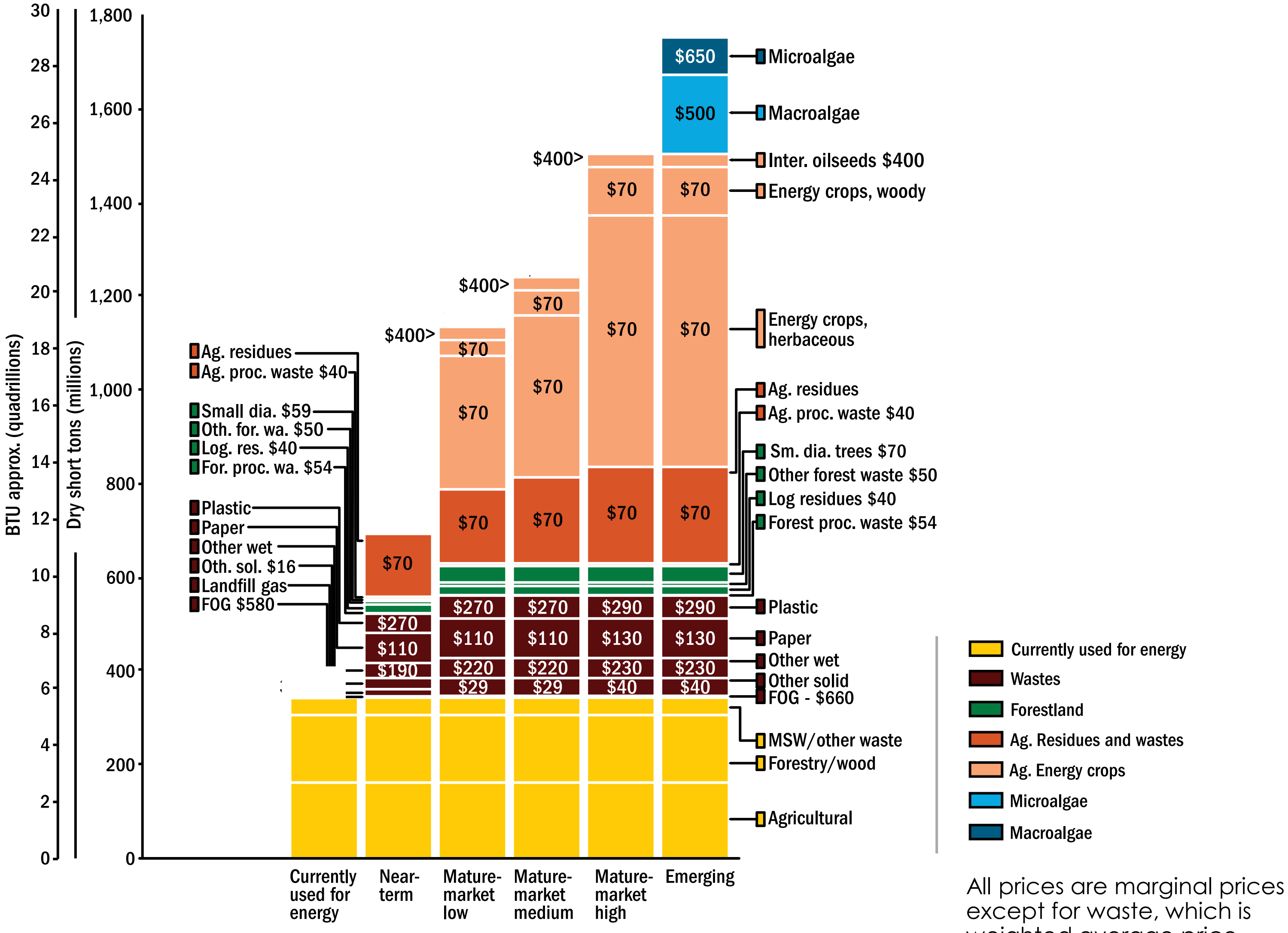
Overview of the 2023 Billion-Ton Report and summary of Roads to Removals BiCRS

Many authors

March 6th, 2024

BT23 results indicate 0.7-1.7 billion tons biomass potential



All prices are marginal prices except for waste, which is weighted average price.

