Biomass Feedstock Logistics

Biomass Research & Development Technical Advisory Committee
San Antonio, Texas
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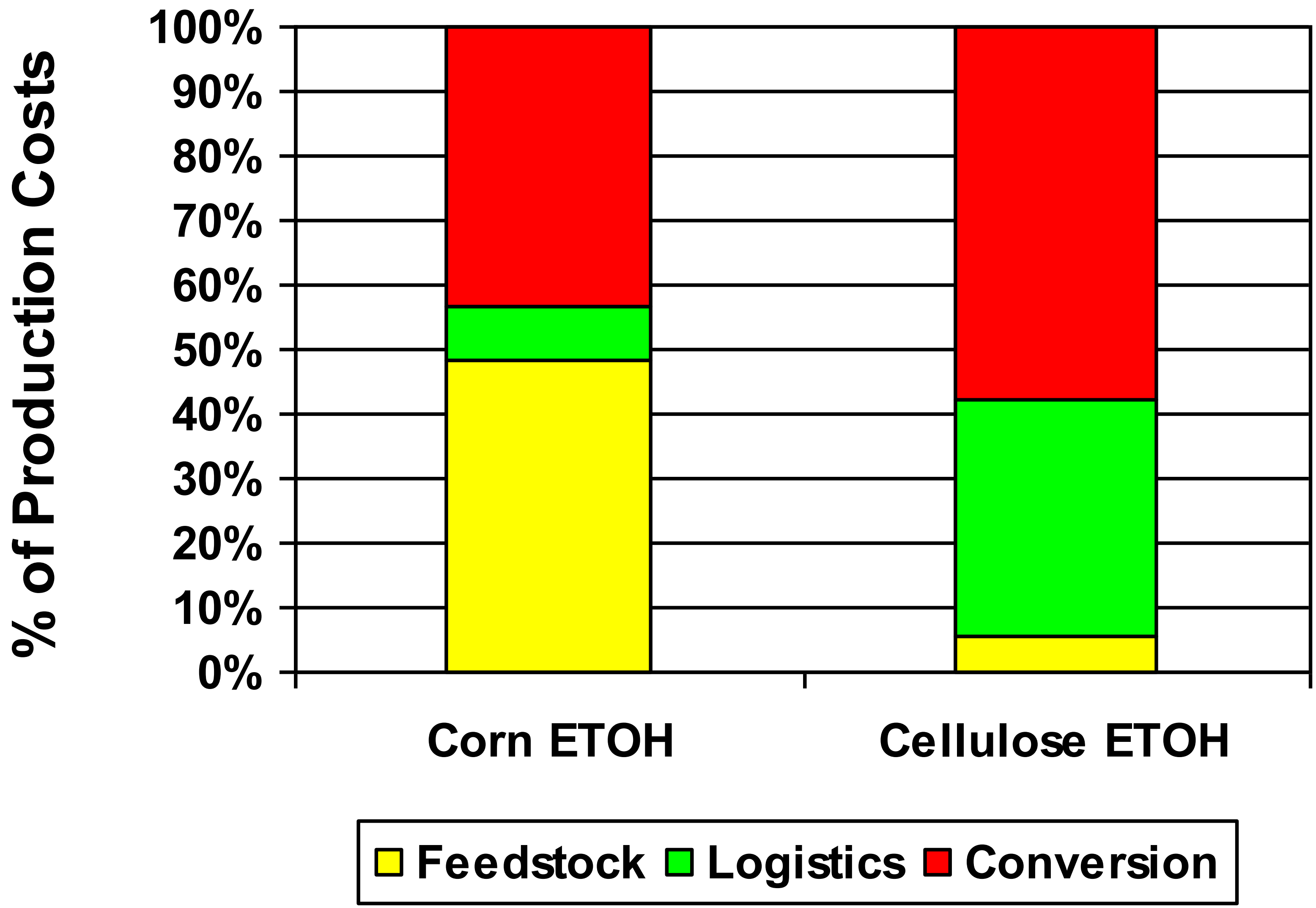
Idaho National Laboratory

Presentation Outline

- Feedstock Logistics State of Technology
- Uniform Format Supply System Designs to Achieve Cost and Volume (60 Billion gals) Targets
- Technical Work to Achieve Supply System Design Targets – Corn Stover example
  - Regional Feedstock Partnerships for Development of Biomass Resources
  - Logistics
  - Feedstock-Conversion Interface Tasks

Feedstock Logistics Cost Challenge



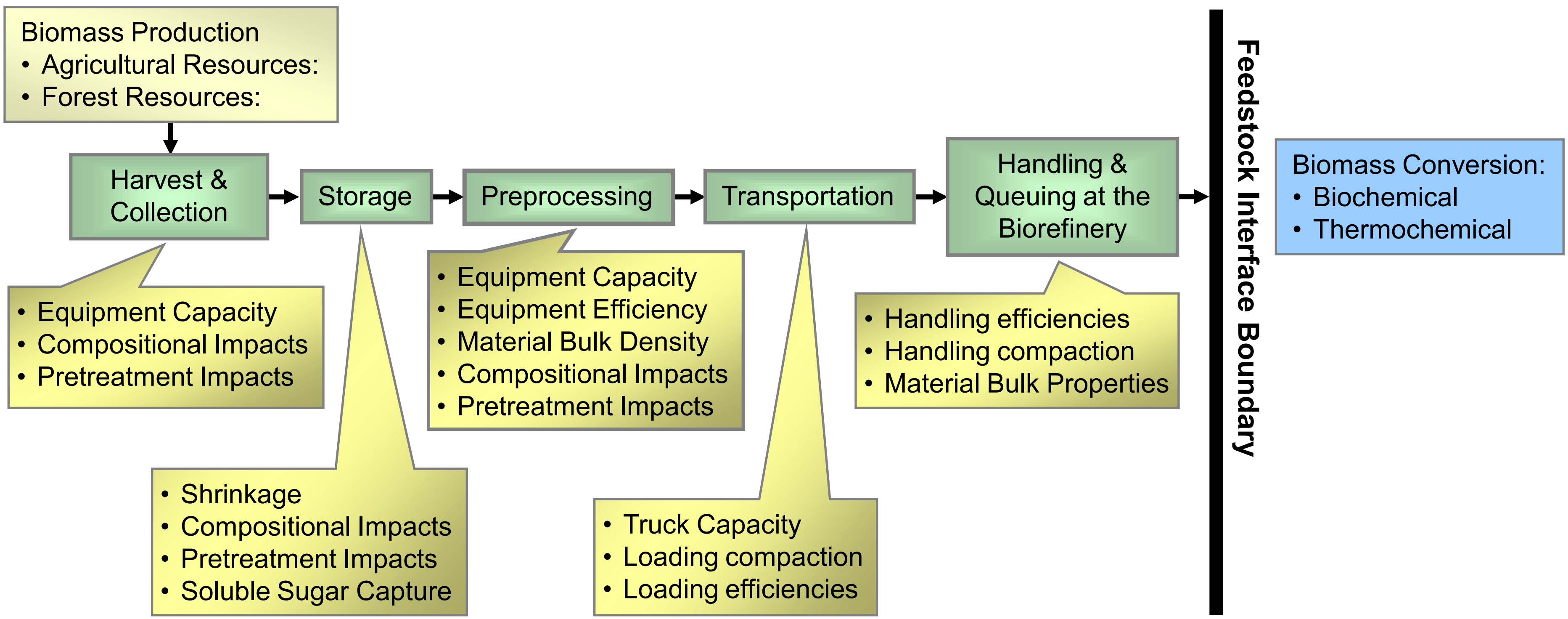
Feedstock Supply System Operations

Biomass Performance Metrics:

- Physical and Rheological Properties
- Product Bulk Density
- Material Stability

Equipment Performance Metrics:

- Equipment Efficiency / Capacity
- Dry Matter Losses
- Operational Window

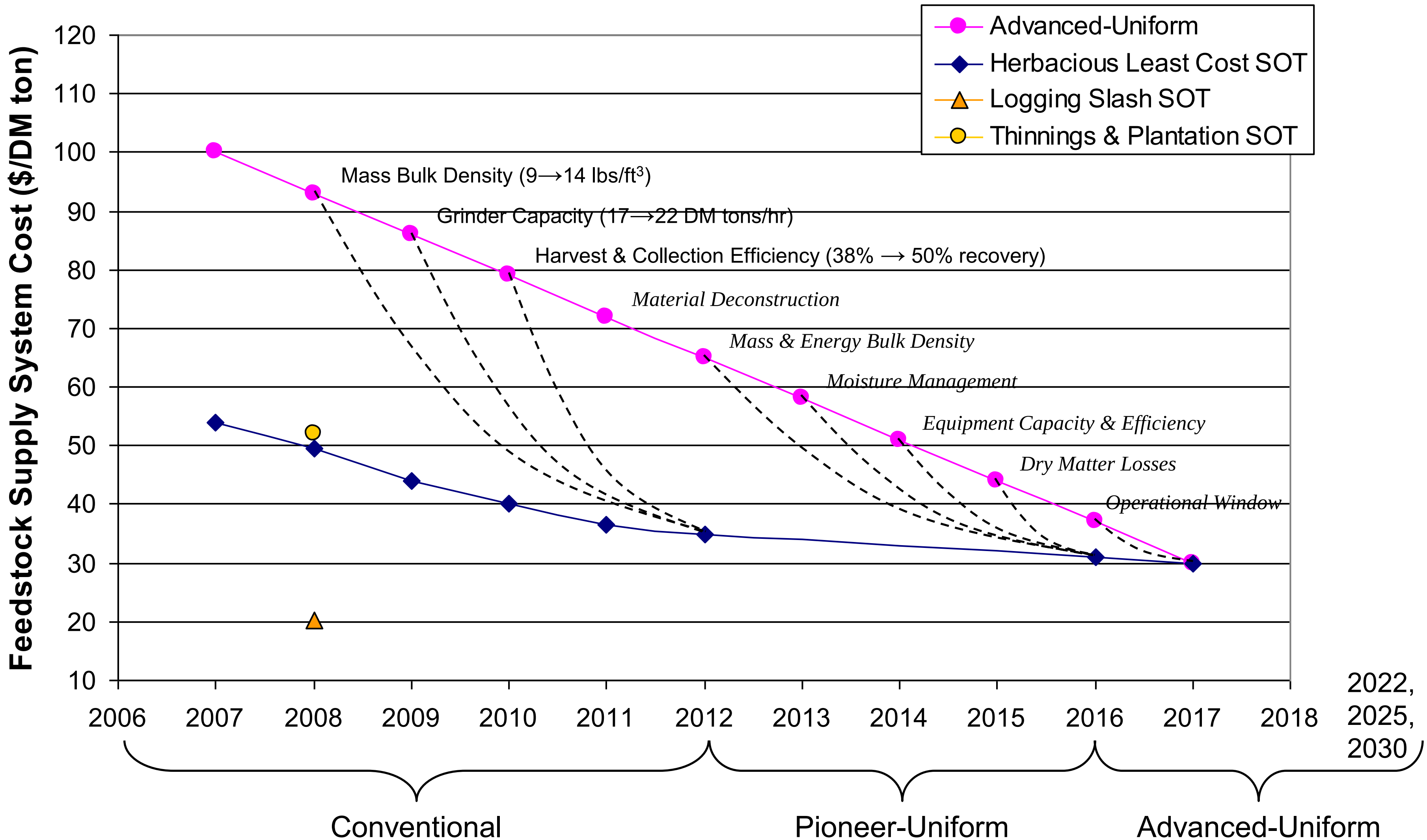


Feedstock Logistics 2008 SOT in 2007$

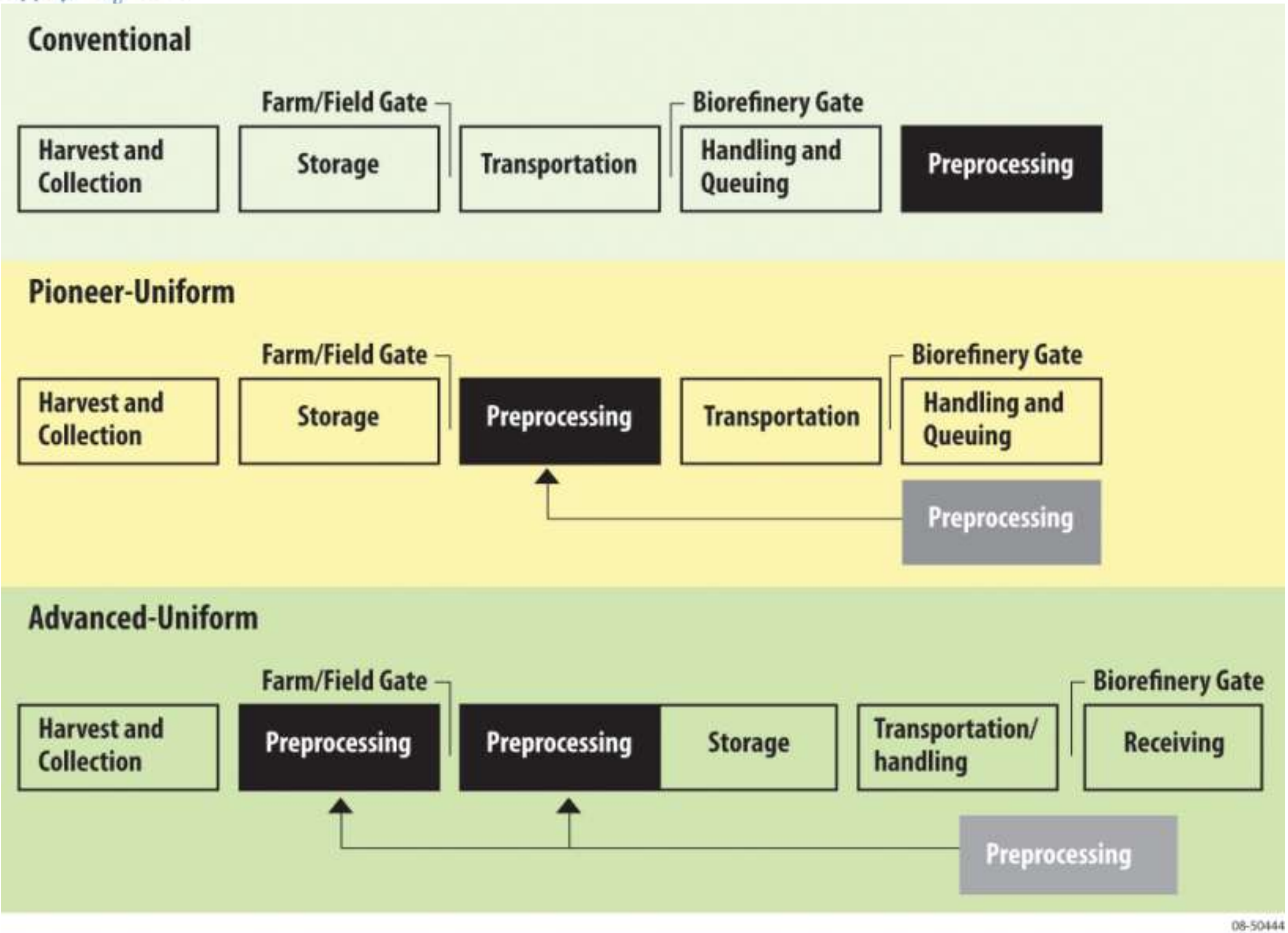
	Herbaceous		Woody
2007$	Corn Stover	Switchgrass	Thinnings & Plantations
2006 Actual	$57.70	–	–
2007 Estimate	$54.00	–	–
2007 Actual *	$53.70	$50.80	$51.85
2008 Estimate	$49.40	$46.50	$47.80
2009 Target	$41.60	$41.20	$42.50
2010 Target	$37.80	$37.20	$38.50
2011 Target	$36.10	$36.00	$36.10
2012 Target	$35.00	$35.00	$35.00
2017 Target	≤ 25% of MESP	≤ 25% of MESP	≤ 25% of MESP

* Assume product specification for conventional SOT to be 1/4 to 1/8 minus particle size at 12% moisture.

