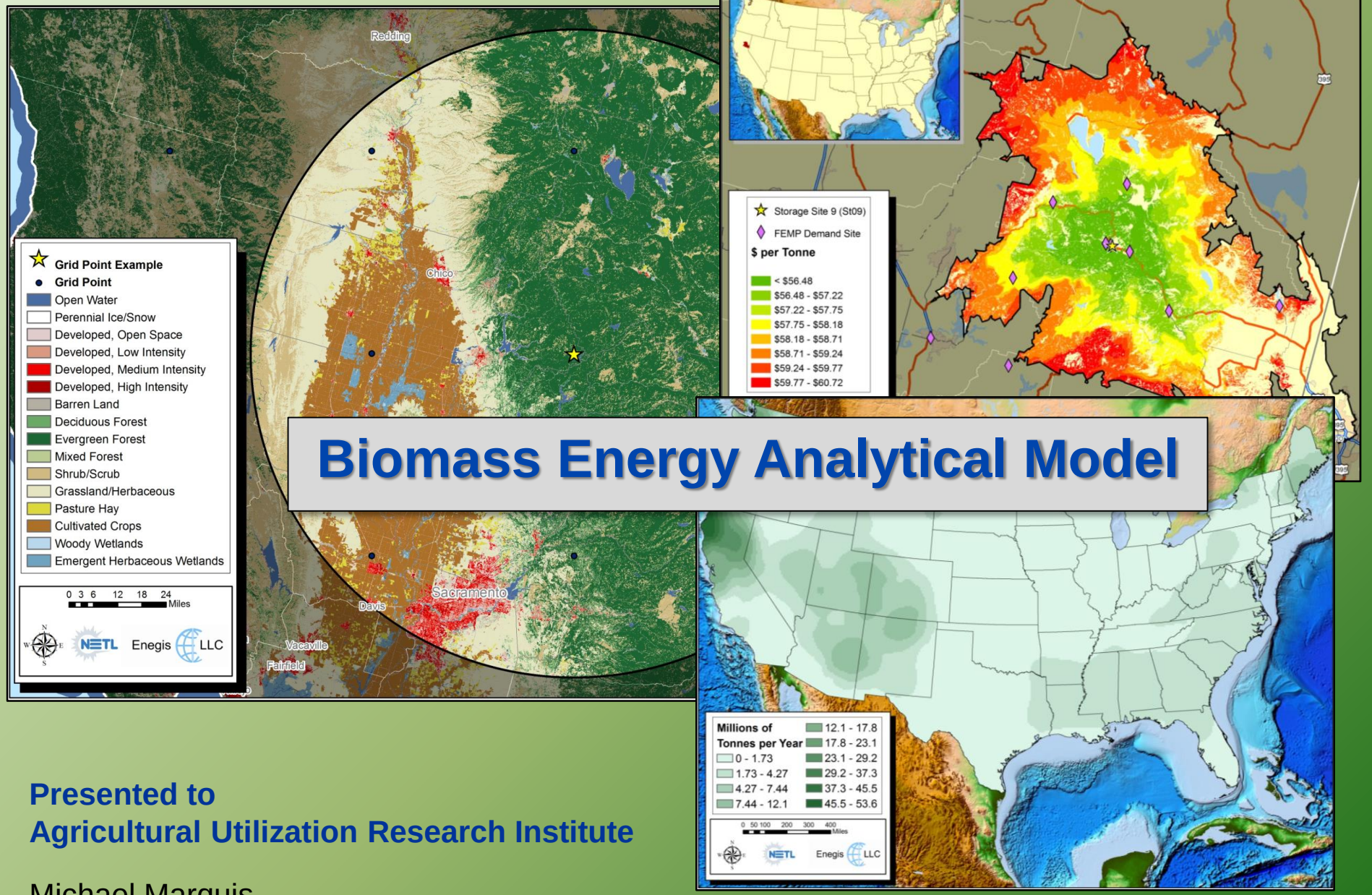


Biomass Energy Analytical Model

Presented to
Agricultural Utilization Research Institute

Michael Marquis
Enegis, LLC

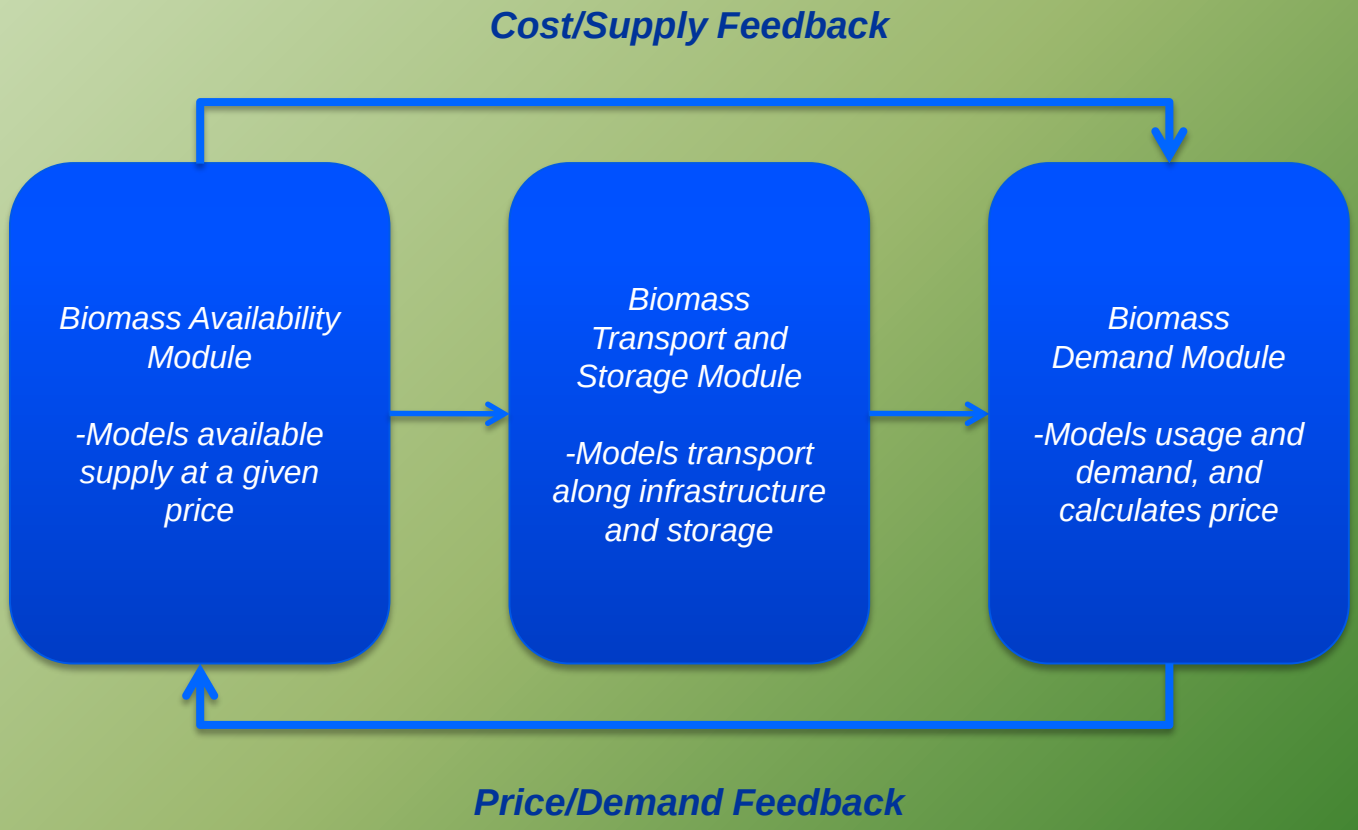
Enegis LLC

BEAM - Goals

- **BEAM was created to 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



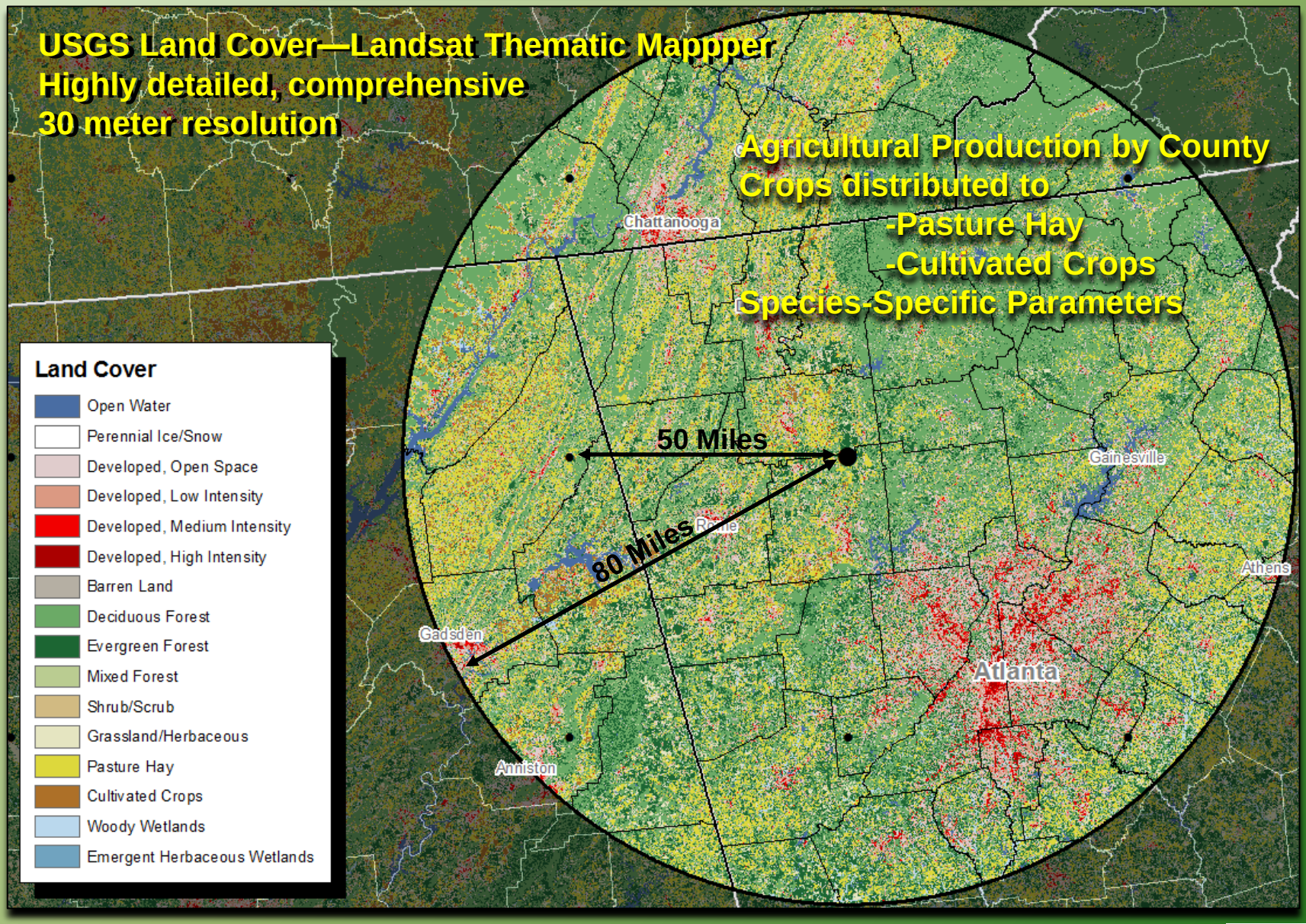
Species-Specific Parameters

~60 Species/Commodities Incorporated

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

Crop Residues



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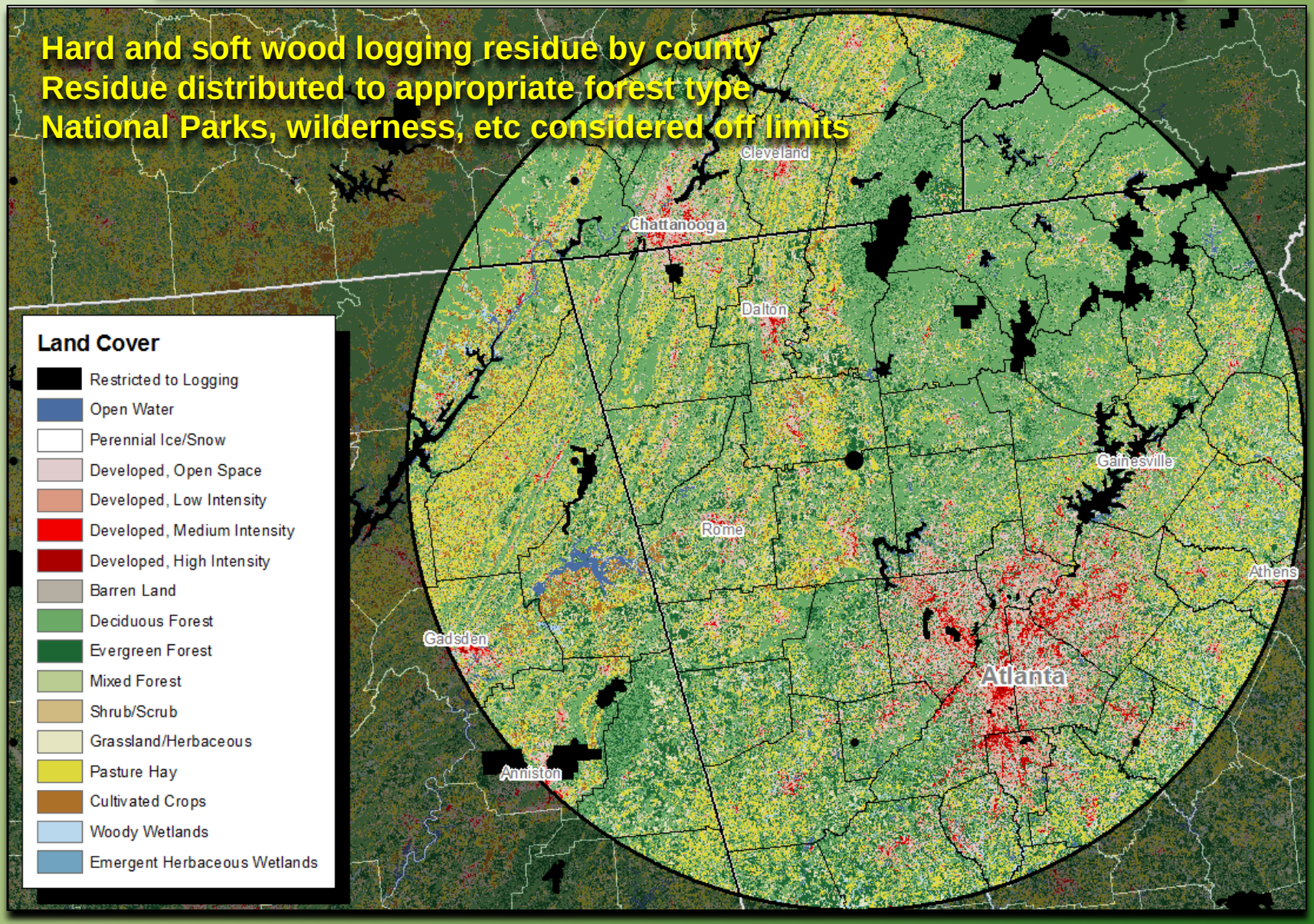
Distributed Woody Residues



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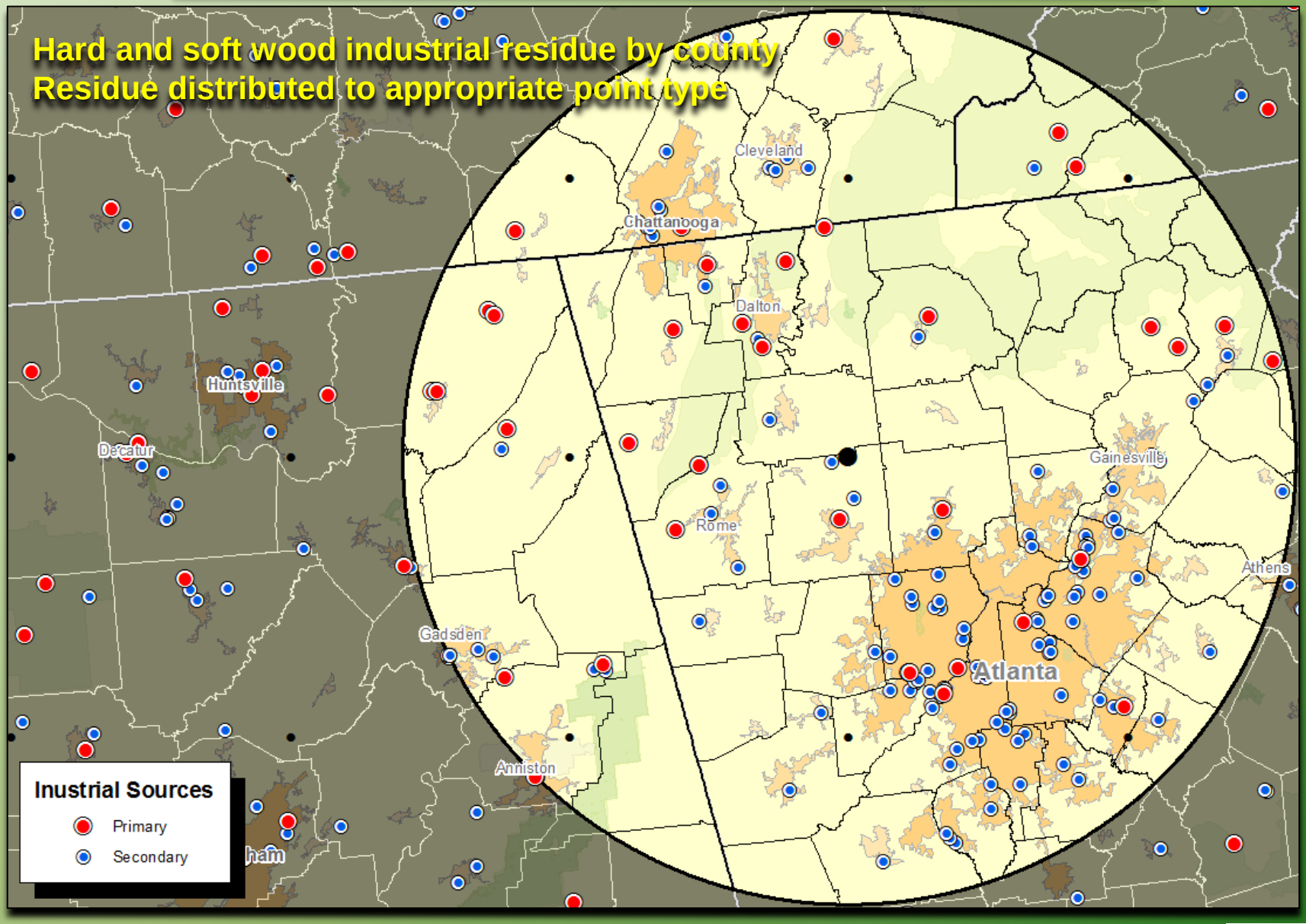
Industrial Wood Residues



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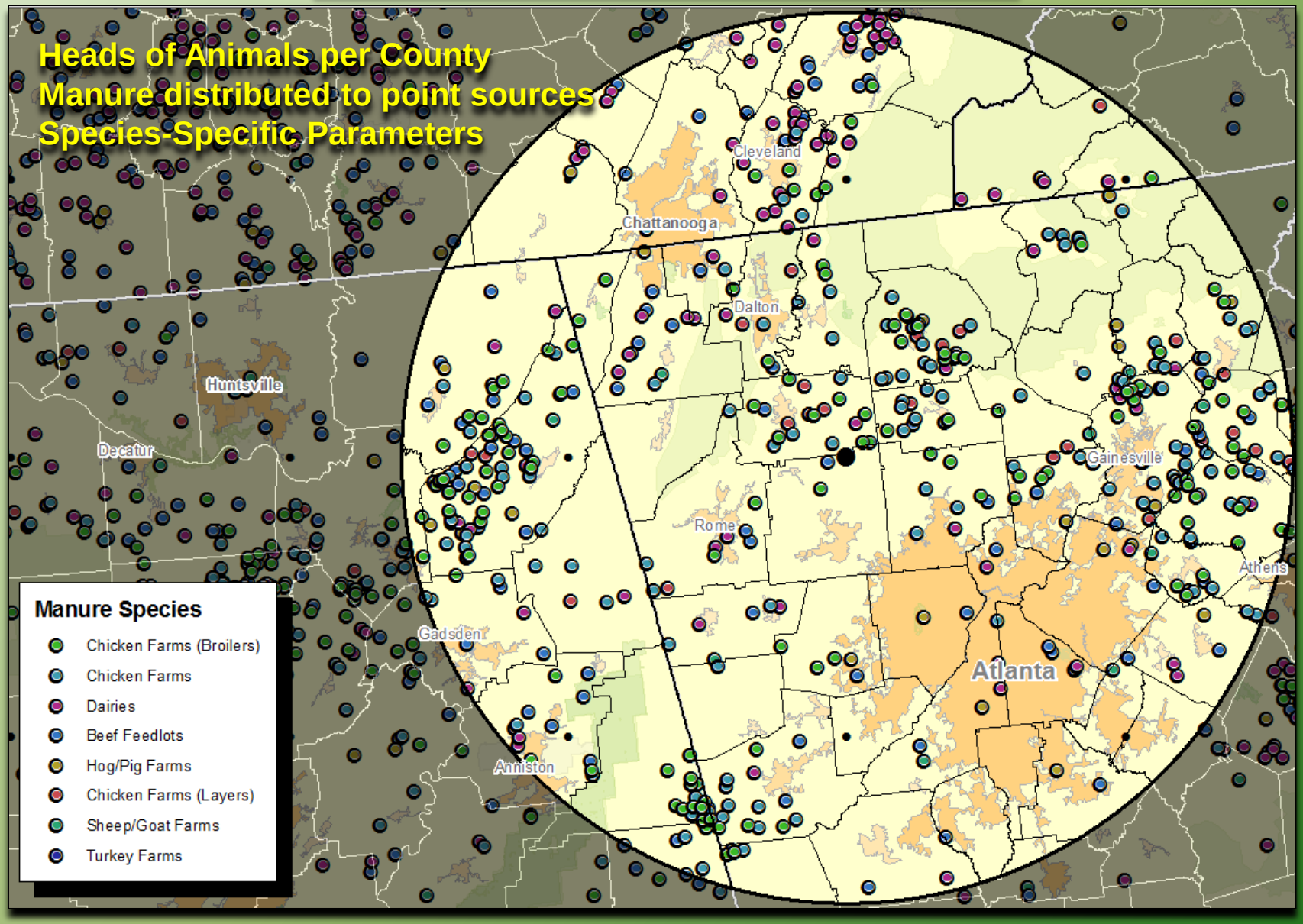
Manure Residues



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Biomass Availability Module

- Purpose: assess supply, availability, and storage options
- Quantifies and classifies total biomass able to be collected to a point within a given harvesting radius
  - Species-specific harvesting and collection parameters
  - Individual species data are carried throughout the model
  - Species are tallied on Btu-equivalent basis
  - Production can be temporally constrained (seasonal or quarterly)
- Grid BAM
  - For regional and national level storage site (St) placement
  - Examines a grid of the potential St (50-mile spacing for US – 1204 points)
  - “Collects” biomass within a given economic limit (– 80 miles)
- Storage/Processing Site BAM (Rosettes)
