Agriculture

Accomplishments and opportunities

Dr. Martha Schlicher
Monsanto Company

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Discussion topics

- **The impact of technology on production today**
- **Illustrative public-private collaborative technology advancement efforts**
  - Enabling the commercial viability of corn stover
  - Barriers to commercial viability of algal biofuels
  - Enabling technologies for parasite solutions
  - Informing models for better crop yield predictions
- **How best to utilize future resources**

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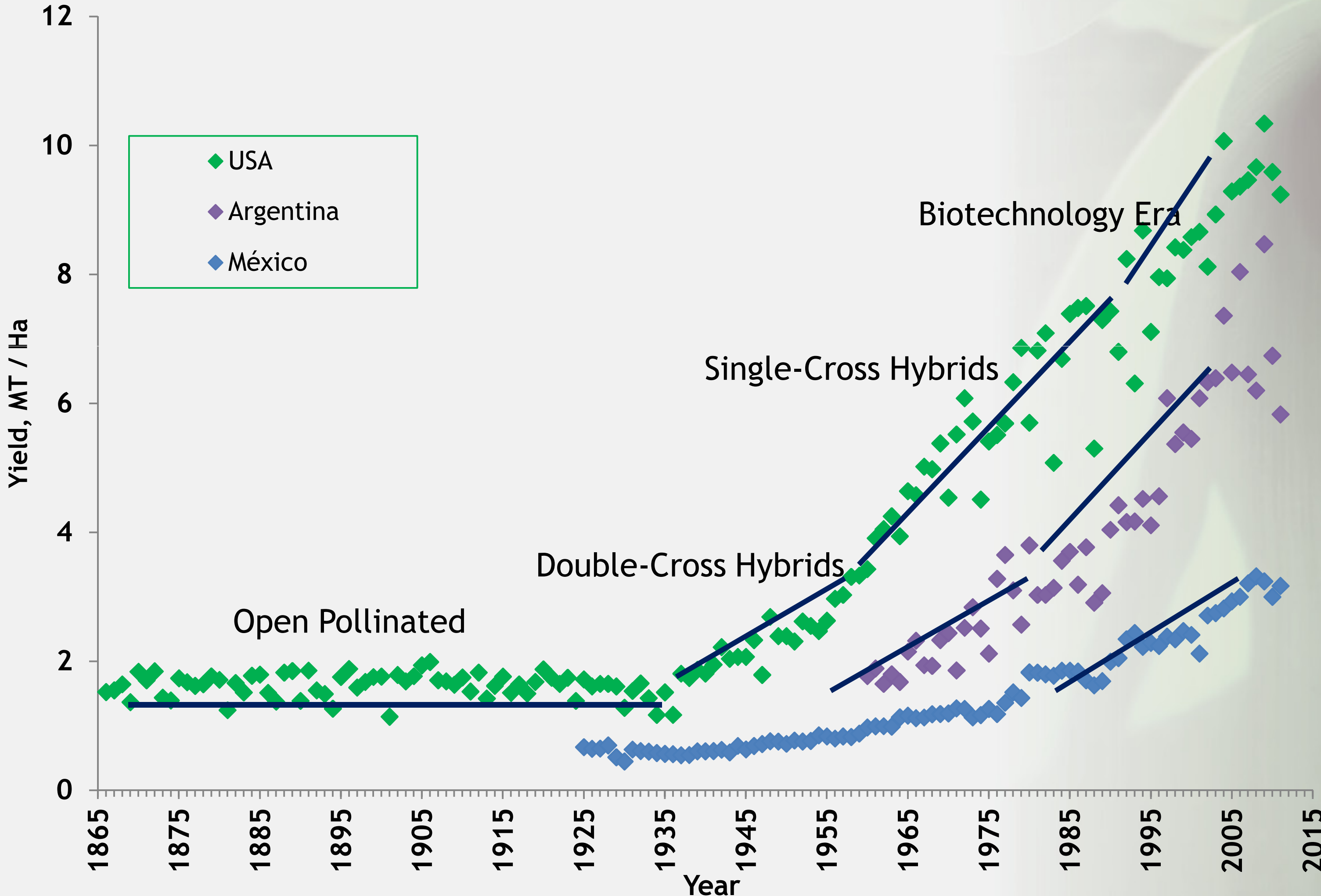
The US has been prolific in delivering agricultural productivity; other countries are repeating the trend



Source: Crop Science. Vol 46:528-543, USDA FAS and SAGARPA

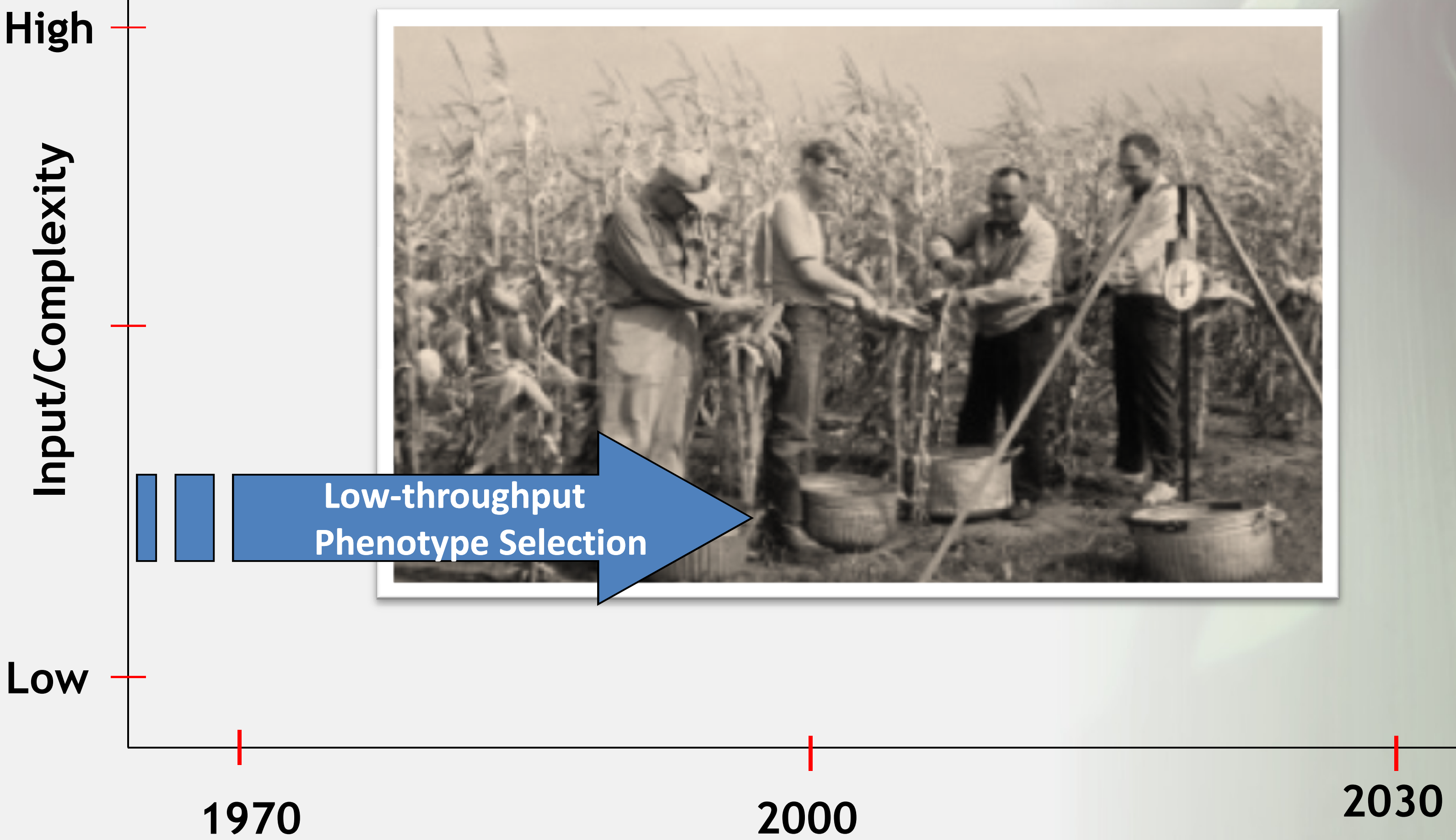
The technical strides that have made this all possible are little known

- Global research investment in the genetic improvement of corn for yield
- Green Revolution – improved agronomics and conservation practices
- Development of equipment for planting, cultivating, harvesting, and storing corn
- The introduction of biotechnology and genomics
- Market and supply chain and channel development

Yield improvements to-date have resulted from technical advancements in three major areas:

Plant breeding is a system of evolving technologies that continue to increase genetic gain

CORN BREEDERS MEASURED 3-5 TRAITS TO MAKE SELECTION DECISIONS



Plant breeding is a system of evolving technologies that continue to increase genetic gain

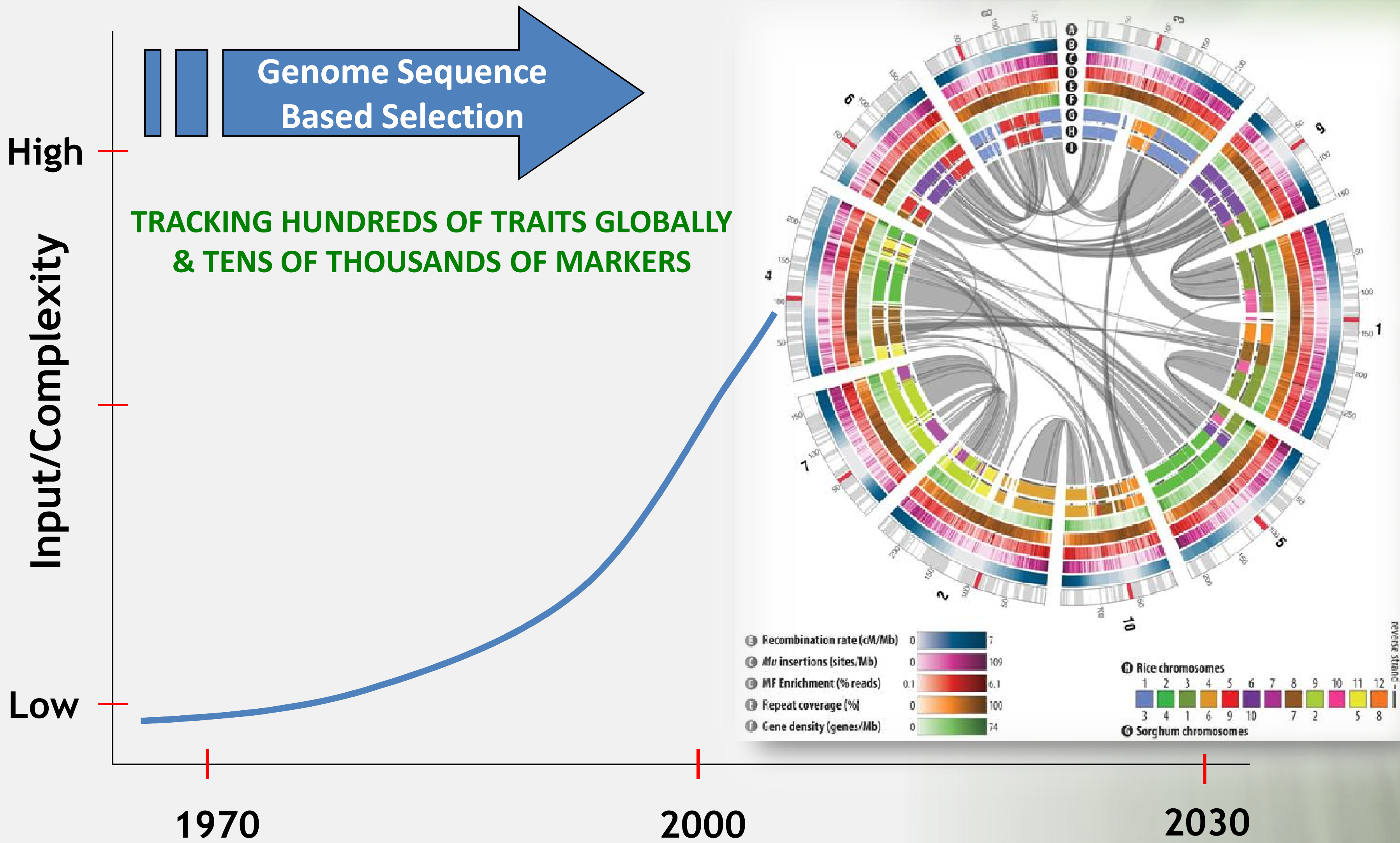
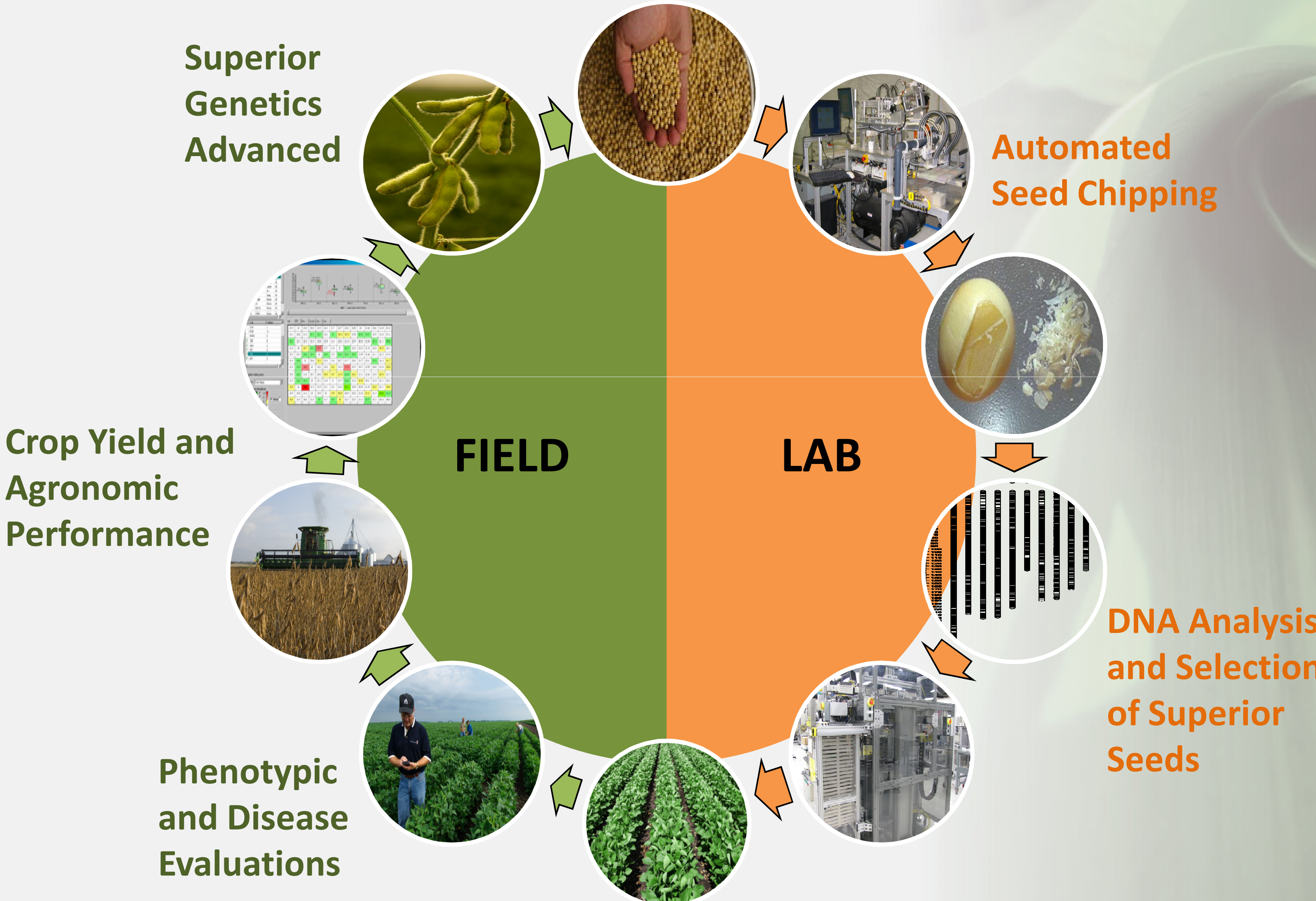


Image from Schnable et al. PLoS & Science, 2009

Stacking selection in the lab with selection in the field - rapidly mining our genetic library



The chipping revolution removes the bottleneck of hand sampling plant tissue

VS.

