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College of Agriculture and Life Sciences

The Future is Now: The Case for an Integrated Biofuels Industry in Southside and Southwest Virginia

Vision

We foresee a network of small, profitable, decentralized biorefineries spread across the forests and fields of Southside and Southwestern Virginia. They will replace two-thirds of the gasoline and more than half the diesel consumed in these 34 counties. *They will revitalize rural economies by creating and investing value in the communities where these advanced biofuels are grown, processed, and burned.* This is a fully sustainable, renewable, and robust system that assures clean low-cost energy for transportation and home heating in the most efficient way possible. It deploys resources against their most preferred use and will enhance the natural and social environments.

Forty-one biorefineries spread across Southside and South-West Virginia would create more than 7,000 direct jobs.

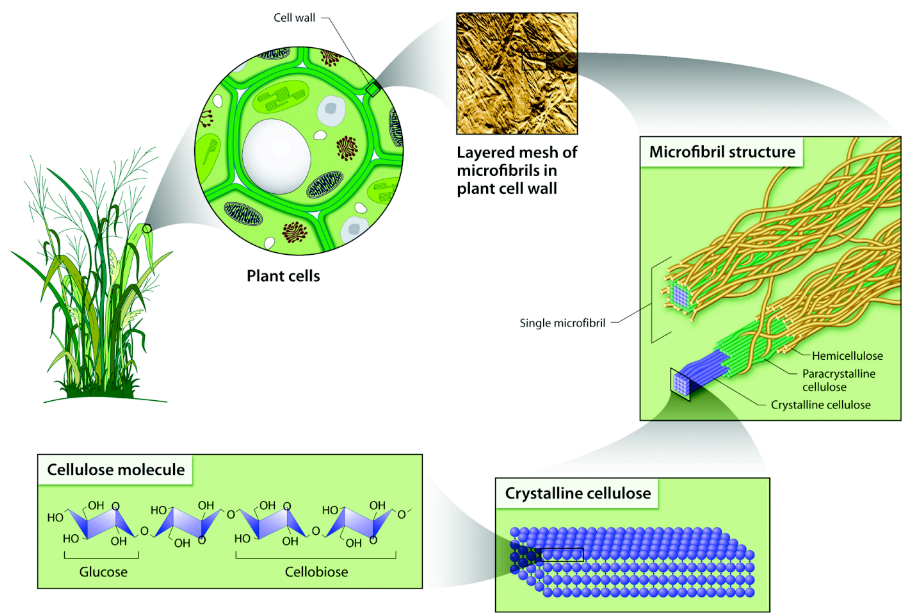
Virginia Tech: A Biofuels Leader

John Fike, of Virginia Tech's Department of Crop, Soil, and Environmental Science, is currently testing optimal switchgrass growing regimes in Virginia and elsewhere in the Southeast. His mentor, Dale Wolf, introduced DOE to switchgrass as a preferred bioenergy crop in 1984.

Virginia Tech's leadership in biofuels development extends back more than two decades. Today, we offer technically and economically superior processes for the manufacture of both cellulosic ethanol and "green diesel," as well as a research base that promises future advances. We possess expertise in biofuels technology and production, logistics, feedstock development and improvement, forestry, public policy, resource economics, and the related fields needed to support the commercialization of an advanced biofuels industry in Virginia and throughout the United States.

Glossary

Cellulosic Ethanol. Ethyl alcohol, or ethanol, is a biofuel that can be produced from *lignocellulose*, a structural material that comprises much of the cell walls of plants and is composed mainly of cellulose, hemicellulose, and lignin. Cellulosic ethanol is chemically identical to ethanol from other sources, such as corn starch or sugar, but has the advantage that the lignocellulose raw material is available from a great quantity and diversity of inexpensive biomass including herbaceous (e.g., switchgrass) and woody (e.g., hardwood) species. The critical issue in its manufacture is separating the cellulose so that it can be broken down into sugar.



The basic problem in making ethanol from cellulose is freeing the fermentable sugars from the other lignocellulose components.

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Glossary

Green Diesel. Green diesel is a biofuel that can be made from any type of biomass containing carbon, hydrogen, and oxygen, including poultry, forestry, and agricultural wastes, and, herbaceous and woody plant species. It can be burned in conventional diesel engines without modification. Green diesel is to be distinguished from *biodiesel*, which can be made only from plant oils, such as soybean or canola or from animal or waste fats from restaurant operations. While our green diesel process yields valuable co-products, biodiesel produces expensive to dispose of waste.

Bench-scale green diesel set-up in the Virginia Tech lab of Dr. Foster Agblevor.

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Why an Integrated Biofuels Industry?

Saab E100 Hybrid

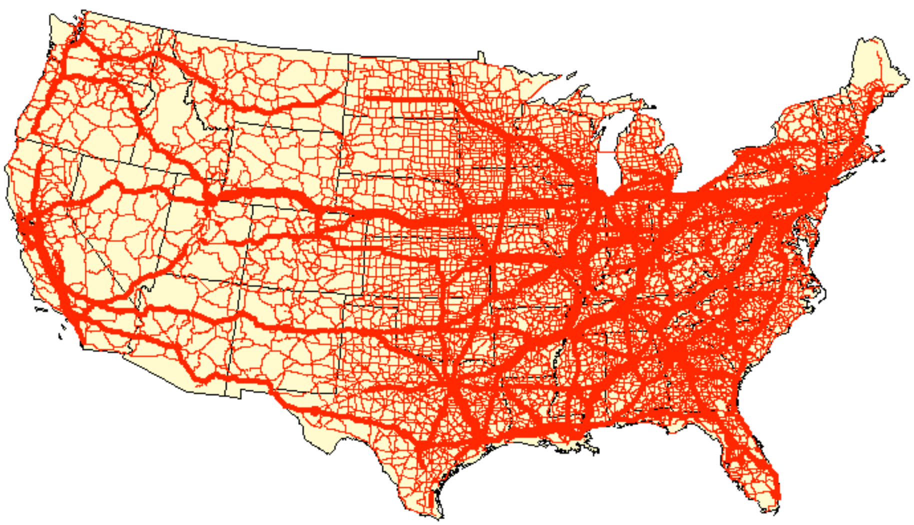
Because if you want to drive one of these. . .