  - Quantifies detailed biomass availability for St
  - Models specific biomass processing facilities
  - Used in specific scenarios to model biomass availability to a discrete St
  - Uses actual time/distance transportation radius based on roads
  - Creates Cost/Supply Curves

North Dakota Alliance for Renewable Energy, I. (2009). "Biomass." Retrieved June 8, 2010, from http://www.ndare.org/NDARE%20PDFs/NDARE-BIOMASS%20Final.pdf.
(2004). Wood Biomass for Energy. TechLine. Forest Products Laboratory.

Species-Specific Parameters

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	
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	
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	
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	
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	
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	
Fine Wood Residue - Hardwood	17.2	16.0	1.5			8.0	-	-		50.8	0.0	
Fine Wood Residue - Softv										49.3	0.0	
Urban Wood Waste - Tree										51.1	0.0	

Biomass Residue Conversions

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

Seasonality Parameters

Species:	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
Wheat Durum	-	-	-	-	-	-	25	50	25	-	-	-	100
Flaxseed	-	-	-	-	-	-	50	50	-	-	-	-	100
Peanuts for Nuts	-	-	-	-	-	-	-	-	25	50	25	-	100
Potatoes All	-	-	-	-	-	-	-	-	25	50	25	-	100
Hay Other (Dry)	-	-	-	-	10	20	30	20	10	10	-	-	100
Oats - (Fall)	-	-	-	-	-	-	25	50	25	-	-	-	100
Rye	-	-	-	-	25	50	25	-	-	-	-	-	100
Safflower	-	-	-	-	-	-	-	50	50	-	-	-	100
Soybeans	-	-	-	-	-	-	-	10	10	30	30	20	100
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

