Feedstock Infrastructure: The US Experience

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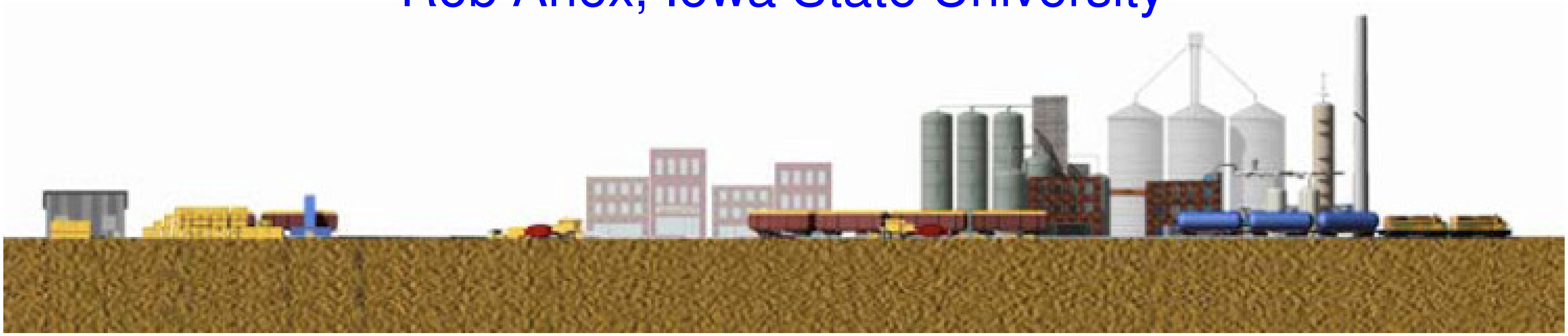
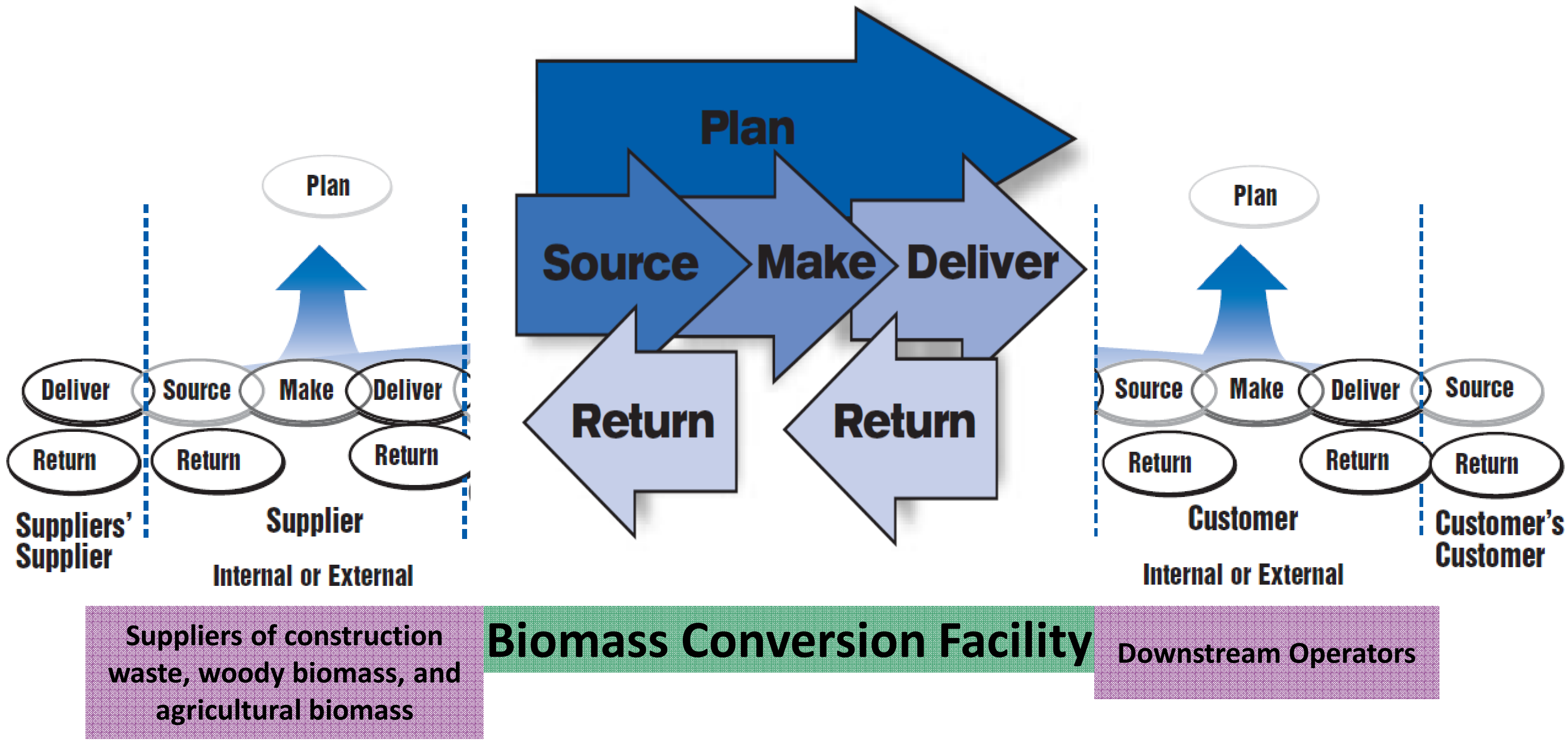
Rob Anex, Iowa State University



Thunder on the horizon

- Diverse conversion processes
- Diverse feedstocks
- Diverse land ownership
- New equipment needs
- New business models
- Sheer volume

Supply Chain Functions



Feedstock Supply Chains

Farm gate

Handling & Transportation

Plant gate

Biomass Production → Harvest & Collection → Off-site pre-processing → Long-haul transport to plant → Handling & Queuing → Conversion Plant

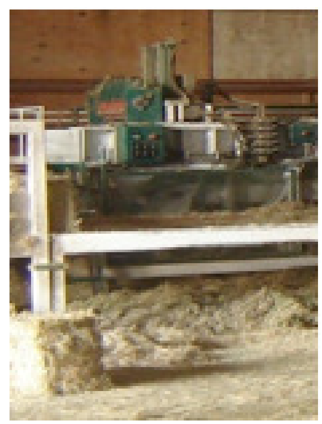
-Cutting & hauling

-Densification (baling, bundling or chipping)

-Grinding and formatting for increased density

-Fractionation, tissue separation, drying, or blending for improved feedstock quality

-Loads directly to transport vehicle



Short supply chains:

Step 1: Grow!

Step 2: Harvest

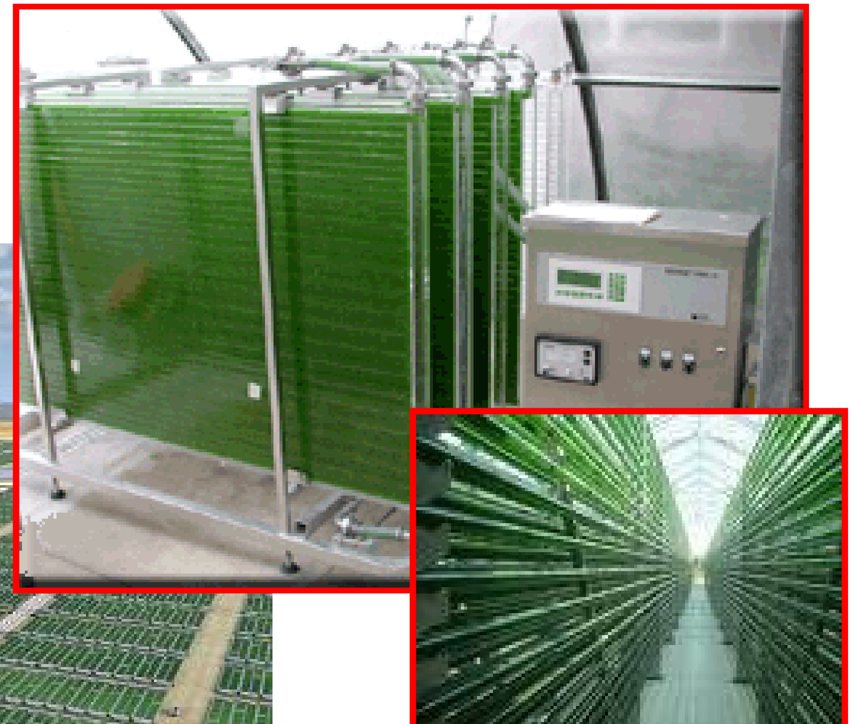
Step 3: Store & Press

Convert to fuel


methanol condensor
seed
oil press
reaction vessel
farmer
fuel drain
seed meal
oil tank
glycerin drain

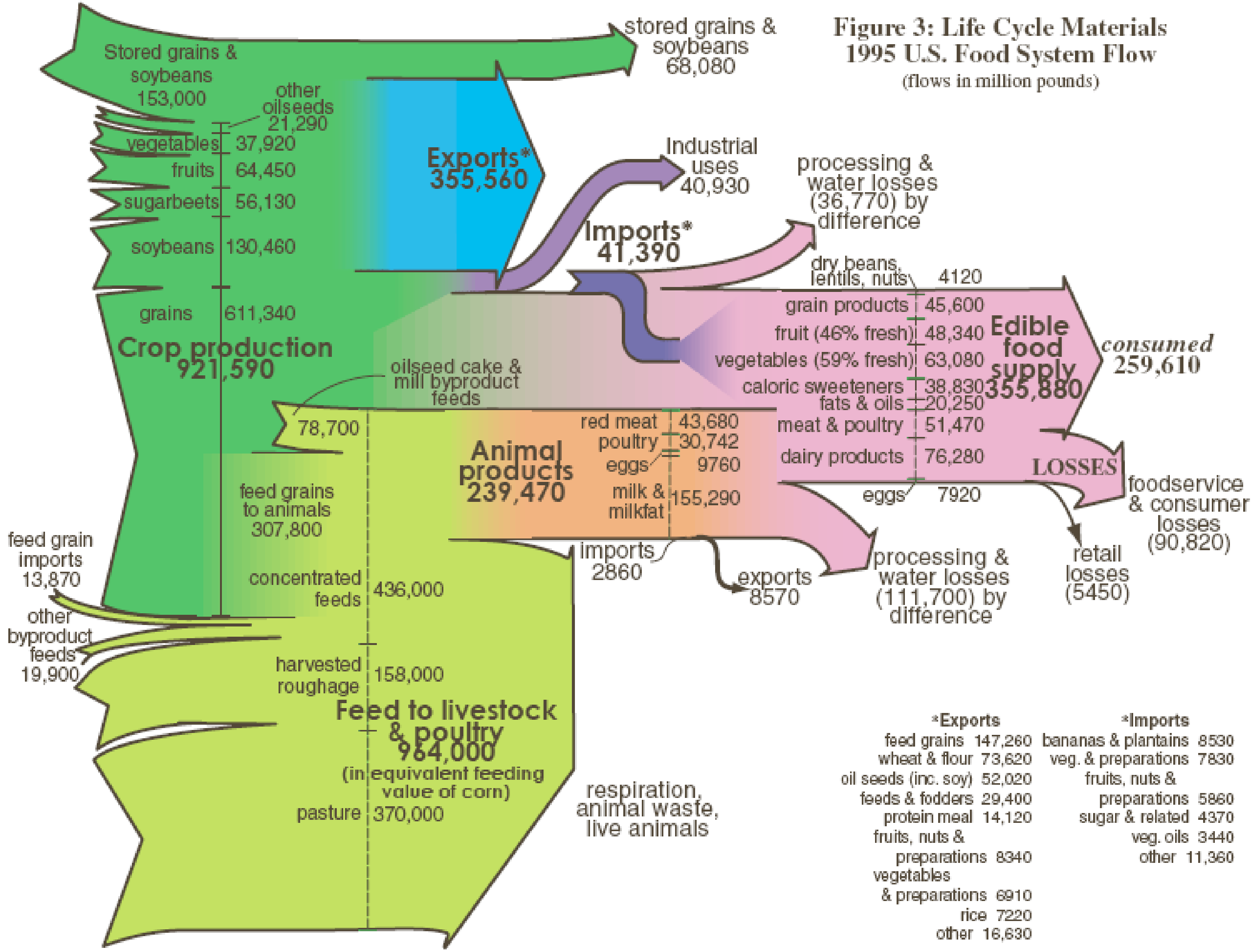
Ethanol too…

And Algae?