- ***Labor intensive***
- ***Time-consuming***
- ***Low-throughput***

Capable of analyzing millions of samples per year!

Genomics allows testing of thousands of candidate genes for new biotech traits

Sequencing	Sequence Bioinformatics	Expression Analysis	Phenotypic Testing
Genomic and cDNA	Discover & Annotate Genes	Functional Predictions	Translate Models to Crops
Billions of Bases	**100,000's of Genes**	**10,000's of Genes**	**1,000's of Genes**

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CCCATGCGCGAATCGATCGATTT
CTGACCATAGCTAGACTAGTCTA
GGCGCTAGATCGATCGATCGATC
GATTTCAGACTGGAAGTCATGCT
CCCATGCGCGAATCGATCGATTT
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GATTTCAGACTGGAAGTCATGCT
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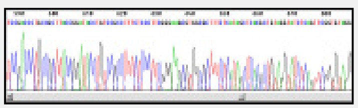
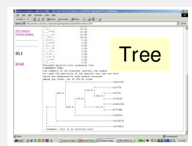
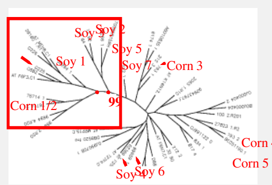
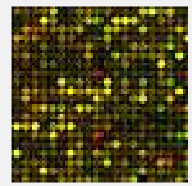
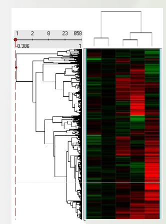




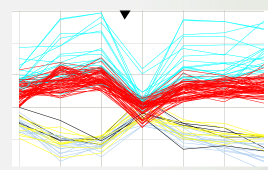


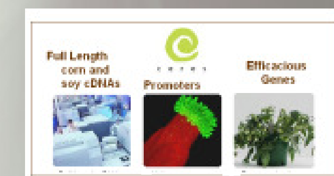
Gene Relationships





Rain



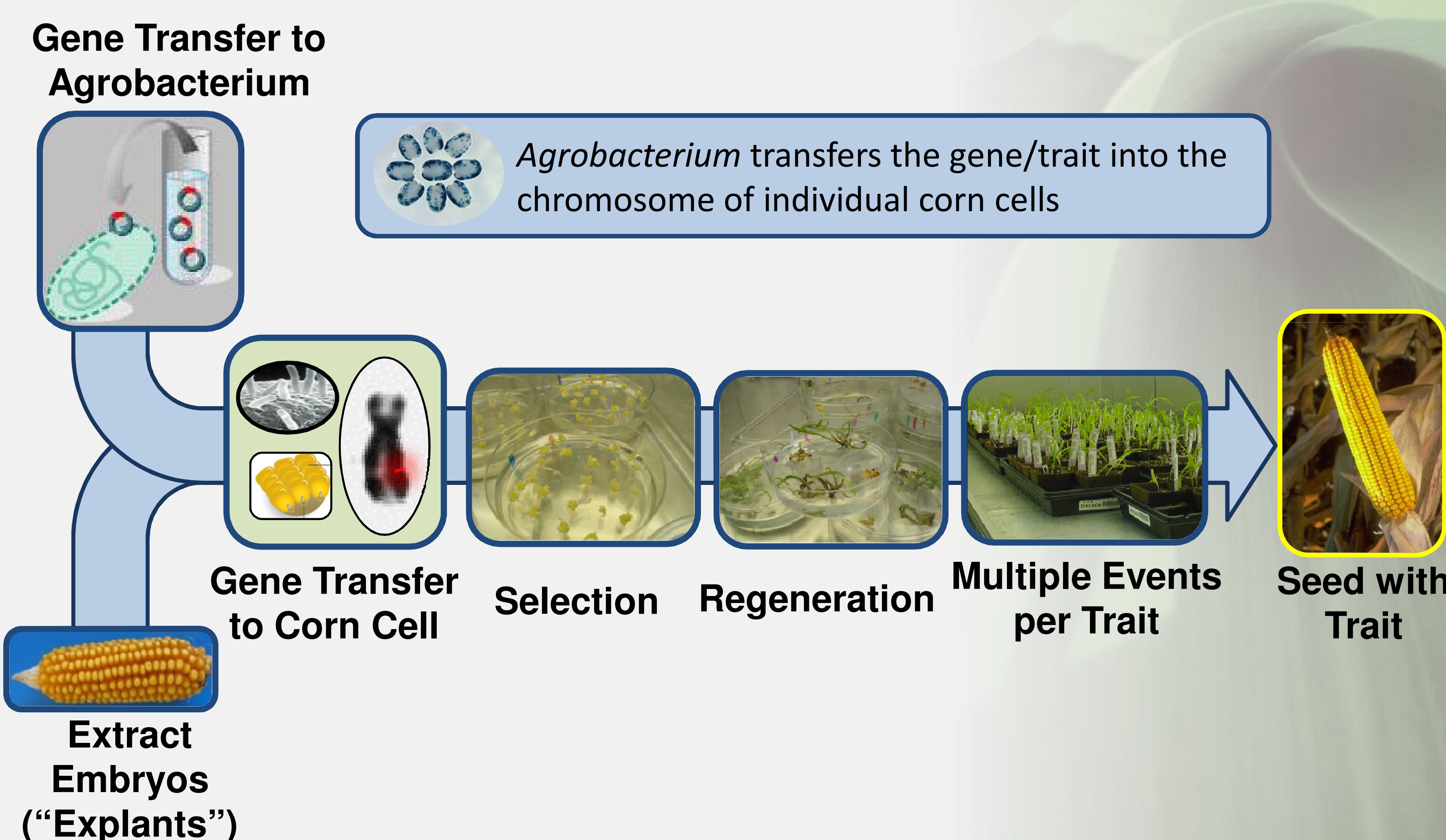


<u>Sequencing</u>

<u>Crops:</u> Corn, Soy, Cotton, Rice, Wheat, Sorghum, Tomato, Bean, etc.
<u>Models:</u> Arabidopsis, Medicago truncatula
<u>Microbes</u>: Aspergillus, Agrobacterium, Bt, etc.
<u>Pests</u>: CRW, SCN
<u>Public data</u> from hundreds of plant and microbial genomes

<u>Transcript Profiling:</u>
Corn, Soy, Rice, Arabidopsis, etc.

Thousands of candidate genes become tens of thousands of transformation events



Automated phenotyping is a key enabler of massively-parallel gene screening

Assembly–Line Automation

- Automated Plant Handling
- Anticipatory Environmental Controls

Plant Growth and Physiology

Corn Soy Cotton

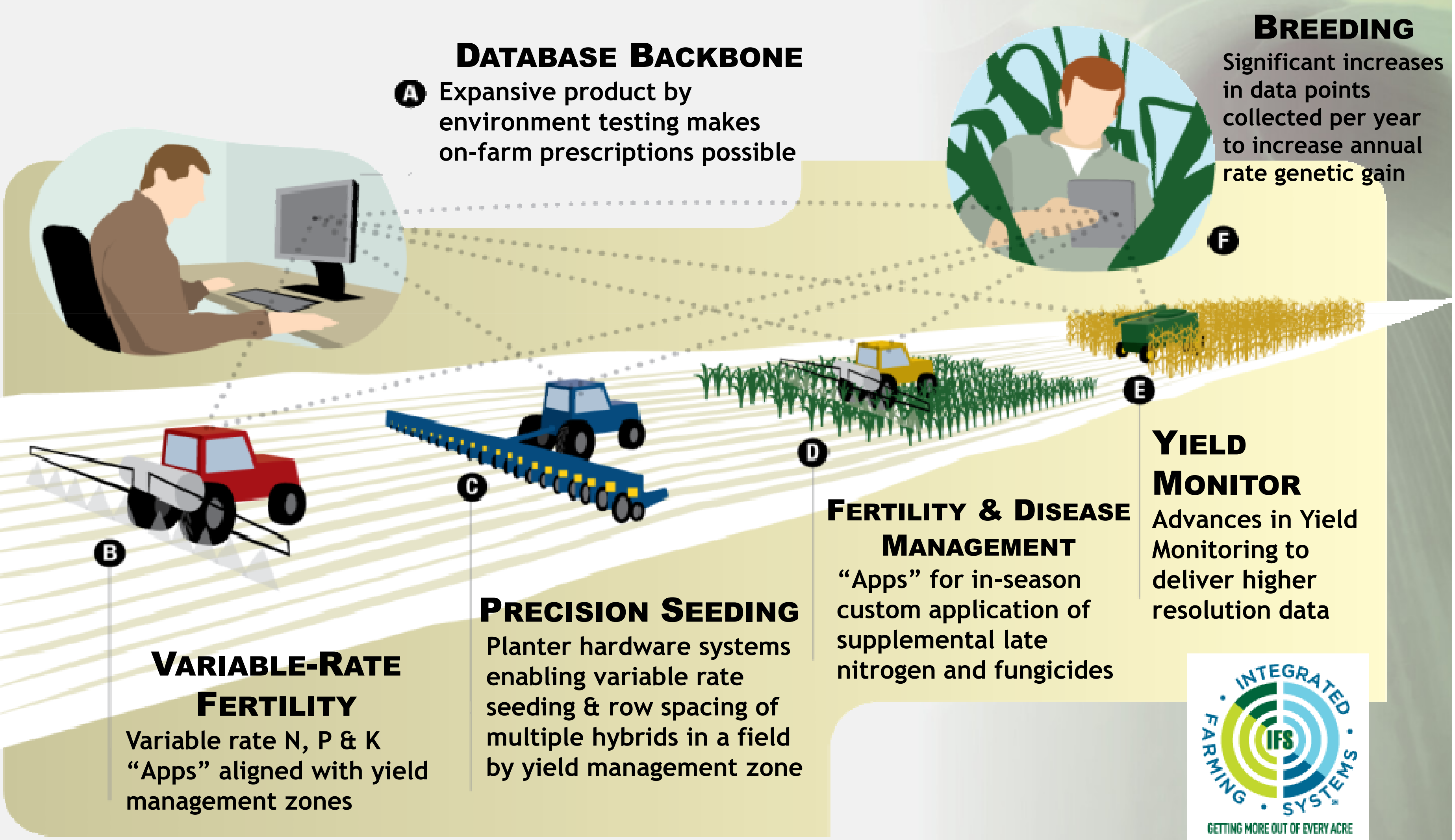
- Drought and Reduced Nitrogen Conditions
- Same Seed is Tested in Field

Image Analysis

- Daily Imaging and Growth Rate
- 1000s of Measurements per Gene
- Visible and Hyperspectral Imaging

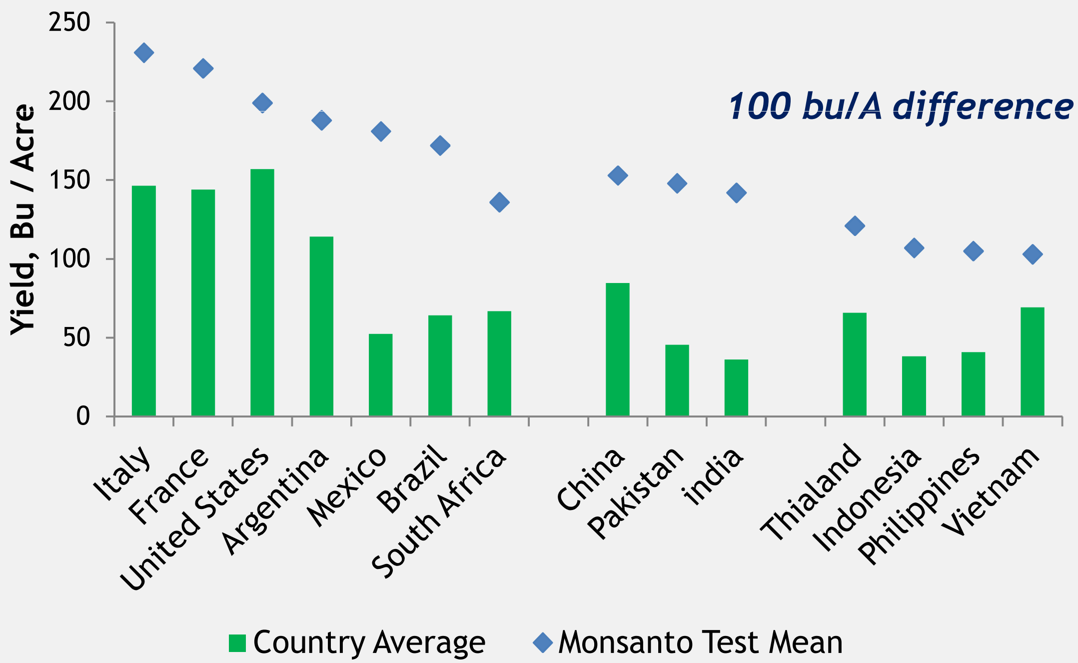
Robust Data Systems

Integrated Farming Systems[SM] would combine advanced seed genetics, on-farm agronomic practices, software and hardware innovations to drive yield



Opportunities for even further yield improvement are evident today

Corn yield differences – Monsanto trials versus “county “averages

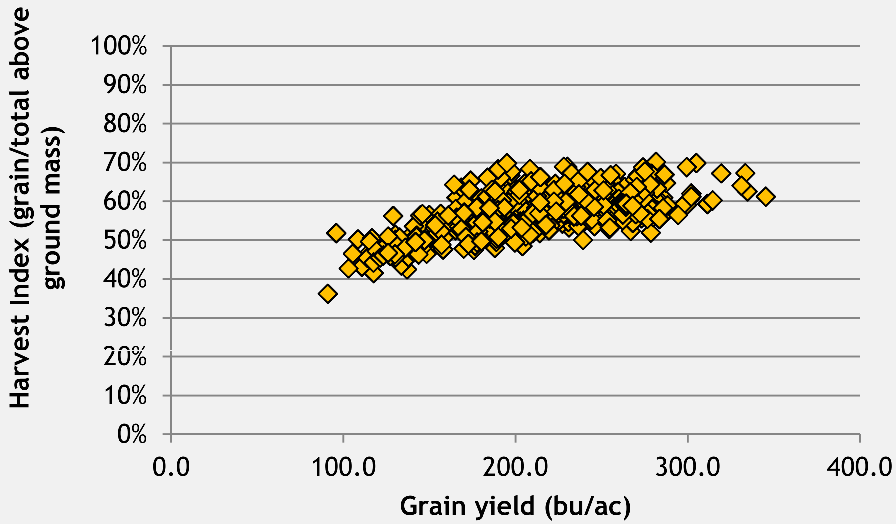


Country	Open Pollinated
Italy	0%
France	0%
United States	0%
Mexico	71%
Brazil	27%
India	54%
Indonesia	20%
Philippines	41%

