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Renewable Energy in Agriculture: Back to the Future?

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There is significant potential for agricultural involvement in the production and consumption of solar, wind, geothermal, and biomass energy. Renewable resources are abundant and widely distributed throughout the United States. A number of commercial technologies are available to harness these resources, and with appropriate support, additional technologies – some potentially paradigm-shifting – could be brought to market.

In many ways, this is a "back-to-the-future" scenario, including a movement toward more self-sufficient farms and a central role for agriculture in the U.S. energy supply. Increased renewable energy in and from agriculture calls to mind Henry Ford envisioning automobiles fueled by alcohol, and windmills powering water pumps. Renewable technologies are now supplying or supplementing many on-farm energy requirements, from water pumping to space heating. Increasingly, farmers and ranchers are selling energy (e.g., electricity generated from wind turbines, biofuels, and products from biomass). This is contributing to greater energy security in agriculture through increased diversity of energy sources, more self-supply of energy, and reduced environmental impact.

The United States faces a choice of energy futures. Continuing the present course is one alternative. Fossil energy for mechanized agriculture has been an important driver of the "Green Revolution" of increasing farm productivity. Today, three energy inputs (diesel fuel, fertilizer, and electricity) account for more than three-quarters of farm energy use. (Miranowski, 2004). At predicted levels of oil production and consumption, America will be increasingly dependent on foreign oil imports in the years ahead, making the Nation even more vulnerable to oil disruptions and price spikes (Figure 1). In agriculture, an energy supply disruption of even a short duration could mean a substantial reduction or the complete loss of an entire growing season. As price-takers for their commodities, farmers are generally unable to pass price increases for energy or fertilizer on to the consumer, and therefore receive a lower return for their products when prices rise (Costantini & Bracceva, 2004).

Renewable energy can address many concerns related to fossil energy use. It produces little or no environmental emissions and does not rely on imported fuels. Renewable resources are not finite (as fossil fuels are) and many are available throughout the country. Price competitiveness has been a concern, but costs have decreased significantly since the initial wave of interest in renewable energy in the 1970s. These technologies now provide 6.1 quadrillion British Thermal Units (Btu) for domestic energy consumption (Figure 2).

Different renewable technologies are at different points in their development. Some are commercially available or nearly so, and others have potential for the longer term. Unfortunately, many benefits that renewable energy can provide are not monetized — they cannot be perceived through price signals. Policies are needed to push or pull these new technologies to full commercial development. This article examines the domestic status and opportunities for a number of renewable energy technologies — solar, wind, geothermal, and biomass.

Solar

Solar technologies produce electrical or thermal energy. Photovoltaic (PV) cells (or "solar cells") that convert sunlight directly into electricity are made of semiconductors such as crystalline silicon or various thin-film materials. Solar thermal technologies collect heat from the sun and then use it directly for space and water heating or convert it to electricity through conventional steam cycles, heat engines, or other generating technologies (concentrating

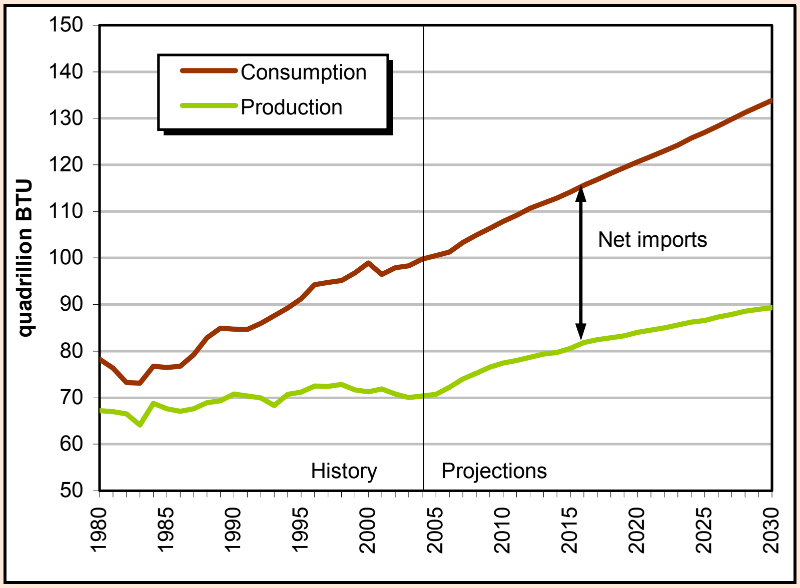

Figure 1. Total energy production and consumption: 1980-2030.

