Princeton's Net-Zero America study
Annex H: Bioenergy supply transition analysis

Ejeong Baik
Department of Energy Resources Engineering, Stanford University

Eric D. Larson
Andlinger Center for Energy and the Environment, Princeton University

11 August 2021

Table of Contents

Conversions used (unless otherwise noted)		**Abbreviations**	
GJ/dry Metric ton biomass (HHV)	19.80	**Million metric dry tons of biomass**	MMDT
GJ/MWh	0.2778	**Million metric ton of CO2**	MMT CO_2
MMBtu/MWh	3.412	**Metric ton**	t
Metric Ton/Short Ton	0.907	**Hectares**	Ha
		Acres	Acres

1 Introduction

Biomass is a critical feedstock for producing zero-carbon fuels such as hydrogen or drop-in liquid and gaseous fuels and for providing negative emissions in the net-zero pathways described in Princeton's Net-Zero America (NZA) study: in all five core scenarios for achieving net-zero emissions by 2050, all biomass potentially available for use for energy is utilized in 2050.

This downscaling analysis was undertaken to provide a detailed picture of how the biomass industry might develop across the US in the net-zero scenarios. The development and spatial distribution of the biomass conversion industry is particularly important because biomass production is highly specific to certain regions, and transportation of biomass is limited to relatively short distances because the low energy density of biomass makes transportation expensive. In our analysis here, understanding where future biomass feedstocks are available informs the painting of geo-specific representations of where future biomass conversion facilities are likely to be located over time across the US.

2 Biomass Supply Scenarios

Two scenarios are used for the potential supply of biomass available to the energy system in the NZA pathways modeling. The lower biomass potential (referred to here as the *delimited biomass potential*) includes agricultural residues, woody residues, and wastes (as projected in [1]), plus our own estimates of perennial energy grasses grown on lands converted over time from growing corn for ethanol and on Conservation Reserve Program lands. With these sources of biomass, the delimited biomass potential involves no change in land use for bioenergy production from current land uses. The higher biomass potential (referred to here as the *high biomass potential*) includes all the potential from the delimited case, plus additional energy crop biomass that requires some conversion of pasture and cropland, as projected in [1].

2.1 Billion Ton Study

The U.S. DOE's 2016 Billion Ton Study (BT16) [1] provides year-by-year county-level projections of biomass feedstocks potentially available for energy uses in the US through 2040. The biomass sources encompass agricultural residues, woody forest and mill residues, wastes, and both woody and herbaceous energy crops. The BT16 projections end in 2040, and for purposes of the NZA study the 2040 levels are assumed to be the maximum available in 2040 and beyond. In the high biomass potential estimate, the full BT16 potential is considered. Table 1 lists the biomass types included from BT16 in the two NZA supply scenarios.

BT16 projects biomass potential by county and estimates the supply available at different farm-gate cost levels. The distribution of currently utilized (in 2020) waste and woody biomass is assumed to be the BT16 potential in 2040 available at $30/dt. The distribution in each county from BT16 is then scaled to match 30 MMDT for waste and 170 MMDT for woody biomass [1]. The future herbaceous, wasted, and woody biomass potential is estimated to be the total biomass supply in 2040 up to a farm-gate price level of $100/dry short ton of biomass. BT16 presents different sets of projections that a user may choose from. The BT16 projections with the following characteristics were adopted for the NZA biomass supply analysis.

- '1% Basecase, all energy crops'
- 'Medium housing, medium energy demands'
- 'Wastes and other residues'

Table 2 provides a national summary of the resulting county-level potential from BT16 utilized in the downscaling process. These totals are in addition to the currently utilized biomass quantities noted above.

Only 62% of the corn stover estimates from the BT16 analysis are included in the delimited and high biomass potentials to account for the current 38% of corn stover that is utilized for producing corn ethanol [2].[a] Forest residues are included in both biomass supply potentials. In the high scenario some whole trees with small diameters are assumed to be harvested under assumptions of maintaining forestland and ensuring no land cover changes [1]. Plastics can be pyrolyzed into fuels as a method of reuse, and are included in the High Biomass case [1].

2.2 Corn Ethanol Lands

Land currently utilized to grow corn for ethanol is assumed to be available for conversion to perennial grass production for energy. The land areas continue to grow corn for ethanol until 2035, after which the land is made available for growing perennial grasses in linearly increasing amounts until all the corn ethanol land is available for grasses by 2050.

Currently, approximately 38% of corn grown in the US is converted to ethanol [2]. To estimate where this ethanol-corn is grown, and hence where land would become available for growing perennial energy grasses, the following methodology was utilized.

The analysis assumes that land conversion from corn to perennial grasses would occur only in the following 25 corn producing states: Alabama, Arkansas, Colorado, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Michigan, Minnesota, Mississippi, Nebraska, New York, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, and Wisconsin. These states accounted for 95% of the harvested corn land in the US in 2018 [4].

Estimates of county-level corn land harvested acreage are from the USDA census [3] (Figure 1). In the census, some counties are aggregated in an 'Other' category. The 'Other' category accounts for approximately 15% of the harvested corn land nationally. The harvested land estimates in the 'Other' counties cannot be attributed to individual counties, so the lignocellulosic production potentials in the identifiable counties are scaled up to account for additional production potential from harvested corn acreage from the unattributed 'Other' counties. The fraction of corn growing land dedicated to corn for ethanol in each county in the 25 states listed above was set at 42%. The national average fraction today is 38% across

[a] BT16 [1] assumes that corn yield increases by approximately 20% from 2014 to 2040, and land dedicated to corn production decreases by 11%. Overall, BT16 projects corn production to increase 6% from 2014 to 2040. For simplicity, our analysis assumes (for purposes of estimating stover potential) that corn grain production and stover-to-grain ratio remain constant at today's level and (for purposes of estimating area converted from growing corn for ethanol to growing perennial energy grasses) that acreage devoted to corn production (before considering conversion to perennial grasses) also remains at today's level. Making adjustments in our assumptions to exactly match BT16 assumptions would result in only small net differences in potential biomass availability.

all corn growing states. The increase to 42% for the analysis here accounts for the estimated energy crop production from the unidentified 'Other' counties.

Table 1 Summary of resource types considered in the delimited and high biomass cases.

Resource Type	Resource	Biomass Potential Case
Herbaceous	Wheat straw	Delimited and High Case
Herbaceous	Rice straw	Delimited and High Case
Herbaceous	Cotton residue	Delimited and High Case
Herbaceous	Sugarcane bagasse	Delimited and High Case
Herbaceous	Cotton gin trash	Delimited and High Case
Herbaceous	Rice hulls	Delimited and High Case
Herbaceous	Sorghum stubble	Delimited and High Case
Herbaceous	Sugarcane trash	Delimited and High Case
Herbaceous	Barley straw	Delimited and High Case
Herbaceous	Oats straw	Delimited and High Case
Waste	Paper and paperboard	Delimited and High Case
Waste	Textiles	Delimited and High Case
Waste	Food waste	Delimited and High Case
Waste	Rubber and leather	Delimited and High Case
Waste	Yard trimmings	Delimited and High Case
Waste	Noncitrus residues	Delimited and High Case
Waste	Tree nut residues	Delimited and High Case
Waste	Citrus residues	Delimited and High Case
Waste	Existing Uses	Delimited and High Case
Woody	Other forest residue	Delimited and High Case
Woody	Other forest thinnings	Delimited and High Case
Woody	Softwood, natural logging residues	Delimited and High Case
Woody	Secondary mill residue	Delimited and High Case
Woody	Softwood, planted logging residues	Delimited and High Case
Woody	Hardwood, lowland logging residues	Delimited and High Case
Woody	Hardwood, upland logging residues	Delimited and High Case
Woody	Mixedwood logging residues	Delimited and High Case
Woody	Primary mill residue	Delimited and High Case
Woody	Pine*	Delimited and High Case
Woody	Existing Uses	Delimited and High Case
Herbaceous	Corn stover*	Delimited and High Case
Herbaceous (Energy Crop)	Miscanthus	High Case
Herbaceous (Energy Crop)	Switchgrass	High Case
Herbaceous (Energy Crop)	Biomass sorghum	High Case
Herbaceous (Energy Crop)	Energy cane	High Case
Waste	Plastics	High Case
Woody (Energy Crop)	Poplar	High Case
Woody (Energy Crop)	Willow	High Case
Woody	Hardwood, upland whole trees	High Case
Woody	Hardwood, lowland whole trees	High Case
Woody	Softwood, planted whole trees	High Case
Woody	Softwood, natural whole trees	High Case
Woody	Mixedwood whole trees	High Case
Woody (Energy Crop)	Eucalyptus	High Case

* **Pine** refers to trees grown on managed plantations. BT16 reports this resource in such a way that a small amount has been included in the delimited case (0.004 of approximately 700 million t/y total biomass potential). A larger quantity is included in the high case.
For **corn stover**, 62% of the BT16 estimated supply potential is included in the delimited and high cases, since corn grown for ethanol is replaced in those cases by production of perennial energy grasses. Since 38% of corn produced today is used for ethanol production, we a ssume that only 62% of stover supply projected in BT16 is available in the NZAP biomass scenarios.

Table 2 Summary of biomass supply potentials by type from BT16 in the delimited and high biomass cases [MMDT]

	Herbaceous	Waste	Woody	Total
Delimited	143	65	214	422
High	692	96	341	1,130

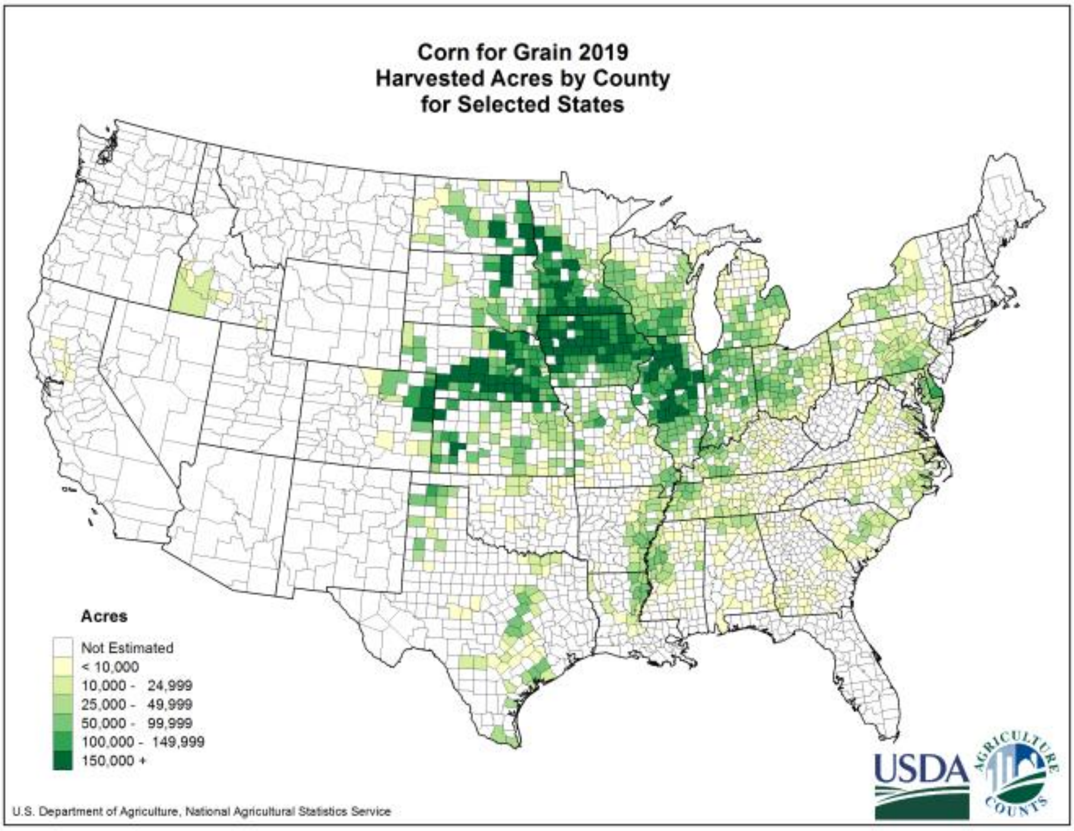


Figure 1 Distribution of harvested corn acreage by county, taken from USDA [4]

The state-average yields for lignocellulosic crops from corn ethanol lands in the 25 states were estimated by visual inspection from maps in Lee *et al*. [5] showing geo-spatially differentiated maximum estimated yields for herbaceous energy feedstocks (switchgrass or Miscanthus) based on an extensive collection of field trial data [5]. Our assumed state-average yields range from 3.2 t/acre to 10.1 t/acre, with an average across all states of 7.6 t/acre (Table 3). The resulting production potential of perennial grasses on former corn-ethanol lands is estimated to be 214 MMDT in both the delimited and high biomass cases.

Table 3 . Summary of assumed yield from corn ethanol lands by state

	Yield [t/acre]		**Yield [t/acre]**
Alabama	10.1	Nebraska	5.7
Arkansas	10.1	New York	5.7
Colorado	3.2	North Carolina	8.1
Georgia	8.1	North Dakota	4.9
Illinois	8.9	Ohio	8.1
Indiana	10.1	Oklahoma	4.0
Iowa	8.9	Pennsylvania	5.7
Kansas	7.3	South Carolina	8.1
Kentucky	8.9	South Dakota	4.9
Louisiana	10.1	Tennessee	10.1
Michigan	8.9	Texas	4.9
Minnesota	7.3	Wisconsin	8.1
Mississippi	10.1	**Total**	**7.6**

2.3 Conservation Reserve Program (CRP) Lands

The CRP is a land conservation program administered by the USDA Farm Service Agency to remove environmentally sensitive lands from agricultural production for improving environmental health and quality of lands including but not limited to water quality, soil erosion, and loss of wildlife habitat [6]. The enrollment period is 10-15 years, and between 1990-2018, an average of 30 million acres of land across the US was enrolled in the CRP program [7]. Conservation Reservation Program Lands (hereafter CRP lands) are often suitable for growing perennial energy crops while still providing conservation services [8]. The roots of most perennial lignocellulosic crops help reduce erosion, stream sedimentation, and nutrient loss by stabilizing soils [9]. Utilizing CRP lands for energy presents no competition for the land to be used for food or fodder production [5].

Based on historic enrollment averages, 30 million acres of CRP land are assumed to be gradually transitioned for crop production by 2050, with a county-level distribution that matches the CRP land enrollment pattern in 2017 (Figure 2) [7]. The annual yield of lignocellulosic biomass from CRP lands by state is taken from Lee et al. (2018)'s biomass yield potential of mixed grasses on CRP lands, and is on average estimated to be 2.6 t/ha [5]. The low yields of energy crops from CRP lands are based on field trials that were managed according to CRP regulations with no nitrogen fertilization [5]. The resulting biomass potential from CRP lands nationally is estimated to be a relatively modest 30 MMDT for both the delimited and high biomass cases.

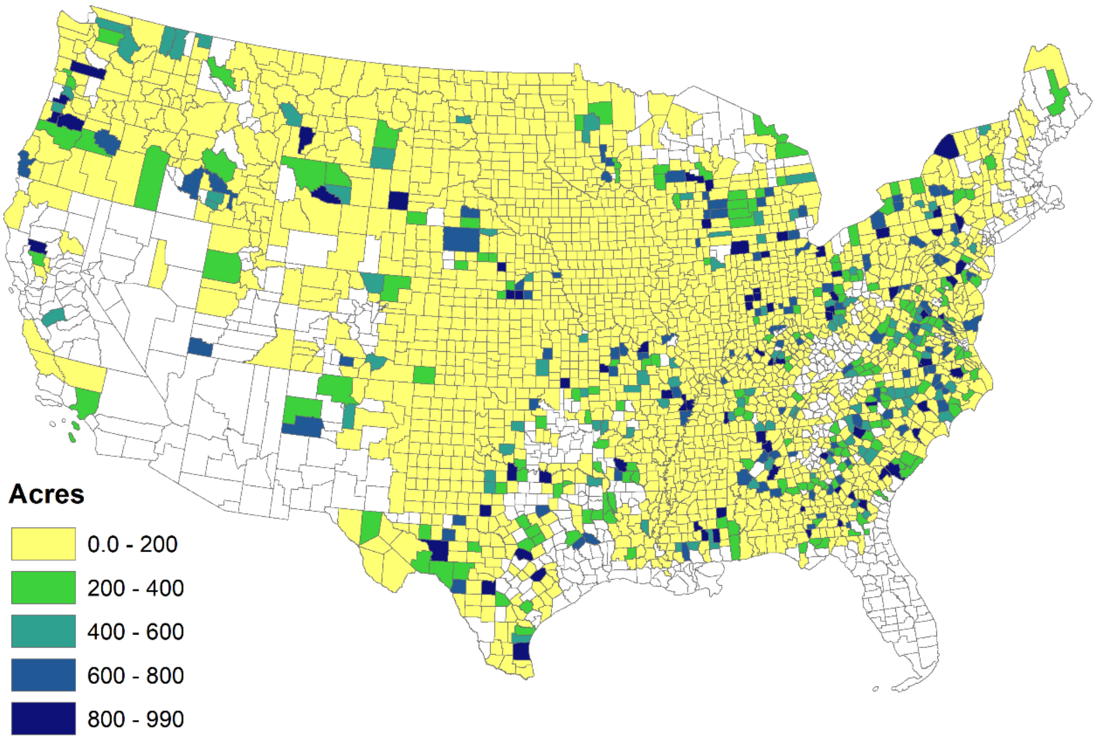


Figure 2 Distribution of CRP lands by county in 2017, taken from USDA [7]

2.4 Summary of biomass supply potentials

The contributions by type of biomass to the total supply potential for the delimited and high cases are shown in Figure 3.

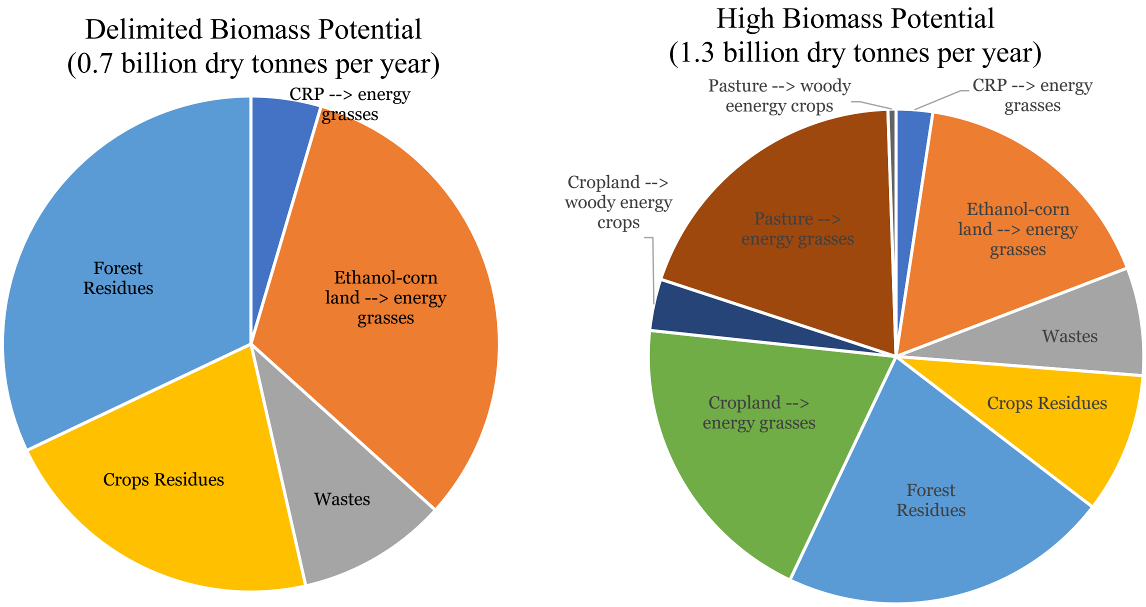


Figure 3 Share of biomass sources in the delimited and high biomass cases

Biomass availability is widespread across the US but particularly significant in the upper Midwest, where there is a significant share of agricultural residue and corn-growing lands. In the high biomass case, additionally the South/Southeast regions are also significant contributors from energy crops grown on converted crop and pasture lands [1] (Figure 4 and 5).

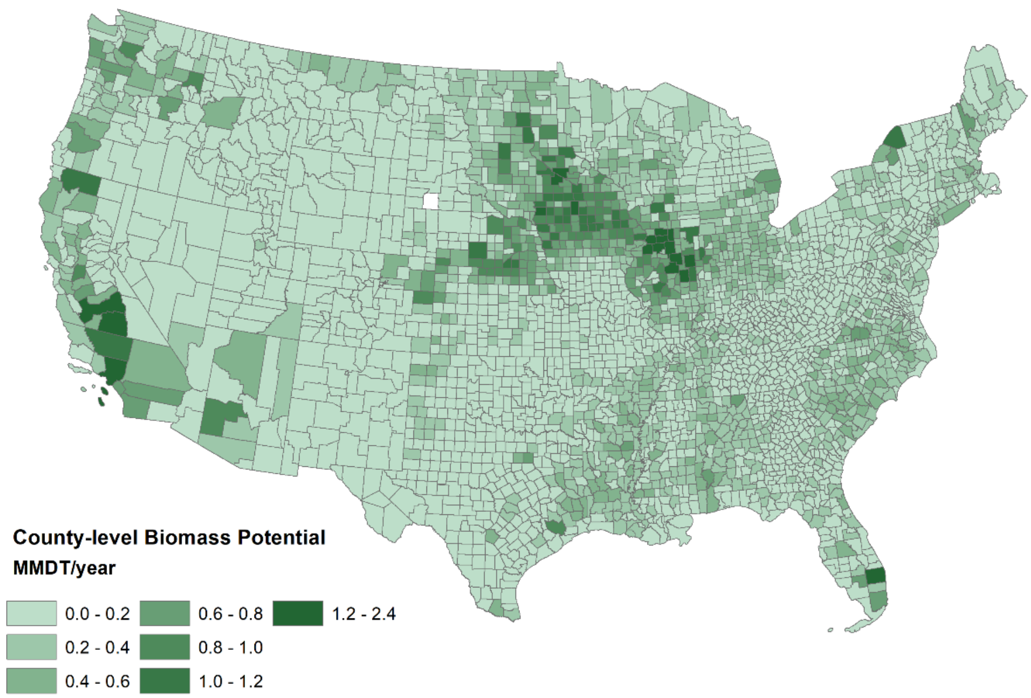


Figure 4 County-level biomass potential in the U.S. in 2050 for delimited biomass case

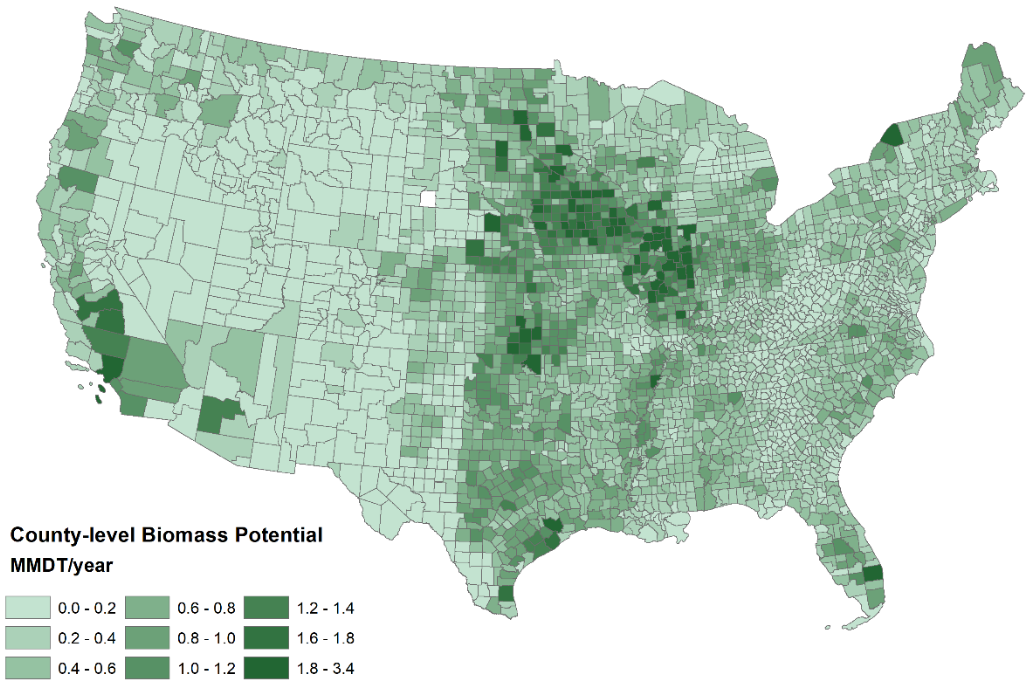


Figure 5 County-level biomass potential in the U.S. in 2050 for high biomass case

Figure 6 and 7 are national biomass cost-supply curves for delivered biomass as used in the net-zero pathways modeling work. These curves use BT16 farm-gate costs for all biomass feedstock potentials estimated from the BT16 projections. An additional $40/t transportation cost is also assumed for woody and herbaceous resources to arrive at delivered costs. Wastes are assumed to be used where produced, i.e., without being transported, or assumed to carry tipping fees that offset transportation costs. Energy grasses from converted corn-ethanol lands are assumed to have delivered costs of $75/t and those from CRP lands of $99/t.

The supply curve for each state is utilized to calculate a weighted average cost of biomass for each state. Table 4 summarizes the weighted average delivered costs per tonne of biomass for the delimited and high biomass cases by state. The high biomass case shows overall higher costs due to the increase in more costly energy crop supply from the BT16 analysis. Appendix H1 and H2 have state-level biomass supply curves in 2050 for the Delimited and High Biomass cases, respectively.

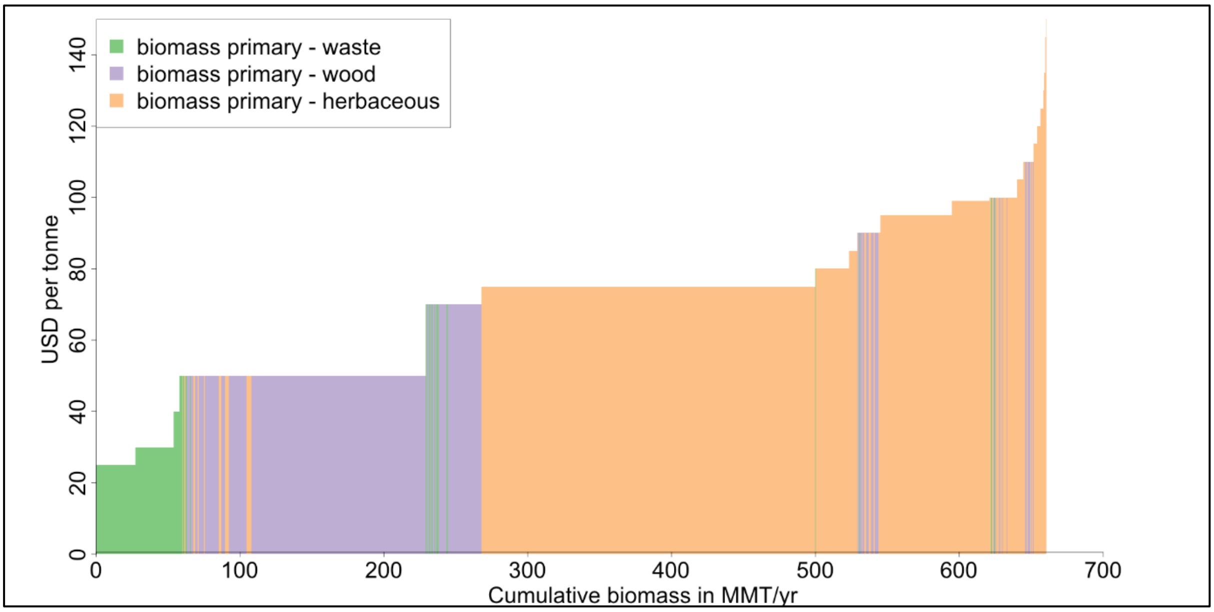


Figure 6. 2050 national biomass cost-supply potential, delimited biomass case; delivered costs in 2016 $/t, including an assumed $40/t for delivery.

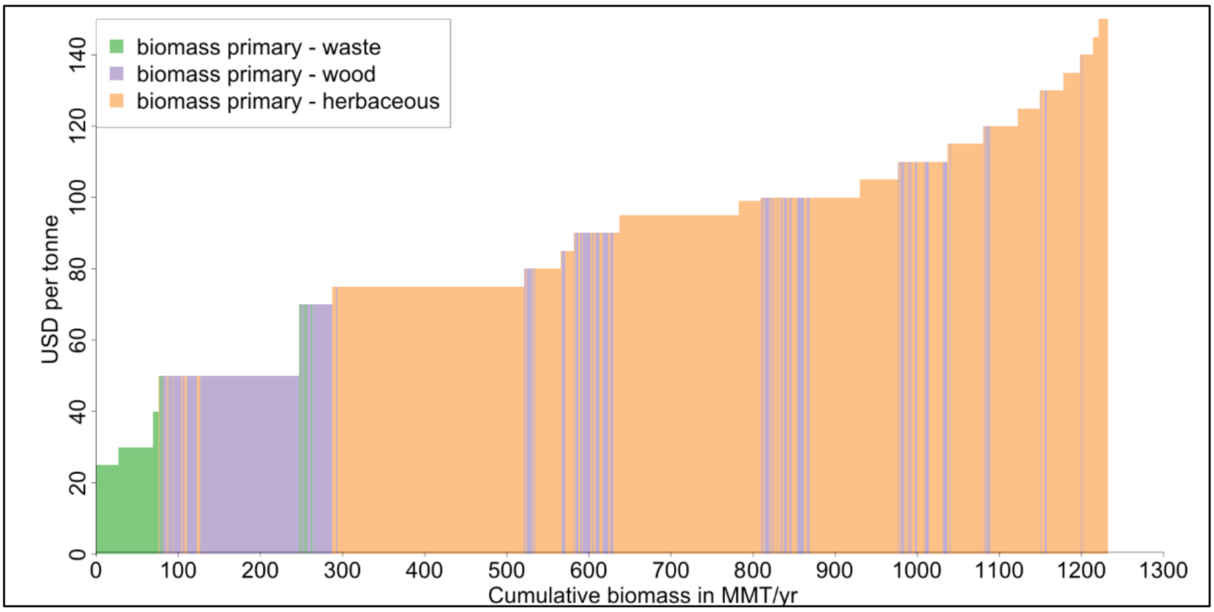


Figure 7 2050 national biomass cost-supply potential, high biomass case; delivered costs in 2016 $/t, including an assumed $40/t for delivery.

Table 4 Weighted average delivered costs by state (2016 $/t).

State	Delimited Biomass Case	High Biomass Case
Alabama	$ 59	$ 95
Arizona	$ 63	$ 91
Arkansas	$ 59	$ 96
California	$ 39	$ 35
Colorado	$ 80	$ 99
Connecticut	$ 41	$ 75
Delaware	$ 66	$ 107
District Of Columbia	$ 41	$ 70
Florida	$ 54	$ 98
Georgia	$ 56	$ 92
Idaho	$ 75	$ 93
Illinois	$ 78	$ 112
Indiana	$ 76	$ 114
Iowa	$ 81	$ 111
Kansas	$ 78	$ 102
Kentucky	$ 63	$ 102
Louisiana	$ 63	$ 94
Maine	$ 53	$ 101
Maryland	$ 52	$ 108
Massachusetts	$ 44	$ 80
Michigan	$ 72	$ 107
Minnesota	$ 82	$ 106
Mississippi	$ 62	$ 98
Missouri	$ 64	$ 103
Montana	$ 89	$ 97
Nebraska	$ 79	$ 90
Nevada	$ 78	$ 104
New Hampshire	$ 52	$ 94
New Jersey	$ 39	$ 100
New Mexico	$ 79	$ 99
New York	$ 55	$ 104
North Carolina	$ 55	$ 92
North Dakota	$ 84	$ 101
Ohio	$ 73	$ 111
Oklahoma	$ 65	$ 103
Oregon	$ 62	$ 84
Pennsylvania	$ 56	$ 105
Rhode Island	$ 45	$ 85
South Carolina	$ 57	$ 90
South Dakota	$ 79	$ 93
Tennessee	$ 60	$ 102
Texas	$ 62	$ 101
Utah	$ 81	$ 102
Vermont	$ 55	$ 107
Virginia	$ 53	$ 102
Washington	$ 62	$ 82
West Virginia	$ 52	$ 104
Wisconsin	$ 74	$ 106
Wyoming	$ 77	$ 98

3 Fishnet Analysis

Transporting biomass is relatively expensive due to its low bulk density and, in some cases, high moisture content. Biomass conversion facilities are thus generally sited relatively close to biomass sources. To assist with siting of bioconversion plants, we first partition the U.S. into grid cells 100 x 100 miles in size using the ArcGIS 'Fishnet' function. To reflect biomass transportation limitations, we assume that biomass produced within each fishnet cell is utilized within that cell. There are approximately 600 fishnet grid cells across the continental U.S.

The biomass supply potential in a fishnet cell is derived from the county-level biomass potential discussed in Section 2. The total biomass potential in a county is split and assigned to the fishnet cells that intersect the county by the fractional area of the county within each cell. The average density of biomass supply potential in a county (t/ha-y) is multiplied by the fractional area of a county within a fishnet cell to find the biomass supply potential from each county attributed to the given fishnet cell. The estimated fractional biomass supply potentials from each county intersecting a fishnet cell are summed to calculate the overall biomass supply potential from each fishnet cell.[b]

The resulting fishnet cells with the lowest densities (t/acre) of biomass supply are removed from consideration on the assumption that biomass gathering and transporting costs would be prohibitive in such areas. For the high biomass case, 98% of the overall biomass potential is retained after removing 35% of the lowest producing counties. The removal percentage is 32% in the delimited case for retaining 98% of the overall biomass potential. Figure 8 and 9 show the resulting fishnet-level biomass supply potentials in 2050 for the delimited and high biomass cases.

Each fishnet cell is associated with the state in which its centroid is located for purposes of aggregating fishnet-level results by state. State-level biomass results are utilized in the employment analysis [10], as well as to calculate state-level capital investments in biomass conversion facilities and annual biomass purchases. In some cases, a fishnet cell straddles one or more states, but its full biomass supply potential is associated with the state in which its centroid falls. The error introduced is small, since most high biomass producing states are large.

Biomass supply potentials at the fishnet cell level are used for siting of biomass conversion facilities called for in the modeled net-zero pathways, as described in the next section.

[b] ArcMap's 'Join' function is utilized to find the proportional area of a county in each fishnet cell. Once the biomass supply potential in a proportional county area is found, the 'Merge' function is utilized to add biomass supply potentials across all the proportional counties in a given fishnet cell.

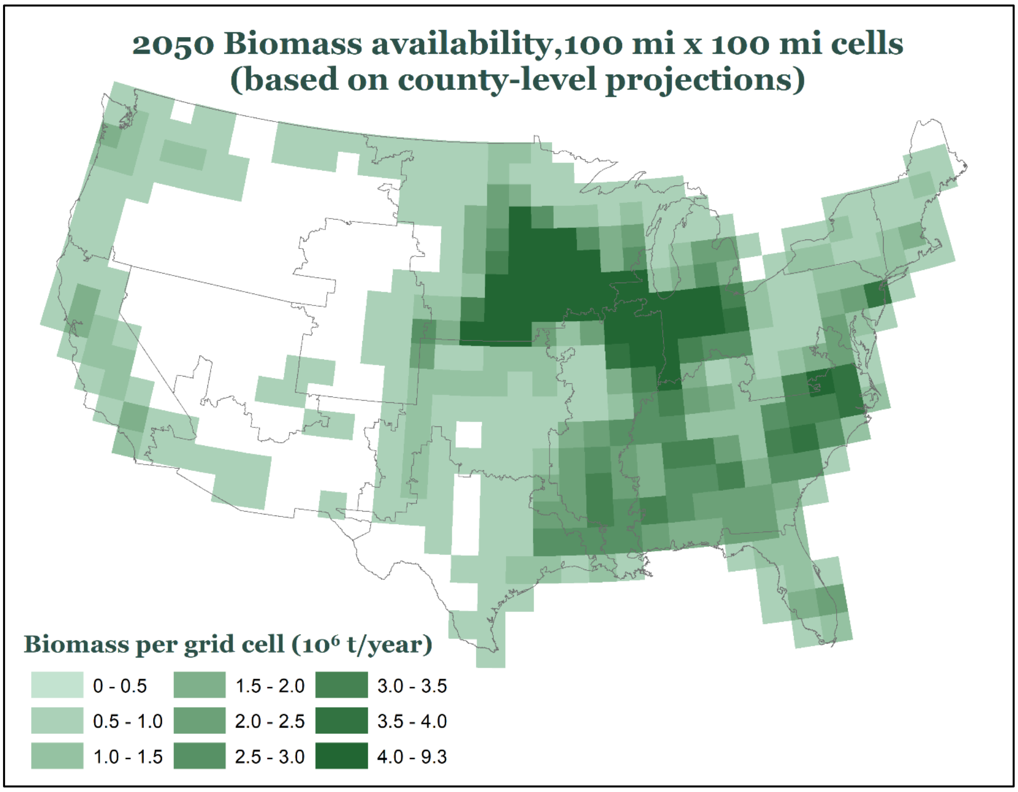


Figure 8. 2050 Biomass potential by fishnet for the delimited biomass case

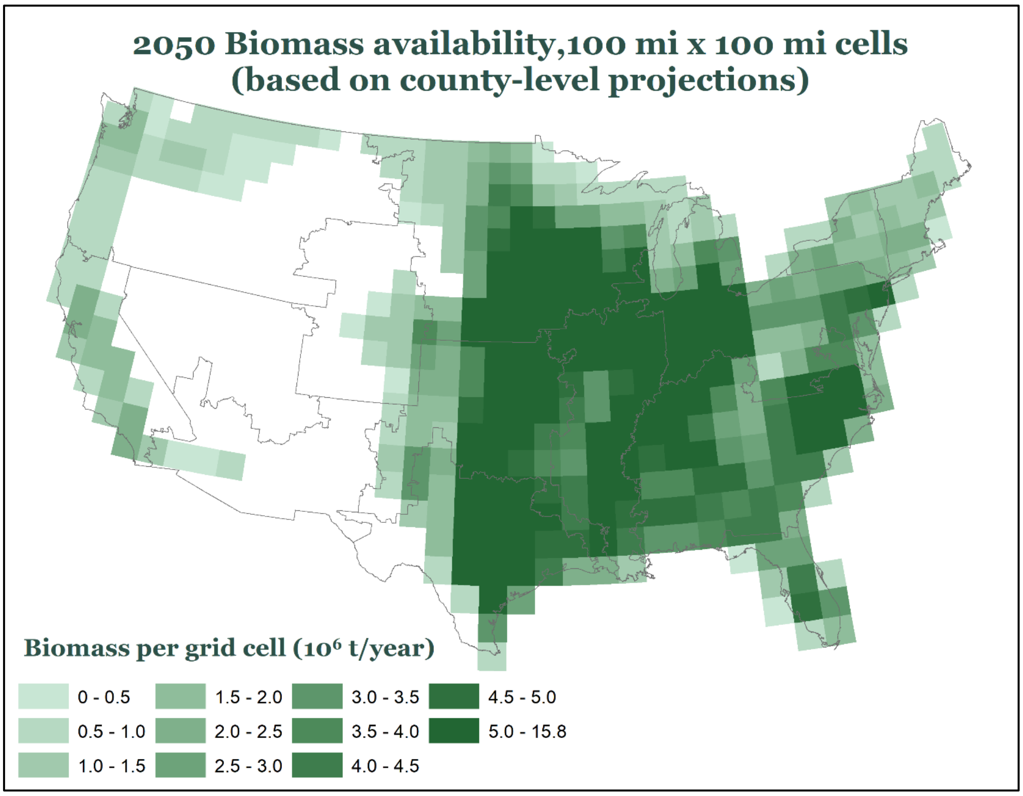


Figure 9. 2050 Biomass potential by fishnet for the high biomass case

4 Siting Biomass Conversion Facilities Analysis

In the future, with the development of CCUS in the U.S. and an increasing need for carbon-neutral and negative fuels, various types of biomass conversion technologies will be needed to reach a net-zero carbon economy. The range of biomass conversion technologies considered in the analysis and their energy products are summarized in Table 5. More than half of the considered biomass conversion technology options utilize carbon capture (CC).

Table 5 Description of new biomass conversion facility types and energy products

Bioconversion Technology	Carbon Capture?	Primary Energy Products
Gasification H_2 w/ CC	Yes	Hydrogen
Pyrolysis w/ CC	Yes	Synthetic petroleum coke blend, coal blend, coke blend, oil blend
Pyrolysis		Synthetic petroleum coke blend, coal blend, coke blend, oil blend
Gasification SNG w/ CC	Yes	Synthetic Natural Gas
Gasification SNG		Synthetic Natural Gas
Gasification Fischer-Tropsch w/ CC	Yes	Synthetic Diesel, Jet fuel, LPG, Oil
Gasification Fischer-Tropsch		Synthetic Diesel, Jet fuel, LPG, Oil
Power w/ CC	Yes	Electricity
Power		Electricity
Gasification Allam Power w/ CC	Yes	Electricity

The regional levels of deployment of biomass conversion technologies projected for two of the modeled net-zero emissions pathways (E+ and E-B+) are downscaled here to show at finer geospatial resolution how an advanced bioenergy industry might evolve in the U.S. The biomass supply potential in the E+ scenario corresponds to the delimited supply potential described above. The E-B+ scenario utilizes a supply potential corresponding to the high biomass potential described above.

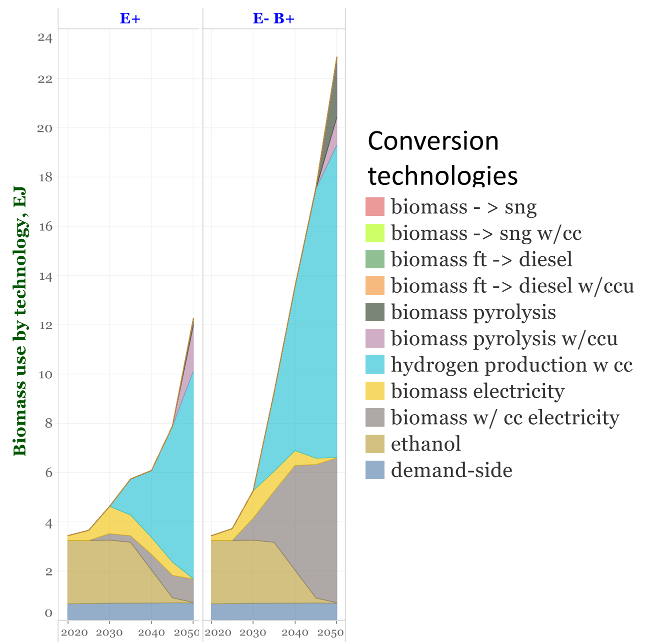


Figure 10 Biomass-energy conversion technologies used over time in two net-zero scenarios.

In both the E+ and E-B+ scenarios, the available biomass supply potential is fully utilized by 2050. Figure 10 shows the biomass use by technology over time. In both scenarios, corn ethanol output declines beginning from 2035, and use of other biomass does not begin to grow significantly until 2030. As corn ethanol output decreases, the associated land transitions to perennial grass production, as total biomass use continues to grow. Table 6 summarizes the total non-food biomass utilization every five years from 2020 to 2050.

For the bioconversion siting analysis, the energy content of biomass input into each type of biomass conversion technology is converted to metric ton of dry biomass input on an annual basis. In the net-zero pathway modeling, biomass input is not distinguished by source or type; simplistically, the modeling assumes that any type of biomass may be used in any conversion technology. In the 14-region net-zero pathway modeling, biomass produced in a region is constrained to be used in that region.

Table 6. Total biomass utilization from 2020 to 2050 in 5 year time steps for E+ and E-B+ scenarios. Units are in Exajoules [EJ].

	2020	2025	2030	2035	2040	2045	2050
E+	0.8	0.9	1.6	2.9	4.4	7.4	12.2
E-B+	0.8	0.9	2.2	6.4	11.9	17.2	22.8

4.1 Reconciling region- and fishnet-level biomass supply potentials

Each fishnet cell and associated biomass supply potential as determined in Section 3 is initially assigned to one of the 14 regions based the location of the fishnet-cell centroid. This results in slight differences between the fishnet-based biomass supply estimate for a region and the biomass supply estimated in the net-zero pathway modeling. The discrepancies arise from two factors. First, for the net-zero pathways modeling, state-level averaged biomass supply potentials were assigned to one of the 14 regions based on the fraction of states' areas in that region, whereas the fishnet analysis takes a more granular approach, assigning biomass from each county and fishnet cell to one of the 14 regions based on the centroid of the fishnet. The granular approach captures varying biomass production densities within a state, which may result in slight discrepancies from taking an averaged approach. Second, a single fishnet may cross more than one region, but the associated biomass is attributed to a single region than being divided accordingly. To adjust for this overall difference, some fishnets that border two or more regions are assigned in their entirely to one or the other of the regions (independent of its centroid location) so as to ensure that the overall biomass supply at the regional level in the net-zero modeling is consistent with the biomass potential estimate based on the fishnets analysis. Figure 11 shows the modified designation of the fishnets relative to the boundaries of the 14 model regions.

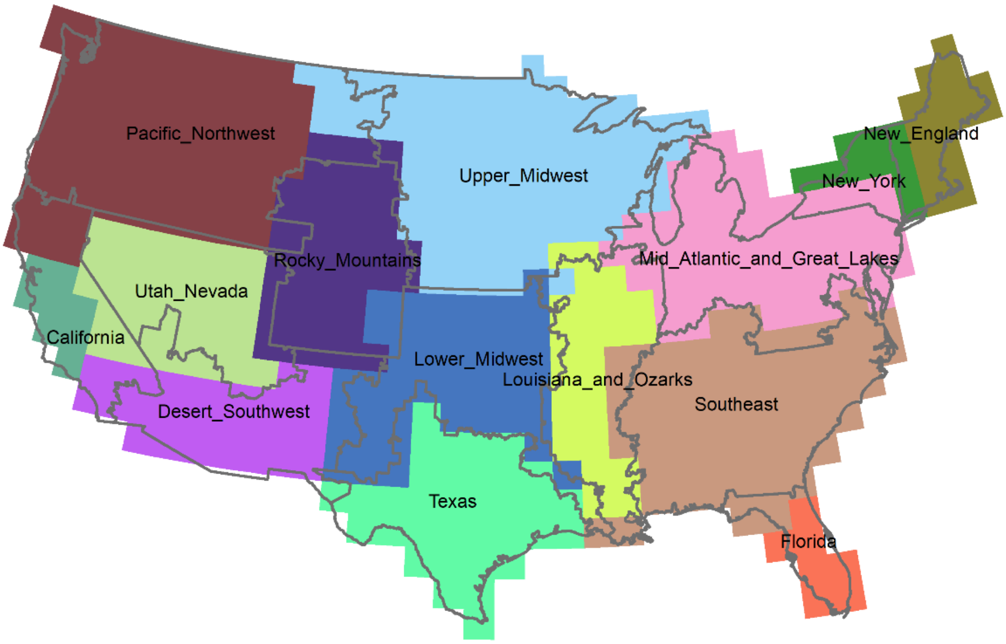


Figure 11 Reconciling biomass supply potentials of fishnet and net-zero pathway model regions.

4.2 Siting Analysis

The objective of the siting analysis is to downscale the annual additions of all biomass conversion facilities from the continental US 14-region level to the fishnet cell level. Overall, the siting analysis assumes that biomass facilities would first deploy in areas with the highest biomass supply density (t/y per fishnet cell) and be sited near storage or CO_2 pipeline networks if the facility captures CO_2. This section provides a detailed description of the downscaling method.

Note that this downscaling method does not include demand-side biomass usage, such as residential heating. As a result, there is excess biomass in each region that is not allocated, largely in the low-density areas of each region, and this is assumed to be utilized for demand-side purposes. Furthermore, the downscaling method only accounts for net addition of biomass usage in all facilities relative to the previous year, and does not conduct a detailed downscaling of the decrease in biomass usage in facilities such as ethanol plants. For some facilities such as biomass power plants, SNG, and SNG w/ CCU plants that have increasing and decreasing biomass usage across years, the downscaling method only considers net additions in biomass usage. This introduces small discrepancies between the biomass usage in the downscaled results relative to results from the RIO modeling, but overall constitutes a small percentage of the overall biomass usage. Total installed stock of biomass conversion facilities by technology type are provided on a regional basis for 5-year increments from 2020 to 2050 from the RIO modeling.

Figure 12 and Figure 13 show the biomass consumption by region and technology in 2050 for the E+ and E-B+ scenarios. For each fishnet cell, the following characteristics are defined: biomass potential (MMDT/year), biomass density (MMDT/y/mile^2), and distance (miles) to the closest CO_2 trunk pipeline or storage site. The locations of trunk pipelines and storage sites are taken from the CO_2 transport and storage siting work described elsewhere [11]. Each fishnet cell is placed in a bucket that stipulates the distance from its centroid to the nearest

CO_2 pipeline or storage site: 0 mi, 0-250mi, 250-500mi, 500-1,000 mi, 1,000-1,500 mi, 1,500-2,000 mi or >2,500 mi. For 0 distance, the centroid is on top of a storage site or within 50 miles of a storage pipeline.[c]

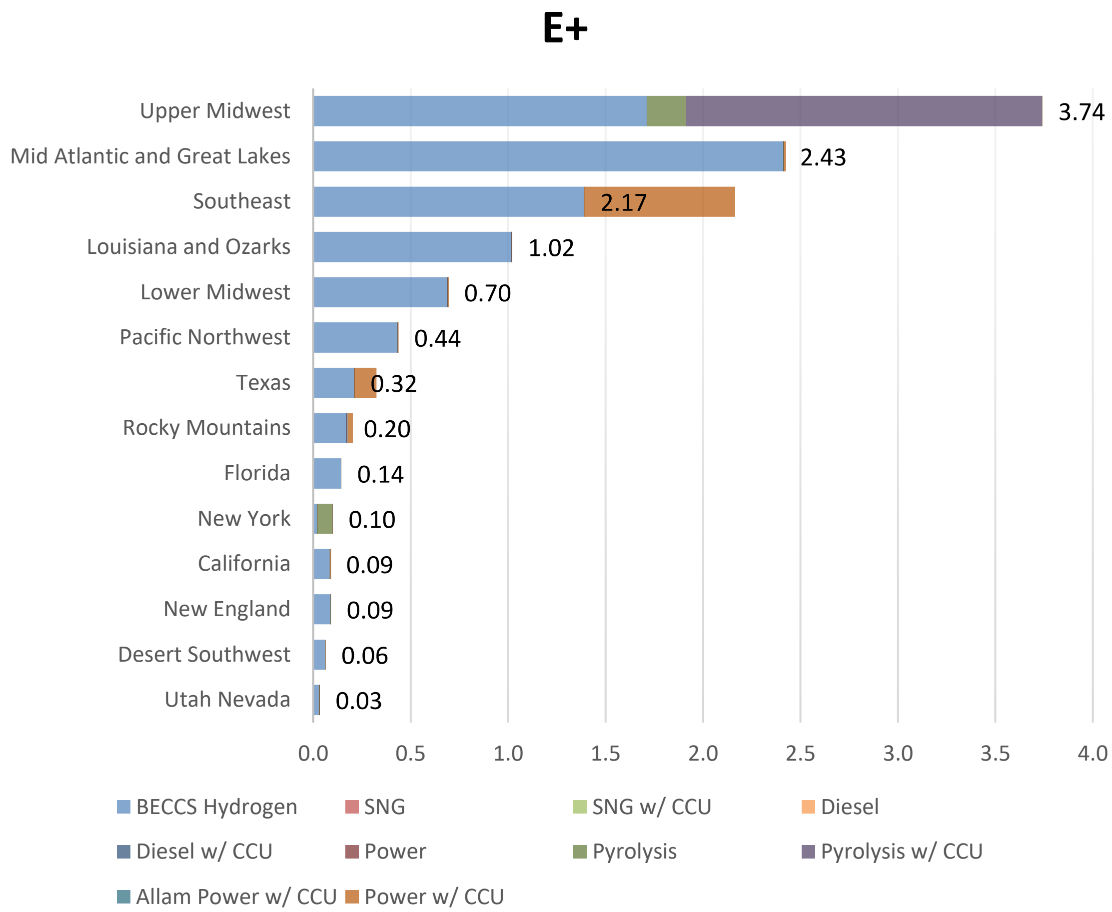


Figure 12 Biomass consumption (EJ) in each region by conversion technology type in 2050 for E+ scenario

[c] A facility can be located anywhere within a fishnet, and can be located conveniently near a pipeline within a fishnet. As long as the CO_2 trunk pipeline is within a fishnet, the fishnet and associated facilities are considered 0 distance to the pipeline.