Enabling the commercial viability of corn stover harvest

A focus on increasing corn grain yield increased corn stover yield and resiliency

Harvest index vs. grain yield



2008 trials– 13 locations, 14 unique hybrids (101 to 111RM)

Planting 2nd yr corn in Nebraska

	200 bu/ac field
Grain makes up about 58% of the biomass in a field at harvest	4.8 dry tons/ac
Stover (stalks, cobs, leaves) makes up about 42% of the biomass	3.4 dry tons/ac

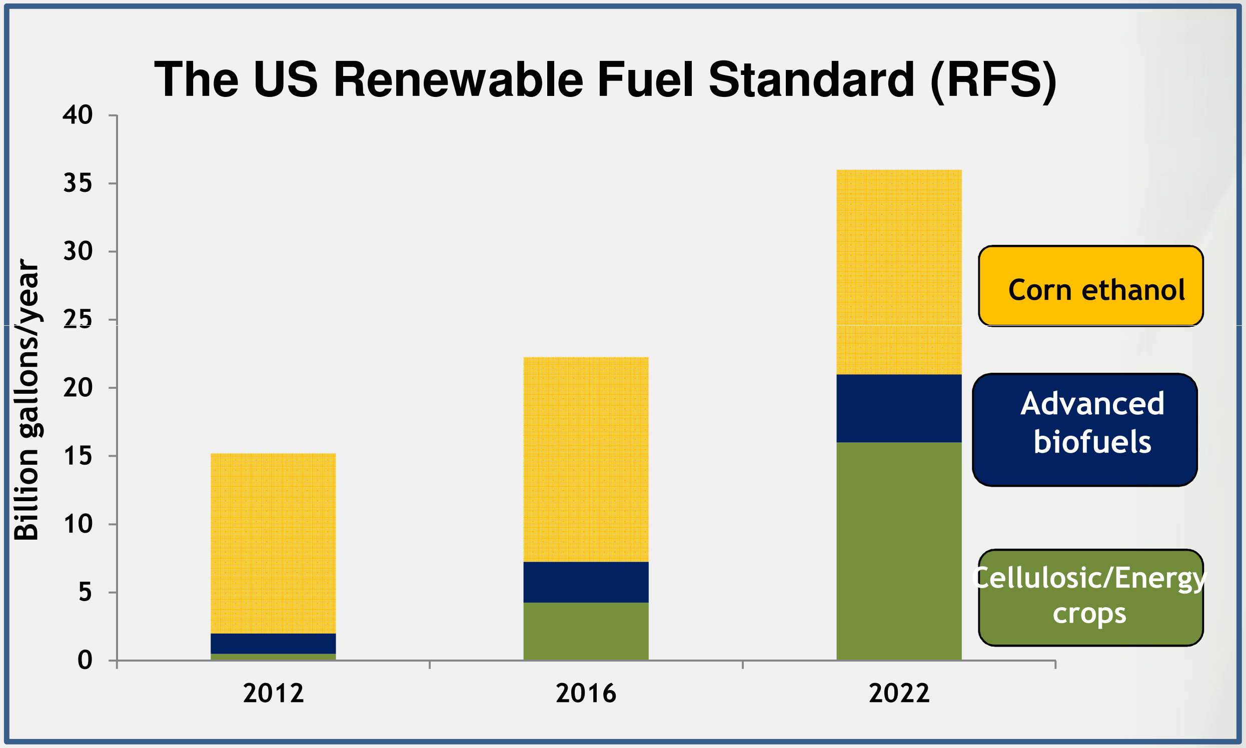
Growers needed demonstrated and sustainable economic removal solutions

Baled field in Iowa

Shredded field in Nebraska with wind drift

- Properly done, corn stover harvests will increase the value of an acre of corn
- Improperly done, corn stover harvests will damage fields

Policy has created a lot of interest in stover removal
The RFS mandates 36 billion gallons per year (BGY) of renewable fuels by 2022 with 16 BG to come from cellulosic feedstocks like stover



20% GHG reduction - 15 BG

50% GHG reduction – 5BG

60% GHG reduction - 16 BG

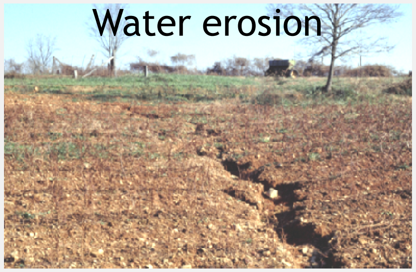
Advanced can be anything except corn starch ethanol – is assumed to be mainly sugarcane

GHG = greenhouse gas (carbon dioxide, methane, nitrous oxide all as CO_2 equivalents)

But there were many opinions on what is actually available to sustainably remove

Study	Spatial Extent	Annual Total Residue Sustainably Available (million metric tons)			Timeframe	Crops
		US	Iowa	Regional		
Larson, 1979	Corn Belt, Great Plains, and Southeast	N/A	N/A	49.0	1975	Corn Stover, Wheat Straw
Nelson, 2002	37 states from the Great Plains to the East Coast	N/A	10.1	47.6	1997	Corn Stover, Wheat Straw
Sheehan et al., 2003	Iowa	N/A	40	N/A	1997	Corn Stover
Nelson et al., 2004	10 Corn Belt and Great Plains States	N/A	59.5	430.3	2001	Corn Stover, Wheat Straw
Perlack et al., 2005;	Whole US	176	14.5	176	2005	Corn Stover, Wheat Straw, Barley Straw, Sorghum Stover
Graham et al., 2007;	Whole US	58.3	13.7	58.3	2000	Corn Stover
Muth and Bryden, 2012	Iowa	N/A	26.5	N/A	2010	Corn Stover, Wheat Straw
Muth et al., 2012	Whole US	150.9	25.9	150.9	2011	Corn Stover, Wheat Straw, Barley Straw, Sorghum Stover, Rice Straw
Muth et al., 2012	Whole US	207.9	37.3	207.9	2030	Corn Stover, Wheat Straw, Barley Straw, Sorghum Stover, Rice Straw

Stover removal must not damage the land



A "Sustainable" harvest must meet both environment and economic requirements

Production and removal must provide value to all participants

Land owner

Grower

Baler

End user

- **Every field is unique: averages are dangerous**
- **Sustainable removal levels will vary with yield**
- **Nutrient replacement costs will vary by field, year and markets**
- **Weather challenges will occur**

MONSANTO imagine®

Feedstock improvement

JOHN DEERE

Improved tillage, planting and harvest

ADM

Biofuel/feed production Improvement

Information and data are being broadly shared and developed

- Coordinated Field Trials
  - Sustainability Metrics
  - Agronomic Practices
- Commercial Scale Trials
  - Learning Curves
  - Testing the Viability of Agronomic Strategies
- Decision Support
  - Advanced Computational Methods
  - Data Management
  - Tool Deployment

SunGrant INITIATIVE

USDA ARS United States Department Of Agriculture Agricultural Research Service

MONSANTO

Renewable Energy Assessment Project

U.S. DEPARTMENT OF ENERGY

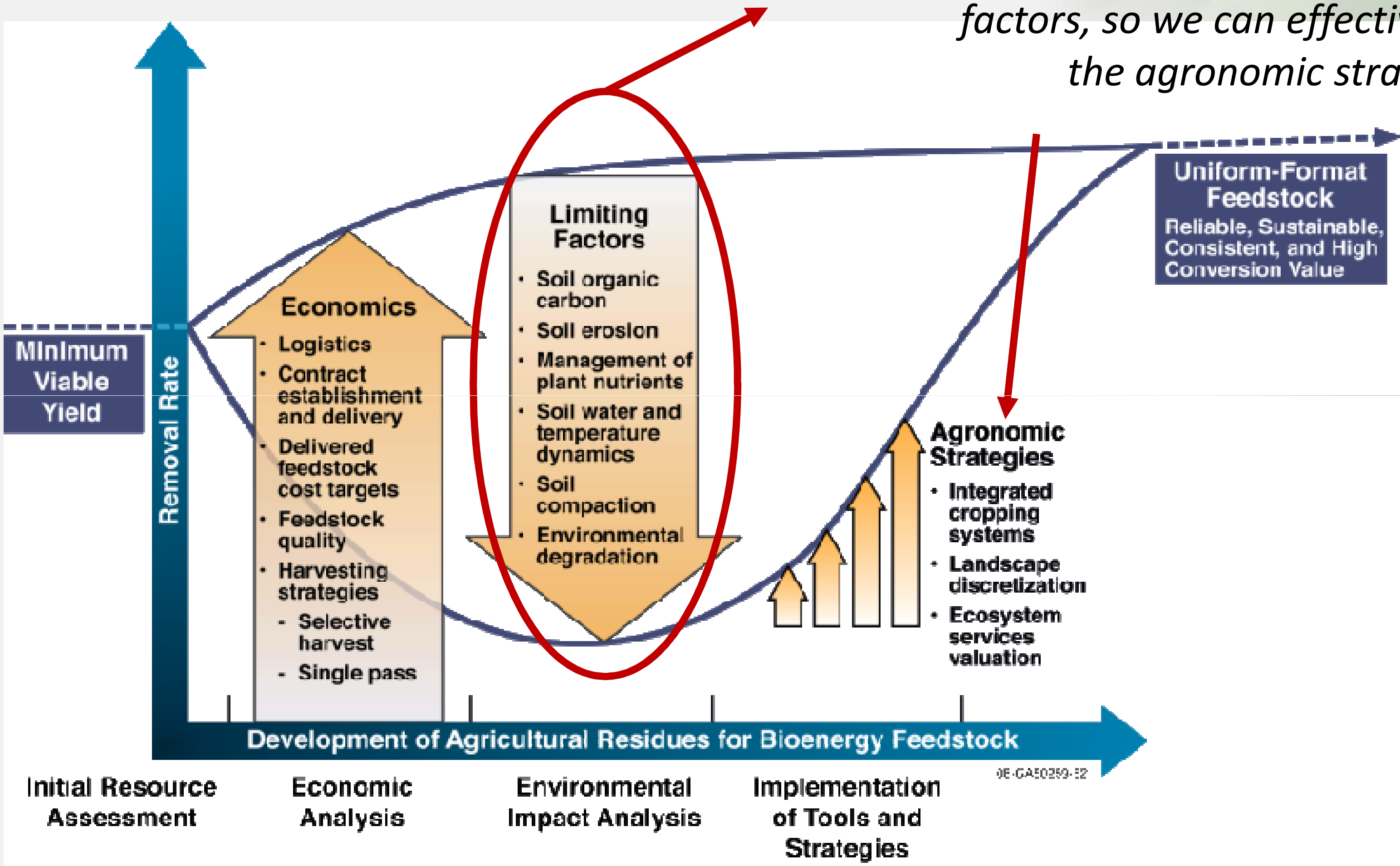
INL Idaho National Laboratory

JOHN DEERE

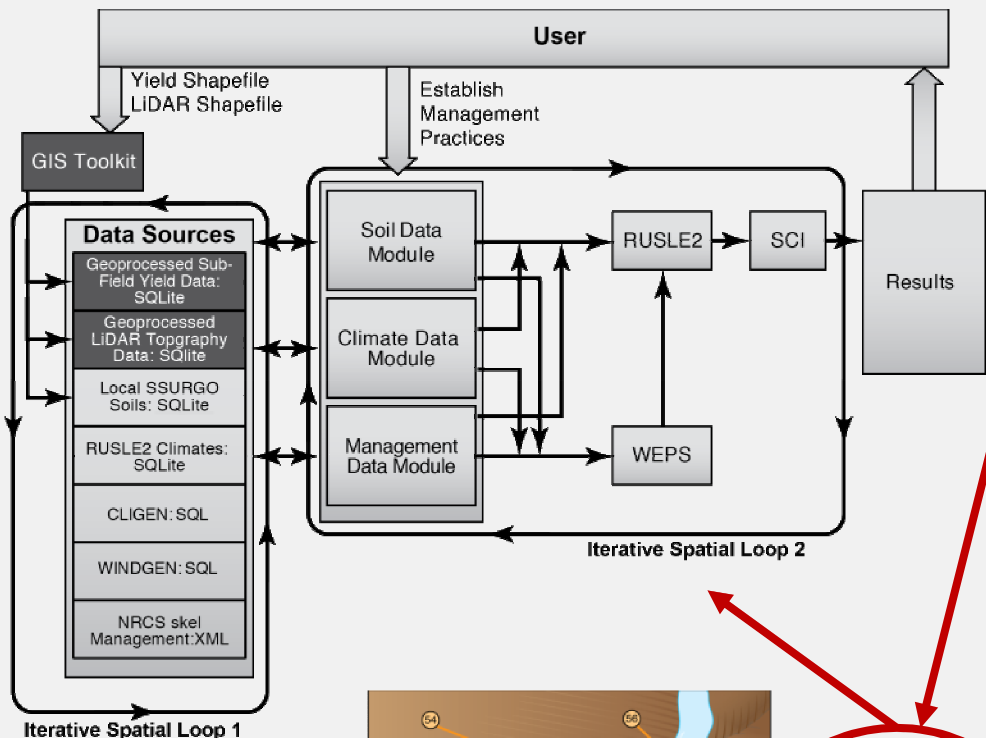
ADM

With a focus on sustainable residue removal

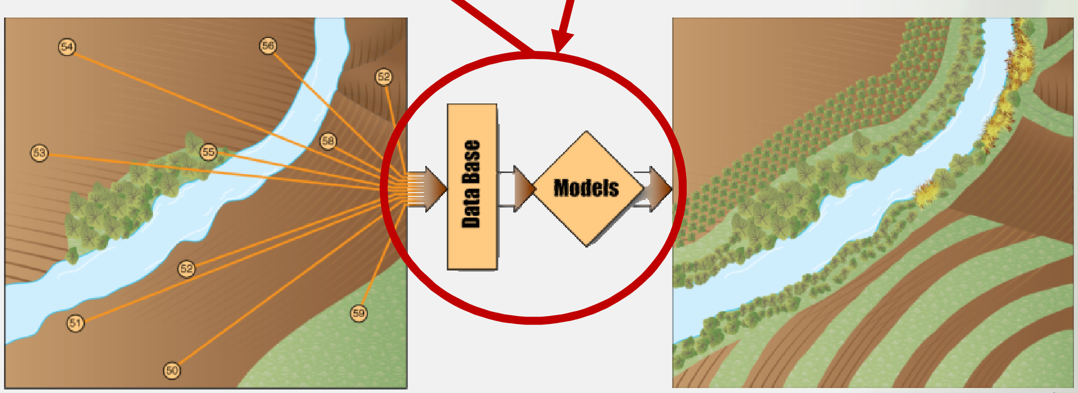
Focused on quantifying the limiting factors, so we can effectively develop the agronomic strategies