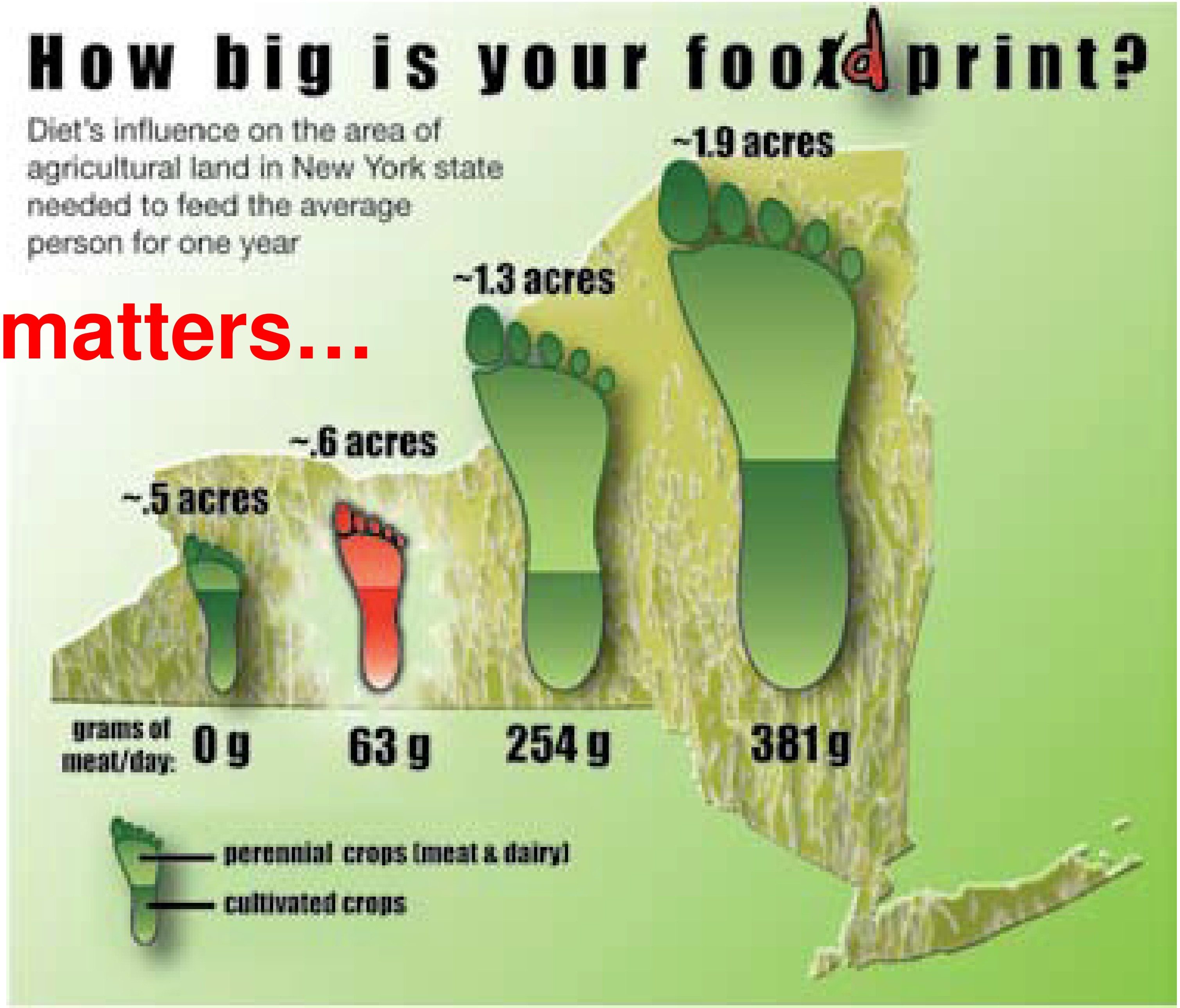


Courtesy Wayne R. Curtis, Penn State

The US Food System



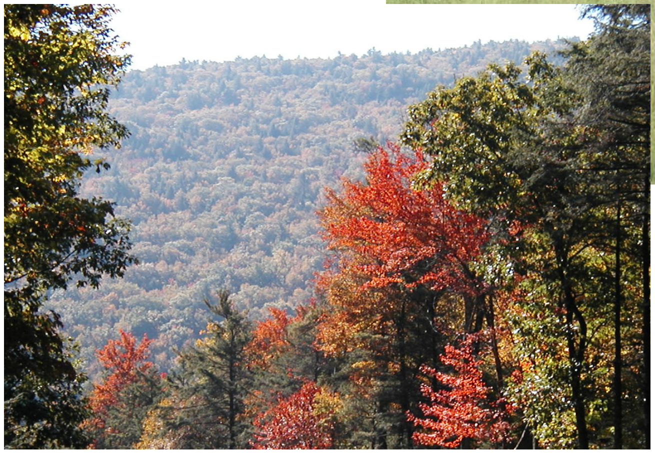
Diet matters…

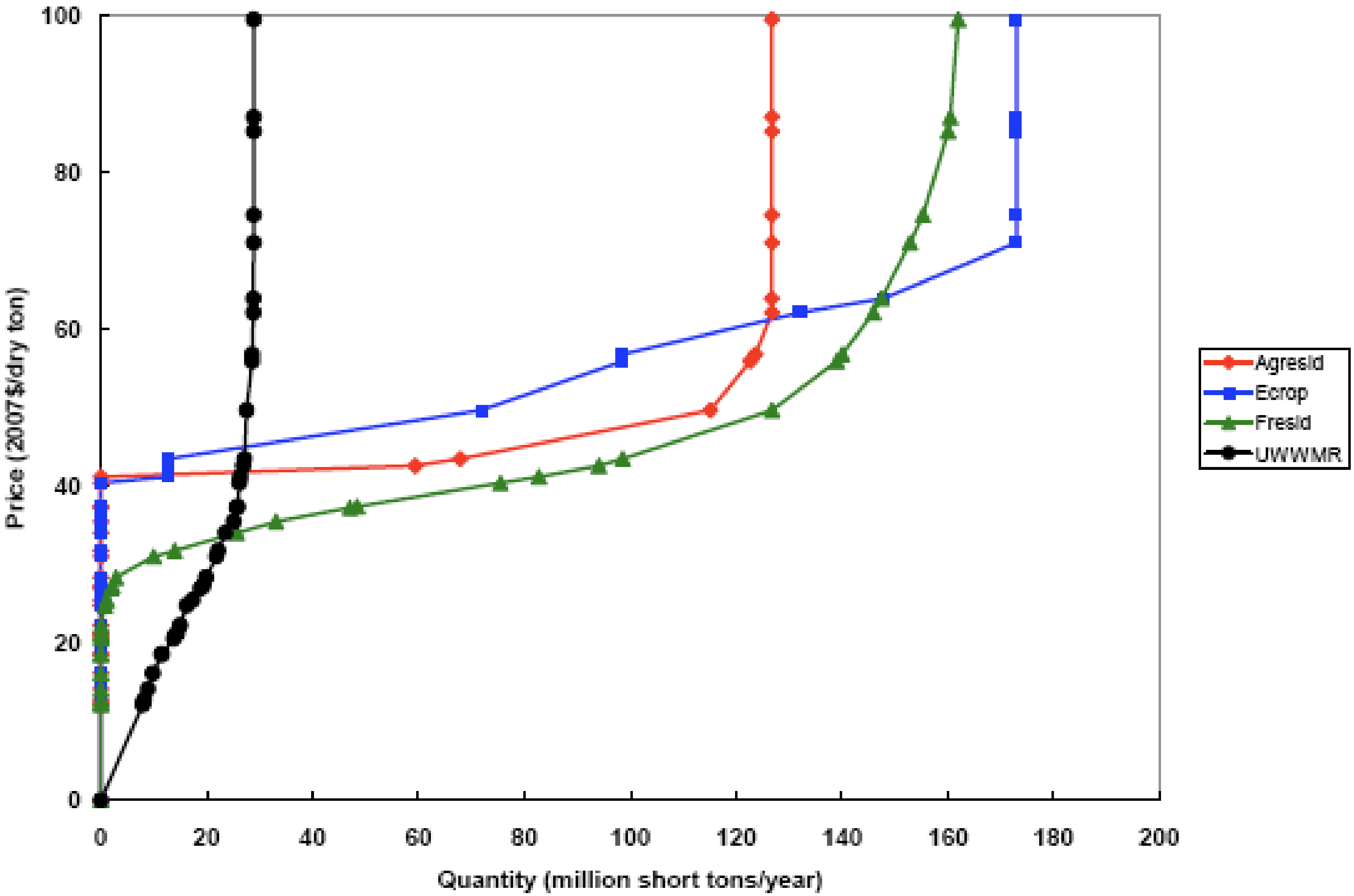


Peters et al. 2006

Four Sustainable Sources

- Organic Wastes
- Perennial Crops
- 21st Century Forestry
- **Multi-functional Agriculture**





Price-Supply Curves

Analysis by Marie Walsh, UofTN, 2005 version of Polysis

1. Organic Wastes

Municipal Solid Waste (MSW), wood processing residues, food processing wastes, livestock wastes and manure.

Photo credits Carla Castagnero, AgRecycle, Inc.; NRCS.

Urban Biomass

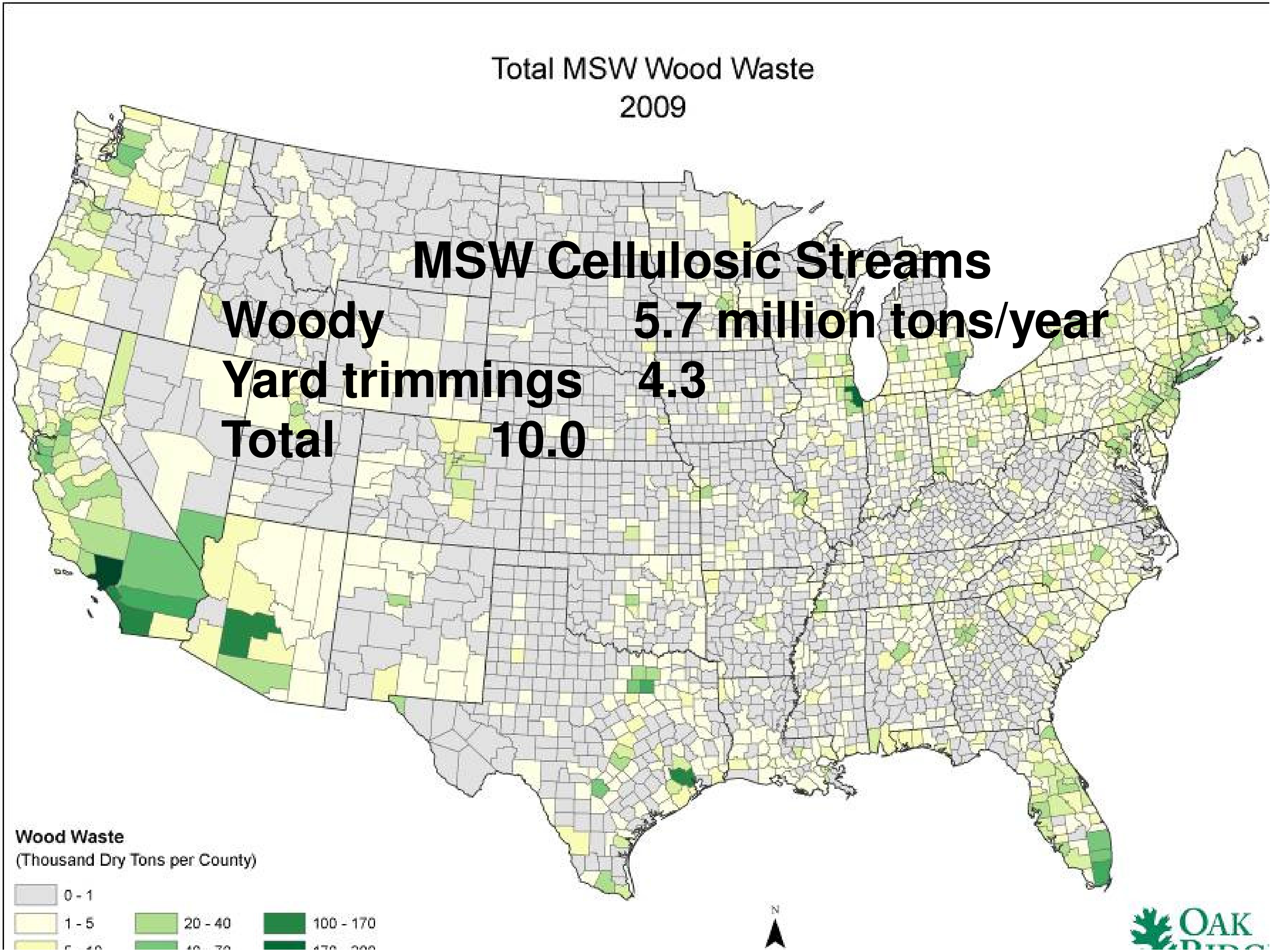
470 million tons/year solid waste, 36% organic

92 million tons/year easily recovered organics

(2005 USEPA estimates)

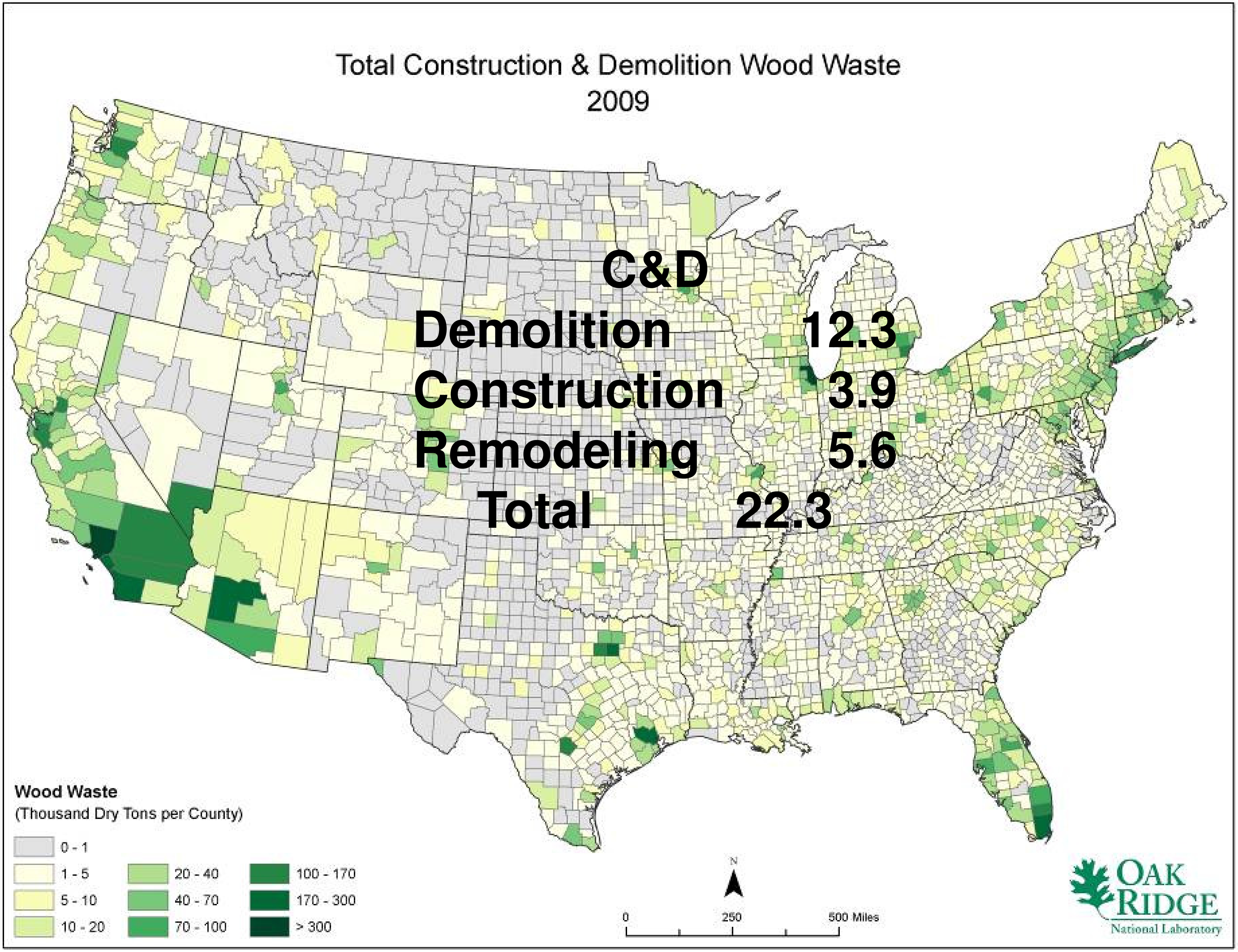
75 million other tons/year organics if separated

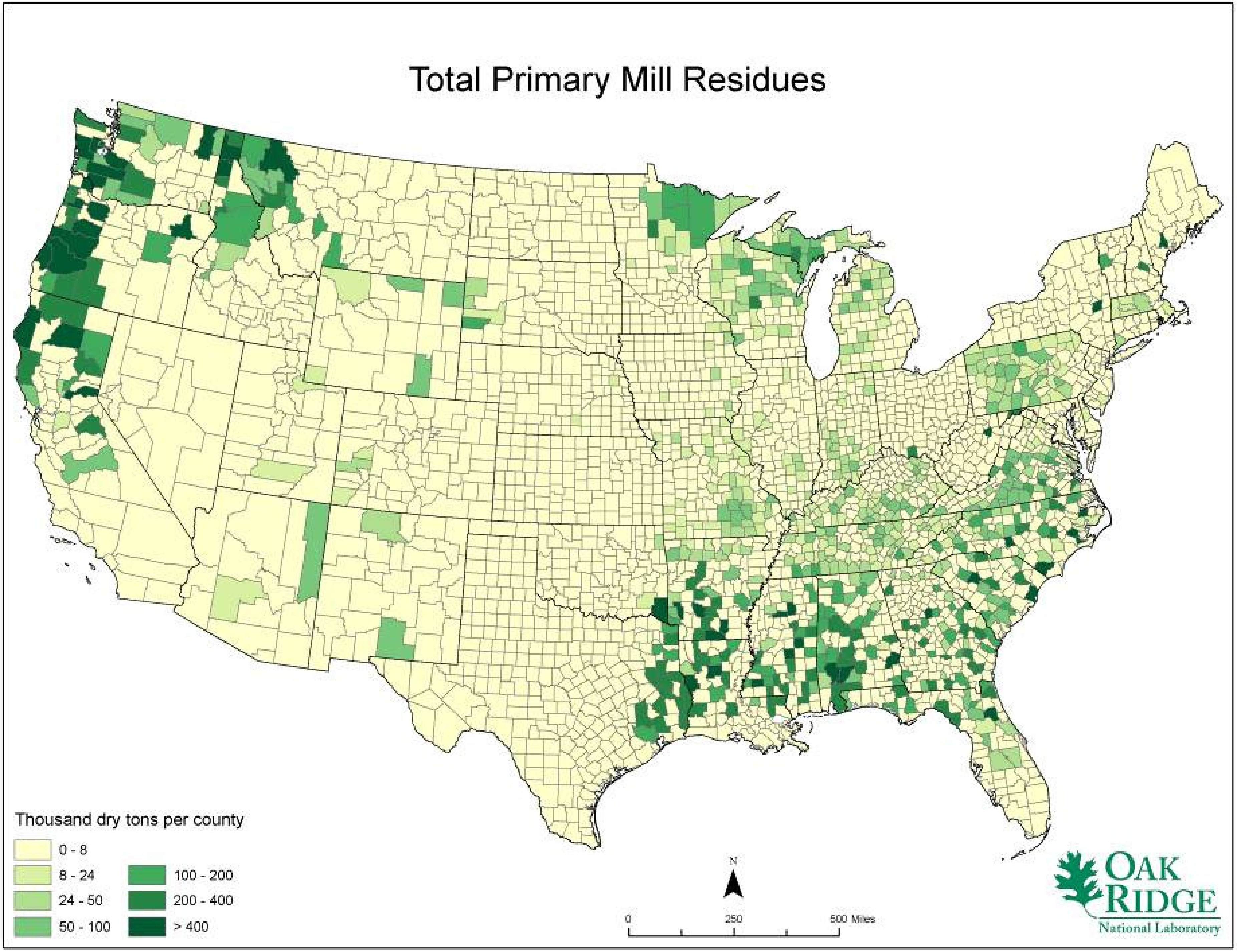
Photo credits Carla Castagnero, AgRecycle, Inc.



