WNIOSEK O PORTFOLIO:

Opracowanie koncepcji zwiększenia ekektywności przetwarzania biomasy

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1. Project Summary

Several green and eco-friendly technologies are already developed and applied world-wide to produce renewable energy. Most of them use the sun energy directly or via energy carriers as the main energy source. In any green energy technology, there are several key aspects. Among them the most important are: high efficiency in energy conversion; energy storage until consumption; carbon foot print; wastes generated; environmental impact etc. However, much attention has been paid to biomass into bio-energy technologies. Accordingly, nowadays a lot of research studies are focused on investigation a proper technology for more efficient biomass production.

Biomass provides opportunities for rural economic development, diminishes the impact of greenhouse gases on the environment, provides a viable option to natural gas and other fossil fuels, and decreases the need for foreign sources of energy. There are a number of technological options available to make use of a wide variety of biomass types as a renewable energy source. Conversion technologies may release the energy directly, in the form of heat or electricity, or may convert it to another form, such as liquid biofuel or combustible biogas. While for some classes of biomass resource there may be a number of usage options, for others there may only one appropriate technology.

There are number of up to date clean technologies nowadays, such as pyrolysis, direct combustion, gasification etc. These technologies are able to convert biomass sources into valuable bio-energy product.

Pyrolysis is the one of the alternative clean and multifunctional technologies based on thermal decomposition of biomass occurring in the absence of oxygen. It is the fundamental chemical reaction that is the precursor of both the combustion and gasification processes and occurs naturally in the first two seconds. The products of biomass pyrolysis include biochar, bio-oil and gases including methane, hydrogen, carbon monoxide, and carbon dioxide. Depending on the thermal environment and the final temperature, pyrolysis will yield mainly biochar at low temperatures, less than 450 ^{o}C, when the heating rate is quite slow, and mainly gases at high temperatures 550-900 ^{o}C, with rapid heating rates. At an intermediate temperature and under relatively high heating rates, the main product is bio-oil. Pyrolysis can be performed at relatively small scale and at remote locations which enhance energy density of the biomass resource and reduce transport and handling costs. Pyrolysis offers a flexible and attractive way of converting solid biomass into an easily stored and transported liquid, which can be successfully used for the production of heat, power and chemicals. A wide range of biomass feedstocks can be used in pyrolysis processes. The pyrolysis process is very dependent on the moisture content of the feedstock. At higher moisture contents, high levels of water are produced and at lower levels there is a risk that the process only produces dust instead of oil. High-moisture waste streams, such as sludge and meat processing wastes, require drying before subjecting to pyrolysis. According to (Tursunov, 2014; Tursunov et al, 2011) temperature and the presence of catalysts are among the most important parameters that influenced the product yield from this process. Studies had also found that maximum pyrolytic oil can be obtained in the temperature range of 400

and 500°C. Due to the secondary reactions, the pyrolytic oil yield decreased parallel with gas amount increasing as temperature operated over 500°C.
Direct combustion is the one of the best established and most commonly used technology for converting biomass to heat. During combustion, biomass fuel is burnt in excess air to produce heat. The first stage of combustion involves the evolution of combustible vapours from the biomass, which burn as flames. The residual material, in the form of charcoal, is burnt in a forced air supply to give more heat. The hot combustion gases are sometimes used directly for product drying, but more usually they are passed through a heat exchanger to produce hot air, hot water or steam. The combustion efficiency depends primarily on good contact between the oxygen in the air and the biomass fuel. The main products of efficient biomass combustion are carbon dioxide and water vapor, however tars, smoke and alkaline ash particles are also emitted. Minimization of these emissions and accommodation of their possible effects are important concerns in the design of environmentally acceptable biomass combustion systems. Biomass combustion systems, based on a range of furnace designs, can be very efficient at producing hot gases, hot air, hot water or steam, typically recovering 65-90% of the energy contained in the fuel. Lower efficiencies are generally associated with wetter fuels. To cope with a diversity of fuel characteristics and combustion requirements, a number of designs of combustion furnaces or combustors are routinely utilized around the world.
Gasification is an another effective technology which based on partial oxidation process whereby a carbon source such as coal, natural gas or biomass, is broken down into carbon monoxide (CO) and hydrogen (H2), plus carbon dioxide (CO2) and possibly hydrocarbon molecules such as methane (CH4). This mix of gases is known as 'producer gas' or product gas (or wood gas or coal gas, depending on the feedstock), and the precise characteristics of the gas will depend on the gasification parameters, such as temperature, and also the oxidizer used. The oxidizer may be air, in which case the producer gas will also contain nitrogen (N2), or steam or oxygen. Gasification technology can be used for: heating water in central heating, district heating or process heating applications; steam for electricity generation or motive force; as part of systems producing electricity or motive force; transport using an internal combustion engine.
If the gasification takes place at a relatively low temperature, such as 700°C to 1000°C, the product gas will have a relatively high level of hydrocarbons compared to high temperature gasification (see below). As a result it may be used directly, to be burned for heat or electricity generation via a steam turbine or, with suitable gas clean up, to run an internal combustion engine for electricity generation. The combustion chamber for a simple boiler may be close coupled with the gasifier, or the producer gas may be cleaned of longer chain hydrocarbons (tars), transported, stored and burned remotely. A gasification system may be closely integrated with a combined cycle gas turbine for electricity generation (IGCC - integrated gasification combined cycle). Higher temperature gasification (1200°C to 1600°C) leads to few hydrocarbons in the product gas, and a higher proportion of CO and H2. This is known as synthesis gas (syngas or biosyngas) as it can be used to synthesize longer chain hydrocarbons using techniques such as Fischer-Tropsch (FT) synthesis. If the ratio of H2 to CO is correct (2:1) FT synthesis can be used to convert syngas into high quality synthetic diesel biofuel which is completely compatible with conventional fossil diesel and diesel engines.
Application of environmentally friendly laser biotechnology could be applied for more efficient increase of biomass for bio-energy production by using different above mentioned clean