A modeling framework was developed for planning



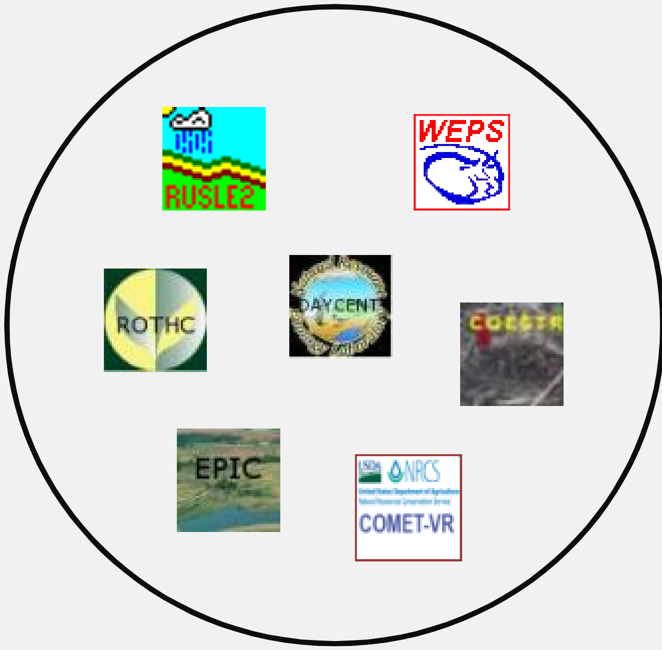
- ➢*Quantitative Soil C Analysis*
- ➢*Green House Gas Fluxes*
- ➢*Water Quality Impacts*
- ➢*Crop Practice Strategies*



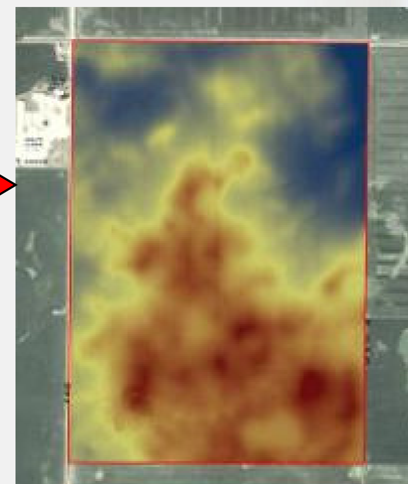
Direction on best residue management is critical

Approach

Simulation Models



Databases – e.g. SURGO

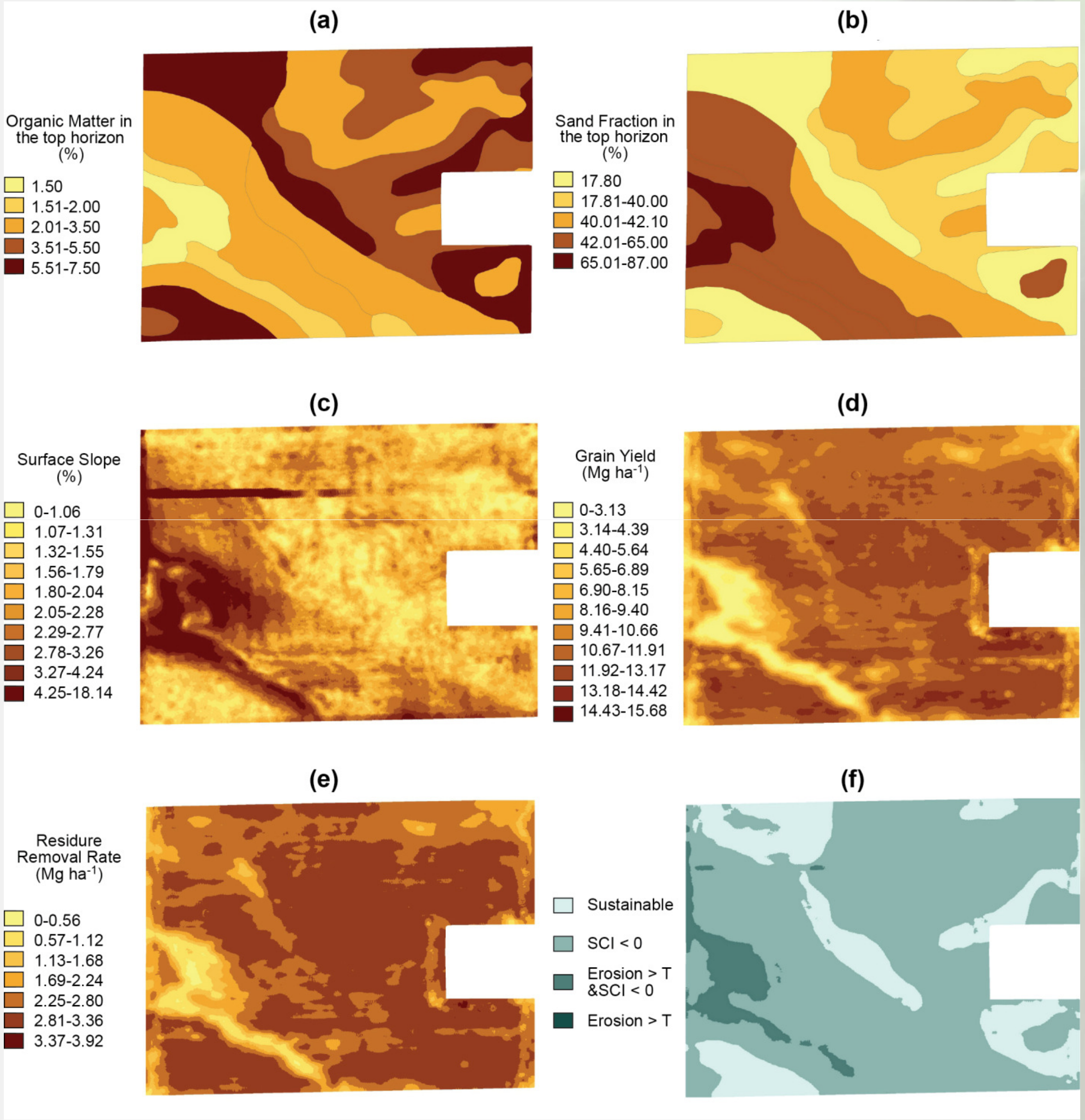


Field Management Decisions

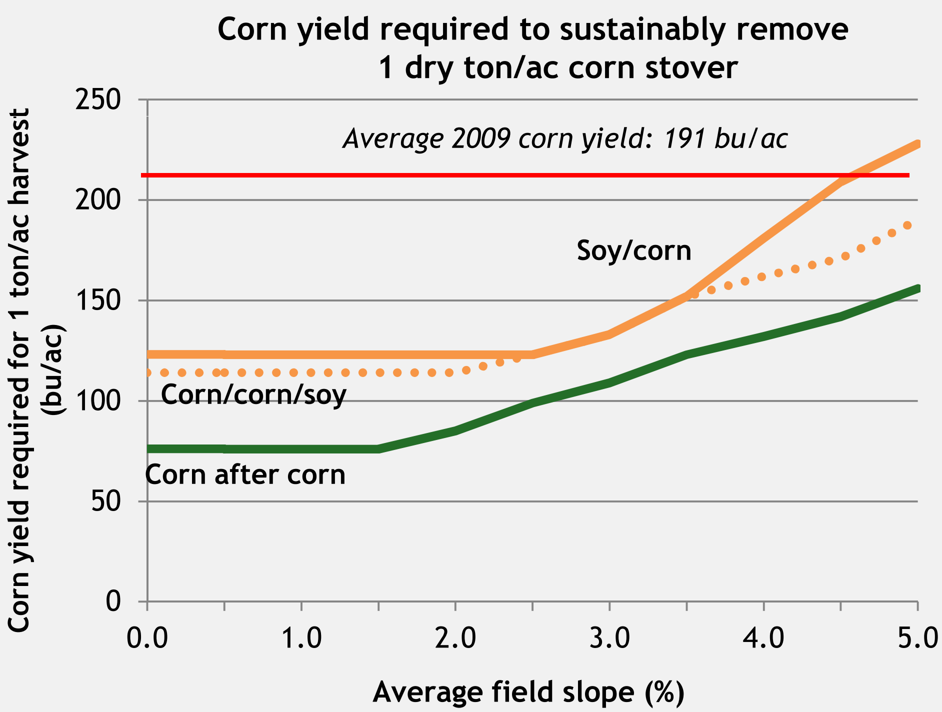
The models and databases exist,

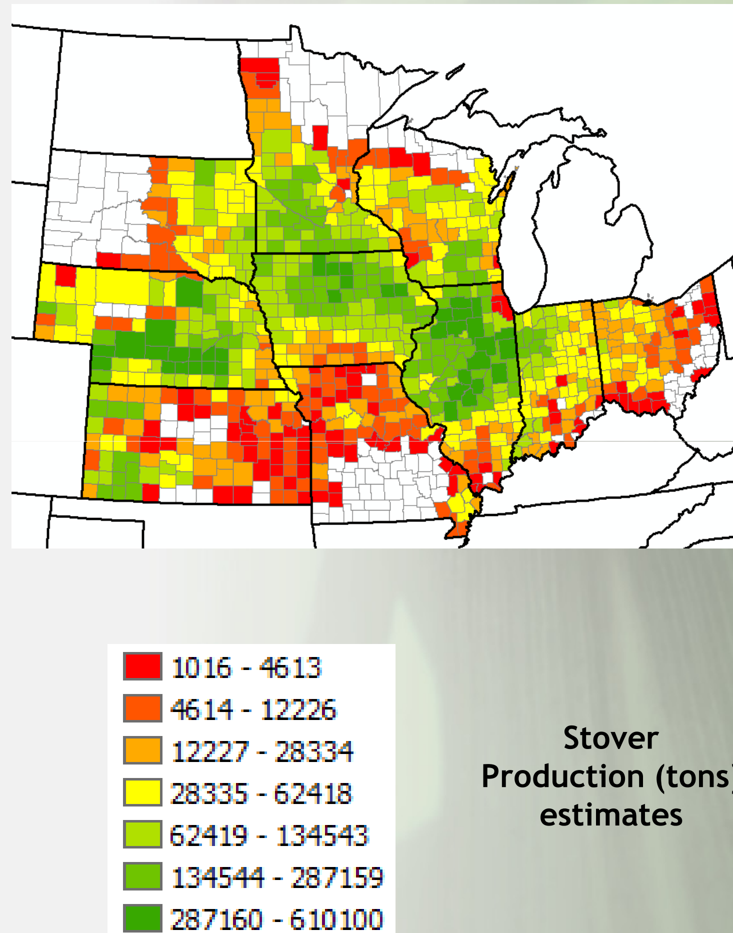
The Residue Management Tool provides a framework where models can plug together to answer questions using available data.

Understanding sustainable harvest: Sub-field scale variability



Ultimately slope, rotation, yield and climate dictate sustainable stover removal rates



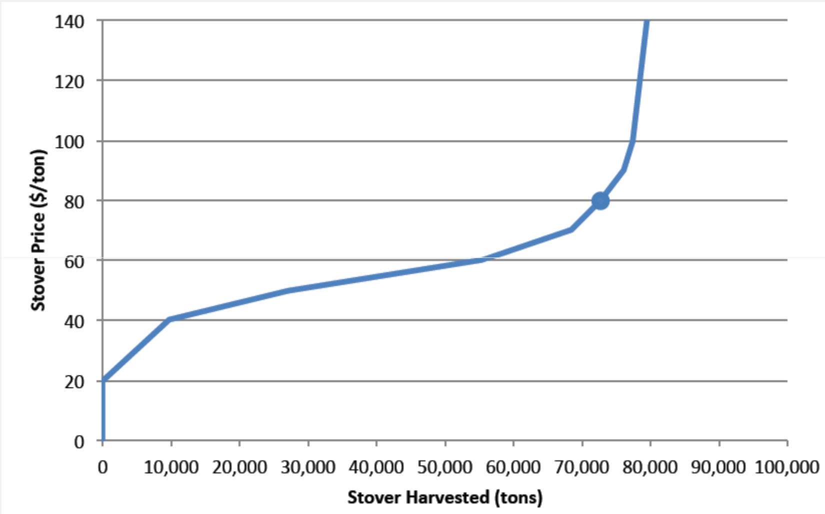


Benton County, Iowa harvest rate estimates

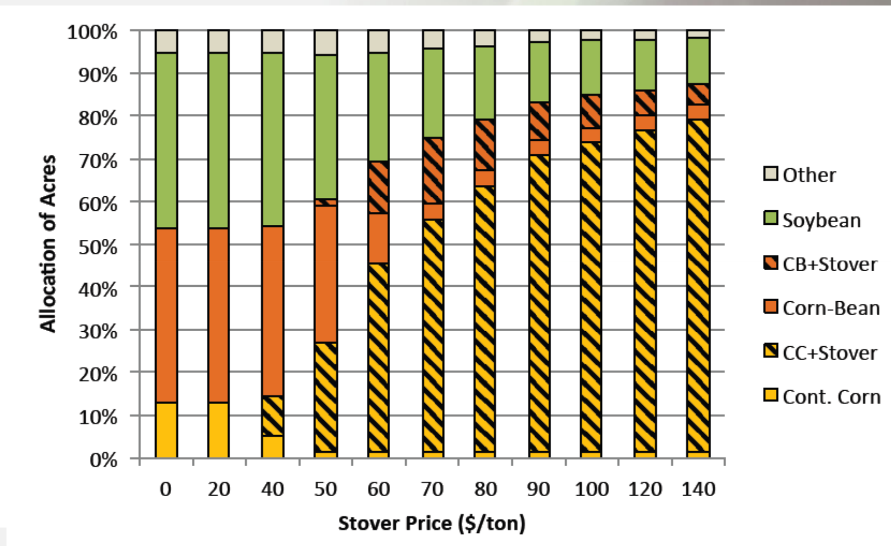
The economics of stover harvest determine use

Economic modeling study from Purdue use costs from stover project

Stover supply vs. price



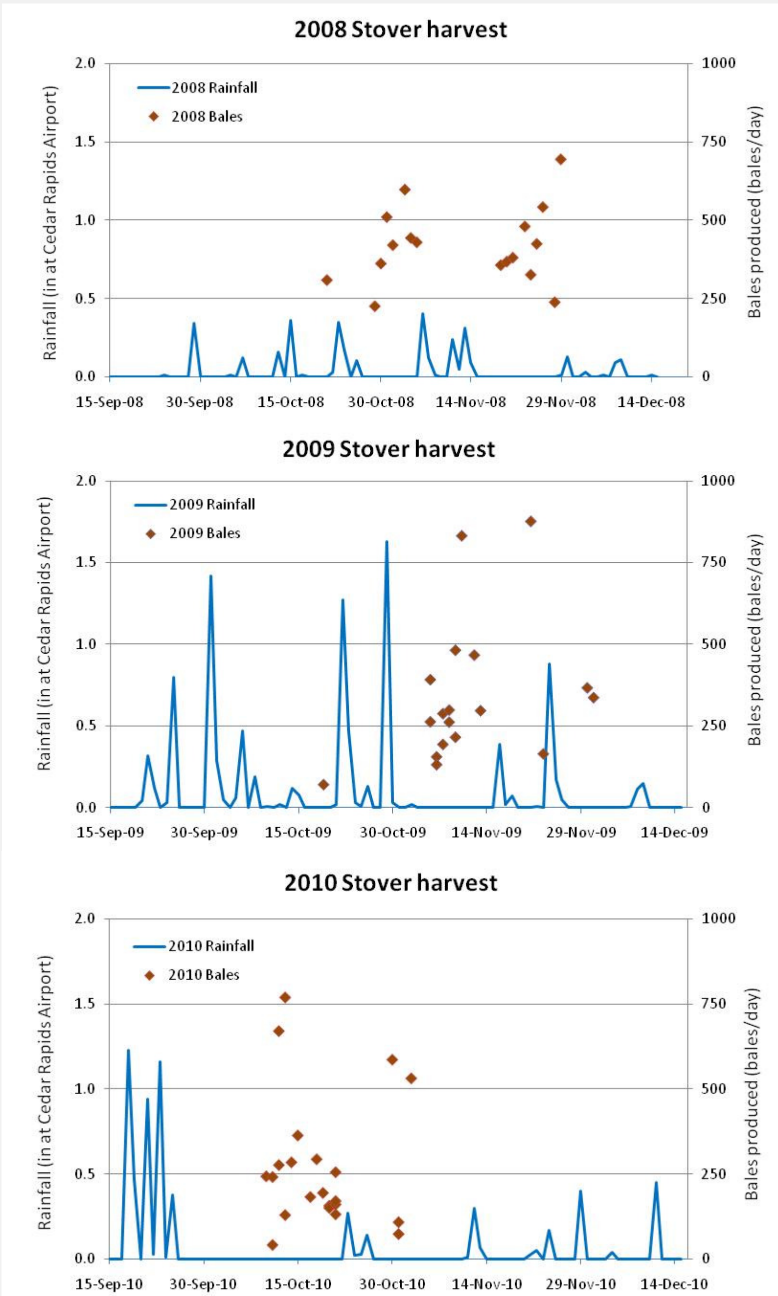
Farmer planting decisions vs. price



Thompson and Tyner (2011) Corn stover for bioenergy production: Cost estimates and farmer supply response. Master's Thesis
Corn Stover for Bioenergy Production: Cost Estimates and Farmer Supply Purdue Ag Extension Bulletin RE-3-W
http://www.extension.purdue.edu/extmedia/EC/RE-3-W.pdf

