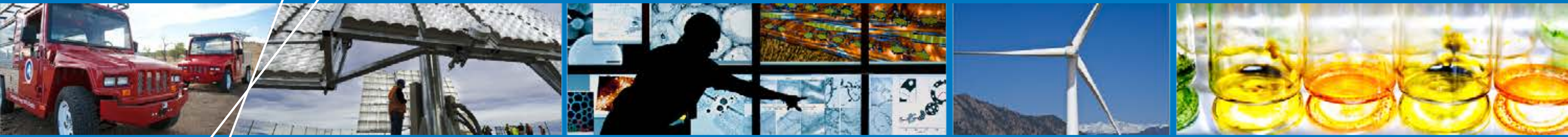
Infrastructure Costs Associated with Central Hydrogen Production from Biomass and Coal.



2012 DOE Hydrogen and Fuel Cells Program Review Washington DC

Darlene Steward

National Renewable Energy Laboratory

May 15, 2012

Project ID AN022

Overview

Timeline

- *Start:* Ongoing
- *End:* September 2012*
- *Complete:* 90% (FY2012 work)

Budget

- Total Project Funding (FY 2011 and 2012): $70k
  - 100% DOE-funded
- FY2011: $50k
- FY2012: $20k

* Project continuation and direction determined annually by DOE.

Barriers

- Stove-piped/Siloed Analytical Capability [4.5.B]
- Suite of Models and Tools [4.5.D]
- Unplanned Studies and Analysis [4.5.E]

Partners

- NREL Team; Darlene Steward, Karen Webster, and Billy Roberts
- Fuel Pathways Integrated Tech Team
- DOE Biomass Program Researchers
- PNL

Collaborations

- **NREL Team; Darlene Steward, Karen Webster, and Billy Roberts**
  - Marc Melaina; the NREL Hydrogen Analysis Team Lead, provided valuable guidance and references for this work
- **USDRIVE Fuel Pathways Integrated Tech Team** Provided industry perspective and review and critique of the approach and conclusions
- **DOE Biomass Program Researchers** at NREL, especially Anelia Milbrandt, provided resource data and valuable insight on competition for biomass resources
- **PNNL** Daryl Brown and Jamie Holladay provided data on biomass transport costs
- **NATCARB** researchers provided assistance with developing the carbon sequestration volume maps.

Overview: Integration with Hydrogen Analysis Program

Biomass and Coal to Hydrogen Infrastructure Study

Analysis Framework

Hydrogen infrastructure Analysis
Hydrogen Resource Analysis

Data: NATCARB carbon sequestration potential
Data: Billion Ton Study current biomass resources
Data: GIS landform and urban coverage data
Data: GIS rail lines and multi-modal point locations

Models & Tools

HDSAM
H2A – Hydrogen production from biomass
H2A – Hydrogen production from coal with carbon sequestration (CCS)
GIS
SERA (planned)

PNNL

Billion Ton Study Infrastructure Analyses (UC Davis & others)

Studies & Analysis

Long-term Analysis
Environmental Analysis
Cross-cut Analysis

DOE FCT Program
DOE Biomass Program
FPITT

Outputs & Deliverables

Modeling output and correlations can be used in other integrated analyses and tools;

- **Report**
- SERA infrastructure tool
- Macrosystem model
- Transportation Energy Futures Study

Relevance:

- **This study seeks to elucidate the location-dependent variability of infrastructure costs for hydrogen production and delivery and the trade-offs inherent in plant location choices.**

Relevance: Impact on Barriers

Barrier	*Impact*

Stove-piped/Siloed Analytical Capability [4.5.B]	• Analysis of the location dependence of infrastructure costs for hydrogen production accounts for the context in which hydrogen production plants would be built
	  • Biomass and sequestration site availability
	  • Existing infrastructure
	  • Effect of population density and terrain on construction costs

Suite of Models and Tools [4.5.D]	• Use of well established H2A and Hydrogen Delivery Components models in combination with detailed GIS data results in enhanced modeling capability without the development of new tools. • Location dependent cost equations can be used in the SERA model.
Unplanned Studies and Analysis [4.5.E]	• Use of existing models reduces the cost and increases the flexibility for analysis • Use of existing models ensures consistency with other Program analyses.

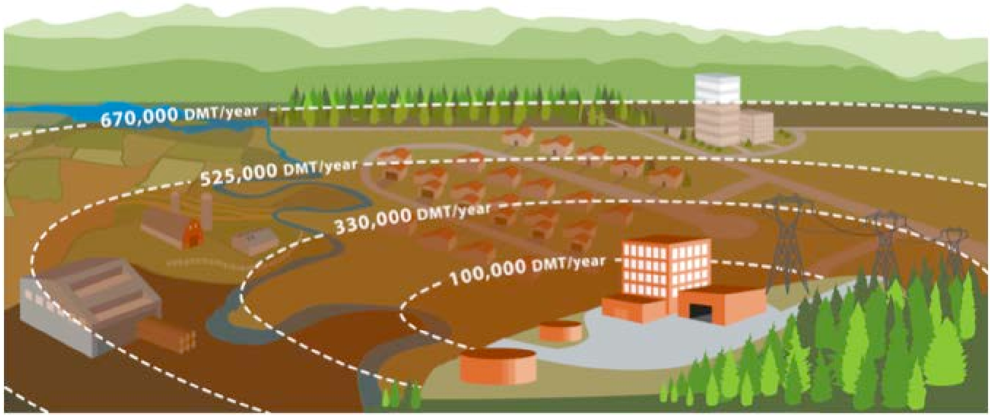
Approach: Combine GIS Data with Established Cost Models

1. Map resources, existing infrastructure, and demand centers
2. Construct infrastructure cost correlations in H2A and Components models based on distance, terrain, and land use.
3. Determine infrastructure costs for a hypothetical plant located at the center of each square kilometer on the map.

Approach: Infrastructure Assumptions and Data for Biomass to Hydrogen Plants

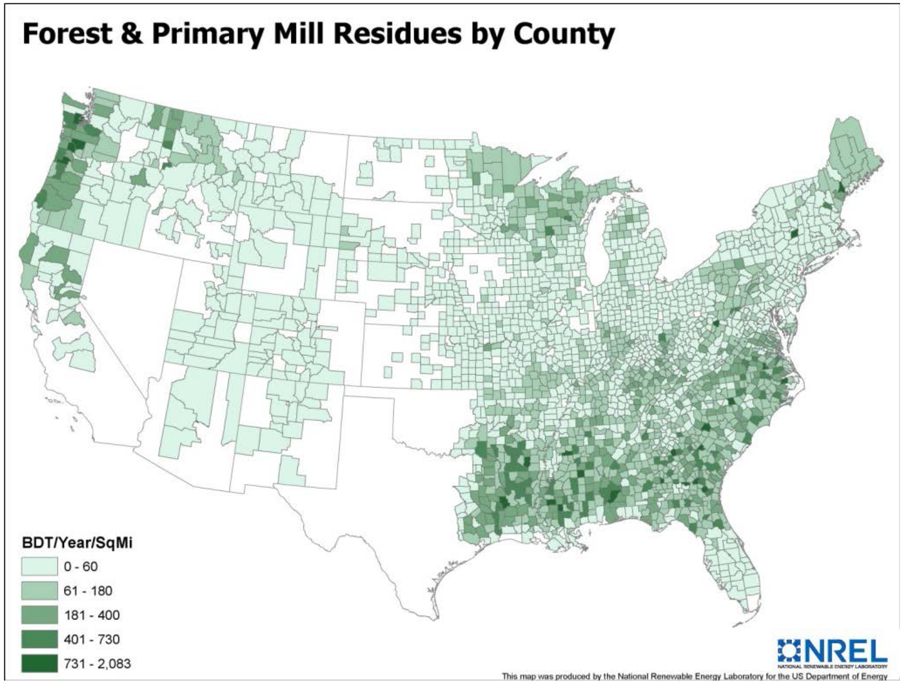
Biomass Infrastructure:

- Harvest, pre-processing, grower payment and truck transport of biomass to plant on existing roads
- Construction of pipeline for transport of H2 to nearest large demand center