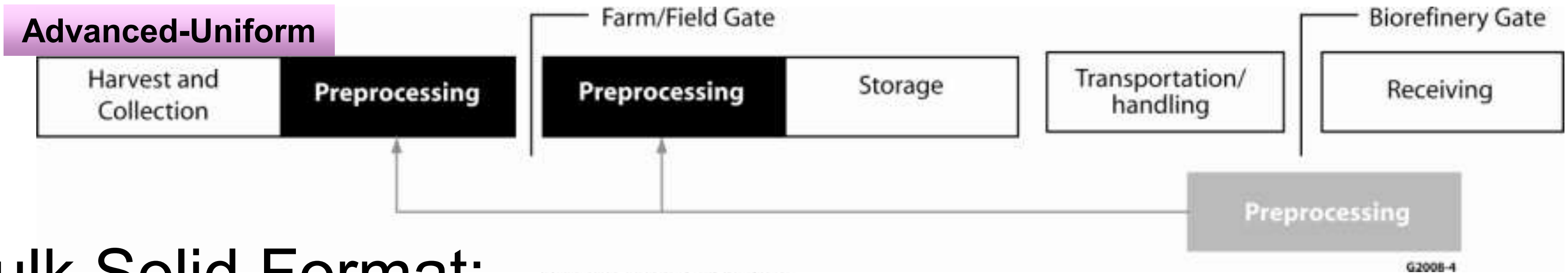
Feedstock Logistics SOT Estimated Progression to Targets



Path to Uniform Feedstock Supply System



Commodities of the Uniform Feedstock Supply System – "Advanced Uniform"

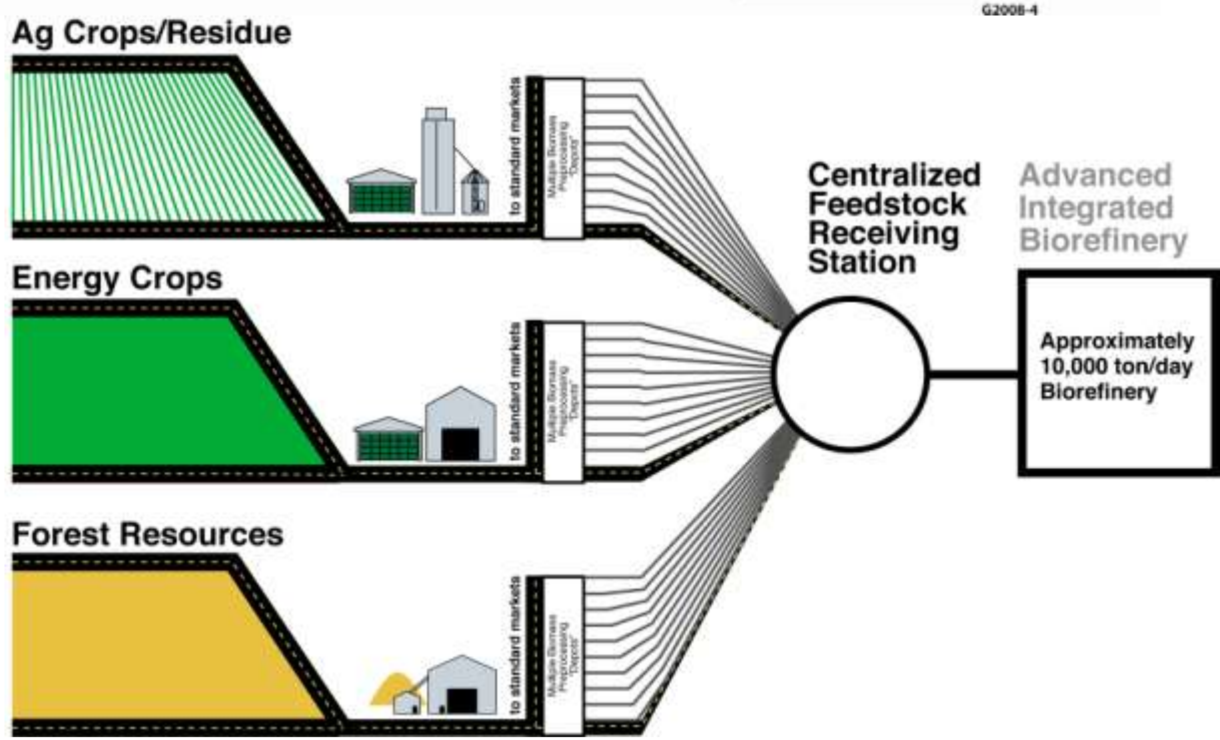


Bulk Solid Format:

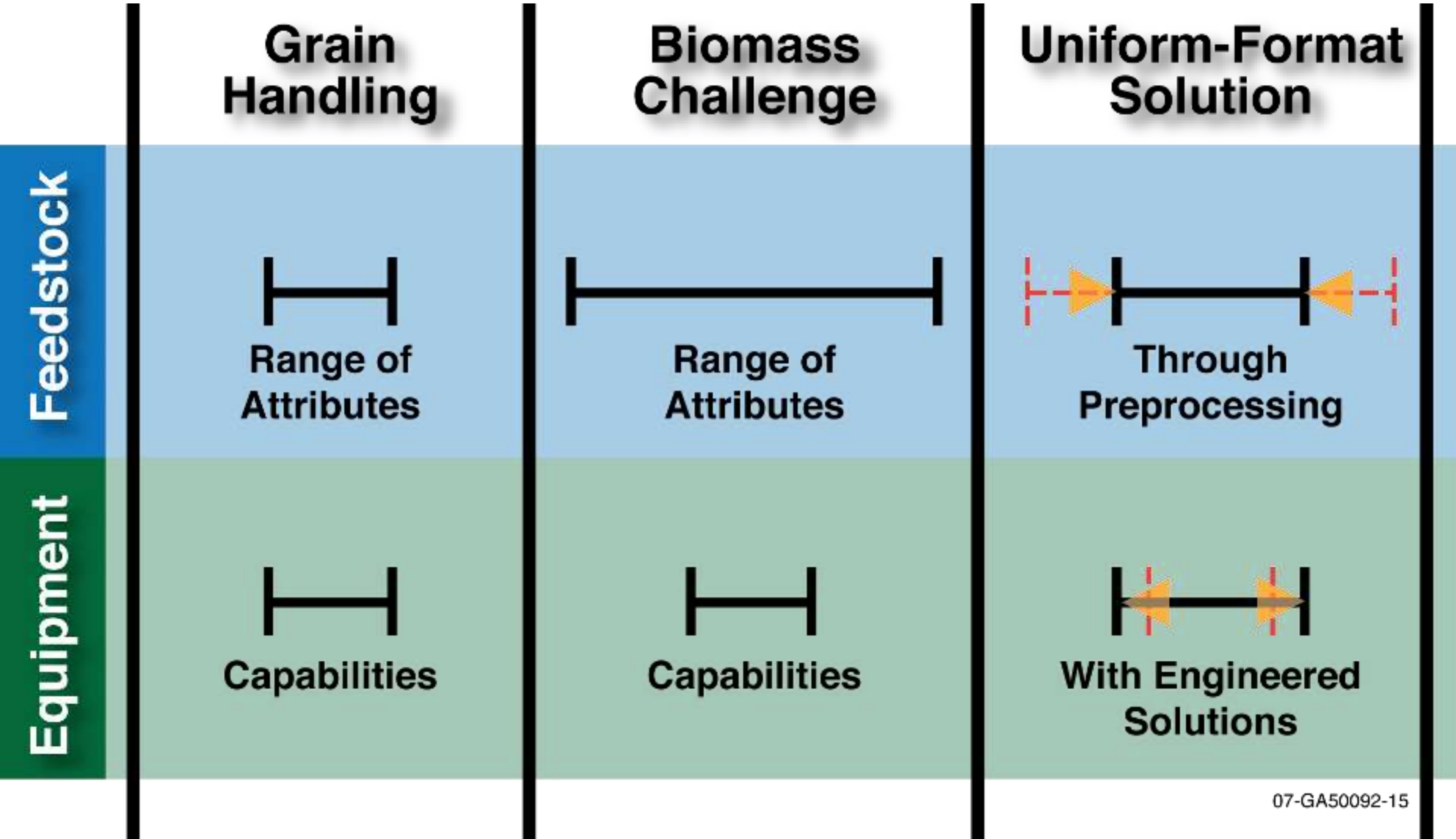
- High Bulk Density Biomass
- Torrefaction

Liquid Format:

- Pyrolysis Oils
- other "Bio-Crude" formats

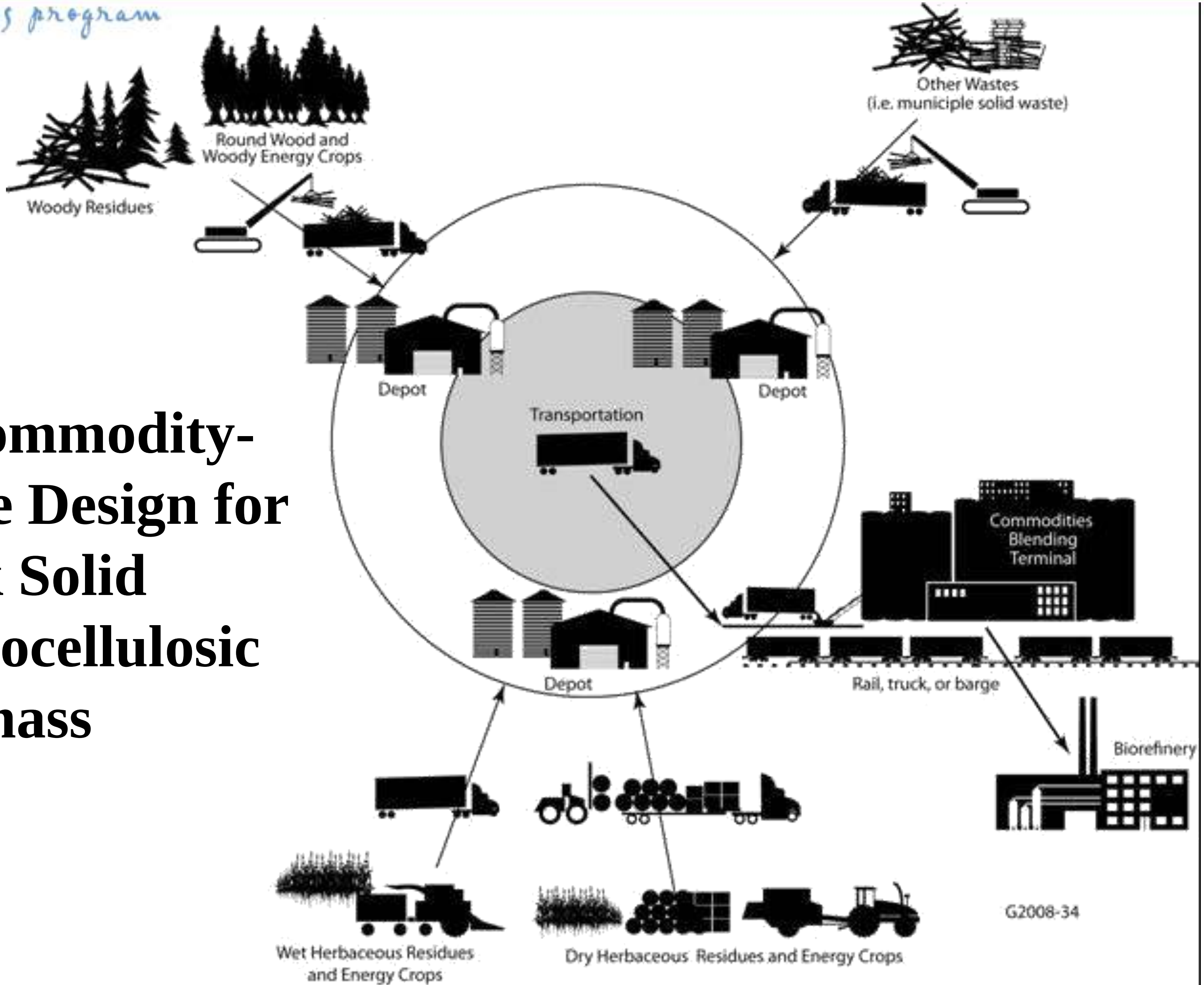


Uniform Format: Alter Feedstock Attributes to Function in Standardized Equipment



Uniform-Format Solid Feedstock Supply System

A Commodity-Scale Design for Bulk Solid Lignocellulosic Biomass



Basis for the Uniform-Format Design Concept

- A highly efficient, large capacity, dependable feedstock supply system for biomass already exists with the nation's commodity-scale grain handling and storage infrastructure.
- There is no alternate supply system design for lignocellulosic biomass that could handle the large quantities at the same or greater efficiencies and reliability than the existing grain handling infrastructure.
- The national goal of annually producing 60 billion gallons of ethanol, which requires supplying roughly of 700 million dry matter tons of biomass to a biorefining industry, can only be effectively accomplished through the development of harvesting and preprocessing systems that reformat lignocellulosic biomass resources into a "Uniform-format bulk solid" that can be stored and handled in an expanded grain (i.e., high density aerobically stable bulk solids) commodity infrastructure.

