Forest Ecology and Management 257 (2009) 1647–1655

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

# International bioenergy synthesis—Lessons learned and opportunities for the western United States

David Nicholls [a,*], Robert A. Monserud [b], Dennis P. Dykstra [b]

[a] USDA Forest Service, Pacific Northwest Research Station, Alaska Wood Utilization Research and Development Center, 204 Siginaka Way, Sitka, AK 99835, USA
[b] USDA Forest Service, Pacific Northwest Research Station, Portland Sciences Laboratory, 620 SW Main St., Suite 400, Portland, OR 97205, USA

ARTICLE INFO

*Article history:*
Received 19 January 2008
Received in revised form 25 November 2008
Accepted 27 November 2008

*Keywords:*
Bioenergy
International
Ecosystem services
Wood pellets
District heating

ABSTRACT

This synthesis examines international opportunities for utilizing biomass for energy at several different scales, with an emphasis on larger scale electrical power generation at stand-alone facilities as well as smaller scale thermal heating applications such as those at governmental, educational, or other institutional facilities. It identifies barriers that can inhibit bioenergy applications, and considers international cases of successful bioenergy production with a focus on Europe and Brazil. Based on the review of international bioenergy applications, important ecosystem service issues having relevance to western U.S. forests are discussed, including hazardous fuel reduction, community development, and sustainability of the wood products industry.



## 1. Introduction—environmental benefits of bioenergy and its potential as an ecosystem service

For the purposes of this paper the term "biomass" is used as shorthand for "woody biomass" and refers to organic material from woody plants, especially trees, that is not otherwise utilized in conventional wood products. Biomass thus includes small stems, branches, twigs, and residues of harvesting and wood processing that could potentially be made available for conversion into energy products. This definition is consistent with usage in the Woody Biomass Utilization Strategy recently published by the U.S. Forest Service (Patton-Mallory, 2008). In addition, biomass can be obtained from non-forest sources such as urban waste, which often includes recycled wood, garden trimmings, and other types of biomass.

Although a plentiful supply of such biomass is available in western U.S. forests (Rummer et al., 2003), challenges remain to find economically viable uses given the high removal costs and relatively limited markets for this material. Because the cost of harvesting and transporting biomass is often several times the final value of products obtained, a key challenge for natural resource managers is to find markets and products that will offset at least part of these costs while providing other benefits such as reducing wildfire risk. Important ecosystem services (defined later) are also provided through removal of biomass having little commercial value for lumber or other wood products.

Global carbon dioxide ($CO_2$) levels and temperatures have increased dramatically during recent years, with $CO_2$ levels now approaching 380 parts per million (ppm) vs. pre-industrial levels of about 280 ppm (Intergovernmental Panel on Climate Change, 2007). Most of the observed global warming over recent decades appears to have resulted from increased greenhouse gas concentrations in the atmosphere. Although the combustion of biomass, either as biofuels or during conversion into bioenergy, results in a range of combustion products and gases, as does combustion of coal and other fossil fuels, biomass can be regrown to sequester the $CO_2$ produced through combustion. Thus, forest biomass sources have the potential to be carbon-neutral (Wahlund et al., 2004).

World-wide, forests serve as an important carbon sink, absorbing about 25 percent of $CO_2$ emissions (Nabuurs et al., 2000). Other estimates indicate that forest and land management decisions could effectively reduce net carbon emissions by 10–20 percent through the year 2050, and that the greatest potential for sequestering carbon is in tropical and sub-tropical forests (Union of Concerned Scientists, 2007). In Europe, boreal forests are estimated to have relatively little carbon sequestration ability while Mediterranean forests have a greater ability to sequester carbon (Nabuurs et al., 2000). Use of forest fuels for bioenergy can potentially negate the effects of carbon sequestration by quickly releasing $CO_2$ upon combustion, although the newly released $CO_2$ can be sequestered by trees in forests or plantations established for that purpose. In addition, incorporation of carbon into durable

* Corresponding author. Tel.: +1 907 747 4312; fax: +1 907 747 4294.
*E-mail address:* dlnicholls@fs.fed.us (D. Nicholls).

0378-1127/$ – see front matter © 2009 Published by Elsevier B.V.
doi:10.1016/j.foreco.2008.11.035

products such as lumber and engineered wood items allows for long-term net carbon sequestration. Unmanaged carbon sequestration, such as in overstocked, small-diameter stands, can result in increased wildfire risk and reduced biodiversity. Thus, global forest management objectives must be formulated to consider tradeoffs between biomass as a potential energy source vs. the storage of carbon in living forests and in durable wood products.

Forest-based mitigation of global warming can occur through three strategies (Union of Concerned Scientists, 2007):

- Conservation of existing forests to avoid emissions associated with forest removals.
- Sequestration by increasing forest carbon absorption capacity through forest management options designed to increase biomass.
- Substitution of sustainable biological products in the place of fossil fuels and non-biological products such as aluminum and concrete.