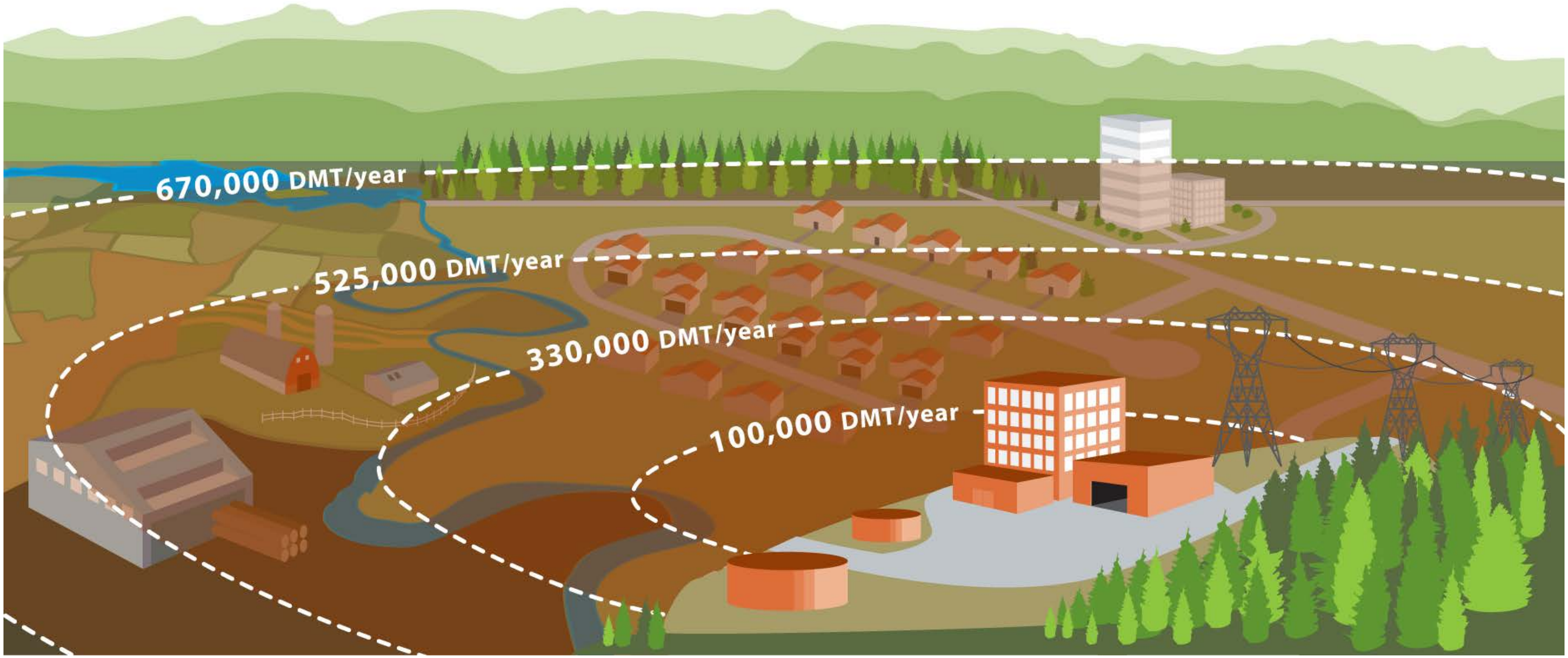


Data:

- Forest & Primary Mill Residues, Urban Wood Waste; 2008 NREL GIS Catalog Data
- Urban centers are MSA's with a population > 1M

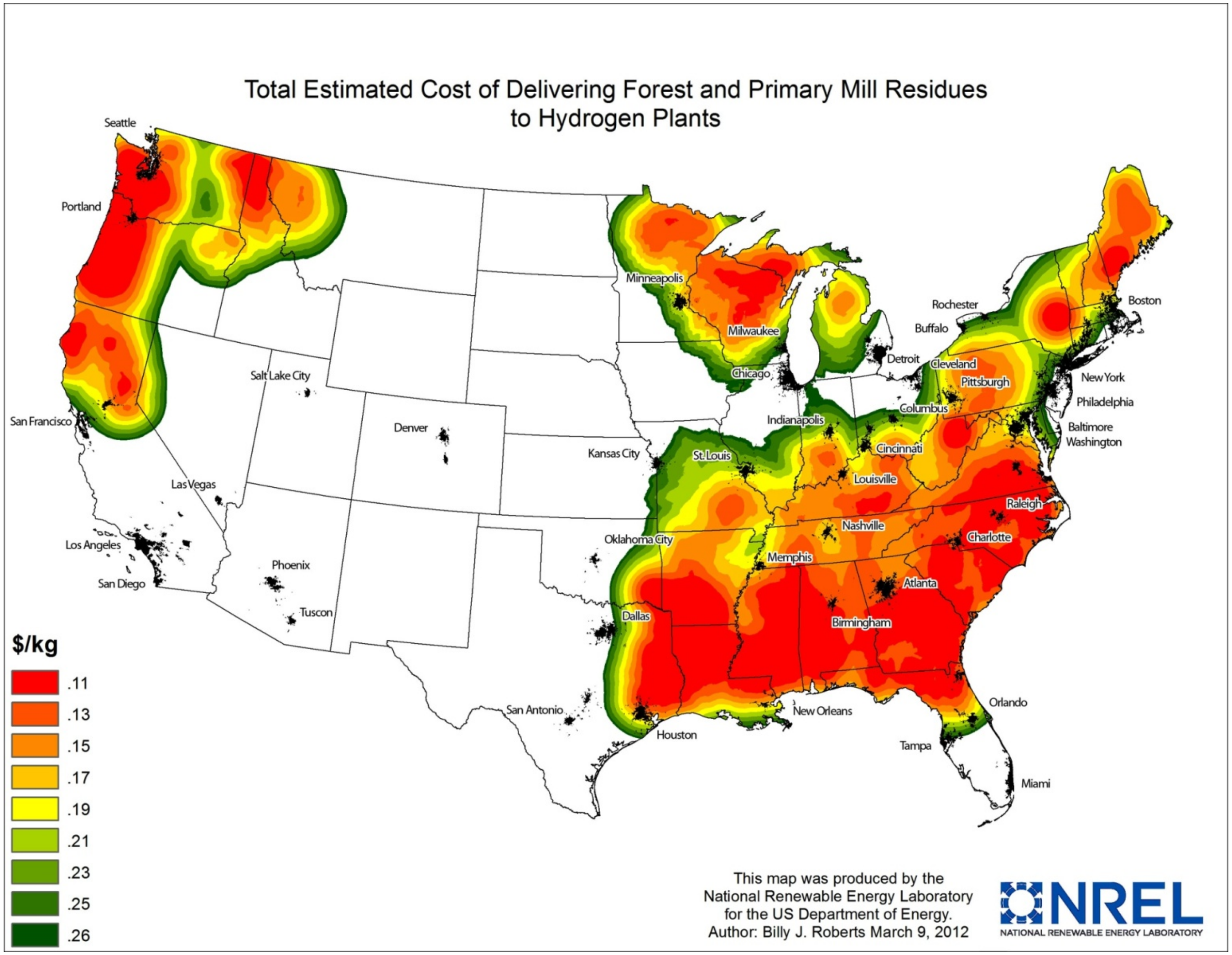


Accomplishment: Biomass Delivery Radius Calculation



- **Algorithm steps out from the plant in 5 mile increments to calculate area required**
- **Transportation distance: miles = ((plant feedrate / land productivity / availability factor) /PI)^0.5 * 1.3 * 0.67**

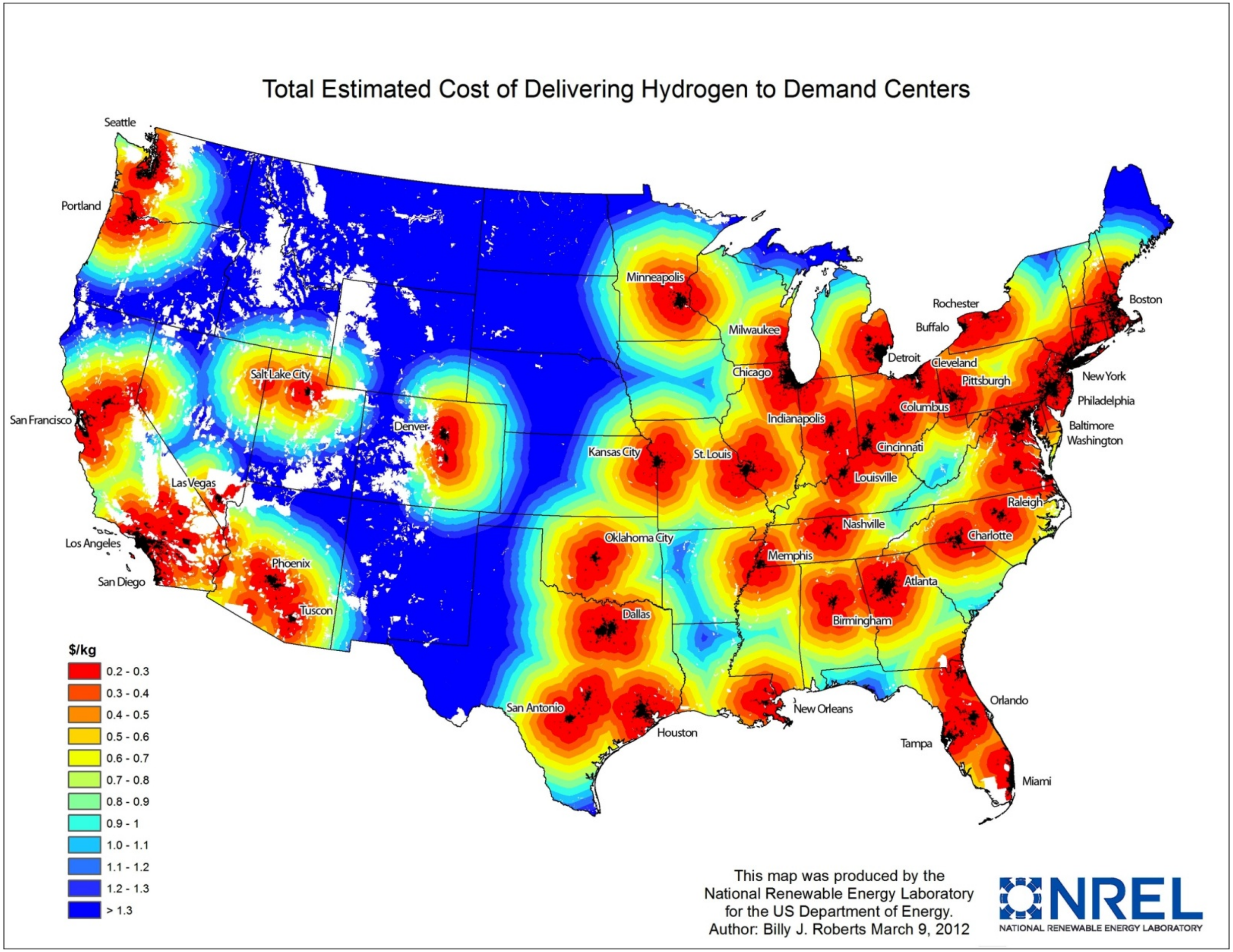
Accomplishment: Forest Residue Delivery Cost – 100 Mile Maximum Transport Distance



