The scheme of the Centres for Environment-friendly Energy Research (FME)
seeks to develop expertise and promote innovation through focus on long-term research
in selected areas of environment-friendly energy, transport and CO_2 management
in close cooperation between prominent research communities and users.

Acronym:
CenBio

Centre name:
Bioenergy Innovation Centre

Start date of centre: 2009-03-01
Duration: 8 years

D5.2.28-1
Collection of Journal Paper Abstracts
(update per March 2015)

Revision: **Final**

Due date of delivery: 2015-02-28
Actual submission date: 2015-03-27

Organisation name of lead partner for this deliverable:
SINTEF Energy Research

Project co-funded by the Research Council of Norway		
Dissemination Level		
PU	Public	X
RE	Restricted to a group specified by the consortium	
CO	Confidential, only for partners of the consortium	

Deliverable number:	D5.2.28-1
Deliverable title:	Collection of journal paper abstracts (update per March 2015)
Lead partner:	SINTEF ER
Work package:	WP5.2 Dissemination

Classification	
	Article (peer-reviewed), **Journal**:
	Article (popular science)
	Conference paper (published)
	Conference presentation (incl. posters)
	Media Contribution (e.g. feature article, interview, participation in radio/TV programme)
	Technical Report
	Chapter in book
	Book (PhD-dissertations, monographs)
	Post doc report
	Master report
X	**Other** (please specify)

Status of deliverable		
Action	**By**	**Date**
Submitted (lead author)	Bodil J. Sætherskar, SINTEF ER	27.03.2015
Verified (lead partner)	Alexis Sevault, SINTEF ER	01.04.2015
Approved (if applicable)	Executive Board	26.06.2015

Author(s)		
Name	**Organisation**	**E-mail**
Bodil J. Sætherskar	SINTEF ER	Bodil.Jane.Satherskar@sintef.no
Stine Lund Davanger	SINTEF ER	Stine.Davanger@sintef.no
Alexis Sevault	SINTEF ER	Alexis.Sevault@sintef.no
Einar Jordanger	SINTEF ER	Einar.JORDANGER@sintef.no

Abstract
This document gathers the abstracts of all journal papers published (or "in press") written within CenBio since the start of the Centre. The abstracts are organized first by sub-project (SP), then by year of publication. Links to the journal webpage and the document in the eRoom are systematically given. This document is meant to be updated at least twice a year, to include the abstract of the new published articles.

Revision history			
Date	**Revision**	**Author(s)**	**Comments**
2015-04-01	Final	Alexis Sevault	Completed and verified and document
2015-03-27	2	Bodil J. Sætherskar	Submitted document
2013.12.20	1	Stine Lund Davanger	Submitted document
2013.11.05	0	Alexis Sevault	Create general template and implemented first abstracts

CenBio: Collection of Journal Paper Abstracts

(Updated per March 2015)

TABLE OF CONTENTS

Page

SP1: BIOMASS SUPPLY AND RESIDUE UTILIZATION

- 2014 -

Applying simulated annealing using different methods for the neighborhood search in forest planning problems

Paulo Borges, Tron Eid, Even Bergseng

Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences, P.O. Box 5003, 1432 Ås, Norway

European Journal of Operational Research
Volume 233, Issue 3, 16 March 2014, pp. 700–710

DOI: 10.1016/j.ejor.2013.08.039
D1.1.14 (Link to eRoom)

Abstract

Adjacency constraints along with even flow harvest constraints are important in long term forest planning. Simulated annealing (SA) is previously successfully applied when addressing such constraints. The objective of this paper was to assess the performance of SA under three new methods of introducing biased probabilities in the management unit (MU) selection and compare them to the conventional method that assumes uniform probabilities. The new methods were implemented as a search vector approach based on the number of treatment schedules describing sequences of silvicultural treatments over time and standard deviation of net present value within MUs (Methods 2 and 3, respectively), and by combining the two approaches (Method 4). We constructed three hundred hypothetical forests (datasets) for three different landscapes characterized by different initial age class distributions (young, normal and old). Each dataset encompassed 1600 management units. The evaluation of the methods was done by means of objective function values, first feasible iteration and time consumption. Introducing a bias in the MU selection improves solutions compared to the conventional method (Method 1). However, an increase of computational time is in general needed for the new methods. Method 4 is the best alternative because, for large parts of the datasets, produced the best average and maximum objective function values and had lower time consumption than Methods 2 and 3. Although Method 4 performed very well, Methods 2 and 3 should not be neglected because for a considerable number of datasets the maximum objective function values were obtained by these methods.

Adjacency constraints in forestry - a simulated annealing approach comparing different candidate solution generators

Paulo Jorge de Almeida Borges, Even Bergseng, Tron Eid

Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences

Mathematical and Computational Forestry & Natural-Resource Sciences
MCFNS March 30, 2014, Vol. 6, Issue 1, pp. 11-25

DOI: http://mcfns.com/index.php/Journal/article/view/6_11
D1.1.18 (Link to eRoom)

Abstract

Adjacency constraints along with harvest volume constraints are important in long term forest management planning. Simulated annealing (SA) has previously been successfully applied when addressing such constraints. The objective of this paper is to assess the performance of SA using three methods for generating candidate solutions. Biased probabilities in the management unit (MU) selection were introduced, one static and one dynamic. The first one (Method 1) is the conventional (static) method. The two other methods were implemented through a search vector used in the candidate solution generator. These methods are based on (Method 2) the number of treatment schedules and standard deviation of NPV within MUs and (Method 3) the MU's potential improvement in the objective function value, the number of URM adjacency violations an MU is involved in, the period specific volume harvested in an MU and the number of times an MU is selected. The methods were tested on a large number of datasets including 300 hypothetical forest landscapes characterized by three different initial age class distributions, respectively young, normal and old. Evaluation of the methods was accomplished by means of objective function values and first feasible iteration. Solutions improved when introducing bias in the probabilities for MU selection (Methods 2 and 3) compared to the conventional method (Method 1) and when the probability bias for selecting MUs is dynamic (Method 3) rather than static (Methods 1 and 2). The mean improvement for the average GAP obtained by Method 3 for young, normal and old forest landscapes was 20.88%, 12.84% and 5.20%, respectively. Whereas for the minimum GAP the mean improvement was 21.96%, 14.30% and 6.05% for young, normal and old forest landscapes, respectively.

Tree root system characterization and volume estimation by terrestrial laser scanning and quantitative structure modelling

Aaron Smith [a], Rasmus Astrup [a], Pasi Raumonen [b], Jari Liski [c], Anssi Krooks [d], Sanna Kaasalainen [d], Markku Åkerblom [b] and Mikko Kaasalainen [b]

[a] Norwegian Forest and Landscape Institute, Mailbox 115, 1431 Ås, Norway
[b] Department of Mathematics, Tampere University of Technology, P.O. Box 553, FI-33101 Tampere, Finland
[c] Finnish Environment Institute, Mechelininkatu 34a, FI-00251 Helsinki, Finland
[d] Finnish Geodetic Institute, Geodeetinrinne 2, FI-02431 Masala, Finland

Forests
Volume 5, Issue 12, 3274-3294, 2014

DOI: [10.3390/f51233274]
D1.1.19 ([Link to eRoom])

Abstract

The accurate characterization of three-dimensional (3D) root architecture, volume, and biomass is important for a wide variety of applications in forest ecology and to better understand tree and soil stability. Technological advancements have led to increasingly more digitized and automated procedures, which have been used to more accurately and quickly describe the 3D structure of root systems. Terrestrial laser scanners (TLS) have successfully been used to describe aboveground structures of individual trees and stand structure, but have only recently been applied to the 3D characterization of whole root systems. In this study, 13 recently harvested Norway spruce root systems were mechanically pulled from the soil, cleaned, and their volumes were measured by displacement. The root systems were suspended, scanned with TLS from three different angles, and the root surfaces from the co-registered point clouds were modeled with the 3D Quantitative Structure Model to determine root architecture and volume. The modeling procedure facilitated the rapid derivation of root volume, diameters, break point diameters, linear root length, cumulative percentages, and root fraction counts. The modeled root systems underestimated root system volume by 4.4%. The modeling procedure is widely applicable and easily adapted to derive other important topological and volumetric root variables.

Deriving cooperative biomass resource transport supply strategies in meeting co-firing energy regulations: A case for peat and wood fibre in Ireland

Ger Devlin [a], Bruce Talbot [b]

[a] School of Biosystems Engineering, University College, Dublin 4, Ireland
[b] Norwegian Forest and Landscape Institute, Box 115, 1431 Aas, Norway

Applied Energy
Volume 113, January 2014, pp. 1700–1709

DOI: 10.1016/j.apenergy.2013.09.019
D1.2.16 (Link to eRoom)

Abstract

The Irish government has undertaken to reduce national CO_2 emissions through a range of measures put out in their Biomass Action Plan and the National Renewable Energy Action Plan. The conversion of peat fired power plants to co-fire with renewable biomass is one of these. This paper considers how the adoption of sweeping policies impact on other actors presently supplying or utilizing woody biomass resources. The SAWMILL sector (18 sawmills), BOARD sector, 3 board plants, and ENERGY sector (3 peat fired power stations) were included in a Linear Programming (LP) based transportation study. Specific transport costs between each residue producing sawmill and each board and energy plant were modeled and used in finding the minimum delivered cost for a number of scenarios. Scenario 2015 represented the status quo, while Scenario 2030 represented a situation with 30% co-firing with woody biomass equivalents in the energy plants. For each time horizon, the problem was solved from the perspective of society at large (GLOBAL), for the benefit of the board sector (BOARD) or with emphasis on minimizing the cost to the energy sector (ENERGY). The cost of transporting alternative sources of renewable energy was varied between €100 and €500 TJ^{-1}. Results showed how overall supply costs increase with increasing alternative energy cost, but also how the dynamics between sectors focus worked. The cost of transport to the Energy sector ranged from €306,043 to €996,842 in Scenario 2015, while the increased demand in 2030 led to a range of between €1,132,831 and €4,926,040, depending on the alternative cost selected. For the Board sector, whose absolute demand remained constant, the total transport cost ranged between €868,506 and €3,454,916 in Scenario 2015. The unchanged demand showed that the transport costs also remained the same for the 2030 Scenario, however, the optimization focusing on the Energy sector, increased the delivery cost to the Board sector by up to €693,730 per year by 2015 and €842,271 per year by 2030, indicating how intervention would be necessary if political ambitions of a 30% co-firing should happen without detriment to other important wood based industries.

Performance of small-scale straw-to-heat supply chains in Norway

Helmer Belbo, Bruce Talbot

Department of Forest Technology, Norwegian Forest and Landscape Institute, Norway

WIREs Energy and Environment
Volume 3, Issue 4, pages 400–407, July/August 2014

DOI: 10.1002/wene.107
D1.2.18 (Link to eRoom)

Abstract

Straw can become an important contributor to the biomass feedstocks of Europe and North America. In Norway, between 12 and 17% of a national target to increase the renewable energy share by 14 TWh can be sustainably met by mobilizing straw feedstocks. However, straw must compete in an energy market with a vast availability of forest-based woody biomass, and a clean electrical energy pool, 95% of which is derived from hydropower. The performance of seven local straw supply chains was monitored over a period of 3 years to estimate straw yields, supply costs, operating costs of the heating plants, and to synthesize experiences on supply solutions. Storage facilities for bales constituted the largest single cost in the supply chain. Square bales were both more economical to use and required considerably less plant management time, making them more preferable than round bales for small-scale utilization. The total cost of straw firing averaged out in the range of 36–42 € MWh^{-1}, which is 40–46% of the current cost of electric heating (~90 € MWh^{-1}). The positive economic outcome provides a good incentive to roll out many more similar plants although heat pumps could be expected to reduce the margin in some applications.

Systems Analysis of Ten Supply Chains for Whole Tree Chips

Helmer Belbo, Bruce Talbot

Department of Forest Technology, Norwegian Forest and Landscape Institute, P.O. Box 115, 1431 Ås, Norway

Forests
Volume 5, Issue 9, 2084-2105, 2014

DOI: [10.3390/f5092084](10.3390/f5092084)
D1.2.19 ([Link to eRoom])

Abstract

Whole trees from energy thinnings constitute one of many forest fuel sources, yet ten widely applied supply chains could be defined for this feedstock alone. These ten represent only a subset of the real possibilities, as felling method was held constant and only a single market (combustion of whole tree chips) was considered. Stages included in-field, roadside landing, terminal, and conversion plant, and biomass states at each of these included loose whole trees, bundled whole trees or chipped material. Assumptions on prices, performances, and conversion rates were based on field trials and published literature in similar boreal forest conditions. The economic outcome was calculated on the basis of production, handling, treatment and storage costs and losses. Outcomes were tested for robustness on a range of object volumes (50–350 m^3_{solid}), extraction distances (50–550 m) and transport distances (10–70 km) using simulation across a set of discrete values. Transport was calculated for both a standard 19.5 m and an extended 24 m timber truck. Results showed that the most expensive chain (roadside bundling, roadside storage, terminal storage and delivery using a 19.5 m timber truck) at 158 € t_d^{-1} was 23% more costly than the cheapest chain (roadside chipping and direct transport to conversion plant with container truck), at 128 € t_d^{-1}. Outcomes vary at specific object volumes and transport distances, highlighting the need to verify assumptions, although standard deviations around mean supply costs for each chain were small (6%–9%). Losses at all stages were modelled, with the largest losses (23 € t_d^{-1}) occurring in the chains including bundles. The study makes all methods and assumptions explicit and can assist the procurement manager in understanding the mechanisms at work.

The COST model for calculation of forest operations costs

Pierre Ackerman [a], Helmer Belbo [b], Lars Eliasson [c], Anjo de Jong [d], Andis Lazdins [e] & John Lyons [f]

[a] Department of Forest and Wood Science, Stellenbosch University, Matieland, South Africa
[b] Norwegian Forest and Landscape Institute, Ås
[c] The Forestry Research Institute of Sweden (Skogforsk), Uppsala
[d] Alterra, Wageningen University & Research Centre, the Netherlands
[e] Latvian State Forest Research Institute "Silava," Salaspils
[f] Coillte (Irish Forestry Board), Macroom

International Journal of Forest Engineering
Volume 25, Issue 1, 2014

DOI: 10.1080/14942119.2014.903711
D1.2.21 (Link to eRoom)

Abstract

Since the late nineteenth century when high-cost equipment was introduced into forestry there has been a need to calculate the cost of this equipment in more detail with respect to, for example, cost of ownership, cost per hour of production, and cost per production unit. Machine cost calculations have been made using various standard economic methods, where costs have been subdivided into capital costs and operational costs. Because of differences between methods and between national regulations, mainly regarding tax rules and subsidies, international comparisons of machine costs are difficult. To address this, one of the goals of the European Cooperation in Science and Technology (COST) Action FP0902 was to establish a simple format for transparent cost calculations for machines in the forest biomass procurement chain. A working group constructed a Microsoft Excel–based spreadsheet model which is easy to understand and use. Input parameters are easy to obtain or possible to estimate by provided rules of thumb. The model gives users a simultaneous view of the input parameters and the resulting cost outputs. This technical note presents the model, explains how the calculations are made, and provides future users with a guide on how to use the model. Prospective users can view the model in the Supplementary Material linked to this article online.

Combined waste resources as compound fertiliser to spring cereals

Eva Brod [a,b], Trond K. Haraldsen [a] & Tore Krogstad [b]

[a] Bioforsk – Norwegian Institute for Agricultural and Environmental Research, Frederik A. Dahls vei 20, 1430 Ås, Norway
[b] Department of Environmental Sciences, Norwegian University of Life Sciences, P.O. Box 5003, 1432 Ås, Norway

Acta Agriculturae Scandinavica, Section B — Soil & Plant Science
Volume 64, Issue 4, 2014

DOI: [10.1080/09064710.2014.907928](https://doi.org/10.1080/09064710.2014.907928)
D1.4.4 (Link to eRoom)

Abstract

There is increasing awareness of the need for efficient nutrient recycling in food production. Therefore, a pot experiment was conducted to contribute to the development of alternative compound fertilisers with balanced nutrient ratios for cereal production. We compared the (1) fertilisation effects and (2) effects on soil chemistry of four organic nitrogen (N)- and phosphorous (P)-rich waste-based products (WBPs), applied with or without potassium (K)-rich bottom wood ash (BWA). WBPs and BWA were applied at two rates (80 kg N ha^{-1} + 35 kg K ha^{-1} and 160 kg N ha^{-1} + 70 kg K ha^{-1}) to spring barley (*Hordeum vulgare*) in year one and spring wheat (*Triticum aestivum*) in year two, and the effects were compared with those of commercial mineral and organic compound fertilisers. The K fertilisation effects of BWA were masked by the soil's ability to provide plant-available K during both years of the experiment. Plant-available N was, therefore, the growth-limiting factor for barley in year one, when there were no differences in grain yield between treatments with and without K-rich BWA. The mineral fertiliser equivalent of WBPs was 64–118% for N uptake in barley grain, but can be expected to be lower under field conditions. During year two, wheat yield was determined by the plant availability of P and N. Meat-rich meat and bone meal caused P deficiency at the lower application rate as a result of alkaline soil conditions, whereas the P in BWA appeared to be almost as plant-available as soluble mineral P.

- 2013 -

Harvest residue potential in Norway – a bio-economic model appraisal

Even Bergseng [a], Tron Eid [a], Øivind Løken [a] and Rasmus Astrup [b]

[a] Department of Ecology and Natural Resource Management , Norwegian University of Life Sciences , Ås , Norway
[b] Norwegian Forest and Landscape Institute, Ås, Norway

Scandinavian Journal of Forest Research
Volume 28, Issue 5, 2013, pp. 470-480

DOI: 10.1080/02827581.2013.766259
D1.1.4 (Link to eRoom)

Abstract

Use of harvest residues for bioenergy is minimal in Norway, and the proposed increase of 14 TWh in annual bioenergy use by year 2020 may thus to a large part be based on residues from conventional timber harvesting. To judge the potential of harvest residues for bioenergy both in the short and long run, we present cost-supply curves for residue harvesting at national and regional levels. We produce different harvesting scenarios using the detailed forest model Gaya/J and a representative description of the Norwegian forest area from Norwegian national forest inventory (NFI) sample plots including environmental restrictions. Forest information is sufficiently detailed to estimate necessary biomass fractions and calculate costs of harvest residue extraction at plot level. We estimate a maximum annual energy production of 5.3 TWh from harvest residues with the present harvest level, which is far from the official target. In principle, there are two solutions for achieving this target; increase harvests and thus the corresponding residue supply, or increase the use of roundwood for energy purposes on the expense of pulpwood. Scenarios with long-run increase in timber production shows an annual energy potential from harvest residues in the range 6–9 TWh. Thus, to reach the political target roundwood must be used for energy production.

The Performance of a Residential Pellets Combustor Operating on Torrefied and Raw Spruce and Spruce Derived Residues

Roger A. Khalil [a], Quang-Vu Bach [b], Øyvind Skreiberg [a] and Khanh-Quang Tran [b]

[a] SINTEF Energy Research, Department of Thermal Energy, NO-7465 Trondheim, Norway
[b] NTNU - Norwegian University of Science and Technology, Department of Energy and Process Engineering, NO-7491, Trondheim, Norway

Energy & Fuels
2013, 27 (8), pp. 4760–4769

DOI: 10.1021/ef400595f
D1.3.5 (Link to eRoom)

Abstract

The heterogeneous nature of solid biomass fuels makes their combustion a substantial challenge compared to the more traditional fuel types, such as fossil fuels and natural gas. Many studies found in the literature attempt at identifying enhancements in fuel properties of biomass after a thermal pretreatment step, such as torrefaction, but only few investigate specifically the combustion behavior of these fuels. In this study, pellet combustion of raw and torrefied spruce and spruce tree tops and branches (T&B) has been investigated with regard to the emissions of gaseous pollutants and particulate matter (PM). The combustion was performed in a residential pellet stove, where a total of six different feedstocks, with and without pretreatment, were tested. The wide range of the feedstock properties was shown to go beyond the design limitations of the pellet stove. This could be seen as combustion instability for the T&B torrefied at 275 °C. Technology adjustments might be needed in terms of combustion air distribution and chamber design for these fuels. Mild torrefaction, in general, reduced the emissions of CO, unburned hydrocarbons, and the organics in particles smaller than 1 μm. Combustion at a low load (low thermal input) resulted as expected in increased emissions of organic compounds, which was again reduced substantially for the mildly torrefied feedstocks. In comparison to raw spruce at low load, a reduction by a factor of 3 from the organic share of the $PM_{1.0}$ particles is obtained. For the same experiments, CO in the flue gas is reduced by 150%. For T&B, similar trends were obtained for organic particles; however, torrefaction resulted in an increase in the total $PM_{1.0}$ emissions. The decrease in the organic share was more than offset by a substantial increase in the inorganic share of the $PM_{1.0}$ emissions. For this reason, torrefaction might not be a viable pretreatment solution for feedstocks with high ash content for use in stoves for residential heating, without combustion technology adjustments.

- 2012 –

Small area estimation of forest attributes in the Norwegian National Forest Inventory

Johannes Breidenbach, Rasmus Astrup

Norwegian Forest and Landscape Institute, Postboks 115, 1431, Ås, Norway

European Journal of Forest Research
July 2012, Volume 131, Issue 4, pp. 1255-1267

DOI: 10.1007/s10342-012-0596-7
D1.1.13 (Link to eRoom)

Abstract

The Norwegian National Forest Inventory (NNFI) provides estimates of forest parameters on national and regional scales by means of a systematic network of permanent sample plots. One of the biggest challenges for the NNFI is the interest in forest attribute information for small sub-populations such as municipalities or protected areas. Frequently, too few sampled observations are available for such small areas to allow estimates with acceptable precision. However, if an auxiliary variable exists that is correlated with the variable of interest, small area estimation (SAE) techniques may provide means to improve the precision of estimates. The study aimed at estimating the mean above-ground forest biomass for small areas with high precision and accuracy, using SAE techniques. For this purpose, the simple random sampling (SRS) estimator, the generalized regression (GREG) estimator, and the unit-level empirical best linear unbiased prediction (EBLUP) estimator were compared. Mean canopy height obtained from a photogrammetric canopy height model (CHM) was the auxiliary variable available for every population element. The small areas were 14 municipalities within a 2,184 km^2 study area for which an estimate of the mean forest biomass was sought. The municipalities were between 31 and 527 km^2 and contained 1–35 NNFI sample plots located within forest. The mean canopy height obtained from the CHM was found to have a strong linear correlation with forest biomass. Both the SRS estimator and the GREG estimator result in unstable estimates if they are based on too few observations. Although this is not the case for the EBLUP estimator, the estimators were only compared for municipalities with more than five sample plots. The SRS resulted in the highest standard errors in all municipalities. Whereas the GREG and EBLUP standard errors were similar for small areas with many sample plots, the EBLUP standard error was usually smaller than the GREG standard error. The difference between the EBLUP and GREG standard error increased with a decreasing number of sample plots within the small area. The EBLUP estimates of mean forest biomass within the municipalities ranged between 95.01 and 153.76 $Mg.ha^{-1}$, with standard errors between 8.20 and 12.84 $Mg.ha^{-1}$.

Combustion Properties of Norwegian Biomass: Wood Chips and Forest Residues

Ehsan Houshfar [a], Judit Sandquist [b], Wilson Musinguzi [a], Roger Antoine Khalil [b], Michaël Becidan [b], Øyvind Skreiberg [b], Franziska Goile [b], Terese Løvås [a] and Lars Sørum [b]

[a] Norwegian University of Science and Technology (NTNU), Department of Energy and Process Engineering, Kolbjørn Hejes vei 1B, NO-7491 Trondheim, Norway
[b] SINTEF Energy Research, Department of Thermal Energy, NO-7465 Trondheim, Norway

Applied Mechanics and Materials
Volumes 110 – 116, pp. 4564-4568

DOI: 10.4028/www.scientific.net/AMM.110-116.4564
D1.3.4: (Link to eRoom)

Abstract

Flue gas emissions and particle size distribution were investigated during combustion experiments of wood, forest residue and mixtures of these two. The combustion experiments were carried out in a grate fired multi-fuel reactor with and without air staging at stable operation conditions and constant temperature of 850 ºC. The overall excess air ratio was held at 1.6, and the primary excess air ratio was 0.8 during air staged experiments. NOx emissions are reduced by air staging. Fly ash particle concentration of forest residues in the flue gas is lower than wood. Aerosols number increased in the staged experiments for fuel blends.

Fertilization effects of organic waste resources and bottom wood ash: results from a pot experiment

Eva Brod [a, b], *Trond Knapp Haraldsen* [a], *Tor Arvid Breland* [b]

[a] Bioforsk, Norwegian Institute for Agricultural and Environmental Research, Fredrik A. Dahls vei 20, 1432 Ås, Norway
[b] Norwegian University of Life Sciences, Department of Plant and Environmental Sciences, P.O.Box 5003, NO-1432 Ås, Norway

Agricultural and Food Science
Vol 21, No 4 (2012), pp. 332-347

DOI: http://ojs.tsv.fi/index.php/AFS/article/view/5159
D1.4.8 (Link to eRoom)

Abstract

We conducted a pot experiment to study the fertilization effects of four N- and P-rich organic waste resources alone and in combination with K-rich bottom wood ash at two application rates (150 kg N ha^{-1} + 120 kg K ha^{-1}, 300 kg N ha^{-1} + 240 kg K ha^{-1}). Plant-available N was the growth-limiting factor. 48–73% of N applied with meat and bone meal (MBM) and composted fish sludge (CFS) was taken up in aboveground biomass, resulting in mineral fertilizer equivalents (MFE%) of 53–81% for N uptake and 61–104% for yield. MFE% of MBM and CFS decreased for increasing application rates. Two industrial composts had weak N fertilization effects and are to be considered soil conditioners rather than fertilizers. Possible P and K fertilization effects of waste resources were masked by the soil's ability to supply plant-available P and K, but effects on plant-available P and K contents in soil suggest that the waste resources may have positive effects under more nutrient-deficient conditions.

- 2011 -

Modelling natural drying efficiency in covered and uncovered piles of whole broadleaf trees for energy use

Tore Filbakk [a], *Olav Høibø* [a], *Juha Nurmi* [b]

[a] Norwegian University of Life Sciences, Department of Ecology and Natural Resource Management, P.O.Box 5003, NO-1432 Ås, Norway
[b] Finnish Forest Research Institute, Kannus Research Unit, P.O.Box. 44, 69101 Kannus, Finland

Biomass and Bioenergy
Volume 35, Issue 1, January 2011, pp. 454–463

DOI: [10.1016/j.biombioe.2010.09.003]
D1.3.2/D1.3.6 ([Link to eRoom])

Abstract

Small dimensions regenerated forests are considered a useful fuel resource for small local heat plants in Norway, since it is not relevant for the timber industry. Most small heat plants built so far are constructed for moisture contents of about 35% on wet basis. Therefore, the material must be dried. Because artificial drying induces additional costs, storing the material in piles roadside as whole trees until desired moisture content is obtained is considered beneficial. Traditionally, leaf seasoning has been considered an efficient method. To increase the understanding of these processes, a study on drying whole trees in piles has been accomplished at three different locations with different climatic conditions. The study focuses on the following explanatory variables: harvesting season, location, climatic conditions, position in the pile, tree species, and relative crown length. The effect of covering the piles in order to reduce the moisture uptake during winter was also studied. Models, estimating the moisture content with time profiles, were developed.

During spring and summer the moisture content was reduced to approximately 35% also when the material was harvested in the autumn the year before. The climatic conditions were important for the drying result, but drying was effective also in the moist climate in western Norway. Covering the dry piles before the winter was important in order to maintain the requested moisture content. The effect of covering the material harvested in autumn was limited.

A simulation approach to determine the potential Efficiency in multitree felling and processing

Helmer Belbo

Norwegian Forest and Landscape Institute, Ås

FORMEC Austria, 2011

DOI:-
D1.2.8 (Link to eRoom)

Abstract

Biomass from first thinning operations is seen as a promising option for widening the biomass resource, and a means to facilitate silvicultural actions for increasing high quality timber production. The main obstacle for this supply chain is the high costs for the in-stand initial felling and piling of young trees. Accumulating harvesting heads is an option to alleviate the strong relation between tree size and productivity in the felling-piling work phase, but no attempt to identify the potential productivity increase, related to the properties of the accumulating harvesting head is yet found in the literature.