technologies. Moreover, effective reclamation and higher biomass production in deteriorated areas as contribution to sustainable development of different areas. Wide-scale application of eco-friendly laser biotechnology could contribute to decrease concentration of green-house gases and primary prevention of climatic change and also to progress in re-naturalization of the rivers regions, increase of water retention and prevention against flood incidents.
Thus this research project is focused on more efficient production of biomass growth in the contaminated areas by using eco-friendly laser biotechnology (initiated by professor Dobrowolski in 1978) and following bio-energy production via effective and economic clean technologies (e.g. pyrolysis, gasification, direct combustion, hydrolysis etc.). As well as, the project is going to explore and modify newly developed catalysts for more efficient and qualitative bio-energy production and significantly to remove the tar yield from the reactor.

a. Objectives Of Research Project

This research project covers the potentiality of biomass as raw material for production of electricity and liquid fuel (bio-gas, bio-oil, bio-fuel), taking in to consideration the actual situation of productivity of specific agro-energy woods of plants and the state of art of biomass conversion technologies. Below are specific objectives:

- to research on increase of the biomass production on energy plantations as a result of adequate laser photostimilation of plants cultivated in unfavourable environmental conditions
- to research on biomass of wood rose characteristics (proximate and ultimate analysis)
- to research on modification of biomass technology and combustion parameters which are immensely essential in bio-energy production from biomass
- to profound study on newly developed catalytic bio-energy production from biomass of wood plants
- to investigate the possible use of the organic fractions of woody biomass as an energy resource through a process of most effective and up to date combustion technology controlled by computer software programs (e.g. direct combustion, gasification, pyrolysis, hydrolysis etc) in a lab-scale reactors with newly discovered catalysts

b. Up to Date Review (Information)

In the last decade, biomass use for the production of modern bioenergy grew significantly in order to oppose the depletion of fossil resources (and associated increasing energy prices) and to reduce greenhouse gas (GHG) emissions (Harvey and Pilgrim, 2011). For both energy and material application of biomass, it is expected that this growth will continue or even accelerate. For example, the Intergovernmental Panel on Climate Change (IPCC) reviewed recent literature and scenarios on long-term biomass deployment potentials and biomass demand for bioenergy (Chum et al, 2011;2014) and (Fischedick et al, 2011). In 2008, global bioenergy use accounted for a primary biomass supply of 50 exajoule (EJ_p) per year. By 2050, the global biomass demand for bioenergy is projected to reach about 77 EJ_p/year in the absence of climate policies (median case of baseline scenarios) and about 155 EJ_p/year under the most stringent GHG mitigation scenarios (Fischedick et al, 2011). In addition, Saygin et al. (2011) estimate an economic potential of biomass use of almost 20 EJ_p/year for substitution of synthetic organic material in the chemical industry in 2050. Hence, a total biomass supply of 100–175 EJ/year would be required to meet the projected