Biomass delivery adds $0.11 – 0.26/kg hydrogen

Potential plant locations are limited by biomass availability

Accomplishment: Hydrogen Pipeline Construction Cost

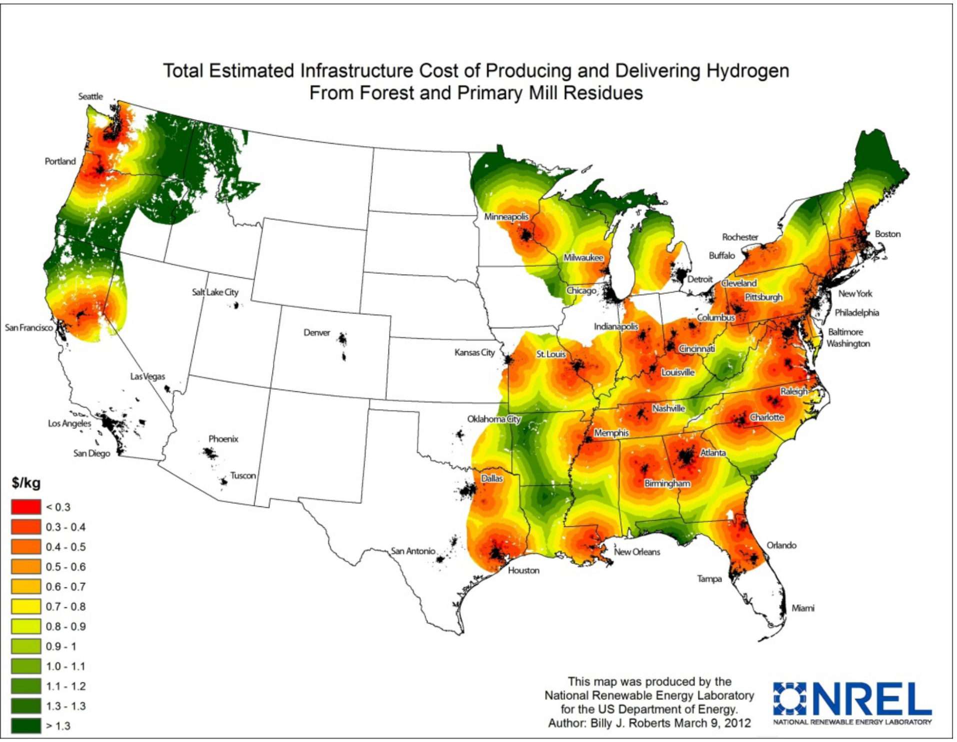


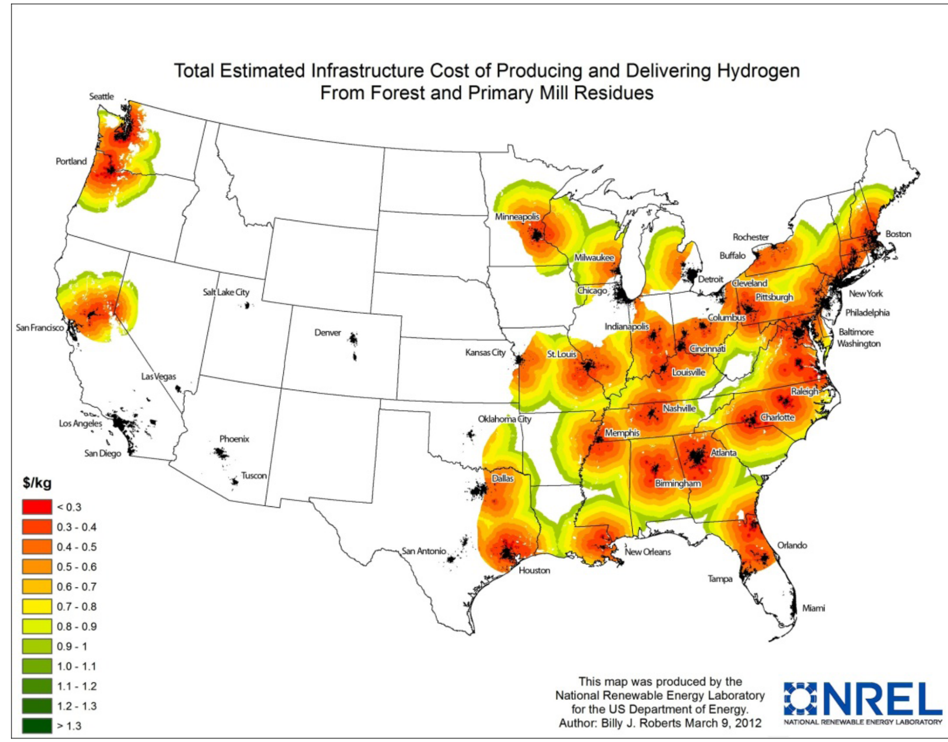
Hydrogen pipeline cost $0.21 – $2.70/kg hydrogen

Terrain & federally protected land restrictions impact costs in the western U.S.

Accomplishment: Forest Residue Delivery and Hydrogen Pipeline Cost – (100 mile biomass transport limit)

Hydrogen pipeline cost dominates the overall cost. Biomass resource availability determines where plants can be built





Total infrastructure cost with 100-mile maximum biomass transport distance [~$0.30 to > $1.30/kg]

Limiting total infrastructure cost to less than $1/kg reduces the number of viable plant locations

Accomplishment: Biomass to Hydrogen Total Infrastructure Cost Varies by Location

Boston has the lowest overall infrastructure cost due to lower hydrogen delivery cost even though the biomass delivery cost is higher than either Houston or Seattle.

City (plant distance to city outskirts - miles)		Biomass Delivery by Truck (¢/kg)	Hydrogen Delivery by Pipeline (¢/kg)	Total Infrastructure Cost (¢/kg)
Boston	(25, W)	19	21	40
	(50, W)	17	24	40
Houston	(25, N)	11	25	35
	(50, N)	11	37	48
Seattle	(25, S)	11	32	43
	(50, S)	10	34	44
San Francisco	(25, N)	23	26	48
	(50, N)	21	35	55
Detroit	(25, W)	24	22	46
	(50, W)	23	35	58

Approach: Infrastructure Assumptions & Data for Coal to Hydrogen Plants

Coal Infrastructure:

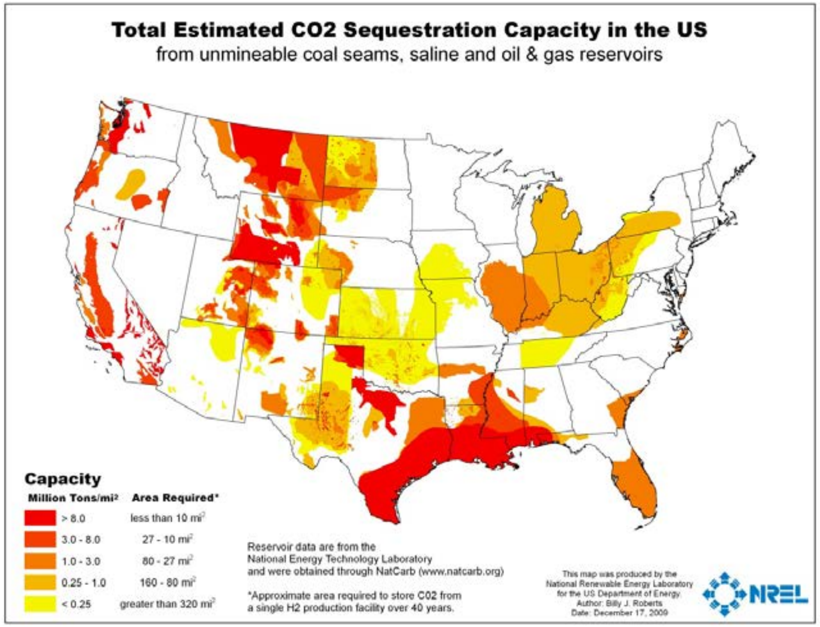
- Construction of rail spur from primary rail line to plant
- Construction of pipeline for transport of CO_2 to sequestration site
- Construction of pipeline for transport of H_2 to nearest large demand center

Carbon Sequestration Potential:

- NatCarb 2008 Atlas (www.natcarb.org/atlas) and the National Energy Technology Laboratory (NETL) – Area extent of reservoirs combined with estimates of volume were combined to calculate area required for 40 years' of storage

