Greenhouse Gas Balances of Bioenergy Systems —

a synopsis prepared by Task 25

Introduction

The IEA Bioenergy Task on Greenhouse Gas (GHG) Balances of Bioenergy Systems offers an opportunity to coordinate the work of national programmes on the ways GHG balances can be set up for a wide range of bioenergy technologies and on ways of implementing GHG mitigation strategies. The Task was started in 1995 as Task XV, with an initial duration of three years, and is continuing as Task 25 until the end of the year 2000.

Surplus straw is regarded a substantial biofuel resource in many countries. (Courtesy of ORNL, USA)

Objectives

The goal of Task 25 is to analyse, on a full fuel-cycle basis, all processes involved in the use of bioenergy systems, with the aim of establishing overall GHG balances.

Particularly, this means to

- collect and compare existing data of net GHG emissions from various biomass production processes in agriculture and forestry and from biomass conversion;
- improve the common analytical framework ("standard methodology") for the assessment of GHG balances developed within Task XV;
- use the standard methodology to compare different bioenergy options and assist in the selection of appropriate national strategies for GHG mitigation;
- compare bioenergy and fossil energy systems in terms of their GHG balance;
- evaluate the trade-offs between strategies of maximized carbon storage (afforestation, forest protection) and maximized fossil fuel substitution with biofuels;
- identify missing data and R&D requirements;
- contribute to the work of IPCC/OECD/IEA, especially to promote the possible role of bioenergy for GHG mitigation.

Apart from the scientific value of the results gained, recommendations made by the Task are considered especially useful for decision-makers wishing to determine the maximum net GHG emission reductions achievable from bioenergy projects.

Focus and output

Workshops

Each year, one or two workshops are organized with the aim of attracting experts in the field from around the world, enabling them to exchange their experiences, and to have a creative forum for collaboration.

Wood logs are an important source of bioenergy. (Courtesy of Joanneum Research, Austria)

Bibliography

A bibliography on the Task topic, containing existing publications, unpublished reports, databases, and a directory of researchers and research groups active in the field, with short descriptions of their projects, was first published in February 1996. An updated version will be available by early 1999.

Standard methodology

One focus of the Task has been to develop a common analytical framework for GHG balances, described in the paper "Towards a standard methodology for greenhouse gas balances of bioenergy systems in comparison with fossil energy systems" (Biomass & Bioenergy, 13(6): 359–375), of which a short description is given in this special feature.

Scientific and technical support

The Task has contributed to the work of the IPCC/OECD/IEA Programme on National Greenhouse Gas Inventories, especially to set up approaches for estimating net emissions of carbon dioxide from harvested wood products. This issue has important implications, e.g., on the incentives to use imported biofuels for GHG mitigation.

Task 25 was also active in interpreting the provisions of the Kyoto Protocol on land use, land use change and forestry, and will contribute to an IPCC special report on that issue, to be completed by the year 2000.

Networking between National Programmes and Experts

The work of the Task is organised such that international expertise is made available to the participating countries and the dissemination of Task-related research findings is fostered.

Soil carbon studies on paired land uses (pasture vs. pine) have been carried out at different sites in New Zealand. (Courtesy of Forest Research, New Zealand)

Cornerstones of the standard methodology

Introduction

The increased reliance on bioenergy systems, in place of fossil fuel-based energy systems, could result in net emission savings of greenhouse gases to the atmosphere. In order to understand when such savings are possible, and the magnitude of the opportunities, a systematic framework for estimating the net effect on GHG emissions for the full bioenergy system and the full energy system that it would displace is needed. The major aspects ("cornerstones") of such a common analytical framework or "standard methodology", and a schematic structure, are introduced below.

Carbon Storage Dynamics

Carbon storage in plants, plant debris and soils can change when biomass is grown and harvested. Such changes in carbon storage might extend over longer periods of time, after which a new equilibrium is approached, thus necessitating time-dependent analyses.

Clear-cut harvest, Finland.(Courtesy of Finnish Forest Research Institute, E. Oksanen, Finland)

Trade-offs

Afforestation or forest protection measures may be regarded as effective measures for mitigating the rise of CO_2 in the atmosphere and may compete with bioenergy strategies for land use opportunities.

In such cases trade-offs between biomass harvest and carbon storage in biomass must be considered. Bioenergy options provide long-term benefits whereas, e.g., afforestation is regarded as a temporary measure only.

Afforestation of erodible, marginal pastures is common in New Zealand. (Courtesy of B. Schlamadinger, Austria)

Permanence

Bioenergy provides an irreversible mitigation effect by reducing carbon dioxide at its source. By contrast, afforestation and forest protection are conditional mitigation options, subject to future management regimes.

Native forest, Cairns/Australia. (Courtesy of B. Schlamadinger, Austria)

Emission factors

Biomass fuels can have higher carbon emission rates (amount of carbon emitted per unit of energy) than fossil fuels (e.g., oil or natural gas). This fact is relevant, however, only when biomass fuels are derived from unsustainable land use practices, where a decrease of biological carbon stocks occur over time.

The Enocell Pulp Mill, Uimaharju/Finland, is a modern chemical pulp mill which produces excess heat and power by using process wastes as fuel. (Courtesy of Enso Group, Finland)

Efficiency

The efficiency of bioenergy systems currently in use may in many cases be lower than that of fossil energy systems. However, more recent installations and technology developments (e.g., Integrated Gasification Combined Cycle – IGCC) have brought about highly efficient bioenergy systems.