The theoretical potential for increased efficiency in early thinning by using accumulating harvesting heads was investigated through simulation. Thinning was performed in corridors perpendicular to the strip road in 75 artificially generated stands with varying average tree size and density. The work pattern and time consumption in the crane work for five sizes of heads, with grapple diameter in the range 10 to 50 cm, was estimated by the simulation model. The efficiency increased rapidly when the grapple diameter increased from two to four times the average diameter in the harvested stand, reducing the time consumption per tree by 15 to 50 percent compared to the single tree handling harvesting head. Further increased grapple dimension also increased the efficiency, but not at the same rate. In real work, the efficiency increase by an accumulating harvesting head will probably be slightly lower due to less optimal harvesting conditions, operator skills and other non-productive work tasks that are not affected by work method. In addition, some effects that might increase the boom movement time and delimbing time for accumulated bunches of trees were not included due to the lack of empirical data.

The influence of storage and drying methods for Scots pine raw material on mechanical pellet properties and production parameters

Tore Filbakk [a], Geir Skjevrak [b], Olav Høibø [a], Janka Dibdiakova [c], Raida Jirjis [d]

[a] Norwegian University of Life Sciences, Department of Ecology and Natural Resource Management, P.O. Box 5003, NO-1432 Ås, Norway
[b] Norwegian University of Science and Technology, Department of Energy and Process Engineering, NO-7491 Trondheim, Norway
[c] Norwegian Forest and Landscape Institute, P.O. Box 115, NO-1431 Ås, Norway
[d] Swedish University of Agricultural Sciences, Department of Energy and Technology, P.O. Box 7032, SE-75007 Uppsala, Sweden

Fuel Processing Technology
Volume 92, Issue 5, May 2011, pp. 871–878

DOI: 10.1016/j.fuproc.2010.12.001
D1.3.6_1 (Link to eRoom)

Abstract

Converting solid biomass into pellets through densification greatly improves logistical handling and combustion processes. Raw material properties can affect pellet quality. This study investigated how storage and drying methods for wood (*Pinus sylvestris* L.) used as a raw material for pellet production influenced pellet durability, bulk density and energy consumption. The pelletization experiments were performed using a Sprout Matador M30 press (nominal production capacity 3.5 tonnes/h). Results showed that pelletization of 11 months stored wood compared to fresh material and high drying temperature (450 °C) compared to 75 °C resulted in higher energy consumption, probably due to increased friction in the matrix caused by the loss of extractives. However, the pellets produced were of higher density than those made from fresh material dried at a low temperature. The latter had the highest durability. Increased energy consumption showed no correlation with pellet durability.

Modelling moisture content and dry matter loss during storage of logging residues for energy

Tore Filbakk [a], Olav Albert Høibø[a], Janka Dibdiakova [b] & Juha Nurmi [c]

[a] Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences, PO Box 5003, NO-1432, Ås, Norway
[b] Norwegian Forest and Landscape Institute, Ås, Norway
[c] Finnish Forest Research Institute, Kannus, Finland

Scandinavian Journal of Forest Research
Volume 26, Issue 3, 2011

DOI: 10.1080/02827581.2011.553199
D1.3.7 (Link to eRoom)

Abstract

To achieve optimal utilisation of logging residues for energy, it is important to know how different handling and storage methods affect fuel properties. The aim of this study was to model how the moisture content and dry matter losses of logging residues develop during storage. Logging residues were collected from five different stands of spruce and pine during different seasons of the year and stored in the same location. The logging residues were stored in covered piles of bundled residues and loose residues. Only minor differences were found in the moisture content profiles between piles of bundles and loose residues. Logging residues located in the centre of both types of piles had considerably lower moisture content than the outer parts. The moisture content significantly affected dry matter loss, with the highest dry matter losses being found in the samples with the least favourable drying conditions. The dry matter losses varied between 1 and 3% per month. Significantly higher dry matter losses were found in the spruce bundles than in the pine bundles. Seasoned logging residues had the lowest dry matter loss, while the logging residues harvested and piled in the autumn had the highest loss.

- 2010 -

Extracting and chipping hardwood crowns for energy

Suadicani, Kjell [a]; Talbot, Bruce Edward [b]

[a] Forest & Landscape Denmark , University of Copenhagen , Rolighedsvej 23, Frederiksberg C, DK-1958,Denmark
[b] Norwegian Forest and Landscape Institute , Forest Technology and Economics , Pb 115, Ås, NO-1431,Norway

Scandinavian Journal of Forest Research
Volume 25, Issue 5, 2010, pp. 455-461

DOI: 10.1080/02827581.2010.509328
D1.2.X

Abstract

This study investigated the feasibility of extracting and chipping hardwood crowns for energy after motor-manual thinning in stands of common beech. Large crowns were extracted and chipped from stands where only sawlogs had been produced, while small crowns were extracted and chipped from stands where sawlogs and firewood had been harvested. The fuel chip yield was 15 m^{-3}_{solid} ha^{-1} when extracting and chipping large crowns, while it was 8 m^{-3}_{solid} ha^{-1} when extracting and chipping small crowns. The productivity for extracting and chipping large crowns was 8.5 m^{-3}_{solid} per workplace hour, and for small crowns was 5.9 m^{-3}_{solid} per workplace hour. Extracting and chipping large crowns gave a net income of €167 ha^{-1} (€11 m^{-3}_{solid}), while extracting and chipping small crowns gave a lower net income of €23 ha^{-1} (€3 m^{-3}_{solid}). The study showed that extracting and chipping large hardwood crowns is feasible and can make a substantial contribution to woody biomass feedstocks. Four product-mix alternatives were considered, but the marginal differences in outcome led the authors to recommend that in addition to sawlogs only one product, firewood or chips, should be produced in each stand.

SP2/SP3: CONVERSION MECHANISMS AND TECHNOLOGIES

- 2014 -

Investigation of Biomass Ash Sintering Characteristics and the Effect of Additives

Liang Wang [a], Geir Skjevrak [b], Johan E. Hustad [b], and Øyvind Skreiberg [a]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway
[b] SINTEF Energy Research, Sem Sælands vei 11, NO-7465 Trondheim, Norway

Energy Fuels
Volume 28, Issue 1, pp 208–218

DOI: 10.1021/ef401521c
D2.1.13_10 (Link to eRoom)

Abstract

In this work, the effects of three additives (sewage sludge, marble sludge, and clay sludge) on the sintering behaviors of two types of biomass ash (wheat straw and wood waste ash) were investigated. The ability of the additives to abate sintering was evaluated by performing standard ash fusion characterization and laboratory-scale sintering tests on mixtures of biomass ash and additives. The possible mechanisms underlying the anti-sintering effects of the additives were examined using a combination of X-ray diffraction (XRD) and scanning electron microscopy–energy-dispersive X-ray spectrometry (SEM–EDX) analyses of residues from the sintering tests. The best anti-sintering effect was achieved when marble sludge was used. The diluting effect of the marble sludge on the biomass ashes is considered to be the main reason for the decreased degree of ash sintering. In addition, Ca from the marble sludge may promote the formation of high-temperature melting silicates and phosphates with low K/Ca ratios. These chemical reactions and consequent products are favorable for reducing ash melt formation and sintering tendency. Sewage sludge served as a suitable additive to mitigate the sintering of the studied biomass ashes. Upon addition of the sewage sludge, compositions of the biomass ash changed from low-temperature melting silicates to high-temperature melting silicates, phosphates, and oxides. The shift of ash chemistry had a considerable positive effect on biomass melting and sintering temperatures. Clay sludge exhibited a poor ability to reduce the sintering tendency of wheat straw ash. Moreover, the addition of clay sludge decreased melting temperatures and caused severe sintering behavior of wood waste ash. SEM–EDX and XRD analyses revealed that, as clay sludge was added, more Si-rich melts were formed in wood waste ash. This occurred because clay sludge provides thermodynamically reactive Si-containing species and promotes the formation of low-melting-temperature alkali silicates.

Towards simulation of far-field aerodynamic sound from a circular cylinder using OpenFOAM

Dmitry A. Lysenko [a], Ivar S. Ertesvåg [a], Kjell Erik Rian [b]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology, Kolbjφrn Hejes vei 1B, NO-7491, Trondheim, Norway
[b] Computational Industry Technologies AS, NO-7462, Trondheim, Norway

Multi Science Publishing
Volume 13, Number 1-2, pp. 141-168

DOI: 10.1260/1475-472X.13.1-2.141
D2.1.25 (Link to eRoom)

Abstract

The low-Mach number flow-induced noise by the flow past a circular cylinder at sub-critical regime was predicted. First, to assess the accuracy of the numerical methodology, the laminar flow over a circular cylinder at the Reynolds number Re = 140 and Mach number M = 0.2 was calculated by direct solution of the unsteady compressible Navier-Stokes equations. Second, the sound generated by a circular cylinder at the Reynolds number Re = 2.2×10^4 and Mach number M = 0.06 was simulated using a technique of large-eddy simulation. For both cases, the calculated acoustic fields showed a dipole directivity, similar to a natural vortex shedding. The impact of the Doppler effect was investigated and discussed as well. In general, the computed aerodynamic and far-field acoustic results were found to be in good agreement with available experimental measurements and analytical relationships.

Numerical Simulations of the Sandia Flame D Using the Eddy Dissipation Concept

Dmitry A. Lysenko [a], Ivar S. Ertesvåg [a], Kjell Erik Rian [b]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology, Kolbjørn Hejes vei 1B, 7491, Trondheim, Norway
[b] Computational Industry Technologies AS, 7462, Trondheim, Norway

Flow, Turbulence and Combustion
2014, Volume 93, Issue 4, pp 665-687

DOI: 10.1007/s10494-014-9561-5
D2.1.X (link to eRoom)

Abstract

A turbulent piloted methane/air diffusion flame (Sandia Flame D) is calculated using both compressible Reynolds-averaged and large-eddy simulations (RAS and LES, respectively). The Eddy Dissipation Concept (EDC) is used for the turbulence-chemistry interaction, which assumes that molecular mixing and the subsequent combustion occur in the fine structures (smaller dissipative eddies, which are close to the Kolmogorov length scales). Assuming the full turbulence energy cascade, the characteristic length and velocity scales of the fine structures are evaluated using a standard k-ϵ turbulence model for RAS and a one-equation eddy-viscosity sub-grid scale model for LES. Finite-rate chemical kinetics are taken into account by treating the fine structures as constant pressure and adiabatic homogeneous reactors (calculated as a system of ordinary-differential equations (ODEs)) described by a Perfectly Stirred Reactor (PSR) concept. A robust implicit Runge-Kutta method (RADAU5) is used for integrating stiff ODEs to evaluate reaction rates. The radiation heat transfer is treated by the P1-approximation. The assumed β-PDF approach is applied to assess the influence of modeling of the turbulence-chemistry interaction. Numerical results are compared with available experimental data. In general, there is good agreement between present simulations and measurements both for RAS and LES, which gives a good indication on the adequacy and accuracy of the method and its further application for turbulent combustion simulations.

Sintering of Rye Straw Ash and Effect of Additives

Liang Wang [a], Øyvind Skreiberg [a], Michael Becidana, Hailong Li [b]

[a] SINTEF Energy Research, Sem Saelends vei 11, Trondheim,7465, Norway
[b] Mälardalens University, Energy Technology, Högskoleplan 1, Västerås 721 23, Sweden

Energy Procedia
Volume 61, 2014, Pages 2008–2011

DOI: 10.1016/j.egypro.2014.12.063
D2.1.26 (Link to eRoom)

Abstract

The effects of kaolin and calcite additives on the rye straw ash sintering behaviors were investigated. The rye straw ash has a high sintering tendency, with observation of severe fusion during combustion. The formation and melting of potassium silicates play key roles in sintering of the rye straw ash at elevated temperatures. Fusion characteristics temperatures of the rye straw ash were significantly increased upon kaolin and calcite addition. Kaolin addition led to formation of high temperature melting potassium aluminum silicates, which were revealed by XRD analyses. Due to formation of high temperature melting species due to kaolin addition, the severe sintering of the rye straw ash was significantly reduced. Addition of calcite provided CaO to react with silica in the rye straw ash, causing generation of high temperature melting calcium rich silicates. In addition, the dilution effect from calcite is a main reason for improved rye straw sintering behaviors.

Investigation of additives for preventing ash fouling and sintering during barley straw combustion

Liang Wang, Øyvind Skreiberg, Michael Becidan

SINTEF Energy Research, Sem Sælands vei 11, 7465 Trondheim, Norway

Applied Thermal Engineering
Volume 70, Issue 2, 22 September 2014, Pages 1262–1269

DOI: 10.1016/j.applthermaleng.2014.05.075
D2.1.27 (Link to eRoom)

Abstract

Formation of potassium chloride reduces ash sintering temperature and causes fouling deposits in biomass combustion applications. In the present work, the capacity of two mineral additives zeolite 24A and kaolin to capture KCl were investigated. A series of thermogravimetric experiments were carried out to measure fractions of KCl retained in the two additives as function of reaction temperature and heating time. The residues from additive-KCl mixtures after heating treatment were analyzed by X-ray diffractometry (XRD). When heated at 900 °C for 1 h, the overall KCl capturing efficiencies of the two additives were 60% and 45% for zeolite 24A and kaolin respectively, which slightly decreased to 50% and 43% as the heating time increased to 12 h. At 1000 °C, the fractions of KCl captured by zeolite 24A and kaolin significantly decreased from 50% and 40% to 26% and 17%, as the KCl-additive mixtures were heated for 1 and 12 h, respectively. The decrease in of the overall KCl capturing efficiencies is mainly attributed to reduction of surface areas and chemically active compounds of the two additives with increasing temperature and heating time. The XRD analysis results showed that both zeolite 24A and kaolin can react with KCl to form different potassium aluminium silicates. It indicates that chemical reactions play an important role in the overall capturing process. The effects of zeolite 24A and kaolin on sintering behaviors of the barley straw ash were also investigated. The residues from sintering tests were analyzed by a combination of X-Ray diffractometry (XRD) and scanning electron microscopy equipped with energy dispersive X-Ray analysis (SEM-EDX). The barley straw ash melted intensively at elevated temperatures. Together with XRD analysis, the SEM-EDX analysis results revealed that severe melting of the barley straw ash was due to formation and fusion of low temperature melting potassium silicates. Addition of kaolin and zeolite 24A significantly reduced the sintering tendency of the barley straw ash. Upon additive addition, high temperature melting potassium aluminium silicates formed in the barley straw ash as revealed by XRD and SEM-EDX analyses. Formation and presence of the refractory potassium aluminium silicates partly explain the improved sintering behaviors of the ash-additive mixtures.

Numerical Simulation of Non-premixed Turbulent Combustion Using the Eddy Dissipation Concept and Comparing with the Steady Laminar Flamelet Model

D. A. Lysenko [a], Ivar S. Ertesvåg [a], Kjell Erik Rian [b]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology, Kolbjørn Hejes vei 1B, NO–7491, Trondheim, Norway
[b] Computational Industry Technologies AS, NO–7462, Trondheim, Norway

Flow, Turbulence and Combustion
December 2014, Volume 93, Issue 4, pp 577-605

DOI: 10.1007/s10494-014-9551-7
D2.1.28 (Link to eRoom)

Abstract

Numerical simulations of the Sandia flame CHNa and the Sydney bluff-body stabilized flame HM1E are reported and the results are compared to available experimental data. The numerical method is based on compressible URANS formulations which were implemented recently in the OpenFOAM toolbox. In this study, the calculations are carried out using the conventional compressible URANS approach and a standard k- ϵ turbulence model. The Eddy Dissipation Concept with a detailed chemistry approach is used for the turbulence-chemistry interaction. The syngas (CO/H_2) chemistry diluted by 30 % nitrogen in the Sandia flame CHNa and CH_4/H_2 combustion in the Sydney flame HM1E are described by the full GRI-3.0 mechanism. A robust implicit Runge-Kutta method (RADAU5) is used for integrating stiff ordinary differential equations to calculate the reaction rates. The radiation is treated by the P1-approximation model. Both target flames are predicted with the Steady Laminar Flamelet model using the commercial code ANSYS FLUENT as well. In general, there is good agreement between present simulations and measurements for both flames, which indicates that the proposed numerical method is suitable for this type of combustion, provides acceptable accuracy and is ready for further combustion application development.

Methane production and energy evaluation of a farm scaled biogas plant in cold climate area

Kristian Fjørtoft [a], John Morken [a], Jon Fredrik Hanssen [b], Tormod Briseid [c]

[a] Department of Mathematical Sciences and Technology, Faculty of Environmental Sciences and Technology, Norwegian University of Life Sciences, P. O. Box 5003, 1432 Ås, Norway
[b] Department of Chemistry, Biotechnology and Food Science, Faculty of Veterinary Medicine and Biosciences, Norwegian University of Life Sciences, P. O. Box 5003, 1432 Ås, Norway
[c] Bioforsk Soil and Environment, Frederik A. Dahls vei 20, 1432 Aas, Norway

Bioresource Technology
Volum 169, October 2014, Pages 72-79

DOI: 10.1016/j.biortech.2014.06.077
D2.4.12 (Link to eRoom)

Abstract

The aim of this study was to investigate the specific methane production and the energy balance at a small farm scaled mesophilic biogas plant in a cold climate area. The main substrate was dairy cow slurry. Fish silage was used as co-substrate for two of the three test periods. Energy production, substrate volumes and thermal and electric energy consumption was monitored.

Methane production depended mainly on type and amount of substrates, while energy consumption depended mainly on the ambient temperature. During summer the main thermal energy consumption was caused by heating of new substrates, while covering for thermal energy losses from digester and pipes required most thermal energy during winter. Fish silage gave a total energy production of 1623 kWh/m^3, while the dairy cow slurry produced 79 kWh/m^3 slurry. Total energy demand at the plant varied between 26.9% and 88.2% of the energy produced.

Effects of a gradually increased load of fish waste silage in co-digestion with cow manure on methane production

Linn Solli, Ove Bergersen, Roald Sørheim, Tormod Briseid

Norwegian Institute for Agricultural and Environmental Research (Bioforsk), Soil and Environment Division, N-1432 Ås, Norway

Waste Management
Volume 34 Issue 8, August 2014, Pages 1553–1559

DOI10.1016/j.wasman.2014.04.011
D2.4.13 (Link to eRoom)

Abstracts

This study examined the effects of an increased load of nitrogen-rich organic material on anaerobic digestion and methane production. Co-digestion of fish waste silage (FWS) and cow manure (CM) was studied in two parallel laboratory-scale (8 L effective volume) semi-continuous stirred tank reactors (designated R1 and R2). A reactor fed with CM only (R0) was used as control. The reactors were operated in the mesophilic range (37 °C) with a hydraulic retention time of 30 days, and the entire experiment lasted for 450 days. The rate of organic loading was raised by increasing the content of FWS in the feed stock. During the experiment, the amount (volume%) of FWS was increased stepwise in the following order: 3% – 6% – 13% – 16%, and 19%. Measurements of methane production, and analysis of volatile fatty acids, ammonium and pH in the effluents were carried out. The highest methane production from co-digestion of FWS and CM was 0.400 L CH_4 gVS^{-1}, obtained during the period with loading of 16% FWS in R2. Compared to anaerobic digestion of CM only, the methane production was increased by 100% at most, when FWS was added to the feed stock. The biogas processes failed in R1 and R2 during the periods, with loadings of 16% and 19% FWS, respectively. In both reactors, the biogas processes failed due to overloading and accumulation of ammonia and volatile fatty acids.

Steam explosion pretreatment for enhancing biogas production of late harvested hay

Alexander Bauer [a,b] , Javier Lizasoain [a,b], Franz Theuretzbacher [a], Jane W. Agger [c], María Rincón [a], Simona Menardo [b,f], Molly K. Saylor [b], Ramón Enguídanos [a], Paal J. Nielsen [d], Antje Potthast [e], Thomas Zweckmair [e], Andreas Gronauer [a], Svein J. Horn [c]

[a] University of Natural Resources and Life Sciences, Department of Sustainable Agricultural Systems, Institute of Agricultural Engineering, Konrad-Lorenz-Strasse 24, A-3430 Tulln, Austria
[b] AlpS-GmbH, Centre for Climate Change Adaptation Technologies, Grabenweg 68, A-6010 Innsbruck, Austria
[c] Department of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences, P.O.Box 5003, N-1432 Ås, Norway
[d] Cambi AS, Skysstasjon 11A, 1383 Asker, Norway
[e] University of Natural Resources and Life Sciences, Department of Chemistry, Institute of Chemistry of Renewable Resources, Konrad-Lorenz-Strasse 24, A-3430 Tulln, Austria
[f] Mechanics Section, Department of Agricultural, Forest and Food Sciences (DISAFA), University of Torino, largo Paolo Braccini 2, 10095 Grugliasco, Torino, Italy

Bioresource Technology
Volume 166, August 2014, Pages 403–410

DOI: 10.1016/j.biortech.2014.05.025
D2.4.15 (Link to eRoom)

Abstract

Grasslands are often abandoned due to lack of profitability. Extensively cultivating grassland for utilization in a biogas-based biorefinery concept could mend this problem. Efficient bioconversion of this lignocellulosic biomass requires a pretreatment step. In this study the effect of different steam explosion conditions on hay digestibility have been investigated. Increasing severity in the pretreatment induced degradation of the hemicellulose, which at the same time led to the production of inhibitors and formation of pseudo-lignin. Enzymatic hydrolysis showed that the maximum glucose yields were obtained under pretreatment at 220 °C for 15 min, while higher xylose yields were obtained at 175 °C for 10 min. Pretreatment of hay by steam explosion enhanced 15.9% the methane yield in comparison to the untreated hay. Results indicate that hay can be effectively converted to methane after steam explosion pretreatment.

A metagenomic study of the microbial communities in four parallel biogas reactors

Linn Solli [a], Othilde Elise Håvelsru [b], Svein Jarle Horn [c], Anne Gunn Rike [d]

[a] Bioforsk, Norwegian Institute for Agricultural and Environmental Research, Frederik A. Dahls vei 20, 1432 Ås, Norway
[b] Department of Microbiology, Oslo University Hospital, P. O. Box 4950 Nydalen, 0424 Oslo, Norway
[c] Department of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences, P. O. Box 5003, N-1432 Ås, Norway
[d] Norwegian Geotechnical Institute, Sognsveien 72, P.O. Box 3930, Ullevål Stadion N-0806, Oslo, Norway

Biotechnology for Biofuels
2014, Volume 7, Issue 146

DOI: 10.1186/s13068-014-0146-2
D2.4.19 (Link to eRoom)

Abstract

Biogas is a renewable energy carrier which is used for heat and power production, or in the form of purified methane, as a vehicle fuel. The formation of methane from organic materials is carried out by a mixed microbial community under anaerobic conditions. However, details about the microbes involved and their function is limited. In this study we compare the metagenomes of four parallel biogas reactors digesting a protein rich substrate, relate microbiology to biogas performance, and observe differences in these reactor's microbial communities compared to the original inoculum culture.

On the Determination of Water Content in Biomass Processing

Jane W. Agger [a], Pål J. Nilsen [b], Vincent G. H. Eijsink [a] and Svein J. Horn [a]

[a] Department of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences, P.O. Box 5003, 1432 Ås, Norway
[b] Cambi AS, P.O. Box 78, 1371 Asker, Norway

BioEnergy Research
March 2014, Volume 7, Issue 1, pp 442-449

DOI: 10.1007/s12155-013-9388-2
D2.4.22 (Link to eRoom)

Abstract

Processing of lignocellulosic materials to fuels such as methane and bioethanol may involve several processing steps including pretreatment, saccharification, fermentation, and anaerobic digestion. The amounts of substrate used in these processes are usually based on dry matter content, and the processes themselves typically lead to a change in dry matter content. Thus, it is of great importance to be able to measure dry matter accurately. Dry matter content is commonly determined by measuring loss of water during oven drying. We have used Karl Fischer (KF) titration to measure the water content in a wide range of biomass fractions and have compared these data to results obtained by oven drying. This revealed considerable differences for all tested materials. For lignocellulosic materials, oven drying tends to overestimate dry matter content for untreated material. On the other hand, oven drying generally underestimates dry matter content in pretreated materials due to loss of organic volatiles. These differences have major consequences for the calculation of mass balances and yields in bioprocessing. The KF method gives more accurate water determination than oven drying due to the unique selectivity of the analysis. The method is suitable for the analysis of lignocellulosic biomasses and is particularly useful for determination of water content in pretreated materials, where oven drying usually underestimates the dry matter content due to loss of volatiles.

A C4-oxidizing Lytic Polysaccharide Monooxygenase Cleaving Both Cellulose and Cello-oligosaccharides

Trine Isaksen [a], Bjørge Westereng [a,b], Finn L. Aachmann [c], Jane W. Agger [a], Daniel Kracher [d], Roman Kittl [d], Roland Ludwig [d], Dietmar Haltrich [d], Vincent G. H. Eijsink [a], and Svein J. Horn [a]

[a] Department of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences, N-1432 Ås, Norway
[b] Forest and Landscape, University of Copenhagen, DK-1958 Frederiksberg C, Denmark
[c] Department of Biotechnology, NOBIPOL, Norwegian University of Science and Technology, N-7491 Trondheim, Norway
[d] Department of Food Science and Technology, BOKU, University of Natural Resources and Life Sciences, A-1190 Vienna, Austria

Journal of Biological Chemistry
2014, 289(5), p. 2632-2642

DOI: 10.1074/jbc.M113.530196
D2.4.23 (Link to eRoom)

Abstract

Lignocellulosic biomass is a renewable resource that significantly can substitute fossil resources for the production of fuels, chemicals, and materials. Efficient saccharification of this biomass to fermentable sugars will be a key technology in future biorefineries. Traditionally, saccharification was thought to be accomplished by mixtures of hydrolytic enzymes. However, recently it has been shown that lytic polysaccharide monooxygenases (LPMOs) contribute to this process by catalyzing oxidative cleavage of insoluble polysaccharides utilizing a mechanism involving molecular oxygen and an electron donor. These enzymes thus represent novel tools for the saccharification of plant biomass. Most characterized LPMOs, including all reported bacterial LPMOs, form aldonic acids, *i.e.*, products oxidized in the C1 position of the terminal sugar. Oxidation at other positions has been observed, and there has been some debate concerning the nature of this position (C4 or C6). In this study, we have characterized an LPMO from *Neurospora crassa* (*Nc*LPMO9C; also known as NCU02916 and *Nc*GH61–3). Remarkably, and in contrast to all previously characterized LPMOs, which are active only on polysaccharides, *Nc*LPMO9C is able to cleave soluble cello-oligosaccharides as short as a tetramer, a property that allowed detailed product analysis. Using mass spectrometry and NMR, we show that the cello-oligosaccharide products released by this enzyme contain a C4 gemdiol/keto group at the nonreducing end.

Changes in the composition of the main polysaccharide groups of oil seed rape straw following steam explosion and saccharification

Peter Ryden [a], Alizée Gautier [a], Nikolaus Wellner [b], Henri S. Tapp [c], Svein J. Horn [d], Vincent G.H. Eijsink [d], Keith W. Waldron [a]

[a] Biorefinery Centre, Institute of Food Research, Norwich Research Park, Colney, Norwich NR4 7UA, United Kingdom
[b] Imaging Partnership, Institute of Food Research, Norwich Research Park, Colney, Norwich NR4 7UA, United Kingdom
[c] Bioinformatics and Statistics Group, Institute of Food Research, Norwich Research Park, Colney, Norwich NR4 7UA, United Kingdom
[d] Department of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences, P.O.Box 5003, N-1432 Ås, Norway

Biomass and Bioenergy
Volume 61, February 2014, Pages 121–130

DOI: [10.1016/j.biombioe.2013.12.003]
D2.4.24 ([Link to eRoom])

Abstract

The composition of oil seed rape straw treated by steam explosion with increasing severity was investigated before and after saccharification. Chemical changes were monitored by FTIR-ATR spectroscopy. Sugar contents were determined after acid hydrolysis. Discriminant analysis of the spectra before and after digestion showed the main compositional changes are losses of carbohydrates and a subsequent increase in the proportion of lignin. Construction of partial least squares (PLS) predictive models for the concentration of eight cell wall sugars indicated different fates for cellulose, hemicelluloses and pectic substances. No cellulose was lost during steam explosion and the amount digested to glucose increased linearly with severity. Pectin was partially degraded during steam explosion, but a bound fraction remained which was only released during saccharification. Hemicelluloses were gradually destroyed in the steam explosion process, and the extent of subsequent saccharification was most strongly associated with the breakdown of xylan-like hemicelluloses.