It isn't easy

3 unusual years = "average" weather



2008 – Delayed crop, frequent light rains, stover harvest during two breaks in rainfall, 17 harvest days

2009 – Very delayed crop, frequent heavy rains, stover harvest during longer break in rainfall, 18 harvest days

2010 – Early crop, excellent weather, 22 harvest days

This is "average" weather

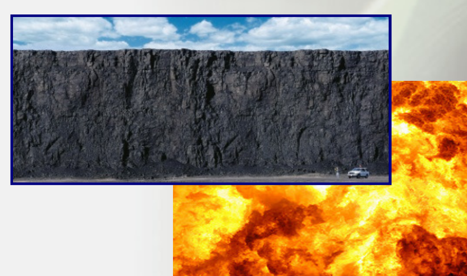
- Harvest day defined as 3rd dry day
- 3.2 ± 0.5 harvest days/wk (1988-2009)
- Assume 6 week harvest window
- "average" is 19.2 harvest days
- 2008 – 2010 average – 19 harvest days/yr

Stover biomass has alternative uses with alternative values

Corn grain production

Stover

Displace coal



90% GHG reduction per BTU

Produce cellulosic ethanol

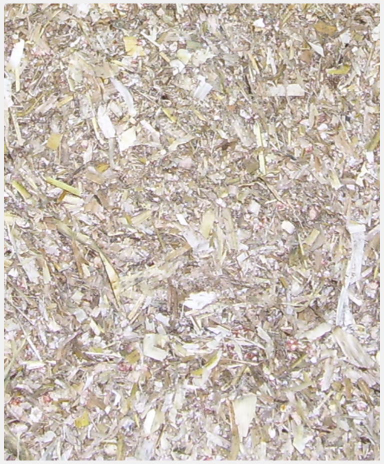
Offsets additional corn or energy crop production

Produce animal feed

Offsets additional corn production

Lime treatment can improve feed value of corn stover

Ground stover



Add calcium hydroxide and water

Treated stover

Lime treatment reduces cell wall components that hinder digestibility

Component	Percent reduction
Acetyl sugars	92%
Lignin	70%
Cellulose polymerization	56%

Kumar et al (2009) Bioresource Tech 100:3948

Improves *in vitro* digestibility by 30-50%

Economics are driving commercialization

Corn stalks chopped

Treated with lime and transported

Bunkered for feeding

Heifers enjoying treated stalks

- Lime treatment increases corn stalk nutritional value
- Treated stalks displace portion of corn in diet
- Grower makes incremental $30-$60/A
- Cattleman makes incremental $10-$20/head
- Stalks as feed effectively increases the productivity of the corn by 50 bu/acre
- Commercial operations developing

KearneyHub.com

Posted: Saturday, October 6, 2012 1:00 pm | *Updated: 1:07 am, Sat Oct 6, 2012.*

Recipe combines attachment, lime for new corn stover harvest method

Innovation creates cattle feed option, added crop value for farmers

Lori Potter, Kearney Hub file

"From a farmer-feeder standpoint, this is just an amazing opportunity, and you still have the corn as a revenue source," *Duane Kristensen said Thursday at a stover harvesting demonstration in his cornfield north of Minden*

"It's almost like a double-crop situation …," *said farmer and KAAPA President Paul Kenney.* **"Stover is a crop. As long as we can keep up productivity and take the stover off, it's a great benefit to us."**

Soil health: Manage to erosion and organic matter targets

Stover is required to maintain soil quality

- Reduces wind erosion
- Reduces water erosion
- Provides organic matter to soil

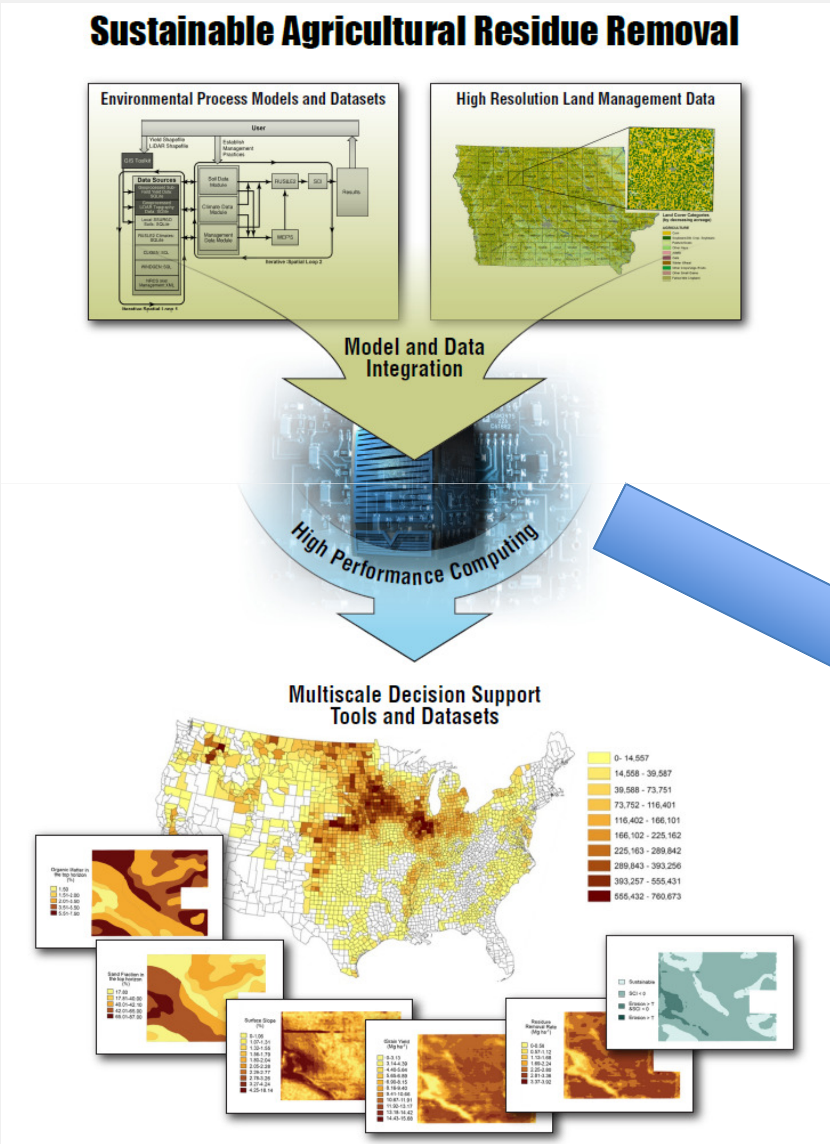
Soil organic matter

- Enhances soil water and nutrient holding capacity
- Improves soil structure (less crusting, compaction and erosion)
- Promotes higher crop yields

Conservation planning tools (RUSLE2, WEPS, and SCI) have been used to estimate field-specific stover retention targets

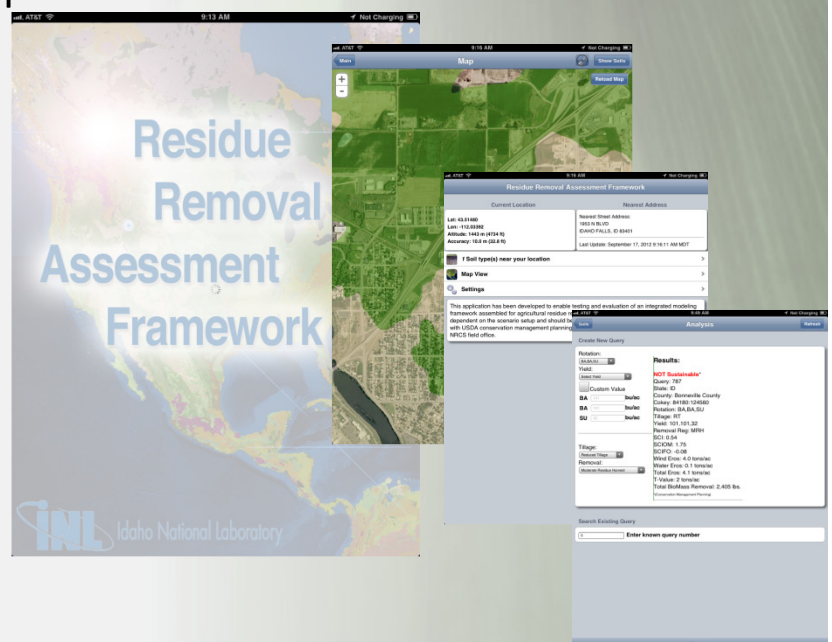
- Andrews S (2006) Crop Residue Removal for Biomass Energy Production: Effects on Soils and Recommendations http://soils.usda.gov/sqi/management/files/agforum_residue_white_paper.pdf
- University of Nebraska Extension: Harvesting Crop Residues http://www.ianrpubs.unl.edu/epublic/pages/index.jsp?what=publicationD&publicationId=1026
- USDA NRCS (2010) Conservation practice standard 344: Residue management, Seasonal. ftp://ftp-fc.sc.egov.usda.gov/NHQ/practice-standards/standards/344.pdf
- USDA NRCS Soil Quality Institute (2003) Interpreting the Soil Conditioning Index: A Tool for Measuring Soil Organic Matter Trends. Technical Note No. 16 http://soils.usda.gov/SQI/management/files/sq_atn_16.pdf

Sustainable residue removal mobile application



<u>Why a Mobile Application?</u>

- Data acquisition and removal decisions are essentially simultaneous
- Need an informed answer that fits with existing workflows
- Engage regulators and conservation planners
- The foundations for mobile app deployment provide a strong platform for the next set of research questions



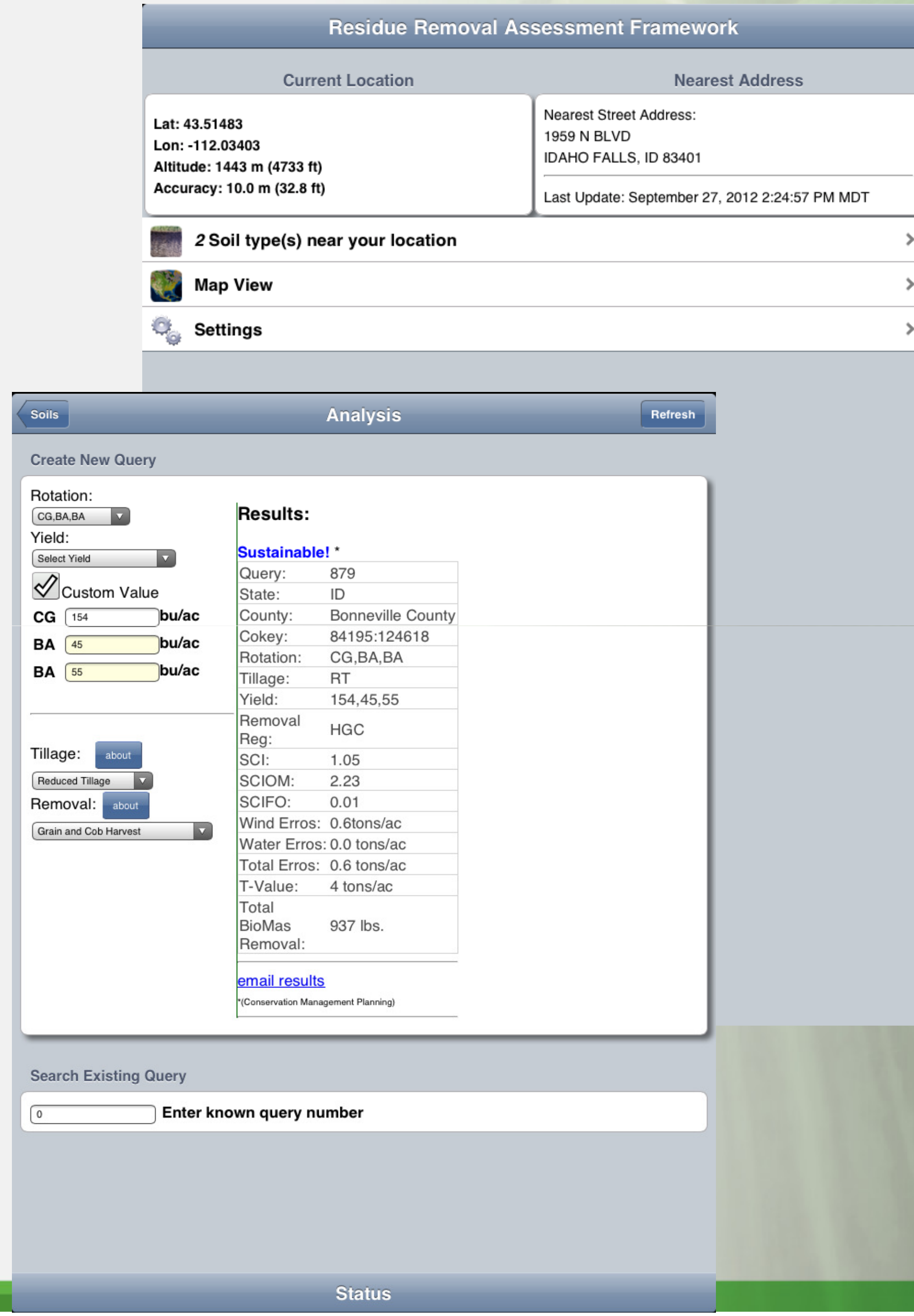
Mobile App Status

Availability

- URL: http://bioenergyldt.inl.gov/mobile
- Desktop URL: http://bioenergyldt.inl.gov
- Mobile App:
  - Available in the App Store in about 3-4 weeks
  - Currently distributed on a user-by-user basis from INL

