

The Biomass Energy Analytical Model

Presented at the
Heating the Midwest with Renewable
Biomass Conference

April 10, 2017 – Minneapolis, MN

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Enegis, LLC

- ★ Grid Point Example
- Grid Point
- Open Water
- Perennial Ice/Snow
- Developed, Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Barren Land
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Shrub/Scrub
- Grassland/Herbaceous
- Pasture Hay
- Cultivated Crops
- Woody Wetlands
- Emergent Herbaceous Wetlands

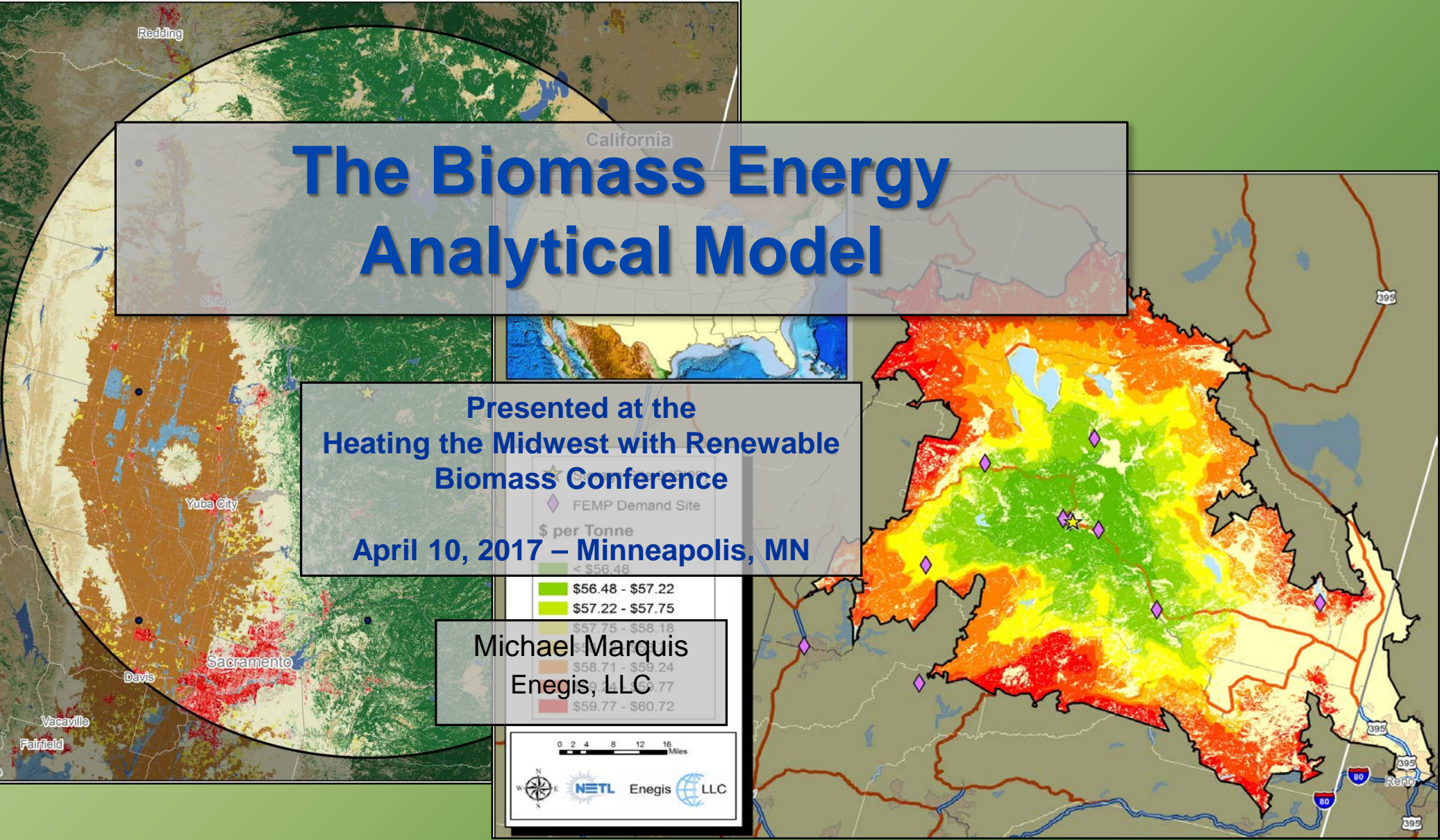
0 3 6 12 18 24 Miles

0 2 4 8 12 16 Miles

◇ FEMP Demand Site

\$ per Tonne

< \$56.48
\$56.48 - \$57.22
\$57.22 - \$57.75
\$57.75 - \$58.18
\$58.18 - \$58.71
\$58.71 - \$59.24
\$59.24 - \$59.77
\$59.77 - \$60.72

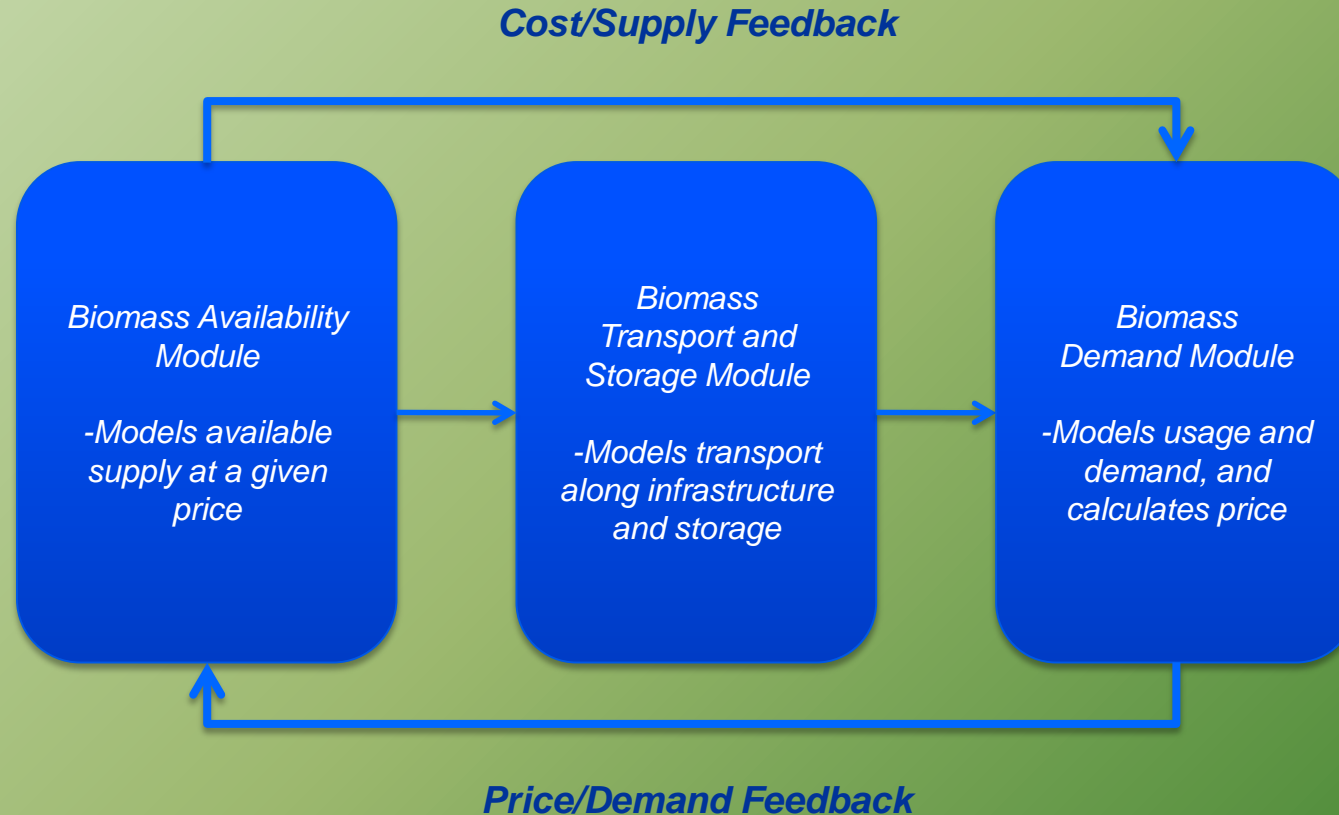


BEAM - Goals

- **Estimate available biomass residues using land cover and other GIS datasets**
- **Inform opportunities for National Energy Technology Laboratory (NETL)'s Biomass & Advanced Methane Fuels (BAMF) working group for biomass use for power generation**
 - Support Federal Energy Management Program's (FEMP) opportunities for biomass energy usage
- **Maximize Federal utilization of renewable energy**
 - Policy framework (esp. the Energy Policy Act of 2005) in place for attaining energy, environmental and economic goals
 - Energy Saving Performance Contracts (ESPCs) between Energy Service Companies (ESCOs) and the Federal agencies require mutually beneficial terms and conditions
 - BEAM can assist the process by:
 - Quantifying and classifying available biomass resource
 - Scenario building for optimization of transport, storage and usage on local and regional scales

BEAM - Structure

Biomass Energy Analytical Model



Species-Specific Parameters

~60 Species/Commodities Incorporated

Data is by county

Agricultural Residues
Woody Residues
Human Wastes
Animal Manures

Species	Data Source
Agriculture Residues:	
Hay All (Dry)	USDA NASS
Hay Alfalfa (Dry)	USDA NASS
Rice All	USDA NASS
Sorghum For Grain	USDA NASS
Barley All	USDA NASS
Canola	USDA NASS
Corn For Grain	USDA NASS
Cotton Amer. Pima	USDA NASS
Cotton Upland	USDA NASS
Beans Dry Edible	USDA NASS
Wheat Durum	USDA NASS
Flaxseed	USDA NASS
Peanuts for Nuts	USDA NASS
Potatoes All	USDA NASS
Hay Other (Dry)	USDA NASS
Oats - (Fall)	USDA NASS
Rye	USDA NASS
Safflower	USDA NASS
Soybeans	USDA NASS
Sugarcane For Sugar	USDA NASS
Sunflower All	USDA NASS
Sweet Potatoes	USDA NASS
Sugarbeets	USDA NASS
Wheat Other Spring	USDA NASS
Tobacco Air-Cured Light Burley	USDA NASS
Tobacco Flue-Cured Class 1	USDA NASS
Green Peas For Processing	USDA NASS
Snap Beans For Processing	USDA NASS

Species	Data Source
Agriculture Residues Cont:	
Sweet Corn For Processing	USDA NASS
Wheat Winter All	USDA NASS
Woody Residues:	
Logging Residue - HardWood	USDA FS
Logging Residue - SoftWood	USDA FS
Forest Management Residue - HardWood	BAMF Hazardous Fuels
Forest Management Residue - SoftWood	BAMF Hazardous Fuels
Coarse Wood Residue - Hardwood	BAMF Industrial Wood Waste
Coarse Wood Residue - Softwood	BAMF Industrial Wood Waste
Fine Wood Residue - Hardwood	BAMF Industrial Wood Waste
Fine Wood Residue - Softwood	BAMF Industrial Wood Waste
Urban Wood Waste - Tree clippings	Based on US Census Bureau Population
Human Produced Wastes:	
Wastewater Treatment Plants	BAMF Anaerobic WWTP
Landfills Producing Methane	EPA
Animal Manure:	
All Goats	USDA NASS & HSIP
Milk Cows	USDA NASS & HSIP
Beef	USDA NASS & HSIP
Hogs All	USDA NASS & HSIP
Sheep	USDA NASS & HSIP
Layer	USDA NASS & HSIP
Broiler	USDA NASS & HSIP
Turkey	USDA NASS & HSIP



Species-Specific Parameters and Biomass Conversion Functions

Detailed Physical Parameters

Species:	Physical Parameters											
	BtuHHV	BtuLHV	Ash Avg	Ash Min	Ash Max	Moisture	Potassium (K)	Sodium (Na)	Chlorine (Cl)	Carbon (C)	Mercury (Hg)	Sulfur (S)
	MMBtu /Tonne	MMBtu /Tonne	%	%	%	%	g/kg (DAF)	g/kg (DAF)	weight % (DAF)	weight %	weight % (DAF)	weight % (DAF)
Logging Residue - HardWood	18.8	17.4	0.9	0.2	2.6	11.3	1.20	0.01	0.0	49.7	0.0	0.1
Logging Residue - SoftWood	19.9	18.5	1.6	0.4	4.1	4.7	1.68	0.25	0.0	51.9	0.0	0.0
Forest Mgmt. Residue - HardWood	18.8	17.4	0.9	0.2	2.6	11.3	1.20	0.01	0.0	49.7	0.0	0.1
Forest Mgmt. Residue - SoftWood	19.9	18.5	1.6	0.4	4.1	4.7	1.68	0.25	0.0	51.9	0.0	0.0
Coarse Wood Residue - Hardwood	18.5	17.2	0.9	0.4	2.1	15.2	0.98	0.04	0.0	50.0	0.0	0.1
Coarse Wood Residue - Softwood	19.3	18.0	0.3	0.3	0.3	9.3	0.38	0.04	0.0	49.8	0.0	0.0
Fine Wood Residue - Hardwood	17.2	16.0	1.5			8.0	-	-		50.8	0.0	0.0
Fine Wood Residue - Softwood	18.4	17.2	1.1			34.9	0.49	0.03	0.0	49.3	0.0	0.0
Urban Wood Waste - Tree clippings	19.5	18.4	15.6	1.4	39.4	35.4	4.15	2.05	0.1	51.1	0.0	0.1

