CENTER FOR
SUSTAINABLE ENERGY
KANSAS STATE UNIVERSITY

Kansas State University Research being conducted on energy and water

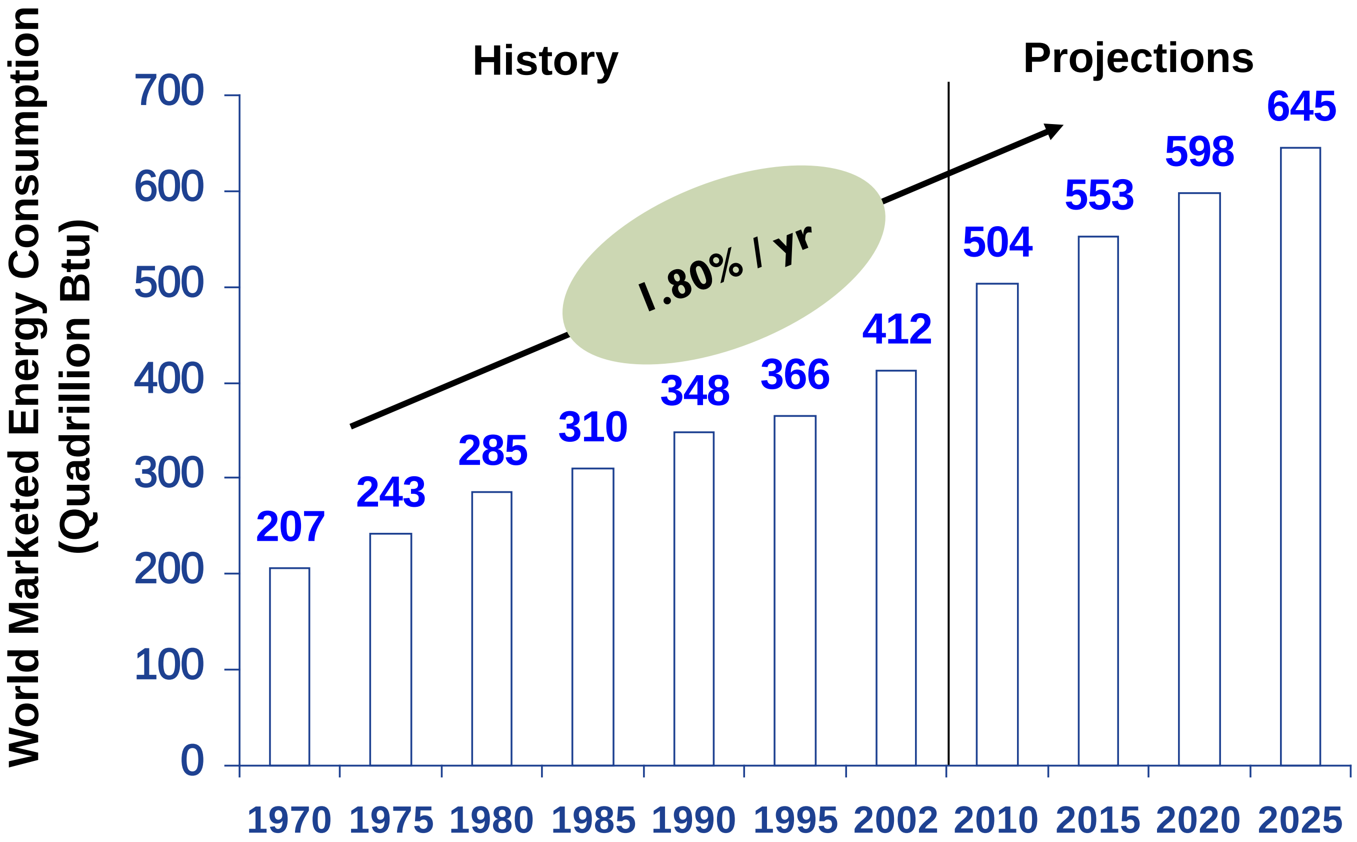
September 9, 2011

Professor Mary Rezac
co-Director, Center for Sustainable Energy
Kansas State University

K-State Research related to:

- Energy
  - BioEnergy
  - Wind
  - Solar
  - Natural Gas
- Water
  - Aquifer Management
  - Drought Tolerant Crops

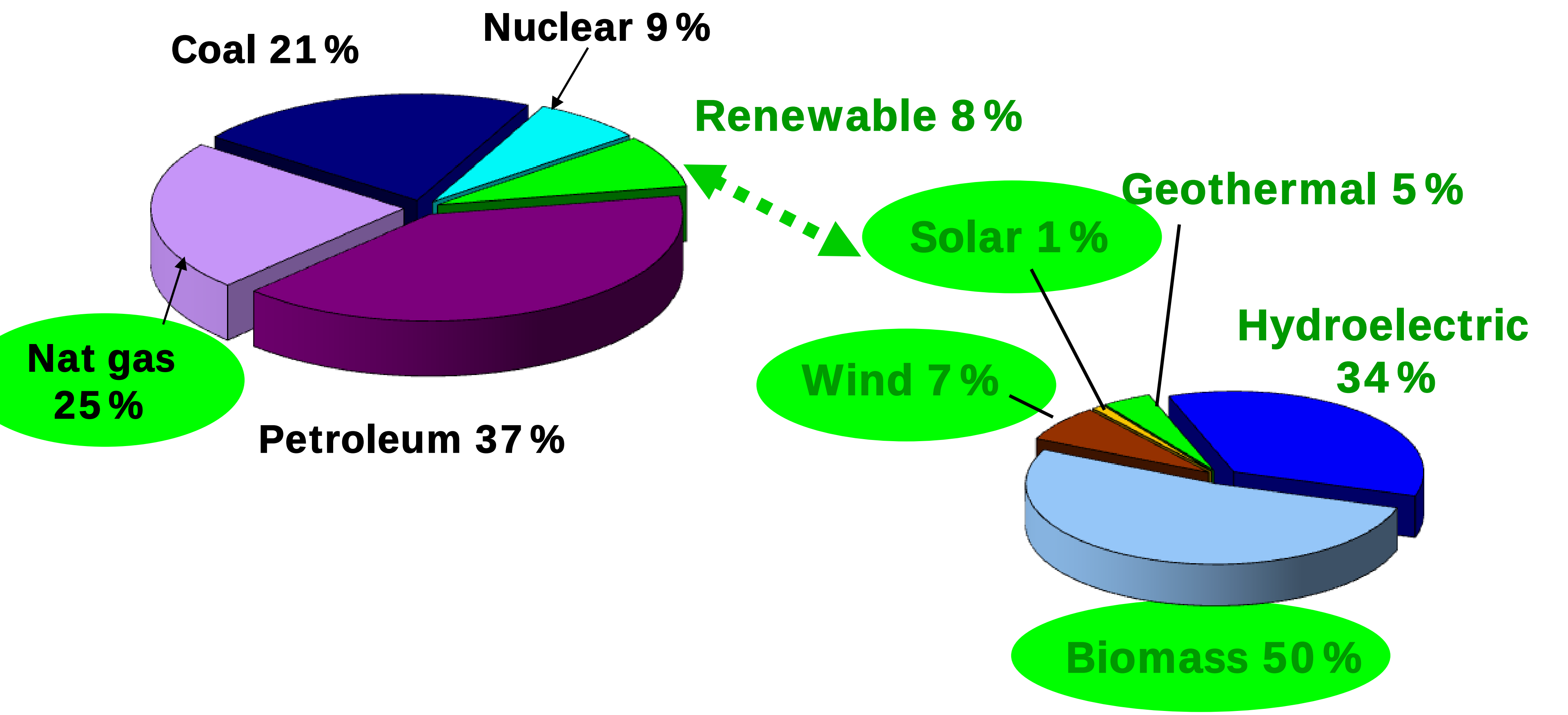
World energy consumption will increase with increasing population