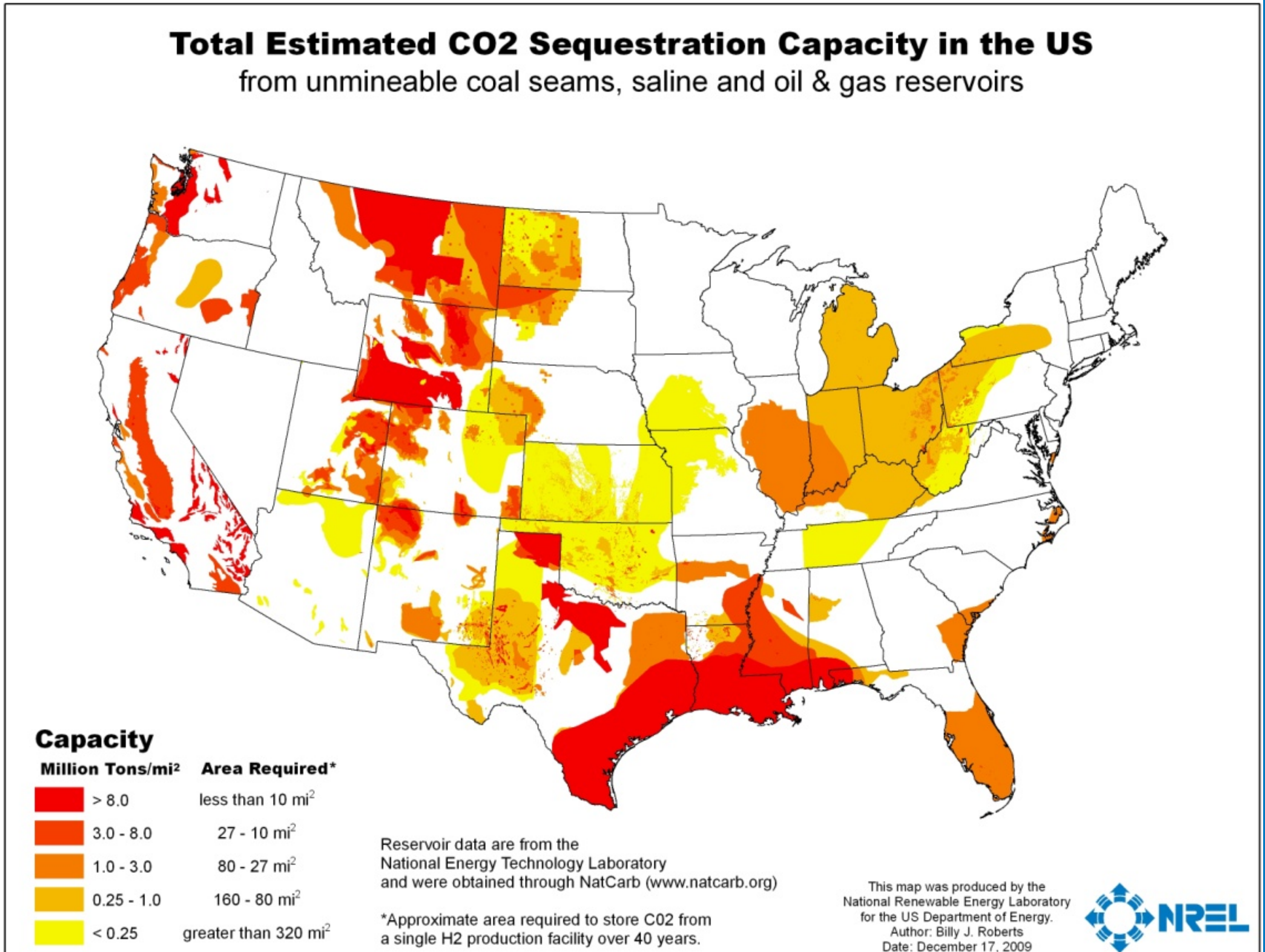
Rail Spur Construction:

- Cost of constructing new rail spurs for coal delivery based on shortest straight-line distance to the nearest existing in-service rail line.
- Rail spur construction costs including consideration of terrain; McCollum 2007, Burton 2004.



Accomplishment: Mapping of Availability of Sufficient Carbon Sequestration Potential

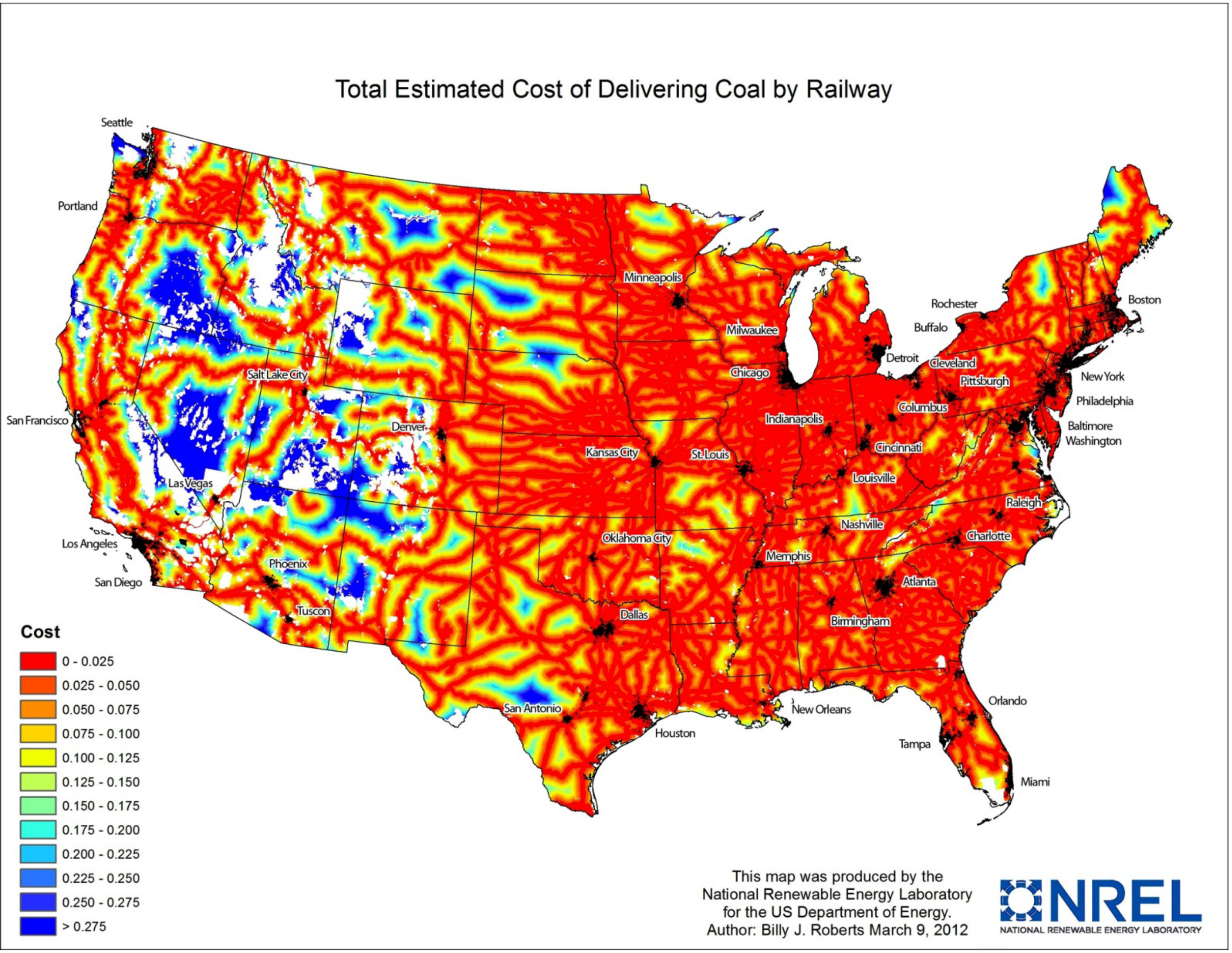
Sites Considered; Unmineable coal seams, saline formations and depleted oil and gas reservoirs with adequate storage for 40 years.



CO2 pipeline costs account for restrictions on sequestration site access based on *proximity*, pipeline *route availability* (avoiding restricted areas, such as national parks etc.) and the impact of *terrain characteristics on installation cost*.

Source: NatCarb 2008 Atlas (www.natcarb.org/atlas) and the National Energy Technology Laboratory (NETL)

Accomplishment: Geospatial Mapping of New Rail Cost



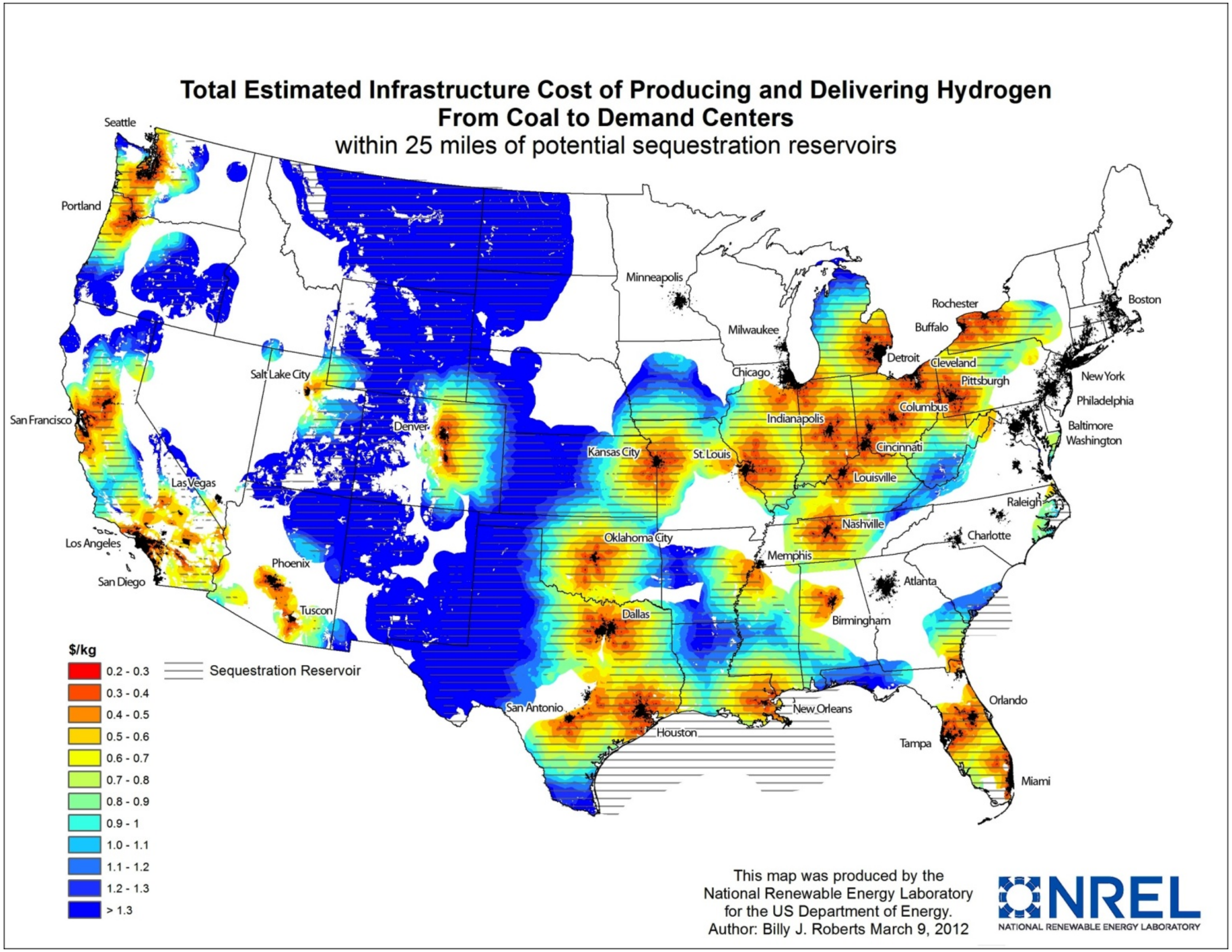
Cost of constructing new rail spurs for coal delivery based on shortest straight-line distance to the nearest existing in-service rail line.