Upstream Energy Inputs

Production, transport and conversion of biomass fuels require auxiliary inputs of energy, which must be included in the assessment, as must the energy requirements for the supply of fossil fuels on which the reference energy system is based.

By-products

Bioenergy is often produced as a by-product. There are also cases where bioenergy is the main product and other by-products have to be considered. The emissions and offsets associated with both products and by-products must be estimated and allocated.

Leakage

The use of biomass fuels does not always avoid the use of fossil fuels to the extent suggested by the amount of bioenergy actually used, a phenomenon commonly referred to as "leakage". Biomass may simply provide a new energy source and add to the total energy consumption.

Other GHGs

Greenhouse gas emissions associated with both fossil and bioenergy fuel chains include not only CO_2, but other gases (e.g., CH_4 and N_2O) that also alter the radiation balance of the earth's atmosphere.

The IGCC plant in Värnamo/Sweden is the first thermal biomass gasification plant worldwide, with a substantially increased power-to-heat ratio relative to conventional boiler/steam turbines. (Courtesy of Sydkraft, Sweden)

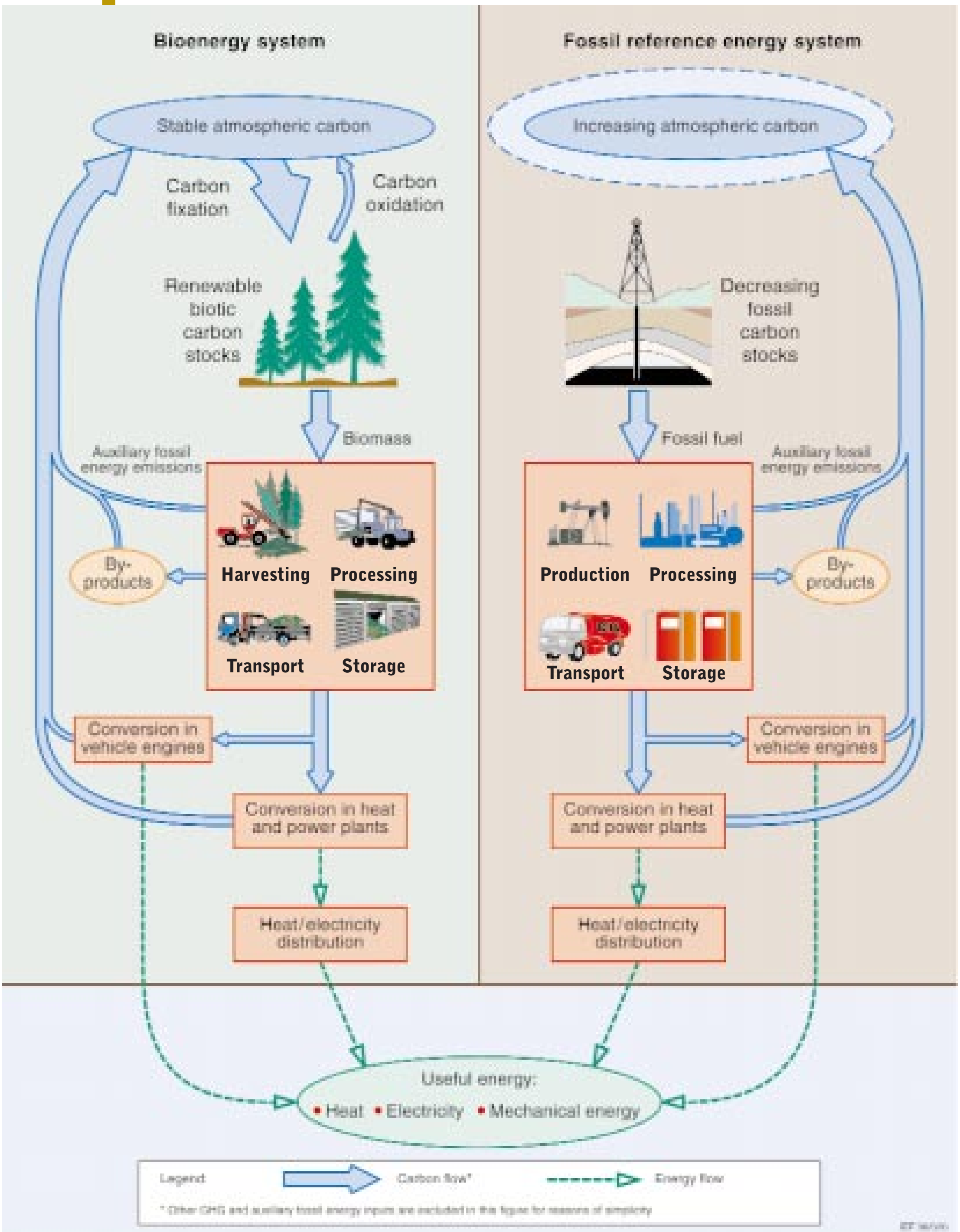
Skidding/forwarding of severed seven-year-old hybrid cotton wood, James River/USA. (Courtesy of ORNL, USA)

Wood from conventional forestry provides residues for energy and is often used for durable wood products, which store carbon and displace more energy-intensive materials. (Courtesy of Forest Research, New Zealand)

Wood chips storage facility for biomass district heating plant, Bad Mitterndorf/Austria. (Courtesy of LEV, Austria)

Seutula landfill gas utilisation plant, Vantaa/Finland. Landfill gas, a mix of methane and CO_2, is explosive and a greenhouse gas of considerable potency. Hence its use for energy has multiple benefits. (Courtesy of Helsinki Metropolitan Area Council YTV, Finland)

Standard methodology: schematic structure



For a description of models based on the standard methodology, developed and applied by Task participants for work relevant to Task 25 (e.g. CBM-CPS/CBM-CFS$_2$, GORCAM, SIMA, STANDPAK/FOLPI, etc.) see: http://www.joanneum.ac.at/iea-bioenergy-task25/model

Selected Results

Selected results of research in the Task 25 countries can be found below. For further information about the work described here please contact the authors directly.