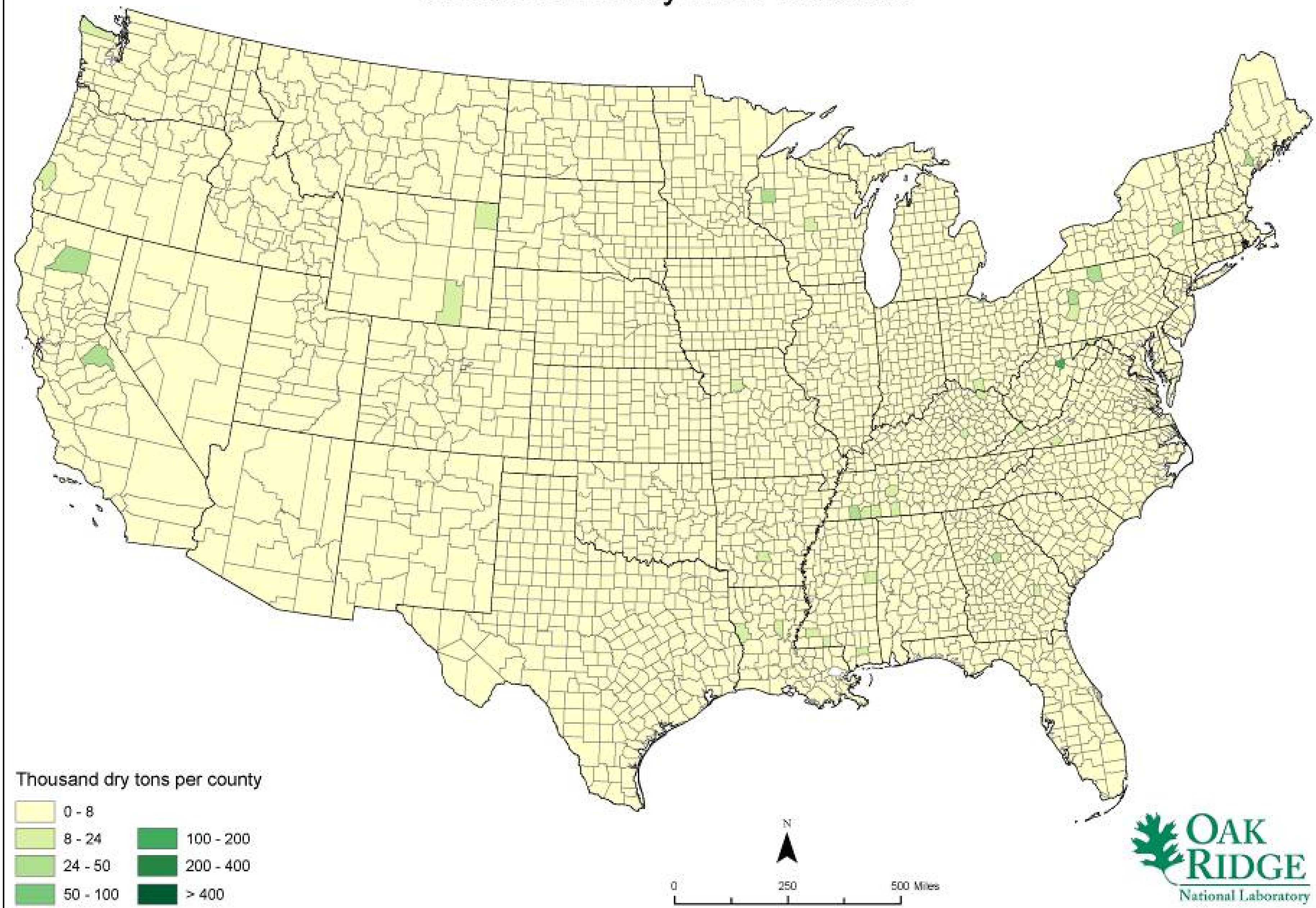
MSW Cellulosic Streams

Woody	**5.7 million tons/year**
Yard trimmings	**4.3**
Total	**10.0**


Total Construction & Demolition Wood Waste
2009
C&D
Demolition 12.3
Construction 3.9
Remodeling 5.6
Total 22.3
Wood Waste
(Thousand Dry Tons per County)
0 - 1
1 - 5
5 - 10
10 - 20
20 - 40
40 - 70
70 - 100
100 - 170
170 - 300
> 300
N
0
250
500 Miles
OAK RIDGE
National Laboratory


Total Primary Mill Residues
Thousand dry tons per county
0 - 8
8 - 24
24 - 50
50 - 100
100 - 200
200 - 400
> 400
N
0
250
500 Miles
OAK RIDGE
National Laboratory

Unused Primary Mill Residues



Organic Waste Supply Chain Issues

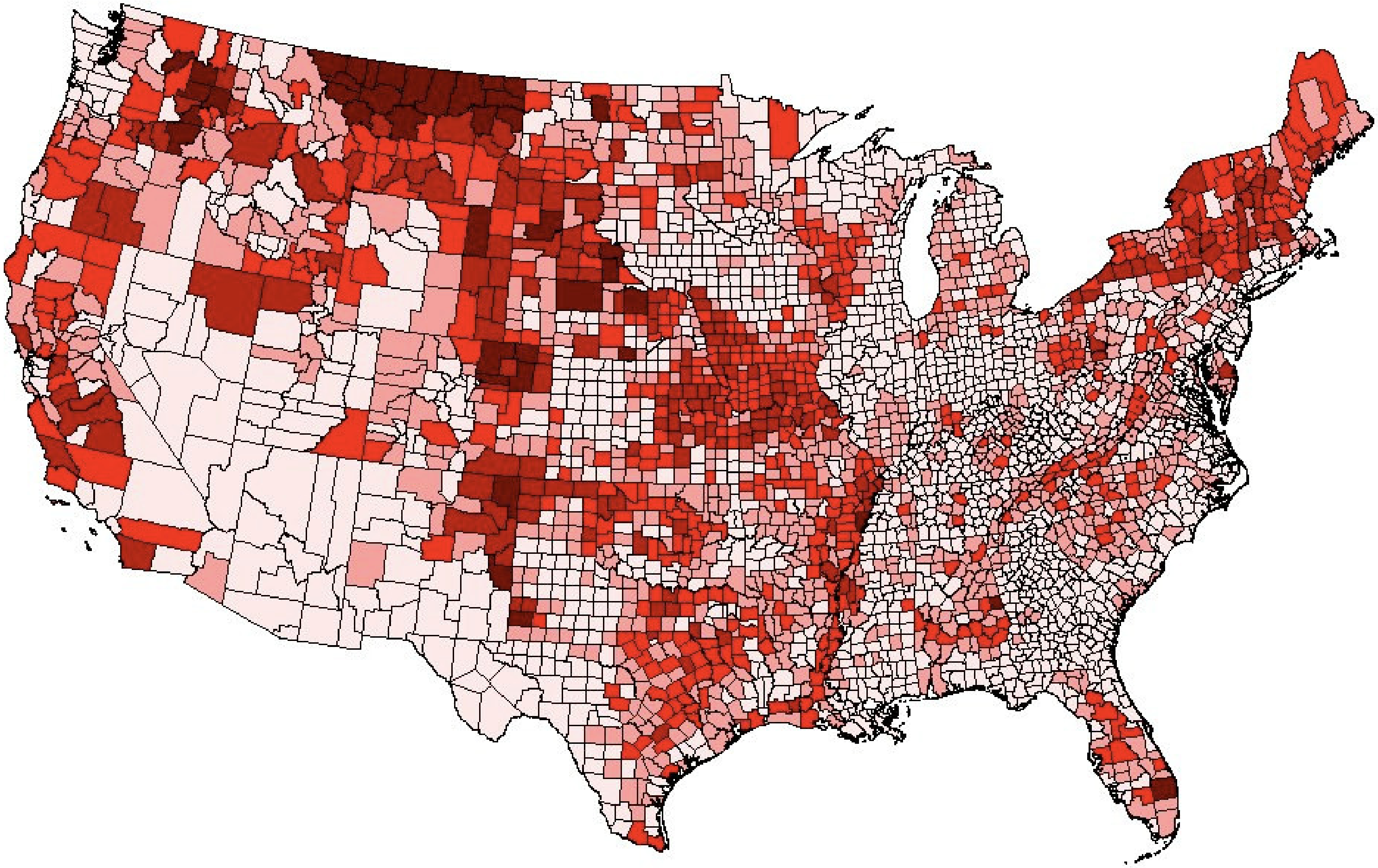
- Competing uses (compost, fertilizer)
- Separation challenges (urban wastes)
- High moisture (grass, manure, food wastes)
- Seasonal variability (grass, leaves, fruit and vegetable processing)

But... collection and transport infrastructure largely exists

2. Perennial crops

Short rotation trees or grasses on abandoned or marginal land, and as streamside buffers and roadside plantings.

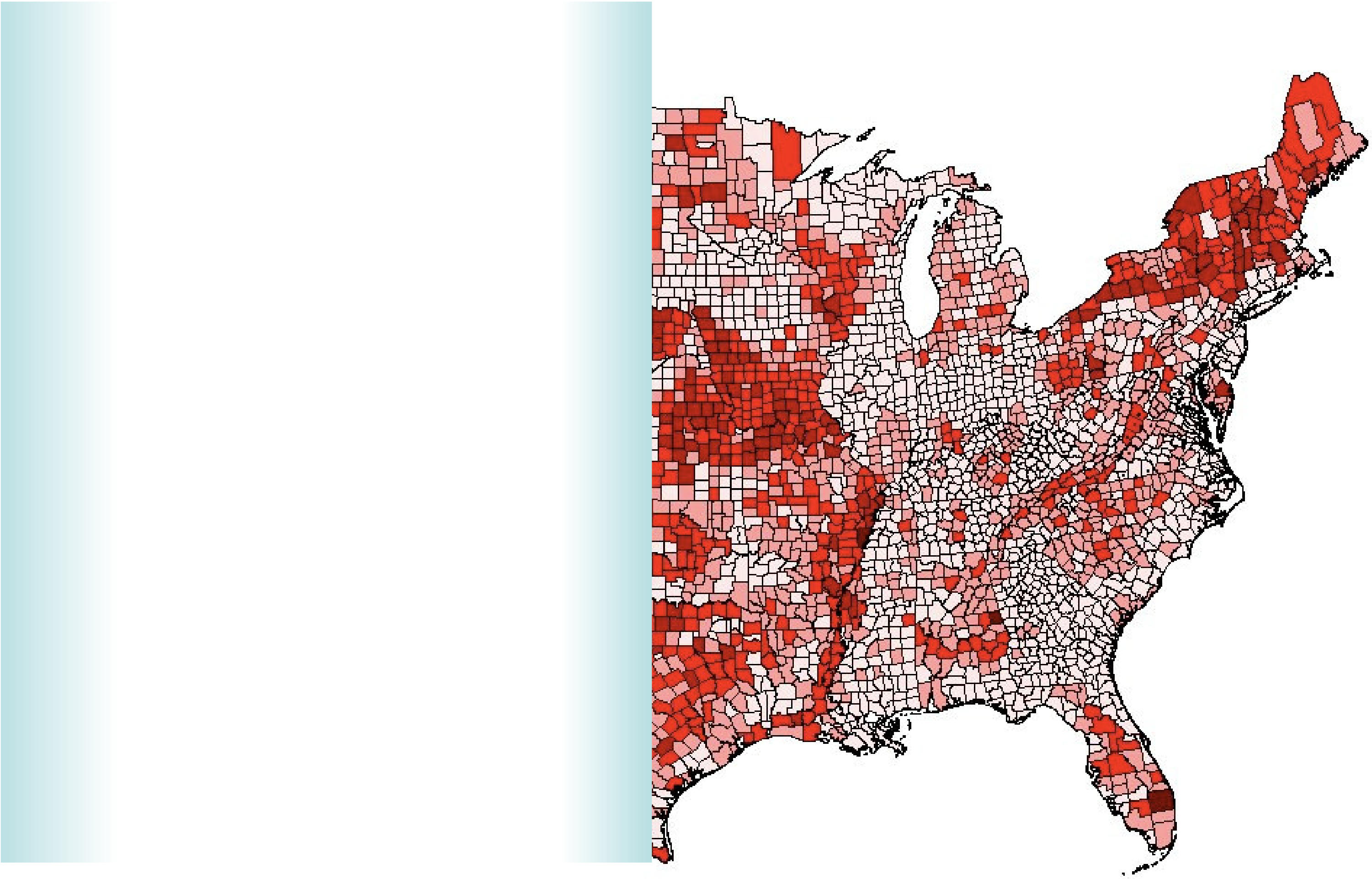
Abandoned Farmland in the US



75 million ha once farmed, no longer in production (or developed)