Feedstock Supply Logistics Barriers

Feedstock Physical Property Challenges:

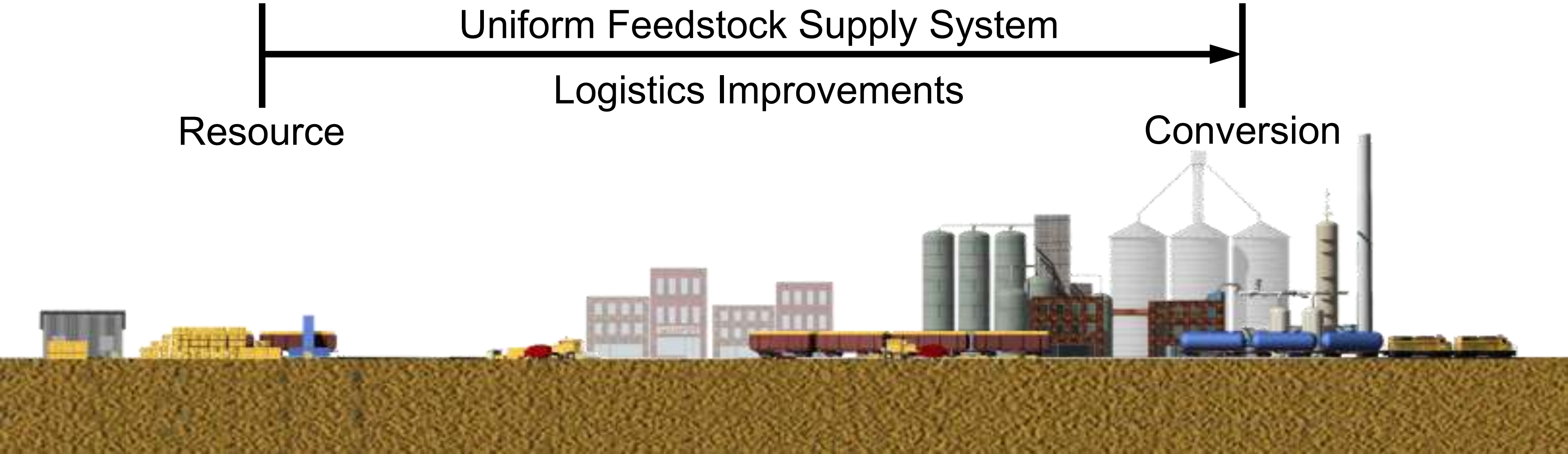
- Material deconstruction – changes in physical form, rheological characteristics
- Product yield density – biomass format and bulk/energy densities
- Moisture management – aerobic stability, post-harvest physiology, temperature impact

Feedstock Equipment Engineering Challenges:

- Capacity and Operational Efficiency
- Dry Matter Losses (including dust collection/control)
- Operational Window

Interface Challenges:

- Resource Quantities/Sustainability (Feedstock Production)
- Biomass Resources Physical Properties (Feedstock Logistics)
- Biomass Resources Chemical Properties (Biochem and Thermochem)



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Energy Efficiency and Renewable Energy

Biomass Feedstock Program

biomass program

Interaction Cycle between Core R&D, Deployable Process Demonstration Units, Industrial Partners, and Demonstration Projects for the Pioneer and Advanced-Uniform Designs

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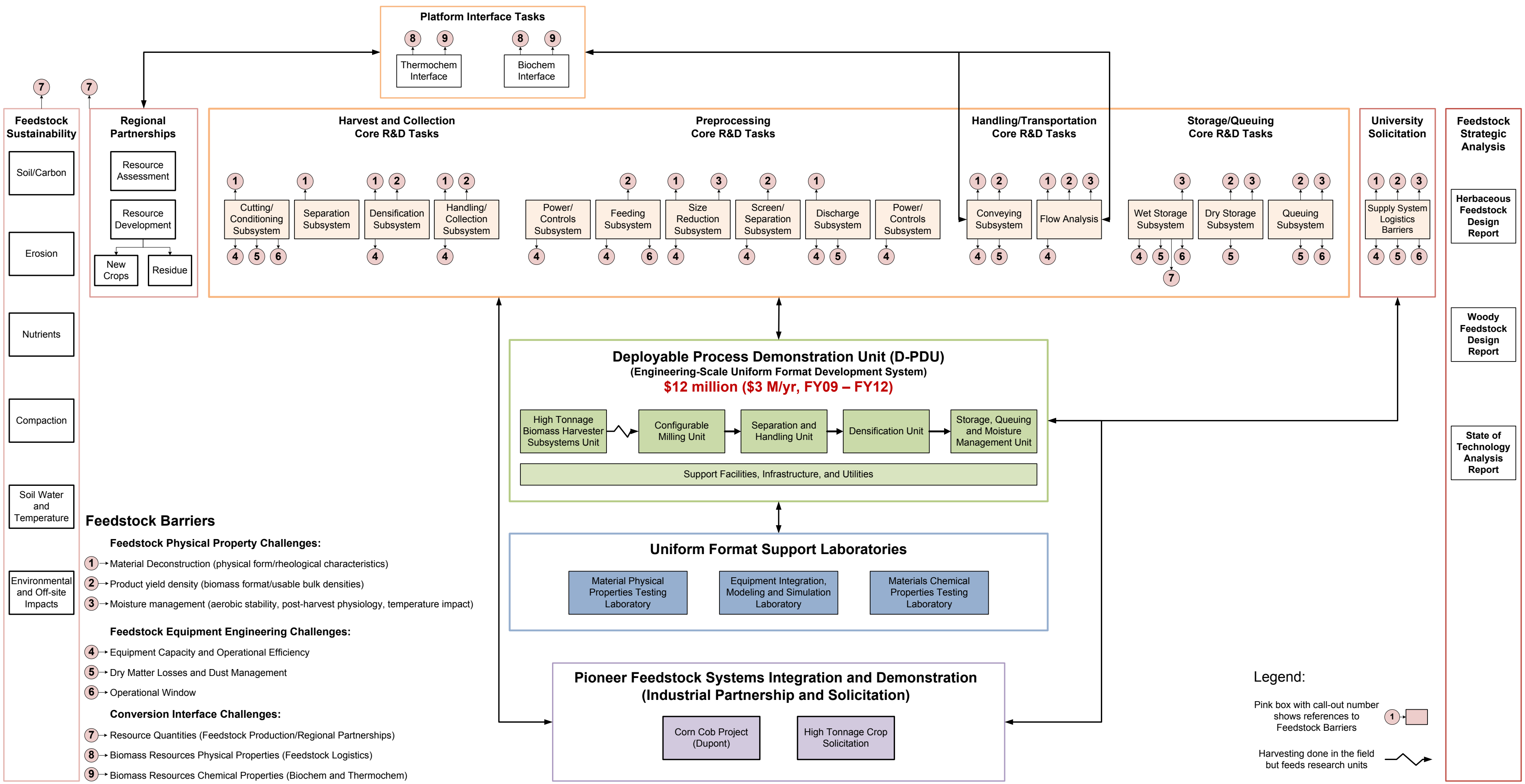
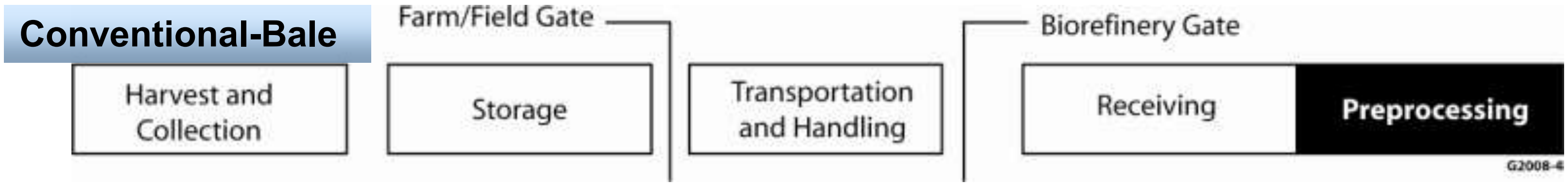


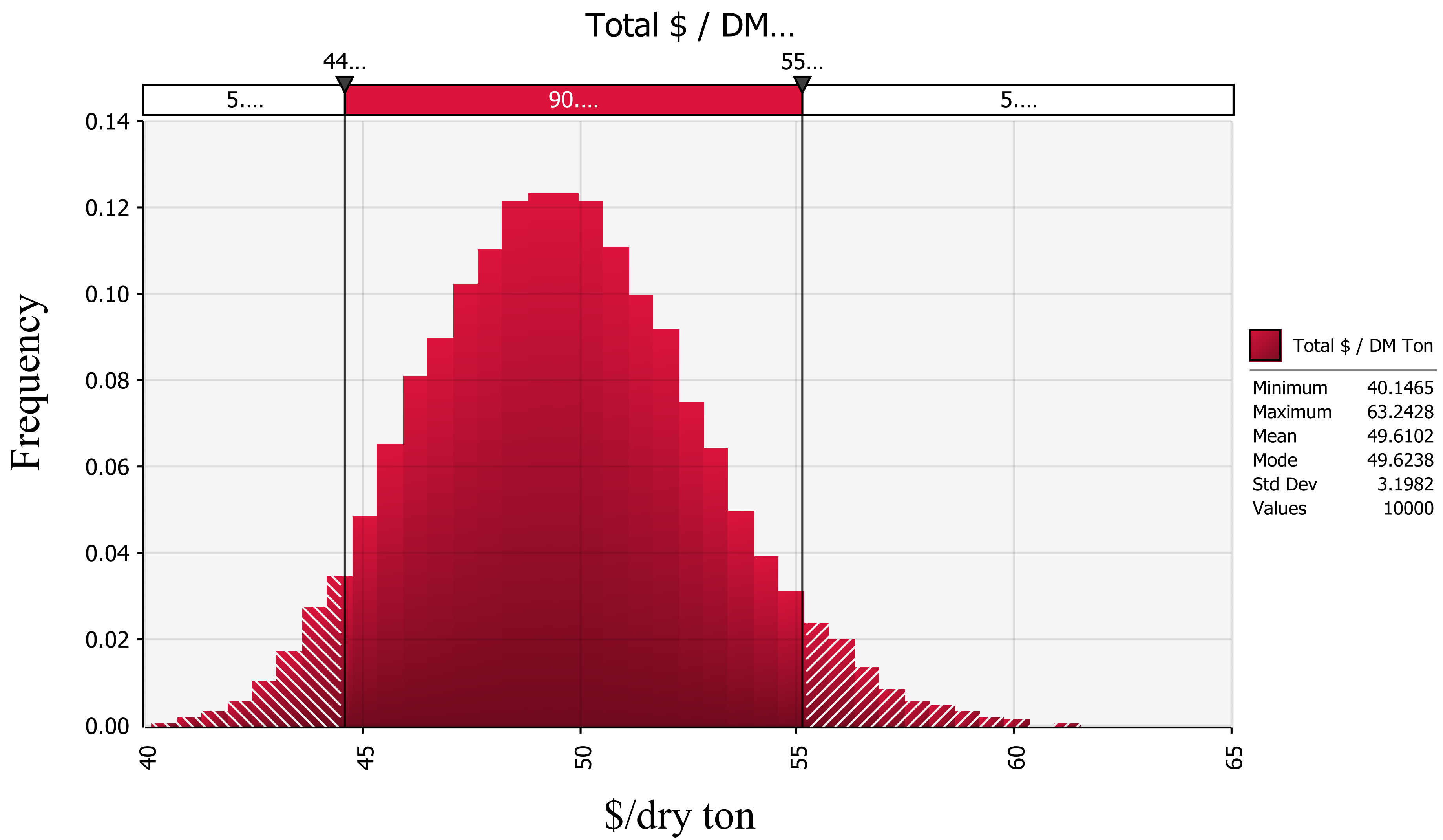
Conventional Square Bale Feedstock Supply System



- Same as the Livestock Forage System
- 10 material intermediates, 3 biomass format changes
- 14 process steps, 21 different types of equipment
- Supply system is bale format specific

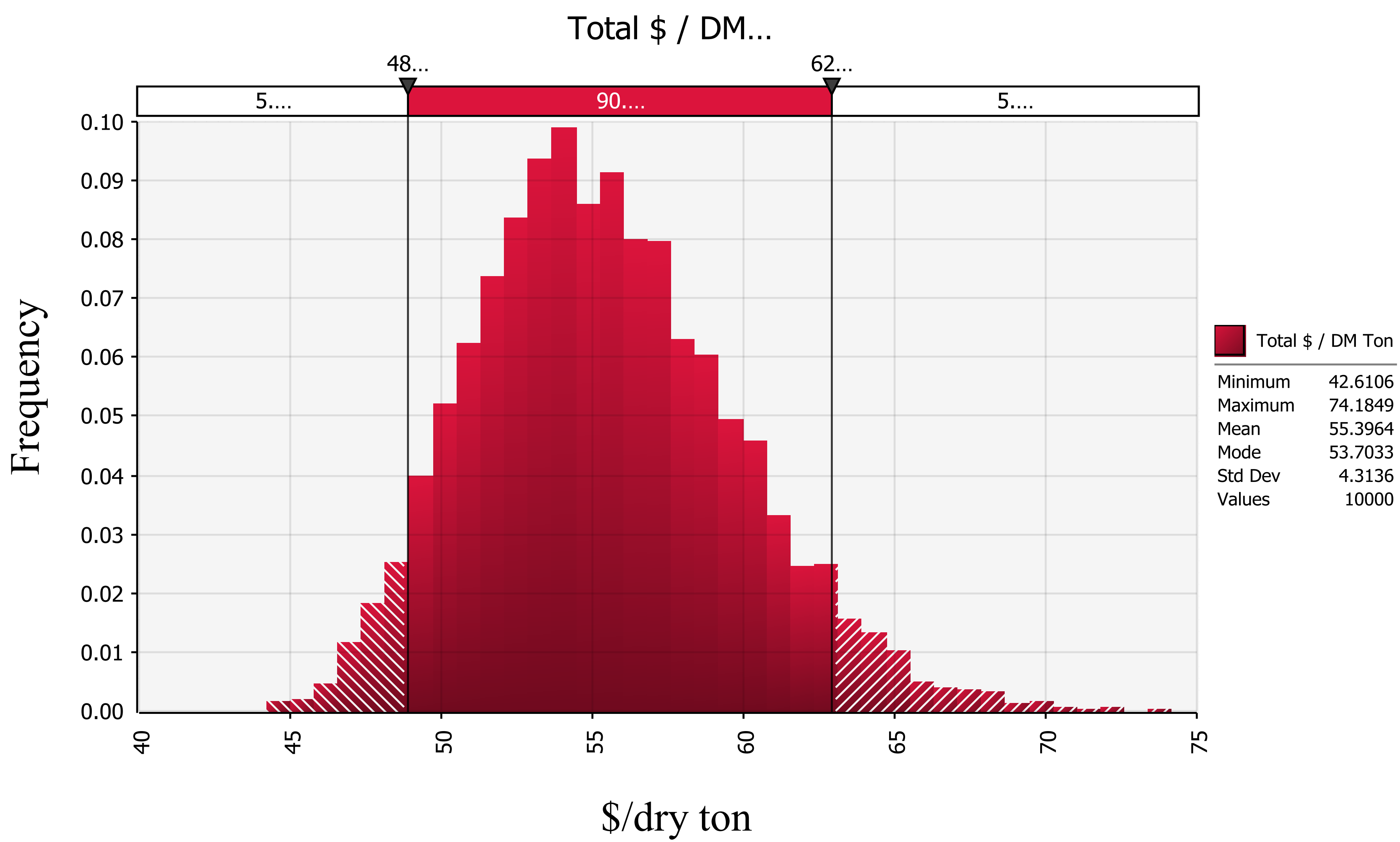
Conventional Bale Supply System Monte Carlo Cost Analysis Results