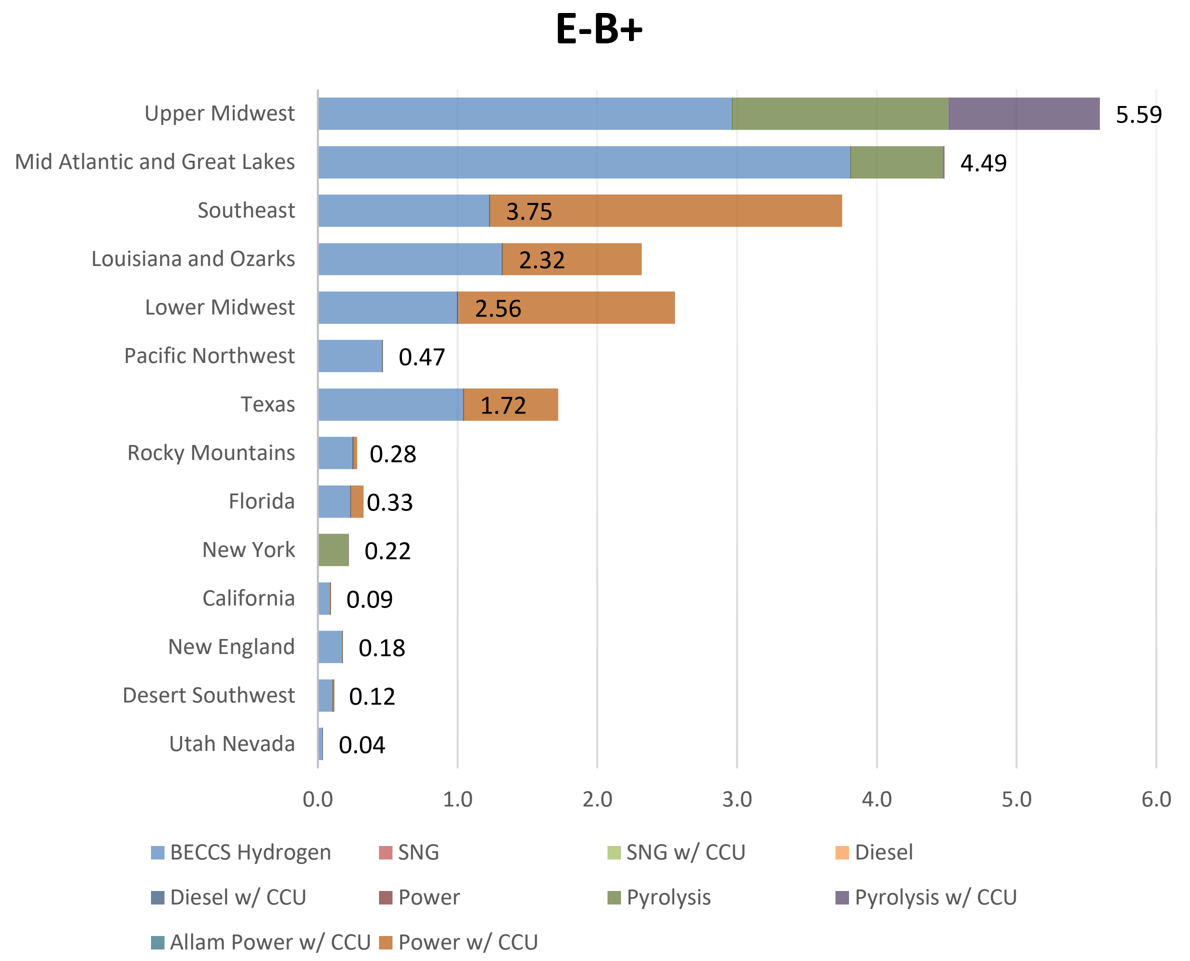


Figure 13 Biomass consumption (EJ) in each region by conversion technology type in 2050 for E-B+ scenario

The siting of biomass conversion facilities is conducted starting from 2020 and progresses in five-year time steps to 2050. The siting algorithm is depicted as a flowchart in Figure 14. Facilities that capture CO_2 are sited first in fishnet cells that fall in the distance-buckets closest to CO_2 pipelines or transportation infrastructure. Within a bucket, facilities are sited first in the fishnet cell having the highest biomass density. Once all the biomass supply potential within a bucket has been assigned to facilities, the siting algorithm progressively chooses the next closest bucket and sites facilities in the highest density areas within that bucket. Meanwhile, facilities that do not capture CO_2 are sited in the farthest bucket first and are progressively sited in the next closer bucket if needed. In a given year, the facility type that collectively uses the highest amount of biomass in 2050 is sited first. Once all facilities are sited for a single year, the algorithm continues to the next year and repeats the siting process. A facility that is assigned a biomass supply in an earlier year is assumed to continue operating in the future and its biomass supply cannot be re-assigned to other facilities in future years.

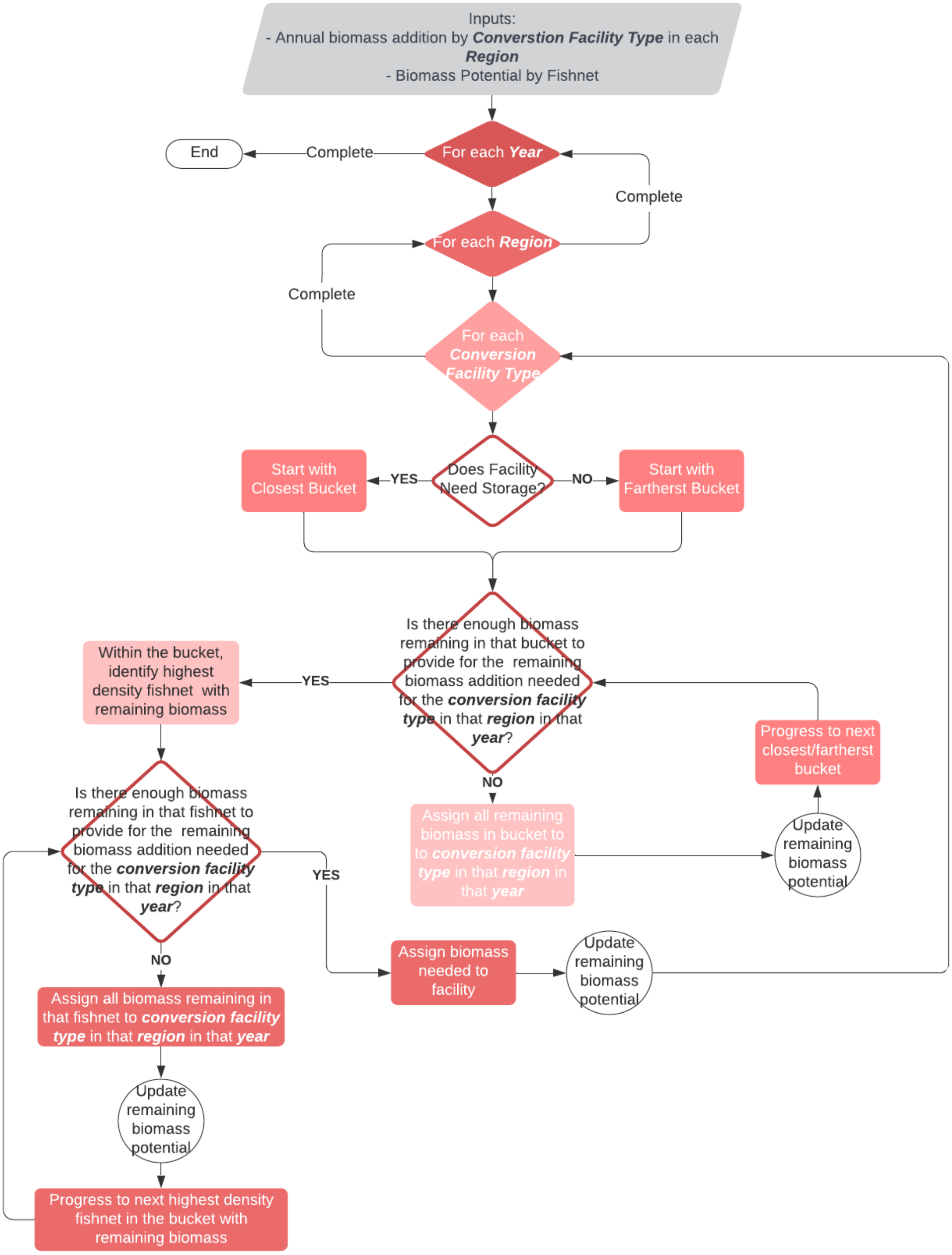


Figure 14 Visualization of the siting algorithm

Once all biomass supply has been assigned to different technology types, the size (capacity) and number of individual facilities of each type within a fishnet cell are estimated for 2050. The sizing analysis assumes that a typical biomass facility, regardless of conversion type, uses approximately 0.7 MMDT biomass per year. The siting analysis outputs biomass utilized in each fishnet cell by each technology type every 5 years. In a given year, some technology types within a fishnet cell will have less than 0.7 MMDT biomass attributed to it. In that case, only one facility of that type is deployed, and its size is the level of biomass attributed to that technology type. If a fishnet cell contains more than 0.7 MMDT biomass attributed to a single technology type, then the total biomass attributed to that type is divided by 0.7 MMDT and rounded down to estimate the number of facilities of that type. The average size of the facilities for that type in a fishnet cell is determined by dividing the total biomass assigned to that technology type by the calculated number of facilities. This results in some facilities using more than 0.7 MMDT/y in some cases. Figures 15 and 16 summarize the size of all biomass conversion facilities in 2050 for the E+ and E-B+ scenarios. Most facilities are approximately 0.7 MMDT/yr in size, but there are also a number of smaller facilities that are generally conversion technologies with little biomass use in each region. With our methodology facilities processing 0.4 MMDT/y or more account for processing of 97% of the biomass supply in 2050 in the E+ case and 99% in the E-B+ case.

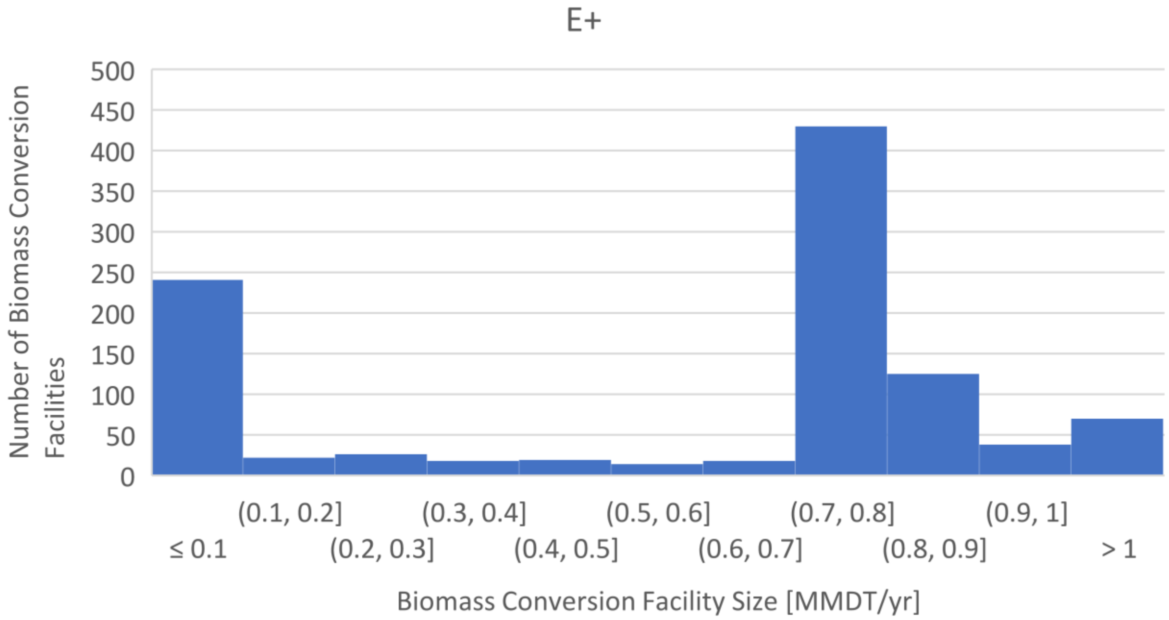


Figure 15 Size distribution of biomass conversion facilities for E+ scenario.

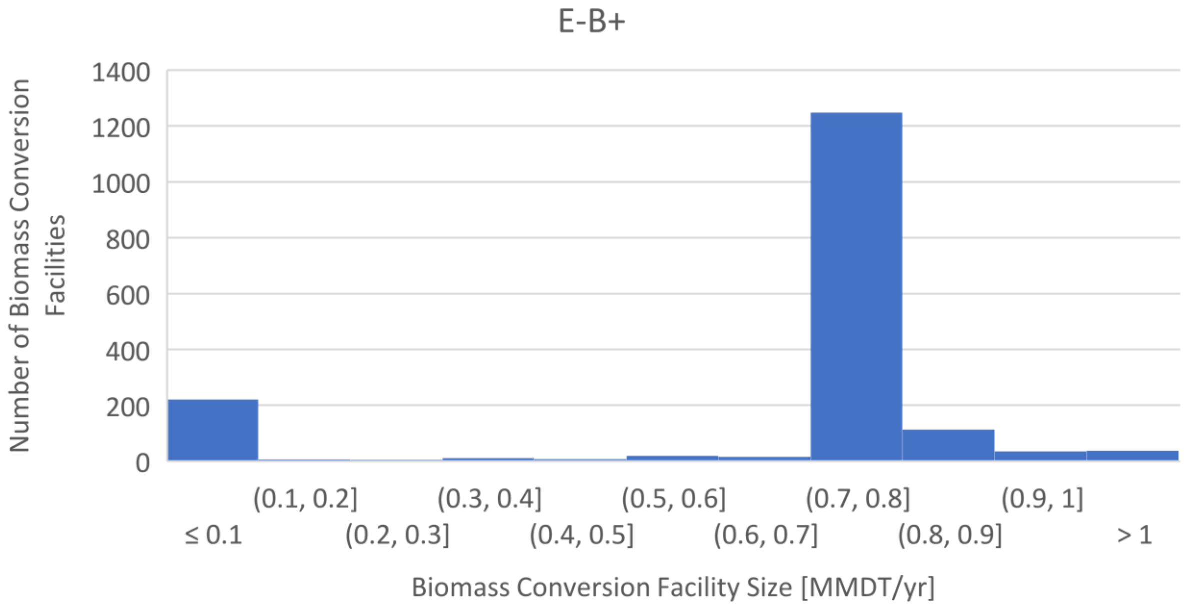


Figure 16 Size distribution of biomass conversion facilities for E-B+ scenario.

Figure 17 and 18 show the spatial distribution of biomass facilities in 2050 for the E+ and E-B+ scenarios, respectively. Appendix H3 includes maps showing the distribution of biomass facilities from 2020-2050 in five-year time steps. Figure 19 shows the total number of facilities by technology type.

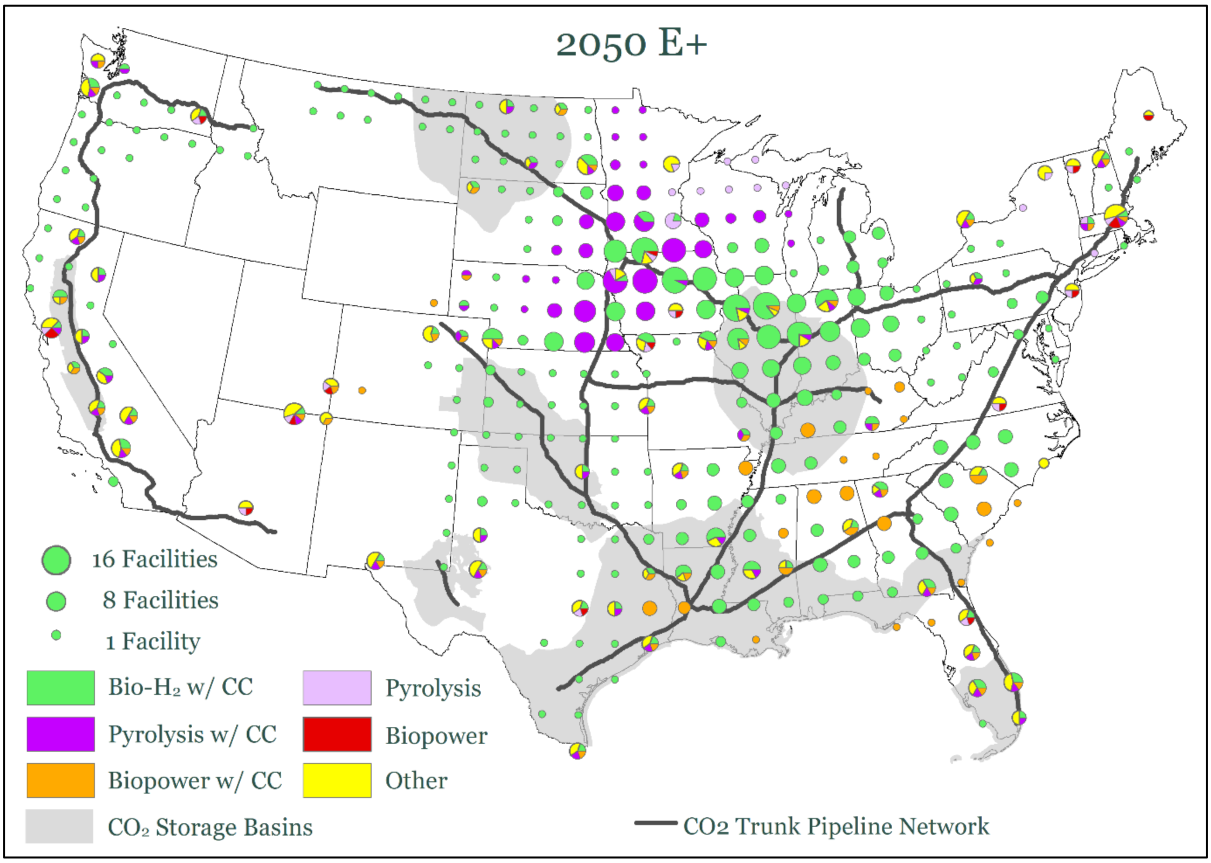


Figure 17 Distribution of biomass conversion facilities across the US by type in 2050 for E+ Scenario

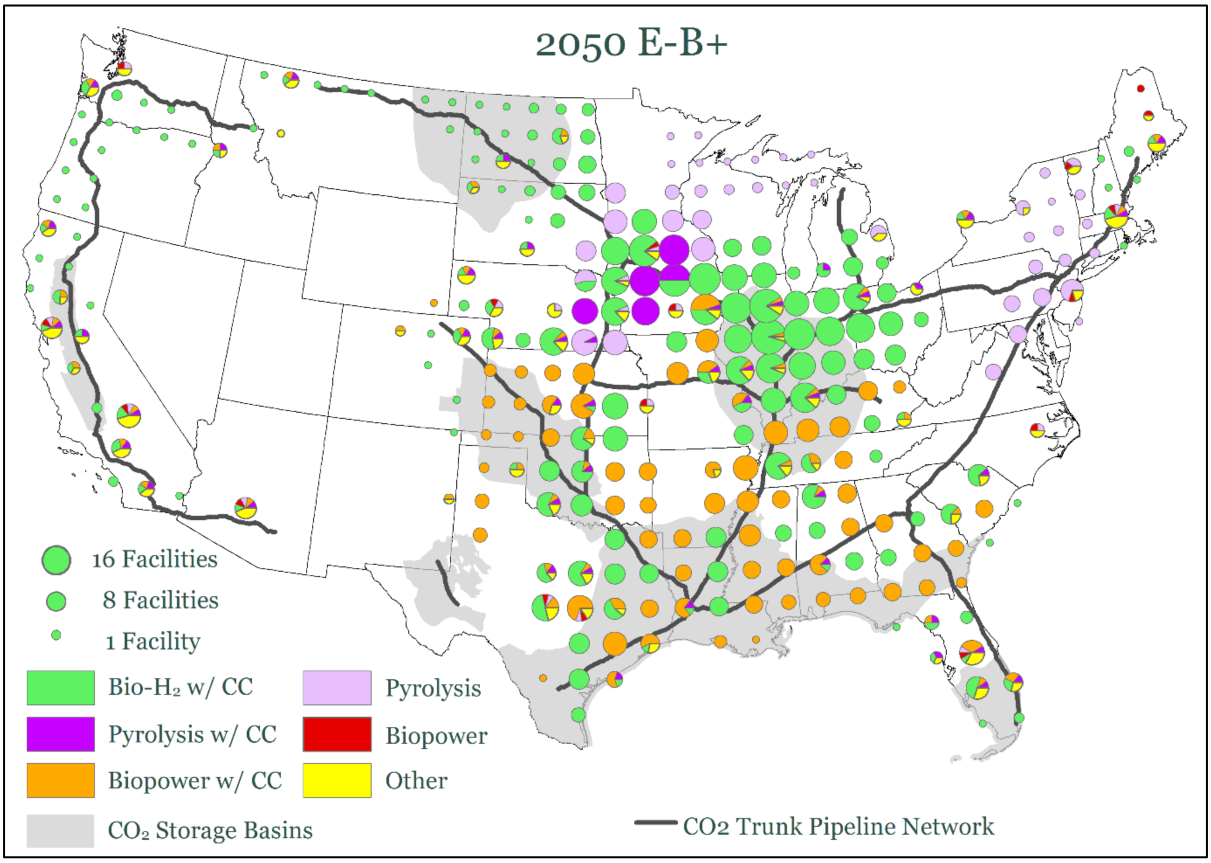


Figure 18 Distribution of biomass conversion facilities across the US by type in 2050 for E-B+ Scenario

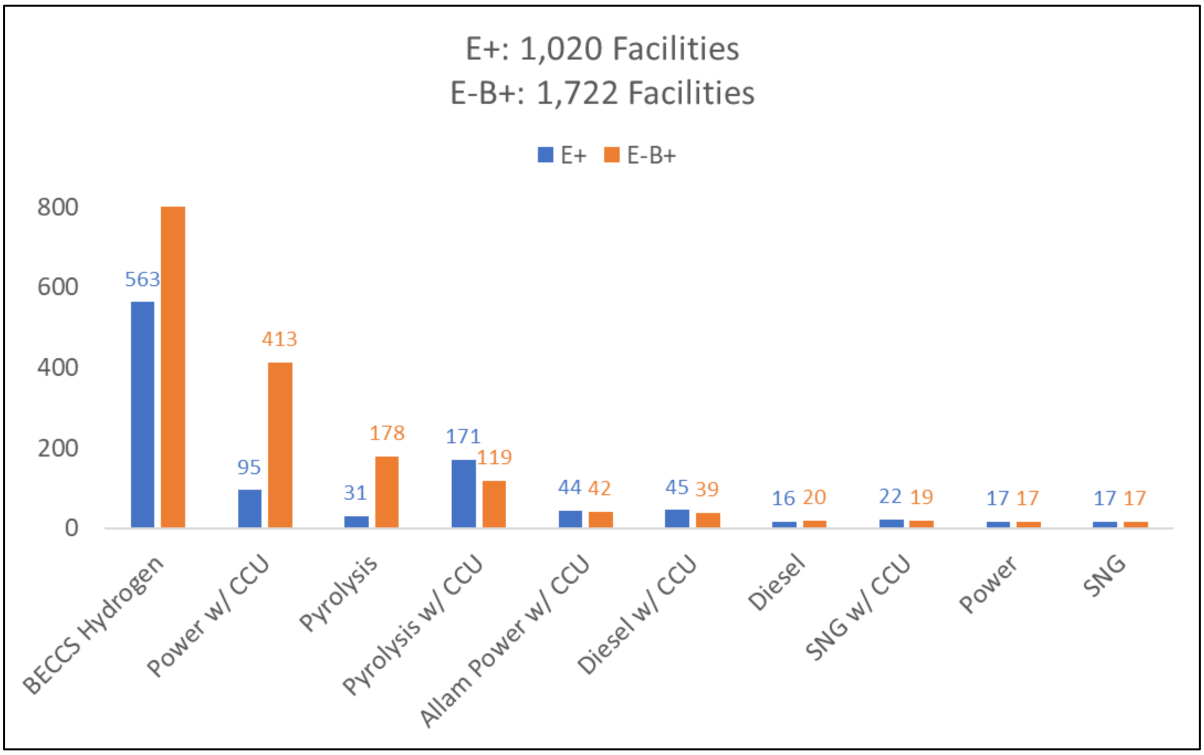


Figure 19 Number of biomass facilities by type in E+ and E-B+ scenarios

5 Investment Cost Analysis

5.1 Investment Cost

The large number of biomass conversion facilities deployed by 2050 in the E+ and E-B+ scenarios represent a considerable investment of capital. Table 6 lists for each technology type the unit installed capital cost and efficiency assumed for it in the net-zero pathway modeling work, along with capacity factor imposed in the modeling (and discussed elsewhere in this report and its appendices). These provide a basis for estimating total investment costs, as in Equation 1. The capital cost and efficiency of each facility is noted in Table 7. In the net-zero pathway modeling, the capacity factors for conversion facilities indicated in the table are enforced. The values in Table 7 are used to convert annual biomass use to installed output capacity values. An inflation factor of 4% was used to convert 2016 dollars to 2018 dollars

Table 7 Capital cost, capacity factor, and efficiency assumptions for various facilities, taken from modeling assumptions [12]

Conversion Facility Type	Capital Cost [2016 $/kW$_{output,HHV}$]	Capacity Factor	Efficiency*
Gasification Allam Power w/ CC	7,144	-	0.40
Gasification H_2 w/ CC	2,599	0.85	0.56
Gasification Fischer-Tropsch	4,215	0.85	0.51
Gasification Fischer-Tropsch w/ CC	4,387	0.85	0.51
Power+	3,329	-	0.25
Power w/ CCU	6,338	-	0.30
Pyrolysis	2,491	0.85	0.65
Pyrolysis w/ CCU	3,992	0.85	0.65
Gasification SNG	2,280	0.85	0.66
Gasification SNG w/ CC	2,376	0.85	0.65

**HHV basis*

+Biomass plant costs are assumed to vary over time: 2020- $3,672/kW; 2025- $3,697/kW; 2030- 3,622 $/kW; 2035- $3,549/kW; 2040- $3,477/kW; 2045- $3,405/kW; 2050-$3,329/kW

$$Investment\ \ Cost = \sum_{All\ \ Facilities} Capital\ \ Cost_{Fac} * Effciency_{type} * \frac{Biomass\ \ Use_{type}}{(8760\ \ hr*Capacity\ \ Factor_{type})} \qquad \text{Eqn 1.}$$

To determine the annual expenditures on biomass by state, the total biomass utilized on an annual basis for all the facilities in a state are multiplied by the state average biomass costs (from Table 4).

Figure 20 and Figure 21 show the top states with the largest cumulative investment in biomass conversion technologies as well as their corresponding spending on biomass in 2050 for the E+ and E-B+ scenarios. Appendix H4 has cumulative investment and annual biomass spending for all states in 5-yr time steps for 2020-2050.

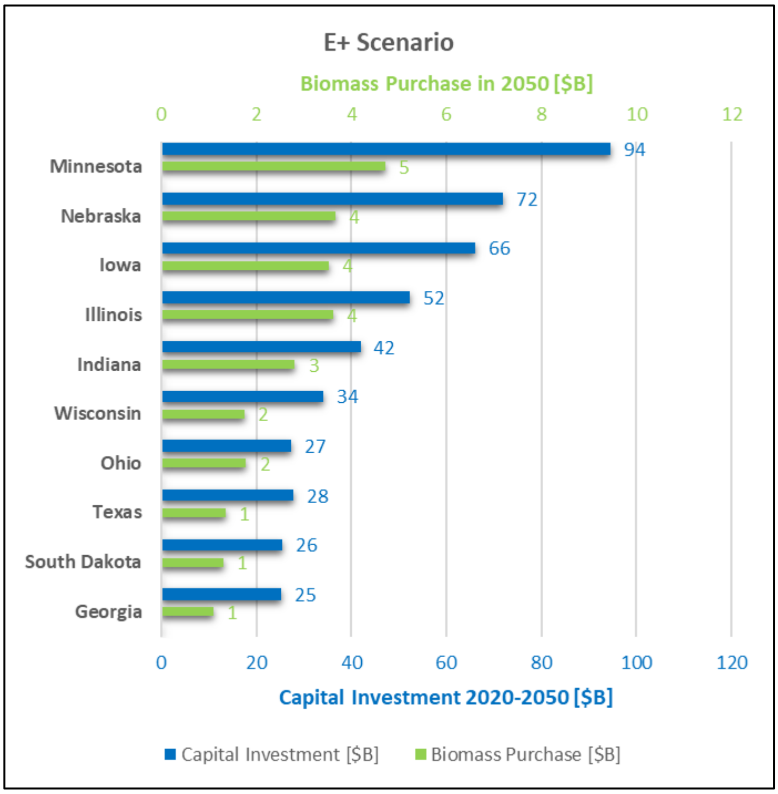


Figure 20 Cumulative capital investment from 2020-2050 in new biomass conversion facilities for the top 10 investing states, and annual biomass purchase in 2050 for the E+ scenario.[d]

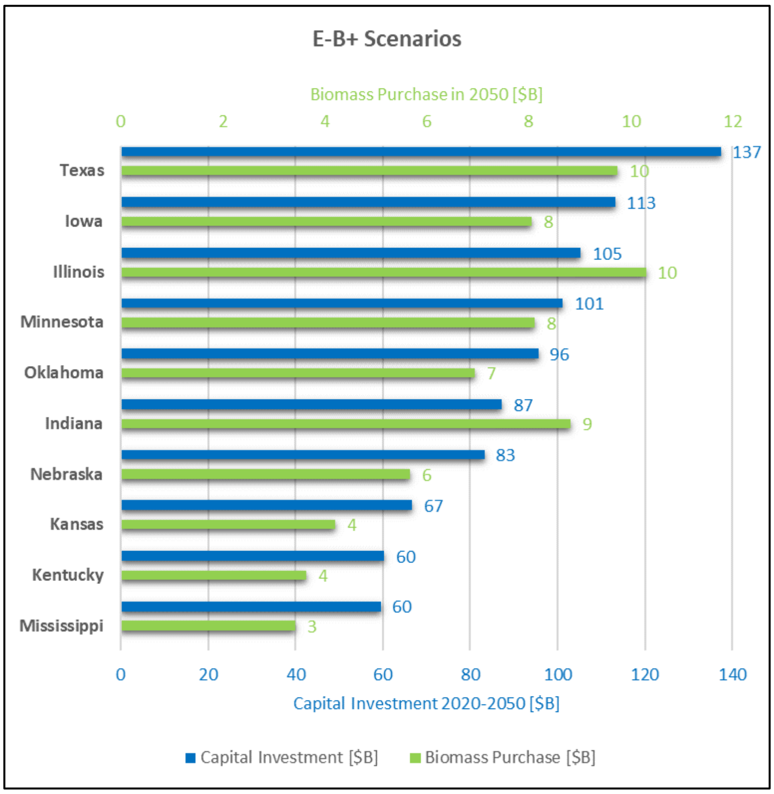


Figure 21 Cumulative capital investment from 2020-2050 in new biomass conversion facilities for the top 10 investing states, and annual biomass purchase in 2050 for the E-B+ scenario.[d]

[d] Biomass purchases in this figure include biomass used in cogeneration facilities existing in 2020 and assumed to remain operating over the modeling period. Biomass purchases in this figure do not include demand-side or ethanol biomass use.

5.2 Comparison to Ethanol Corn Purchase costs

Currently in the US, approximately 5,700 million bushels [bu] of corn are converted to ethanol annually [2]. The average corn price in 2019 was $3.75/bu [2], resulting in estimated annual expenditures for corn in the current bioethanol industry of approximately $21 B. While annual purchases of corn for ethanol decline after 2035 in the net-zero scenarios, expenditures on other biomass types increase. Figures 22 and 23 show the change in biomass purchases through 2050 for the E+ and E-B+ scenarios.

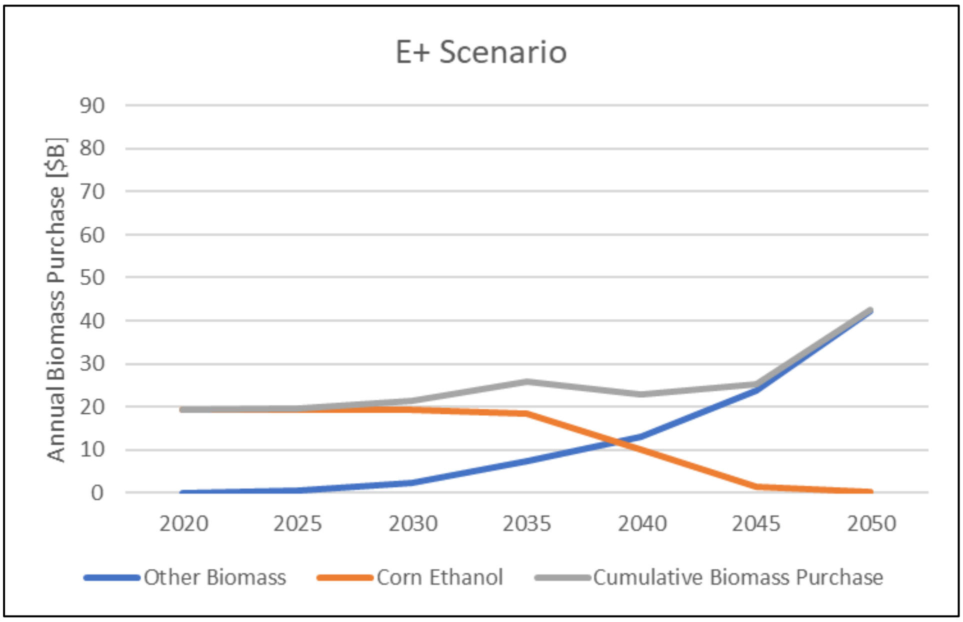


Figure 22 Annual biomass purchases through 2050 in the US for the E+ Scenario[d]

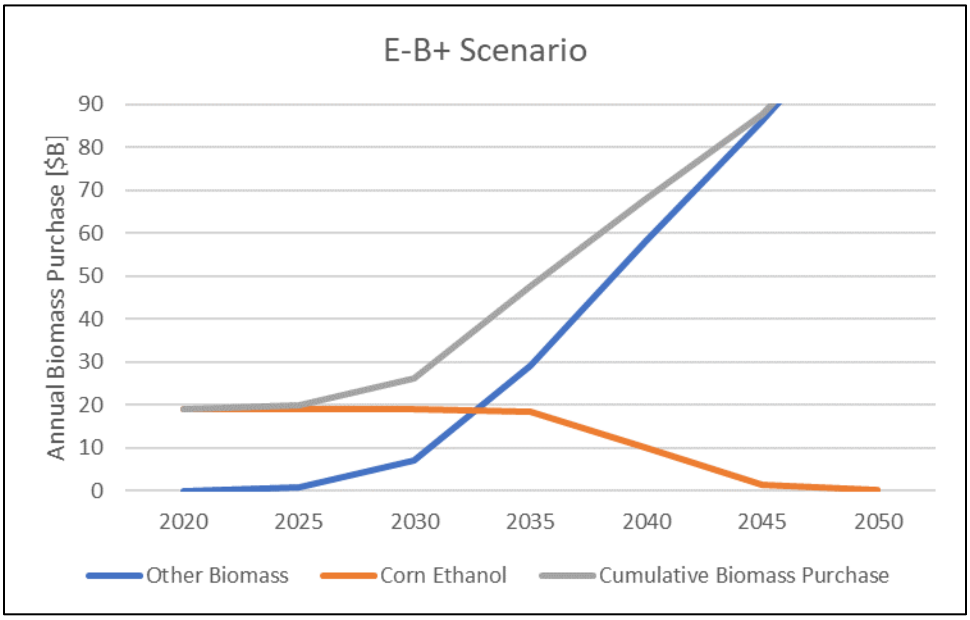


Figure 23 Annual biomass purchases through 2050 in the US for the E-B+ Scenarios[d]

6 References

[1] E. L. Langholtz MH, Stokes BJ, “2016 Billion-Ton Report,” vol. I, no. July, pp. 1–411, 2016, [Online]. Available: https://energy.gov/sites/prod/files/2016/12/f34/2016_billion_ton_report_12.2.16_0.pdf.

[2] USDA Economic Research Service, “U.S. Bioenergy Statistics,” *USDA*, 2020. https://www.ers.usda.gov/data-products/us-bioenergy-statistics/us-bioenergy-statistics/#Feedstocks.

[3] USDA National Agricultural Statistics Service, “Corn: Harvested Acreage by County,” *USDA*, 2020. https://www.nass.usda.gov/Charts_and_Maps/Crops_County/cr-ha.php.

[4] USDA National Agricultural Statistics Service, “National Statistics for Corn,” *USDA*, 2020. https://www.nass.usda.gov/Statistics_by_Subject/result.php?7B832B80-F468-398F-8A28-F9C76A50551B&sector=CROPS&group=FIELD CROPS&comm=CORN.

[5] D. K. Lee *et al.*, “Biomass production of herbaceous energy crops in the United States: field trial results and yield potential maps from the multiyear regional feedstock partnership,” *GCB Bioenergy*, vol. 10, no. 10, pp. 698–716, 2018, doi: 10.1111/gcbb.12493.

[6] USDA Farm Service Agency, “Conservation Reserve Program,” *USDA*, 2020. https://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/index.

[7] USDA Farm Service Agency, “Conservation Reserve Program Statistics,” *USDA*, 2020. https://www.fsa.usda.gov/programs-and-services/conservation-programs/reports-and-statistics/conservation-reserve-program-statistics/index.

[8] I. Gelfand, T. Zenone, P. Jasrotia, J. Chen, S. K. Hamilton, and G. P. Robertson, “Carbon debt of Conservation Reserve Program (CRP) grasslands converted to bioenergy production,” *Proc. Natl. Acad. Sci. U. S. A.*, 2011, doi: 10.1073/pnas.1017277108.

[9] I. Gelfand, R. Sahajpal, X. Zhang, R. C. Izaurralde, K. L. Gross, and G. P. Robertson, “Sustainable bioenergy production from marginal lands in the US Midwest,” *Nature*, 2013, doi: 10.1038/nature11811.

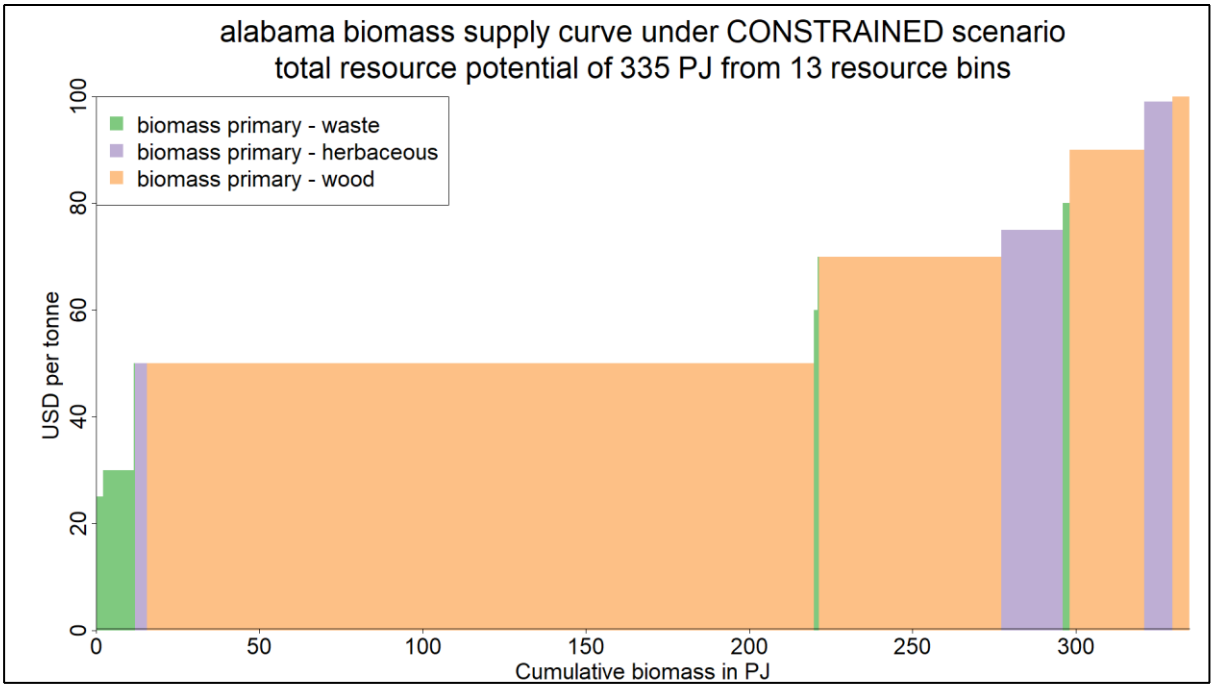
[10] E. Mayfield, J. Jenkins, E. Larson, and C. Greig, "Princeton’s Net-Zero America study, Annex R: Employment Transition (Methods)," 17 February 2021.

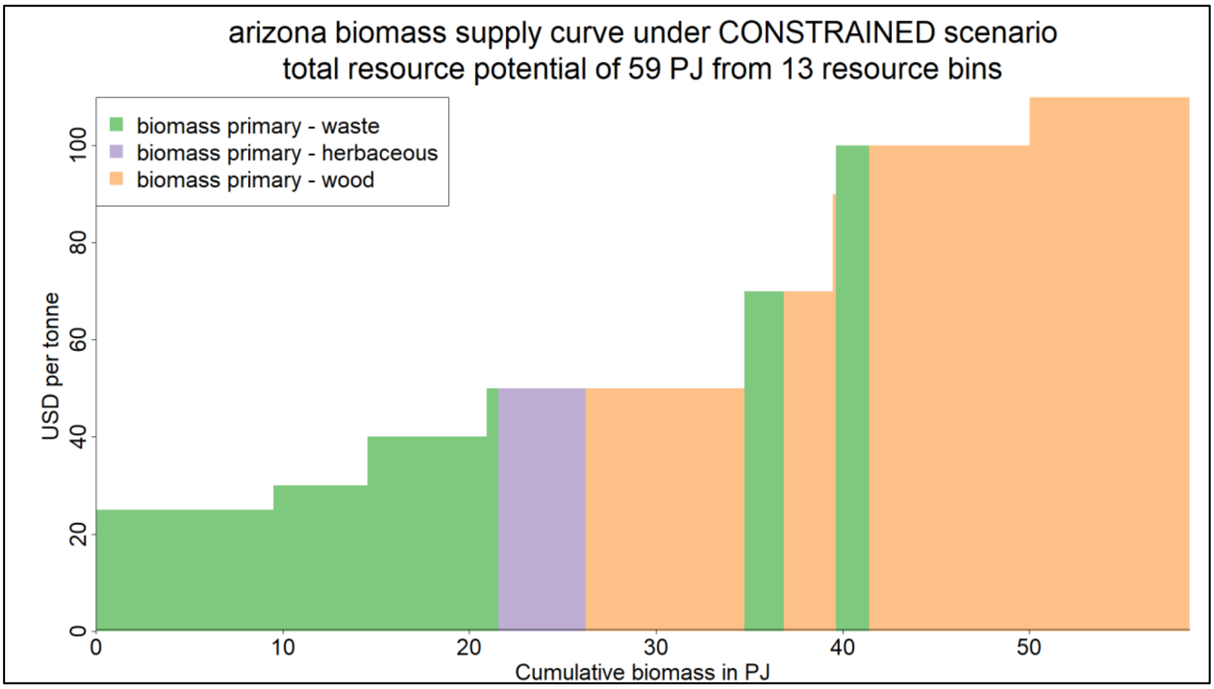
[11] C. Greig and A. Pascale, " Princeton’s Net-Zero America study, Annex I: CO_2 Transport and Storage Infrastructure Transition Analysis," August 2021.

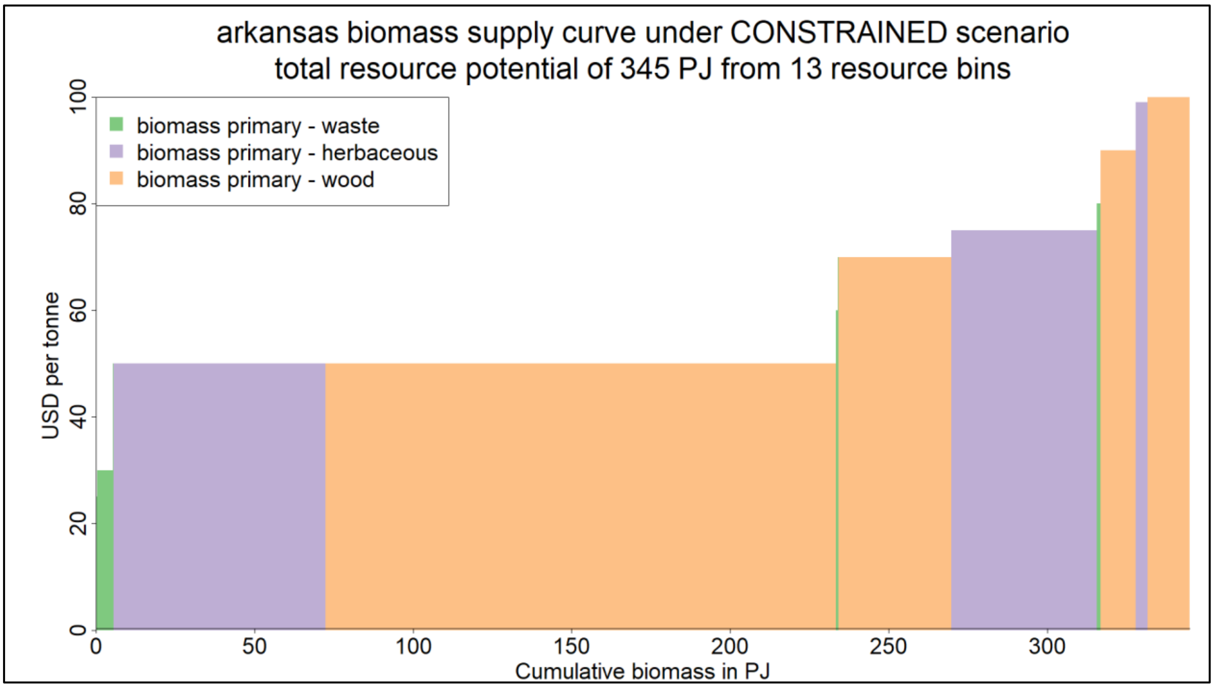
[12] R. Jones and B. Haley, " Princeton’s Net-Zero America study, Annex A," Evolved Energy Research final report to Princeton, June 2020.

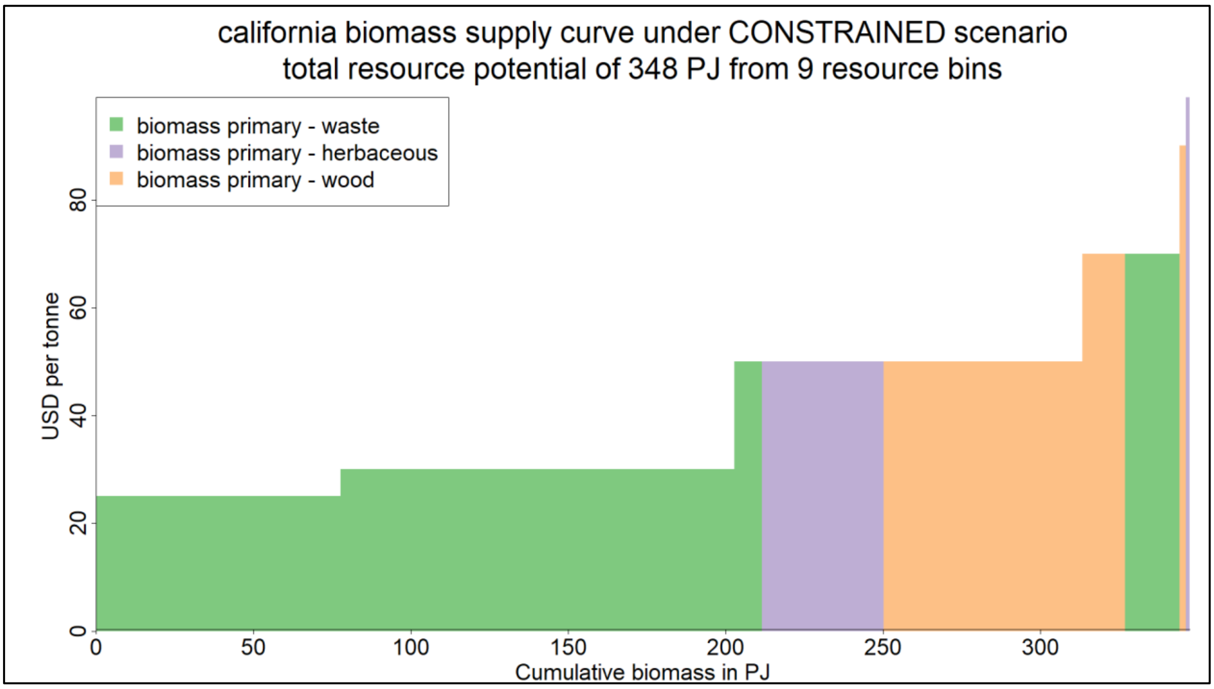
Appendix H1: State biomass cost-supply curves (Delimited)

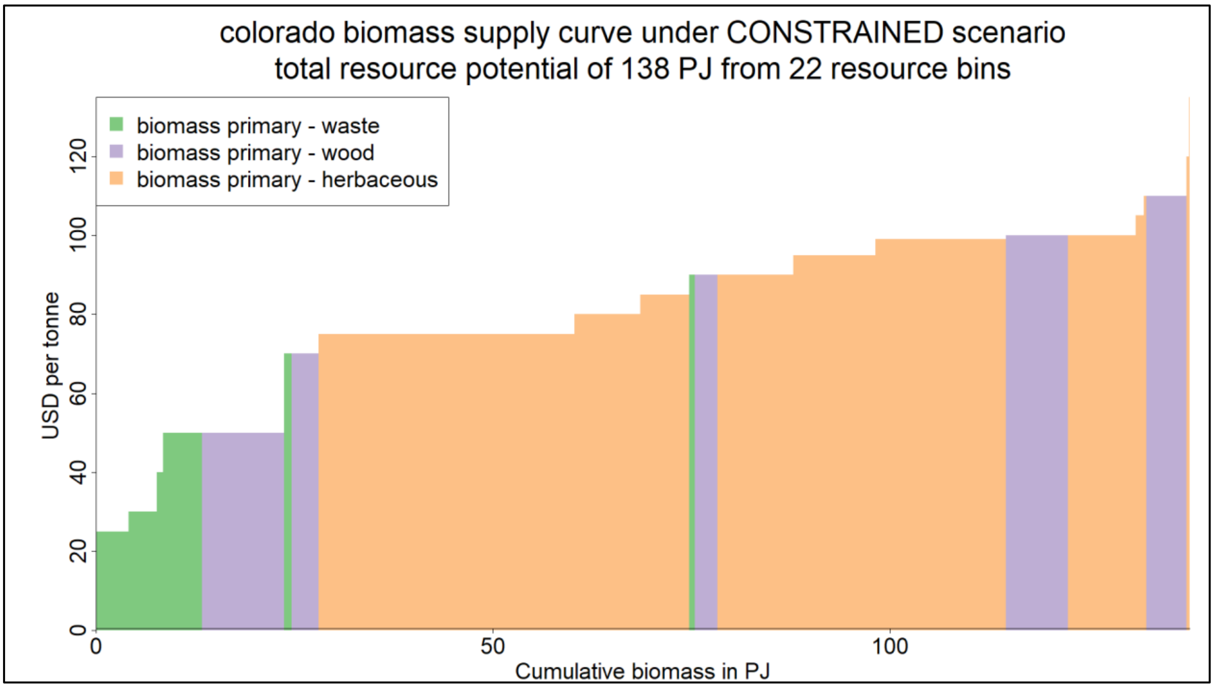
State-level supply curves for Delimited Biomass Case in 2050 in Petajoules. (Delimited Biomass Case is labeled "CONSTRAINED Scenario" in these figures.)