Why an Integrated Biofuels Industry?

. . .someone had better be driving one of these! Motor fuel (and other) trucks burn diesel, not ethanol!

Why an Integrated Biofuels Industry?

The U.S. consumes not only 140 billion gallons of gasoline per year, but also 64 billion gallons of diesel fuel. The interstate trucks and the railroads upon which the economy depends use diesel exclusively. Diesel powers these systems and other types of heavy equipment because of its greater efficiency per ton-mile than gasoline. Major manufacturers including Mercedes and GM are developing diesel hybrids that can achieve 50 MPG and use clean, green diesel without modification.



U.S. Truck Freight Flows, All Commodities, Highway Freight Density in Tons. USDOT, FHWA, 2002.

Mercedes diesel hybrid SUV Vision GL 420 BLUETEC will go on sale in the U.S. in 2008.

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Why an Integrated Biofuels Industry?

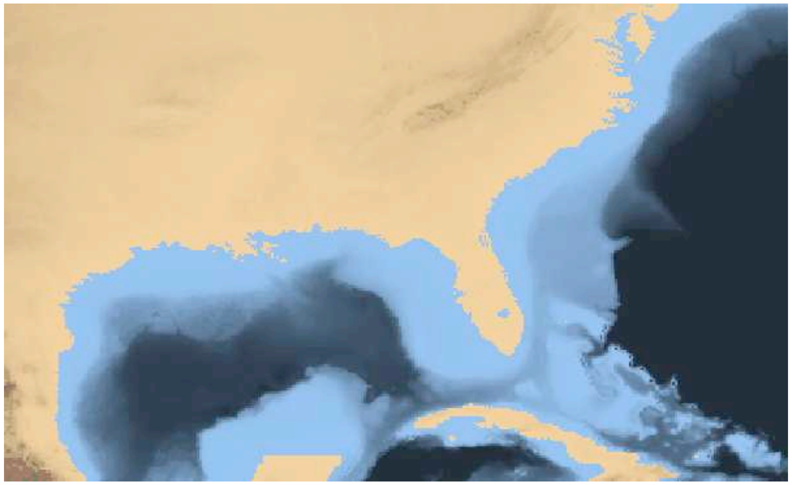
Each year, the forests of the 34 counties of Southside and Southwest Virginia generate more than 7.1 million dry tons of net new growth and residues from merchant logging operations. This is enough wood to replace some 65% of the gasoline and more than 50% of the diesel fuel consumed in those counties, without competing with other uses. By allocating resources efficiently we can build a regional system that is truly energy independent, which can serve to revitalize the regional economy, and which could serve residents with a reliable supply of liquid fuels at prices at least 25% below current levels.

Why the Push for Cellulosics and Other Biomass-Based Fuels?

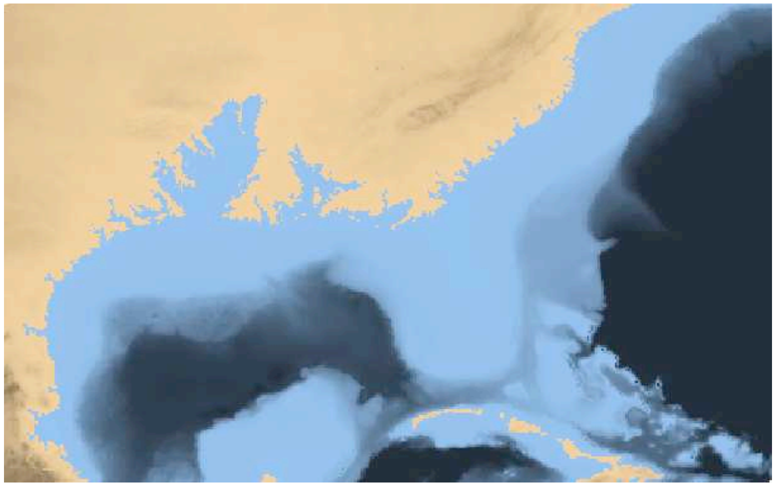
On December 19, the Energy Independence and Security Act of 2007 was signed into law. This comprehensive energy legislation amended the Renewable Fuels Standard (RFS) of 2005 and mandates the production of 9 billion gallons of renewable fuels in 2008, rising to 36 billion gallons by 2022. Of that 36 billion, at least 21 billion gallons must be cellulosic or biomass-based renewable fuels that reduce greenhouse gas (GHG) emissions by at least 50% compared to baseline lifecycle GHG emissions.

A broad bipartisan coalition of Congressional leaders looked on as President Bush signed the 2007 Energy Independence Act.

Why the Push for Cellulosics and Other Biomass-Based Fuels?



Coastline of the Southeastern United States, circa 2008.



Coastline of the Southeastern United States, following a 75-meter rise in sea level.

Atmospheric CO_2 levels stood at 280 ppm prior to the Industrial Revolution. Today, they have risen to 380 ppm, this up from 315 ppm just 50 years ago, a rate of increase of about 2 ppm per year. At 450 ppm, the scientific consensus is that there would be a great risk of the Greenland and Western Antarctic icecaps melting over many centuries, causing a rise in sea levels of 75 meters. At 2 ppm per year, 450 ppm is just 35 years away.

Why the Push for Cellulosics and Other Biomass-Based Fuels?

Twenty percent of the world's oil supply must pass through the Straits of Hormuz, which divide Saudi Arabia and the Gulf States from Iran. At their narrowest, the Straits are just 21 miles wide. Any disruption of the oil supply coming through the Straits would have grave consequences for U.S. national security, and would likely require the full commitment of U.S. military assets. Today, some 60% of America's oil is imported, a proportion that is likely to grow if current demand trends continue. Oil price shocks and price manipulation by OPEC have cost our economy dearly – about $7 trillion from 1979 to 2000.