Switchgrass

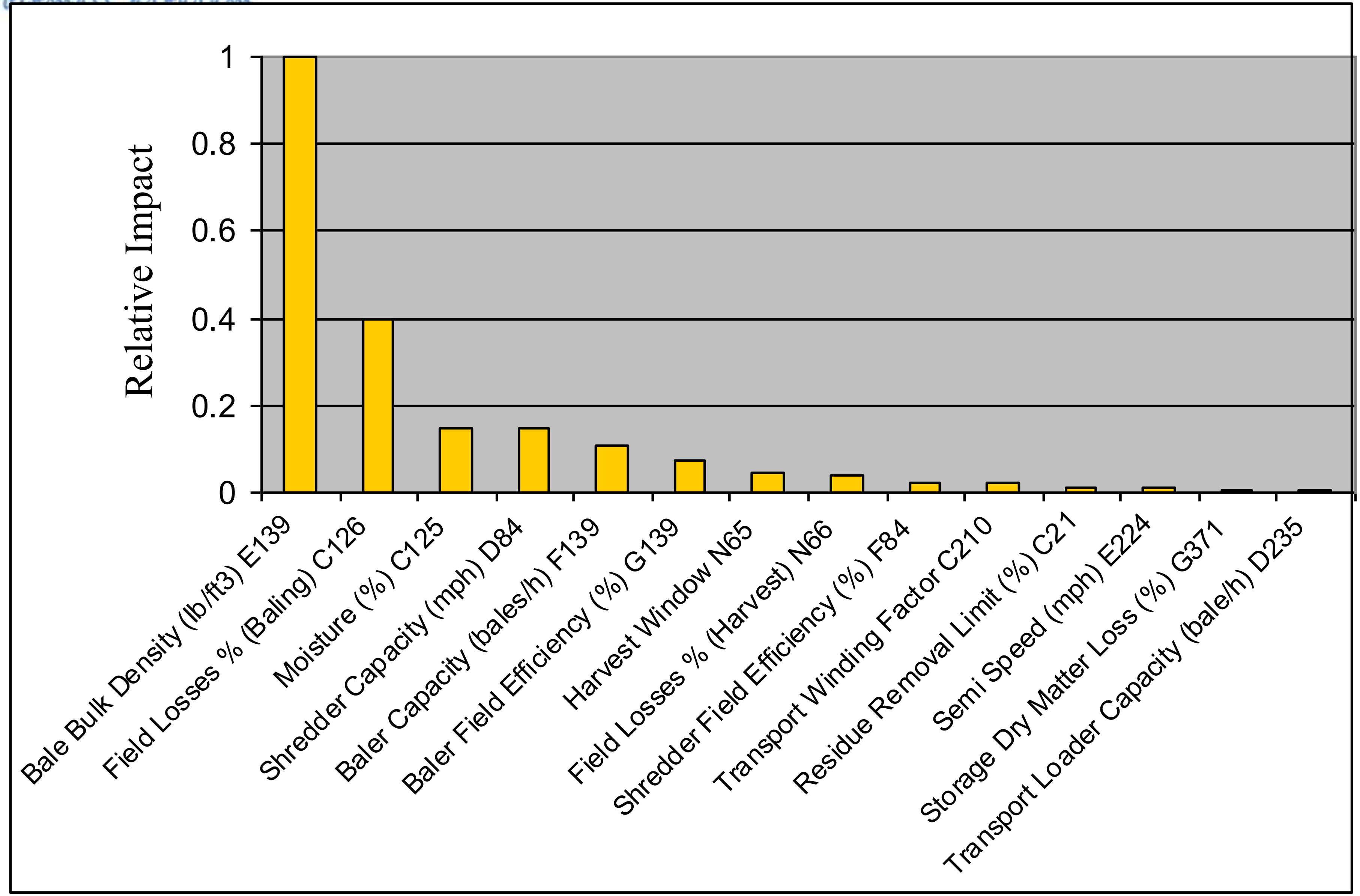


Conventional Bale Supply System Monte Carlo Cost Analysis Results

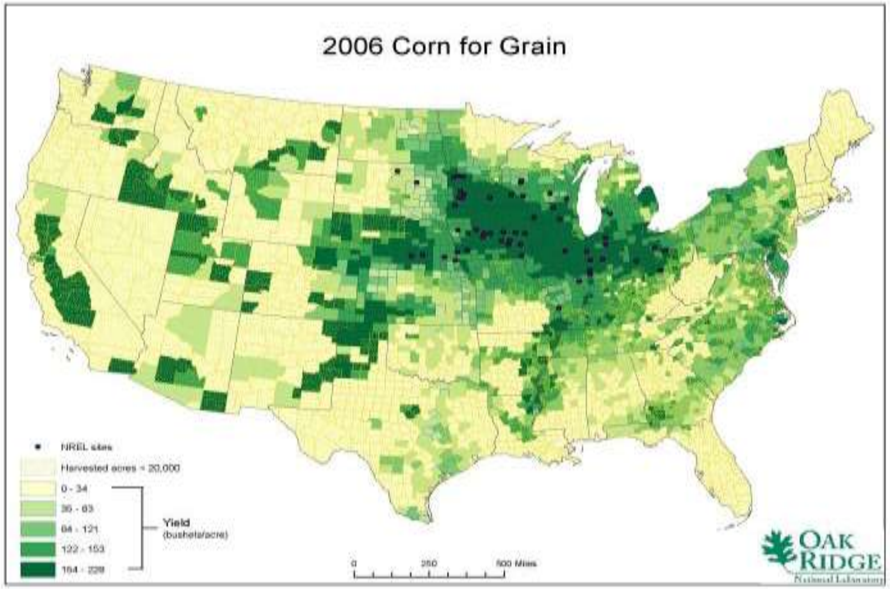
Corn Stover

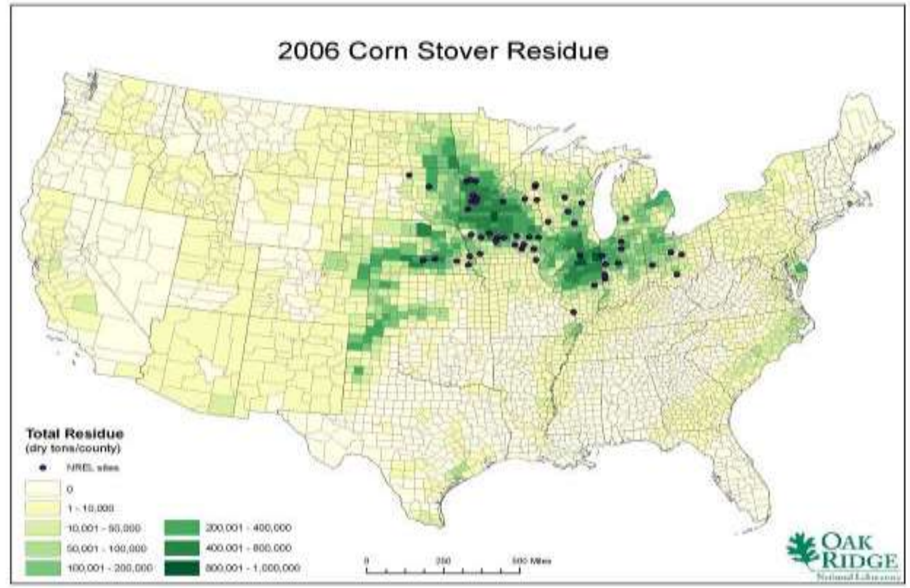


Ranking of Factors Influencing Costs in the Conventional Bale Supply System



Competing Uses - Stover Production versus Availability



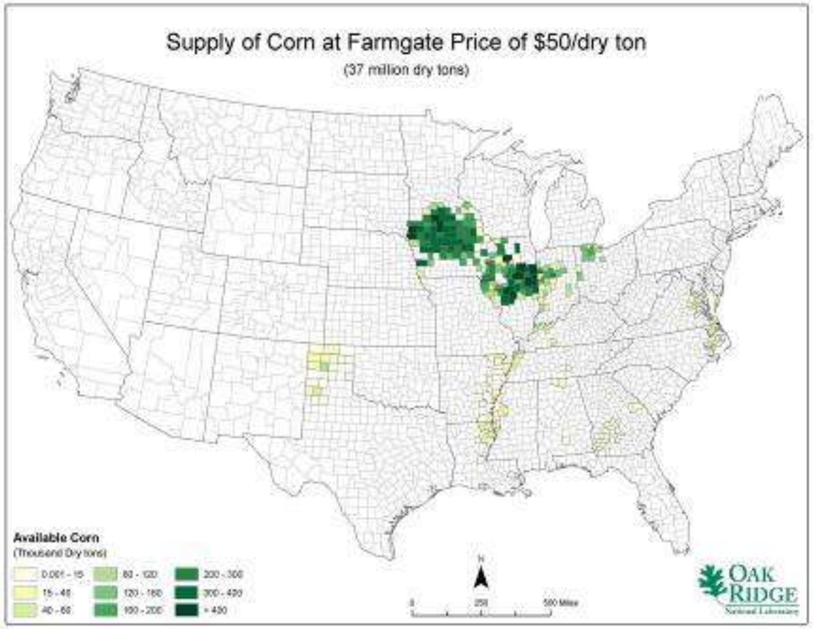


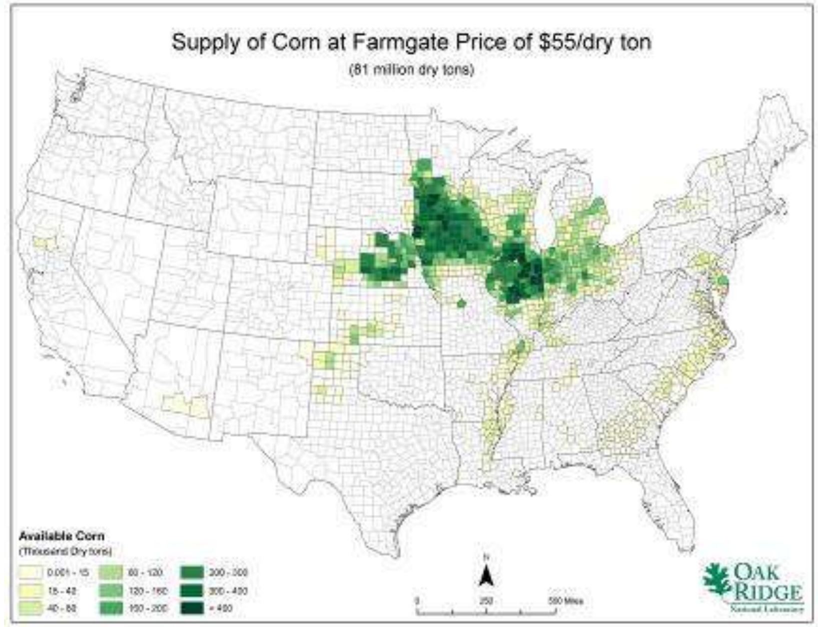
Issues:

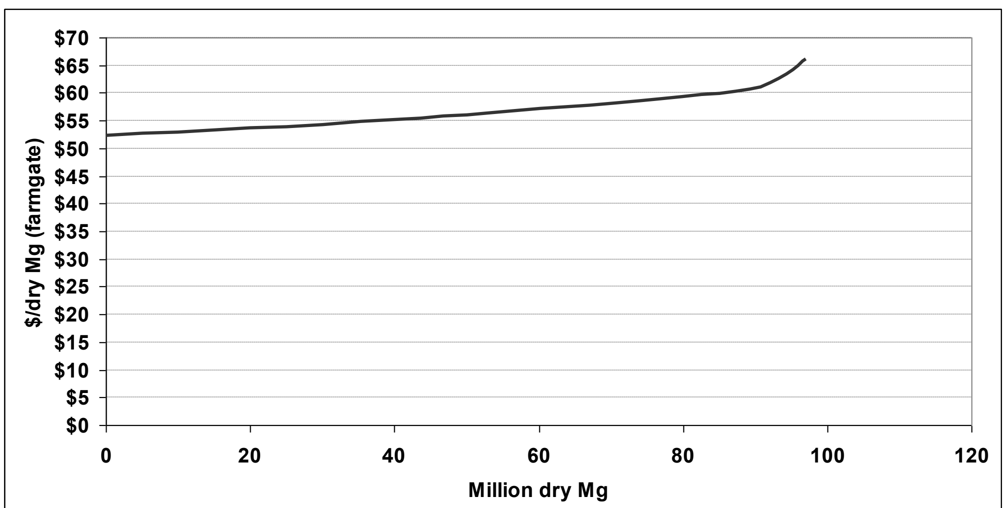
- Depending on conditions removal rates range from 0% up to 50%
- Yearly production rates can vary significantly
- Because of variability it will be necessary to contract substantially more stover supply than actually needed

* (Perlack et.al, 2007)

Supply is very sensitive to farm gate price





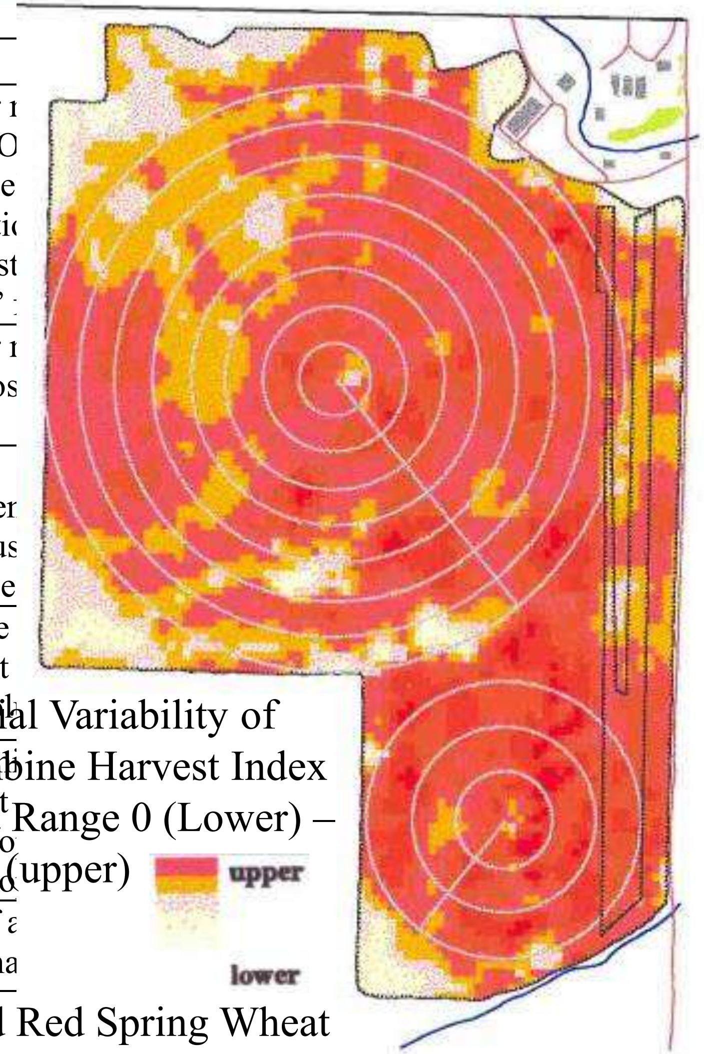


Corn stover national supply curve is very elastic. At low prices the feedstock is largely confined to the corn belt.