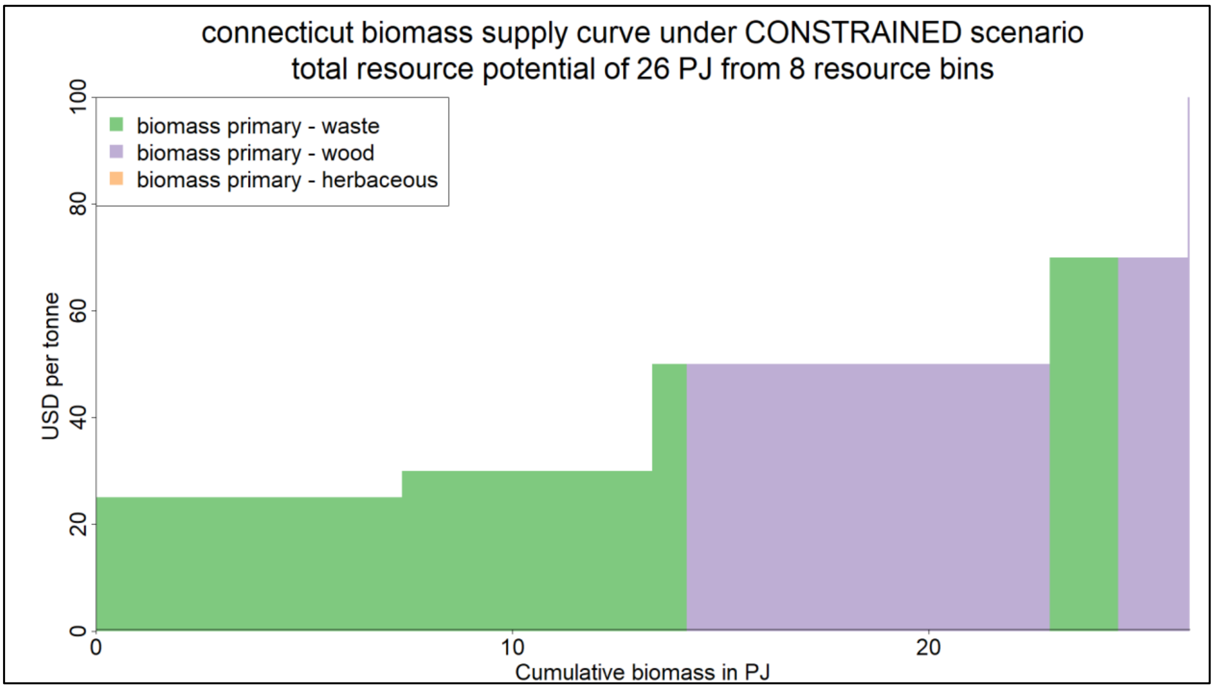


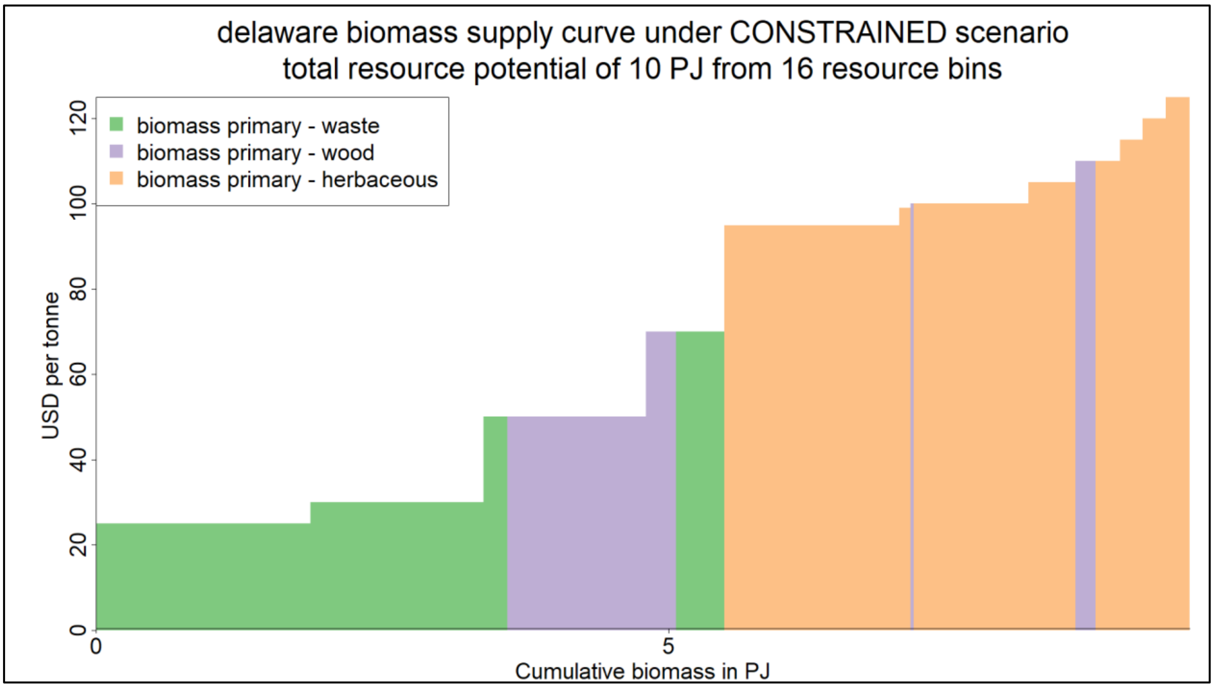



arkansas biomass supply curve under CONSTRAINED scenario
total resource potential of 345 PJ from 13 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
0
50
100
150
200
250
300
Cumulative biomass in PJ

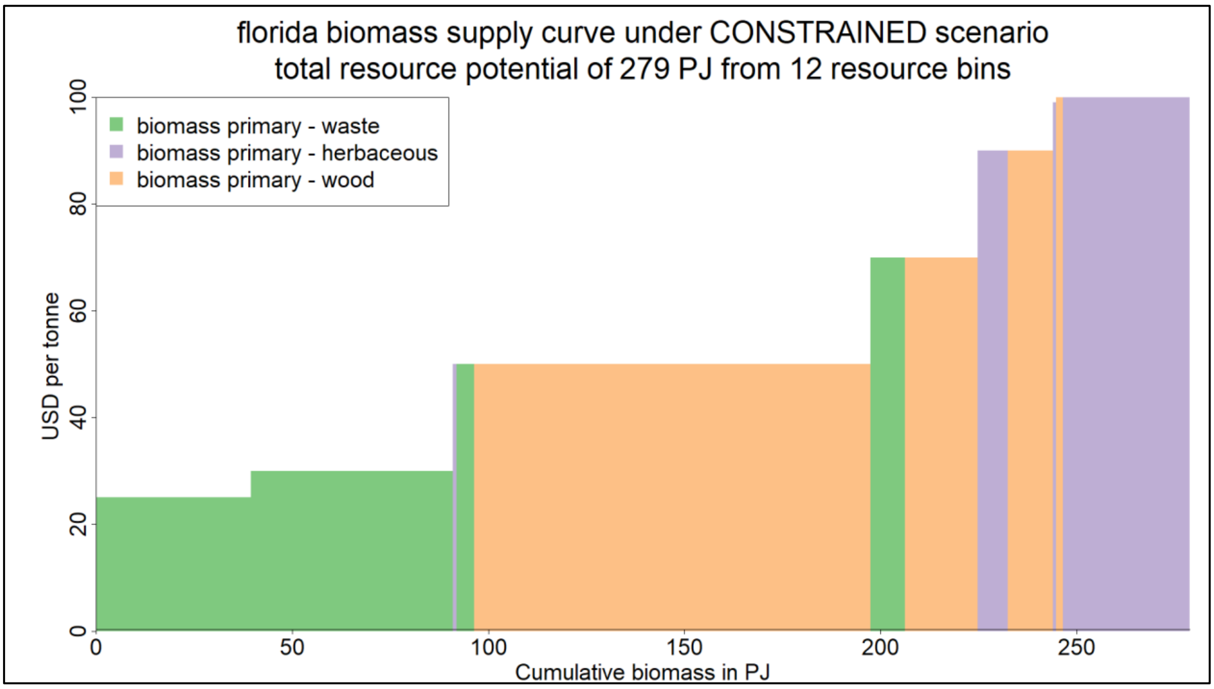

california biomass supply curve under CONSTRAINED scenario
total resource potential of 348 PJ from 9 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
0
50
100
150
200
250
300
Cumulative biomass in PJ


colorado biomass supply curve under CONSTRAINED scenario
total resource potential of 138 PJ from 22 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
0
50
100
Cumulative biomass in PJ

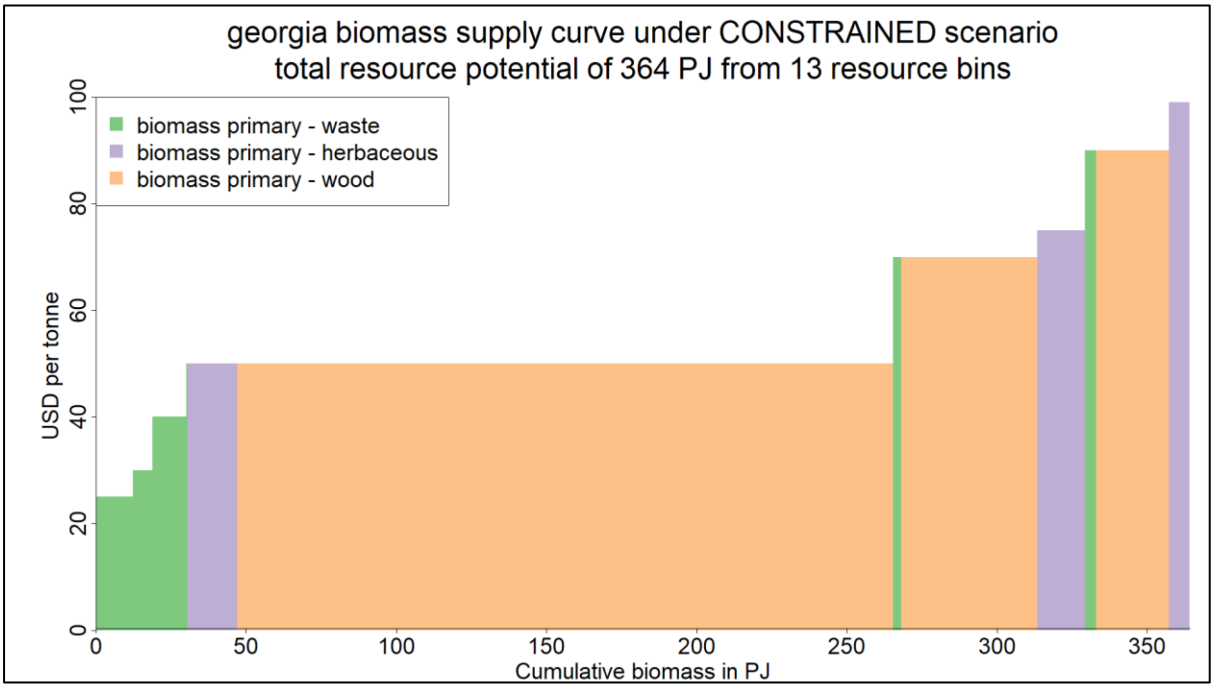

connecticut biomass supply curve under CONSTRAINED scenario
total resource potential of 26 PJ from 8 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
0
10
20
Cumulative biomass in PJ

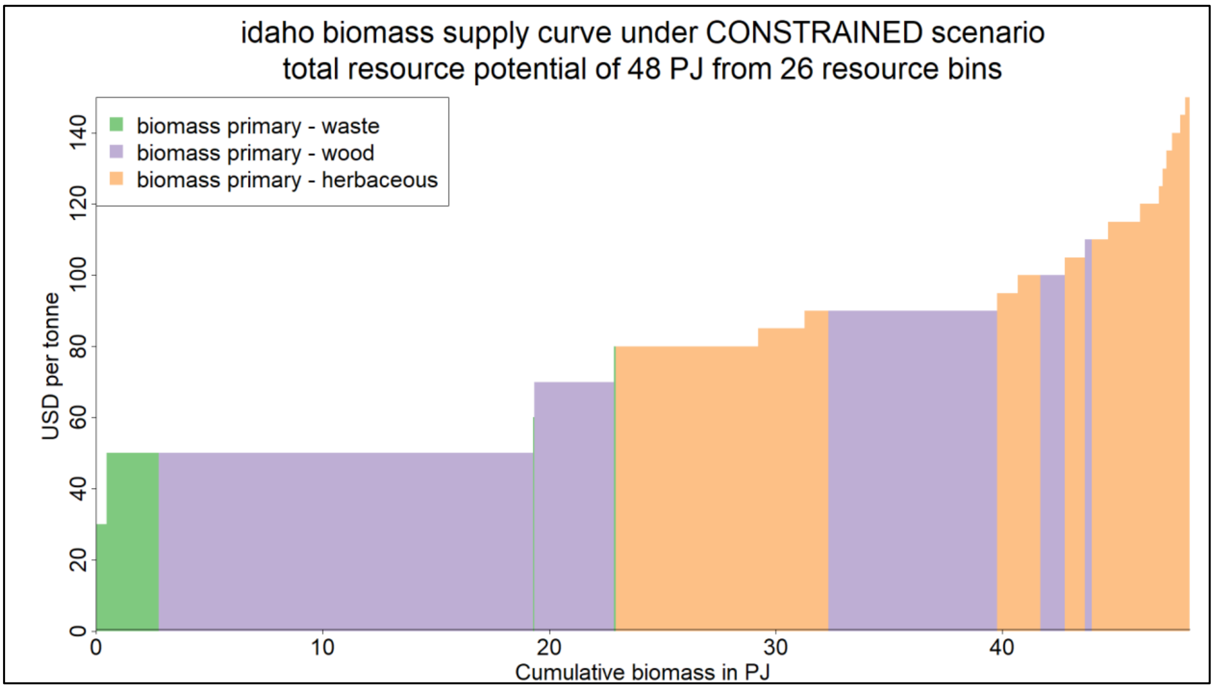


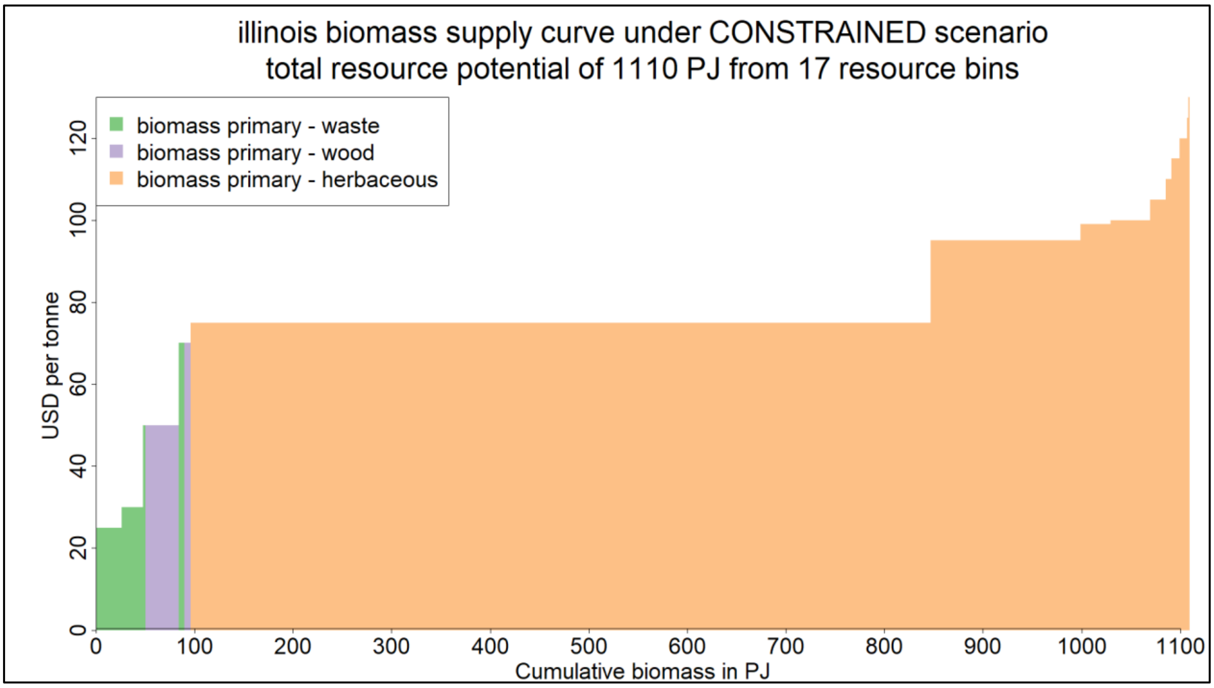
delaware biomass supply curve under CONSTRAINED scenario
total resource potential of 10 PJ from 16 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
0
5
Cumulative biomass in PJ

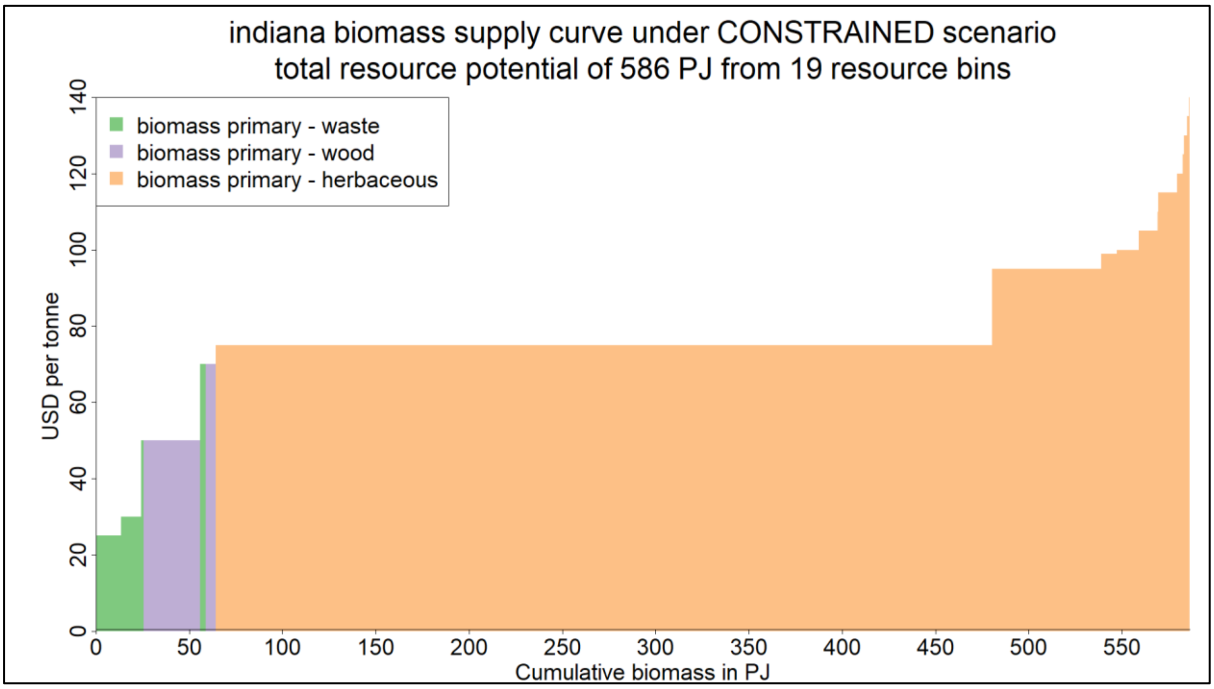


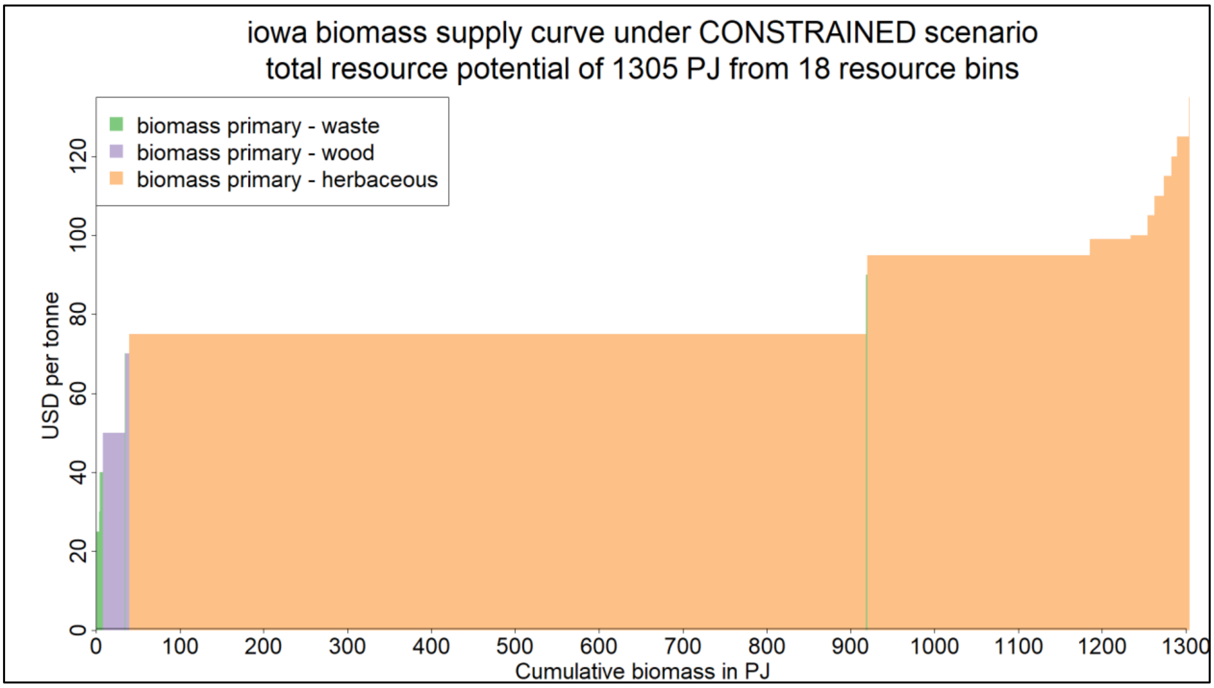
florida biomass supply curve under CONSTRAINED scenario
total resource potential of 279 PJ from 12 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
0
50
100
150
200
250
Cumulative biomass in PJ

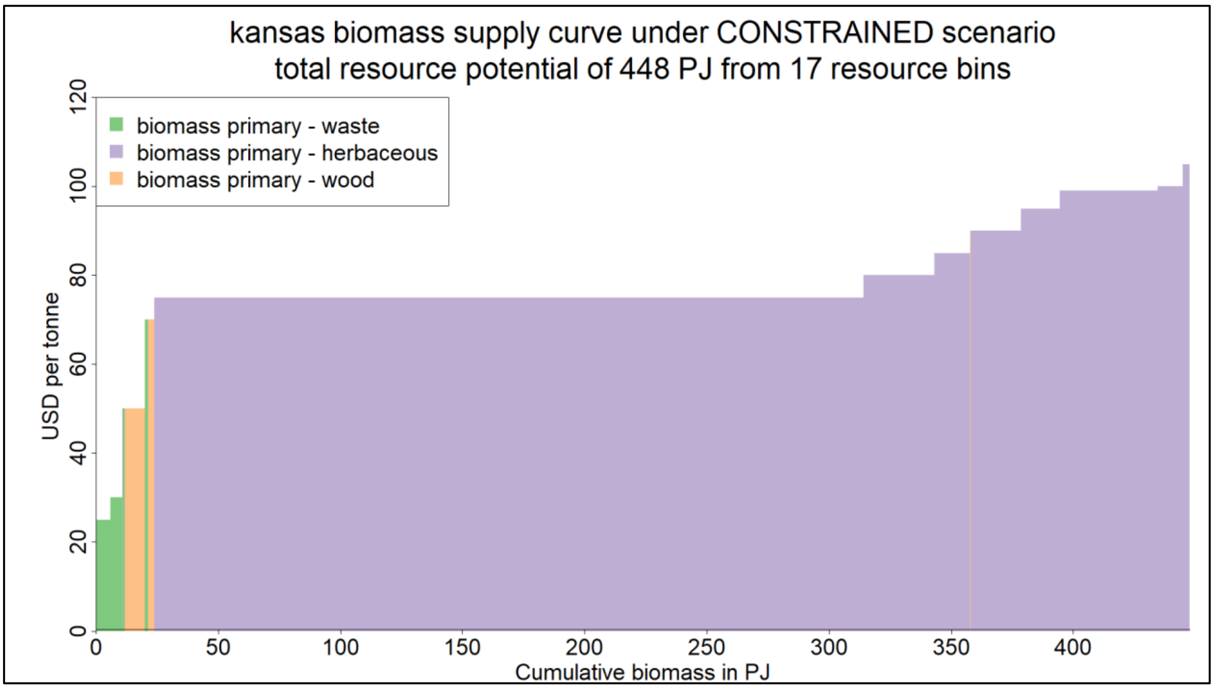

georgia biomass supply curve under CONSTRAINED scenario
total resource potential of 364 PJ from 13 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
0
50
100
150
200
250
300
350
Cumulative biomass in PJ

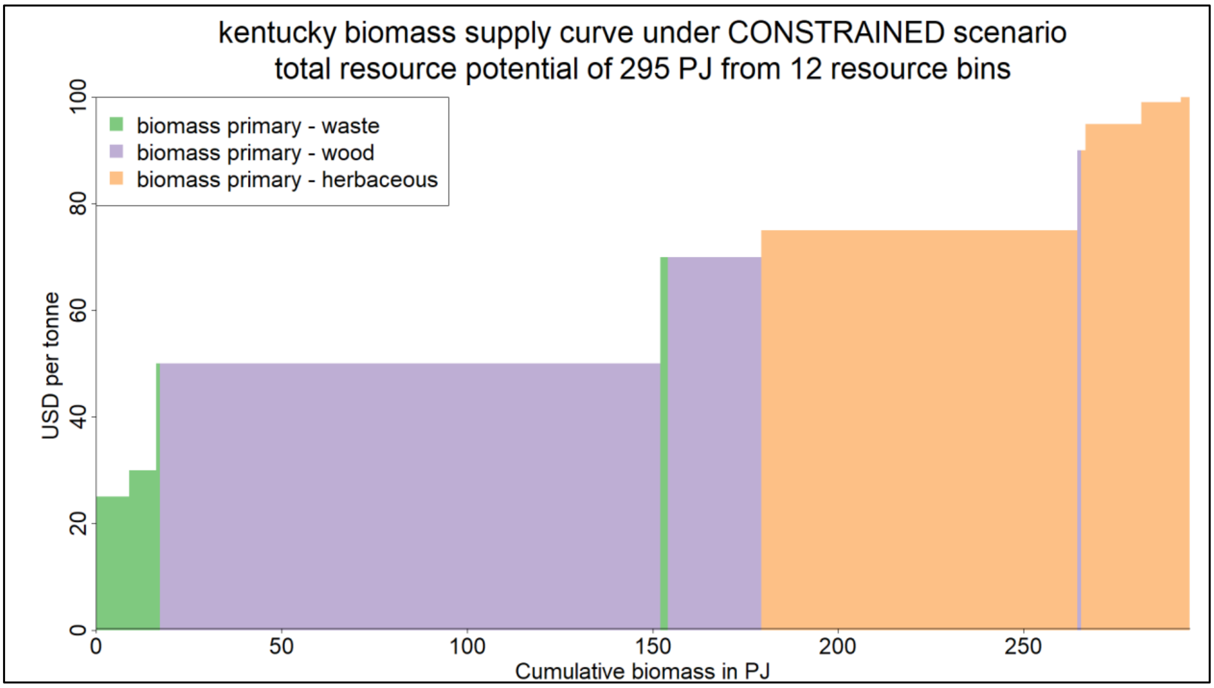

idaho biomass supply curve under CONSTRAINED scenario
total resource potential of 48 PJ from 26 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
10
20
30
40
Cumulative biomass in PJ

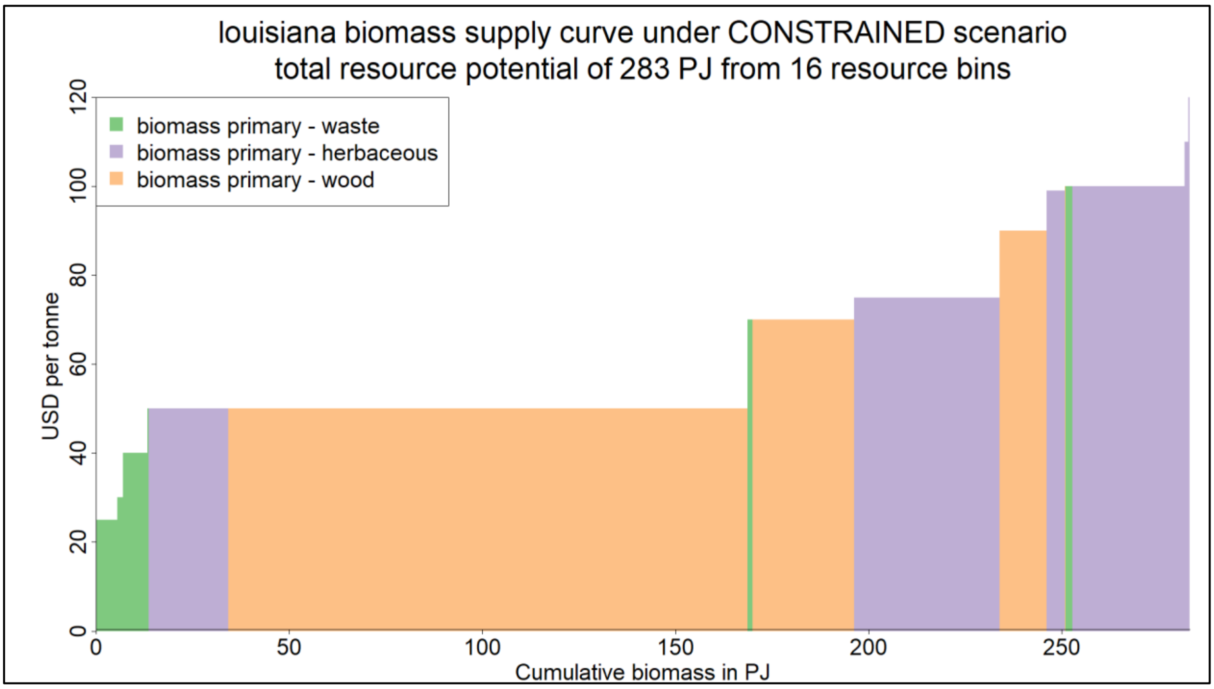

illinois biomass supply curve under CONSTRAINED scenario
total resource potential of 1110 PJ from 17 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
0
100
200
300
400
500
600
700
800
900
1000
1100
Cumulative biomass in PJ

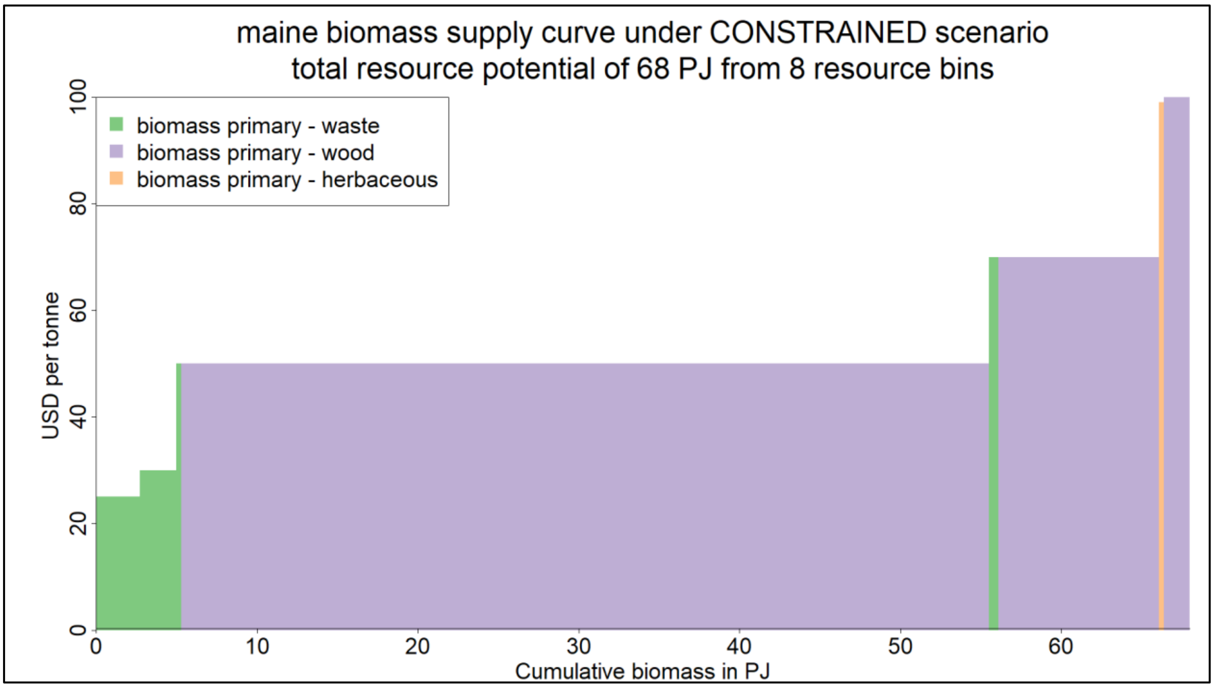

indiana biomass supply curve under CONSTRAINED scenario
total resource potential of 586 PJ from 19 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450
500
550
Cumulative biomass in PJ

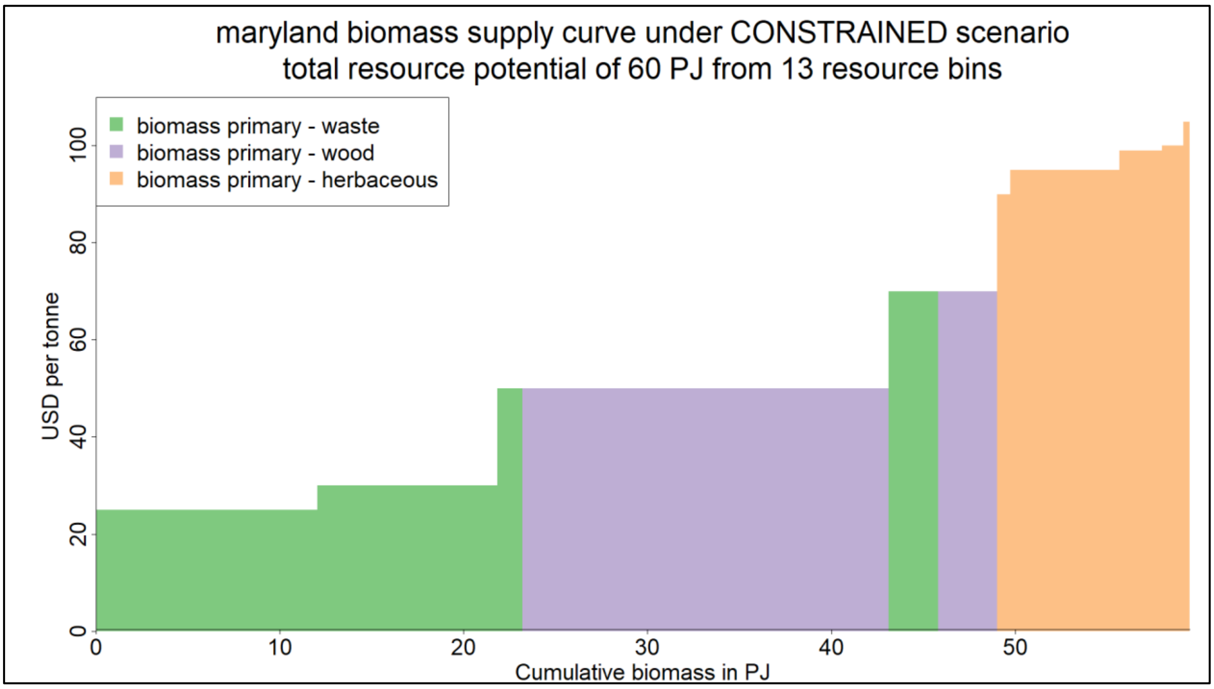

iowa biomass supply curve under CONSTRAINED scenario
total resource potential of 1305 PJ from 18 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Cumulative biomass in PJ

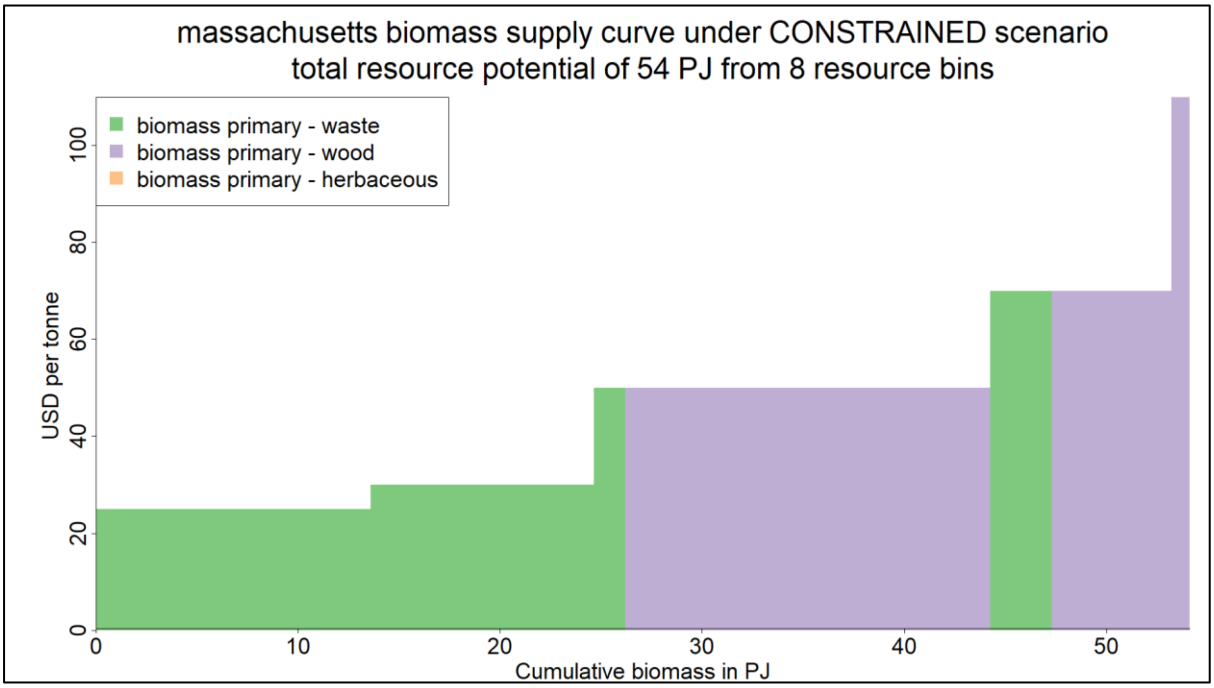

kansas biomass supply curve under CONSTRAINED scenario
total resource potential of 448 PJ from 17 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
0
50
100
150
200
250
300
350
400
Cumulative biomass in PJ

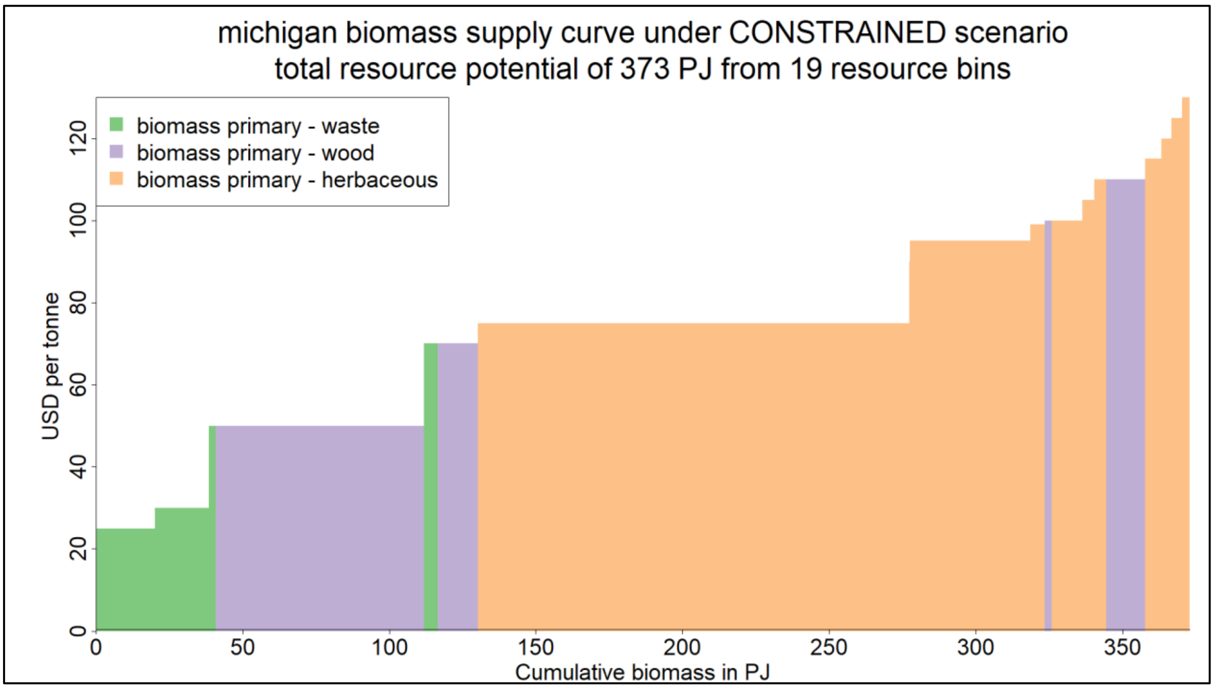

kentucky biomass supply curve under CONSTRAINED scenario
total resource potential of 295 PJ from 12 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
0
50
100
150
200
250
Cumulative biomass in PJ

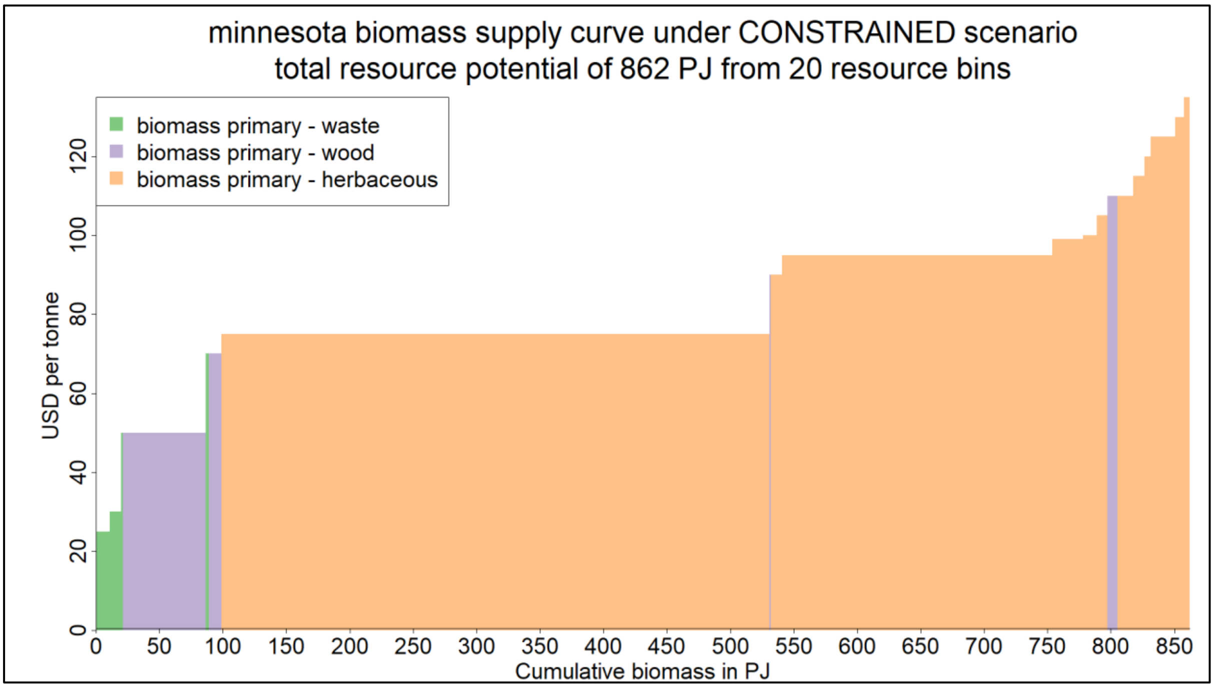

louisiana biomass supply curve under CONSTRAINED scenario
total resource potential of 283 PJ from 16 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
0
50
100
150
200
250
Cumulative biomass in PJ

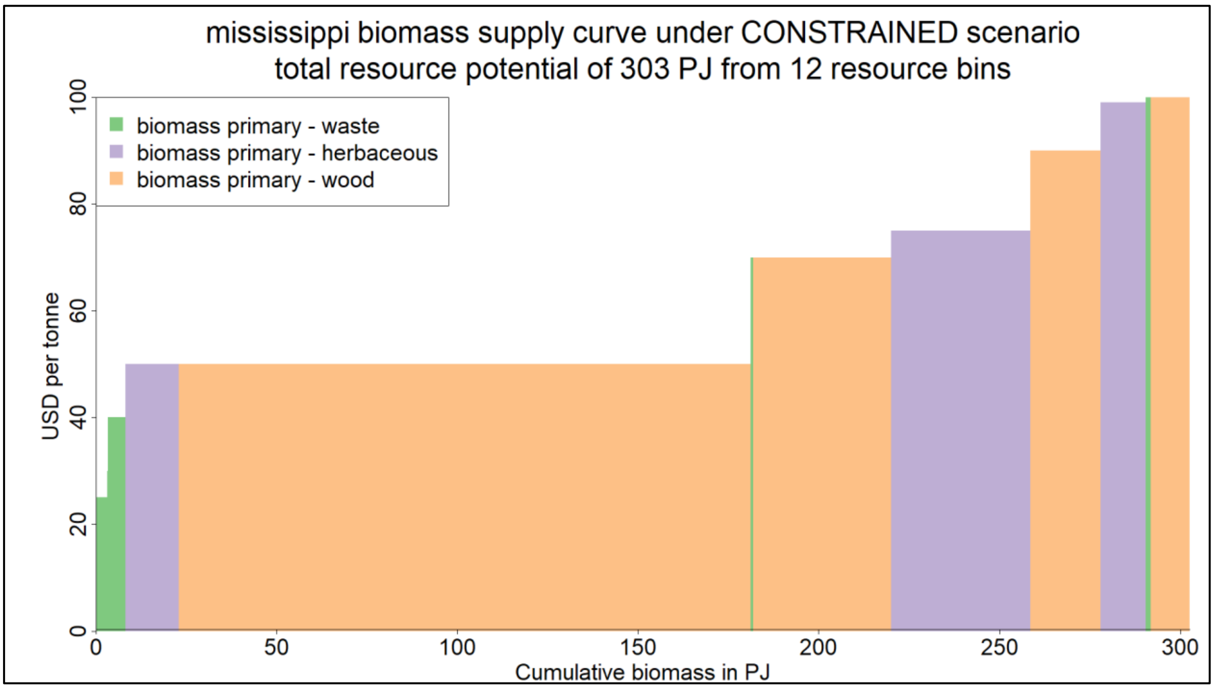

maine biomass supply curve under CONSTRAINED scenario
total resource potential of 68 PJ from 8 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
0
10
20
30
40
50
60
Cumulative biomass in PJ

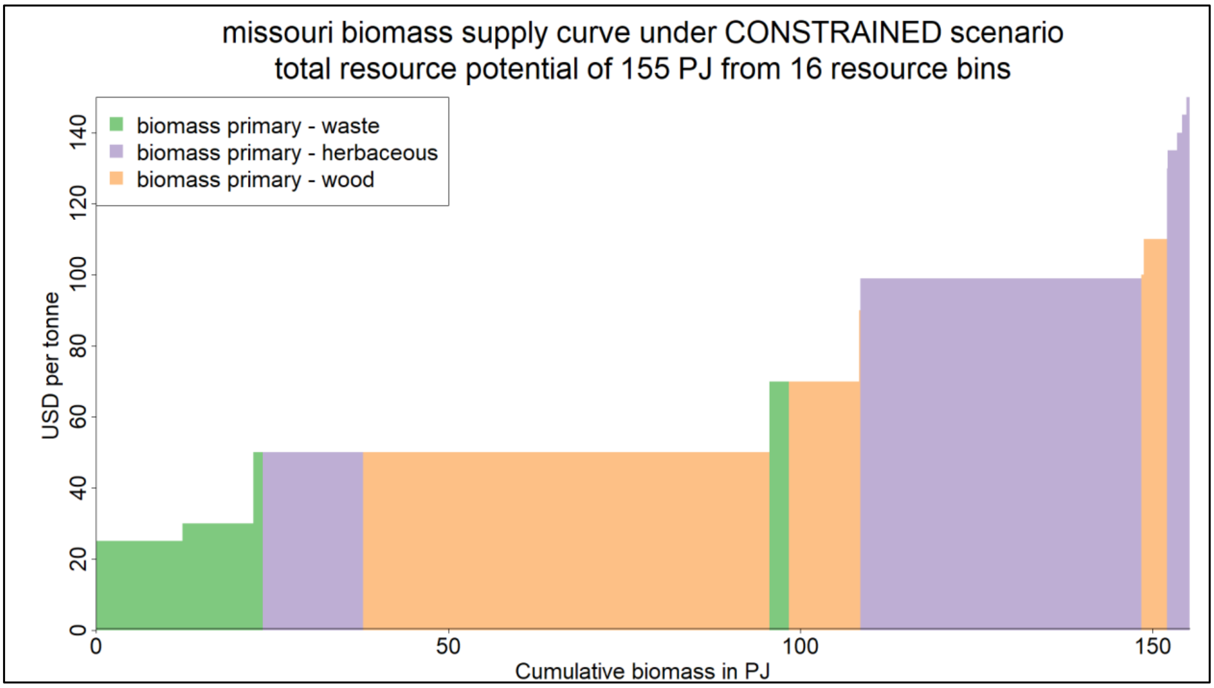

maryland biomass supply curve under CONSTRAINED scenario
total resource potential of 60 PJ from 13 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
0
10
20
30
40
50
Cumulative biomass in PJ

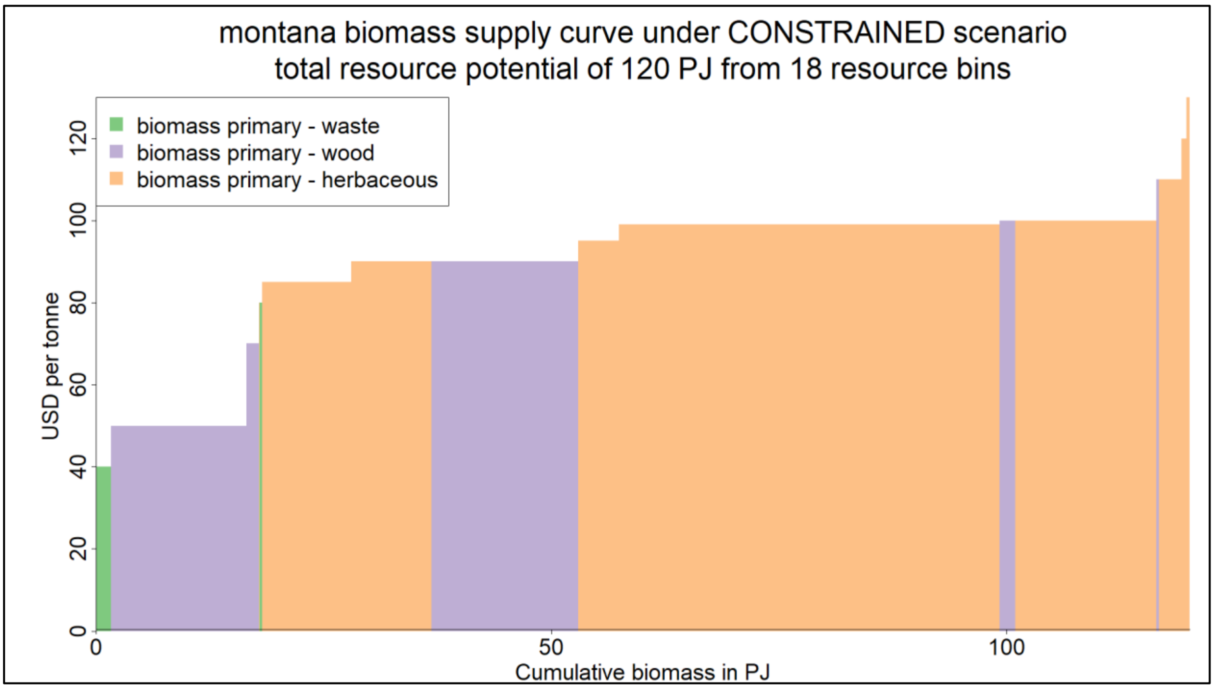

massachusetts biomass supply curve under CONSTRAINED scenario
total resource potential of 54 PJ from 8 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
0
10
20
30
40
50
Cumulative biomass in PJ