Torrefaction Influence on Pelletability and Pellet Quality of Norwegian Forest Residues

Nevena Mišljenović [a], Quang-Vu Bach [b], Khanh-Quang Tran [b], Carlos Salas-Bringas [a] and Øyvind Skreiberg [c]

[a] Department of Mathematical Sciences and Technology, Norwegian University of Life Sciences, Post Office Box 5003, N-1432 Ås, Norway
[b] Department of Energy and Process Engineering, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway
[c] Department of Thermal Energy, SINTEF Energy Research, NO-7465 Trondheim, Norway

Energy Fuel
2014, 28 (4), pp 2554–2561

DOI: [10.1021/ef4023674](https://doi.org/10.1021/ef4023674)
D2.5.5 (Link to eRoom)

Abstract

The main purpose of this paper is to determine how the torrefaction influences the pelletability of birch (hardwood) and spruce (softwood). Woods were torrefied at two different temperatures (225 and 275 °C) for 30 min. Energy loss (EL) and weight loss (WL), higher heating value (HHV), moisture uptake, water activity (a_w), and particle size distribution of raw and torrefied woods were determined to characterize the materials before pelleting and to see how torrefaction affects physical properties of wood. The impact of biomass type, temperature, and compacting pressure on pellet strength and compressibility of raw and torrefied wood was investigated using a single pellet press method. Pellets were produced at three different temperatures (60, 120, and 180 °C) and eight different compacting pressures (5, 10, 20, 40, 80, 160, 240, and 300 MPa). Torrefaction at 275 °C significantly increased the HHV of both types of wood, in contrast to torrefaction at 225 °C. Compressing pressure and pelleting temperature had a significant positive impact on the material compressibility and strength. The strongest pellets were produced from raw spruce (68.62 ± 1.69 N/mm) and birch torrefied at 275 °C (86.34 ± 3.33 N/mm). Compression strength and density of the pellets were strongly correlated following a power low trend ($R^2 > 0.98$). Torrefied material required higher force for pellet discharge because of the higher friction generated on the pellet surface–die area.

A simulation study on the torrefied biomass gasification

Dhruv Tapasvi [a], Rajesh S. Kempegowda [b], Khanh-Quang Tran [a], Øyvind Skreiberg [b], Morten Grønli [a]

[a] Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway
[b] SINTEF Energy Research, NO-7465 Trondheim, Norway

Energy Conversion and Management
Volume 90, 15 January 2015, Pages 446–457

DOI: 10.1016/j.enconman.2014.11.027
D2.5.12 ([Link to eRoom]())

Abstract

Many studies have evaluated biomass behavior in a gasification process. Similar studies with torrefied biomass are needed to evaluate the improvements in biomass properties with torrefaction. This forms the basis of this study. A two-stage biomass gasification model is presented by using Aspen Plus as the simulation and modeling tool. The model included the minimization of the Gibbs free energy of the produced gas to achieve chemical equilibrium in the process, constrained by mass and energy balances for the system. Air and steam were used as the oxidizing agent in the process that uses both untreated and torrefied biomass as feedstocks. Three process parameters, equivalence ratio (ER), Gibbs reactor temperature and steam-to-biomass ratio (SBR), were studied. 27 cases were included in the analysis by operating the system below the carbon deposition boundary with all carbon in gaseous form in the product gas. Product gas composition in the form of hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4) and nitrogen (N_2) was analyzed together with cold gas energy and exergy efficiencies for all the cases. Overall, mole fractions of H_2, CO, CO_2 and N_2 were between 0.23–0.40, 0.22–0.42, 0.01–0.09 and 0.14–0.36 for torrefied wood and 0.21–0.40, 0.17–0.34, 0.03–0.09 and 0.15–0.37 for untreated wood, respectively. Similarly, cold gas energy and exergy efficiencies were between 76.1–97.9% and 68.3–85.8% for torrefied wood and 67.9–91.0% and 60.7–79.4% for untreated wood, respectively. Torrefied biomass has higher H_2 and CO contents in the product gas and higher energy and exergy efficiencies than the untreated biomass. Overall efficiencies of an integrated torrefaction–gasification process depend on the mass yields of the torrefaction process. Results from this study were validated using a C–H–O ternary diagram and with results from other similar studies.

CO_2 Gasification of Torrefied Wood: A Kinetic Study

Liang Wang [a], *Gábor Várhegyi* [b], *and Øyvind Skreiberg* [a]

[a] SINTEF Energy Research, Postboks 4761 Sluppen, NO-7465 Trondheim, Norway
[b] Institute of Materials and Environmental Chemistry, Research Centre for Natural Sciences, Hungarian Academy of Sciences, Post Office Box 286, Budapest 1519, Hungary

Energy Fuels
2014, 28 (12), pp 7582–7590

DOI: 10.1021/ef502308e
D2.5.14 (Link to eRoom)

Abstract

The CO_2 gasification of torrefied wood samples was examined by thermogravimetric analysis (TGA) at linear, modulated, and constant reaction rate (CRR) temperature programs. The untreated raw materials and chars prepared at 750 °C were also included in the study. The gasification temperature range separated sufficiently from the pyrolysis in the experiments for its separate analysis. Characteristic gasification reactivity differences were observed between the samples that were due to the differences of the char-forming reactions at different conditions. Various groups of experiments were evaluated together by the method of least squares, under various hypotheses on the dependence of the reaction rate upon the reacted fractions. The differences between the samples were described by different pre-exponential factors, while the rest of the kinetic parameters were kept identical during an evaluation. The effect of thermal annealing on the gasification kinetics was also expressed by the values of the pre-exponential factors. When the experiments of the samples prepared from birch were evaluated together, self-accelerating kinetics was obtained with E = 225 kJ/mol. The experiments belonging to the samples prepared from spruce resulted in n-order kinetics with E = 223 kJ/mol.

Influences of wet torrefaction on pelletability and pellet properties of Norwegian forest residues

Quang-Vu Bach [a], Nevena Mišljenovića [b], Khanh-Quang Tran [a], Carlos Salas-Bringas [b], and Øyvind Skreiberg [c]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway
[b] Department of Mathematical Sciences and Technology, Norwegian University of Life Sciences, Post Office Box 5003, N-1432 Ås, Norway
[c] Department of Thermal Energy, SINTEF Energy Research, NO-7465 Trondheim, Norway

Annual Transactions of the Nordic Rheology Society
2014, Volume 22, pp. 61-68

DOI: -
D2.5.10 (Link to eRoom)

Abstract

The compressibility of Norway spruce and birch tree branches torrefied in subcritical water conditions and the mechanical strength of the obtained pellets were experimentally studied in comparison with the raw materials. The pelletization was performed on a single pellet press. The pellet strength was investigated via diametric compression tests, employing a 60 mm diameter probe connected to a Lloyd LR 5K texture analyzer. The results showed that wet torrefaction improved the compressibility and strength of the tested material. In addition, compressing pressure affected both the pellet density and strength, while pelletizing temperature influenced the pellet strength only.

Torrefaction Kinetics of Norwegian Biomass Fuels

Quang-Vu Bach [b], Roger A. Khalil [a], Khanh-Quang Tran [b], Øyvind Skreiberg [a]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491, Trondheim, Norway
[b] Department of Thermal Energy, SINTEF Energy Research, NO-7465 Trondheim, Norway

Chemical Engineering Transactions
Volume 37, 49-54, 2014

DOI: 10.3303/CET1437009
D2.5.6 (Link to eRoom)

Abstract

Torrefaction kinetics of Norwegian biomass fuels, including spruce (softwood) and birch (hardwood) was studied using a thermogravimetric analyser. Small samples of approximately 10 mg and particle size of 63−125 µm were heated at a constant heating rate of 5 °C/min and kept afterwards for 4 hours in isothermal conditions at different temperatures (230, 240, 250, 260, 270 and 280 °C). A two-step kinetic model was employed to simulate the recorded mass loss curves. The results showed that the decomposition of the initial biomass in the first step, to form an intermediate solid and volatiles, exhibited a higher conversion rate compared with the second step. The rate constants (in s^{-1}) for two steps are: $k_1 = 21.2 \exp\left(\frac{-48109.7}{RT}\right)$, $k_2 = 4.74.10^9 \exp\left(\frac{-149639.9}{RT}\right)$ for spruce and $k_1 = 106.6 \exp\left(\frac{-55112.8}{RT}\right)$, $k_2 = 2.80.10^{10} \exp\left(\frac{-163263.7}{RT}\right)$ for birch. Moreover, the final solid yield, which decreased gradually with increasing torrefaction temperature, reproduced the experimental results well.

Effects of CO_2 on wet torrefaction of biomass

Quang-Vu Bach [a], Khanh-Quang Tran [a], Øyvind Skreiberg [b], Roger A. Khalil [b]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway
[b] Department of Thermal Energy, SINTEF Energy Research, NO-7465 Trondheim, Norway

Energy Procedia
Volume 61, 2014, Pages 1200–1203

DOI: 10.1016/j.egypro.2014.11.1055
D2.5.7 (Link to eRoom)

Abstract

Effects of CO_2 on the yield and fuel properties of the solid product obtained from wet torrefaction of biomass were experimentally investigated. Norwegian forest residues were used as feedstock. CO_2 and N_2 were employed as purge gas, separately. The results show that, compared with wet torrefaction in N_2, the process in CO_2 is taking place faster, producing 4.6-6.0% less solid product with lower heating value in identical condition. A reduction of 6.5kWh/t in SGE and an increase of up to 1.4% in EMC were observed for the solid product obtained from WT in CO_2 compared with that in N_2. In addition, CO_2 enhances the capacity of wet torrefaction to remove ash elements from solid biomass fuels.

Wet torrefaction of forest residues

Quang-Vu Bach [a], Khanh-Quang Tran [a], Roger A. Khalil [b] and Øyvind Skreiberg [b]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway
[b] Department of Thermal Energy, SINTEF Energy Research, NO-7465 Trondheim, Norway

Energy Procedia
Volume 61, 2014, Pages 1196–1199

DOI: 10.1016/j.egypro.2014.11.1052
D2.5.8 (Link to eRoom)

Abstract

Wet torrefaction of forest residues, which is one of the cheap and most abundant biomass resources in Norway, was experimentally studied. Freshly cut branches of Norway birch and spruce were used as feedstock, without and with pre-drying to simulate the drying during fuel storage prior to torrefaction. The results show that both torrefaction temperature and holding time have significant effects on the solid yield and its fuel properties. Increases in heating value of up to 13.0-13.5% and reductions of specific grinding energy of 13.3-27.5 times could be achieved via wet torrefaction. Torrefied forest residues have lower ash contents compared with the raw materials. Pre-drying and especially the drying methods have significant effects on the solid yield.

Effects of wet torrefaction on reactivity and kinetics of wood under air combustion conditions

Quang-Vu Bach [a], Khanh-Quang Tran [a], Øyvind Skreiberg [b], Roger A. Khalil [b], Anh N. Phan [c]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway
[b] Department of Thermal Energy, SINTEF Energy Research, NO-7465 Trondheim, Norway
[c] School of Chemical Engineering & Advanced Materials, Newcastle University, Newcastle Upon Tyne NE1 7RU, UK

Fuel
Volume 137, 1 December 2014, Pages 375–383

DOI: 10.1016/j.fuel.2014.08.011
D2.5.9 (Link to eRoom)

Abstract

This work continues our assessment of wet torrefaction for energy applications, looking at effects of the process parameters (temperature, holding time and pressure) on the reactivity and intrinsic kinetics of wood under air combustion conditions. Woody materials, Norway spruce and birch, were wet torrefied in various conditions (temperature: 175, 200, 225 °C; holding time: 10, 30, 60 min; and pressure: 15.54, 70, 160 bar). The reactivity of the treated and untreated woods was thermogravimetrically examined under a synthetic air environment (21% O_2 and 79% N_2 in volume). A four-pseudo-component model with different reaction orders was adopted for kinetic modelling and extracting the kinetic parameters. The results showed that when increasing either torrefaction temperature or holding time, the torrefied woods behaved more char-like than the raw fuels. However, pressure did not show significant effect on the reactivity. Relatively longer char combustion stages and higher conversion rates (up to 0.5×10^{-3} s^{-1}) were observed for the woods after torrefaction. The activation energy was decreased for hemicellulose and char, but increased for cellulose after torrefaction, whereas the trend for lignin is not clear. In addition, the hemicellulose mass fraction decreased after torrefaction (from 0.15 to 0.05 for spruce and from 0.23 to 0.06 for birch). The amount of char in the torrefied woods increased gradually with increasing torrefaction temperature or holding time (from 0.24 to 0.40 for spruce, and from 0.18 to 0.34 for birch).

On the proper integration of wood stoves in passive houses under cold climates

Laurent Georges [a], Øyvind Skreiberg [b], Vojislav Novakovic [a]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), Kolbjørn Hejes vei 1B, 7491 Trondheim, Norway
[b] Department of Thermal Energy, SINTEF Energy Research, Kolbjørn Hejes vei 1A, 7465 Trondheim, Norway

Energy and Buildings
Volume 72, April 2014, Pages 87–95

DOI: 10.1016/j.enbuild.2013.12.023
D3.1.5 (Link to eRoom)

Abstract

The space-heating (SH) of residential buildings using a wood stove is an attractive solution. The way to properly integrate stoves in passive houses (PH) is still in question: current nominal powers are generally oversized compared to the PH needs (i.e. overheating risk) and it is not well understood how one stove can contribute to the SH of the entire building during a heating season. This question has already been addressed for the temperate climate of Belgium in a previous paper. The present work investigates cold climates also using a larger range of stove parameters. This is done using detailed dynamic simulations (TRNSYS) on a typical Norwegian single-family house typology. Using a large sensitivity analysis, recommendations to prevent overheating are given with a distinction between pellet and log stoves. Results also show that the overheating risk is somehow comparable between cold climates. On the contrary, the ability of one stove to ensure alone the thermal comfort strongly depends on the local climate. For the milder climates, the stove can cover a significant part of the SH while, for colder climates, the stove should only be considered as a part of the total SH emission system.

- 2013 -

Large-Eddy Simulation of the Flow Over a Circular Cylinder at Reynolds Number 2×10^4

Dmitry A. Lysenko [a], Ivar S. Ertesvåg [a], Kjell Erik Rian [b]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology, Kolbjørn Hejes vei 1B, 7491 Trondheim, Norway
[b] Computational Industry Technologies AS, 7462 Trondheim, Norway

Flow, Turbulence and Combustion
September 2013

DOI: [10.1007/s10494-013-9509-1](10.1007/s10494-013-9509-1)
D2.1.19 (Link to eRoom)

Abstract

The flow over a circular cylinder at Reynolds number 2×10^4 was predicted numerically using the technique of large-eddy simulation (LES). Both incompressible and compressible flow formulations were used. The present results obtained at a low-Mach number ($M = 0.2$) revealed significant inaccuracies like spurious oscillations of the compressible flow solution. A detailed investigation of such phenomena was carried out. It was found that application of blended central-difference or linear-upwind schemes could damp artificial waves significantly. However, this type of schemes has a too dissipative nature compared to pure central-differences. The incompressible flow results were found to be consistent with the existing numerical studies as well as with the experimental data. Basic flow features and flow mechanics were found to be in good agreement with existing experimental data and consistent with previously obtained LES. Special emphasis was put on the spectral analysis. Here, the classical Fourier transform as well as the continuous wavelet transform were applied. Based on the latter, the separated shear-layer instability was precisely clarified. It was found that the Reynolds number dependency between vortex shedding and shear-layer instabilities had a power law relation with $n = 0.5$.

Influence of drag force correlations on periodic fluidization behavior in Eulerian–Lagrangian simulation of a bubbling fluidized bed

Xiaoke Ku, Tian Li, Terese Løvås

Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), 7491 Trondheim, Norway

Chemical Engineering Science
Volume 95, 24 May 2013, pp. 94–106

DOI: 10.1016/j.ces.2013.03.038
D2.1.16 (Link to eRoom)

Abstract

In this paper, an Eulerian–Lagrangian approach, in which the gas flow is solved by the volume-averaged Navier–Stokes equation and the motion of individual particles is obtained by directly solving Newton's second law of motion, is developed within the OpenFOAM framework to investigate the effects of three well-known inter-phase drag force correlations (Gidaspow, 1994 and Di Felice, 1994 and EHKL, 2006) on the fluidization behavior in a bubbling fluidized bed reactor. The inter-particle and particle–wall collisions are modeled by a soft-sphere model which expresses the contact forces with the use of a spring, dashpot and friction slider. The simulation results are analyzed in terms of particle flow pattern, bed expansion, bed pressure drop and fluctuation frequency. Qualitatively, formation of bubbles and slugs and the process of particle mixing are observed to occur for all the drag models, although the Gidaspow model is found to be most energetic and the Di Felice and EHKL models yield minor difference. The flow behavior also shows a strong dependency on the restitution coefficient e and the friction coefficient μ and no bubbling and slugging occur at all for the ideal-collision case (e=1, μ=0). Quantitatively, the mean pressure drops predicted by the three models agree quite well with each other and the amplitudes of the fluctuations measured by the standard deviation are also comparable. However, a significant difference in fluctuation frequency is found and the Gidaspow model predicts a lowest fluctuation frequency whereas the Di Felice model gets a highest one. Finally, effects of the spring stiffness and the discontinuity in the Gidaspow model are studied. The results show that both mean bed pressure drop and fluctuation frequency slightly decrease as the spring stiffness increases for all the three drag models and no significant differences are observed in the mean bed pressure drop and fluctuation frequency between the Gidaspow model and the linear continuous model.

The effect of peat ash addition to demolition wood on the formation of alkali, lead and zinc compounds at staged combustion conditions

Backman R.[a], Khalil R.[a], Todorovic D.[b], Becidan M.[a], Skreiberg Ø.[a], Goile F.[a], Skreiberg A.[a] and Sørum L.[a]

[a] SINTEF Energy Research, Energy Processes, NO-7465 Trondheim, Norway
[b] University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade, Serbia

Fuel Processing Technology
Volume 105, January 2013, pp. 20–27

DOI: [10.1016/j.fuproc.2011.04.035]
D2.1.13_3 ([Link to eRoom])

Abstract

Combustion experiments were performed in a multi-fuel reactor with continuous feed of pellets by applying staged air combustion. Total characterization of the elemental composition of the fuel, the bottom ash and some particle size stages of fly ash was performed. This was done in order to follow the fate of some of the problematic compounds in demolition wood as a function of peat-ash addition and other combustion related parameters. A method was developed to estimate the composition and speciation of the salt part of aerosols based on SEM/EDX analysis. The results show that the concentrations of zinc and lead account for 40–50% of the salts produced for the small particles (0.093 μm) and up to 90% for the larger particles (1.59 μm). A considerable part of these metals are chemically bound to chlorides and sulfates together with potassium and sodium indicating extensive volatilization of zinc and lead. The experiments show that the reactions of potassium, zinc and lead are the most affected. This gives rise to higher concentrations of zinc and lead in the aerosols. The chloride content in the aerosols decreases with increased peat ash addition. This will have an inhibiting effect on corrosion, but the higher Zn and especially Pb concentrations will lead to a lower first melting point of the aerosol particles. This may promote deposition and cause corrosion.

Automatic generation of kinetic skeletal mechanisms for biomass combustion

Terese Løvås [a], Ehsan Houshfar [b], Mette Bugge [c] and Øyvind Skreiberg [c]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology, Kolbjørn Hejes vei 1B, NO-7491 Trondheim, Norway
[b] Technical Department, ENERGOS AS, Kvenildmyra 5, NO-7072 Heimdal, Norway
[c] SINTEF Energy Research, Kolbjørn Hejes vei 1A, NO-7465 Trondheim, Norway

Energy & Fuels
2013, 27 (11), pp. 6979–6991

DOI: 10.1021/ef400949h
D2.1.8 (Link to eRoom)

Abstract

We present in this paper simplified chemical mechanisms for gas phase biomass combustion based on automatic reduction of detailed and comprehensive kinetics. The reduction method that has been employed is a combined reaction flow and sensitivity analysis well-known to combustion, resulting in a *necessity index* ranking all chemical species for automatic reduction. The objective is to obtain more compact chemical models, so-called skeletal mechanisms, for implementation into computational fluid dynamics, CFD, in order to reduce computational time. In the current work, the physical system used for the development and validation of the chemical models is that of a tubular reactor, or plug flow reactor, with operating conditions typically found in biomass reactors. The focus has been on gas phase reactions only, and the fuel composition is based on experimental values from biomass and coal gasification. Emphasis has been on the reliability of the simplified models and the correct prediction of important emission parameters such as NO_x and important intermediate species. The original chemical model, consisting of several sub models for important reaction paths known in biomass combustion, contained 81 species and 1401 reactions. This was successfully reduced down to 36 species, providing a compact and reliable chemical model for implementation into CFD. The model still contains the reaction paths of C_2 species, allowing for more realistic fuel gas compositions. The model has been experimentally validated for a wide range of temperatures including low temperature chemistry and reducing conditions for NO_x. The computational time saved using the simplified models was significant with over 80% reduction in CPU time.

The smart biofuels of the future

Øyvind Skreiberg [a], Morten G. Grønli [b], Michael Jerry Antal Jr. [c]

[a] SINTEF Energy Research, Kolbjørn Hejes vei 1A, NO-7465 Trondheim, Norway
[b] Norwegian University of Science and Technology, Department of Energy and Process Engineering, Kolbjørn Hejes vei 1B, NO-7491 Trondheim, Norway
[c] Hawaii Natural Energy Institute, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, Honolulu, Hawaii 96822, United States

Biofuels
March 2013, Vol. 4, No. 2, pp. 159-161

DOI: 10.4155/bfs.12.91
D2.3.11 (Link to eRoom)

First paragraphs

From the dawn of civilization mankind have utilized bioenergy and enjoyed the coziness of open fire. Knowledge and care about energy efficiency and emissions, not to mention sustainability, is something that has developed only very recently in the bioenergy history. Today a wide variety of biofuels exist – solid, liquid and gaseous – and it is not straightforward to select the right fuel for the right purpose. Liquid biofuels is a hot topic these days, brought forward by the future lack of fossil fuel certainty and the awareness of a fast-increasing GHG effect. In the future, we will need something other than fossil gasoline or diesel to fuel our motorized vehicles, but it is the fast-increasing GHG effect that is the main driver today.

Biomass can, in principle, be used to produce any kind of biofuel, through mechanical, thermal and/or chemical upgrading. Mechanically you can upgrade physically impractical biomass to pellets as a physically well defined, transport friendly, quite energy dense and versatile biofuel. Thermal upgrading opens up a wide variety of possibilities through thermal processes such as torrefaction (dry and wet [in hot compressed water]), pyrolysis, carbonization, gasification and liquefaction. Adding chemical upgrading into the picture, a number of transport fuels can be produced from biomass (e.g., diesel, ethanol, CH_4, dimethyl ether and hydrogen). In principle, any kind of biomass can be used in these thermal and chemical processes. In practice there are, or should be, some limitations. The question arises, which biofuels will be the smart biofuels of the future?

Is Elevated Pressure Required to Achieve a High Fixed-Carbon Yield of Charcoal from 2 Biomass? Part 2: The Importance of Particle Size

Liang Wang [a], Øyvind Skreiberg [a], Morten Gronli [b], Gregory Patrick Specht [c], and Michael J. Antal, Jr. [c]

[a] SINTEF Energy Research, Sem Saelands vei 11, Trondheim, Norway
[b] Department of Energy and Process Engineering, Norwegian University of Science and Technology, Kolbjørn Hejes vei 1B, Trondheim, Norway
[c] Hawaii Natural Energy Institute, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, Honolulu, Hawaii 96822, United States

Energy & Fuels
2013, 27 (4), pp. 2146–2156

DOI: [10.1021/ef400041h]
D2.3.6 ([Link to eRoom])

Abstract

The prosperity of Silicon Valley is built upon a foundation of wood charcoal that is the preferred reductant for the manufacture of pure silicon from quartz. Because ordinary pyrolysis processes offer low yields of charcoal from wood, the production of silicon makes heavy demands on the forest resource. The goal of this paper is to identify process conditions that improve the yield of charcoal from wood. To realize this goal, we first calculate the theoretical fixed-carbon yield of charcoal by use of the elemental composition of the wood feedstock. Next, we examine the influence of particle size, sample size, and pressure on experimental values of the fixed-carbon yields of the charcoal products and compare these values with the calculated theoretical limiting values. The carbonization by thermogravimetric analysis of small samples of small particles of wood in open crucibles delivers the lowest fixed-carbon yields, closely followed by standard proximate analysis procedures that employ a closed crucible and realize somewhat improved yields. The fixed-carbon yields (as determined by thermogravimetry) improve as the sample size increases and as the particle size increases. Further gains are realized when pyrolysis occurs in a closed crucible that hinders the egress of volatiles. At atmospheric pressure, high fixed-carbon yields are obtained from 30 mm wood cubes heated in a closed retort under nitrogen within a muffle furnace. The highest fixed-carbon yields are realized at elevated pressure by the flash carbonization process. Even at elevated pressure, gains are realized when large particles are carbonized. These findings reveal the key role that secondary reactions, involving the interaction of vapor-phase pyrolysis species with the solid substrate, play in the formation of charcoal. Models of biomass pyrolysis, which do not account for the impacts of sample size, particle size, and pressure on the interactions of volatiles with the solid substrate, cannot predict the yield of charcoal from biomass. These findings also offer important practical guidance to industry. Size reduction of wood feedstocks is not only energy and capital intensive; size reduction also reduces the yield of charcoal and exacerbates demands made on the forest resource.

Effect of different steam explosion conditions on methane potential and enzymatic saccharification of birch

Vivekanand Vivekanand, Elisabeth F. Olsen, Vincent G.H. Eijsink, Svein J. Horn

Department of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences, P.O. Box 5003, N-1432 Ås, Norway

Bioresource Technology
Volume 127, January 2013, pp. 343–349

DOI: [10.1016/j.biortech.2012.09.118]
D2.4.9 ([Link to eRoom])

Abstract

Birch (*Betula pubescens*) was steam exploded at 13 different conditions with temperatures ranging from 170 to 230 °C and residence times ranging from 5 to 15 min. Increasing severity in the pretreatment led to degradation of xylan and formation of pseudo-lignin. The effect of the pretreatments was evaluated by running enzymatic saccharification and anaerobic digestion followed by analysis of sugar and methane yields, respectively. Enzymatically released glucose increased with pretreatment severity up to 220 °C for 10 min and levels of solubilized glucose reached 97% of the theoretical maximum. The highest methane yield (369 mL gVS^{-1}) was obtained at a severity factor of 4.5 and this yield was 1.8 times higher than the yield from untreated birch. Enzymatic glucose yields and methane yields were generally correlated. The results indicate that steam-exploded birch can be effectively converted to either glucose or methane.