Perlack et al, 2008
Oak Ridge National Laboratory

Agronomic Factors Limiting Crop Potential

Limiting factor	*Issues*	
Loss of soil organic carbon	Supply/replenish SOC Soil quality Future production capacity	Restrict stover r maintain SO Fractional or se Develop situati amount of st “RUSLE2”
Soil erosion	Water erosion and runoff management Wind erosion management Off-site effects	Restrict stover r keep soil los WEPS
Loss of plant nutrients	Increased fertilizer application and production costs or reduced crop yield and producer income	Retain stover Improve nutrier Return ligneous Fractional or se
Soil water and temperature dynamics	Complex interactions Condition-specific solutions necessary	Need help here We know what cool wet soil
Soil compaction	Compaction of soil due to increase field traffic for residue removal and/or transition to no-till cropping system	Reduce or elimi Use equipment Conduct field o Conduct field o
Environmental degradation	Off-site erosion impacts Nutrient loss to surface water	Reduce runoff a Develop alterna



- Spatial Variability of Combine Harvest Index
- Data Range 0 (Lower) – 0.75 (upper)
- Hard Red Spring Wheat
- Ashton, ID - 1996

Crop Organic Matter return rate recommendations (or biomass input) must be managed just like fertilizers and other crop production inputs

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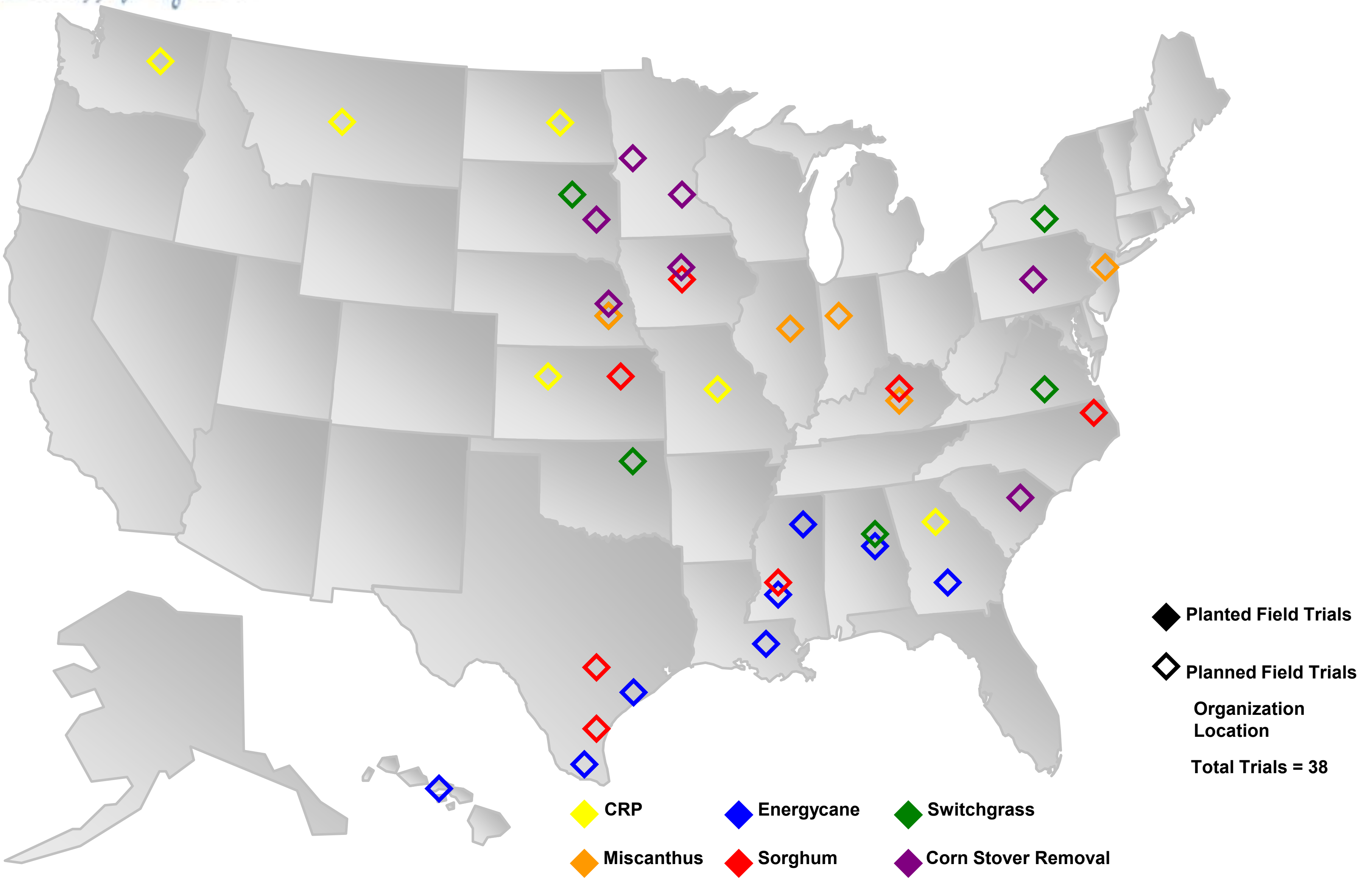
Regional Biomass Energy Feedstock Partnership 2008 Bioenergy Crop Trials

biomass program



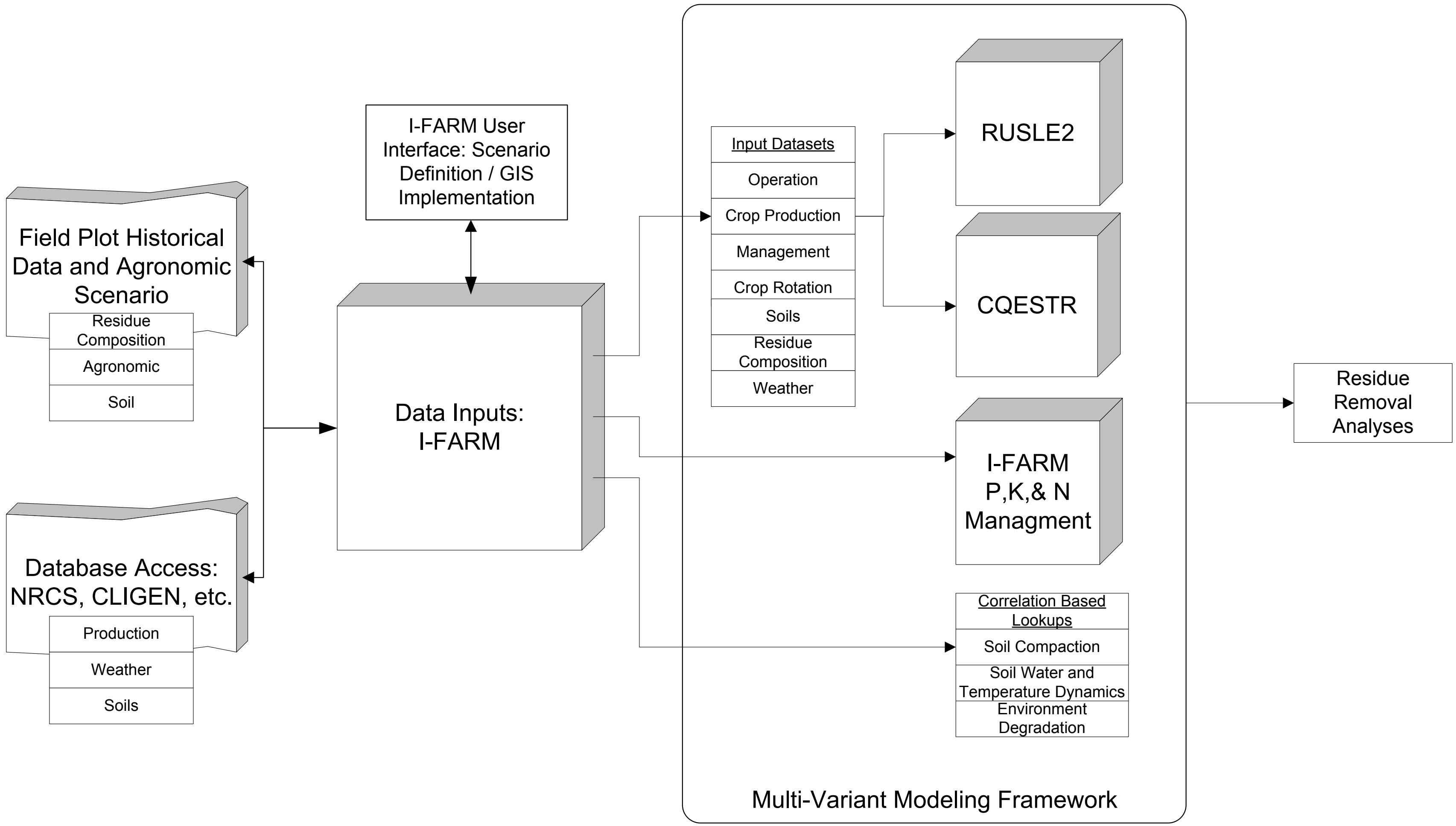
Regional Partnership Agronomy Field Trials

Core Treatment

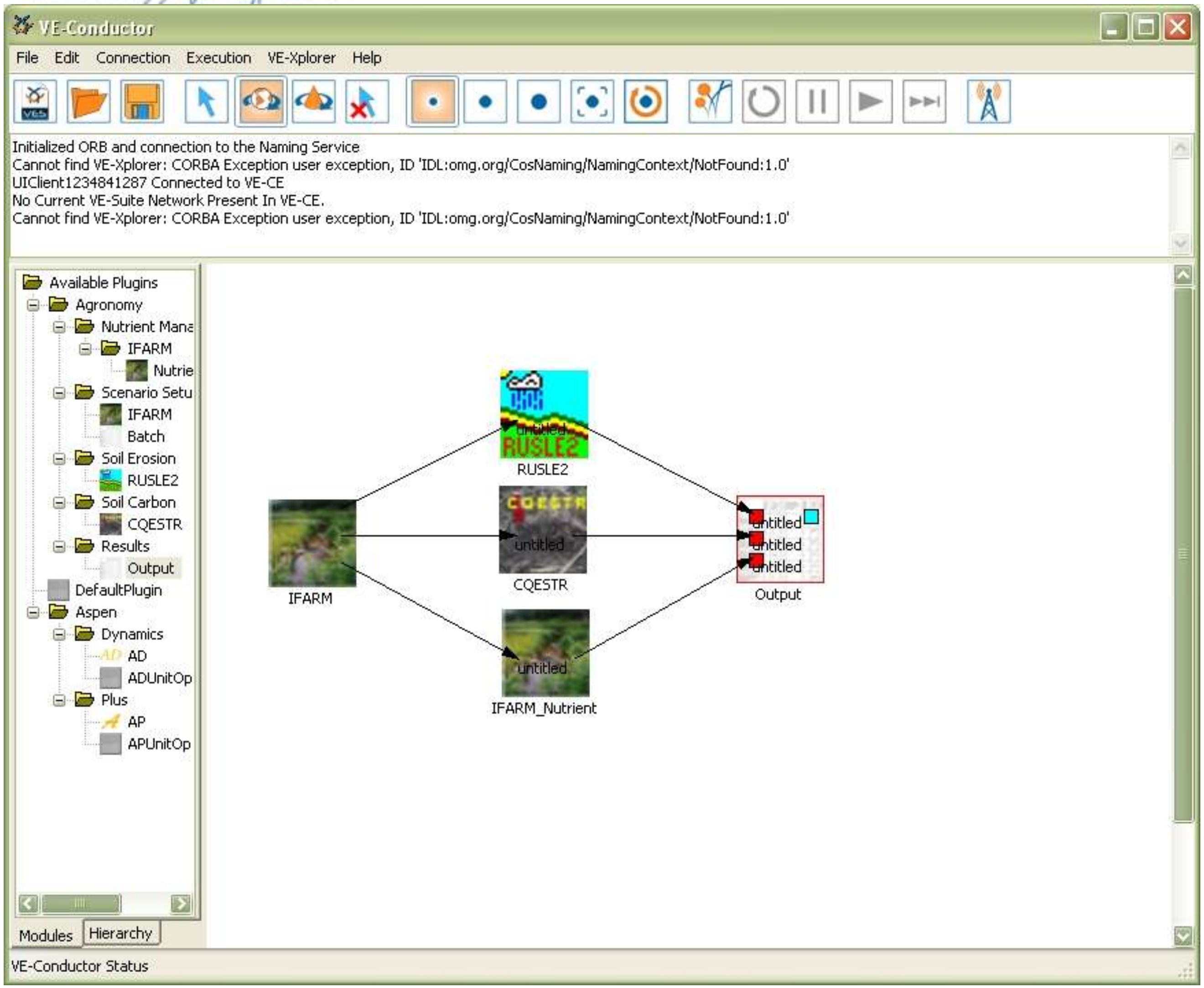
- Continuous Corn
- No (or minimum possible) Tillage
- Stover removal treatments of 0%, 50%, maximum possible removal
- Soil sampling protocol
- Management data reporting protocol
- Biomass sampling protocol

Residue Removal Tool Status

Initial Coupling and Data Flow



Residue Removal Tool Status



- Ports on the plugins are then used to connect the components directing the calculation
- Through each of the plugins the scenario definition and computation model specific settings are accessible
- With the system assembled and scenario defined, the network is ready for calculation

Residue Removal Tool Status

Model Integration Status

Erosion

- RUSLE2:
  - Fully integrated and functional utilizing the shared library built at the University of Tennessee.

Soil Organic Carbon

- CQESTR:
  - Fully integrated utilizing a custom built interface class.
  - Model is compiled into an ActiveX executable and integrated using the Microsoft COM API (Common Object Model, and Application Programming Interface).
  - Model code was not altered preserving validation.
  - Finishing work removing the RUSLE1 model dependence.

Nutrient Management

- I-FARM
  - Nutrient cycling functioning within I-FARM analysis framework.

Scenario Setup

- I-FARM
  - Working through remaining server access issues for data sharing, expected to be solved within 1-2 weeks.
- Batch Data Mode
  - Currently functioning ability to setup and run a suite of scenarios through a batch mode.

Residue Removal Tool Status

Demonstration Scenario:

Four Management Treatments

1. Standard Tillage: Chisel Plow, Field Cultivate, Planter Double Disk Opener
2. No Tillage: Planter Double Disk Opener w/Fluted Coulter
3. No Tillage with Winter Wheat Cover: Drilled in 7 inch rows. Chemically killed in late boot stage. Not harvested for grain.
4. No Tillage with Interseeded Legume Cover and Perennial Red Clover Cover: Red Clover regrowth after harvest of corn that has had clover aerially or highboy seeded in growing corn. Covers are chemically killed, mow and bale is possible.