Species-Specific Parameters and Biomass Conversion Functions

Detailed Physical Parameters

Seasonality Parameters

Species:	BtuHHV	Btu	Seasonal Availability												Mercury (Hg) weight % (DAF)	Sulfur (S) weight % (DAF)	
			Jan %	Feb %	Mar %	Apr %	May %	Jun %	Jul %	Aug %	Sep %	Oct %	Nov %	Dec %			Annual Total %
Hay All (Dry)			-	-	-	-	10	20	30	20	10	10	-	-	100		
Hay Alfalfa (Dry)			-	-	-	-	10	20	30	20	10	5	5	-	100		
Rice All			-	-	-	-	-	-	10	20	40	30	-	-	100		
Sorghum For Grain			-	-	-	-	-	-	-	10	15	45	30	-	100		
Barley All			-	-	-	-	-	-	25	50	25	-	-	-	100		
Canola			-	-	-	-	20	30	30	20	-	-	-	-	100		
Corn For Grain			-	-	-	-	-	-	-	-	25	50	25	-	100		
Cotton Amer. Pima			-	-	-	-	-	-	-	-	20	50	15	15	100		
Cotton Upland			-	-	-	-	-	-	-	-	20	50	15	15	100		
Beans Dry Edible			-	-	-	-	-	-	-	25	50	25	-	-	100	7	0.0
Wheat Durum			-	-	-	-	-	-	25	50	25	-	-	-	100	9	0.0
Flaxseed			-	-	-	-	-	-	50	50	-	-	-	-	100	7	0.0
Peanuts for Nuts			-	-	-	-	-	-	-	-	25	50	25	-	100	9	0.0
Potatoes All			-	-	-	-	-	-	-	-	25	50	25	-	100	0	0.0
Hay Other (Dry)			-	-	-	-	10	20	30	20	10	10	-	-	100	3	0.0
Oats - (Fall)			-	-	-	-	-	-	25	50	25	-	-	-	100	3	0.0
Rye			-	-	-	-	25	50	25	-	-	-	-	-	100	3	0.0
Safflower			-	-	-	-	-	-	-	50	50	-	-	-	100	3	0.0
Soybeans			-	-	-	-	-	-	-	10	10	30	30	20	100	1	0.0
Sugarcane For Sugar			15	15	10	5	-	-	-	-	-	10	20	25	100		
Sunflower All			-	-	-	-	-	-	-	5	20	50	25	-	100		
Sweet Potatoes			-	-	-	-	-	-	-	25	50	25	-	-	100		
Sugarbeets			-	-	-	-	-	-	-	-	25	50	25	-	100		
Wheat Other Spring			-	-	-	-	-	-	25	50	25	-	-	-	100		
Tobacco Air-Cured			-	-	-	-	-	-	-	25	50	25	-	-	100		
Tobacco Flue-Cured			-	-	-	-	-	20	30	30	20	-	-	-	100		
Green Peas For Processing			2	3	5	10	11	15	20	11	10	8	3	2	100		
Snap Beans For Processing			-	-	2	5	7	20	30	20	10	3	2	1	100		
Sweet Corn For Processing			-	-	-	-	5	10	30	30	10	10	5	-	100		
Wheat Winter All			-	-	-	-	10	25	30	25	10	-	-	-	100		

Species-Specific Parameters and Biomass Conversion Functions

Detailed Physical Parameters

Seasonality Parameters

Biomass Residue Conversions

	BtuHHV	EM
Species:	MMBtu	N
	/Tonne	/
Logging Residue - HardWood	18.8	
Logging Residue - SoftWood	19.9	
Forest Mgmt. Residue - HardWood	18.8	
Forest Mgmt. Residue - SoftWood	19.9	
Coarse Wood Residue - Hardwood	18.5	
Coarse Wood Residue - Softwood	19.3	
Fine Wood Residue - Hardwood	17.2	
Fine Wood Residue - Softwood	18.4	
Urban Wood Waste - Tree clippings	19.5	

Biomass Commodities			Commodity to Biomass Conversion							
Process	UID	Species	Category	Product	Unit	Conversion to Biomass	Residue Cover	Animal Feed	Other Use	Collection
						factor	%	%	%	%
Y	AH08	Hay All (Dry)	Crop Residue	Grass/plant	tonnes	1.00	0.30	0.25	0.15	0.30
Y	AL08	Hay Alfalfa (Dry)	Crop Residue	Grass/plant	tonnes	1.00	0.30	0.25	0.15	0.30
Y	AR08	Rice All	Crop Residue	Husk/Shell/Pit	tonnes	1.40	0.30	0.25	0.15	0.30
Y	AS08	Sorghum For Grain	Crop Residue	Straw (stalk/cob/ear)	tonnes	1.40	0.30	0.25	0.15	0.30
Y	AW08	Wheat All	Crop Residue	Straw	tonnes	1.30	0.30	0.25	0.15	0.30
Y	BR08	Barley All	Crop Residue	Straw (stalk/cob/ear)	tonnes	1.20	0.30	0.25	0.15	0.30
Y	CN08	Canola	Crop Residue	Stalks	tonnes	2.20	0.30	0.25	0.15	0.30
Y	CR08	Corn For Grain	Crop Residue	Corn stover	tonnes	1.00	0.30	0.25	0.15	0.30
Y	CTP08	Cotton Amer. Pima	Crop Residue	Cotton Stalks	tonnes	4.50	0.30	0.25	0.15	0.30
Y	CTU08	Cotton Upland	Crop Residue	Cotton Stalks	tonnes	4.50	0.30	0.25	0.15	0.30
Y	DB08	Beans Dry Edible	Crop Residue	Straw (stalk/cob/ear)	tonnes	1.20	0.30	0.25	0.15	0.30
Y	DW08	Wheat Durum	Crop Residue	Straw (stalk/cob/ear)	tonnes	1.30	0.30	0.25	0.15	0.30
Y	FX08	Flaxseed	Crop Residue	Straw (stalk/cob/ear)	tonnes	1.20	0.30	0.25	0.15	0.30
Y	PE08	Peanuts for Nuts	Crop Residue	Husk/Shell/Pit	tonnes	1.00	0.30	0.25	0.15	0.30
Y	PT08	Potatoes All	Crop Residue	Stalks/Leaves	tonnes	0.40	0.30	0.25	0.15	0.30
Y	OH08	Hay Other (Dry)	Crop Residue	Grass/plant	tonnes	1.00	0.30	0.25	0.15	0.30
Y	OT08	Oats - (Fall)	Crop Residue	Straw	tonnes	1.30	0.30	0.25	0.15	0.30
Y	RY08	Rye	Crop Residue	Straw	tonnes	1.60	0.30	0.25	0.15	0.30
Y	SAF08	Safflower	Crop Residue	Straw (stalk/cob/ear)	tonnes	1.20	0.30	0.25	0.15	0.30
Y	SB08	Soybeans	Crop Residue	stalks/leaves	tonnes	2.10	0.30	0.25	0.15	0.30
Y	SC08	Sugarcane For Sugar	Crop Residue	Bagasse	tonnes	1.60	0.30	0.25	0.15	0.30
Y	SF08	Sunflower All	Crop Residue	Straw (stalk/cob/ear)	tonnes	2.10	0.30	0.25	0.15	0.30
Y	SP07	Sweet Potatoes	Crop Residue	Stalks/Leaves	tonnes	1.00	0.30	0.25	0.15	0.30
Y	SU08	Sugarbeets	Crop Residue	Grass/plant	tonnes	0.20	0.30	0.25	0.15	0.30
Y	SW08	Wheat Other Spring	Crop Residue	Straw	tonnes	1.30	0.30	0.25	0.15	0.30
Y	TBU08	Tobacco Air-Cured Light Burley (Type 31)	Crop Residue	stalks / stems	tonnes	0.75	0.50	-	-	0.50
Y	TFC08	Tobacco Flue-Cured Class 1 (11-14)	Crop Residue	stalks / stems	tonnes	0.33	0.50	-	-	0.50
Y	VGP08	Green Peas For Processing	Crop Residue	stems / leaves	tonnes	1.50	-	-	-	1.00
Y	VSB07	Snap Beans For Processing	Crop Residue	stems / leaves	tonnes	2.10	-	-	-	1.00
Y	VSC08	Sweet Corn For Processing	Crop Residue	Corn stover	tonnes	1.00	0.30	0.25	0.15	0.30
Y	WW08	Wheat Winter All	Crop Residue	Straw	tonnes	1.30	0.30	0.25	0.15	0.30

Species-Specific Parameters and Biomass Conversion Functions

Detailed Physical Parameters

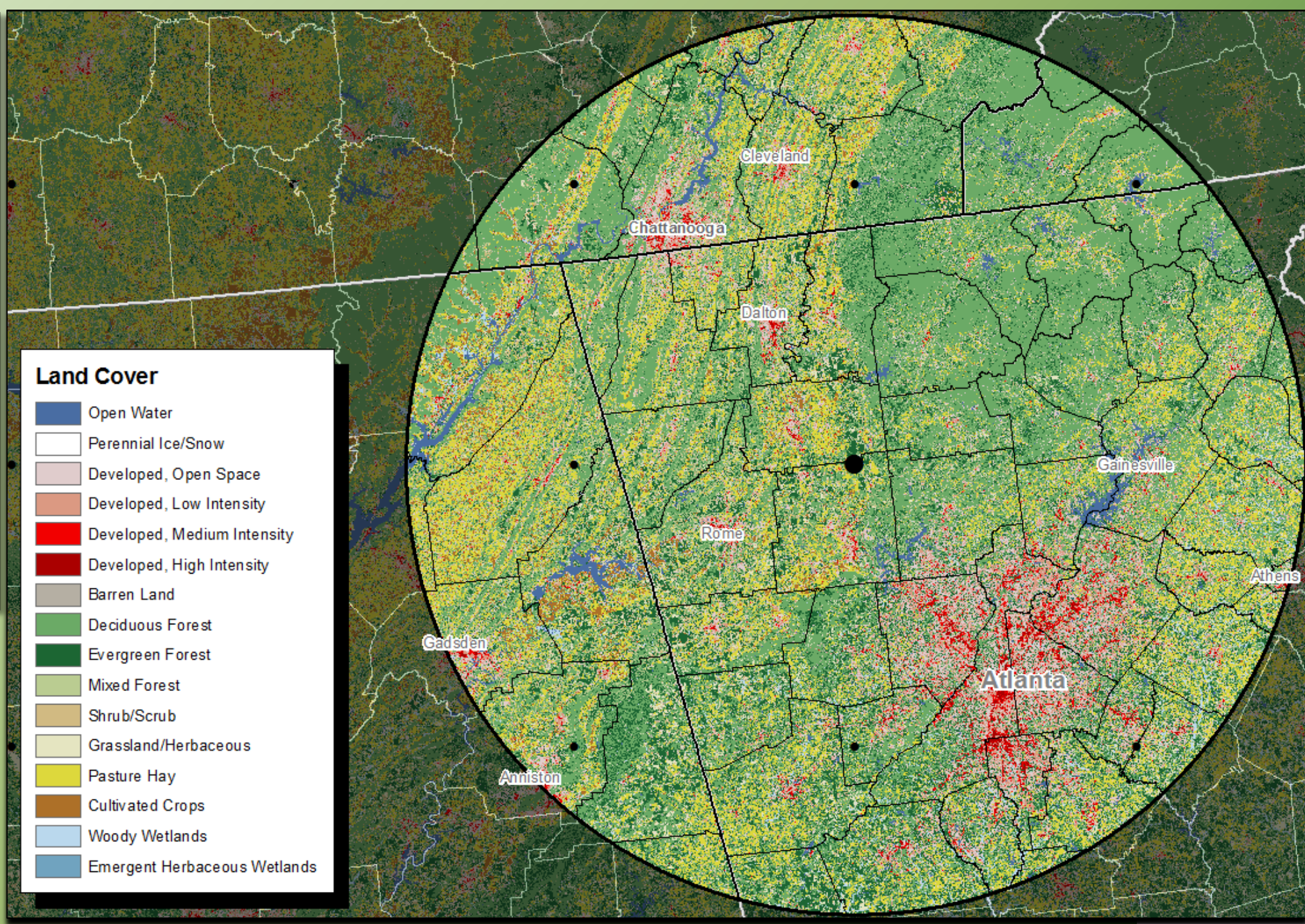
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Coarse Wood Residue - Hardwood	18.5	17.2	0.9	0.4	2.1	15.2	0.98	0.04	0.0	50.0	0.0	0.1
Coarse Wood Residue - Softwood	19.3	18.0	0.3	0.3	0.3	9.3	0.38	0.04	0.0	49.8	0.0	0.0
Fine Wood Residue - Hardwood	17.2	16.0	1.5			8.0	-	-		50.8	0.0	0.0
Fine Wood Residue - Softwood	18.4	17.2	1.1			34.9	0.49	0.03	0.0	49.3	0.0	0.0
Urban Wood Waste - Tree clippings	19.5	18.4	15.6	1.4	39.4	35.4	4.15	2.05	0.1	51.1	0.0	0.1

