Advanced Biofuels USA, a nonprofit educational organization, advocates for the adoption of advanced biofuels as an energy security, economic development, military flexibility and climate change solution.

Biofuel & Biomaterial Crops: We Might Be Doing It Wrong

By Robert Kozak*

As I was recently dulling blades chopping switchgrass for some enzyme hydrolysis experiments, I started thinking whether the ***"high yield perennial grasses on marginal land"*** paradigm makes any sense for biofuels. On the plus side, there are many positives about using perennial grasses. They are low maintenance, high yield, require low additional nutrients, and have broad growing ranges. These positives are really evident when compared to algae which are highly sensitive to low temperatures, always require large quantities of water, are easily disrupted by other microorganisms, and do not readily secrete oils that are used for bioproducts.

Even with these salient advantages and decent government funding, the "high yield perennial grasses on marginal land" paradigm has not yet become a reality. Three key elements seem to be holding it back.

1. Is the high lignin (woody biomass) content of these grasses, which accounts for the 15-20 percent of total biomass that raises per acre yield above 10 tons, of real benefit or is it just a major interference to biomass conversion?

2. Is there an entrepreneurial agricultural community, including financial institutions, in the Eastern and Southern US (which are targeted as growing areas for the grasses) that could translate the perennial grass biomass paradigm into a profitable industry?

3. Is the very high value bio-carbon fiber market that is touted as the economic driver for these grasses a reality or merely a hopeful illusion?

If these problems cannot be overcome quickly, is there another way to sustainably, and quickly, produce low-input non-food biofuel and biomaterial feedstocks that could create a sustainable Advanced Biofuel/Biomaterial industry?

What follows are my thoughts on these questions. I can't say they are completely thought out. However, I think they do provide enough ideas to get the Advanced Biofuels/Biomaterial community to seriously consider two points:

- The current pathway to commercializing grass biomass is not working.
- We need to find new systems that work.

The Hard Road of Miscanthus, Switchgrass, etc.

In his 2006 State of the Union Address, President George W. Bush spoke enthusiastically of a biofuels future that would be based on switchgrass. Stock prices of companies that sold switchgrass seeds soared and much USDA/DOE bioenergy funding was quickly shifted to high yield perennial grasses.

Unfortunately, despite rather substantial funding, eight years later there is no US commercial implementation of a perennial grass system. (The recently dedicated POET prototype plant uses corn stover residue cellulose to produce ethanol.)

To explain this failure, the DOE/USDA approach was deficient in the following ways:

1. Instead of developing a biofuel/bioproduct processing model that was suited to the disbursed, small stand nature of perennial grass agriculture, DOE clung to an integrated biorefinery model that overlooked the transportation costs of biomass. With the value of biomass sugars not exceeding $.15/lb, biomass cannot be economically transported over 40-50 miles. Hence, DOE integrated biorefineries could not be larger than the corn ethanol plants of the Midwest. (See http://advancedbiofuelsusa.info/the-distributedcentralized-bioproduction-approach-sustainable-biofuels-and-bioproducts-are-possible-through-the-significant-reduction-of-biomass-transportation-costs)

2. The crop improvement work on grasses focused on increasing yields and reducing nutrient inputs. Virtually no genetic effort was put into understanding grass cell wall structure so that it could be more easily converted into either simple sugars or polymers for biofuel or bioproduct feedstocks.

3. No programs were ever initiated to try approaches not in the preconceived DOE model. This meant any breakthroughs in biomass deconstruction or enzyme design were not going to occur at labs depending on DOE or USDA funding.

And so, at the end of 2014, the acreage of switchgrass planted because of USDA bioenergy subsidies is rapidly disappearing as growers go back to profitable soybeans and corn. Without biofuel or biomaterial demand, the $.02/lb being paid for these grasses as animal bedding barely covers harvesting costs.

On the processing side, pyrolysis and gasification test units are being fed switchgrass and miscanthus, but hemicelluloses still “gum up the works” on too many occasions and air emissions still require clean-up technologies to meet EPA criteria pollutant standards.

And at “out of the box” research labs, work is either slow, starting to be funded by international concerns, or has been abandoned for more lucrative fields.

So, could perennial grasses work as sustainable biofuel crops?

