ERRC

ARS

USDA

Eastern Regional Research Center

Crop Conversion Science & Engineering Research Unit

Kevin Hicks, Research Leader

NP213 BIOENERGY MEETING

11-29-06 TO 12-1-06

BELTSVILLE, MD

SPECIFIC BIOENERGY RESEARCH THRUSTS

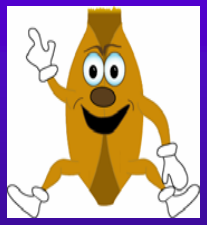
1. **Develop New Processes to Improve the Conversion of Corn to Fuel Ethanol and Valuable Co-Products (Lower the Cost and Energy Requirements)**

2. **Develop Processes to Use Other Feedstocks to Produce Fuel Ethanol Outside the Corn Belt.**
   - **Other Grains, Like Barley, and Biomass**

3. **Develop Thermochemical Processes to Convert Biomass and Crop Residues to Hydrogen and Liquid Fuels.**

CCSE RESEARCH PROGRAM

- 4 Major Research Projects (3 in Bioenergy)
- 15 Senior Scientists, 30 Total Employees
- ~$5 Million Base Funds
- COMMODITIES
  - CORN
  - BARLEY
  - SORGHUM AND OTHER SMALL GRAINS
  - OILSEEDS
  - ENERGY CROPS / PERENNIAL GRASSES
  - CITRUS
  - SUGAR BEET
  - APPLES



CCSE BIOENERGY RESEARCH CAPABILITIES

- **STAFF DISCIPLINES:** Chemistry, Plant Physiology, Biochemistry, Food Science, and Chemical-, Mechanical-, Agricultural-, and Cost Engineering
- **INSTRUMENTATION**: HPLC and LC-MS, GC, GC-MS, PY-GC-MS, HPSEC, HPAEC, MALDI TOF TOF, FT-NIR, Microwave and Automated Extraction Systems, Ankom Fiber Analyzer
- **FACILITIES**: NMR, Imaging, Genomics and Proteomics, Mechanical Design and Fabrication, Bioenergy Pilot Plants with Fermentation, Grain Fractionation, and Pyrolysis/Gasification, see http://www.ars.usda.gov/Main/docs.htm?docid=8694
- **SPECIAL CAPABILITIES**: Process Simulation and Techno-Economic Modeling with ASPEN +® and SuperPro Designer® Software

Current Research Projects and Objectives

CRIS 1935- 41000-069 - *Aqueous/Enzymatic Corn Oil Extraction*
NP 213/306

BOB MOREAU, LS (.6 FTE)
2006 DUTTON AWARDEE AOCS

NICK PARRIS (.5 FTE)
RES CHEM

Support Staff
0.6 FTE M. Powell, GS 9 Biol
0.8 FTE M. Dallmer, GS 9 CET
0.5 FTE J. Minutolo, GS 7 CET
0.5 FTE R. Moten, GS 11 Chem
0.1 FTE J. Kenny

LEE DICKEY (1 FTE)
RES CHEM ENGR

KEVIN HICKS (.05FTE)
RES CHEM

CRIS 1935-41000-069-00D -- *Aqueous Enzymatic Extraction of Corn Oil and Value-Added Products from Corn Germ* R. Moreau, LS, NP 307 and NP 306

- **Objectives:**
  - Develop New Hexane-Free Enzymatic Process to Produce Valuable Corn Oil from Corn Germ, Produced as a Co-Product from Fuel Ethanol Plants.
  - Fully Exploit Value of other Co-Products in Corn Germ by Developing New Protein and Carbohydrate Co-Products.

Aqueous Enzymatic Oil Extraction
Extracting Corn Oil without Hexane!

Corn Kernels

Corn Germ

+ H_2O

Enzymes

*Shear
*Agitation
*Physical
Treatments

corn oil

Corn Proteins for Food and Feed

Poly- and Oligosaccharides for Foods and Fuels

Density and Membrane Separations

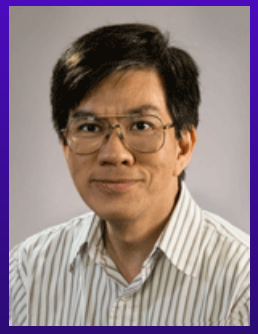
Moreau, R.A., D.B. Johnston, M.J. Powell, and K.B. Hicks, A Comparison of Commercial Enzymes for the Aqueous Enzymatic Extraction of Corn Oil from Corn Germ, J. Am. Oil. Chem. Soc. 81;1071-1075 (2004).