Path Forward

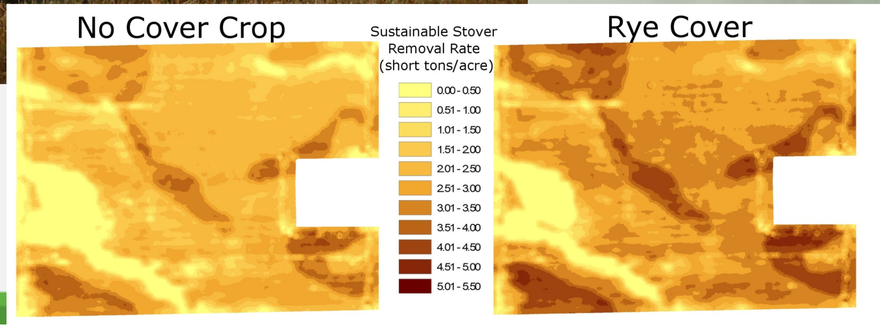
- Current support 4 simultaneous users, will increase as necessary
- NRCS test plan
- Map selection interface
- Advanced agronomic strategies
- Advanced equipment designs



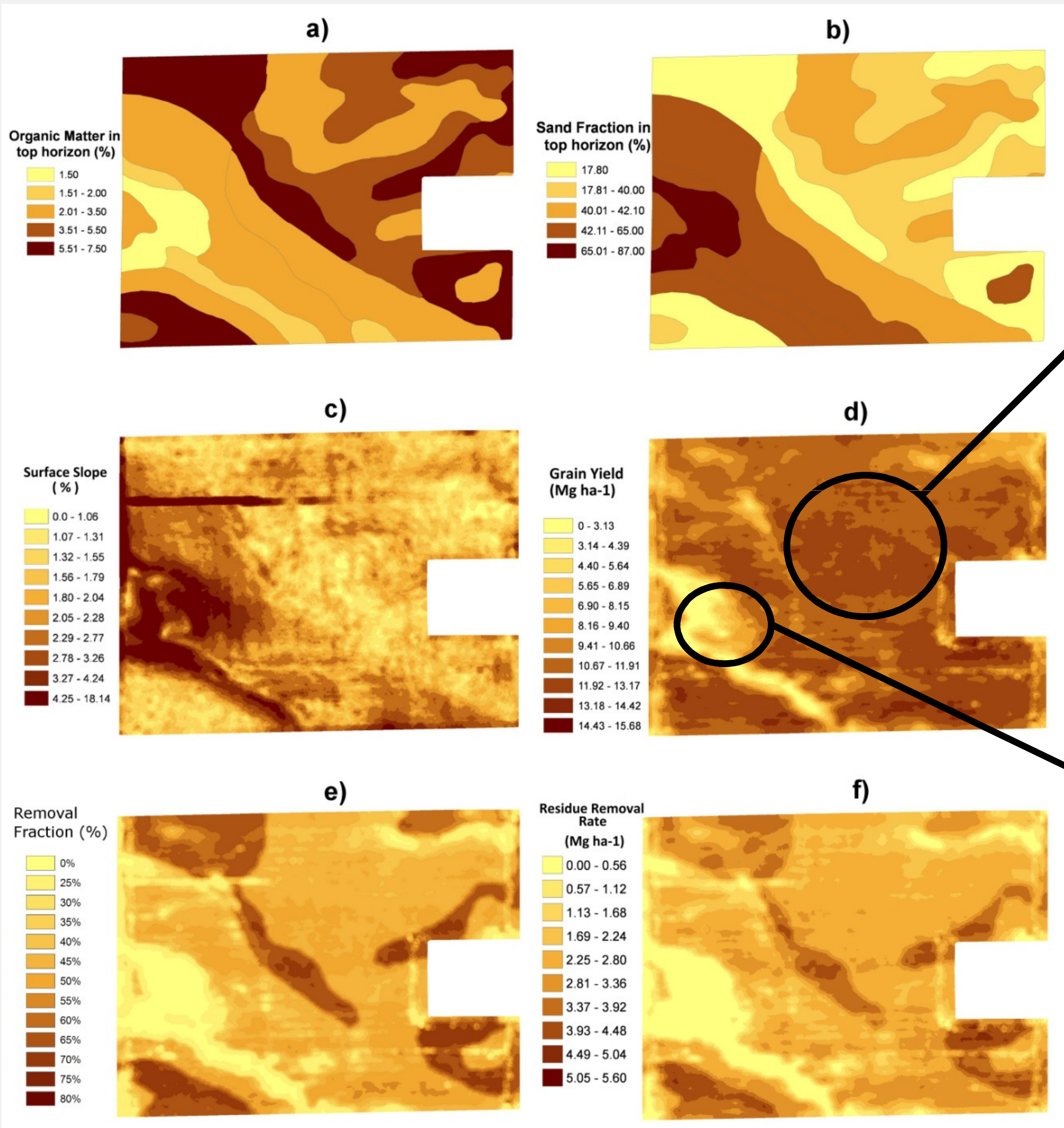
Strategies for increasing residue removal

Sustainable management options

- Lower removal rates via equipment choice or interval removal schemes
- Advanced equipment development, i.e. variable rate
- Agronomic strategies
  - Tillage
  - Cover crops
  - Landscape management concepts



Implementing sustainable harvest: Variable removal rates



- 200+ bu/acre corn

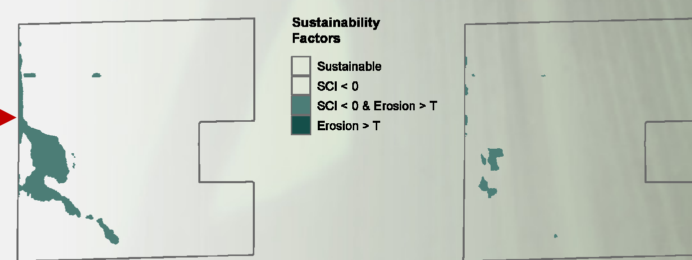
10 miles difference

- Less than 65 bu/acre

Whole-Field Cover Crop Effects

Rake and Bale Removal	Reduced Tillage		
	Annual Sustainable Residue (metric tons)	Percentage of Field Managed Sustainably	Annual Soil Loss (metric tons)
Modeling Scenario† 1 (Corn/Soy)	36	21%	316
Modeling Scenario 2 (Corn/Rye/Soy)	140	83%	182

Impact of row crop production management decisions implemented within the whole field

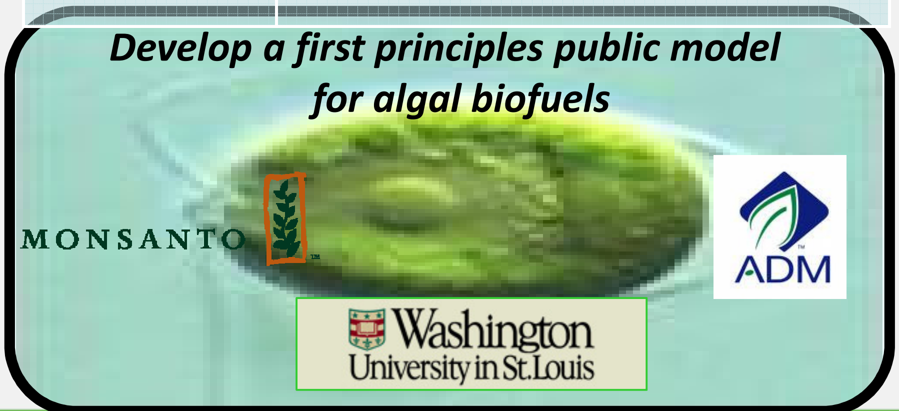


† Modeling designations from Table 4 in Karlen and Muth, 2012. Agrociencia Uruguay, Special Issue:98-106.

Barriers to commercial viability of algal biofuels

Algae for biofuels garnered enormous Interest; feasibility was unclear

ALGENOL BIOFUELS Harnessing the Sun to Fuel the World™	Ethanol in enclosed photobioreactors, Florida, Mexico, collaboration with Dow Chemical
	In 2009 DOE Announces $85 Million for Algal and Advanced Biofuels
Phycal	Dick Sayre, Danforth center, "milking" & "heteroboost", Hawaii then Southeastern US
Sapphire Energy	Pilot-scale production in New Mexico planned for 2010
solazyme	Fermenters, starting with higher-value non-fuel products, collaboration with Chevron
SYNTHETIC GENOMICS	Craig Venter, 2009 $600M collaboration with Exxon/Mobil



Algal Claims

- Demonstrated >10x per acre yield than terrestrial crops
- Can utilize marginal land – no competition with food
- Can use CO_2 from smoke stacks (makes coal "green")

Algal Challenges

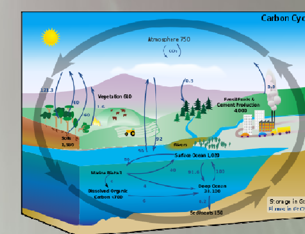
- Energy drain: centrifugation and drying may consume more energy than is in the biofuel
- Needs added CO_2 to grow, so may be dependent on fossil fuels/locations
- Unsolved problems of scale & contamination
- Weekly harvesting
- Huge capital investment

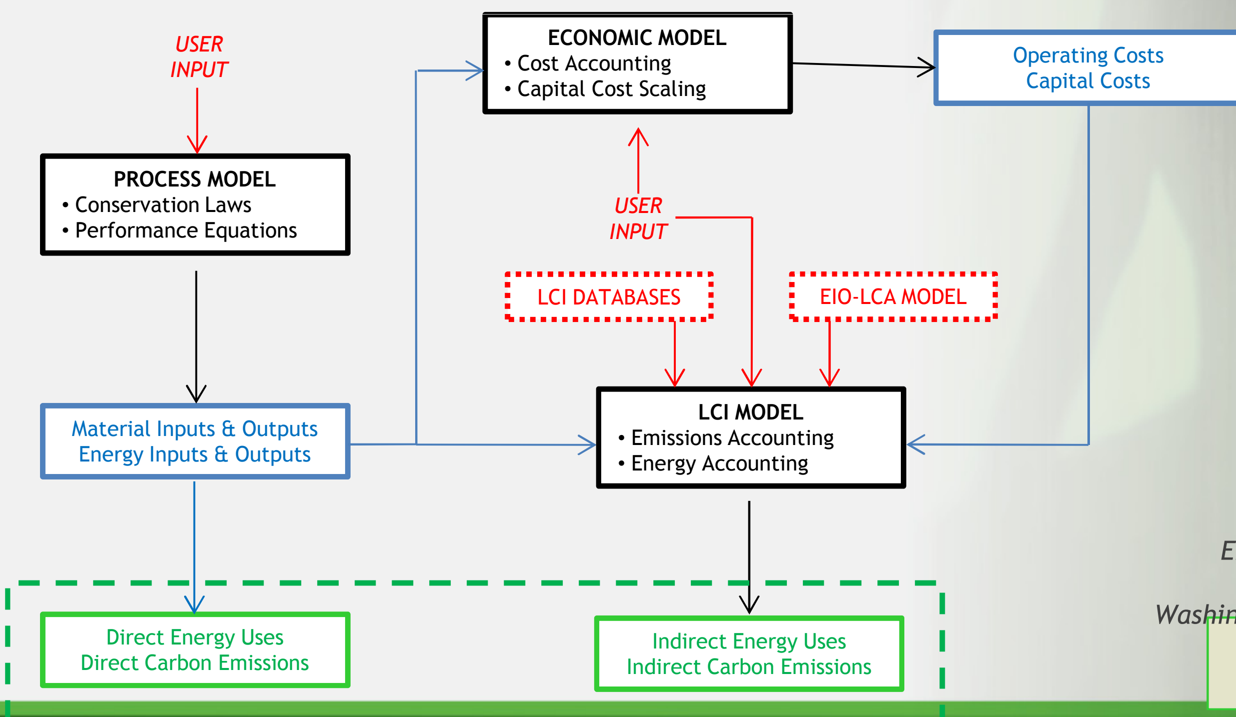
Telcim: Modeling the production of microalgal biodiesel

If we assume that commercial-scale microalgal biodiesel production is technically feasible…

- *What is its Net Energy Return?*
- *How much will it cost?*
- *What is its carbon intensity?*

Photos from Getty Images: http://www.gettyimages.com; chart from http://earthobservatory.nasa.gov

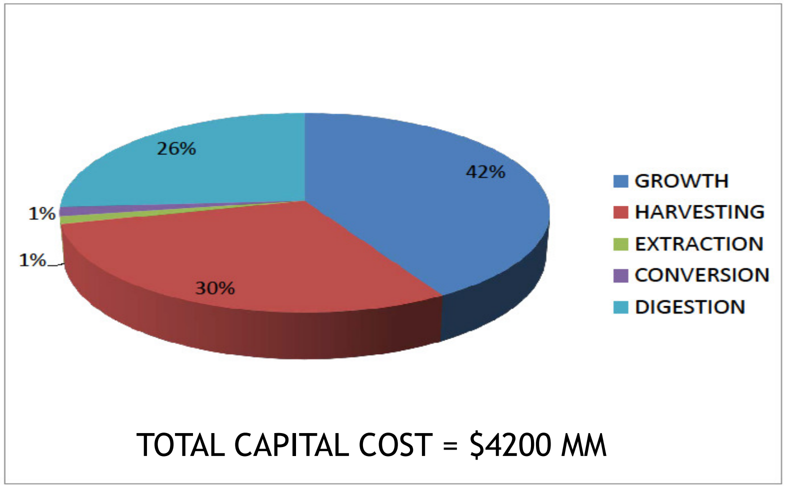


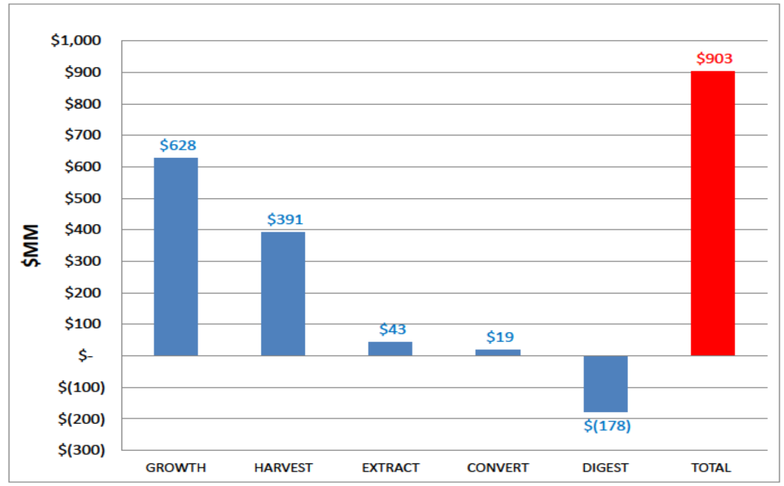


Mark Henson
Department of Energy, Environmental and Chemical Engineering
Washington University in St. Louis