Yes, but funding would have to be made available to correct the mistakes listed above. Specific changes would have to include:

- Harvest grasses early in season to decrease lignin and increase moisture content – while yields and soil nutrients would decrease, these two improvements are needed to make sugar hydrolysis economical.

- Develop cell wall deconstruction and saccharification processes that could operate in decentralized or portable systems that would allow higher density, higher value soluble sugars or oils that could be transported hundreds of miles by tank truck or rail and retain plant cell wall proteins for soil nutrients.

- Change the genetics of perennial grasses to either: a) modify the cell wall structure to facilitate deconstruction and saccharification; and/or, b) include enzymes and harvest actuated promoters that would internally initiate cell wall depolymerization.

In other words if sufficient research funds were made available, in a decade or so perennial grasses grown on marginal lands could be a sustainable biofuel and biomaterial feedstock.

However, given the anti-biofuel focus of the Obama "*Natural Gas is Good for the Environment"* Administration and both parties in Congress, it is very unlikely this will happen any time soon.

Furthermore, even if the expenditure of funds was made, could implementing a complete system in the East and Southeast, the regions containing the largest quantities of "marginal lands," happen without significant improvements in their agricultural support system?

Can the Eastern and Southern Agricultural Industry Initiate a New Commodity Crop System?

As you approach Cleveland from the west on the Ohio Turnpike the miles and miles of corn fields you thought would never end start to thin out. By the time you reach the Pennsylvania border the fields are much, much smaller. You see more grazing land until the mountains are covered with hardwood forests. Coming down on the eastern side of the Appalachian shield the fields remain small by Midwestern standards. The suburbs seem to be everywhere. You see some corn and soybeans, but no longer much tobacco. You do see grazing animals, organic vegetables, wineries, horses, and tourist farms. Going further south, the soil starts to play out in central South Carolina. That state's agricultural industry looks like it never recovered from the enslaved system ended by the Civil War. Going further east, across the Chesapeake Bay, you enter the realm of mass chicken production – a large agricultural enterprise of irrigated corn and large chicken "factories."

The people looking after the corn and running those chicken factories are all on the short end of production contracts with Purdue and the other chicken marketers. These people do not own the fancy boats or the expensive houses on the picturesque creeks of the Eastern Shore. This chicken production system has been described as being essentially feudal. The poultry companies control the land, the financial system and all aspects of the production system, including nutrients for the soil and feed for the birds.

Besides, with the ocean level rising, not only is irrigation water becoming more saline, but land is also being lost. Projections being made by the State of Maryland don't predict much of a long term future for the agricultural land on the Eastern Shore.

So, do the Middle Atlantic and Southeastern states currently look capable of putting together a complex new commodity crop production system? Are the agricultural financial resources in place? Are the transportation systems ready? Do the land-grant universities have the expertise and courses ready to support such a change?

I would say, not now.

The False Promise of the Bio-Carbon Fiber Market

While working on the production side of biofuels and bioproducts, DOE recognized the tight profit margins of biofuels. In response they have been trying to develop more profitable bioproducts markets that would energize private investment.

The result of this DOE effort was a singular focus on what they identified as a very fast growing, very high value market – the aircraft and automotive carbon fiber/composite market.

Since this market was going to be fueled by manufacturing efforts addressing environmental concerns, it seemed logical that low GHG biomass sources for the carbon fiber would be required.

In 2004, when Boeing announced the first orders for the carbon fiber/composite 787, a new expanding market for expensive ($20+/lbs) carbon fiber material seemed very real. Estimates for the growth of this carbon fiber market grew exponentially with the passage of new US automotive fuel economy regulations. Meeting the 54 mpg requirements by 2022 meant reductions in vehicle weight would be absolutely necessary. Lighter weight cars and trucks would mean smaller engines, which meant less fuel used.

Taken together, it seemed that biomass sources for carbon fiber would be the high-end market bioenergy investors were looking for.

Flash forward ten years later to 2014. The 787 has been a disaster for Boeing. High production costs and delays that pushed deliveries back a minimum of three years caused Boeing, and its one competitor Airbus, to change plans for the next decade of commercial aircraft production. The next generation 777 and 737 will be primarily aluminum, instead of carbon fiber/composite construction. Similar sized Airbus models will be built the same way.