Barry Evans, Penn State University

Abandoned Farmland in the US

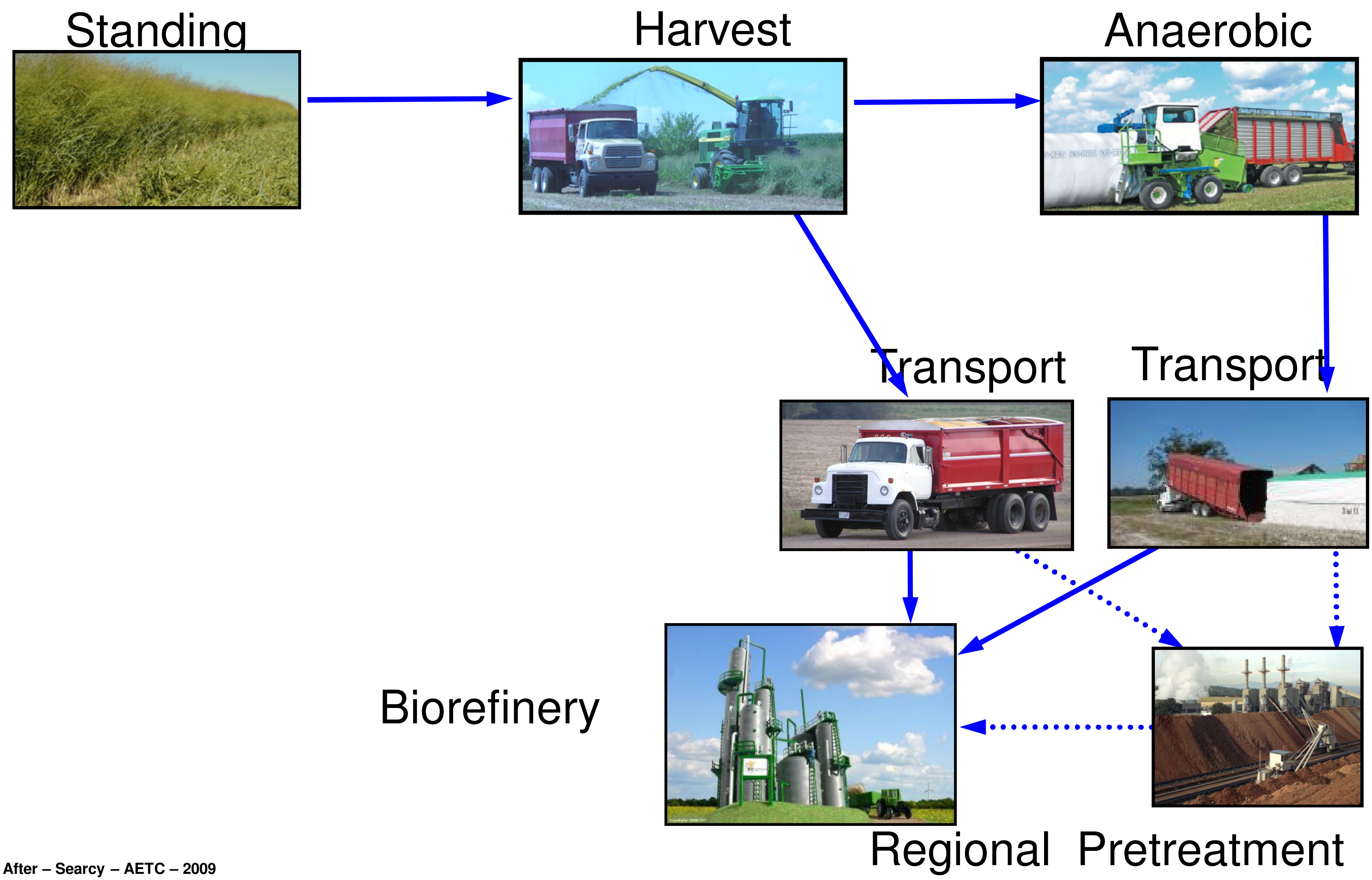


About half of it in rainfed regions

Major Feedstock Challenges

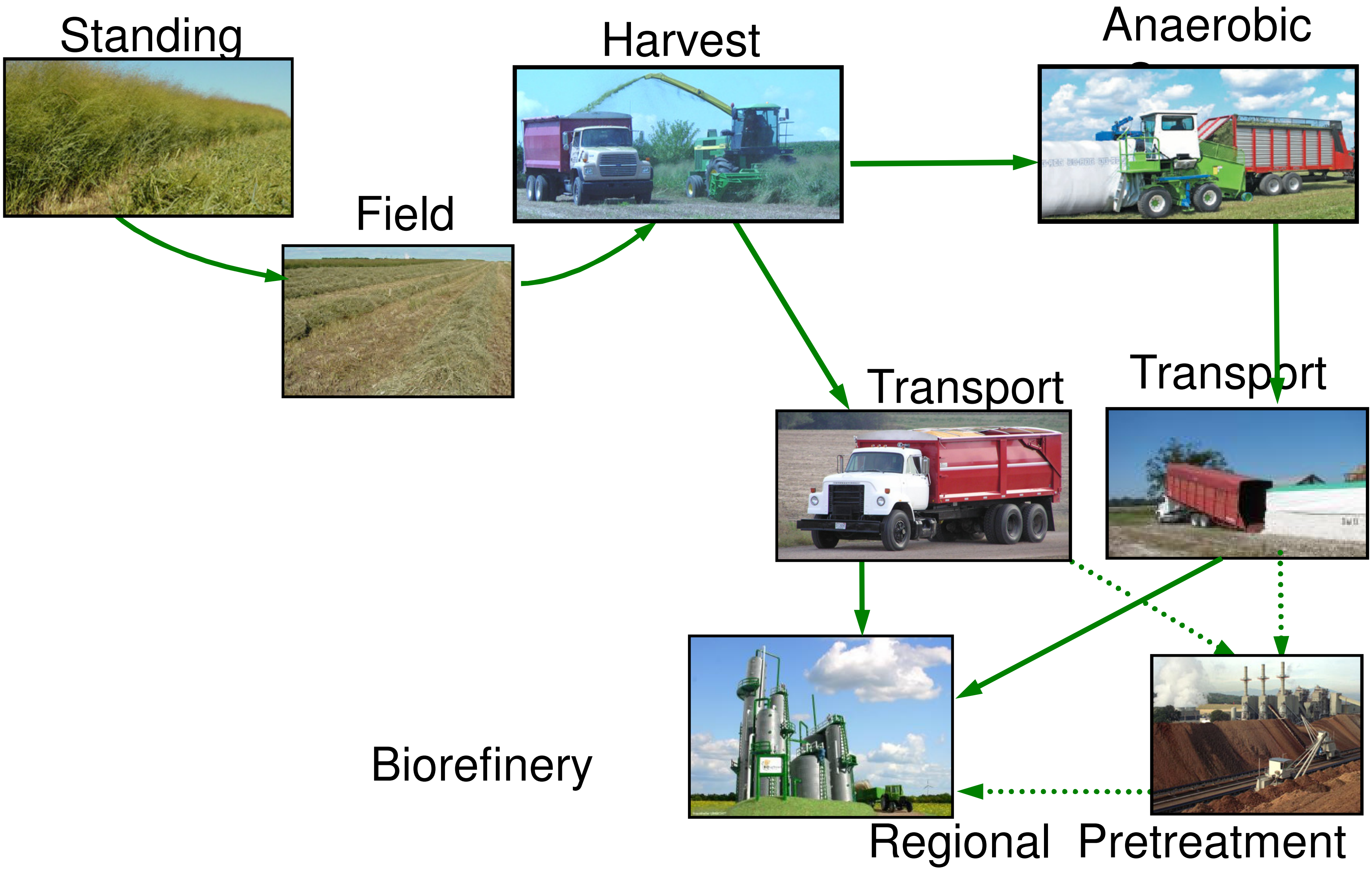
- Low-cost logistics:
  - Fewest operations – always adding value
- Transportation:
  - Always achieve legal limit – ship DM
- Physical form:
  - Wet or dry: Chopped, baled, cubes
- Chemical composition:
  - Fractionation or pretreatment