The Straits of Hormuz, a major chokepoint in America's oil lifeline to the Middle East. Iran is at the top of the photograph.

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Why the Push for Cellulosics and Other Biomass-Based Fuels? The Advantages of Cellulosic Ethanol

Cheaper Energy than from Corn-Derived Ethanol or Petroleum. Per unit of energy, cellulosic feedstock costs about 84% less than petroleum, and 50 to 67% less than energy derived from corn.

Cellulosic Feedstocks are Plentiful and Widely Dispersed. USDOE reports 1.3 billion tons of cellulosic biomass per year in the U.S., enough – using our process – to replace up to 50% of annual gasoline consumption.

Corn Can't Do the Job. Even if we used every kernel of corn grown in the U.S., we could replace only 12% of the Nation's annual gasoline consumption.

A Much Better Environmental Profile. 86% lower GHG emissions versus gasoline, as compared to corn-based ethanol's 18% to 29% reduction, and vastly reduced fertilizer and herbicide inputs.

Why the Push for Cellulosics and Other Biomass-Based Fuels? The Advantages of Green Diesel

Biodiesel Can't Do the Job Alone. There is not enough of it (250 million gallons in 2006) to meet U.S. demand, and it is too expensive. At current and projected near-term feedstock prices, B100 must sell for > $4.01 per gallon wholesale, and $4.50 – $5.00 retail. We estimate the production cost of green diesel at < $1.50 per gallon.

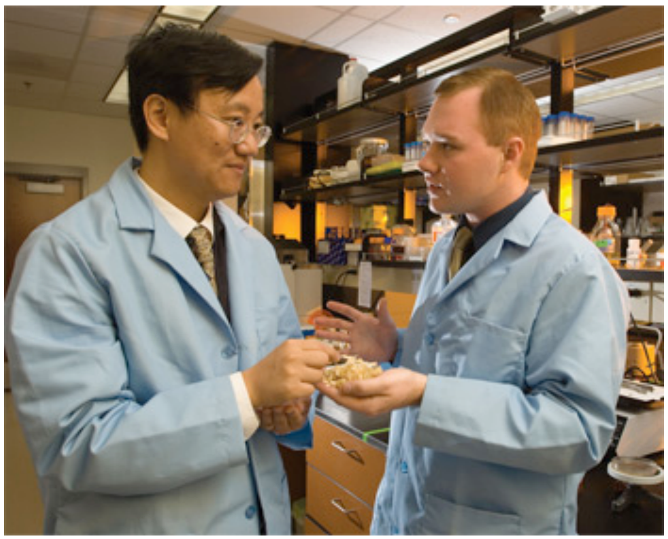
A Much Better Environmental Profile than Either Petroleum-Based or Biodiesel. Green diesel produces 61% lower particulate emissions than petroleum diesel, and no emissions of carbon (net), sulfur, or aromatics. Compared to petroleum diesel or biodiesel, green diesel is more energy dense, containing, respectively, 10% and 20% more BTUs.

Green Diesel Will Not Compete with Feedstock Demand for Cellulosic Ethanol Production. Softwoods – and wastes such as chicken litter, paper mill, forestry, and cotton gin refuse – are optimal for green diesel production, but not, using our process, for cellulosic ethanol.

The Six DOE Funded Demonstration Projects

Abengoa Bioenergy	KS	\$76 MM 11.4MGY	Pyrolysis → gasification → Diesel Thermochemical hydrolysis → LSS → Enzymatic hydrolysis → Fermentation → EtOH
ALICO	FL	\$33 MM 13.9 MGY	Thermochemical → Syngas → Fermentation → EtOH
BlueFire Ethanol	CA	\$40 MM 19.0 MGY	Concentrated H_2SO_4 → Sugar → Fermentation → EtOH
Broin	IA	\$80 MM 31.3 MGY	Dilute acid → Enzymatic Hydrolysis → Fermentation → EtOH
Iogen	ID	\$80 MM 18.0 MGY	Steam Explosion → Enzymatic Hydrolysis → Fermentation → EtOH
Range Fuels	GA	\$76 MM 40.0 MGY	Gasification → Syngas → EtOH (chemical catalysis)

I. Four Pillars of the Virginia Tech Approach



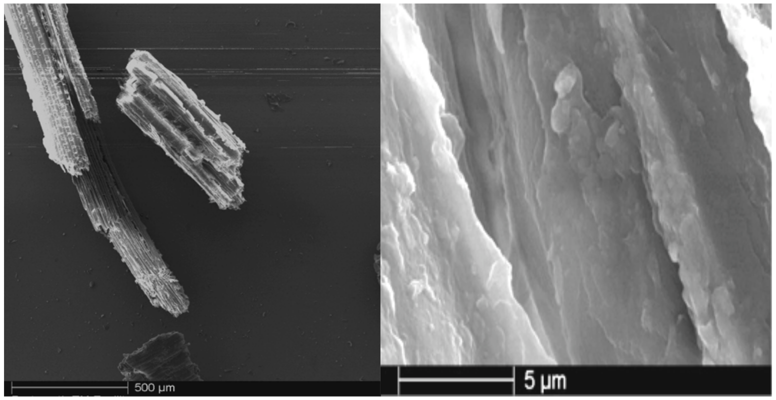
Dr. Percival Zhang consults with graduate student Geoff Moxley during a cellulosic ethanol experiment in his Latham Hall laboratory.

A Superior Process for Manufacturing Cellulosic Ethanol. Our process for refining cellulosic ethanol:

- Is at least 32% more efficient than *any* competing process, and can produce cellulosic ethanol for $1.36 – $1.56 per gallon.
- Uses a novel strategy for pre-treating the cellulosic feedstock to produce maximum ethanol yields.
- Results in both lower initial capital and on-going operating costs.
- Produces valuable co-products that result in biorefinery revenues significantly higher than those for a conventional biorefinery.