USGS Land Cover Data

Interpreted from
Landsat Thematic Mapper

Highly detailed, &
comprehensive

30-meter
resolution



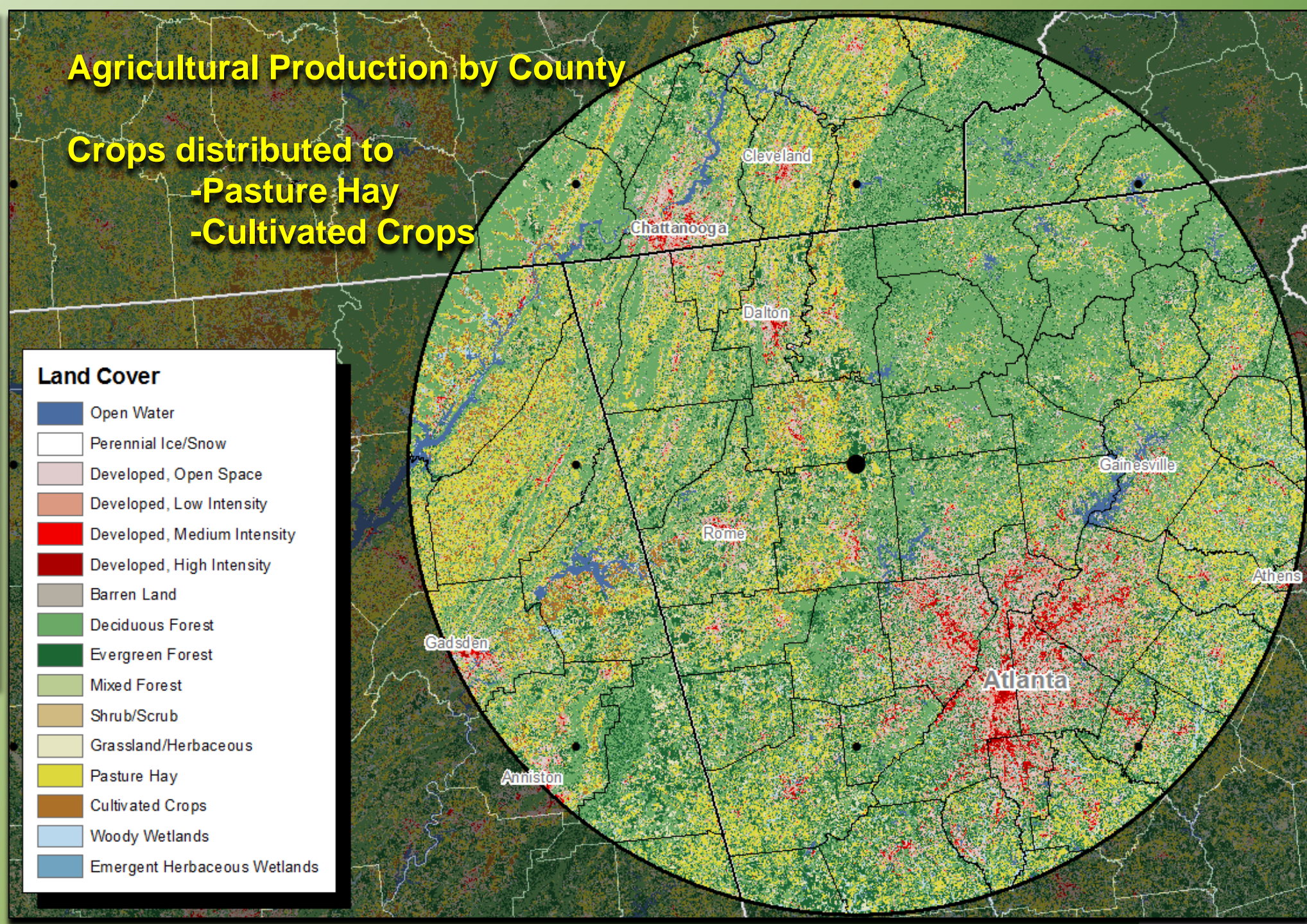
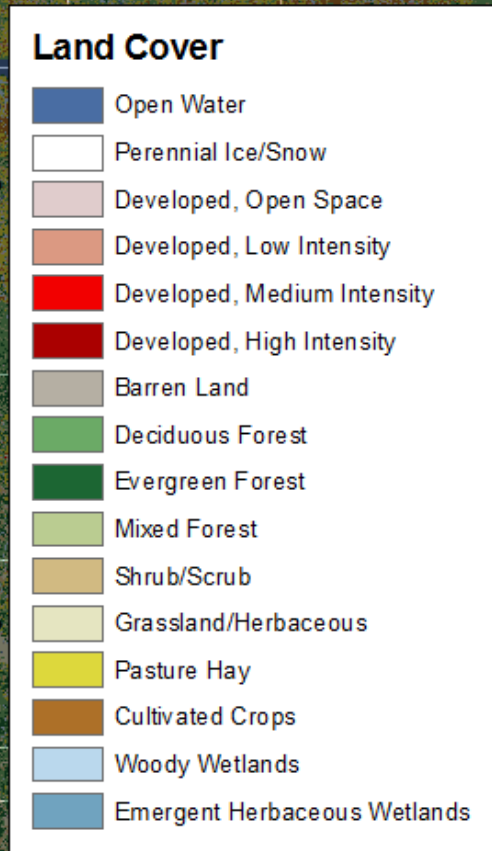
Biomass Species

Assigned to appropriate land cover type

Species-specific parameters and biomass conversion functions

Agricultural Production by County

Crops distributed to
- Pasture Hay
- Cultivated Crops



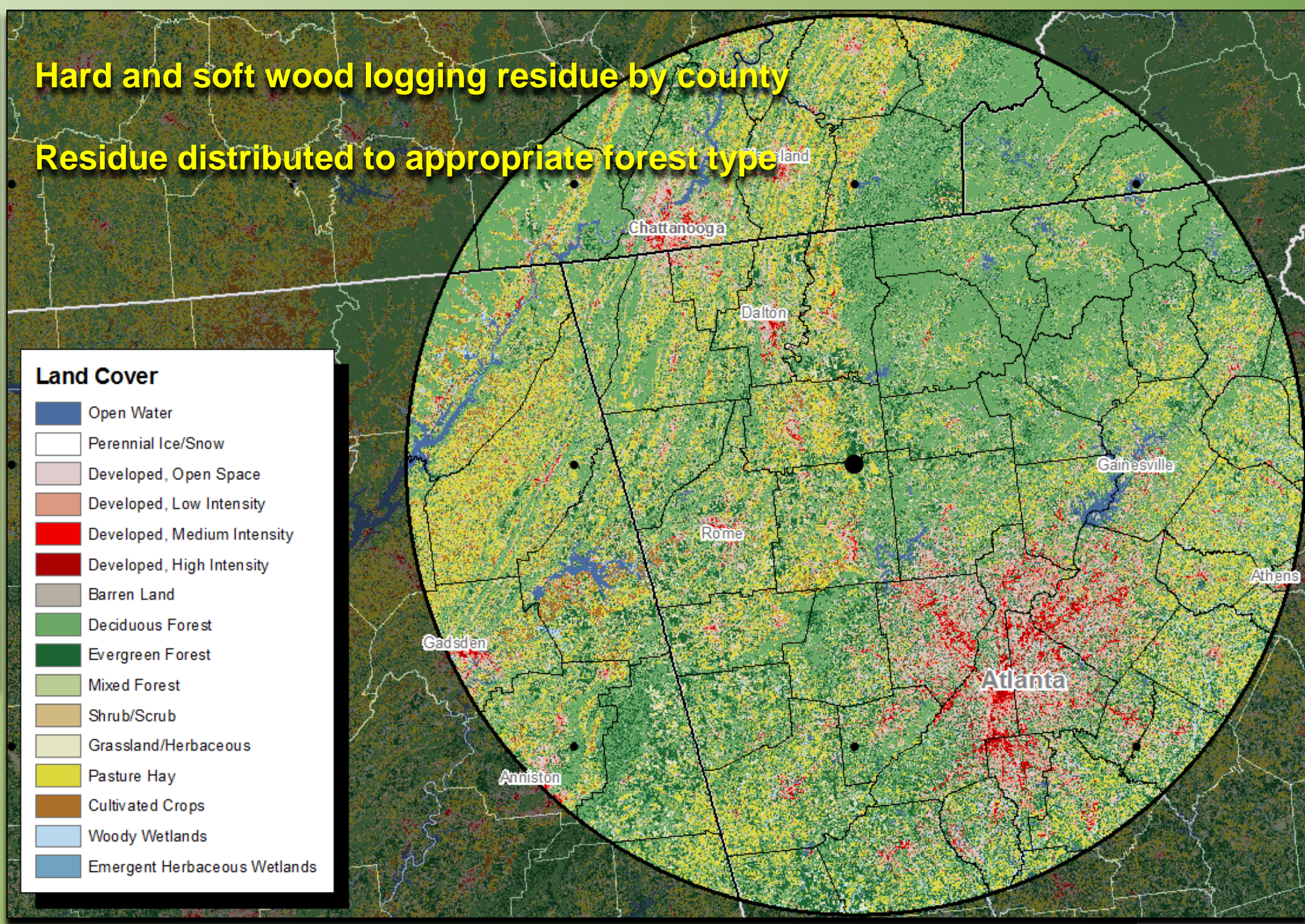
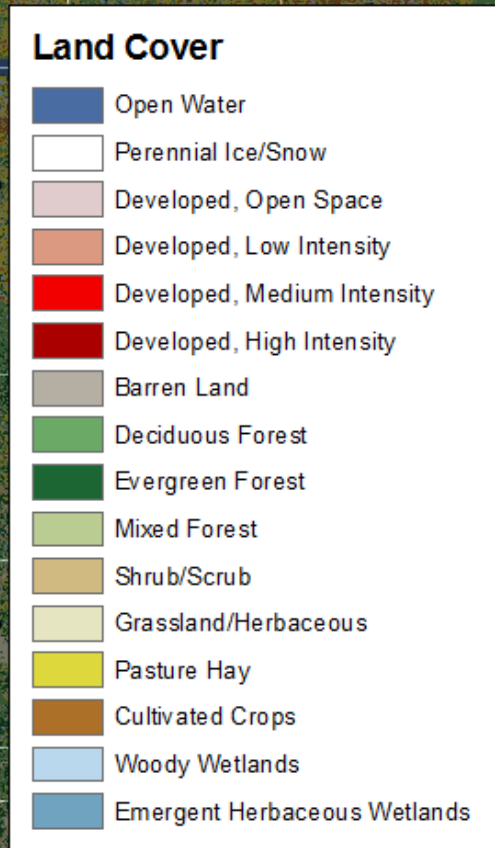
Biomass Species

Assigned to appropriate land cover type

Species-specific parameters and biomass conversion functions

Hard and soft wood logging residue by county

Residue distributed to appropriate forest type



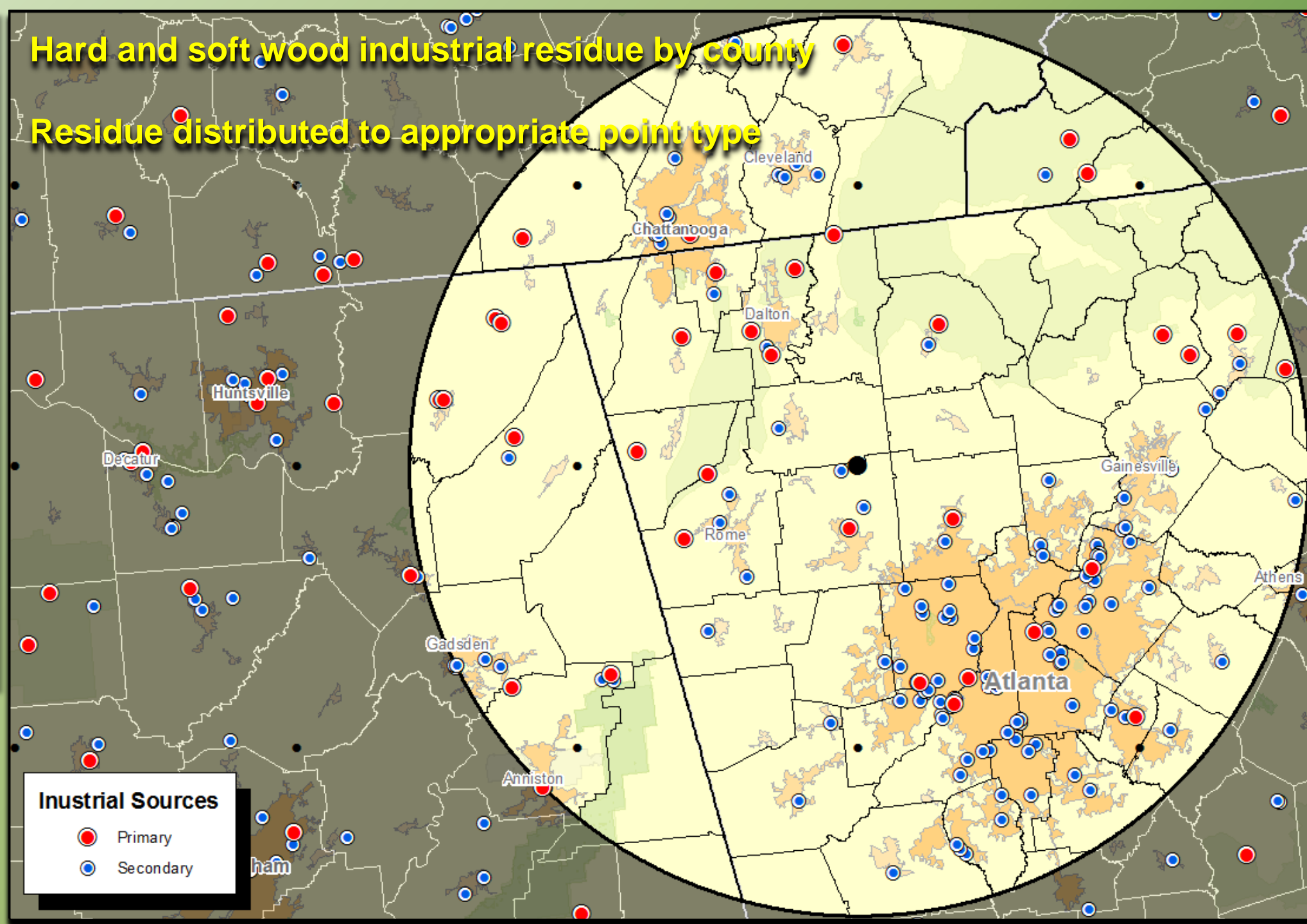
Biomass Species

Assigned to appropriate land cover type

Species-specific parameters and biomass conversion functions

Hard and soft wood industrial residue by county

Residue distributed to appropriate point type



Industrial Sources

- Primary
- Secondary

Biomass Species

Assigned to appropriate land cover type

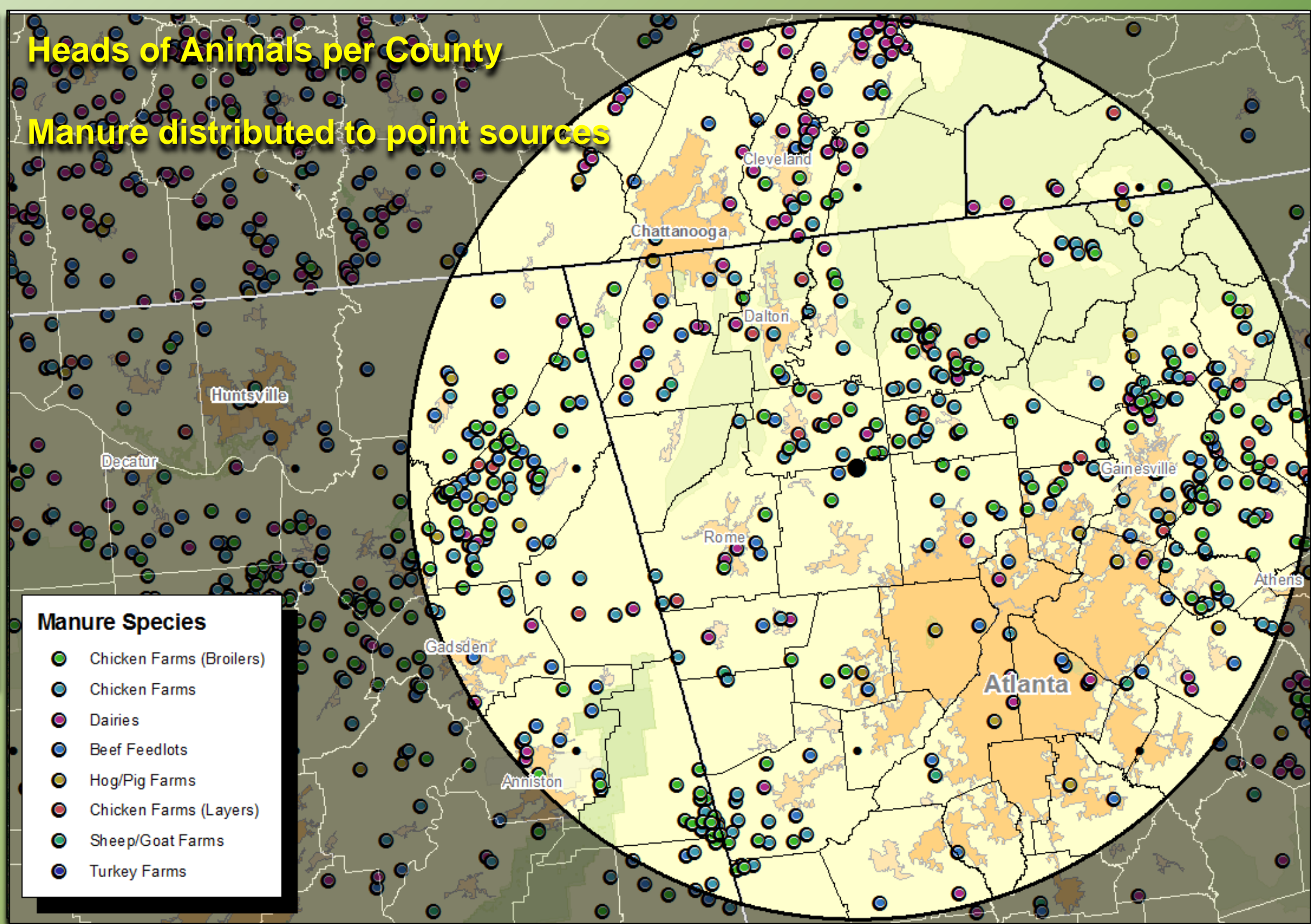
Species-specific parameters and biomass conversion functions