CRIS 1935-41000-070-OOD -- *Enzyme-Based Technologies for Milling Grains and Producing Biobased Products and Fuels, NP 306/213*

DAVID JOHNSTON, LS (.85 FTE)
2006 ROTHBART AWARDEE
2006 PRES. E.C. SCIENTIST

MADHAV YADAV (1 FTE)
RES CHEM

Support Staff
1 FTE J. Thomas, GS 7 Biol
1 FTE A. Wanner, GS 6 BLT
0.5 FTE J. Minutolo, GS 7 CET
0.15 FTE M. Kurantz, GS 12 Chem
0.3 FTE K. Schafer, WG 10 Mech
0.15 FTE W. Yee, GS 11 Chem E
0.25 FTE J. Kenny



JOHN NGHIEM (.85 FTE)
R&D 100 AWARD-CITRIC ACID
RES CHEM ENG

KEVIN HICKS (.1 FTE)
RES CHEM

NICK PARRIS (.5 FTE)
RES CHEM

CRIS 1935-41000-070-OOD -- *Enzyme-Based Technologies for Milling Grains and Producing Biobased Products and Fuels*. D. Johnston, LS, NP 306 and NP 307

- **Objectives:**
  - **Develop New "Green" (Environmentally Sustainable) Enzymatic Corn Wet Milling Processes that Avoid use of Sulfite, Use Less Energy and Reduce Product Costs.**
  - **Develop New Enzymatic Methods for the Dry Grind Ethanol Process that Reduce Cost of Ethanol Produced, Increase Ethanol Net Energy Value, and Increase Value of Co-Products**
  - **Develop Valuable Co-Products**

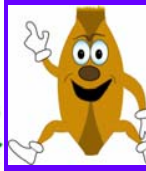
CRIS 1935-41000-072-OOD – *Economic Competitiveness of Renewable Fuels Derived from Grains and Related Biomass,* NP 307

KEVIN HICKS, LS
0.85 FTE

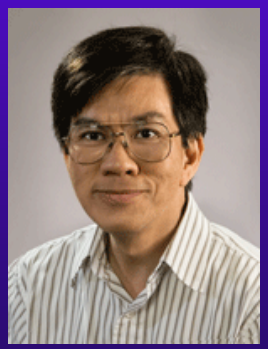
DAVID JOHNSTON
0.15 FTE

AKWASI BOATENG
1.0 FTE

BOB MOREAU
0.4 FTE



FRANK TAYLOR
1.0 FTE

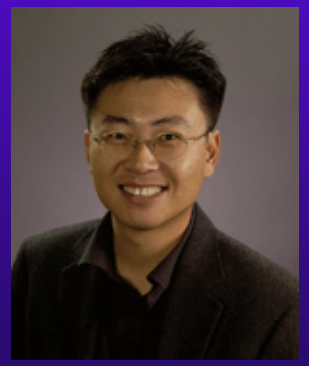


JOHN NGHIEM
0.15FTE

New RA from 2006 Program Increase for "Hydrogen From Biomass"

