Mr. Chairman, thank you for this opportunity to testify on the future of the renewable fuels industry. I would also like to thank Senator Harkin for his long-term support of biomass research at Iowa State University and his personal vision for a bioeconomy.

The Chicago Board of Trade recently reported that "the U.S. ethanol industry is experiencing exponential growth and this trend is expected to continue." In other words, the sky's the limit. If this sounds like the heady days of the 1990's Internet boom, there are indeed parallels. The Washington Post notes that both the Internet and the renewable fuels industry started from relatively small bases, they are dependent upon technological innovation for growth, and both were underinvested relative to the size of the potential market. This parallel has not been lost on the original investors of the Internet who are among the largest investors in the renewable fuels industry today. With a growth rate averaging 22% in the last four years and a doubling expected in the next five years, it is hard not to be excited. However, we must realize that decisions made today will determine whether this industry meets expectations or whether it falls victim to irrational exuberance.

The Department of Energy calls for renewable fuels to meet 20% of U.S. transportation demand by 2030. Currently, ethanol represents only 3% of transportation fuels but even the most optimistic scenarios do not predict grain ethanol to displace more than 6-8% of gasoline demand. Agriculture must think beyond corn and soybean production if it is to supply a significant fraction of U.S. transportation fuels.

The U.S. Department of Agriculture recently performed an assessment of biomass resources for the United States. This study concludes that over 1.2 billion tons of dry biomass could be produced in a sustainable manner from a variety of resources including animal wastes, milling residues, crop residues, and dedicated energy crops such as switchgrass. Equivalent to 21 billion GJ of energy, this biomass supply could be used to fulfill one-third or more of U.S. demand for transportation fuel. Agriculture will have to reinvent itself to achieve this potential.

At Iowa State University I teach students about biorenewable resources in one of the only such graduate programs in the United States. As a class exercise I ask my students, given the choice of growing an acre of corn, soybeans, or switchgrass, which would yield the most transportation fuel and which would produce the greatest quantity of dietary protein. Most students choose corn for fuel and soybeans for protein. They are surprised to learn that an acre of switchgrass could yield almost twice the biofuel as an acre of corn and almost the same amount of protein as an acre of soybeans. Much work remains to make this intriguing possibility a reality.

The emergence of the renewable fuels industry is only part of a bigger movement known as the bioeconomy. The Des Moines Register recently characterized this movement "a revolution;" indeed, proponents of a bioeconomy call for nothing less than the complete replacement of petroleum with plant-based chemicals and materials in the manufacture of not only transportation fuels but a variety of biobased products. Already commercially available biobased products include adhesives, cleaning compounds, detergents, dielectric fluids, dyes, hydraulic fluids, inks, lubricants, packaging materials, paints and coatings, paper and box board, plastic fillers, polymers, solvents, and sorbents.

We must be careful in our delineation of goals for the bioeconomy. Often people confuse pathways with goals. For example, converting corn into ethanol is not a goal of the bioeconomy but rather a pathway, and possibly a transitory one at that, as new technologies present more efficient and high yielding pathways. I suggest four goals for the bioeconomy.

The first goal is to reduce reliance on imported petroleum. If we discover after a decade of "exponential growth" in the renewable fuels industry that we still import more than 60% of our transportation fuels, then the bioeconomy is not fulfilling its promise.

The second goal is to improve environmental quality, especially reducing emissions of greenhouse gases into the atmosphere. In principle, the manufacture of biofuels yields no net emissions of greenhouse gases, while innovations in agriculture can substantially sequester carbon into soils. In practice, these advantages are diminished by over reliance on fossil fuels in the production of biofuels and failure to employ sustainable agricultural practices. We must be diligent about keeping the "renewable" in renewable fuels.

The third goal is to expand markets for U.S. agriculture products. Although these products might be traditional cash crops, they might also be new commodity crops that better meet the needs of a bioeconomy.

The fourth goal is to provide economic development opportunities for rural America. Outsourcing by U.S. corporations is often justified as "following the resource." In the bioeconomy, the resources are the rich agricultural lands of rural America. We can expect the manufacture of biofuels and biobased products to occur in communities close to this resource, which will boost our rural economies.

To meet these goals we will have to develop and deploy biorefineries, which efficiently separates biomass into individual plant components and converts them into diverse marketplace products. Three distinct kinds of biorefineries are visualized for the United States: corn-based biorefineries, lignocellulosic biorefineries, and oleochemical biorefineries.

