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SYSTEMS STUDIES

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Abstract - The Systems Studies Activity had two objectives: (1) to investigate nontechnical barriers to the deployment of biomass production and supply systems and (2) to enhance and extend existing systems models of bioenergy supply and use. For the first objective, the Activity focused on existing bioenergy markets. Four projects were undertaken: a comparative analysis of bioenergy in Sweden and Austria; a one-day workshop on nontechnical barriers jointly supported by the Production Systems Activity; the development and testing of a framework for analyzing barriers and drivers to bioenergy markets; and surveys of wood pellet users in Sweden, Austria and the U.S.A. For the second objective, two projects were undertaken. First, the Activity worked with the Integrated Bioenergy Systems (IBS) Activity of IEA Bioenergy Task XIII to enhance the BioEnergy Assessment Model (BEAM). This model is documented in the final report of the IBS Activity. The Systems Studies Activity contributed to enhancing the feedstock portion of the model by developing a coherent set of willow, poplar, and switchgrass production modules relevant to both the U.S.A. and the U.K. The Activity also developed a pretreatment module for switchgrass. Second, the Activity sponsored a three-day workshop on modelling bioenergy systems with the objectives of providing an overview of the types of models used to evaluate bioenergy and promoting communication among bioenergy modelers. There were nine guest speakers addressing different types of models used to evaluate different aspects of bioenergy, ranging from techno-economic models based on the ASPEN software to linear programming models to develop feedstock supply curves for the U.S.A. The papers from this workshop have been submitted to *Biomass and Bioenergy* and are under editorial review.

Keywords - Systems modelling; bioenergy markets; biomass

1. INTRODUCTION AND OVERVIEW

The Systems Studies Activity had two objectives: (1) to investigate nontechnical barriers to the deployment of biomass production and supply systems and (2) to enhance and extend existing systems models of bioenergy supply and use. For the first objective, the Activity focused on existing bioenergy markets and evaluated both barriers and drivers to successful market creation. Four projects were undertaken: a comparative analysis of bioenergy in Sweden and Austria; a one-day workshop on nontechnical barriers jointly sponsored by the Production Systems Activity; the development and testing through case studies of a framework for analyzing barriers and drivers to bioenergy markets; and surveys of wood pellet users in Sweden, Austria, and the U.S.A. For the second objective, two projects were undertaken. First, the activity worked with the Integrated Bioenergy Systems (IBS) Activity of the International Energy Agency (IEA) Task XIII to enhance the BioEnergy Assessment Model (BEAM). This model is documented in the final report of the IBS Activity. The Systems Studies Activity contributed to enhancing the feedstock portion of the model by developing a coherent set of willow, poplar, and switchgrass production modules relevant to both the U.S.A. and the U.K. The Activity also developed a pretreatment module for switchgrass. Second, the Activity sponsored a three-day workshop on modelling bioenergy systems with the objectives of providing an overview of the types of models used to evaluate bioenergy and promoting communication among modelers. There were nine guest speakers addressing different types of models used to evaluate different aspects of bioenergy, ranging from techno-economic models based on the ASPEN software to linear programming (LP) models to develop feedstock supply curves for the U.S.A. The papers from this workshop have been submitted to *Biomass and Bioenergy* and are under editorial review.

2. BIOENERGY MARKET BARRIERS AND DRIVERS

When the Activity was conceived in 1994, there was little work designated on nontechnical barriers to bioenergy. Soon thereafter, however, several major initiatives were started to address barriers to bioenergy commercialization. These included the AFB-NETT project and an EU-JOULE project. The AFB-NETT project identified nontechnical barriers to bioenergy implementation in European Union member counties and formulated recommendations for overcoming these barriers.[1] The EU-JOULE project addressed barriers to renewable energy technologies.[2] Wanting to contribute something unique to this general area of interest, the Activity chose to focus on examining the barriers and drivers that have shaped existing successful bioenergy markets. Thus the activity had a focus on existing rather than future bioenergy technologies and on markets rather than individual projects, reasoning that IEA's ultimate goal is the expansion of bioenergy markets and an examination of successful markets might provide insight into how to create new markets.