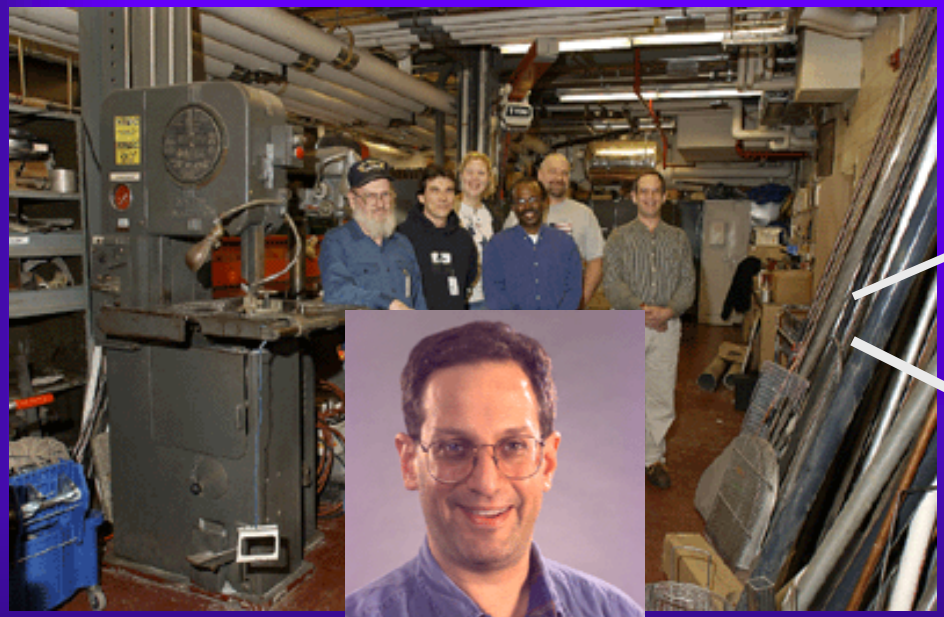
VACANT, NEW
1.0 FTE

VACANT, (FLORES)
1.0 FTE

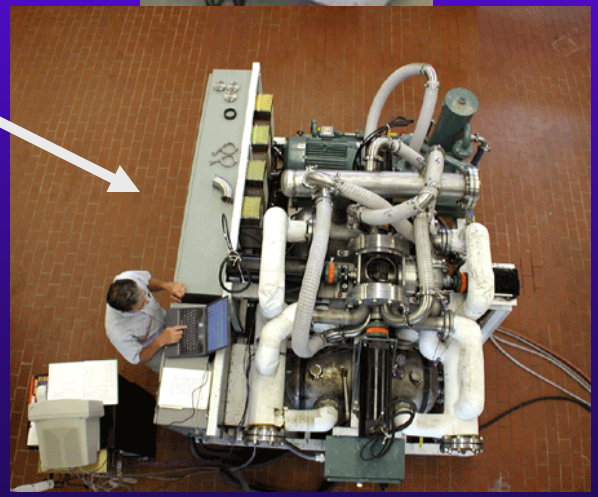


TAE HYUN KIM
RA CHEM ENGR

SUPER SUPPORT:
Equipment Design and Development



NEIL GOLDBERG
MECH ENG



SUPER SUPPORT:
Process and Cost Simulation Models on ASPEN+® and SuperPro Designer® Software

ANDY MCALOON
COST ENGINEER

WINNIE YEE
CHEM ENGINEER

Examples of Models:

Ethanol Dry Milling Models 15, 25, 40 MM gal/yr
- Quick Germ Modification

Corn Wet Milling Model
- Enzymatic Wet Milling Modification

Biodiesel Model
- Alternate Substrates Model

Integration of cellulose to ethanol and starch to ethanol process w/ NREL

CRIS 1935-41000-072-OOD – *Economic Competitiveness of Renewable Fuels Derived from Grains and Related Biomass,* NP 306 & 307

- **Objectives:**
  - **Lower Cost of Fuel Ethanol from Corn by Improved Pre-Treatment, Dry-Fractionation, and Fermentation Techniques**
  - **Develop Processes to Make Hulled and Hulless Barley Viable Fuel Ethanol Feedstocks in Corn-deficit States**
  - **Fractionate Grains into High-Starch Fermentation Feedstocks and Low- "Carb" High-Protein, -Fiber, and Healthy Lipid Food Ingredients**
  - **Develop Thermochemical Processes to Convert Low-valued Grain Fractions, Agr. Residues, and Energy Crops into Hydrogen and Related Liquid Fuels and Integrate this Technology with Dry-Grind Ethanol Plants**

Recent Accomplishments

- Pre-Treatment of Feedstock
  - Aqueous Ammonia Pretreatment for Biomass
  - Anhydrous Ammonia Continuous Pretreatment for Grain
- Enzymes
  - Discovery of key β-glucosidase and β-glucanase enzymes that enhance production of ethanol from barley
  - Discovery of key enzymes to replace sulfites in wet milling
  - Assisted in the development of commercial granular starch hydrolyzing enzymes