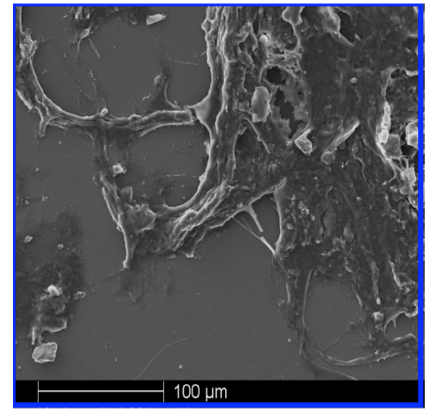
A Visible Difference in Effectiveness

Virginia Tech Pretreatment Method

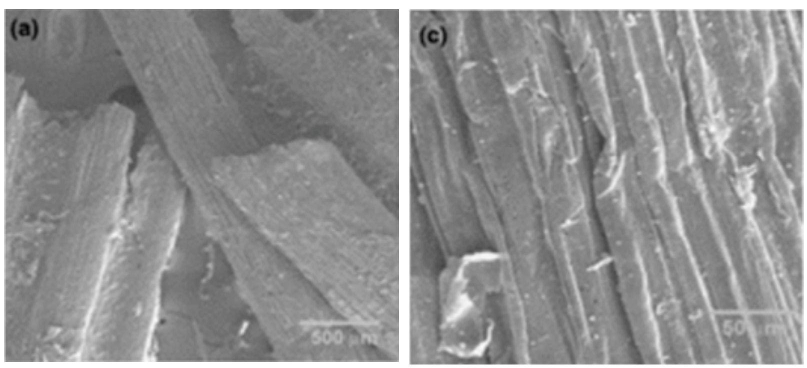


Intact corn stover

50°C,
Atmospheric
pressure

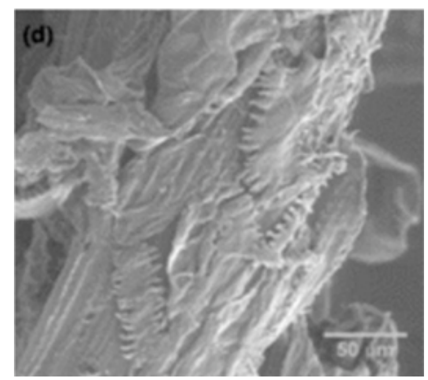


Ammonia Recycle Percolation (Control)



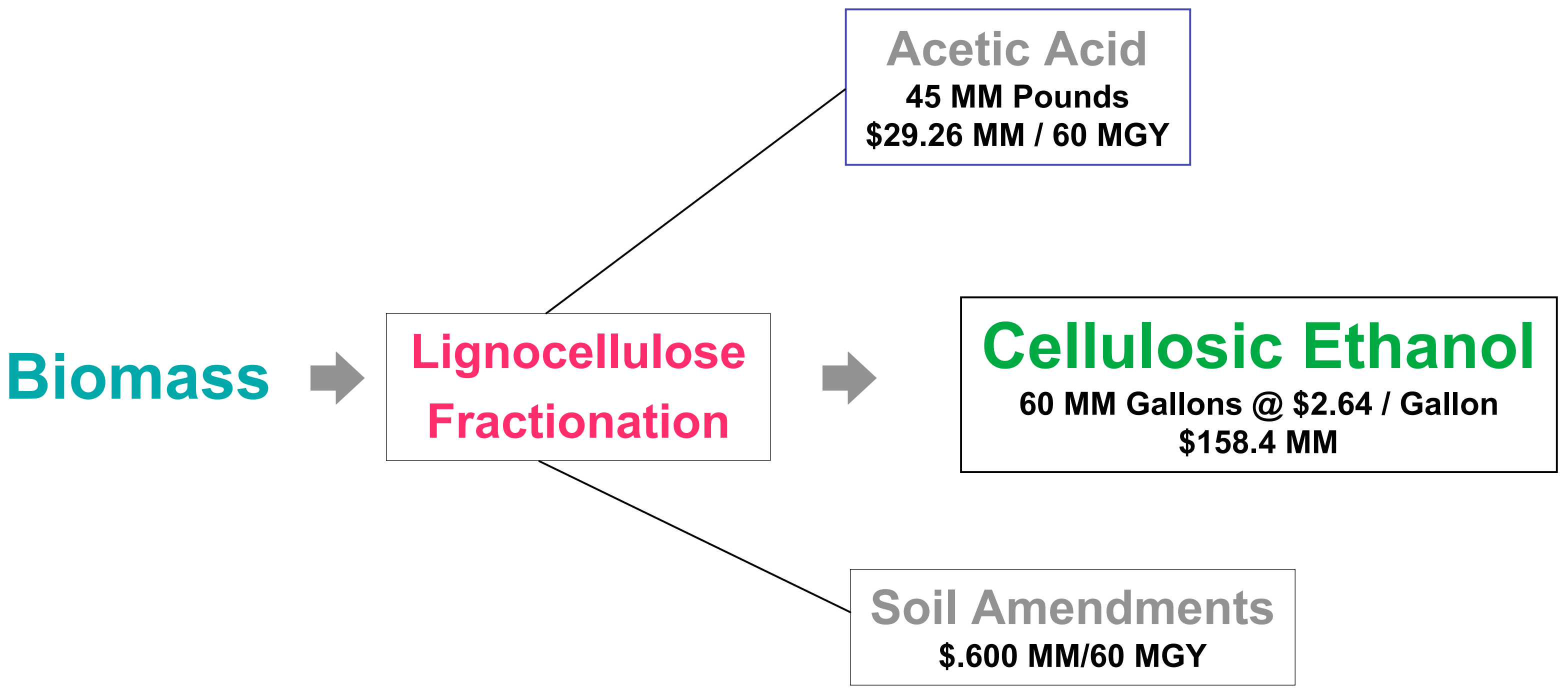
Intact corn stover

170°C, 2.3 MPa
15 wt.% of ammonia,
5 mL/min of flow rate



Kim and Lee. Biores. Technol. 2005, 96, 2005.