As for the automotive industry, the need to make money while reducing weight and fuel use while retaining vehicle safety caused manufacturers to chose much less expensive aluminum as their lightweight material for the next decade. The new 2015 Ford F-150 pickup (the best-selling vehicle in the US) is making extensive use of that metal to shed 700 pounds as compared to the 2014 model. In Europe, aluminum is also the material of choice by even such high-end builders as Audi or Jaguar that have the extra profit margin that could absorb some carbon fiber use.

Simply put, for at least the next 10 years, the non-military carbon fiber market will not be expanding much beyond the current 787 demand.

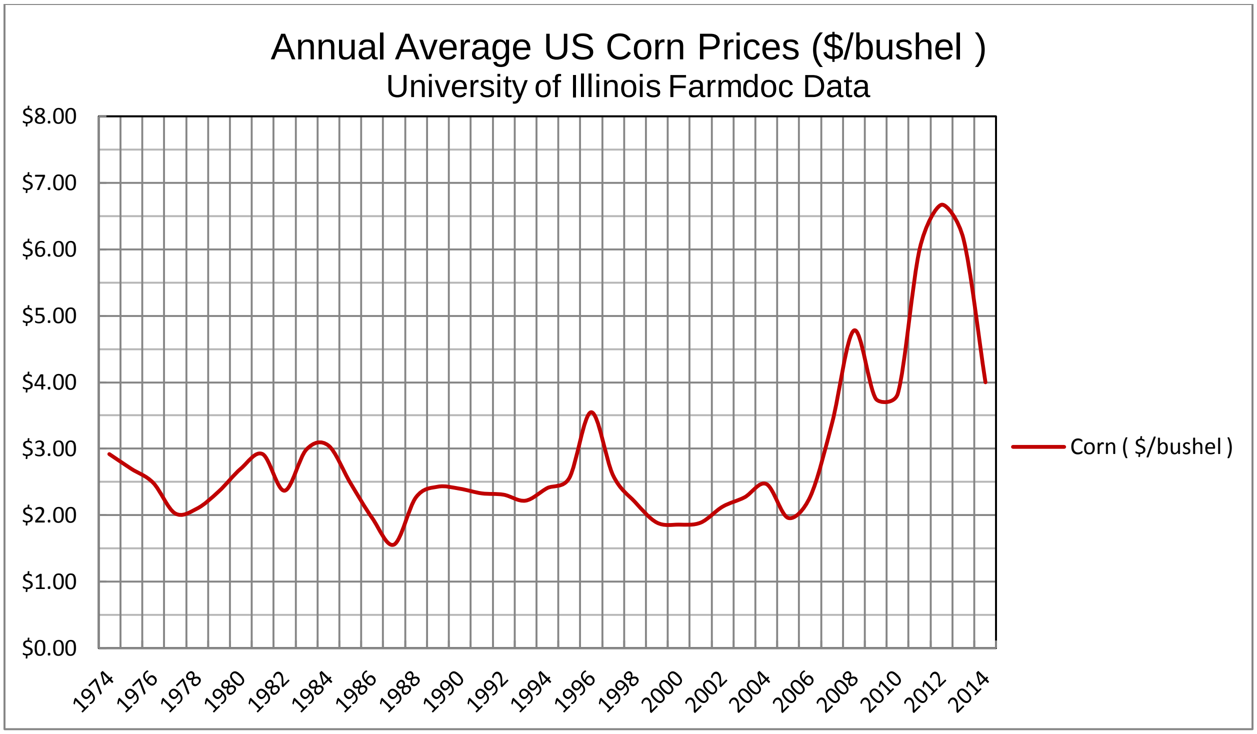
Instead of this “hit the lottery” market, producers of bio-feedstocks will instead have to work closely with a variety of biomaterial and biochemical producers to develop streamlined platforms that can produce a variety of biopolymers for a broad range of uses. Projects as the multi-nation Global Innovation Initiative “Transatlantic Discovery, Characterization, and Application of Enzymes for the Recycling of Polymers and Composites” are beginning to tackle this difficult assignment.

A Possible, Sustainable Future

While this is has been a depressing analysis that might cause some people to give up on anything other than corn starch ethanol, I think there is a simple, sustainable, and successful alternative for the next decade that would finally create a multiproduct “advanced” biomass industry.