Under the umbrella of investigating non-technical barriers, the Activity undertook four projects the results of which are described briefly below.

2.1 *Comparison of biomass in Swedish and Austrian energy markets*

Christian Rakos, with Activity funding for travel, examined the introduction of biomass into the energy markets of Sweden and Austria[3]. Both countries have developed successful biomass district heating markets over the last 10 to 15 years. This study considered the market conditions in both countries, the policies and factors that influenced those markets, and the potential for those markets to expand in the future.

Current market conditions in the two countries are outlined in Table 1. Noticeable differences include the much higher cost of chips from forest thinning in Austria. The terrain differences, mountainous vs level, are probably the main reason for this difference. The high level of chunkwood use in rural residential heating in Austria is another major difference.

Table 1. Current market conditions

Austria	Sweden
Population ~ 8 million	Population ~ 8 million
40% rise in energy supply from 1970 (824PJ) to 1993 (1143PJ)	Level energy supply of ~1600 PJ from 1970 to 1993
Real biofuel prices have dropped from 34 ECU/MWh (1980) to ~14 ECU/MWh	Real biofuel prices have dropped from 35 ECU/MWh (1980) to ~14 ECU/MWh
Chips from thinning cost ~39 ECU/Mwh	Chips from thinning cost ~23 ECU/MWh
12% of energy supply from biomass (1994) - 63% chunkwood - 13% black liquer - 8% wood fuels - 7% bark - 5% municipal solid waste - 4% other	17% of energy supply from biomass (1995) - 40% black liquor - 16% chunkwood - 13% wood fuels - 11% paper industry wastes - 10% sawmill wastes - 6% municipal solid waste - 4% peat

The policies that influenced the development of bioenergy markets in these countries are quite different. Austria encouraged the development of biomass district heating systems through R&D commitments to biomass combustion technologies and incentives for constructing biomass district heating systems. These incentives included subsidies up to 30% of the construction cost and low cost loans up to 35% of the capital. The incentives varied according to the operator of the district heating system, being most favorable for farmer cooperatives and least favorable for private operators. Austria also encouraged the market by providing free consultancy, establishing dedicated energy offices, and encouraging information flow. Sweden encouraged the development of biomass energy through strong R&D support to a wide range of bioenergy-related technologies and most importantly through the tax structure. Both a general energy tax applied to all energy forms but biomass and a CO_2 tax have been in place since 1992. A sulphur tax and a levy on NO_x emissions are also charged. It is important, however, to note that industry is exempted from the energy tax and only charged 25% of the CO_2 tax. These taxes have had a profound effect on bioenergy use in Sweden, increasing biomass use by 5 PJ each year.

There are both opportunities and constraints to further biomass expansion in both countries. With regard to the industrial sector, both countries are fully utilizing the biomass that is economically competitive under the current market conditions. In both countries policy changes, such as taxes, will be required to increase the further use of biomass for energy. The rapid extension of natural gas pipelines across Austria poses considerable competition for bioenergy. Although natural gas is not a major competitor for bioenergy in Sweden now, it may become so if Sweden decides to quickly phase-out its nuclear power programme. A rapid phase-out would disproportionately benefit natural gas. There is little room for biomass district heating expansion in Sweden as virtually all the easily converted district heating plants have been converted and expansion in the Stockholm area is constrained by the lack of low-cost wood fuel. There is room for expansion of district heating in Austria, but the uncertainty of subsidies is discouraging as is the ease of natural gas hook-ups to individual homes.