New Value-Added Chemical Manufacturing Using Lignocellulose Fractionation Co-Products



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Costs of Production for Cellulosic Ethanol Using Lignocellulose Fractionation Process

Cost Component	Cost per Gallon
Feedstock @ $40 per dry ton	$0.44[1]
Pretreatment	$0.30 – 0.45
Enzyme	$0.10
Fermentation	$0.15
Distillation	$0.20
Capital Depreciation	$0.45 – 0.50
Subtotal	$1.64 – 1.84
Credits (Co-products)	-$0.28[2]
Net Cost per Gallon	**$1.36 – 1.56**

[1] Assumes 90 gallon EtOH yield per dry ton of feedstock.

[2] Credits for co-products include $0.26 per gallon of EtOH for acetic acid, $0.01 per gallon for electricity, and $0.01 per gallon for ash.

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Dare to Compare

Steam Explosion (Iogen)

Special H-P&T reactors
Hemicellulose loss
Low cellulose digestibility
Detoxification needed
No co-products
High enzyme loading needed
High steam consumption

Cost ~ $2.20 per U.S. Gallon

Lignocellulose Fractionation

32% more sugars for EToH
100% more revenues from co-products
5-fold reduction in enzyme use
Reduced steam consumption
Reduced capital investment

Cost ~ $1.36 – 1.56 per U.S. Gallon

II. Four Pillars of the Virginia Tech Approach

A Superior Process for Manufacturing Green Diesel.

Our process for refining green diesel:

- Will produce diesel fuel with a higher cetane rating than either petroleum-based or conventional vegetable oil-based biodiesel for < $1.50 per gallon.
- Can use as feedstock soft-woods and wastes that would otherwise impose substantial economic and environmental costs.
- Produces co-products (low molecular weight phenol) that are worth substantially more than the fuel, thus increasing plant revenues and diversifying the revenue stream.

Pyrolysis oil, an intermediate product in the creation of green diesel, produced in Dr. Foster Agblevor's Seitz Hall laboratory.

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New Value-Added Chemical Manufacturing Utilizing Catalytic Pyrolysis Co-Products

Plastics
Insecticides
Adhesives
Carbon Fiber

Biomass → Fractional Catalytic Pyrolysis → Syngas → Green Diesel

Activated Carbon
Carbon Black
Soil Amendments

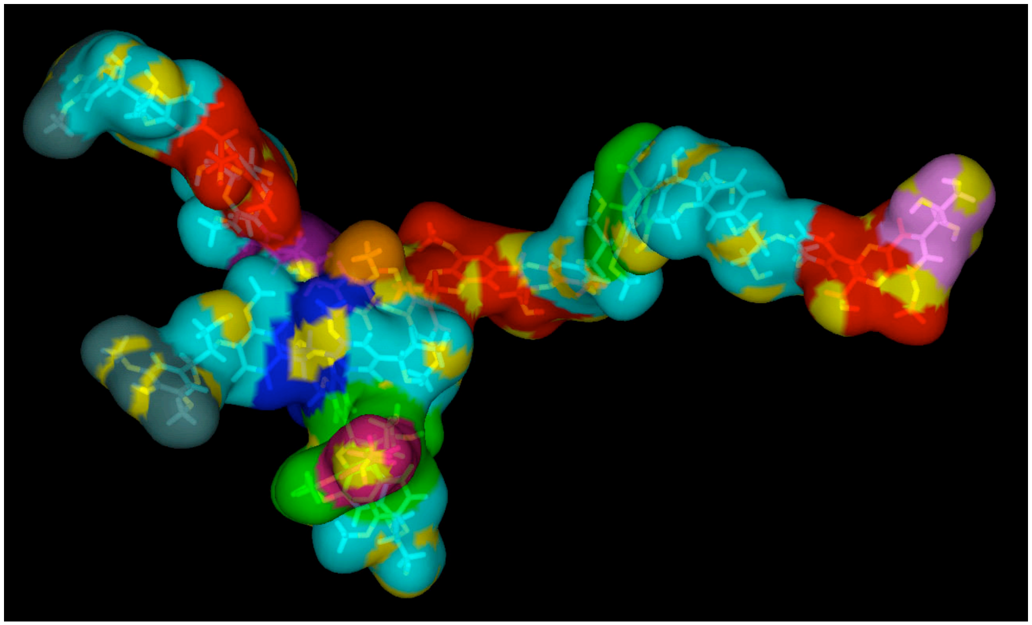
Phenol Co-Product

For 10 MGY Plant, 100 MM Pounds LMW Phenol @ $0.60 / Pound = $60 MM / Year

Green Diesel Fuel

For 10 MGY Plant @ $2.69 / Gallon = $26.9 MM / Year

The Secret: Unlocking Low Molecular Weight Phenol from the Complex Lignin Molecule



NMR characterization of lignins from transgenic poplars with suppressed caffeic acid O-methyltransferase activity. J. Chem. Soc., Perkin Trans. 1: 2939-45.

Lignin contains economically valuable phenols. However, until the advent of Fractional Catalytic Pyrolysis, it was not economically feasible to de-polymerize the lignin into monomers, thus leaving only non-reactive high molecular weight lignins that could only be burned for their energy value. Dr. Foster Agblevor's Fractional Catalytic Pyrolysis process depolymerizes the lignin during pyrolysis, thus yielding about 10 pounds of valuable low molecular weight phenols for every gallon of green diesel produced, an amount worth about twice the fuel itself.

Costs of Production for Green Diesel Using Fractional Catalytic Pyrolysis

Cost Component	Cost per Gallon
Feedstock @ $40 per dry ton[1]	$1.00
Grinding	$0.64
Pyrolysis	$0.10
Fischer-Tropsch Conversion	$0.10
Capital Depreciation[2]	$0.60
Subtotal	$2.44
Credits (LMW Phenol at $0.60/lb.)	-$6.00
Net Cost per Gallon	**-$3.56**

[1] Assumes 40 gallon green diesel yield per dry ton of feedstock.