Major energy consumption increase will be in the Emerging economies

Source: EIA International Energy Outlook 2005

U.S. Energy Sources



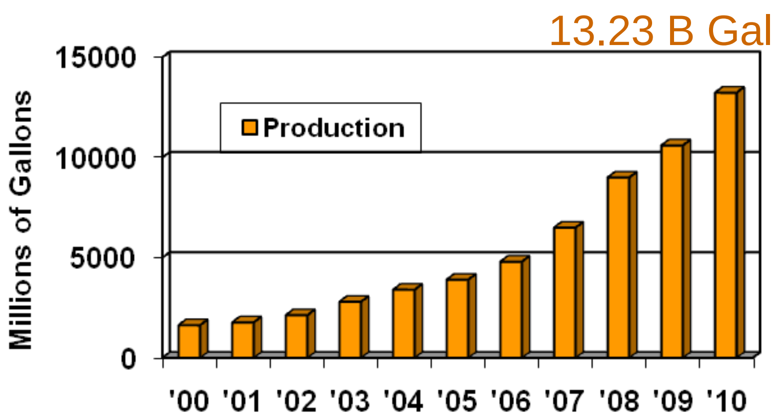
Need increased renewable base

Data source: USDOE-EIA

BioEnergy

Ethanol is Dominant BioEnergy Source

U.S. fuel Ethanol Production

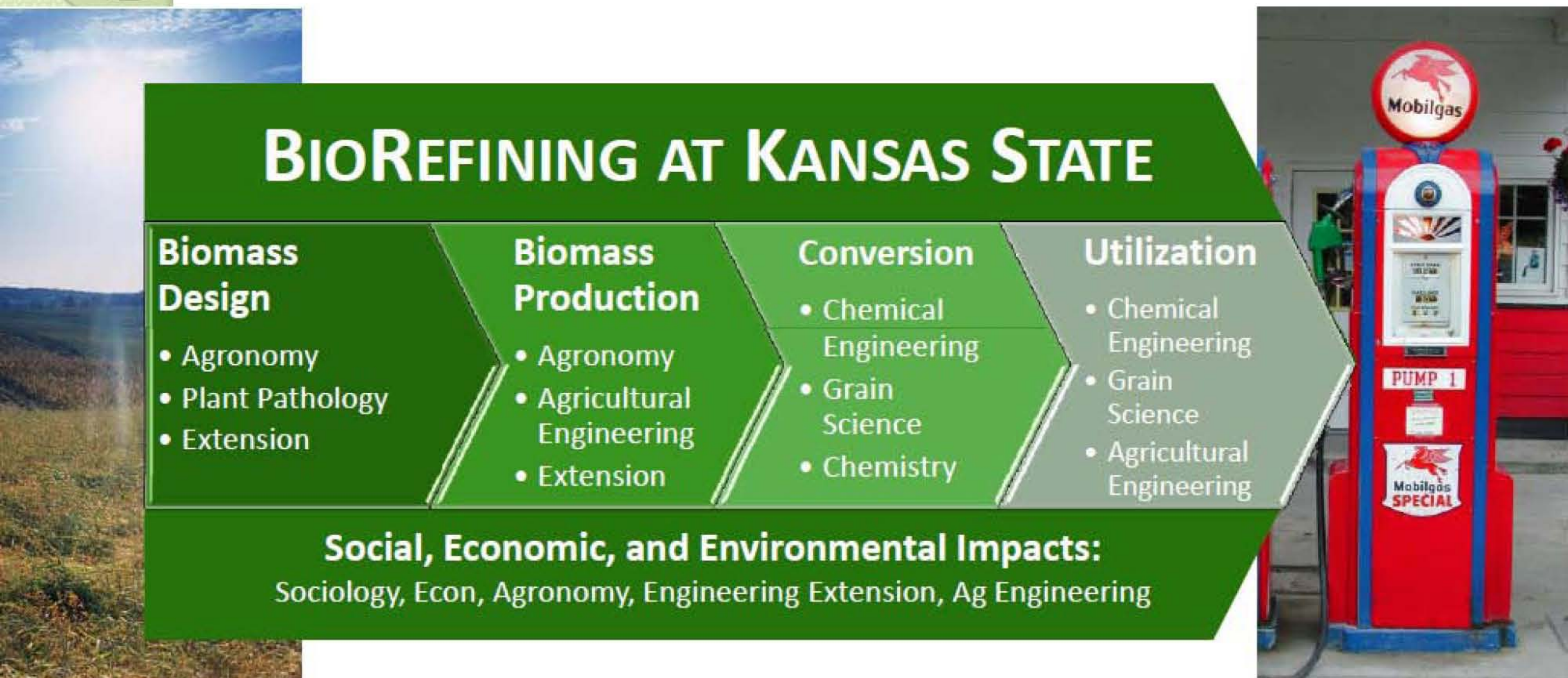


U.S CELLULOSIC ETHANOL PROJECTS UNDER DEVELOPMENT AND CONSTRUCTION

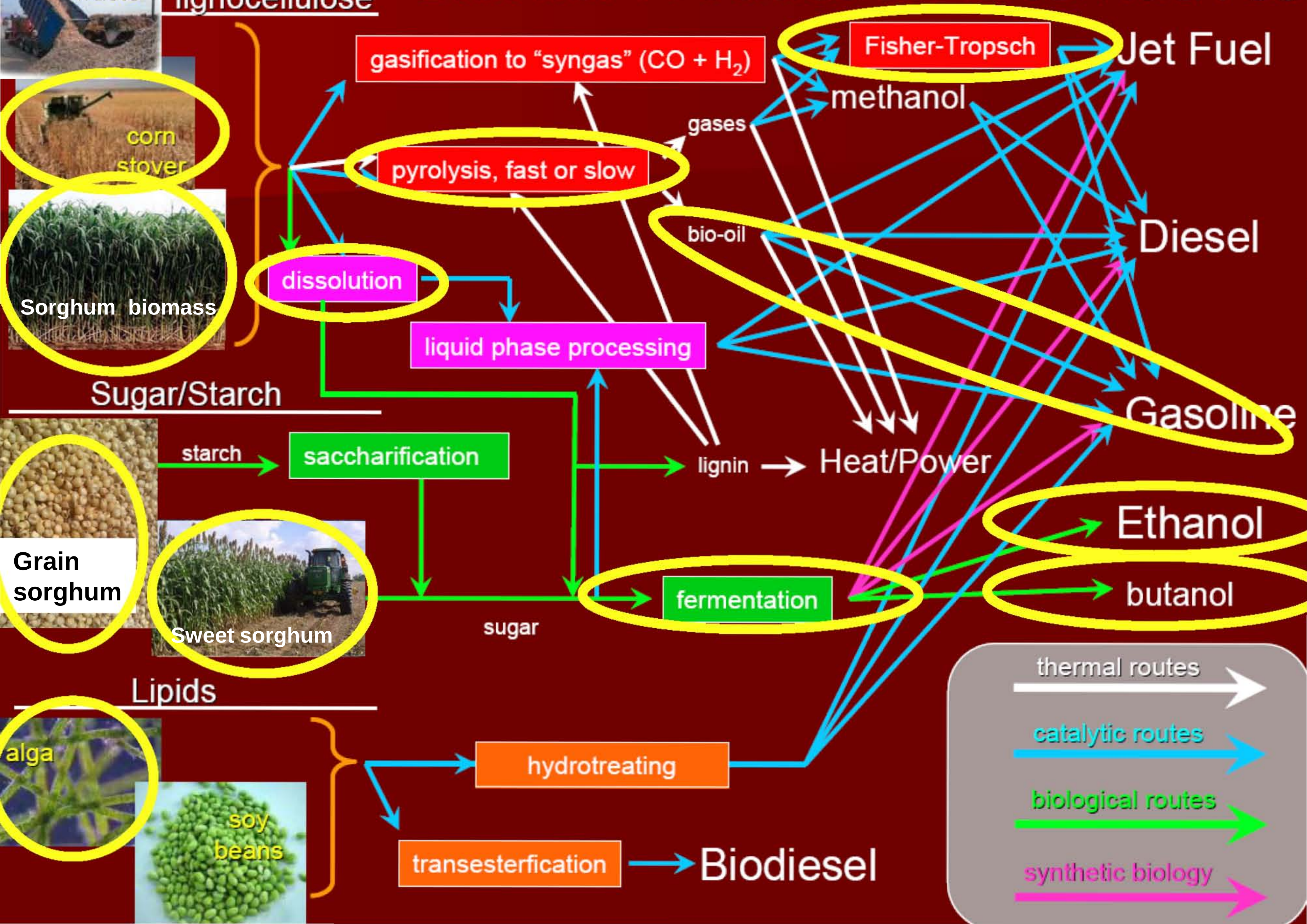
Energy Act of 2007 mandates that 15 B Gal be used in gasoline. Beyond that, no tax incentives (and likely little use).

Further Technology development will be required prior to commercial production of Cellulosic Ethanol

Kansas State Expertise by Area



Biofuel Production Alternatives



SELECTED RESEARCH RELATING TO FERMENTATION OF SUGARS / GRAINS

Sweet sorghum for biofuel

Potential ethanol yield (gallons/acre)

Biomass yield	Sorghum juice sugar content		
	15%	17%	19%
25 tons/acre	325	368	412
30 tons/acre	390	442	495
35 tons/acre	455	516	578

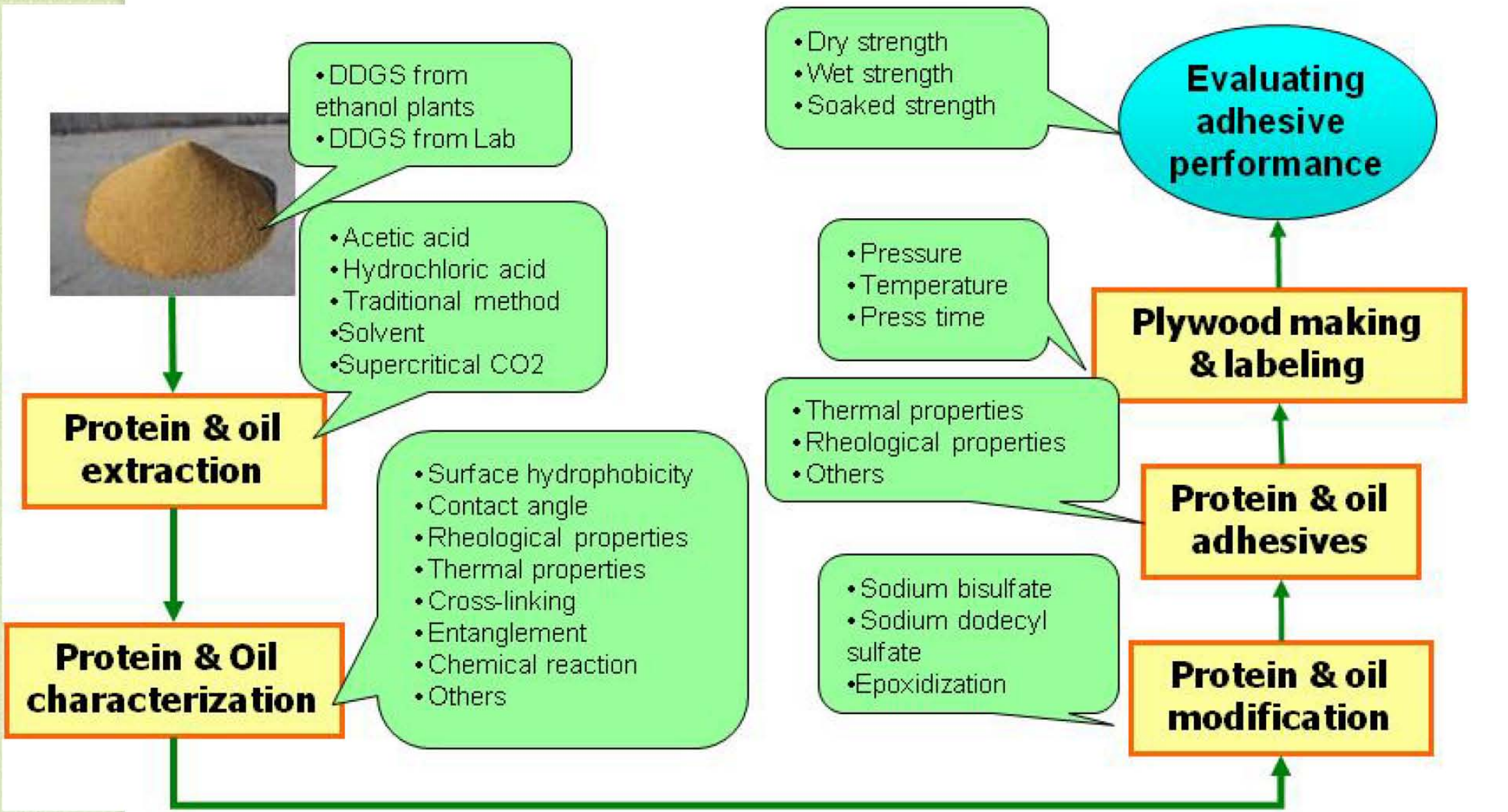
Based on 55% juice expression ratio and 92% conversion efficiency

Current Yields – with virtually no breeding or biotech to improve yields

The ethanol yield from **corn**: 448 gal/acre based on national average yield 160 bu/acre

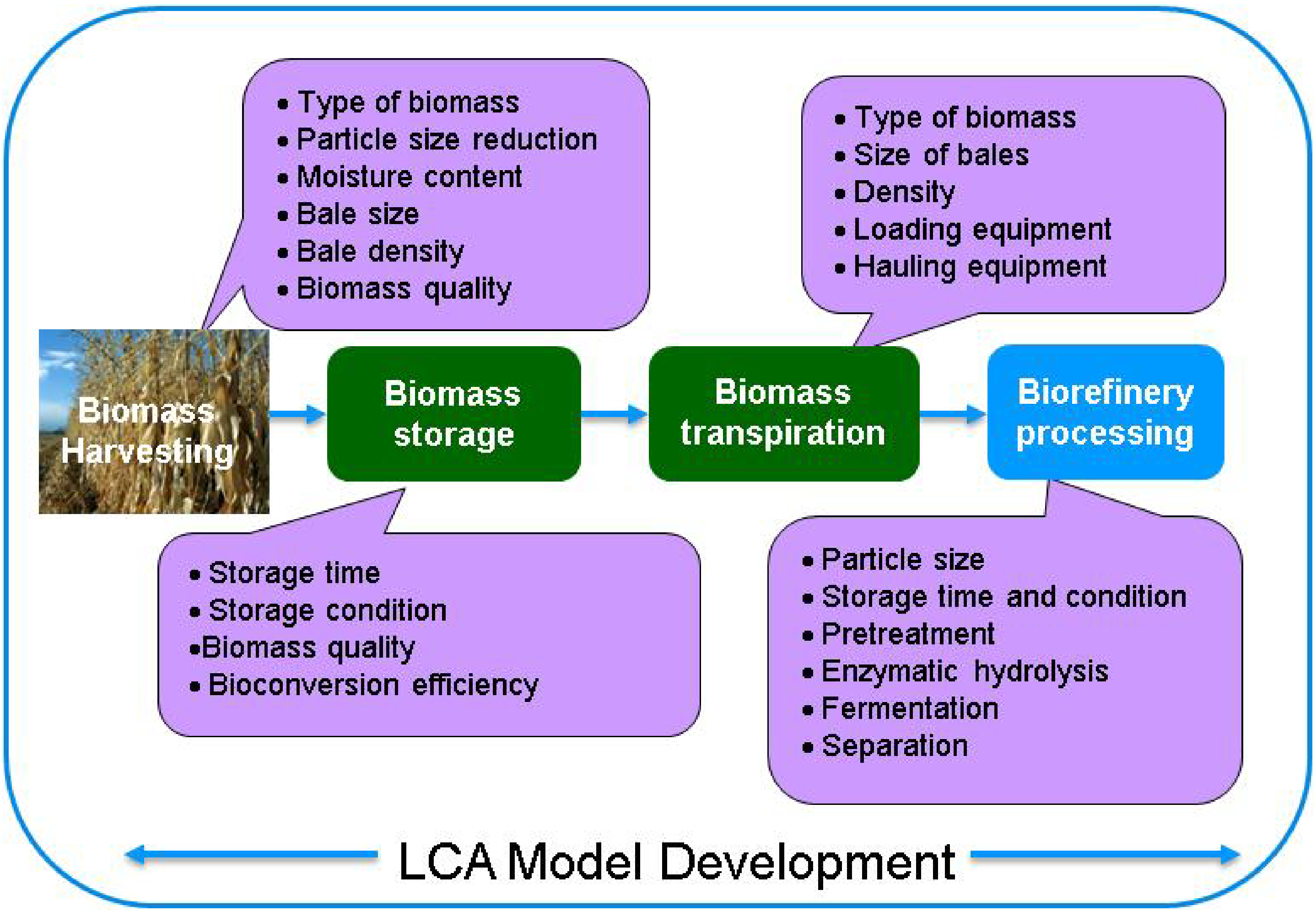
X. Wu, S. Staggenborg, J. Propheter, W. Rooney, J. Yu, D. Wang. 2010. Features of sweet sorghum juice and their performance in ethanol production. *Industrial Crops and Products*. 31:164-170.