Biogas production from wheat straw and manure - impact of pretreatment and process operating parameters

Risberg K. [a], *Sun L.* [a], *Levén L.* [c], *Horn S.J.* [b], *Schnürer A.* [a]

[a] Department of Microbiology, Swedish University of Agricultural Science, Uppsala BioCenter, P.O. Box 7025, SE-750 07 Uppsala, Sweden
[b] Department of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences, P.O. Box 5003, N-1432 Ås, Norway
[c] JTI – Swedish Institute of Agricultural and Environmental Engineering, P.O. Box 7033, SE-750 07 Uppsala, Sweden

Bioresource Technology
Volume 149, December 2013, Pages 232–237

DOI: 10.1016/j.biortech.2013.09.054
D2.4.X (Link to eRoom)

Abstract

Non-treated or steam-exploded straw in co-digestion with cattle manure was evaluated as a substrate for biogas production compared with manure as the sole substrate. All digestions were performed in laboratory-scale CSTR reactors (5 L) operating with an organic loading late of approximately 2.8 g VS/L/day, independent of substrate mixture. The hydraulic retention was 25 days and an operating temperature of 37, 44 or 52 °C. The co-digestion with steam exploded straw and manure was evaluated with two different mixtures, with different proportion. The results showed stable performance but low methane yields (0.13–0.21 N L CH4/kg VS) for both manure alone and in co-digestion with the straw. Straw appeared to give similar yield as manure and steam-explosion treatment of the straw did not increase gas yields. Furthermore, there were only slight differences at the different operating temperatures.

Crystal structure and computational characterization of the lytic polysaccharide monooxygenase GH61D from the Basidiomycota fungus Phanerochaete chrysosporium

Miao Wu [a], Gregg T. Beckham [b,c], Anna M. Larsson [a], Takuya Ishida [d], Seonah Kim [b], Christina M. Payne [b,e], Michael E. Himmel [b], Michael F. Crowley [b], Svein J. Horn [f], Bjørge Westereng [f], Kiyohiko Igarashi [d], Masahiro Samejima [d], Jerry Ståhlberg [a], Vincent G. H. Eijsink [f] and Mats Sandgren [a]

[a] Department of Molecular Biology, Swedish University of Agricultural Sciences, P.O. Box 7026, SE-750 07 Uppsala, Sweden
[b] National Bioenergy Center and Biosciences Center, National Renewable Energy Laboratory, Golden, Colorado 80401
[c] Department of Chemical Engineering, Colorado School of Mines, Golden, Colorado 80401
[d] Department of Biomaterial Sciences, Graduate School of Agricultural and Life Sciences, University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113- 8657, Japan
[e] Department of Chemical and Materials Engineering, University of Kentucky, Lexington, Kentucky 40506
[f] Department of Chemistry, Biotechnology, and Food Science, Norwegian University of Life Sciences, N-1432 Ås, Norway

2013, Journal of Biological Chemistry, 288, pp 12828-12839

DOI: 10.1074/jbc.M113.459396
D2.4.X (Link to eRoom)

Abstract

Carbohydrate structures are modified and degraded in the biosphere by a myriad of mostly hydrolytic enzymes. Recently, lytic polysaccharide mono-oxygenases (LPMOs) were discovered as a new class of enzymes for cleavage of recalcitrant polysaccharides that instead employ an oxidative mechanism. LPMOs employ copper as the catalytic metal and are dependent on oxygen and reducing agents for activity. LPMOs are found in many fungi and bacteria, but to date no basidiomycete LPMO has been structurally characterized. Here we present the three-dimensional crystal structure of the basidiomycete Phanerochaete chrysosporium GH61D LPMO, and, for the first time, measure the product distribution of LPMO action on a lignocellulosic substrate. The structure reveals a copper-bound active site common to LPMOs, a collection of aromatic and polar residues near the binding surface that may be responsible for regio-selectivity, and substantial differences in loop structures near the binding face compared with other LPMO structures. The activity assays indicate that this LPMO primarily produces aldonic acids. Last, molecular simulations reveal conformational changes, including the binding of several regions to the cellulose surface, leading to alignment of three tyrosine residues on the binding face of the enzyme with individual cellulose chains, similar to what has been observed for family 1 carbohydrate-binding modules. A calculated potential energy surface for surface translation indicates that P. chrysosporium GH61D exhibits energy wells whose spacing seems adapted to the spacing of cellobiose units along a cellulose chain.

Kinetic behavior of torrefied biomass in an oxidative environment

Dhruv Tapasvi [a], Roger Antoine Khalil [b], Gabor Varhegyi [c], Øyvind Skreiberg [b], Khanh-Quang Tran [a], and Morten G. Gronli [a]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway
[b] SINTEF Energy Research, Post Office Box 4761, Sluppen, NO-7465 Trondheim, Norway
[c] Institute of Materials and Environmental Chemistry, Research Centre for Natural Sciences, Hungarian Academy of Sciences, Post Office Box 17, Budapest 1525, Hungary

Energy & Fuels, 2013, 27 (2), pp. 1050–1060

DOI: [10.1021/ef3019222]
D2.5.1_2 ([Link to eRoom])

Abstract

The combustion of four torrefied wood samples and their feedstocks (birch and spruce) was studied at slow heating programs, under well-defined conditions by thermogravimetry (TGA). Particularly low sample masses were employed to avoid the self-heating of the samples because of the huge reaction heat of the combustion. Linear, modulated, and constant reaction rate (CRR) temperature programs were employed in the TGA experiments in gas flows of 5 and 20% O_2. In this way, the kinetics was based on a wide range of experimental conditions. The ratio of the highest and lowest peak maxima was around 50 in the experiments used for the kinetic evaluation. A recent kinetic model by Várhegyi et al. (Várhegyi, G.; Sebestyén, Z.; Czégény, Z.; Lezsovits, F.; Könczöl, S. *Energy Fuels* 2012, *26*, 1323−1335) was employed with modifications. This model consists of two devolatilization reactions and a successive char burnoff reaction. The cellulose decomposition in the presence of oxygen has a self-accelerating (autocatalytic) kinetics. The decomposition of the non-cellulosic parts of the biomass was described by a distributed activation model. The char burnoff was approximated by power-law (*n*-order) kinetics. Each of these reactions has its own dependence upon the oxygen concentration that was expressed by power-law kinetics too. The complexity of the applied model reflects the complexity of the studied materials. The model contained 15 unknown parameters for a given biomass. Part of these parameters could be assumed common for the six samples without a substantial worsening of the fit quality. This approach increased the average experimental information for an unknown parameter by a factor of 2 and revealed the similarities in the behavior of the different samples.

Thermal decomposition kinetics of woods with emphasis on torrefaction

Dhruv Tapasvi [a], Roger A. Khalil [b], Gabor Varhegyi [c], Khanh-Quang Tran [a], Morten G. Gronli [a] and Øyvind Skreiberg [b]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway
[b] SINTEF Energy Research, Post Office Box 4761, Sluppen, NO-7465 Trondheim, Norway
[c] Institute of Materials and Environmental Chemistry, Research Centre for Natural Sciences, Hungarian Academy of Sciences, Post Office Box 17, Budapest 1525, Hungary

Energy & Fuels, 2013, 27 (10), pp. 6134–6145

DOI: 10.1021/ef4016075
D2.5.2 (Link to eRoom)

Abstract

The pyrolysis kinetics of Norwegian spruce and birch wood was studied to obtain information on the kinetics of torrefaction. Thermogravimetry (TGA) was employed with nine different heating programs, including linear, stepwise, modulated and constant reaction rate (CRR) experiments. The 18 experiments on the 2 feedstocks were evaluated simultaneously via the method of least-squares. Part of the kinetic parameters could be assumed common for both woods without a considerable worsening of the fit quality. This process results in better defined parameters and emphasizes the similarities between the woods. Three pseudo-components were assumed. Two of them were described by distributed activation energy models (DAEMs), while the decomposition of the cellulose pseudo-component was described by a self-accelerating kinetics. In another approach, the three pseudo-components were described by *n*-order reactions. Both approaches resulted in nearly the same fit quality, but the physical meaning of the model, based on three *n*-order reactions, was found to be problematic. The reliability of the models was tested by checking how well the experiments with higher heating rates can be described by the kinetic parameters obtained from the evaluation of a narrower subset of 10 experiments with slower heating. A table of data was calculated that may provide guidance about the extent of devolatilization at various temperature–residence time values during wood torrefaction.

A comparative assessment of wet torrefaction

Quang-Vu Bach [a], Khanh-Quang Tran [a], Roger A. Khalil [b], Øyvind Skreiberg [b], Gulaim Seisenbaeva [c]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway
[b] Department of Thermal Energy, SINTEF Energy Research, NO-7465 Trondheim, Norway
[c] Department of Chemistry, Swedish University of Agricultural Sciences, SE-75007 Uppsala, Sweden

Energy & Fuels, 2013, 27 (11), pp 6743–6753

DOI: 10.1021/ef401295w
D2.5.3 (Link to eRoom)

Abstract

Wet torrefaction of typical Norwegian biomass fuels was studied within the temperature window of 175–225 °C, using a benchtop autoclave reactor of 250 mL in volume from Parr Instrument. Two types of local biomass fuels were employed as feedstock, Norway spruce (softwood) and birch (hardwood). Effects of process parameters including pressure, reaction temperature, holding time, and feedstock particle size on the yield and properties of the solid products were investigated. It appears that birch wood is more reactive and produces less solid products than spruce wood in the same wet torrefaction conditions. Increasing pressure above the saturated vapor pressure of water enhances the torrefaction rate. Both reaction temperature and holding time have significant effects on solid product yield and fuel properties of wet torrefied biomass. The yield of solid products is slightly reduced with decreasing feedstock particle size. The ash content of biomass fuel is significantly reduced by wet torrefaction. In addition, a comparison between wet and dry torrefaction supported by regression analyses and numerical predictions shows that wet torrefaction can produce solid fuels with greater heating values at much lower temperatures and shorter holding times.

Modeling of turbulent separated flows using OpenFOAM

D. Lysenko [a], I.S. Ertesvåg [a], K.E. Rian [b]

[a] Norwegian University of Science and Technology, Kolbjørn Hejes vei 1B, 7491-NO Trondheim, Norway
[b] Computational Industry Technologies AS, 7462-NO Trondheim, Norway

Computers and Fluids
Volume 80, 10 July 2013, pp. 408–422

DOI: 10.1016/j.compfluid.2012.01.015
D2.1.13_11 (Link to eRoom)

Abstract

Turbulent separated planar bluff-body flows were numerically analyzed using the state-of-the-art OpenFOAM and ANSYS FLUENT technologies, based on the conventional URANS approach. Several popular in fluid dynamics test problems such as laminar and turbulent flows over a circular cylinder and turbulent fully developed flows over a triangular cylinder in a channel were numerically replicated with the goal of validation of the selected numerical methods. The detailed, face-to-face comparison between OpenFOAM, FLUENT and experimental data was discussed. Parallel performance in the terms of a strong and weak scalability was assessed up to 1024 cores and compared as well. In general, the present results demonstrated minimum deviations between OpenFOAM and FLUENT and agreed fairly well with the experimental data and other numerical solutions.

- 2012 -

Numerical investigation of particles turbulent dispersion in channel flow

Tian Li, Li-Hao Zhao, Xiaoke Ku, Helge Andersson, Terese Løvås

Department of Energy and Process Engineering, Norwegian University of Science and Technology, Trondheim, Norway

Thermal Science
Volume 16, Issue 5, pp. 1510-1514

DOI: 10.2298/TSCI1205510L
D2.1.18 (Link to eRoom)

Abstract

This paper investigates the performance of Reynolds-averaged Navier-Stokes model on dispersion of particles in wall turbulence. A direct numerical simulation of wall-bounded channel flow with particles suspensions was set as a benchmark. The standard k-ω model coupled with two different eddy interaction models was used in Reynolds-averaged Navier-Stokes model and compared to the direct numerical simulation. Detailed comparisons between direct numerical simulation and Reynolds-averaged Navier-Stokes model on particle distribution evolving over time were carried out.

Eulerian-Lagrangian simulation of a bubbling fluidized bed reactor: Assessment of drag force correlations

Xiaoke Ku, Tian Li, Terese Løvås

Department of Energy and Process Engineering, Norwegian University of Science and Technology, Trondheim, Norway

Thermal Science
Year 2012, Vol. 16, No. 5, pp. 1442-1445

DOI: 10.2298/TSCI1205442K
D2.1.17 (Link to eRoom)

Abstract

An Eulerian-Lagrangian approach is developed within the OpenFOAM framework to investigate the effects of three well-known inter-phase drag force correlations on the fluidization behavior in a bubbling fluidized bed reactor. The results show a strong dependency on the restitution coefficient and the friction coefficient and no occurrence of bubbling and slugging for the ideal-collision case. The mean pressure drops predicted by the three models agree quite well with each other.

Enhanced NOx Reduction by Combined Staged Air and Flue Gas Recirculation in Biomass Grate Combustion

Ehsan Houshfar [a], *Roger Antoine Khalil* [b], *Terese Løvås* [a], *Øyvind Skreiberg* [b]

[a] Norwegian University of Science and Technology (NTNU), Department of Energy and Process Engineering, NO-7491, Trondheim, Norway
[b] SINTEF Energy Research, Department of Thermal Energy, NO-7465, Trondheim, Norway

Energy & Fuels
2012, 26 (5), pp. 3003–3011

DOI: [10.1021/ef300199g](10.1021/ef300199g)
D_KRAV: (Link to eRoom)

Abstract

Flue gas recirculation (FGR) is a conventional means of reducing NO_x emissions that involves lowering the peak flame temperature and reducing the oxygen concentration in the combustion region. Staged air combustion is also an effective means of NO_x reduction, especially in biomass combustion. This article reports results on NO_x emissions in a set of experiments combining FGR and staged air combustion in a grate-fired laboratory-scale reactor. Two different compositions of the recirculated flue gas were used: CO_2 and CO_2 + NO. The CO_2 concentration varied between 0–8 vol % of the total inlet flow rate and the NO concentration varied between 0 and 64 ppm. Two different FGR locations were also tested: above and below the grate. The results are compared with a reference experiment performed without FGR. The NO_x reduction level from staged air combustion at the optimal primary excess air ratio is ~70%, while employing FGR can reduce the NO_x emissions by an additional 5%–10%. The optimal primary excess air ratio range is 0.9–1. However, FGR more effectively reduces NO_x when employed outside of the optimum primary excess air ratio range, i.e., excess air ratios higher than 1 and less than 0.9. The experiments with FGR located above the grate exhibit higher reduction potential, while FGR located below the grate produces decreased reduction. The recycled-NO conversion factor, which gives a measure of maximal FGR efficiency, at the maximum point, is nearly 100% when FGR is applied below the grate and is 85%–100% in the case of recirculation above the grate.

NOx Emission Reduction by Staged Combustion in Grate Combustion of Biomass Fuels and Fuel Mixtures

Ehsan Houshfar [a], Øyvind Skreiberg [b], Dušan Todorovic [c], Alexandra Skreiberg [b], Terese Løvås [a], Aleksandar Jovovic [c] and Lars Sørum [b]

[a] Norwegian University of Science and Technology (NTNU), Department of Energy and Process Engineering, Kolbjørn Hejes vei 1B, NO-7491 Trondheim, Norway
[b] SINTEF Energy Research, Postboks 4761 Sluppen, NO-7465 Trondheim, Norway
[c] University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11000 Belgrade, Serbia

Fuel
Volume 98, August 2012, pp. 29–40

DOI: 10.1016/j.fuel.2012.03.044
D_KRAV (Link to eRoom)

Abstract

NO_x and N_2O emissions have been investigated for different pelletized biomass fuels and fuel mixtures thereof both with and without air staging in a grate fired multi-fuel reactor. The fuels investigated are wood, demolition wood and coffee waste, and selected mixtures of these. The multi-fuel reactor was operated at close to constant operating conditions due to impactor (ELPI) measurements, with a total excess air ratio of about 1.6, and a primary excess air ratio of about 0.8 in the air staging experiments. The reactor set point temperature was held constant at 850 °C. NO_x emission levels as a function of air supply mode and fuel nitrogen content are reported, showing a large NO_x reduction potential, up to 91% and corresponding to less than 20 ppm NO_x at 11% O_2 for a fuel containing about 3 wt.% fuel-N, using air staging. The effect on N_2O, however, is adverse at the selected set point temperature and optimum primary excess air ratio for NO_x reduction. The effect of fuel mixing and fuel nitrogen content on the conversion of fuel nitrogen to NO_x is also reported and discussed. Fuel mixing has a positive influence on the NO_x emission level, but a negative influence on the overall conversion factor for fuel-N to NO_x and N_2O.

Reduced Chemical Kinetics Mechanisms for NOx Emission Prediction in Biomass Combustion

Ehsan Houshfar [a], Øyvind Skreiberg [b], Peter Glarborg [c] and Terese Løvås [a]

[a]Department of Energy and Process Engineering, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway
[b] SINTEF Energy Research, NO-7465 Trondheim, Norway
[c] Department of Chemical and Biochemical Engineering, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark

International Journal of Chemical Kinetics
Volume 44, Issue 4, April 2012, pp. 219–231

DOI: 10.1002/kin.20716
D_KRAV (Link to eRoom)

Abstract

Because of the complex composition of biomass, the chemical mechanism contains many different species and therefore a large number of reactions. Although biomass gas-phase combustion is fairly well researched and understood, the proposed mechanisms are still complex and need very long computational time and powerful hardware resources. A reduction of the mechanism for biomass volatile oxidation has therefore been performed to avoid these difficulties. The selected detailed mechanism in this study contains 81 species and 703 elementary reactions. Necessity analysis is used to determine which species and reactions are of less importance for the predictability of the final result and, hence, can be discarded. For validation, numerical results using the derived reduced mechanism are compared with the results obtained with the original detailed mechanism. The reduced mechanism contains much fewer reactions and chemical species, that is, 35 species and 198 reactions, corresponding to 72% reduction in the number of reactions and, therefore, improving the computational time considerably. Yet, the model based on the reduced mechanism predicts correctly concentrations of NO_x and CO that are essentially identical to those of the complete mechanism in the range of reaction conditions of interest, especially for the medium-temperature range. The reduced mechanism failed to predict the concentrations in the high- and low-temperature range. Therefore, two more reduced mechanisms are also proposed for the high- and low-temperature range with 26 and 52 species, respectively. The modeling conditions are selected in a way to mimic values in the range of temperature 700–1400°C, excess air ratio 0.8–3.3, and four different residence times: 1, 0.1, 0.01, and 0.001 s, since these variables are the main affecting parameters on NO_x emission.

Experimental Investigation on NOx Reduction by Primary Measures in Biomass Combustion: Straw, Peat, Sewage Sludge, Forest Residues, and Wood Pellets

Ehsan Houshfar [a], Terese Løvås [a] and Øyvind Skreiberg [b]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), Kolbjørn Hejes Vei 1B, Trondheim NO-7491, Norway
[b] SINTEF Energy Research, Trondheim NO-7465, Norway

Energies
2012, 5, 270-290

DOI: 10.3390/en5020270
D_KRAV (Link to eRoom)

Abstract

An experimental investigation was carried out to study the NO_x formation and reduction by primary measures for five types of biomass (straw, peat, sewage sludge, forest residues/Grot, and wood pellets) and their mixtures. To minimize the NO_x level in biomass-fired boilers, combustion experiments were performed in a laboratory scale multifuel fixed grate reactor using staged air combustion. Flue gas was extracted to measure final levels of CO, CO_2, C_xH_y, O_2, NO, NO_2, N_2O, and other species. The fuel gas compositions between the first and second stage were also monitored. The experiments showed good combustion quality with very low concentrations of unburnt species in the flue gas. Under optimum conditions, a NO_x reduction of 50–80% was achieved, where the highest reduction represents the case with the highest fuel-N content. The NO_x emission levels were very sensitive to the primary excess air ratio and an optimum value for primary excess air ratio was seen at about 0.9. Conversion of fuel nitrogen to NO_x showed great dependency on the initial fuel-N content, where the blend with the highest nitrogen content had lowest conversion rate. Between 1–25% of the fuel-N content is converted to NO_x depending on the fuel blend and excess air ratio. Sewage sludge is suggested as a favorable fuel to be blended with straw. It resulted in a higher NO_x reduction and low fuel-N conversion to NO_x. Tops and branches did not show desirable NO_x reduction and made the combustion also more unstable. N_2O emissions were very low, typically below 5 ppm at 11% O_2 in the dry flue gas, except for mixtures with high nitrogen content, where values up to 20 ppm were observed. The presented results are part of a larger study on problematic fuels, also considering ash content and corrosive compounds which have been discussed elsewhere.

Cost modeling approach and economic analysis of biomass gasification integrated solid oxide fuel cell systems

Kempegowda, Rajesh Shivanahalli [a]; Skreiberg, Øyvind [b]; Tran, Khanh-Quang [a]

[a] Department of Energy and Process Engineering, NTNU, 7491 Trondheim, Norway
[b] SINTEF Energy Research, 7491 Trondheim, Norway

Journal of Renewable and Sustainable Energy
Volume 4, Issue 4

DOI: 10.1063/1.4737920
D_KRAV (Link to eRoom)

Abstract

This paper presents a cost modeling approach and the economic feasibility for selected plant configurations operating under three modes: air gasification, mixed air-steam gasification, and steam gasification combined cycle solid oxide fuel cell (SOFC)systems. In this study, three cases of biomass gasification integrated SOFC without combined cycle (base case 1) are compared with biomass gasification integrated SOFC-gas turbine (GT) with heat recovery steam generator (HRSG) hybrid configuration (case 2) and biomass gasification integrated SOFC-steam turbine (ST) cycle (case 3) for biomass feed stock. The plant design cases of integrated biomass gasification processes, SOFC, and combined cycles are investigated primarily employing aspen plus™ flow sheeting models. Based on the mass and energy balance results of the system simulations, the economic model calculates the size and cost estimates for the plant configuration equipments. Detailed purchase cost estimations for each piece of equipments and the corresponding total bare module cost were established based on the bare module factor, and the total direct permanent investment were established. The calculated direct permanent investment was used for economic feasibility analysis of the cogeneration plant configuration. The economic feasibility decision parameters, such as purchase cost estimations, total specific plant cost per kW, the financial net present value (FNPV), internal rate of return, and benefit to cost ratio for the system configurations were compared for three design cases. The results shows that the cost of the steam gasification system is shown to be highest compared to the mixed air steam gasification system and air gasification system due to the higher hydrogen production. Other than the SOFC and gasification costs, a significant cost towards the heat exchangers is about 15% to 20% of the total equipment purchase cost. The specific plant cost for the air gasification varied from the 16 600 US$/kW to 19 200 US$/kWe. For the case of biomass gasification-integrated SOFC-GT configuration, the major cost portions are shared by the SOFC, HRSG, and gasifier. The HRSG equipment shared a cost portion of 25% to 30% for all the operating modes. The cost is decreased with a similar trend as that of steam, mixed air-steam and air gasification systems. For the case of biomass gasification integrated with SOFC-ST configuration, the total equipment purchase cost decreases at a rate of 15% to 20% for both mixed air steam and air gasification system. Plant specific cost for the steam gasification mode varied from 15 200 to 17 200 US $/kW which is significantly very high.

Techno-economic evaluations of various Biomass CHP technologies and policy measures under Norwegian conditions

Kempegowda, Rajesh Shivanahalli [a]; Skreiberg, Øyvind [b]; Tran, Khanh-Quang [a]

[a] Department of Energy and Process Engineering, NTNU, Kolbj¿rn Hejes vei 1A, 7491 Trondheim, Norway
[b] SINTEF Energy Research, Sem Saelends vei 11, 7465 Trondheim, Norway

Energy Procedia
Volume 20, 2012, pp. 1–10

DOI: 10.1016/j.egypro.2012.03.002
D_KRAV (Link to eRoom)

Abstract

This work deals with evaluations of different possible cost-effective small-scale combined heat and power (CHP) solutions based on biomass for the Norwegian market. Many CHP technologies and systems exist and can easily be proposed as candidates for introduction and/or widespread use in the Norwegian market. However, today they may be far from cost-effective given the current energy market and framework situation. These constraints can, however, change relatively fast. Hence, it is important to evaluate the feasibility of small-scale CHP technologies and systems in this perspective. What will the most promising small-scale CHP technologies based on biomass be in the near to medium term future? What are the limiting factors? What can be done to speed up the introduction of small-scale CHP solutions based on biomass in the Norwegian market? This work evaluates techno-economics of various CHP solutions based on biomass in the Norwegian market. Traditional financial indicators such as financial internal rate of return and net present value are used to assess the solutions. The methodology includes the following sequential steps: estimation of the economic production costs of various options for biomass CHP for power and heat generation and sorting these options in ascending order of costs to present the supply curve to meet the national target. Finally, the analysis includes various incentive schemes, feed-in tariffs/green certificates, investment based tax exemptions (8 years for each technology), prolonged tax exemption (+5 years for each technology), investment subsidies (in % for each technology) and low-interest loans (decided for each technology). Based on the evaluations, MSW backpressure turbine, biogas engine and industrial backpressure turbine are profitable without any subsidy under Norwegian framework conditions. With additional subsidy from grid deduction fee and green certificates, district heat ORC, district heat backpressure turbine and gasification with micro gas turbine are feasible with profitability of internal rate of return above 11%. Other gasification technologies are feasible under prevailing market conditions. In addition, a cost supply curve is generated for 10 years framework conditions based on the planned CHP installations.

Process synthesis and economics of combined biomethanol and CHP energy production derived frombiomass wastes

Kempegowda, Rajesh Shivanahalli [a]; Selvam, P V Pannir [b]; Skreiberg, Øyvind [c]; Tran, Khanh-Quang [a]

[a] Department of Energy & Process Engineering, NTNU, Trondheim, Norway.
[b] DEQ – Departamento de Engenharia Quimica, CT – Centro de Tecnologia/UFRN, Lagoa Nova – Natal/RN, Campus Universitario. CEP: 59.072-970, North East, Brazil
[c] SINTEF Energy Research, Trondheim, Norwa

Journal of chemical technology and biotechnology
July 2012, Volume 87, Issue 7, pp. 897–902

DOI: 10.1002/jctb.3696/abstract
D_KRAV (Link to eRoom)

Abstract

BACKGROUND: This paper reports on process synthesis and economics of combined methanol and CHP (combined heat and power) energy production from crude biooil, waste glycerol produced in biodiesel factories and biomass wastes using integrated reactor design for hydrogen rich syngas. This new process consists of three process steps: (a) pyrolysis of organic waste material to produce biooil, char and pyrogas; (b) steam assisted hydrogasification of the crude glycerol wastes, biooil mixed with pyrogas for hydrogen rich gas; and (c) a low temperature methanol synthesis process. The H_2-rich gas remaining after methanol synthesis is recycled back to the pyrolysis reactor, the catalytic hydro-gasification process and the heat recovery steam generator (HRSG).

RESULTS: The breakeven price of the Hbiomethanol process yields positive net financial NPV and IRR above 600 USD per tonne. The total capital cost for a small-scale methanol plant of capacity 2 tonne h^{-1} combined with a cogeneration plant of capacity 2 MWe power is estimated to be 170.5 million USD.

CONCLUSION: Recycling gas allows the methanol synthesis reactor to perform at a relatively lower pressure than conventionally while the plant still maintains a high methanol yield. The integrated hydrogasification reactor and energy recovery design process minimizes heat loss and increases the process thermal efficiency. The Hbiomethanol process can convert any condensed carbonaceous material and liquid wastes, to produce methanol and CHP.

Large-eddy simulation of the flow over a circular cylinder at Reynolds number 3900 using the OpenFOAM toolbox

Dmitry A. Lysenko [a], *Ivar S. Ertesvåg* [a], *Kjell Erik Rian* [b]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology, Kolbjørn Hejes vei 1B, Trondheim 7491, Norway
[b] Computational Industry Technologies AS, Trondheim 7462, Norway

Springer
December 2012, Volume 89, Issue 4, pp. 491-518

DOI: 10.1007/s10494-012-9405-0
D2.1.13_12 (Link to eRoom)

Abstract

The flow over a circular cylinder at Reynolds number 3900 and Mach number 0.2 was predicted numerically using the technique of large-eddy simulation. The computations were carried out with an O-type curvilinear grid of size of 300 × 300 × 64. The numerical simulations were performed using a second-order finite-volume method with central-difference schemes for the approximation of convective terms. A conventional Smagorinsky and a dynamic *k*-equation eddy viscosity sub-grid scale models were applied. The integration time interval for data sampling was extended up to 150 vortex shedding periods for the purpose of obtaining a fully converged mean flow field. The present numerical results were found to be in good agreement with existing experimental data and previously obtained large-eddy simulation results. This gives an indication on the adequacy and accuracy of the selected large-eddy simulation technique implemented in the OpenFOAM toolbox.