Three Removal Rates per Treatment

1. 0%
2. Approx. 50%
3. Maximum Possible: Approx. 100%

Calculations Performed

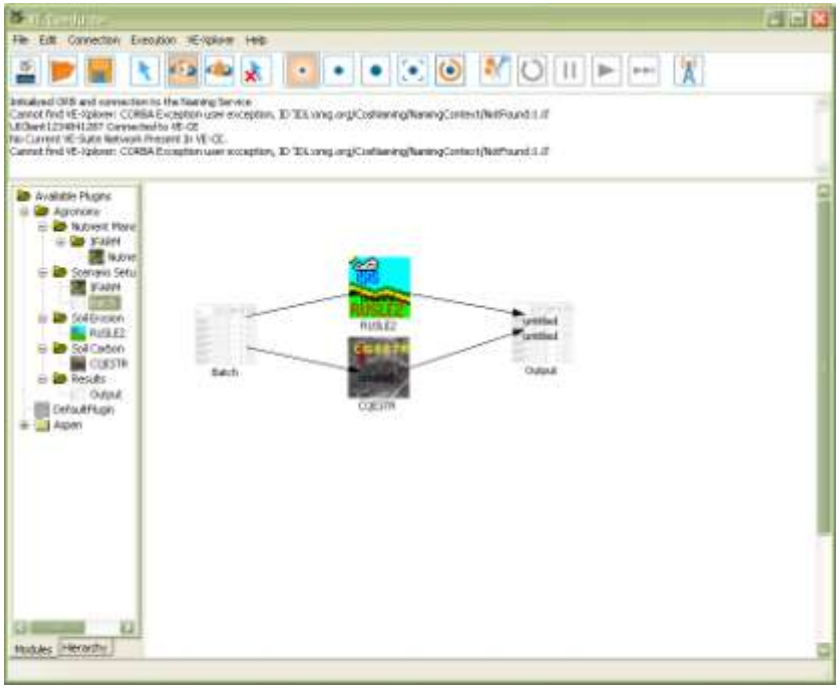
- Erosion through RUSLE2
- SOC through CQESTR

Residue Removal Tool Status

Demonstration Scenario:

25 Acre Site near Ames, IA

180 bu/acre average yield



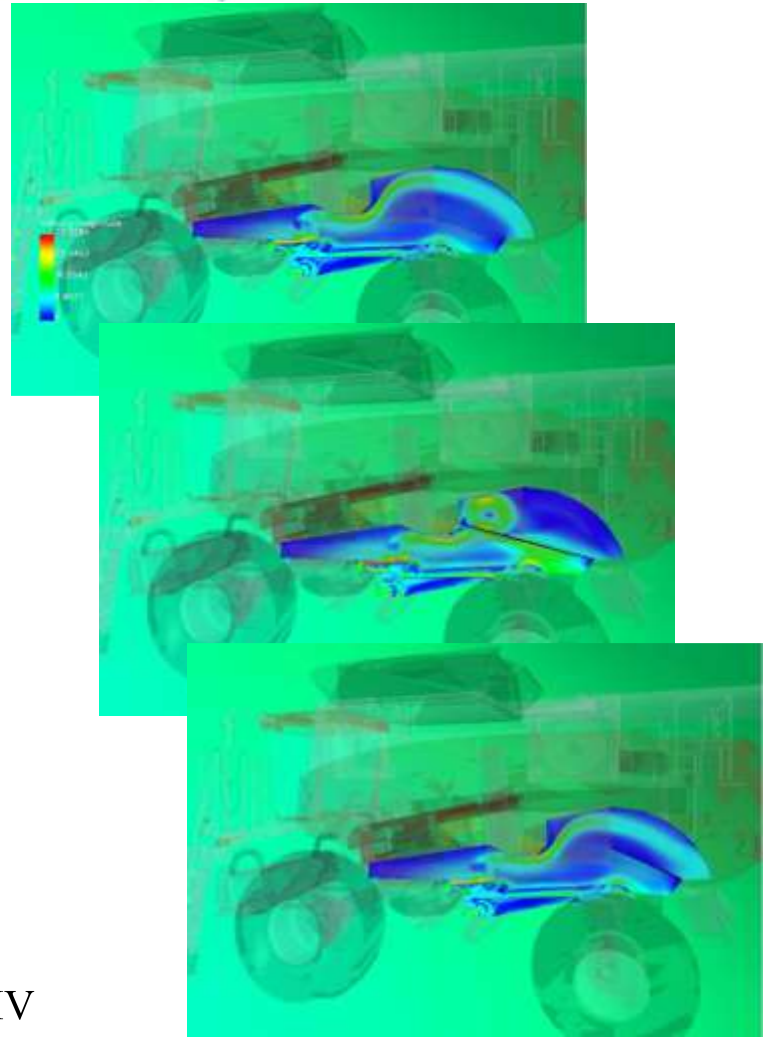
	Erosion (T=5.0) (t/acre/yr)				SOC (lbs/acre/yr)			
Removal Rate	Conv Till	No Till	NT w/Annual Cover	NT w/Perennial Cover	Conv Till	No Till	NT w/Annual Cover	NT w/Perennial Cover
0%	0.6	0.061	0.1	0.025	-152.58	-105.77	7.57	176.88
50%	2.1	0.21	0.24	0.043	-191.79	87.47	-40.48	136.06
100%	2.2	1.1	0.57	0.39	-211.28	-184.04	-77.79	95.18

Outlier currently being reviewed

Management Strategy Studies; Fractional Single-Pass vs. Mow and Rake

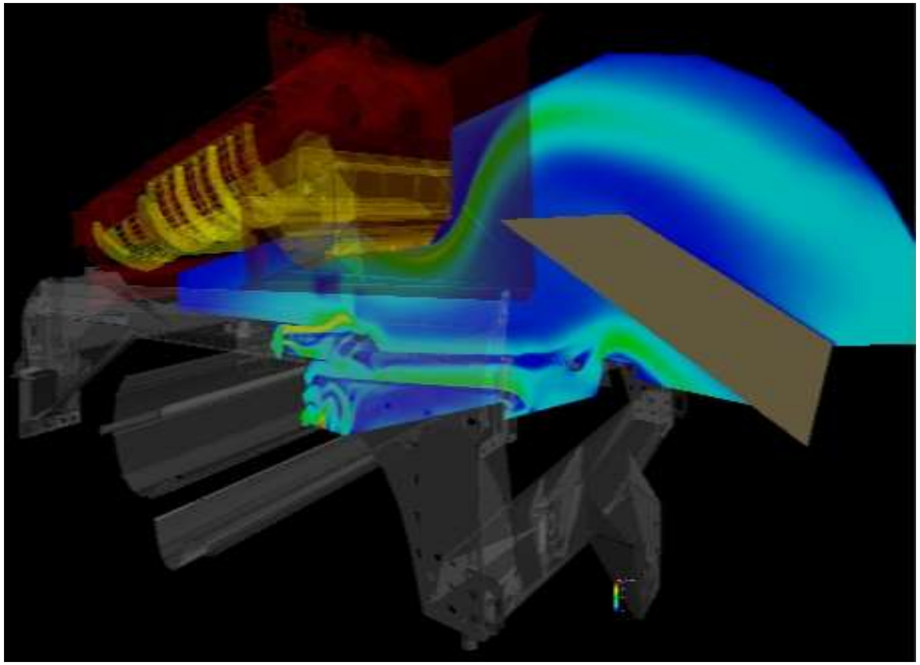
- Single-pass High cut harvested 72% of stover produced (i.e., 12% more stover collected per acre than billion ton study assumptions), so
- 70% removed with combine
    - Low moisture
    - Reduced pretreatment severity
    - Short soil half-life (Kumar and Goh, 2000; Eiland et al. 2001)
- 30% of stalk left behind
    - High moisture
    - Highly recalcitrant
    - Long soil half-life
- 40% removed with mow and rake – mostly stalk material

Harvest and Collection



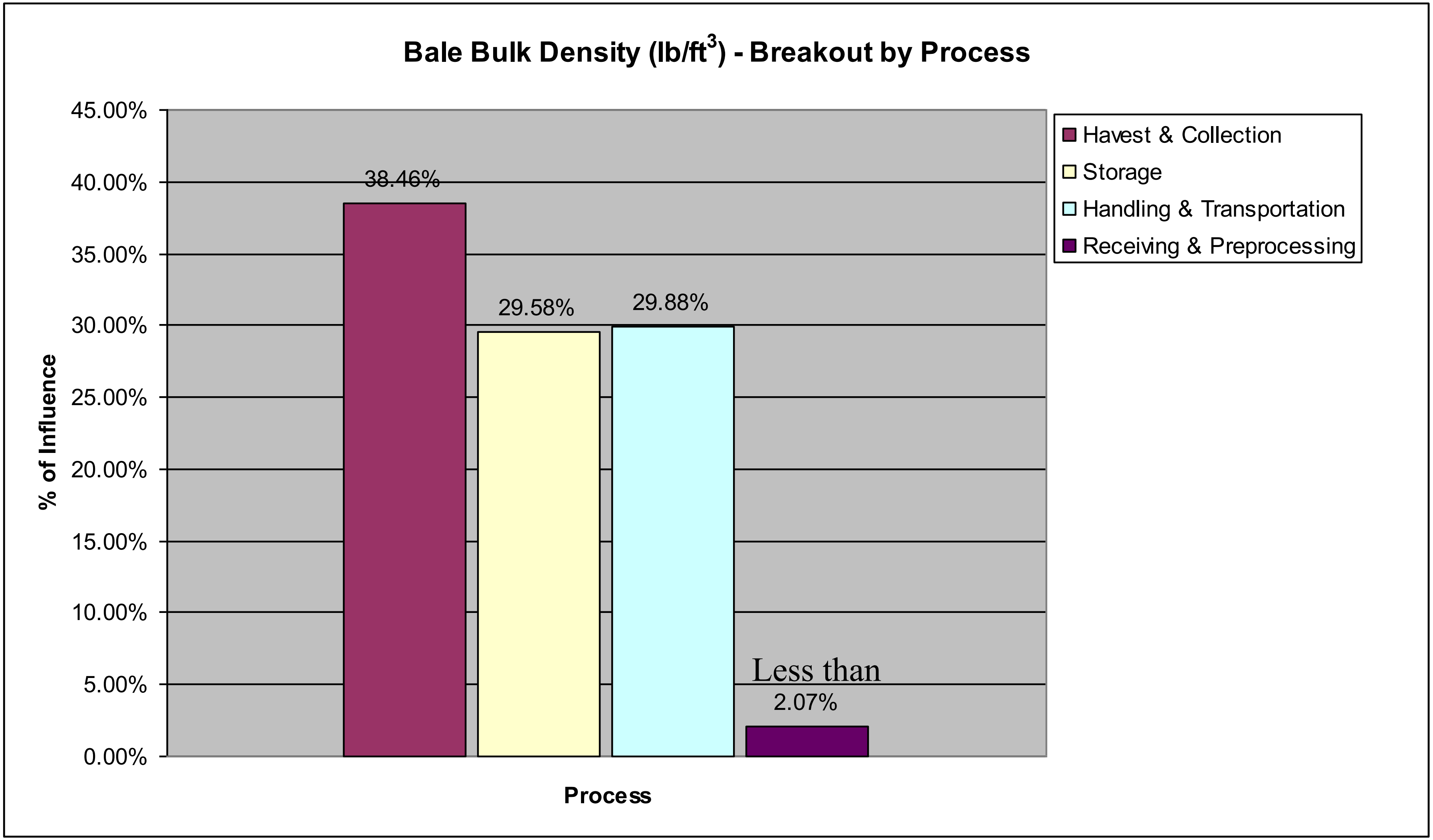
PIV

Field Testing



- Computational Fluid Dynamics Models (CFD)
- Particle Image Velocimetry (PIV)
- Interactive Design Canvas
- Successful Real-World Application of modified separation chamber

Relative Impact of Biomass Bulk Density on Supply System Unit Operations



Yield and bulk density data for large square bales

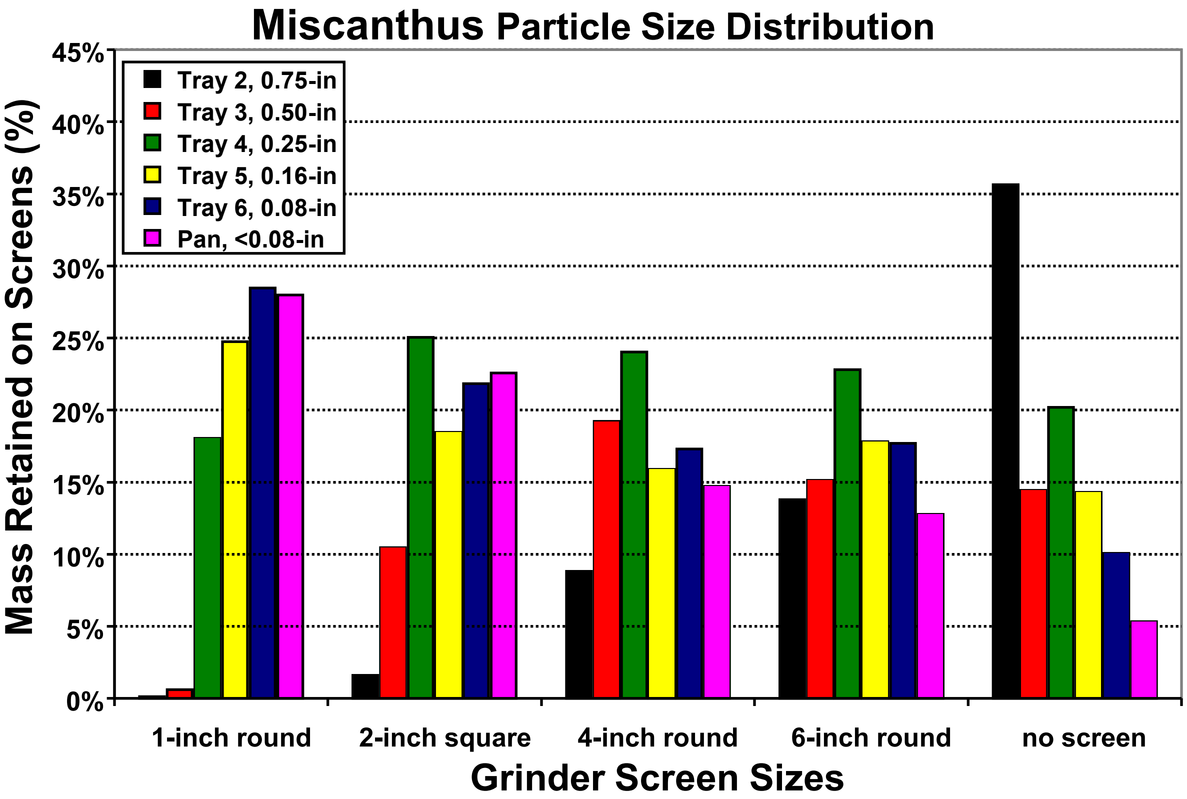
	Crop Yield (baled DM ton/acre)	DM Bulk Density (lb/ft^3)	Bales (4×4×8-ft) /Acre	Bales (3×4×8-ft) /Acre
Corn Stover	1.6	8–9	2.8–3.1	3.7–4.2
Cereal Straws	1.1	7–9	1.9–2.5	2.6–3.1
Switchgrass	4.0	11–12	7.0–7.8	9.3–10.4
Miscanthus	5.1	9–11	8.9–10.0	11.8–13.3

DM Bulk Density Targets (point at which bulk density ceases to be a predominant limiting factor) :

- Collection and Transportation =16 lbs/ft^3
- Handling and Storage >30 lbs/ft^3

Preprocessing Impact on Feedstock Quality Properties

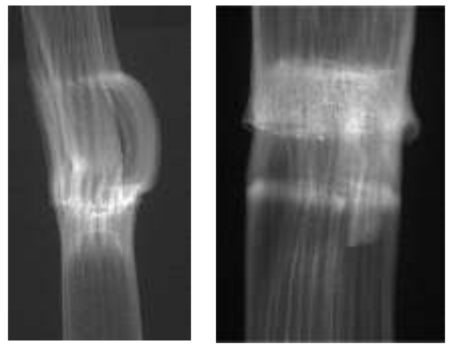
Material was ground using a commercial tub grinder in the field and separated in various size fractions using a forage separator



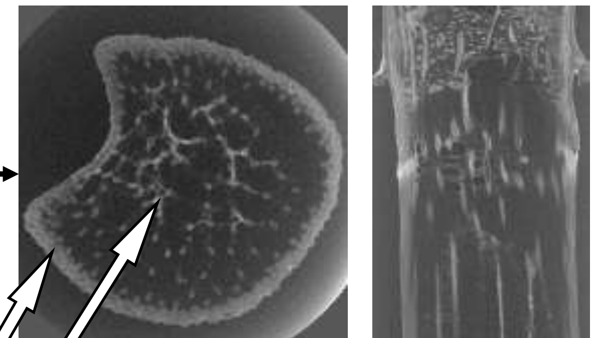
Corn Stover Radiography Tests

- Radiography Techniques show internal structures and potential source of mechanical strength/weakness