Potential Biomass Logistic Schemes



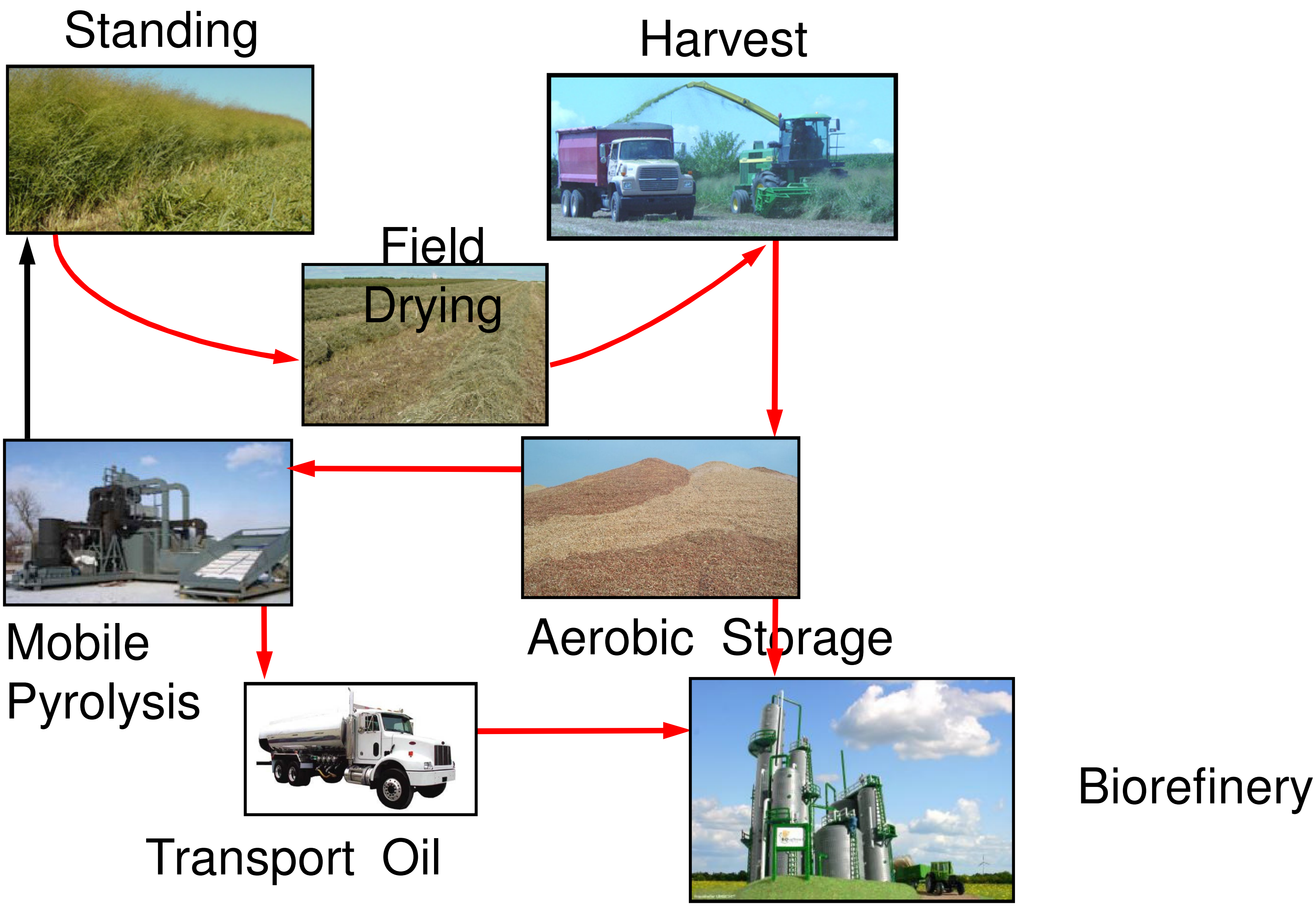
After – Searcy – AETC – 2009

Potential Biomass Logistic Schemes



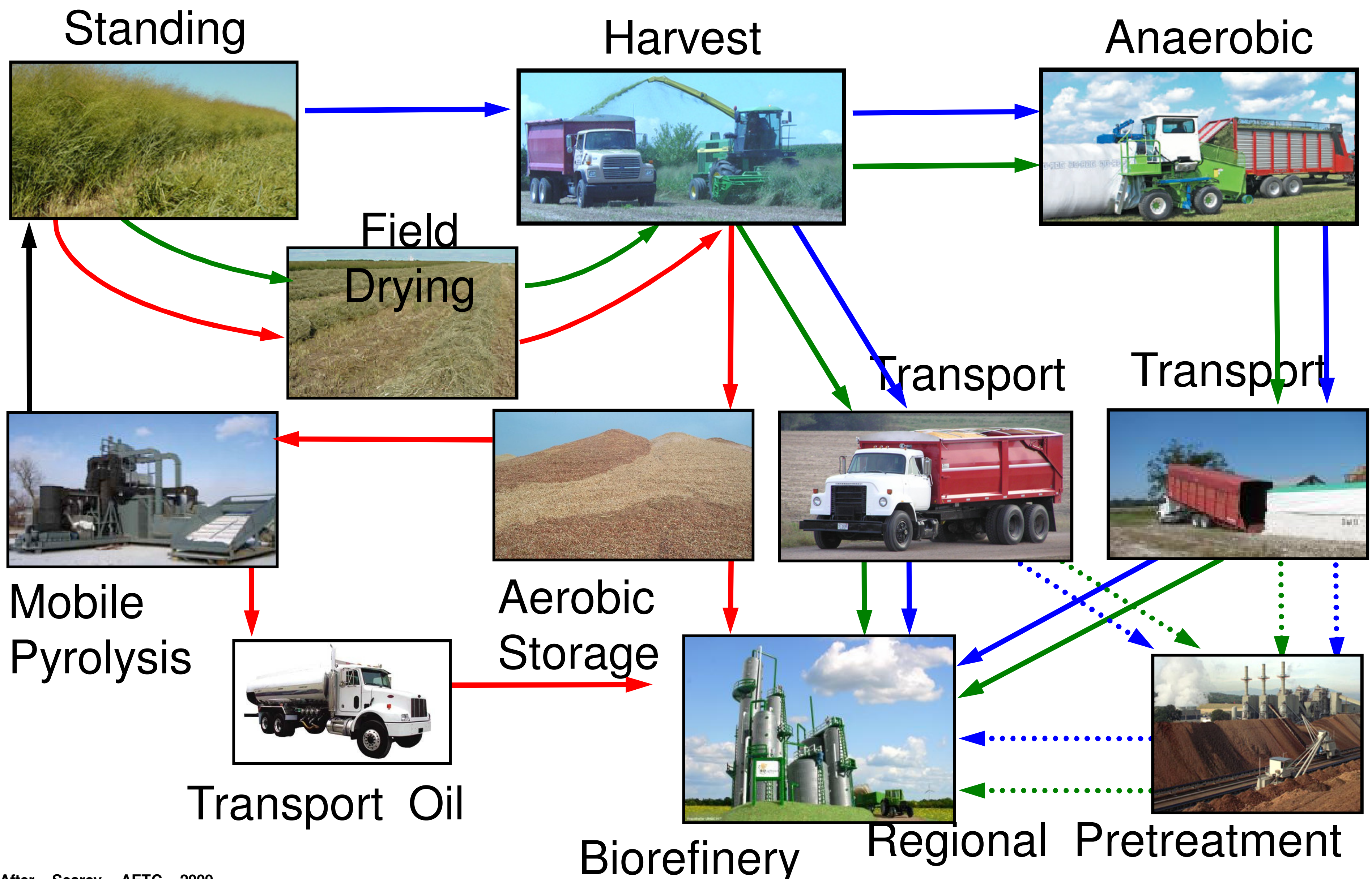
After – Searcy – AETC – 2009

Potential Biomass Logistic Schemes



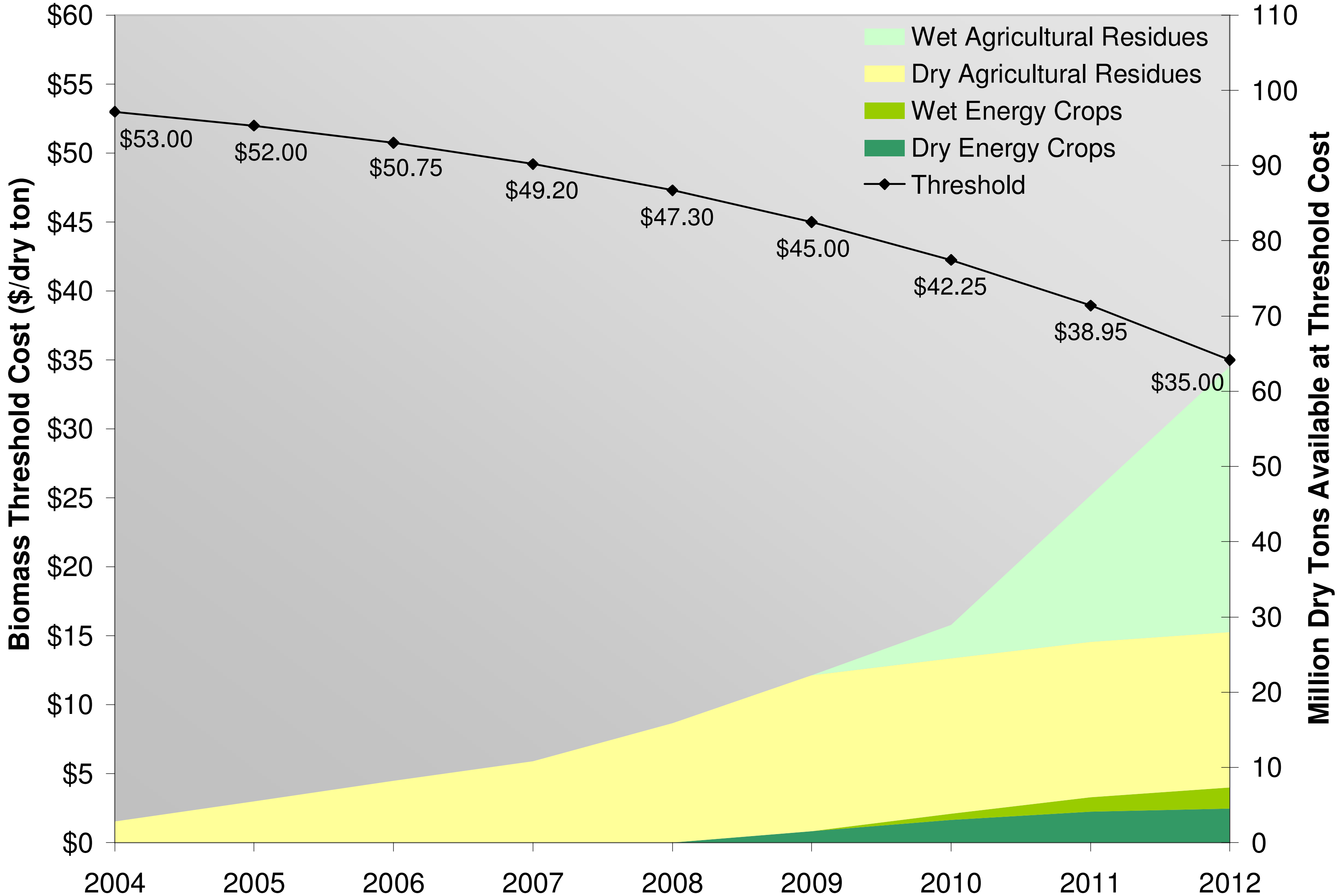
After – Searcy – AETC – 2009

Potential Biomass Logistic Schemes



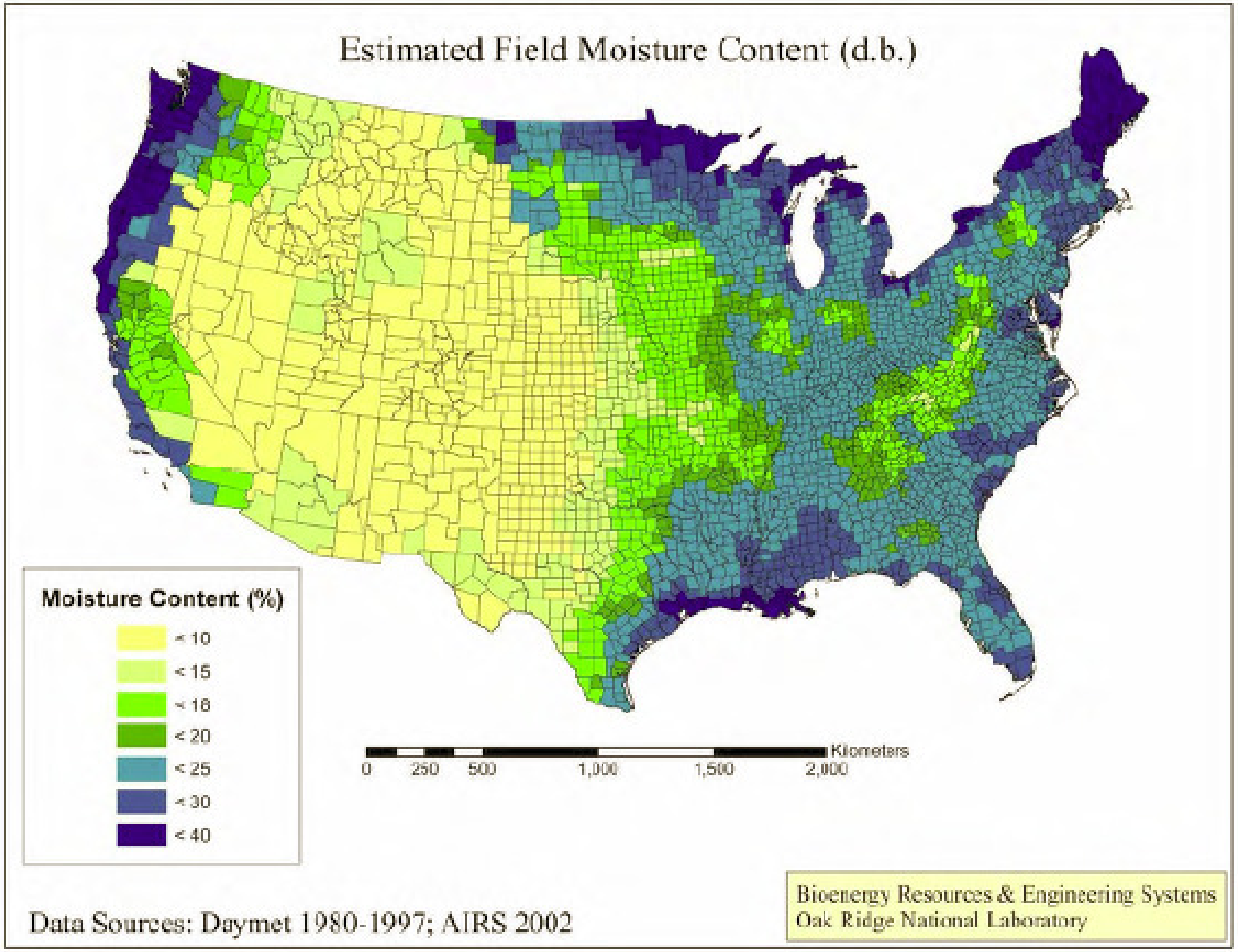
After – Searcy – AETC – 2009

DOE Projections – Near Term



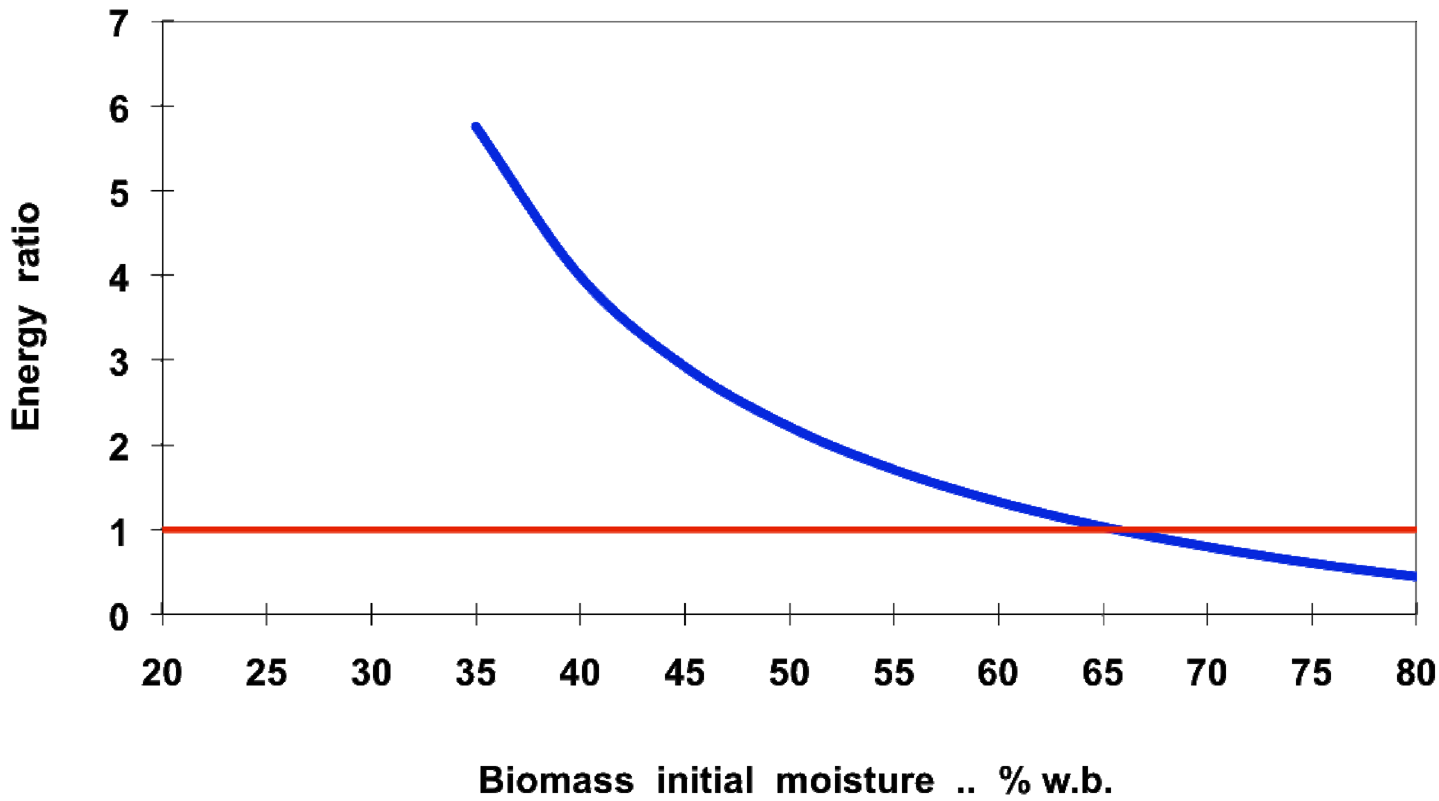
Perlack and Hess 2006

Most Biomass is Wet



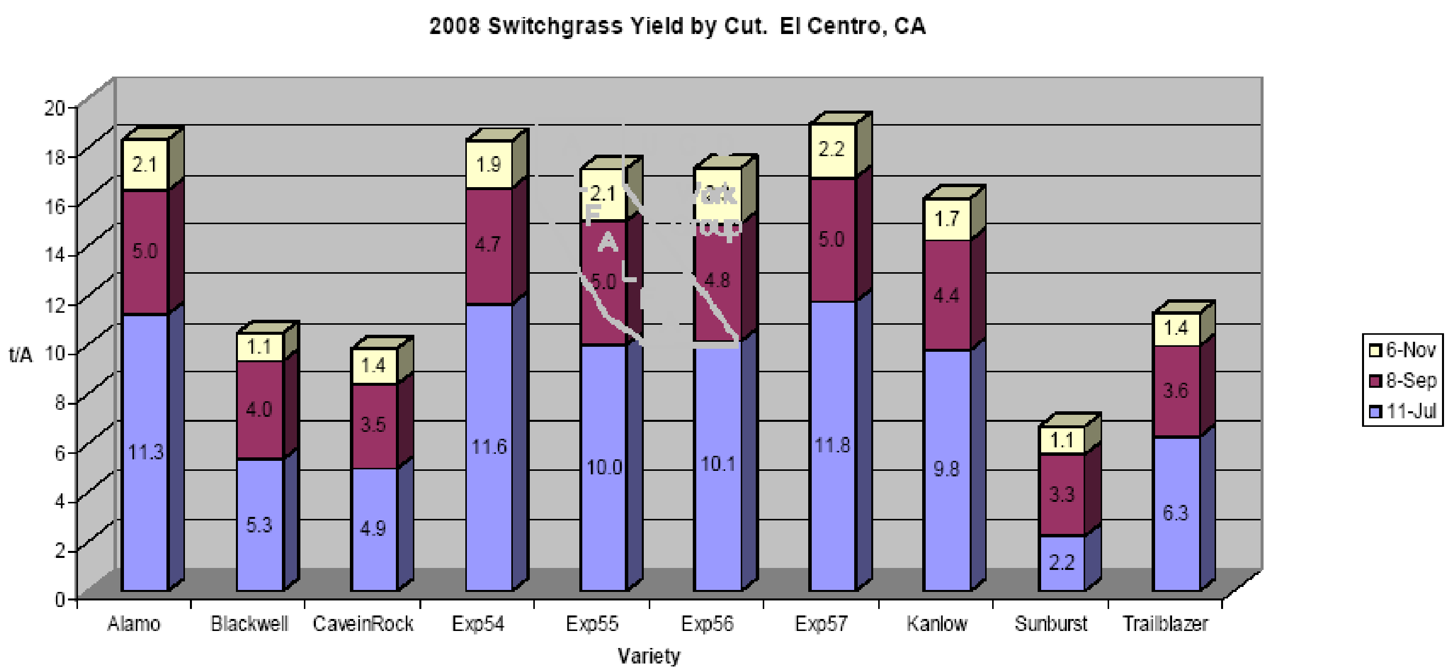
Crop Moisture Issues

- Must field dry because we can't afford to dry



Harvest Frequency

- When might we harvest more than once?
  - Require both biomass and animal feed
  - Yield advantages – still must consider cost



Putnum et al., 2009

Harvest Date

- Perennials
  - Late fall or early spring
- Residues
  - At grain harvest
- Coppice
  - Early spring

Spring Harvest of Grasses

- Advantages
  - Dry when harvested, fewer weeds
  - Better chemical composition, less ash
  - Nutrient cycling
- Disadvantages
  - Timing harvest
  - Losses
  - Risk!

Spring Harvest of Grasses

Harvest Frequency

	Yield .. Mg DM / ha	
Reed canarygrass		
Mid-summer	8.7	12.2
Late fall	3.5	
Early fall	9.8	
Late spring	6.8	

Shinners et al., 2008

Harvest Frequency

	Dry matter .. Mg DM / ac	
Switchgrass	**PSU[1]**	**UW[2]**
Late summer	**10.1**	**13.3**
Late fall	**8.4**	**9.9**
Spring	**5.4**	**8.6**

1 – Adler et al., 2006

2 – Shinners et al., 2008

Harvesting Strategies

- Harvest Methods
  - Single-pass
  - Multi-pass
  - Fractional harvest

Single-pass Harvesting – Switchgrass

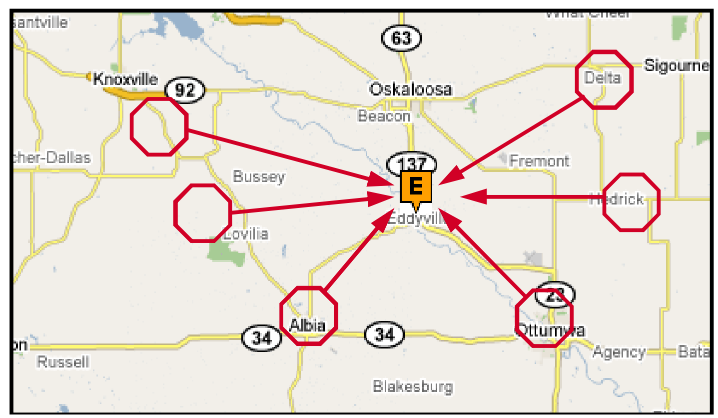
Single-pass Harvesting – Corn Stover

Single-pass Harvesting – Wheat Straw

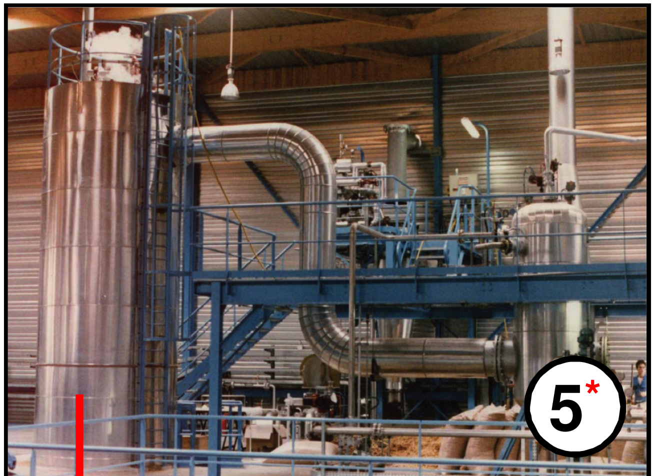
Single-pass Harvesting – Coppice

Single-Pass Harvesting

Regional Biomass Processing Center

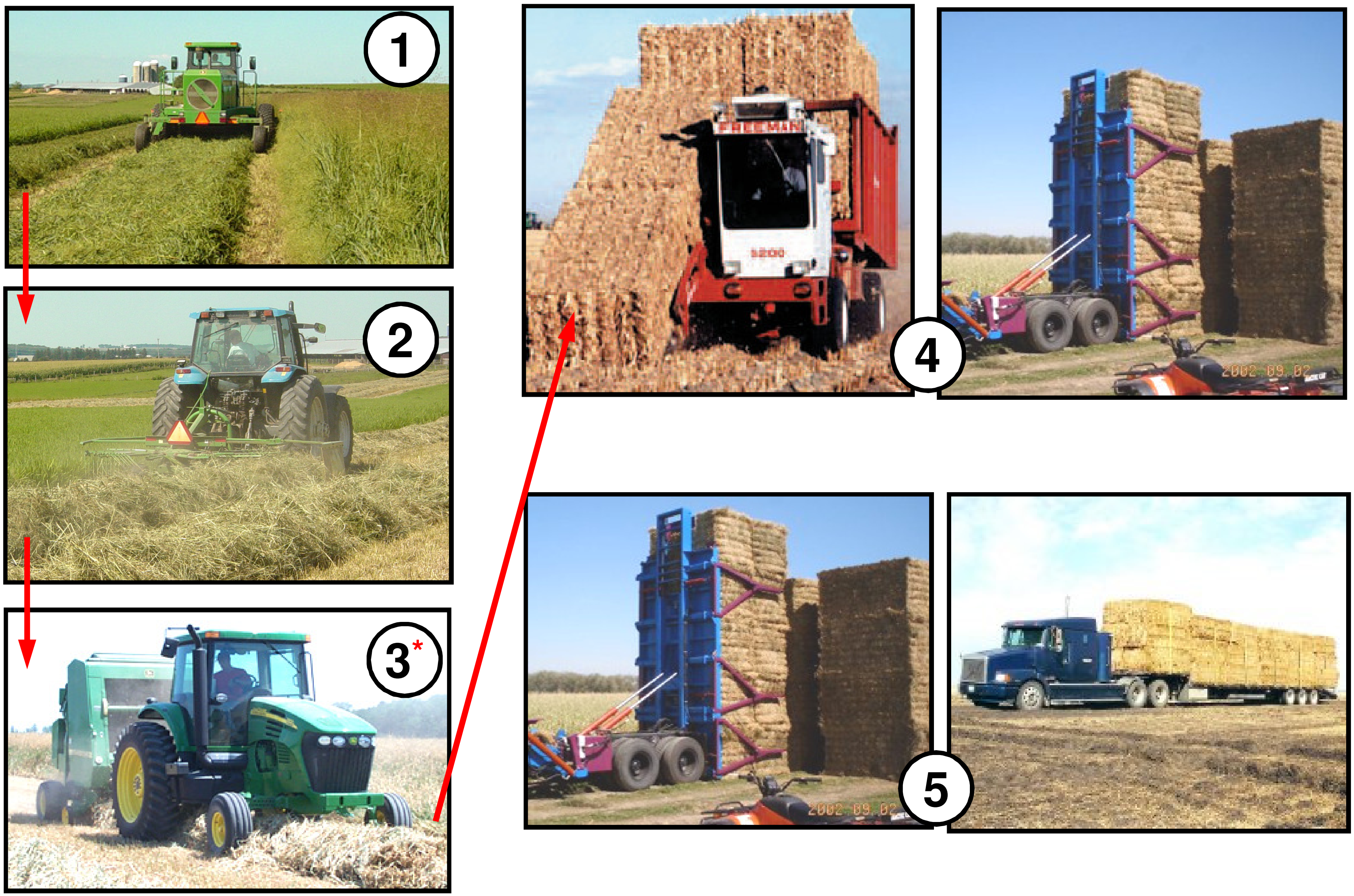


Single-Pass Harvesting



Biorefinery

Multi-Pass Harvesting



Multi-Pass Harvesting

Multi-Pass Harvesting

Biorefinery

2-pass: Self-loading Wagon

Multi-pass Harvesting

- Advantages
  - Equipment legacy
  - Dry product
    - Storage & transport
  - High density
    - Transport

Multi-pass Harvesting

- Disadvantages
  - Many operations
    - Costs!
  - Weather delays
  - Soil contamination