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demand for both bioenergy in 2050. By the same year, the technical biomass deployment potential is estimated to be in the range of 100–300 EJ_p/year (Chum et al, 2011;2014). The increasing demand for biomass will intensify the competition between biomass feedstocks as well as their applications; not only between food and non-food uses, but also between non-food applications for energy and materials. Thus, to ensure sustainable expansion of biomass use, we need insight in which routes (biomass value chains) are the most promising for producing heat, power, fuels and materials in terms of their technological, economic and environmental performance. This requires (i) a clear view on the status and prospects of potential value chains; and (ii) assessment and comparison of their economic and environmental performance in the short and longer term. Assessment of the performance over time is important, because biomass value chains are in different stages of development and have different potentials for improvement. For example, on the short term, new technologies may be more expensive than established technologies. But, as capacity deployment increases, with technological learning, they could become cheaper in the longer term. Key indicators for the economic and environmental performance of biomass value chains are levelized production costs, avoided greenhouse gas emissions and GHG abatement costs. Although these aspects have been assessed widely in the literature, earlier (review) work mainly considers bioenergy, and especially biofuels (Gnansounou et al, 2009), (Bauen et al, 2009), (Bain 2007) and (Obernberger et al, 2008). This literature generally considers either environmental or economic aspects (Gnansounou et al, 2009), (Obernberger et al, 2008), (Bain 2007), (Larson 2006) and (von Blottnitz and Curran, 2007). In addition, most studies that consider bioenergy focus on environmental impacts (see, e.g., (Hermann et al, 2007), (Weiss et al, 2012) and (Ren and Patel, 2009)), while the number of economic assessments is limited (Ren et al, 2009) and (Hermann and Patel, 2007). Comparative work between bioenergy only includes environmental aspects (Dornburg et al, 2004) or biomass use in the manufacturing sector (Saygın and Patel, 2010). However, as energy and material applications in different sectors are competing for biomass feedstocks, only an assessment that includes both their economic and environmental impact can generate better insight in the overall performance of the various biomass value chains. Finally, for various bioenergy systems and their components, the literature has analyzed the role of technological learning in historical cost developments (van den Wall Bake et al, 2009), (Hettinga et al, 2009) and (Junginger et al, 2006). For a good understanding of economic improvement potentials over time, and of potential speeds of technological development and deployment, these insights need to be included in a comparative assessment.
Consequently, sustainable biomass supply is critically dependent on land, water and biodiversity management. This includes minimising the use of prime agricultural land, maximising soil fertility and carbon sinks, ensuring balanced nutrient cycles and water budgets while promoting regenerative practices with respect to native habitats and ecosystems in impacted regions. There are strategic sustainability advantages of biomass sourced from multispecies native assemblages. Hence, One of the most promising alternatives to meet the increasing demands of the human population for energy sources is the production of bio-energy from biomass of plants. According to Dobrowolski et al. (2012). laser simulation can be used for a more efficient soil reclamation, wastewater treatment process, increase of bioremediation abilities and increase growth of energetic and food crops. Results of experiments showed that laser stimulation caused an increase of plant biomass and greater uptake of trace and biogenic elements from contaminated water and

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soil. Application of laser biotechnology could be used in environmental engineering technologies, according to ideas of sustainable development. Application of laser stimulation of different species of plants, soil bacteria and fungi in environmental biotechnology was introduced by Dobrowolski in 1978, for the optimization of bioremediation processes, e.g. removal of pollutants from sewage and soil reclamation as well as for increase of biomass production by plants cultivated in polluted soils (Dobrowolski, 2000; Dobrowolski, 2001).
In order to address some of the shortcomings identified in the existing literature, the aim of this project is to evaluate existing and potential biomass value chains for heat, power, fuels and materials.

c. Significance of Research Project

Widespread implementation of biomass energy systems will not take place until a variety of questions – technical, financial, and managerial – are addressed. Thus far, technology deployment, at best, has been sparse across the world. Without deployment, there have been limited efforts in developing information for sustainable management of biomass resources.
Biomass is a versatile energy source that can be used for production of heat, power, transport fuels and biomaterials, apart from making a significant contribution to climate change mitigation. Currently, biomass-driven combined heat and power, co-firing, and combustion plants provide reliable, efficient, and clean power and heat. Feedstock for biomass energy plants can include residues from agriculture, forestry, wood processing, and food processing industries, municipal solid wastes, industrial wastes and biomass produced from degraded and marginal lands.

Figure 1: Biomass sources and sort of Biomass-to-Energy technologies

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The terms biomass energy, bioenergy and biofuels cover any energy products derived from plant or animal or organic material. The increasing interest in biomass energy and biofuels has been the result of the following associated benefits:
- Potential to reduce GHG emissions.
- Energy security benefits.
- Substitution for diminishing global oil supplies.
- Potential impacts on waste management strategy.
- Capacity to convert a wide variety of wastes into clean energy.
- Technological advancement in thermal and biochemical processes for waste-to-energy transformation.

Biomass can play the pivotal role in production of carbon-neutral fuels of high quality as well as providing feedstocks for various industries. This is a unique property of biomass compared to other renewable energies and which makes biomass a prime alternative to the use of fossil fuels. Performance of biomass-based systems for heat and power generation has been already proved in many situations on commercial as well as domestic scales. Biomass energy systems have the potential to address many environmental issues, especially global warming and greenhouse gases emissions, and foster sustainable development among poor communities. Biomass fuel sources are readily available in rural and urban areas of all countries. Biomass-based industries can provide appreciable employment opportunities and promote biomass re-growth through sustainable land management practices.