Value-added products from DDGS



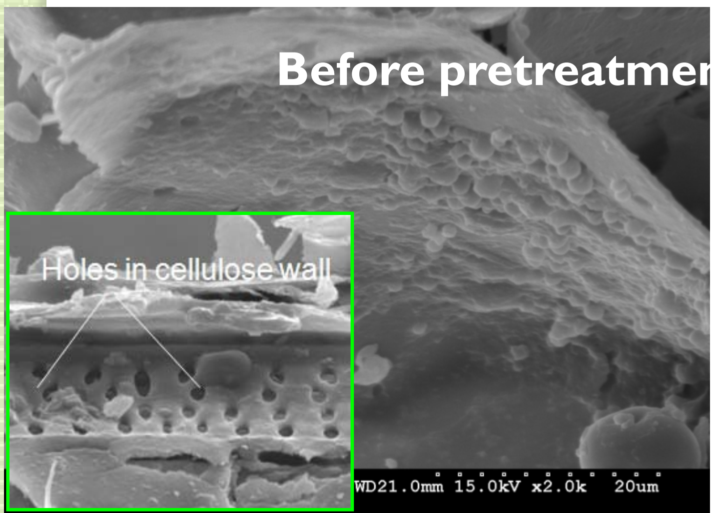
SELECTED RESEARCH RELATING TO FERMENTATION OF CELLULOSE

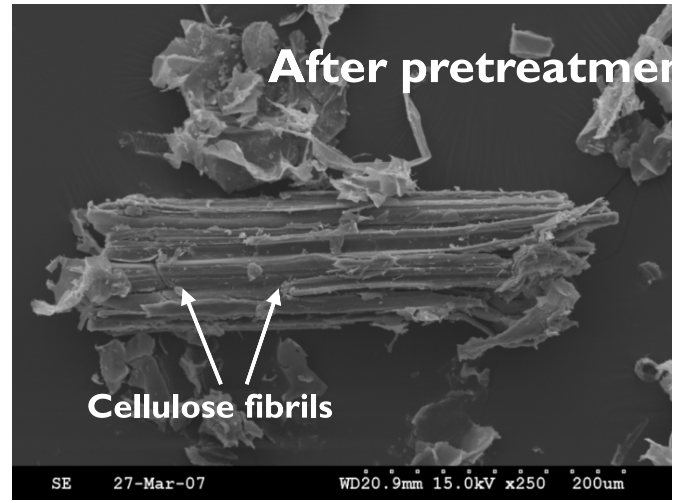
K-State Research on cellulosic biofuel
(sorghum is primary model compound, native grasses, bioenergy crops also examined)

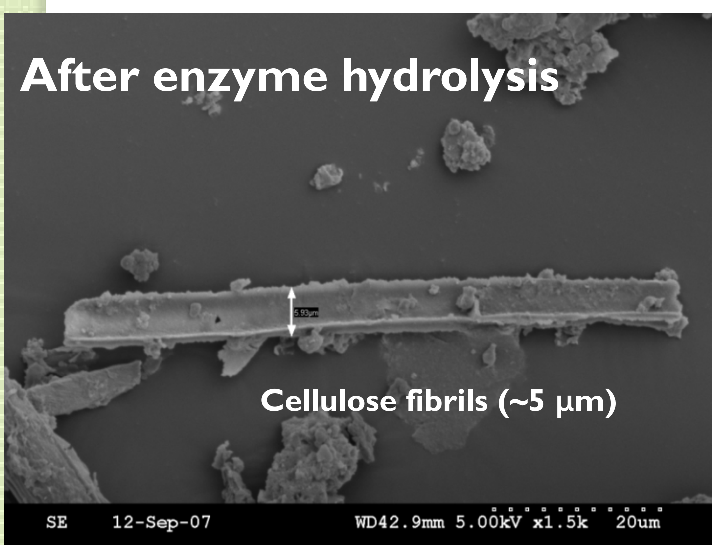


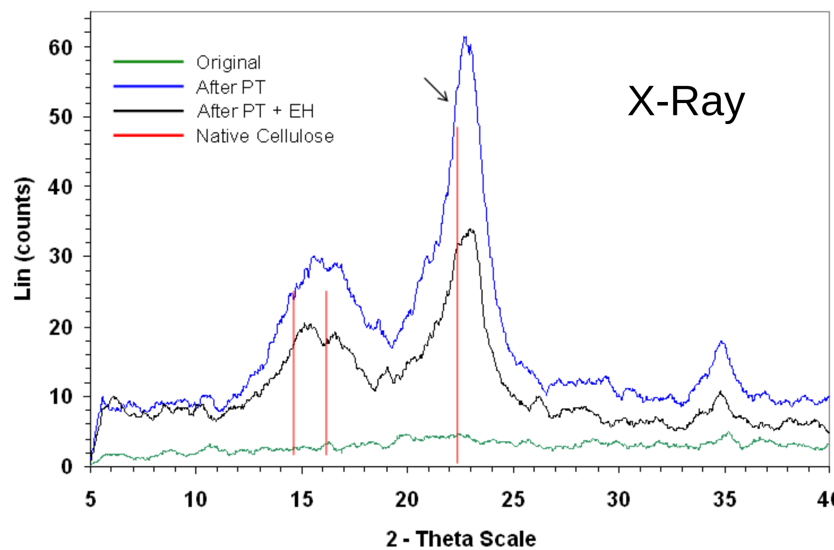
Developing treatments which promote facile conversion of cellulose to ethanol

