Are Advanced Agri-based Materials the Key to Sustainability?[i]

John Ikerd[ii]

We are here today at this symposium concerning advanced agri-based materials because the world in running out of cheap fossil energy. All materials are highly concentrated forms of energy and energy is a dispersed form of mass or matter, as Albert Einstein explained in his famous equation, $E=MC^2$, where E is energy, M is mass, and C is the speed of light. When we talk about advanced agricultural based materials, we are talking about advanced uses of concentrated forms of biological energy. We are interested in new forms of bioenergy and biomaterials today primarily because the world is running out of cheap fossil energy.

The past 200 years of industrial development has been driven by an abundance of cheap energy – first wood, next coal, and then petroleum. We cut the old-growth forests, mined surface coal, and then pumped the shallow petroleum; energy was cheap because it was abundant and easy. Today, there is no abundant source of easily accessible energy left. We are not running out of energy, but we are just running out of cheap energy. Equally important, we are beginning to understand that energy has been abundant and cheap only because it was a gift of nature from times past. The old forests that had grown over hundreds of years were cleared during the first century after the industrial revolution. Nearly half of the fossil energy collected and stored by nature over tens of millions of years in the form of petroleum has been extracted during the second century of industrialization. We are approaching the halfway point in depletion of natural gas, coal, and other sources of fossil energy, as human population and energy consumption continues to grow exponentially. We face an additional challenge in that the remaining sources of fossil energy all represent significant risks to the natural environment. The issue of global climate change is linked directly to the buildup of carbon dioxide and other greenhouse gasses in the atmosphere, which is a direct consequence of the inevitable release of carbon and other elements whenever energy is released from fossil fuels.

All fossil energy is biological in origin, solar energy captured by biological organisms and stored in the earth by natural phenomena. All biological energy originates in the sun. Each day we receive a new supply of solar energy. Instead of living off of this continually renewed allocation of solar energy, however, we have been using up the finite stocks of solar energy that were stored in the earth over tens of millions of years. If we continue to withdraw energy from the fossil energy endowment, without replacing what we have used, eventually we will run out. Sooner of later, humanity must confront the uncomfortable reality that we simply cannot continue doing what we have been doing.

---

[i] Prepared for an invited symposium presentation, *Advanced Materials Using Agricultural Commodities*, American Chemical Society Annual Meeting, New Orleans, LA, April 7, 2008.
[ii] John Ikerd is Professor Emeritus, University of Missouri, Columbia, MO – USA; Author of, *Sustainable Capitalism*, http://www.kpbooks.com , *A Return to Common Sense*, http://www.rtedwards.com/books/171/, *Small Farms are Real Farms*, Acres USA , http://www.acresusa.com/other/contact.htm,and *Crisis and Opportunity: Sustainability in American Agriculture*, University of Nebraska Press http://nebraskapress.unl.edu;
Email: JEIkerd@centurytel.net; Website: http://faculty.missouri.edu/ikerdj/.

The purpose of this symposium is to discuss the possibility of reducing our reliance on fossil energy by using materials that rely on the renewable solar energy collected and stored by agricultural plants. The specific focus is on making novel products from biochemical feedstocks, including proteins, oils, and carbohydrates derived from agriculture sources. The primary goal is to replace *petroleum-based* products with bio-based products by using non-food commodities and current agricultural "wastes" to produce useful products. Ethanol and biodiesel are probably the most common of such products, but the emphasis up to now has been on using corn and soybeans, food crops, to produce fuel. Non-food commodities and agricultural wastes are potentially more significant sources of alternatives to fossil energy but have received far less attention.

Our quest for renewability is a quest for sustainability and sustainability ultimately is a matter of energy. Everything that is of use to humanity – our cars, houses, clothes, food – requires energy to make, energy to use, in fact, are just concentrated forms of energy. All useful human activities – working, managing, thinking – also require energy. Equally important and relevant to renewability, the usefulness of human energy is a product of society. We are not born as productive individuals but as helpless infants. We have to be nurtured, socialized, and educated by society before we are capable of being useful to society, all of which requires biological energy.

In addition, the energy that fuels our bodies, and the bodies of all other living things, comes from the same energy flow that we use to make and to fuel our cars and our homes. Fossil energy has been stored for a time but eventually returns to the energy flow. "Everything on earth is interconnected with everything else," so proclaims the first principle of ecology. Or as the noted naturalist John Muir put it, "Everything eats, everything excretes, everything is food for something." We humans are no exception. We are not nearly as dependent on the materials in our cars, houses, clothes, or adult toys as we are on the material things we eat. We obviously need clothing, shelter, and some means of mobility but many humans do very well with only the basic necessities of life. We are most critically dependent on the things we eat, and they are just as dependent upon us. Our energy use affects the energy available for everything else.