Recent Accomplishments

- Co-Products – Corn Fiber Biorefinery
  - Discovery, evaluation, and patenting of corn fiber oil as a nutraceutical and food ingredient
  - Development and patenting of process to produce corn fiber gum (arabinoxylan) as a food additive and industrial chemical

ERRC/ARS/USDA Corn Fiber Biorefinery

A Process that Makes Valuable Products from Grain Byproducts

Corn Fiber

Aleurone Cells

Solvent Extraction

Defatted Corn Fiber

A.H.P. Extraction

Saccharification/Fermentation

?

?

?

Cellulose/ Arabino-Xylan (CAX)

Corn Fiber Gum (CFG)

L-Arabinose

EtOH

Corn Fiber Oil (CFO)

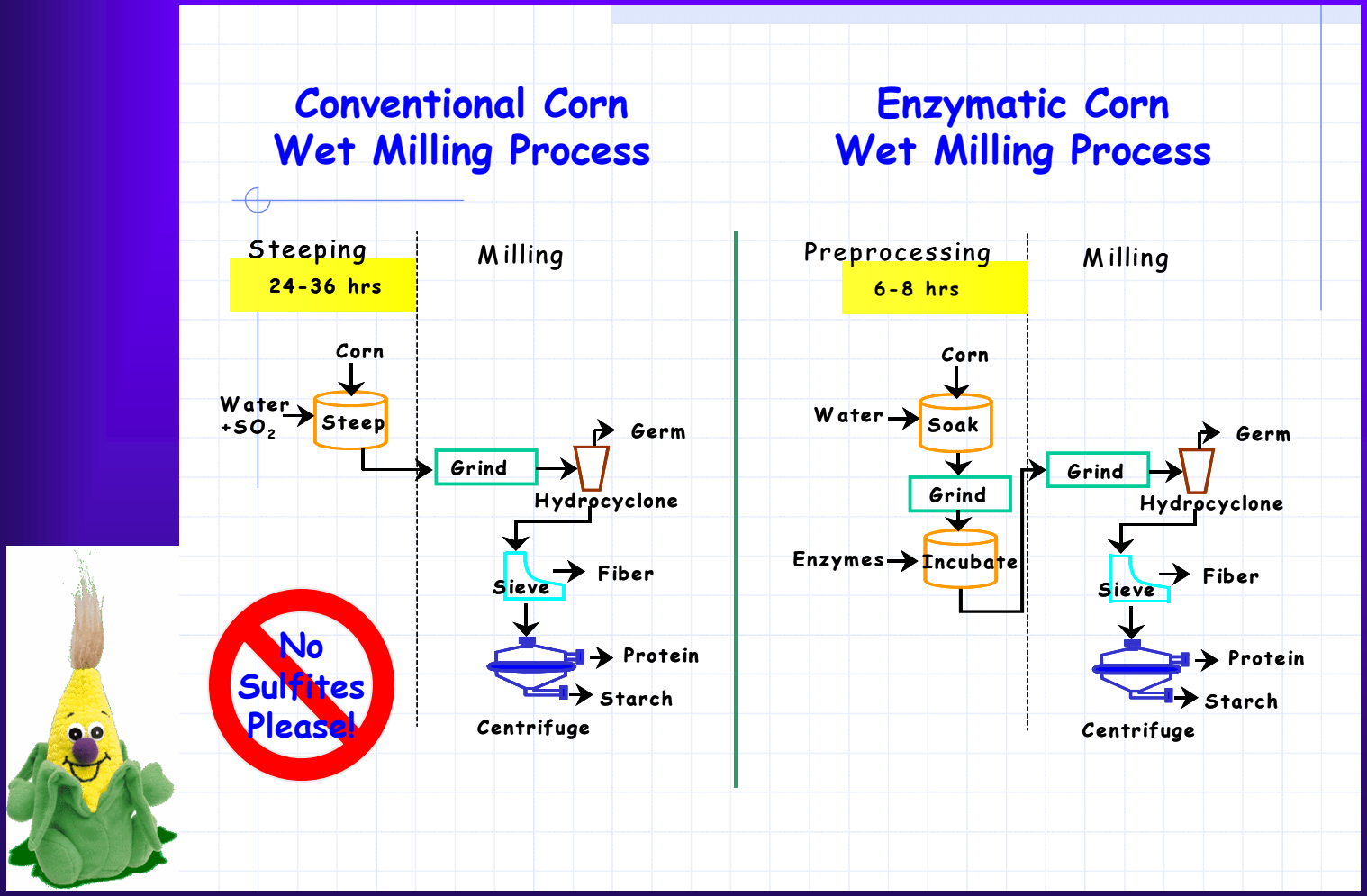
Polyamine Conjugates (DFP, CFP)