Individual home heating is the market in both countries with the greatest potential for expansion without policy changes. In Sweden, 200 PJ of electricity and oil are currently used to heat homes. Given the current tax structure, biomass heating is significantly cheaper than either electricity or oil. Possible explanations for the continued reliance on more expensive energy are the capital costs of installing a new biomass-based heating system, the lack of residential-scale equipment on the market, the lack of infrastructure to provide fuel and furnace/stove maintenance, and finally the perceived risk of change (Swedish winters can be quite cold). In Austria, the lack of a fuel market for chips and pellets is a major barrier as is the easy access to natural gas. The chunkwood market is very informal. Farmers may bring some chunkwood to a village market or buyers must seek out a landowner to supply the wood. Whereas there are many producers of technically very good stoves, the market for stoves is uncoordinated. None of the manufacturers sell very many stoves and consequently stove prices are quite high.

Table 2. Solutions to barriers to bioenergy

Biomass Heating	Biomass power
Provide training for operators and consumers through educational extension opportunities	Policy actions - environmental taxation to internalize social and environmental costs of fossil fuels - require renewable energy portfolios - provide tax credits for green capital - develop policy based on credible life-cycle analysis of competing energy production systems - establish clear political targets and mechanisms such as non-fossil fuel obligation (NFFO) to achieve them
Create systems with remote controls from the plant for individual homes	Education - utilize existing forestry and agriculture extension services to get information to farmers - participate in local planning process to create opportunities for using heat and electricity combinations - encourage "green" consumerism
Provide city planners more education about district heating opportunities Conduct tours of successful district heating systems When introducing the concept, use well- trained facilitators to assist in project acceptance Promote competitions among communities to be the "greenest"	Research & development - link R&D activities to specific government cost-shared activities - involve farmers early in the development process of energy crops to facilitate innovation - develop good life-cycle analysis information and environmental auditing processes - facilitate public environmental discussions including a broad crosssection of stakeholders - provide a good research base to support commercialization of new crop and conversion technologies for bioenergy production

2.3 *A framework for analyzing barriers and drivers to bioenergy markets*

The objective of this project, which was lead by Dr. Anders Roos, a colleague of Bo Hektor, and partially funded by the Activity, was to develop a means or framework for analyzing nontechnical barriers and drivers to bioenergy market growth using economic concepts and models from transaction cost theory and industrial organization. It was intended that the framework should be relevant to decision-makers within bioenergy systems and be tested with case studies of successful bioenergy markets in the U.S.A., Sweden, and Austria.[4,5,6,7]

Six critical factors were identified (Table 3) and five successful markets were analyzed: district heating in Austria; district heating in Sweden; biomass power in Maine, U.S.A.; pellet stoves in the U.S.A.; and pellet stoves in Sweden. Tables 4–9 elaborate on these six critical factors and the corresponding text gives some of the results from the case studies. The six critical factors affect productivity, production costs, and transaction costs. Ultimately they determine if a bioenergy technology can compete with other energy forms.

Table 3. Critical factors in bioenergy markets

Integration with other economic activity
Scale effects within the industry
Competition *within* the bioenergy market
Competition with other businesses
Government policy
Local policy and opinion

2.3.1 *Integration with other economic activity (Table 4)*

Most successful bioenergy markets are integrated with other economic activities, especially the forest products industry. Examples of integration are the use of sawdust from mills for pellet manufacturing or the use of tops and branches from forest-product-related thinning for bioenergy chips. Integration may also involve infrastructure, e.g., forest roads, equipment or knowledge.