Heads of Animals per County

Manure distributed to point sources

Manure Species

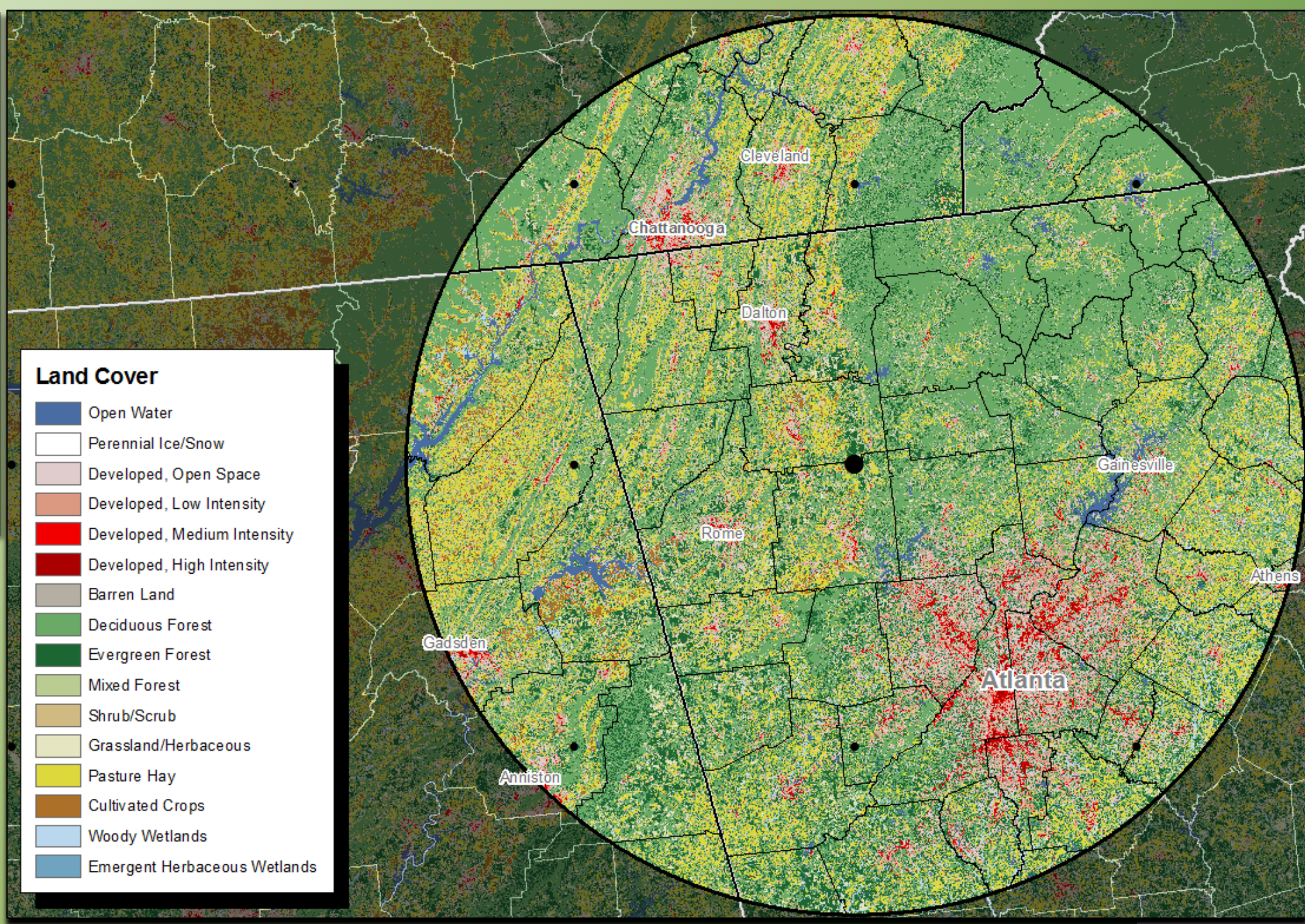
- Chicken Farms (Broilers)
- Chicken Farms
- Dairies
- Beef Feedlots
- Hog/Pig Farms
- Chicken Farms (Layers)
- Sheep/Goat Farms
- Turkey Farms



Biomass Availability

How much of what is where?

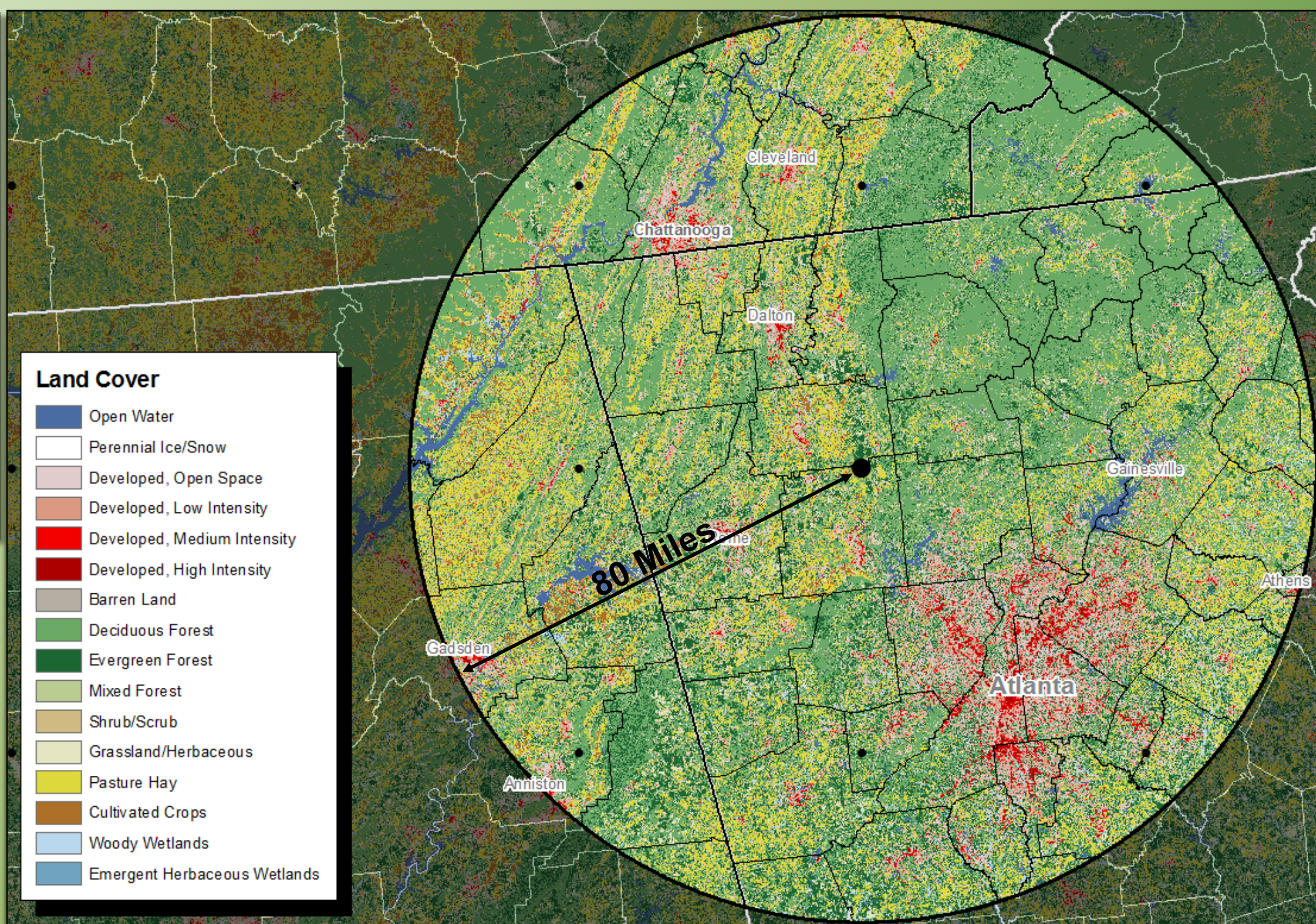
How much biomass is available within X miles of a point?



Biomass Availability

How much of what is where?

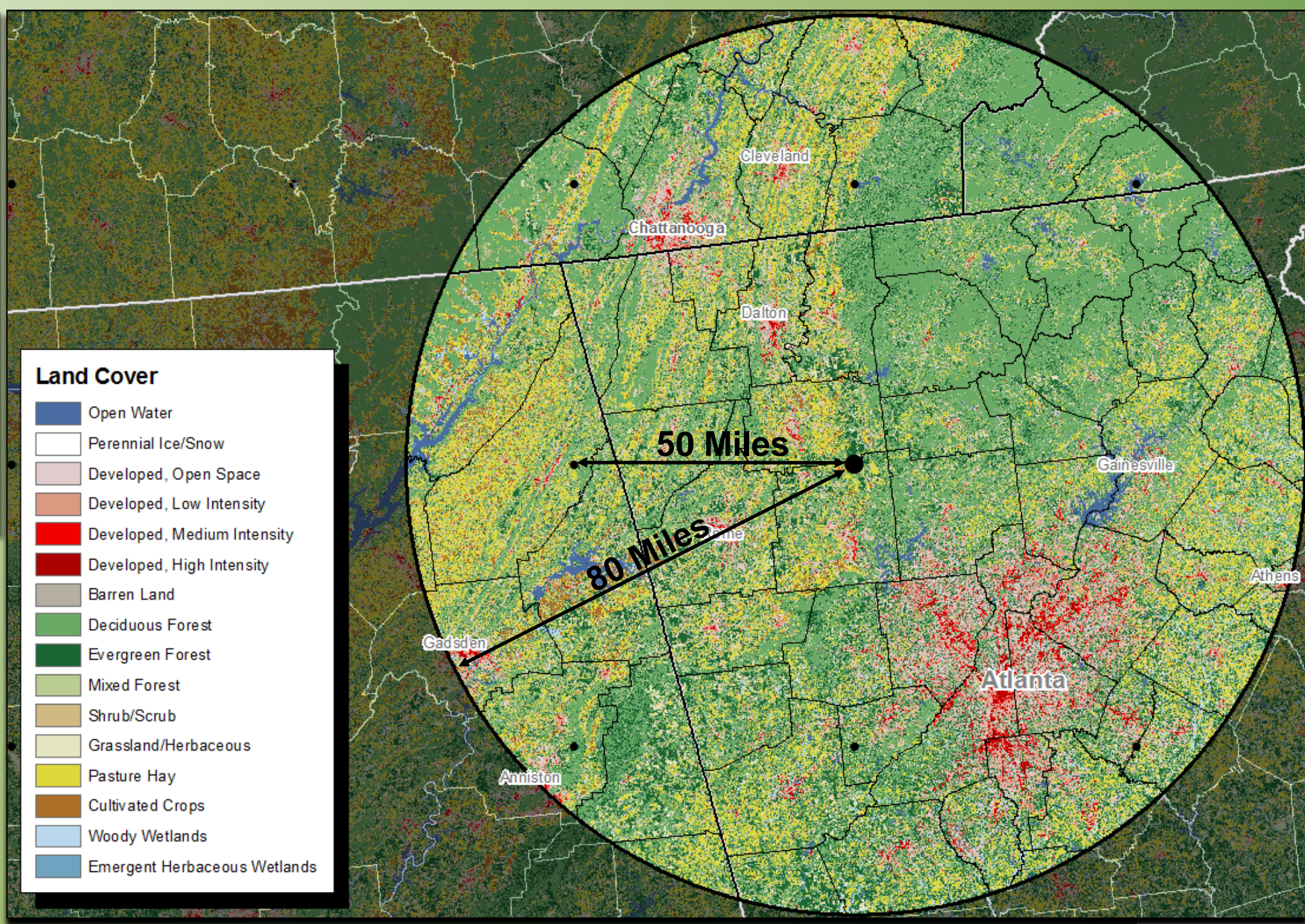
How much biomass is available within X miles of a point?



Biomass Availability

How much of what is where?

