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Bauhaus-Institut für zukunftsweisende Infrastruktursysteme (b.is)

Das Bauhaus-Institut für zukunftsweisende Infrastruktursysteme (b.is) verfolgt das Ziel, die Kooperation der derzeit beteiligten Professuren Siedlungswasserwirtschaft, Biotechnologie in der Ressourcenwirtschaft und Urban Energy Systems zu intensivieren sowie die Honorarprofessur Urbanes Infrastrukturmanagement, um Lehr-, Forschungs- und Beratungssaufgaben auszubauen. So werden beispielsweise die Weiterentwicklung von Studiengängen, gemeinsame Doktorandenkolloquien oder gemeinsame Forschungs- und Entwicklungsaufgaben durchgeführt.

Das b.is will sich deutlich sichtbar im Bereich der Infrastrukturforschung aufstellen. Die Forschung und Lehre in diesem Bereich orientiert sich am medienübergreifenden Modell der nachhaltigen Gestaltung von Stoff- und Energieflüssen sowie ressourcenökonomisch ausgerichteten Systemen, die verbindendes Konzept der Kernprofessuren des Instituts sind. Die Professur Betriebswirtschaftslehre im Bauwesen ist mit dem b.is assoziiert.

Bauhaus-Institute for Infrastructure Solutions (b.is)

The Bauhaus-Institute for Infrastructure Solutions (b.is) aims to strengthen the cooperation of the university´s research teams in Urban Water Management and Sanitation, Biotechnology in Resources Management and Urban Energy Systems in the areas of teaching, research and consultancy work. This encompasses the further development of degree programmes, joint doctorate colloquia and joint research and development activities.

Currently the chair of urban water management and sanitation, the chair of biotechnology in resources management and the chair of urban energy systems as well as the honorary professorship for urban infrastructure management are members of the institute. The chair of construction economics is associated with the institute.

The b.is will increase its visibility in infrastructure research. Education and research are geared to the comprehensive model of sustainable material and energy flows and resource economy oriented systems, which are the linkage of the institute's chairs.

Energy Production from Biomass with the E-M-F-System

Dissertation zur Erlangung des akademischen Grades
Doktor Ingenieur (Dr.-Ing.)
an der Fakultät Bauingenieurwesen der
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Weimar, 01.07.2014

Preface

Over the last 15 years renewable energies have witnessed a huge increase in Germany. A significant proportion is based on the conversion of renewable raw materials. Biomass is now in focus for two reasons. On one hand it is the basis for renewable, climate-neutral raw materials for the generation of energy. On the other hand, biomass is the largest share of waste produced by humans next to those from mining. Whilst initially fundamental questions of conversion technologies were in the focus, in the meantime increasingly energy efficiency, climate impact and overall economic sustainability are the main points of interest. The existing biomass potentials in Europe and worldwide are immense, but must be used sensibly.

Against this background, on the energy side innovative, sustainable strategies for biomass conversion with centralized or decentralized energy supply systems, resource efficiency and high conversion productivity are increasingly gaining importance. This even includes the use of soils which can no longer be used for food production, such as for instance soils with a high salinity level. Worldwide, every minute three hectares of agricultural land for food production are lost due to salinization, mostly irreversibly. It is regarded as the most common reason for the destruction of fertile soil and affects now some 20% of agricultural land and 50% of all irrigated land worldwide. The cultivation of energy crops, however, would be possible on these soils without competing with food production.

In terms of disposal we are faced with the task to achieve a significant increase in energy efficiency. This is the starting point of the work presented by Ms. Liu Yang. It takes up the idea to increase the energy yield from biomass by multistage processes and simultaneously to recover nutrients for crop production.

Therefore, the energy part of the work considers the production of bio-ethanol and the production of methane from the residue of the first stage. Additionally the nutrient recovery by composting of the digestate is investigated. This thus offers the possibility of generating a closed circuit system from the agricultural production via the energy generation through to the recycling of plant nutrients and humus for use in agriculture, which releases no waste.