Table 4. Integration with other economic industry

Do synergy effects with other activities exist (e.g., forestry) and are they exploited?
Is the integration formal or informal?
Is the integration vertical or horizontal?
Where is the integration? - feedstock - equipment - infrastructure - knowledge

2.3.2 *Scale effects in the industry (Table 5)*

Because larger markets can support specialization, bigger series, and standards, positive scale effects are to be expected. The lack of standards in pellets has slowed pellet stove markets in Sweden. Brokers have entered the wood fuel supply market in Sweden, but wood supplies are still fairly informal in Austria, and this is problematic for further expansion. An examination of scale effects in the Austrian district heating market yielded counterintuitive results. Heating costs did not go down as facility size went up nor did efficiency improve over time. Positive network externalities mean the benefit of using the technology increases as others use the technology. For instance, enough homes heat with pellet stoves in the U.S.A. that spare parts are easily available and skilled labor for stove maintenance is available as well. In Sweden where there are far fewer pellet stoves this is not the case.

Table 5. Scale effects in the industry

Are units costs being reduced with larger production series?
Are positive network externalities being acquired?
Have standards been introduced that reduce transaction costs?
Are specialists (e.g., brokers, consultants) entering the market and improving market performance?
Is learning and R&D supporting a growing market in a positive feedback loop?

2.3.3 *Competition within the bioenergy market (Table 6)*

Competition within the bioenergy market appears important in cost reduction. The technical quality of the American pellet stove improved as a consequence of competition among manufacturers. In Sweden, Austria, and Maine feedstock costs for bioenergy decreased as bioenergy use expanded. However, the cost of heat in Austrian district heating plants has not decreased because capital costs have not decreased. This may be the result of the policy of government subsidies for the construction of the district heating systems that may reduce the stimulus to be cost-effective. As a market is starting, cooperation among various bioenergy suppliers may be important in creating resources for effective marketing and for acquiring political clout. For example, Austrian stove manufacturers would do well to join forces in marketing the concept of wood stoves for modern, "green" home heating.

Table 6. Competition *within* the bioenergy market

Is competition within the bioenergy market improving innovation and productivity? -equipment or fuel
Is the market sufficiently unregulated and are there enough players to foster competition?
Is the balance good between cooperation and competition?

2.3.4 *Competition with other business (Table 7)*

Often only competition with other energy forms for consumers is examined, and only price is considered. Competition for feedstock supplies should not be ignored nor should quality or services. The presence of particleboard manufacturers may mean cheap sawdust is unavailable to pellet manufacturers. Pellet stoves in Sweden are only slowly penetrating the home heating market even though the price of wood heat is far lower than that of electricity (39 ECU/MWh vs 64 ECU/MWh). Because the infrastructure to support the stoves is weak, individuals are reluctant to take the risk of changing. In the state of New Hampshire, U.S.A., wood as a bioenergy source for home heating is seen as more reliable than oil; the ambiance of wood is also considered desirable. There may also be such "barriers to entry" as the perception that pure gasoline is "better" than ethanol/gasoline blends or that wood stoves are old-fashioned or "dirty."

Table 7. Competition with other business

What is bioenergy's competitive strength compared with other businesses?
-feedstock
-equipment
-consumers
Is the competition with regards to:
Price?
Quality?
Services?
"Barriers to entry"?

2.3.5 *Government policy (Table 8)*

Of the five case market studies only one (pellet stoves in the U.S.A.) was not heavily influenced by Government policies. Energy and CO_2 taxes have promoted biomass district heating and pellet stoves in Sweden. Subsidies for district heating construction influenced district heating in Austria. Biomass power in the U.S.A. was largely created by the Public Utility Regulation Policies Act legislation that encouraged renewable electricity production by small non-utility producers. Utilities were required to enter into long-term contracts with such suppliers to purchase power at the utilities' marginal cost. These contracts were negotiated at a time when oil prices were high and expected to go higher and cheap natural gas was not yet available. These are examples of policies expressly designed to promote renewable- or bio-energy; however, other government policies may indirectly have profound effects on bioenergy market potentials. For example, agricultural subsidies to conventional crops may artificially raise land rents and thus increase the cost of biomass from energy crops. The Austrian decision to support natural gas pipelines created a strong energy competitor for biomass energy.