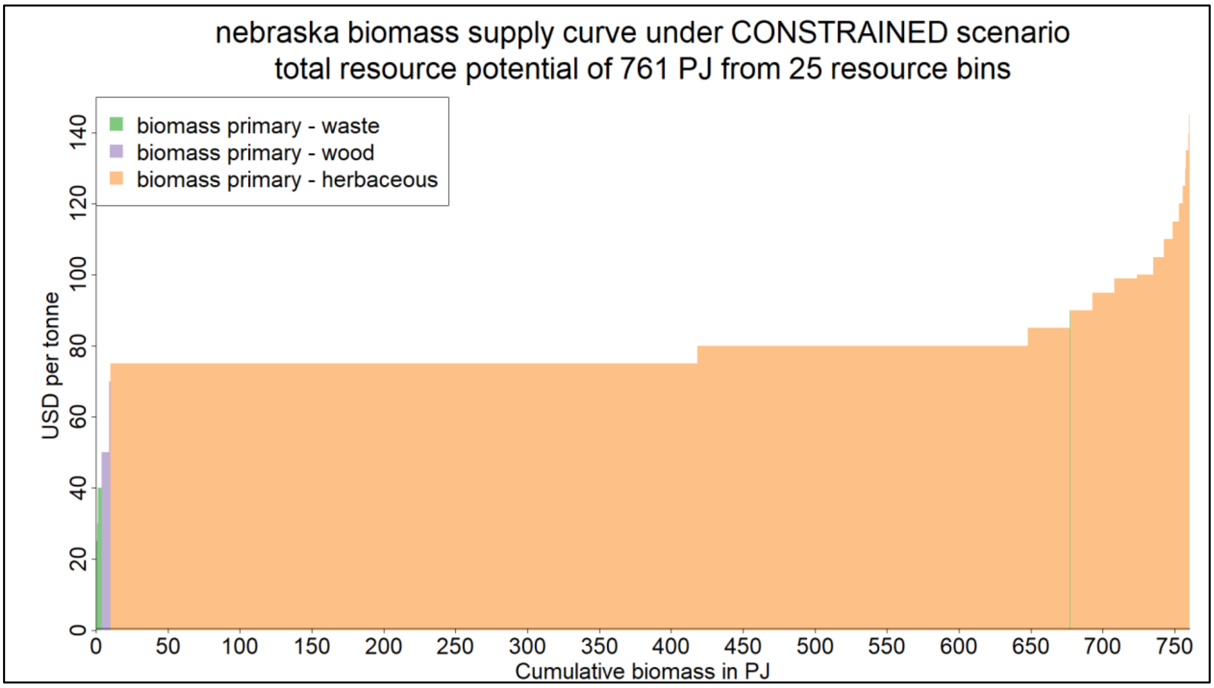

michigan biomass supply curve under CONSTRAINED scenario
total resource potential of 373 PJ from 19 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
0
50
100
150
200
250
300
350
Cumulative biomass in PJ

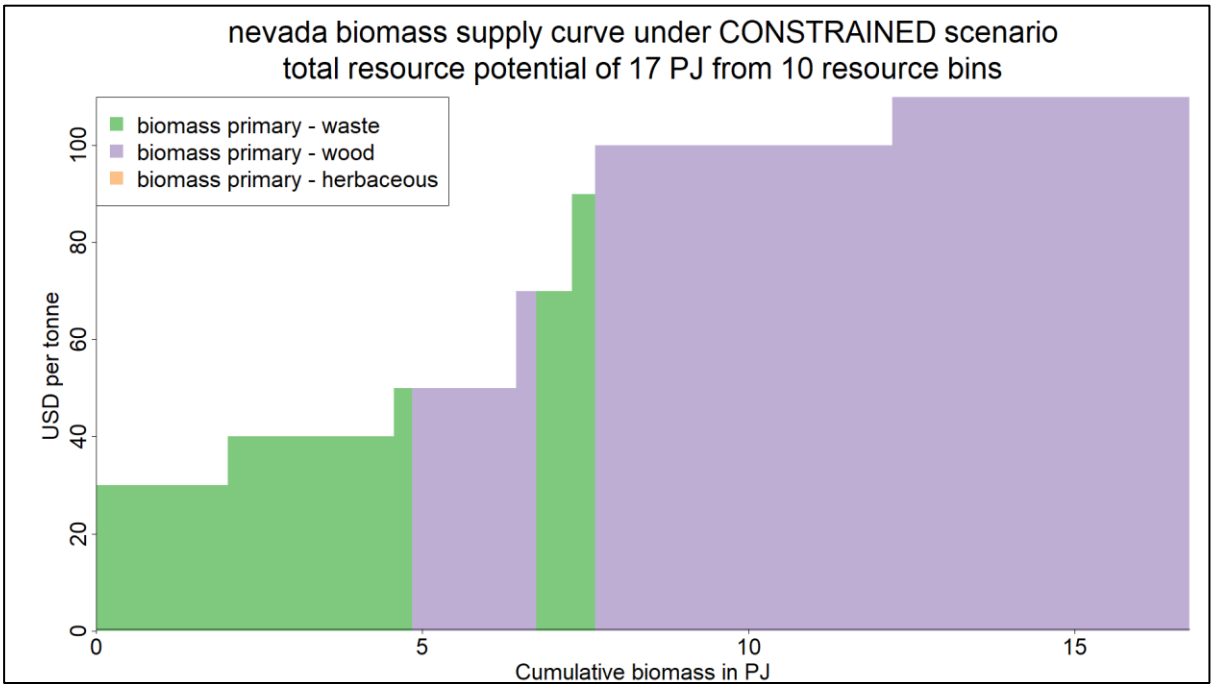

minnesota biomass supply curve under CONSTRAINED scenario
total resource potential of 862 PJ from 20 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
Cumulative biomass in PJ

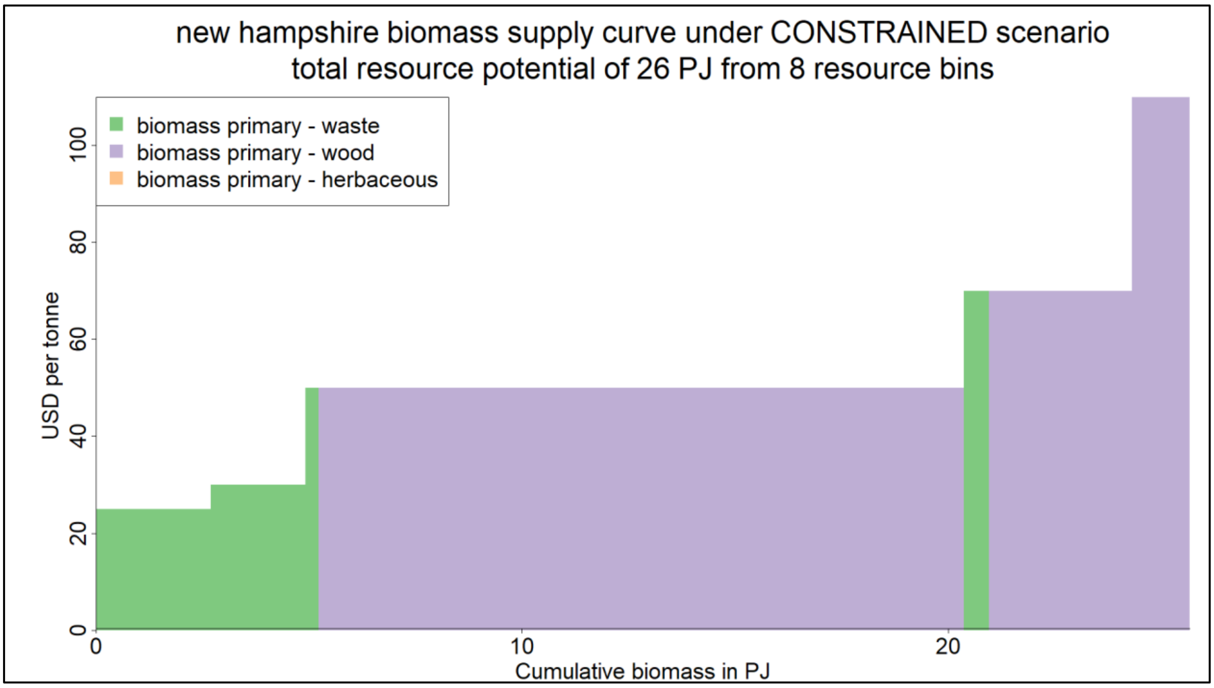

mississippi biomass supply curve under CONSTRAINED scenario
total resource potential of 303 PJ from 12 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
0
50
100
150
200
250
300
Cumulative biomass in PJ

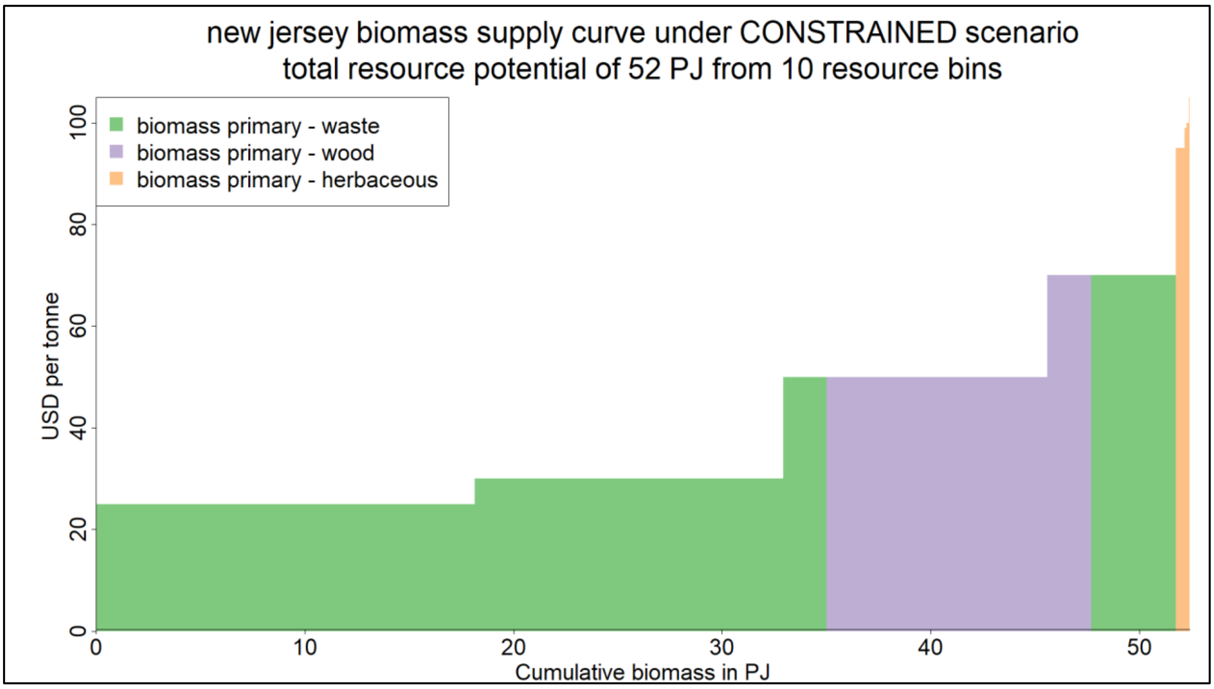

missouri biomass supply curve under CONSTRAINED scenario
total resource potential of 155 PJ from 16 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
Cumulative biomass in PJ

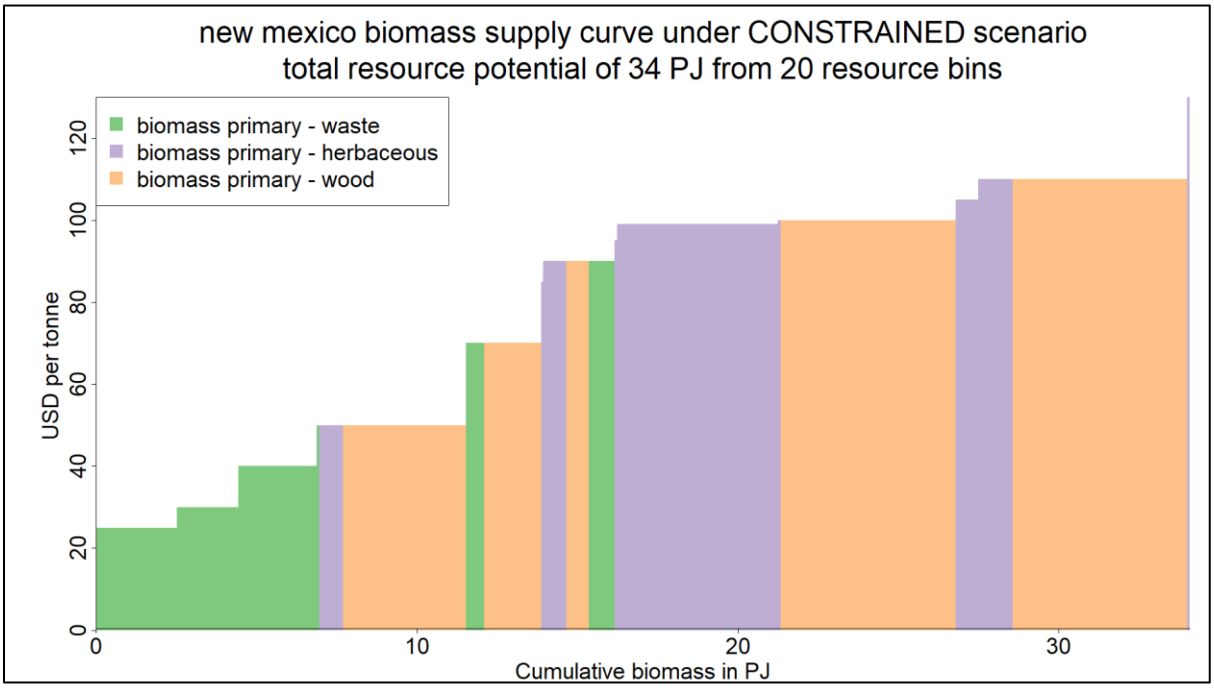

montana biomass supply curve under CONSTRAINED scenario
total resource potential of 120 PJ from 18 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
0
50
100
Cumulative biomass in PJ

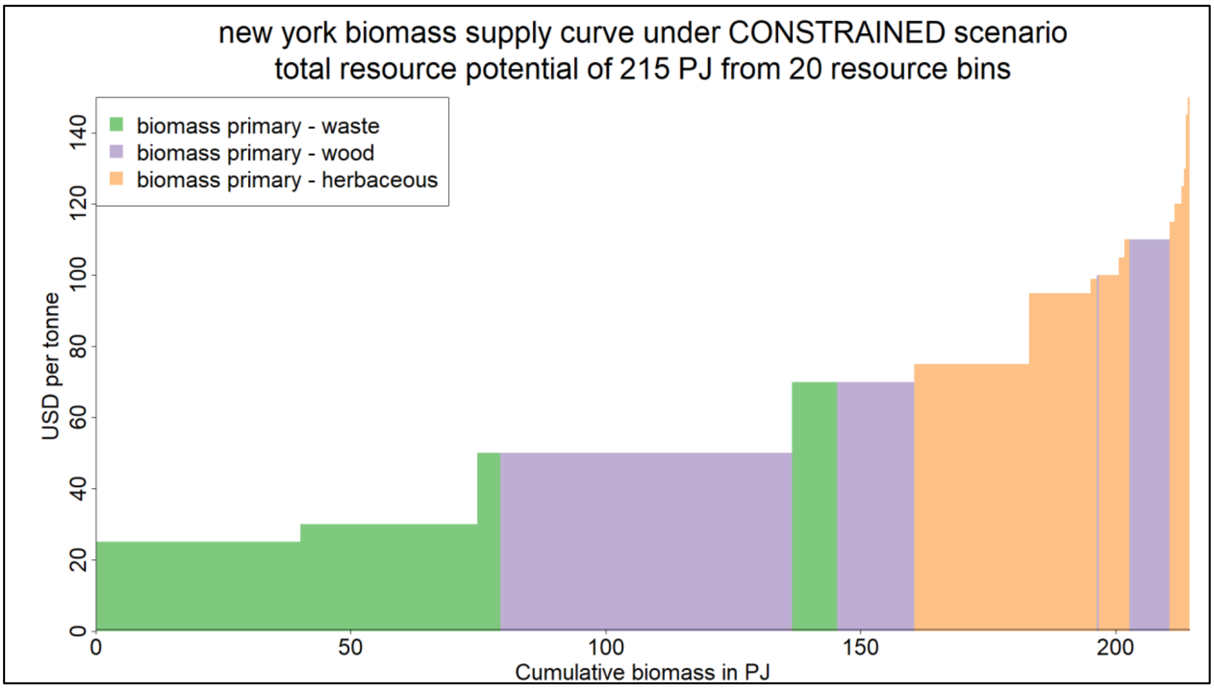

nebraska biomass supply curve under CONSTRAINED scenario
total resource potential of 761 PJ from 25 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Cumulative biomass in PJ

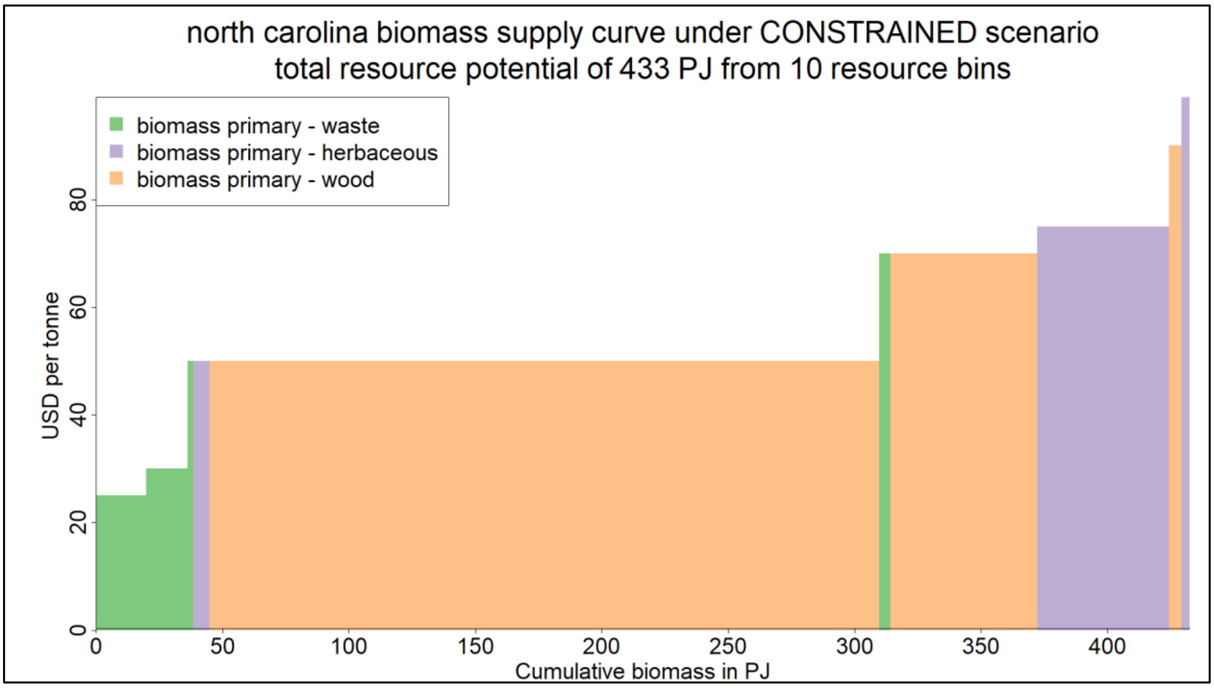

nevada biomass supply curve under CONSTRAINED scenario
total resource potential of 17 PJ from 10 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
0
5
10
15
Cumulative biomass in PJ

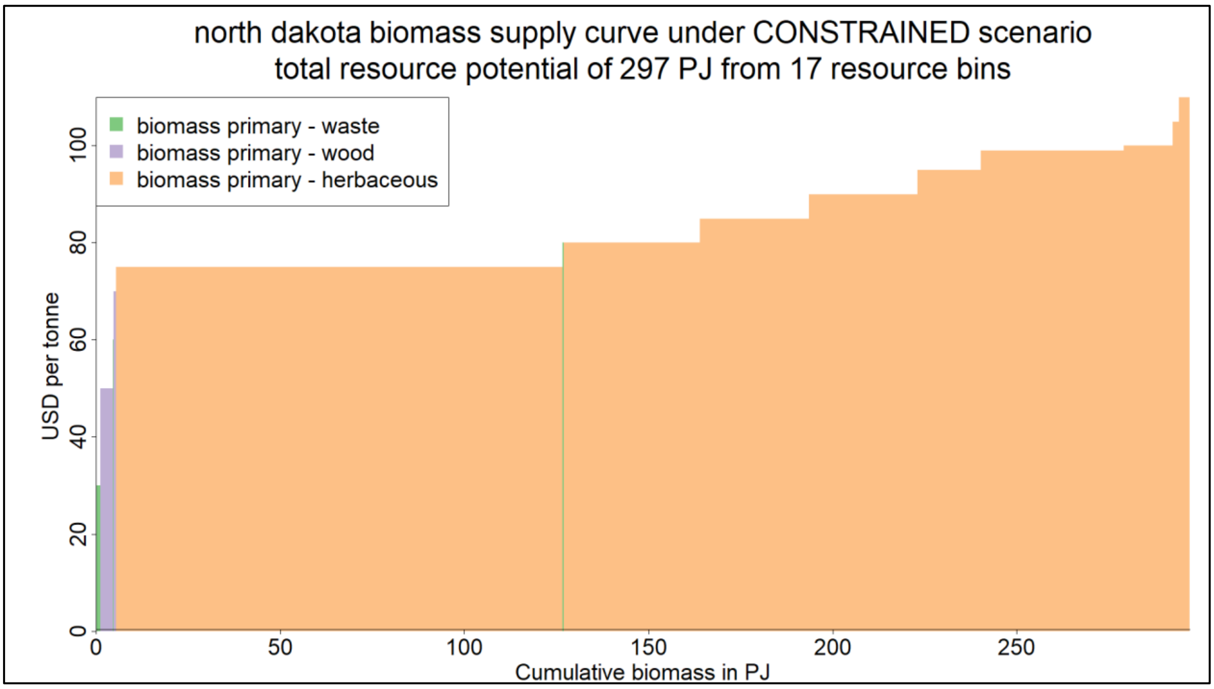

new hampshire biomass supply curve under CONSTRAINED scenario
total resource potential of 26 PJ from 8 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
0
10
20
Cumulative biomass in PJ

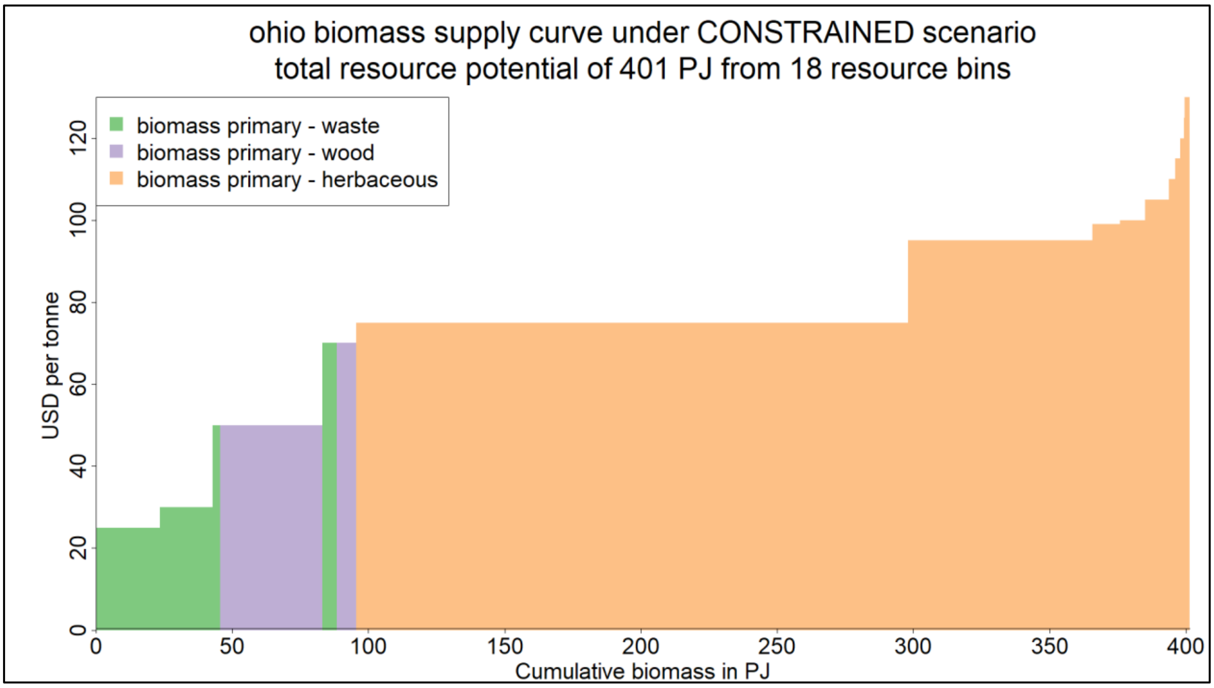

new jersey biomass supply curve under CONSTRAINED scenario
total resource potential of 52 PJ from 10 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
0
10
20
30
40
50
Cumulative biomass in PJ

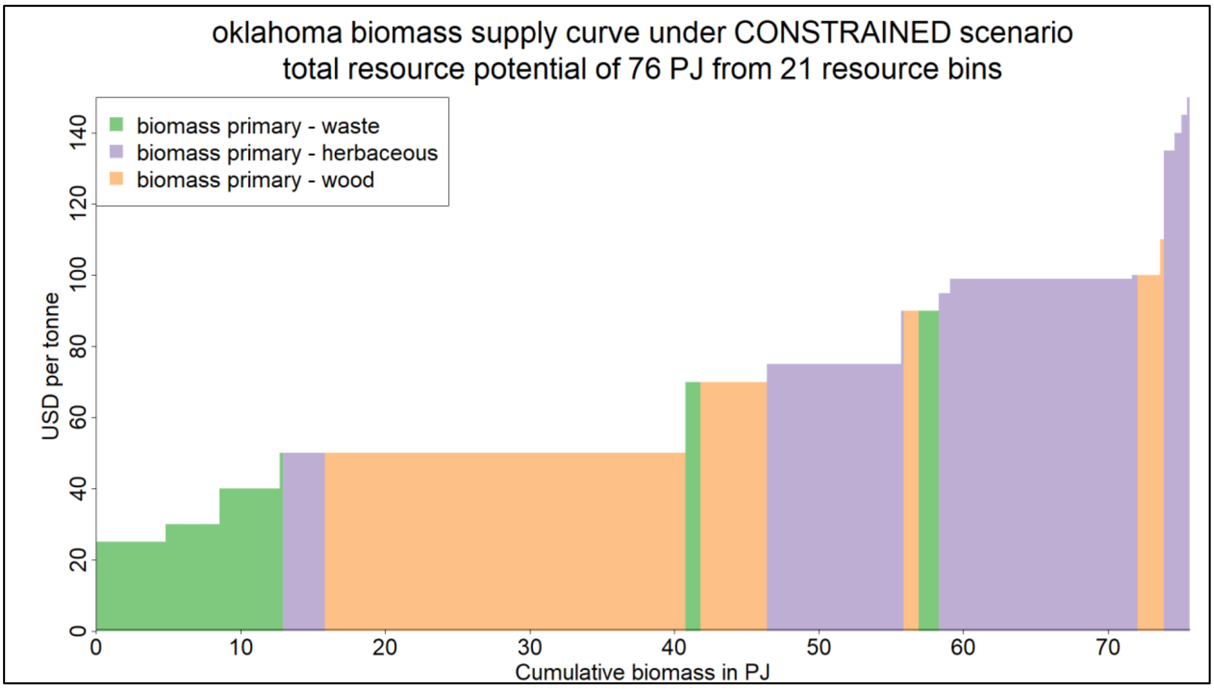

new mexico biomass supply curve under CONSTRAINED scenario
total resource potential of 34 PJ from 20 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
0
10
20
30
Cumulative biomass in PJ

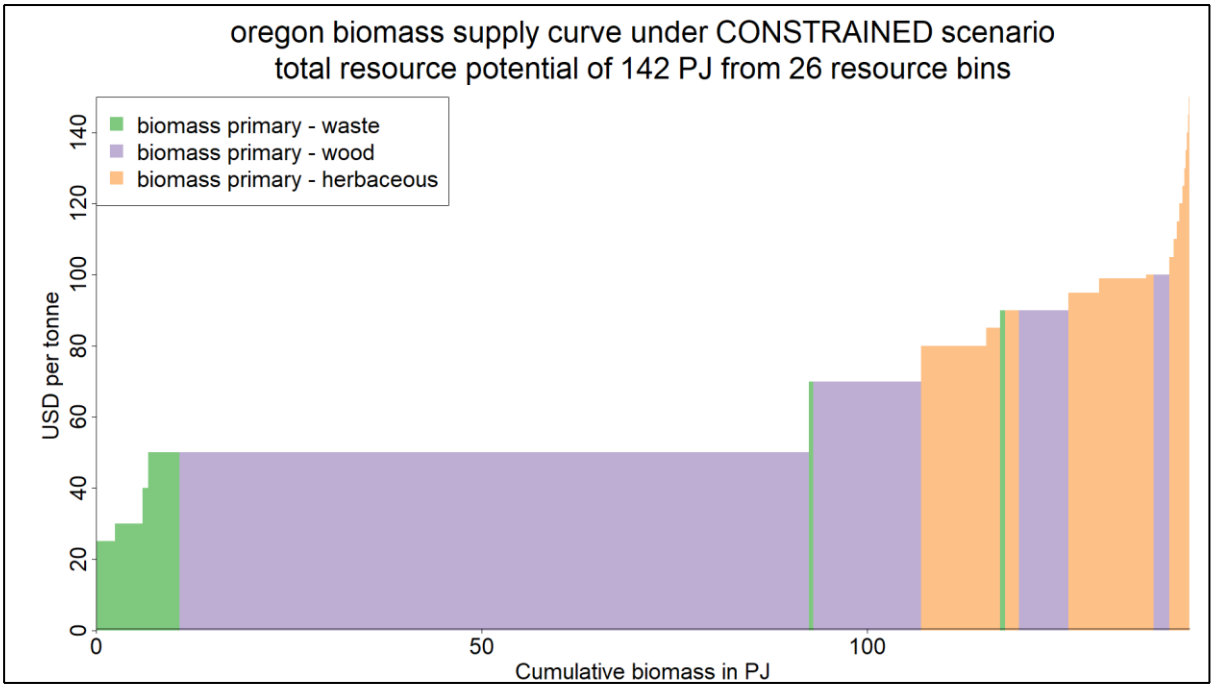

new york biomass supply curve under CONSTRAINED scenario
total resource potential of 215 PJ from 20 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
Cumulative biomass in PJ

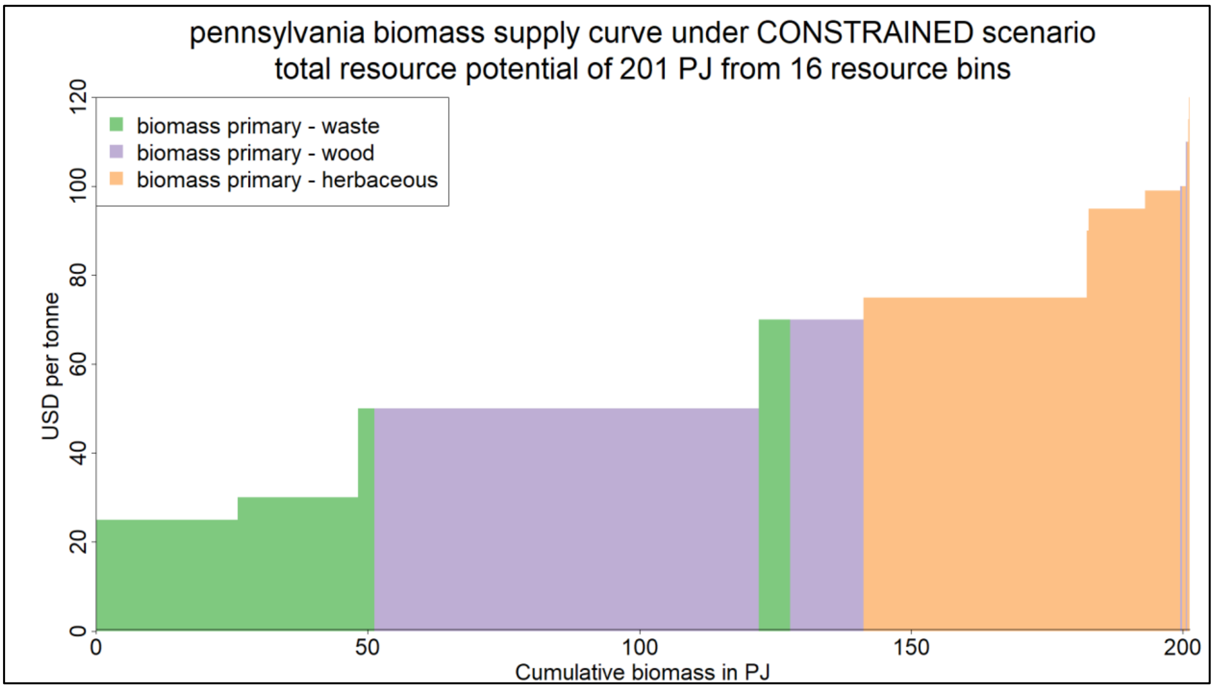

north carolina biomass supply curve under CONSTRAINED scenario
total resource potential of 433 PJ from 10 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
0
50
100
150
200
250
300
350
400
Cumulative biomass in PJ

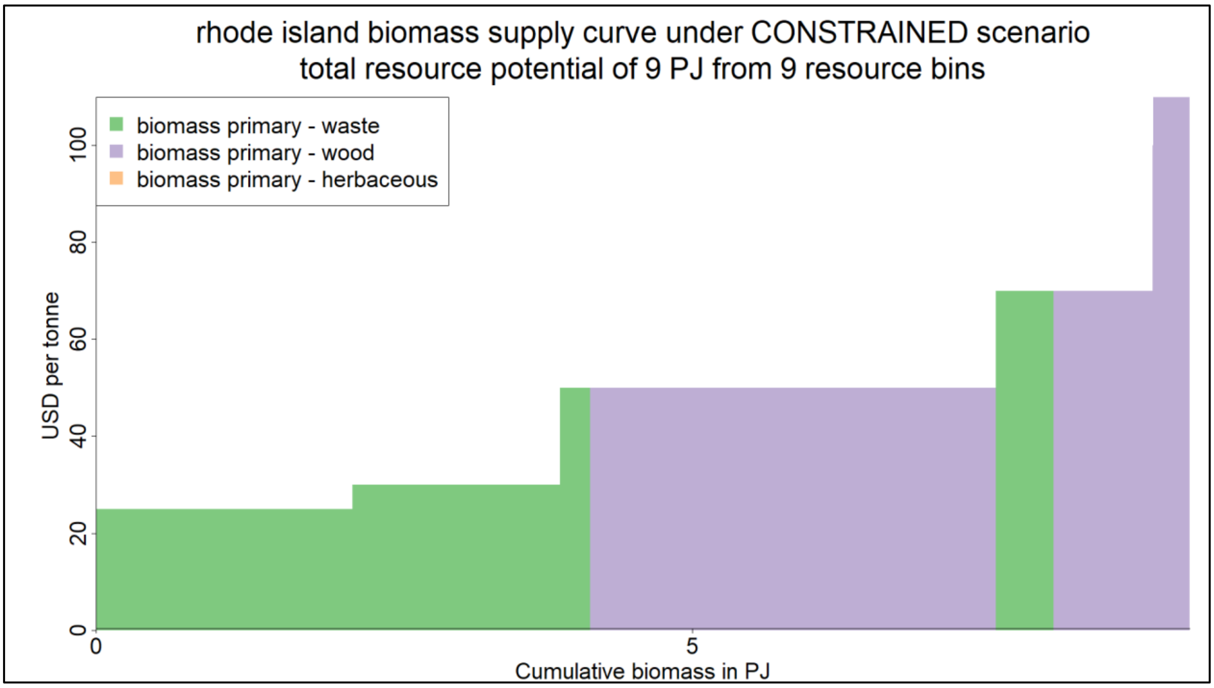

north dakota biomass supply curve under CONSTRAINED scenario
total resource potential of 297 PJ from 17 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
0
50
100
150
200
250
Cumulative biomass in PJ

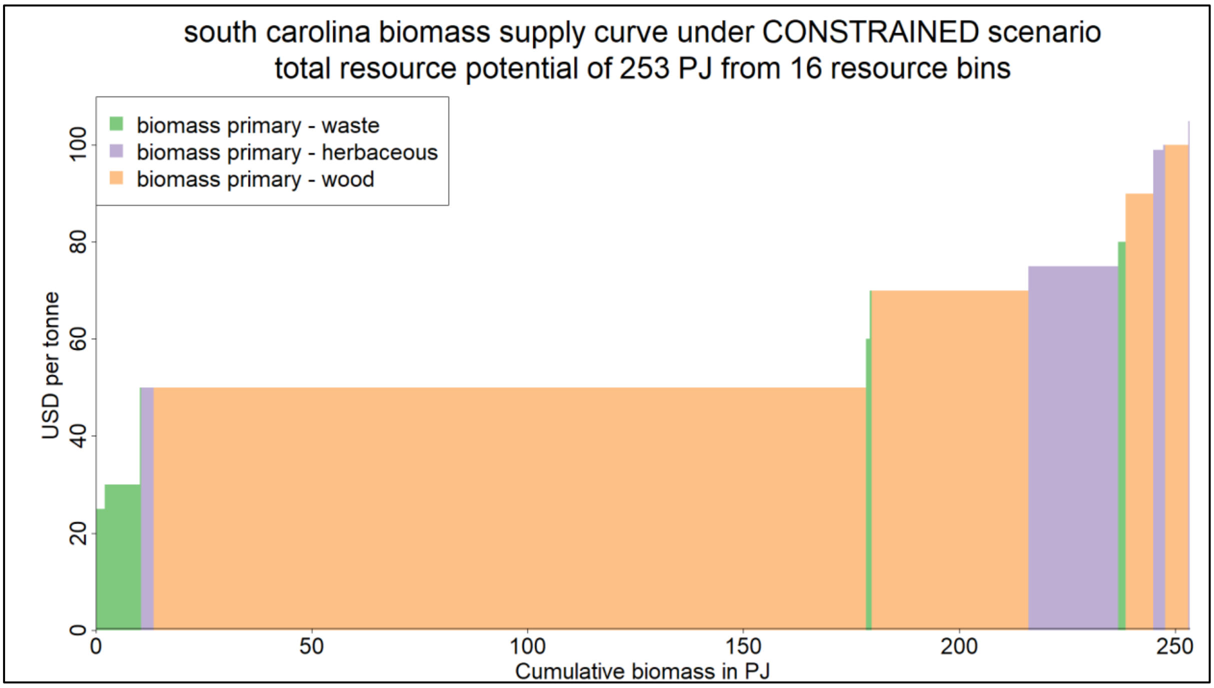

ohio biomass supply curve under CONSTRAINED scenario
total resource potential of 401 PJ from 18 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
0
50
100
150
200
250
300
350
400
Cumulative biomass in PJ

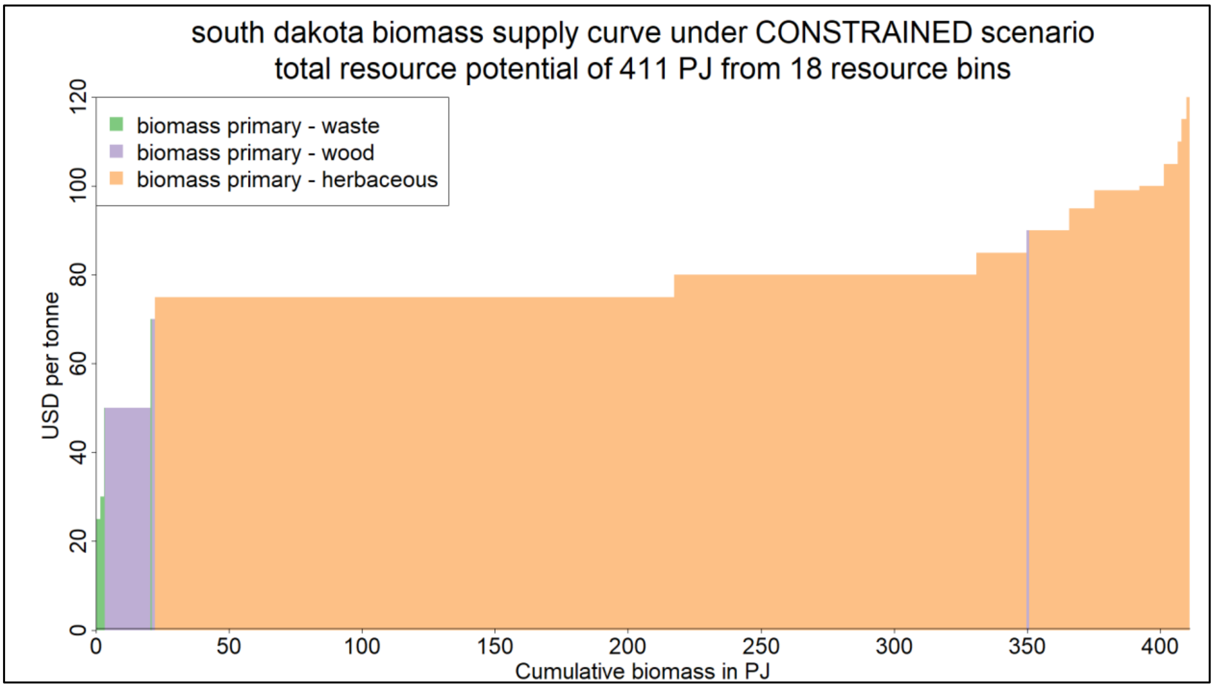

oklahoma biomass supply curve under CONSTRAINED scenario
total resource potential of 76 PJ from 21 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
140
0
10
20
30
40
50
60
70
Cumulative biomass in PJ


oregon biomass supply curve under CONSTRAINED scenario
total resource potential of 142 PJ from 26 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
Cumulative biomass in PJ

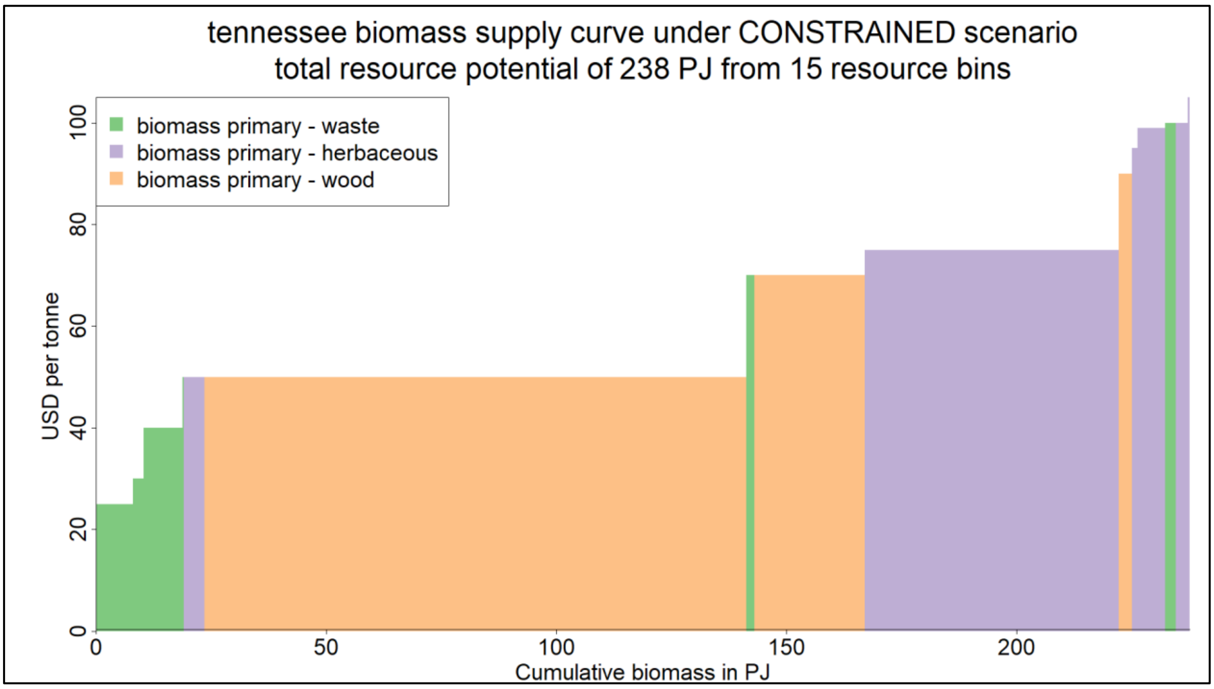

pennsylvania biomass supply curve under CONSTRAINED scenario
total resource potential of 201 PJ from 16 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
0
50
100
150
200
Cumulative biomass in PJ


rhode island biomass supply curve under CONSTRAINED scenario
total resource potential of 9 PJ from 9 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
0
5
Cumulative biomass in PJ

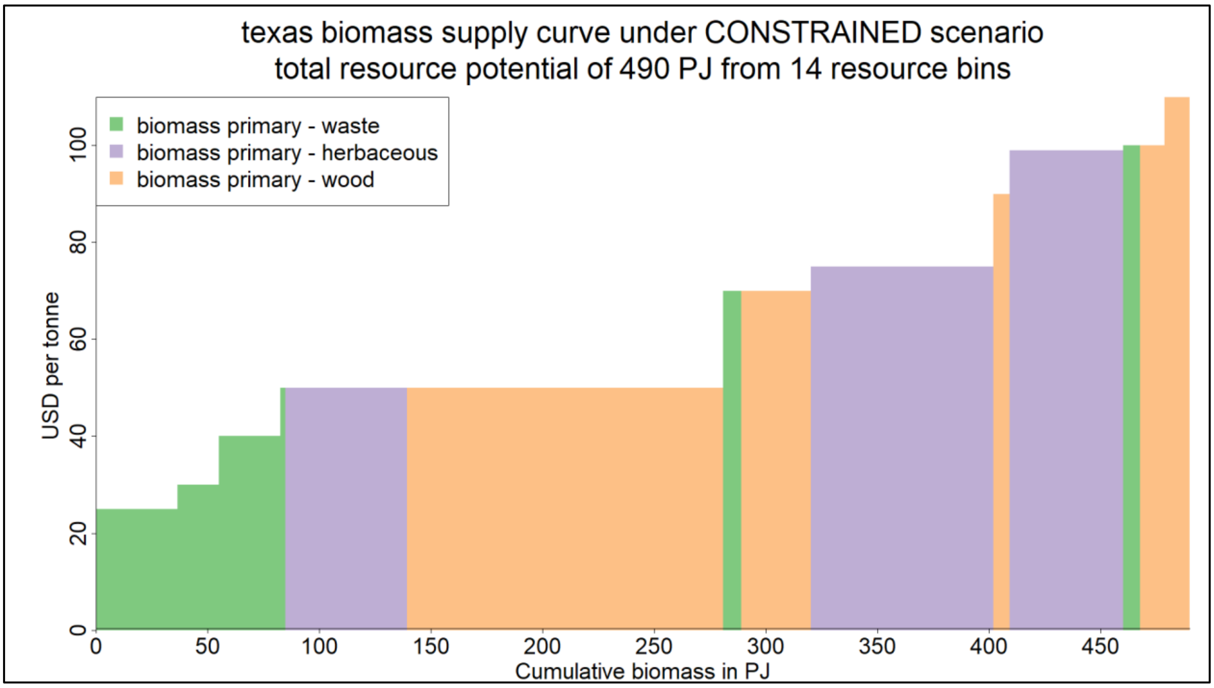

south carolina biomass supply curve under CONSTRAINED scenario
total resource potential of 253 PJ from 16 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
0
50
100
150
200
250
Cumulative biomass in PJ

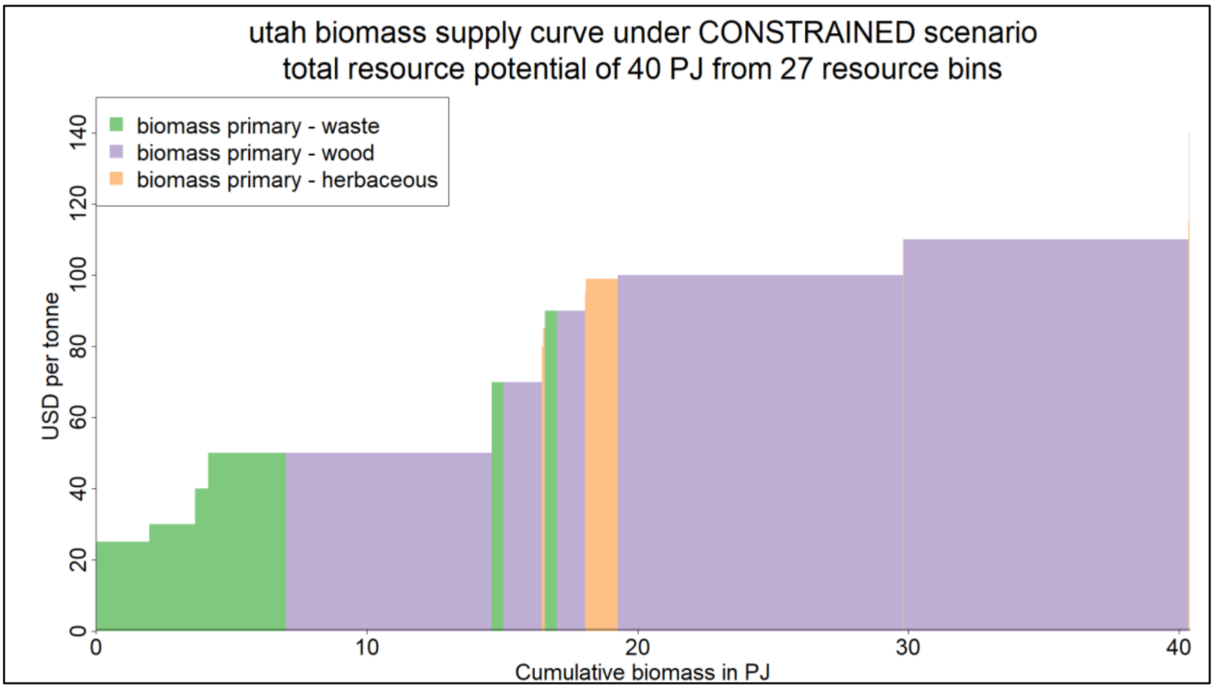


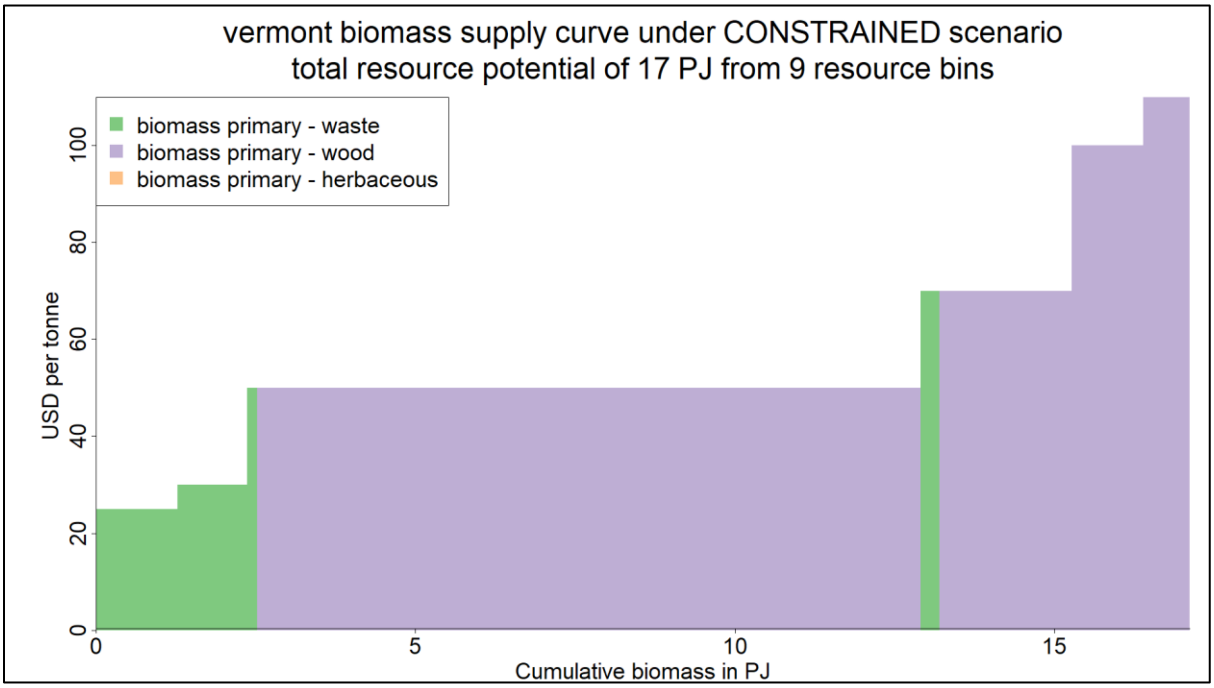
south dakota biomass supply curve under CONSTRAINED scenario
total resource potential of 411 PJ from 18 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
0
50
100
150
200
250
300
350
400
Cumulative biomass in PJ