- Bioeconomy currently provides 340 million tons biomass (5 Quads or 5% total)
- Currently available resources can double biomass in **near-term**
- **Mature market** induces another 440-800 million tons biomass depending on yield assumptions
- Emerging resources can supply another 250 million tons
- All estimates include sustainability constraints

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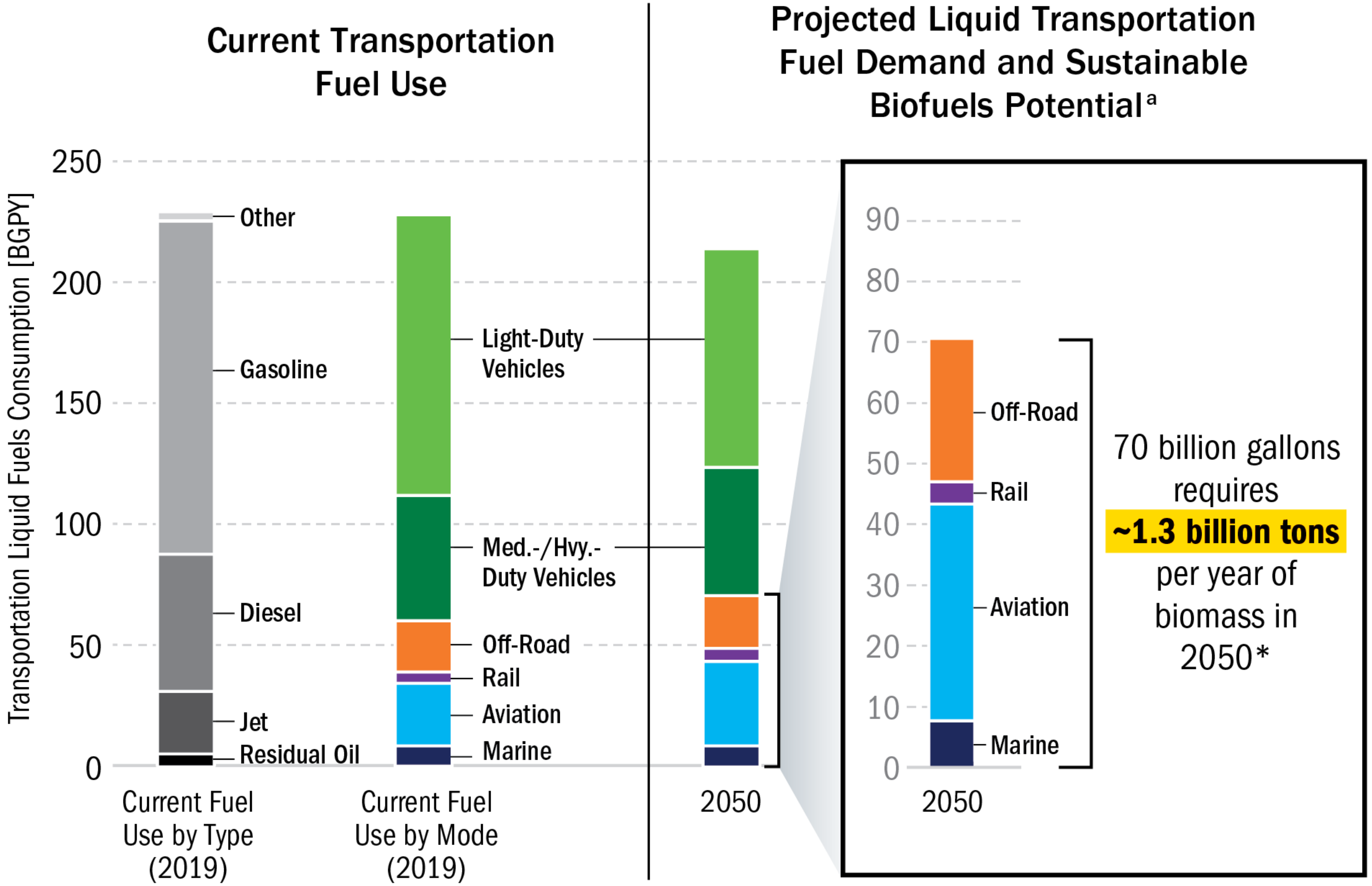
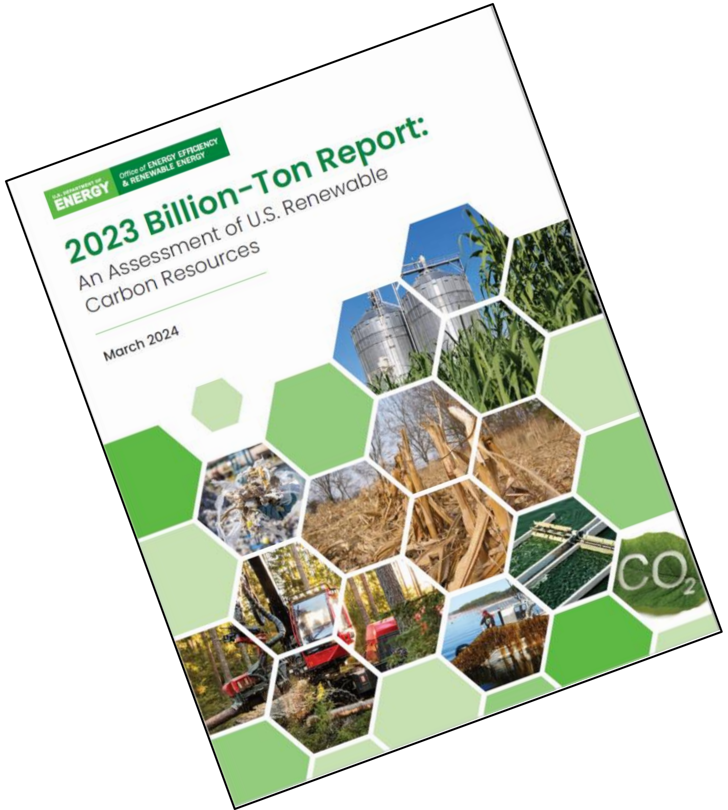
Potential Bioenergy Resource and Sustainable Fuel Supply