Market regulation can also affect competitiveness. The current deregulation of the utility industry in the U.S.A. is discouraging risk-taking and placing a premium on cost-competitiveness, both of which discourage biomass power. On the other hand, the deregulation will improve the chances of small low-cost power generators that formerly had little opportunity to sell power.

Groups within society may influence policy. The presence of an indigenous fossil fuel industry may discourage pro-bioenergy policy if policymakers fear such policies will have negative implications to local economies currently dependent on coal production. Environmental groups may or may not be supportive of bioenergy. In Sweden, Swedish environmental organizations tend to support bioenergy whereas international organizations, such as Greenpeace, tend to be indifferent to or oppose bioenergy.

Table 8 . Government policy

What policies are influencing bioenergy competitiveness relative to other energy forms? -market regulation - R&D funding - subsidies - taxes - information flow
What groups are influencing policy? - Industrial competitors - environmental groups

2.3.6 *Local decision-makers and opinion (Table 9)*

Within Austria the support of local decision-makers overrode cost considerations in the biomass district heating market. Villages that were knowledgeable about biomass heating were more likely to adopt it as were villages with a tradition of community spirit and action. In the U.S.A., pellet stove technology fared best in regions where a tradition of wood heating already existed. The professional reward system of district heating plant operators in Sweden affected the early acceptance of biomass use in district heating plants.

Table 9. Local decision-makers and opinion

Is the local populace aware and knowledgeable about bioenergy systems?
Are local decision-makers supportive of bioenergy systems?
Is local opinion supportive of the bioenergy system?

2.4 *Pellet surveys*

One of the drawbacks of biomass fuel is the form in which it is often supplied. The quality of chips or chunkwood is difficult to quantify or keep consistent. Bales of straw vary in density and moisture content. The nature of biomass material makes handling a major issue. The Hawaiian biomass gasifier project suffered major setbacks because of the difficulties encountered in feeding sticky, fibrous bagasse into the gasifier. Pellets are one way to ensure a uniform feedstock that is comparatively easy to handle and which ships and stores well. Whereas pellets are currently expensive to manufacture, quality and ease of handling considerations may override fuel cost considerations. Some new technologies for pellet manufacturing are under development that promise to reduce the costs.

The objective of our survey is to develop better information on why individuals chose pellet heating systems and the problems they may or may not have encountered with them. Surveys have been mailed to pellet users in the U.S.A., Sweden, and Austria. The surveys are completed for Sweden and the U.S.A. and the Austrian surveys are expected to be completed in late spring 1998. Working with colleagues, Anders Roos will analyze the survey results and present and publish them in the proceedings of the Bioenergy 1998 conference in Madison, Wisconsin.

3. ENHANCING AND EXTENDING BIOENERGY SYSTEM MODELS

3.1 *Enhancements to the BioEnergy Assessment Model (BEAM)*

In 1992 an IEA Bioenergy project was initiated to develop a computer-based model that could compare entire bioenergy systems from feedstock generation and feedstock preparation through the conversion process. Up to that time there were few studies that tackled an entire system and none that tackled multiple systems in a common format. Thus there was no way to compare systems or to explore how the components of a particular system related to each other. The three-year effort, which involved two IEA Activities, produced a modelling system called BEAM (BioEnergy Assessment Model) that was satisfactory but not as complete as one might wish.[8]

Thus, at the time Tasks XII and XIII were beginning in 1995, it was decided to enhance BEAM. The Integrated Bioenergy Systems Activity of Task XIII took the lead on this enhancement and most of their Activity was devoted to this. The Systems Study Activity also participated in the enhancement of BEAM largely through contributions to the feedstock supply component of the model, although the Activity also provided extensive review of the model. In particular, the Systems Studies Activity created feedstock production modules for U.S.A. and U.K. willow production, U.S.A. poplar production, and U.S.A. switchgrass production. The Activity also developed a switchgrass feedstock preparation module.