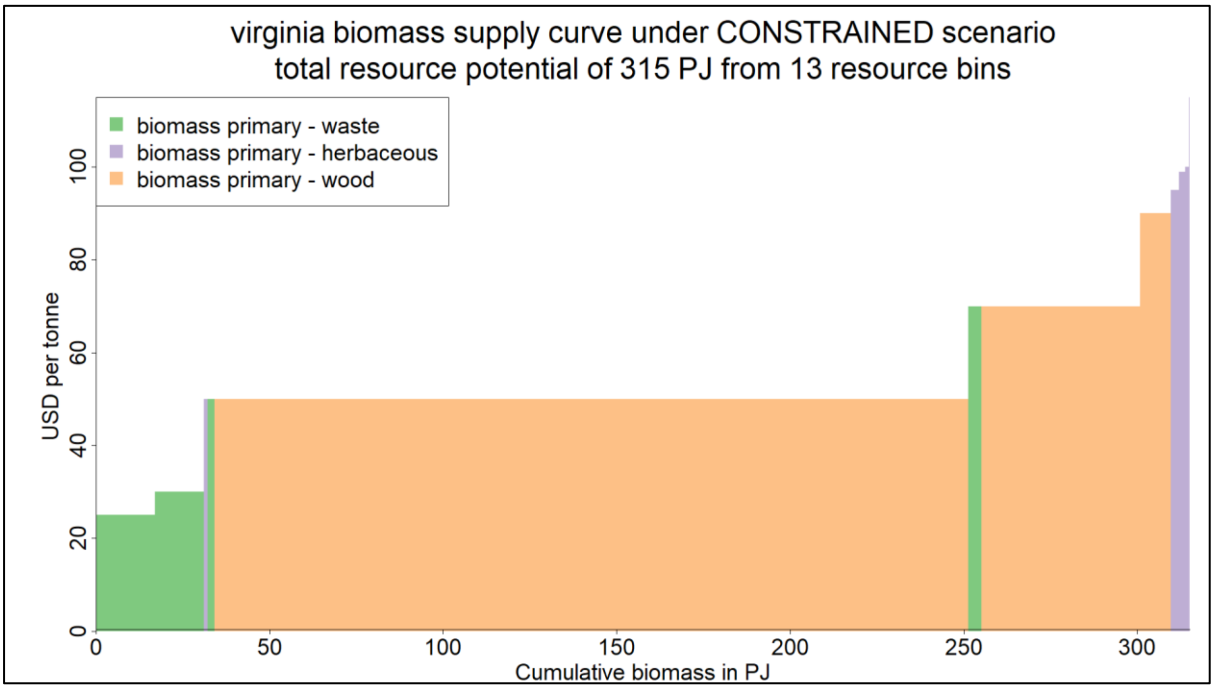


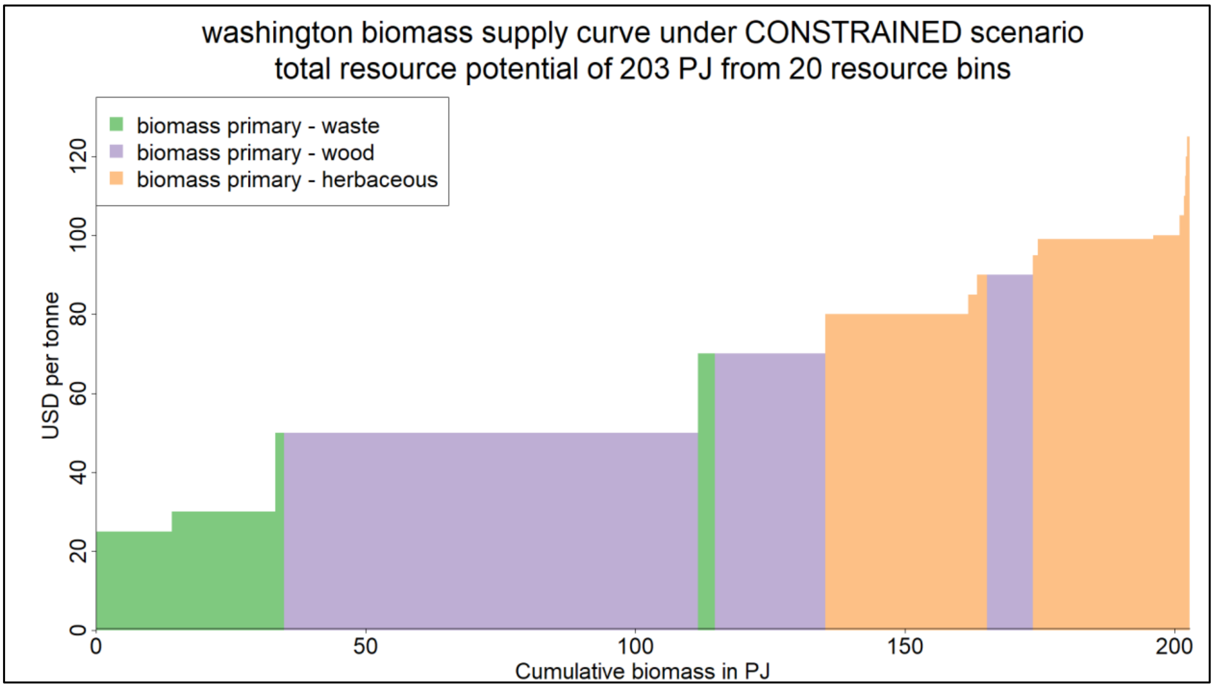
tennessee biomass supply curve under CONSTRAINED scenario
total resource potential of 238 PJ from 15 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
0
50
100
150
200
Cumulative biomass in PJ

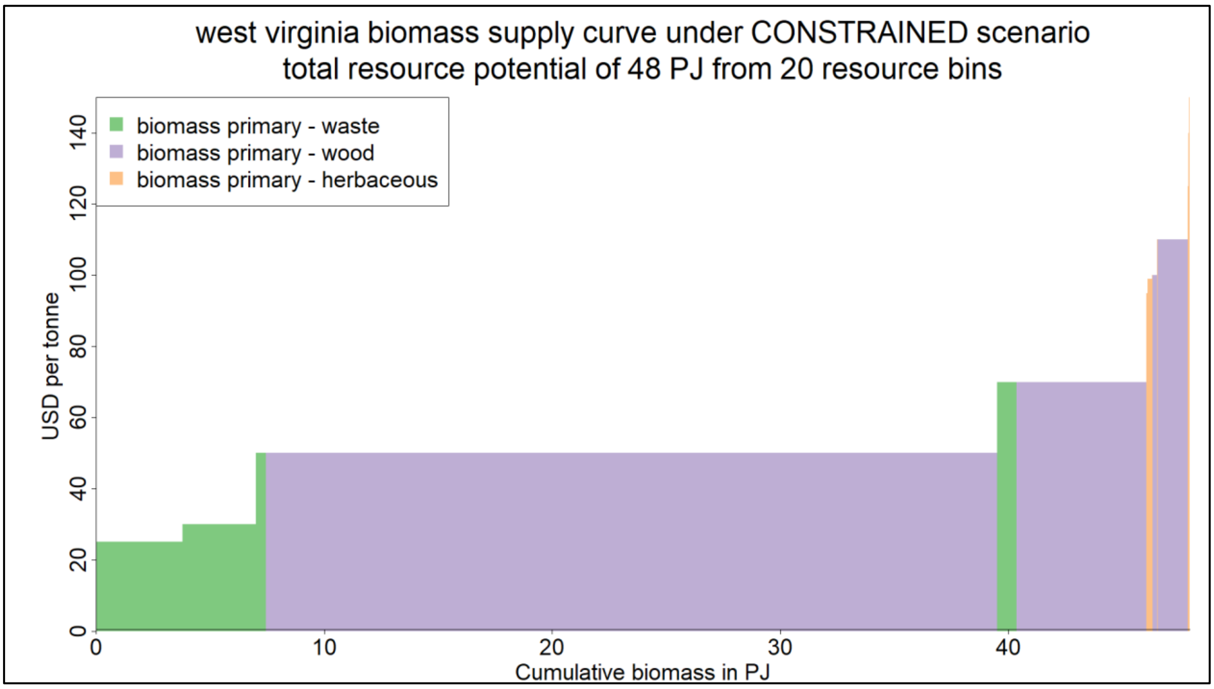

texas biomass supply curve under CONSTRAINED scenario
total resource potential of 490 PJ from 14 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
0
50
100
150
200
250
300
350
400
450
Cumulative biomass in PJ

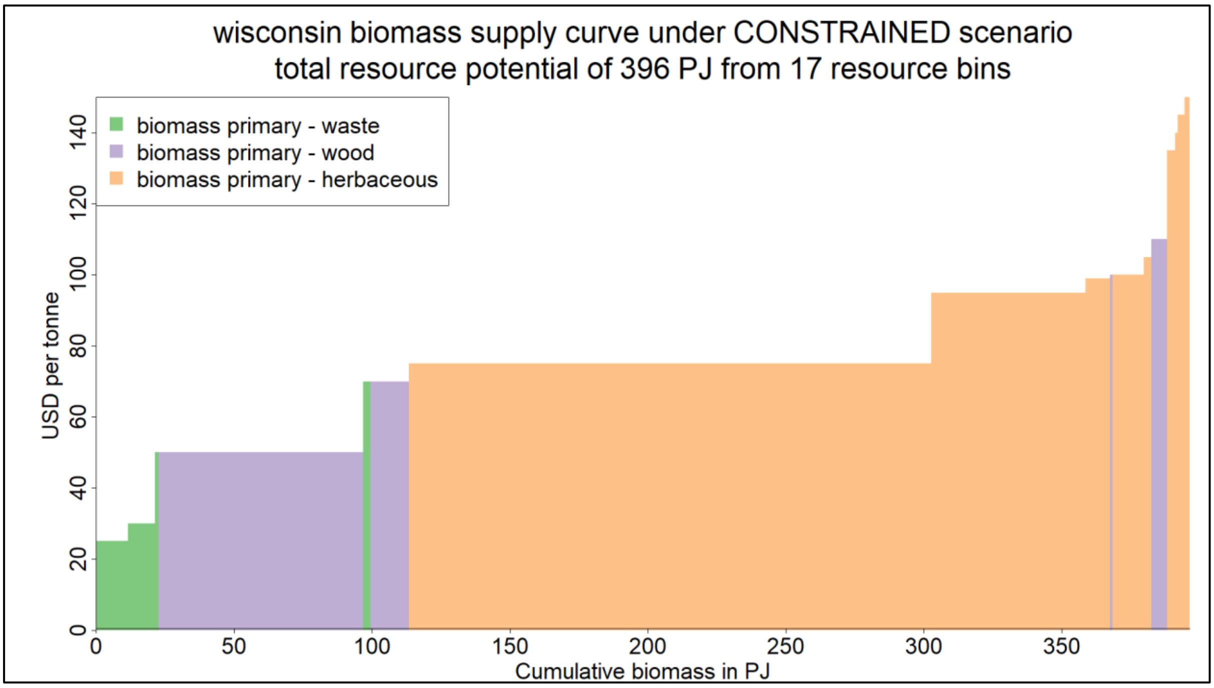

utah biomass supply curve under CONSTRAINED scenario
total resource potential of 40 PJ from 27 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
10
20
30
40
Cumulative biomass in PJ

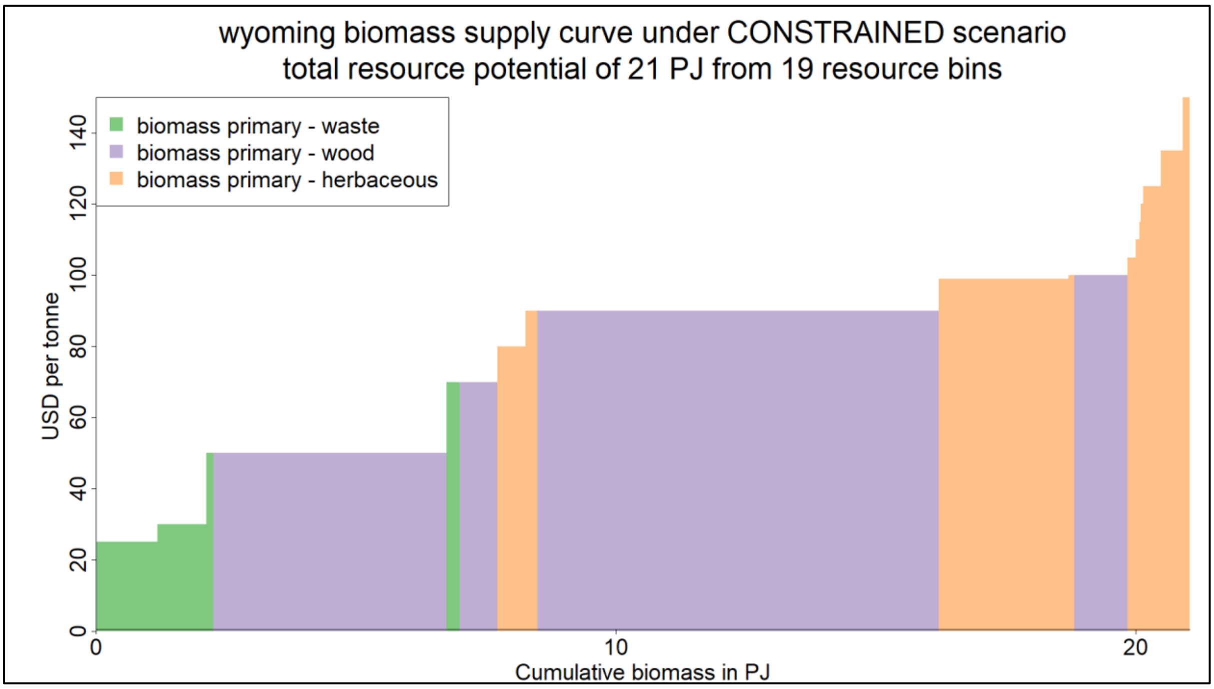

vermont biomass supply curve under CONSTRAINED scenario
total resource potential of 17 PJ from 9 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
0
5
10
15
Cumulative biomass in PJ


virginia biomass supply curve under CONSTRAINED scenario
total resource potential of 315 PJ from 13 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
0
50
100
150
200
250
300
Cumulative biomass in PJ


washington biomass supply curve under CONSTRAINED scenario
total resource potential of 203 PJ from 20 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
0
50
100
150
200
Cumulative biomass in PJ

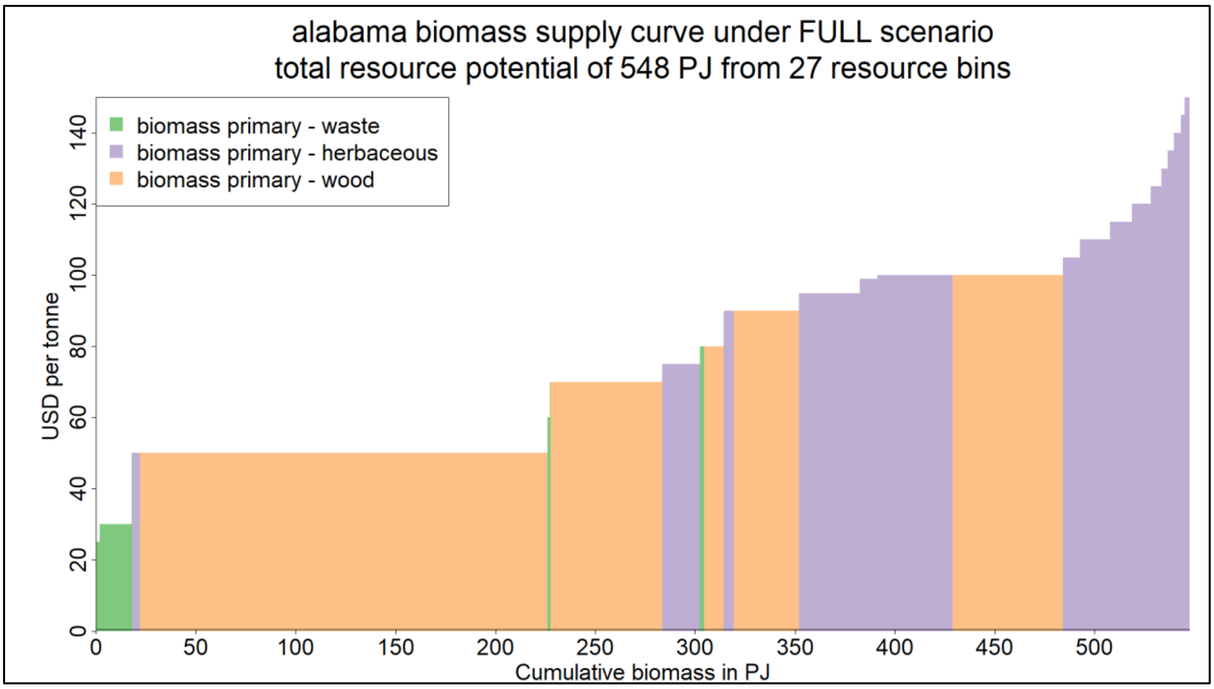

west virginia biomass supply curve under CONSTRAINED scenario
total resource potential of 48 PJ from 20 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
10
20
30
40
Cumulative biomass in PJ

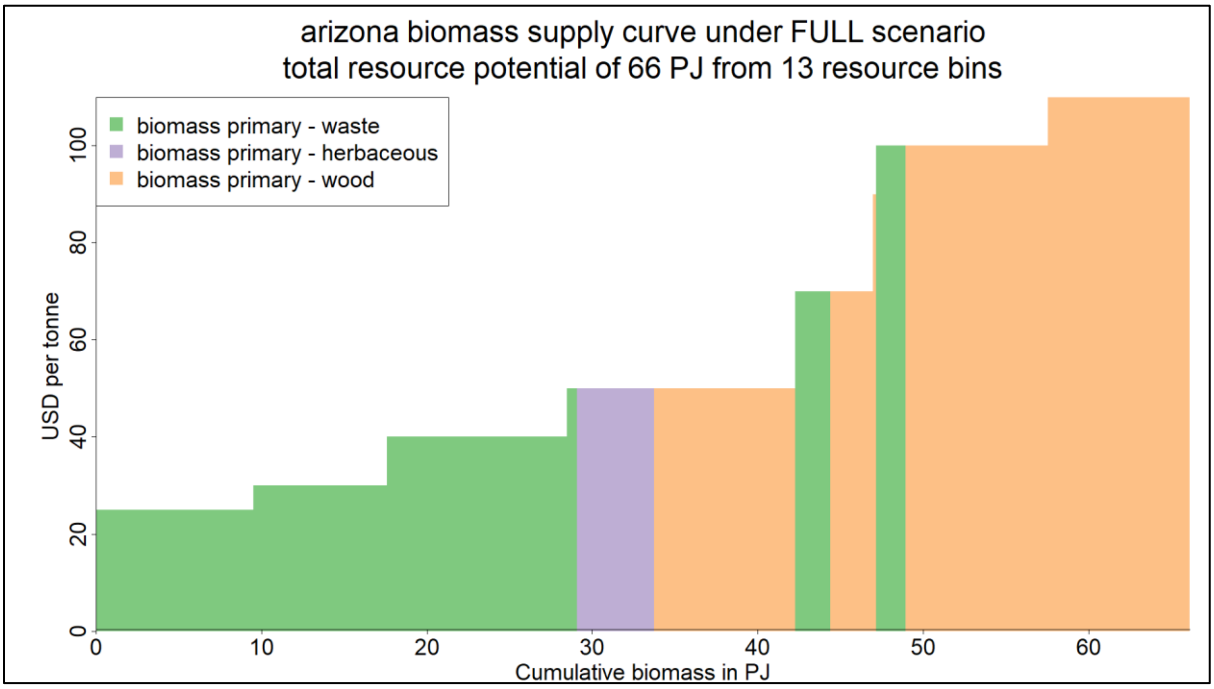

wisconsin biomass supply curve under CONSTRAINED scenario
total resource potential of 396 PJ from 17 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
Cumulative biomass in PJ

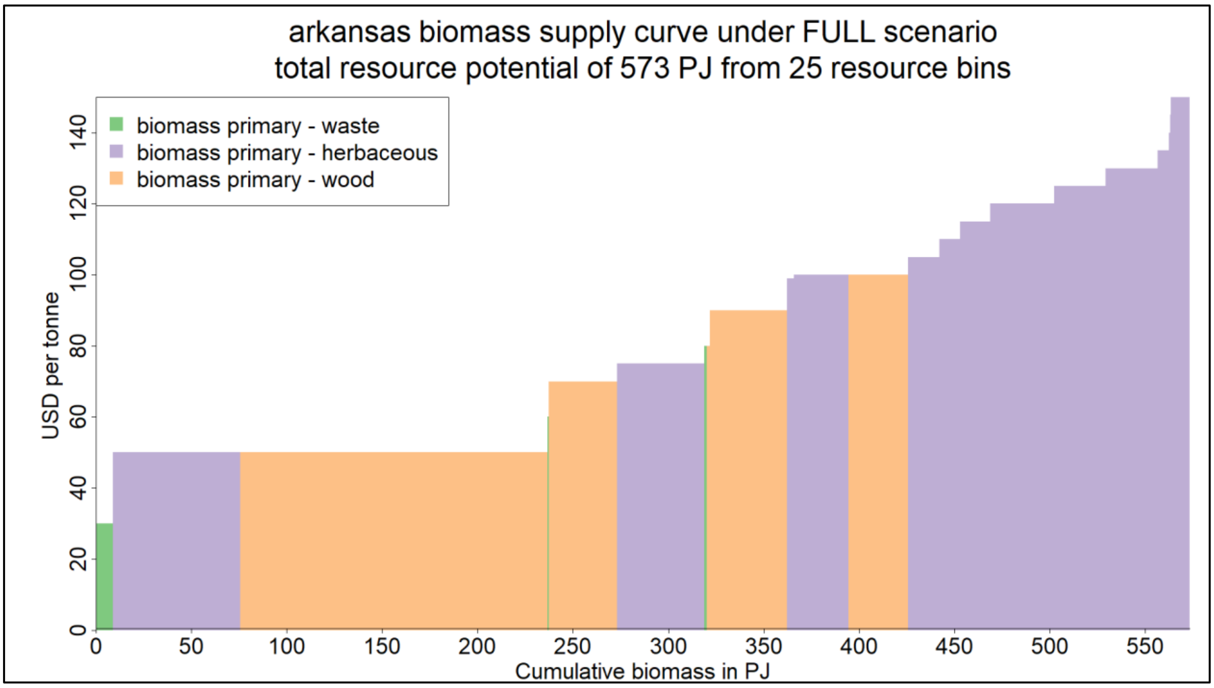

wyoming biomass supply curve under CONSTRAINED scenario
total resource potential of 21 PJ from 19 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
10
20
Cumulative biomass in PJ

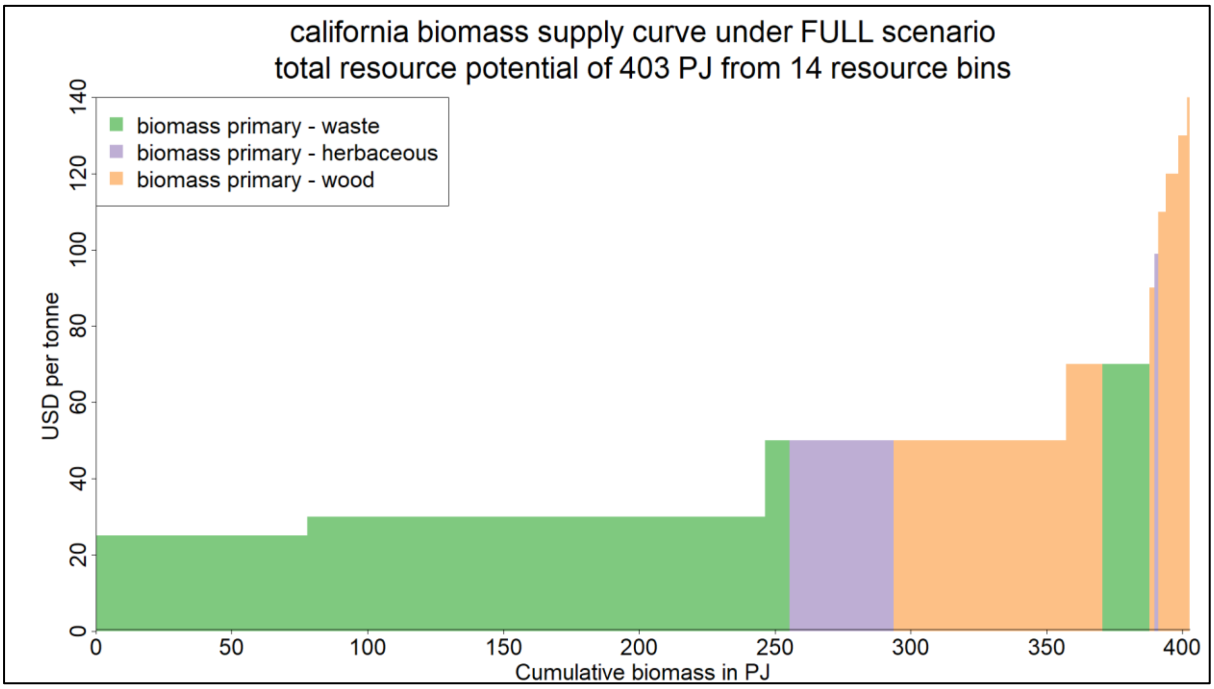
Appendix H2: State biomass cost-supply curves (High)

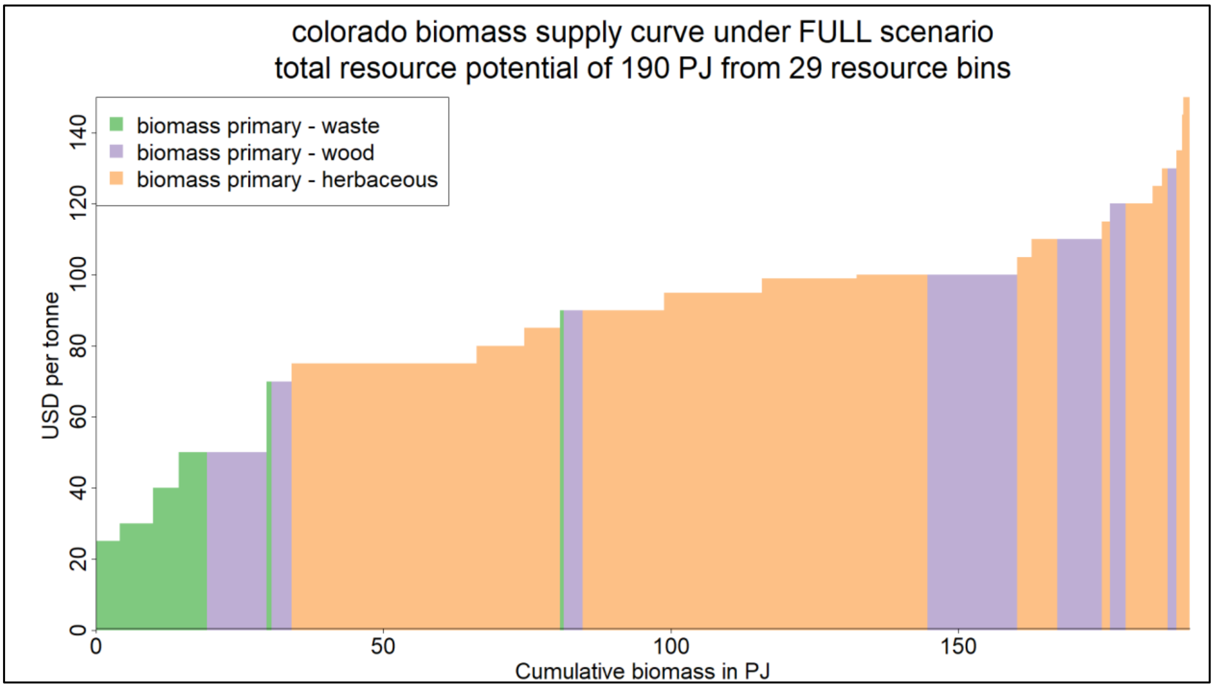
State-level supply curves for High Biomass Case in 2050 in Petajoules. (High Biomass Case is labeled "FULL Scenario" in these figures.)

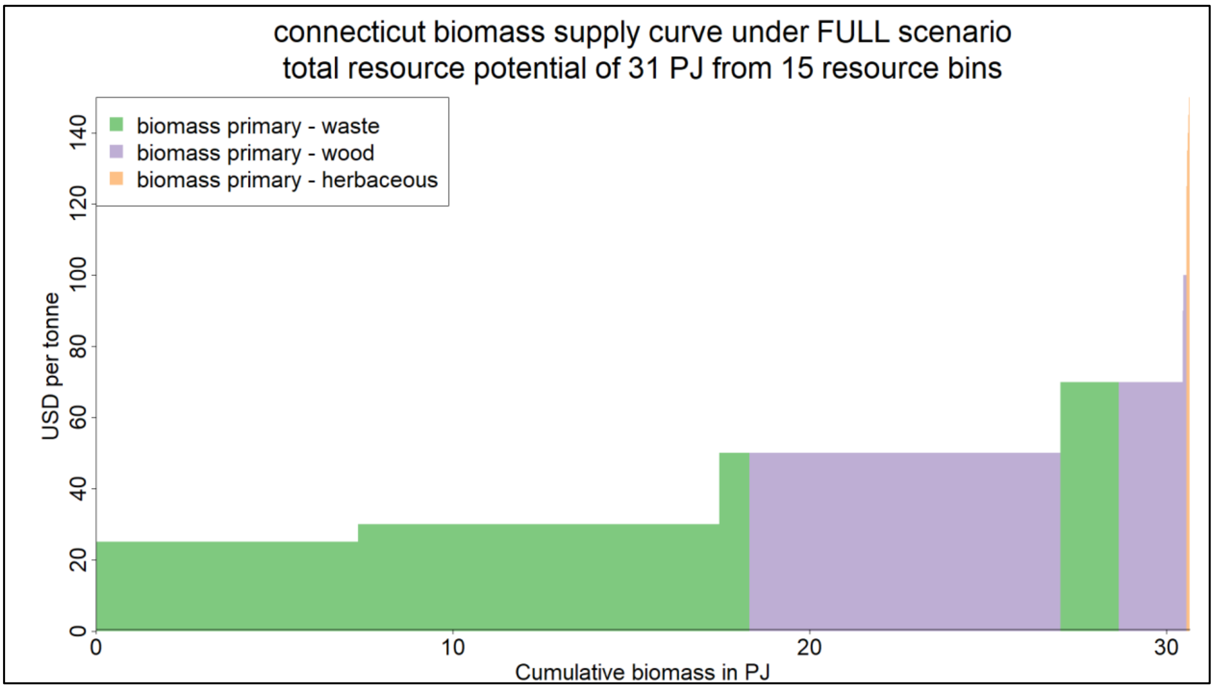


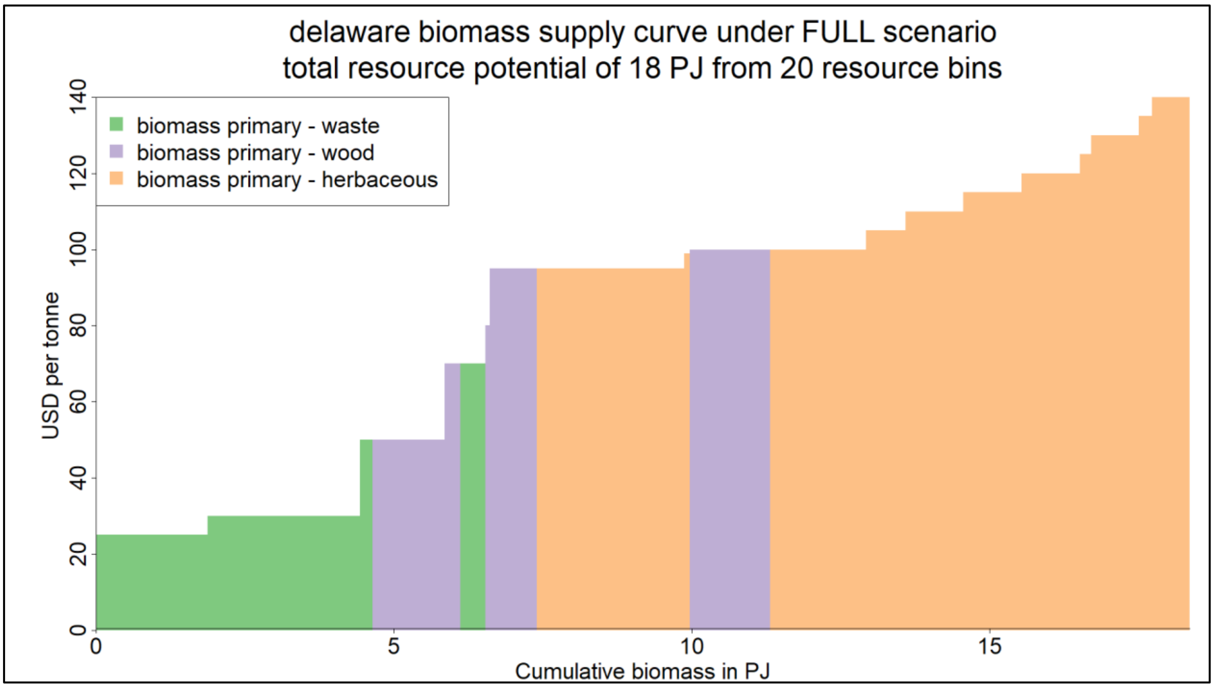


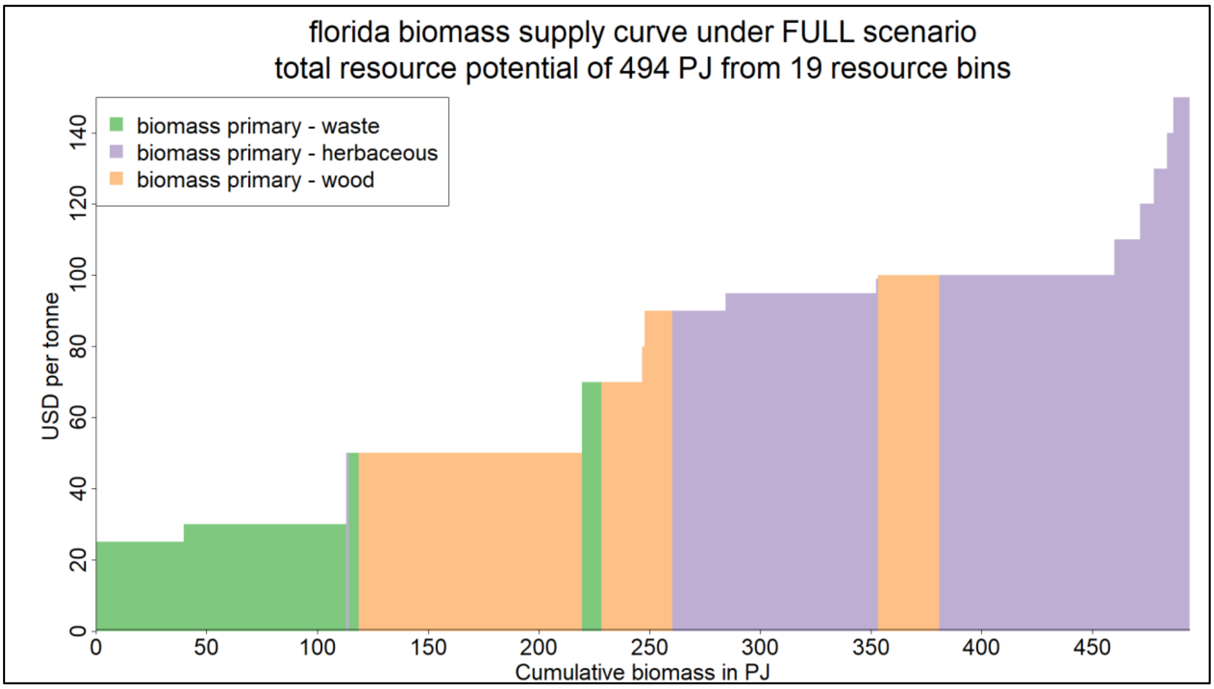

arkansas biomass supply curve under FULL scenario
total resource potential of 573 PJ from 25 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450
500
550
Cumulative biomass in PJ

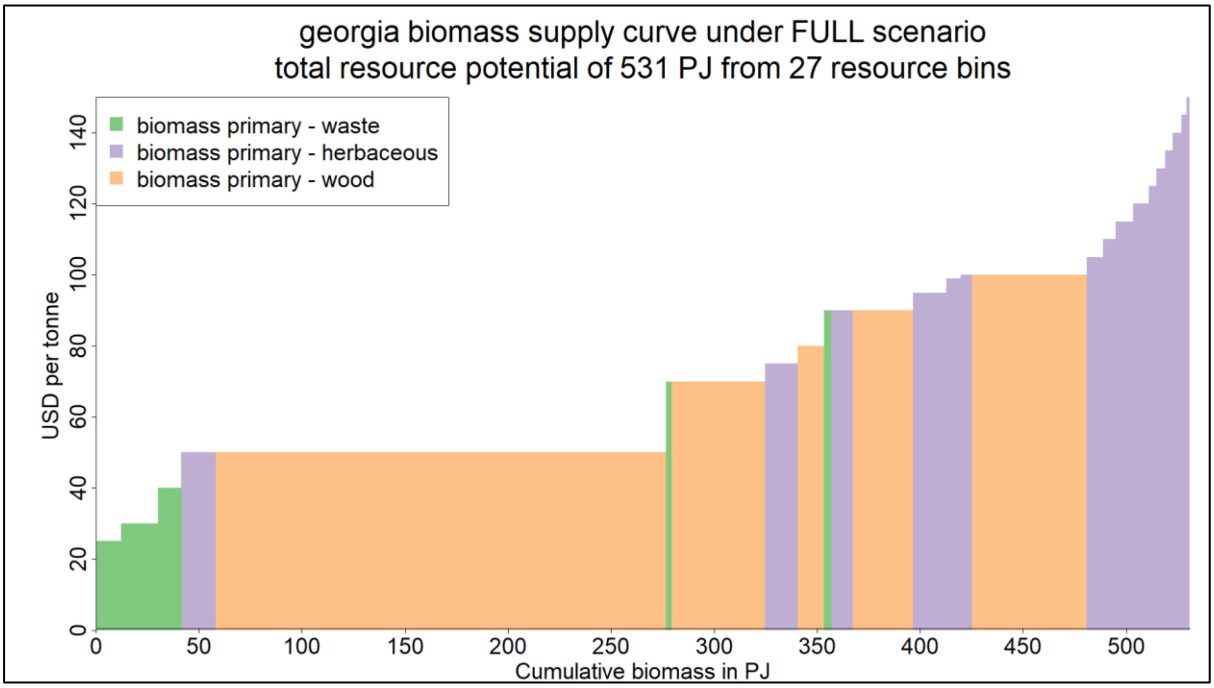

california biomass supply curve under FULL scenario
total resource potential of 403 PJ from 14 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
Cumulative biomass in PJ

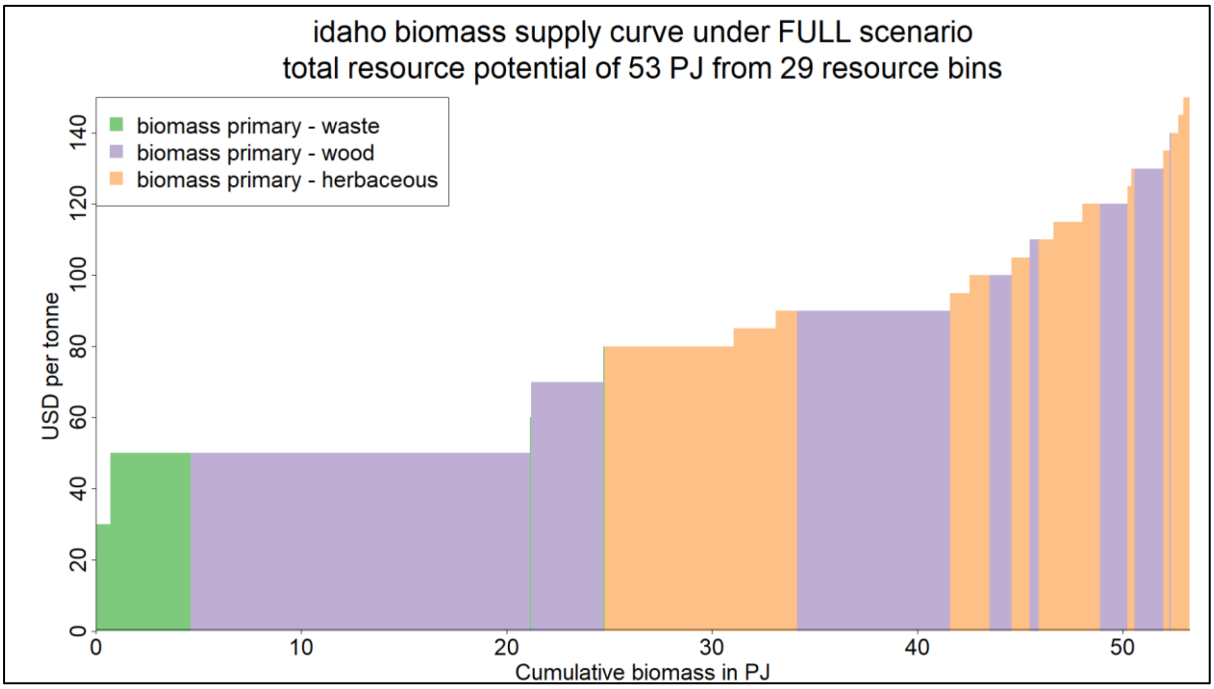

colorado biomass supply curve under FULL scenario
total resource potential of 190 PJ from 29 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
Cumulative biomass in PJ

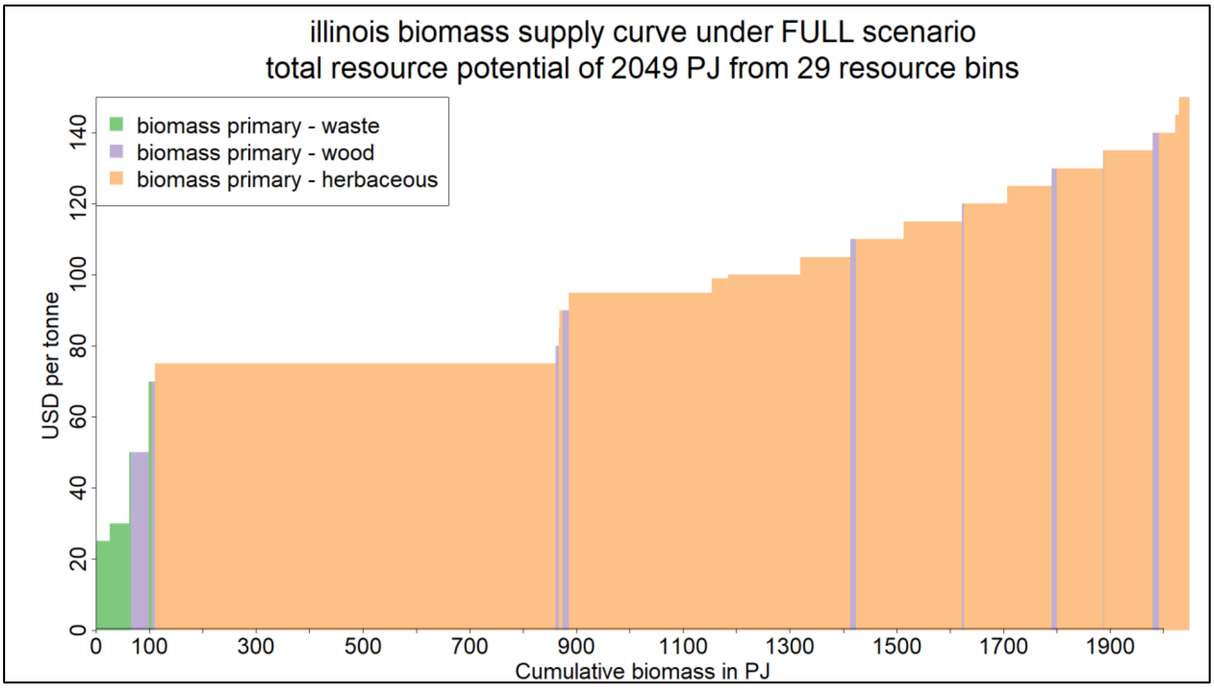

connecticut biomass supply curve under FULL scenario
total resource potential of 31 PJ from 15 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
10
20
30
Cumulative biomass in PJ

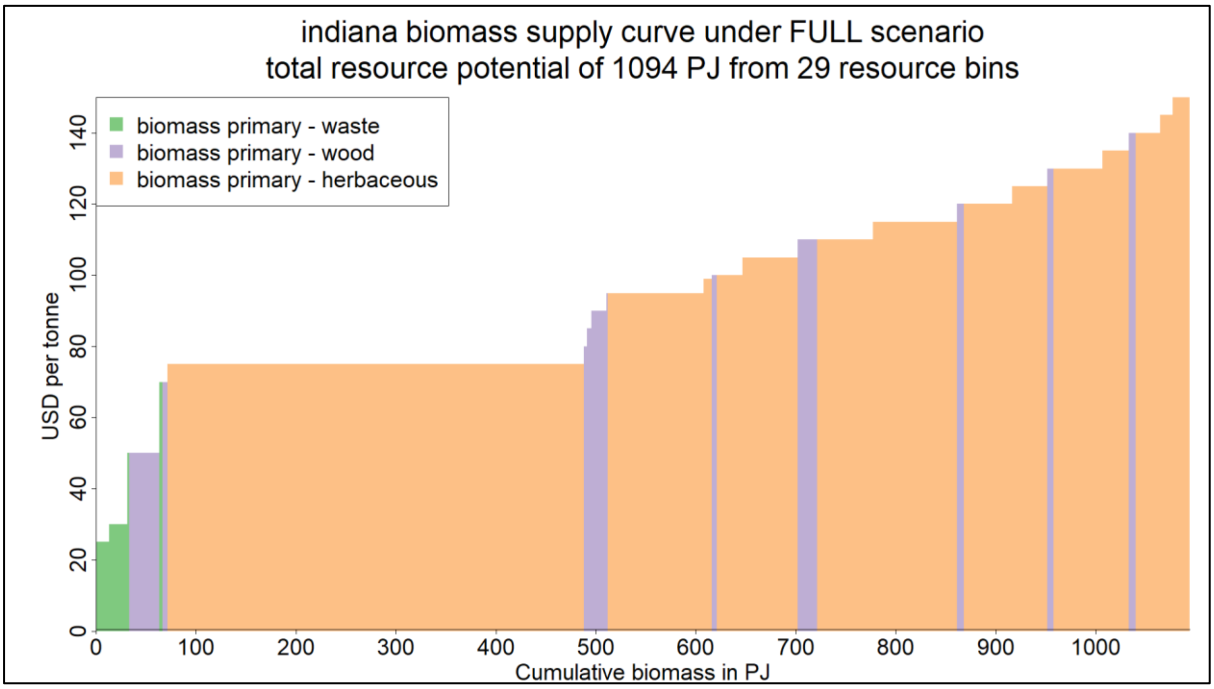

delaware biomass supply curve under FULL scenario
total resource potential of 18 PJ from 20 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
5
10
15
Cumulative biomass in PJ

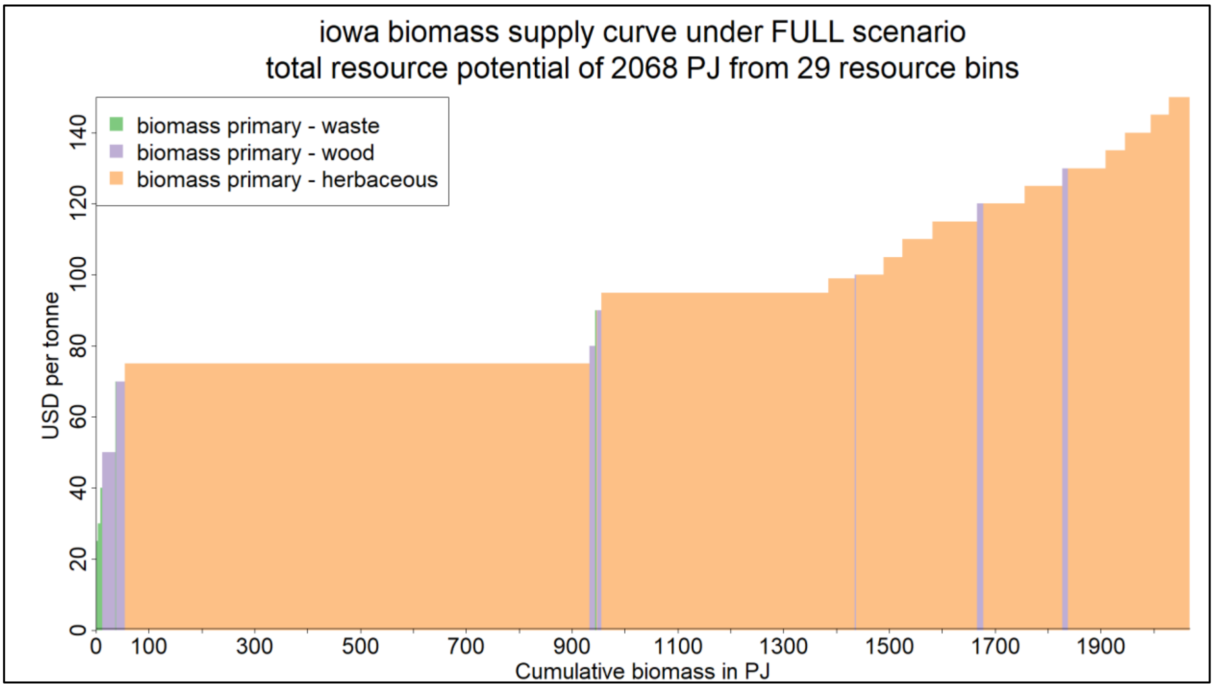

florida biomass supply curve under FULL scenario
total resource potential of 494 PJ from 19 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450
Cumulative biomass in PJ

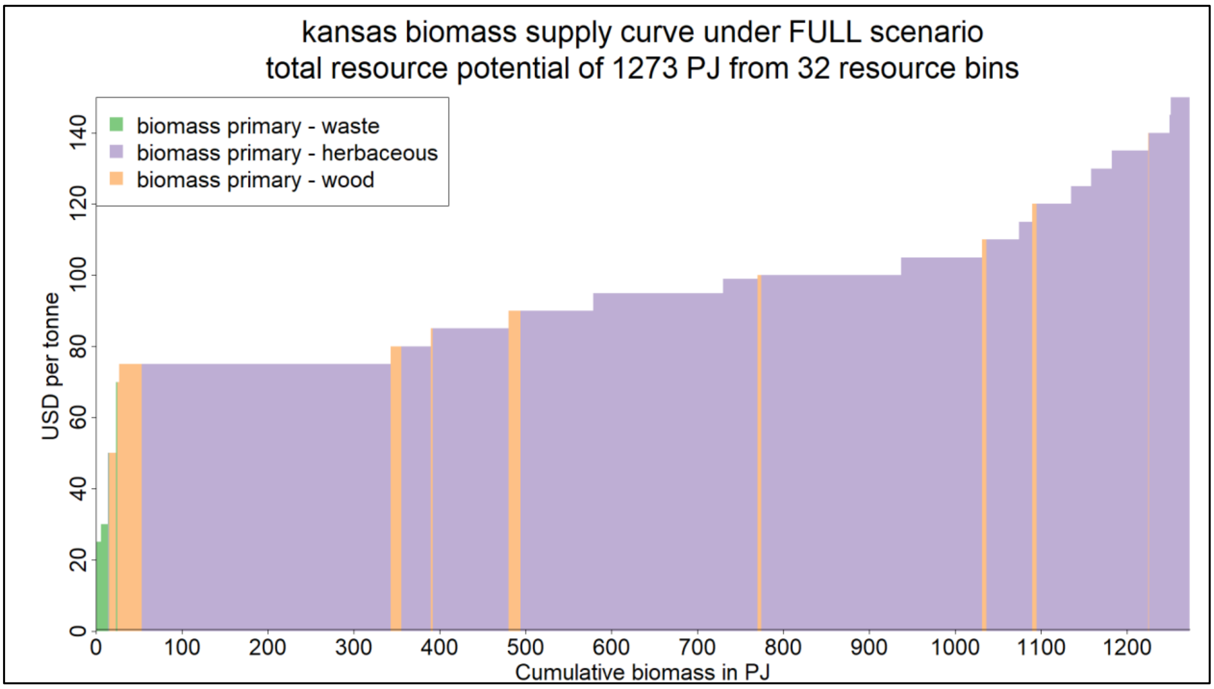

georgia biomass supply curve under FULL scenario
total resource potential of 531 PJ from 27 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450
500
Cumulative biomass in PJ