Bale Density

	Bale density - kg/m^3	
	Wet	Dry
Stover[1]		
LRB	130 – 140	95 - 115
LSB	160 – 180	130 – 140
Perennial Grasses[2]		
LRB	160 – 180	130 – 145
LSB	210 – 225	175 – 190

1 – Shinners et al., 2007a

2 – Shinners et al., 2006b

Single-pass Fractional Harvest

- Concept
  - Targeted harvest of desirable fractions
  - Ship only desirable fractions

Fractional Harvest

- Corn Cob Harvest

Fractional Harvest

	Area needed ac x 1000	Transportation cost $ x 1000
Cob	642	1,418
Cob, husk and top stalk	327	1,177
Cob, husk, and stalk	150	990

Fractional Harvest

Fractional Harvest

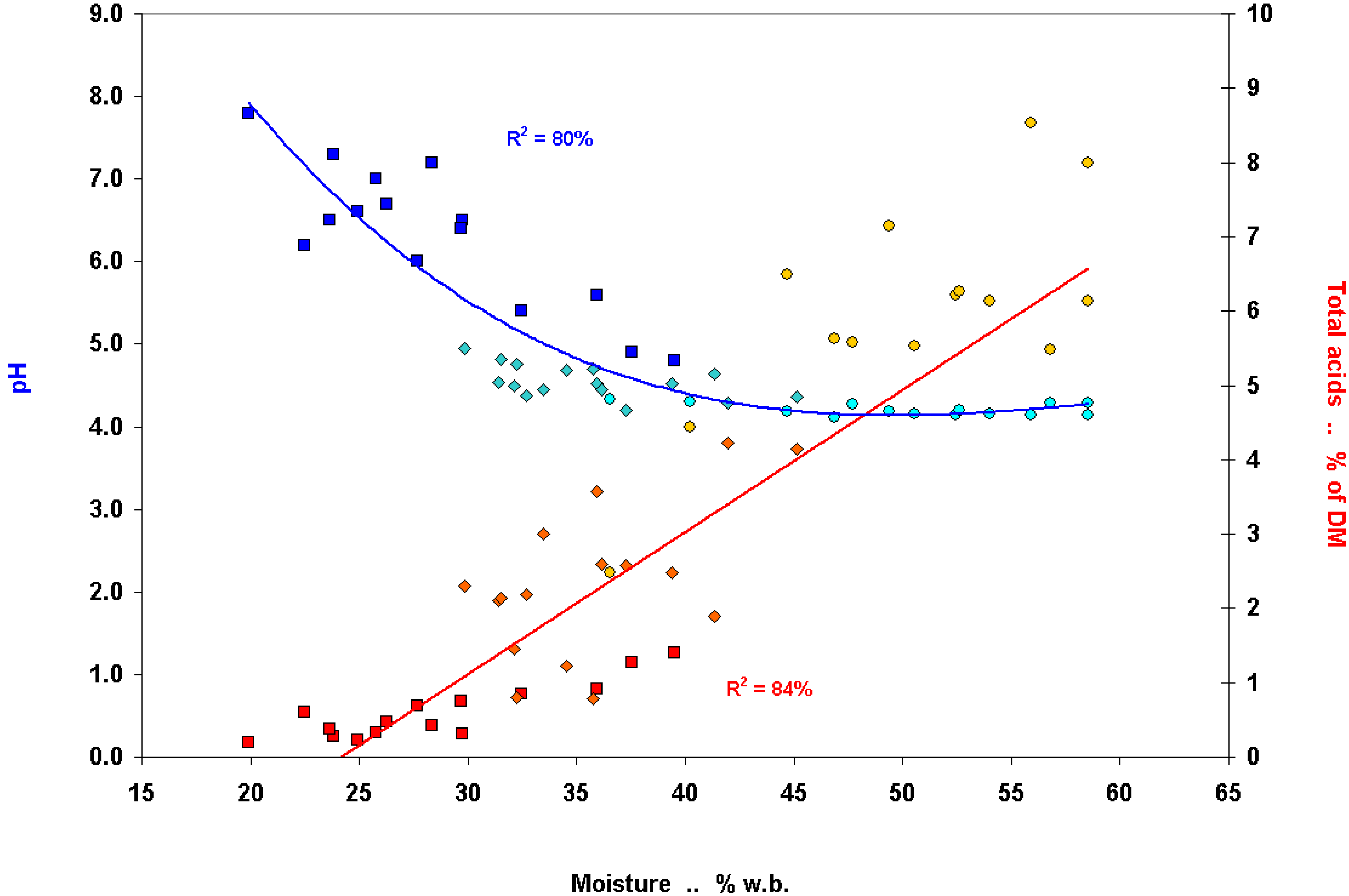
Wet Storage – DM Loss

	Moisture	DM loss
	% w.b.	% of total
Stover [1]	30 – 50	2 – 5
Perennial grasses [2]	40 – 50	1 – 3

1 – Shinners et al., 2007b

2 – Shinners et al., 2006b

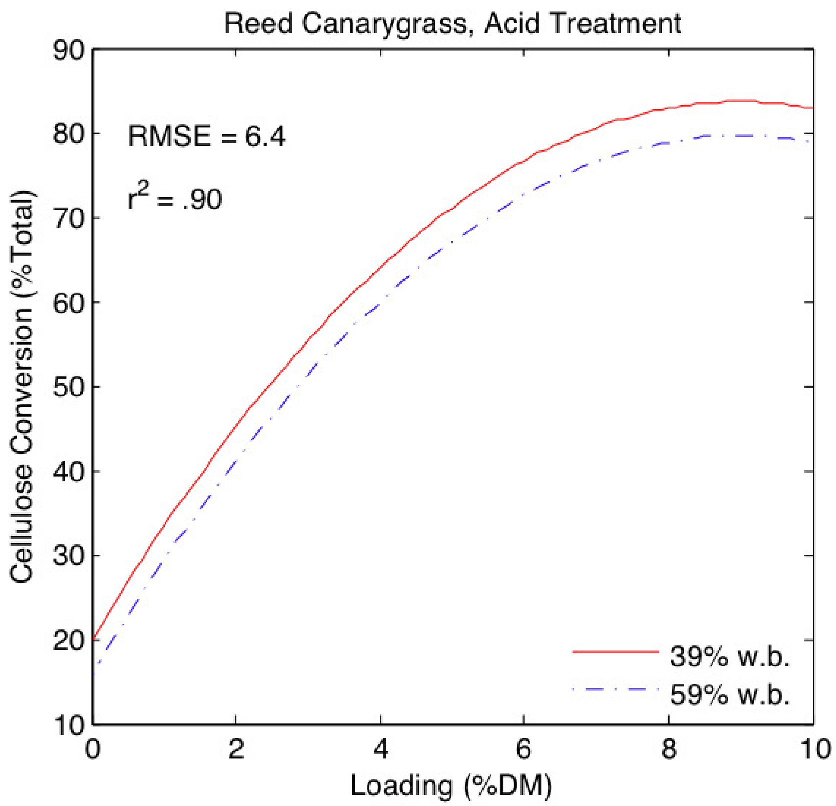
Wet Storage – Fermentation Acids

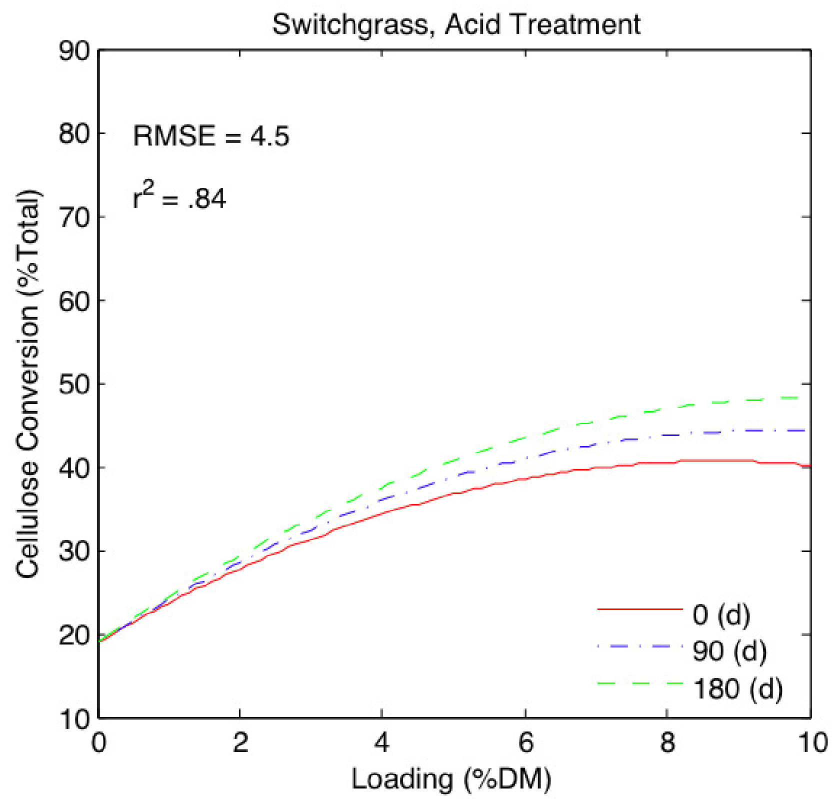


Adding Value in Storage

- Pre-treating

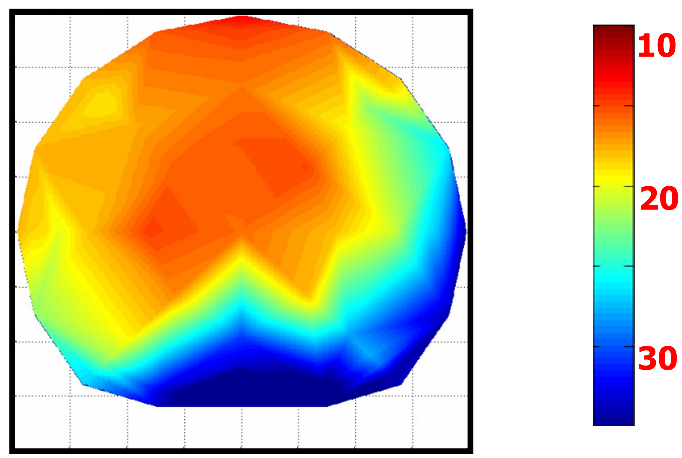
Ambient Pre-Treatment





Dry Bale Storage

	Moisture Content … % w.b.	
	Grasses	Stover
Outdoor	18 – 25	24 – 59
Inside	14 – 16	14 – 19



Dry Bale Storage

	Dry matter loss ... % of total	
	Grasses	Stover
Outdoor	7.7 – 14.9	11.2 – 37.3
Inside	3.3	3.3

Cost Example – Switchgrass

	$ per Mg DM
Establishment & production	$90
Gathering & handling	$7
Storage	$19
Transportation	$10
Total	$126

Duffy – ISU – 2008 http://www.extension.iastate.edu/agdm/crops/html/a1-22.html

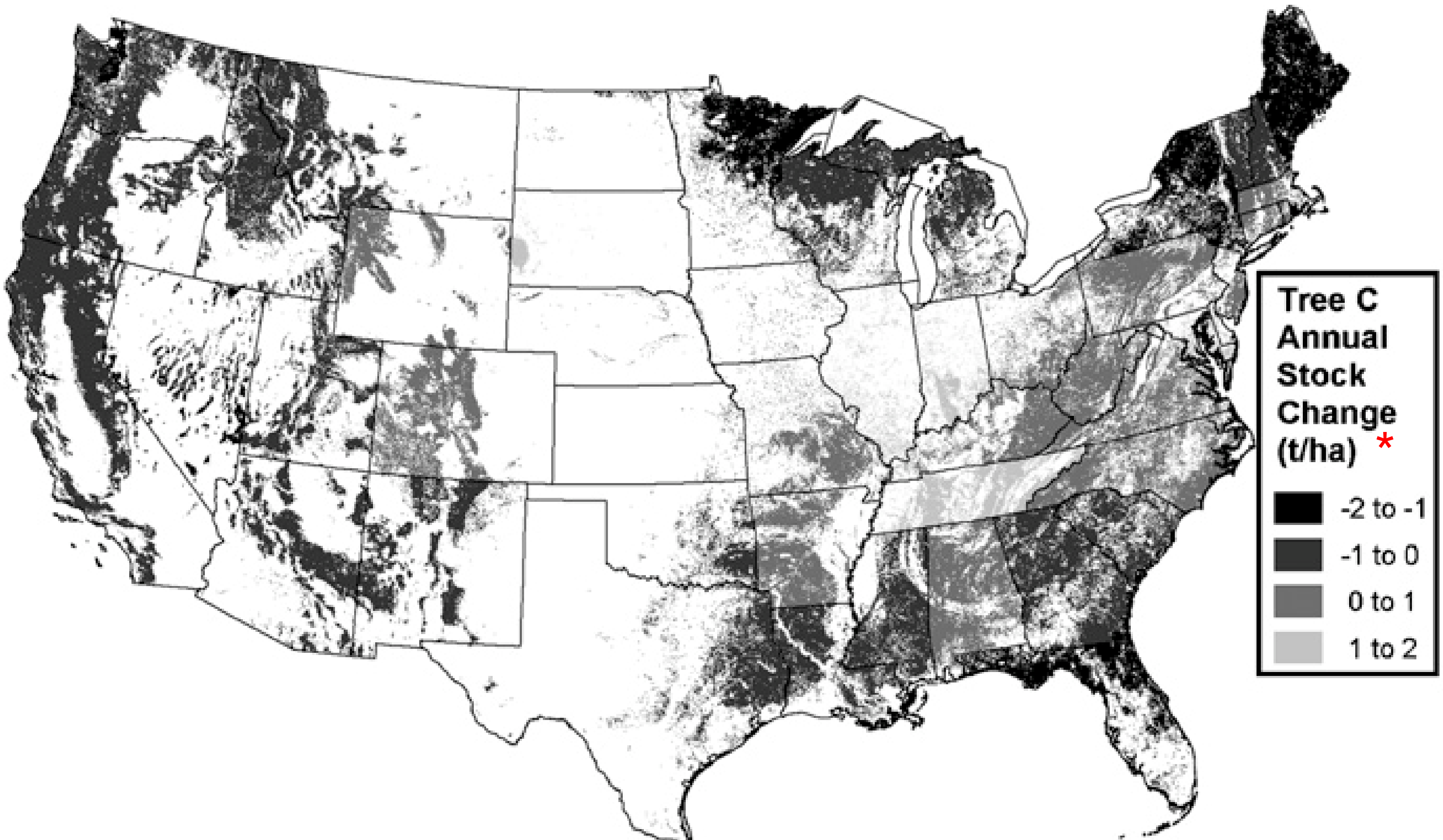
Perennial Grass Supply Chain Issues

- Yield x acreage conversion
- Refinery size and haul distance
- Harvest density and compaction
- Moisture and particle characteristics
- Satellite processing and densification

3. 21st Century Forestry

- Biomass harvest can improve forest productivity, timber quality, and wildlife habitat.