This approach of an ideal closed loop without residues, apart from carbon dioxide, had not been previously supported with factual information. There was a lack of studies related to feasibility, efficiency with respect to the energy yield, carbon footprint as well as material flow analysis and assessment. From the present investigation, although only on a laboratory scale, it can be seen that such a system indeed leads to increasing energy yields and that nutrients can be recycled. This important finding now offers a basis to develop design parameters and performance audits, which make it possible to design systems for the efficient use of biomass.

Weimar, July 2015

Prof. Dr.-Ing. habil. Werner Bidlingmaier   Prof. Dr.-Ing. Eckhard Kraft

Acknowledgements

I can describe bachelors, masters and doctoral work as follows:

A professor says to his students “Now we are going to do a project.”

When speaking to an undergraduate student, the professor is extremely specific, stating,

“Now we are doing this project, and this project is like this: we will do a laboratory test of fish blood as a nitrogen resource for flocculation in the disposal of municipal wastewater. You need to read the following references and prepare several kinds of fish blood and turn in the following work at the end of this month….”

When speaking to a masters student the professor is less specific,

“Now we are doing this project, and I have some ideas about this project: we would like to find a type of nitrogen resource for flocculation in the disposal of wastewater, but you must tell me what ideas you have, how, what, when, where do you intend to do the project?”

When speaking to a doctoral student, the professor is wide open,

“Now tell me what do you intend to do?”

An experienced scholar, Prof. Bidlingmaier has guided me through all of these periods, through my doctoral, masters and bachelor life in Germany. He has opened my eyes to the whole world, and given me all kinds of support during my doctoral work. Especially, even during his retirement, he continued to work with me until I completed the last part of my dissertation. Prof. Bidlingmaier gave me the knowledge not only how to do doctoral work, but also is an inspirational figure due to his hard work and life achievements. I am exceedingly grateful to him. He is a cherished teacher and a harmonizing element that brings order to my life. First of all, I would like to express my deepest gratitude to my dearest Prof. Bidlingmaier.

During these 6 years' of doctoral study, my supervisor - Prof. Kraft has given me professional guidance, has been untiringly patient in his supervision, and immensely considerate of our entire group. He has given me so much support to finish my work despite many obstacles and problems. He is a powerful leader, who guides us towards achievement, just as his name, Kraft, which means 'force' suggests. I am extremely grateful to him.

I also would like to give my personal thanks to Ms. Westphalen Carola, who has supplied me with many opportunities both in study and in life. She has given me many chances to make cooperative projects between China and Germany.
Besides, she has also shown me lots about life and in Germany and how people are here. She is my dearest cooperative partner and a close friend.

As an expert in the field of energy, Dr. Hanfler has given me so much advice that my dissertation fairly sparkles with his knowledge and energy. Thanks a lot.

Especially, I would also like to express gratitude to our secretary Ms. Cornelia Ritter. She has done so much for me during the course of my study. I am very grateful.

Furthermore, I would like to express thanks to the following people, who have given me so much support during my doctoral life in Germany. With my sincere gratitude, I would like to first acknowledge my colleges: Thomas Haupt, Christian Springer, Sonja Keller, Laura Weitze, Stefan Sebök, Anton Ivanov, Stefan Thurau and all the students in the laboratory. They have given me a lot of suggestions and advice about my study, have shown me so much about the life, the people and culture of Germany and helped me a lot in the laboratory in finishing my experiments.

Additionally, I would like to give my thanks to my dear son, my mother in law and my husband. My son has given me the chance to learn how to become a mother and fills my life with sunshine and daily adventures. My mother in law has helped me in so many ways, allowing me to finally finish my work in the end. My husband has lived with me since I came to Germany. He is the intimate, closes person in my life.

Finally, I would like to give my sincere thanks to Ms. Margarita Garcia. As an English speaker, she helped by proofreading and correcting my work, editing it more than once or even twice and in a short time frame. I am very appreciative of her help.