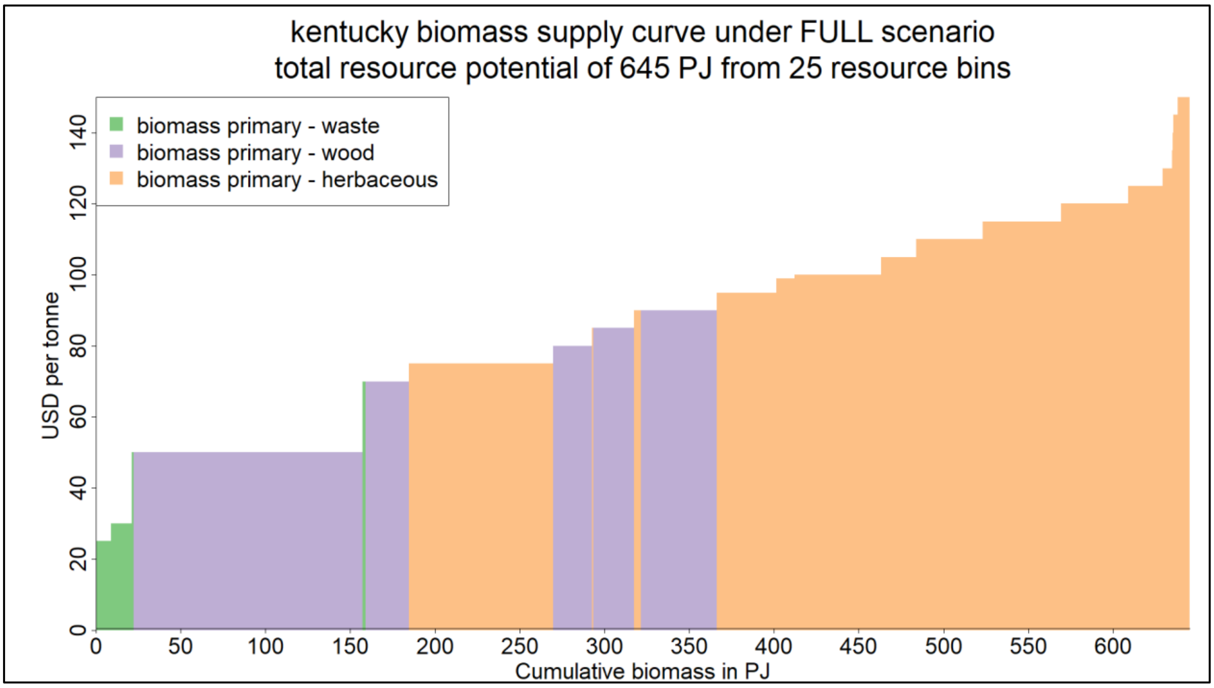

idaho biomass supply curve under FULL scenario
total resource potential of 53 PJ from 29 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
10
20
30
40
50
Cumulative biomass in PJ

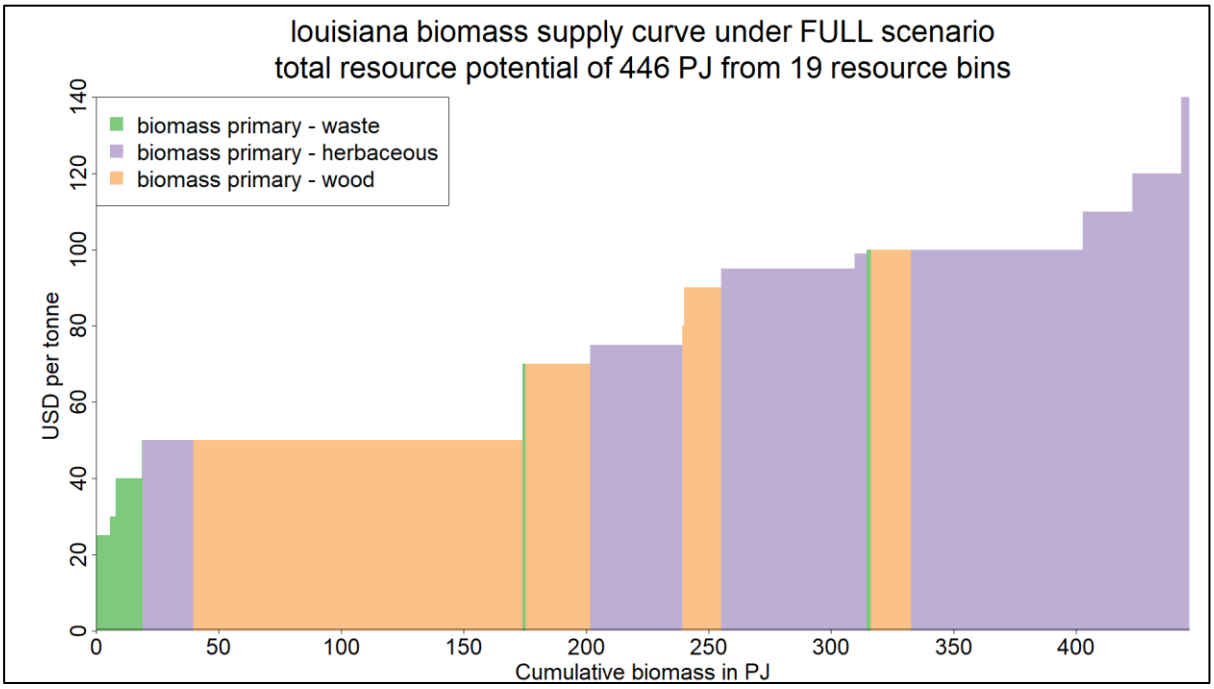

illinois biomass supply curve under FULL scenario
total resource potential of 2049 PJ from 29 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
100
300
500
700
900
1100
1300
1500
1700
1900
Cumulative biomass in PJ

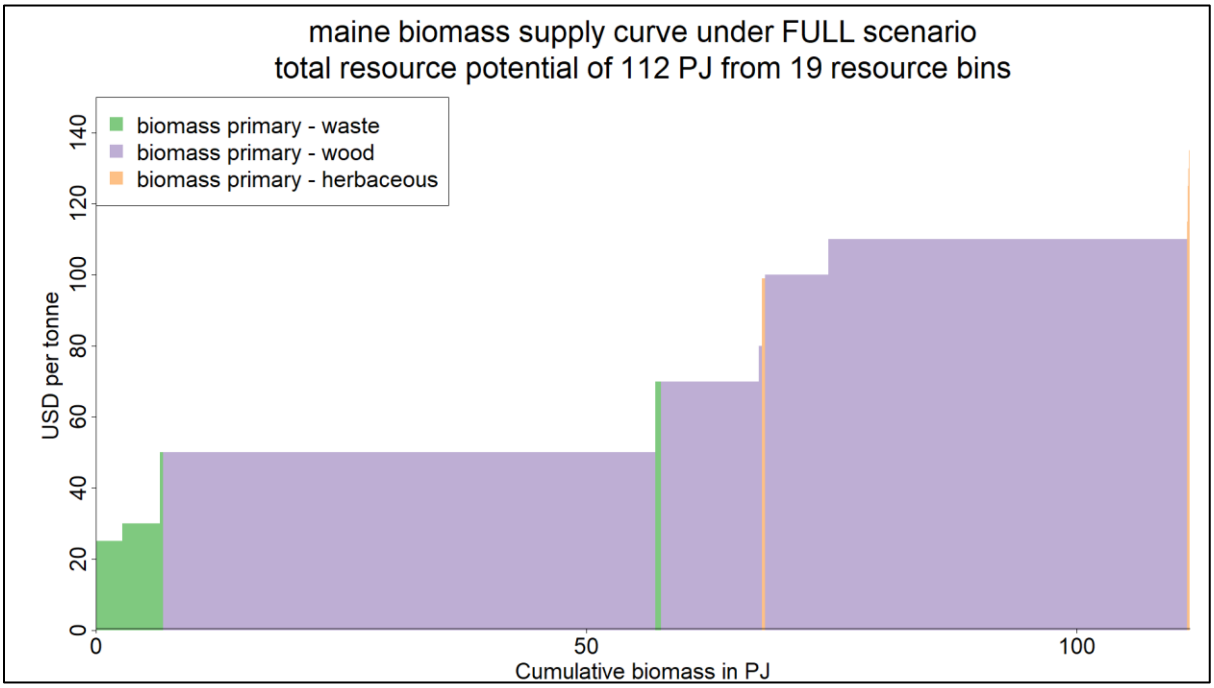

indiana biomass supply curve under FULL scenario
total resource potential of 1094 PJ from 29 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
100
200
300
400
500
600
700
800
900
1000
Cumulative biomass in PJ

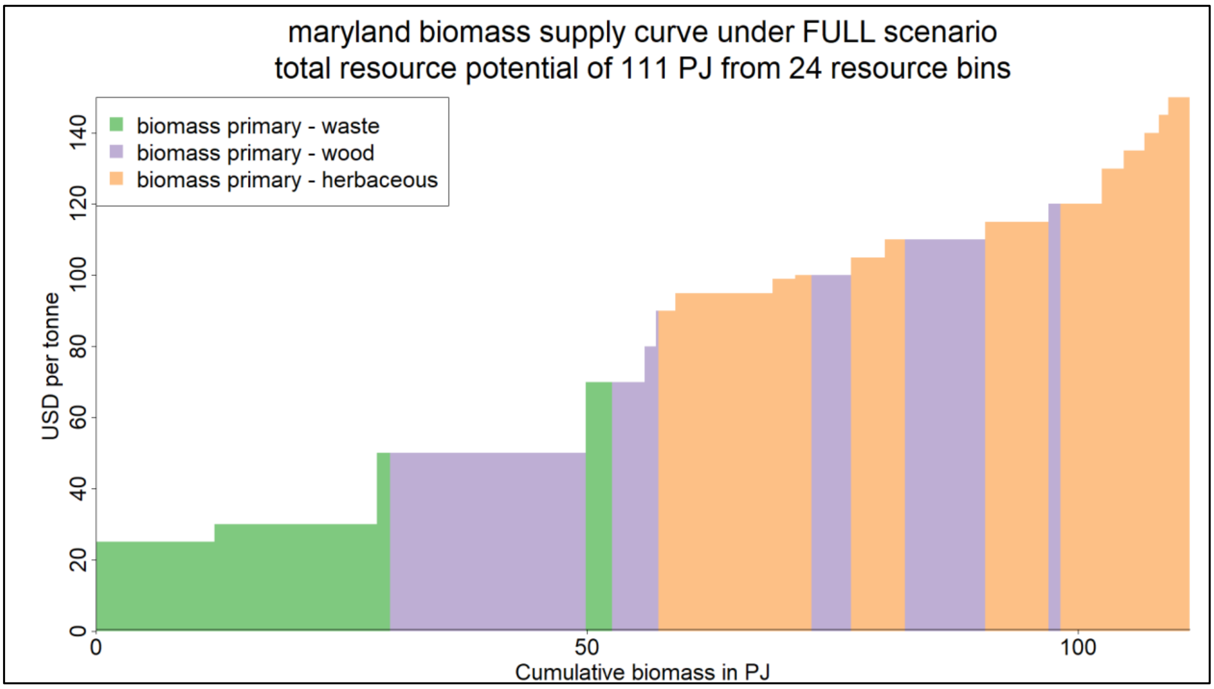

iowa biomass supply curve under FULL scenario
total resource potential of 2068 PJ from 29 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
100
300
500
700
900
1100
1300
1500
1700
1900
Cumulative biomass in PJ

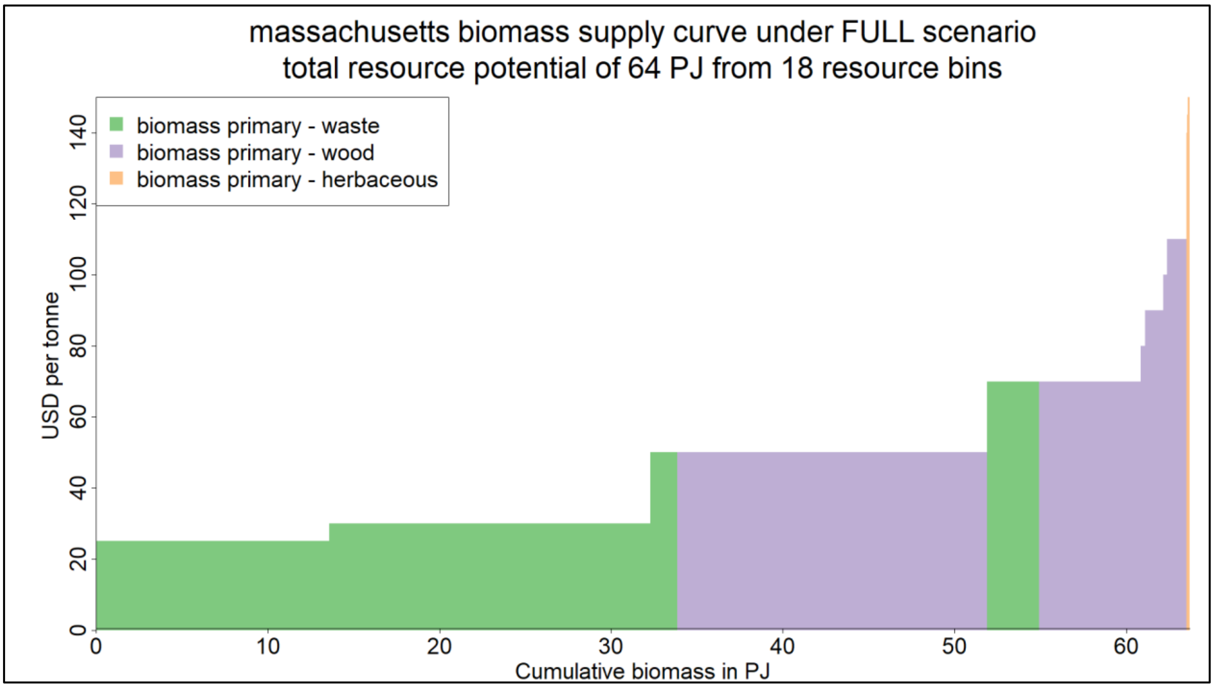

kansas biomass supply curve under FULL scenario
total resource potential of 1273 PJ from 32 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
140
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Cumulative biomass in PJ

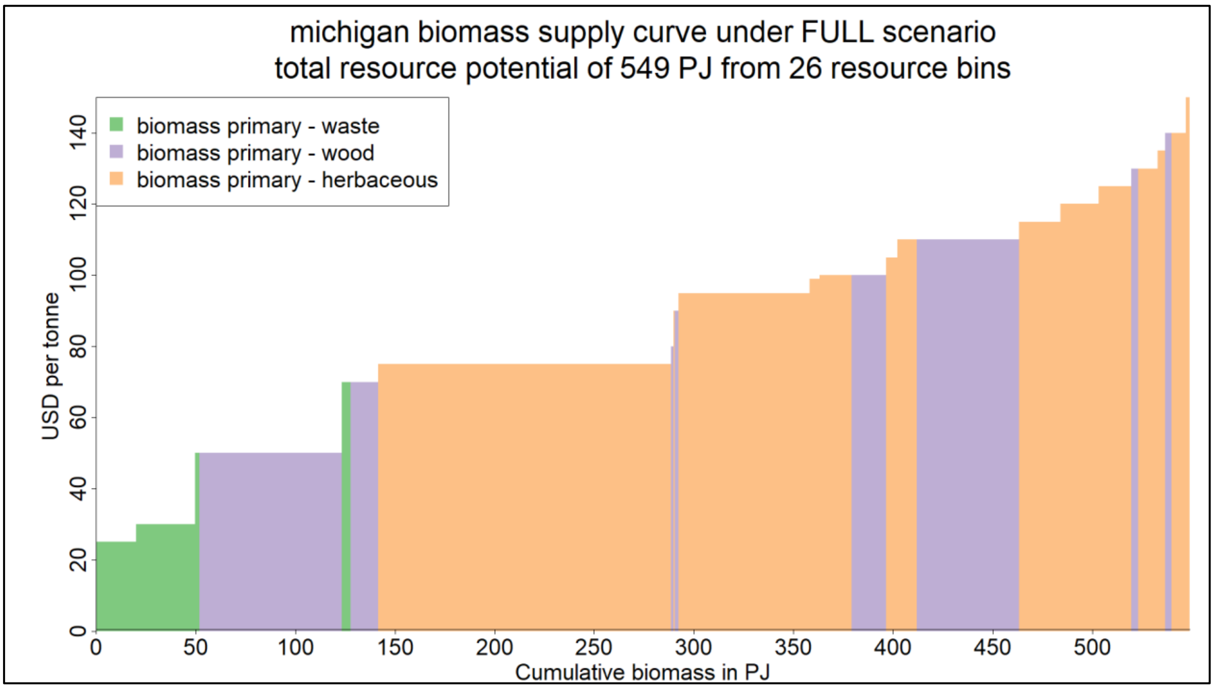

kentucky biomass supply curve under FULL scenario
total resource potential of 645 PJ from 25 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450
500
550
600
Cumulative biomass in PJ

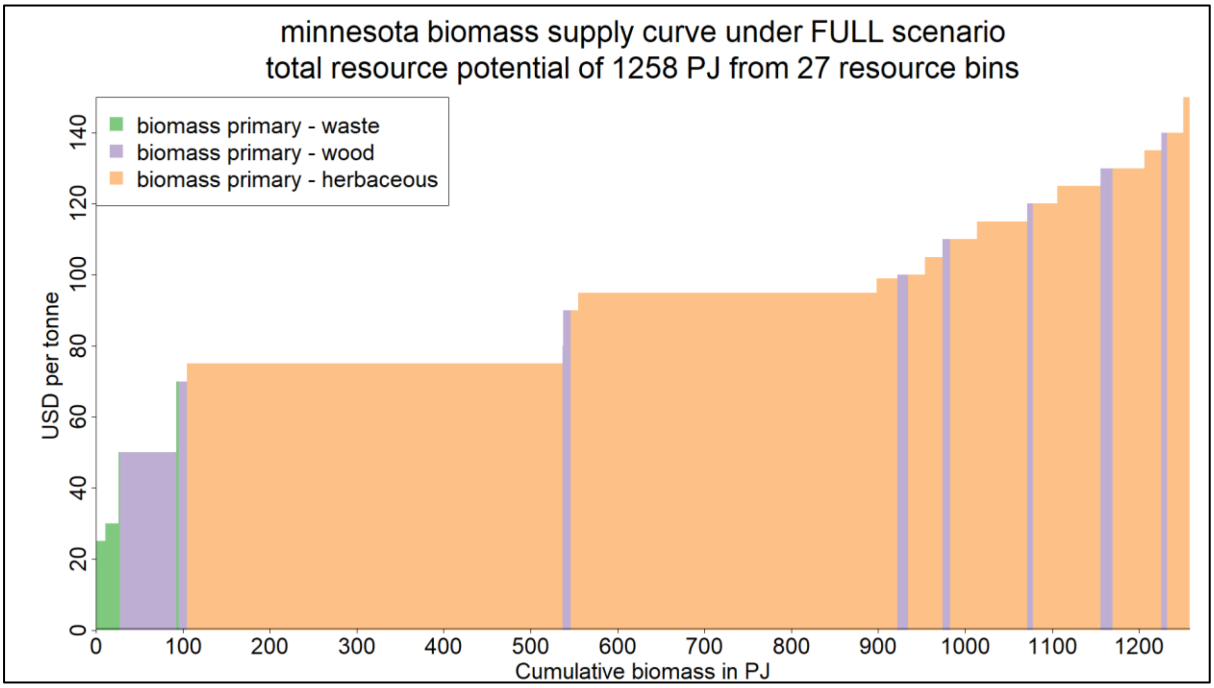

louisiana biomass supply curve under FULL scenario
total resource potential of 446 PJ from 19 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
Cumulative biomass in PJ

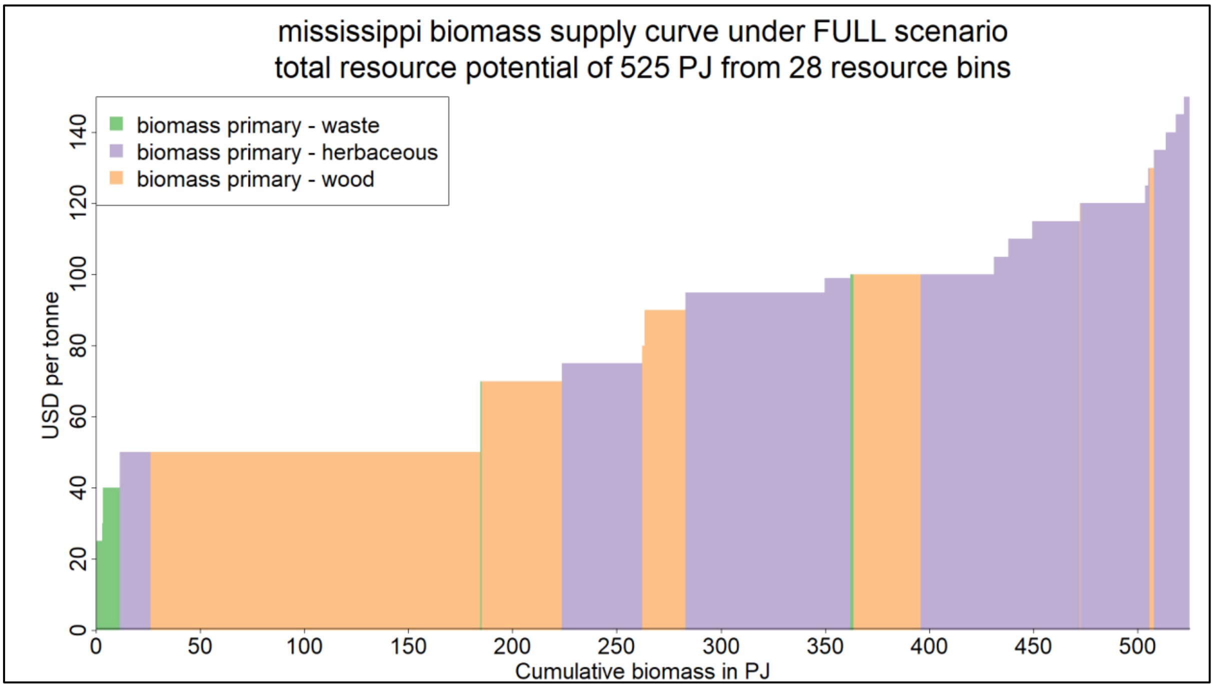

maine biomass supply curve under FULL scenario
total resource potential of 112 PJ from 19 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
Cumulative biomass in PJ

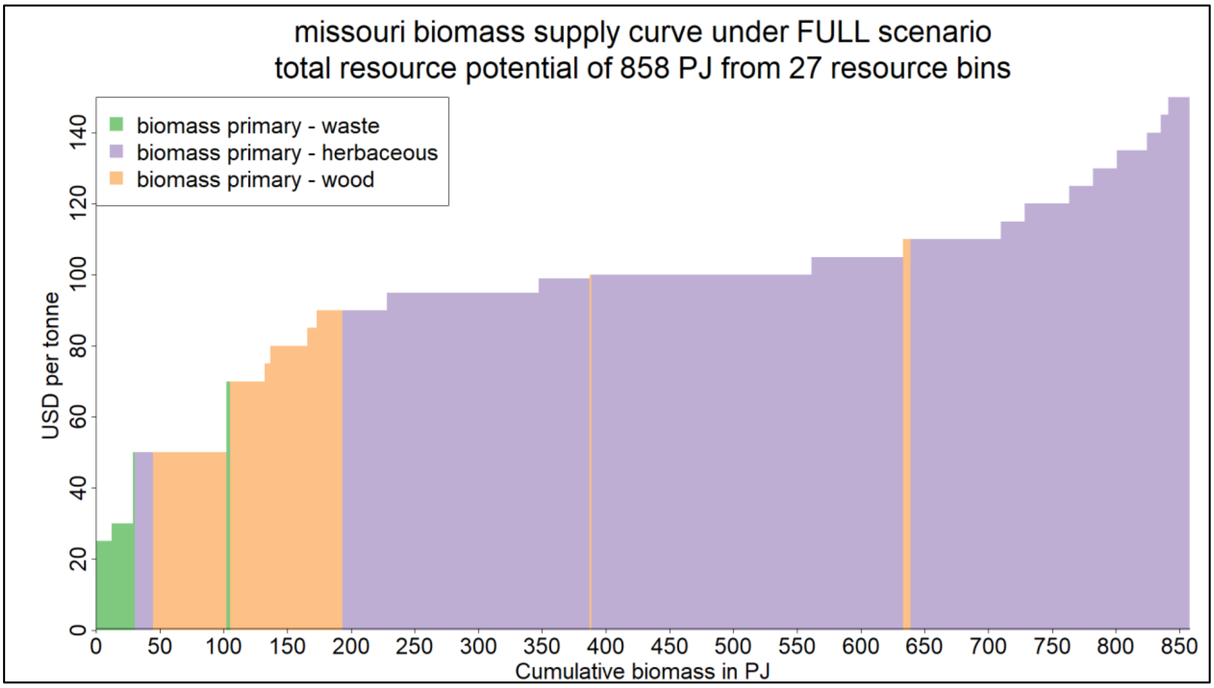

maryland biomass supply curve under FULL scenario
total resource potential of 111 PJ from 24 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
Cumulative biomass in PJ

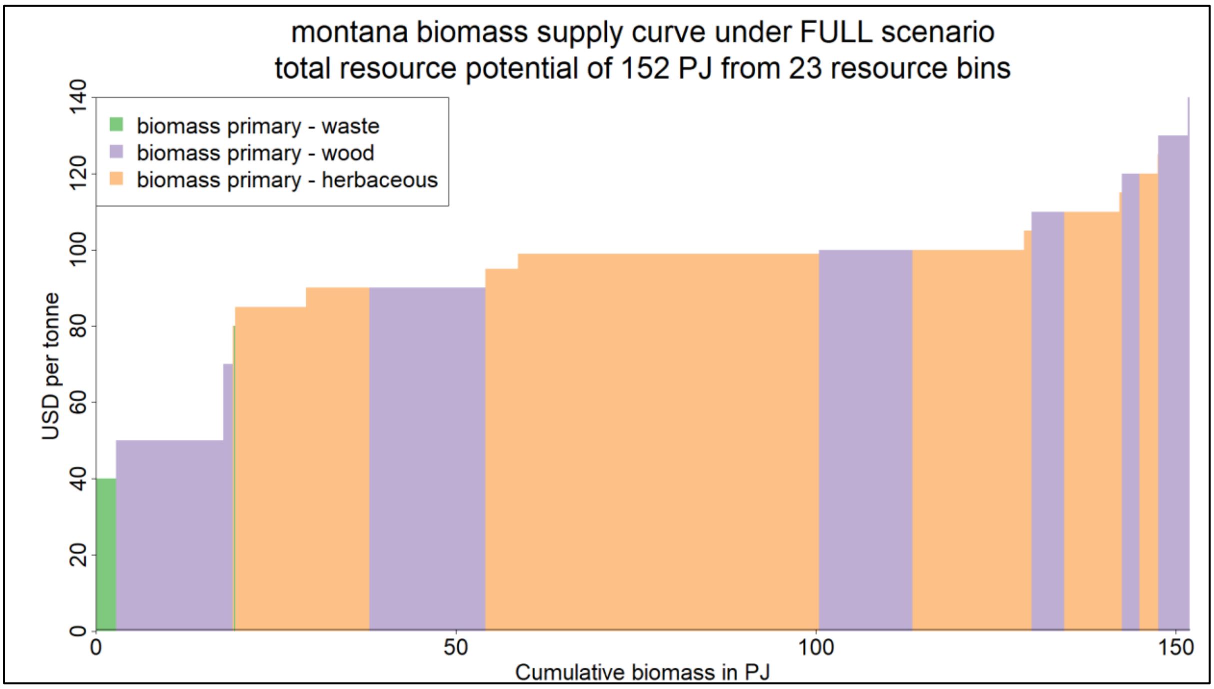

massachusetts biomass supply curve under FULL scenario
total resource potential of 64 PJ from 18 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
10
20
30
40
50
60
Cumulative biomass in PJ

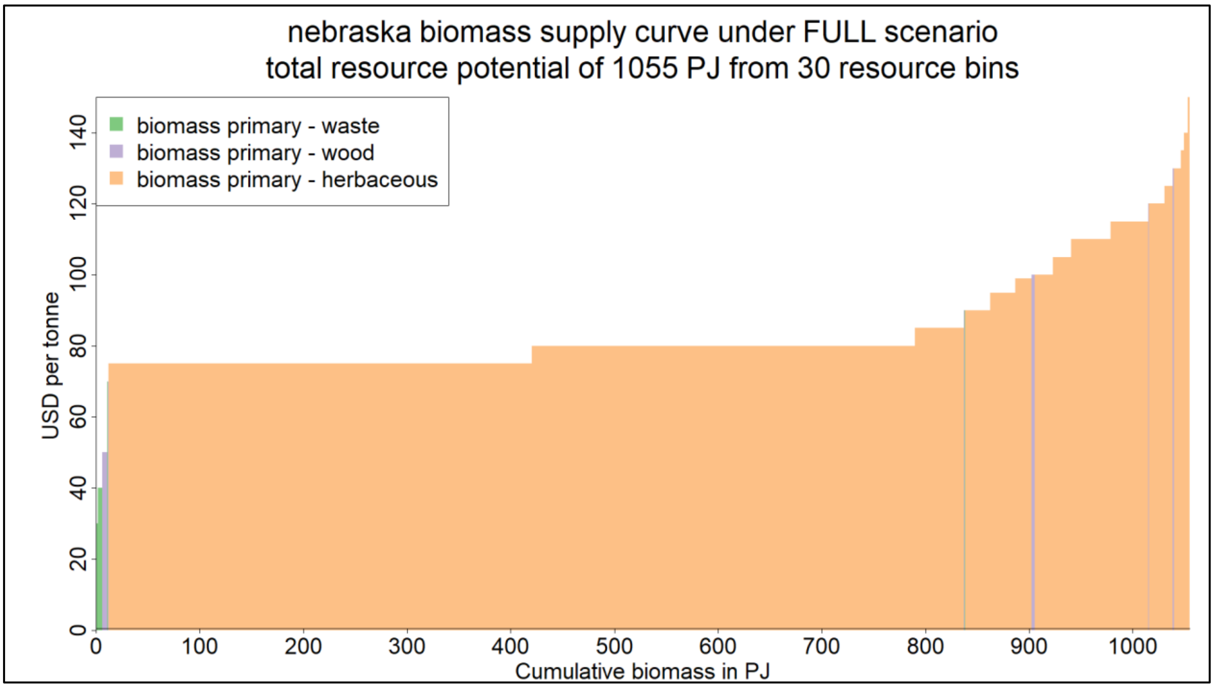

michigan biomass supply curve under FULL scenario
total resource potential of 549 PJ from 26 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450
500
Cumulative biomass in PJ

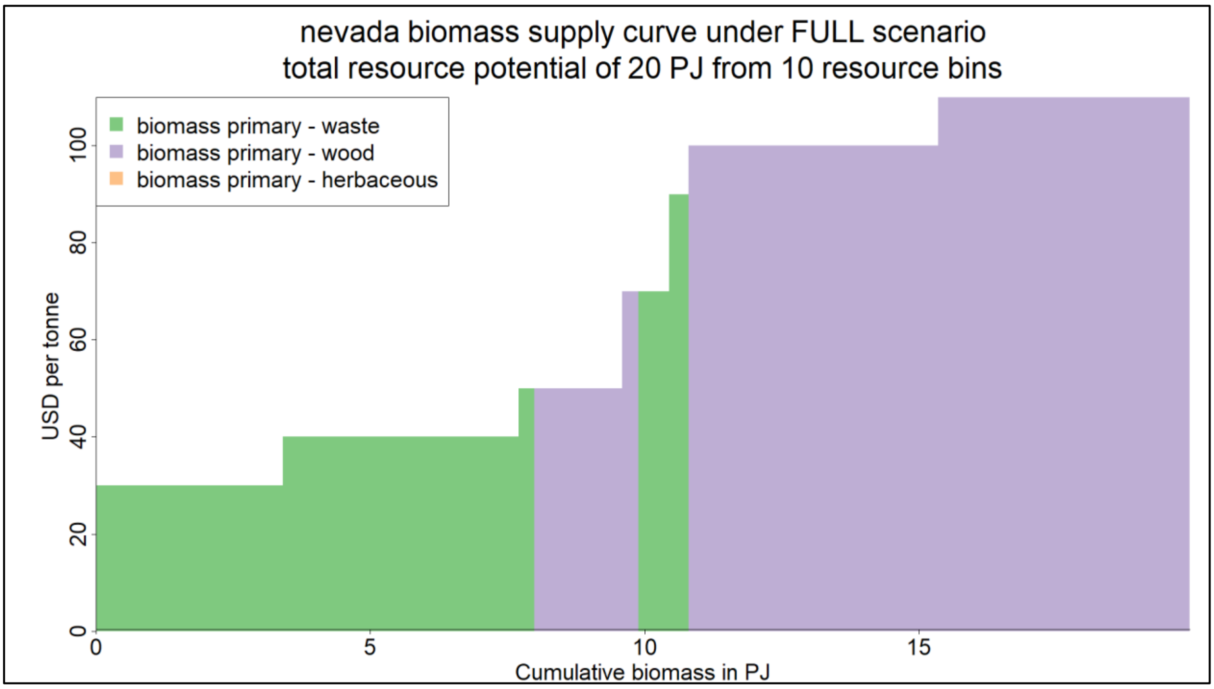

minnesota biomass supply curve under FULL scenario
total resource potential of 1258 PJ from 27 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
Cumulative biomass in PJ

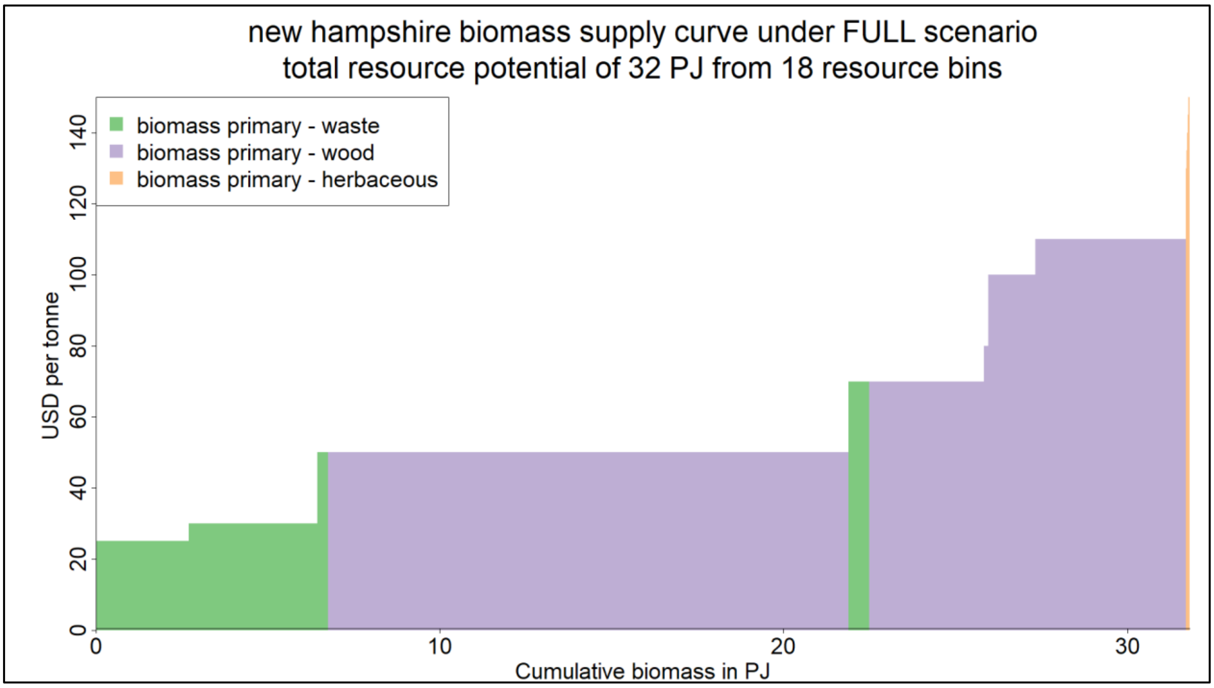

mississippi biomass supply curve under FULL scenario
total resource potential of 525 PJ from 28 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
Cumulative biomass in PJ

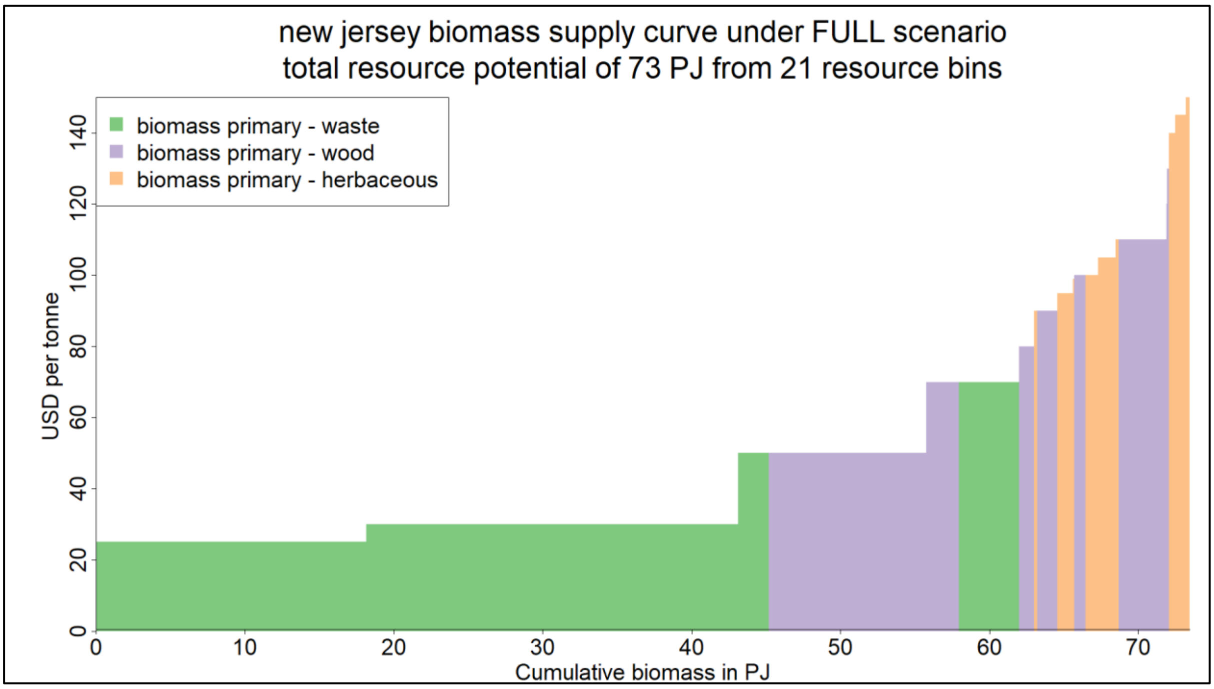

missouri biomass supply curve under FULL scenario
total resource potential of 858 PJ from 27 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
Cumulative biomass in PJ

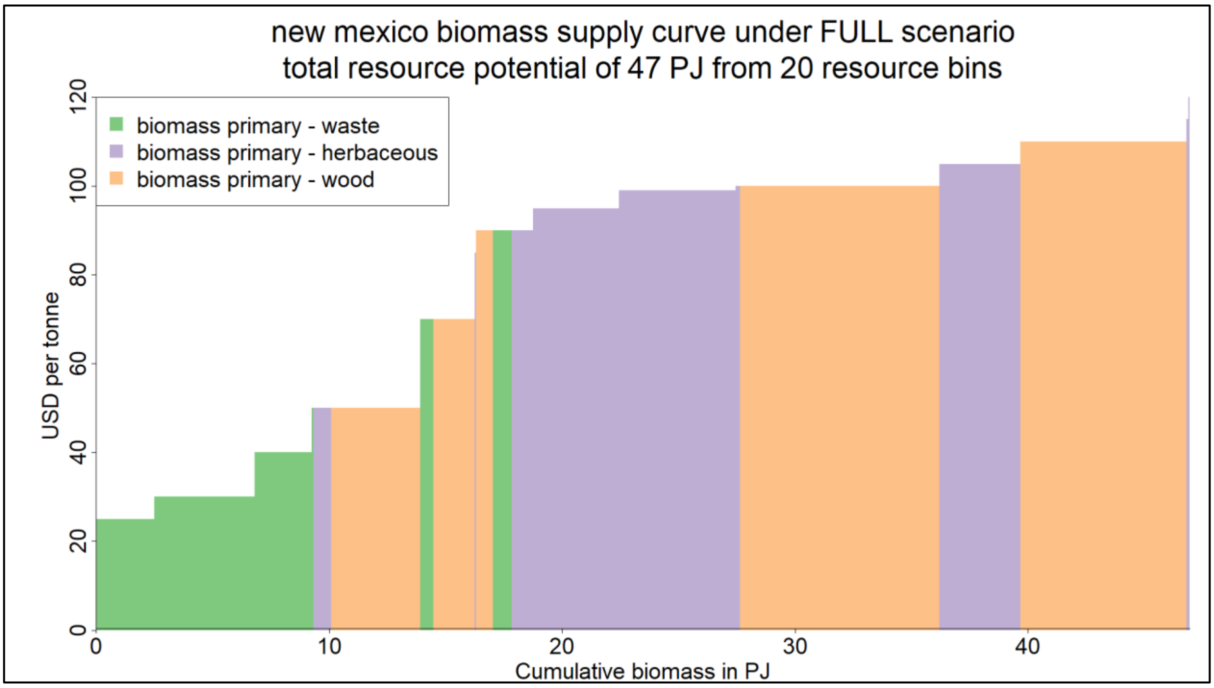

montana biomass supply curve under FULL scenario
total resource potential of 152 PJ from 23 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
Cumulative biomass in PJ

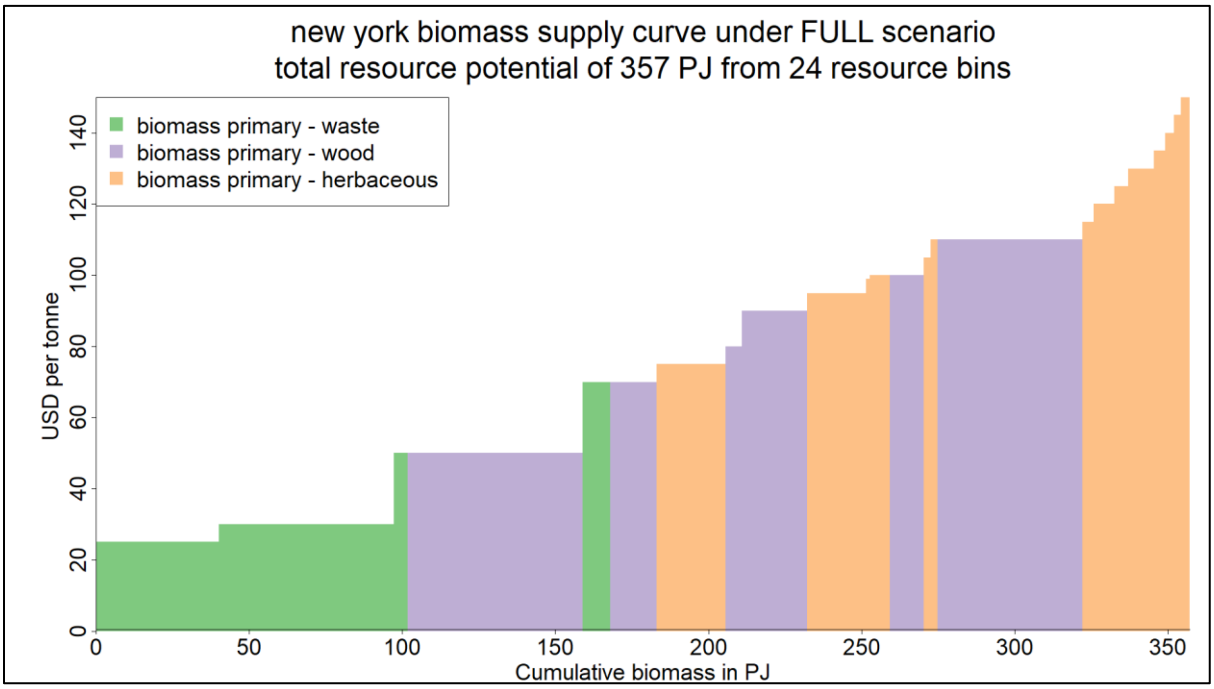

nebraska biomass supply curve under FULL scenario
total resource potential of 1055 PJ from 30 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
100
200
300
400
500
600
700
800
900
1000
Cumulative biomass in PJ

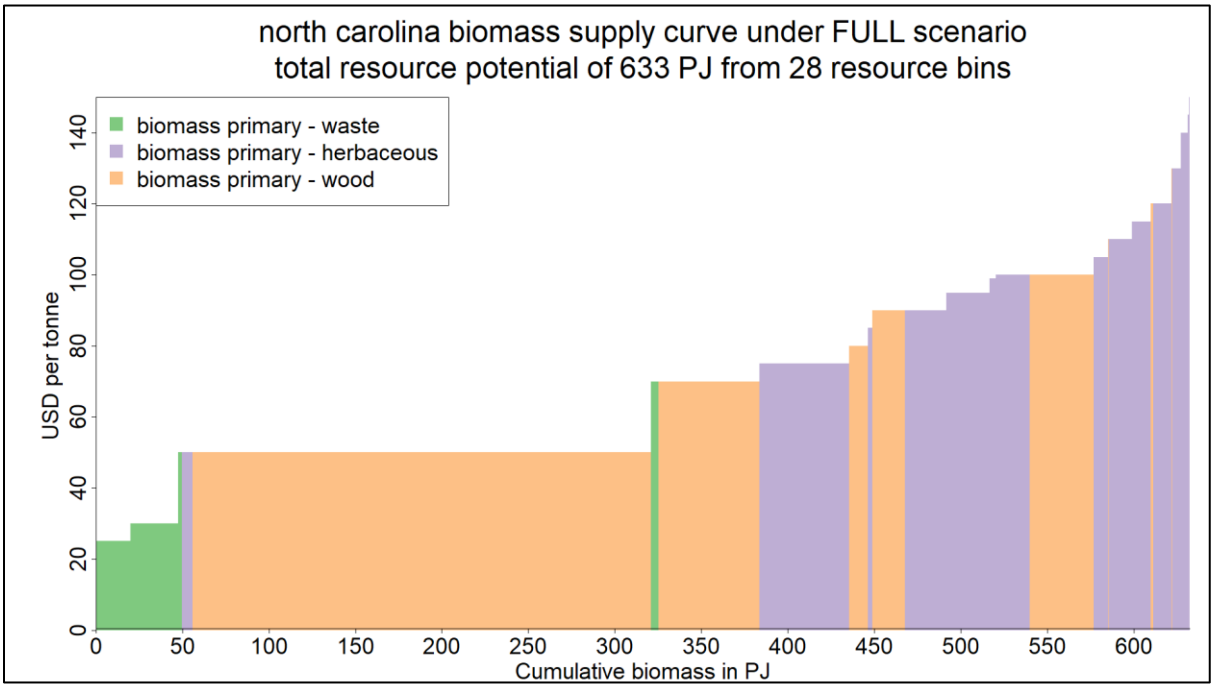

nevada biomass supply curve under FULL scenario
total resource potential of 20 PJ from 10 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
0
5
10
15
Cumulative biomass in PJ

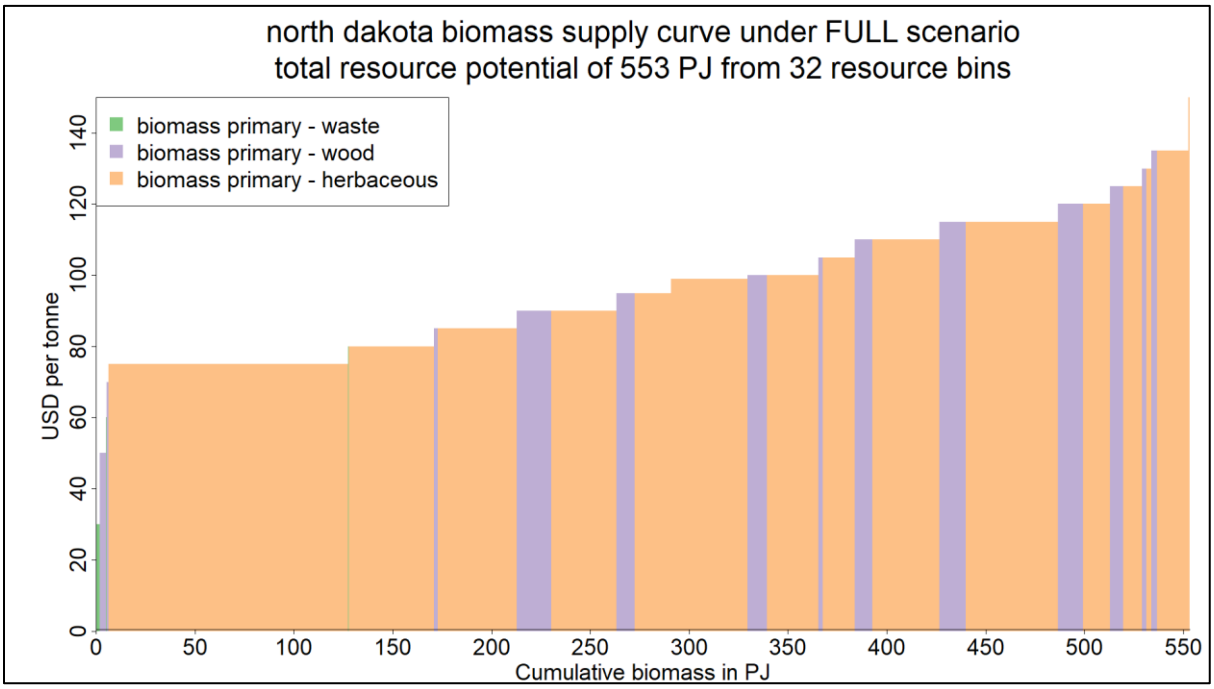

new hampshire biomass supply curve under FULL scenario
total resource potential of 32 PJ from 18 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
10
20
30
Cumulative biomass in PJ

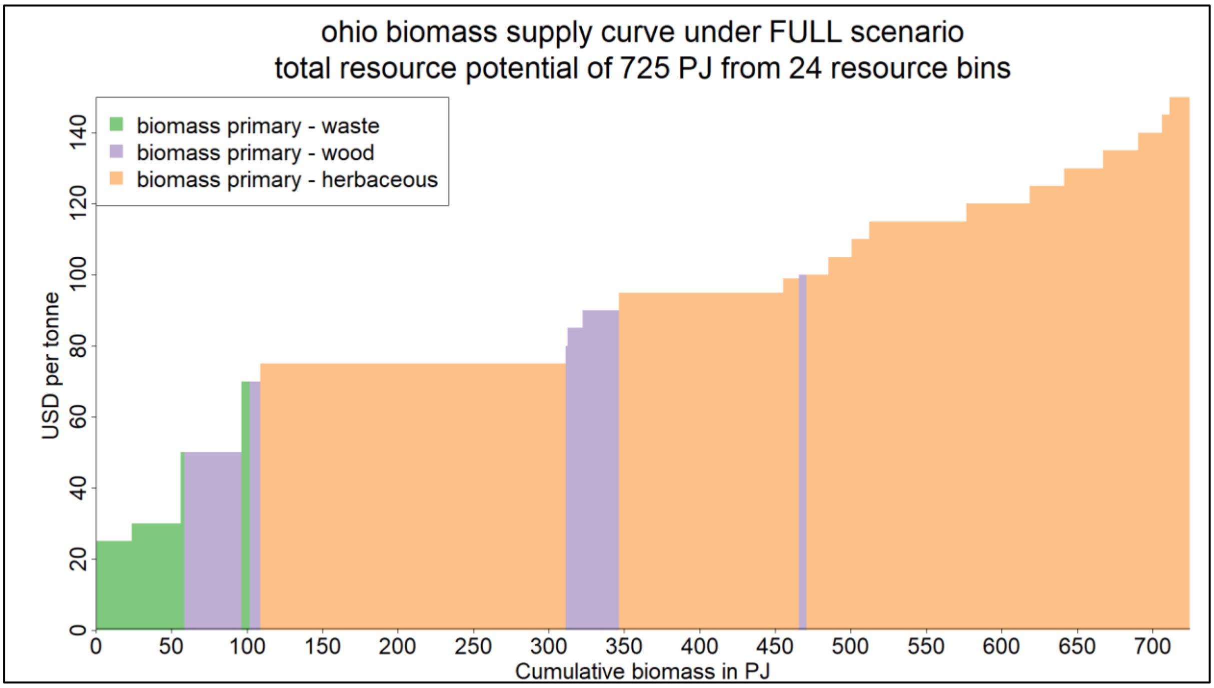

new jersey biomass supply curve under FULL scenario
total resource potential of 73 PJ from 21 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
10
20
30
40
50
60
70
Cumulative biomass in PJ