A model of lifecycle energy use and greenhouse gas emissions of transportation fuels and electricity

Prepared by M.A. Delucchi
(madelucchi@ucdavis.edu)

This model of fuel cycle energy use and emissions, developed with funding from the University of California and the U.S. Dept. of Energy, is one of the most detailed and thoroughly documented of its kind. The model or its results have been used by a wide range of public agencies and private firms, including the U.S. Dept. of Energy, the International Energy Agency, and the Intergovernmental Panel on Climate Change.

The model estimates emissions of greenhouse gases and other pollutants, and the use of energy, for the complete fuel cycle for a variety of combinations of energy feedstocks, fuels, and end-use technologies.

The Table below shows a sample of the output (CO_2 equivalent emissions in g/mile, and % changes relative to gasoline, in the year 2010) for light-duty vehicles using biofuels. Even with a full accounting of all fossil-fuel inputs, biofuels based on biomass, as process energy, still provide substantial reductions in life-cycle emissions of greenhouse gases relative to gasoline.

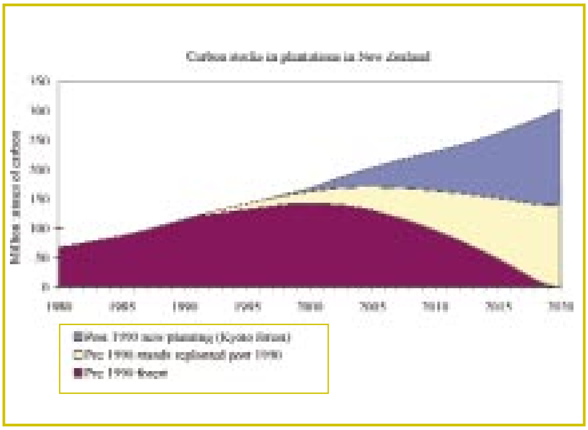
General fuel	**Ethanol**	**Ethanol**	**Methanol**	**Natural gas**
Fuel spec (feedstock)	85% ethanol from corn, 15% gasoline	85% ethanol from wood/perenn grass, 15% gas	85% methanol from wood, 15% gasoline	Compressed natural gas from wood
Vehicle operation	338.4	338.4	326.6	312.3
Carbon recycled through photosynthesis	-207.7	-207.7	-185.8	-214.7
Fuel dispensing, storage and distribution	9.7	5.9	7.2	14.9
Fuel production	168.1	35.6	48.2	22.8
Feedstock transport	6.8	8.2	8.5	7.6
Feedstock and fertilizer production	67.8	27.3	21.3	19.8
Land use changes, cultivation ("-": C sink)	44.5	-53.4	-69.4	-73.7
CH_4 and CO_2 leaks and flares	2.2	2.2	2.7	7.0
Emissions credits for co-products	-34.1	-43.6	0.0	0.0
Total (fuel cycle)	**395.7**	**112.9**	**159.3**	**96.1**
% changes vs. gasoline (fuel cycle)	**-15.8**	**-76.0**	**-66.1**	**-79.6**

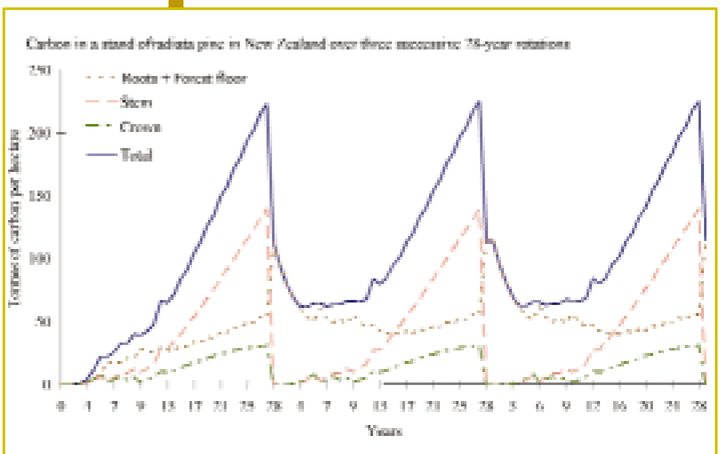
Carbon modelling in New Zealand

Prepared by J. Ford-Robertson, P. Maclaren, and K. Robertson (robertsj@rimu.fri.cri.nz)

The calculations to derive carbon stocks in Pinus radiata stands are performed within the CARBON module of the stand modelling system STANDPAK, which is widely used by the forest industry in New Zealand. Based on the silvicultural regime of a particular stand, the carbon content of different fractions of the stand can be estimated for the entire rotation, or subsequent rotations. In the Figure below, elements have been combined into major groupings for a 28-year rotation, which includes pruning at age 6, 8 and 9 years, and thinning (to waste) at age 6 and 9 years. Logs are only extracted from the site at clearfell (age 28).