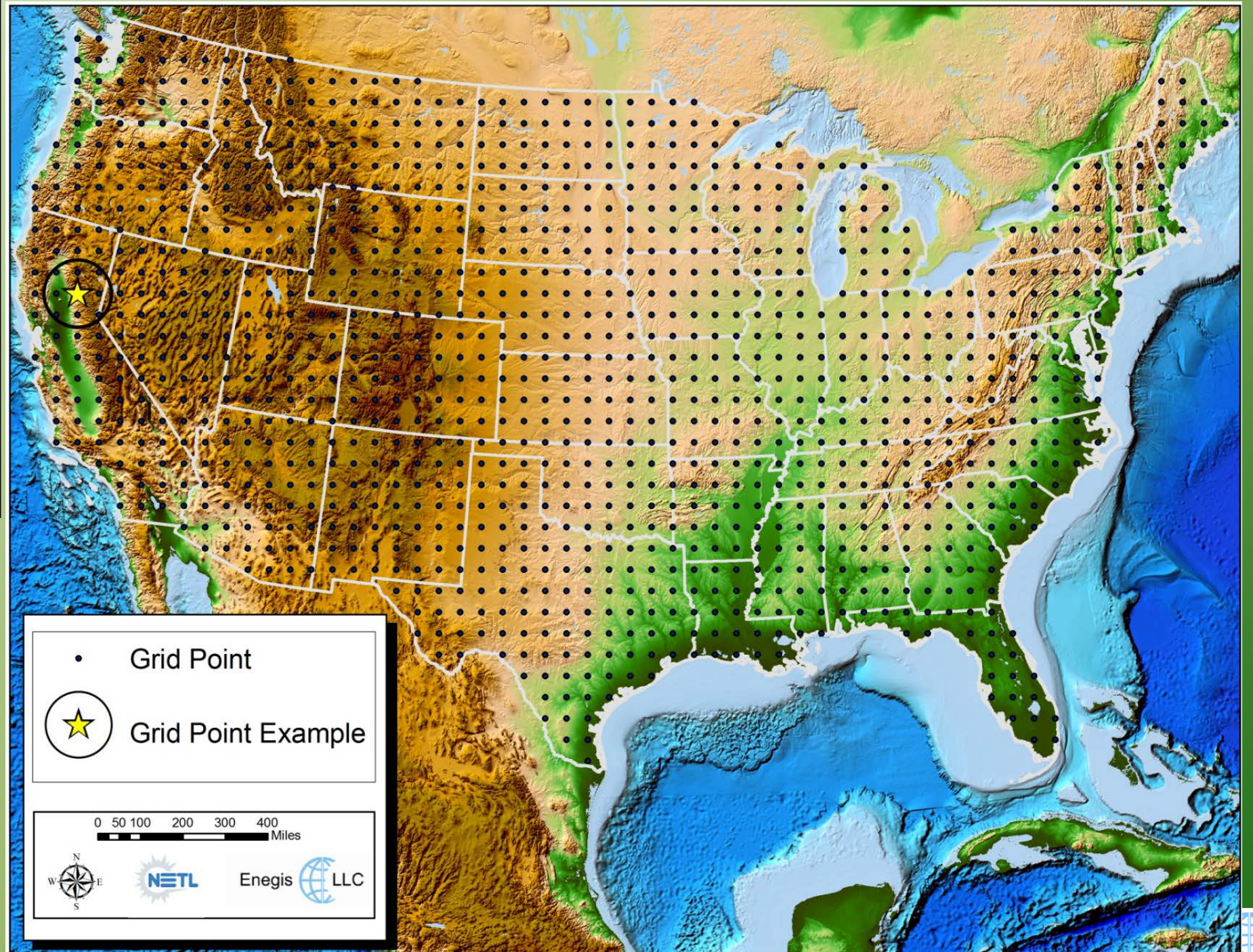
How much biomass is available within X miles of a point?