Documentation of the model can be found in the final report of the IBS Activity. The success of the effort is mixed. The difficulty in parameterizing different bioenergy systems in different states of development leads to a situation where comparisons between systems are problematic. For example, combustion and steam turbine biomass power systems are a mature technology. The costs and engineering aspects of the technology are well known. Thus the costs associated with this technology in BEAM are reflective of the n^{th} plant. On the other hand, fast pyrolysis and diesel engine technology is not yet commercial nor is pressurized gasification with a gas turbine. Thus the costs for these systems are reflective of the 1^{st} plant. An uncritical comparison of the three systems using BEAM would suggest that combustion and a steam turbine is the lowest cost technology for producing electricity under virtually all scenarios and one need not waste time nor money on these other technologies when in reality the cost advantage of the traditional system is the result of how the systems were modeled. BEAM is, however, very useful for examining the effect on the whole system of changes in cost or efficiency at some point within the system (e.g., the effect of reducing fuel cost on electricity price). It is also useful as a heuristic tool for quickly demonstrating the inter-linkages within a bioenergy system. The model is not appropriate for site-specific analysis but rather gives a first-order approximation of costs.

3.2 *Workshop on modelling bioenergy*

Bioenergy systems are complicated because they interface three major sectors: agriculture, forestry, and energy. Each sector has its own way of characterizing the world and its own way of evaluating costs. For example, U.S. agriculture often uses net present value to compare profitability of crops whereas return on investment is more often used on an energy construction project.

In addition, because bioenergy systems are generally novel, one must often resort to models rather than data to attempt to understand them. Often only one piece of the system is modeled and always from a certain perspective. This creates a situation where to model a whole system, multiple models must be linked. Under these circumstances, it is very important that the assumptions and paradigms implicit in each linked model are clear and compatible with the other models. Making models compatible was one of the greatest challenges faced in the development of BEAM. Whereas this compatibility would seem straightforward, it is not, because it requires an understanding of the different paradigms of the different disciplines that are the basis of the models. A process model built by an ecologist has a different perspective on uncertainty, time, and cost than a techno-economic model built by a chemical engineer.

The Systems Studies Activity, therefore, sponsored a workshop on approaches to modelling bioenergy systems. The objective of the workshop was to provide a setting where modelers of bioenergy systems could come together and explore each other's modelling paradigms. The workshop was by invitation only to keep the number of participants to a level where good discussion could occur. Nine speakers (Table 10) were asked to give a one-hour presentation on the type of modelling they did. They were asked to focus on the nature of the modelling (assumptions, limitations, objectives, users) rather than on model results. Following each presentation was a half-hour of discussion.

Each author was asked to contribute a paper for publication in *Biomass and Bioenergy*. These papers have been reviewed by other participants in the workshop and are currently in editorial review. Some of the common themes from the discussion were the difficulties in dealing with data limitations and the manpower and money commitments behind models or modelling frameworks. In the experience of the modelers, the most useful models were either simple relations developed from years of data/experience or the result of several to many person years of effort, developed over several years, constantly being updated and representing an investment in excess of US$100,000. All the modelers acknowledged the common misuse of models and the need to make explicit the appropriate uses for specific models.

Table 10. Speakers at modelling workshop

Topic	Speaker
Techno-economic analysis	M. Mann, National Renewable Energy Lab
Life-cycle analysis	K. Humphreys, Pacific Northwest Lab
Decision support systems	P. Mitchell, Aberdeen Univ.
Planning models	B. Hektor, Swedish Univ. of Ag. Sciences
Feedstock supply modelling	M. Walsh, Oak Ridge Nat'l Lab
LP national policy modelling	D. Ray, Univ. of Tennessee
GIS-based modelling	R. Graham, Oak Ridge Nat'l Lab
Limits of modelling	A. Roos, Swedish Univ. of Ag. Sciences
Modelling's role in bioenergy	R. Overend, National Renewable Energy Lab

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