According to the laws of thermodynamics, energy inevitably changes form whenever it is used to do anything useful, which physicists call *work*. Specifically, anytime energy is used to do work, it always changes from more concentrated to less concentrated forms, as when gasoline explodes when ignited in the engine of a car. Energy is never destroyed by use, but each time it is used and reused, it becomes less concentrated and thus less useful. So each time energy is used to do something useful, some of its *usefulness* is lost. Some forms of energy can be reconcentrated and restored, but this process requires energy which is then unavailable for any other use. This is the essence of the law of entropy. Conserving, reusing, and recycling stored energy can improve the efficiency of energy use, but cannot offset the inevitable loss of energy to entropy. The only source of energy available to offset entropy is solar energy – the only truly renewable energy.

However, while our free-market capitalist economy provides powerful incentives to use and reuse energy, it provides no incentives to collect and store new solar energy to offset the energy lost to entropy. Even the solar energy captured through agriculture and forestry has been put in the marketplace for consumption rather than used to regenerate and renew the energy resources needed to sustain future productivity. This basic problem arises from the fact that economic value is inherently individualistic; it accrues to individuals, and thus, must be expected to accrue during the lifetime of the individual decision maker. Investments for the sole benefit of others, including those of future generations, are of no economic value.

The diminishing time-value of economic benefits is clearly reflected in market rates of interest, which heavily discount the value of future events. For example, economic benefits expected to accrue a decade in the future are worth less than fifty cents today for each dollar expected later (using a discount rate of seven percent). The ultimate depletion of fossil energy and the related global climate change are of little *economic* importance today because their ultimate impacts are still beyond the five-to-ten year planning horizons of most corporations.

The current economic interest in biological alternatives to petroleum-based fuels and materials means that the expected “peak” and subsequent decline in global petroleum production is now within the five-to-ten year planning horizons of most corporate managers. They are responding to near-term *scarcity*, not long-term *depletion*. From everything we know about the basic nature of natural ecosystems and human societies, today's economic planning horizons are simply too “shortsighted” to ensure the long run sustainability of the economy or humanity.

Less appreciated but no less important, capitalist economies also dissipate the *social* energy needed to sustain humanity because they weaken human relationships. Economic efficiency requires that people relate to each other *impartially*, which means *impersonally*. People must compete rather than cooperate if markets are to work efficiently, and competition degrades personal relationships. Economic incentives encourage people to devote the maximum time possible to work, which leaves little time and energy for sustaining families, communities, or society. An economy driven by economic self-interests cannot sustain the civility of human society and thus cannot sustain the economic productivity of humans.

All economic value comes either from nature or from society. An economy creates nothing; it is simply a means of facilitating relationships among people and between people and the earth. When the economy has extracted all of the energy or usefulness from its natural and human resources, there will be nothing left from which to extract additional economic value. Today's capitalist economies are degrading the productivity of nature and society and quite simply are not sustainable.

Sustainability is ultimately a matter of intergenerational equity, of meeting the needs of the present without compromising opportunities of the future. It is a matter of stewardship, of ethics. Economics simply doesn't address matters of ethics or stewardship; that's why markets place so little value on the future. Thus, sustainability will require the active involvement of people working together, through government, for the common good of society and humanity.

Public policies that promote sustainability inevitably will result in higher prices for fossil energy-based fuels and materials. It's simply cheaper to extract and exploit than to renew and regenerate. The economy simply does not produce enough economic value to compensate everyone for the things society must do to ensure sustainability. Consequently, society must develop public policies that impose restrictions and prohibitions on economic activities that threaten ecological and social sustainability. Under such policies, individual investors who choose to develop alternative fuels and materials from renewable resources will not have to compete with those who would otherwise continue extracting and exploiting.

Both public policies and private enterprises related to bio-based materials must be grounded in the reality of living, biological systems. Living systems are essential to sustainability. Living plants have the capacity to capture and store new solar energy to offset the loss of usefulness of energy to entropy. Living things produce but they also reproduce, by nature. Even we humans are capable of capturing and storing solar energy; we just do it with windmills, dams, and photovoltaic cells. Humans also have an inherent tendency to produce and reproduce, even when we have no economic incentive to do so. Otherwise, few of us would ever choose to raise children. Obviously, an individual life is not sustainable but communities of living individuals clearly have the capacity to be productive while devoting a significant part of their life's energy to conceiving and nurturing the next generation. All of life's energy, including human energy, is biological energy captured and stored by living systems.