Lower 48 Biomass Availability

50 Mile Spacing

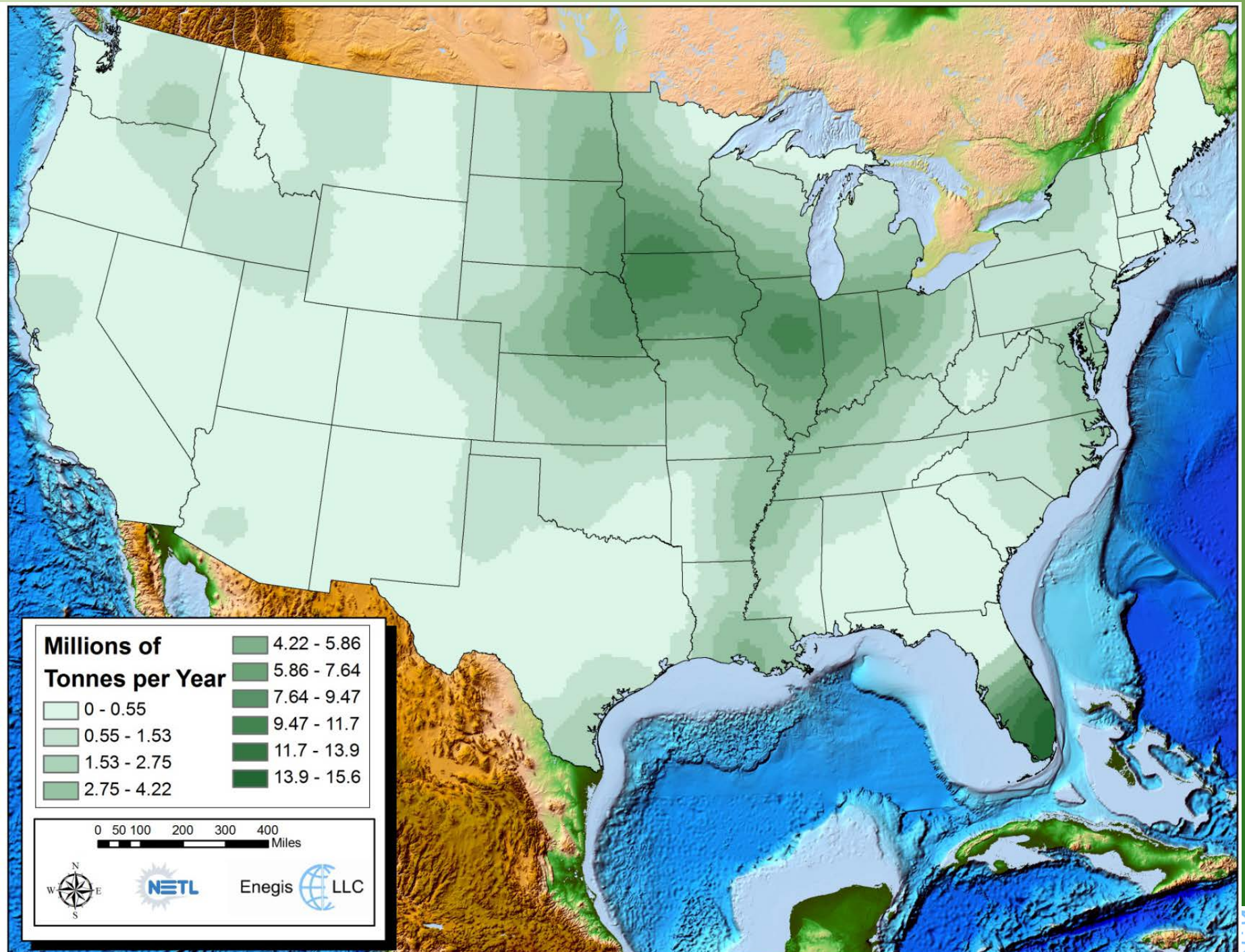
1204 Grid Points



Lower 48 Biomass Availability

Agriculture Residues
Results—All Species

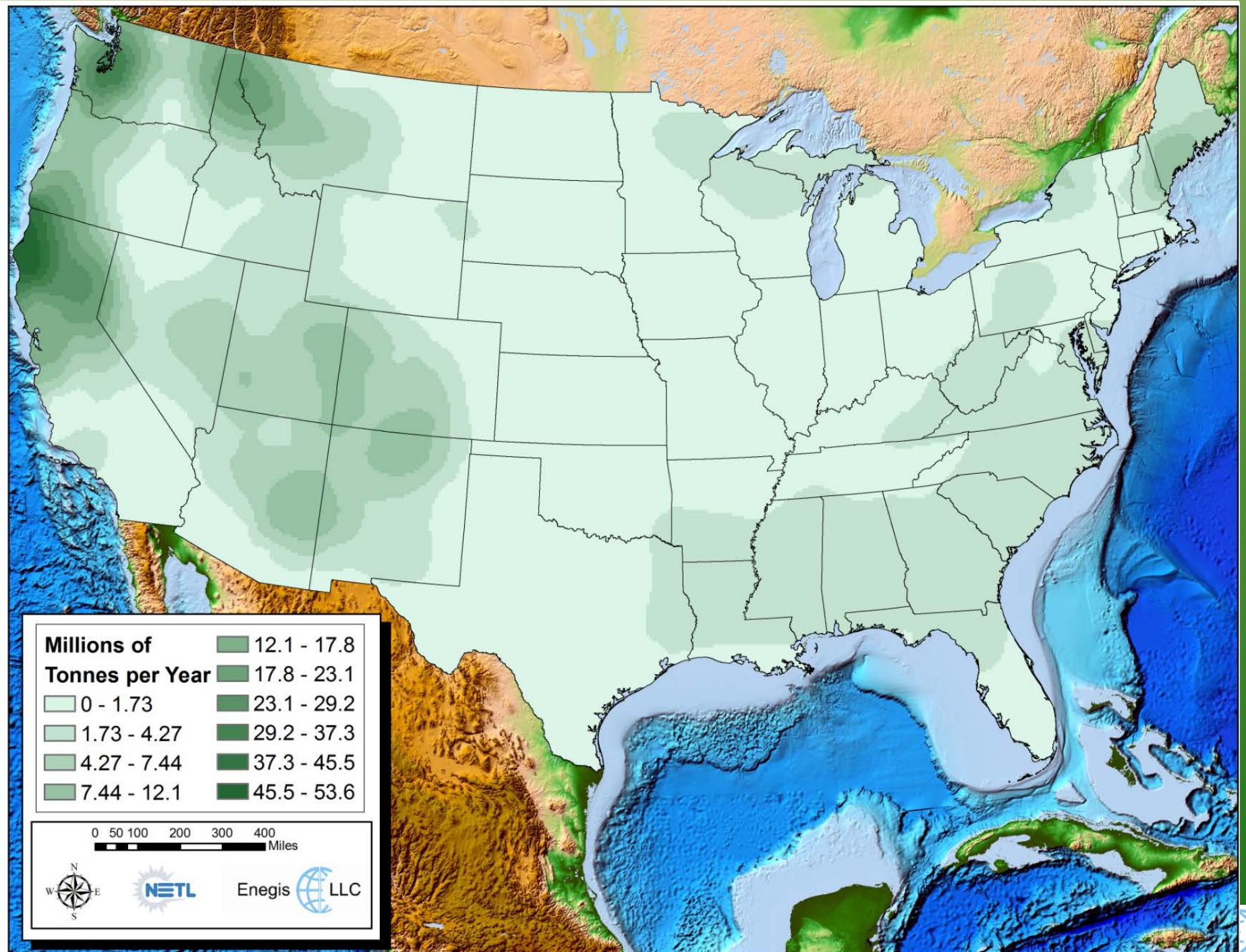
Tonnes per Year
within 80 miles



Lower 48 Biomass Availability

Woody Residues
Results—All Species

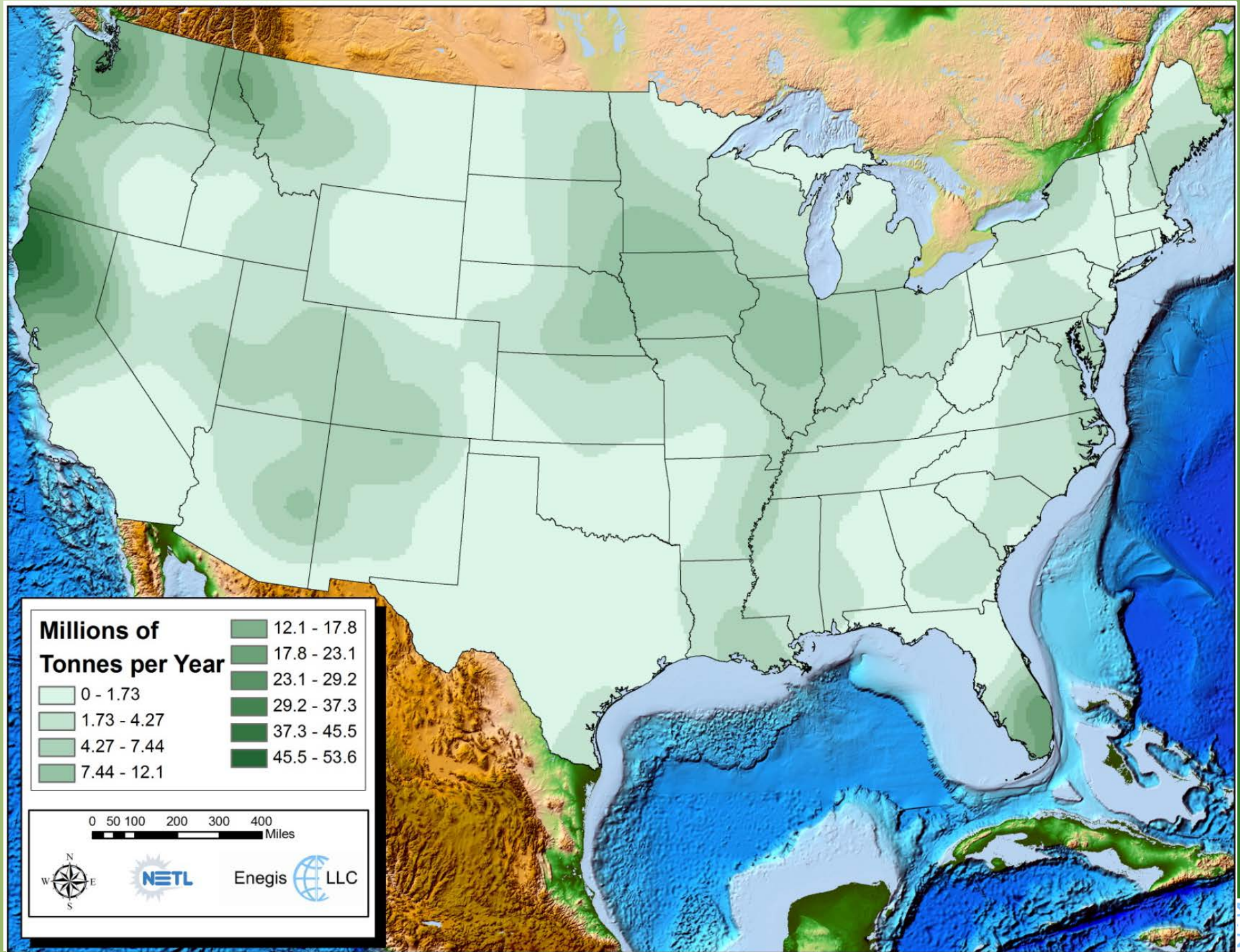
Tonnes per Year
within 80 miles



Lower 48 Biomass Availability

Agriculture and
Woody Results—All
Species

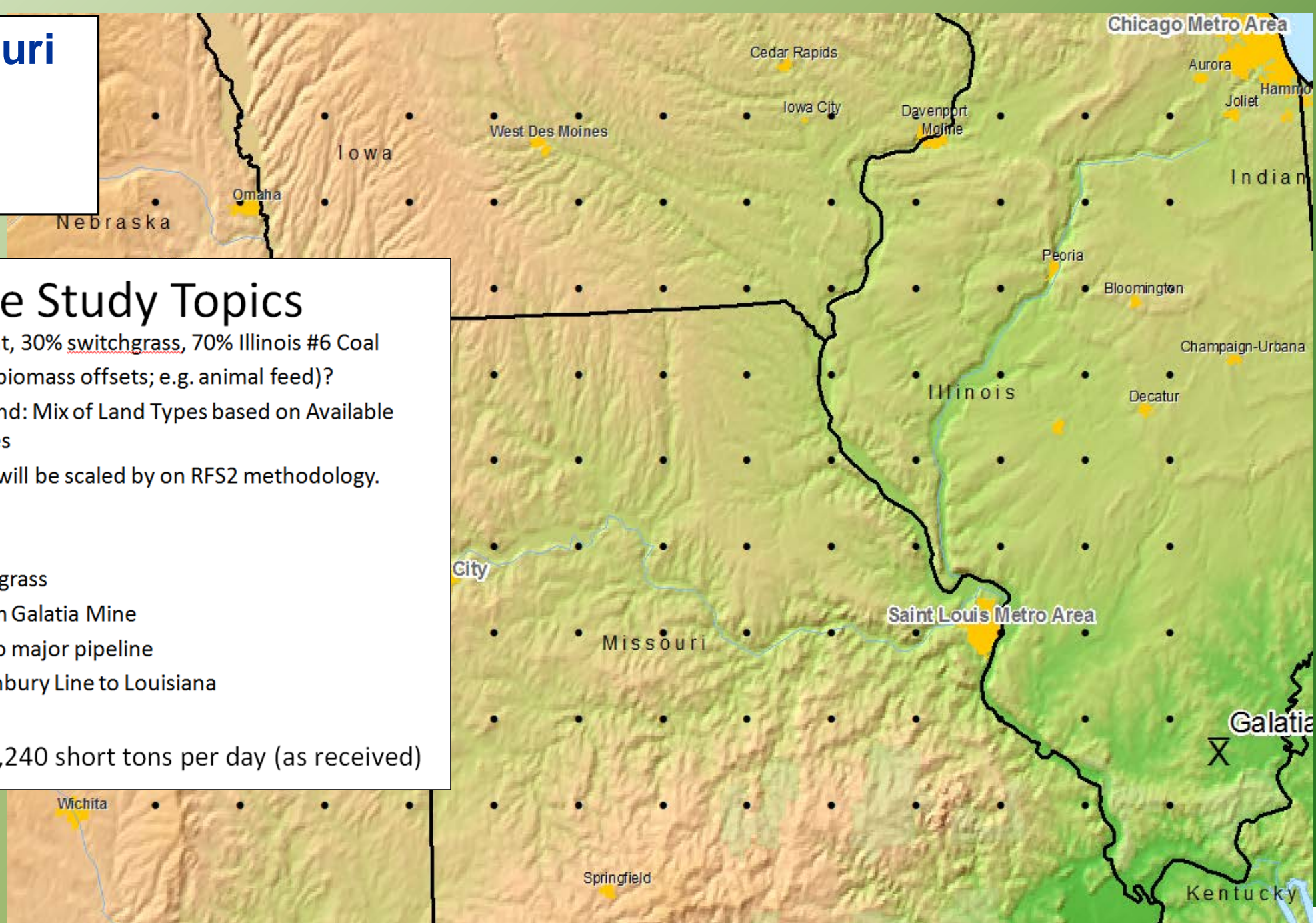
Tonnes per Year
within 80 miles



Northern Missouri Switchgrass Exercise

CBTL Case Study Topics

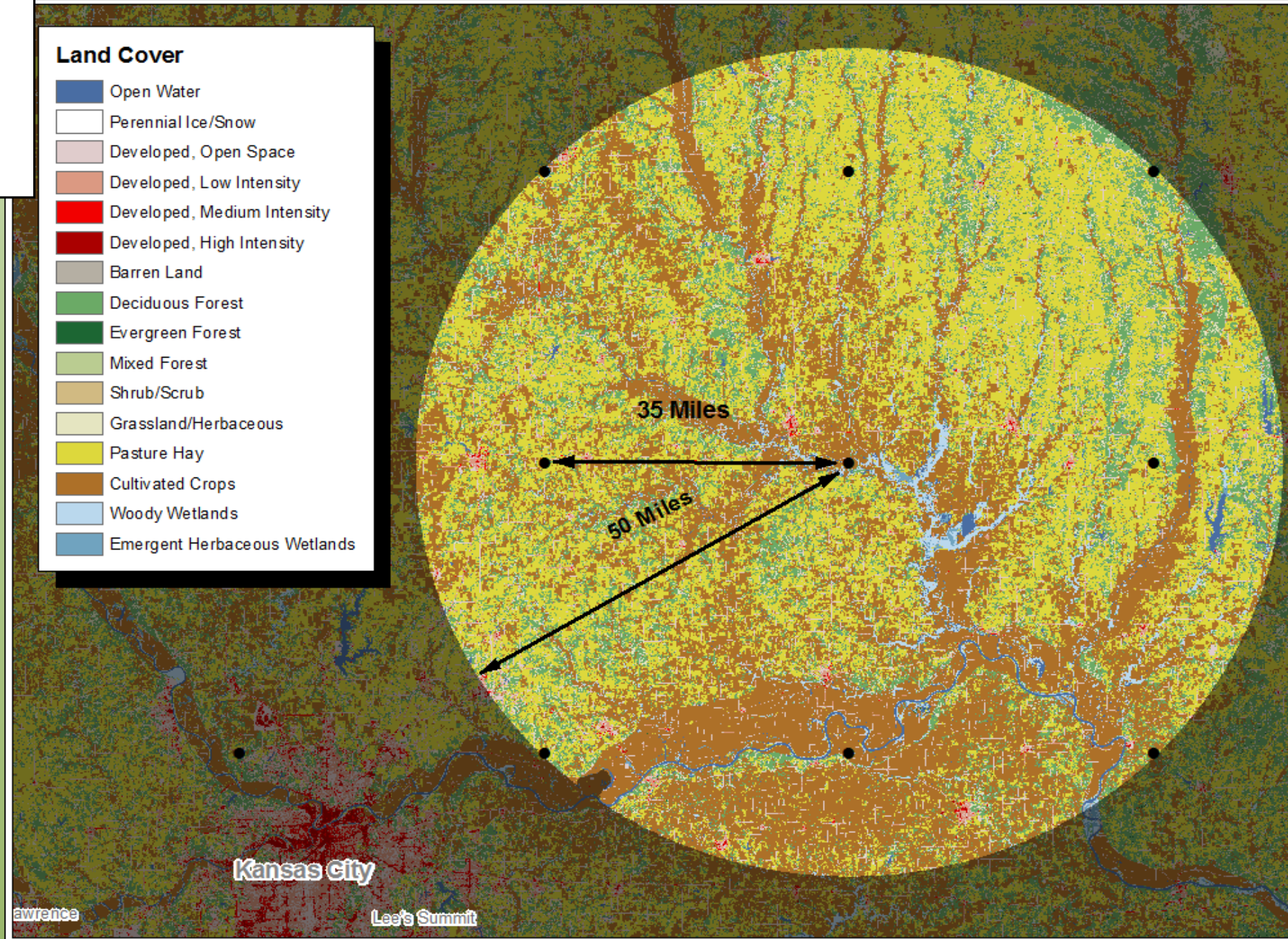
- Scope: Single 30,000 bpd Plant, 30% switchgrass, 70% Illinois #6 Coal
 - Effects to other markets (biomass offsets; e.g. animal feed)?
 - **DECISION:** Switchgrass Land: Mix of Land Types based on Available Land Types within 50-miles
 - Indirect Land use change will be scaled by on RFS2 methodology.
- Plant Location
 - Northern Missouri
 - Within 50-miles of Switchgrass
 - Rail transport of Coal from Galatia Mine
 - EOR Field, Spur pipeline to major pipeline
 - EOR Field: Preference Danbury Line to Louisiana
- Switchgrass Feed Rate: 4,240 short tons per day (as received)



Northern Missouri Switchgrass Exercise

Land Cover

- Open Water
- Perennial Ice/Snow
- Developed, Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Barren Land
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
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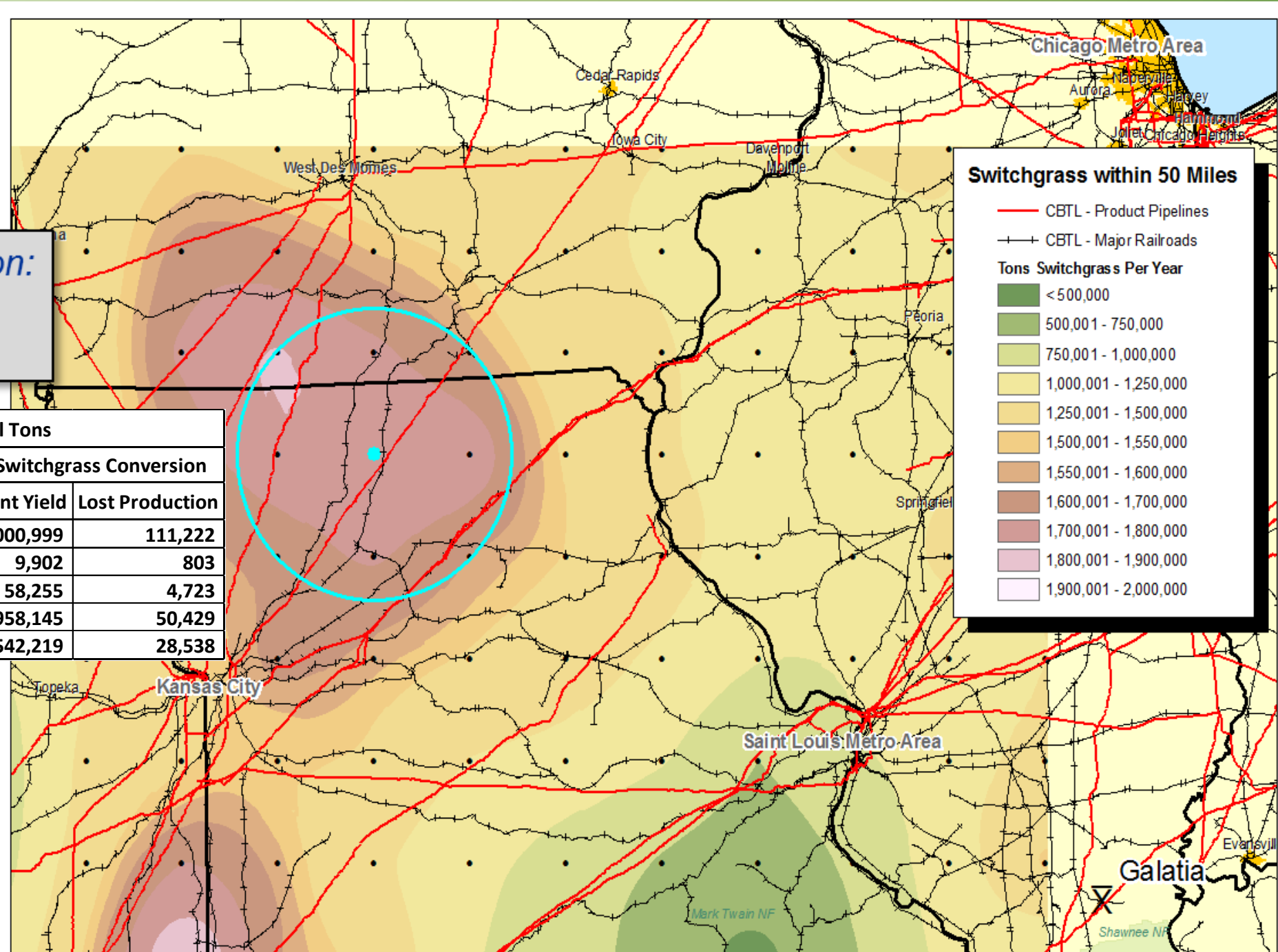


Northern Missouri Switchgrass Exercise

Required Land Conversion:

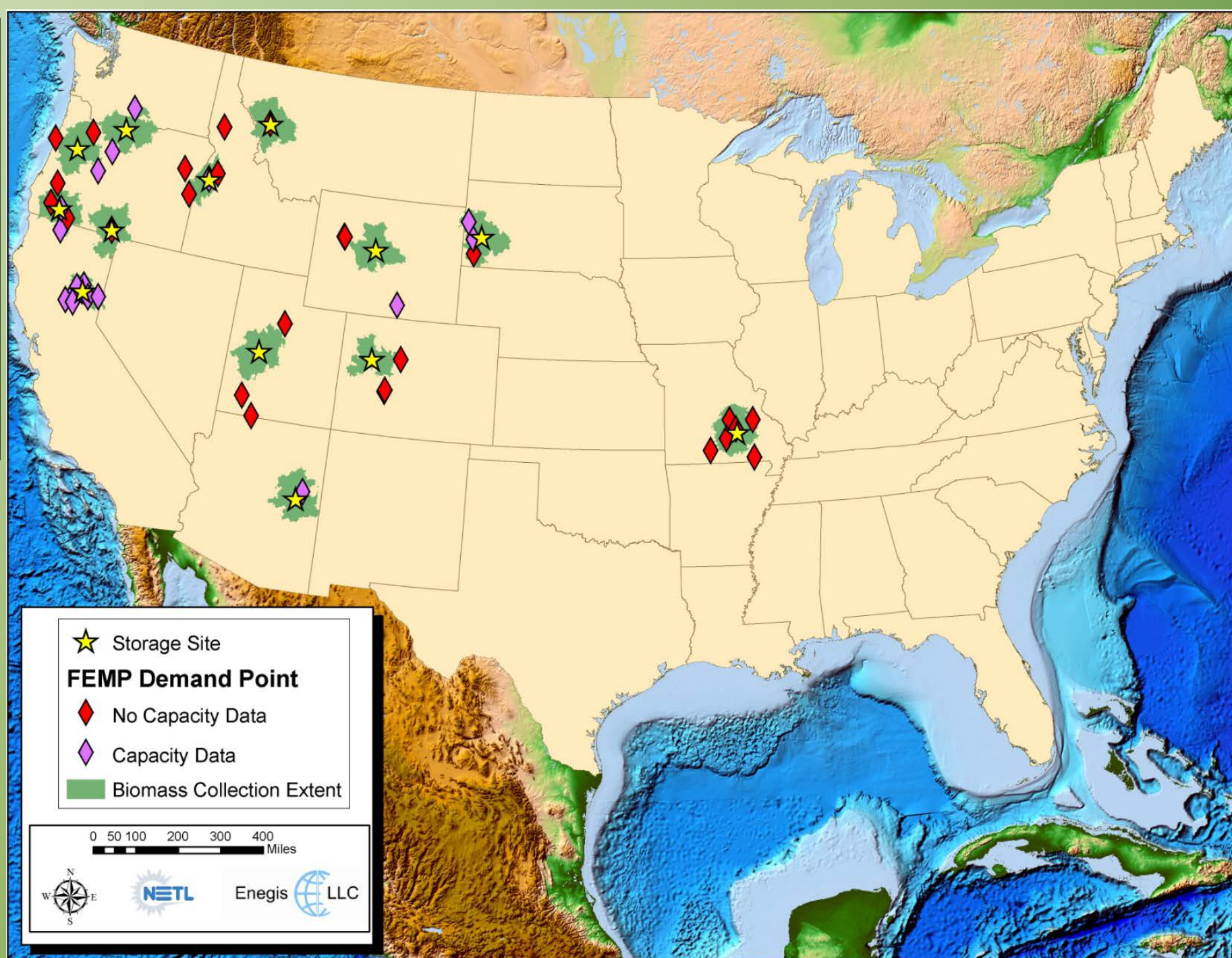
- 10% Hay/Pasture
- 5% Cultivated Cropland