Source: Energy Information Administration, Annual Energy Outlook 2005, http://www.eai.doe.gov/oiaf/aeo/overview.html.

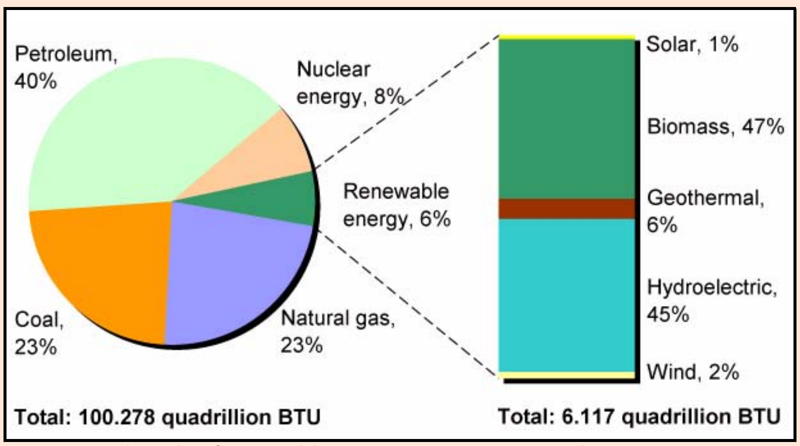

Figure 2. The role of renewable energy consumption in the Nation's energy supply, 2004.

Source: Energy Information Administration, Renewable Energy Trends, 2004 edition, http://www.eai.doe.gov/cneaf/solar.renewables/page/trends/rentrends04.html.

solar systems). In the future, solar energy could produce hydrogen to provide transportation fuels, chemicals, and electricity, and to serve as energy storage at times when the sun is not shining.

As a result of technological advances, the costs of these technologies have been steadily decreasing, and high electricity costs can bridge the gap further. Although solar resources are greatest in the Southwest (about 25 percent higher than the national average), solar electricity may be more cost effective in states with high electricity costs. For example, New York electricity prices can be 50 percent higher than in Arizona (U.S. Department of Energy, Solar Energy Technologies Program, 2003). In agriculture, PV can economically provide electricity where the distance is too great to justify new power lines. Solar electric systems are used to provide electricity for lighting, battery charging, small motors, water pumping, and electric fences.

Livestock and dairy operations often have substantial air and water heating requirements. For example, commercial dairy farms use large amounts of energy to heat water for cleaning equipment. Heating water and cooling milk can account for up to 40 percent of the energy used on a dairy farm. Solar water heating systems may be used to supply all or part of these hot water requirements. Other solar applications include greenhouse heating and solar crop drying (National Renewable Energy Laboratory, n.d.).

The number of solar energy applications is expected to grow as new technologies increase solar cell efficiency and reduce costs. New "quantum dot" materials could theoretically more than double efficiency, converting 65 percent of the sun's energy into electricity, as compared to the best commercially available solar cells today, which have conversion efficiencies of up to 30 percent. Research is also being conducted to reduce the cost of solar water heating systems through the use of materials like plastics instead of metals and glass.

Wind Energy

Wind technologies provide mechanical and electrical energy. Wind turbines operate on a simple principle: Wind turns rotor blades, which drive an electric generator, turning the kinetic energy of the wind into electrical energy. The wind is a renewable energy source, and windmills do not produce harmful environmental emissions. Utility-scale turbines range in size from 750 kilowatts (kW) to 5 megawatts (MW), with most turbines exceeding 1 MW. Turbines are often grouped into wind farms, which provide bulk power to the electrical grid. Small wind turbines range in size from 0.4 to 1.5 kW generators for small loads, such as battery charging for sailboats and small cabins, to 3 to 15 kW systems for a home, to those that generate up to 100 kW of electricity for larger loads, such as small commercial operations.