Levelized cost of new rail spurs ranges from ~ \$0.01/ kg H_2 to ~\$0.40/ kg H_2

- Elevations over 10,000 feet, National Parks (etc.), and steep terrain excluded (white)
- Distance ranges from 0 to 120 miles

Costs for construction of a rail spur should be considered especially for the western U.S. where existing rail lines are more dispersed and the terrain is more mountainous

Accomplishment: Total Infrastructure Cost for Hydrogen Production from Coal with Sequestration (25-Mile Cut-off)

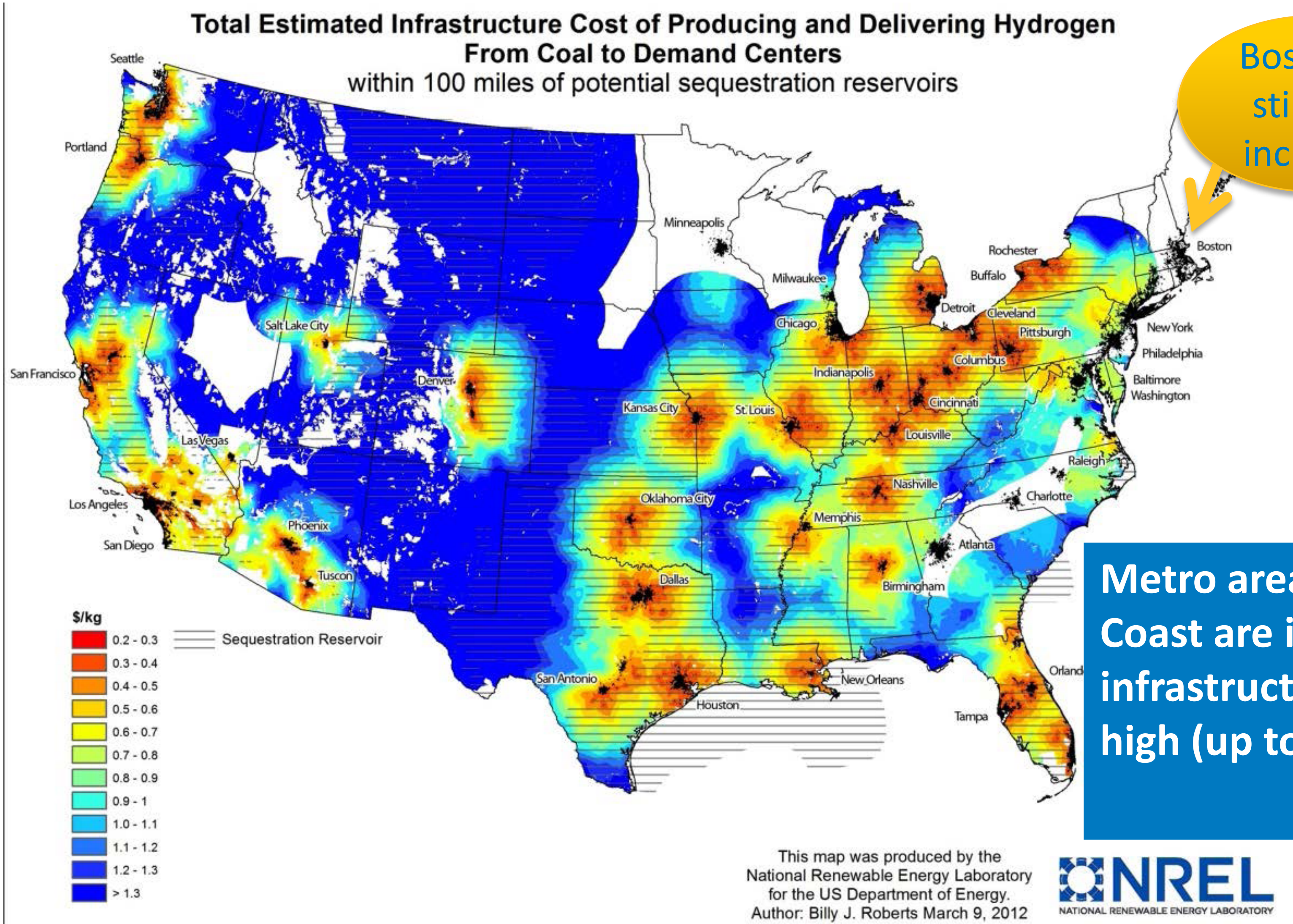


Plants must be located within 25 miles of sequestration sites.

Lack of proximity to sequestration sites prevents plants from being built near many major metropolitan areas

Infrastructure cost includes construction of rail spur, construction of CO2 pipeline and construction of hydrogen pipeline and does not include hydrogen production cost

Accomplishment: Increasing the Allowable CCS Pipeline Length Increases Coverage of Metro Areas on the East Coast



Boston is still not included

Metro areas on the East Coast are included, but infrastructure costs are high (up to $1/kg)

Accomplishment: Coal to Hydrogen Total Infrastructure Cost Varies by Location

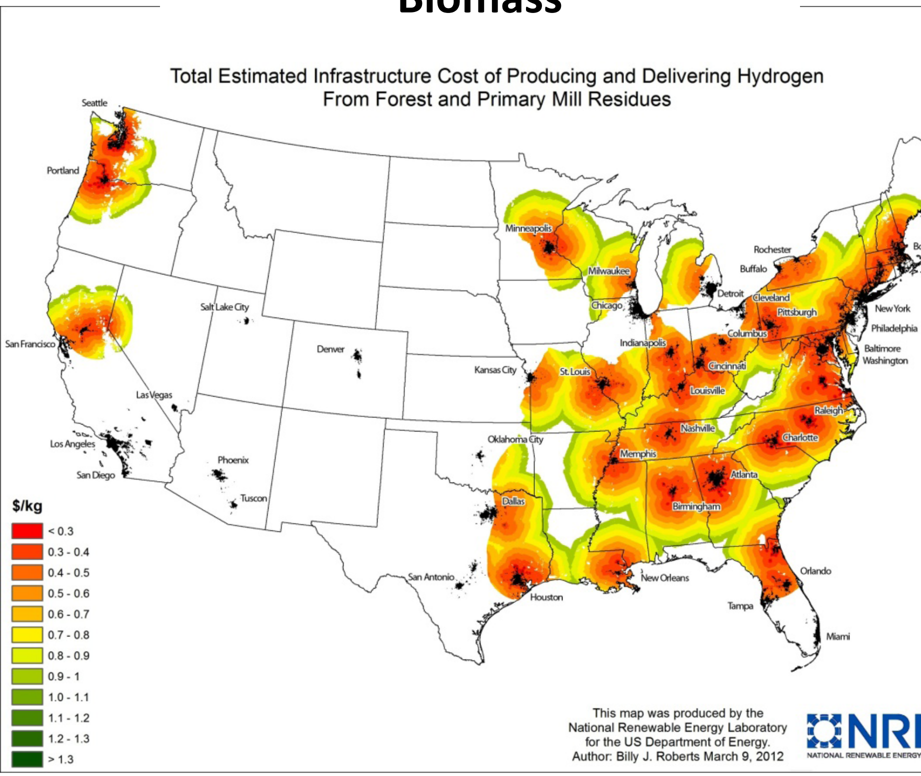
Boston has high infrastructure costs because suitable carbon sequestration sites are far from the city.

City (plant distance to city outskirts - miles)		CO_2 Pipeline (¢/kg)	Rail Spur (¢/kg)	Hydrogen Delivery by Pipeline (¢/kg)	Total Infrastructure Cost (¢/kg)
Boston	(25, W)	72	3	21	96
	(50, W)	60	0	24	84
Houston	(25, N)	17	5	25	47
	(50, N)	17	2	37	56
Seattle	(25, S)	17	3	32	52
	(50, S)	17	14	34	65
San Francisco	(25, N)	24	0	26	50
	(50, N)	23	11	35	69
Detroit	(25, W)	17	3	22	42
	(50, W)	17	1	35	53

