



Introduction and History of Bioenergy

Lecture 2 - Recent Bioenergy History

Welcome back! In this lecture we are going to discuss more recent developments and some historical patterns in energy/fuels.

Week 1 - Early & Recent Bioenergy History

-Learning Objectives-

- ▶ List some of the major historical steps in the development of bioenergy from the beginning of human civilization until today.
- ▶ Describe some of the people associated with these developments
- ▶ Identify something about carbon energy history that you would change if you could and discuss why you would change it.

World War 1 (1914-1918) and World War 2 (1939-1945)

- ▶ Haber Bosch process drives incredible agricultural production
- ▶ Germans discover how to produce diesel and gasoline from coal & biomass
- ▶ Vehicles are designed to run on wood chips
- ▶ When the wars ended, oil rapidly returned as the preferred carbon energy source



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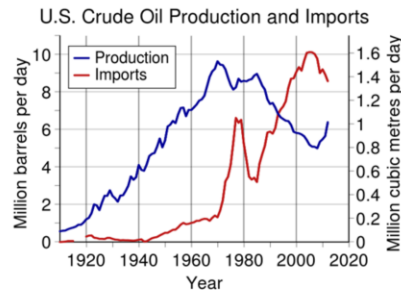
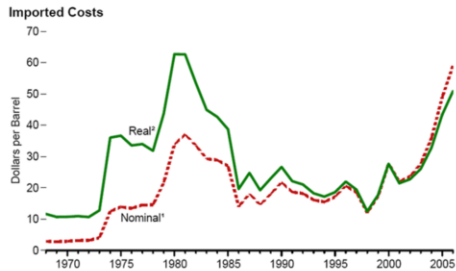
By WW1 the world had rapidly converted to internal combustion engines that were powered on diesel and gasoline. Despite ethanol's popularity for well over 100 years, oil was cheap and plentiful and it became the standard fuel for use in engines. In some ways, petroleum fuels and engines were developed at the same time and grew up together – the technology fit the fuel and the fuel fit the technology. This is extremely important to remember when assessing new fuels, since anything that burns has the potential to be a good fuel in an engine designed to use it. We may suffer more from limited engine designs, than we do from limited fuel options.

The photo on the left is of Fritz Haber and Carl Bosch working on the first Haber Bosch reactor. The Haber Bosch process changed the world by allowing us to produce ammonia from natural gas and air. Shortly after this accomplishment, another German research team with Franz Fischer and Hans Tropsch developed the Fischer-Tropsch process which allowed the German military to produce diesel and gasoline from coal & biomass. The Fischer Tropsch process has been used by South Africa to meet all its fuel needs (through coal conversion) since the 1980's.

During WW2 especially, the shortage of oil in Europe led to engine modifications and vehicles that were designed to run on wood chips like the one shown in the photo on the right. When the wars ended, oil rapidly returned as the preferred carbon energy source because it was much simpler to use than wood chips and far more available than ethanol (since most of the large plants had gone bankrupt by this point).

1970's Energy Crises

- ▶ For a brief period oil became expensive and supply tightened
- ▶ Major efforts were made to find substitutes and many are "re-discovered"
- ▶ When oil price dropped, market pressures overwhelmed the new technologies
- ▶ We are witnessing the same "re-discoveries" of the 1970's today
- ▶ Shale oil and gas fracking are dropping the price again, but the market is different now



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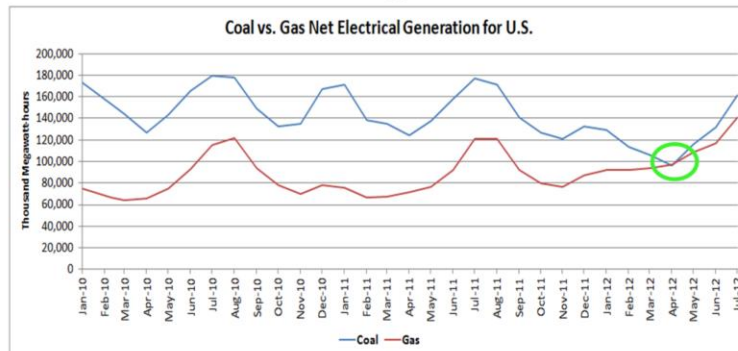
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History often goes in circles for reasons that baffle historians. Many of the bioenergy technologies being developed today were researched in the 1970's during the energy crisis. Ironically, many of the technologies researched in the 1970's were based on ideas that been practiced more than 100 years earlier to produce energy and fuels for a world going crazy for engines and struggling to find a fuel of choice.

So, here we are again. The price of oil has been high and for 10 years or so there has been considerable enthusiasm for bioenergy. However, now we are potentially looking at producing more oil than we consume and interest in bioenergy is waning again. The graphs above show what oil prices did in the 1970s and what the balance of oil production/imports has looked like for the last 100 years. It's interesting to note that with the exception of the last 10 years in general the US has always produced more than oil than it has imported.