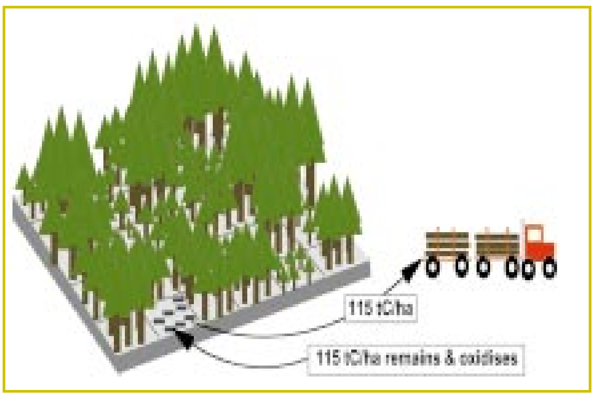
The Diagram below shows results from the CARBON module for individual stands, used in conjunction with the National Exotic Forest Description (a database of age and silvicultural regime for all plantations in New Zealand) in the estate modelling system FOLPI. This can be used to model scenarios of new planting rates and estimated rotation lengths to derive estimates of the carbon stocks in the national forest estate.





In a 'normal forest' there is an equal area in each age class. In this case (as shown in the Figure below) when one stand is felled, approximately half of the stand carbon is removed in the logs, and the remainder is oxidised over time in the forest. The remaining stands in the forest continue to sequester carbon thus maintaining an equilibrium of total carbon stock in the entire forest.

Under the Kyoto Protocol, only forests that have been planted since 1990 can be offset against emissions. In New Zealand, it is expected that commercial forests planted after 1990 ("Kyoto forest") will become increasingly important relative to the existing estate.



Modelling the Finnish forest sector carbon balance

Prepared by K. Pingoud and T. Karjalainen (kim.pingoud@vtt.fi)

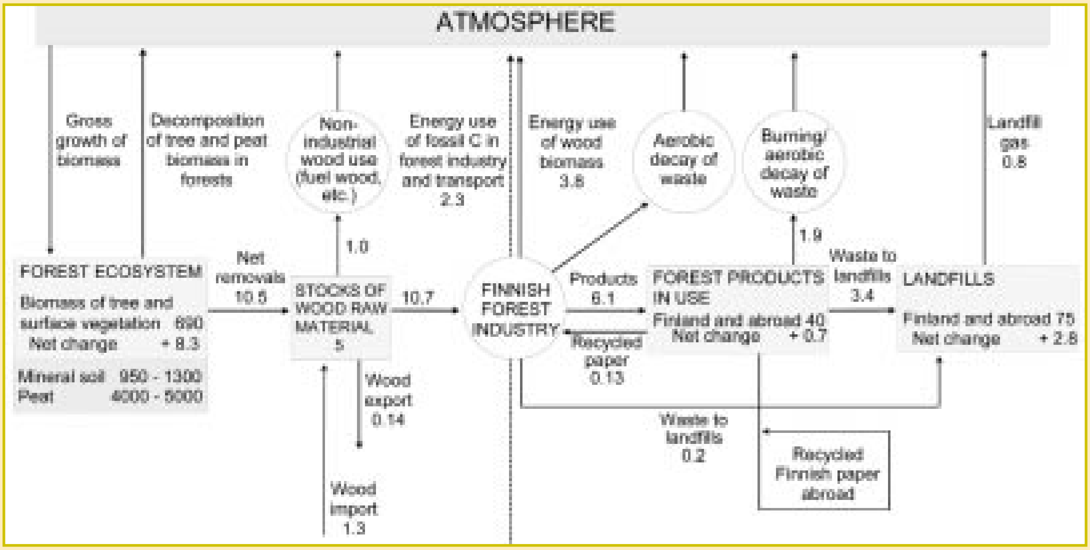
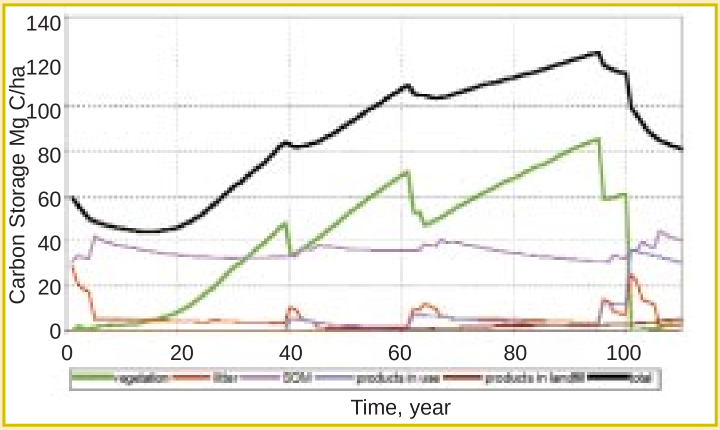


Figure top: The carbon reservoirs (Tg C), the changes in them and the fluxes (Tg C a-1) of the Finnish forest sector in 1990 were estimated by Pingoud et al.(1996). The carbon reservoir of wood-based products in Finland and its rate of change were estimated with the aid of direct inventories of wood products in buildings and elsewhere. However, most of the products were exported, and the total reservoir estimates including the exports are based on an extrapolation. The calculated greenhouse gas balance of the Finnish forest sector depends crucially on the approach for estimating the fate of carbon from forest harvesting and wood products (Pingoud, 1997).