Recent Accomplishments

- New Biochemical Conversion Processes
  - New patented enzymatic wet milling process
  - New patented E-milling corn pre-fractionation and fuel ethanol process

Enzymatic Corn Wet Milling

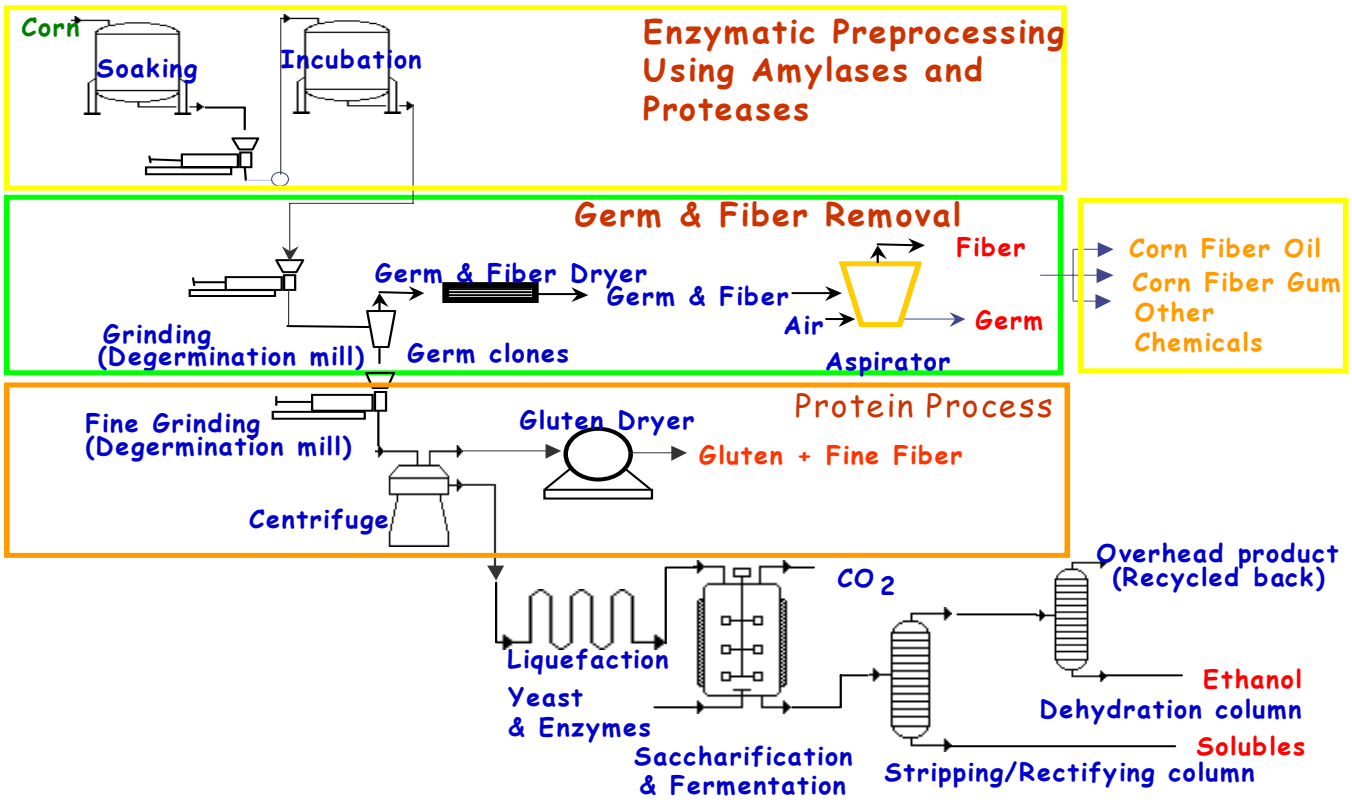
Johnston et al., U.S. Pat. 6,566,125, (2003) now being licensed by major enzyme company.