Microstructure before and after treatment

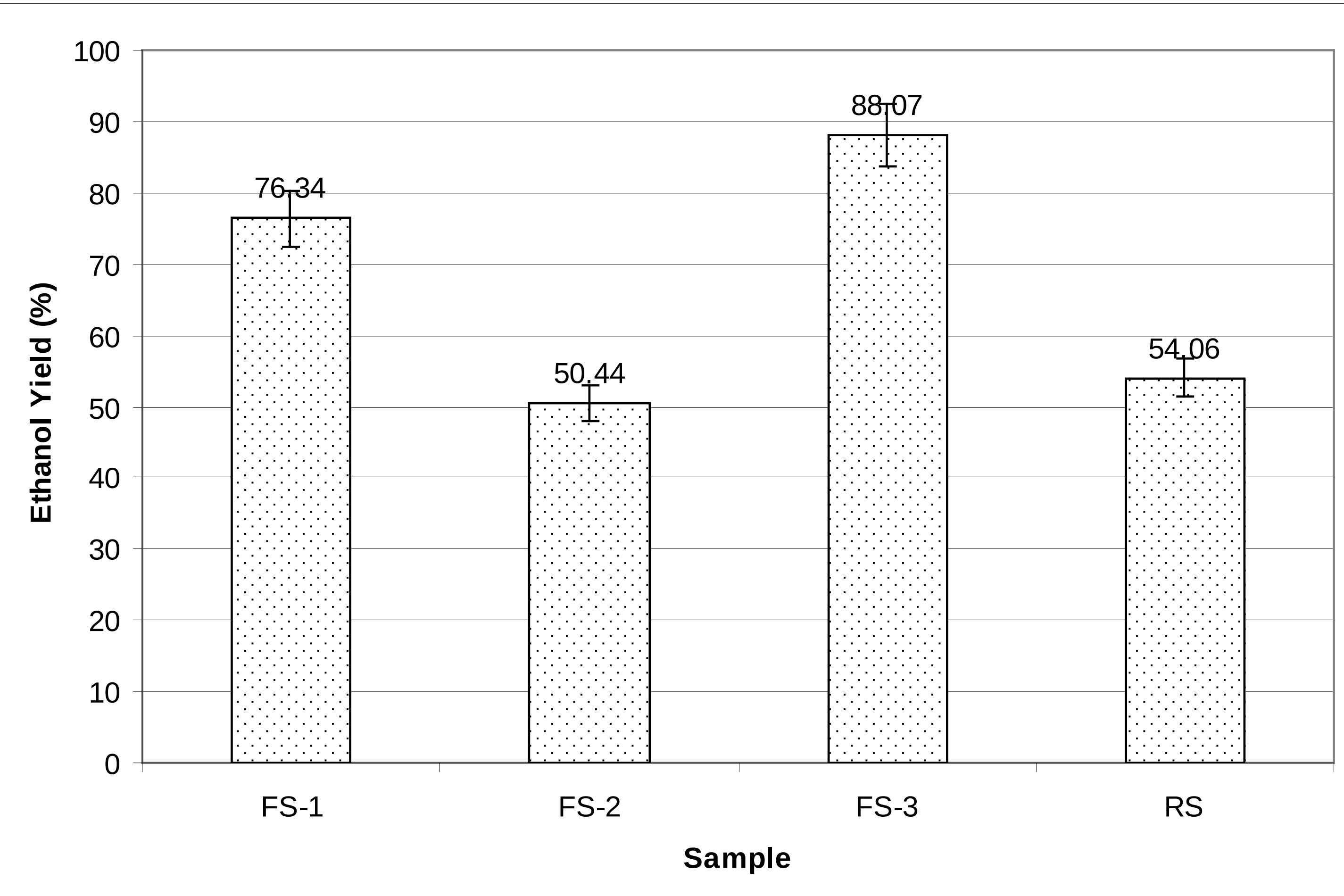


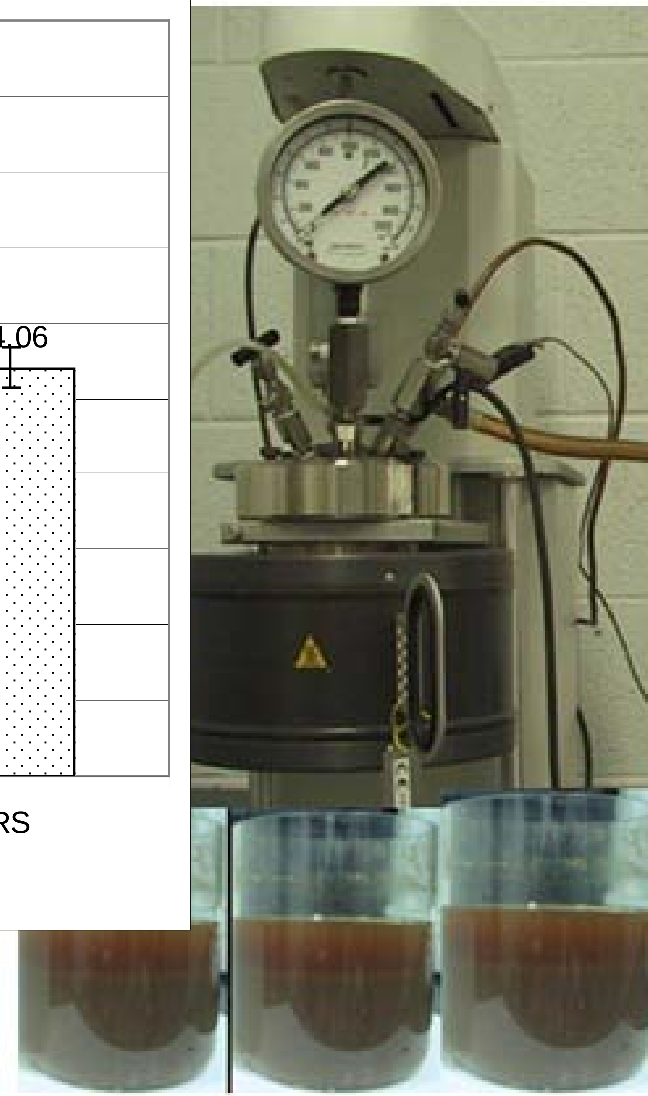






Ethanol yield of Forage Sorghum following Pretreatment





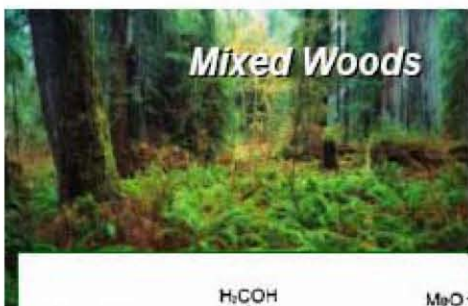
1. D. Corredor, J. Salazar. K. Hohn, S. Bean, and D. Wang. 2009. Evaluation and characterization of forage sorghum as feedstock for fermentable sugar production. *Appl Biochem Biotechnol*. 158:164-179.
2. D. Corredor, X.S. Sun, J. Salazar. K. Hohn, and D. Wang. 2008. Enzymatic hydrolysis of soybean hulls using dilute acid and modifiend steam-explosion pretreatments. *J. Biobased Materials and Bioenergy*. 2:43-50

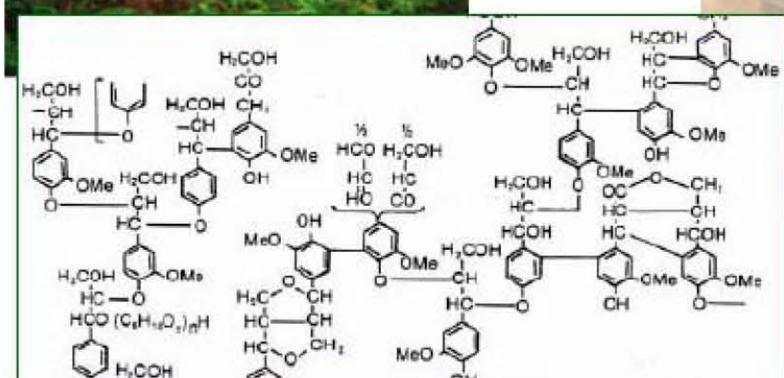
SELECTED RESEARCH RELATING TO THERMOCHEMICAL CONVERSION OF CELLULOSE

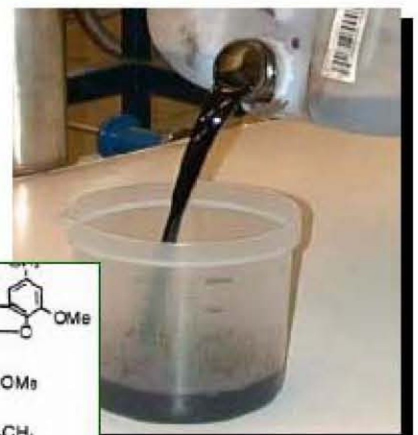
Biomass to fuels via pyrolysis

Biomass → Pyrolysis → Stabilization → Biocrude → Deoxygenate / Other Refinery Processes →

- Gasoline
- Diesel
- Jet
- Chemicals

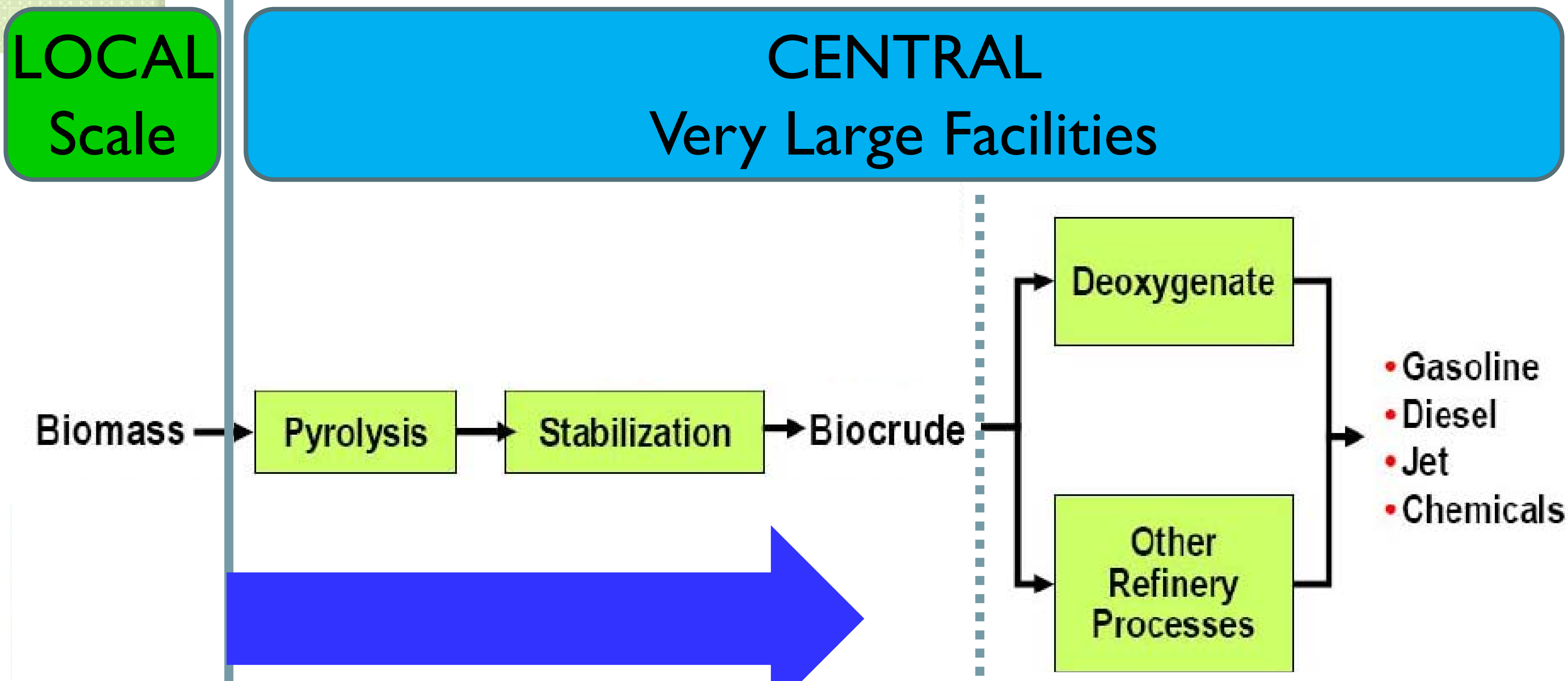






Source: UOP, LLC

Biomass to fuels via pyrolysis



Shifting boundary to achieve more local processing will:

- reduce transportation costs
- Increase local revenue
- Enhance profitability

BUT, will require new technology for stabilizing biocrude

Pyrolysis Research @ K-State

- Fast pyrolysis unit converts sorghum into bio-oil & bio-char.
- Process time < 5 minutes.
- 500-900 °C.
- Produced oils for stabilization research.
- The effect of bio-char as a soil amendment has also been studied.

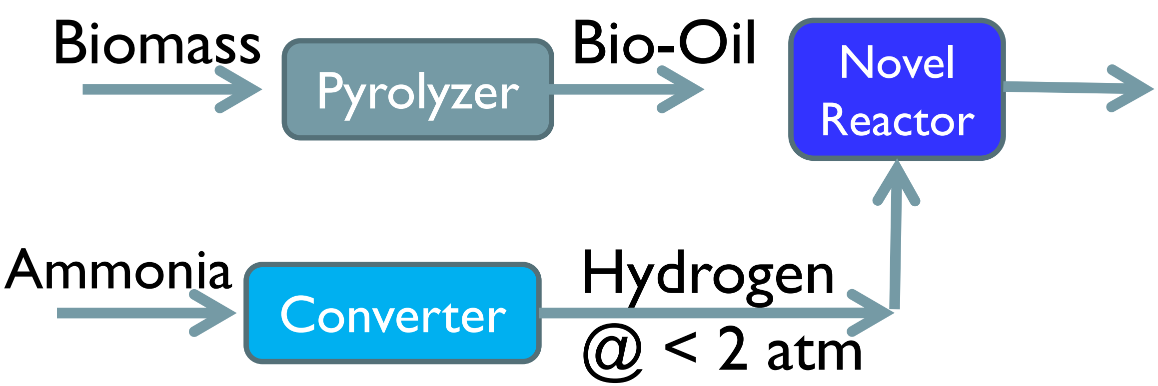
BioOil Stabilization Technology

Conventional Technology

Oil must be processed within a day or properties degrade

Processing requires Hydrogen at pressures of ~ 100 ATM (not suitable for distributed processing)