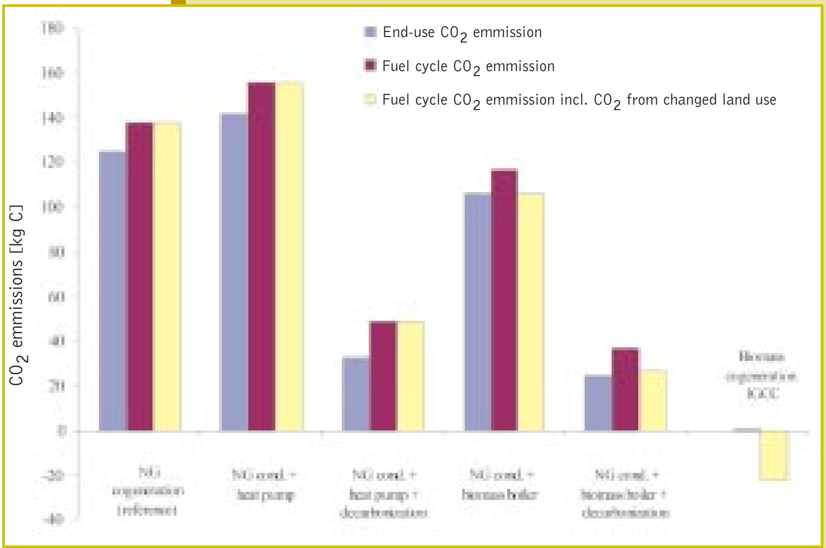
An example of the development of carbon stocks in forests and wood products is shown in the Figure lower right. The simulation was made with a carbon budget model for forests and wood-based products (Karjalainen, 1994). The simulation was started after clearcut. The whole system is a source of carbon during the first ten years, while more carbon is released from decomposing litter and soil organic matter (SOM) than is sequestered by young, growing trees. The stand is thinned tree times (years 39, 61 and 94) and clearcut year 100. After each harvest, part of the living biomass is transferred to litter (harvest residues), to wood products and into the atmosphere (processing losses). The model has been applied to estimate the impact of different forest management practices and climate change on forest and wood product carbon budget, both on stand level and on regional level (e.g. Karjalainen 1996, Pussinen et al. 1997, Mäkipää et al. 1998).

CO_2 mitigation cost for biomass and natural gas systems with decarbonization

Prepared by L. Gustavsson and A. Karlsson
(leif.gustavsson@miljo.lth.se)

Reductions of greenhouse gas emissions can be achieved by several technological options in the energy supply sector. We have analysed the carbon mitigation cost for biomass systems and natural gas systems with decarbonization.

Diagram upper left: End-use and fuel-cycle CO_2 emission of producing 1.0 MWh of power and 1.0 MWh of heat for different energy systems, as well as the CO_2 emission balance when both the fuel-cycle CO_2 emission and the CO_2 emission from the change of land use are included. Biomass is Salix cultivated instead of annual food crops.



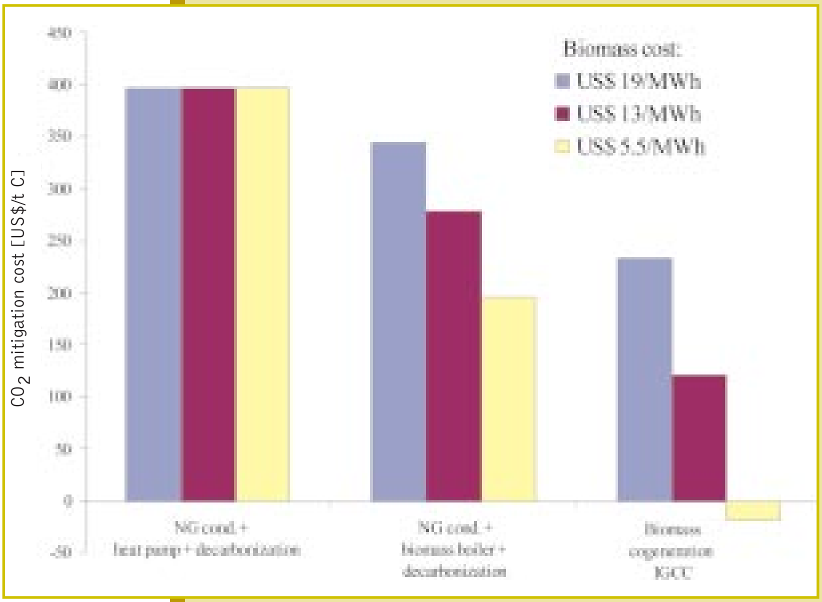


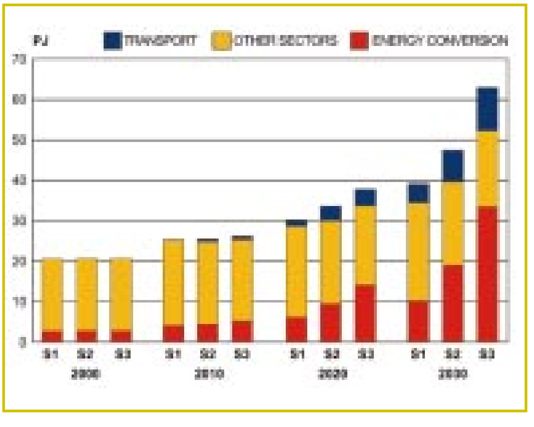
Diagram lower left: CO_2 mitigation cost when considering the fuel-cycle CO_2 emission including the CO_2 emission from change in land use. The reference energy system is a natural gas-fired, cogeneration plant with combined cycle technology and the reference land use is the cultivation of annual food crops on mineral soils. The current cost of Salix in Sweden is about 19 US$/MWhfuel which might be reduced to 13 US$/MWhfuel by improvements in plant breeding and cultivation methods. Transportation cost of 3 US$/MWhfuel is included. Salix is also a suitable crop for a vegetation filter and if used for waste water treatment, the cost including transportation might be 3-8 US$/MWhfuel. The CO_2 mitigation cost is lower for biomass systems using IGCC technology than for natural gas systems using decarbonization and the cost could even be negative.
[L. Gustavsson and P. Börjesson (1998) Energy Policy 26:9, pp. 699–713].