Ecosystem services can be defined as *the benefits people obtain from ecosystems*, and can include provisioning services (e.g., food, water, timber, and fiber), regulating services (e.g., flood control, water quality, and carbon sequestration), cultural services (e.g., recreational, aesthetic, and spiritual benefits), and supporting services (e.g., soil formation, photosynthesis, and nutrient cycling) (Millenium Ecosystem Assessment, 2005). Ecosystem services have also been defined as "components of nature, directly enjoyed, consumed, or used to yield human well-being" (Boyd and Banzhaf, 2007). In forests, economic benefits derived from ecosystem services can be broadly grouped into two categories: extractive goods, which include timber, hunting, and non-timber products, and non-extractive goods and services, which include water supply and quality, soil quality, carbon sequestration, biodiversity, and recreation (Rose and Chapman, 2003). Costanza et al. (1997) estimated the value of the earth's ecosystem services conservatively at US$ 33 trillion per year.

## 2. International bioenergy production and applications

Many nations have already made substantial gains in using biomass for energy, and have committed to lowering greenhouse gas emissions through the Kyoto Protocol or other initiatives. As of 2004, bioenergy production for heat, electricity, and liquid fuels accounted for close to 14 percent of global energy use (Parikka, 2004). However, the potential sustainable use of biomass energy globally is estimated to be about 30 percent, more than double the current level.

Faaij (2006) outlined several conversion technologies for power and heat having bioenergy applications in Europe, including district heating, direct combustion, gasification, and co-combustion of biomass with coal. Several countries in the European Union (EU) are now meeting a substantial portion of their primary energy needs with biomass (i.e. Finland, Sweden, and Austria). Other nations such as Germany and the Netherlands have also made significant progress in bioenergy applications, and will be discussed later in this paper. Bioenergy successes in the EU have been motivated by government incentives for biomass utilization (including financial incentives such as the carbon tax), a willingness to develop and test new technologies, and by strong research and developments efforts. Between 1990 and 2000, biofuel production among EU nations increased about eightfold to a 2000 contribution of about two-third of the total renewable energy production (Faaij, 2006). Other EU nations presently using bioenergy at lower levels have set ambitious goals for the next few decades. For example, Poland, with a bioenergy use of about 4 percent of primary energy, has set a target of 14 percent by year 2020 (Nilsson et al., 2006).

EU strategies for increasing bioenergy use have been documented in two widely cited papers. The White Paper (European Commission, 1997) was adopted to help achieve overall energy policy objectives related to security of supply and competitiveness, and to improve and reinforce environmental protection and sustainable development (Fagernäs et al., 2006). The Green Paper (European Commission, 2000) stated a goal of doubling the share of renewables in the EU 15–12 percent of primary energy use by 2010 (Faaij, 2006). Fig. 1 shows the increasing use of biomass and other renewable energy sources for electricity generation between 1990 and 2003.

EU directives have been used to set targets for renewable energy production, to encourage low-carbon energy production, and to set limits on emissions from biomass combustion or disposal (Faber et al., 2006). Several EU directives have been designed specifically to support biomass for heat and power generation, including the following broad areas: renewable energy sources, emission trading, landfills, and biofuels (Fagernäs et al., 2006). Other EU efforts aimed at limiting greenhouse gas emissions include an EU emissions trading scheme. Initiated in 2005, this program covers all 25 EU nations and is the first international agreement of its kind in the world. EU members set limits on $CO_2$ emissions from energy-intensive companies, including about 12,000 steel factories, oil refineries, paper mills, cement installations, and power plants having thermal capacities greater than 20 MW (Fagernäs et al., 2006). Close to 45 percent of the EU's total $CO_2$ emissions are accounted for by participation in this program.

These examples from Europe are significant in that a unified approach to bio-energy production has been established and is seen as a way to clarify the need for bioenergy production while allowing individual nations to capitalize on their strengths. For example, Austria has set a target of 78 percent of electricity to be produced from renewable energy sources by 2010, while Hungary's target is 3.6 percent (Faber et al., 2006).

In this synthesis of international biofuel use we examine several successful ventures, identifying factors that could be potentially adopted for the forests of the western U.S., given the resources and

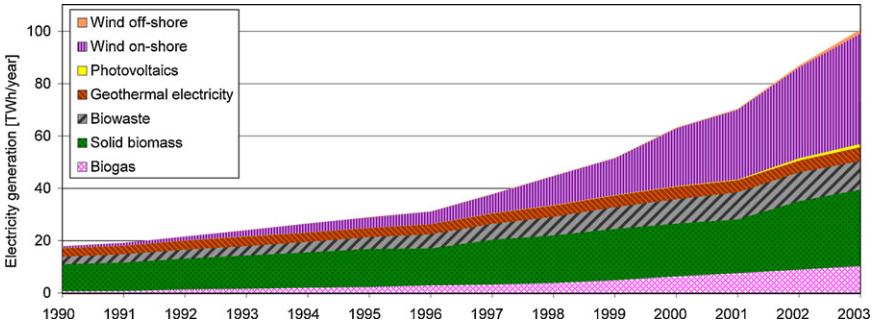


**Fig. 1.** Trends in electricity generation from renewable energy sources in the EU25 from 1990 to 2003. *Source*: European Commission (2005).