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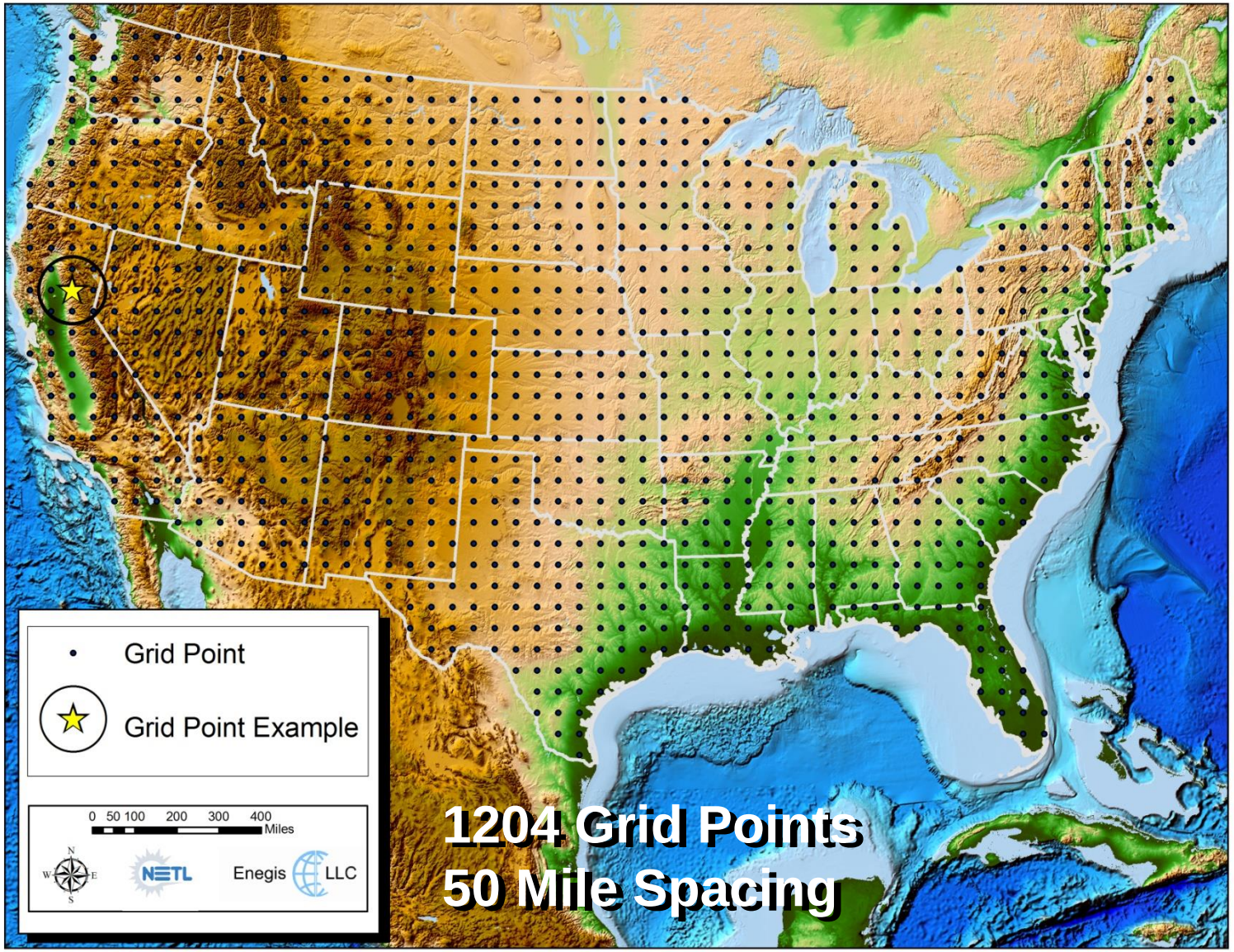
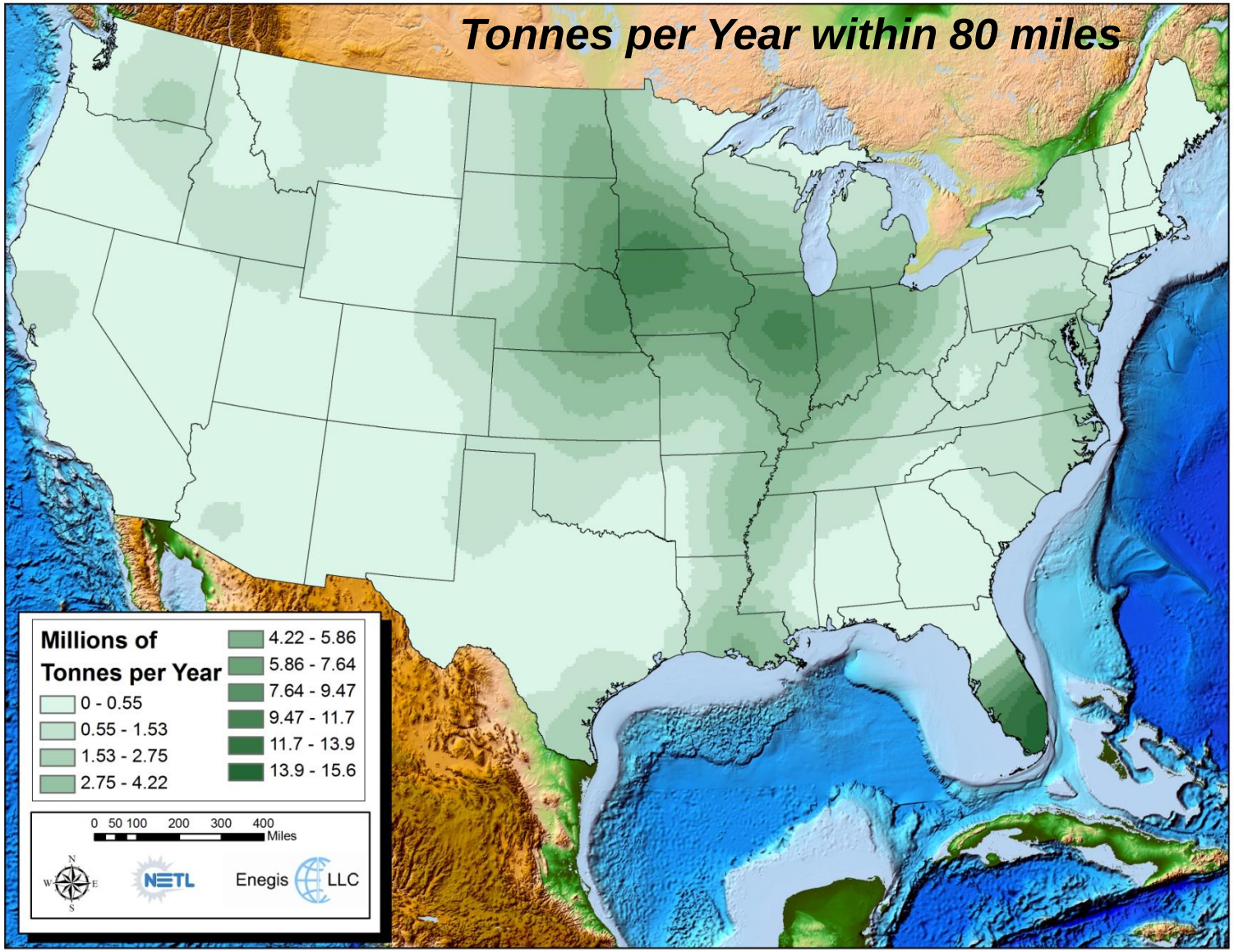
Grid BAM Scenario Examples—Lower 48 Resource Availability

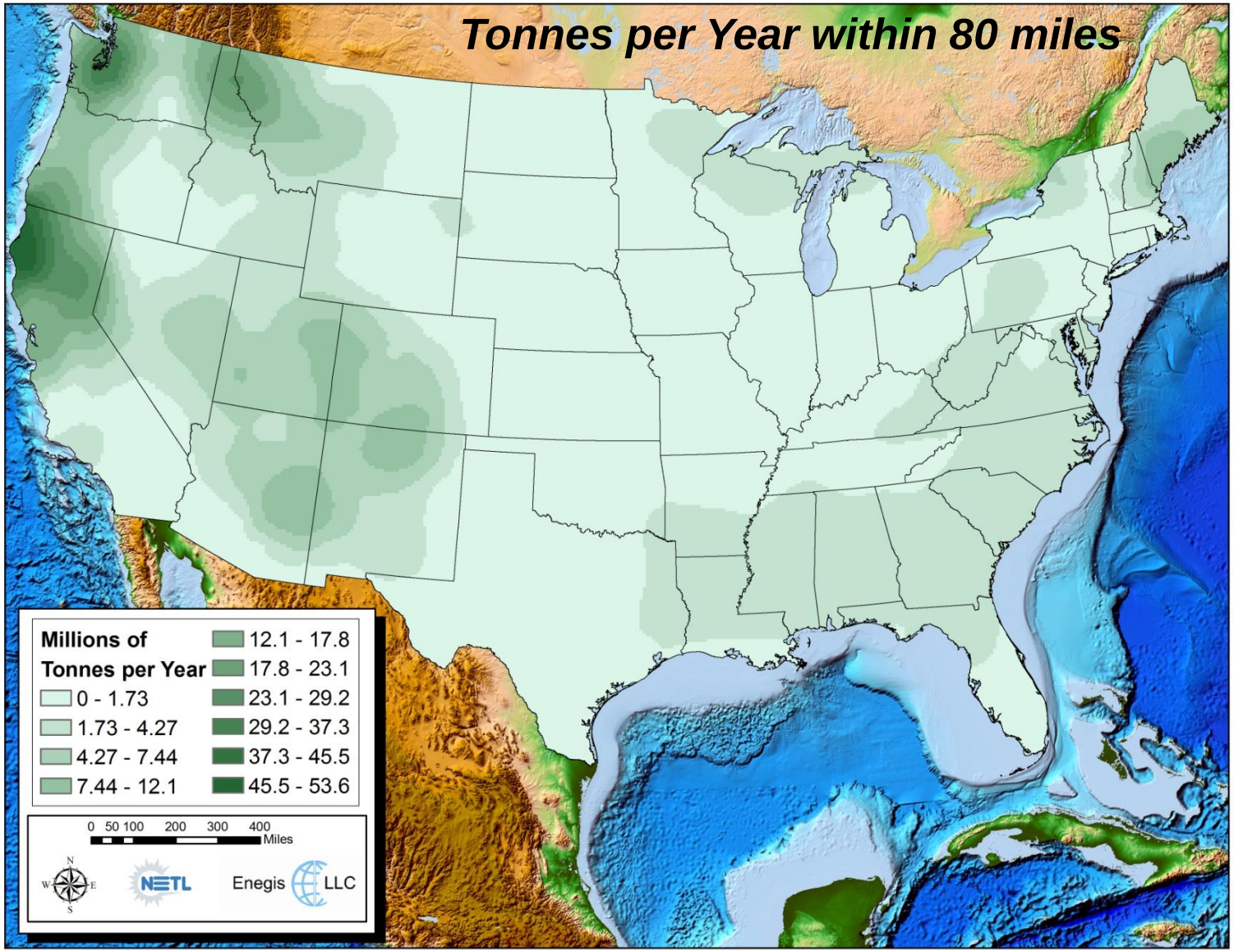
Lower 48 Biomass Availability Module



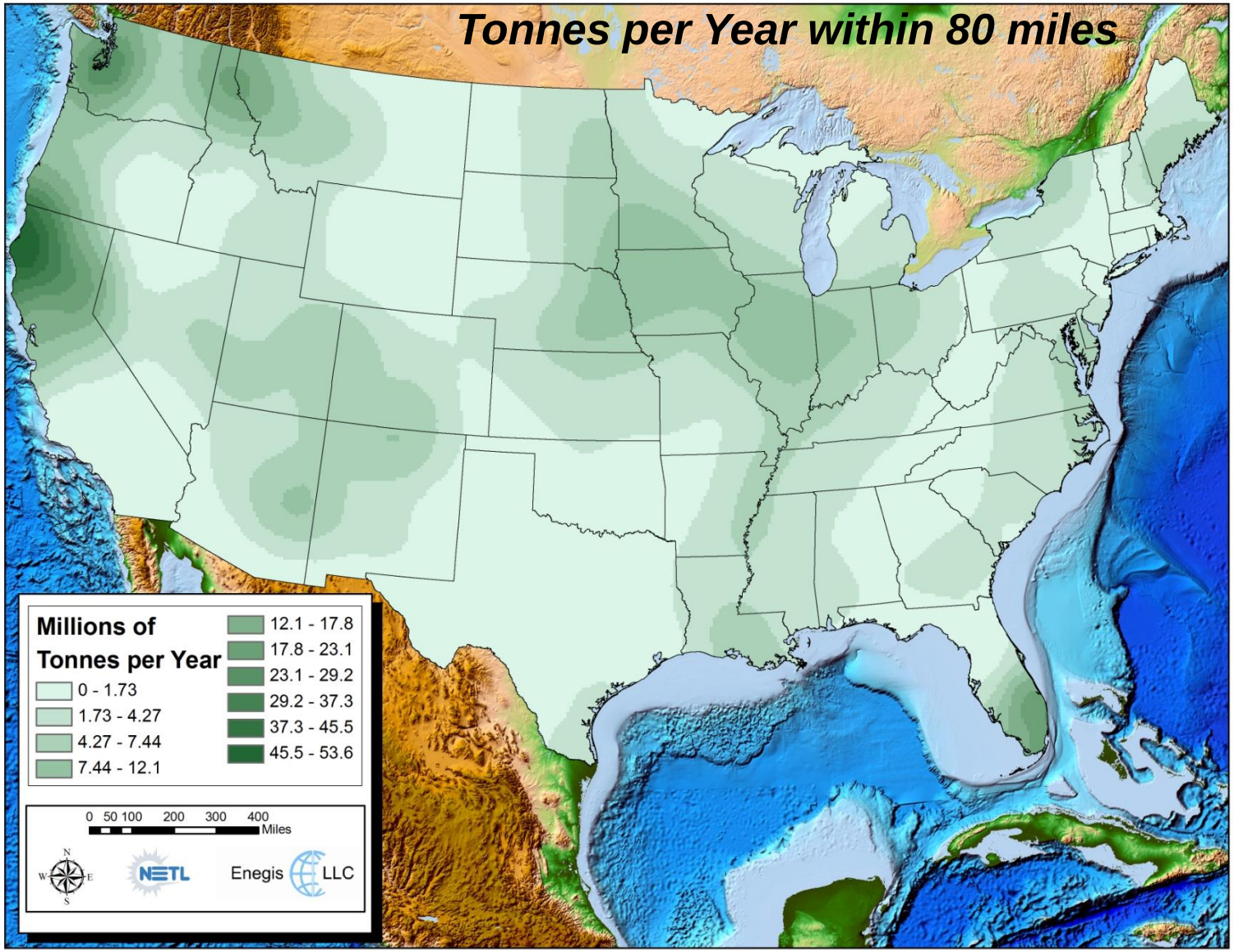
Agriculture Residues Results—All Species