Sintering Characteristics of Sewage Sludge Ashes at Elevated Temperatures

Liang Wang, Geir Skjevrak, Johan E. Hustad, Morten Grønli

Department of Energy and Process Engineering, Norwegian University of Science and Technology, Kolbjørn Hejes vei 1A, 7491, Trondheim, Norway

Fuel Processing Technology
Volume 96, April 2012, pp. 88–97

DOI: 10.1016/j.fuproc.2011.12.022
D2.1.13_13 (Link to eRoom)

Abstract

In this work the sintering characteristics and mineral transformation behaviors of sewage sludge ash (SSA) at elevated temperatures were investigated by using ash fusion analyzer, X-ray fluorescence (XRF), X-ray diffraction (XRD) and scanning electron microscopy equipped with energy dispersive X-ray spectrometry (SEM/EDX). High initial fusion temperatures above 1100 °C were detected from the sewage sludge ashes (SSA 1 and SSA 2) with high Al contents. Corundum, quartz and calcium aluminum silicates were dominating crystalline phases identified from SSA 1 and SSA 2 sintered at elevated temperatures. For the SSA 3 with a high Fe content, low initial melting temperature of 994 °C was detected with observation of severe fusion behavior from the ash sintering tests. SEM analysis revealed that SSA 3 melted completely into a more homogeneous and continuous phase at high sintering temperatures. A significant amount of Fe bearing mineral phases and quartz (SiO_2) was identified from the sintered SSA 3. Diffraction intensities of hematite (Fe_2O_3), quartz (SiO_2) and alkali feldspar decreased with increasing sintering temperatures, suggesting interaction and re-assemblage of these mineral phases. In combining the XRD and SEM/EDX analyses, it is believed that formation of low melting temperature iron silicates is the main reason for sintering of SSA 3.

Sintering Characteristics and Mineral Transformation Behaviors of Corn Cob Ashes

Liang Wang, Johan E. Hustad, Morten Grønli

Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway

Energy & Fuels
2012, 26 (9), pp. 5905–5916

DOI: 10.1021/ef300215x
D2.1.13_14 (Link to eRoom)

Abstract

The aim of this work was to investigate the sintering characteristics and mineral transformation behaviors of three corn cob ashes using a combination of inductively coupled plasma–atomic emission spectroscopy (ICP–AES), ash fusion analysis, X-ray diffraction (XRD), and scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM–EDX). The sintering degrees of the corn cob ashes at elevated temperatures were graded by performing laboratory-scale sintering tests. The WCob ash has a significantly low melting temperature of 834 °C and showed severe sintering behaviors during testing. The SEM–EDX and XRD analyses revealed that the fused WCob ash consisted of a mixture of potassium-rich silicate–phosphate melts. The WCob is dominated by potassium, silicon, and phosphorus, along with small amounts of alkali earth metals. Therefore, the formation and melting of potassium-rich silicates and phosphates are favored, causing severe sintering of the WCob ash at elevated temperatures. In contrast, a relatively higher melting temperature of 998 °C and a moderate sintering degree were observed from the PCob ash. High contents of chlorine, calcium, and magnesium in the PCob may promote potassium release from ash residues, instead of being incorporated into the silicate and phosphate structures. This process could inhibit the formation of low-temperature-melting silicates and phosphates and reduce ash sintering consequently. The abundance of calcium and magnesium in the PCob also led to the formation of high-temperature-melting silicates and phosphates, restraining ash melt formation and the extent of ash sintering. Results from the experimental work and analyses indicate that the combustion of corn cob may be challenging because of ash sintering. The transformation and melting behaviors of corn cob ashes are highly dependent upon the fuel compositions.

Thermal Characterization of Uganda's Acacia Hockii, Combretum Molle, Eucalyptus Grandis and Terminalia Glaucescens for Gasification

Wilson Babu Musinguzi [a], Mackay A.E. Okure [a], Liang Wang [b], Adam Sebbit [a], Terese Løvås [b]

[a] School of Engineering, Makerere University, P.O. Box 7062, Kampala, Uganda
[b] Department of Energy and Process Engineering, NTNU, Kolbjørn Hejes vei 1B, 7491 Trondheim, Norway

Biomass & Bioenergy
Volume 46, November 2012, pp. 402–408

DOI: 10.1016/j.biombioe.2012.08.001
D2.1.13_15 (Link to eRoom)

Abstract

In this paper, thermal characterization of four Ugandan woody biomass species was carried out in order to ascertain their suitability for gasification for small-scale biopower generation. The analyses and tests covered the aspects of proximate analysis, ultimate analysis, heating value, Thermogravimetric Analyses (TGA), ash melting and chemical composition. *Eucalyptus grandis* revealed ideal properties that make it the most promising wood specie for gasification applications. Furthermore, the low ash content in *E. grandis* significantly minimizes the possibilities of ash deposits on the gasifier and heat exchanger surfaces. The high fixed carbon in *Terminalia glaucescens*, *Acacia hockii* and *Combretum molle* makes these species ideal for charcoal making (pyrolysis). Due to high ash melting temperatures demonstrated by these samples, their pyrolysis and gasification can therefore take place with minimal worry of the ash related problems.

The effect of kaolin on the combustion of demolition wood under well-controlled conditions

Khalil R. [a], Todorovic D. [b], Skreiberg Ø. [a], Becidan M. [a], Backman R. [a], Goile F. [a], Skreiberg A. [a] and Sørum L. [a]

[1] SINTEF Energy Research, Department of Energy Processes, Trondheim, Norway
[2] Faculty of Mechanical Engineering, University of Belgrade, Belgrade, Serbia

Waste Management and Research
July 2012 vol. 30 no. 7, pp. 672-680

DOI: [10.1177/0734242X11427942](10.1177/0734242X11427942)
D2.1.13_2 (Link to eRoom)

Abstract

In an attempt to look at means for reduction of corrosion in boilers, combustion experiments are performed on demolition wood with kaolin as additive. The experiments were performed in a multi-fuel reactor with continuous feed of pellets and by applying staged air combustion. A total characterization of the elemental composition of the fuel, the bottom ash and some particle size stages of fly ash was performed. This was done in order to follow the fate of some of the problematic compounds in demolition wood as a function of kaolin addition and other combustion-related parameters. In particular chlorine and potassium distribution between the gas phase, the bottom ash and the fly ash is reported as a function of increased kaolin addition, reactor temperature and air staging. Kaolin addition of 5 and 10% were found to give the least aerosol load in the fly ash. In addition, the chlorine concentration in aerosol particles was at its lowest levels for the same addition of kaolin, although the difference between 5 and 10% addition was minimal. The reactor temperature was found to have a minimal effect on both the fly ash and bottom ash properties.

Ash related behaviour in staged and non-staged combustion of biomass fuels and fuel mixtures

Becidan M. [a], Todorovic D. [b], Skreiberg Ø. [a], Khalil R. [a], Backman R. [a], Goile F. [a], Skreiberg A. [a], Jovovic A. [b] and Sørum L. [a]

[a] SINTEF Energy Research, Kolbjørn Hejes vei 1A, NO-7465 Trondheim, Norway
[b] University of Belgrade, Faculty of Mechanical Engineering, 11000 Belgrade, Serbia

Biomass and Bioenergy
Volume 41, June 2012, pp. 86–93

DOI: 10.1016/j.biombioe.2012.02.005
D2.1.13_5 (Link to eRoom)

Abstract

The fate of selected elements (with focus on the important players in corrosion i.e. Na, K, Pb, Zn, Cl and S) are investigated for three biomasses (wood, demolition wood and coffee waste) and six mixtures of these as pellets both with and without air staging in a laboratory reactor. In order to get a complete overview of the combustion products, both online and offline analytical methods are used. Information is collected about: flue gas composition, particle (fly ash) size distribution and composition, bottom ash composition and melting properties. The main findings are: (1) complex interactions are taking place between the mixed fuels during combustion; (2) the mode of occurrence of an element as well as the overall structure of the fuel are important for speciation; (3) the pelletisation process, by bringing chemical elements into intimate contact, may affect partitioning and speciation; (4) staging and mixing might simultaneously have positive and negative effects on operation; (5) staging affects the governing mechanisms of fly ash (aerosols) formation.

A Critical Review on Additives to Reduce Ash Related Operation Problems in Biomass Combustion Applications

Liang Wang [a], Johan E. Hustad [a], Øyvind Skreiberg [b], Geir Skjevrak [a], Morten G. Grønli. [a]

[a] Norwegian University of Science and Technology, Kolbjørn Hejes vei 1A, 7491 Trondhiem, Norway
[b] SINTEF Energy Research, Sem Saelends vei 11, 7465 Trondheim, Norway

Energy Procedia
Volume 20, 2012, pp. 20–29

DOI: 10.1016/j.egypro.2012.03.004
D2.1.13_6 (Link to eRoom)

Abstract

Biomass combustion has a huge potential to produce power and heat in a sustainable way. However, some biomass fuels have high potassium contents, which react with other ash forming elements (i.e. Cl, Si, P and S) and lead to different ash related operational problems. Utilization of additives to abate these problems have been studied and tested for several decades. This work reviews current knowledge and studies about properties and effects of additives reported in the literature. Various additives can mitigate ash related issues by the following possible mechanisms: 1) capturing problematic ash species via chemical adsorption and reactions, 2) physical adsorption and elutriating troublesome ash species from combustion facilities, 3) increasing the biomass ash melting temperature by enhancing inert elements/compounds in ash residues, and 4) restraining biomass ash sintering by diluting and powdering effects from the additives. Additives are grouped according to the contained reactive compounds, including Al-silicates based additives, sulphur based additives, calcium based additives, and phosphorous based additives. Additives with strong chemical adsorption and reaction capacities can minimize K related ash sintering, deposition and slagging during biomass combustion processes. The effective chemical reaction mechanisms are closely related to K-Al-Si, K-Ca-Si and K-Ca-P systems. The capacities of additives to reduce ash related problems are heavily influenced by mass/molar ratios between the reactive components in the additives and the problematic elements in the biomass ash, as well as the reaction atmosphere and combustion technology. More detailed studies on high temperature reactions between additives and ashes from biomass combustion are needed.

Effects of additives on barley straw and husk ashes sintering characteristics

Liang Wang [a], Geir Skjevrak [a], Johan E. Hustad [a], Morten G. Grønli [a], Øyvind Skreiberg [b]

[a] Norwegian University of Science and Technology, Kolbjørn Hejes vei 1A, 7491 Trondheim, Norway
[b] SINTEF Energy Research, Sem Saelands vei 11, 7465 Trondheim, Norway

Energy Procedia
Volume 20, 2012, pp. 30–39

DOI: 10.1016/j.egypro.2012.03.005
D2.1.13_7 (Link to eRoom)

Abstract

A growing interest has been observed for producing sustainable heat and power by combustion of residues from local agricultural production. However, ash related problems are inclined to occur due to high contents of problematic ash forming matter in such residues. The aims of this work were to examine ash characteristics of barley straw and husk and to find mixtures of fuels and additives that can be used as basis for producing pellets giving minimal problems during combustion. Influence of kaolin and calcite additives on the two fuel ashes' sintering behaviors were investigated by X-ray fluorescence (XRF), ash fusion analyzer and X-ray diffraction (XRD) analysis. The results showed that, compared to barley straw ash, the barley husk ash has a higher sintering tendency, with observation of severe melting during combustion. Kaolin and calcite addition increased the melting temperatures of ashes from both barley straw and husk. Reactions between kaolin and potassium containing species in the barley straw and husk ashes were revealed by XRD analyses. With formation of high temperature melting species due to kaolin addition, the severe sintering of barley straw and husk ashes were significantly reduced. The dilution effect from calcite is supposed to be a main reason for improved barley straw and husk ash sintering behaviors. In addition, calcite addition led to formation of more calcium rich phases, which have higher melting points and contribute to low ash sintering degrees. Therefore, by using the additives, agricultural residues can be competitive for energy production in the future.

Sintering behavior of agricultural residues ashes and effects of additives

Liang Wang, Michaël Becidan, Øyvind Skreiberg

SINTEF Energy Research, Sem Sælands vei 11, Trondheim, Norway

Energy & Fuels
2012, 26 (9), pp. 5917–5929

DOI: [10.1021/ef3004366](10.1021/ef3004366)
D2.1.6 (Link to eRoom)

Abstract

In this work the ash sintering behaviors and effects of aluminum silicates based additives (kaolin, zeolite 24A, and zeolite Y) during combustion of wheat straw and barley husk were investigated. The sintering degrees of fuel ashes and corresponding mixtures with additives were evaluated by performing standard ash fusion tests and laboratory scale sintering tests. The ash chemistry and microstructures were investigated by a combination of X-ray diffraction (XRD) and SEM-EDX analyses. It was found that the wheat straw and barley husk ashes have high sintering and melting tendencies. At elevated temperatures, formation and fusion of low temperature melting potassium salts and potassium silicates contributed to severe sintering of the two fuel ashes. Sintering of the barley husk ash is also associated with the presence of low melting points potassium phosphates with high K/Ca ratios. The experimental results from investigating the reactions between additives and KCl showed that kaolin and zeolite 24A can both bind KCl with formation of different potassium aluminum silicates. No clear reactions between zeolite Y and KCl were observed. Both kaolin and zeolite 24A were effective to increase sintering temperatures of the wheat straw and barley husk ashes. The reactions between kaolin and zeolite 24A with potassium containing species in the two reference ashes were revealed by XRD and SEM-EDX analyses. Identification of high temperature melting potassium aluminum silicates partially explains the higher sintering and melting temperatures of the ash-additives mixtures. Zeolite Y showed a poor ability to abate sintering of the studied ashes in this work.

Kinetics of Corncob Pyrolysis

Marta Trninic [a], Liang Wang [b], Gábor Várhegyi [c], Morten Grønli [b] and Øyvind Skreiberg [d]

[a] Department of Process Engineering, Faculty of Mechanical Engineering, University of Belgrade, Kraljice Marije 16, 11000 Belgrade, Serbia
[b] Norwegian University of Science and Technology, Department of Energy and Process Engineering, Kolbjørn Hejes vei 1A, 7491 Trondheim, Norway
[c] Institute of Materials and Environmental Chemistry, Research Centre for Natural Sciences, Hungarian Academy of Sciences, PO Box 17, Budapest, Hungary 1525
[d] SINTEF Energy Research, Sem Saelands vei 11, 7465 Trondheim, Norway

Energy & Fuels
2012, 26 (4), pp. 2005–2013

DOI: 10.1021/ef3002668
D2.3.8 (Link to eRoom)

Abstract

Two different corncob samples from different continents and climates were studied by thermogravimetry at linear and nonlinear heating programs in inert gas flow. A distributed activation energy model (DAEM) with three and four pools of reactants (pseudocomponents) was used due to the complexity of the biomass samples of agricultural origin. The resulting models described well the experimental data. When the evaluation was based on a smaller number of experiments, similar model parameters were obtained which were suitable for predicting experiments at higher heating rates. This test indicates that the available experimental information was sufficient for the determination of the model parameters. The checks on the prediction capabilities were considered to be an essential part of the model verification. In another test, the experiments of the two samples were evaluated together, assuming more or less common kinetic parameters for both cobs. This test revealed that the reactivity differences between the two samples are due to the differences in their hemicelluloses and extractives. The kinetic parameter values from a similar earlier work on other biomasses (Várhegyi, G.; Bobály, B.; Jakab, E.; Chen, H. *Energy Fuels*, **2011**, *25*, 24–32) could also been used, indicating the possibilities of a common kinetic model for the pyrolysis of a wide range of agricultural byproduct.

Impact of steam explosion on biogas production from rape straw in relation to changes in chemical composition

Vivekanand Vivekanand [a], Peter Ryden [b], Svein J. Horn [a], Henri S. Tapp [c], Nikolaus Wellner [d], Vincent G.H. Eijsink [a], Keith W. Waldron [b]

[a] Department of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences, P.O. Box 5003, N-1432 Ås, Norway
[b] Biorefinery Centre, Institute of Food Research, Norwich Research Park, Colney, Norwich NR4 7UA, United Kingdom
[c] Bioinformatics and Statistics Group, Institute of Food Research, Norwich Research Park, Colney, Norwich NR4 7UA, United Kingdom
[d] Imaging Partnership, Institute of Food Research, Norwich Research Park, Colney, Norwich NR4 7UA, United Kingdom

Bioresource Technology
Volume 123, November 2012, pp. 608–615

DOI: 10.1016/j.biortech.2012.06.088
D2.4.18 (Link to eRoom)

Abstract

An 81 day trial compared the cumulative production of methane from rape straw pre-treated by steam explosion at 15 levels of severity. The final methane yields were similar. The temporal variation in production rate exhibited two peaks: maximum production occurred in the first peak at around 21 days with heights that increased with severity; the height of the second peak reduced with severity and peaked between 32 and 36 days. Changes in the straw composition were investigated using mid-infrared spectroscopy. These were also strongly related to the degree of severity, allowing good predictive models to be built of severity and subsequently the rate of methane production. The main spectral changes showed the degradation of cellulose and xylose-containing hemicelluloses and production of furfural-like components commonly associated with biomass pre-treatments. Only small changes to lignin were associated with increased methane generation suggesting a structural rather than chemical role in this process.

Torrefaction of Norwegian birch and spruce – An experimental study using macro-TGA

Dhruv Tapasvi [a], Roger A. Khalil [b], Øyvind Skreiberg [b], Khanh-Quang Tran [a], Morten G. Grønli. [a]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway
[b] Department of Thermal Energy, SINTEF Energy Research, NO-7465 Trondheim, Norway

Energy & Fuels
2012, 26 (8), pp. 5232–5240

DOI: 10.1021/ef300993q
D2.5.1_1 (Link to eRoom)

Abstract

This work aims to analyze the torrefaction process with Norwegian birch and spruce as feedstocks. Torrefaction experiments were performed in a macro-TGA (thermogravimetric analysis) reactor with provisions for continuous volatile measurements through micro-GC (gas chromatography) and FTIR (Fourier transform infrared spectroscopy). The process temperature (225 and 275 °C), holdup time (30 and 60 min), and sample size (10 and 40 mm cubes) were included as variations in the experimental matrix. Fuel characterizations, DTG (derivative thermogravimetric) curves, product yields, hydrophobicity tests, grinding energies, and particle-size distributions are discussed. The raw fuels were used as a reference for the comparisons. It was found that the birch has a higher devolatilization rate than the spruce under all tested conditions, resulting in a larger percentage increase in its carbon content. An increase in the temperature has the strongest effect on the properties of the torrefied product among all of the studied parameters. At 275 °C, the solid yield decreased to 63% and 75% for the torrefied birch and spruce, respectively. In terms of torrefied product properties, the torrefied samples absorbed approximately one-third of the moisture compared to the raw fuels. The total grinding energy decreased up to 40–88% for the torrefied samples of both feedstocks. An increased percentage of fine particles (<180 μm) was found in the particle-size distributions of most of the torrefied samples. Overall, considerable improvements were observed in the properties of the torrefied products for both feedstocks. Results obtained from this study form the basis of a torrefaction feasibility study in Norway.

- 2011 -

Experimental Investigation on Corrosion Abatement in Straw Combustion by Fuel Mixing

Roger A. Khalil [a], Ehsan Houshfar [b], Wilson Musinguzi [b], Michaël Becidan [a], Øyvind Skreiberg [a], Franziska Goile [a], Terese Løvås [b], Lars Sørum [a]

[a] Department of Energy Processes, SINTEF Energy Research, NO-7465 Trondheim, Norway
[b] Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway

Energy & Fuels
2011, 25 (6), pp. 2687–2695

DOI: 10.1021/ef200232r
D2.1.13_1 (Link to eRoom)

Abstract

In an attempt to minimize corrosion in biomass-fired boilers, combustion experiments were performed using binary mixtures of straw with peat, sewage sludge, or grot (branches and treetops). The mixing ratios were carefully selected using literature and thermodynamic calculations. All mixtures were pelletized. The combustion experiments were performed in a laboratory-scale multi-fuel reactor. Extensive analytical analysis of the system included the gas concentration and particle size distribution in the flue gas, the elemental composition of the fuel, and the bottom ash and specific particle size fractions of fly ash. This allowed for the determination of the fate of the main corrosive compounds, in particular, chlorine. The corrosion risk associated with the three fuel mixtures was quite different. Grot was found to be a poor corrosion-reduction additive because of its marginal influence on the chlorine share in aerosols. Grot could not serve as an alternative fuel for co-firing with straw either because no dilution effect on the particle load was measured. Peat was found to reduce the corrosive compounds only at high peat additions (50 wt %). Sewage sludge was the best alternative for corrosion reduction because 10 wt % addition almost eliminated chlorine from the fly ash.

Effects of Sewage Sludge and Marble Sludge Addition on Slag Characteristics during Wood Waste Pellets Combustion

Liang Wang, Geir Skjevrak, Johan E. Hustad, Morten Grønli

Department of Energy and Process Engineering, Norwegian University of Science and Technology, Trondheim, Norway

Energy & Fuels
2011, 25 (12), pp. 5775–5785

DOI: 10.1021/ef2007722
D2.1.13_16 (Link to eRoom)

Abstract

The objectives of the present work were to investigate the effects of sewage sludge and marble sludge addition on slagging tendency and obtain better understandings for slag formation processes during the combustion of problematic wood waste pellets. Wood waste pellets produced with and without additives were combusted in a boiler (1.2 MW_{th}) with continuous measurements of the combustion temperature and flue gas composition. The chemical composition, mineral phase, and microchemistry of the collected bottom ash and slag were examined by X-ray fluorescence (XRF), X-ray diffraction (XRD), and scanning electron microscopy coupled with energy dispersive X-ray analysis (SEM/EDX). Reference wood waste pellets showed a high slagging tendency with 34 wt % of the ingoing fuel ash formed as slag on the grate. XRF and SEM/EDX analyses revealed high contents of Si, K, and Na in the slag and a clear correlation among the three elements. It implies melted fractions of the slag consist of alkali silicates indirectly observed as glass phases by XRD analysis. The severe slagging of wood waste pellets was reduced distinctly upon addition of marble sludge. For two marble sludge added combustion tests, less than 3 wt % of the ingoing fuel ash formed as low sintering degrees slag. The mineral compositions of the resultant slag were changed from low melting point silicates to high temperature melting calcium based silicates, oxides, and hydroxides. SEM/EDX revealed enhancement of Ca and Mg in the melted slag, which were possibly originated from marble sludge and dissolved in ash melts. This may lead to release of alkali metals from the ash melts thereby reducing the formed melt amount. In addition, marble sludge addition restrained sintering and accumulation of melted ash into a continuous phase and resulted in fragile slag particles. Addition of 4 wt % sewage sludge has a minor effect on the slag formation of wood waste pellets combustion. The sizes and sintering degrees of the formed slag were considerably decreased and the mineral compositions in the slag were dominated by high temperature melting corundum and calcium silicates. The enrichment of kalsilite observed in the slag was probably caused by the reactions of aluminum silicates in the sewage sludge with potassium from the fuel. The corundum, calcium silicates, and kalsilite have higher melting temperatures and thus gave a lower ash melt fraction in the slag. However, as a result of the addition of sewage sludge, both the ash content and the Si level of ingoing fuel pellets were enhanced. Thereby the formed slag amount increased slightly for the combustion of the 8 wt % sewage sludge blended wood waste pellets.

Optimal mixtures to reduce the formation of corrosive compounds during straw combustion: a thermodynamic analysis

Michaël Becidan [a], Ehsan Houshfar [b], Roger A. Khalil [a], Øyvind Skreiberg [a], Terese Løvås [b], Lars Sørum [b]

[a] Department of Energy Processes, SINTEF Energy Research, NO-7465 Trondheim, Norway
[b] Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway

Energy & Fuels
2011, 25 (7), pp. 3223–3234

DOI: 10.1021/ef2002475
D2.1.13_4 (Link to eRoom)

Abstract

The thermodynamic analysis carried out focuses on biomass mixing to reduce the formation of corrosive (mainly alkali) chlorides during straw combustion. The calculations confirm the reduction abilities of sewage sludge and peat and provide information on the addition levels at which no corrosive compounds are expected to form. The calculations provide insight into the mechanisms responsible for the disappearance of alkali chlorides. The mechanisms that can potentially take place are known (reaction with sulfur and reaction with or adsorption on aluminosilicates or other ash compounds). However, many aspects remain unclear, and calculations cast light on several of them. The main result obtained in this study is that, in a given binary mixture, the chemical elements involved in the decomposition of corrosive alkali chlorides (or preventing them from forming) change with the mixing proportions, an important fact never mentioned to our knowledge. The practical implications are significant: in a real system, local elemental concentrations will vary; this means that several mechanisms will simultaneously fight the formation of corrosive alkali compounds. This new result may explain why the experimental results from the literature are often confusing or even contradictory even for a given mixture; the overall chemical picture is not static. The chemical elements reacting with alkalis during co-combustion of straw with sewage sludge or peat are predicted to be S, Ca–S, and aluminosilicates.

Effect of Excess Air Ratio and Temperature on NOx Emission from Grate Combustion of Biomass in the Staged Air Combustion Scenario

Ehsan Houshfar [a], Øyvind Skreiberg [b], Terese Løvås [a], Dušan Todorovic [c] and Lars Sørum [b]

[a] Norwegian University of Science and Technology (NTNU), Department of Energy and Process Engineering, Kolbjørn Hejes vei 1B, NO-7491 Trondheim, Norway
[b] SINTEF Energy Research, Postboks 4761 Sluppen, NO-7465 Trondheim, Norway
[c] University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11000 Belgrade, Serbia

Energy & Fuels
2011, 25 (10), pp. 4643–4654

DOI: 10.1021/ef200714d
D2.1.2 (Link to eRoom)

Abstract

The combustion of biomass, in this case demolition wood, has been investigated in a grate combustion multifuel reactor. In this work a temperature range of 850–1000 °C is applied both for staged air combustion and nonstaged combustion of biomass to investigate the effects of these parameters on the emission levels of NOx, N_2O, CO, hydrocarbons (C_xH_y) and different other components. The composition of the flue gas is measured by four advanced continuous gas analyzers including gas chromatograph (GC), two Fourier transform infrared (FTIR) analyzers, and a conventional multispecies gas analyzer with fast response time. The experiments show the effects of staged air combustion, compared to nonstaged combustion, on the emission levels clearly. A NOx reduction of up to 85% is reached with staged air combustion. An optimum primary excess air ratio of 0.8–0.95 is found as a minimizing parameter for the NOx emissions for staged air combustion. Air staging has, however, a negative effect on N_2O emissions. Even though the trends show a very small reduction in the NOx level as temperature increases in nonstaged combustion, the effect of temperature is not significant for NOx and C_xH_y, neither in staged air combustion or nonstaged combustion, while it has a great influence on the N_2O and CO emissions, with decreasing levels with increasing temperature.