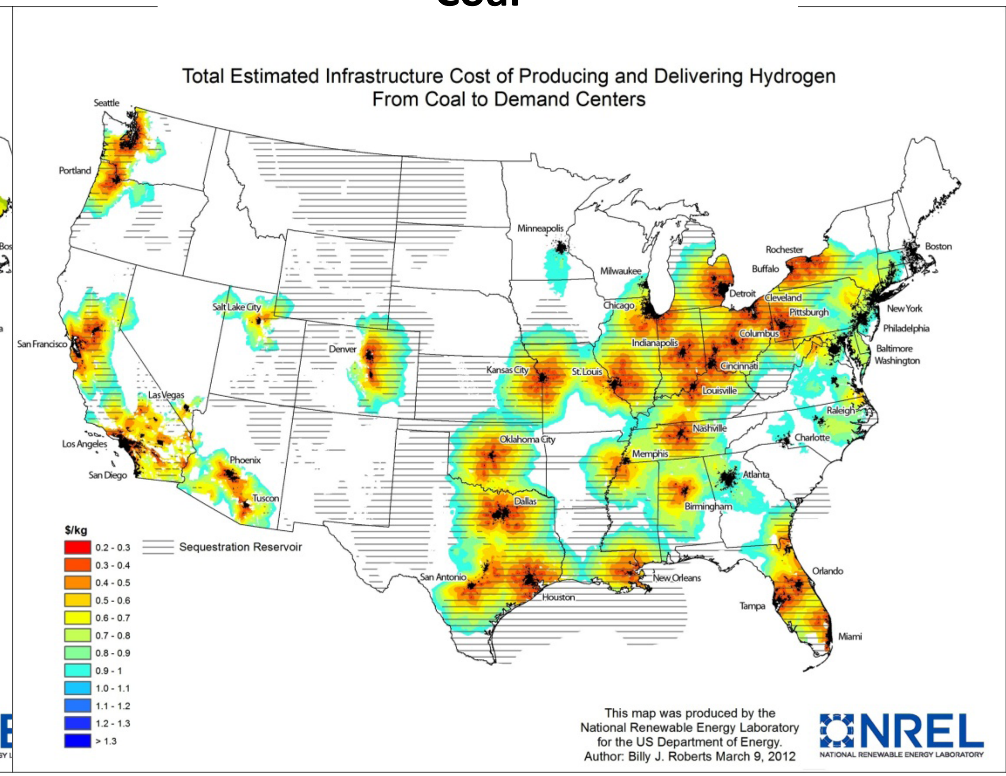
Summary: Comparison of Infrastructure Costs for Biomass & Coal to Hydrogen Plants

Infrastructure for coal to hydrogen plants is usually more expensive than infrastructure for biomass to hydrogen plants, but some metropolitan areas are eliminated from consideration for biomass plants with short-haul truck delivery of biomass.

Biomass



Coal



Maps for biomass (left) and coal (right) infrastructure costs clipped at $1/kg H_2 to illustrate differences in geographic distribution of favorable plant locations for the two technologies.

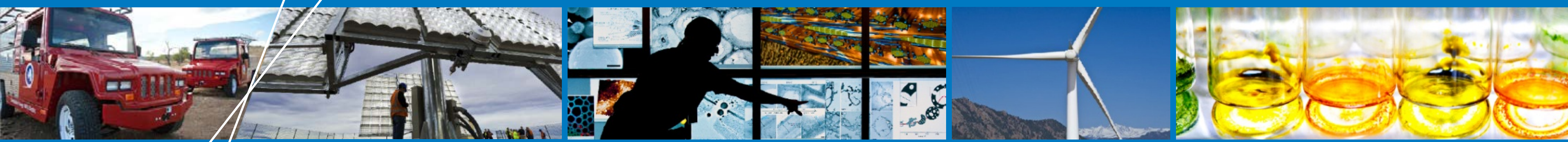
Future Plans: Optimize Plant Location Analyses & Generate Hydrogen Supply Curves

Both studies will be prepared for publication in FY12

Various strategies could be investigated to refine and/or reduce infrastructure costs.

- Infrastructure cost correlations need to be updated to $2007
- Rail delivery of biomass could increase the geographic availability of this technology
- Use of smaller biomass plants could increase geographic availability of biomass to hydrogen technology
- Costs for sequestration of CO2 need to account for differences in reservoir permeability, size.
- Cost curves should be developed for infrastructure costs for both technologies.

The SERA model could be used to optimize infrastructure locations.



Backup Slides

This project was not reviewed in 2011

Example Infrastructure Cost Equations – Biomass Cost Data Converted to $/kg H2 as a Function of Transport Distance

Biomass fixed cost (grower payment, harvest, preprocessing ($2005/DMT) = $49.50

Transport cost including loading and unloading

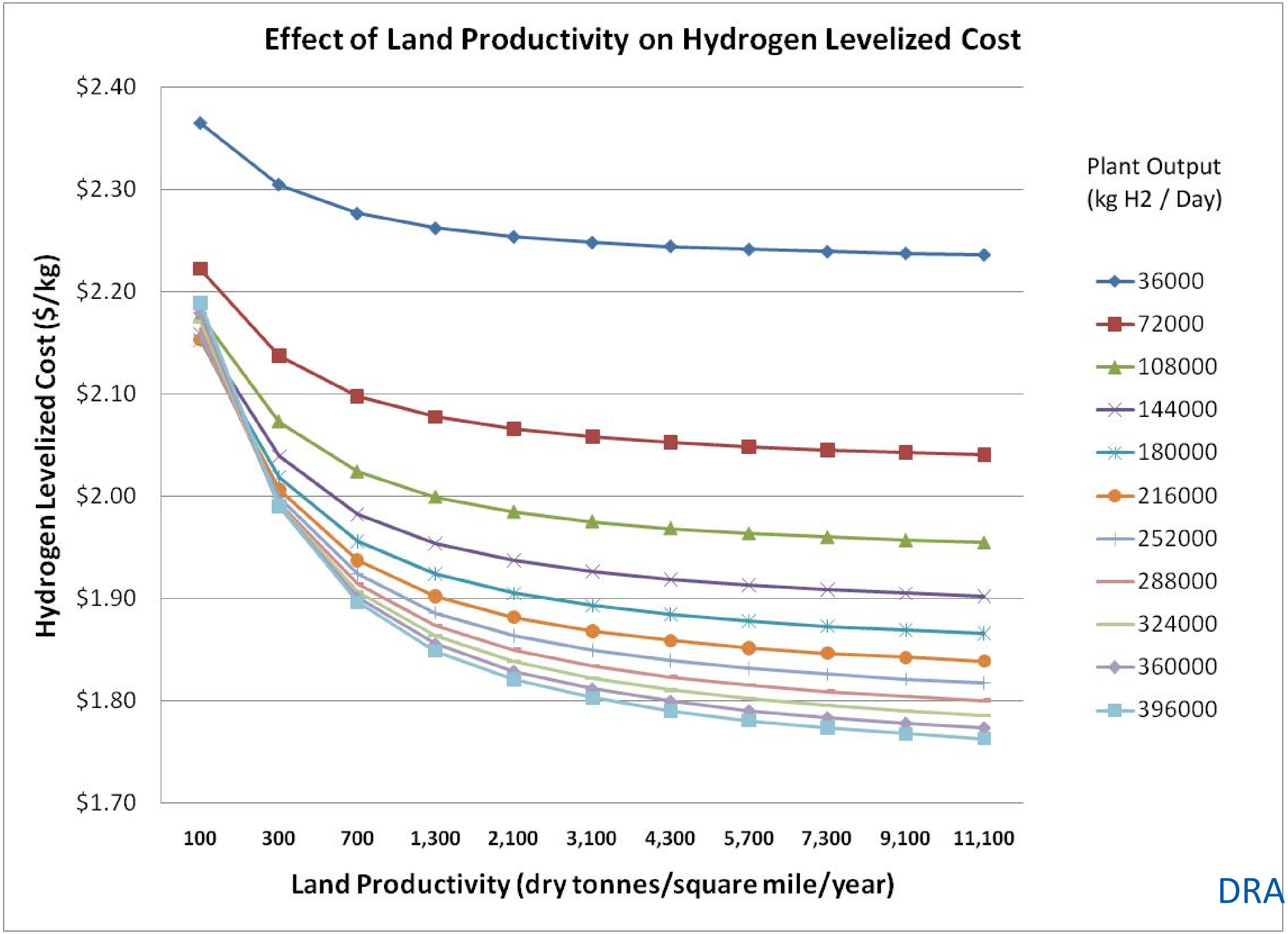
Cost Category	
Loading/unloading (truck)	2.84 ($2005/dry metric tonne)
Transport (truck)	0.165 ($2005/dry metric tonne/mile)
Loading/unloading (rail)	7.79 ($2005/dry metric tonne)
Transport (rail)	0.026 ($2005/dry metric tonne/mile)

Transport by rail could allow plants to be built closer to demand centers

Values plugged into H2A model to develop biomass delivery cost correlations in $/kg H2 as a function of distance. The same strategy was used for all cost correlations

Source: adapted from Daryl Brown, Personal communication from PNNL internal report.