Thus, it is quite logical that we turn our attention to new biological sources of materials in our quest for sustainability, but in doing so, we must respect the ecological realities of biological energy. David Pimentel of Cornell University estimates that if all of the solar energy collected by all of the green plants in the United States could be magically converted into fossil energy, it would replace less than *one-half* of the fossil energy consumed each year in the United States.[1] Some bioenergy advocates have attempted to discredit Pimentel's work, but he has been focusing his research efforts on bioenergy since the 1970s and is highly respected among those who have followed his work over the years. He also has estimated that agriculture and forestry account for less than one-third of all green plants, and thus, solar energy captured by the whole of farms and commercial forests amounts to less than *one-sixth* of annual U.S. fossil energy use.[2] These estimates are confirmed by other energy experts, as in a recent National Academy of Science report indicating that converting the total U.S. corn and soybean crops to ethanol and biodiesel would replace only about 12 percent of gasoline and 6 percent of diesel use respectively. [3]

Utilization of non-food crops and agricultural wastes would seem to avoid some of the growing concerns currently associated with ethanol and biodiesel production. Most non-food crops are perennial crops, with less soil erosion than corn or soybeans, and most use less nitrogen fertilizer and pesticides than corn, meaning less pollution of streams and groundwater. Utilization of livestock wastes for fuels and materials also reduces the pollution potential of animal agriculture. Perhaps the greatest perceived advantage, however, is that utilization of non-food crops and agricultural residues and waste do not compete with food production. Recent expansion in ethanol production, for example, has causes dramatic shifts in production from food crops to fuel crops, resulting in rising food prices and even food shortages in some countries. Utilizing agricultural residues, wastes, and non-food plants for biomaterials at least blunts some of the questions raised by using food crops for fuel.

Utilization of agricultural wastes and fibrous plants also adds considerably to the total bioenergy potential of agriculture and forestry, as suggested previously. Food crops account for only about one-sixth of the total solar energy captured by agriculture and forestry, whereas forage crops account for about two-thirds, and forests account for the remaining one-sixth. Thus, the solar energy collected by food crops amounts to only about one-fifth as great as the energy collected by forage crops and forests. Of course, forage crops are currently used to feed meat animals that end up as food for humans. But 80 to 90 percent of the energy in crops grown for forages, as well as grain fed to livestock, either remains in the fields as crop residues or is excreted in livestock manure. Both are potential sources of biomaterials. Agriculture is incapable of providing a significant replacement for fossil energy-based materials, but forests, forages, and agricultural wastes contain far more bioenergy than do potential food crops.

This brings the discussion back to ecology. Crop residues, livestock manure, and other so-called agricultural wastes are not wastes when viewed from an ecological perspective. The complex ecological system, through which all bioenergy flows, may be represented as a pyramid made up of various layers. The bottom layer is the soil, the next layer is plants, the next is all those things that feed on plants, including insect and animal *herbivores*, next is the things that feed on both plants and animals, the *omnivores*, mainly humans, and the top layer is the things that eat only animals, the meat-eating *carnivores*. A generalization exists in ecology that on average, about 10 percent of the energy available in one layer will be passed on to the next higher level. “Not everything in the lower levels gets eaten, not everything that is eaten is digested, and energy is always being lost as heat”[4] – to entropy. So each higher level of the pyramid contains only about 10 percent as much as energy as the level immediately below it. As Aldo Leopold put it, “for every carnivore, there are hundreds of his prey, thousands of their prey, millions of insects, and uncountable plants.”[5]

A critically important part of this pyramid of life is its foundation, the billions and trillions of microorganisms in the soil, the *decomposers*. Living organisms in the soil extract and live from the energy remaining in the wastes generated at all levels in the pyramid, including crop residues, livestock manure, and other so-called wastes. All *new* energy enters the biological pyramid at the level of plants, the solar collectors, and ultimately escapes into space as heat, the end product of entropy. However, the inorganic nutrients – nitrogen, phosphorus, potassium, calcium – that plants must combine with carbon and hydrogen in storing energy – as carbohydrates or sugars – are continuously recycled through the soil's biological system. Many of these inorganic plant nutrients become available to plants only after they have been released from wastes and stored by decomposers. The foods that support earthworms, bacteria, fungi, nematodes, and other decomposers in the soil is the energy left in the things that we humans call wastes, the energy that we now propose to extract to make biomaterials and biofuels.