Is Elevated Pressure Required To Achieve a High Fixed-Carbon Yield of Charcoal from Biomass? Part 1: Round-Robin Results for Three Different Corncob Materials

Liang Wang [a], Marta Trninic [b], Øyvind Skreiberg [c], Morten Gronli [a], Roland Considine [d] and Michael Jerry Antal, Jr. [d]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), Kolbjørn Hejes vei 1B, NO-7491 Trondheim, Norway
[b] Department of Process Engineering, Faculty of Mechanical Engineering, University of Belgrade, Kraljice Marije 16, 11000 Belgrade, Serbia
[c] SINTEF Energy Research, Sem Saelands vei 11, NO-7465 Trondheim, Norway
[d] Hawaii Natural Energy Institute, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, Honolulu, Hawaii 96822, United States

Energy & Fuels
2011, Volume 25, issue 7, pp. 3251–3265

DOI: 10.1021/ef200450h
D2.3.5 (Link to eRoom)

Abstract

Elevated pressure secures the highest fixed-carbon yields of charcoal from corncob. Operating at a pressure of 0.8 MPa, a flash-carbonization reactor realizes fixed-carbon yields that range from 70 to 85% of the theoretical thermochemical equilibrium value from Waimanalo corncob. The fixed-carbon yield is reduced to a range from 68 to 75% of the theoretical value when whole Waimanalo corncobs are carbonized under nitrogen at atmospheric pressure in an electrically heated muffle furnace. The lowest fixed-carbon yields are obtained by the standard proximate analysis procedure for biomass feedstocks; this yield falls in a range from 49 to 54% of the theoretical value. A round-robin study of corncob charcoal and fixed-carbon yields involving three different thermogravimetric analyzers (TGAs) revealed the impact of vapor-phase reactions on the formation of charcoal. Deep crucibles that limit the egress of volatiles from the pyrolyzing solid greatly enhance charcoal and fixed-carbon yields. Likewise, capped crucibles with pinholes increase the charcoal and fixed-carbon yields compared to values obtained from open crucibles. Large corncob particles offer much higher yields than small particles. These findings show that secondary reactions involving vapor-phase species (or nascent vapor-phase species) are at least as influential as primary reactions in the formation of charcoal. Our results offer considerable guidance to industry for its development of efficient biomass carbonization technologies. Size reduction handling of biomass (e.g., tub grinders and chippers), which can be a necessity in the field, significantly reduces the fixed-carbon yield of charcoal. Fluidized-bed and transport reactors, which require small particles and minimize the interaction of pyrolytic volatiles with solid charcoal, cannot realize high yields of charcoal from biomass. When a high yield of corncob charcoal is desired, whole corncobs should be carbonized at elevated pressure. Under these circumstances, carbonization is both efficient and quick.

Biogas production and saccharification of Salix pretreated at different steam explosion conditions

Horn SJ [a], Estevez MM [b], Nielsen HK [c], Linjordet R [d], Eijsink VG [a]

[a] Department of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences, P.O. Box 5003, N-1432 Ås, Norway
[b] Department of Mathematical Sciences and Technology, Norwegian University of Life Sciences, P.O. Box 5003, N-1432 Ås, Norway
[c] Faculty of Engineering and Science, University of Agder, P.O. Box 509, N-4898 Grimstad, Norway
[d] Bioforsk, Norwegian Institute for Agricultural and Environmental Research, N-1432 Ås, Norway

Bioresource Technology
Volume 102, Issue 17, September 2011, pp. 7932–7936

DOI: 10.1016/j.biortech.2011.06.042
D2.4.8 (Link to eRoom)

Abstract

Different steam explosion conditions were applied to *Salix* chips and the effect of this pretreatment was evaluated by running both enzymatic hydrolysis and biogas tests. Total enzymatic release of glucose and xylose increased with pretreatment harshness, with maximum values being obtained after pretreatment for 10 min at 210 °C. Harsher pretreatment conditions did not increase glucose release, led to degradation of xylose and to formation of furfurals. Samples pretreated at 220 and 230 °C initially showed low production of biogas, probably because of inhibitors produced during the pretreatment, but the microbial community was able to adapt and showed high final biogas production. Interestingly, final biogas yields correlated well with sugar yields after enzymatic hydrolysis, suggesting that at least in some cases a 24 h enzymatic assay may be developed as a quick method to predict the effects of pretreatment of lignocellulosic biomass on biogas yields.

SP4: SUSTAINABILITY ASSESSMENTS

- 2014-

Climate change implications of shifting forest management strategy in a boreal forest ecosystem of Norway

Ryan M. Bright [a], Clara Anton Fernandez [b], Rasmus Astrup [b], Francesco Cherubini [a], Maria Kvalevåg [c] and Anders H. Strømman[a]

[a] Industrial Ecology Program, Energy and Process Engineering, Norwegian University of Science and Technology, Høgskoleringen 5, E-1, 7491 Trondheim, Norway,
[b] Norwegian Forest and Landscape Institute, P.O. Box 115, 1431 Ås, Norway,
[c] Center for International Climate and Environmental Research – Oslo (CICERO), P.O. Box 1129, Blindern, 0318 Oslo, Norway

Global Change Biology
Volume 20, Issue 2, pages 607–621, February 2014

DOI: 10.1111/gcb.12451
D4.1.36 (Link til eRoom)

Abstract

Empirical models alongside remotely sensed and station measured meteorological observations are employed to investigate both the local and global direct climate change impacts of alternative forest management strategies within a boreal ecosystem of eastern Norway. Stand-level analysis is firstly executed to attribute differences in daily, seasonal, and annual mean surface temperatures to differences in surface intrinsic biophysical properties across conifer, deciduous, and clear-cut sites. Relative to a conifer site, a slight local cooling of −0.13 °C at a deciduous site and −0.25 °C at a clear-cut site were observed over a 6-year period, which were mostly attributed to a higher albedo throughout the year. When monthly mean albedo trajectories over the entire managed forest landscape were taken into consideration, we found that strategies promoting natural regeneration of coniferous sites with native deciduous species led to substantial global direct climate cooling benefits relative to those maintaining current silviculture regimes – despite predicted long-term regional warming feedbacks and a reduced albedo in spring and autumn months. The magnitude and duration of the cooling benefit depended largely on whether management strategies jointly promoted an enhanced material supply over business-as-usual levels. Expressed in terms of an equivalent CO_2 emission pulse at the start of the simulation, the net climate response at the end of the 21st century spanned −8 to −159 Tg-CO^2-eq., depending on whether near-term harvest levels increased or followed current trends, respectively. This magnitude equates to approximately −20 to −300% of Norway's annual domestic (production) emission impact. Our analysis supports the assertion that a carbon-only focus in the design and implementation of forest management policy in boreal and other climatically similar regions can be counterproductive – and at best – suboptimal if boreal forests are to be used as a tool to mitigate global warming.

Linearity between temperature peak and bioenergy CO_2 emission rates

Francesco Cherubini [a], Thomas Gasser [b,c], Ryan M. Bright [a], Philippe Ciais [c], Anders Hammer Strømman [a]

[a]Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), Trondheim – Norway

[b]Centre International de Recherche sur l'Environnement et le Développement, CNRS-PontsParisTech-EHESS - AgroParisTech-CIRAD, Nogent-sur-Marne – France

[c]Laboratoire des Sciences du Climat et de l'Environnement, Institut Pierre-Simon Laplace, CEA-CNRS-UVSQ, Gif-sur-Yvette – France

Nature Climate Change
4, 983–987 (2014)

DOI: [10.1038/nclimate2399]
D4.1.42 ([Link to eRoom])

Abstract

Many future energy and emission scenarios envisage an increase of bioenergy in the global primary energy mix. In most climate impact assessment models and policies, bioenergy systems are assumed to be carbon neutral, thus ignoring the time lag between CO_2 emissions from biomass combustion and CO_2 uptake by vegetation. Here, we show that the temperature peak caused by CO_2 emissions from bioenergy is proportional to the maximum rate at which emissions occur and is almost insensitive to cumulative emissions. Whereas the carbon–climate response (CCR) to fossil fuel emissions is approximately constant, the CCR to bioenergy emissions depends on time, biomass turnover times, and emission scenarios. The linearity between temperature peak and bioenergy CO_2 emission rates resembles the characteristic of the temperature response to short-lived climate forcers. As for the latter, the timing of CO_2 emissions from bioenergy matters. Under the international agreement to limit global warming to 2 °C by 2100, early emissions from bioenergy thus have smaller contributions on the targeted temperature than emissions postponed later into the future, especially when bioenergy is sourced from biomass with medium (50–60 years) or long turnover times (100 years).

Biogenic CO_2 fluxes, changes in surface albedo and biodiversity impacts from establishment of a miscanthus plantation

Susanne V. Jørgensen [a, b], *Francesco Cherubini* [c], *Ottar Michelsen* [c]

[a] Technical University of Denmark (DTU), Department for Management Engineering, Division for Quantitative Sustainability Assessment, 2800 Kgs. Lyngby, Denmark
[b] Novozymes A/S, Krogshøjvej 36, 2880 Bagsværd, Denmark
[c] Norwegian University of Science and Technology (NTNU), The Industrial Ecology Programme, Department of Energy and Process Engineering, NO-7491 Trondheim, Norway

Journal of Environmental Management
Volume 146, 15 December 2014, Pages 346–354

DOI: 10.1016/j.jenvman.2014.06.033
D4.1.43 (Link to eRoom)

Abstract

Depletion in oil resources and environmental concern related to the use of fossil fuels has increased the interest in using second generation biomass as alternative feedstock for fuels and materials. However, the land use and land use change for producing second generation (2G) biomass impacts the environment in various ways, of which not all are usually considered in life cycle assessment.

This study assesses the biogenic CO_2 fluxes, surface albedo changes and biodiversity impacts for 100 years after changing land use from forest or fallow land to miscanthus plantation in Wisconsin, US. Climate change impacts are addressed in terms of effective forcing, a mid-point indicator which can be used to compare impacts from biogenic CO_2 fluxes and albedo changes. Biodiversity impacts are assessed through elaboration on two different existing approaches, to express the change in biodiversity impact from one human influenced state to another.

Concerning the impacts from biogenic CO_2 fluxes, in the case of conversion from a forest to a miscanthus plantation (case A) there is a contribution to global warming, whereas when a fallow land is converted (case B), there is a climate cooling. When the effects from albedo changes are included, both scenarios show a net cooling impact, which is more pronounced in case B. Both cases reduce biodiversity in the area where the miscanthus plantation is established, though most in case A.

The results illustrate the relevance of these issues when considering environmental impacts of land use and land use change. The apparent trade-offs in terms of environmental impacts further highlight the importance of including these aspects in LCA of land use and land use changes, in order to enable informed decision making.

- 2013 -

A review of recent developments and applications of partial equilibrium models of the forest sector

Gregory S. Latta [a], Hanne K. Sjølie [b], Birger Solberg [b]

[a] Department of Forest Engineering, Resources and Management, Oregon State University, Corvallis, OR 97331, USA
[b] Norwegian University of Life Sciences, Department of Ecology and Natural Resource Management, Box 5003, 1432 Ås, Norway

Journal of Forest Economics
Volume 19, Issue 4, December 2013, pp. 350–360

DOI: [10.1016/j.jfe.2013.06.006](10.1016/j.jfe.2013.06.006)
D4.3.22 (Link to eRoom)
http://www.nature.com/doifinder/10.1038/nclimate2399

Abstract

Recent history has seen an increase in the utilization of partial equilibrium based forest sector models to identify potential impacts of various policies or timber market shocks. These models are particularly useful in that they employ economic theory to capture the interaction of supply and demand in a framework where commodity prices are endogenous to the policy or shock simulated. We present recent developments and linkages between models and review applications of these models to forest policy questions over the previous decade. We conclude with a discussion of potential future directions for such research.

Wood biomass use for energy in Europe under different assumptions of coal, gas and CO_2 emission prices and market conditions

Alexander Moiseyev[a], *Birger Solberg*[a], *A. Maarit I. Kallio*[b]

[a] Department of Ecology and Natural Resource Management, Norwegian University of Life Science, Ås, Norway
[b] METLA (Finnish Forest Research Institute), Vantaa, Finland

Journal of Forest Economics
Volume 19, Issue 4, December 2013, pp. 432–449

DOI: 10.1016/j.jfe.2013.10.001
D4.3.24 (Link to eRoom)

Abstract

This study examines the effects of different coal, natural gas and carbon emission prices and market situations on the use of wood for electricity and heat production in the European Union. The analysis is carried out using the global forest sector model EFI-GTM expanded to cover electricity and heat production from wood, coal, natural gas, wind and solar energy. Analysis shows that with low coal and gas prices, use of wood for energy will be limited to low cost logging residues. With high coal, and especially natural gas prices, industrial wood also comes to be used for energy. At a carbon price of 100 €/tCO_2, some 32 Mm^3 of industrial wood, in addition to 224 Mm^3 of logging residues, are projected to be used for electricity and heat in the EU region (including Norway and Switzerland) in 2030. The relatively low quantity of industrial wood used by the energy sector despite the collapse of the use of coal is explained by the fact that under high CO_2 prices, other energy forms like natural gas, solar and wind energy become more and more competitive. However, the amount of industrial wood used for energy may substantially increase with subsidies for using wood for electricity and heat, even with relatively low carbon prices. With a high coal and gas price and a carbon price of 100 €/t, a subsidy of 30 €/MWh to the wood based and coal with wood co-firing electricity production will have a significant impact on the European wood based sector. Depending on the development of the market demand for forest industry products, such a subsidy may cause a 10-12.5% reduction in forest products production, a 6-9% increase in harvest level, about 30-60% increase in the pulpwood prices, and a 6-9 fold increase of wood imports in the EU, compared to the respective case without a subsidy in 2030.

Land use impacts on biodiversity from kiwifruit production in New Zealand assessed with global and national datasets

Carla R. V. Coelho [a], Ottar Michelsen [b]

[a] Landcare Research, C. R. V. Coelho, Geospatial Programme Delivery, Auckland Council, L7 8 Hereford St, Auckland 1011, New Zealand
[b] The Industrial Ecology Programme, Norwegian University of Science and Technology NTNU, 7491 Trondheim, Norway

The International Journal of Life Cycle Assessment
September 2013

DOI: 10.1007/s11367-013-0628-7
D4.1.40 (Link to eRoom)

Abstract

Purpose

Habitat loss is a significant cause of biodiversity loss, but while its importance is widely recognized, there is no generally accepted method on how to include impacts on biodiversity from land use and land use changes in cycle assessment (LCA), and existing methods are suffering from data gaps. This paper proposes a methodology for assessing the impact of land use on biodiversity using ecological structures as opposed to information on number of species.

Methods

Two forms of the model (global and local scales) were used to assess environmental quality, combining ecosystem scarcity, vulnerability, and conditions for maintaining biodiversity. A case study for New Zealand kiwifruit production is presented. As part of the sensitivity analysis, model parameters (area and vulnerability) were altered and New Zealand datasets were also used.

Results and discussion

When the biodiversity assessment was implemented using a global dataset, the importance of productivity values was shown to depend on the area the results were normalized against. While the area parameter played an important role in the results, the proposed alternative vulnerability scale had little influence on the final outcome.

Conclusions

Overall, the paper successfully implements a model to assess biodiversity impacts in LCA using easily accessible, free-of-charge data and software. Comparing the model using global vs. national datasets showed that there is a potential loss of regional significance when using the generalized model with the global dataset. However, as a guide to assessing biodiversity impact, the model allows for consistent comparison of product systems on an international basis.

Biogenic CO_2 fluxes from bioenergy and climate—A response

Francesco Cherubini, Anders H. Strømman, Edgar Hertwich

Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway

Ecological Modelling
Volume 253, 24 March 2013, pp. 79–81

DOI: 10.1016/j.ecolmodel.2013.01.007
D4.1.39 (Link to eRoom)

Abstract

In his short communication, Holtsmark (2013) builds on our methodology for impulse response functions (IRF) of biogenic CO_2 emissions (Cherubini et al., 2011a and Cherubini et al., 2011b) and proposes some adjustments in order to include counterfactual CO_2 fluxes in the IRF. At the same time, concerns are expressed over the insights that can be gathered from the IRF and the following emission metrics like the global warming potential (GWP, labeled GWP_{bio} when applied to biogenic CO_2).

In this letter, we make evident that the "adjustments" proposed by Holtsmark conflict with the definition of IRFs and their intended applications, and neither contradict nor invalidate our findings. IRFs and subsequent emission metrics clearly discern the atmospheric response to CO_2 emissions sourced from fossils/deforestation to that of CO_2 from regenerative biomass irrespective of any application involving forest scenarios. By embedding scenarios directly into the IRFs rather than in a separate analysis, Holtsmark unnecessarily and unconventionally makes emission metrics dependent on counterfactual aspects, deviating from the main rationale behind physics-based emission metrics.

Global climate impacts of forest bioenergy: what, when and how to measure?

Francesco Cherubini, Ryan M. Bright and Anders H. Strømman

Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway

Environmental Research Letters
Volume 8, number 1

DOI: 10.1088/1748-9326/8/1/014049
D4.1.38 (Link to eRoom)

Abstract

Environmental impact studies of forest bioenergy systems usually account for CO_2 emissions and removals and identify the so-called carbon debt of bioenergy through comparison with a reference system. This approach is based on a simple sum of fluxes and does not consider any direct physical impact or climate system response. Other recent applications go one step further and elaborate impulse response functions (IRFs) and subsequent metrics for biogenic CO_2 emissions that are compatible with the life-cycle assessment (LCA) methodology. However, a thorough discussion about the role of the different metrics in the interpretation of the climate impacts of forest bioenergy systems is still missing. In this work, we assess a single LCA dataset of selected bioenergy systems using different emission metrics based on cumulative CO_2 emissions, radiative forcing and global surface temperature. We consider both absolute and normalized metrics for single pulses and sustained emissions. The key challenges are the choice of end point (emissions, concentration, radiative forcing, change in temperature, etc), the type of measure (instantaneous or time-integrated) and the treatment of time. Bioenergy systems usually perform better than fossil counterparts if assessed with instantaneous metrics, including global surface temperature change, and in some cases can give a net global cooling effect in the short term. The analysis of sustained, or continuous emissions, also shows that impacts from bioenergy systems are generally reversible, while those from fossil fuels are permanent.

As shown in this study, the metric choice can have a large influence on the results. The dominant role traditionally assigned to cumulative metrics in LCA studies and climate impact accounting schemes should therefore be reconsidered, because such metrics can fail to capture important time dependences unique to the biomass system under analysis (to which instantaneous metrics are well suited).

Bioenergy vs. natural gas for production of district heat in district heat in Norway: Climate implications

Francesco Cherubini, Anders Hammer Strømman

Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), Trondheim - Norway

Energy Procedia
Volume 40, 2013, pp. 137–145

DOI: 10.1016/j.egypro.2013.08.017
D4.1.37 (Link to eRoom)

Abstract

Production of district heat is increasing in Norway, and this paper simulates the possibility to use its abundant national resources of forests and/or natural gas as energy carriers. In this study we analyze an idealized future energy scenario and compare the climate impacts from using forest biomass or natural gas as energy sources. Results show that bioenergy is a better energy option than natural gas, mainly thanks to the cooling contributions from the change in surface albedo that can more than offset the warming associated with biogenic CO_2.

Global Warming Potential of Carbon Dioxide Emissions from Biomass Stored in the Anthroposphere and Used for Bioenergy at End of Life

Guest Geoffrey, Cherubini Francesco, Strømman Anders H.

Norwegian University of Science and Technology (NTNU), Trondheim, Norway.

Journal of Industrial Ecology
February 2013, Volume 17, Issue 1, pp. 20–30

DOI: 10.1111/j.1530-9290.2012.00507.x
D4.1.23 (Link to eRoom)

Abstract

There is growing interest in understanding how storage or delayed emission of carbon in products based on bioresources might mitigate climate change, and how such activities could be credited. In this research we extend the recently introduced approach that integrates biogenic carbon dioxide (CO_2) fluxes with the global carbon cycle (using biogenic global warming potential [GWP_{bio}]) to consider the storage period of harvested biomass in the anthroposphere, with subsequent oxidation. We then examine how this affects the climate impact from a bioenergy resource. This approach is compared to several recent methods designed to address the same problem. Using both a 100- and a 500-year fixed time horizon we calculate the GWP_{bio} factor for every combination of rotational and anthropogenic storage periods between 0 and 100 years. The resulting GWP_{bio} factors range from −0.99 (1-year rotation and 100-year storage) to +0.44 (100-year rotation and 0-year storage). The approach proposed in this study includes the interface between biomass growth and emissions and the global carbon cycle, whereas other methods do not model this. These results and the characterization factors produced can determine the climate change benefits or impacts associated with the storage of biomass in the anthroposphere, and the subsequent release of biogenic CO_2 with the radiative forcing integrated in a fixed time window.

Bioenergy from forestry and changes in atmospheric CO_2: Reconciling single stand and landscape level approaches

Cherubini F., Guest G., Strømman AH.

Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), 7491 Trondheim, Norway

Journal of Environmental Management
Volume 129, 15 November 2013, pp. 292–301

DOI: 10.1016/j.jenvman.2013.07.021
D4.1.28 (Link to eRoom)

Abstract

Analyses of global warming impacts from forest bioenergy systems are usually conducted either at a single stand level or at a landscape level, yielding findings that are sometimes interpreted as contrasting. In this paper, we investigate and reconcile the scales at which environmental impact analyses of forest bioenergy systems are undertaken. Focusing on the changes caused in atmospheric CO_2 concentration of forest bioenergy systems characterized by different initial states of the forest, we show the features of the analyses at different scales and depict the connections between them. Impacts on atmospheric CO_2 concentration at a single stand level are computed through impulse response functions (IRF). Results at a landscape level are elaborated through direct application of IRFs to the emission profile, so to account for the fluxes from all the stands across time and space. Impacts from fossil CO_2 emissions are used as a benchmark. At a landscape level, forest bioenergy causes an increase in atmospheric CO_2 concentration for the first decades that is similar to the impact from fossil CO_2, but then the dynamics clearly diverge because while the impact from fossil CO_2 continues to rise that from bioenergy stabilizes at a certain level. These results perfectly align with those obtained at a single stand for which characterization factors have been developed. In the hypothetical case of a sudden cessation of emissions, the change caused in atmospheric CO_2 concentration from biogenic CO_2 emissions reverses within a couple of decades, while that caused by fossil CO_2 emissions remains considerably higher for centuries. When counterfactual aspects like the additional sequestration that would have occurred in the forest if not harvested and the theoretical displacement of fossil CO_2 are included in the analysis, results can widely differ, as the CO_2 debt at a landscape level ranges from a few years to several centuries (depending on the underlying assumptions considered).

The role of forest residues in the accounting for the global warming potential of bioenergy

Guest Geoffrey, Cherubini Francesco, Strømman Anders H.

Norwegian University of Science and Technology (NTNU), Trondheim, Norway.

Global Change Biology Bioenergy
July 2013, Volume 5, Issue 4, pp. 459–466

DOI: 10.1111/gcbb.12014
D4.1.31 (Link to eRoom)

Abstract

Bioenergy makes up a significant portion of the global primary energy pie, and its production from modernized technology is foreseen to substantially increase. The climate neutrality of biogenic CO_2 emissions from bioenergy grown from sustainably managed biomass resource pools has recently been questioned. The temporary change caused in atmospheric CO_2 concentration from biogenic carbon fluxes was found to be largely dependent on the length of biomass rotation period. In this work, we also show the importance of accounting for the unutilized biomass that is left to decompose in the resource pool and how the characterization factor for the climate impact of biogenic CO_2 emissions changes whether residues are removed for bioenergy or not. With the case of Norwegian Spruce biomass grown in Norway, we found that significantly more biogenic CO_2 emissions should be accounted towards contributing to global warming potential when residues are left in the forest. For a 100-year time horizon, the global warming potential bio factors suggest that between 44 and 62% of carbon-flux, neutral biogenic CO_2 emissions at the energy conversion plant should be attributed to causing equivalent climate change potential as fossil-based CO_2 emissions. For a given forest residue extraction scenario, the same factor should be applied to the combustion of any combination of stem and forest residues. Life cycle analysis practitioners should take these impacts into account and similar region/species specific factors should be developed.

Climate impact potential of utilizing forest residues for bioenergy in Norway

Geoffrey Guest, Francesco Cherubini and Anders Hammer Strømman

Norwegian University of Science and Technology (NTNU), Trondheim, Norway.

Mitigation and Adaptation Strategies for Global Change
Volume 18, Issue 8, pp. 1089-1108

DOI: [10.1007/s11027-012-9409-z](10.1007/s11027-012-9409-z)
D4.1.32 (Link to eRoom)

Abstract

The utilization of forest residues for bioenergy in Norway is foreseen to increase due to the government call to double bioenergy output by 2020 to thirty Tera-Watt hours. This study focuses on the climate impacts of bioenergy utilization where four forest residue extraction scenarios at clear-cut are considered: i) 75 % above ground residues (branches, (25 %) foliage, tops); ii) 75 % above and below ground residues (branches, tops, (25 %) foliage, stumps, coarse and small roots); iii) extracting 100 % of all available forest residue; and iv) leaving all residues in the forest. The Yasso07 soil-carbon model was utilized to quantify the carbon flux to the atmosphere due to the forest residues that are left in the forest in each scenario. The climate impact potential for each scenario was then calculated for the carbon-flux neutral Norway Spruce (*Picea abies)* forest system in five regions of Norway. The biogenic carbon dioxide emissions associated to decomposition upon forest floor, procurement losses and bioenergy conversion are included in these calculations. Results suggest that if such bioenergy can directly replace a fossil source of energy, the utilization of this biomass was found to be climatically beneficial in most fossil energy replacement cases and time horizons when compared to leaving the residues in the forest. Integrated global temperature change displacement factors have been developed which have been used to estimate the magnitude of this climate change mitigation over a particular time horizon.

Empirical models of monthly and annual albedo in managed boreal forests of interior Norway

Ryan M. Bright [a], Rasmus Astrup [b], Anders H. Strømman [a]

[a] Industrial Ecology Programme, Energy and Process Engineering, Norwegian University of Science and Technology, Høgskoleringen 5, E-1, 7491 Trondheim, Norway
[b] Norwegian Forest and Landscape Institute, P.O. Box 115, 1431 Ås, Norway

Climatic change
(2013) 120, pp. 183–196

DOI: 10.1007/s10584-013-0789-1
D4.1.34 (Link to eRoom)

Abstract

An 11-year remotely sensed surface albedo dataset coupled with historical meteorological and stand-level forest management data for a variety of stands in Norway's most productive logging region is used to develop regression models describing temporal changes in forest albedo following clear-cut harvest disturbance events. Datasets are grouped by dominant tree species, and two alternate multiple regression models are developed and tested following a potential-modifier approach. This result in models with statistically significant parameters ($p < 0.05$) that explain a large proportion of the observed variation, requiring a single canopy modifier predictor coupled with either monthly or annual mean air temperature as a predictor of a stand's potential albedo. Models based on annual mean temperature predict annual albedo with errors (RMSE) in the range of 0.025–0.027, while models based on monthly mean temperature predict monthly albedo with errors ranging between of 0.057–0.065 depending on the dominant tree species. While both models have the potential to be transferable to other boreal regions with similar forest management regimes, further validation efforts are required. As active management of boreal forests is increasingly seen as a means to mitigate climate change, the presented models can be used with routine forest inventory and meteorological data to predict albedo evolution in managed forests throughout the region, which, together with carbon cycle modeling, can lead to more holistic climate impact assessments of alternative forest harvest scenarios and forest product systems.

Consistent quantification of climate impacts due to biogenic carbon storage across a range of bio-product systems

Geoffrey Guest, Ryan M. Bright, Francesco Cherubini, Anders H. Strømman

Norwegian University of Science & Technology (NTNU), Norway

Environmental Impact Assessment Review
Volume 43, November 2013, pp. 21–30

DOI: 10.1016/j.eiar.2013.05.002
D4.1.35 (Link to eRoom)

Abstract

Temporary and permanent carbon storage from biogenic sources is seen as a way to mitigate climate change. The aim of this work is to illustrate the need to harmonize the quantification of such mitigation across all possible storage pools in the bio- and anthroposphere. We investigate nine alternative storage cases and a wide array of bio-resource pools: from annual crops, short rotation woody crops, medium rotation temperate forests, and long rotation boreal forests. For each feedstock type and biogenic carbon storage pool, we quantify the carbon cycle climate impact due to the skewed time distribution between emission and sequestration fluxes in the bio- and anthroposphere. Additional consideration of the climate impact from albedo changes in forests is also illustrated for the boreal forest case. When characterizing climate impact with global warming potentials (GWP), we find a large variance in results which is attributed to different combinations of biomass storage and feedstock systems. The storage of biogenic carbon in any storage pool does not always confer climate benefits: even when biogenic carbon is stored long-term in durable product pools, the climate outcome may still be undesirable when the carbon is sourced from slow-growing biomass feedstock. For example, when biogenic carbon from Norway Spruce from Norway is stored in furniture with a mean life time of 43 years, a climate change impact of 0.08 kg CO_2eq per kg CO_2 stored (100 year time horizon (TH)) would result. It was also found that when biogenic carbon is stored in a pool with negligible leakage to the atmosphere, the resulting GWP factor is not necessarily − 1 CO_2eq per kg CO_2 stored. As an example, when biogenic CO_2 from Norway Spruce biomass is stored in geological reservoirs with no leakage, we estimate a GWP of − 0.56 kg CO_2eq per kg CO_2 stored (100 year TH) when albedo effects are also included. The large variance in GWPs across the range of resource and carbon storage options considered indicates that more accurate accounting will require case-specific factors derived following the methodological guidelines provided in this and recent manuscripts.