Woody Residues Results—All Species



Agriculture and Woody Results—All Species

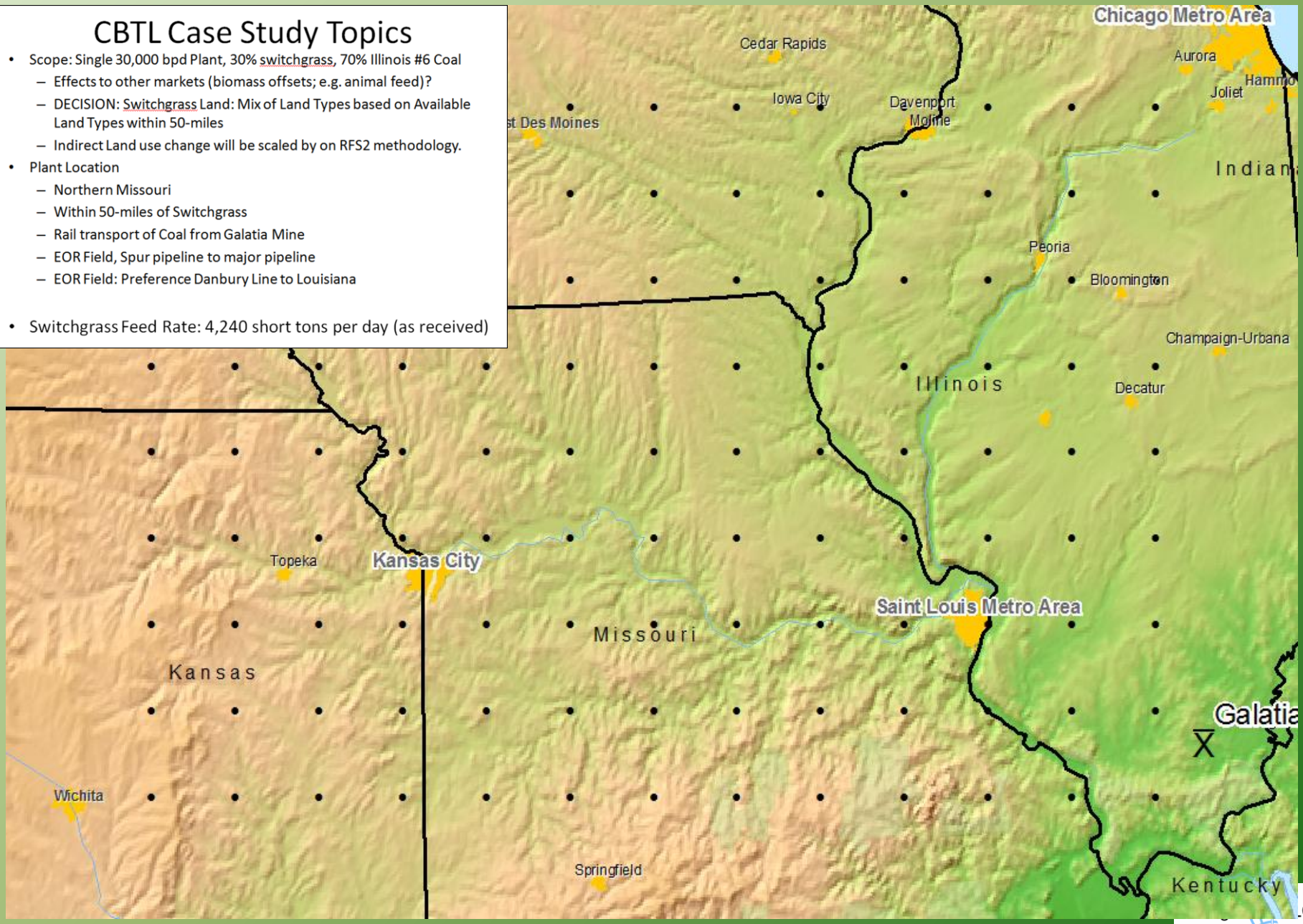


Grid BAM Scenario Examples—
Northern Missouri (NOMO)Switchgrass

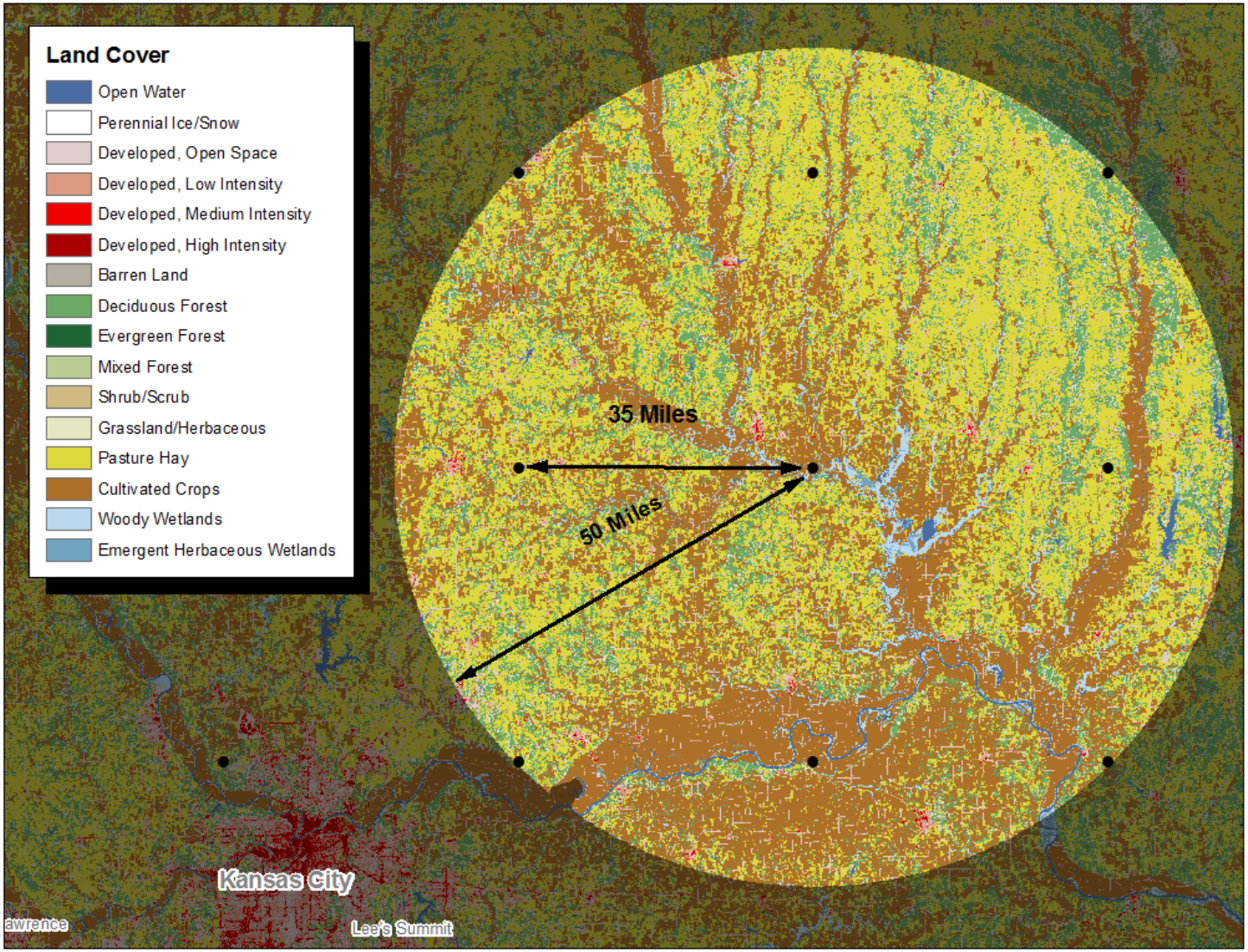
Northern Missouri Switchgrass Exercise

CBTL Case Study Topics

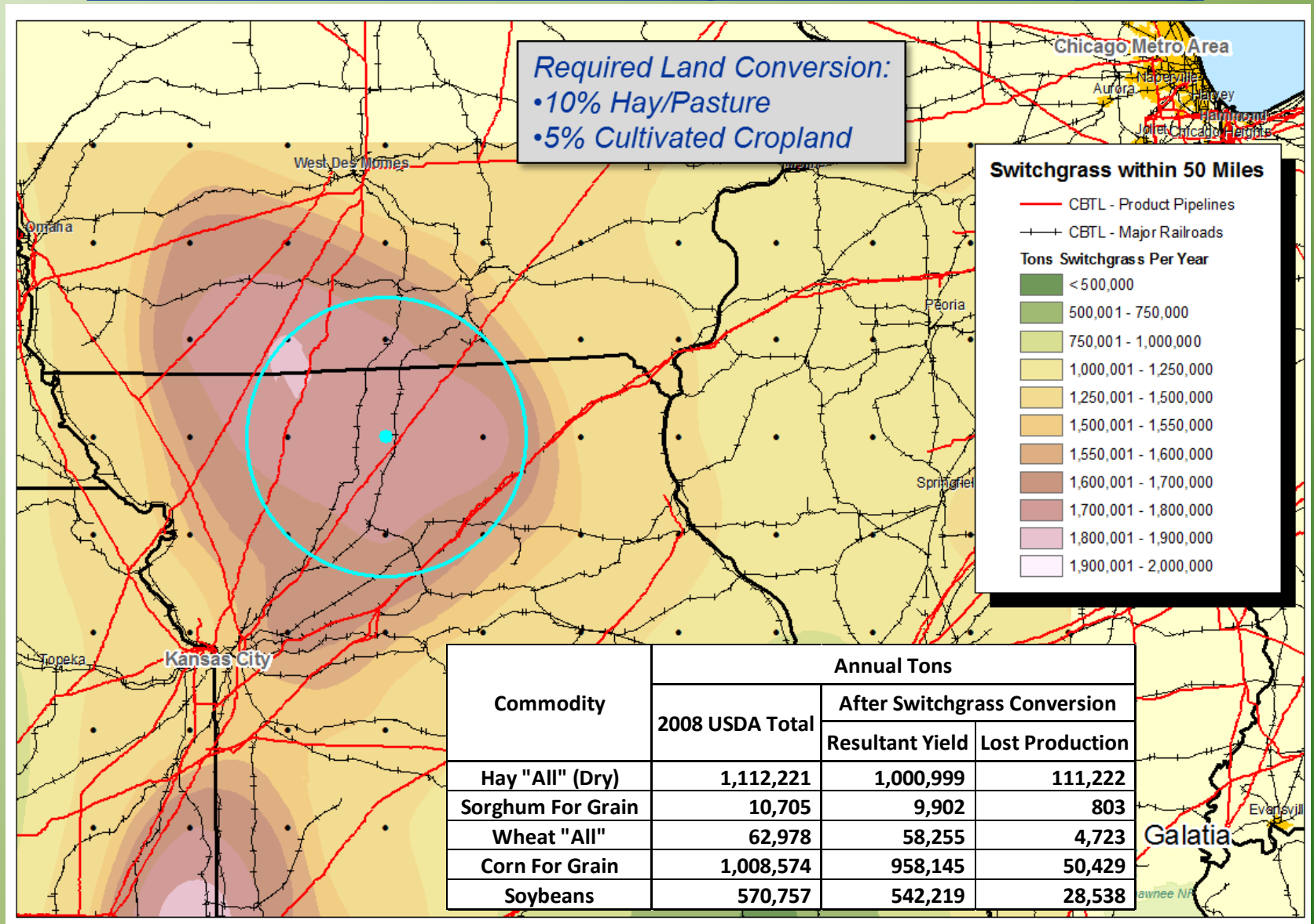
- Scope: Single 30,000 bpd Plant, 30% switchgrass, 70% Illinois #6 Coal
  - Effects to other markets (biomass offsets; e.g. animal feed)?
  - DECISION: Switchgrass Land: Mix of Land Types based on Available Land Types within 50-miles
  - Indirect Land use change will be scaled by on RFS2 methodology.
- 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 (cont)