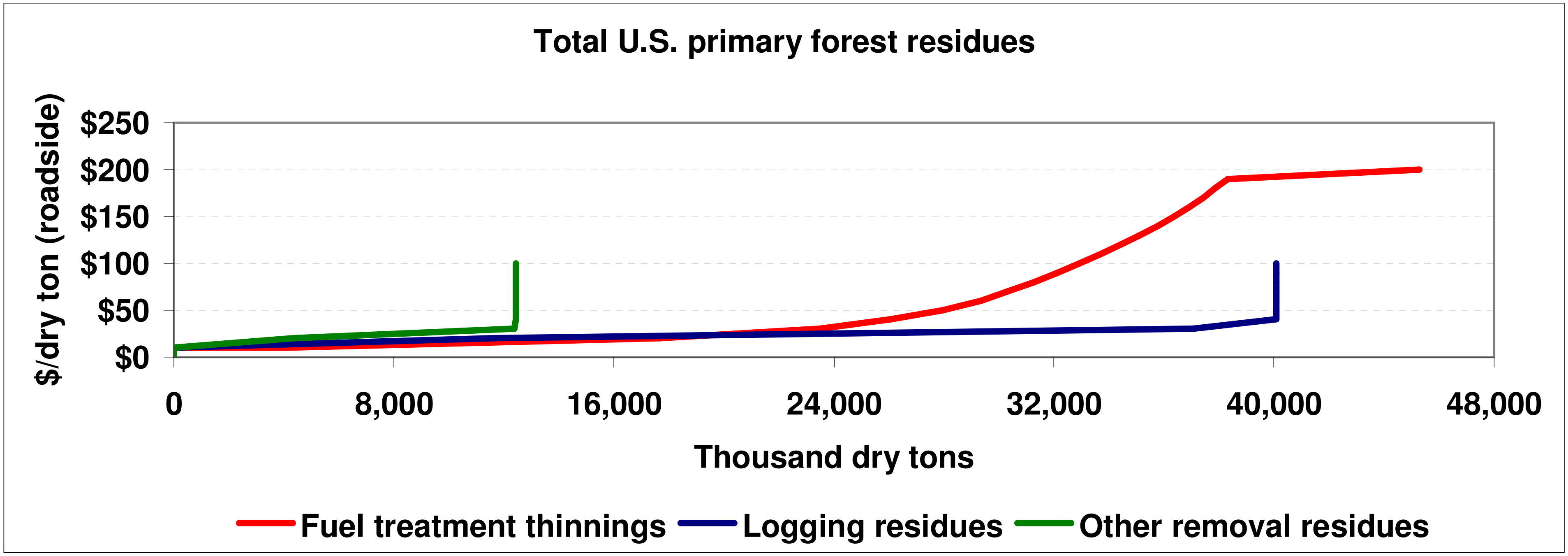
Change in Forest Carbon Stocks

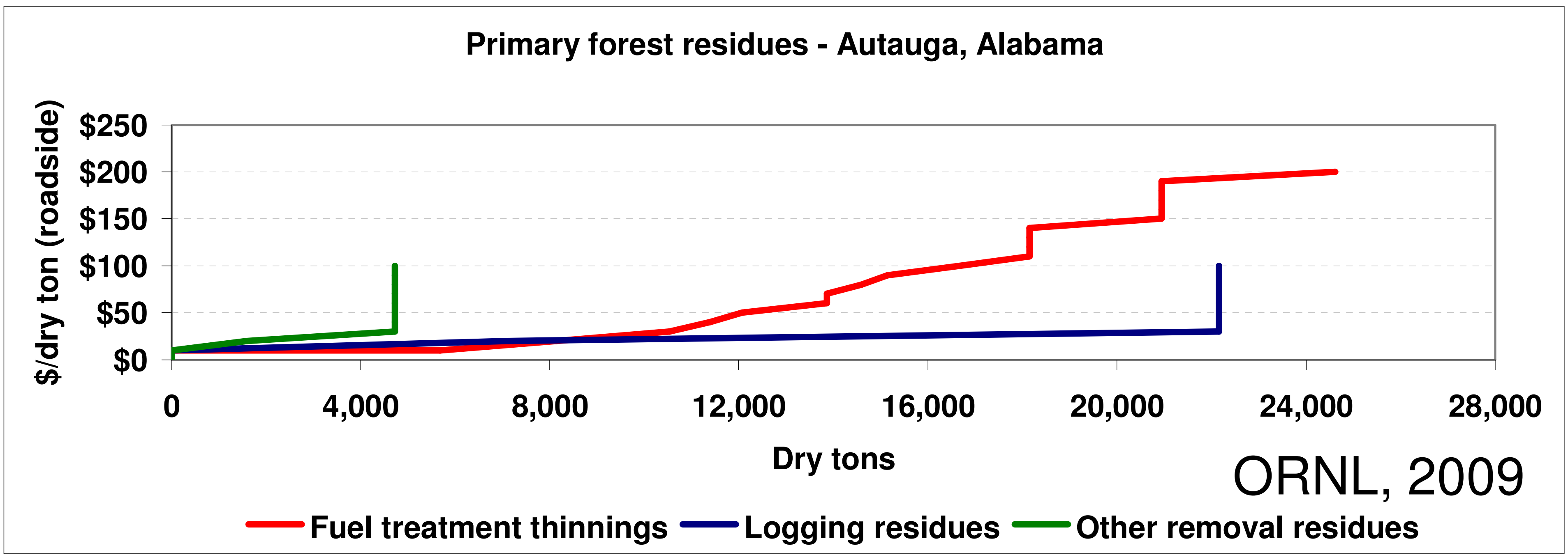


80 – 100 million tons/year in forest,
plus 30 – 70 Mt/yr encroachment

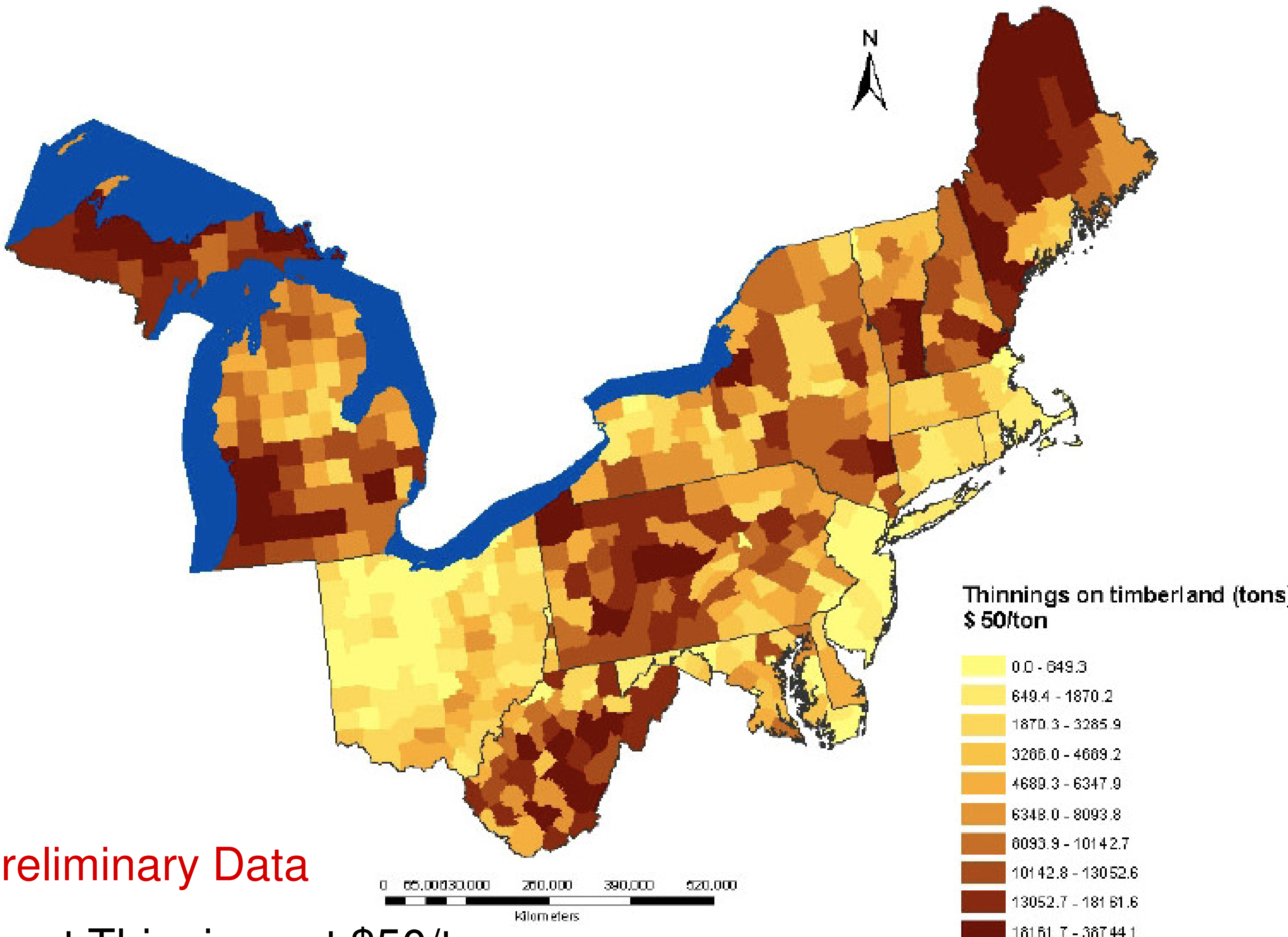
*Negative values indicate sequestration

Woodbury et al. 2007


Total U.S. primary forest residues
$/dry ton (roadside)
$250
$200
$150
$100
$50
$0
0
8,000
16,000
24,000
32,000
40,000
48,000
Thousand dry tons
Fuel treatment thinnings
Logging residues
Other removal residues


Primary forest residues - Autauga, Alabama
$/dry ton (roadside)
$250
$200
$150
$100
$50
$0
0
4,000
8,000
12,000
16,000
20,000
24,000
28,000
Dry tons
Fuel treatment thinnings
Logging residues
Other removal residues

ORNL, 2009



Preliminary Data

Forest Thinnings at $50/ton

Courtesy Peter Woodbury, Cornell University.   Source: USFS and ORNL

Forest Management Yields

Site	Clearcut	Shelterwood	Highgrade	Thinning
Tons Per Acre Chips	72	39	0	66
Tons Per Acre Saw Logs	29	11	23	0
Total Tons Per Acre	119	59	23	81

Multi-Pass Harvesting – Woody

Multi-Pass Harvesting – Woody

Multi-Pass Harvesting – Woody

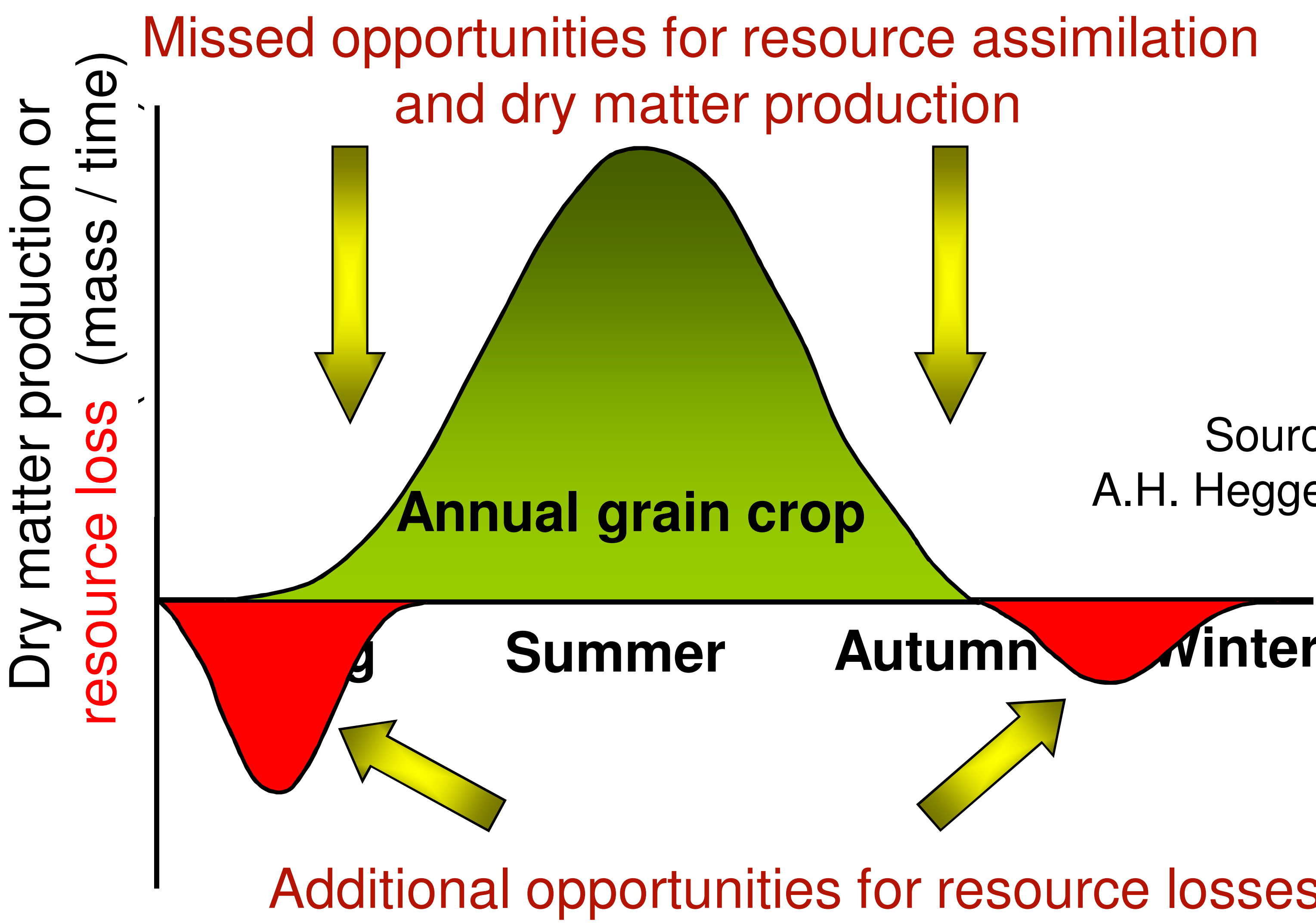
Forest Supply Chain Issues

- Sustainable yield
- Landowner values
- Competing uses
- Public expectation
- Legacy may not last…

4. Multi-functional Agriculture

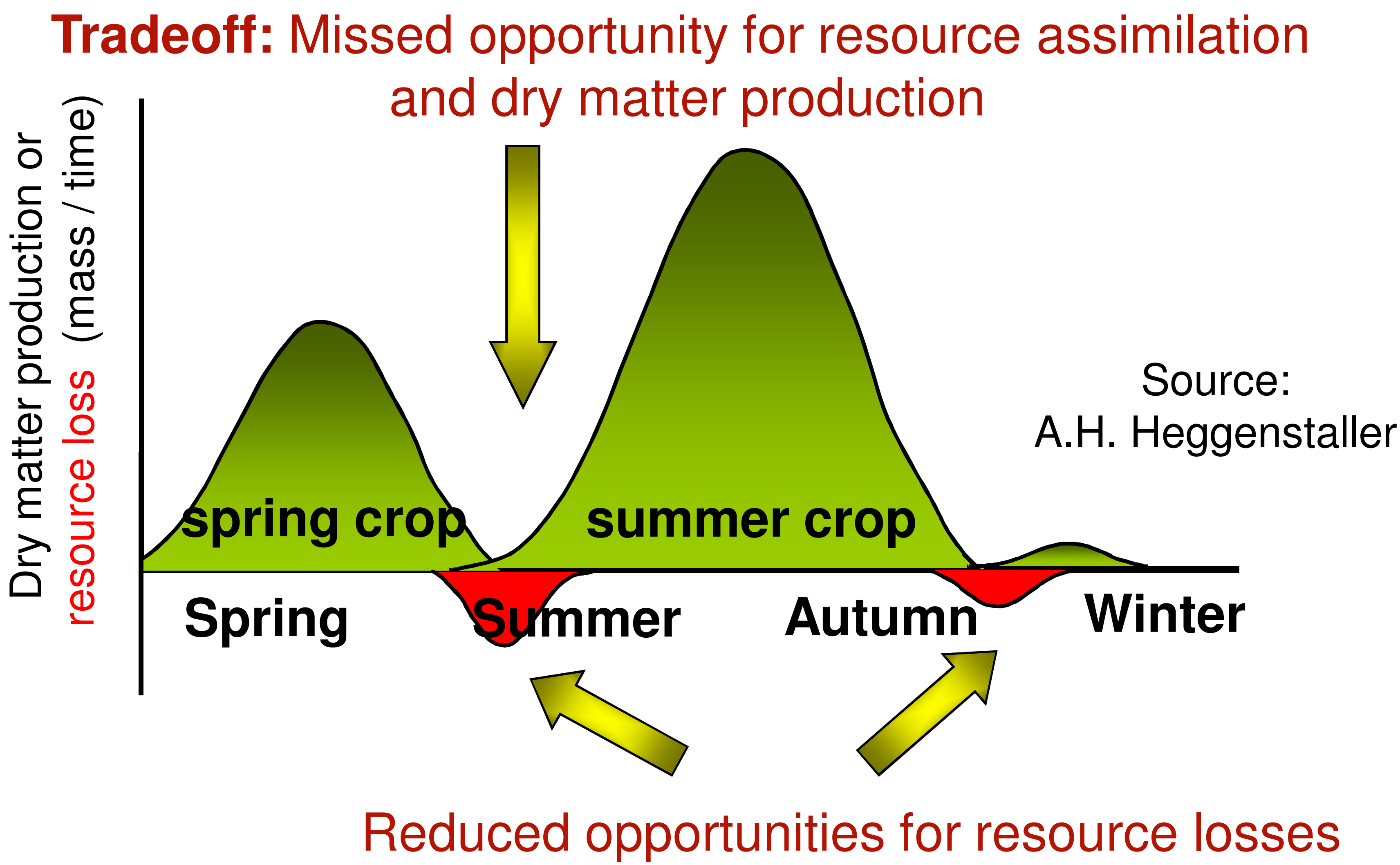
- Integration of energy crops with food crops to increase the productivity of existing agricultural land, without reducing food production, and with enhanced environmental outcomes.
  - Perennial crops on steep slopes and streamside buffers
  - Perennials in extended, diverse rotations
  - Winter cover crops as energy double crops