Wind power technology is already in widespread use due to substantial progress in reducing costs for areas with consistently high wind speeds. At the end of 2005, wind was responsible for 9,149 MW of electrical generating capacity in the United States. At an average capacity factor of 31 percent, this is equivalent to producing the annual amount of electricity that is used by over 2 million average American households. There are commercial wind energy installations in 30 states (American Wind Energy Association, 2006). Today's state-of-the-art wind turbines, operating in high-wind areas, can produce electricity for a few cents per kilowatt-hour (kWh), which is competitive with the cost of fossil fuel-fired plants.

Small wind systems can serve agriculture in traditional ways, such as using mechanical energy to pump water or grind grain. As costs decrease, small systems used to generate electricity may also become economically efficient by avoiding the expense of installing transmission wires, especially in more remote applications. Where connected to the electricity distribution grid, small windmills can generate revenue through electricity sales when generation exceeds internal requirements. Decentralized wind systems can be combined with other energy sources to create a hybrid energy system, where the low cost and intermittent wind resource is supplemented by more expensive small generators such as diesel generators or batteries, to provide power that is both relatively inexpensive and reliable (Bergey, 2000). The small wind turbine industry estimates that 60 percent of the United States has enough wind resources for small turbine use, and 24 percent of the population lives in rural areas where zoning and construction codes permit installation (National Renewable Energy Technology, 2004). As technological improvements continue to increase the economic efficiency of wind energy, agricultural producers are likely to increase their use of wind power to lower energy costs and become more energy self-sufficient.

Geothermal

Geothermal technologies produce electrical or thermal energy. Three types of geothermal power plants are operating today: dry steam plants, flash steam plants, and binary-cycle plants. High-temperature geothermal resources (greater than 300°F) are used for power generation.

Individual power plants can be as small as 100 kW or as large as 100 MW. The technology is suitable for rural electric mini-grids, as well as national grid applications.

The heat from geothermal energy can also be utilized directly. Geothermal fluids can be used for such purposes as heating buildings, growing plants in greenhouses, dehydrating onions and garlic, heating water for fish farming, and pasteurizing milk. Generally, low-to-medium temperature resources (between 70°F and 300°F) are used. Another technology, geothermal heat pumps, can provide space heating and cooling. This technology does not require a hydrothermal (hot water) resource, but instead uses the near-surface ground as a heat source during the heating season and as a heat sink during the cooling season.

While the costs of geothermal electric plants are dependent on the character of the resource and project size, the average cost of geothermal-generated power has been decreasing. In 1980, geothermal electricity costs ranged from 10–14 cents per kWh. Due to improved technologies that have reduced exploration, production field, and power plant costs, it now ranges from 4–7 cents per kWh.

Installed geothermal electricity capacity provides over 2,500 MWe in the United States at capacity factors often exceeding 90%. This is equivalent to providing the power needs for almost 2 million households.

Direct or non-electric generation provides over 10,000 thermal megawatts (MW_t), including geothermal heat pumps. The power from direct use systems is measured in megawatts of heat as opposed to power plants that measure power in megawatts of electricity (Lund, 2005). Some geothermal projects "cascade" geothermal energy by using the same resource for different purposes simultaneously, such as heating and power. Cascading uses the resource more efficiently and improves economics.

The geothermal resource base for low-to-medium temperatures is much more plentiful and widespread than the high-temperature resource base. Low- and medium-temperature geothermal resources exist throughout the western United States. The Geo-Heat Center in Oregon has identified more than 9,000 thermal wells and springs, more than 900 low-to-moderate temperature geothermal resource areas, and hundreds of sites using this energy for direct use applications in 16 western states. There are 404 resource sites in these states that are within five miles of communities, with the potential to serve 9.2 million people (Geo-Heat Center, n.d.).