Whole-tree thinnings in stands of Scots Pine (Pinus sylvestris) and Norway spruce (Picea abies): Short- and long-term growth results

Bjørn Tveite, Kjersti Holt Hanssen

Norwegian Forest and Landscape Institute, P.O. Box 115, NO-1431 Ås, Norway

Forest Ecology and Management
Volume 298, 15 June 2013, pp. 52–61

DOI: [10.1016/j.foreco.2013.02.029]
D4.2.11 ([Link to eRoom])

Abstract

The relative volume growth effects of thinning after whole-tree harvesting (WTH) compared to a conventional stem-only harvest (CH) in young stands of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) were analyzed, using a series of four pine and four spruce field experiments. The series was established in the years 1972–1977, and thinning was performed only once.

Results are shown periodically and cumulatively. All sites were included for 20 (19) years in pine and 25 years in spruce. The total experimental period varied between 19 and 35 years for individual sites.

Four models assuming additive or multiplicative effects gave only slightly varying results. The inclusion of standing volume after thinning as a covariate was effective in spruce independent of whether the covariate was treated as multiplicative or additive. A logarithmic model with a multiplicative effect of the covariate was preferred in further presentations.

Results for pine stands after 20 years indicated a non-significant loss of 5% with confidence limits ($p = 0.05$) of ±6–7%, while the spruce stands showed a significant growth loss of 11% with confidence limits of ±4–5% after 25 years. The difference between the species in relative growth effects was significant, and amounted to 8% for a cumulative 20-year period.

No indications of trends in response were found during a 20-year period in pine and a 25-year period in spruce.

An analysis of growth effects in the first years showed that basal area increment in spruce was significantly reduced already in the first growing season after thinning.

Economic sustainability for wood pellets production – A comparative study between Finland, Germany, Norway, Sweden and the US

Erik Trømborg [a], Tapio Ranta [b], Jörg Schweinle [c], Birger Solberg [a], Geir Skjevrak [d], Douglas G. Tiffany [e]

[a] Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences, PO Box 5003, N-1432 Ås, Norway
[b] Lappeenranta University of Technology, Prikaatinkatu 3E., FIN-50100 Mikkeli, Finland
[c] Johann Heinrich von Thünen-Institute (vTI) Federal Research Institute for Rural Areas, Forestry and, Fisheries, Institute of Forest Based Sector Economics, Postbox 80 02 09, 21002 Hamburg Leuschnerstr. 91, 21031 Hamburg, Germany
[d] Norwegian University of Science and Technology, Department of Energy and Process Engineering, Kolbjørn Hejes v. 1, N-7481 Trondheim, Norway
[e] University of Minnesota, Extension. 316D Ruttan Hall, 1994 Buford Avenue, St. Paul, MN 55108, USA

Biomass & Bioenergy
Volume 57, October 2013, pp. 68–77

DOI: 10.1016/j.biombioe.2013.01.030
D4.3.15 (Link to eRoom)

Abstract

The consumption of wood pellets grew rapidly during the last decade. In this paper we compare the development of the production factors for wood pellet markets in Finland, Germany, Sweden, Norway and the US; we analyze how domestic market prices for pellet production factors as well as domestic market prices for pellets vary among the countries. The analyses are based on two model plants. The first represents common technologies for small scale pellet production based on dry residues from sawnwood production, while the second represents large scale production based on a blend of dry and wet materials. The results show how differences in costs of feedstock, energy and labor affect the profitability of pellet production and hence the development of pellet production in the analyzed countries. Pellet producers in the US have lower feedstock costs than producers in the analyzed European countries. The economic sustainability for European pellet producers depends to a large extent on their domestic markets as internationally traded pellets are priced lower than their production costs. Future pellet production will, to a greater extent, be based on wet feedstock such as roundwood and wet sawdust. These feedstocks are also demanded by wood-based industries (pulp and paper, particle- and fiber-board) as well as for traditional fuelwood. The transition from smaller pellet plants using dry feedstock to larger plants using wet feedstock in future pellet production, can be expected to follow comparative advantages regarding feedstock and energy costs, but also with respect to economies of scale.

- 2012 -

Impact assessment of biodiversity and carbon pools from land use and land use changes in LCA, exemplified with forestry operations in Norway

Michelsen O, Cherubini F, Strømman AH

Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway

Journal of Industrial Ecology
April 2012, Volume 16, Issue 2, pp. 231–242

DOI: 10.1111/j.1530-9290.2011.00409.x
D4.1.20 (Link to eRoom)

Abstract

There is a strong need for methods within life cycle assessment (LCA) that enable the inclusion of all complex aspects related to land use and land use change (LULUC). This article presents a case study of the use of one hectare (ha) of forest managed for the production of wood for bioenergy production. Both permanent and temporary changes in above-ground biomass are assessed together with the impact on biodiversity caused by LULUC as a result of forestry activities. The impact is measured as a product of time and area requirements, as well as by changes in carbon pools and impacts on biodiversity as a consequence of different management options. To elaborate the usefulness of the method as well as its dependency on assumptions, a range of scenarios are introduced in the study. The results show that the impact on climate change from LULUC dominates the results, compared to the impact from forestry operations. This clearly demonstrates the need to include LULUC in an LCA of forestry products. For impacts both on climate change and biodiversity, the results show large variability based on what assumptions are made; and impacts can be either positive or negative. Consequently, a mere measure of land used does not provide any meaning in LCA, as it is not possible to know whether this contributes a positive or negative impact.

Site-specific global warming potentials of biogenic CO_2 for bioenergy: contributions from carbon fluxes and albedo dynamics

Cherubini F., Bright R. M., Strømman A. H.

Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway

Environmental Research Letters
2012, Volume 7, Number 4

DOI: 10.1088/1748-9326/7/4/045902
D4.1.29 (Link to eRoom)

Abstract

Production of biomass for bioenergy can alter biogeochemical and biogeophysical mechanisms, thus affecting local and global climate. Recent scientific developments have mainly embraced impacts from land use changes resulting from area-expanded biomass production, with several extensive insights available. Comparably less attention, however, has been given to the assessment of direct land surface–atmosphere climate impacts of bioenergy systems under rotation such as in plantations and forested ecosystems, whereby land use disturbances are only temporary. Here, following IPCC climate metrics, we assess bioenergy systems in light of two important dynamic land use climate factors, namely, the perturbation in atmospheric carbon dioxide (CO_2) concentration caused by the timing of biogenic CO_2 fluxes, and temporary perturbations to surface reflectivity (albedo). Existing radiative forcing-based metrics can be adapted to include such dynamic mechanisms, but high spatial and temporal modeling resolution is required. Results show the importance of specifically addressing the climate forcings from biogenic CO_2 fluxes and changes in albedo, especially when biomass is sourced from forested areas affected by seasonal snow cover. The climate performance of bioenergy systems is highly dependent on biomass species, local climate variables, time horizons, and the climate metric considered. Bioenergy climate impact studies and accounting mechanisms should rapidly adapt to cover both biogeochemical and biogeophysical impacts, so that policy makers can rely on scientifically robust analyses and promote the most effective global climate mitigation options.

Application of probability distributions to the modeling of biogenic CO_2 fluxes in LCA

Francesco Cherubini, Geoffrey Guest, Anders H. Strømman

Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491, Trondheim, Norway

Global Change Biology Bioenergy
November 2012, Volume 4, Issue 6, pp. 784–798

DOI: 10.1111/j.1757-1707.2011.01156.x
D4.1.30 (Link to eRoom)

Abstract

In life cycle assessment (LCA), the same characterization factors are conventionally applied irrespective of when the emissions occur (the same importance is given to emissions in the past, present, and future). When the assessment is constrained by fixed timeframes, the appropriateness of this paradigm is questioned and the temporal distribution of emissions becomes of relevance. One typical example is the accounting for biogenic CO_2 emissions and removals. This article proposes a methodology for assessing the climate impact of time-distributed CO_2 fluxes using probability distributions. Three selected wood applications, such as fuel, nonstructural panels, and housing construction materials are assessed. In all the cases, CO_2 sequestration in growing trees is modeled with an appropriate forest growth function, whereas CO_2 emissions from wood oxidation are modeled with different probability distributions, such as the delta function, the uniform distribution, the exponential distribution, and the chi-square distribution. The combination of these CO_2 fluxes with the global carbon cycle provides the respective changes caused in CO_2 atmospheric concentration and hence in the radiative forcing. The latter is then used as basis for climate impact metrics. Results demonstrate the utility of using emission and removal functions rather than single pulses, which generally overestimate the climate impact of CO_2 emissions, especially in presence of short time horizons. Characterization factors for biogenic CO_2 are provided for selected combinations of biomass species, rotation periods, and probability distributions. The time discrepancy between biogenic CO_2 emissions and capture through regrowth results in a certain climate impact, even for a system that is carbon neutral over time. For the oxidation rate of wooden products, the use of a chi-square distribution appears the most reliable and appropriate option under a methodological perspective. The feasibility of its adoption in LCA and emission accounting from harvested wood products deserves further scientific considerations.

Continent-wide response of mountain vegetation to climate change

Michael Gottfried[a], Harald Pauli, Andreas Futschik, Maia Akhalkatsi, Peter Barančok, José Luis Benito Alonso, Gheorghe Coldea, Jan Dick, Brigitta Erschbamer, Marı´a Rosa Fernández Calzado, George Kazakis, Ján Krajči, Per Larsson, Martin Mallaun, Ottar Michelsen[b], Dmitry Moiseev, Pavel Moiseev, Ulf Molau, Abderrahmane Merzouki, Laszlo Nagy, George Nakhutsrishvili, Bård Pedersen[b], Giovanni Pelino, Mihai Puscas, Graziano Rossi, Angela Stanisci, Jean-Paul Theurillat, Marcello Tomaselli, Luis Villar, Pascal Vittoz, Ioannis Vogiatzakis, & Georg Grabherr

[a] Institute of Mountain Research (IGF), Austrian Academy of Sciences, c/o University of Vienna, Rennweg 14, 1030 Wien, Austria
[b] Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491, Trondheim, Norway

Nature Climate Change
2012, Volume 2, pp. 111–115

DOI: [10.1038/nclimate1329]
D4.1.33_1 ([Link to eRoom])

Abstract

Climate impact studies have indicated ecological fingerprints of recent global warming across a wide range of habitats. Although these studies have shown responses from various local case studies, a coherent large-scale account on temperature-driven changes of biotic communities has been lacking. Here we use 867 vegetation samples above the treeline from 60 summit sites in all major European mountain systems to show that ongoing climate change gradually transforms mountain plant communities. We provide evidence that the more cold-adapted species decline and the more warm-adapted species increase, a process described here as thermophilization. At the scale of individual mountains this general trend may not be apparent, but at the larger, continental scale we observed a significantly higher abundance of thermophilic species in 2008, compared with 2001. Thermophilization of mountain plant communities mirrors the degree of recent warming and is more pronounced in areas where the temperature increase has been higher. In view of the projected climate change the observed transformation suggests a progressive decline of cold mountain habitats and their biota.

Climate impacts of bioenergy: Inclusion of carbon cycle and albedo dynamics in life cycle impact assessment

Bright, R.M., F. Cherubini, and A.H. Strømman

Industrial Ecology Program, Department of Energy and Process Engineering, Norwegian University of Science and Technology, Høgskoleringen 5, E-1, 7491 Trondheim, Norway

Environmental Impact Assessment Review
Volume 37, November 2012, pp. 2–11

DOI: 10.1016/j.eiar.2012.01.002
D4.1.33_2 (Link to eRoom)

Abstract

Life cycle assessment (LCA) can be an invaluable tool for the structured environmental impact assessment of bioenergy product systems. However, the methodology's static temporal and spatial scope combined with its restriction to emission-based metrics in life cycle impact assessment (LCIA) inhibits its effectiveness at assessing climate change impacts that stem from dynamic land surface–atmosphere interactions inherent to all biomass-based product systems. In this paper, we focus on two dynamic issues related to anthropogenic land use that can significantly influence the climate impacts of bioenergy systems: i) temporary changes to the terrestrial carbon cycle; and ii) temporary changes in land surface albedo—and illustrate how they can be integrated within the LCA framework.

In the context of active land use management for bioenergy, we discuss these dynamics and their relevancy and outline the methodological steps that would be required to derive case-specific biogenic CO_2 and albedo change characterization factors for inclusion in LCIA. We demonstrate our concepts and metrics with application to a case study of transportation biofuel sourced from managed boreal forest biomass in northern Europe. We derive GWP indices for three land management cases of varying site productivities to illustrate the importance and need to consider case- or region-specific characterization factors for bioenergy product systems. Uncertainties and limitations of the proposed metrics are discussed.

A comment to "Large-scale bioenergy from additional harvest of forest biomass is neither sustainable nor greenhouse gas neutral": Important insights beyond greenhouse gas accounting

Ryan M. Bright [a], Francesco Cherubini [a], Rasmus Astrup [b], Neil Bird [c], Annette L. Cowie [d], Mark J. Ducey [e], Gregg Marland [f], Kim Pingoud [g], Ilkka Savolainen [g], Anders H. Strømman [a]

[a] Industrial Ecology Program, Department of Energy and Process Engineering, Norwegian University of Science and Technology, Trondheim, Norway
[b] Department of Forest Resources, Norwegian Forest and Landscape Institute, Ås, Norway
[c] Joanneum Research, Resources, Institute for Water, Energy and Sustainability, Graz, Austria
[d] Department of Primary Industries, Rural Climate Solutions, University of New England/NSW, Armidale, Australia
[e] Department of Natural Resources & the Environment, University of New Hampshire, Durham, N. H, USA
[f] Research Institute for Environment, Energy, and Economics, Appalachian State University, Boone, North Carolina, USA
[g] VTT Technical Research Center of Finland, Espoo, Finland

Global Change Biology Bioenergy
November 2012, Volume 4, Issue 6, pp. 617–619

DOI: [10.1111/j.1757-1707.2012.01190.x]
D4.1.33_3 ([Link to eRoom])

Introduction

In their recent editorial, Schulze and colleagues (Schulze et al., 2012) discuss the implications of a large-scale increase in the harvest of forest biomass to provide 20% of the current global primary energy supply. They present several well-founded concerns regarding the economic and ecological sustainability of such a scenario, concerns we largely share. However, the authors express particular apprehension regarding greenhouse gas (GHG) consequences of expanded forest bioenergy production that we do not entirely share. GHGs – while important – should not be the sole evaluation criterion when the objective is climate protection. The peer reviewed literature provides important insights beyond that presented which warrants additional commentary in order to give a more holistic and balanced perspective on the subject of forest bioenergy and climate.

In particular, the authors overlook two attributes fundamental to forest based bioenergy that distinguish it from fossil-fuel energy: (1) forests can affect climate in many ways extending beyond the biosphere-atmosphere cycling of carbon, and sometimes in ways that are in direct opposition to the carbon cycle, (2) CO_2 emissions from bioenergy sourced from a sustainably managed forest generates less warming than the same mass of CO_2 from fossil fuels.

These attributes can have positive implications for the inclusion of forest based bioenergy as part of an integrated climate mitigation strategy.

Influences of international forest policy processes on national forest policies in Finland, Norway and Sweden

Lindstad B. H., Solberg B.

Norwegian University of Life Sciences, P.O. Box 5003, N-1432 Ås, Norway

Scandinavian Journal of Forest Research
2012, Volume 27, Issue 2, pp. 210-220

DOI: 10.1080/02827581.2011.635079
D4.3.21_1

Abstract

Several international processes provide recommendations for sustainable forest management, including the Convention on Biological Diversity, the Ministerial Conference on the Protection of Forests in Europe and the United Nations Forum on Forests. This paper explores to what degree and how these processes have influenced national forest policies in Finland, Norway and Sweden employing methods developed for studying effectiveness of international agreements. Empirical data on changes in response to the international recommendations were collected, revealing influences on all policy elements in Finland. In Sweden, minor influences were identified on only two out of five investigated elements, while Norway is in an intermediate position. The variations in influences on selected policy elements in rather similar countries indicate different national considerations in response to the international recommendations, signalling challenges in determining effects of the international processes. The assessed influences are next used for an initial investigation of how the international forest policy recommendations influence national policies. Evidence indicates multifaceted and complex ways of influences, and signals of both calculative and normative influences, and their interactions, are found. Elements requiring further investigations are identified, emphasising the casual relationships in determining to what extent and how national policies are affected by international policy processes.

Biodiversity protection and economics in long term boreal forest management — A detailed case for the valuation of protection measures

Bergseng E. [a], *Ask J. A.* [a], *Framstad E.* [b], *Gobakken T.* [a], *Solberg B.* [a], *Hoen H. F.* [a]

[a] Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences, P.O. Box 5003, N-1432 Ås, Norway
[b] Norwegian Institute for Nature Research, P.O. Box 736 Sentrum, N-0105 Oslo, Norway

Forest Policy and Economics
Volume 15, February 2012, pp. 12–21

DOI: 10.1016/j.forpol.2011.11.002
D4.3.21_2 (Link to eRoom)

Abstract

Increased protection of forest biodiversity implies reduced income from timber production both for society and forest owners, and consistent analysis of the relationships between biodiversity benefits and corresponding costs is important both for forest managers as well as policy makers. Using a complex dynamic forest optimization model, we analyse impacts on economy and biodiversity of forest management restrictions implemented to protect biodiversity. A reference scenario is compared to two preservation regimes based on 1) the current Norwegian forest certification system and 2) an expert judgement designed to put strong emphasis on biodiversity protection in boreal forests. Economic impacts are expressed as net present value and harvesting level, while impacts on forest structure are expressed by a vector of variables including old forest proportions, growing stock, number of retention trees, size of buffer zones and amount of dead wood. A rather detailed description of forest structure and biodiversity measures represents the main improvements compared to previous analyses. Different restrictions result in 10–45% decrease in economic value of the forest compared to no restrictions. The most costly measures are found to be 50% increased rotation and keeping old-growth proportions higher than 20%.

- 2011 -

Impacts of combining partial and general equilibrium modelling in freight transport analyses - a forest sector case study from Norway

Hovi I. B. [a], *Madslien A.* [a], *Sjølie H. K.* [b], *Solberg B.* [b], *Trømborg E.* [b], *Veisten K.* [a]

[a] Institute of Transport Economics , Gaustadalleen 21, NO-0349, Oslo, Norway
[b] Department of Ecology and Natural Resource Management , Norwegian University of Life Sciences , PO Box 5003, NO-1432, Ås, Norway

Transportation planning and technology
Volume 34, Issue 3, pp. 259-275, 2011

DOI: [10.1080/03081060.2011.565182](https://doi.org/10.1080/03081060.2011.565182)
D4.3.x

Abstract

The forest sector in Norway is very transport intensive, accounting for approximately 14% of total domestic freight transport traffic on Norwegian roads. This paper presents an analysis linking a general equilibrium freight transport modelling tool with a partial equilibrium model of the forest sector. The freight transport model predicts transport costs, modal split and transport patterns, and the results are treated as inputs to the forest sector model. The objective of the paper is to analyse the modelling effect of taking forest sector model effects back into the freight transport model and treated as new demand. Compared to a base scenario for the year 2020, we compare analyses with and without this new demand from the forest sector model back into the freight transport modelling tool.

Optimal forest management with carbon benefits included

Raymer A. K., Gobakken T., Solberg B.

Norwegian University of Life Sciences, Department of Ecology and Natural Resource Management, P.O. Box 5003, N-1432 Ås, Norway

Silva Fennica
Volume 17, issue 3, pp. 395-414

DOI: http://www.metla.fi/silvafennica/abs/sa45/sa453395.htm
D4.3.x (Link to eRoom)

Abstract

In this paper, we analyse how optimal forest management of even aged Norway spruce changes when economic values are placed on carbon fixation, release, and saved greenhouse gas emissions from using wood instead of more energy intensive materials or fossil fuels. The analyses are done for three different site qualities in Norway, assuming present climate and with a range of CO_2 prices and real rates of return. Compared to current recommended management, the optimal number of plants per ha and harvest age are considerably higher when carbon benefits are included, and increase with increasing price on CO_2. Furthermore, planting becomes more favourable compared to natural regeneration. At the medium site quality, assuming 2% p.a. real rate of return and 20 euros per ton CO_2, optimal planting density increases from 1500 per ha to 3000 per ha. Optimal harvest age increases from 90 to 140 years. Including saved greenhouse gas emissions when wood is used instead of more energy intensive materials or fossil fuels, i.e. substitution effects, does not affect optimal planting density much, but implies harvesting up to 20 years earlier. The value of the forest area increases with increasing price on CO_2, and most of the income is from carbon. By using the current recommended management in calculations of carbon benefit, our results indicate that the forest's potential to provide this environmental good is underestimated. The study includes many uncertain factors. Highest uncertainty is related to the accuracy of the forest growth and mortality functions at high stand ages and densities, and that albedo effects and future climate changes are not considered. As such, the results should be viewed as exploratory and not normative.

Impacts of agent information assumptions in forest sector modelling

Sjølie H. K. [a], Latta G. S. [b], Adams D. M. [b], Solberg B. [a]

[a] Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences, P.O. Box 5003, 1432 Ås, Norway
[b] Department of Forest Engineering, Resources and Management, Oregon State University, Corvallis, OR 97331, USA

Journal of Forest Economics
Volume 17, Issue 2, April 2011, pp. 169–184

DOI: [10.1016/j.jfe.2011.02.009]
D4.3.x ([Link to eRoom])

Abstract

The forest sector faces changing political paradigms and volatile policy measures. Policy makers rely on economic and biological models to inform them of the impacts and risks associated with both anticipated and unforeseen policies or shocks to the system. Assumptions about agents' knowledge of future events are fundamental in all forms of models suggesting that the degree of information of future events may have large behavioral impacts. Despite the importance of this assumption, few studies have looked into what this difference in information may imply, and few studies have analyzed the importance of varying the degree of *a priori* information on the impacts of policy measures. This paper attempts to elucidate some of these impacts by comparing how an exogenous shock affects the Norwegian forest sector if the agents are assumed to have: (i) perfect information, (ii) information about the market shift only a limited time before its implementation or (iii) no *a priori* information. The shock analyzed is an import ban on all coniferous wood into Norway, which is possible if the Pinewood nematode (PWN) becomes more widespread in Europe. To examine this question, we adapt the Norwegian forest sector model NorFor to reflect perfect, limited and no prior information. The results indicate that if the agents anticipate the shock, they will begin to adjust harvest and production levels before it occurs. Due to high opportunity costs, harvest is reduced in the first periods to allow increases later. Bioenergy, with much lower profit than pulp and paper on the margin, is the hardest hit by the ban, while paper production is little affected. This may also be due to high capital costs in the paper industry and a perfectly elastic wood demand curve for bioenergy use. Substantial price increases for both raw materials and final products are suggested under either limited or perfect foresight. The analysis may provide useful insight about how agents react to sudden changes depending on their *a priori* information.

Greenhouse gas emission impacts of use of Norwegian wood pellets: a sensitivity analysis

Sjølie H. K., Solberg B.

Norwegian University of Life Sciences, Norway

Environmental Science and Policy
Volume 14, Issue 8, December 2011, pp. 1028–1040

DOI: 10.1016/j.envsci.2011.07.011
D4.3.x ([Link to eRoom]())

Abstract

The rapid growth in wood pellet consumption in Europe has promoted an increase in imports from other continents. In this study, we analyse: (i) the resource use and greenhouse gas (GHG) emissions over the life cycle of wood pellets produced in Western Europe, (ii) the net GHG emission effects of replacing the fossil fuels lignite, hard coal and paraffin with these pellets, (iii) the most important factors impacting on GHG emissions, and (iv) the costs of replacing these fossil fuels with the pellets compared to changes in the net GHG emissions. Over the life cycle of wood pellets, starting from wood harvesting, total emissions amount to 236 kg CO_2eq/tonne pellets (43 kg CO_2eq/GJ energy output), but can vary between 113 and 482 kg CO_2eq/tonne pellets. Substituting lignite in power plants can reduce GHG emissions by about 298 kg CO_2eq/GJ energy output (1620 kg CO_2eq/tonne pellets), but only by 58 kg CO_2eq/GJ energy output in the "Min. substitution effect" scenario where the emissions in the pellet production chain were high and paraffin replaced. The criteria for carbon neutrality are discussed. Including all CO_2 emissions from pellet combustion but not carbon sequestration in forest, GHG emissions from the use of pellets are slightly less than from the replaced lignite. The results of our sensitivity analyses indicate the importance of utilizing bioenergy efficiently. Including all or no CO_2 emissions from combustion are both simplifications, and, depending on the conditions, net CO_2 emissions from pellets lie somewhere between the two. Simple cost estimates suggest that reducing GHG emissions by replacing lignite and hard coal with pellets costs about 60–70 €/tonne CO_2eq. Replacement of paraffin with pellets has however positive net returns due to the higher market prices for paraffin than for pellets.

Radiative Forcing Impacts of Boreal Forest Biofuels: A Scenario Study for Norway in Light of Albedo

Bright, R.M. [a], *A.H. Strømman* [a], *and G.P. Peters* [b]

[a] Industrial Ecology Program, Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway
[b] Center for International Climate and Environmental Research – Oslo (CICERO), Norway

Environmental Science & Technology
2011, 45 (17), pp. 7570–7580

DOI: 10.1021/es201746b
D4.1.x (Link to eRoom)

Abstract

Radiative forcing impacts due to increased harvesting of boreal forests for use as transportation biofuel in Norway are quantified using simple climate models together with life cycle emission data, MODIS surface albedo data, and a dynamic land use model tracking carbon flux and clear-cut area changes within productive forests over a 100-year management period. We approximate the magnitude of radiative forcing due to albedo changes and compare it to the forcing due to changes in the carbon cycle for purposes of attributing the net result, along with changes in fossil fuel emissions, to the combined anthropogenic land use plus transport fuel system. Depending on albedo uncertainty and uncertainty about the geographic distribution of future logging activity, we report a range of results, thus only general conclusions about the magnitude of the carbon offset potential due to changes in surface albedo can be drawn. Nevertheless, our results have important implications for how forests might be managed for mitigating climate change in light of this additional biophysical criterion, and in particular, on future biofuel policies throughout the region. Future research efforts should be directed at understanding the relationships between the physical properties of managed forests and albedo, and how albedo changes in time as a result of specific management interventions.

CO_2 emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming

Cherubini F [a], Peters GP [b], Berntsen T [b], Strømman AH [a], Hertwich E [a]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway,
[b] Center for International Climate and Environmental Research – Oslo (CICERO), Oslo, Norway,
[c] Department of Geosciences, University of Oslo, Norway

Global Change Biology Bioenergy
October 2011, Volume 3, Issue 5, pp. 413–426

DOI: 10.1111/j.1757-1707.2011.01102.x
D4.1.15 (Link to eRoom)

Abstract

Carbon dioxide (CO_2) emissions from biomass combustion are traditionally assumed climate neutral if the bioenergy system is carbon (C) flux neutral, i.e. the CO_2 released from biofuel combustion approximately equals the amount of CO_2 sequestered in biomass. This convention, widely adopted in life cycle assessment (LCA) studies of bioenergy systems, underestimates the climate impact of bioenergy. Besides CO_2 emissions from permanent C losses, CO_2 emissions from C flux neutral systems (that is from temporary C losses) also contribute to climate change: before being captured by biomass regrowth, CO_2 molecules spend time in the atmosphere and contribute to global warming. In this paper, a method to estimate the climate impact of CO_2 emissions from biomass combustion is proposed. Our method uses CO_2 impulse response functions (IRF) from C cycle models in the elaboration of atmospheric decay functions for biomass-derived CO_2 emissions. Their contributions to global warming are then quantified with a unit-based index, the GWP_{bio}. Since this index is expressed as a function of the rotation period of the biomass, our results can be applied to CO_2 emissions from combustion of all the different biomass species, from annual row crops to slower growing boreal forest.