This revolutionary new process dramatically decreases steeping time (an energy intensive step) and decreases time and chemicals needed for corn wet milling. It was successfully demonstrated at a corn wet milling plant in Asia in 8/2005. The process has higher yields of products, will save significant energy, and prevent pollution for the industry

Enzymatic (E-Mill) Ethanol Process

Johnston, et al., U.S. Pat. 6,899,910, May 31 2005



This new process uses protease enzymes and “wet prefractionation” to make fuel ethanol more efficiently. More ethanol will be produced by smaller ethanol plants, and more valuable DDGS is produced. The result will be cheaper ethanol and more valuable coproducts.

Recent Accomplishments

- New Thermochemical (TC) Equipment and Conversion Processes
  - Determined TC conversion potential for several ARS bioenergy crops and crop residues
  - Built and Tested First ARS Pilot Scale Pyrolysis System (Kwasinator)

Pyrolysis GC MS System

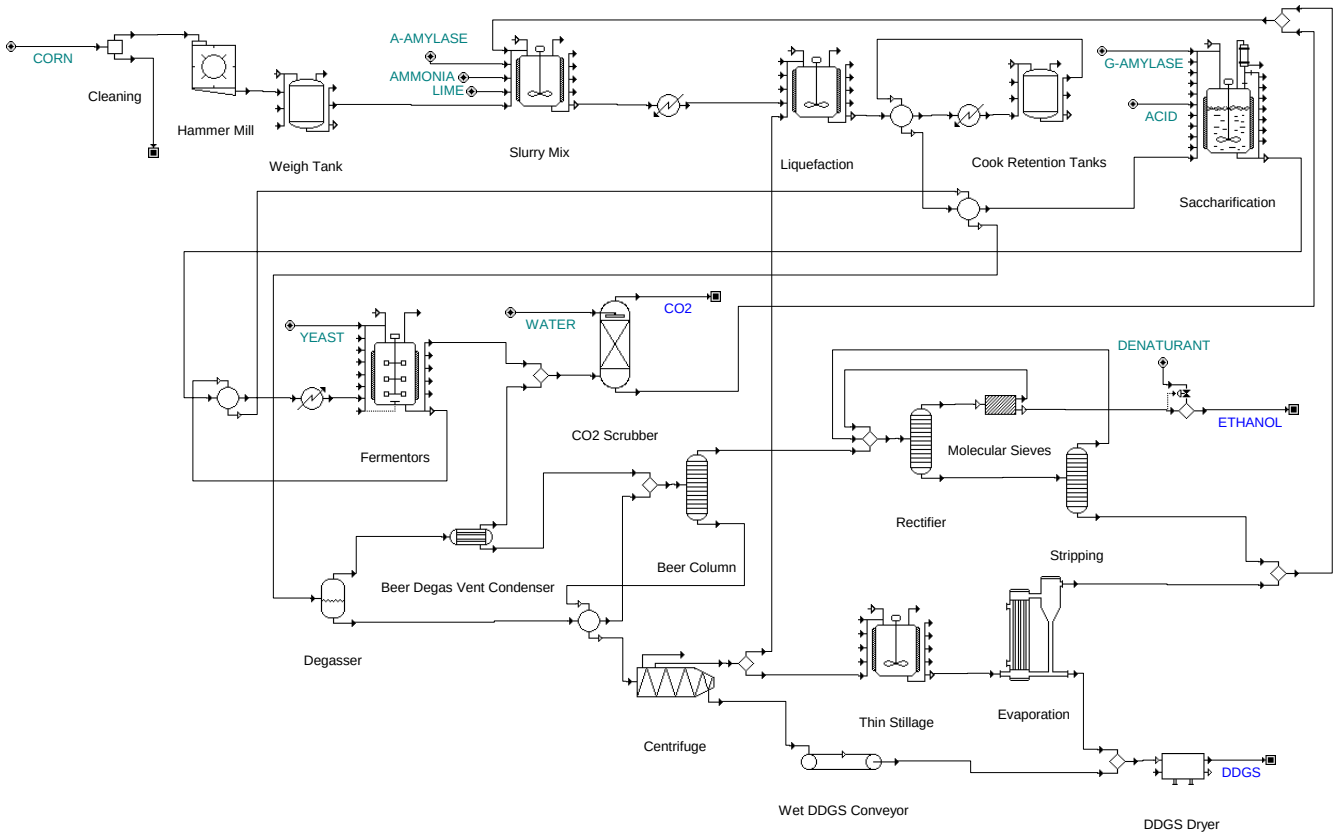
ERRC's 3" Fluidized Bed Pilot Pyrolysis Unit