Geothermal energy has many agricultural applications. Vegetables, flowers, ornamentals, and tree seedlings are raised in 43 greenhouse operations heated by geothermal energy. Forty-nine geothermal aquaculture operations raise catfish, tilapia, shrimp, alligators, tropical fish, and other aquatic species. Agri-industrial applications include food dehydration, grain drying, and mushroom culture. The drying of onions and garlic is the largest industrial use of geothermal energy (Lund, 2005).

Ground source heat pumps can be applied in most rural areas. It is estimated that 600,000 – 800,000 ground source heat pumps are now in use in the United States. The majority of the geothermal heat pump installations in the United States are in the mid-west, mid-Atlantic, and southern states (from North Dakota to Florida) (Lund, 2005).

In the future, new technologies such as enhanced geothermal systems (EGS) promise to reduce the cost of geothermal power. These can be developed by fracturing rock to increase underground fluid flow and permit heat extraction. Projects underway in Europe and Australia are advancing knowledge on how to use EGS for power production

Biorefineries

Discussion of renewable energy from biomass centers on the concept of the "biorefinery," where new technologies are being used to extract energy and other valuable products from biomass resources. Like oil refineries, biorefineries are envisioned as industrial facilities that convert a stream of raw material into a varied slate of products, maximizing value by shifting the mix of output to match dynamic market conditions. Potential biorefinery products include liquid fuels, such as ethanol and biodiesel, electricity, steam, and high-value chemicals and materials. Many of these products have the potential to replace petroleum, either as a vehicle fuel or as a chemical feedstock, resulting in increased energy security and reduced environmental emissions.

In a sense, biorefineries already exist. They process corn into ethanol, corn syrup, animal feed, and other products, or transform trees into a variety of wood products, electricity, and heat, to name two examples. For the next generation of biorefineries, researchers are developing processes for exploiting the large amount of energy contained in plant cellulose — a difficult but potentially rewarding goal. In one biochemical process (referred to as the sugar platform), enzymes are used to break apart cellulose molecules, creating sugars that can be fermented into ethanol or processed further to create industrial and consumer products. A thermochemical process (the syngas platform) involves heating biomass to turn it into a gas composed of a few basic molecules, then processing this raw material into fuels and products through chemical or biological techniques. Researchers are also pursuing ways of turning biomass resources into useful products by using advances in plant genetics and biochemistry to develop crops designed for specific biorefinery endproducts.

Bioproducts may be the key to biorefinery development. They could provide higher economic value than bulk energy production, and increased diversification in the product slate for these industrial facilities would provide flexibility in responding to dynamic markets. An example of a product made with biorefinery technology is Toyota Motor Corporation's bioplastics, used to make automobile components. Already used in the Toyota Raum (sold in Japan), this plastic is made from sweet potatoes and other plants. Another example is DuPont's Sorona, a family of polymers made from 1,3-propanediol (PDO) that can be used in fabrics, plastics, and in other applications. PDO can be made from sugars derived from corn.

The United States has significant biomass resources. It has been estimated that the cellulose available from just forestland and agricultural land, the two largest potential biomass sources, could amount to 1.3 billion dry tons per year. While this quantity is six times greater than current production, researchers believe that it could be achieved with relatively modest changes in land use and agricultural and forestry practices (Perlack et al., 2005). Another biomass resource with significant potential is municipal solid waste, a byproduct of modern life.

Expanding the Potential of Renewable Energy

Renewable energy technologies are being used in a variety of applications on farms and ranches and there are many opportunities to expand their use in the future. For example, renewable, farm-based biomass and other renewable energy sources may be able to fuel hydrogen production; agricultural vehicles running on hydrogen could have the same efficiency and environmental benefits planned for light-duty cars and trucks; and hydrogen fuel cell technology could provide power for remote locations and communities.

Where do we go from here to encourage renewable sources of energy that are important to agriculture, such as solar, wind, geothermal, and biomass? The development of a new energy future will require research, development, demonstration, deployment, and commercialization of new technologies. Each of these activities must function as part of a continuum flowing from the research bench to commercial application, with feedback loops among the various steps. Collaboration, education, and policy will all be important.

For More Information

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