash: optimal synthesis conditions and preliminary tests on CO2 adsorption. Journal of Hazardous Material, 196(2011): 180-186.

Articles in international scientific compilations

S. Beszédes, N. Pap, E. Pongrácz, C. Hodúr and R.L. Keiski (2010) Concentration of meat processing industry wastewater by reverse osmosis and anaerobic digestion of the concentrate. Venice 2010 Symposium. Third International Symposium on energy from biomass and waste, Venice, Italy 8-11 November 2010. CD-ROM of Proceedings, ISBN 978-88-6265-008-3. 13p.

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