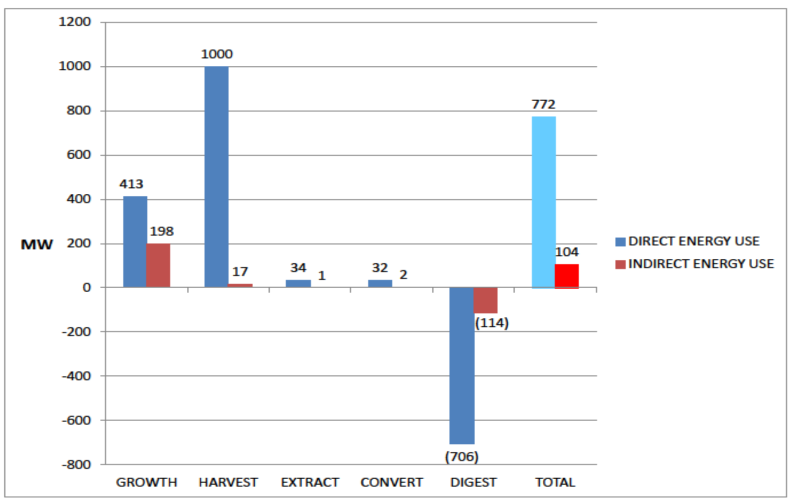
Washington University in St.Louis

TELCIM outputs: Cost, energy return, and carbon footprint





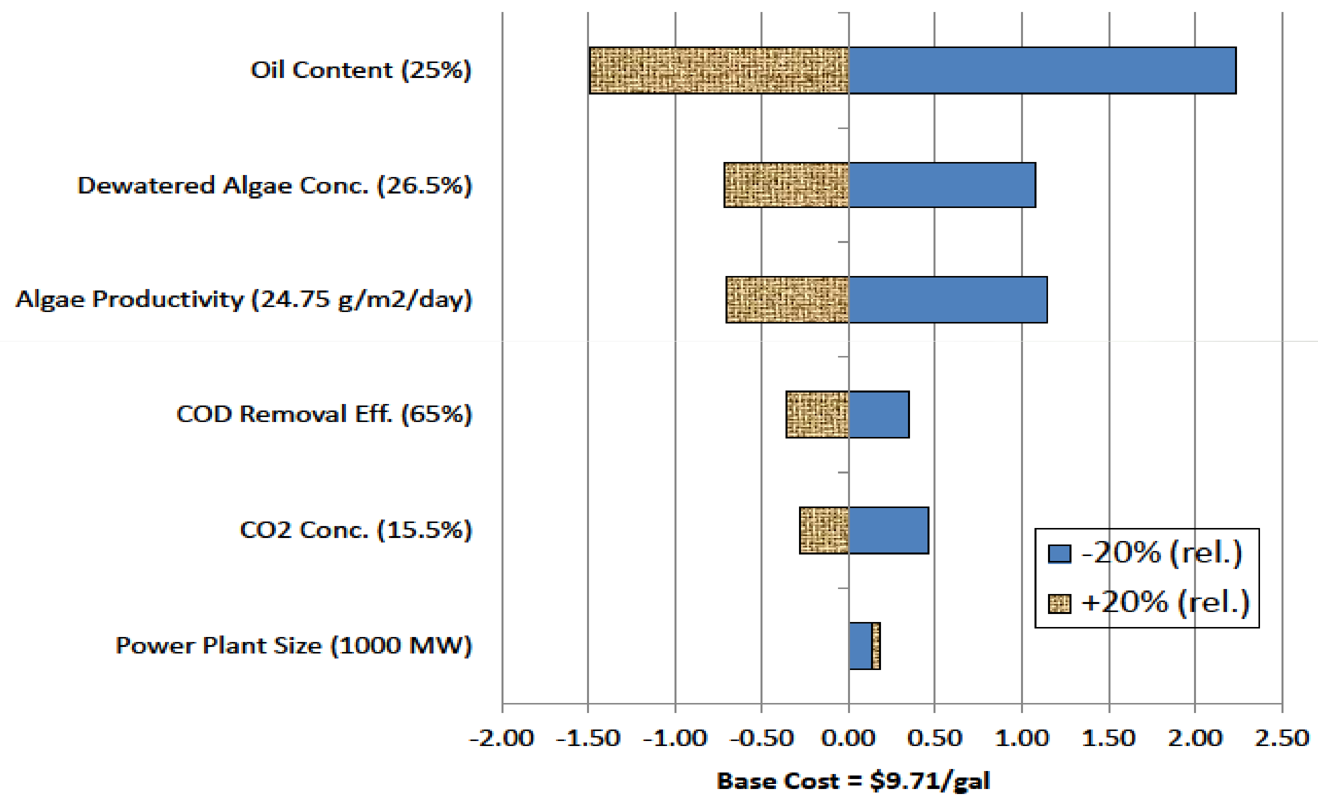
BIODIESEL PRODUCTION COST = $9.71/gal



NER = 0.43 (JOULES OUT PER JOULE IN)

	INPUTS			OUTPUTS		
	ALGAE PRODUCTIVITY (g/m^2/day)	LIPID CONTENT (%, afdw)	WATER CONTENT AT EXTRACTION (wt. %)	PRODUCTION COST ($/gal)	NET ENERGY RETURN (J out/J in)	CARBON INTENSITY (gCO_2e/MJ)
PETRO-DIESEL	N/A	N/A	N/A	(?)	4.35*	84.3**
TEST SCENARIO	24.75	25	10	$9.71	0.43	59.3
NAABB R&D GOALS	20	50	10	$5.84	0.60	73.6
NO DRYING	24.75	25	73.5	$6.42	1.73	(57.3)
NAABB GOALS & NO DRYING	20	50	73.5	$4.19	1.74	3.3

Single parameter sensitivity



Enabling technologies for parasite control

Public funding enables a network of ~50 collaborators to explore parasite structural and functional genomics of roundworms

Update — *TRENDS in Parasitology* Vol.19 No.7 July 2003

400 000 nematode ESTs on the Net

John Parkinson[1], Makedonka Mitreva[2], Neil Hall[3], Mark Blaxter[1] and James P. McCarter[2]

Genome Biology 2003, 4:R26

Analysis and functional classification of transcripts from the nematode *Meloidogyne incognita*

James P McCarter*†, Makedonka Dautova Mitreva*, John Martin*, Mike Dante*, Todd Wylie*, Uma Rao*, Deana Pape*, Yvette Bowers*, Brenda Theising*, Claire V Murphy*, Andrew P Kloek†, Brandi J Chiapelli†, Sandra W Clifton*, David McK Bird‡ and Robert H Waterston*§

Review — *TRENDS in Parasitology* Vol.20 No.10 October 2004

Genomic filtering: an approach to discovering novel antiparasitics

James P. McCarter

Divergence Inc., 893 North Warson Road, St Louis, MO 63141, USA

Nucleic Acids Research, 2004, Vol. 32, Database issue **D423–D426**

Nematode.net: a tool for navigating sequences from parasitic and free-living nematodes

Todd Wylie[1,*], John C. Martin[1], Michael Dante[1], Makedonka Dautova Mitreva[1], Sandra W. Clifton[1], Asif Chinwalla[1], Robert H. Waterston[1,2], Richard K. Wilson[1] and James P. McCarter[1,3]

Genome Research
www.genome.org

Comparative Genomics of Gene Expression in the Parasitic and Free-Living Nematodes *Strongyloides stercoralis* and *Caenorhabditis elegans*

Makedonka Mitreva,[1,5,6] James P. McCarter,[1,2,5] John Martin,[1] Mike Dante,[1] Todd Wylie,[1] Brandi Chiapelli,[1,2] Deana Pape,[1] Sandra W. Clifton,[1] Thomas B. Nutman,[3] and Robert H. Waterston[1,4]

ELSEVIER — Available online at www.sciencedirect.com — SCIENCE DIRECT — MOLECULAR & BIOCHEMICAL PARASITOLOGY

Molecular & Biochemical Parasitology 137 (2004) 297–305

mRNA sequences for *Haemonchus contortus* intestinal cathepsin B-like cysteine proteases display an extreme in abundance and diversity compared with other adult mammalian parasitic nematodes

Douglas P. Jasmer[a,*], Makedonka Dautova. Mitreva[b], James P. McCarter[b,c]

nature genetics — **ARTICLES**

A transcriptomic analysis of the phylum Nematoda

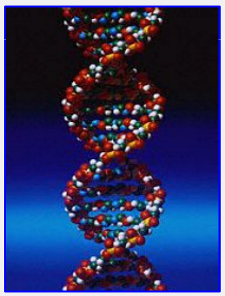
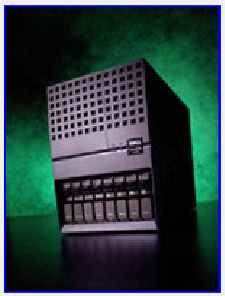
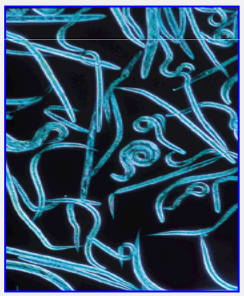
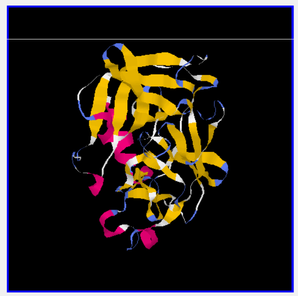
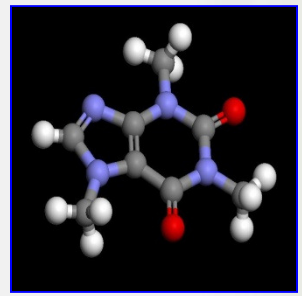
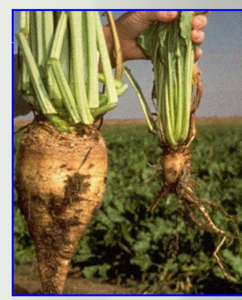
John Parkinson[1,2], Makedonka Mitreva[3], Claire Whitton[2], Marian Thomson[2], Jennifer Daub[2], John Martin[3], Ralf Schmid[2], Neil Hall[4,6], Bart Barrell[4], Robert H Waterston[3,6], James P McCarter[3,5] & Mark L Blaxter[2]

These data inform a pipeline to develop novel products to control plant & animal parasites

DIVERGENCE – A Proven Discovery Pipeline

Targeting Genes…

Genome Data → **Informatics Selection** → **RNAi Target Validation** → **Target Gene Collection**

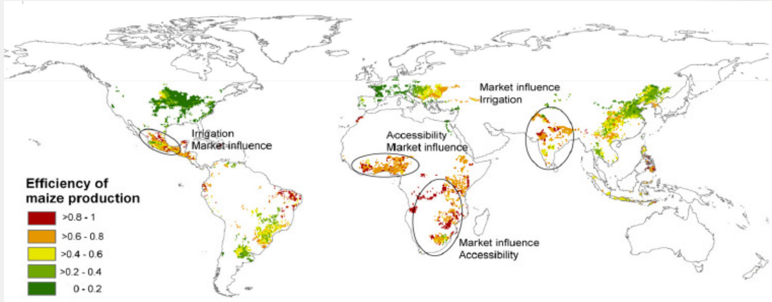

Target Gene Collection → **Identify Target Gene Inhibitors** →

- **Nematicides**
- **Anti-parasitic Drugs**
- **Resistance Genes**
- **Vaccines**

… Then Products

Informing models for predicting crop yields

Factors affecting maize production efficiency



Neumann et al., 2011

Dated economic and crop models are inadequate for current needs

- Current efforts to project the impact of climate change on current and future crop productivity are severely hampered by the weakness of the mechanistic crop simulation models

- Policy decisions for agriculture are using black box economic models instead of crop models

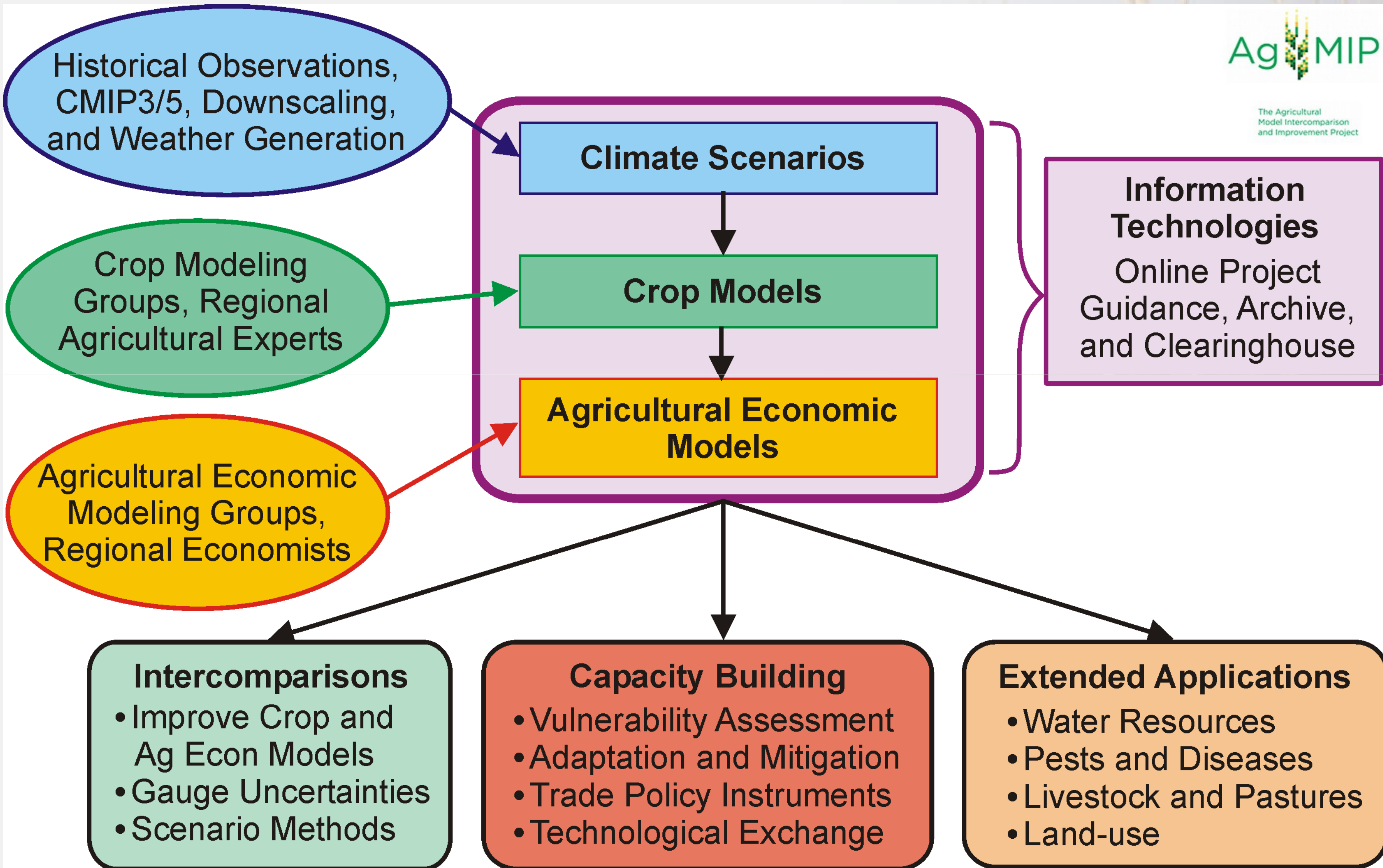
- Many of these models were developed using hybrids developed 20-30 years ago, and have not been significantly modified to incorporate results of recent physiology and agronomic research.