Our Technology

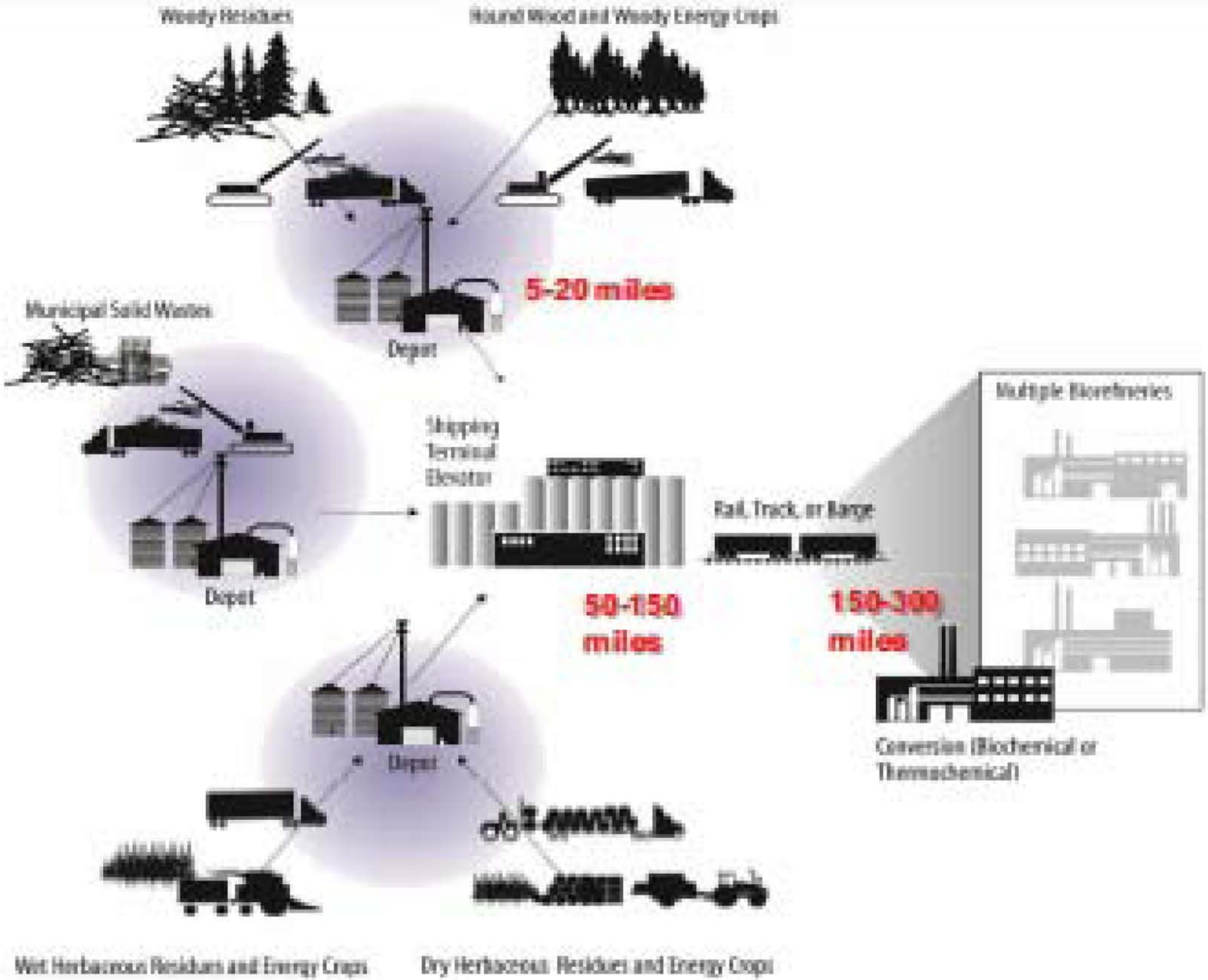


Stabilized Oil which can be held for extended periods without property loss

Commercialization Potential: Good

- Working with Major Petrochemical Company on the commercialization of bio-oil stabilization technology
- Coordinating with Ag machinery suppliers and farmers’ groups as to the optimum design

DoE's Distributed Biomass Processing Model



Wind Research

High-Plains Small Wind Test Center
Colby, KS

Research Activities	Impacts
▪ Test small wind turbines (<50kW) against national standard ▪ Provide support for consumers	▪ Ensure market of safe, reliable wind turbines ▪ Long-term facility: jobs in Colby

Partners

NREL

Midwest Energy, Inc.

AMI ADVANCED MANUFACTURING INSTITUTE

COLBY COMMUNITY COLLEGE

WECC

Wind Applications Center Kansas

Kansas Wind Consortium
(KSU – WSU Joint Project)

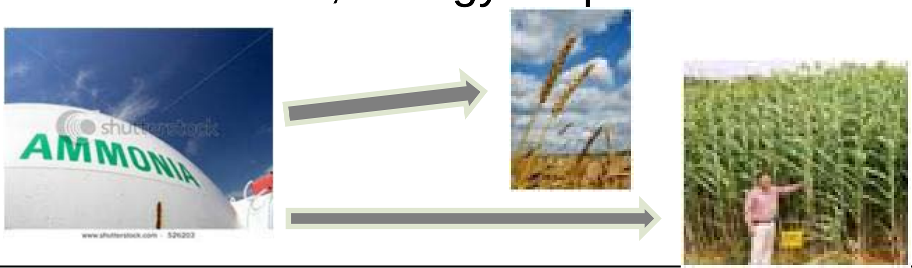
Research Activity	Impact
• Develop new equipment for testing turbine vibration	• better assess turbine health; prevent mechanical failures
• Design new inverter for wind generators	• design, build, market novel, improved inverter for wind generators
• Optimize power grid communications and interconnections to minimize failures	• safely increase % renewable energy on grid, reduce emissions, increase ability to use Kansas wind resources safely
• Develop a network protocol to monitor and control elec grid in real time, allow "islanding"	• Help electric utilities better use renewable energy: reduce costs, prevent outages, reduce emissions
• Develop electricity pricing structures for optimal renewable energy use	• electricity pricing advice to utilities and consumers to increase renewable energy use

Solar Research

Ammonia from air and water via solar energy

Peter Pfromm, Ronny Michalsky, Vincent Amanor-Boadu, Bryon Parman, Kansas State University

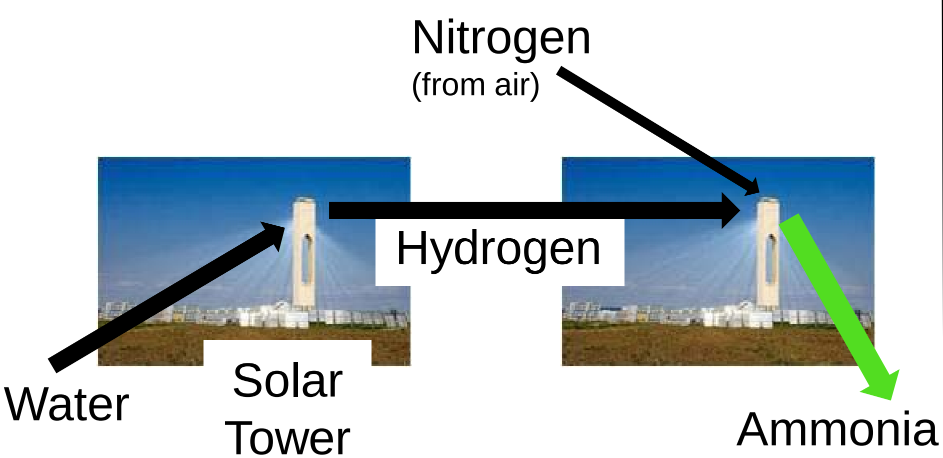
- Ammonia production consumes 3% of the world's total energy budget, all as natural gas
- Natural gas price/supply is volatile
- Ammonia demand will rise: rising world food demand, energy crop cultivation



Advantages:

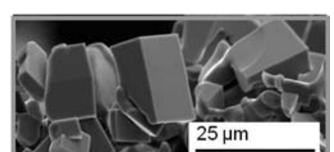
- Decouple fertilizer from natural gas
- Green house gas reduction
- Solar energy is stored as chemical energy
- Easy to store/transport ammonia (established infrastructure)
- Can be scaled down or performed in developing nations

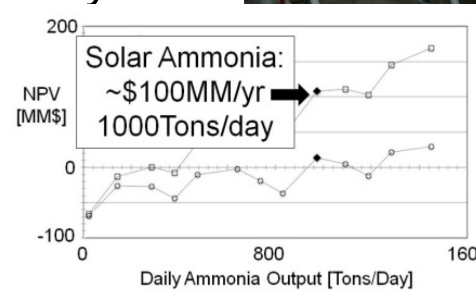
Approach: concentrate solar energy to produce ammonia from water and air



Status:

- Basic thermodynamics and materials have been successfully tested
- Economic modeling projects profitability