Northern Missouri Switchgrass Exercise (cont)



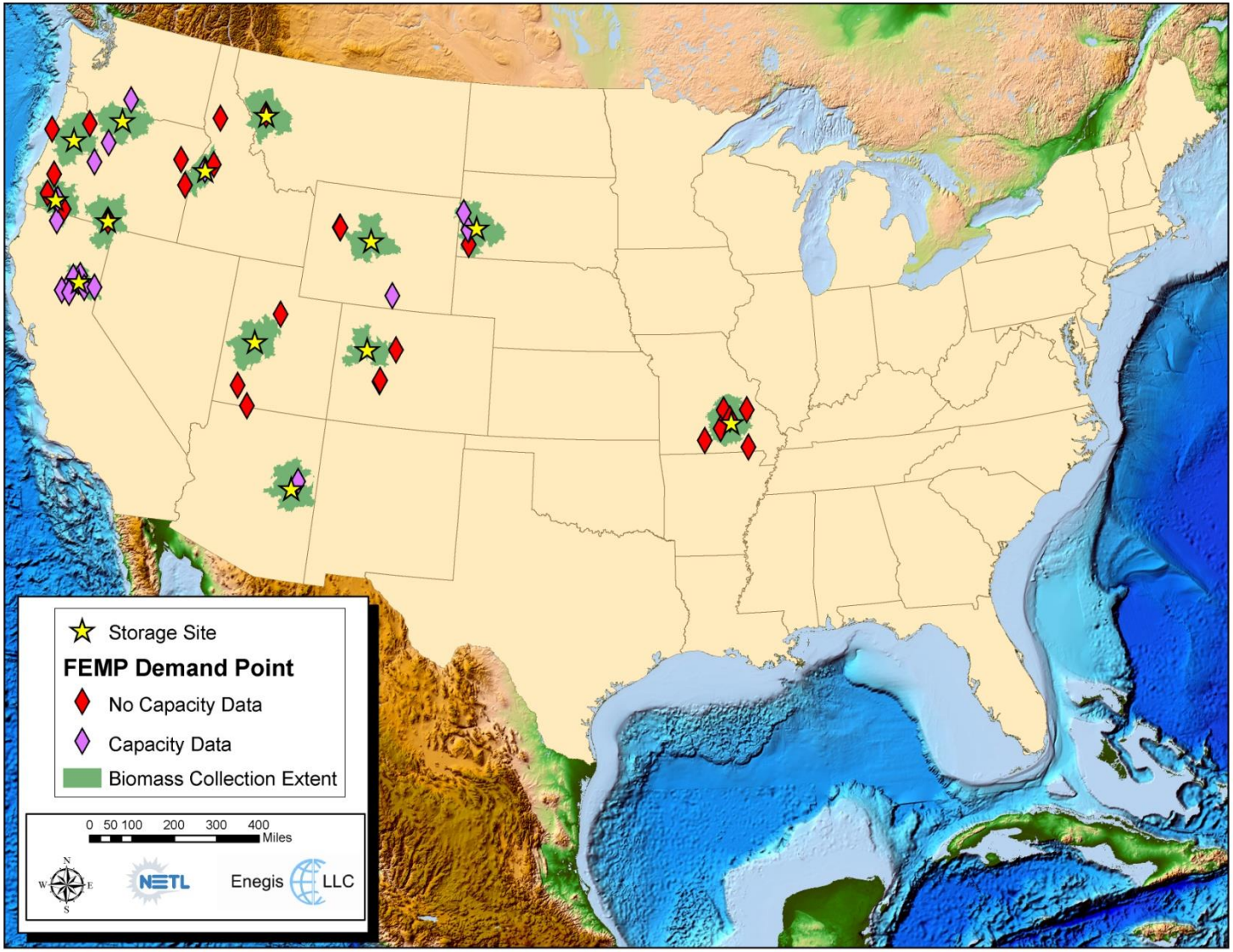
Commodity	Annual Tons		
	2008 USDA Total	After Switchgrass Conversion	
		Resultant Yield	Lost Production
Hay "All" (Dry)	1,112,221	1,000,999	111,222
Sorghum For Grain	10,705	9,902	803
Wheat "All"	62,978	58,255	4,723
Corn For Grain	1,008,574	958,145	50,429
Soybeans	570,757	542,219	28,538

Storage/Processing BAM Scenario Examples—*FEMP Sites Scenario Analysis*

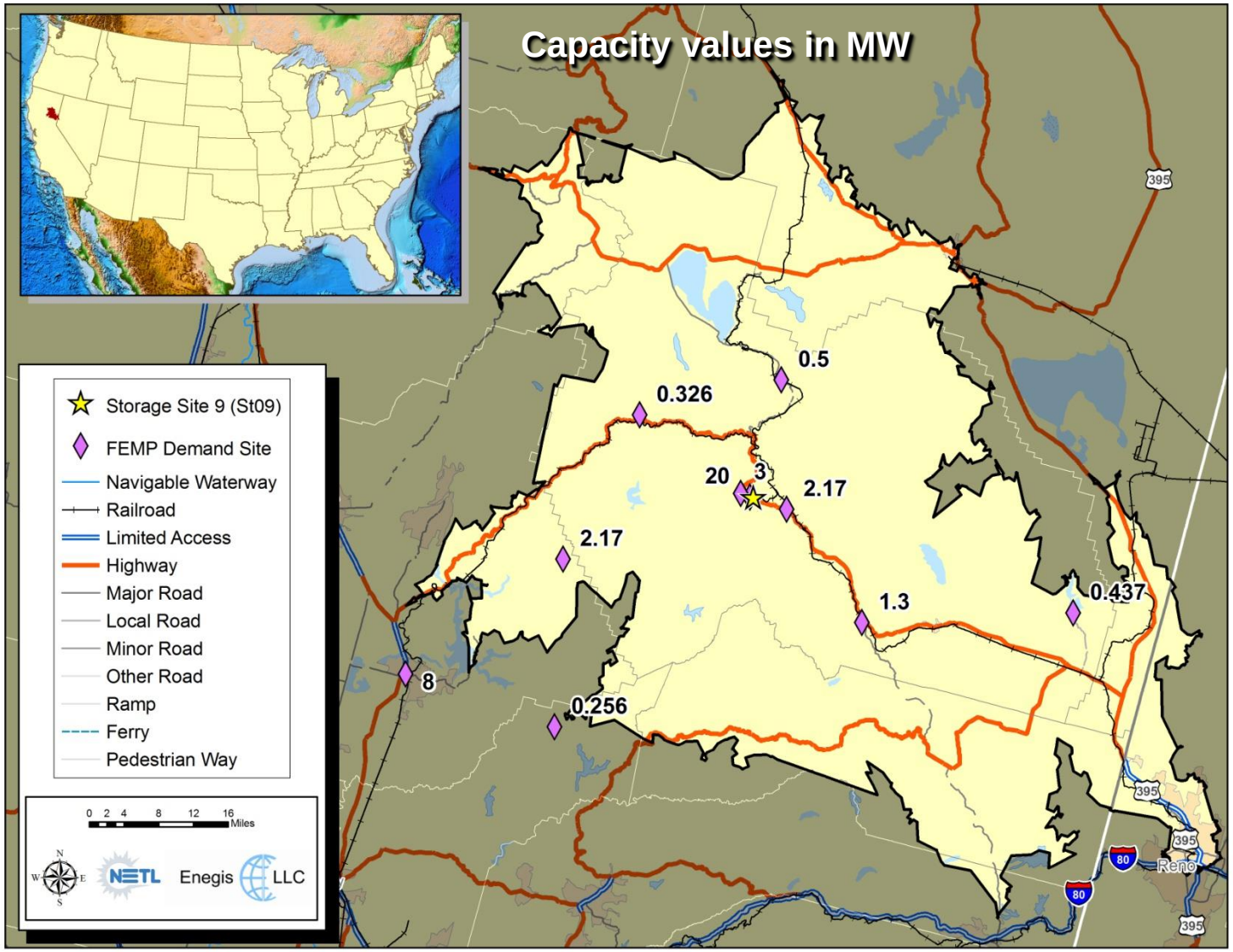
FEMP Sites Scenario Analysis

- **Approximately 50 sites**
  - In the western US
  - Ranging from combined heat and power plants to administration building heating
  - Demand is highly project-specific
- **Evaluate clusters of demand**
  - A central storage site feeds into surrounding FEMP demand sites

