Biomass to Biofuels Research at the University of Toledo

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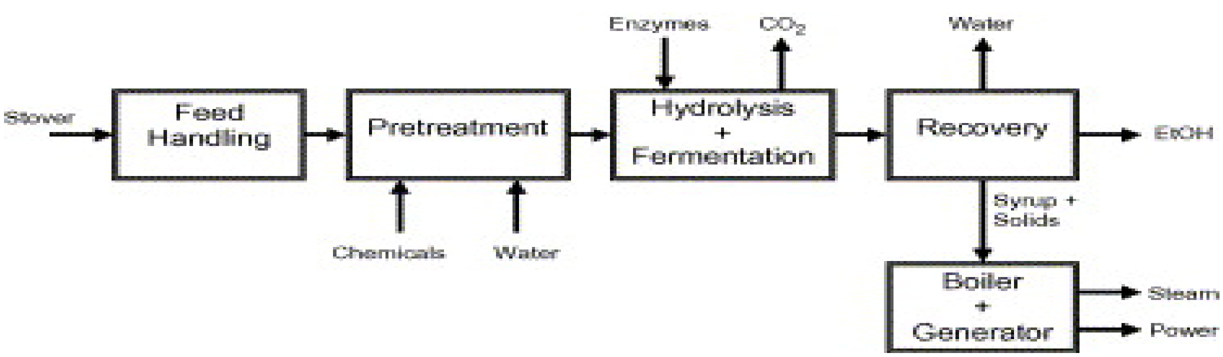
Biomass feedstocks encompass a wide range of sources from corn kernels to corn stalks; prairie grasses, hardwoods, and forest residues; municipal and food waste to soybean, canola oils, animal fats and even algae. These diverse sources of biomass can be converted through *biochemical*, *chemical*, and *thermo-chemical* conversion processes into a diverse mix of 'bio-fuels' and chemicals. Some conversion technologies are well developed (particularly those that use food feedstocks); other technologies require breakthrough development for commercial application, particularly for non-food sources. Sustainable production of bio-fuels from non-food sources are an important part of the solution to the DOE's stated goal of replacing 15% of the nation's transportation fuel needs through renewable fuels by 2017. Researchers at the University of Toledo have developed highly imaginative and effective solutions to address production of bio-fuels from biomass.

Specific Projects, Teams and Qualifications

Ethanol, today's largest volume biofuel, is currently produced through a *biochemical* conversion process of grain crops. In this process, yeasts ferment sugars from starch and sugar crops into ethanol. However, biochemical conversion techniques can make use of sugars found in abundant and sustainable "lignocellulosic" biomass sources such as grasses, trees, and agricultural residues. Producing ethanol economically from biomass has proved to be a highly challenging technical problem due to the complex structure of the biomass (comprised of cellulose, hemicellulose and lignin) and due to the *crystalline* nature of the cellulose fraction.

The figure below is a schematic of a typical process for producing fuel ethanol from biomass.



In the critical *pretreatment* step, the structural integrity of biomass is unraveled to make it amenable to the *hydrolysis* step where the biomass is decomposed into sugars by enzymes. Pretreatment is a costly step and has a major influence on the economics of both prior (e.g., size reduction) and subsequent (e.g., enzymatic hydrolysis and fermentation) operations in fuel production. We (***Drs. Sasidhar Varanasi, Constance Schall and Jared Anderson***) have developed a *new strategy for pretreatment of lignocellulosic biomass using Ionic Liquids (ILs) to facilitate efficient and rapid enzymatic hydrolysis of cellulose. This technology is patented and licensed. We are working with our industrial partner to develop the technology for commercial implementation through a DOE-SBIR contract.*

Another critical step in lignocellulose conversion to ethanol is fermentation of the mixed sugars present in this feedstock. The glucose recovered from lignocellulose, can be converted readily into ethanol by baker's or brewer's yeast (*Saccharomyces cerevisiae*). However, xylose obtained from the hemi-cellulose fraction is not fermentable by the same yeast. Successfully fermenting xylose increases the bio-fuel production from lignocellulosic biomass by about 40%. While genetically modified microorganisms (GMOs) capable of fermenting both glucose and xylose are being developed, these tend to be fragile and could pose serious regulatory issues. We (***Drs. Sasidhar Varanasi and Patricia Relue***) have developed *a novel strategy* for efficiently fermenting both glucose and xylose using native *Saccharomyces cerevisiae. This technology is also patented and licensed to a company interested in commercial development. We have recently received funding through the Third Frontier Advanced Energy Program of the state of Ohio in support of this technology.*

Biomass pretreatment often produces undesired byproducts (e.g., aliphatic acids) that are detrimental to subsequent enzymatic hydrolysis and fermentation processes. These compounds, notably acetic acid, inhibit enzyme activity and are toxic to microbial growth. ***Dr. Glenn Lipscomb*** is collaborating with scientists at Idaho National Laboratories on the development of a membrane reactor for selective removal of these byproducts from fermentation broths on a DOE funded project.