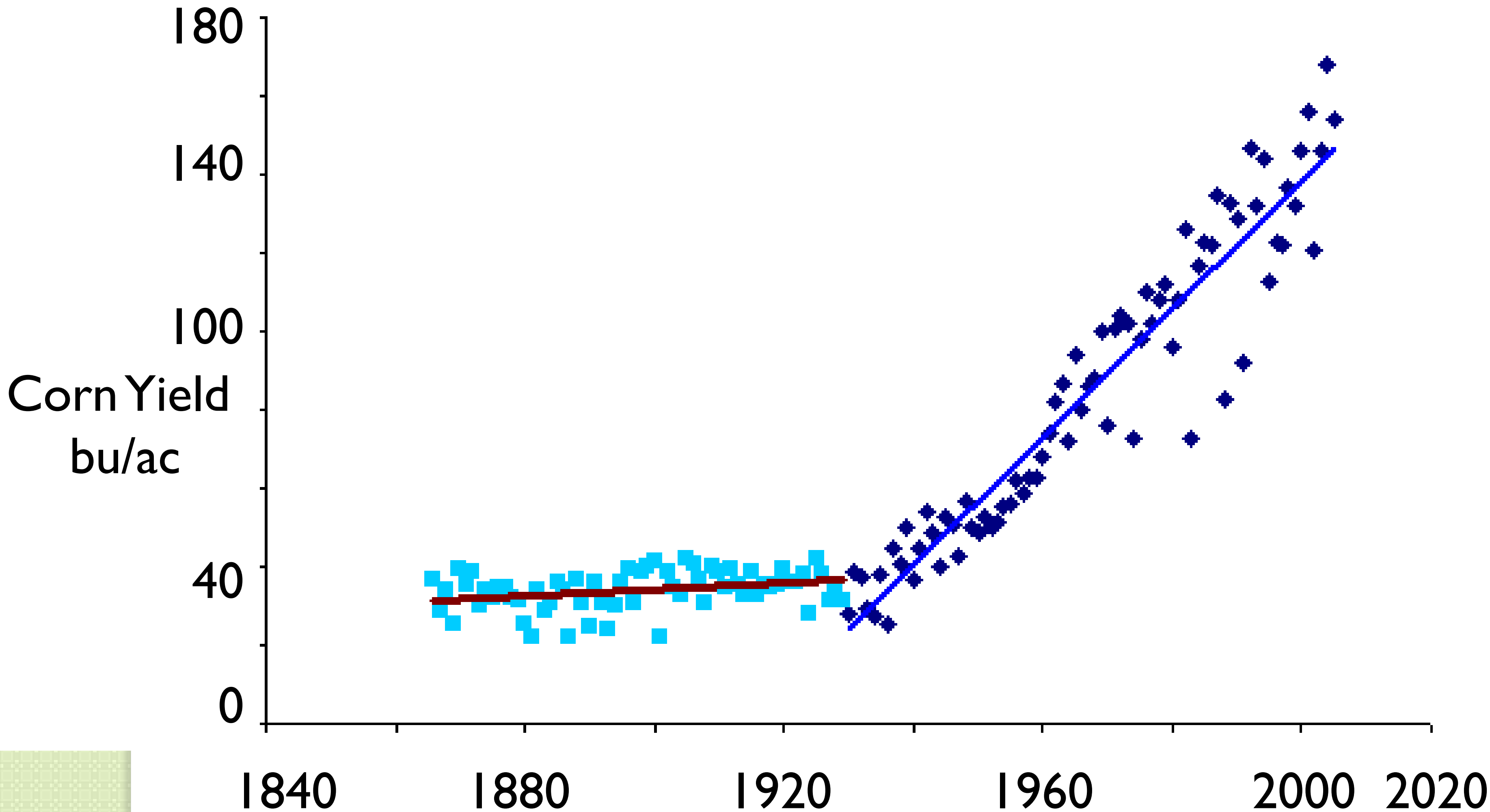
The Water – Energy Nexus

Water : Energy Nexus

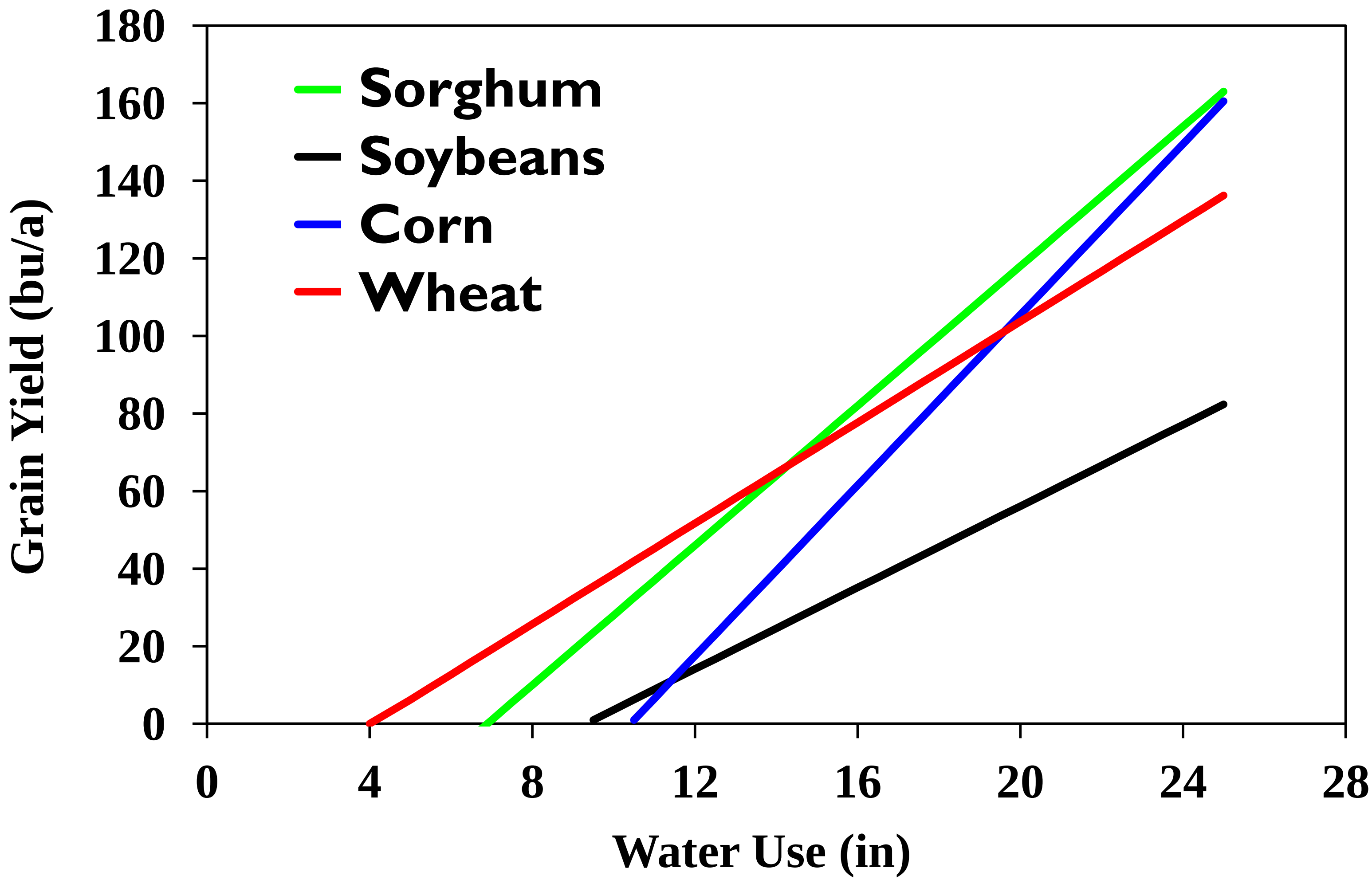
both challenges must be addressed together

ENERGY ... is needed to purify WATER ... is needed to generate ENERGY

BioTech and improved agronomic practices have resulted in dramatic yield improvements



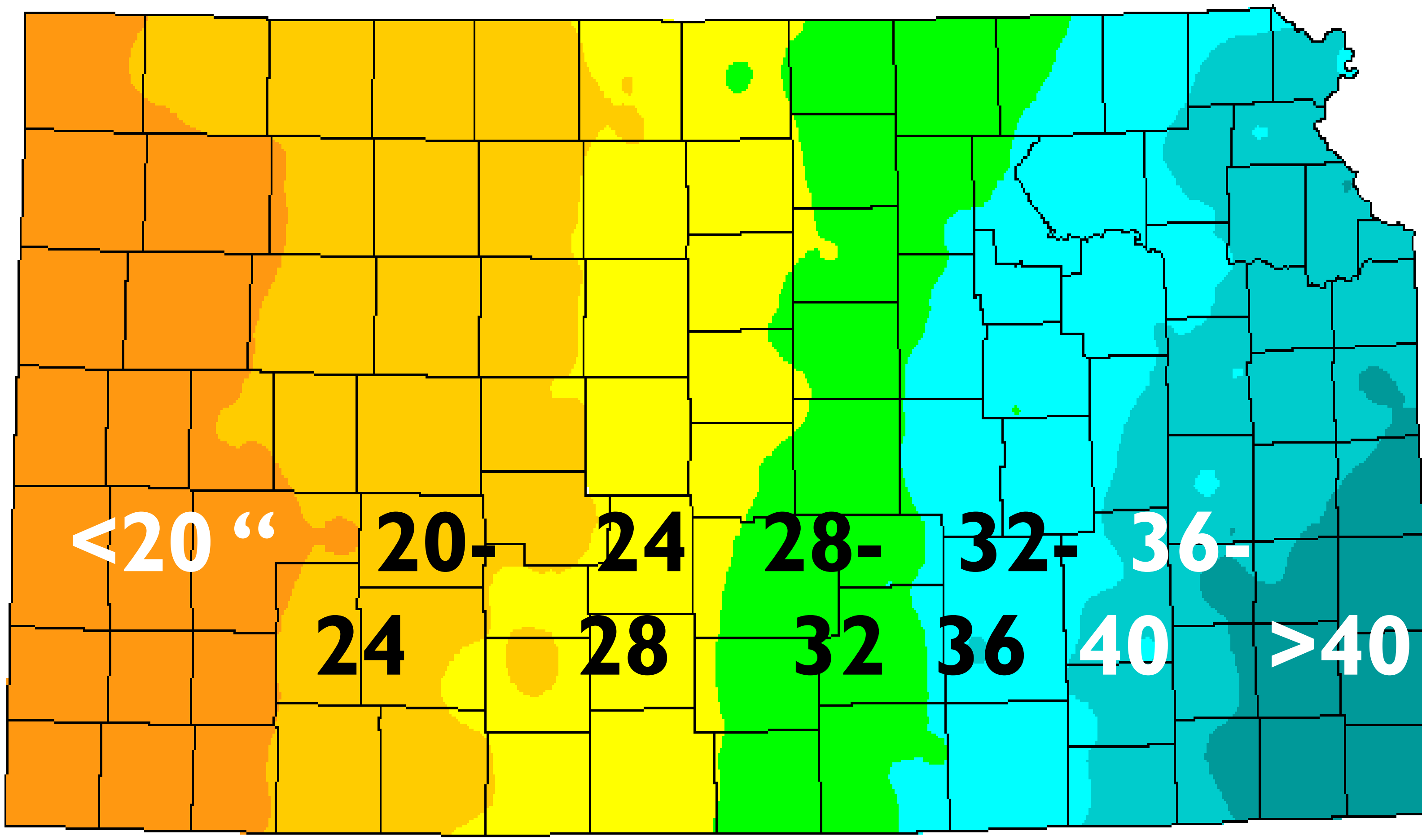
But productivity requires water



L.R. Stone

Kansas has Some, but not overly abundant, rainfall

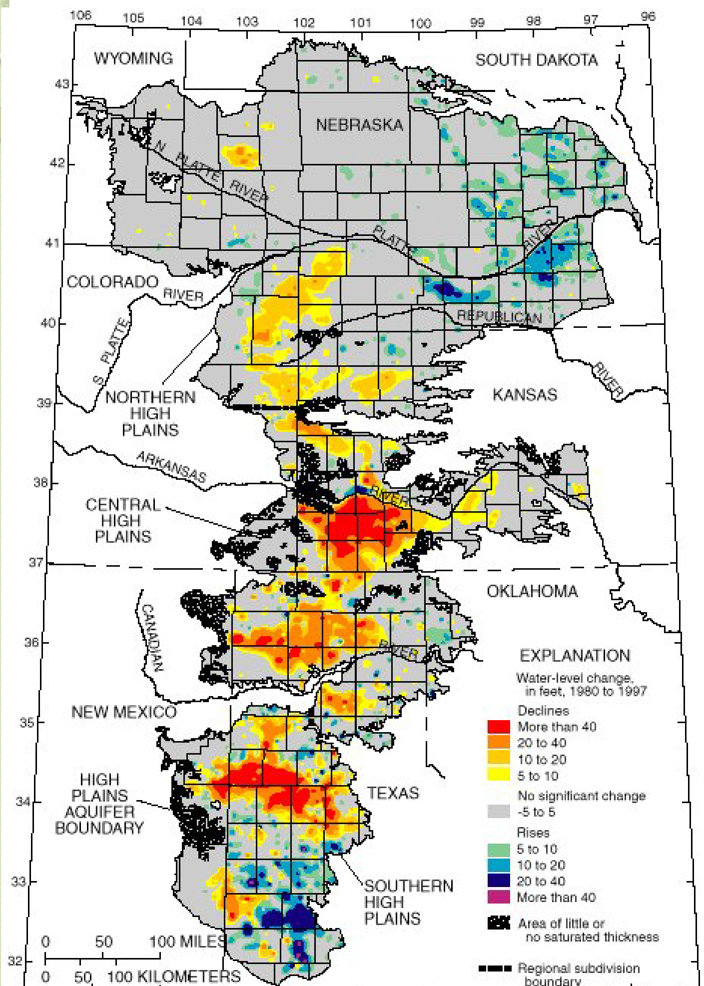
Average Annual Precipitation 1971 - 2000



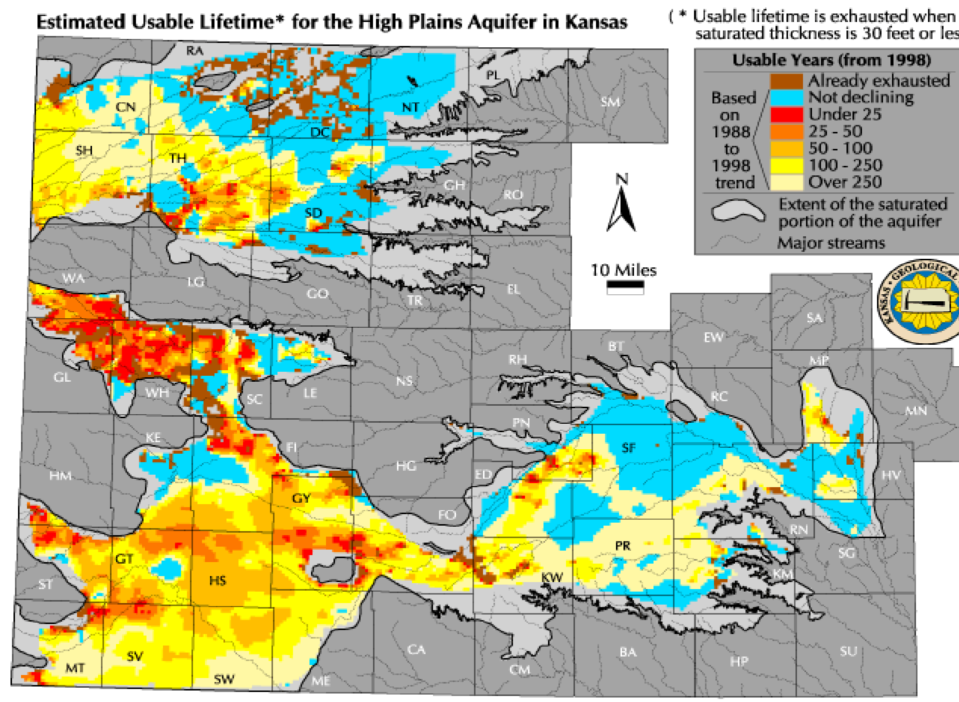
How to use diminishing water supply?