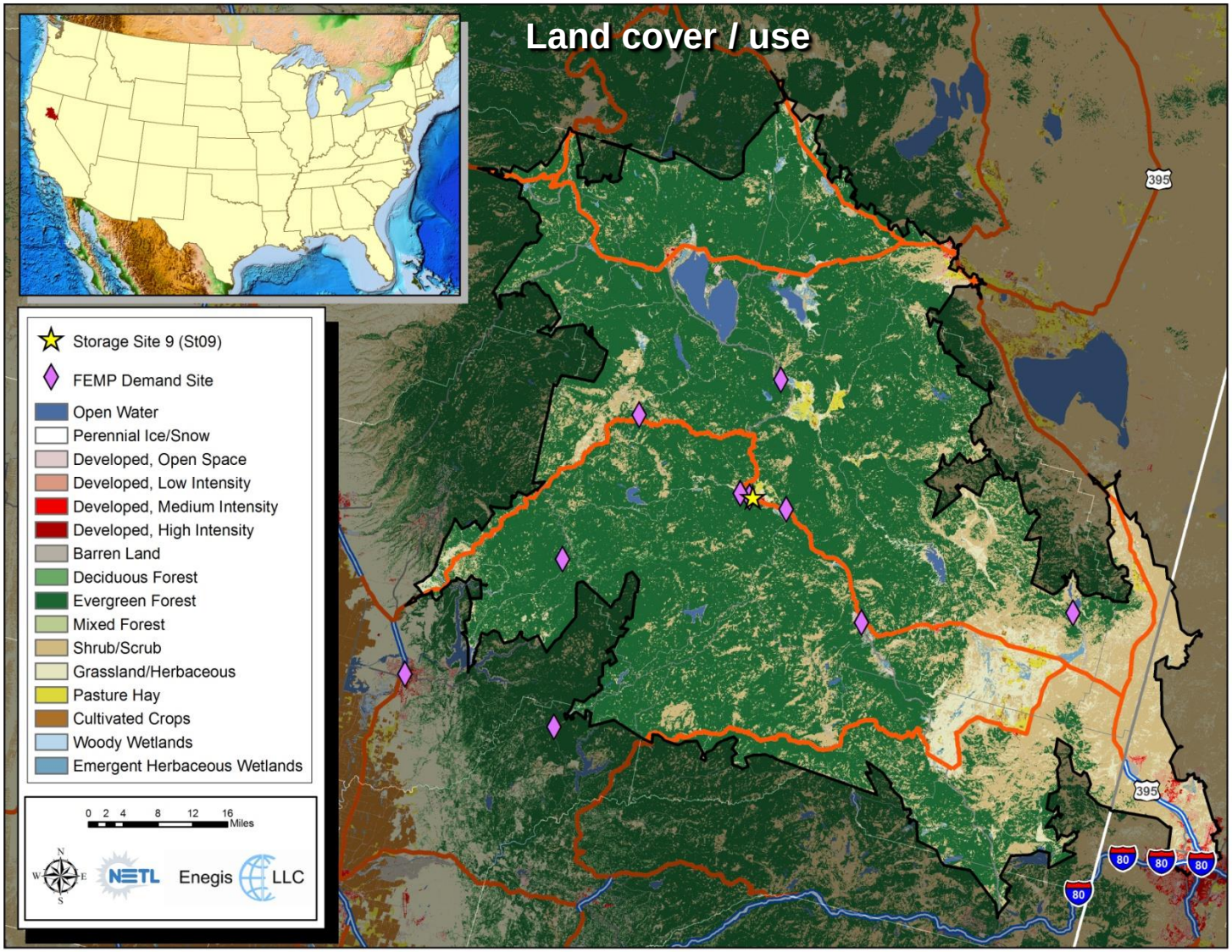
FEMP Sites Scenario



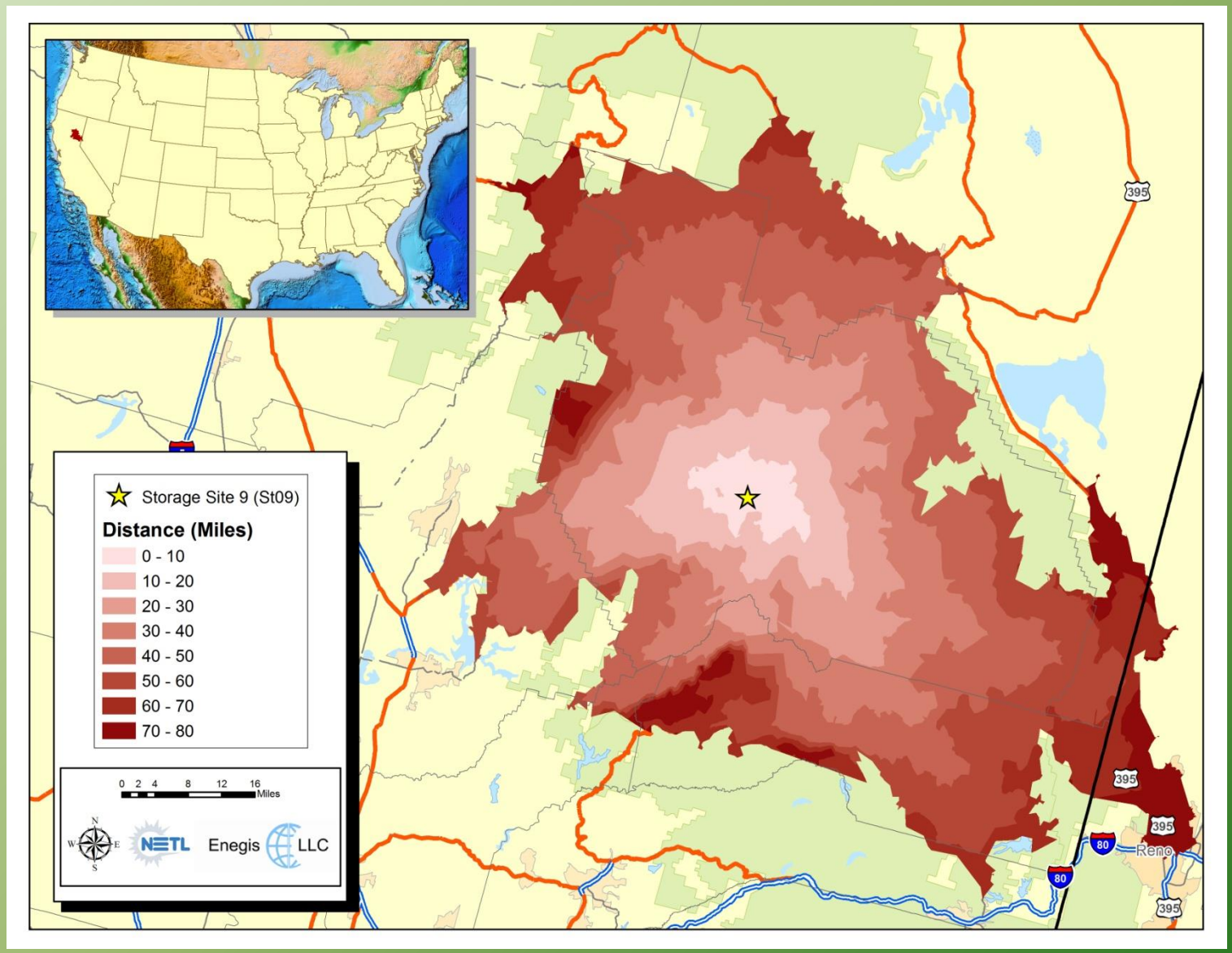
Storage Site 9, California



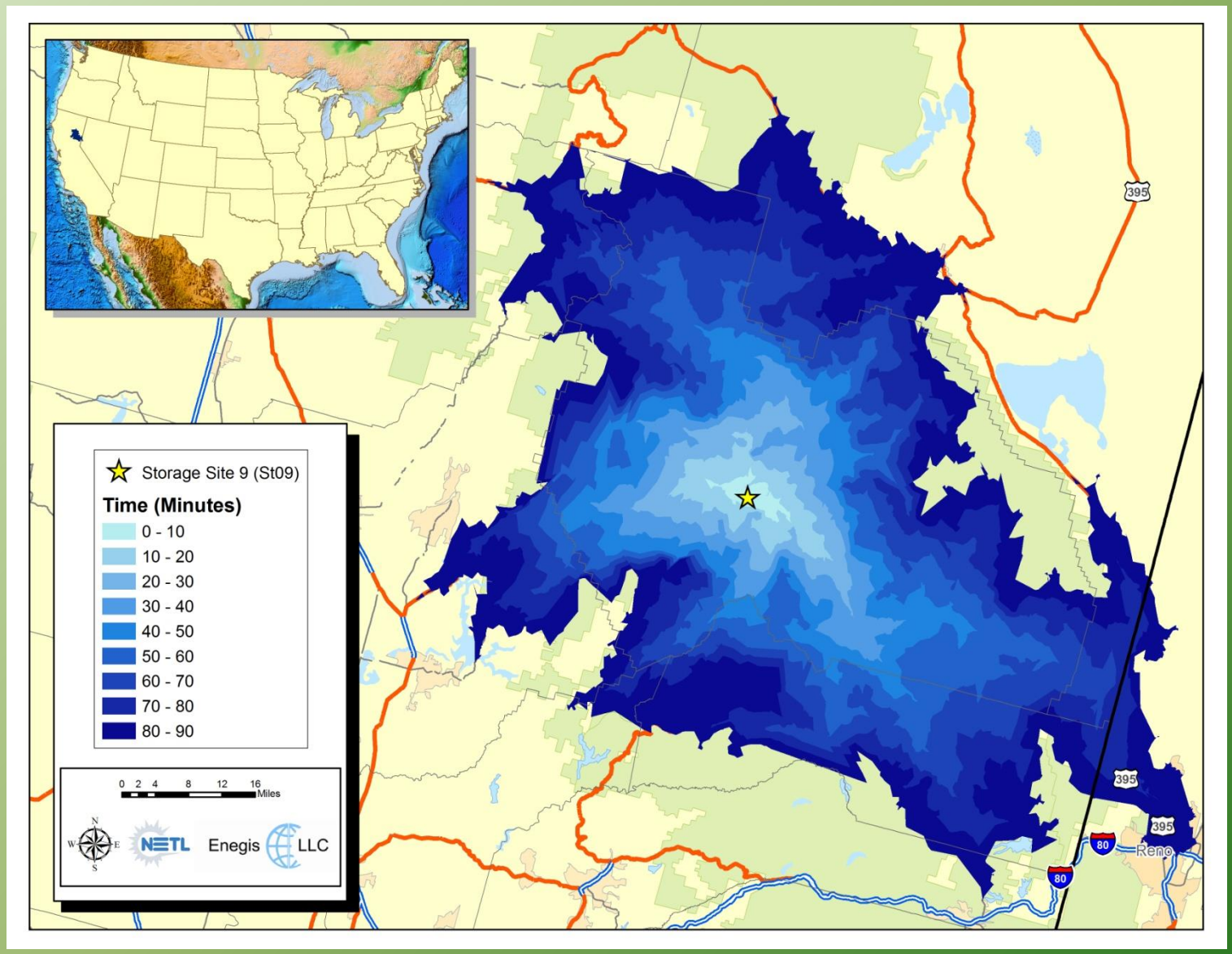
Storage Site 9, California



Storage Site 9, California



Storage Site 9, California



Biomass Process Flow

Biomass

Wood Chips, Wood Bundles, or Wood As Is / *Agricultural Bundle*

Wood Chips, Wood Bundles, or Wood As Is / *Agricultural Bundle*

Pellets, Briquettes, Torrefied Briquettes, or Chips

Pellets, Briquettes, Torrefied Briquettes, or Chips

Process

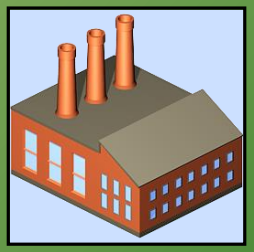
Biomass Cultivation, Harvest & In Situ Densification

Transportation (Trucking)

Processing & Storage

Transportation (Truck, Rail, or Barge)

Demand Plant



Stage & Calculations

To Farm/Forest Gate:
1. Cultivation
2. Harvest
3. In Situ Densification

Producer Payment

To Pre-Densification:
1. Trucking
2. Loading and Unloading

To Post-Densification:
1. Densification
   - A. Pelletization
   - B. Briquettization
   - C. Torrefaction
   - D. Chipping
2. Storage

To Plant Gate:
1. Delivery Cost
   - A. Truck
   - B. Rail
   - C. Barge

Storage Profit

Credits/Allowances/Incentives

Track *Cost*, *Carbon Footprint* and *Energy Balance* at each stage

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

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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

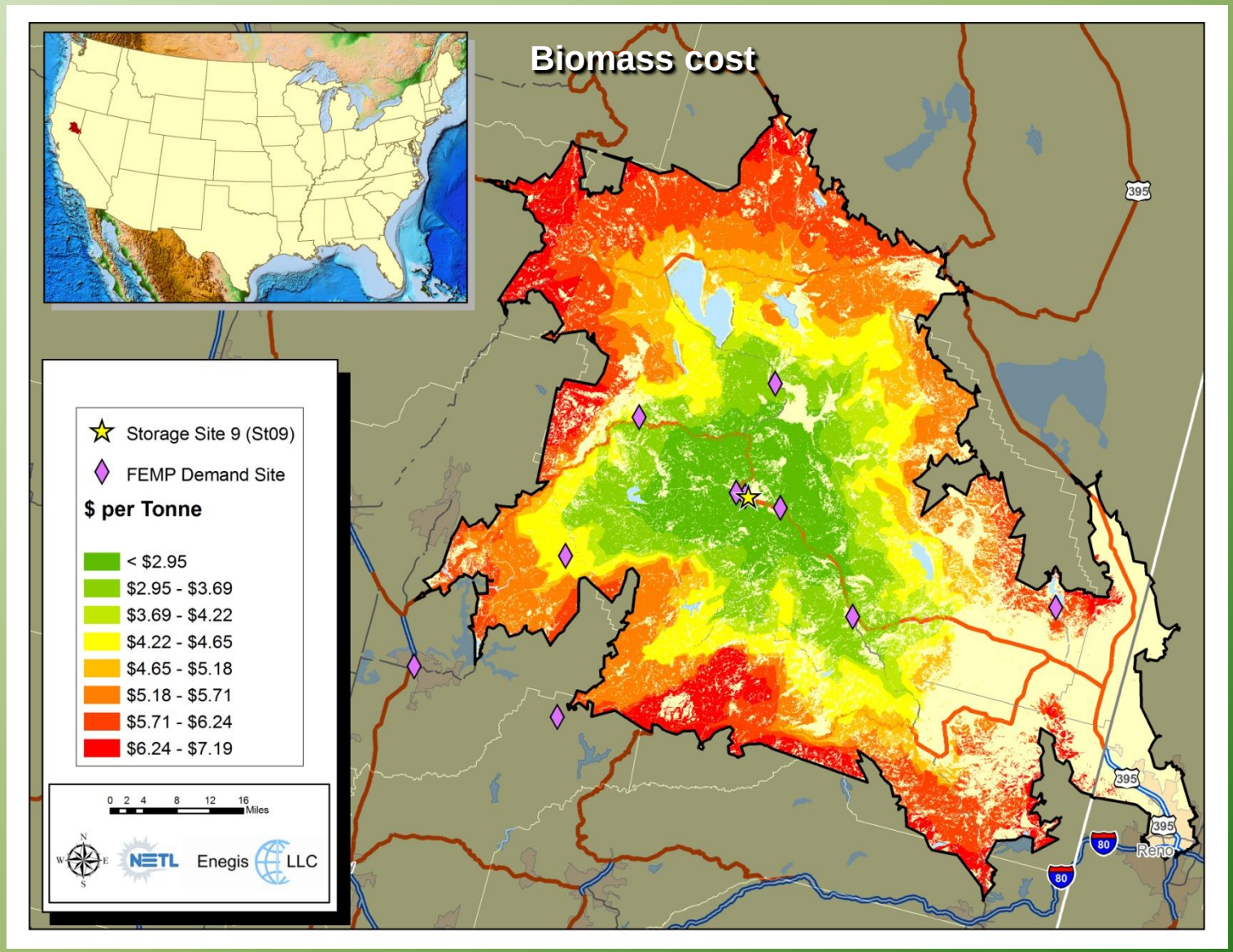
Activity		Energy Balance MBtu / tonne	Carbon Footprint kg CO2 / tonne	Energy Balance MBtu / tonne / mile	Carbon Footprint kg CO2 / tonne / mile
Farm Gate	Wood Bundler	38.60	2.99		
	Wood Chipper - Small	79.50	6.15		
	Wood Chipper - Large	13.00	1.04		
	Wood As is	0.00	0.00		
	Ag Bundler - Gen	52.90	4.09		
	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		
	Briquettization with Chipper	3,780	357		
	Torrefacation with Chipper	1,220	133		
	Pelletization	3,780	357		
	Briquettization	3,760	355		
	Torrefacation	1,200	132		
	Storage	30.60	2.37		