Image Radiography Equipment



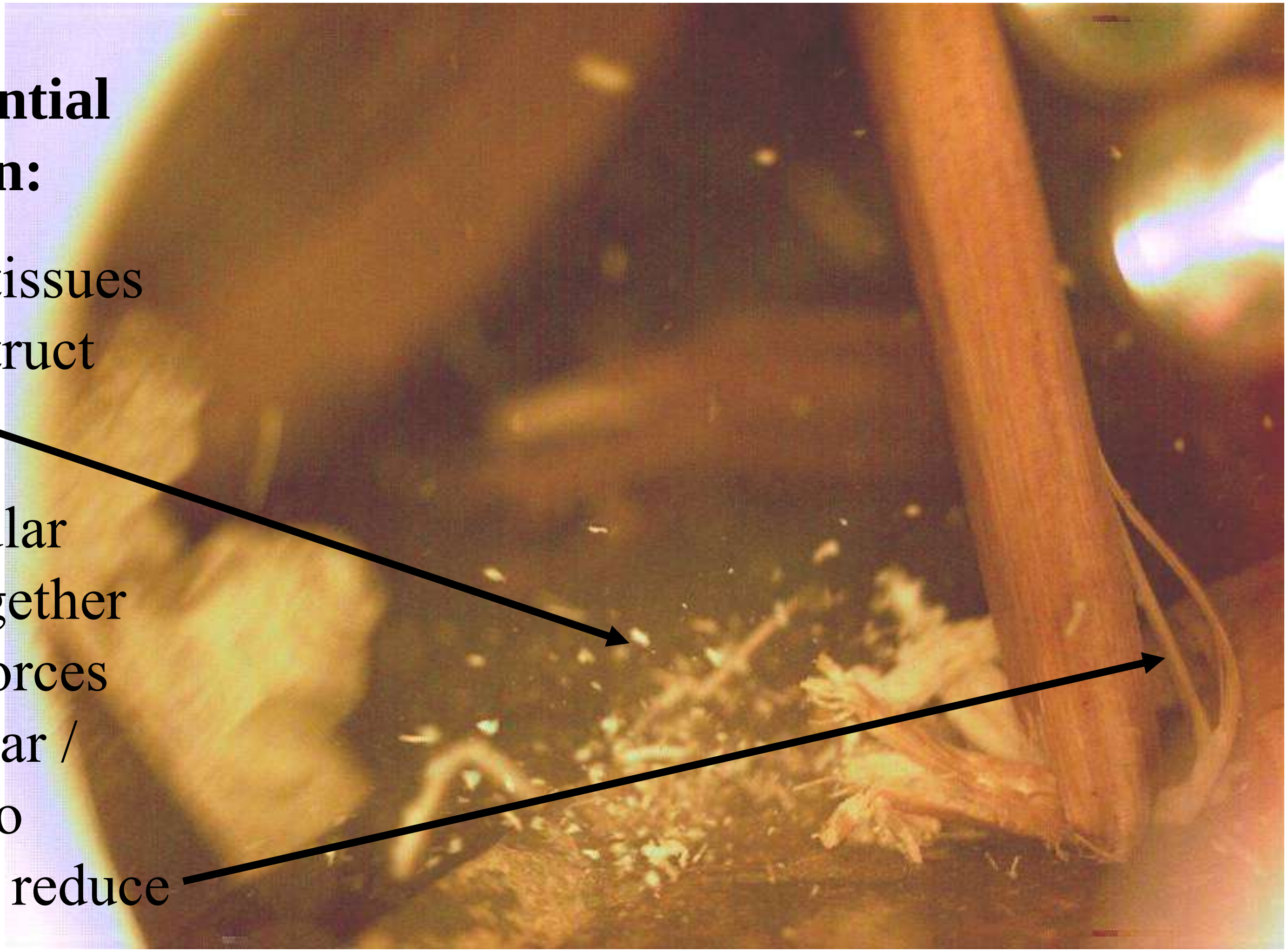
Radiograph projections of barley stover (left) and corn stover (right)



Horizontal and vertical tomographic slices of corn stover.

Un-ground corn stover left in tub

Real time fragmentation of corn stover in a grinder



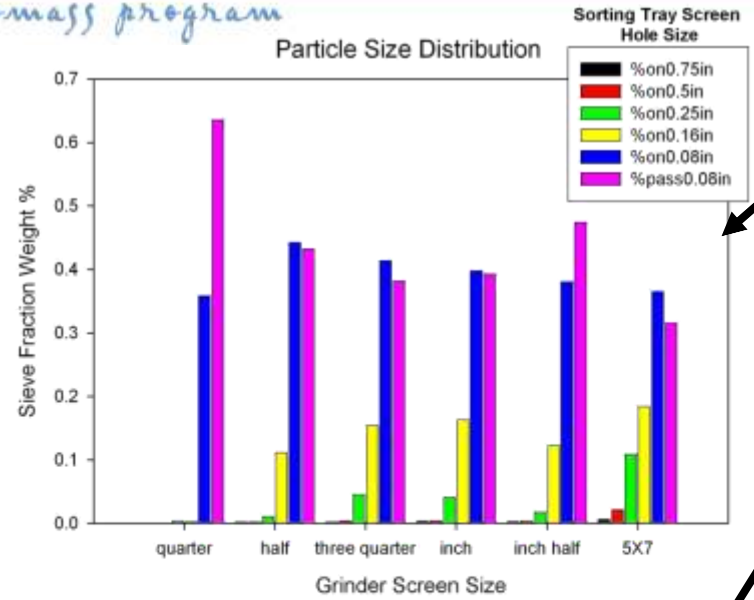
Biomass Differential Deconstruction:

- Pith and other tissues rapidly deconstruct upon impact
- Rind and vascular tissues hold together under impact forces and require shear / torsion forces to effectively size reduce

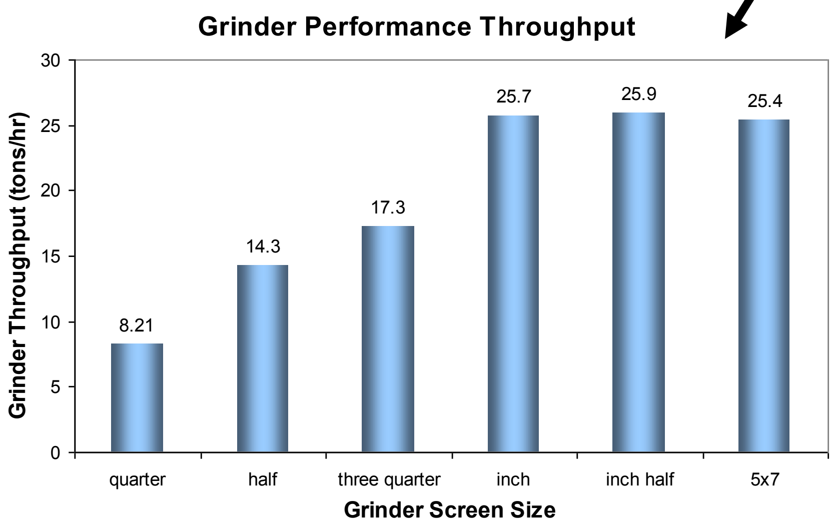
Video of Operating Grinding Drum – 30 fps

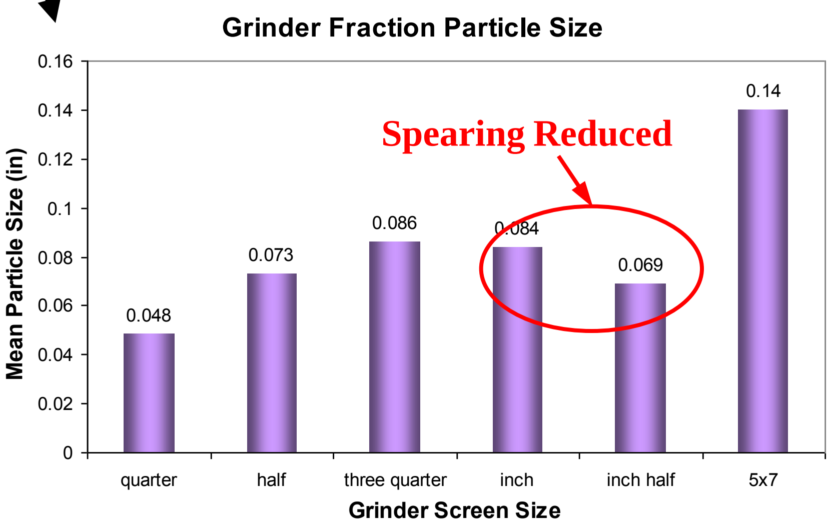
Real-time video of grinding Miscanthus

Preprocessing Deconstruction Characteristics



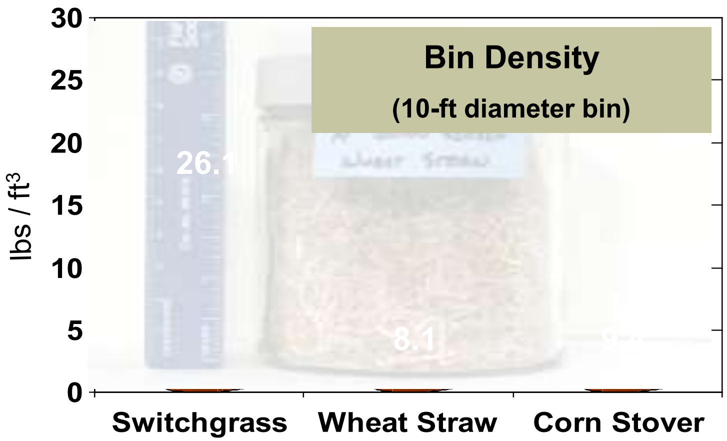
- Different screen sizes cause a differential rate of deconstruction of the material
- Screen geometry directly affects throughput (particle escape) and spearing (loss of size reduction)



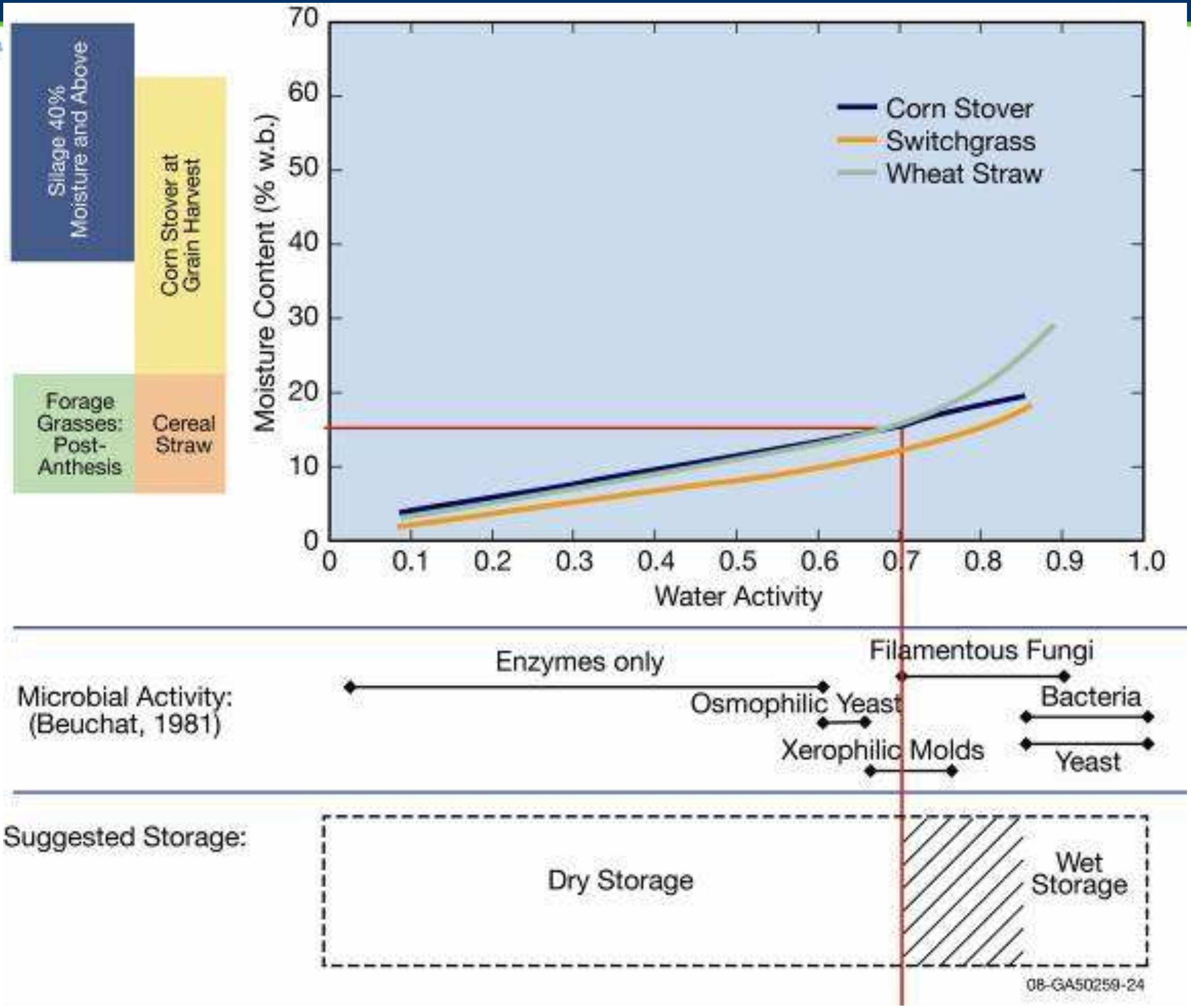


Differential Properties of Preprocessed Biomass Materials

Feedstock (¼-inch minus)	**Switchgrass**	**Wheat Straw**	**Corn Stover**
Mean Particle Diameter	0.276 mm	0.498 mm	0.346 mm
Particle Size Distribution (wt%)	29.4% > 0.85 mm 0.212 mm < 50.7% < 0.85 mm 18.6% < 0.212 mm	41.6% > 0.85 mm 0.212 mm < 46.9% < 0.85 mm 10.3% < 0.212 mm	24.9% > 0.85 mm 0.212 mm < 56.1% < 0.85 mm 16.9% < 0.212 mm
Bin Density (10-ft diameter bin)	26.1 lbs/ft^3	8.1 lbs/ft^3	9.4 lbs/ft^3
Compressibility (Δ% 0-500 lb/ft^2)	18%	31%	35%
Flowability Factor	5.7 (easily flowing)	1.1 (cohesive)	1.2 (very cohesive)
Permeability	0.27 ft/sec	0.83 ft/sec	0.18 ft/sec
Springback	4.1 %	7.6 %	5.6 %
Angle of Repose	33.6 degrees	35.4 degrees	35.3 degrees