Weimar, June, 2014 Yang Liu

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Abbreviation and definition

AD:	anaerobic digestion.
AbfAbIV:	Abfallablagerungsverordnung, solid waste deposit order.
AFAU:	Acid fungal amylase units
AGU:	Amyloglucosidase Units
BGK:	Bundesgütegemeinschaft Kompost. German equivalent of the US Composting Council.
bio-energy:	the conversion of biomass to energy.
biogas:	a fuel gas produced from biomass and/or from the bio-degradable fraction of waste, that can be purified to natural gas quality, to be used as bio-fuel, or wood gas.
bio-ethanol:	ethanol produced from biomass and/or the bio-degradable fraction of waste, to be used as bio-fuel; in this study, bio-ethanol production is especially from dry grind corn process.
bio-fuels:	liquid or gaseous fuels made from plant matter and residues, such as agricultural crops, municipal wastes, and agricultural and forestry by-products.
biomass:	the bio-degradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the bio-degradable fraction of industrial and municipal waste; In particular, biomass can be referred to as solar energy stored in the chemical bonds of organic material.
C:	carbon.
CHP:	combined heat and power.
$CO_{2\text{-eq.}}$:	The Greenhouse gases (GHG) include emission from combustion of fossil fuel as well as any venting of methane and nitrous oxide to the atmosphere occurring during the process.
composting:	the aerobic biological process.
DDGS:	dried distillers' grain with solubles. It is one of the products of the dry grind ethanol process. DDGS is produced by mixing thick stillage with evaporated thin stillage and drying.

digestion: used in the course of biogas production, anaerobic process in this study.

DM: total dry matter, which can be also named TS in Germany.

dry mills: **(grind) of bio-ethanol -** the process of steeping the corn for up to 48 hours to assist in separating the parts of the corn kernel. Processing the slurry separates the germ from the rest of the kernel, which is processed further to separate the fiber, starch, and gluten. The fiber and corn gluten become components of animal feed while the starch is fermented to become ethanol, corn starch, or corn syrup.

E-M-F-System: Ethanol-Methane-fertilizer-System, the abbreviation of the first letter of the main products in this system.

fermentation: in this study it means the course of bio-ethanol production, different from the course of biogas production, which is named as digestion.

FM: fresh matter.

FNR: Fachagentur Nachwachsende Rohstoffe e.V.: in English Agency for Renewable Resources.

kg: kilo.

LHV: The lower heating value (also known as net calorific value) of a fuel is defined as the amount of heat released by combusting a specified quantity (initially at 25°C) and returning the temperature of the combustion products to 150°C, which assumes the latent heat of vaporization of water in the reaction products is not recovered.

melasse: a viscous by-product of the processing of sugar cane, grapes or sugar beets into sugar.

MTBE: Methyl tert-butyl ether, also known as methyl tertiary butyl ether, is an organic compound with molecular formula $(CH_3)_3COCH_3$.

molasses:	blackstrap molasses. There are several grades of blackstrap molasses depending on sugar content, ash content, and color. Whereas blackstrap molasses is a by-product of sugar crystallization, high test molasses is a concentration of the virgin juice normally intended for use in food products. High test molasses is often acidified to prevent crystallization of sugars during storage. Unless otherwise stated, the term molasses is used to mean blackstrap molasses.
NEV:	net energy value
oDM:	organic dry matter, or volatile solids, which is also named VS in English.
t:	tone.
thick stillage:	wet distillers' grains; after the process of centrifugation of the whole stillage, the 'solid' (thick sticky) part of the whole stillage.
thin stillage:	light stillage or clear stillage; after the process of centrifugation of the whole stillage, the liquid part of the whole stillage. It is normally evaporated to produce syrup, also called condensed distillers' solubles. Together with thick stillage, it is dried to produce DDGS.
VDI 4630:	German Standard Procedure. Fermentation of organic materials: Characterization of substrate, sampling, collection of material data, fermentation tests.
vinasse:	a byproduct of the sugar industry. After the removal of the desired product (alcohol, ascorbic acid, etc.) the remaining material is called vinasse. Commercially-offered vinasse comes either from sugar cane and is called cane-vinasse or from sugar beet and is called beet-vinasse.
wet mills:	(grind) of bio-ethanol - the process of grinding the whole corn kernel and mixing it with water and enzymes. The mash is then cooked to liquefy the starch further. The mash is then cooled and mixed with more enzymes to convert the remaining sugar polymers to glucose before fermenting into ethanol.
whole stillage:	heavy stillage and/or thin stillage in some factories. It is the liquid stream from bio-ethanol distillation bottom, which contains fiber, oil, protein, other unfermented components of the raw materials, and yeast cells.