Resource utilization in annual cropping systems



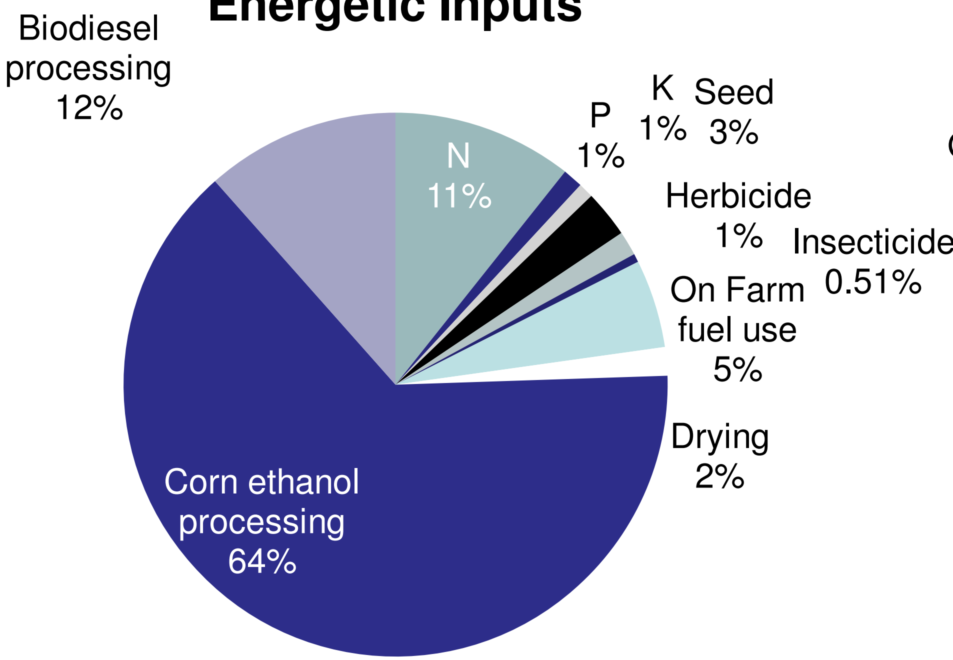
Source:
A.H. Heggenstaller

Biomass production in double crop systems

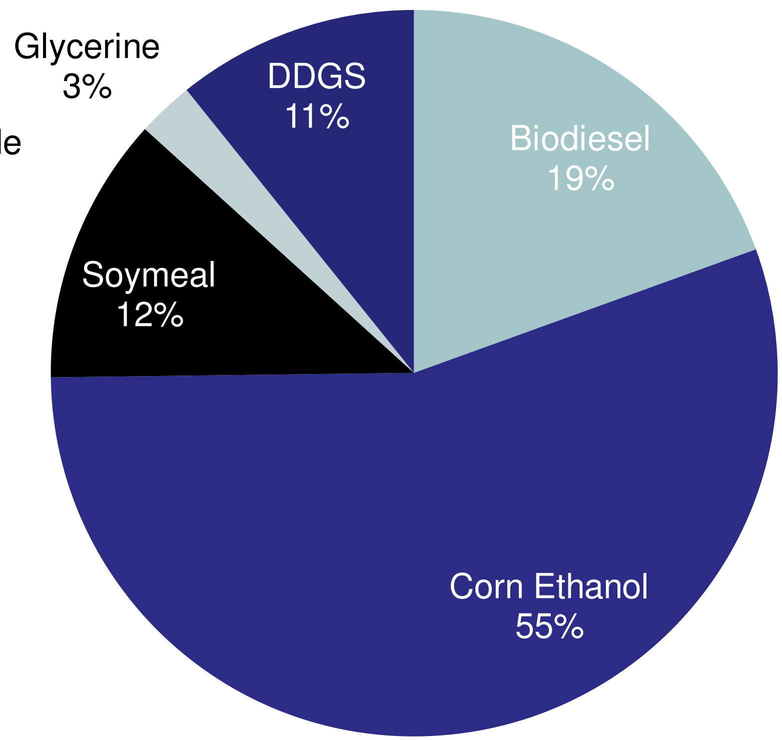


Corn-Soy

Energetic Inputs



Energetic Outputs

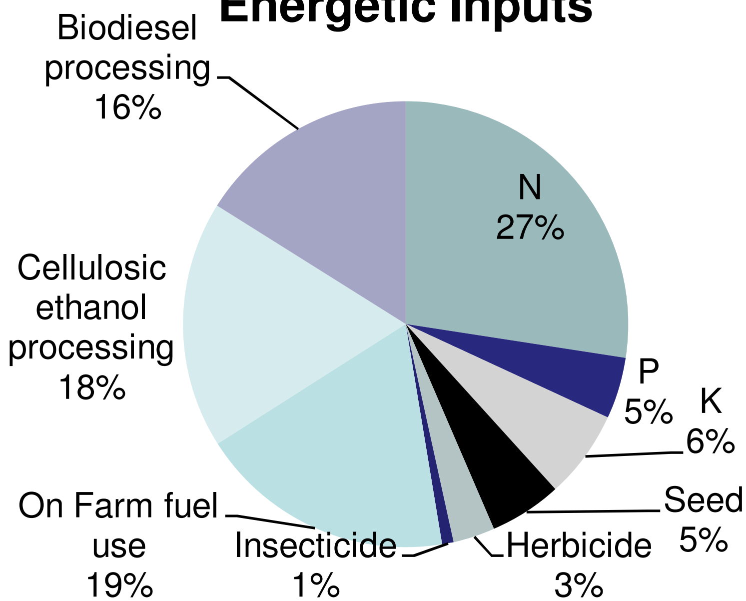


Energy	Quantity	Unit
Energy input	38,655	MJ/ha
Energy output	62,187	MJ/ha
Net Energy Value(NEV)	23,532	MJ/ha
Net Energy Ratio (NER)	1.61	
Products	**Quantity**	**Unit**
Biodiesel	327	L/ha
Corn Ethanol	1,624	L/ha
Co-Products	**Quantity**	**Unit**
Soymeal	1.31	Mg/ha
Glycerine	0.03	Mg/ha
DDGS	0.60	Mg/ha

Notes:
No recycled biomass energy

Soy-Corn/Rye

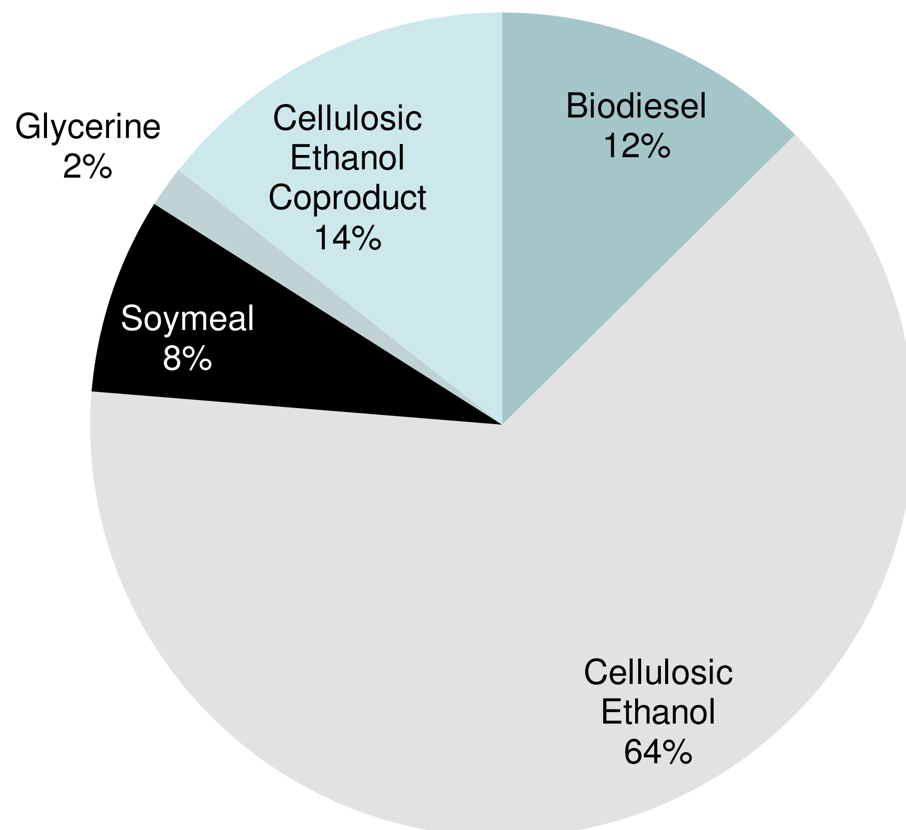
Energetic Inputs



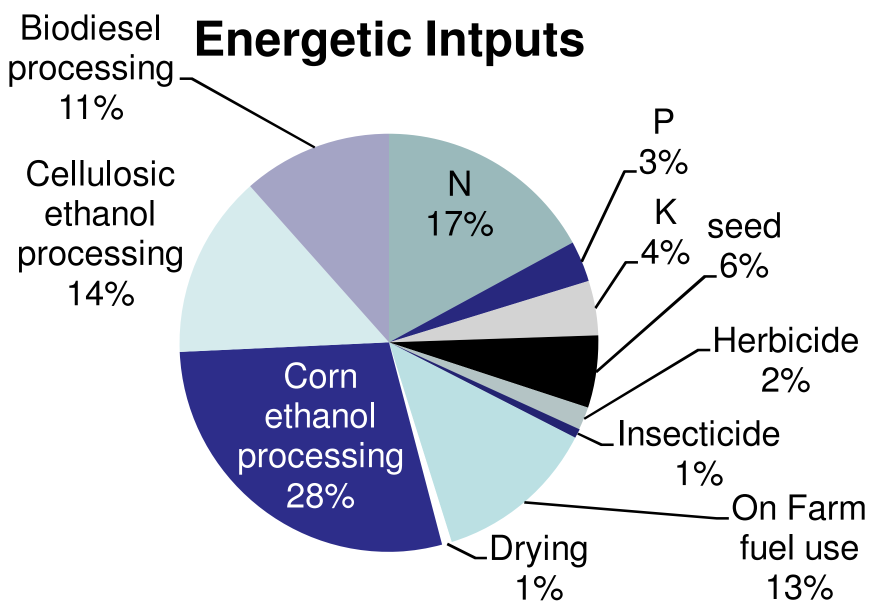
Energy	Quantity	Unit
Energy input	24,368	MJ/ha
Energy output	84,554	MJ/ha
Net Energy Value(NEV)	60,187	MJ/ha
Net Energy Ratio (NER)	3.47	
Co-products	**Quantity**	**Unit**
Biodiesel	288	L/ha
Corn Ethanol	0	L/ha
Cellulosic Ethanol	2,541	L/ha
Soymeal	1.15	Mg/ha
Glycerine	0.03	Mg/ha

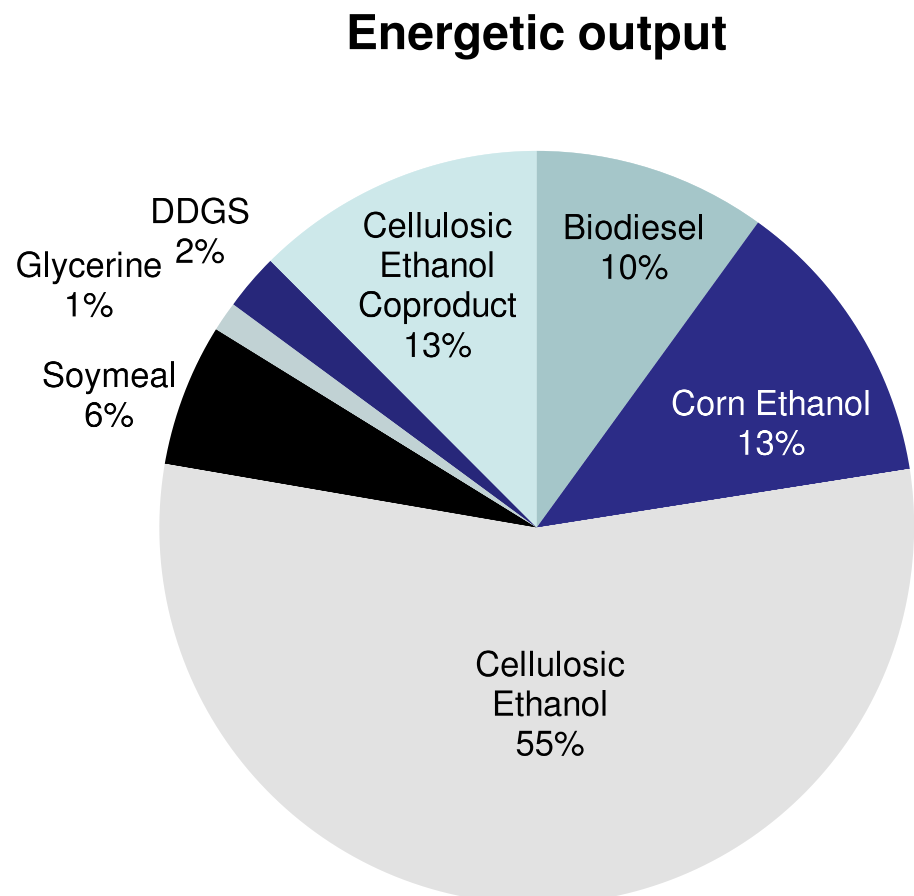
Notes:
Recycled biomass energy : 26.3 MJ/L

Energetic Outputs



Soy/Wheat – Red Clover - Corn





Energy	Quantity	Unit
Energy input	22,881	MJ/ha
Energy output	72,158	MJ/ha
Net Energy Value(NEV)	49,277	MJ/ha
Net Energy Ratio (NER)	3.15	MJ/ha
Products	**Quantity**	**Unit**
Biodiesel	195	L/ha
Corn Ethanol	426	L/ha
Cellulosic Ethanol	1,879	L/ha
Co-Products	**Quantity**	**Unit**
Soymeal	0.78	Mg/ha
Glycerine	0.02	Mg/ha
DDGS	0.16	Mg/ha

Notes:
Recycled biomass energy : 26.3 MJ/L

Agricultural Supply Chain Issues

- Federal programs
- Landowner values
- Commodity crop prices
- Ecosystem services
- Equipment availability
- Value-chain ownership and motivation

Landowner buy-in will require:

- Experience – Tradition, training, technical assistance
- Ability – Time, labor, management
- Technology – Owned, leased, contracted equipment
- Profit – Income, expenses, subsidies
- Risk – weather, markets, insurance
- Environment – Recreation, sustainability, stewardship

Multi-functional Decision Support

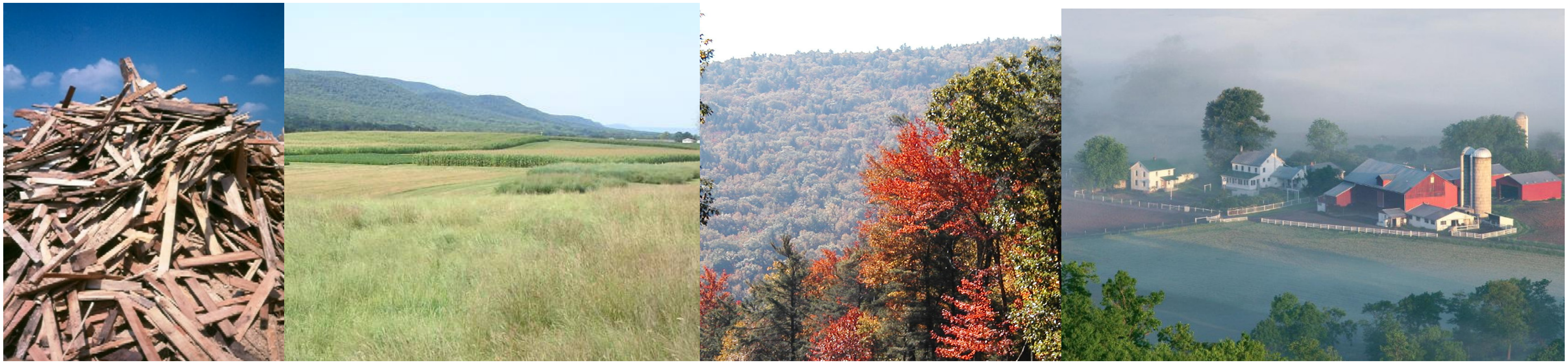
http://i-farmtools.org

What about other criteria? Biodiversity? Risk? Babies per square mile?

Four Sustainable Strategies…

- Organic Wastes
- Perennial Crops
- 21st Century Forestry
- Multi-functional Agriculture

Who will grow the infrastructure?




Give me six hours to chop down a tree and I will spend the first four sharpening the axe.
Abraham Lincoln, 1809 - 1865
www.bioenergy.psu.edu