Groundwater Depletion

Estimated Usable Lifetime

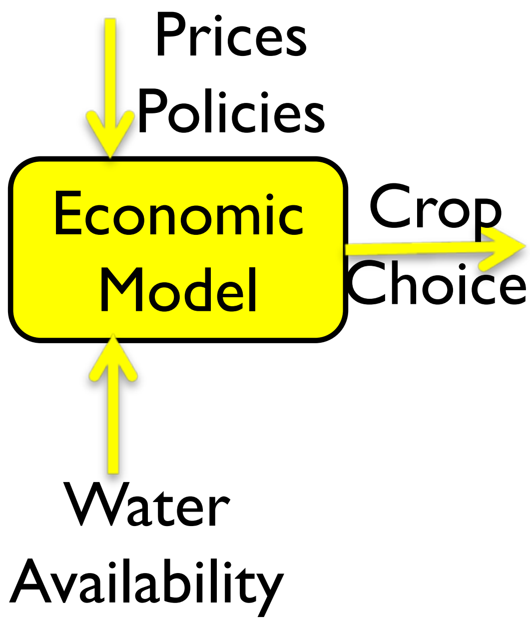


Source: USGS (water.usgs.gov)



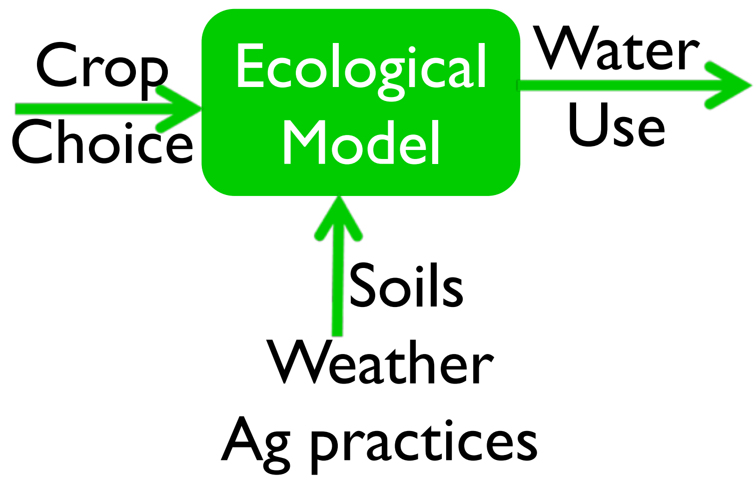
Source: KGS (www.kgs.ukans.edu)

Developing a meaningful model through Integration



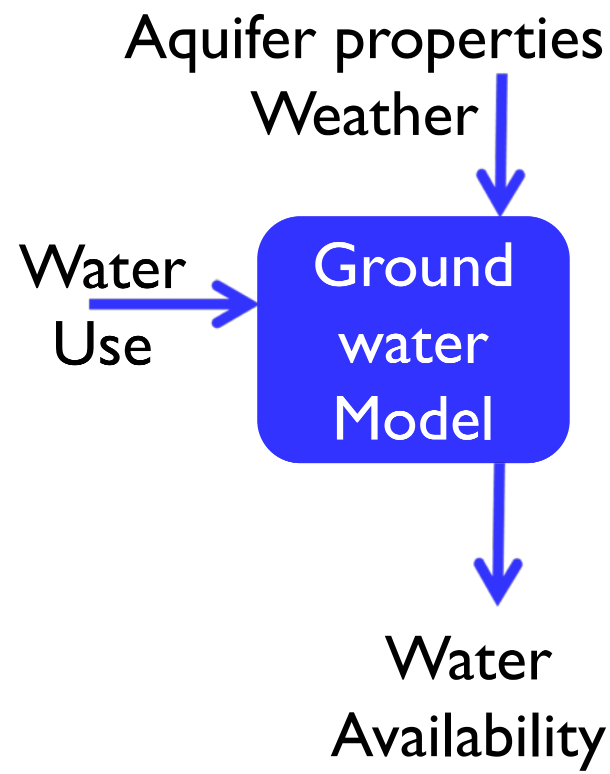
Steward et al. (2009)

Developing a meaningful model through Integration



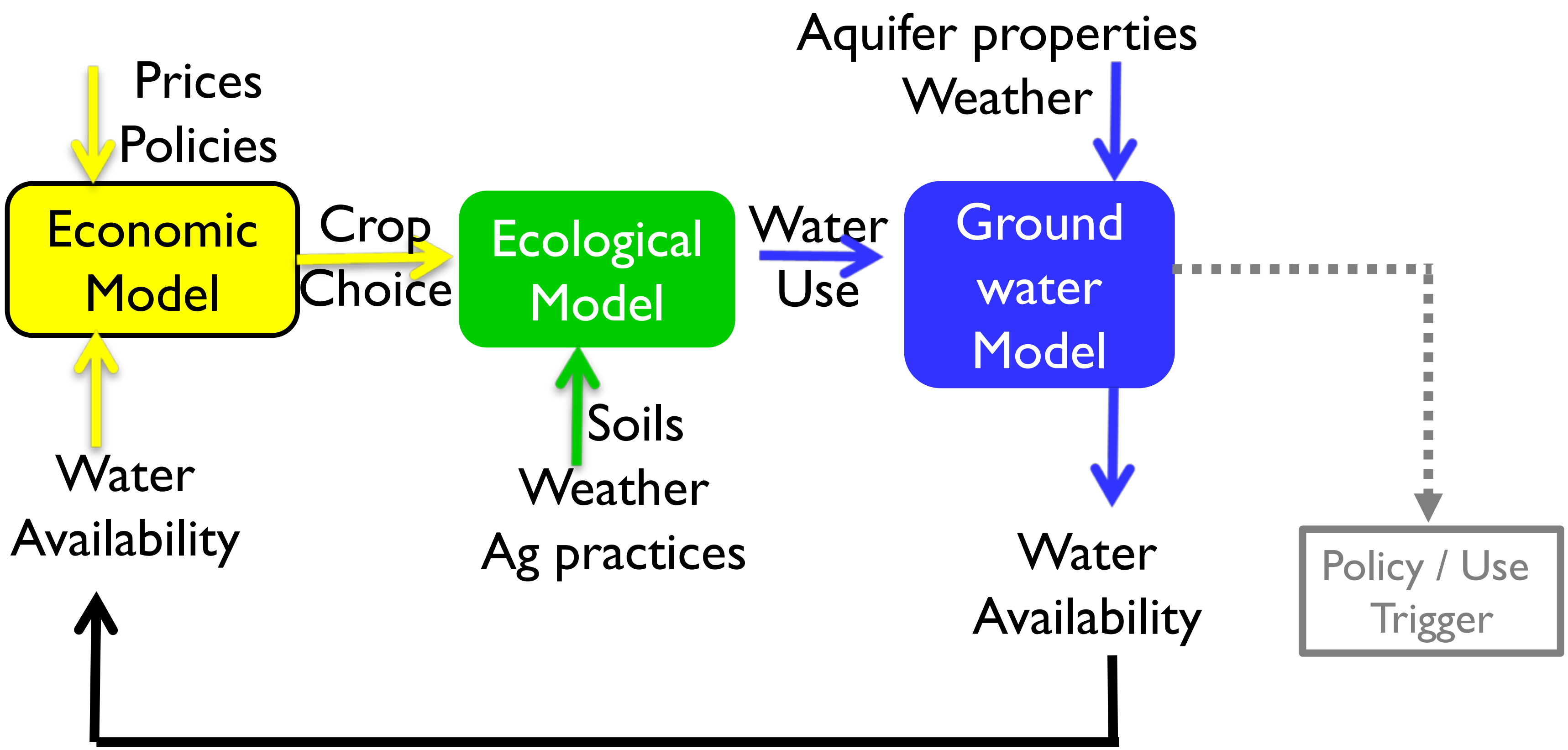
Bulatewicz et al. (2009)

Developing a meaningful model through Integration



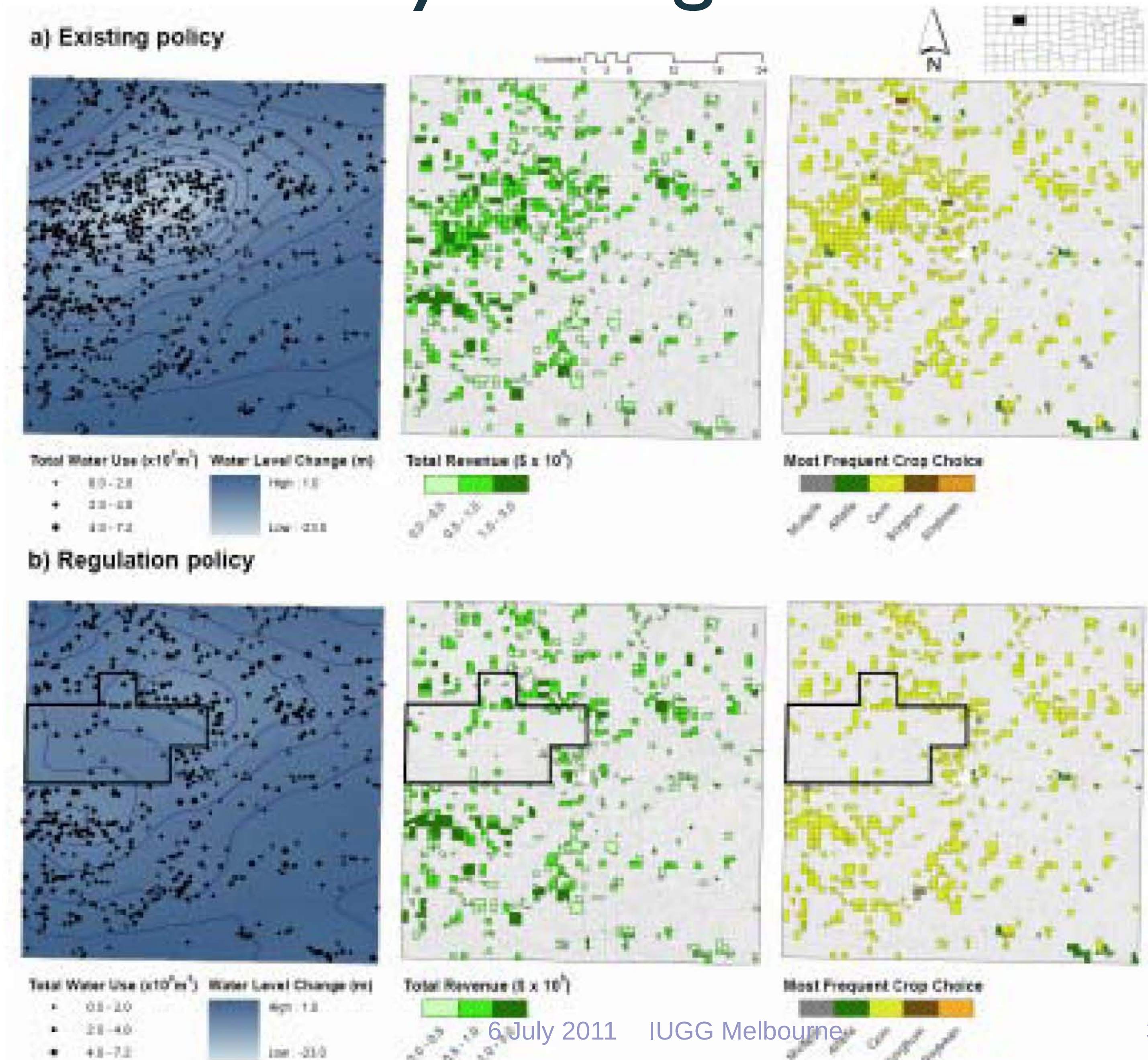
Yang et al. (2010)

Developing a meaningful model through Integration



Bulatewicz, Yang, Peterson, Staggenborg, Steward, Welch (2010)

Impact of Policy Change



Bulatewicz, Yang, Peterson, Staggenborg, Steward, Welch (2010)

Aquifer Modeling and Management

- Integrating models from
  - Economics
  - Ecology
  - Aquifer properties

Allows for the prediction of user behavior in response to external stimuli (i.e., policy change).