Future Work – Investigate the Effect of Plant Size



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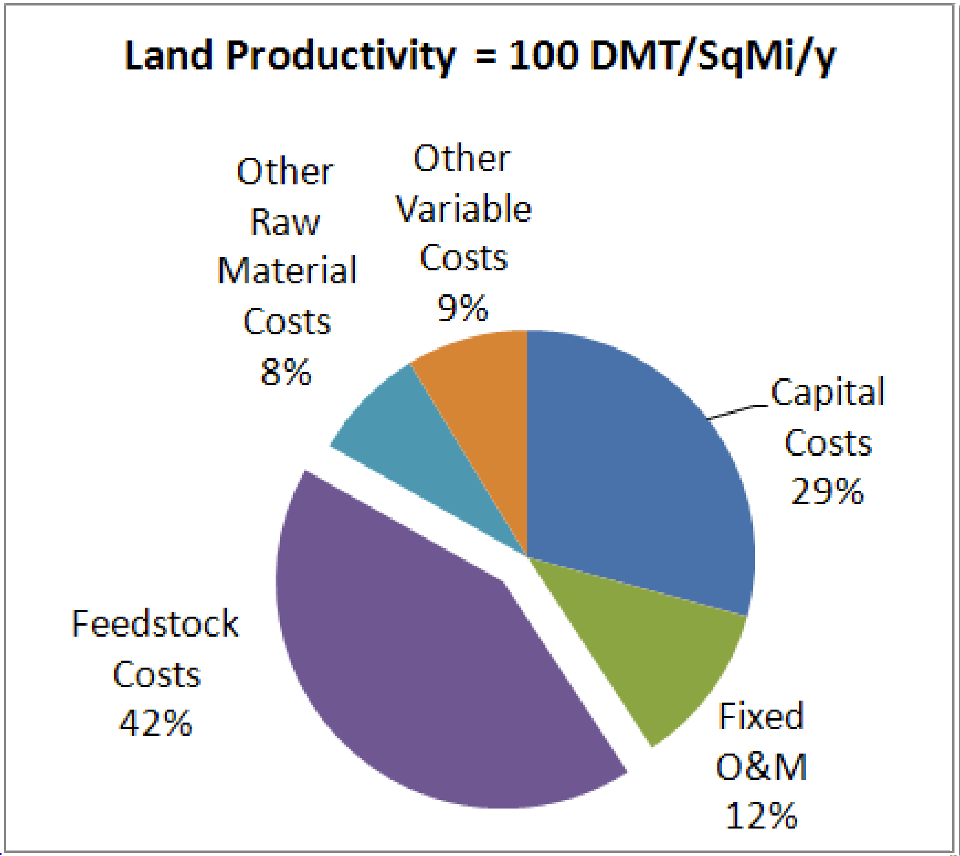
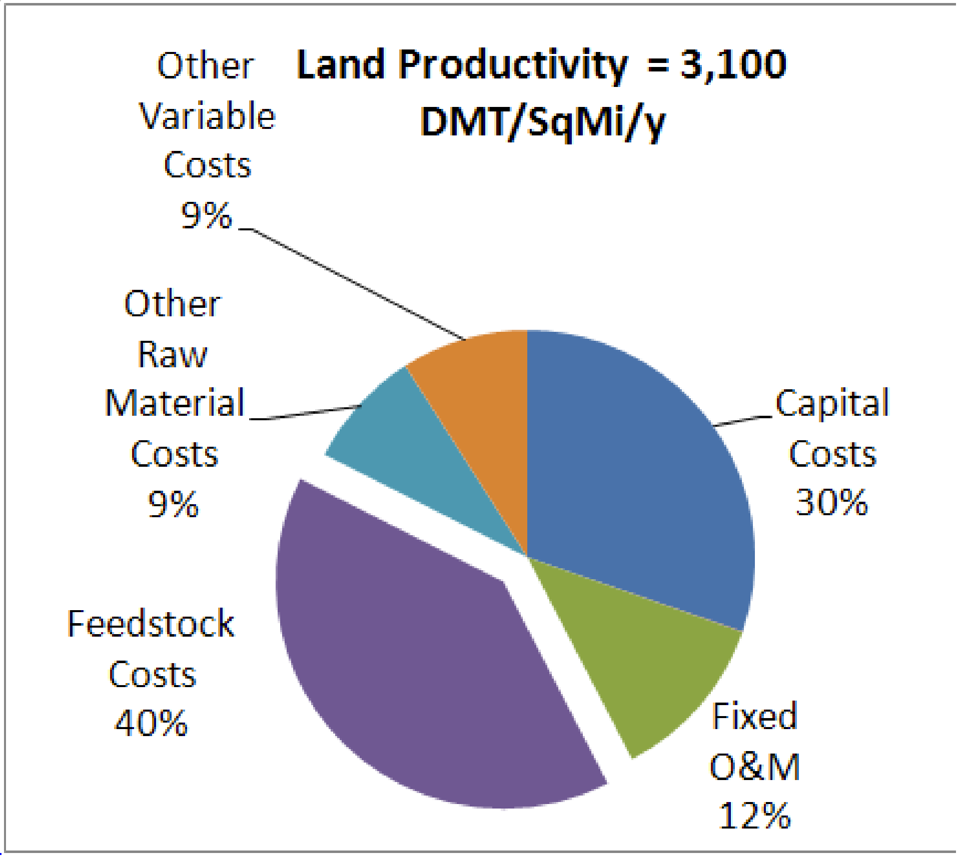
Future Work - Higher Land Productivity Reduces Feedstock Cost Contribution

144,000 kg/day biomass plant.





H2 levelized cost:	$1.83	H2 levelized cost:	$1.76
Avg. transport distance	40 mi	Avg. transport distance	7 mi
Biomass price	$59/DMT	Biomass price	$54/DMT

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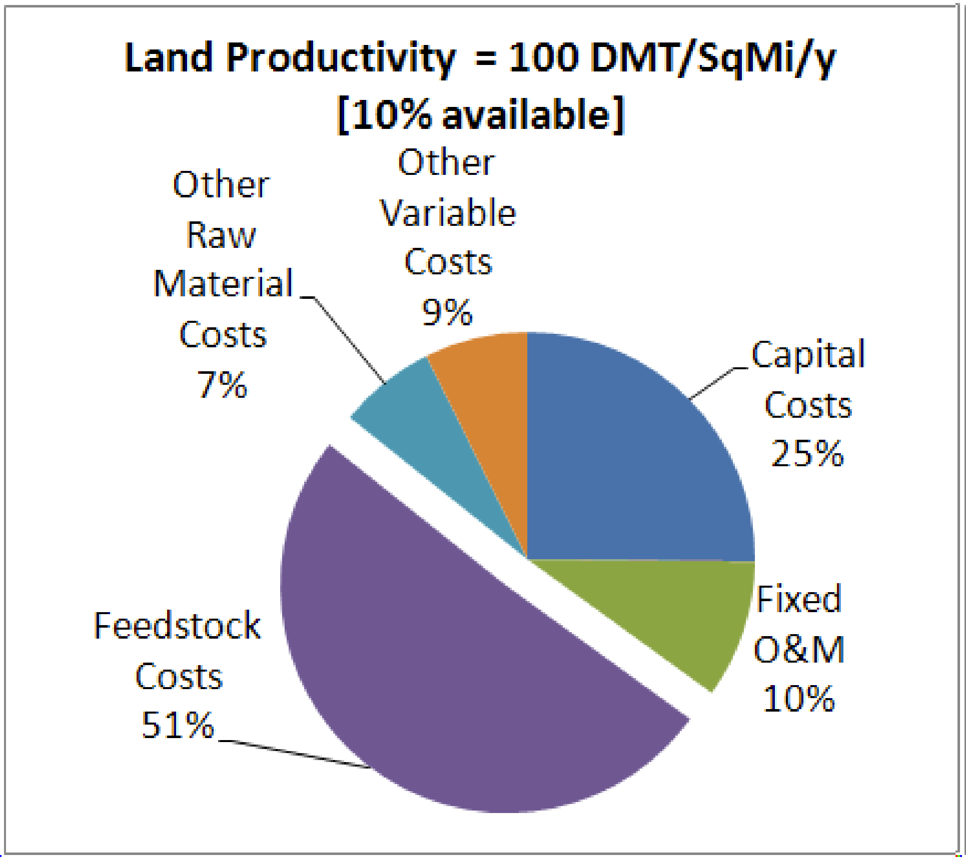
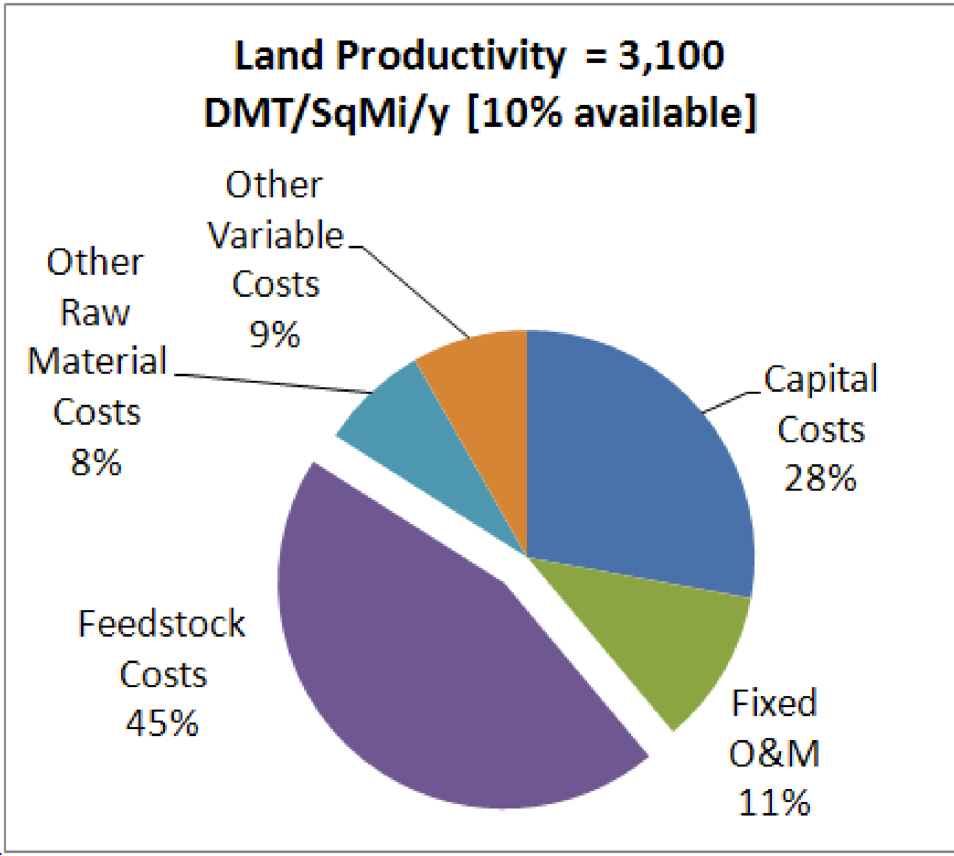
Future Work - Low Land Availability Increases Feedstock Cost Contribution

144,000 kg/day biomass plant.