Bio Oil (Pyrolytic Oil)

Recent Accomplishments

- Techno-economic Modeling
  - Detailed models for dry grind ethanol, corn wet milling, and biodiesel production available in ASPEN plus®, SuperPro Designer®, and Microsoft Excel®.
  - Co-located corn and corn stover ethanol plant and integration of facilities (w/ NREL)

Dry-Grind Ethanol from Corn Process Model



Kwiatkowski, et al., Industrial Crops and Products 23 (2006) 288-296.

ACTIVITIES PLANNED FOR NEXT 2-3 YEARS

FINISH MILESTONES!

FUTURE ACTIVITIES AND COLLABORATORS FOR CRIS-069, MOREAU

- Planned Activities:
  - Continue to improve AEE Process
  - Engineer a Pilot Scale Process
  - Develop Protein Co-products
  - Utilize Carbohydrate Residues for Ethanol Production
- Collaborators (Outside ERRC):
  - Phil Shane, ICMB, CRADA Partner
  - Germ Suppliers – Bunge, ADM, Broin, GrainValue,
  - Enzyme Suppliers – Novozymes, Genencor
  - Larry Johnson, Vijay Singh

FUTURE ACTIVITIES AND COLLABORATORS FOR CRIS-070, JOHNSTON

- Planned Activities:
  - Complete Commercialization of Enzymatic Wet Milling
  - Demonstrate E-Mill Ethanol Process at Larger Scale
  - Develop CoFermentation Process for Ethanol and High Value Feed Products
  - Initiate Research on CoFermentation Processes to Utilize (Sequester) CO_2 Produced During Fermentation
  - Develop High Valued Polysaccharide CoProducts
- Collaborators (Outside ERRC):
  - Vijay Singh, U of IL
  - Genencor
  - National Starch and Chemical Company
  - Corn Refiners' Association

FUTURE ACTIVITIES AND COLLABORATORS FOR CRIS-072, Hicks

- Planned Activities:
  - Develop Continuous Fermentation and Product Recovery Processes for Fuel Ethanol
  - Determine Economics of Dry PreFractionation Processes for Dry Grind Ethanol
  - Develop First FT-NIR Analysis Method for Barley
  - Complete Analysis of New Hulless Barley Lines for Fuel Ethanol
  - Continue Development of 1st and 2nd Generation Processes for Converting Hulled and Hulless Barley to Ethanol to Support Ethanol Production outside the Corn Belt
  - Complete Comparison of the Mass and Energy Balances for Converting Biomass to Liquid Fuels for Biochemical versus Thermochemical Methods. Which is better for what feedstock.
  - Continue to Develop Thermochemical Processes to Convert Energy Crops and Crop Residues to Liquid Fuels and Hydrogen.

FUTURE ACTIVITIES AND COLLABORATORS FOR CRIS-072, Hicks

- COLLABORATORS
  - ADM (CRADA)
  - Genencor (CRADA)
  - D. Himmelsbach/W.Barton, ARS, Athens
  - Rolando Flores, University of Nebraska, Lincoln
  - Carl Griffey and Winse Brooks, Virginia Polytechnic Institute and State University (Virginia Tech)
  - Robert Brown, Iowa State University
  - ARS Corvallis, Gary Banowetz, et al.
  - ThermalNet Consortium, EU
  - Monona Farms, PA