The Future of US Corn Ethanol Land

Contrary to the dire predictions of long-time corporate farming critics, anti-corn foodies, and several economists, the increase in US corn planting needed to meet the 10% motor vehicle ethanol requirement did not result in a world-wide food price disaster. In fact, a combination of improved farming practices, new corn genetics, high non-drought corn production stimulated by the ethanol market, stabilized ethanol demand, and financial speculators leaving agricultural futures for markets they could more easily manipulate, has led to corn prices under $4.00/bushel since July 2014. In fact the current price of about $3.30/bushel is close to not only the 2006 price but also to prices in the 1970s and 1980s. (Note, these prices are not corrected for inflation so in comparative terms corn is cheaper than it was thirty years ago.)



With these falling prices the US agricultural industry is entering a period of decision making similar to earlier periods of low corn and other commodity prices. When prices have fallen in the past, three types of actions took place: 1) Corn land was used for other more profitable crops; 2) Farmers joined government programs such as the Conservation Reserve Program (CRP) that took agricultural land out of production to stabilize prices; or 3) More profitable markets were found for corn products.

In the 1970s and 80s corn growers and processors aggressively followed the last course to both diversify and expand the market for corn. The primary market targets were sweeteners and fuel. As the following table shows they were very successful.

Table 1
Expanded Corn Markets
(USDA/ERS Data)

Year	High Fructose Corn Syrup (million bushels)	Glucose & Dextrose (million bushels)	Fuel Ethanol (million bushels)
1980	165	156	35
2000	536	226	629
2013	483	305	5,125

This product diversification also meant value-added opportunities for growers. For example, if a grower or a growers' co-op was able to become part owner of a corn ethanol plant, they would be able to reap the value of the end-products, ethanol and distiller dry grain (DDGS), rather the commodity price of corn. Even at current prices, per acre gross income would more than double; $1,373 versus $536 (Table 2).

Table 2
Comparison of Corn Commodity and Ethanol/DDG Prices
(All Yields Based on 162 bushels/acre)

Corn	$/Bushel	Bushels/Acre	Value/Acre
	$3.31	162	**$536**
Ethanol/Bushel (gallons)	$/Gallon	Ethanol/Acre (gallons)	
2.5	$1.65	405	$668
DDGs/Bushel (lbs)	$/Lb.	DDGs/Acre (lbs)	
17.4	$ 0.25	2,819	$705
		Total Ethanol & DDG	**$1,373**
		% Increase	**256%**

However, with US ethanol demand currently being capped by the Administration's decisions on both RFS ethanol volume obligations and E30 certification fuel, the combination of excess corn production and excess ethanol capacity will continue to drive both corn and ethanol prices lower.

In addition, while anhydrous ammonia fertilizer costs are stabilized because natural gas prices are currently below $4/million BTUs, fracked gas producers need a price closer to $6/million BTUs to keep investment coming. That price may well be reached next year as gas producers continue to decrease production and begin to export liquefied natural gas (LNG), meaning corn nutrient input prices will increase as well.

This combination of saturated markets and increasing production costs may soon cause corn growers to either start returning land to CRP and other programs (and increasing US taxpayer costs) or to growing other crops.

An Opportunity for an Advanced Biofuel & Biomaterial Renaissance?

So, with approximately 20-25 percent of current US corn production being used for fuel ethanol, the questions for growers become:

- Could portions of this land be used for lower nutrient input biomass crops that would produce comparable income from ethanol or other biofuels and biomaterials?
- Could corn land not within current shipping distance of existing ethanol refineries also be used for biofuel/biomaterial crops?

I think the right answers to these questions could not only retain current grower incomes but more importantly, could be an opportunity to build the foundation of a ***true Advanced Biofuel and Biomaterial System.*** This system would have the following characteristics.

- Biofuel/biomaterial crops would be low in lignin, high in both C-6 and C-5 polysaccharides.
- These crops would be drought and excess moisture resistant and would not have human food use.
- The biomass would be easy to process into soluble monomeric sugars or multi-unit polymers (saccharification) in the field with portable non-toxic, low-energy use units.
- Plant proteins could continue to be used as animal feed.
- Precursors produced in the field could be used in a variety of biofuel and biomaterial production systems.
- These higher density and higher value soluble sugar or polymer precursors could be transported hundreds of miles by truck or rail to multiproduct biorefineries.
- These biorefineries could be much larger than current corn starch ethanol plants or corn stover plants (50-100 MGY) because the transportation cost hurdle of low density biomass would be overcome by the portable saccharification step.
- The biorefineries would also become crop independent since the input sugars or polymers would be the same when they arrived.
- Some current ethanol plants could serve as the basis for these refineries.