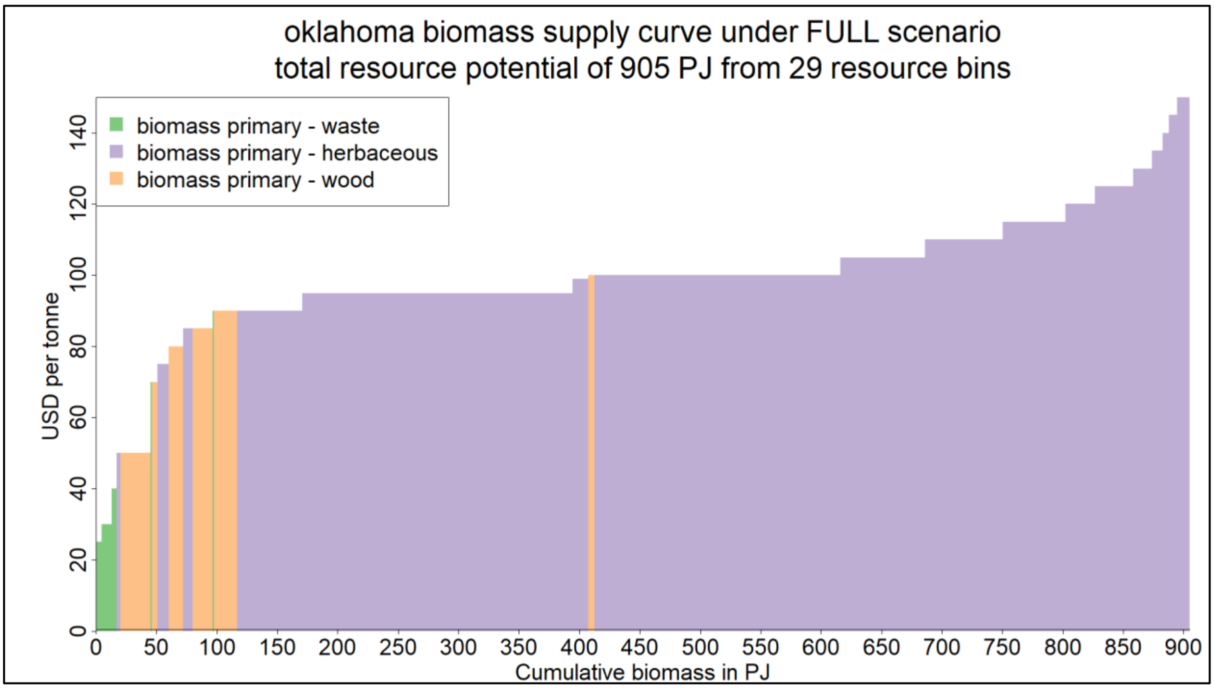

new mexico biomass supply curve under FULL scenario
total resource potential of 47 PJ from 20 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
0
10
20
30
40
Cumulative biomass in PJ

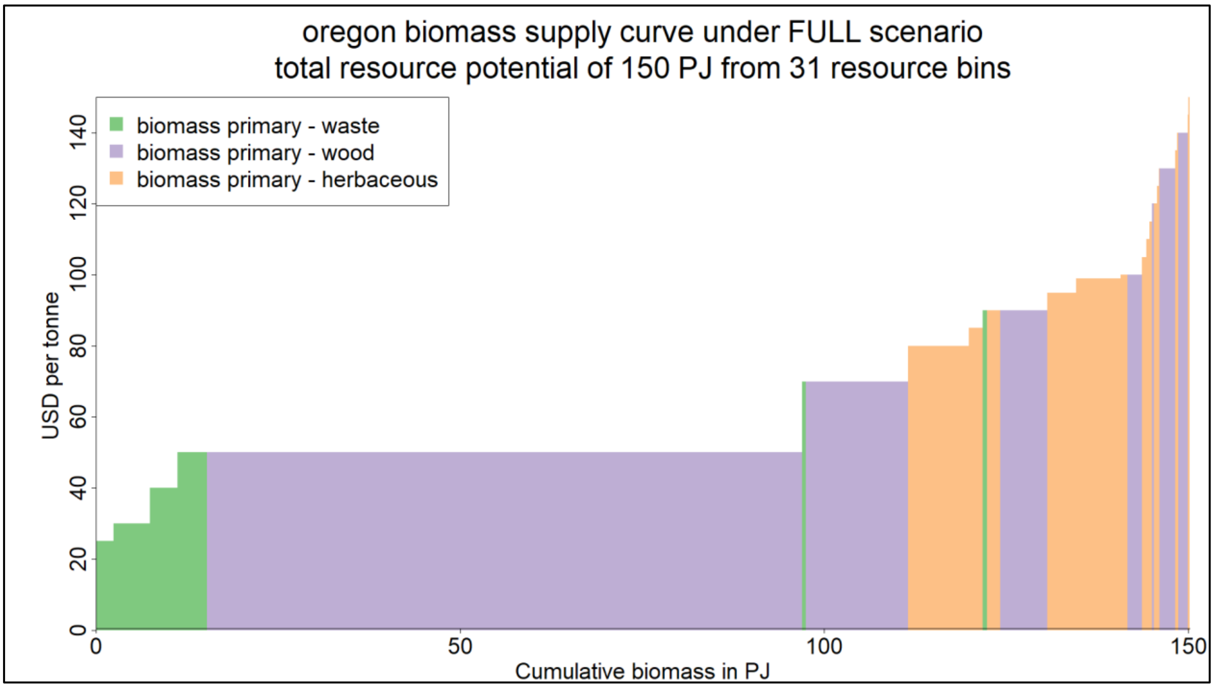

new york biomass supply curve under FULL scenario
total resource potential of 357 PJ from 24 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
Cumulative biomass in PJ

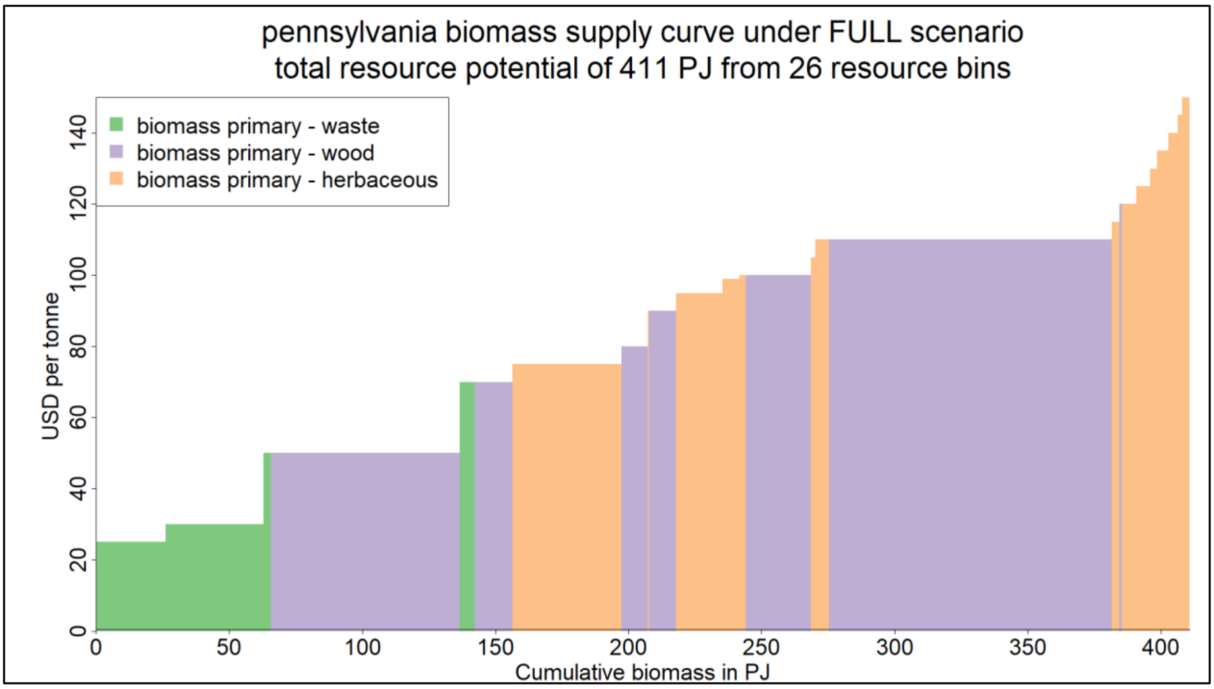

north carolina biomass supply curve under FULL scenario
total resource potential of 633 PJ from 28 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450
500
550
600
Cumulative biomass in PJ

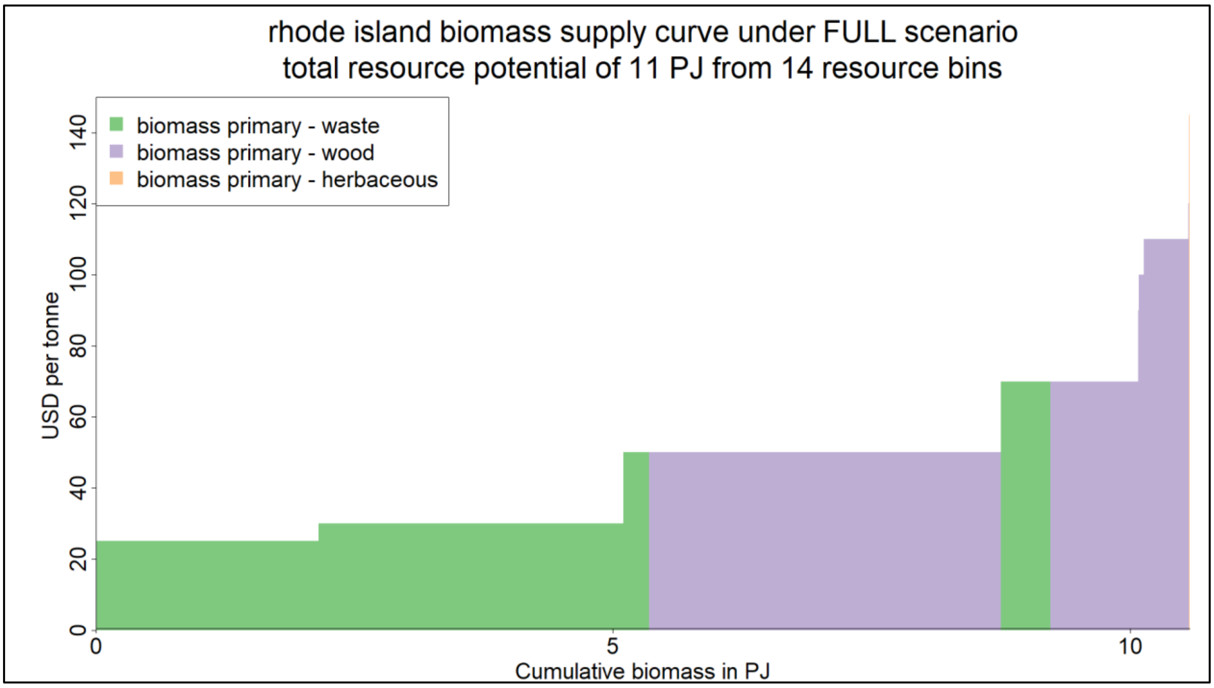

north dakota biomass supply curve under FULL scenario
total resource potential of 553 PJ from 32 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450
500
550
Cumulative biomass in PJ

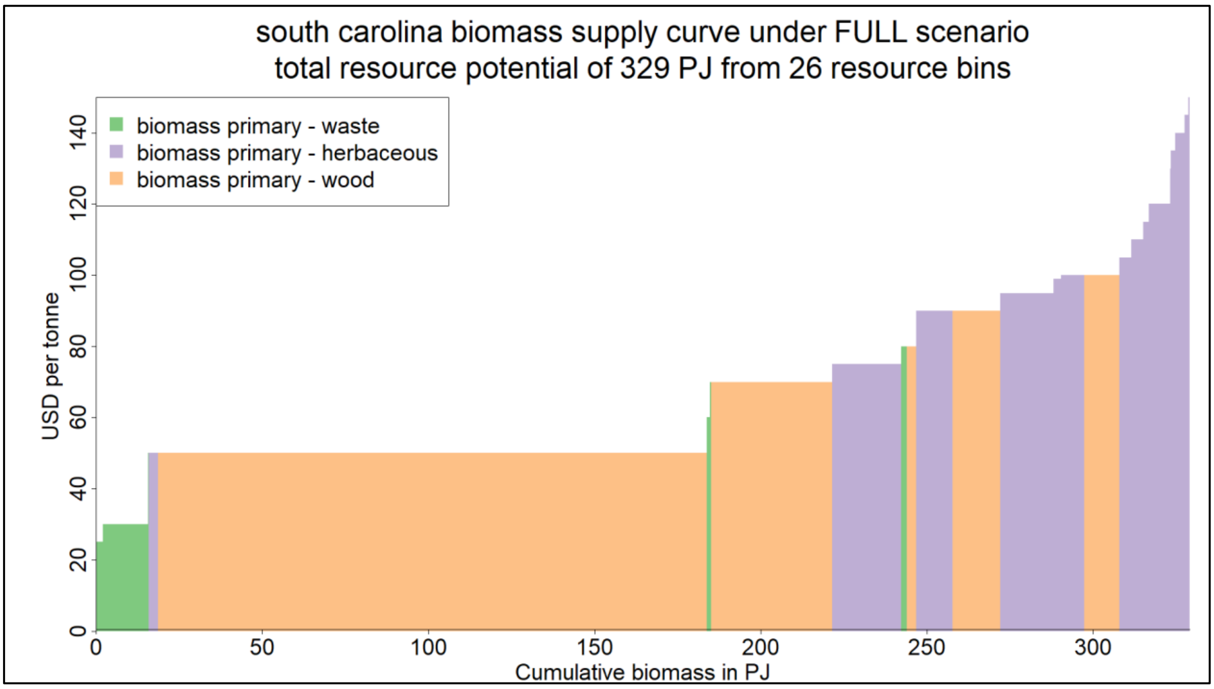

ohio biomass supply curve under FULL scenario
total resource potential of 725 PJ from 24 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
Cumulative biomass in PJ

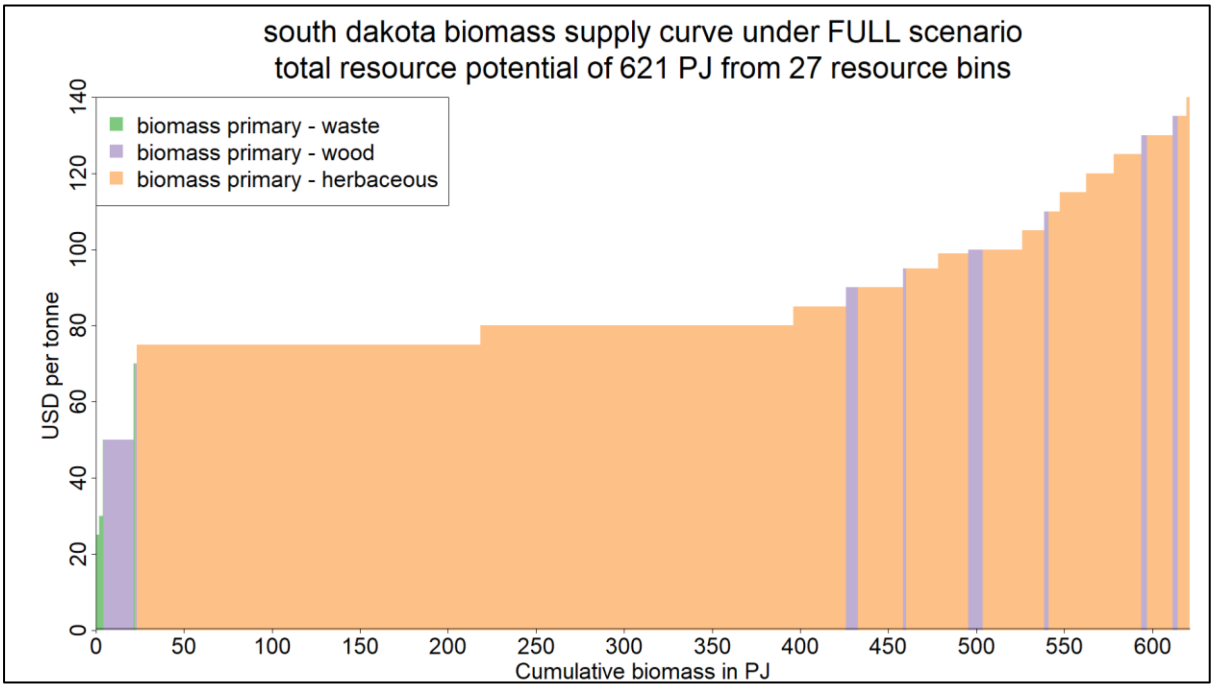

oklahoma biomass supply curve under FULL scenario
total resource potential of 905 PJ from 29 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
Cumulative biomass in PJ

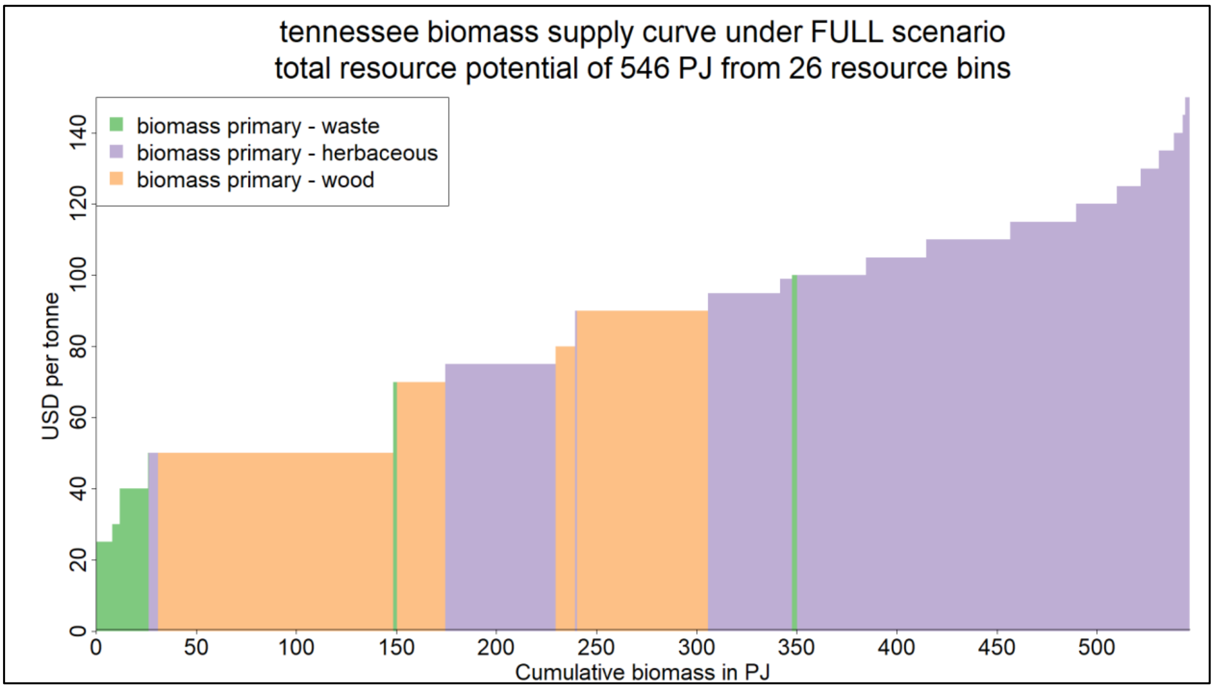

oregon biomass supply curve under FULL scenario
total resource potential of 150 PJ from 31 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
Cumulative biomass in PJ

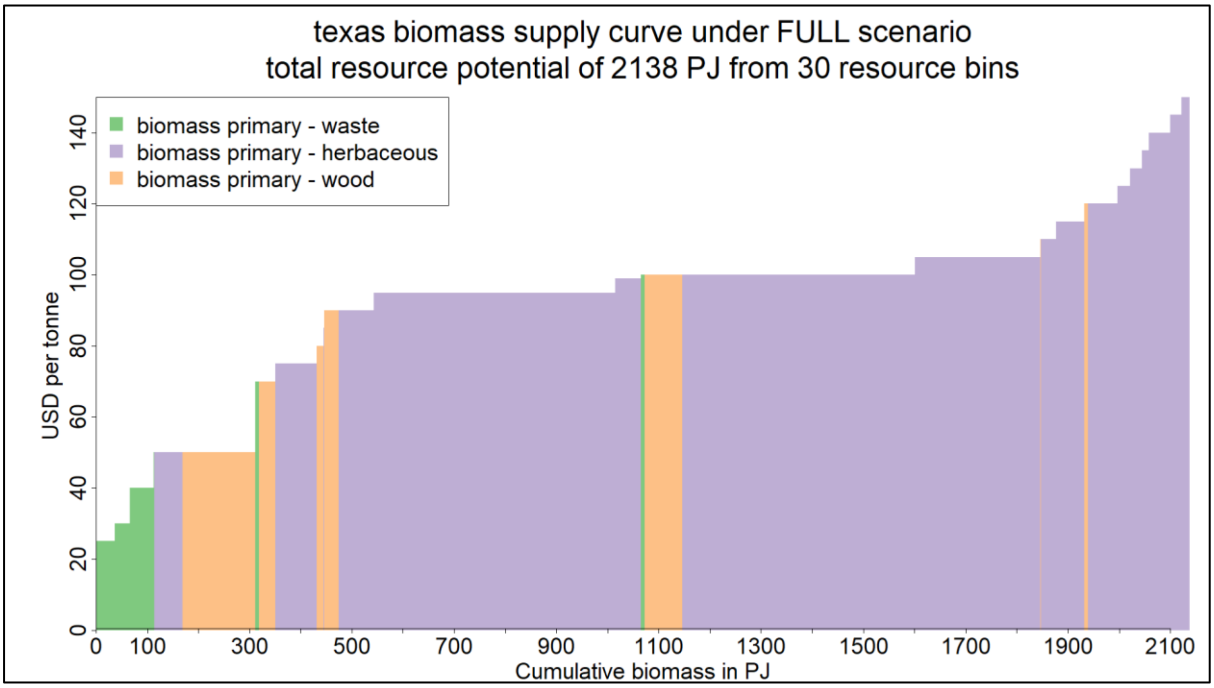

pennsylvania biomass supply curve under FULL scenario
total resource potential of 411 PJ from 26 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
Cumulative biomass in PJ

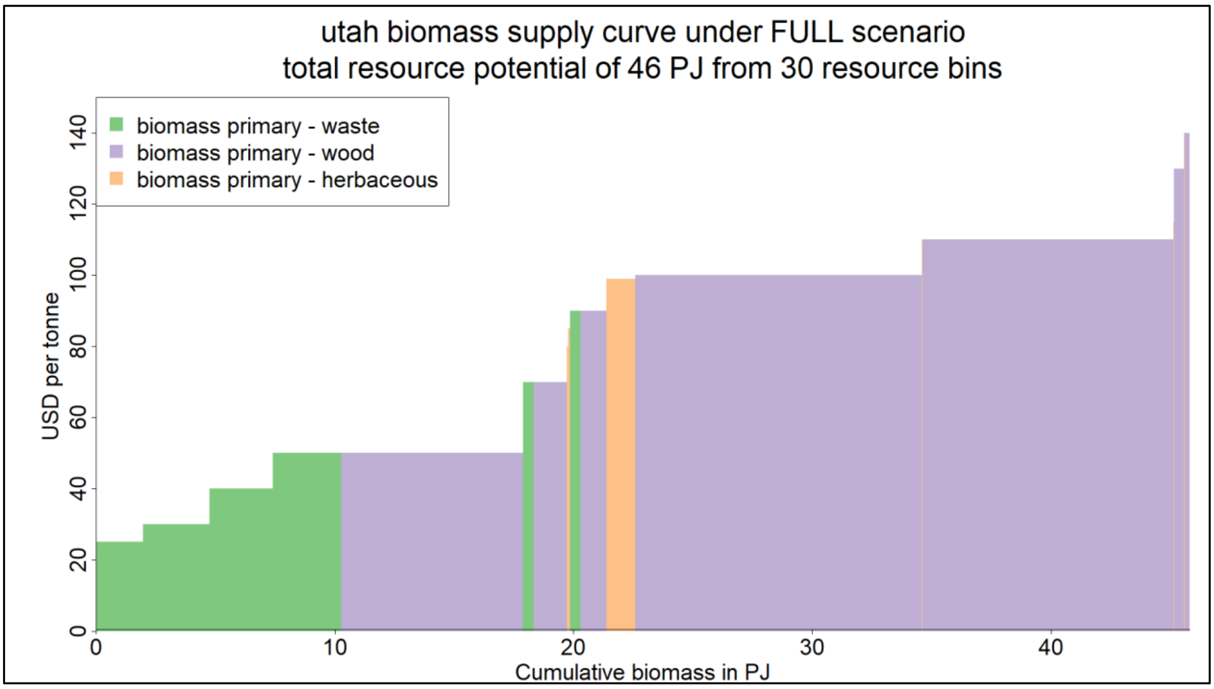

rhode island biomass supply curve under FULL scenario
total resource potential of 11 PJ from 14 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
5
10
Cumulative biomass in PJ

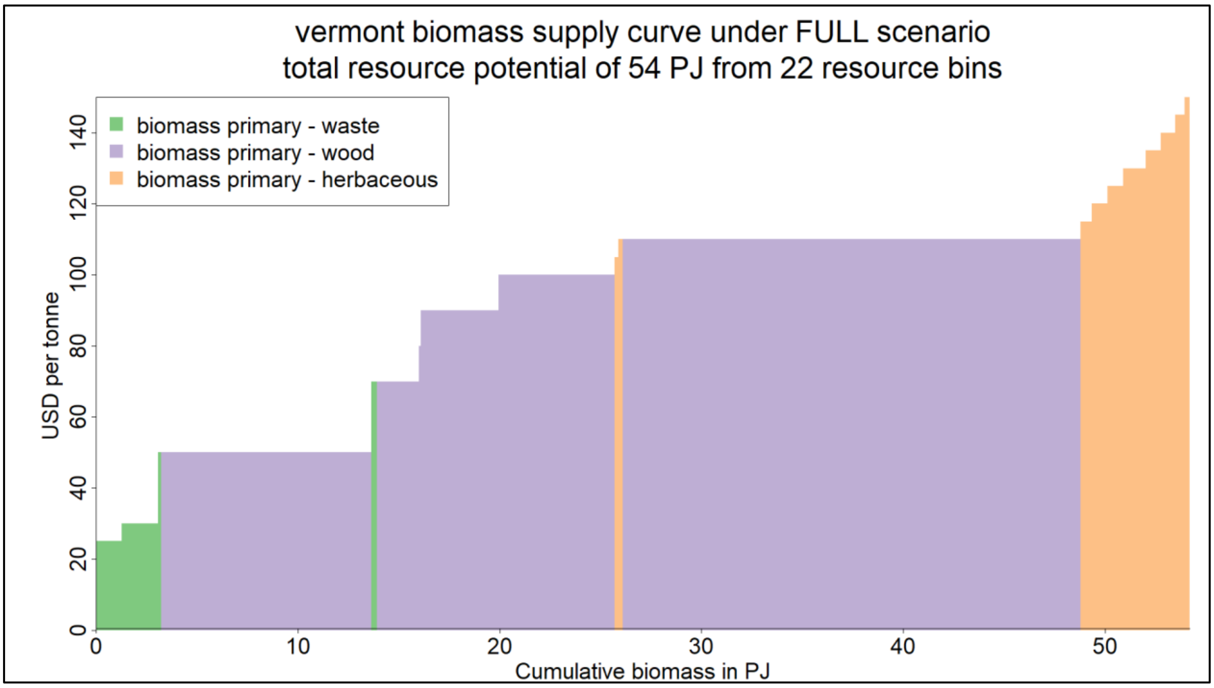

south carolina biomass supply curve under FULL scenario
total resource potential of 329 PJ from 26 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
Cumulative biomass in PJ

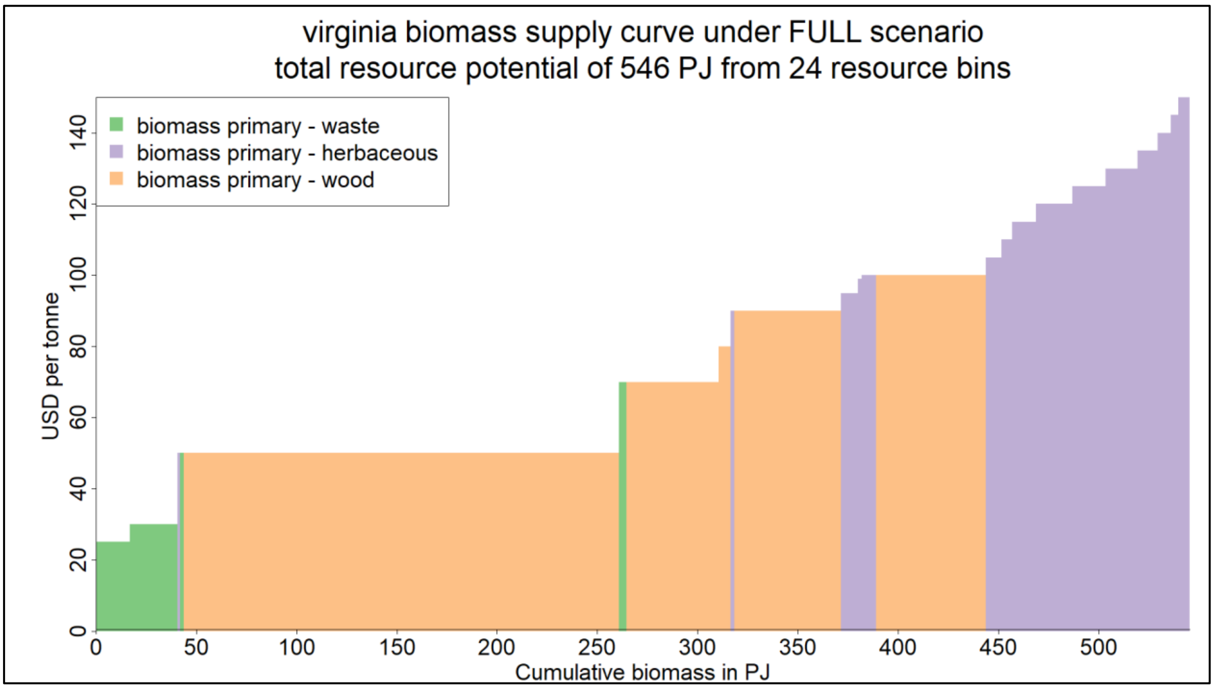

south dakota biomass supply curve under FULL scenario
total resource potential of 621 PJ from 27 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450
500
550
600
Cumulative biomass in PJ

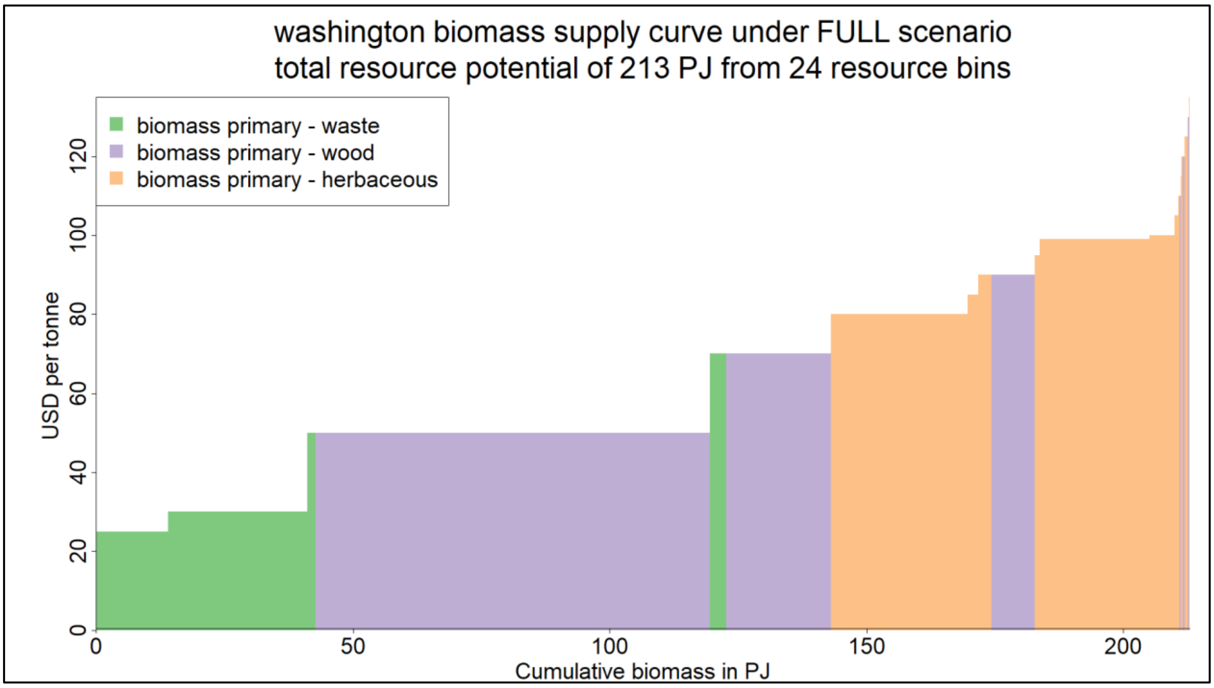

tennessee biomass supply curve under FULL scenario
total resource potential of 546 PJ from 26 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450
500
Cumulative biomass in PJ

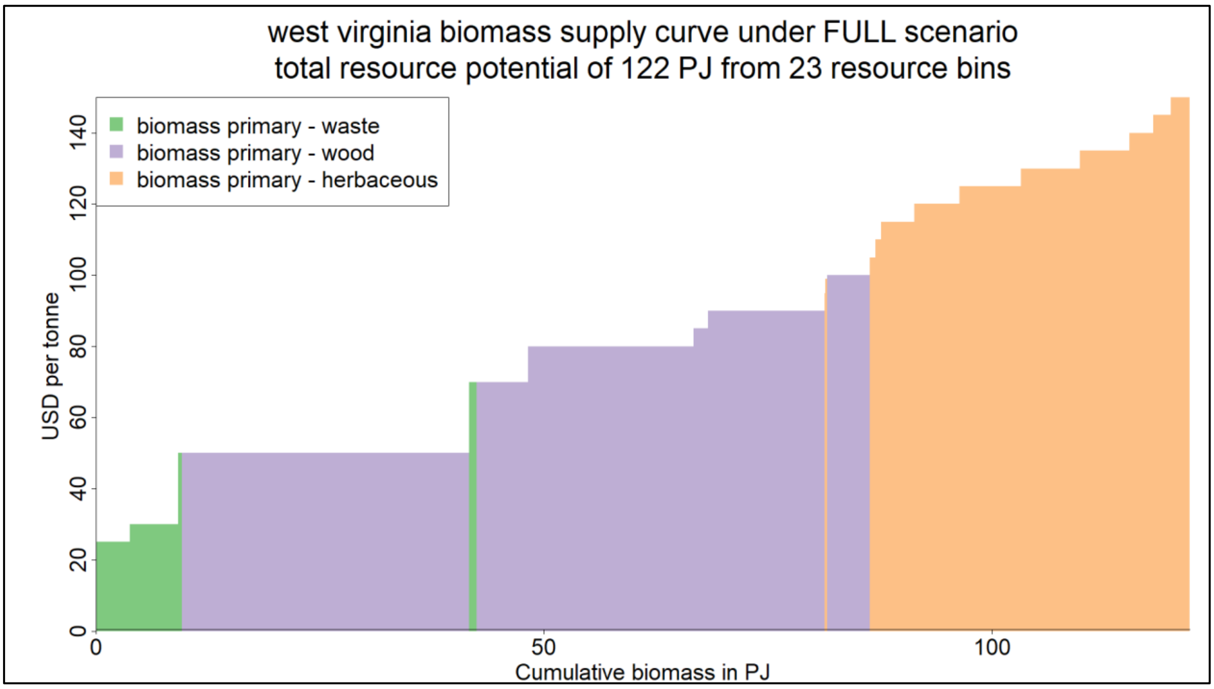

texas biomass supply curve under FULL scenario
total resource potential of 2138 PJ from 30 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
140
0
100
300
500
700
900
1100
1300
1500
1700
1900
2100
Cumulative biomass in PJ

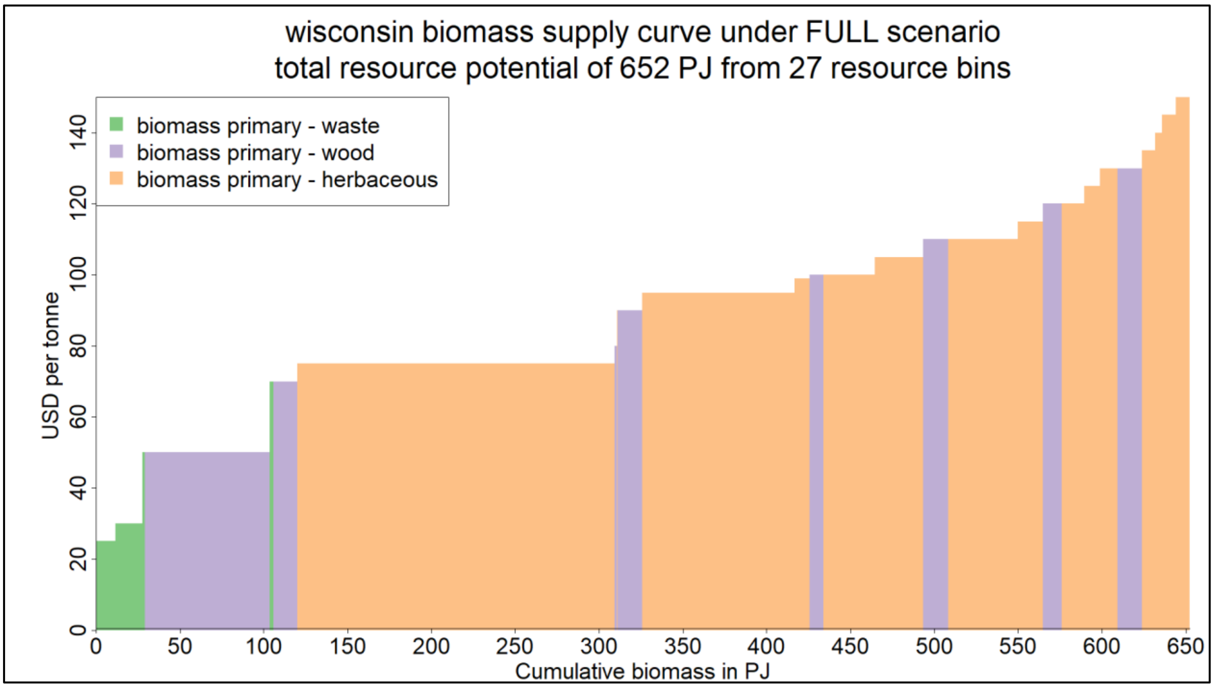

utah biomass supply curve under FULL scenario
total resource potential of 46 PJ from 30 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
10
20
30
40
Cumulative biomass in PJ

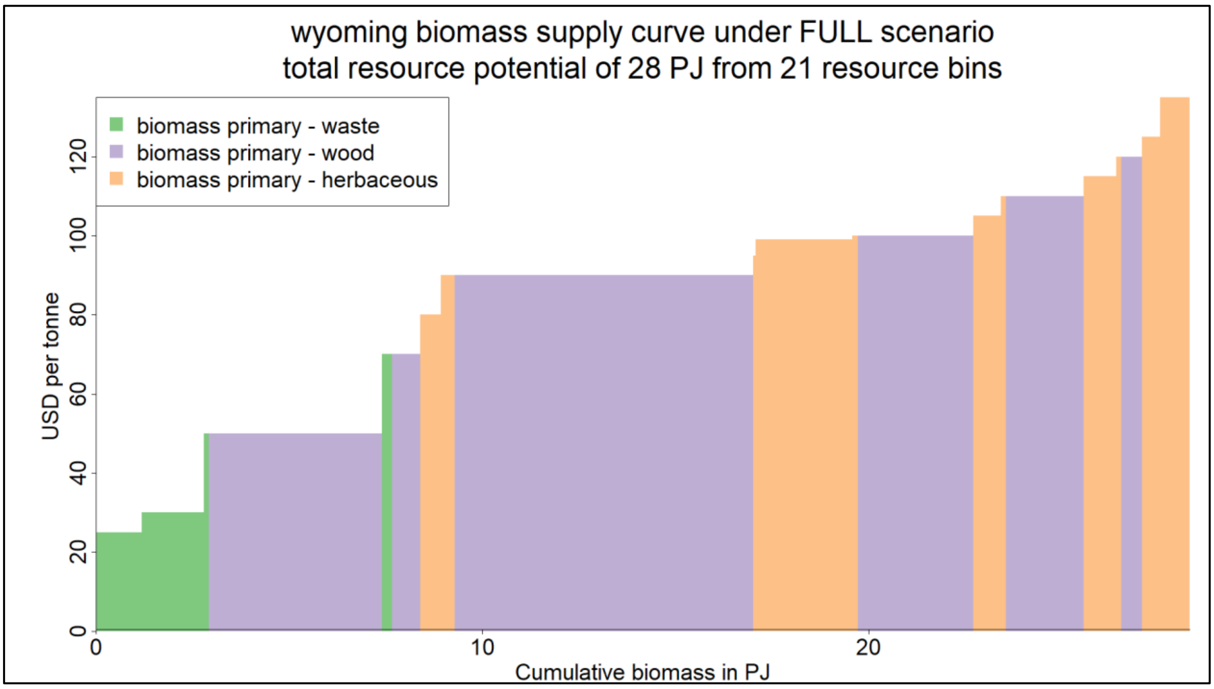

vermont biomass supply curve under FULL scenario
total resource potential of 54 PJ from 22 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
10
20
30
40
50
Cumulative biomass in PJ


virginia biomass supply curve under FULL scenario
total resource potential of 546 PJ from 24 resource bins
biomass primary - waste
biomass primary - herbaceous
biomass primary - wood
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450
500
Cumulative biomass in PJ


washington biomass supply curve under FULL scenario
total resource potential of 213 PJ from 24 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
0
50
100
150
200
Cumulative biomass in PJ

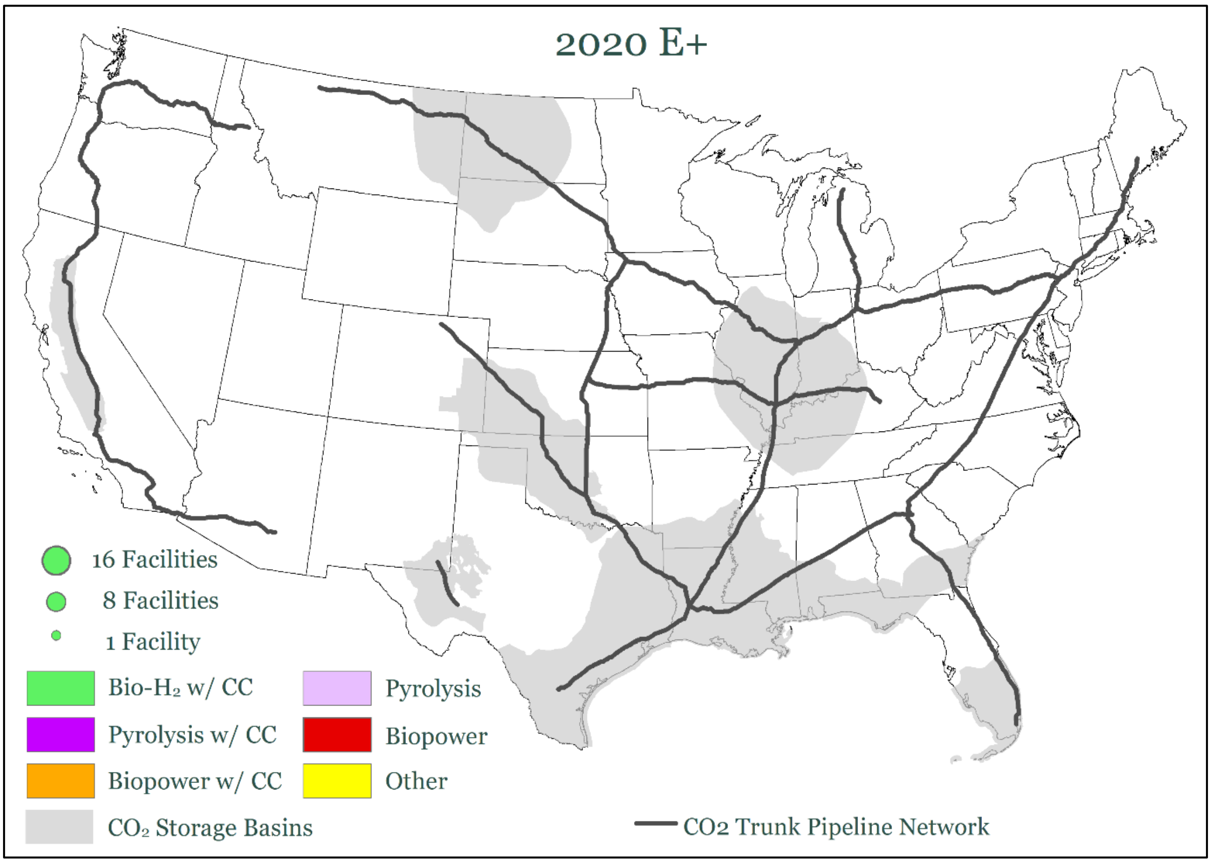

west virginia biomass supply curve under FULL scenario
total resource potential of 122 PJ from 23 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
Cumulative biomass in PJ

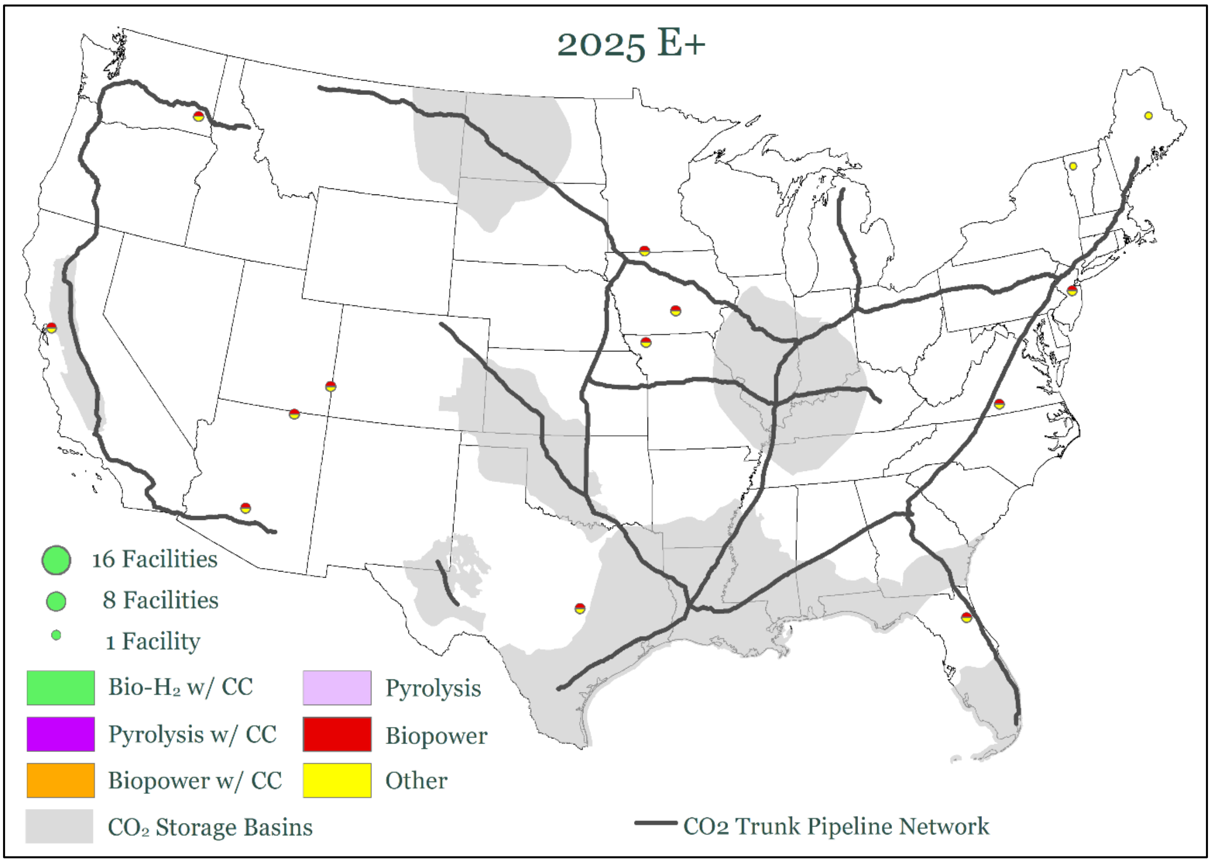

wisconsin biomass supply curve under FULL scenario
total resource potential of 652 PJ from 27 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450
500
550
600
650
Cumulative biomass in PJ

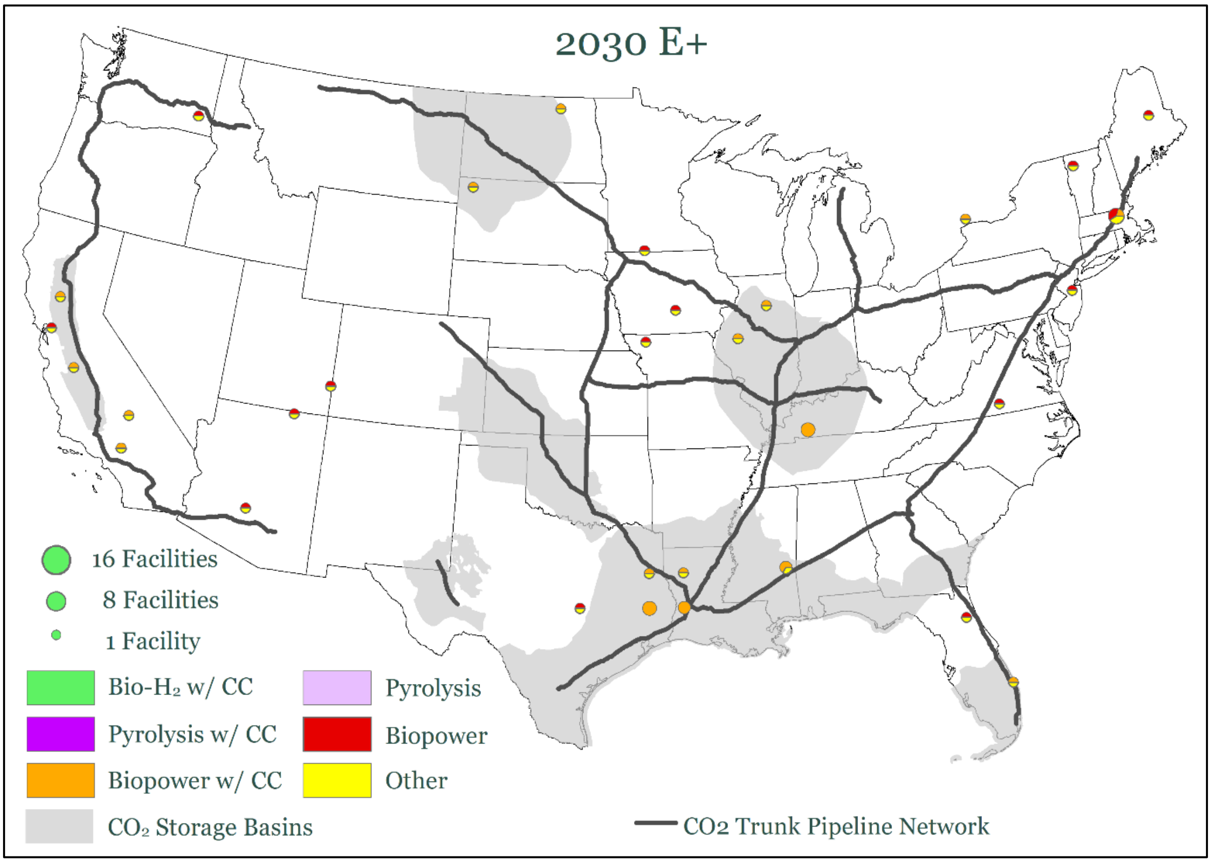

wyoming biomass supply curve under FULL scenario
total resource potential of 28 PJ from 21 resource bins
biomass primary - waste
biomass primary - wood
biomass primary - herbaceous
USD per tonne
0
20
40
60
80
100
120
0
10
20
Cumulative biomass in PJ

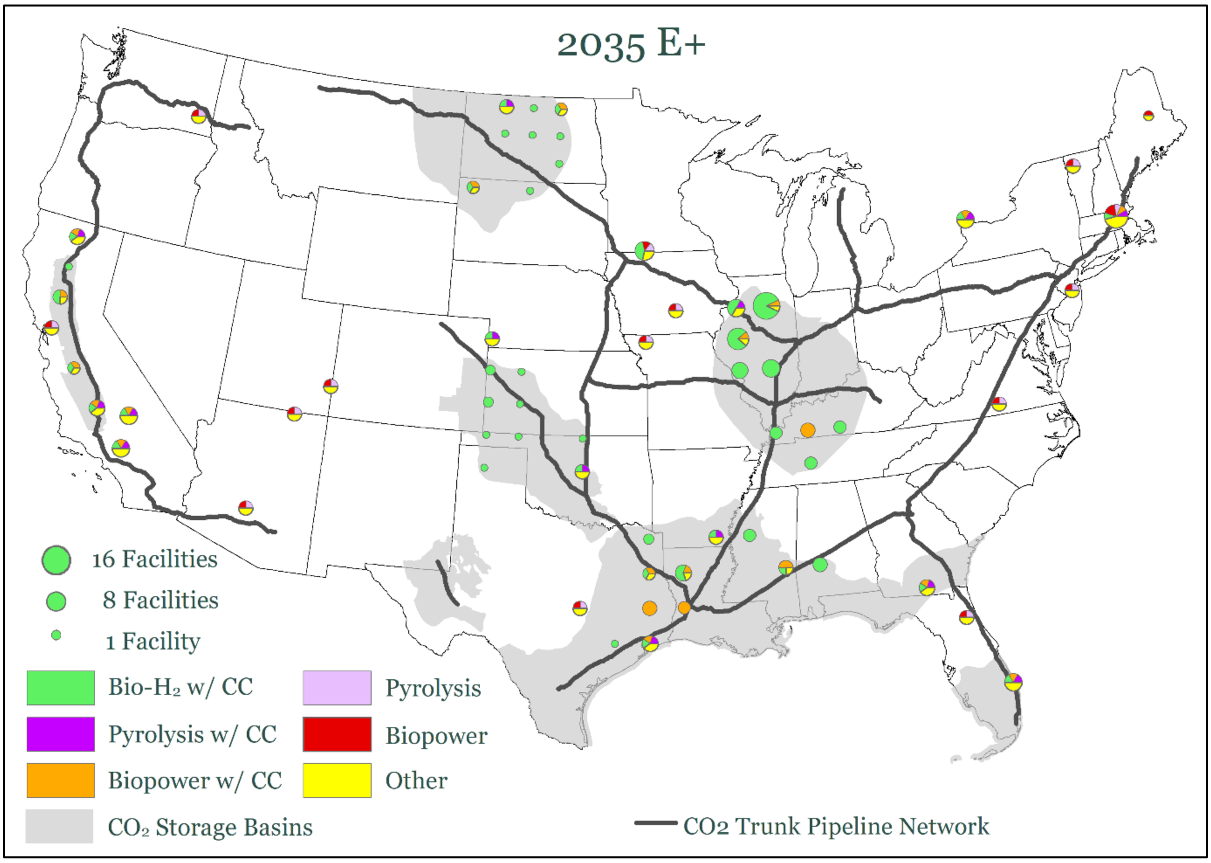
Appendix H3: Geospatial evolution of bioconversion facilities

Maps show the development in 5-year time steps of the geospatial distribution of biomass conversion facilities from 2020-2050. The first set of maps is for the E+ (Delimited biomass) scenario. The second set of maps is for the E-B+ (High biomass) scenario.