Energy Strategy of Croatia: bioenergy use and related GHG emission reductions

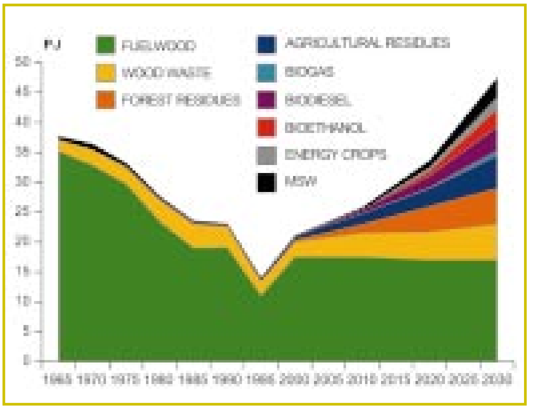
Prepared by J. Domac and V. Jelavic
(jdomac@eihp.hr)

The Energy Strategy of the Republic of Croatia, issued in 1998, has considered three different scenarios. The first of them (S-1, "low'') was based on a slow introduction of advanced technologies and does not include any governmental support. The second scenario (S-2, ''moderate'') includes stronger concerted policy for introduction of new technologies, use of renewables and increasing energy efficiency. Finally, the third scenario (S-3, ''high''), a ''very environmental'' scenario, comprises that problems with pollution and greenhouse effects will significantly affect energy policy in Croatia as early as 2010. Unlike other renewables, bioenergy has a significant position in all scenarios (see Figure below).

Energy scenarios for biomass use in Croatia



Past and future energy production and biomass use in Croatia



Bioenergy systems in Croatia offer significant possibilities for GHG emission reductions in Croatia (more than 10% in scenario S-3) and should be given more attention in the future (see Figure above and Table below).

Contribution of bioenergy systems to GHG emission reductions in Croatia

Scenario/year	2010	2030
S-1 (''low'')	5.9 %	5.4 %
S-2 (''moderate'')	6.3 %	7.0 %
S-3 (''high'')	6.5 %	10.1 %

Research of GHG balances of bioenergy systems in Croatia involves scientists and experts from the following institutions: EKONERG holding, Energy Institute ''Hrvoje Pozar'', and the State Directorate for Environment.

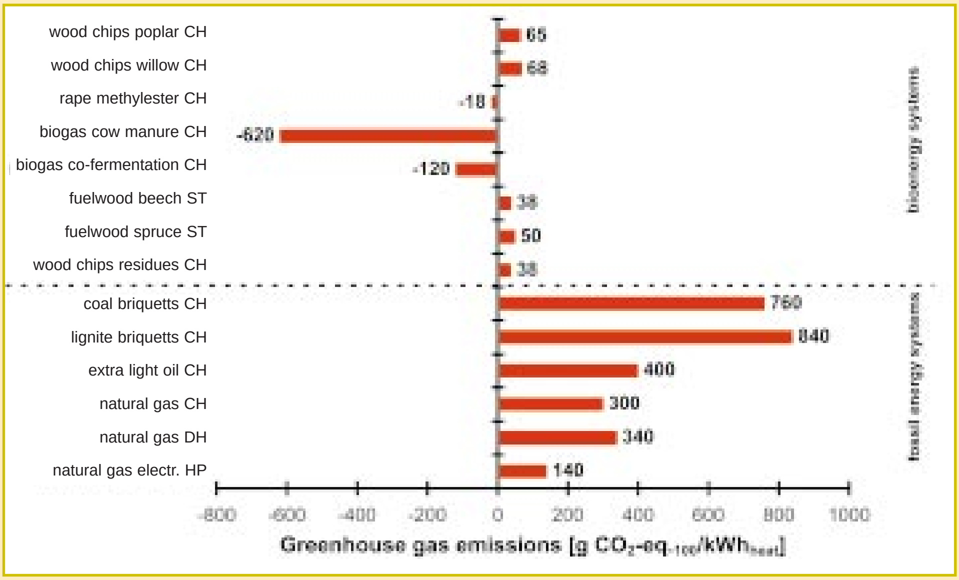
Greenhouse gas balances of bioenergy systems in Austria – first results

Prepared by G. Jungmeier
(gerfried.jungmeier@joanneum.ac.at)

In this project we apply the standard methodology developed by IEA Bioenergy Task 25. Different bioenergy systems, supplying electricity and/or heat from various sources of biomass, are analysed based on the situation in Austria in 2000 and 2020. The life cycle emissions of greenhouse gases (CO_2, N_2O, CH_4) are calculated for about 300 biomass and 100 fossil energy systems and compared with each other. Greenhouse gas implications of land use changes, reference use of biomass and of by-products are considered.