Modern wet corn milling plants can rightly claim to be a form of corn-based biorefinery, producing starch, ethanol, high fructose corn syrup, and animal feed. However, advanced corn-based biorefineries will process fibrous byproducts into higher valued products than animal feed. This will be accomplished through the development of new enzymes that release sugars from cellulose fibers.

Lignocellulosic biorefineries will convert fibrous biomass such as switchgrass and cornstover into sugars and lignin. The sugars will be fermented into "cellulosic" ethanol although the same carbohydrate derivatives contemplated for corn-based biorefineries are also possible secondary products for a fiber-based biorefinery. Lignin, a phenylpropane-based polymer, is not fermentable but has potential as a urea-formaldehyde substitute or even the starting point for the production of hydrocarbon fuels. First generation biorefineries, however, are expected to simply use lignin as boiler fuel.

A fundamentally different approach to lignocellulosic biorefineries thermally gasifies plant material into a mixture of carbon monoxide and hydrogen known as syngas. This simple gas mixture can be catalytically upgraded to a wide variety of compounds, including alcohols, carboxylic acids, and hydrocarbons. It is the process proposed for the production of "green" diesel in Europe.

The oleochemical biorefinery is based on plant oils or animal fats. For a biorefinery based on oilseed crops such as soybeans the primary products are oil (triglyceride) and meal, the later of which contains significant quantities of protein and fiber and some residual oil. The oil can be either hydrolyzed to fatty acids and glycerol or converted into methyl (or ethyl) esters and glycerol.

The fatty acids and esters are potential platform chemicals for the production of a vast array of derivative chemicals used in high value products. Much of the focus on methyl esters today has been on their use as biodiesel but there has also been limited diversification into ester-based solvents and lubricants. The industry has shown only limited interest in upgrading the glycerol byproduct although technologies are rapidly emerging for its conversion to 1, 3-propanediol, a precursor to the production of plastics. Similarly, although the protein in the meal as potential to replace urea-formaldehyde in adhesives, commercialization has been slow to emerge.

The question of whether renewable fuels return more energy than is consumed as fossil fuels in their production is a seemingly interminable debate.

Research into this question yields answers ranging from a 60% deficit to a 110% gain in energy, depending upon who is performing the analysis.

There are several reasons for the wide range of reported values for this energy return in the production of ethanol. First, different study groups make different assumptions about the production yield of corn grain. For example, one study group averages corn yields over all fifty states with the intention that this best represents a national average for corn yield while another averages yields over the top ten corn producing states, arguing that these are where grain ethanol plants are clustered. Second, there are major disagreements about the amount of energy needed to produce anhydrous ammonia fertilizer. Third, there is no consensus on the amount of ethanol that can be produced from a bushel of grain, probably because this number depends on the age and size of the fermentation facility. Finally, there are questions as to the amount of fossil energy consumed within the production facility. Clearly, a large amount of natural gas is consumed in drying DDGS and distilling ethanol, but it is difficult to accurately assess energy consumption in an industry that is rapidly growing and changing.

Ultimately, the disagreements among researchers likely reflect the difficulty of assigning average values for these parameters to the whole industry. Very likely there are older and smaller corn ethanol plants that are operating with energy ratios less than unity while larger, more modern facilities are operating above unity.

At any rate, there is substantial room for improvement in the grain ethanol industry. Averaging the results of 14 distinct studies suggests that grain ethanol currently provides a 30% energy gain over the fossil energy used in its manufacture (in comparison, and there is little disagreement on this point, the production of gasoline from petroleum results in a 20% energy deficit). There is no theoretical reason why the manufacture of renewable fuels should not have energy gains of 500% or higher. Several things could be done to reduce the use of fossil fuels in ethanol production: tractors could run on pure biodiesel; cornstover could be the energy source for fertilizer production; byproducts could be used as sources of energy for drying and distillation.

The way to a bioeconomy is not clear even with a well defined set of goals. It is too early to pick winners and losers among the technologies that can transform biomass into biofuels and biobased products. Much of the recent public discussion has been about the development of advanced enzymes to produce cellulosic ethanol, but other possibilities include Fisher-Tropsch liquids or alcohols from syngas, co-refining bio-oils and petroleum crude, and hydrogen generation from algae, to name a few. Expanded research both applied and fundamental in nature, is the best way for government to help industry distinguish the winners for commercialization.

Thank you for your time this morning. I would be happy to answer any questions you have for me.