Candidate Biofuel/Biomaterial Crops

So, what type of crops could serve as the basis for this system? A very good starting point would be root crops. Why? A root has the ground around it providing support. This support means a large quantity of biomass can be accumulated without the complex cell wall structure needed to support a plant stalk. Without that structure, the primary cell walls of the root can be more easily accessed by enzymes. This means a quicker, less expensive biomass conversion process is possible.

In addition, since biofuel/biomaterial root crops would not be used for food, meaning the quality of specific characteristics would not have to be maintained, they can be stored in-place, including over-wintered. Crops could instead be harvested on an “as-needed” basis which would result in significant storage cost and production plant size reductions.

Furthermore, specific polymer production and storage in the root should become a topic of future agricultural research. Current work on rubber production from the TKS dandelion is a pioneer in this direction.

Finally, plant proteins can be extracted from root crops and sold as animal feed. This would continue to provide growers with an income similar to corn DDGS.

Energy Beets: A Place to Start

Seed companies such as Beta Seeds have been developing high biomass, low sucrose sugar beets that they call Energy Beets. While small projects in the Dakotas are being pursued to use them as feedstock for anaerobic digester-electrical production systems, these beets would be better used for higher value biofuels and biomaterials. As shown in Table 3 below, ethanol production triples the income from electrical production since lower cost natural gas sets the price for electrical production.

Table 3
Comparison of Biomass Energy Markets

	Price Determination	Price/lb Biomass sugars	Price/Ton (Utilized biomass)
Combustion Electricity	7,091 BTUs/lb compared to Natural Gas @ $3.50/million BTUs	$.025	$50
Ethanol Production	15 lbs sugars/gallon @ $.15/lb sugar	$.15	$180
Fabric Polymer Production	$.28/lb (price for recycled polymers)	$.28	$336

If energy beets were substituted for corn, preliminary estimates based on current energy beet yields and sugar conversion data (provided by Atlantic Biomass Conversions, Inc.) show that energy beets could provide sufficient income for growers (Table 4).

Table 4
Comparison of Energy Beets and Corn

	Energy Sugar Beets	Corn
Tons/Acre	8	
Sugar Tons /Acre @ 70% Recoverable Sugars	5.6	
Gallons Ethanol/Acre @ 15.6 lb/gal	1026	405
Wholesale Ethanol/Acre @ $1.65/gal	$1,692	$668
Proteins lbs/acre @ 12% biomass	1,920	2,819
Price @ $ .25/lb	$ 480	$705
Total/Acre	**$2,172**	**$1,373**

Also as shown in this table, if the yields could be maintained, the acreage needed to produce current ethanol levels from energy beets could be significantly reduced. This could produce opportunities for additional beet acreage to be used for bio-jetfuels or biomaterials. For instance, the relatively high C-5 (hemicellulose) content, about 22%, could provide a kick-start to a bio-hexane industry. In addition, other root crops, especially ones that could provide medium to high-value polymers should be considered for specialty markets.

The result of the switch from ethanol corn to more profitable general use biofuel/biomaterial crops could provide the crop-independent, reliable supply of biomass feedstock needed to create and sustain a diverse Advanced Biofuel and Biomaterial Industry. By so doing, it would create a financial climate that would bring private investors back to the arena. Researchers on the crop development side would have the money to develop lower input, higher yield crops while biochemists and biologists could bring bio-based polymers with built-in recycling “triggers” that would be activated by new families of enzymes to market as well. And, who knows, maybe even new generations of perennial grasses that could be grown on marginal lands could be developed as well!

**This is not a statement of Advanced Biofuels USA policy. A thought-piece, it reflects the considered individual opinions of Robert E. Kozak, President of Atlantic Biomass Conversions and Co-founder, Treasurer of Advanced Biofuels USA. An Ohio native, Kozak conducts research in enzymatic conversion of biomass to sugars; and also serves Advanced Biofuels USA as an expert on engines and fuels. He can be reached at AtlanticBiomass@aol.com or 301-644-1396*