The first results of the life-cycle greenhouse gas emissions, here for heat supply systems, demonstrate that some bioenergy systems are associated with "negative" emissions, as shown in the diagram below for biogas and methylester. In the case of biogas this is mainly because emissions from the reference biomass use are avoided (the reference use of manure is storing the manure – associated with uncontrolled emissions of methane). In the case of biodiesel it is due to substitution effects of by-products (the by-products of methylester are glycerin that substitutes for conventionally-produced glycerin for chemical use and rape cake that substitutes for soybean feed).

The comparison of bioenergy systems with fossil energy systems shows that a significant reduction of greenhouse gas emissions is predicted in all possible "combinations" of bioenergy and fossil energy systems in the Diagram. The net reduction of emissions is greatest when central heating based on lignite briquettes is displaced by central heating with biogas from cow manure.



CH	*Central Heating*
ST	*Stove*
DH	*District Heating*
HP	*Heat Pump*

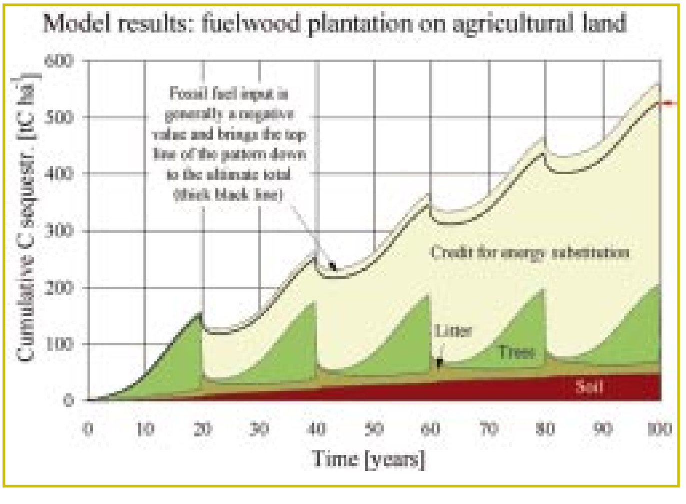
1 g CO_2 = 1 g CO_2 Eq.100, 1 g CH_4 = 21 g CO_2 Eq.100, 1 g N_2O = 310 g CO_2 Eq.100

Some results from the Graz/Oak Ridge Carbon Accounting Model (GORCAM)

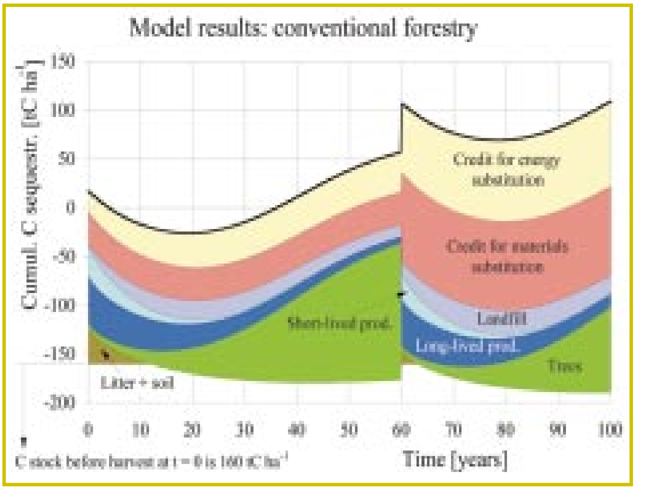
Prepared by B. Schlamadinger and
G. Marland
(bernhard.schlamadinger@joanneum.ac.at)

GORCAM is an Excel spreadsheet model that has been developed to calculate the fluxes and stock changes of carbon associated with land use, land use change, bioenergy and forestry projects. The model considers 1) changes of carbon (C) stored in vegetation, plant litter and soil, 2) reduction of C emissions because biofuels replace fossil fuels, 3) C storage in wood products, 4) reduction of C emissions because wood products replace energy-intensive materials like steel or concrete, 5) recycling or burning of waste wood, and 6) auxiliary fossil fuels used for production of biofuels and wood products. Some illustrations of model output are shown below.

The diagram below shows the modelled scenario for 1 hectare of agricultural land that is afforested to produce biofuels on a 20 year harvest cycle. The diagram shows, successively from the bottom, net carbon (C) uptake in soil and litter, net C increase in trees, and saved C emissions from fossil fuels because biofuels from the plantation are used instead.



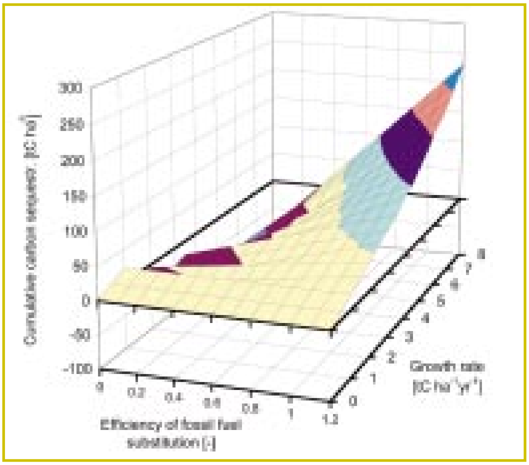
There is an input of fossil fuels required for land management, processing biofuels, etc. To the extent that this exceeds the comparable energy requirements of the displaced fossil fuel, the appropriate amount of C emissions is subtracted from the top line and the final net gain in C sequestration is represented by the line indicated with the red arrow.



The diagram above, shows the scenario for a forest of 160 tC/ha that is harvested at time = 0 to produce wood products and biofuels and is then replanted. Due to the initial harvest there is an initial net loss of on-site carbon, so that the baseline of the plot starts at -160 tC/ha. The harvest-rotation period is 60 years.