- The Agricultural Intercomparison & Improvement Project (AgMIP) was initiated to address these shortfalls

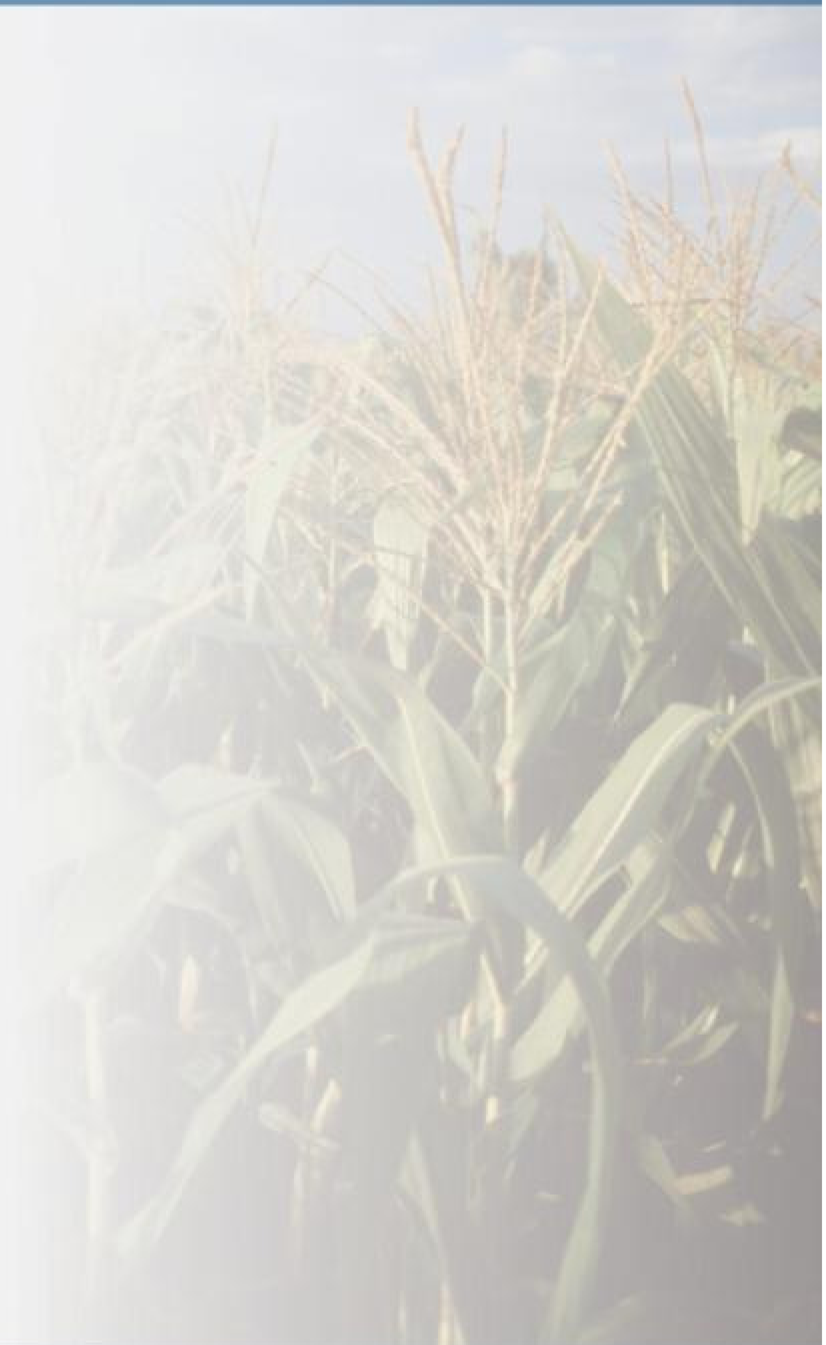
- Monsanto has donated the resources (data and personnel) to improve the DSSAT Ceres Maize corn simulation model: Posting/donating selected test-mean yields from MON global breeding trial database for use in model-validation

- Additional field phenology data (multi-site, multi-year) are needed to calibrate/validate the new model

AgMIP interlinks climate, crop, and economic models



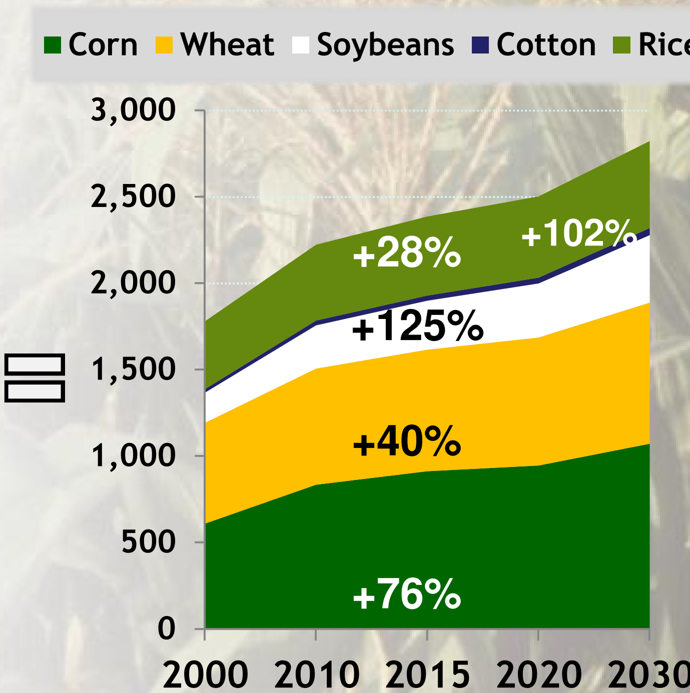
Future challenges



A simple equation with complex solutions

BY 2030…

=



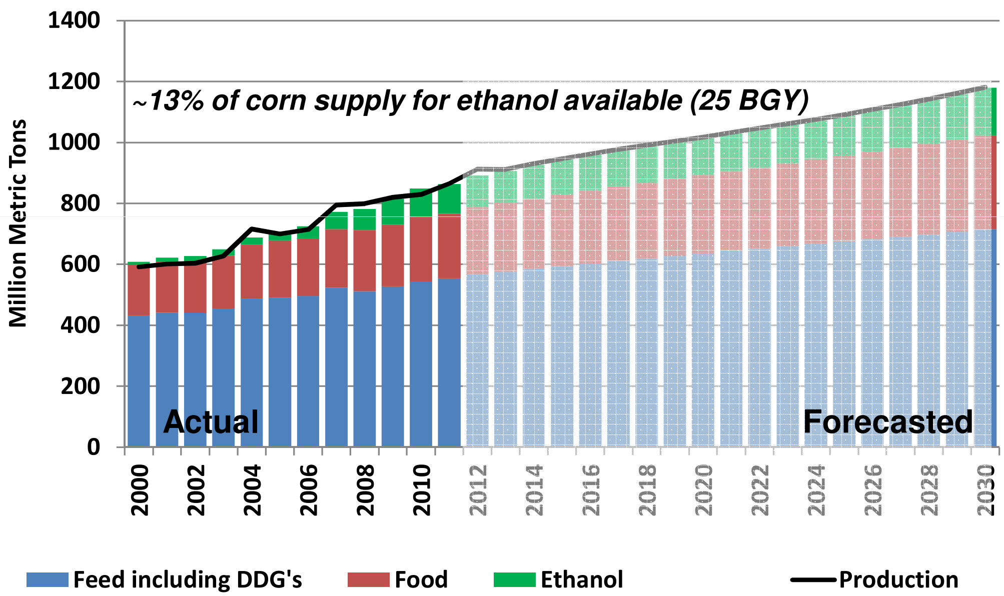
TODAY + **1.4 B PEOPLE** + **100% INCREASE** + **30% INCREASE**

GLOBAL GRAIN DEMAND (M MT)

Source: IHS Global Insights, Agriculture Division

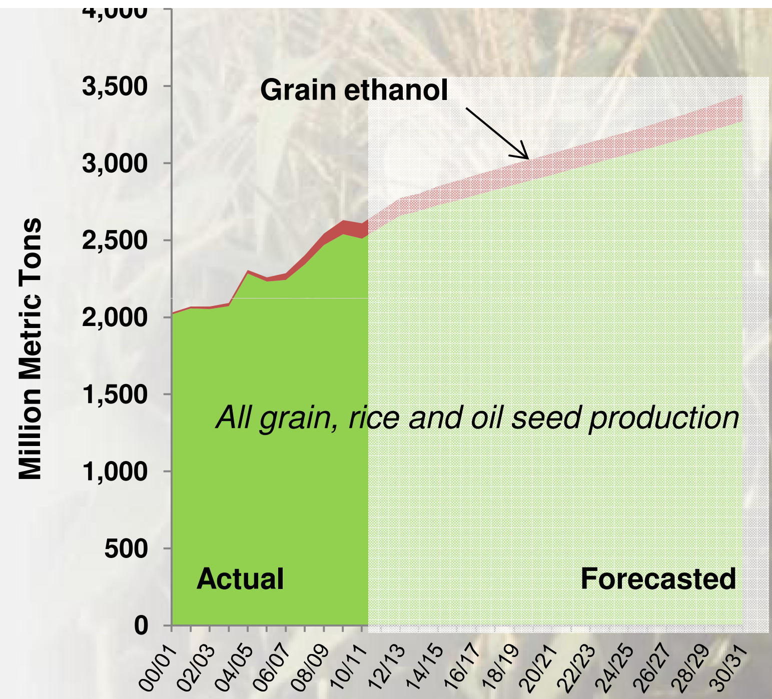
Grain ethanol use represents only a small portion of overall agricultural food and feed commodity use

Even with projected 8x growth in China corn demand, surplus corn is available for renewables



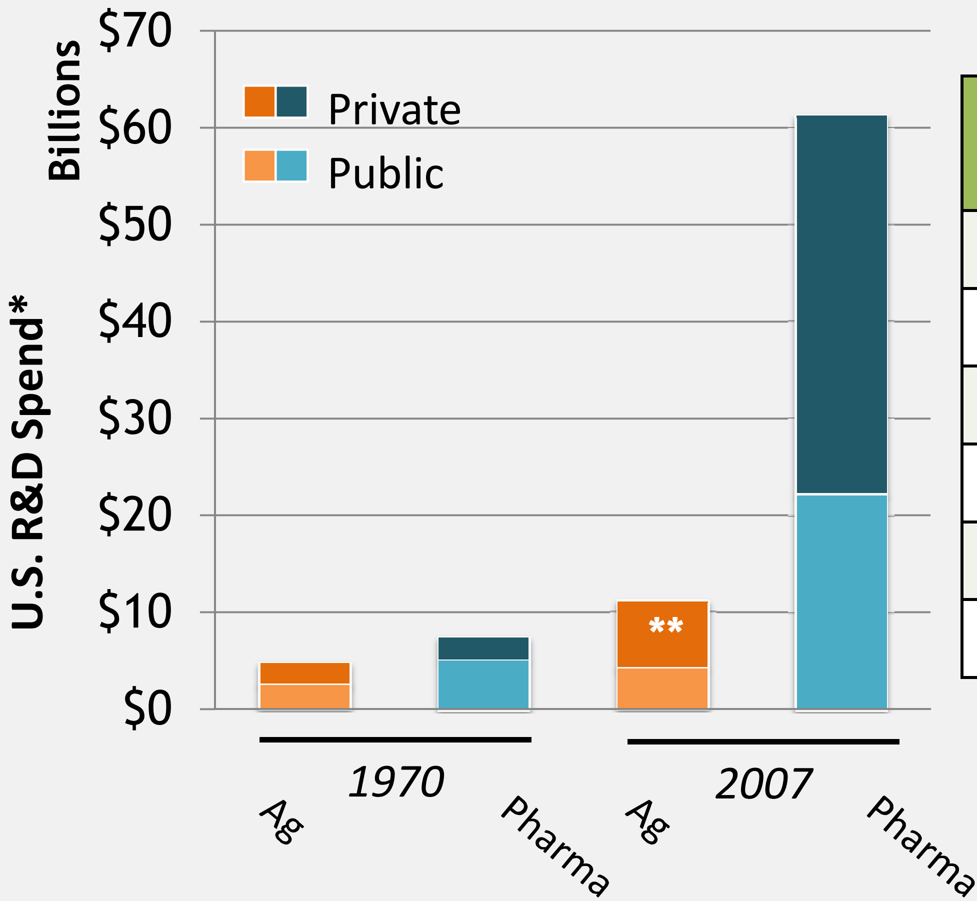
Source: USDA through 2011, WAEES forecast thereafter

Grain ethanol remains <5% of global feed/food use



WAEES

U.S. agriculture supports food security globally, but R&D funding has been significantly outpaced by other industries



U.S. Agricultural Exports	1970 *FY*	2007 *FY*
Total Value*	$6.96 B	$82.2 B
	M MT	
Corn	12.9	61.9
Soybean	11.8	31.5
Wheat	20.2	34.4
Cotton	3.9	13.6

*nominal dollars

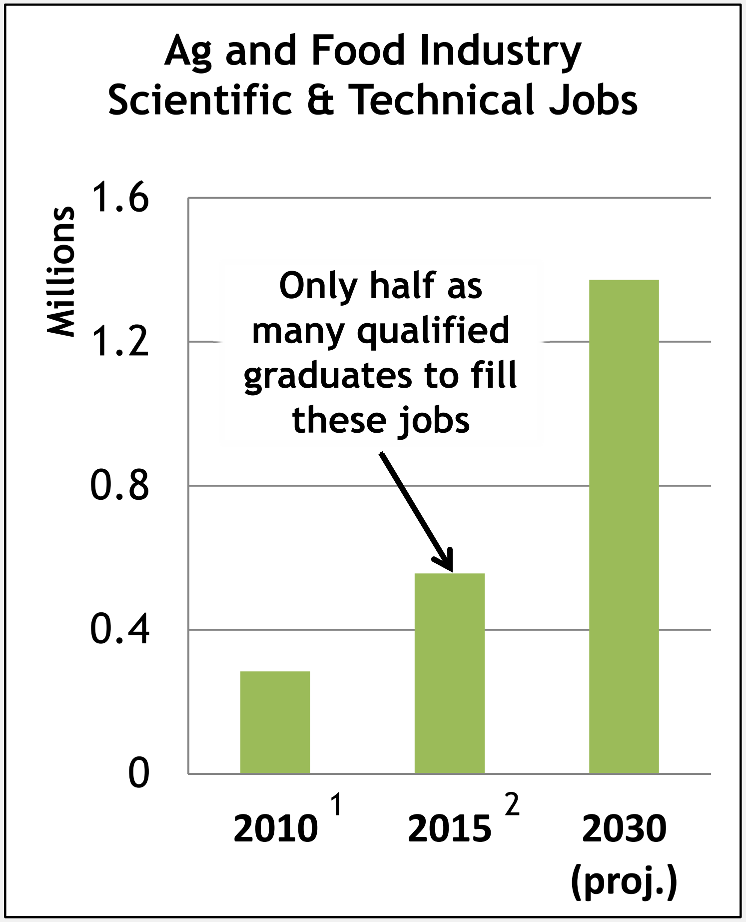
Sources: USDA ERS and USDA FAS PSD Database

*adjusted to 2001 dollars

Sources: USDA ERS Data Product "Agricultural Research Funding in the Public and Private Sectors" (Feb 2010); National Institutes of Health Office of Budget (2011); NSF Industrial Research and Development Information System

** Monsanto estimate based on 2007 R&D spend reported by Phillips McDougall (agrochemical and seed industry) and NSF Industrial Research and Development Information System (food and ag-derived products manufacturing)

Development of the scientific workforce is critical



Ag-Related Growth Occupations[2]	% increase 2010-2015
Biochemists/Biophysicists	37.4
Environmental Scientists	27.9
Hydrologists	18.3
Computer and Information Systems	16.9
Food Scientists	16.3
Soil and Plant Scientists	15.5

Shortfall of plant geneticists/plant breeders

[1] U.S. Dept of Labor Bureau of Labor Statistics
[2] Goecker et al. 2010 http://www.csrees.usda.gov/nea/education/part/education_part_employment.html