In the 1970's GE developed gas turbines that could run on ethanol and lignin

- ▶ Coal and gas power plants can be retrofitted to utilize biomass & biofuels
- ▶ Gas turbines are a form of “distributed power” compared to coal/nuke/hydro which are “centralized power”
- ▶ Biomass is a “distributed” type of carbon energy compared to oil and coal which are “centralized” sources of carbon energy



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One of my favorite stories from the 1970's is that GE, fearing a loss of gas supply for their turbines, developed a way to convert their gas turbines to a more available fuel composed of ethanol and lignin. Ethanol provided the vapor characteristics and lignin provided the energy content – the combination was apparently quite functional. However, these days there is very little discussion about powering turbines with biomass, just burning biomass in coal plants. I show the graph of coal vs. gas electrical generation because this discussion may get another chance. If natural gas is successful in upsetting coal as the preferred energy source because it is cleaner, more efficient, and easier to build, then the foundation of our energy infrastructure will be dramatically different.

Back in the days of Edison and Westinghouse private investment and government policy led to centralized energy production over distributed energy production. Westinghouse wanted distributed power and Edison wanted centralized. If things continue going the way they are, our grid may someday look the way Westinghouse wanted. Distributed energy production fits bioenergy much better than centralized energy production, so from a bioenergy perspective, the conversion from coal to natural gas is a welcome development.

~100 years after the diesel engine, biodiesel began to be commercially produced (1989)

- ▶ Diesel engines were designed to be efficient, not to run on vegetable oil
- ▶ Vegetable oil can only be used as a fuel with some engine modifications
- ▶ Biodiesel does not have this problem and can be used with little modification
- ▶ Vegetable oil is readily available, but it is also quite expensive (remember ethanol)



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Ethanol had technically been an engine fuel since the early 1800's, but we currently have more access to engines that run on biodiesel than we do to ethanol engines. Why? It has nothing to do with conspiracy and everything to do with convenience and in-place investments.

Biodiesel recipes had been publicly available for around 50 years before the first commercial plant was built. It is produced by modifying vegetable oil so that it functions better in most common diesel engines. Interestingly, if the engine is modified, the vegetable oil doesn't have to be. It's a fine fuel in an engine designed to use it.

However, using vegetable oil to power vehicles could only ever be a regional solution, not a national solution. Vegetable oil is fairly expensive in a lot of places, but then ethanol can be as well. Ethanol prices have been between \$1.5 - \$2/gallon for about 10 years now and vegetable oil is just about the same. Ethanol has better octane value, but vegetable oil has better energy content. So, one is not necessarily better than the other, they just need different engines. It's a mystery to a lot of people why more farmers aren't taking advantage of this. Crude oil goes for between \$80-\$100/barrel these days and an oil barrel has 42 gallons in it, so crude oil goes for \$2-\$2.5/gallon.

In 2012 we began commercially producing something called “renewable diesel”

- ▶ Renewable diesel is not biodiesel and is often produced through thermal treatments and the addition of hydrogen
- ▶ In normal engines this product is a “blend-stock” like ethanol. It can not completely replace diesel or gasoline



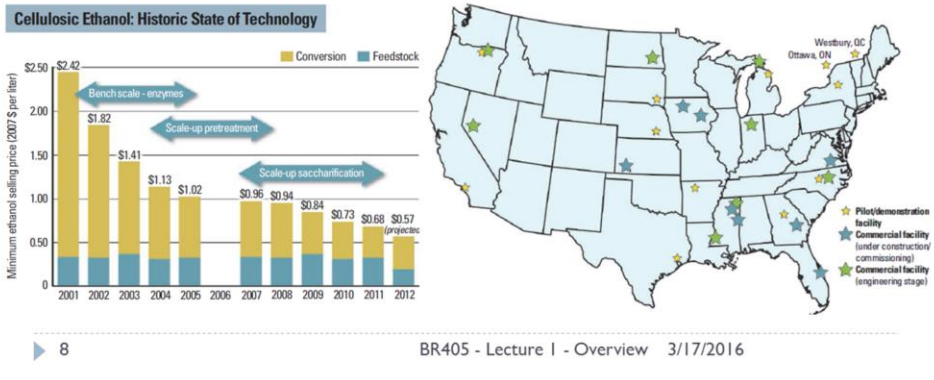
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This was a big step for the bioenergy community. KiOR owns this refinery. It utilizes 500 tons/day biomass and produces over 13 million gallons of fuel blend-stock annually. The technology utilized at this refinery is very similar to what is used at commercial petroleum refineries. KiOR is currently working hard to improve the efficiency of the plant so that the economics are better. Petroleum refining is very expensive and this expense is handled in part by taking advantage of economy of scale. Biomass cannot be used at the same economy of scale and this presents a significant economics challenge in trying to treat biomass like petroleum. That said, this is still a very exciting development and an important step on the path towards the production of distributed/renewable sources of hydrocarbon.