The diagram over page shows, successively from the bottom, net carbon (C) uptake in soil and litter (net decreases are represented by a drop in the baseline of the plot), net C increase in trees, net C storage in long-lived products, net C storage in short-lived products, net C storage in landfills, C in fossil fuels not burned due to substitution of wood-based materials for more energy-intensive materials, and C in fossil fuels displaced by biofuels.

This diagram shows the relative advantage after a period of 40 years if surplus agricultural land is used for biofuel production (and fossil fuel substitution) rather than for afforestation without harvest. The net carbon advantage depends on the growth rate of the site and on the efficiency with which fossil fuel carbon emissions are reduced through the use of biofuels. Biofuel production is the better choice especially with efficient use of biomass and for high growth rates.

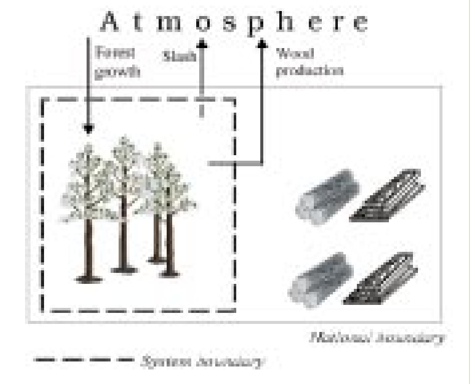


Accounting for wood products in national greenhouse gas inventories

Prepared by B. Schlamadinger
(bernhard.schlamadinger@joanneum.ac.at)

The Intergovernmental Panel on Climate Change (IPCC) has prepared guidelines which countries use to prepare inventories of their greenhouse gas emissions. For carbon fluxes in forestry and wood products the IPCC approach (shown in the Diagram right) has been used in the last few years, which essentially only considers carbon stock changes in forests. IPCC is now investigating alternative approaches (1 to 3 in the Diagrams following) to better deal with wood products. These approaches are presented here. The Task 25 involvement comes from our concern that biomass fuels continue to be treated as a renewable source of energy in national greenhouse gas inventories.

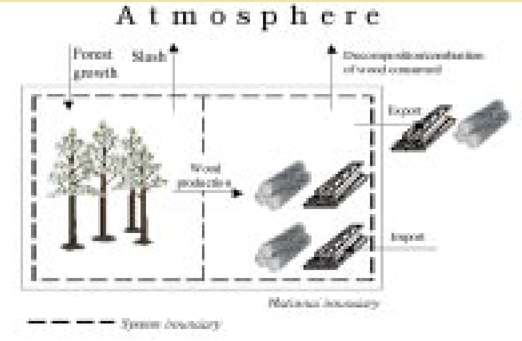
Current IPCC approach:



Stock changes in forests of a country are accounted for in the national inventory of greenhouse gas emissions. The system boundary is around the forest of a particular country. Biomass fuels are accounted for as CO_2 neutral.

Stock change = forest growth - slash - wood production

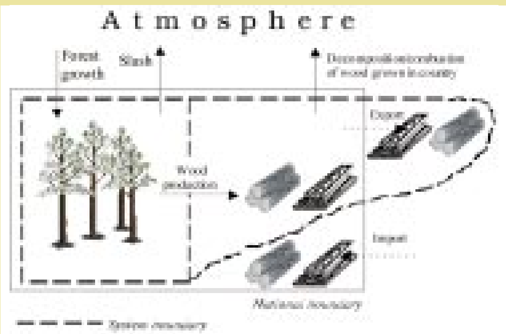
Alternative 1:



Stock change approach: Stock changes in forests of a country, and in addition in wood products used in that country, are accounted for in the national inventory of greenhouse gas emissions. The system boundary is around the forests and wood products of a particular country. Biomass fuels are accounted for as CO_2 neutral.

Stock change = (forest growth - slash - wood production) + (wood consumption - decomposition / combustion of wood consumed)

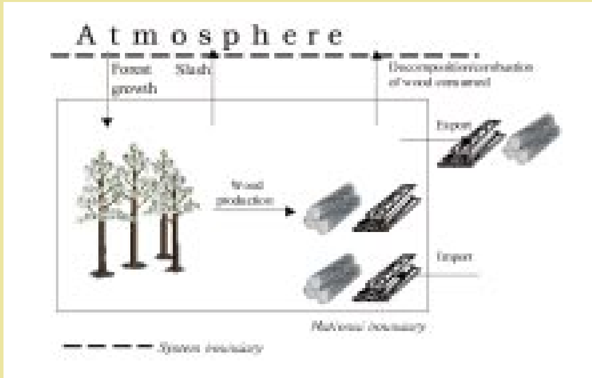
Alternative 2:



Production approach: Stock changes in forests of a country, and in addition in wood products produced by that country, are accounted for in the national inventory of greenhouse gas emissions. The system boundary is around the forests of a particular country, and around the products from wood grown in that country. Biomass fuels are accounted for as CO_2 neutral.

Stock change = (forest growth - slash - wood production) + (wood production - decomposition/combustion of wood grown in country)

Alternative 3:



Atmospheric flow approach: Carbon flows to and from the atmosphere are accounted for in the national inventory of greenhouse gas emissions. The system boundary is between the country and the atmosphere. Biofuels are treated like fossil fuels, i.e., the end user reports emissions from combustion.

Atmospheric flow = forest growth - slash - decomposition / combustion of wood consumed