	100 DMT/SqMi/y	3,100 DMT/SqMi/y
H2 levelized cost:	$2.16	$1.93
Avg. transport distance	127 mi	23 mi
Biomass price	$83/DMT	$66/DMT

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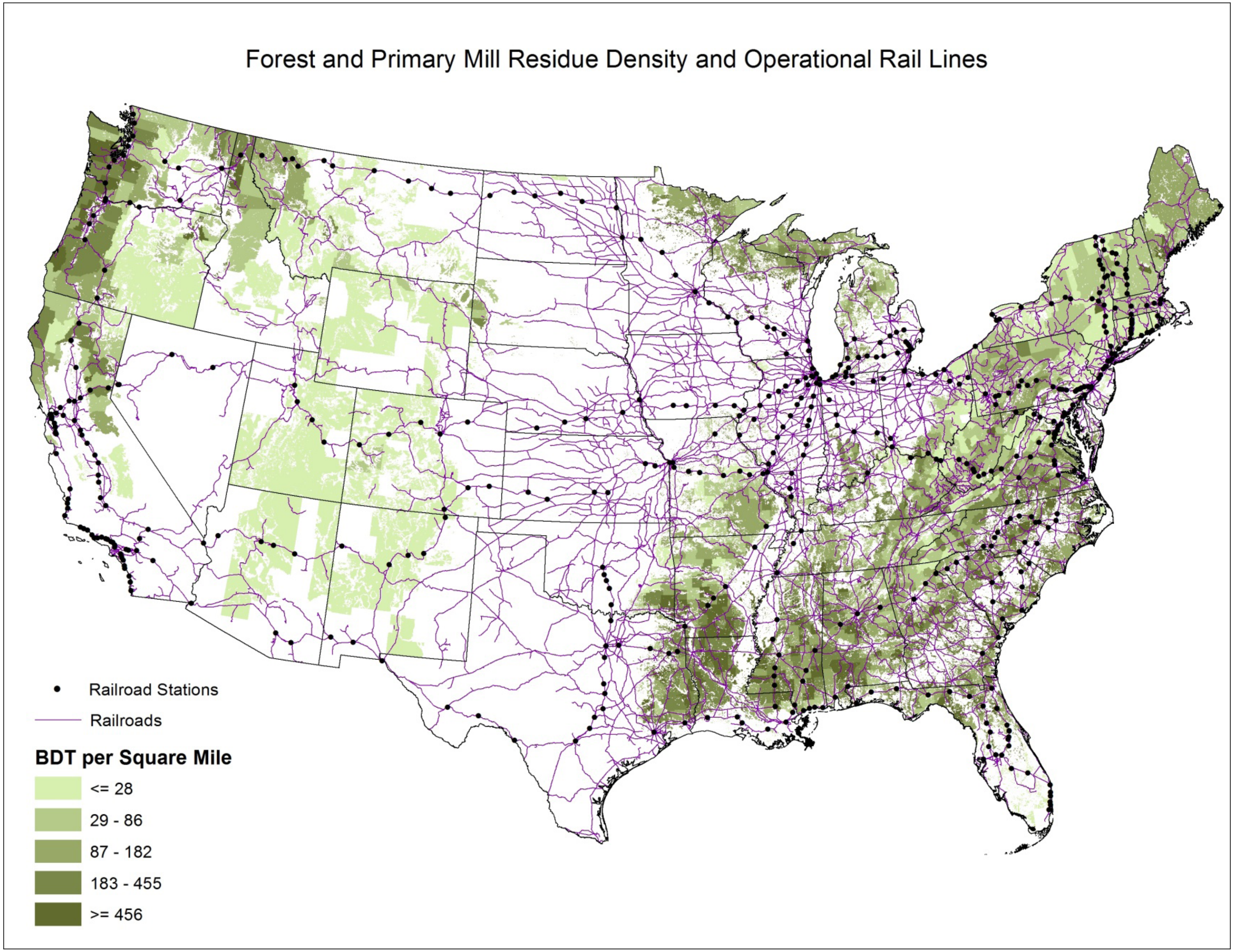
Future Work – Investigate Rail Delivery of Biomass



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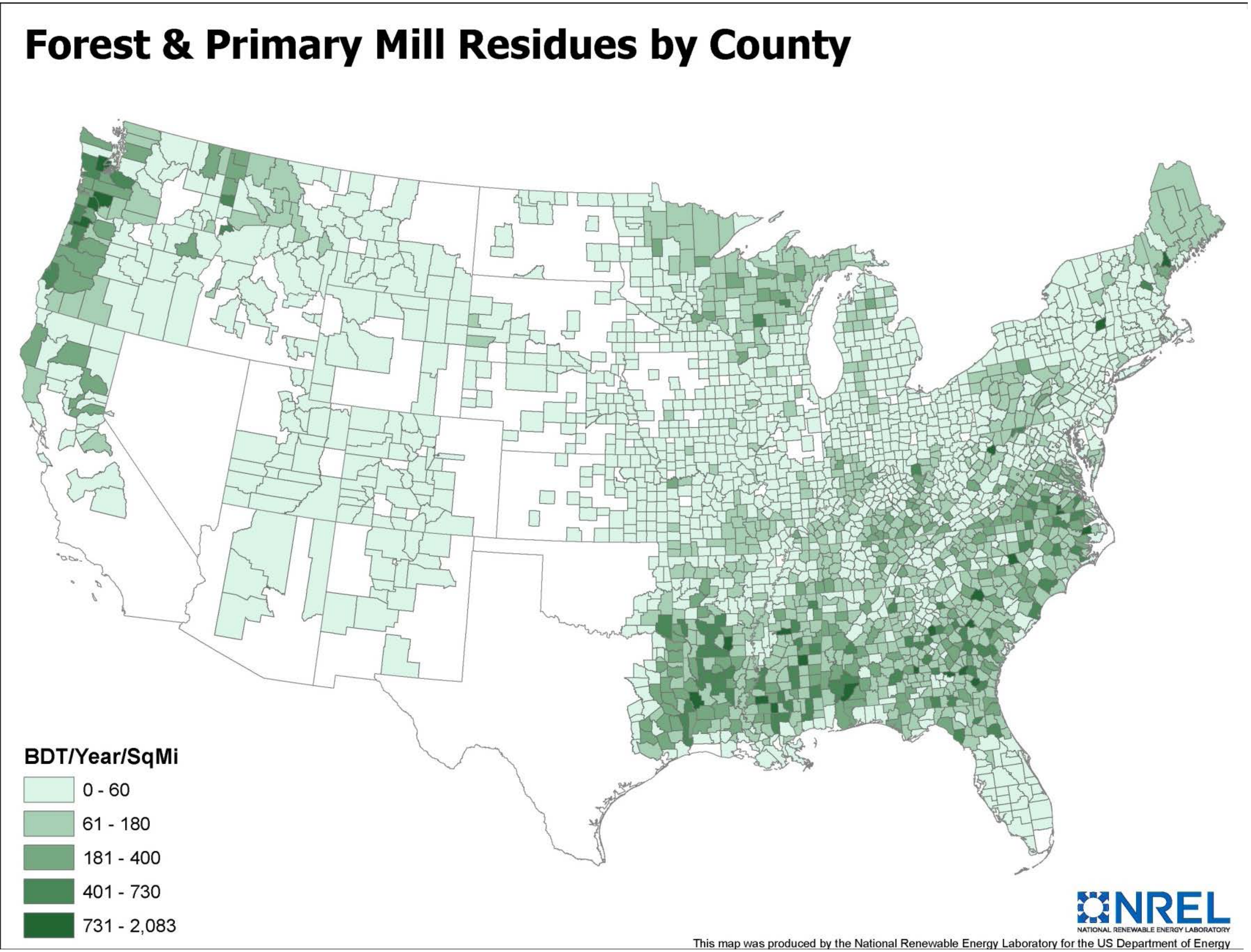
Assumptions & Data: Map Combined Forest and Primary Mill Resources



Hybrid poplar (with fertilization) ~3,500 BDT/SqMi/year. **Source:** Mann and Spath, *Life Cycle Assessment of a Biomass Gasification Combined-Cycle System*

Data – Woody Biomass Resources

- **Urban wood waste - Urban wood wastes include wood (discarded furniture, pallets, containers, packaging materials and lumber scraps), yard and tree trimmings, and construction and demolition wood. ORNL 2008 resource data by county**
- **Forest residues - This category includes logging residues and other removable material left after carrying out silviculture operations and site conversions. Logging residue comprises unused portions of trees, cut or killed by logging and left in the woods. Other removable materials are the unutilized volume of trees cut or killed during logging operations. Source: USDA, Forest Service's Timber Product Output database, 2007.**
- **Primary mill residues - Wood materials (coarse and fine) and bark generated at manufacturing plants (primary wood-using mills) when round wood products are processed into primary wood products, such as slabs, edgings, trimmings, sawdust, veneer clippings and cores, and pulp screenings. Source: USDA, Forest Service's Timber Product Output database, 2007.**
- **Secondary mill residues - Wood scraps and sawdust from woodworking shops — furniture factories, wood container and pallet mills, and wholesale lumberyards. Data on the number of businesses by county was gathered from the U.S. Census Bureau, 2002 County Business Patterns.**

Infrastructure Cost Equations – Transportation Distance

Variable	Units	Value	Notes
Plant feedrate	(dry metric tonnes [DM]/year)	727,472	01D_Current_Central_Hydrogen_Production_via_Biomass_Gasification_version_2.1.2.xls
Plant output	Kg/day	~155,000	
Land Productivity			See maps
Availability factor	%	From 10 to 100	Lower value of range based on Mann and Spath biomass gasification LCA, 1997 – 100% availability assumed for the preview analysis based on resource data.
Road tortuosity factor	none	1.3	Overend 1982

Data - Terrain Factors

Hydrogen and CO2 Pipeline Installation Terrain Cost Factors

CO2 Pipeline	
Terrain	**Factor**
cultivated land	1.1
grassland	1
wooded	1.05
jungle	1.1
stony desert	1.1
<20% Mountainous	1.3
>50% Mountainous	1.5

Source: McCollum 2006, Ogden 2004

Rail Spur Installation Terrain Cost Factors

Rail	
Terrain	**Factor**
Flat	718,331 $/mile
Rolling	1,527,470 $/mile
Mountainous	5,178,622 $/mile

Source: McCollum 2007, Burton 2004