Commodity	Annual Tons		
	2008 USDA Total	After Switchgrass Conversion	
		Resultant Yield	Lost Production
Hay "All" (Dry)	1,112,221	1,000,999	111,222
Sorghum For Grain	10,705	9,902	803
Wheat "All"	62,978	58,255	4,723
Corn For Grain	1,008,574	958,145	50,429
Soybeans	570,757	542,219	28,538

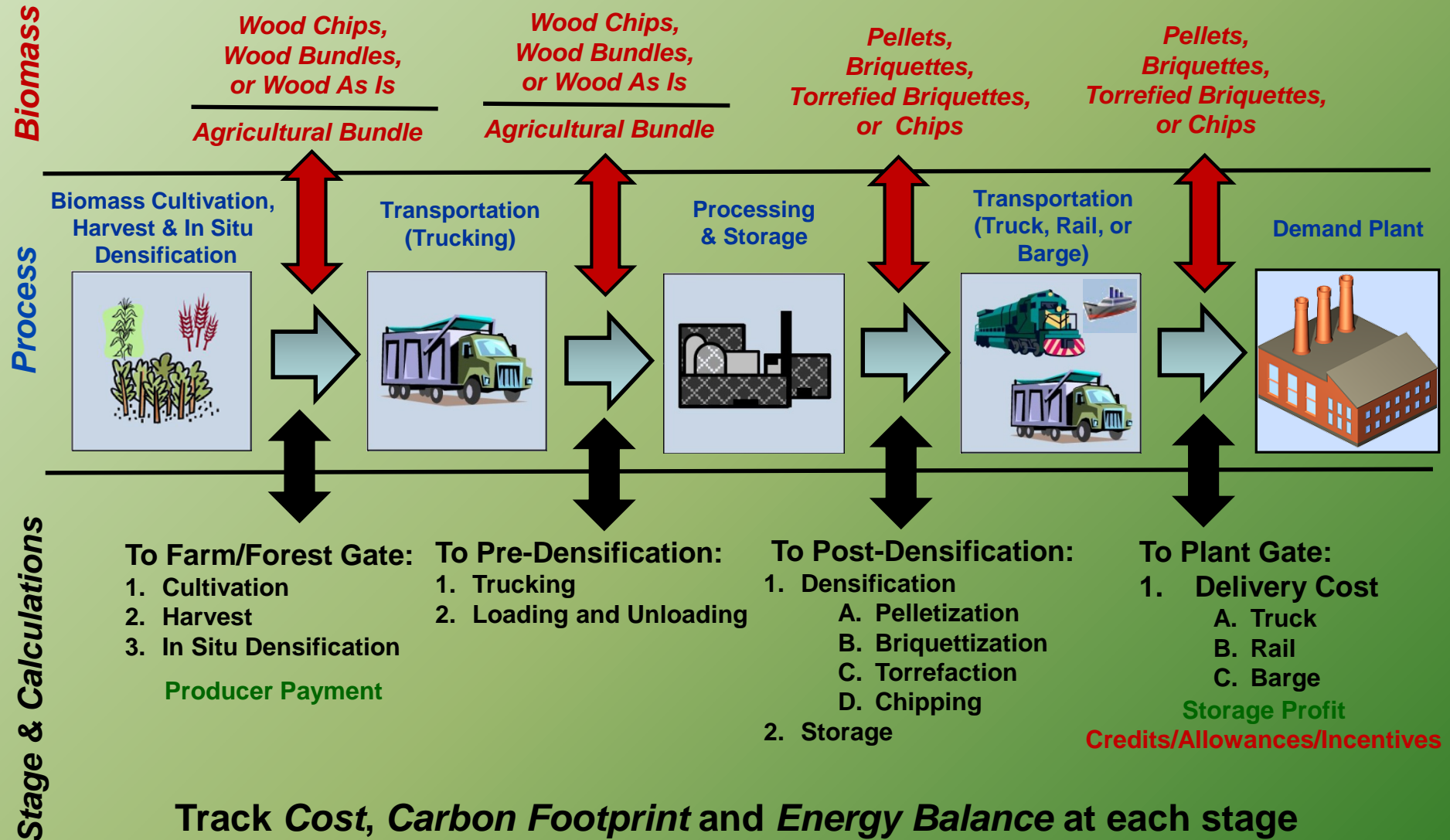


FEMP Sites Scenario

20 Federal Facilities looking to heat/fuel with biomass



Biomass Process Flow



(2008). "Icon Easy: Easy Free Download High Quality Icons." Retrieved June 11, 2010, from <http://www.iconey.com/>. (2009). Affordable, Low-Carbon Diesel Fuel Domestic Coal and Biomass. <http://www.usde.net/>. Affordable, Low-Carbon Diesel Fuel Domestic Coal and Biomass. USDE/NETL.

Processing In Situ (Farm Gate)

- **Agriculture residues – function of type**
 - Bale/bundle grassy residue
 - Bale/bundle other types of residue
- **Woody residues:**
 - Option 1: chip and/or grind
 - Increases density
 - Facilitates transportation
 - Speeds decomposition
 - Option 2: bale/bundle
 - Increases density
 - Retards decomposition
 - Option 3: haul as is

Pre/Post Densification Transportation Options

- **All pre-densification transport is performed by truck**
- **Choice of In Situ Densification**
- **Trucking capacity is volume-limited**
 - Increases the tonnes per truck load
 - Affects the outcome for cost, carbon footprint and energy efficiency for transport
- **Preprocess: chip/grind and drying—biomass needs to be < ¼ inch for different processes:**
 - Option 1: pelletize
 - Compress biomass into small pellets
 - Option 2: briquette
 - Compress biomass into large pellets
 - Option 3: torrefaction
 - Pyrolysis of biomass to create char
 - Add binding agent (starch) to char and create a pellet or briquette

Biomass Energy Balance and Carbon Footprint

Process Flow

Activity		Energy Balance	Carbon Footprint	Energy Balance	Carbon Footprint
		MBtu / tonne	kg CO2 / tonne	MBtu / tonne / mile	kg CO2 / tonne / mile
Farm Gate	Wood Bundler	38.60	2.99		
	Wood Chipper - Small	79.50	6.15		
	Wood Chipper - Large	13.00	1.04		
	Wood As is	0.00	0.00		
	Ag Bundler - Gen	52.90	4.09		
	Ag Bundler - Grassy	73.40	5.68		
Pre-Densification	Trucking Cost Description	Loading & Unloading		Truck	
	Wood Bundle	30.60	2.37	1.18	0.09
	Wood Chips	-	-	1.18	0.09
	Wood As Is	30.60	2.37	3.65	0.28
	Ag Bundle	30.60	2.37	1.49	0.12
Post-Densification	Pelletization with Chipper	3,800	358		
	Briquetization with Chipper	3,780	357		
	Torrefacation with Chipper	1,220	133		
	Pelletization	3,780	357		
	Briquetization	3,760	355		
	Torrefacation	1,200	132		
	Storage	30.60	2.37		

Biomass Costs

Process Flow

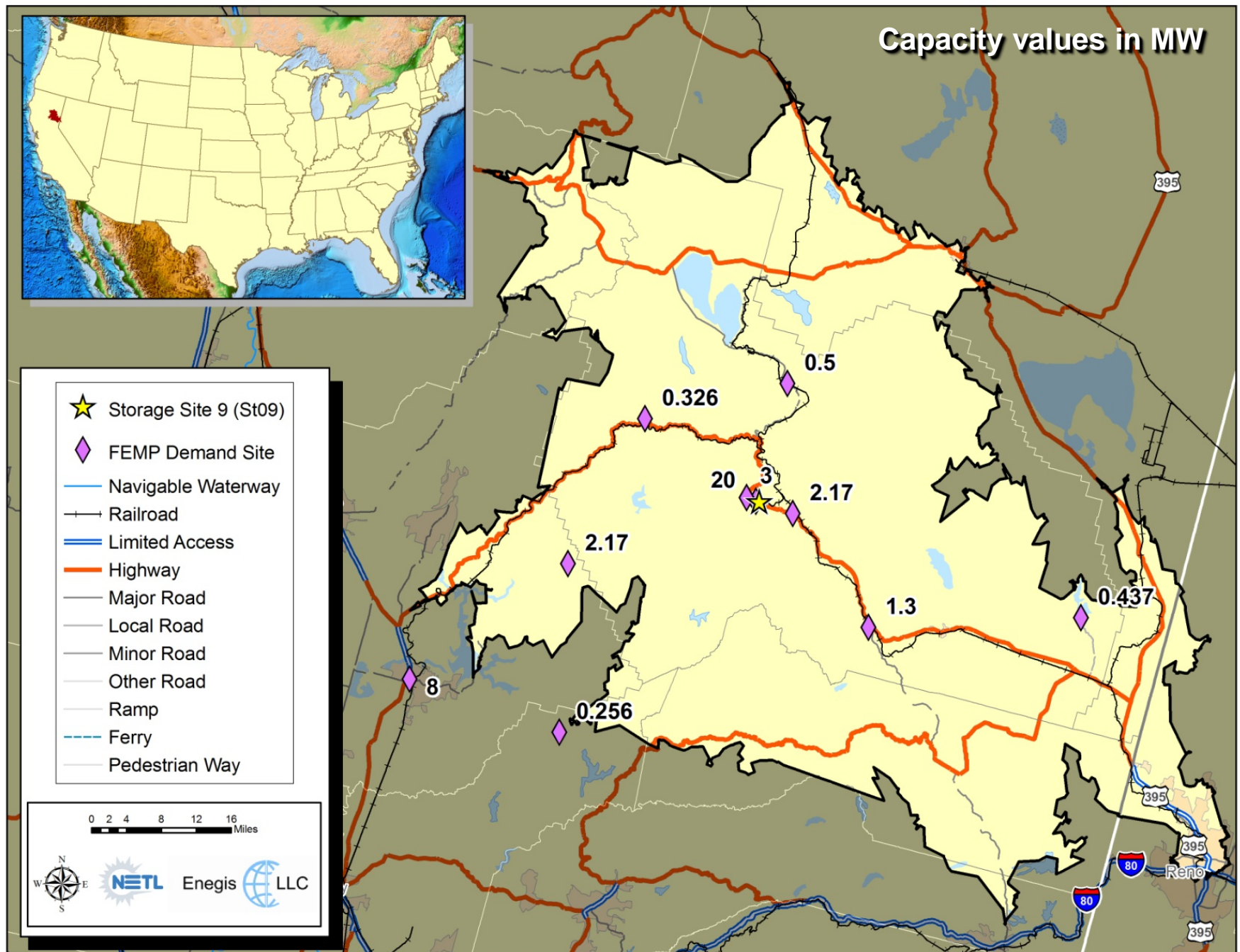


Activity		\$/tonne		\$/tonne/hour		\$/tonne/mile
		CAPEX	OPEX	CAPEX	OPEX	OPEX
Farm Gate	Wood Bundler	0.89	13.78			
	Wood Chipper - Small	0.51	10.38			
	Wood Chipper - Large	0.08	0.64			
	Wood As is	0.00	0.00			
	Ag Bundler - Gen	1.64	8.6			
	Ag Bundler - Grassy	3.03	5.89			
Pre-Densification	Trucking Cost Description	Loading & Unloading		Truck	Labor	Fuel, Insurance, etc.
	Wood Bundle	0.73	1.52	0.45	0.83	0.05
	Wood Chips	-	0.31	0.45	0.83	0.05
	Wood As Is	2.25	4.69	1.39	2.55	0.16
	Ag Bundle	0.92	1.92	0.57	1.04	0.07
Post-Densification	Pelletization with Chipper	12.31	36.16			
	Briquettization with Chipper	16.40	32.71			
	Torrefacation with Chipper	13.86	39.61			
	Pelletization	11.71	32.71			
	Briquettization	15.80	29.27			
	Torrefacation	13.27	36.16			
	Storage	6.91	2.20			