Biomass Costs

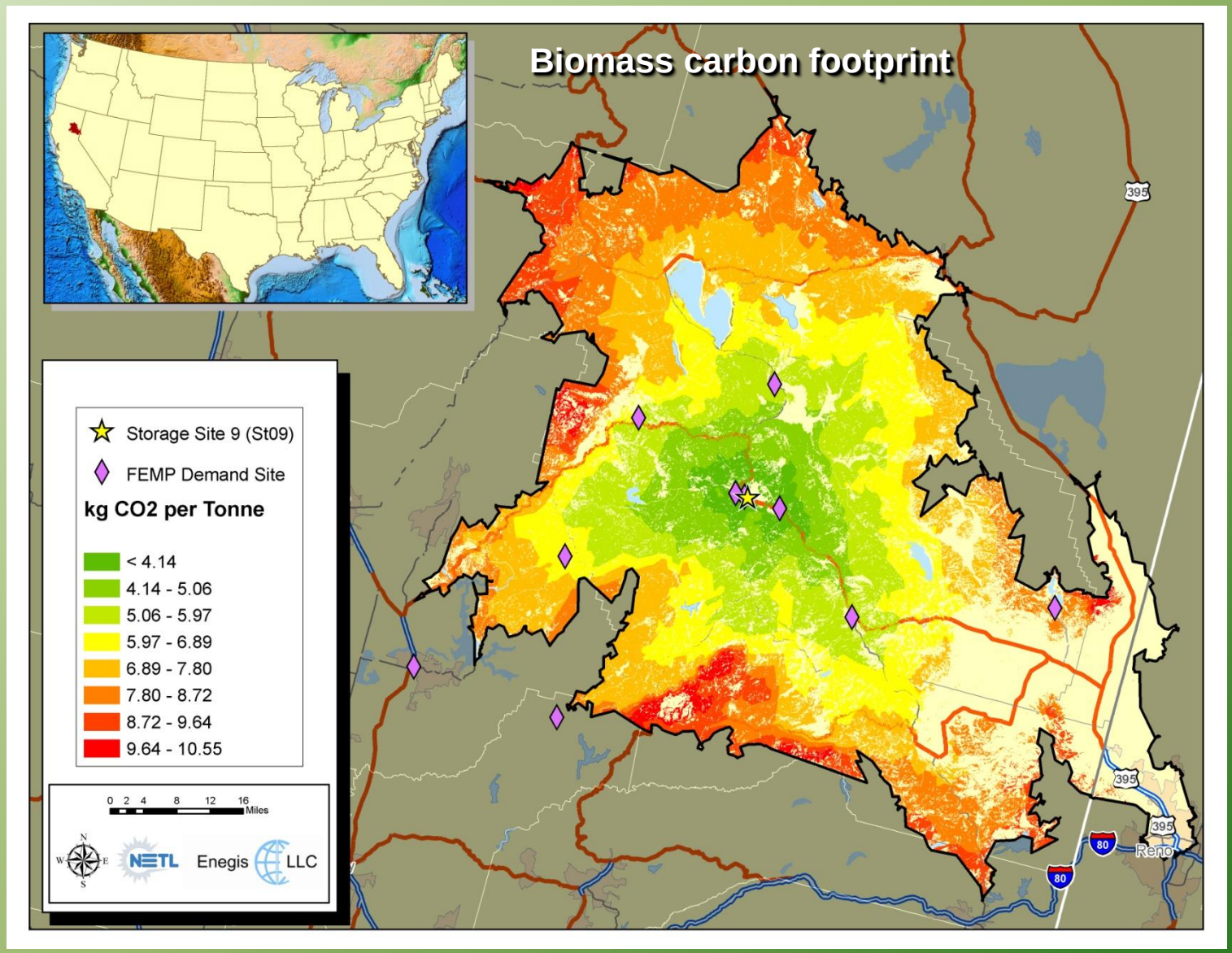
Process Flow

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			

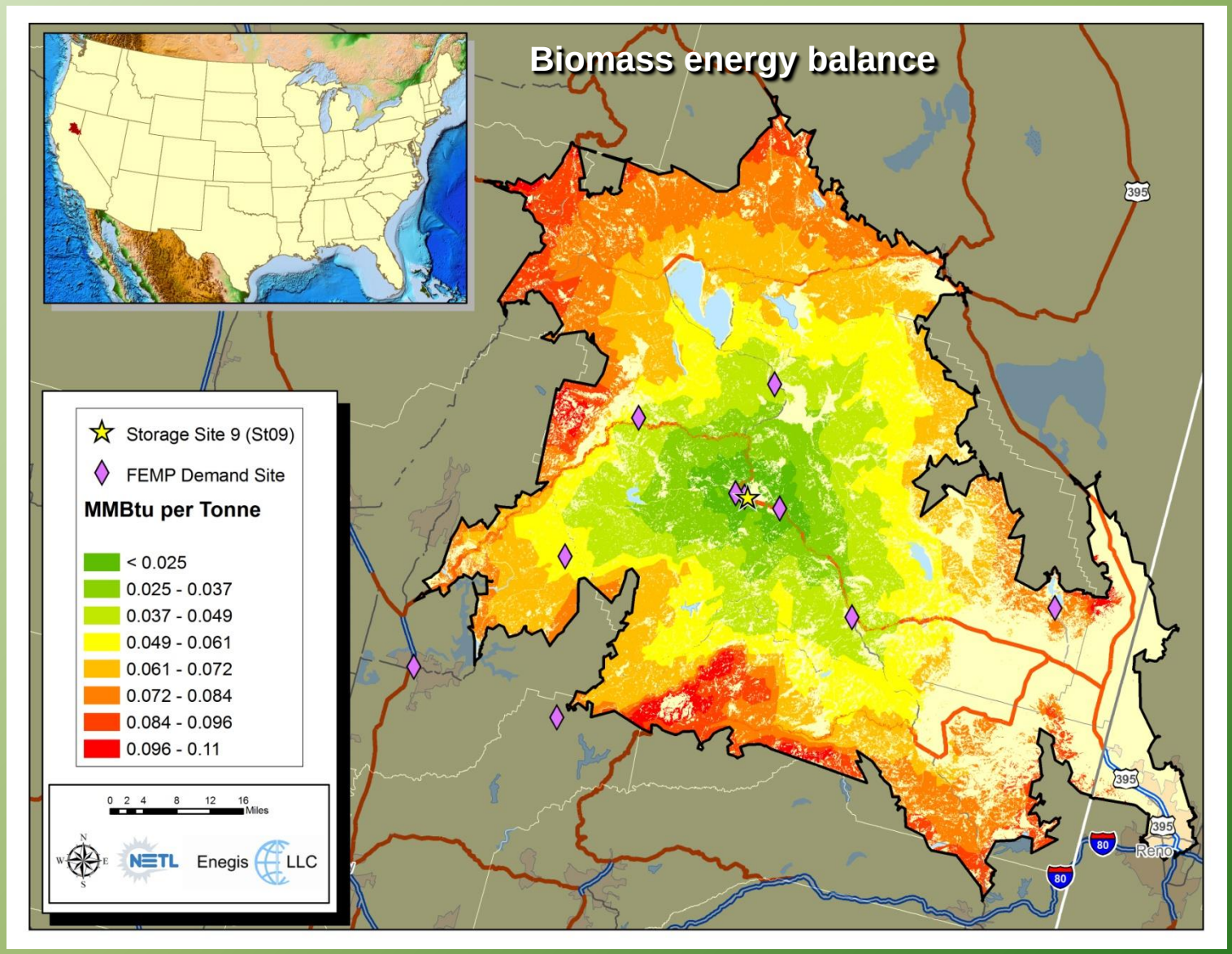
Storage Site 9, California—Pre-Densification



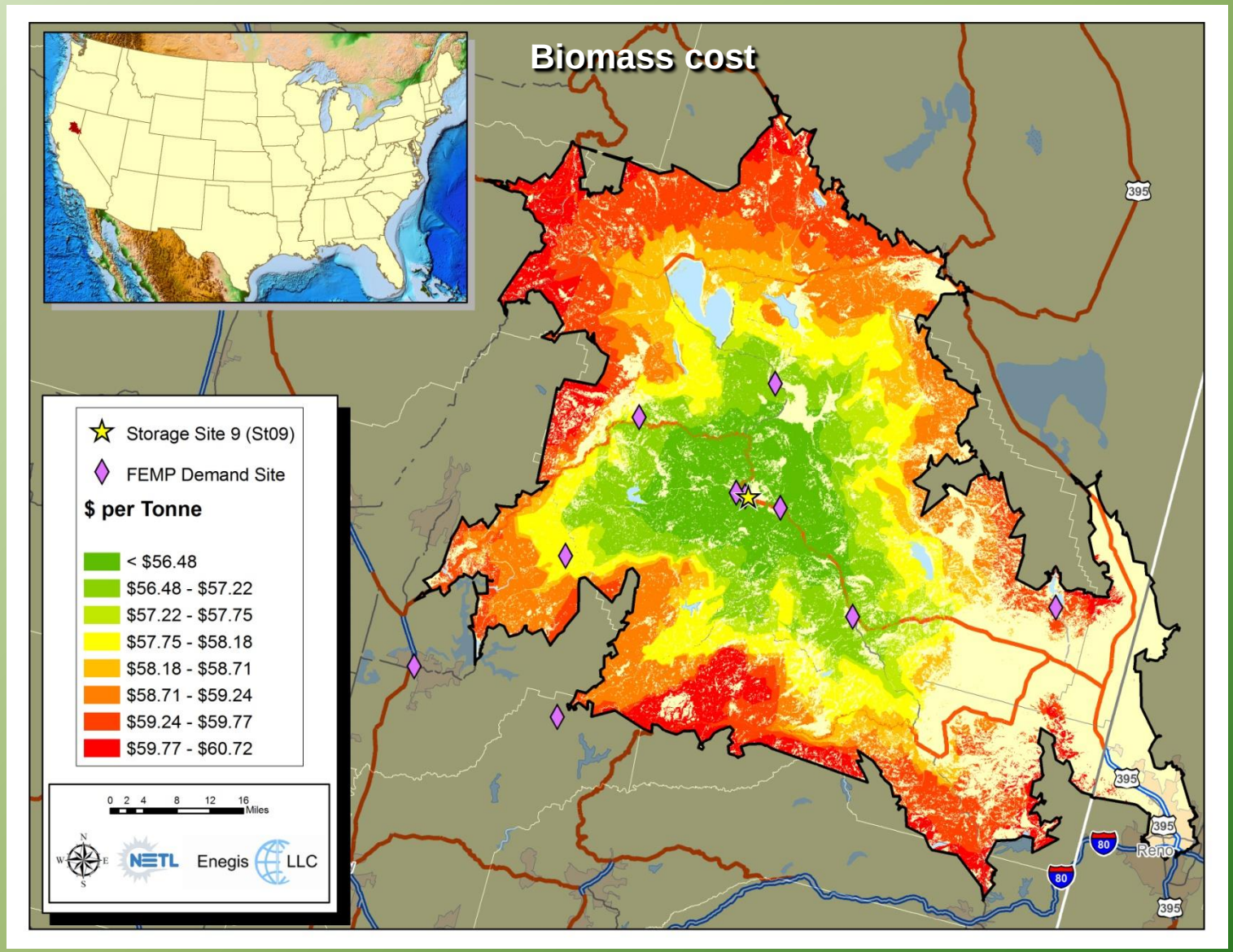
Storage Site 9, California—Pre-Densification



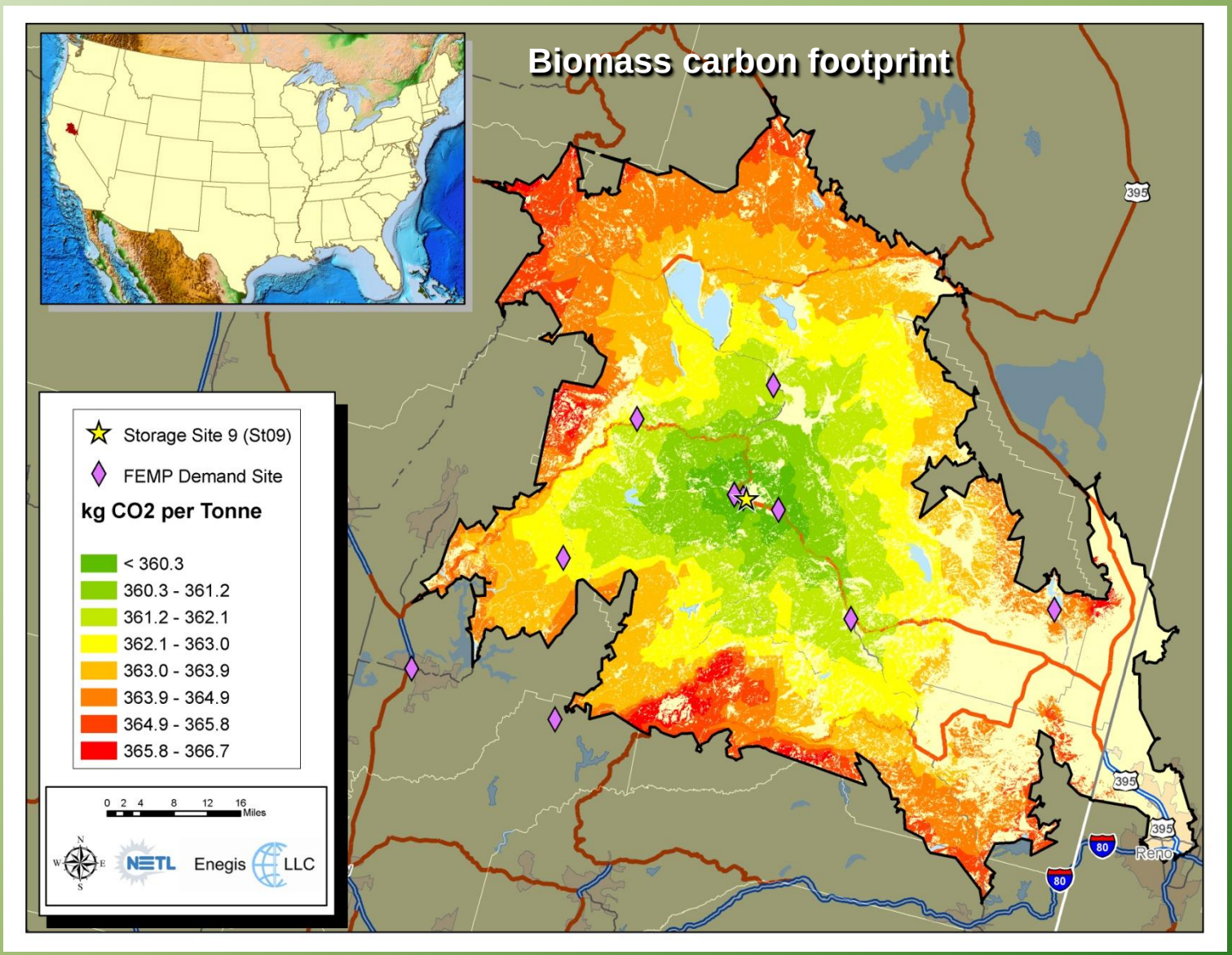
Storage Site 9, California—Pre-Densification