Finally, ethanol is traditionally recovered from the relatively dilute fermentation broth (about 10% ethanol) by distillation – a separation step that accounts for almost 40 to 50 % of the total energy needed for conversion of biomass to ethanol. The ability to continuously isolate ethanol from the fermentation broth as it is produced, has the potential to improve fermentor efficiency significantly and lower capital equipment costs. *We (**Drs. Glenn Lipscomb and Sasidhar Varanasi**) are developing a pervaporation-membrane-fermentor system that effectively addresses these issues.*

Our present research efforts in biochemical conversion of lignocellulosic biomass into fuels, described above, are focused on further developing (i) pretreatment, (ii) fermentation, and (iii) ethanol recovery strategies to enable successful commercialization of cellulosic ethanol production. *So far we have 5 patents (issued and pending) and more than 12 peer-reviewed publications in this research area.*

We (***Drs. Steve LeBlanc, Sasidhar Varanasi, Abdul-Majed Azad, Dong-shik Kim, and Glenn Lipscomb***) are also developing a *thermochemical* processes for converting *biomass to liquid fuels in collaboration with a Toledo-based company: Red-Lion Bioenergy*. This process involves a patented technology involving pyrolysis of biomass (which thermally decomposes biomass in the absence of air), followed by steam-reformation to produce *hydrogen rich synthesis gas*. *The syngas will be converted to ethanol and higher alcohols using patented rare-earth based novel catalytic formulations. We are seeking funding for this work through the Third Frontier Wright Project program, and the Ohio Coal Development Office.*

Drs. Constance Schall, Tom Bridgeman, Steve Heckathorn, and Sasidhar Varanasi are exploring algae feedstocks as a source of oil for biodiesel production in collaboration with American Biodiesel and the Center for Innovative Food Technology (CIFT). Microalgae grown in aquaculture systems have the potential to offer much higher yields of oil per acre compared to land-grown vegetable oils, and could also be employed for CO_2 capture and reuse. The focus of this work is on (1) culturing algae with high lipid content, (2) developing new and more efficient methods of oil extraction, (3) developing facile catalytic technologies for converting algal oil to jet fuel or diesel, and (4) exploring alcohol production from the biomass residue of the algae, following oil extraction. *This work is funded by CIFT, and a large scale photo bioreactor for harvesting algae was recently purchased* *from the Dutch company ALGAE-LINK and will be maintained by American-Biodiesel in collaboration with the research group*.

Collaborations:

With federal laboratories:

- Dr Connie Schall is collaborating closely with scientists from Los Alamos, Oak Ridge and Argonne National Laboratories on projects related to biomass structure characterization prior to and following IL-pretreatment.
- Drs. Sasidhar Varanasi and Connie Schall are collaborating with the scientists at USDA, Peoria, IL on biomass feed stocks and on various aspects of fermentation.
- Dr. Sasidhar Varanasi is also interacting with an NREL scientist on enzymatic saccharification of pretreated biomass.
- We are also teaming with Dr. Matt Dewitt at Air Force Research Base, Dayton Ohio on issues related to lipid analysis in biodiesel production from algae.
- Dr. Glenn Lipscomb is collaborating with scientists at Idaho National Laboratories

Industrial collaborations:

UT researchers are closely working with the following industry partners on the above projects:

- SuGanit Systems Inc.
- Center for Innovative Food Technologies
- American Biodiesel
- Red Lion Bio Energy
- Novozyme
- Separation Kinetics

Funding: The following agencies funded our work

- Third Frontier Advanced Energy Program (State of Ohio)
- DOE / DOE (SBIR)
- CPBR (Consortium for Plant Biotechnology Research)
- USDA (through sub-contract to CIFT)
- We also have proposals pending with NSF, DOE and CPBR.
- NSF (career award for Dr. Jared Anderson)

IP: Since 2005 the UT team received/filed for 5 patents, with 3 patents licensed to industrial partners.

Potential Collaborations with other universities and agencies in the state

- OARDC-OSU (in conversations with Dr. Steve Slack)
- BGSU
- EMTEC (in conversations with Dr. Le Richardson and Dr. Mike Martin)
- Ohio University, and
- RGP