Water: Drought - Tolerant Crops

Sorghum, Wheat, Canola Development

- Sorghum Improvement Center working to develop new varietals adapted to bioenergy requirements.
- Canola is being examined as a drought-tolerant oil-seed crop
- Wheat genome information is being used as the basis for biotech development for native grasses

Forage sorghum biomass

- Grows primarily in semiarid and drier regions
- Produces more dry mass per acre (80 Mg ha-1, 65% MC) than corn
- Significant soluble sugar content
- Low lignin content
- *"Forage sorghum yields have been similar to that achieved with corn and in most years required at least 40% less irrigation water than fully irrigated corn." Brent Bean, TAMU, Amarillo, TX*

	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Soluble Sugar (%)
PS sorghum	**36**	**20**	**12**	**18**
Corn Stover[a]	36 – 41	26 – 35	17 – 21	NR
Switchgrass[b]	32 – 37	22 – 27	18 – 21	NR
Wheat straw[c]	37 – 47	23 – 32	8 – 19	NR

[a] Lloyd and Wyman 2005; Zeng 2007; Zhao et al. 2009; [b] Alizadeh et al. 2005; Suryawati et al. 2008; Xu et al. 2010; [c] Sun and Chen 2008; Zhu et al. 2006; NR: not reported.

Photoperiod Sensitive Forage Sorghum

Switchgrass

Miscanthus

Biomass Crop Performance
(K-State Test Fields in RL and DP counties)

Crop	2007	2008	2009
	Tons/acre		
			11.0
			7.8
			9.8
			8.2
			9.0
Rotated Corn P33K40	9.9	8.8	11.5
Cont. Corn P33K40	9.0	8.0	10.5
			2.6
			5.1
			6.7

Sorghum yields equal or exceed corn and grasses …. But require 40% less water (no irrigation ?)

Grasses take several years to establish, appear to have more modest yields than sorghum and corn, and there are serious concerns regarding farmers' willingness to commit to these crops.

Educational Activities

BioEnergy Educational Activities

Activity	Funding Agency	Target Audience	Students served in 2011
Graduate Certificate & Distance Courses	Sun Grant / USDA	Professionals & MS/PhD	137
Interdisciplinary Research & Training	NSF	PhD	30
International Travel/Training	DoEd	Faculty BS/MS/PhD	18
Research Training	NSF	BS	36

Wind Energy Educational Programs

Funding Source, Objective, Amount	**Applications**
DOE-NREL Wind Powering America: **Wind for Schools** •help K-12 schools install wind turbines and use them in curriculum •Teacher workshops, KidWind activities locally and statewide •Engineering education: wind energy classes for the wind workforce	•Increase workforce in engineering, and in wind energy specifically •Increase understanding and acceptance of wind energy in state, to increase growth of wind industry in Kansas
DOE: **Wind Curriculum Development** •Develop laboratory activities to complement wind energy classes	•Prepare engineers for careers in wind •State-of-the-art electronics laboratory in wind & solar energy engineering

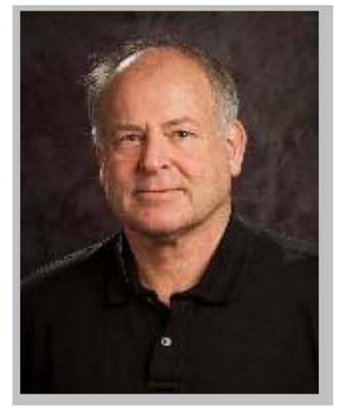
Take Home Messages

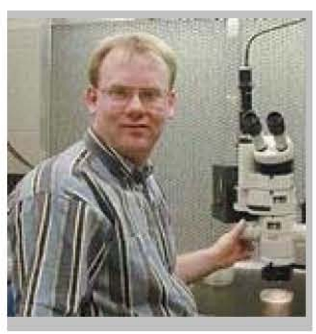
- Wind Energy is important for Kansas and represents economic opportunities
- Sustainable biomass for energy production provides economic opportunities to Kansas farmers
- Production of new biomass varietals has potential to generate income for the state
- Additional technology must be developed before large-scale biorefineries can succeed
  - Development of this locally will allow it to be optimized for KS conditions (dry-land farming, beef operations, oil/natural gas processing, strong local Farmers Cooperatives, etc.)
  - Examples: Distributed Pyrolysis and Bio-oil stabilization technologies.

Supplemental Materials

THE FOLLOWING SLIDES PROVIDE INFORMATION REGARDING INDIVIDUAL RESEARCHERS AND RESEARCH PROJECTS

K-State Biomass Design Faculty





K-State Biomass Production Faculty

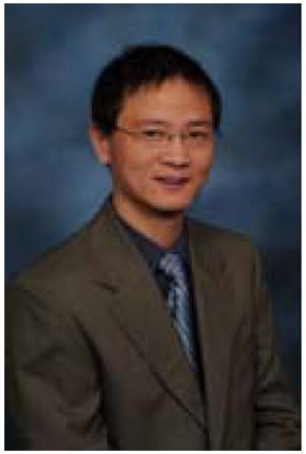






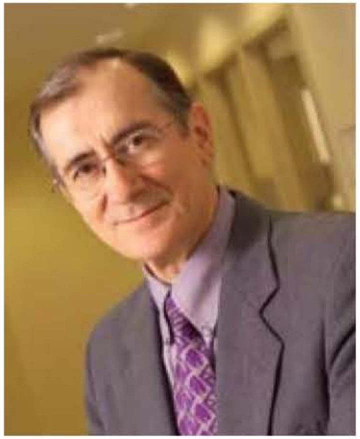


K-State Conversion Faculty

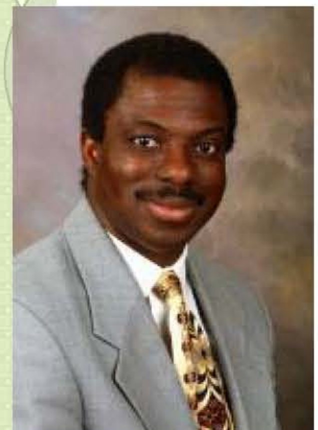
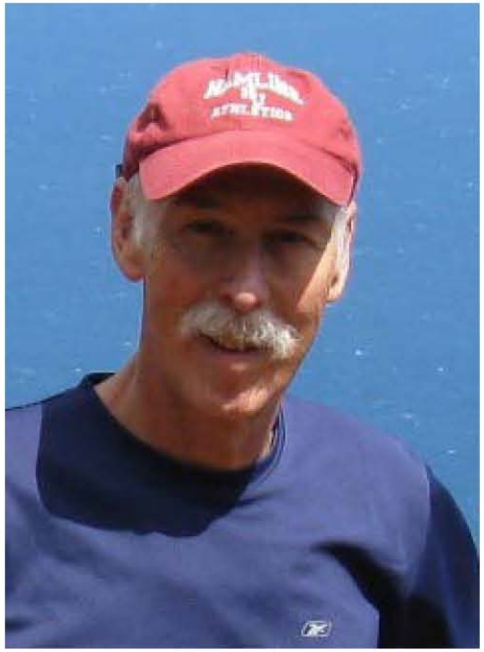





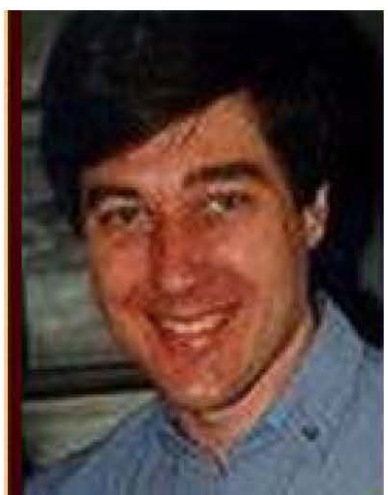


K-State Water & SocioEconomic Faculty





K-State Wind Energy Faculty

Center for Sorghum Improvement

Breeding & Genetics

- Ramasamy Perumal Tesfaye Tesso Jianming Yu

Plant Physiology/Crop Production

- David Mengel P.V. Vara Prasad Scott Staggenborg

Weed Science

- Curtis Thompson

Plant Pathology

- John Leslie Chris Little

Entomology

- Brian McCornak John Reese

Utilization

- Fadi Aramouni - Food Science Institute
- Scott Bean - USDA ARS
- Joe Hancock- Department of Animal Sciences and Industry
- Donghai Wang- Department of Biological & Agricultural Engineering

Recent National Science Foundation (NSF) BioEnergy-Related Support (incomplete)

Principle Investigator	Title	Period	Funding
Rice	Epscor: Renewable Energy and Climate Change	'09-'14	$20,000,000**
Rezac	IGERT: I-STAR BioEnergy	'09-'14	$4,375,000
Rezac	BioEnergy Lab Renovations	'10-'12	$1,600,000
Hohn	Sustainable Energy REU	'09-'12	$270,000
Nelson	BioEnergy IUCRC	'08-'13	$255,000
Yuan	Career: Algae	'10-'15	$400,000
Jankowaik	Photosynthetic Complexes	'10-'13	$380,000
Pei, Wang	Pelleting of Biomass	'10-13	$360,000
Hohn, Wang	Hydrolysis of Cellulosic Biomass	'10-13	$323,000
Aikens	Career: Photocatalysis	'10-15	$600,000
Edgar	FESEM Acquisition	'09-'12	$519,000
Kramer	PFI: BioEnergy	'10-'13	~$600,000

Other Multi-PI, Recent BioEnergy-Related Support (incomplete)

PI	Sponsor	Title	Period	Funding
Rezac	DoE	Thermochemical Conversion of Biomass	‘09 – ‘11	$1,214,000
Rezac	USDA	BioEnergy Grad Program	‘09-’13	$490,000
Rezac	ConocoPhillips	CSE Support	‘09-’13	$750,000
Nelson	KBA	KS Resource Assessment	‘08-’09	$300,000
Multiple	Sun Grant	BioEnergy Research	‘07 – ‘12	~$700,000
Madl	Dept of Education	FIPSE: International Student Travel	‘09-’12	$250,000
Rice	Dept of Education	FIPSE: International Student Travel	‘09-’12	$250,000
Prasad	USDA	Great Plains Sorguhm Improvement Center	‘10-13	$930,000
Rezac	USDA	BioOil Stabilization	‘11-14	$690,000

Industrial Partners (incomplete)

- Abengoa Bioenergy
- ADM
- AGCO
- Burns & McDonnell
- ConocoPhillips
- Dow Corning
- ICM, Inc
- Idaho National Labs
- Kansas Farm Bureau
- Kansas Ethanol
- MGP Ingredients
- Nanoscale Technologies
- Netcrystals

Academic Partners (incomplete)

- Colorado State University
- Haskell Indian Nations University
- Iowa State University
- North Carolina State University
- Oklahoma State University
- South Dakota State University
- South Dakota School of Mines and Technology
- University of Arkansas
- University of Hawaii
- University of Kansas
- Wichita State University