Everything we do affects everything else, including us. When we turn wastes from forestry operations into biomaterials, we are depriving the decomposers in forest soils of food, and thus are depriving future trees in forests of food, which can hardly be called renewable or sustainable. When we utilize crop residues, forage crops, animal manure, and other agricultural wastes to make biomaterials, we are depriving the decomposers in agricultural soils of the food they need to make food available for plants. We humans are biological beings; we eat other biological organisms. We can't eat the sun or digest the electricity generated by windmills, falling water, or photovoltaic cells. If we replaced even ten percent of our current fossil energy use with energy from biomass, we would be depriving the decomposers of approximately 75 percent of so-called waste energy currently available to produce food for plants. When we make biological materials from agricultural residues and wastes, we are depriving people of food just as surely as when we generate energy from food crops; the process is just a bit more complex.

The same basic ethical and ecological questions raised by making biological materials from non-food crops, residues, and wastes are raised by using food crops to produce ethanol and biodiesel. In addition, depriving the soil decomposers of their life's energy may represent an even more serious threat to the future of humanity than does depriving the earth of its remaining fossil energy. Even if we deplete the earth of its “solar endowment” of fossil energy, humanity might still learn to live from the earth's daily “solar inflow.” If we destroy the foundation of the earth's living pyramid, the decomposers, we may well have deprived future humanity of any possibility of living from the earth's daily “solar inflow.”

Our food system currently requires about 17 percent of the total fossil energy used in the U.S., in addition to the solar energy captured and stored by plants.[6] In fact, each kcal of food energy produced requires approximately ten kcals of fossil energy. Most of this energy is used in food manufacturing, distribution, and marketing, but even at the farm level, three kcals of fossil energy are required for each kcal of food energy. The highest priority for agriculture today should be learning how to produce enough food for more people with less fossil energy, not learning how to turn the food needed by decomposers into biological materials to support the extravagances of an affluent society.

Every kcal of energy that we take from the energy flow of the biological pyramid potentially deprives someone of some future generation of food energy. This doesn't mean that we should halt research and development of new biomaterials, just that we should remain ever conscious and vigilant regarding the potential long run ecological and social implications of our short run economic decisions. Everything we do affects everything else. We could most certainly be more efficient in returning biological wastes to the earth in the forms, places, and at times that would be most beneficial to the decomposers. Much of the agricultural residues today are not returned to the soil to feed the decomposers but instead is volatized directly into the atmosphere in the form of greenhouse gasses. Perhaps we could remove significant quantities of bio-materials without compromising the integrity of the pyramid if we simultaneously improved the efficiency of biological energy recycling processes. But, we ignore the limits of ecological reality at our peril, because we simply cannot avoid the ultimate ecological consequences of our actions.

Advanced agri-based material could be one of many keys, although certainly not *the* key, to sustainability. *The* key to sustainability will not be found in another source of energy to extract to serve the short-run, economic interests of individual or corporate investors. The key to sustainability will be found in learning to work together – informally and through government, on farms, in rural communities, and in cities – to create a social and economic environment in which we can work and live, willingly and peacefully, in harmony with nature, from the earth's daily inflow of solar energy. There is no other sustainable source of energy, or materials.

End Notes

[1] From a presentation by David Pimentel, Cornell University, at *Local Solutions to Energy Dilemma*, New York City, April 28-29, 2006. Revised to account for increased energy use from earlier estimate published in David and Marcia Pimentel, *Food, Energy, and Society* (Niwot, CO: University Press of Colorado), 1996.
[2] David and Marcia Pimentel, *Food, Energy, and Society* (Niwot, CO: University Press of Colorado), 1996, 20.
[3] Jason Hill, Erik Nelson, David Tilman, Stephen Polask, and Douglas Tiffany, 2006, "Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels," National Academy of Science Report, http://www.pnas.org/cgi/content/short/103/30/11206.
[4] Dave McShaffrey, "Environmental Biology- Ecosystems," Department of Biology and Environmental Science, Marietta College http://www.marietta.edu/~biol/102/ecosystem.html.
[5] Aldo Leopold, A Sand County Almanac, "The Land Ethic" (1949, New York: Ballantine Books, 1966), 252.
[6] Energy estimates in this paragraph also from Pimentel, *Food, Energy, and Society*.