[2] Capital cost is $120 million for a plant producing 10 MGY, with a useful life of 20 years. Thus, $120MM/20 years = $6MM/year. $6MM/10MGY = $0.60/gallon.

Comparison of Liquid Fuel Prices

By comparison with our production costs of < $1.50 for green diesel and $1.36 – $1.56 for cellulosic ethanol, as of April 8, 2008 average prices (per gallon) in the United States for liquid fuels were as follows:

Heating Oil (retail)	$3.85
Grain Ethanol (wholesale)	$2.64
Gasoline (retail)	$3.32
Diesel (retail)	$3.97
B100 (retail)	$4.50 – $5.00

III. Four Pillars of the Virginia Tech Approach

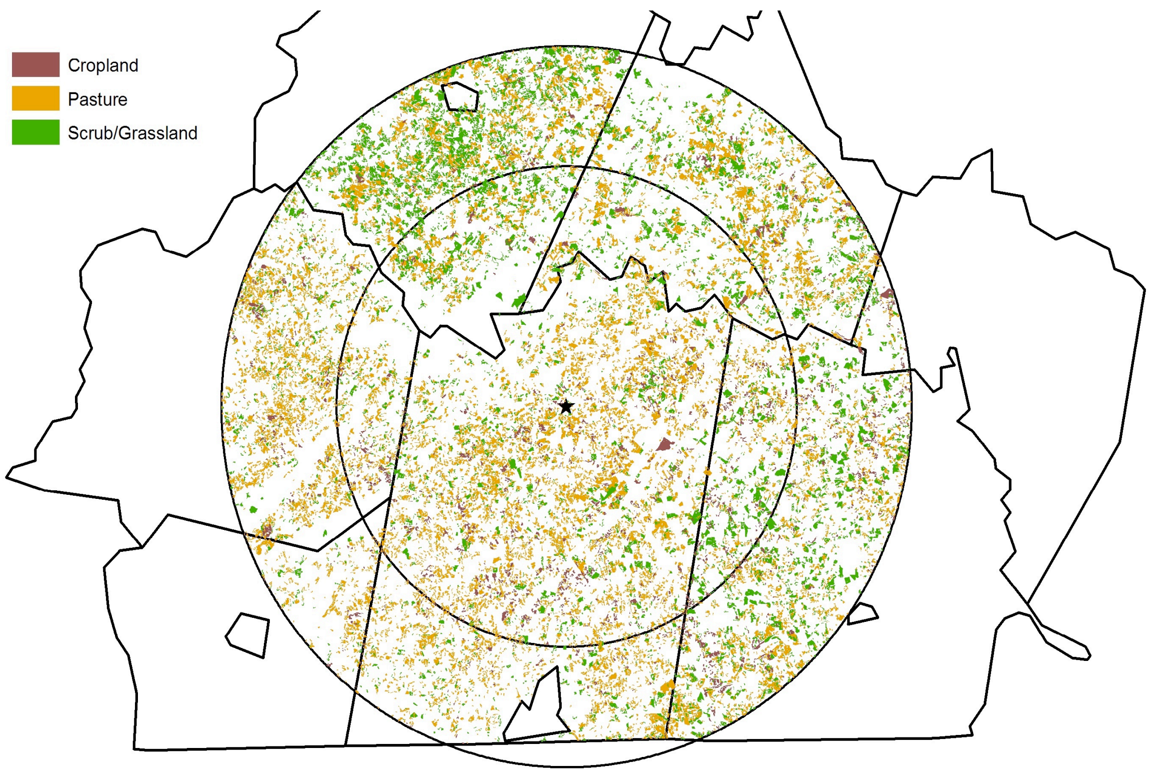
A Keen Understanding of the Economics of Feedstock Supply and Logistics. A reliable feedstock supply can amount to a third—or more—of the total cost of fuel production; transportation can easily account for half of that.

Mechanical grappling systems reduce loading labor costs by 50% and truck load time, thus increasing loads hauled per day, and decreasing feedstock costs.

- Foresters and biological systems engineers at Virginia Tech have developed innovative systems for moving large amounts of both woody and herbaceous feedstocks from forest or field to the biorefinery.
- Our expertise includes integrated truck and rail systems, and feedstock harvesting, handling, hauling, unloading, storage and pre-processing system optimization.

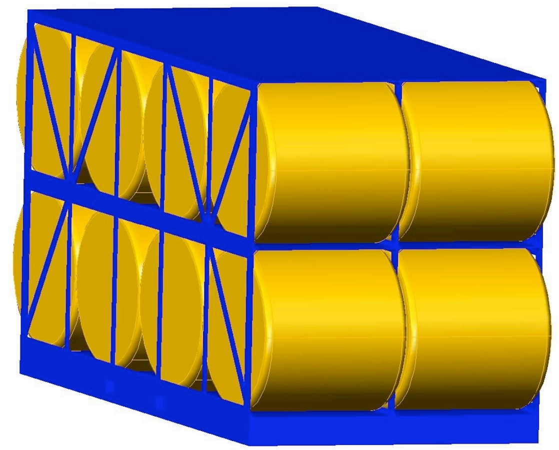
Locating and Planning Feedstock Systems

We have developed a unique GIS-based system for identifying – down to the level of the individual field – agricultural land suitable for growing switchgrass and other herbaceous feedstocks within a given radius of any proposed biorefinery location. The map reveals types of lands within 20- and 30-mile radii of Gretna, Virginia, a site proposed for the development of a cellulosic ethanol refinery in Pittsylvania County, the heart of Virginia's Southside region. This tool is indispensable to investors and economic developers alike.