In 2013 we began commercially producing cellulosic ethanol, ~180 years after ethanol was 1st used in engines

- ▶ INEOS Bio owns this refinery. It produces over 8 million gallons of ethanol and 6 MW of power annually
- ▶ Dozens of cellulosic ethanol plants are scheduled to come on-line around the world in the next couple years
- ▶ This development also effects cellulosic butanol and cellulosic acetic acid



It's here! After being five years away, for 20 years, cellulosic ethanol is finally a real thing and growing. The map and statistics are only for North America and there are equally mature developments happening in Europe and South America. The United States has been a net exporter of ethanol for over five years now. So, it will be interesting to see how the industry changes as more feedstock flexible production capacity comes online.

So why are we addicted to oil
instead of alcohols?

Consider the history...

- ▶ Oil was extremely cheap to produce in massive quantities and if it could get to market the profits were incredible (no taxes)
- ▶ Since Standard Oil, oil companies have proved to be exceedingly good at aligning their efforts and creating markets for their products
- ▶ The distribution network for oil and oil products is unparalleled in today's world (water & electric maybe)
- ▶ In-place infrastructure and engines are overwhelmingly powered by oil products (and coal)
- ▶ The wealth generated from an oil reserve is impressive both in size and rate



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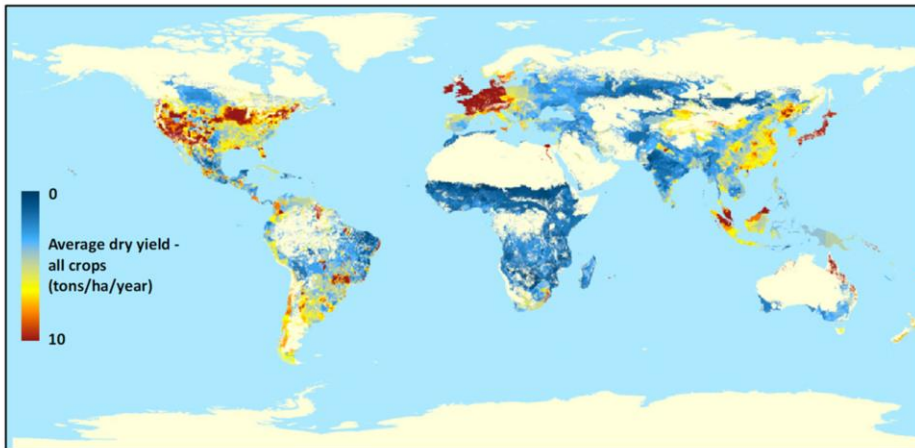
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At \$40/barrel, the Trans Alaska Pipeline (TAPS) moves \$80 MUSD in oil/day – approx. 1-2 million barrels/day.

A supertanker has capacity for 2-3 million barrels of oil and only costs \$120 million new.

Cost is no object when it comes to oil production. Imagine drilling holes in the ground and connecting them to a pipe so that you can make \$80MUSD/day every day for coming on 40 years now ... lots of money.

But if we do want to grow “replacement oil”
the U.S. is pretty well suited ...



West et al. | www.pnas.org/cgi/doi/10.1073/pnas.1011078107



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This is a map of agricultural productivity in the world. A lot of this productivity is related to advanced agricultural practices meant to maximize productivity using lots of water, fertilizer and pesticides. There are many environmental challenges to consider moving forward, but at the moment North America and Europe, the world’s largest consumers of petroleum, are also in possession of the most productive agricultural land in the world. To the extent that we choose to leverage this development for the production of fuels, we certainly have a lot of in-place investment.

However, it is also important to consider the ridiculous food vs. fuel argument. Energy crops are not economic unless they are grown using advanced agricultural practices so that they can achieve the high productivities/yields expected from a commercial crop. This means that regardless of whether it can be eaten or not, it will require water, soil, fertilizer and pesticides – the exact same resources required by food crops. Therefore, it is impossible to grow energy crops that do not compete with food crops and we should stop looking at the situation this way and start thinking about how to optimize both, using the available resources we have.

Timeline Recap

- ▶ 1914-1918 – WWI drives major innovations in engines and oil refining
- ▶ 1939-1945 – (WW2) Haber-Bosch and Fischer-Tropsch change the world
- ▶ 1950's – U.S. moves from municipal gasifiers to natural gas
- ▶ 1970's – Oil crisis leads to fresh round of engine/fuel innovations
- ▶ 1980's – Innovations are mostly put aside because oil is cheap again
- ▶ 1989 – Commercial biodiesel is produced
- ▶ 2012 – Commercial renewable diesel is produced
- ▶ 2013 – Commercial cellulosic ethanol is produced
- ▶ 2014 – U.S. oil/gas productivity skyrockets due to improved recovery techniques (fracking, etc). Need for bioenergy is questioned.

Bioenergy will succeed in markets where it is the better solution, not just because it's different than fossil fuels

Bioenergy has an important role to play in supporting distributed and sustainable energy, but the history shows us we must leverage it's strengths and not compete with oil directly. Bioenergy will succeed in markets where it is the better solution, not just because it's different than fossil fuels.

Next Lecture – Fossil Fuels



(Image: NASA Earth Observatory image by Jesse Allen and Robert Simmon/VIIIRS/Suomi NPP)

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This is a photo of the gas flares from Wyoming and North Dakota at night. It is interesting to consider the scale of this development, especially when compared to the lights of cities across the nation.