Storage Site 9, California

Ranger Stations,
Post Offices, etc

<1 to 8MW capacity

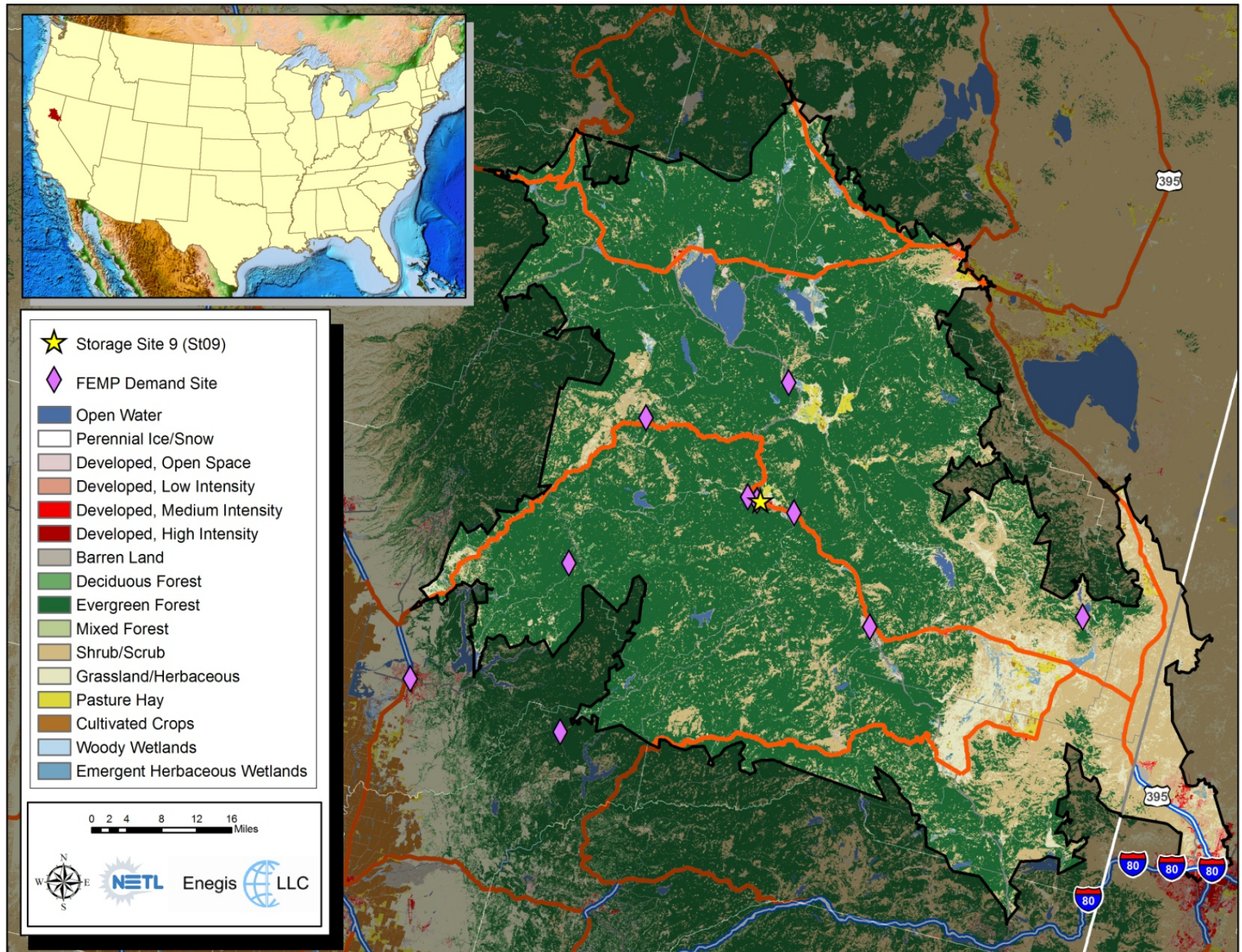


Storage Site 9, California

Ranger Stations, Post
Offices, etc

<1 to 8MW capacity

Dominated by forest
with some agriculture



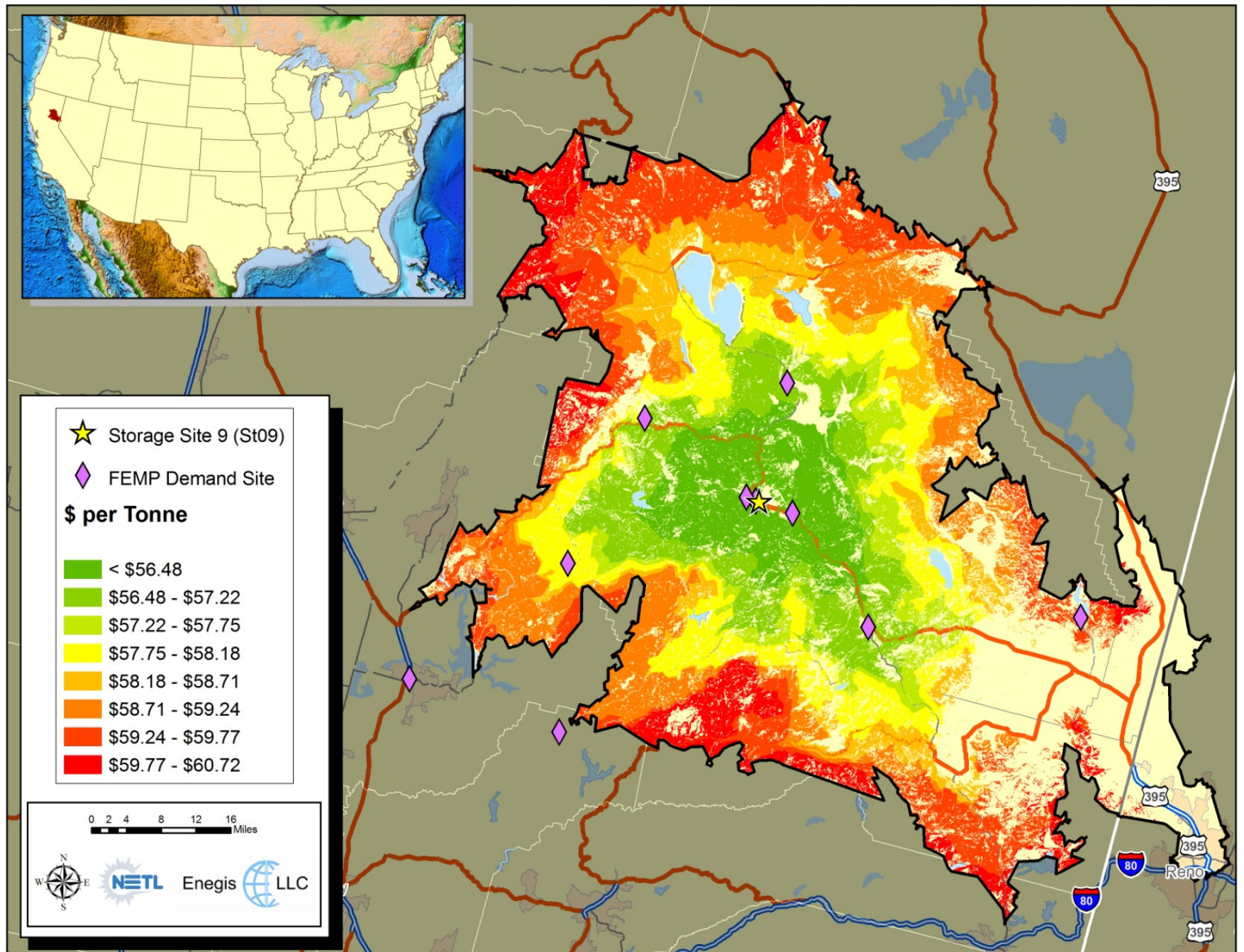
Storage Site 9, California

Ranger Stations, Post
Offices, etc

<1 to 8MW capacity

Dominated by forest
with some agriculture

Scenario Parameters:
Large chippers in field
Truck transport
Pellet Factory



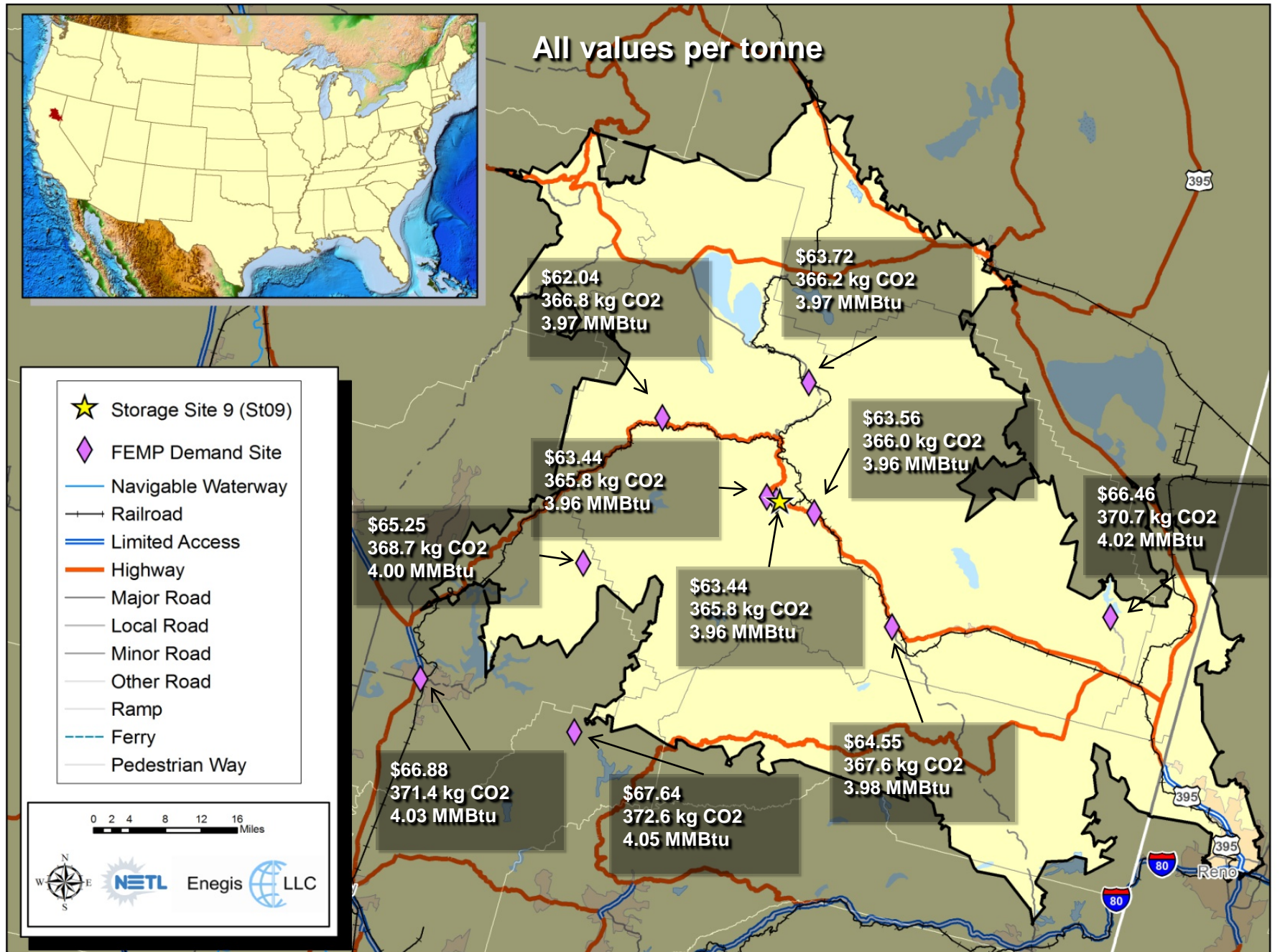
Storage Site 9, California

Ranger Stations, Post
Offices, etc

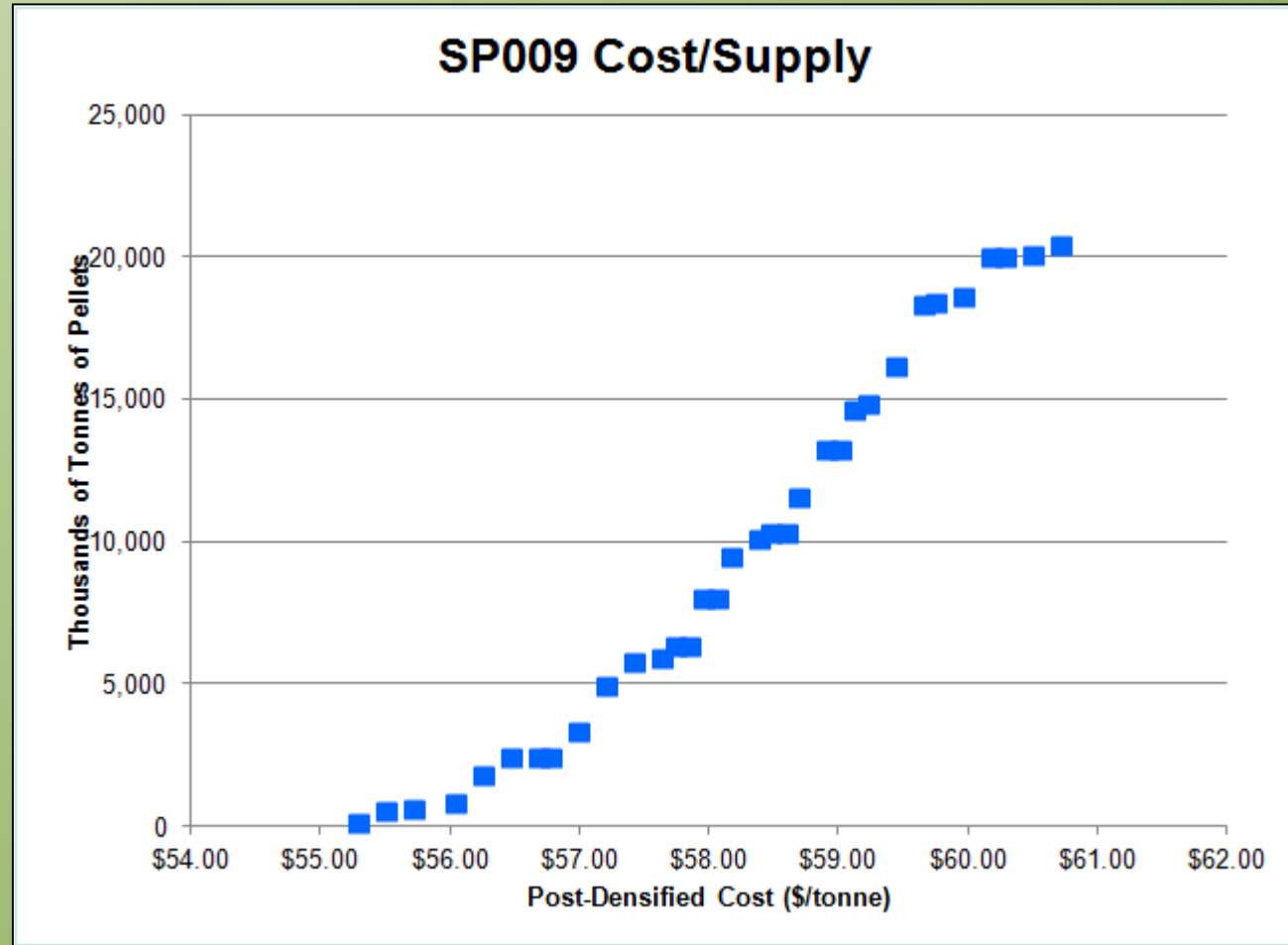
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Cost-Supply Curve



About Enegis

- **Small business, located in Fairfax, VA**
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