Effects of boreal forest management practices on the climate impact of CO_2 emissions from bioenergy

Cherubini F, Strømman AH, Hertwich E

Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway

Ecological modelling
Volume 223, Issue 1, 24 December 2011, pp. 59–66

DOI: 10.1016/j.ecolmodel.2011.06.021
D4.1.19 (Link to eRoom)

Abstract

In Life Cycle Assessment (LCA), carbon dioxide (CO_2) emissions from biomass combustion are traditionally assumed climate neutral if the bioenergy system is CO_2 flux neutral, i.e. the quantity of CO_2 released approximately equals the amount of CO_2 sequestered in biomass. This convention is a plausible assumption for fast growing biomass species, but is inappropriate for slower growing biomass, like forests. In this case, the climate impact from biomass combustion can be potentially underestimated if CO_2 emissions are ignored, or overestimated, if biogenic CO_2 is considered equal to anthropogenic CO_2. The estimation of the effective climate impact should take into account how the CO_2 fluxes are distributed over time: the emission of CO_2 from bioenergy approximately occurs at a single point in time, while the absorption by the new trees is spread over several decades. Our research target is to include this dynamic time dimension in unit-based impact analysis, using a boreal forest stand as case study. The boreal forest growth is modelled with an appropriate function, and is investigated under different forestry regimes (affecting the growth rate and the year of harvest). Specific atmospheric decay functions for biomass-derived CO_2 are then elaborated for selected combinations of forest management options. The contribution to global warming is finally quantified using the GWP_{bio} index as climate metric. Results estimates the effects of these practices on the characterization factor used for the global warming potential of CO_2 from bioenergy, and point out the key role played by the selected time horizon.

Life cycle assessment of bioenergy systems: State of the art and future challenges

Cherubini F. and Strømman A.H.

Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway

Bioresource Technology
Volume 102, Issue 2, January 2011, pp. 437–451

DOI: 10.1016/j.biortech.2010.08.010
D4.1.2 (Link to eRoom)

Abstract

The use of different input data, functional units, allocation methods, reference systems and other assumptions complicates comparisons of LCA bioenergy studies. In addition, uncertainties and use of specific local factors for indirect effects (like land-use change and N-based soil emissions) may give rise to wide ranges of final results. In order to investigate how these key issues have been addressed so far, this work performs a review of the recent bioenergy LCA literature. The abundance of studies dealing with the different biomass resources, conversion technologies, products and environmental impact categories is summarized and discussed. Afterwards, a qualitative interpretation of the LCA results is depicted, focusing on energy balance, GHG balance and other impact categories. With the exception of a few studies, most LCAs found a significant net reduction in GHG emissions and fossil energy consumption when bioenergy replaces fossil energy.

Chemicals from lignocellulosic biomass: opportunities, perspectives, and potential of biorefinery systems

Cherubini, F. and Strømman, A. H.

Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway

Biofuels, bioproducts and biorefining
September/October 2011, Volume 5, Issue 5, pp. 548–561

DOI: [10.1002/bbb.297]
D4.1.21 ([Link to eRoom])

Abstract

Most of the chemical products used today in our society originate from fossil sources through refinery operations. The continual price increase of fossil resources, their uncertain availability, and the environmental concerns of their exploitation have led to a demand for the elaboration of alternative chemical production patterns based on renewable sources. Besides fossils, the only resource available for producing chemicals is biomass, and the establishment of biorefinery complexes is increasingly perceived as a promising alternative to oil refineries. This work is a position paper that provides an insight in the emerging biorefinery concept, with special focus on the opportunities, perspectives, and potential regarding the use of lignocellulosic biomass as raw material in the preparation of platform chemicals needed to meet the existing demand. Results show that replacing fossil resources with wood requires large amounts of biomass and has several technological barriers that are still far from being overcome. This paper identifies the key reactions where major efficiency improvements and research efforts are needed (dehydration, fermentation, hydrogenation, etc.), as well as the possibilities when it comes to enhancing biomass conversion performances through the synthesis of new platform chemicals, with higher oxygen content, so as to accommodate the original biomass composition.

Material, energy and environmental performance of technological and social systems under a Life Cycle Assessment perspective

Ulgiati S [a], Ascione M [b], Bargigli S [a], Cherubini F [c], Franzese P [a], Raugei M [d], Viglia S [a], Zucaro A. [a]

[a] Department of Sciences for the Environment, Parthenope University of Napoli Centro Direzionale - Isola C4, 80143, Napoli, Italy
[b] Department of Chemistry, University of Rome "La Sapienza", Piazzale Aldo Moro, 5, 00185, Roma, Italy
[c] Department of Energy and Process Engineering, Industrial Ecology Programme, Norwegian University of Science and Technology (NTNU) Høgskoleringen 5, E1, NO-7491, Trondheim, Norway
[d] Grup d'Investigació en Gestió Ambiental, Environmental Management Research Group, GiGa (ESCI-UPF), Passeig Pujades, 1, E-08003, Barcelona, Spain

Ecological modelling
Volume 222, Issue 1, 10 January 2011, pp. 176–189

DOI: 10.1016/j.ecolmodel.2010.09.005
D4.1.22 (Link to eRoom)

Abstract

Selected energy and material resource conversion systems are compared in this paper under an extended LCA point of view. A multi-method multi-scale assessment procedure is applied in order to generate consistent performance indicators based on the same set of input data, to ascertain the existence of constraints or crucial steps characterized by low conversion efficiency and to provide the basis for improvement patterns. Optimizing the performance of a given process requires that many different aspects are taken into account. Some of them, mostly of technical nature, relate to the local scale at which the process occurs. Other technological, economic and environmental aspects are likely to affect the dynamics of the larger space and time scales in which the process is embedded. These spatial and time scale effects require that a careful evaluation of the relation between the process and its surroundings is performed, so that hidden consequences and possible sources of inefficiency and impact are clearly identified. In this paper we analyse and compare selected electricity conversion systems, alternative fuels and biofuels, waste management strategies and finally the time evolution of an urban system, in order to show the importance of a multiple perspective point of view for the proper evaluation of a system's environmental and resource use performance.

Life Cycle Assessment of Biomass-based Combined Heat and Power Plants

Guest G, Bright RM, Cherubini F, Michelsen O, Strømman AH

Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway

Journal of Industrial Ecology
December 2011, Volume 15, Issue 6, pp. 908–921

DOI: 10.1111/j.1530-9290.2011.00375.x
D4.1.6 (Link to eRoom)

Abstract

Norway, like many countries, has realized the need to extensively plan its renewable energy future sooner rather than later. Combined heat and power (CHP) through gasification of forest residues is one technology that is expected to aid Norway in achieving a desired doubling of bioenergy production by 2020. To assess the environmental impacts to determine the most suitable CHP size, we performed a unit process-based attributional life cycle assessment (LCA), in which we compared three scales of CHP over ten environmental impact categories—micro (0.1 megawatts electricity [MWe]), small (1 MWe), and medium (50 MWe) scale. The functional units used were 1 megajoule (MJ) of electricity and 1 MJ of district heating delivered to the end user (two functional units), and therefore, the environmental impacts from distribution of electricity and hot water to the consumer were also considered. This study focuses on a regional perspective situated in middle-Norway's Nord- and Sør-Trøndelag counties. Overall, the unit-based environmental impacts between the scales of CHP were quite mixed and within the same magnitude. The results indicated that energy distribution from CHP plant to end user creates from less than 1% to nearly 90% of the total system impacts, depending on impact category and energy product. Also, an optimal small-scale CHP plant may be the best environmental option. The CHP systems had a global warming potential ranging from 2.4 to 2.8 grams of carbon dioxide equivalent per megajoule of thermal (g CO_2-eq/MJ_{th}) district heating and from 8.8 to 10.5 grams carbon dioxide equivalent per megajoule of electricity (g CO_2-eq/MJ_{el}) to the end user.

Influence of allocation methods on the environmental performance of biorefinery products—A case study

Cherubini F [a], Strømman AH [a], Ulgiati S [b]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway
[b] Department of Sciences for the Environment, Parthenope University of Naples, 80143 Napoli, Italy

Resources, Conservation & Recycling
Volume 55, Issue 11, September 2011, pp. 1070–1077

DOI: 10.1016/j.resconrec.2011.06.001
D4.1.9 (Link to eRoom)

Abstract

Life Cycle Assessment (LCA) methodology is the prevailing framework for estimating the environmental performances of a product/service. The application of LCA frequently requires practitioners to address allocation issues, especially when a large number of co-products are produced. The choice of an allocation approach for multifunctional processes is among the most debated methodological aspects in the LCA community, given its potentially large influence on final outcomes. Despite numerous efforts, a uniform consensus on the best allocation practice is still lacking and no single method appears as the most suitable for all situations.

The aim of this paper is to assess how different allocation methods affect the environmental performances of a lignocellulosic biorefinery. Biorefinery systems represent a good example of a multifunctional process, since they co-produce multiple energy and material products. The following allocation procedures are applied: system expansion (also named substitution method), partitioning method according to different features of co-products (mass, energy, exergy and economic value), and hybrid approach (given by a combination of the previous ones). In order to enhance the clarity of the discussion, a mathematical notation for these allocation procedures is adopted, and analytical interrelations are investigated. Results show the influence of the allocation methods on the environmental impacts assigned to the individual products, both on a unit and annual flow basis.

An economic analysis of the potential contribution of forest biomass to the EU RES target and its implications for the EU forest industries

Alexander Moiseyev [a], Birger Solberg [a], A. Maarit I. Kallio [b], Marcus Lindner [c]

[a] Department of Ecology and Natural Resource Management, Norwegian University of Life Science, Ås, Norway
[b] METLA (Finnish Forest Research Institute), Vantaa, Finland
[c] European Forest Institute, Joensuu, Finland

Journal of Forest Economics
April 2011, volume 17, issue 2. Pp 197-213

DOI: 10.1016/j.jfe.2011.02.010
D4.3.10 (Link to eRoom)

Abstract

This study addresses the effects of increasing energy wood prices on the EU forest sector and on the use of wood biomass for energy. We examine different energy wood price levels under two contrasting scenarios of future global development, defined by the A1 and B2 storylines of IPCC. A1 depicts increased globalization and rapid economic growth. In B2, the economic growth is more modest, and the world is more environmentally conscious and regionally oriented. The analysis carried out using the global forest sector model EFI-GTM shows that as energy wood prices increase, the wood imports and reallocation of wood from competing industrial users such as board manufacturers or the pulp and paper industry also increase strongly. The quantity of wood directed from the forest industry to the energy sector would at most be around 20 Mte (million tons of oil equivalent) in terms of energy, given a price of 100 €/m^3 of energy wood. Still, this would cover only around 8% of the European Union's RES target for 2020, and an even lower share for 2030. For some forest industry sectors like production of pulp and panels that would mean an important output reduction, around 20-25%. Additional felling could be an important source of wood for bioenergy in the near future, when utilization of the forest resource potential is still not very high. However, toward 2030, forest resource utilization is projected to increase and might become a limiting factor for additional biomass potentials. Given the relatively high economic growth assumed in the scenarios and the rather strong development in the demand for forest industry products, there is a considerable chance that the supply of wood biomass for energy will be largely limited to logging residues in the long run.

- 2010 –

Crop residues as raw materials for biorefinery systems – A LCA case study

Cherubini F. [a], *Ulgiati S* [b]

[a] Joanneum Research, Institute of Energy Research, Elisabethstraße 5, 8010 Graz, Austria
[b] Parthenope University of Naples, Department of Environmental Sciences, Centro Direzionale, Isola C4, 80143 Napoli, Italy

Applied Energy
Volume 87, Issue 1, January 2010, pp. 47–57

DOI: 10.1016/j.apenergy.2009.08.024
D4.1.x (Link to eRoom)

Abstract

Our strong dependence on fossil fuels results from the intensive use and consumption of petroleum derivatives which, combined with diminishing oil resources, causes environmental and political concerns. The utilization of agricultural residues as raw materials in a biorefinery is a promising alternative to fossil resources for production of energy carriers and chemicals, thus mitigating climate change and enhancing energy security. This paper focuses on a biorefinery concept which produces bioethanol, bioenergy and biochemicals from two types of agricultural residues, corn stover and wheat straw. These biorefinery systems are investigated using a Life Cycle Assessment (LCA) approach, which takes into account all the input and output flows occurring along the production chain. This approach can be applied to almost all the other patterns that convert lignocellulosic residues into bioenergy and biochemicals. The analysis elaborates on land use change aspects, i.e. the effects of crop residue removal (like decrease in grain yields, change in soil N_2O emissions and decrease of soil organic carbon). The biorefinery systems are compared with the respective fossil reference systems producing the same amount of products/services from fossils instead of biomass. Since climate change mitigation and energy security are the two most important driving forces for biorefinery development, the assessment focuses on greenhouse gas (GHG) emissions and cumulative primary energy demand, but other environmental categories are evaluated as well.

Results show that the use of crop residues in a biorefinery saves GHG emissions and reduces fossil energy demand. For instance, GHG emissions are reduced by about 50% and more than 80% of non-renewable energy is saved. Land use change effects have a strong influence in the final GHG balance (about 50%), and their uncertainty is discussed in a sensitivity analysis. Concerning the investigation of the other impact categories, biorefinery systems have higher eutrophication potential than fossil reference systems. Based on these results, a residues-based biorefinery concept is able to solve two problems at the same time, namely find a use for the abundant lignocellulosic residues and ensure a mitigation effect for most of the environmental concerns related to the utilization of non-renewable energy resources.

Therefore, when agricultural residues are used as feedstocks, best management practices and harvest rates need to be carefully established. In fact, rotation, tillage, fertilization management, soil properties and climate can play an important role in the determination of the amount of crop residue that can be removed minimizing soil carbon losses.

Production of Biofuels and Biochemicals from Lignocellulosic Biomass: Estimation of Maximum Theoretical Yields and Efficiencies Using Matrix Algebra

Cherubini F., Strømman A. H.

Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway

Energy & Fuels
24 (4), pp. 2657–2666

DOI: 10.1021/ef901379s
D4.1.14 (Link to eRoom)

Abstract

The dependence on fossil fuels in developed countries is causing increasing concern. Global warming, issues related to peak oil, sustainability issues, and mounting concern for national energy security are the main drivers for a worldwide effort toward a reduction in fossil fuel consumption. The challenge is substantial, because fossil resources are such an integral part of our economy. However, there are many efforts to address this challenge. Development of conversion technologies fed by renewable resources is seen as a promising option. Many technologies for renewable energy are already well-developed and competitive in the market. Emerging technologies include biorefinery complexes, where biomass is used as a renewable carbon-based source for the production of bioenergy and biochemicals. The latter is perceived as a promising alternative to oil-based chemicals. Given the constraints on availability for renewable biomass supply, the importance of efficient use of biomass with a maximization of useful final products is well-acknowledged. Assessing the potentials for biochemicals can be achieved with an a priori estimation of the maximum theoretical yields, as well as a prediction of the conversion efficiencies (in terms of mass, carbon, and energy efficiency) of selected biorefinery production chains. This paper addresses this issue, providing a calculation procedure with which the theoretical yields and efficiencies of some biorefinery systems are estimated. Among the possible biomass sources, lignocellulosic biomass is selected as the raw material, because it is the most-widespread renewable source available in the world, it is locally available in many countries, and it does not compete with food and feed industries. The conversion of biomass to biofuels and chemicals requires conversion of the feedstock from a solid to a liquid state, but also the addition of hydrogen and rejection of excess oxygen, together with other undesired elements. The carbon contents of lignocellulosic biomass components (cellulose, hemicellulose, and lignin) and products are calculated with the help of mathematical equations, and then the chemical reactions for the conversion of feedstock to products are modeled using matrix algebra: the maximum amount of biofuels and/or biochemicals from biomass and the maximum mass, energy, and carbon conversion efficiency of the biorefinery pathway are determined. Following this calculation procedure, an application to some biorefinery systems is performed and discussed. Combining the best feedstock with the most promising final products, results show that up to 0.33 kg of bioethanol, 0.06 kg of furfural, and 0.17 kg of FT-diesel per kg of softwood can be produced and mass, carbon, and energy conversion efficiencies of 56%, 70%, and 82%, respectively, are achieved.

GHG balances of bioenergy systems – Overview of key steps in the production chain and methodological concerns

Cherubini F.

Industrial Ecology Programme, Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), 7491 Trondheim, Norway

Renewable Energy
Volume 35, Issue 7, July 2010, pp. 1565–1573

DOI: 10.1016/j.renene.2009.11.035
D4.1.24 (Link to eRoom)

Abstract

This paper deals with a methodology for calculating the greenhouse gas (GHG) balances of bioenergy systems producing electricity, heat and transportation biofuels from biomass residues or crops. Proceeding from the standard Life-Cycle Assessment (LCA) as defined by ISO 14040 norms, this work provides an overview of the application of the LCA methodology to bioenergy systems in order to estimate GHG balances. In this paper, key steps in the bioenergy chain are identified and the bioenergy systems are compared with fossil reference systems producing the same amount of final products/services. The GHG emission balances of the two systems can thus be compared. Afterwards, the most important methodological assumptions (e.g. functional unit, allocation, reference system, system boundaries) and key aspects affecting the final outcomes are discussed. These key aspects are: changes in organic carbon pools, land-use change effects (both direct and indirect), N_2O and CH_4 emissions from agricultural soils and effects of crop residue removal for bioenergy use. This paper finally provides some guidelines concerning the compilation of GHG balances of bioenergy systems, with recommendations and indications on how to show final results, address the key methodological issues and give homogenous findings (in order to enhance the comparison across case studies).

The biorefinery concept: using biomass instead of oil for producing energy and chemicals

Cherubini F.

Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway

Energy Conversion and Management
Volume 51, Issue 7, July 2010, pp. 1412–1421

DOI: 10.1016/j.enconman.2010.01.015
D4.1.25 (Link to eRoom)

Abstract

A great fraction of worldwide energy carriers and material products come from fossil fuel refinery. Because of the on-going price increase of fossil resources, their uncertain availability, and their environmental concerns, the feasibility of oil exploitation is predicted to decrease in the near future. Therefore, alternative solutions able to mitigate climate change and reduce the consumption of fossil fuels should be promoted. The replacement of oil with biomass as raw material for fuel and chemical production is an interesting option and is the driving force for the development of biorefinery complexes. In biorefinery, almost all the types of biomass feedstocks can be converted to different classes of biofuels and biochemicals through jointly applied conversion technologies. This paper provides a description of the emerging biorefinery concept, in comparison with the current oil refinery. The focus is on the state of the art in biofuel and biochemical production, as well as discussion of the most important biomass feedstocks, conversion technologies and final products. Through the integration of green chemistry into biorefineries, and the use of low environmental impact technologies, future sustainable production chains of biofuels and high value chemicals from biomass can be established. The aim of this bio-industry is to be competitive in the market and lead to the progressive replacement of oil refinery products.

LCA of a biorefinery concept producing bioethanol, bioenergy and chemicals from switchgrass

Cherubini F [a], Jungmeier G [b]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway
[b] Joanneum Research, Institute of Energy Research, Elisabethstr. 5, 8010 Graz, Austria

International Journal of Life Cycle Assessment
Volume 15, issue 1, pp 53-66

DOI: DOI: [10.1007/s11367-009-0124-2](10.1007/s11367-009-0124-2)
D4.1.26 (Link to eRoom)

Abstract

Background, aim, and scope: The availability of fossil resources is predicted to decrease in the near future: they are a non-renewable source, they cause environmental concerns, and they are subjected to price instability. Utilization of biomass as raw material in a biorefinery is a promising alternative to fossil resources for production of energy carriers and chemicals, as well as for mitigating climate change and enhancing energy security. This paper focuses on a biorefinery concept which produces bioethanol, bioenergy, and biochemicals from switchgrass, a lignocellulosic crop. Results are compared with a fossil reference system producing the same products/services from fossil sources.

Materials and methods: The biorefinery system is investigated using a Life Cycle Assessment approach, which takes into account all the input and output flows occurring along the production chain. This paper elaborates on methodological key issues like land use change effects and soil N_2O emissions, whose influence on final outcomes is weighted in a sensitivity analysis. Since climate change mitigation and energy security are the two most important driving forces for biorefinery development, the assessment has a focus on greenhouse gas (GHG) emissions and cumulative primary energy demand (distinguished into fossil and renewable), but other environmental impact categories (e.g., abiotic depletion, eutrophication, etc.) are assessed as well.

Results: The use of switchgrass in a biorefinery offsets GHG emissions and reduces fossil energy demand: GHG emissions are decreased by 79% and about 80% of non-renewable energy is saved. Soil C sequestration is responsible for a large GHG benefit (65 kt CO_2 -eq/a, for the first 20 years), while switchgrass production is the most important contributor to total GHG emissions of the system. If compared with the fossil reference system, the biorefinery system releases more N_2O emissions, while both CO_2 and CH_4 emissions are reduced. The investigation of the other impact categories revealed that the biorefinery has higher impacts in two categories: acidification and eutrophication.

Discussion: Results are mainly affected by raw material (i.e., switchgrass) production and land use change effects. Steps which mainly influence the production of switchgrass are soil N_2O emissions, manufacture of fertilizers (especially those nitrogen-based), processing (i.e., pelletizing and drying), and transport. Even if the biorefinery chain has higher primary

energy demand than the fossil reference system, it is mainly based on renewable energy (i.e., the energy content of the feedstock): the provision of biomass with sustainable practices is then a crucial point to ensure a renewable energy supply to biorefineries.

Conclusions: This biorefinery system is an effective option for mitigating climate change, reducing dependence on imported fossil fuels, and enhancing cleaner production chains based on local and renewable resources. However, this assessment evidences that determination of the real GHG and energy balance (and all other environmental impacts in general) is complex, and a certain degree of uncertainty is always present in final results. Ranges in final results can be even more widened by applying different combinations of biomass feedstocks, conversion routes, fuels, end-use applications, and methodological assumptions.

Recommendations and perspectives: This study demonstrated that the perennial grass switchgrass enhances carbon sequestration in soils if established on set-aside land, thus, considerably increasing the GHG savings of the system for the first 20 years after crop establishment. Given constraints in land resources and competition with food, feed, and fiber production, high biomass yields are extremely important in achieving high GHG emission savings, although use of chemical fertilizers to enhance plant growth can reduce the savings. Some strategies, aiming at simultaneously maintaining crop yield and reduce N fertilization application through alternative management, can be adopted. However, even if a reduction in GHG emissions is achieved, it should not be disregarded that additional environmental impacts (like acidification and eutrophication) may be caused. This aspect cannot be ignored by policy makers, even if they have climate change mitigation objectives as main goal.

Forest sector impacts of the increased use of wood in energy production in Norway

Erik Trømborg, Birger Solberg

Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences, PO Box 5044, NO-1432 Ås, Norway

Forest Policy and Economics
Volume 12, Issue 1, January 2010, pp. 39–47

DOI: 10.1016/j.forpol.2009.09.011
D4.3.3 (Link to eRoom)

Abstract

The main objective of this study was to analyse the impacts of increased energy prices on the traditional forest sector (forestry and forest industries) in Norway The study applied a regionalized partial equilibrium model covering forestry, forest industries and the bioenergy sector. In the model, an increase in the energy price from NOK 0.50/kWh (0.06 Euro/kWh) to NOK 0.70/kWh by the year 2015 reduces production by 12% for particleboard and by 4% for pulp (mainly sulphate), whereas the production of fibreboard was unaffected. The pulp and paper industries in Norway are mainly relying on spruce pulpwood, which is only partly affected by increased bioenergy prices. In the sawmill industries, the negative impact of higher energy prices (input of electricity) is compensated by higher prices received for chips, sawdust and bark. The production of pine sawnwood (accounting for about 31% of the sawnwood production in Norway) increased by 3% by 2015 when the energy price increased from NOK 0.50 to 0.70 NOK per kWh, whereas the production of spruce sawnwood (accounting for 69% of the sawnwood production) decreased by 0.4%. Future, improvements of the model should include even more detailed descriptions of bioenergy technologies, the supply of wood residues and the energy market, including consumer behaviour and investment decisions.

Effects and costs of policies to increase bioenergy use and reduce GHG emissions from heating in Norway

Hanne K. Sjølie [a], Erik Trømborg [a], Birger Solberg [a], Torjus F. Bolkesjø [b]

[a] Norwegian University of Life Sciences, P.O. Box 5003, 1432 Ås, Norway
[b] Point Carbon, P.O. Box 7120 St.Olav, 0130 Oslo, Norway

Forest Policy and Economics
Volume 12, Issue 1, January 2010, pp. 57–66

DOI: 10.1016/j.forpol.2009.08.011
D4.3.4 (Link to eRoom)

Abstract

In many European countries, the use of policy measures to decrease greenhouse gas (GHG) emissions from energy consumption, including heating, is high on the political agenda. Also, increasing the absolute consumption of bioenergy seems to partly be an objective in itself. But neither the costs of replacing fossil fuels with bioenergy in heating, nor the effects on the GHG emission account are clear.

This study analyses first the avoided GHG emissions from substituting one energy unit of fossil fuel with forest based bioenergy (wood fuel) in several heating technologies. Secondly, the effects on bioenergy production of two policy measures in Norway - higher tax on domestic heating oil and paraffin and investment grants to district heating installations based on wood fuels - are investigated. Thereafter, the results are combined to display how the emissions from heating are affected. Finally, the achievements are compared to the costs. The analysis is done by using a partial, spatial equilibrium model of the Norwegian forest sector, wood fuels included.

Based on model runs we conclude that a tax of 60 €/CO_2eq on competing fossil fuels could increase the bioenergy use in district heating installations with almost 4000 GWh/year. The same amount of bioenergy could be used in pellet stoves and central heating systems, but a higher tax is then necessary. 50% investment grant to district heating installations may also have a large effect on the bioenergy use, but the effect of the subsidies decreases rapidly if applied together with a tax. Around 70% of the emissions from heating in Norway may potentially be avoided, but such achievements depend on very high taxes on fossil fuels. Both taxes and subsidies may greatly influence the energy market, but should be used with caution in order to obtain the preferred goals. Few similar studies are carried out in this field, and the results might be of interest for the bioenergy industry and the energy policy authorities.

Forest sector market impacts of changed roundwood export tariffs and investment climate in Russia

Birger Solberg [a], Alexander Moiseyev [b], A. Maarit I. Kallio [c], Anne Toppinen [d]

[a] Norwegian University of Life Sciences, Department of Ecology and Natural Resource Management, P.O. Box 5003, 1432 Ås, Norway
[b] European Forest Institute, Torikatu 34, 80100 Joensuu, Finland
[c] Finnish Forest Research Institute, P.O. Box 18, 01301 Vantaa, Finland
[d] University of Helsinki, Department of Forest Economics, P.O. Box 27, 00014 Helsinki, Finland

Forest Policy and Economics
Volume 12, Issue 1, January 2010, pp. 17–23

DOI: 10.1016/j.forpol.2009.09.016
D4.3.5 (Link to eRoom)

Abstract

The Russian Federation is the world's largest net exporter of roundwood. To encourage shift in exports from roundwood to value-added industrial products, Russia has set large tariffs on its roundwood exports, and announced that even higher ones would be introduced in the future. Using a global forest sector model, the EFI-GTM, we analyse how the Russian and global forest product markets will evolve towards 2020 under alternative tariff levels and assumptions on investment climate in Russia. Our results show that the tariffs decrease harvest and roundwood prices in Russia, but improve the speed of development in the Russian sawnwood and pulp industry. The results also suggest that policies which improve the investment climate in Russia are more vital than the tariffs for the Russian forest industry to develop favourably. Among the tariff settings considered, the prevailing one of 15€ per cubic meter with non-coniferous pulpwood exempted, seems most beneficial for Russia. With a tax of 50€ per cubic meter, its forest industry would not develop much stronger than in the 15€ case, but forestry would suffer from a drastic harvest decrease caused by a nearly complete stop in the Russian roundwood exports, and negligible tax income would be generated. Outside Russia, the main importers of Russian roundwood would experience significant wood price increases and decreased forest industry production. The decline in the forest industry output would be largest in Asia, due to scarce supply there of raw material substitutes for wood imported from Russia, whereas the highest relative increase in roundwood prices would take place in the EU.