The negative aspects of traditional biomass utilization in developing countries can be mitigated by promotion of modern waste-to-energy technologies which provide solid, liquid and gaseous fuels as well as electricity as shown. Biomass sources can be transformed into clean and efficient energy by biochemical as well as thermochemical technologies.

The most common technique for producing both heat and electrical energy from biomass wastes is direct combustion. Thermal efficiencies as high as 80 – 90% can be achieved by advanced gasification technology with greatly reduced atmospheric emissions. Combined heat and power (CHP) systems, ranging from small-scale technology to large grid-connected facilities, provide significantly higher efficiencies than systems that only generate electricity. Biochemical processes, like anaerobic digestion and sanitary landfills, can also produce clean energy in the form of biogas and producer gas which can be converted to power and heat using a gas engine.

In addition, biomass can also yield liquid fuels, such as cellulosic ethanol, which can be used to replace petroleum-based fuels. Cellulosic ethanol can be produced from grasses, wood chips and agricultural residues by biochemical route using heat, pressure, chemicals and enzymes to unlock the sugars in cellulosic biomass. Algal biomass is also emerging as a good source of energy because it can serve as natural source of oil, which conventional refineries can transform into jet fuel or diesel fuel.

Biomass energy resources are readily available in rural and urban areas of all countries. Biomass-based industries can provide appreciable employment opportunities and promote biomass re-growth through sustainable land management practices. The negative aspects of traditional biomass utilization in developing countries can be mitigated by promotion of modern waste-to-energy technologies which provide solid, liquid and gaseous fuels as well as electricity. Biomass wastes encompass a wide array of materials derived from agricultural, agro-industrial, and timber residues, as well as municipal and industrial wastes.

Bioenergy systems offer significant possibilities for reducing greenhouse gas emissions due to their immense potential to replace fossil fuels in energy production. Biomass reduces emissions and enhances carbon sequestration since short-rotation crops or forests established on abandoned agricultural land accumulate carbon in the soil.

Bioenergy usually provides an irreversible mitigation effect by reducing carbon dioxide at source, but it may emit more carbon per unit of energy than fossil fuels unless biomass fuels are produced unsustainably. Biomass can play a major role in reducing the reliance on fossil fuels by making use of thermo-chemical conversion technologies. In addition, the increased utilization of biomass-based fuels will be instrumental in safeguarding the environment, generation of new job opportunities, sustainable development and health improvements in rural areas.

The development of efficient biomass handling technology, improvement of agro-forestry systems and establishment of small and large-scale biomass-based power plants can play a major role in rural development. Biomass energy could also aid in modernizing the agricultural economy.

When compared with wind and solar energy, biomass plants are able to provide crucial, reliable base load generation. Biomass plants provide fuel diversity, which protects communities from volatile fossil fuels. Since biomass energy uses domestically-produced fuels, biomass power greatly reduces our dependence on foreign energy sources and increases national energy security.

A large amount of energy is expended in the cultivation and processing of crops like sugarcane, coconut, and rice which can met by utilizing energy-rich residues for electricity production. The integration of biomass-fueled gasifiers in coal-fired power stations would be advantageous in terms of improved flexibility in response to fluctuations in biomass availability and lower investment costs. The growth of the bioenergy industry can also be achieved by laying more stress on green power marketing.

d. Methodology of Research Project

This research project will follow the standard framework of the Faculty of Mining Surveying and Environmental Engineering, Center of Energy, as well as Department of Applied Computer Science of AGH University of Science and Technology.

Below is the list of analysis (investigations) of methodological part of the research project:

1 Analysis of wood biomass characteristics
- Sampling of wood biomass and separation into two groups: control and laser treated
- Proximate analysis: determination of moisture content, volatile matter, fixed carbon, calorific value and ash in biomass
- Ultimate analysis: elemental analysis of CHNS/O, thermo gravimetric analysis

2. Experimental procedure and design
- Two-level fractional factorial design
- Response surface methodology (RSM)
- Bio-energy characterization using gas chromatographic / mass spectroscopy (GC/MS)
- Analysis of catalyst properties
- Overall bio-yield analysis from combustion technologies (e.g. direct combustion, pyrolysis, gasification, torrefaction etc)

e. Research Project Outcomes (Results)

Bioenergy from biomass is expected to play a key role in our ability to meet the 2020 renewables target as well as longer term carbon reduction targets to 2030 and 2050. It is however recognized that bioenergy is not automatically low carbon, renewable or sustainable: alongside its many positives, bioenergy carries risks. Additionally, expected outcome is enhanced contribution of most efficient biomass technology for bio-energy production and deliver it to people's livelihoods and sustainable growth processes in the context of environmental and climate change.

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