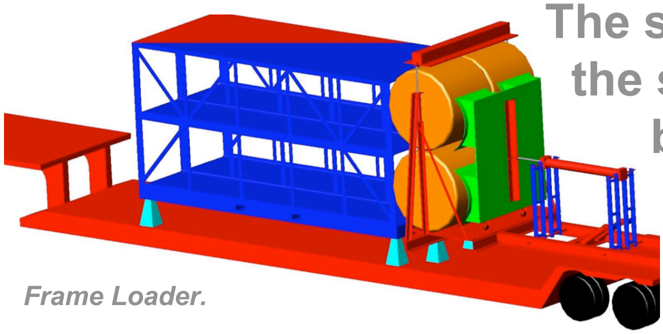


A Mechanical System for Moving Switchgrass

We have designed a mechanical system that integrates four new machines to produce the only cost-efficient means of moving large amounts of switchgrass from the field to the biorefinery. This system permits us to achieve the most efficient trucking utilization possible, by reducing truck load time to < 20 minutes for ~ 12 tons, and unload time at the bio-refinery to < 10 minutes.



Shipping Frame.

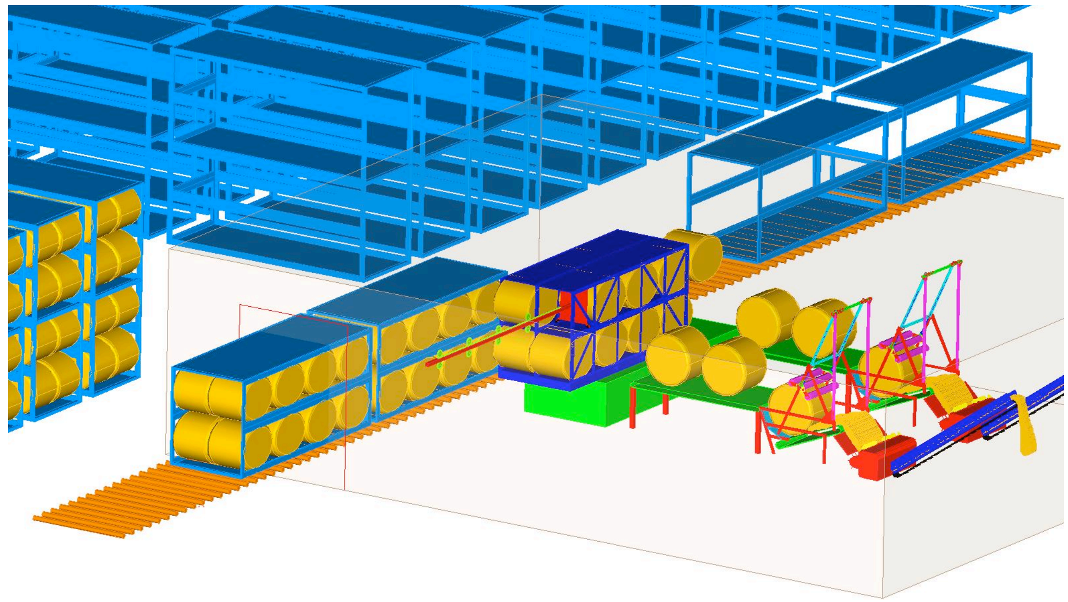


Frame Loader.

The system is based on the standard 5-ft. round bale found throughout the Southeast, and a frame that emulates the dimensions of a 20-ft. ISO container. In this system the farmer places his round bales at the farmgate to be picked up by the trucking operation and using a special grappler, loaded four bales at a time into the shipping frame.

Processing Switchgrass at the Biorefinery

At the biorefinery, these individual bales must be unrolled and the switch-grass chopped into small pieces so that the material will flow on a conveyer belt into the biorefinery, much as do woodchips now at paper mills and wood-burning electricity generation stations. Pictured is a bioenergy plant with full and empty frames in at-plant storage showing two unroller-choppers. This concept emulates the bin system used by sugar mills in South Florida and South Texas and the cotton module system used throughout the Southeastern U.S.. This is one of the advantages of this system--it is based on proven, mature technologies.



Two unroller-choppers moving switchgrass from the frames into the biorefinery.

IV. Four Pillars of the Virginia Tech Approach

Private Partnerships. We have developed robust commercial partnerships to commercialize these technologies. A European firm with an interest in enzymes is evaluating Dr. Percival Zhang's ethanol technology for licensing. An American Fortune 500 firm is similarly pursuing licensing discussions for Dr. Foster Agblevor's green diesel process. Dr. John Cundiff has organized a consortium of firms interested in building and marketing his switchgrass logistics system, led by Amadas Industries of Suffolk, Virginia's largest manufacturer of agricultural equipment.

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Why Virginia?

In the lab, feedstock availability and logistics systems are of no consequence because only grams or perhaps a few kilograms of material are processed at any one time. But in the real world, what matters is the efficiency of the integrated system connecting feedstock supplies to the biorefineries, and the biorefineries to the end-user. With a mild climate, ample supplies of both woody and (potentially) herbaceous species, and its closeness to major East Coast cities, Virginia is the ideal location not only to develop new biofuels technologies, but to build a robust biofuels industry.

On March 31, 2007 Taylor Cole of Augusta County, Virginia harvested the first ton of switchgrass for biofuels development in the Commonwealth. Virginia Tech, which introduced switchgrass to the bioenergy world in 1984, was there.

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Virginia: A Sweet Spot on the Bioenergy Map

Our Mild Climate Enables Virginia to Produce Two Kinds of Feedstocks, Not One. Virginia can produce both woody and herbaceous cellulosic stocks. The Corn Belt produces only one – corn stover. Feedstock flexibility lowers costs.

Virginia Can Also Attain Higher Feedstock Yields per Acre Than Can the Corn Belt . The Corn Belt can harvest only 2 tons/acre/year of corn stover. In Virginia we can easily harvest 3 to 6 tons/acre/year for wood, and > 5 tons/acre/year for switchgrass. In the economics of biomass, <u>density</u> <u>is</u> <u>destiny</u>.