Wet versus Dry Biomass Effects

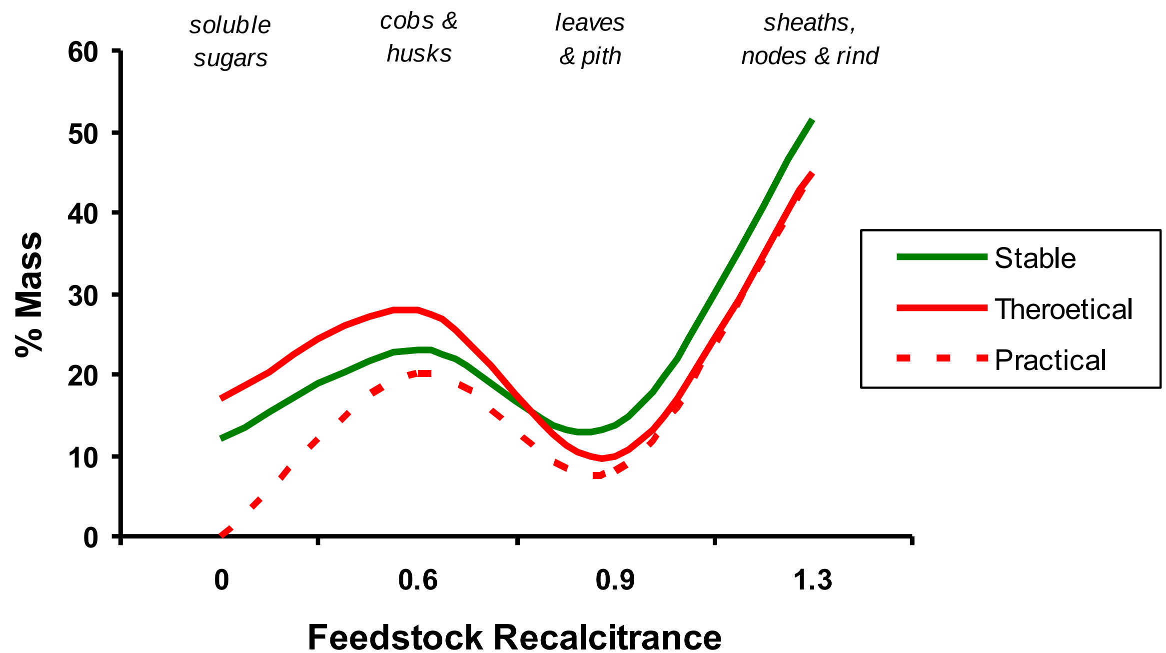


Storage and Queuing R&D

R&D Details:

- Assess soluble sugar capture systems
- Expand wet design concepts for $35 target
- Assess performance of key storage systems
- Investigate function / composition tradeoffs *(i.e., can we stabilize & destabilize together?)*

- Extend dry systems for use in wet climates



Biomass	Compositional Quality % structural sugars (Δ $/ton)	Functional Quality % xylan yield (Δ $/ton)
Unstored Whole Stover	60.8% (baseline)	ND
Bunker-Most Stable	51.9% (- 10.3)	ND
Bunker-High Least Stable	47.9% (- 16.0)	ND
Unstored Cobs	71.7% (baseline)	70.0% (baseline)
Cobs	69.3% (-2.21)	73.5 ($1.35)
Unstored Leaves	75.3% (baseline)	72.1% (baseline)
Leaves	59.3% (-16.0)	69.4% (-$1.04)
Unstored Stalks	64.9% (baseline)	52.7% (baseline)
Stalks	59.2% (-6.5)	56.8% ($1.57)

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Opportunities for Quality Changes

biomass program

Harvesting

- Use single pass harvesting to minimize contamination
- Selective harvest
    - Plant fractions with varying compositional qualities
- Schedule harvest
    - minimize moisture content
    - alter mineral content
    - lignin to cellulose ratio

Preprocessing

- Grind to smaller particle sizes to increase bulk density
- Alter particle shape factors
- Selectively screen and separate to increase quality

Silo

Large Vertical Structures

Storage/Queuing

- Reduce dry material losses
- Apply pretreatments to impact physical properties
- Leach out contaminates

www.uwex.edu/ces/crops/inoc.htm

www.wwvrailway.com

Key Feedstock Attributes Summary

Attributes	**Conversion System Impact**	**Assembly System Impact**
Physical Properties		
Moisture	Heat and mass transfer Energy balance Product composition	Grinding Efficiency Transportation economics Feeding and Handling Efficiency Storage Stability
Particle Size Shape Density Porosity Permeability Thermal Conductivity Heat Capacity Thermal Diffusivity Emissivity	Feeding and entrainment Solids loading Heat and Mass Transfer Reactivity Acid pretreatment Devolatilization Kinetics	Grinding Efficiency Storage capacity Feeding and Handling Efficiency Drying Efficiency Transportation Economics

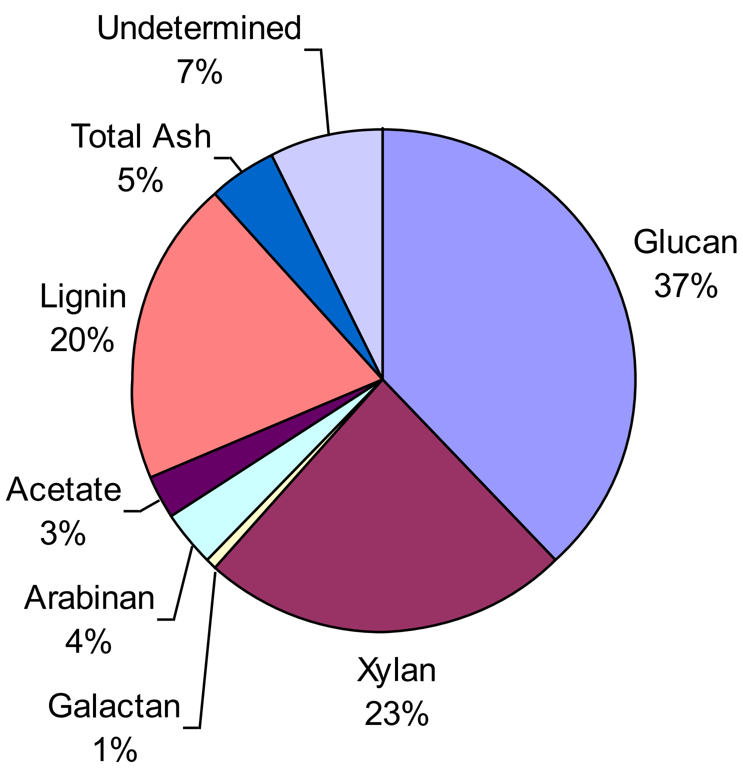
Key Attribute Summary Cont.

Attribute	Conversion System Impact	Assembly System Impact
Chemical Properties		
Fixed Carbon	Reactivity	
Volatile Matter	Product yield	
O:C ratio	Energy Content	
H:C ratio	Tar Formation	
Cellulose:lignin	Ethanol yield	
N	NO_x Production	
S	Fuel Quality, Catalysis activity, Lifetime	
Cl	Facilitates Ash Formation, Corrosion	
Ash	Lowers Energy Density	Equipment Wear
	Acid treatment buffering	
Si	System Fouling	
Na	Ash Softening	
K	Corrosion, Erosion	
Mg	Catalytic properties	
P	Decomposition Temperature	
Ca	Influences Product Distribution	
Fe	and Yield	

Stover Characteristics

- Average chemical composition
- Variability of composition

Corn Stover Composition



Images of Feedstock Size Fractions

Tray 2

Tray 4

Tray 6

Pan

- The process of size reduction does not randomly reduce all the different components of biomass materials in a uniform manner
  - Different size fractions may differ significantly in their chemical properties
    - partial separation of inorganic and organic matter

Preprocessing Impact on Feedstock Biochemical Quality

Tray 2

Tray 4

Tray 6

Pan

Grinder Screen 2-inch	GLUCAN (%)	XYLAN (%)	GALACTAN (%)	ARABINAN (%)	Total Sugars	MES
No Screen	36.57	16.68	0.91	1.70	55.86	1.25
Tray 2	39.74	16.77	0.78	1.36	58.65	1.19
Tray 3	39.08	16.98	0.79	1.44	58.29	1.20
Tray 4	37.80	16.99	0.84	1.54	57.18	1.22
Tray 5	36.11	17.24	1.00	1.64	55.99	1.25
Tray 6	31.76	16.04	1.32	1.83	50.95	1.37
Pan	22.39	11.93	1.82	1.80	37.94	1.8

Preprocessing Impact on Feedstock Thermochemical Quality

	No Screen	Tray 3	Tray 4	Tray 5	Tray 6	Pan
Proximate Analysis (% dry fuel)						
Fixed C	11.06	12.17	12.73	13.37	12.68	11.63
Volatiles	70.40	85.29	84.25	82.37	78.43	79.87
Ash	18.54	2.54	3.02	4.26	8.89	8.50
Ultimate Analysis (% dry fuel)						
C	41.60	49.79	49.63	49.12	46.69	46.93
H	4.98	5.73	5.72	5.69	5.41	5.44
O (Diff.)	34.25	41.75	41.39	40.70	38.65	38.83
N	0.57	0.16	0.17	0.18	0.29	0.24
S	0.06	0.03	0.07	0.05	0.07	0.06
Cl	0.016	0.023	0.018	0.022	0.016	0.016
Elemental Composition of Ash (%)						
SiO_2	79.17	69.07	70.67	72.21	77.32	77.31
K_2O	2.44	9.45	7.67	6.09	3.52	3.68
NaO_2	0.59	0.36	0.63	0.38	0.85	0.55
MgO	0.89	2.68	2.55	1.82	1.40	1.31
CaO	2.71	4.92	4.86	4.36	3.20	2.88
P_2O_5	0.88	3.95	3.30	2.62	1.42	1.40
Fe_2O_3	2.76	1.83	2.02	2.35	2.67	2.81
Al_2O_3	6.20	2.80	3.71	4.02	5.68	5.92
TiO_2	0.36	0.22	0.21	0.21	0.31	0.31
Higher Heating Value (Btu/lb)						
HHV	6906	8050	8146	7944	7743	7705

General Feedstock Material Attribute Observations

- Feedstock supply system is most sensitive to physical property attributes
  - **Moisture**
  - **Bulk density**
- Conversion systems are most sensitive to compositional attributes
  - **Carbohydrate**
  - **Lignin**
  - **Ash**
- Conversion systems may also be sensitive to physical properties, depending upon process design
  - **Moisture**
  - **Particle size and size distribution**

Overall Assessment for Corn Stover

- Corn stover removal causes real issues with sustainable agricultural practices, but prescriptive removal tools and selective harvest technologies can address these issues.
- Initially, new corn stover biorefineries will operate with conventional (dry) forage supply systems or employ corn cob only technologies
- Baled-based systems (i.e., conventional forage technologies) cannot simultaneously meet
  - 2012 and beyond cost targets (< $32.80 per dry ton)
  - 2030 tonnage targets (600-700 million dry tons annually)
- Lignocellulosic biomass supply systems must be developed into commodity-scale systems based on advanced uniform formats. Corn cob system represent a 1st generation implementation of such.
- Densification and moisture management is key to performance
- Harvest and supply system losses must be minimized
- Single pass harvest methods will improve system performance

Recommendations for Corn Stover

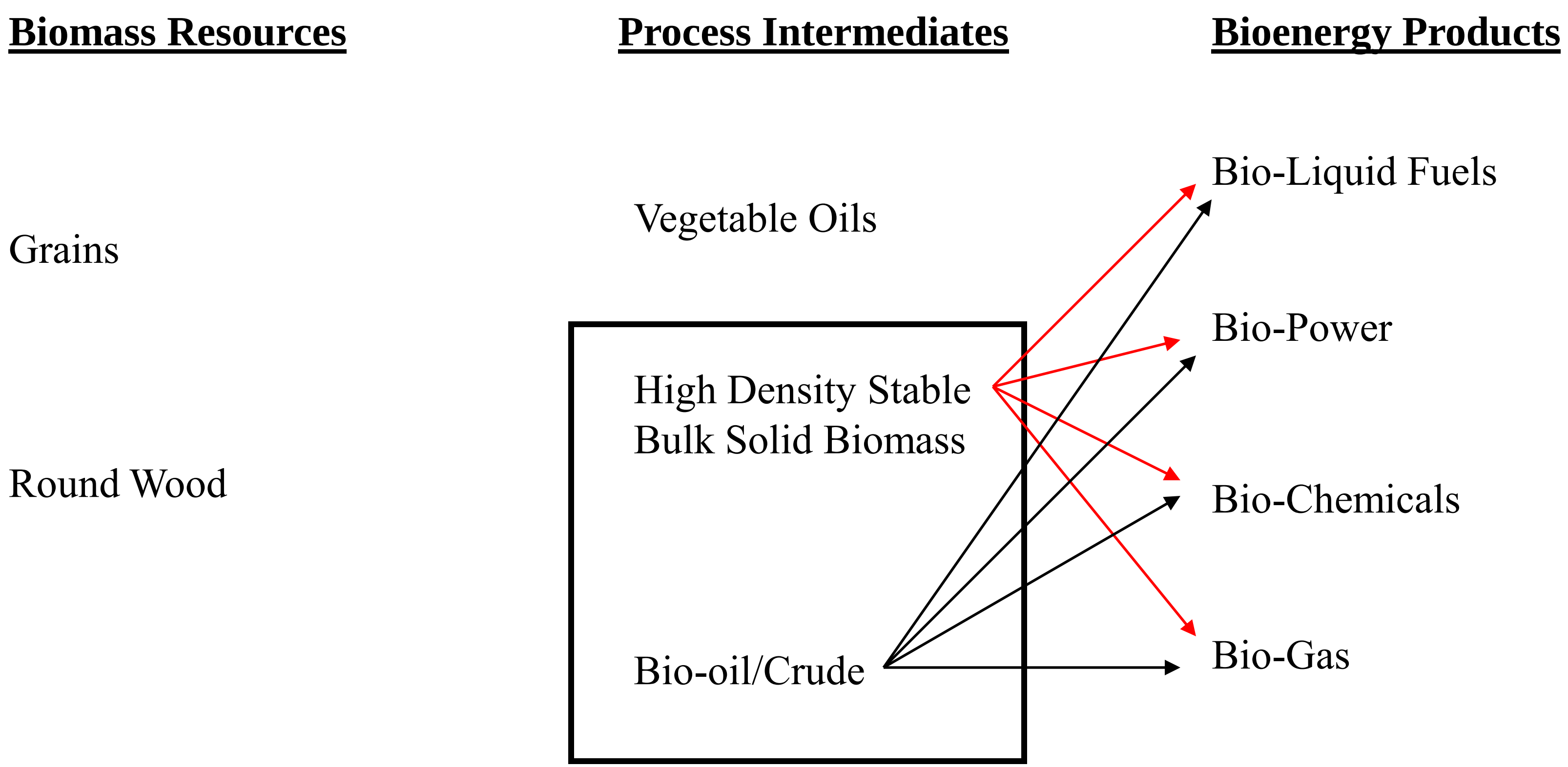
1st Generation Pioneer Systems

- Selective Harvest/Prescriptive removal address sustainability
- Dry Feedstock System
- Locate in dry high productive Corn Belt Region (north/west regions)
- Square Bale with conventional equipment
- Corn Cob only supply systems for wetter or sustainably sensitive regions

Advance-Uniform Supply System

- Cover Crops, Energy Crops, and Improved Corn Crop Genetics solve sustainability issues
- Single Pass Harvester
- Multiple Resources (e.g., corn stover and energy crops together)
- Active moisture mitigation/material stabilization
- Material Bulk and Energy Densification
- Commodity-Scale Solid and/or Liquid based supply systems

Feedstock Logistics Research Focus – Commodity-Scale Process Intermediates



Collectively, Many Biomass Preprocessing Depots Produce Infrastructure Compatible Lignocellulosic Intermediates at a Commodity-Scale

U.S. Department of Energy
Energy Efficiency and Renewable Energy

Biorefining Depends on Feedstock