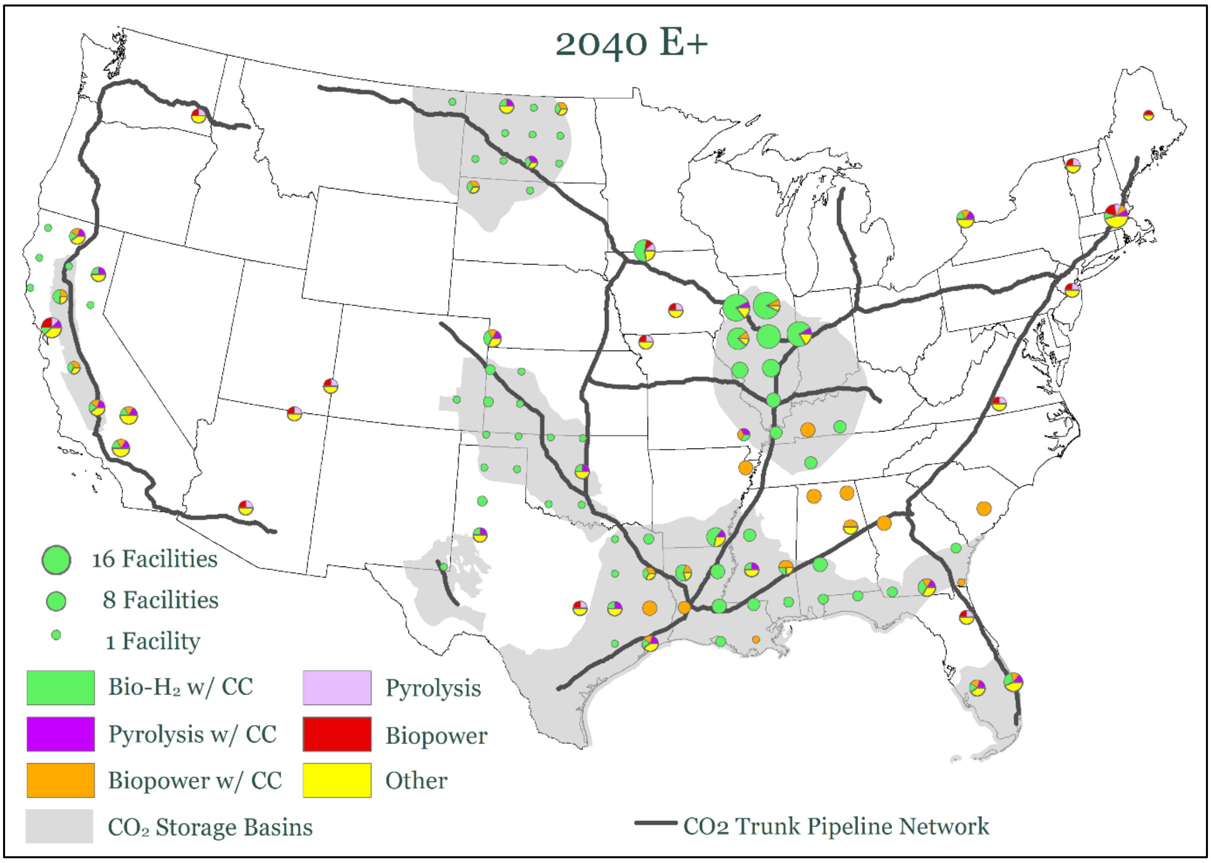



2025 E+
16 Facilities
8 Facilities
1 Facility
Bio-H₂ w/ CC
Pyrolysis
Pyrolysis w/ CC
Biopower
Biopower w/ CC
Other
CO₂ Storage Basins
CO2 Trunk Pipeline Network

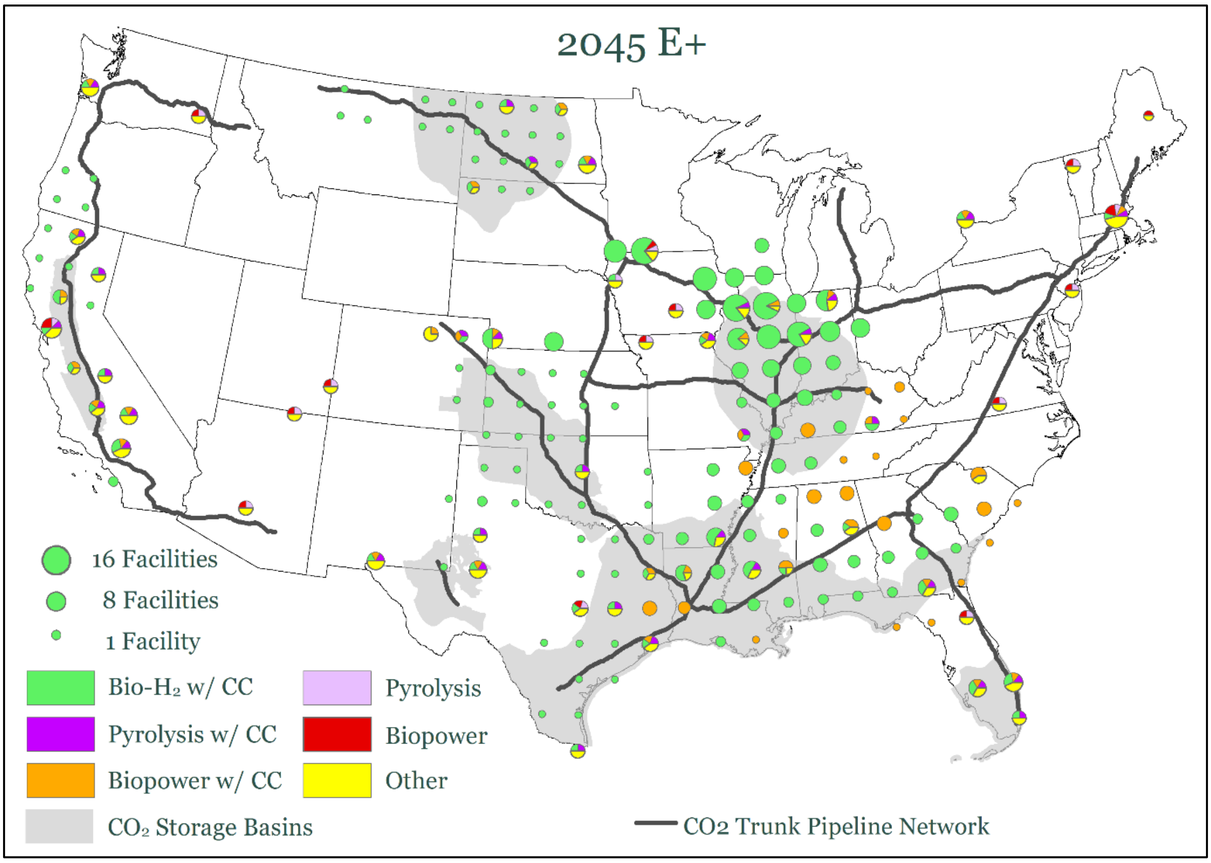

2030 E+
16 Facilities
8 Facilities
1 Facility
Bio-H₂ w/ CC
Pyrolysis
Pyrolysis w/ CC
Biopower
Biopower w/ CC
Other
CO₂ Storage Basins
CO2 Trunk Pipeline Network

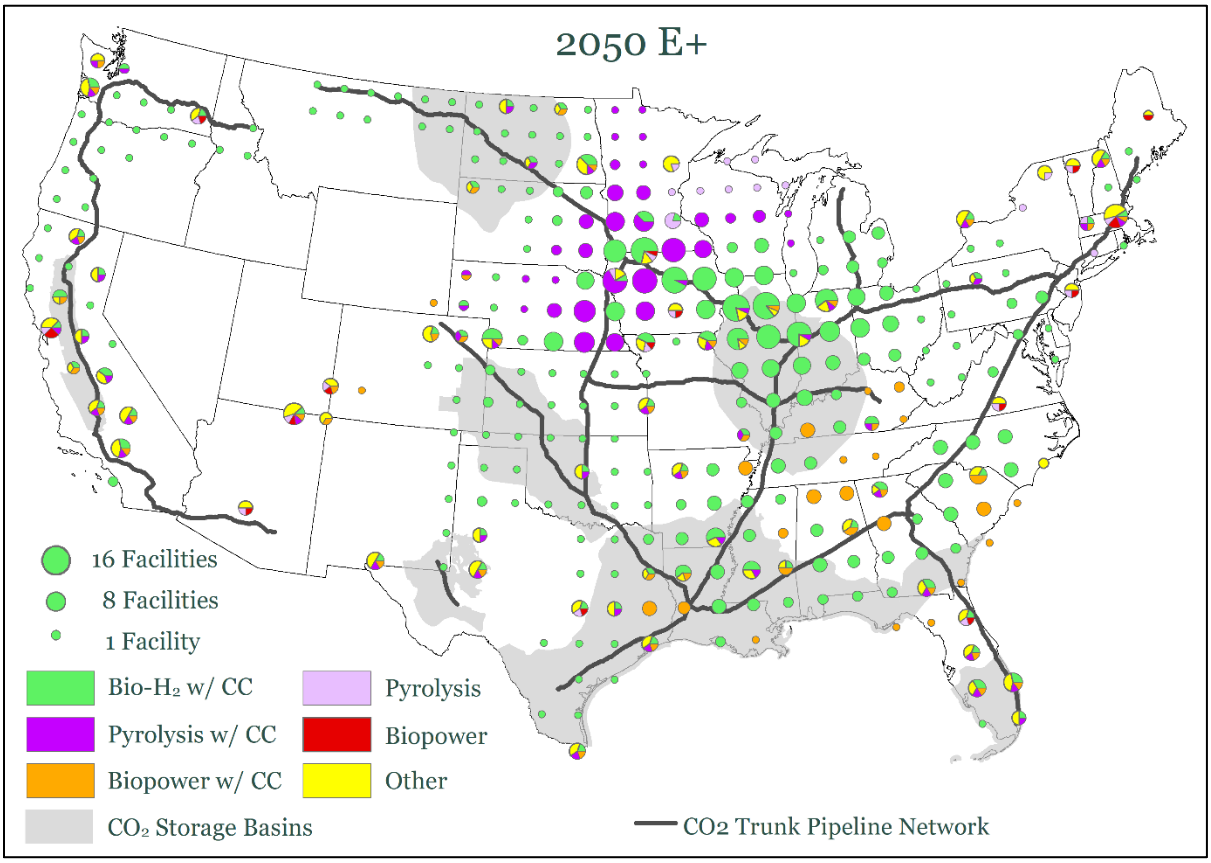


2035 E+
16 Facilities
8 Facilities
1 Facility
Bio-H₂ w/ CC
Pyrolysis
Pyrolysis w/ CC
Biopower
Biopower w/ CC
Other
CO₂ Storage Basins
CO2 Trunk Pipeline Network

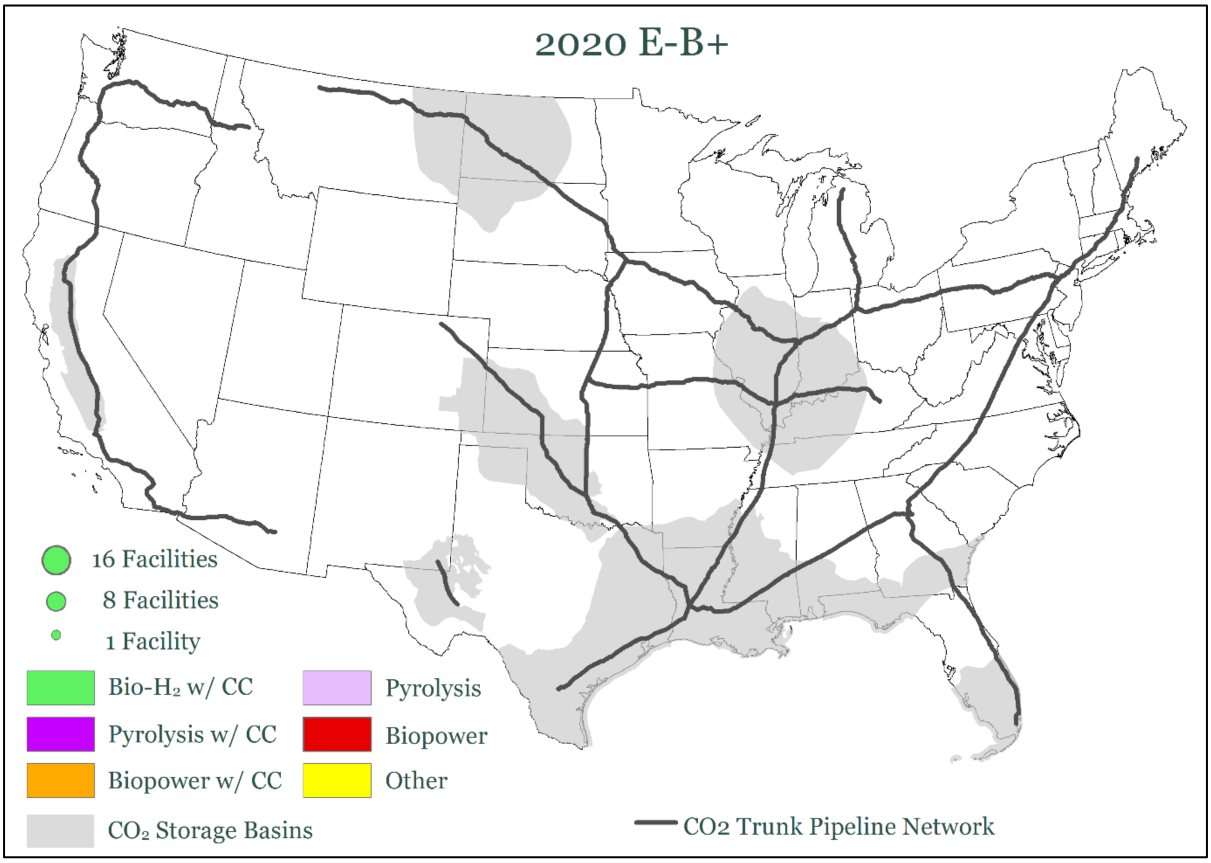


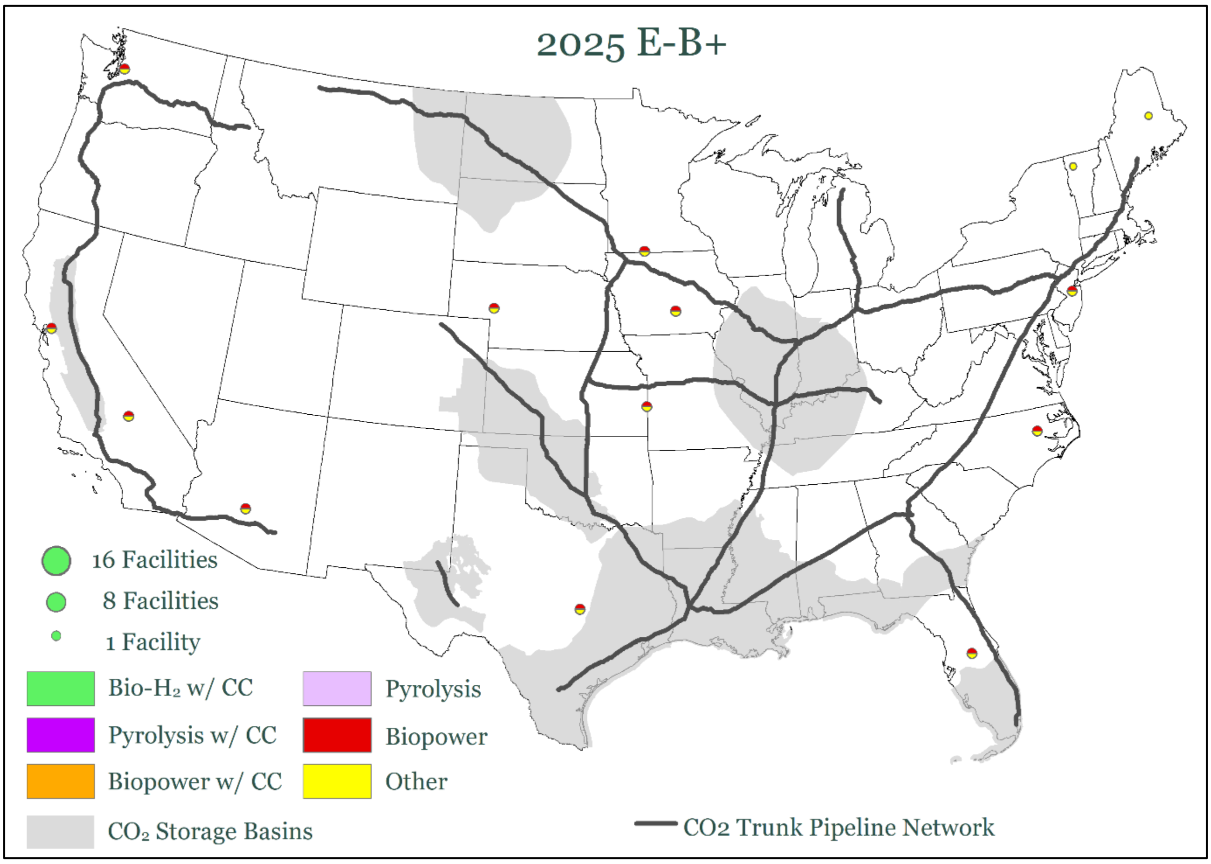
2040 E+
16 Facilities
8 Facilities
1 Facility
Bio-H₂ w/ CC
Pyrolysis
Pyrolysis w/ CC
Biopower
Biopower w/ CC
Other
CO₂ Storage Basins
CO2 Trunk Pipeline Network

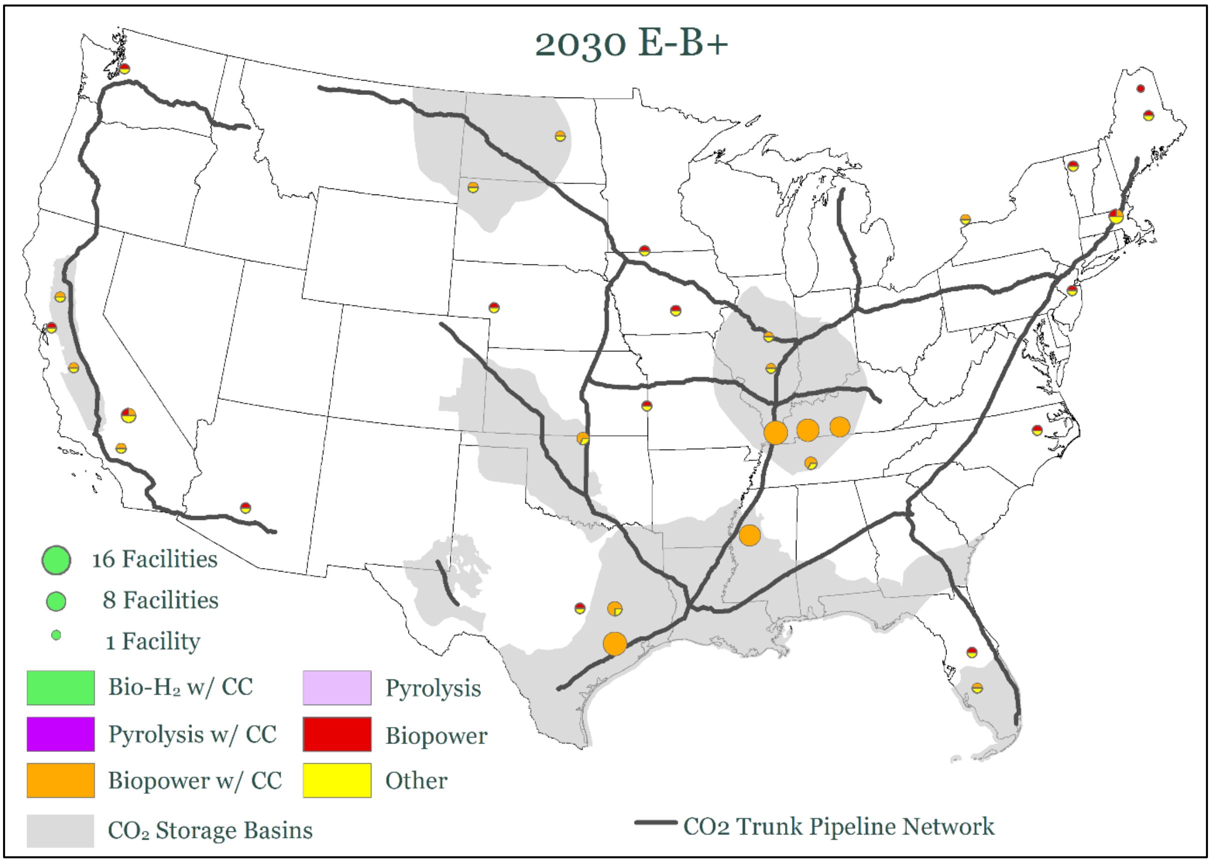




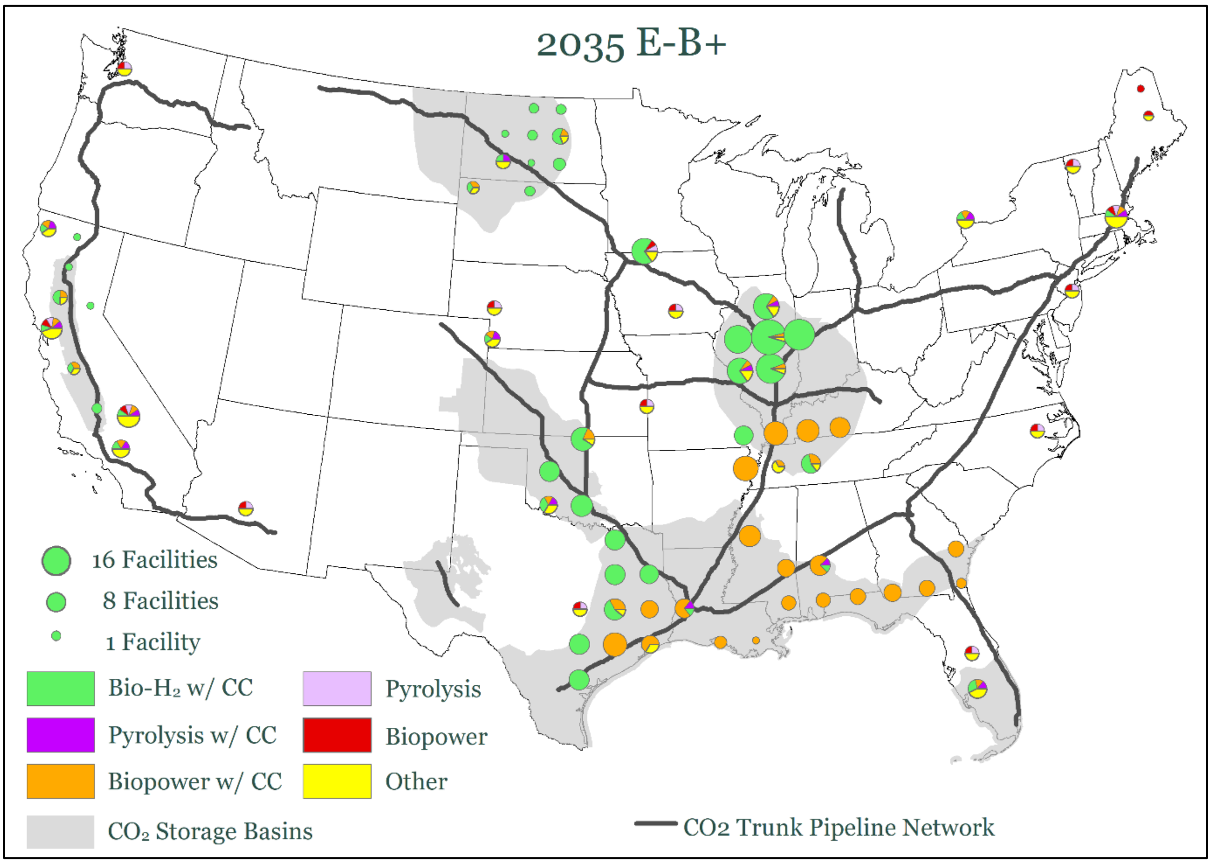
Geospatial evolution of biomass conversion facilities, 2020-2050, for E-B+ Scenario.


2020 E-B+
16 Facilities
8 Facilities
1 Facility
Bio-H_2 w/ CC
Pyrolysis
Pyrolysis w/ CC
Biopower
Biopower w/ CC
Other
CO_2 Storage Basins
CO2 Trunk Pipeline Network

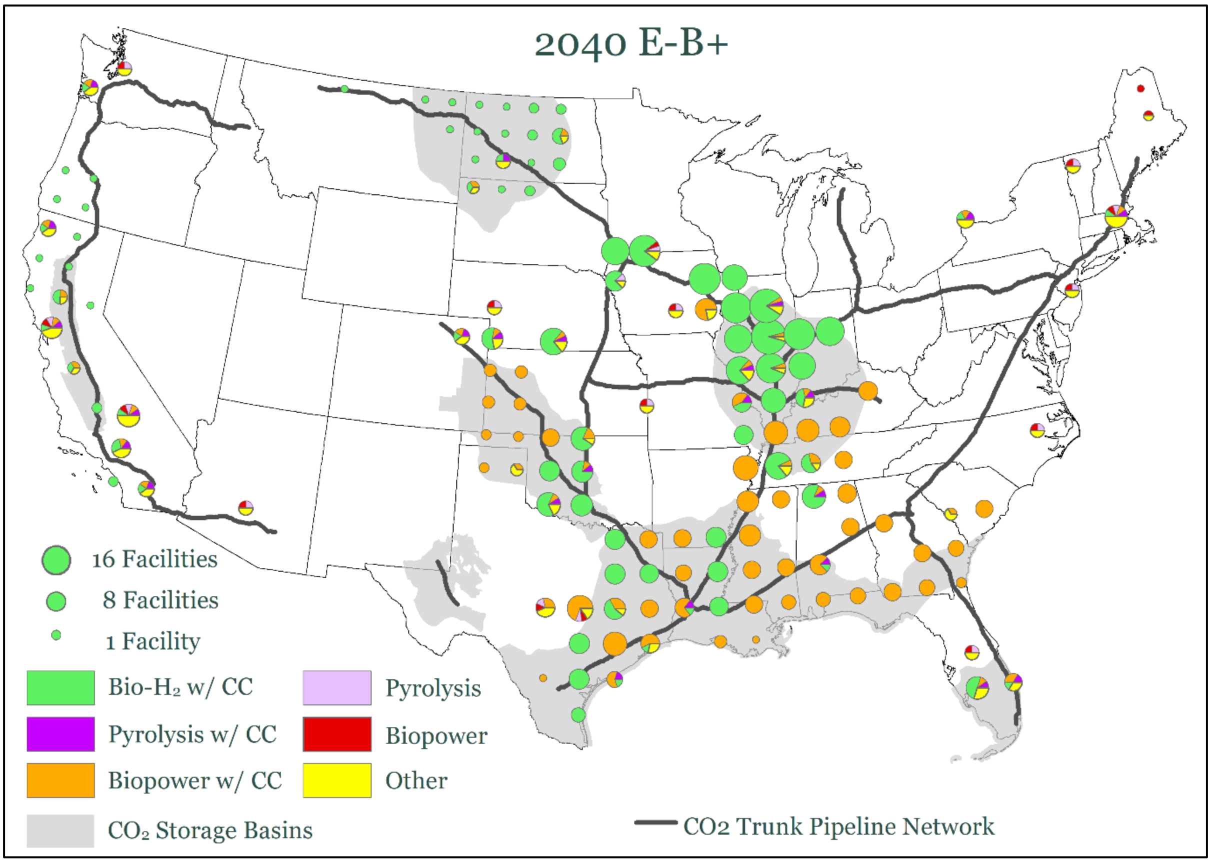

2025 E-B+
16 Facilities
8 Facilities
1 Facility
Bio-H_2 w/ CC
Pyrolysis
Pyrolysis w/ CC
Biopower
Biopower w/ CC
Other
CO_2 Storage Basins
CO2 Trunk Pipeline Network

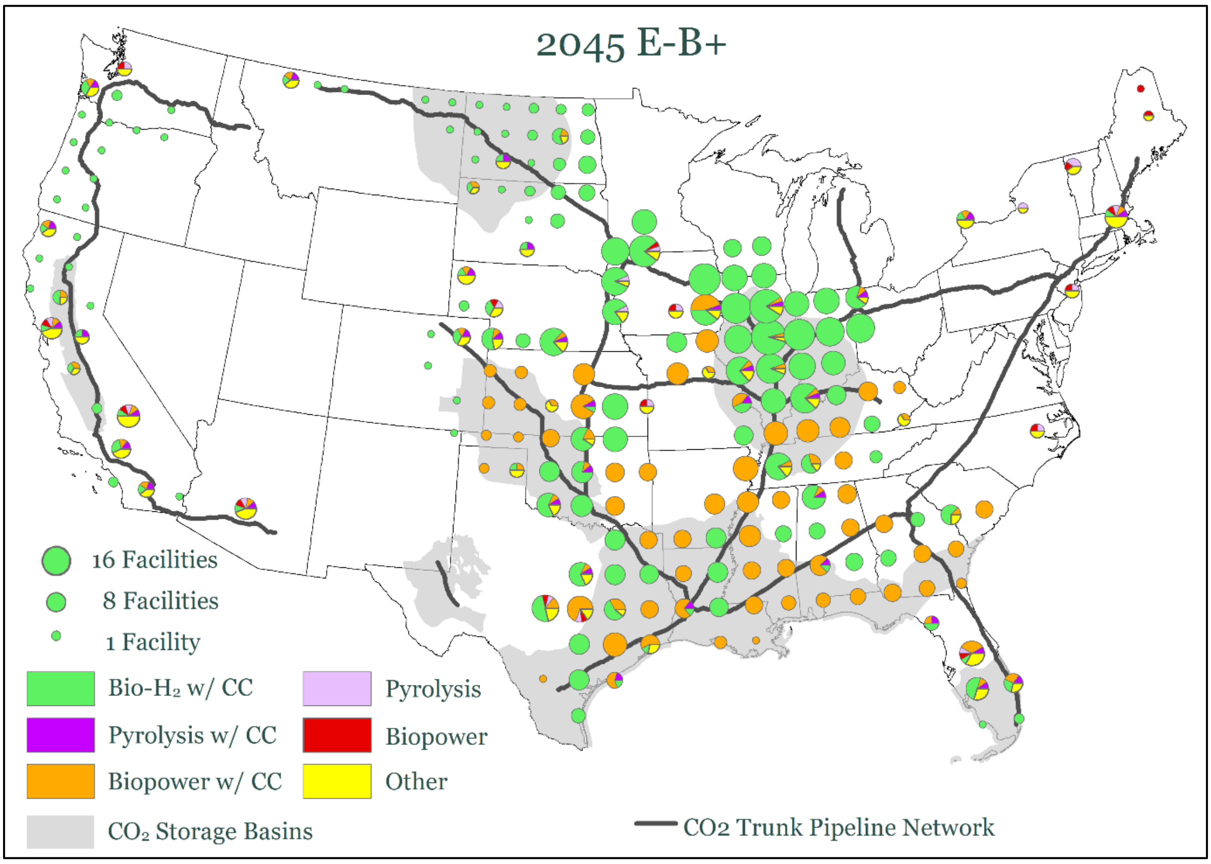


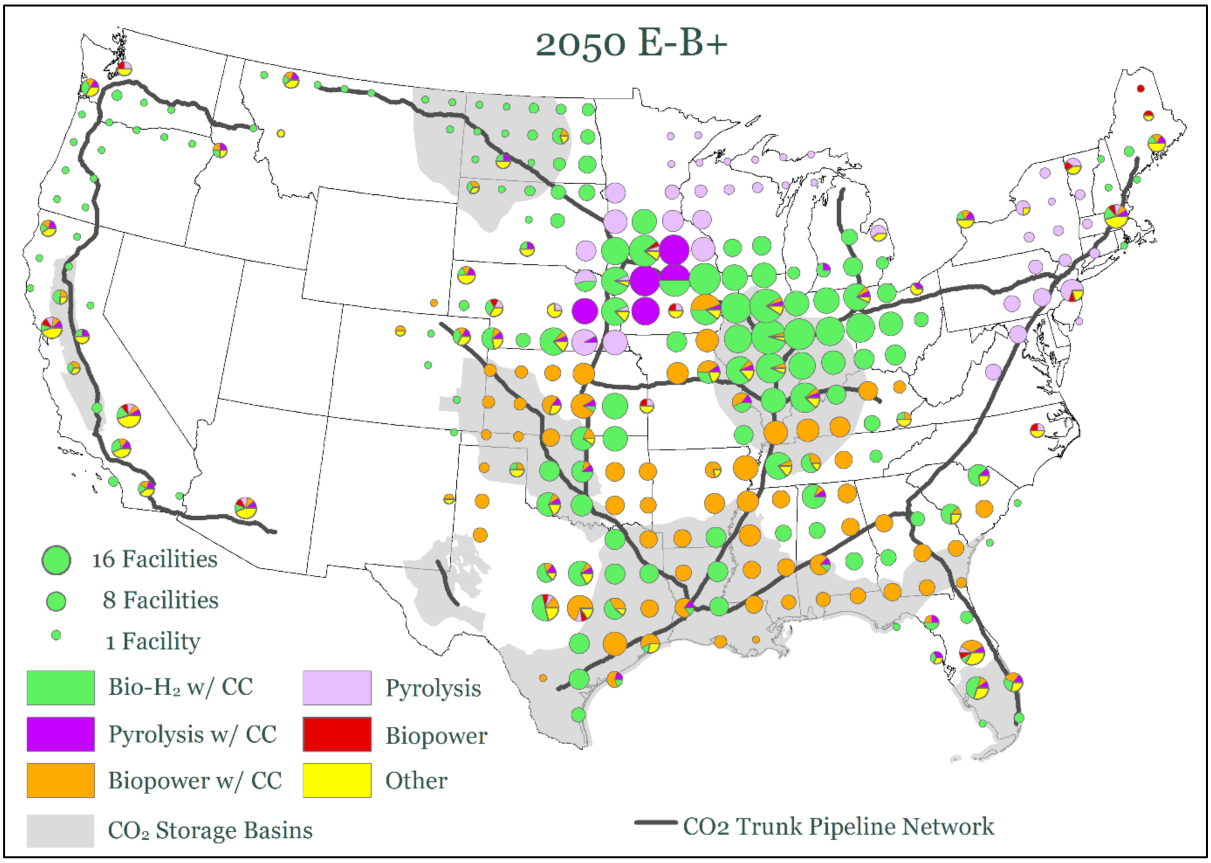
2030 E-B+
16 Facilities
8 Facilities
1 Facility
Bio-H₂ w/ CC
Pyrolysis
Pyrolysis w/ CC
Biopower
Biopower w/ CC
Other
CO₂ Storage Basins
CO2 Trunk Pipeline Network



2035 E-B+
16 Facilities
8 Facilities
1 Facility
Bio-H₂ w/ CC
Pyrolysis
Pyrolysis w/ CC
Biopower
Biopower w/ CC
Other
CO₂ Storage Basins
CO2 Trunk Pipeline Network


2040 E-B+
16 Facilities
8 Facilities
1 Facility
Bio-H2 w/ CC
Pyrolysis
Pyrolysis w/ CC
Biopower
Biopower w/ CC
Other
CO2 Storage Basins
CO2 Trunk Pipeline Network


2045 E-B+
16 Facilities
8 Facilities
1 Facility
Bio-H2 w/ CC
Pyrolysis
Pyrolysis w/ CC
Biopower
Biopower w/ CC
Other
CO2 Storage Basins
CO2 Trunk Pipeline Network


2050 E-B+
16 Facilities
8 Facilities
1 Facility
Bio-H₂ w/ CC
Pyrolysis w/ CC
Biopower w/ CC
CO₂ Storage Basins
Pyrolysis
Biopower
Other
CO2 Trunk Pipeline Network

Appendix H4: Cumulative capital investment and annual biomass purchase by state

Table H4-1. Cumulative capital investment in new biomass conversion facilities by state every 5 years for E+ Scenario

Capital Investment [$B]	2025	2030	2035	2040	2045	2050
Alabama	0.0	0.0	3.4	17.8	24.5	24.5
Arizona	0.0	0.2	0.2	0.2	0.2	0.9
Arkansas	0.0	0.0	1.5	9.1	17.7	21.6
California	0.0	1.7	9.2	13.0	16.4	18.4
Colorado	0.0	0.0	0.0	0.3	2.6	4.8
Connecticut	0.0	0.0	0.0	0.0	0.0	1.6
Delaware	0.0	0.0	0.0	0.0	0.0	0.0
Florida	0.0	0.3	1.0	6.5	12.4	14.9
Georgia	0.0	0.0	0.4	15.2	22.9	25.3
Idaho	0.0	0.0	0.0	0.0	0.0	0.7
Illinois	0.0	0.2	28.4	46.8	52.4	52.4
Indiana	0.0	0.0	0.0	7.5	41.3	41.9
Iowa	0.0	0.2	0.2	0.2	16.2	66.0
Kansas	0.0	0.0	6.4	6.4	11.8	13.8
Kentucky	0.0	6.2	11.8	11.8	20.3	20.3
Louisiana	0.0	4.8	7.6	20.5	20.5	20.5
Maine	0.0	0.2	0.2	0.2	0.2	2.5
Maryland	0.0	0.0	0.0	0.0	0.0	4.6
Massachusetts	0.0	1.4	1.4	1.4	1.4	3.3
Michigan	0.0	0.0	0.0	0.0	0.0	14.1
Minnesota	0.1	0.7	3.8	4.9	17.3	94.5
Mississippi	0.0	3.4	7.6	11.4	20.4	20.4
Missouri	0.0	0.0	0.1	2.1	3.9	11.6
Montana	0.0	0.0	0.0	0.6	3.0	4.3
Nebraska	0.0	0.0	0.7	1.7	9.5	72.0
Nevada	0.0	0.0	0.0	0.0	0.0	0.0
New Hampshire	0.0	0.0	0.0	0.0	0.0	1.5
New Jersey	0.0	0.4	0.5	0.4	0.5	0.5
New Mexico	0.0	0.0	0.0	0.2	1.2	2.7
New York	0.0	0.0	0.0	0.0	0.0	4.9
North Carolina	0.0	0.0	0.0	0.0	0.0	13.9
North Dakota	0.0	0.1	5.4	6.9	8.0	13.3
Ohio	0.0	0.0	0.0	0.0	5.9	27.4
Oklahoma	0.0	0.0	3.2	4.4	6.9	8.1
Oregon	0.0	0.0	0.0	0.0	2.2	7.0
Pennsylvania	0.0	0.0	0.0	0.0	0.0	8.7
Rhode Island	0.0	0.0	0.0	0.0	0.0	1.1
South Carolina	0.0	0.0	0.0	5.3	14.8	19.6
South Dakota	0.0	0.0	1.1	1.1	1.4	25.6
Tennessee	0.0	0.0	3.1	3.1	10.9	10.9
Texas	0.0	7.9	14.3	20.2	27.2	27.8
Utah	0.0	0.0	0.1	0.1	0.1	0.5
Vermont	0.0	0.0	0.1	0.1	0.1	0.3
Virginia	0.0	1.1	1.1	1.1	1.1	3.1
Washington	0.0	0.3	0.3	0.3	1.2	9.2
West Virginia	0.0	0.0	0.0	0.0	0.0	2.8
Wisconsin	0.0	0.0	0.0	0.0	9.6	34.1
Wyoming	0.0	0.0	0.0	0.0	0.0	0.4

Table H4-2. Annual biomass purchase by state every 5 years for E+ Scenario[e]

Annual Biomass Purchase [$B]	2025	2030	2035	2040	2045	2050
Alabama	0.0	0.0	0.2	0.7	1.0	1.0
Arizona	0.0	0.0	0.0	0.0	0.0	0.0
Arkansas	0.0	0.0	0.1	0.4	0.8	1.0
California	0.0	0.1	0.3	0.5	0.6	0.6
Colorado	0.0	0.0	0.0	0.0	0.2	0.3
Connecticut	0.0	0.0	0.0	0.0	0.0	0.1
Delaware	0.0	0.0	0.0	0.0	0.0	0.0
Florida	0.0	0.0	0.0	0.3	0.6	0.7
Georgia	0.0	0.0	0.0	0.6	1.0	1.1
Idaho	0.0	0.0	0.0	0.0	0.0	0.0
Illinois	0.0	0.0	2.0	3.2	3.6	3.6
Indiana	0.0	0.0	0.0	0.5	2.8	2.8
Iowa	0.0	0.0	0.0	0.0	1.2	3.5
Kansas	0.0	0.0	0.4	0.4	0.8	0.9
Kentucky	0.0	0.2	0.5	0.5	0.9	0.9
Louisiana	0.0	0.2	0.3	1.0	1.0	1.0
Maine	0.0	0.0	0.0	0.0	0.0	0.1
Maryland	0.0	0.0	0.0	0.0	0.0	0.2
Massachusetts	0.0	0.1	0.1	0.1	0.1	0.1
Michigan	0.0	0.0	0.0	0.0	0.0	0.9
Minnesota	0.0	0.1	0.3	0.4	1.3	4.7
Mississippi	0.0	0.1	0.4	0.6	1.0	1.0
Missouri	0.0	0.0	0.0	0.1	0.2	0.6
Montana	0.0	0.0	0.0	0.0	0.2	0.3
Nebraska	0.0	0.0	0.0	0.1	0.7	3.7
Nevada	0.0	0.0	0.0	0.0	0.0	0.0
New Hampshire	0.0	0.0	0.0	0.0	0.0	0.1
New Jersey	0.0	0.0	0.0	0.0	0.0	0.0
New Mexico	0.0	0.0	0.0	0.0	0.1	0.2
New York	0.0	0.0	0.0	0.0	0.0	0.2
North Carolina	0.0	0.0	0.0	0.0	0.0	0.7
North Dakota	0.0	0.0	0.4	0.5	0.6	1.0
Ohio	0.0	0.0	0.0	0.0	0.4	1.8
Oklahoma	0.0	0.0	0.2	0.3	0.4	0.5
Oregon	0.0	0.0	0.0	0.0	0.1	0.4
Pennsylvania	0.0	0.0	0.0	0.0	0.0	0.4
Rhode Island	0.0	0.0	0.0	0.0	0.0	0.0
South Carolina	0.0	0.0	0.0	0.2	0.5	0.8
South Dakota	0.0	0.0	0.1	0.1	0.1	1.3
Tennessee	0.0	0.0	0.2	0.2	0.5	0.5
Texas	0.0	0.3	0.6	1.0	1.3	1.4
Utah	0.0	0.0	0.0	0.0	0.0	0.0
Vermont	0.0	0.0	0.0	0.0	0.0	0.0
Virginia	0.0	0.1	0.1	0.1	0.1	0.2
Washington	0.0	0.0	0.0	0.0	0.1	0.5
West Virginia	0.0	0.0	0.0	0.0	0.0	0.1
Wisconsin	0.0	0.0	0.0	0.0	0.6	1.8
Wyoming	0.0	0.0	0.0	0.0	0.0	0.0

[e] Biomass purchases in this table include biomass used in cogeneration facilities existing in 2020 and assumed to remain operating over the modeling period. Biomass purchases do not include demand-side biomass use or corn used in ethanol facilities.

Table H4-3. Cumulative capital investment by state every 5 years for E-B+ Scenario

Capital Investment [$B]	2025	2030	2035	2040	2045	2050
Alabama	0.0	0.0	8.6	35.6	44.8	44.8
Arizona	0.0	0.1	0.1	0.1	0.3	0.5
Arkansas	0.0	0.0	15.8	30.2	40.7	46.9
California	0.0	2.6	14.2	20.6	22.6	23.2
Colorado	0.0	0.0	0.0	1.4	5.1	5.8
Connecticut	0.0	0.0	0.0	0.0	0.0	2.3
Delaware	0.0	0.0	0.0	0.0	0.0	0.8
Florida	0.0	0.7	16.6	22.6	35.6	40.1
Georgia	0.0	0.0	24.8	41.0	48.8	49.5
Idaho	0.0	0.0	0.0	0.0	0.0	1.1
Illinois	0.0	2.3	61.2	105.3	105.3	105.3
Indiana	0.0	0.0	15.5	43.2	87.3	87.3
Iowa	0.0	0.2	0.2	30.2	42.5	113.1
Kansas	0.0	0.0	0.1	16.6	53.9	66.7
Kentucky	0.0	38.4	38.4	48.0	59.2	60.3
Louisiana	0.0	0.0	13.9	41.9	41.9	41.9
Maine	0.0	1.1	1.1	1.1	1.0	4.6
Maryland	0.0	0.0	0.0	0.0	0.0	5.3
Massachusetts	0.0	0.5	0.6	0.6	0.6	5.1
Michigan	0.0	0.0	0.0	0.0	0.0	23.9
Minnesota	0.1	0.5	8.3	24.4	34.0	101.2
Mississippi	0.0	12.2	26.1	55.0	59.5	59.5
Missouri	0.0	0.0	5.8	12.9	46.3	52.9
Montana	0.0	0.0	0.0	3.1	4.4	5.4
Nebraska	0.0	0.0	1.5	13.3	30.0	83.2
Nevada	0.0	0.0	0.0	0.0	0.0	0.0
New Hampshire	0.0	0.0	0.0	0.0	0.0	3.0
New Jersey	0.0	0.4	0.5	0.5	0.5	6.9
New Mexico	0.0	0.0	0.0	0.0	0.7	2.6
New York	0.0	0.0	0.0	0.0	0.1	12.3
North Carolina	0.0	1.1	1.1	1.1	1.1	1.1
North Dakota	0.0	0.1	13.6	18.5	29.2	29.2
Ohio	0.0	0.0	0.0	0.0	18.5	55.0
Oklahoma	0.0	3.1	28.6	53.4	89.0	95.6
Oregon	0.0	0.0	0.0	3.0	7.7	8.3
Pennsylvania	0.0	0.0	0.0	0.0	0.0	14.4
Rhode Island	0.0	0.0	0.0	0.0	0.0	1.5
South Carolina	0.0	0.0	0.0	8.8	13.1	19.8
South Dakota	0.0	0.0	2.2	2.8	16.5	23.9
Tennessee	0.0	3.6	7.5	24.3	27.4	27.4
Texas	0.0	18.2	69.0	106.9	121.7	137.4
Utah	0.0	0.0	0.0	0.0	0.0	0.0
Vermont	0.0	0.1	0.1	0.2	1.8	3.7
Virginia	0.0	0.0	0.0	0.0	0.0	4.5
Washington	0.0	0.3	0.3	1.6	6.8	7.4
West Virginia	0.0	0.0	0.0	0.0	0.0	0.0
Wisconsin	0.0	0.0	0.0	0.0	20.8	39.1
Wyoming	0.0	0.0	0.0	0.0	0.0	0.8

Table H4-2. Annual biomass purchase by state every 5 years for E-B+ Scenario (see footnote e)

Annual Biomass Purchase [$B]	2025	2030	2035	2040	2045	2050
Alabama	0.0	0.0	0.5	2.1	2.9	2.9
Arizona	0.0	0.0	0.0	0.0	0.0	0.0
Arkansas	0.0	0.0	0.9	1.8	2.4	2.7
California	0.0	0.1	0.4	0.6	0.7	0.7
Colorado	0.0	0.0	0.0	0.1	0.4	0.5
Connecticut	0.0	0.0	0.0	0.0	0.0	0.1
Delaware	0.0	0.0	0.0	0.0	0.0	0.1
Florida	0.0	0.1	1.0	1.5	2.4	2.8
Georgia	0.0	0.0	1.3	2.1	2.8	2.8
Idaho	0.0	0.0	0.0	0.0	0.0	0.1
Illinois	0.0	0.1	5.9	10.3	10.3	10.3
Indiana	0.0	0.0	1.6	4.4	8.8	8.8
Iowa	0.0	0.0	0.0	2.6	3.8	8.1
Kansas	0.0	0.0	0.0	1.0	3.5	4.2
Kentucky	0.0	2.2	2.2	2.8	3.5	3.6
Louisiana	0.0	0.0	0.8	2.6	2.6	2.6
Maine	0.0	0.1	0.1	0.1	0.1	0.4
Maryland	0.0	0.0	0.0	0.0	0.0	0.5
Massachusetts	0.0	0.0	0.0	0.1	0.1	0.4
Michigan	0.0	0.0	0.0	0.0	0.0	2.2
Minnesota	0.0	0.1	0.8	2.3	3.2	8.1
Mississippi	0.0	0.7	1.4	3.0	3.4	3.4
Missouri	0.0	0.0	0.5	1.0	3.2	3.7
Montana	0.0	0.0	0.0	0.3	0.4	0.5
Nebraska	0.0	0.0	0.1	1.1	2.4	5.7
Nevada	0.0	0.0	0.0	0.0	0.0	0.0
New Hampshire	0.0	0.0	0.0	0.0	0.0	0.3
New Jersey	0.0	0.1	0.1	0.1	0.1	0.6
New Mexico	0.0	0.0	0.0	0.0	0.1	0.2
New York	0.0	0.0	0.0	0.0	0.0	1.0
North Carolina	0.0	0.1	0.1	0.1	0.1	0.1
North Dakota	0.0	0.0	1.2	1.7	2.6	2.6
Ohio	0.0	0.0	0.0	0.0	1.8	5.4
Oklahoma	0.0	0.2	2.4	4.2	6.6	7.0
Oregon	0.0	0.0	0.0	0.2	0.6	0.6
Pennsylvania	0.0	0.0	0.0	0.0	0.0	1.2
Rhode Island	0.0	0.0	0.0	0.0	0.0	0.1
South Carolina	0.0	0.0	0.0	0.4	0.8	1.3
South Dakota	0.0	0.0	0.2	0.2	1.4	1.9
Tennessee	0.0	0.2	0.6	1.8	2.1	2.1
Texas	0.0	1.0	5.1	7.4	8.7	9.7
Utah	0.0	0.0	0.0	0.0	0.0	0.0
Vermont	0.0	0.0	0.0	0.0	0.2	0.3
Virginia	0.0	0.0	0.0	0.0	0.0	0.4
Washington	0.0	0.0	0.0	0.1	0.5	0.5
West Virginia	0.0	0.0	0.0	0.0	0.0	0.0
Wisconsin	0.0	0.0	0.0	0.0	2.0	3.5
Wyoming	0.0	0.0	0.0	0.0	0.0	0.0