Virginia's Mild Climate Permits the Harvesting of Feedstock 365 days per Year. In the Corn Belt , the stover harvest is limited to 50 days. In that region, each 100 MGY refinery will require an average of $109 million for <u>indoor</u> feedstock storage, substantially increasing capital costs. In Virginia, both woody and herbaceous feedstocks may be stored "on the stump" until needed.

What They Are Saying in the Corn Belt

"Economic, technological, and environmental obstacles stand in the way of Iowa producing as much ethanol from crop waste and other biomass as it does from corn grain. Harvesting, trucking and storing the huge amounts of crop waste will be expensive and might require more taxpayer subsidies. ***Other states with cheaper land and longer growing seasons may be better suited to growing trees and grasses that could be converted to ethanol."***

The Des Moines Register, March 18, 2007

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Our View of Virginia's Permanent Competitive Advantage Over the Corn Belt

- **Immutable differences in geography, climate, and feedstock diversity give Virginia a permanent competitive advantage** in economically efficient production of cellulosic feedstocks.

- **The business implications of these differences are enormous.** For *one* typical 100 MGY cellulosic ethanol plant, these include:

Storage Costs	***42 - 81% less,*** or ~ $46 - 88 million less in capital costs.
Hauling Miles	***30% less,*** or likely > $1 million less per year in hauling costs.
Fertilizer Costs	***87% less***, or ~ $9.2 million less per year.

Environmental Advantages of the Virginia versus the Corn Belt System

Carbon Sequestration

Virginia Switchgrass	About 0.76 to ≥ 1.00 tons of carbon per acre per year.
Virginia Hardwoods	Up to 1.00 ton per acre per year, or more.
Corn Belt Stover	Probably a net CO_2 emitter, 0 to > 1 tons of carbon per acre per year.

Herbicide Needed to Produce 125,000 Tons of Feedstock

Virginia	5,000 pounds
Corn Belt	120,000 pounds (~67% Atrazine)

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The Bottom Line

There are Untapped Hardwood and Softwood Feedstock Supplies in Southwest and Southside Virginia Sufficient to:

- Produce 411 MGY of cellulosic ethanol, equal to 65% of the Region's annual gasoline consumption.
- Produce at least 102 MGY of green diesel, or about 53% of the Region's annual conventional diesel consumption.

We Can Do This in Southwest and Southside Virginia for a Capital Investment of $4.911 Billion, and Create 9,225 New Jobs. This will require:

- 7 cellulosic ethanol plants at a capital cost of $903 million.
- 34 green diesel plants at a capital cost of $4.08 billion.
- These 41 biorefineries will create 7,185 direct jobs, plus 544 agricultural, 680 forestry production, and 816 trucking jobs.

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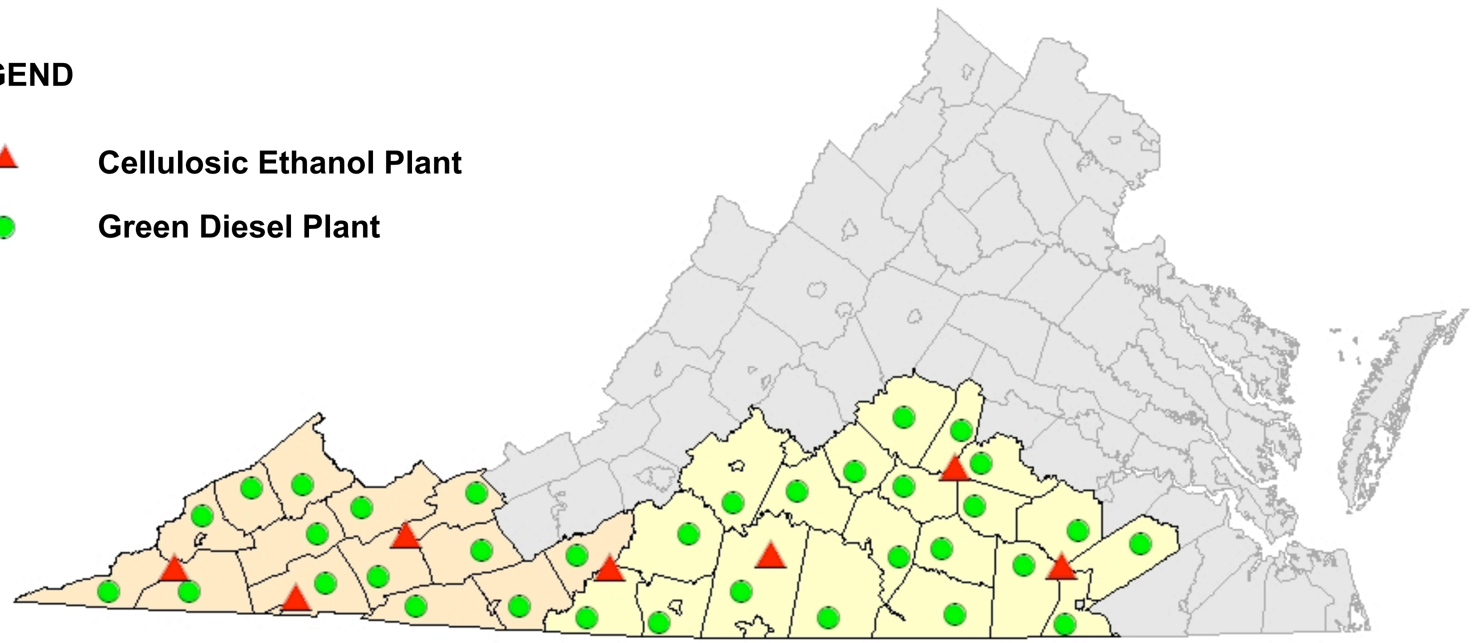
The Future in 2017

LEGEND

▲ Cellulosic Ethanol Plant

● Green Diesel Plant



A minimum of one biorefinery in each of the 34 Southwest and Southside counties, producing > 500 MGY of value-added fuels plus co-products with an annual wholesale value of > $4.0 billion (expressed in 2008 dollars).