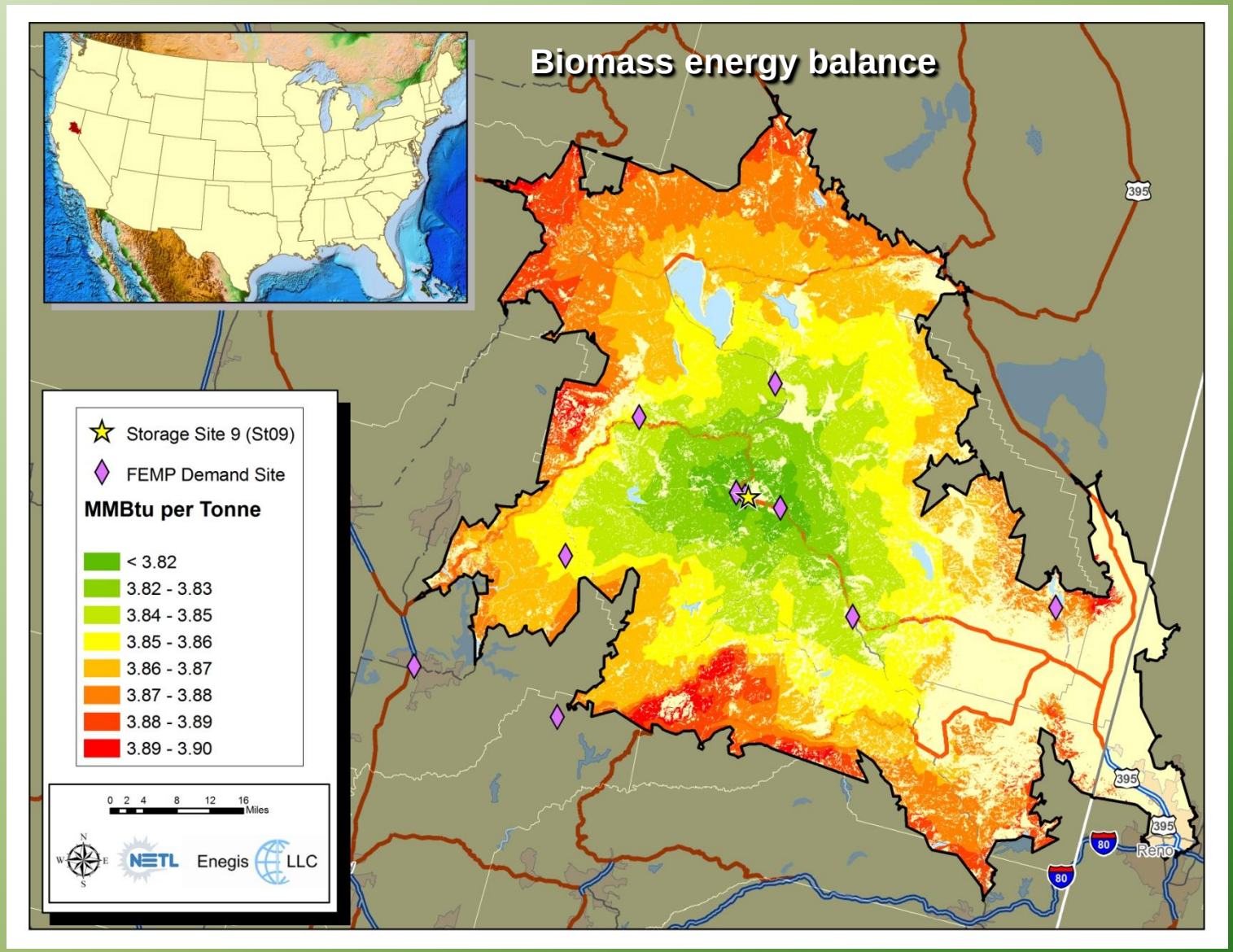
Storage Site 9, California—Post-Densification



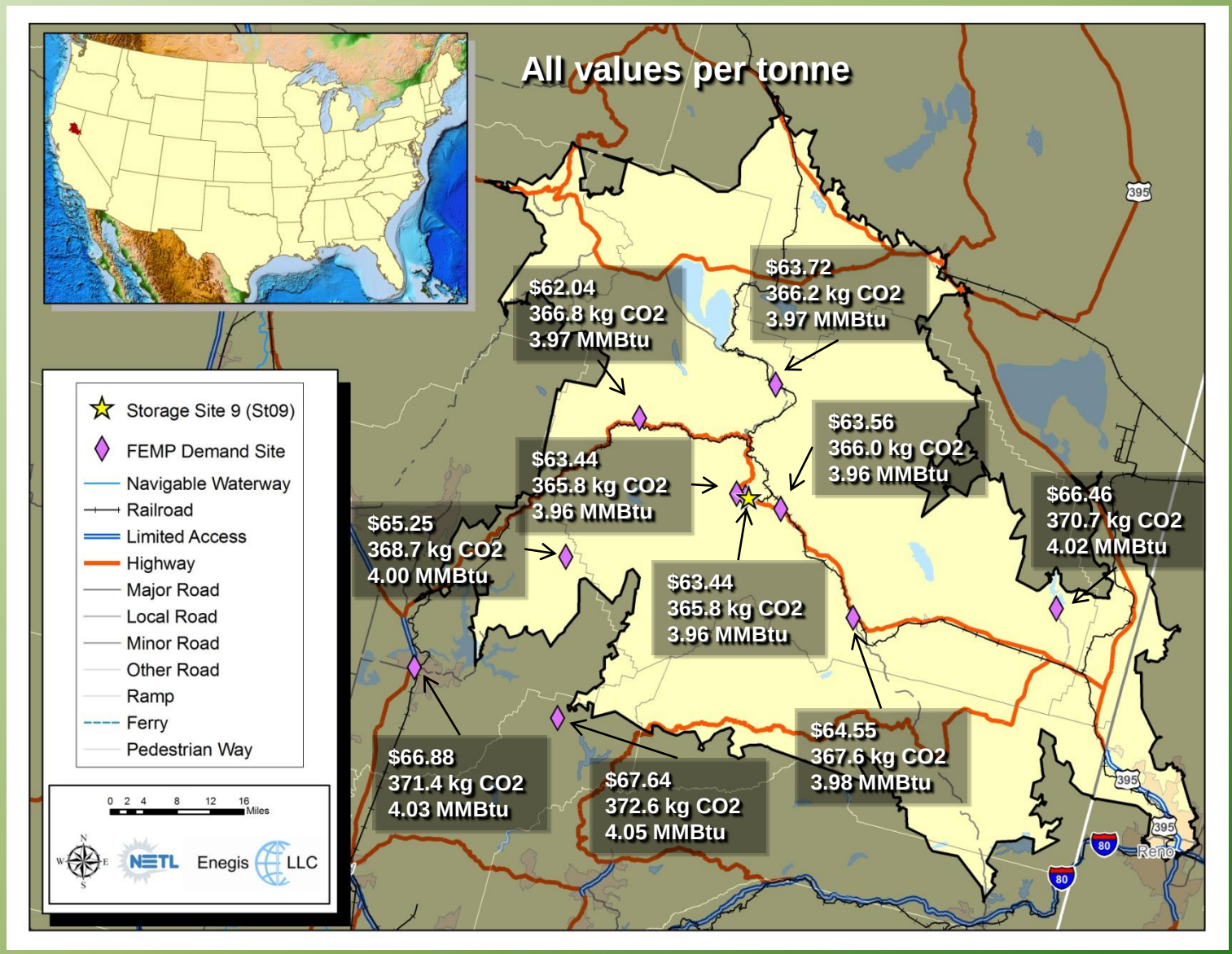
Storage Site 9, California—Post-Densification



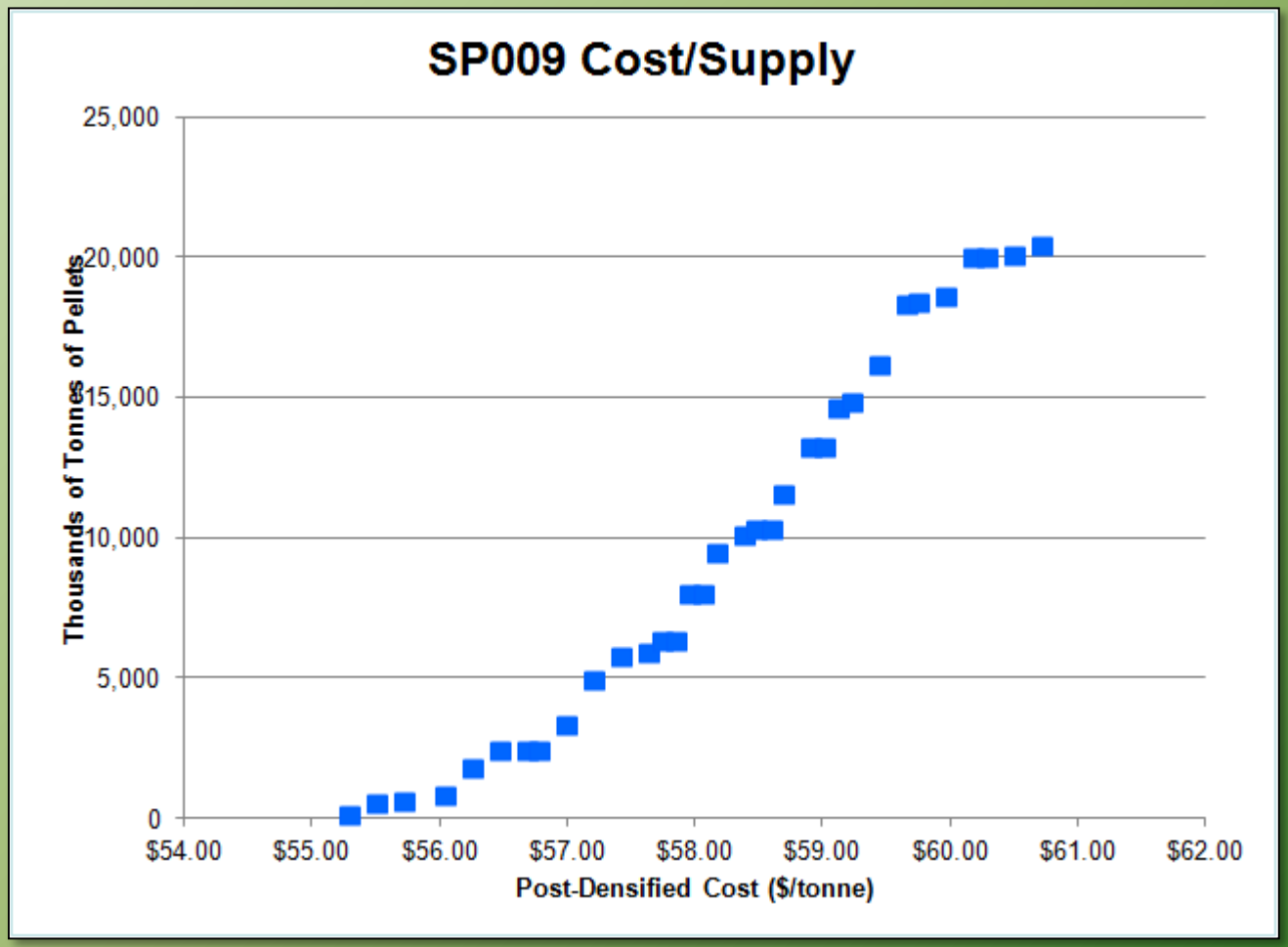
Storage Site 9, California—Post-Densification



Storage Site 9, California—Plant Gate



Cost-Supply Curve



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