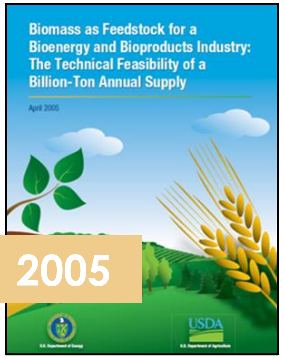


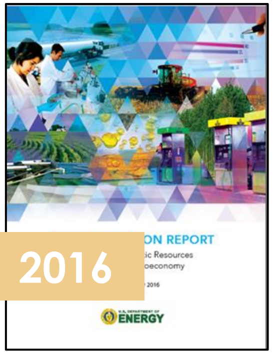
[a] The Base case and Expanded scenario bars above are reported on a GGE basis

* Assumes a conversion rate of 55 gallons per ton

2023 Billion-Ton Report (BT23) is 4th in a series







- To inform research, development, and deployment strategies.
- Update to latest economic conditions
- Better clarity in terms of
  - Production capacity by market maturity
  - Level of resource utilization
- New resources (e.g. oilseeds, macroalgae)

- **Not targets**
- **Not predictions**
- **Policy agnostic**
- **End-use agnostic**

Billion-Ton 2023 Collaborators

Fifty-four contributors

Thirty reviewers

BT23 considers current, available, and future resources

Currently used for energy and coproducts

Currently available

Emerging resources

- Currently used resources
- Wastes
- Timberland
- Agricultural resources
- Microalgae
- Macroalgae
- CO2

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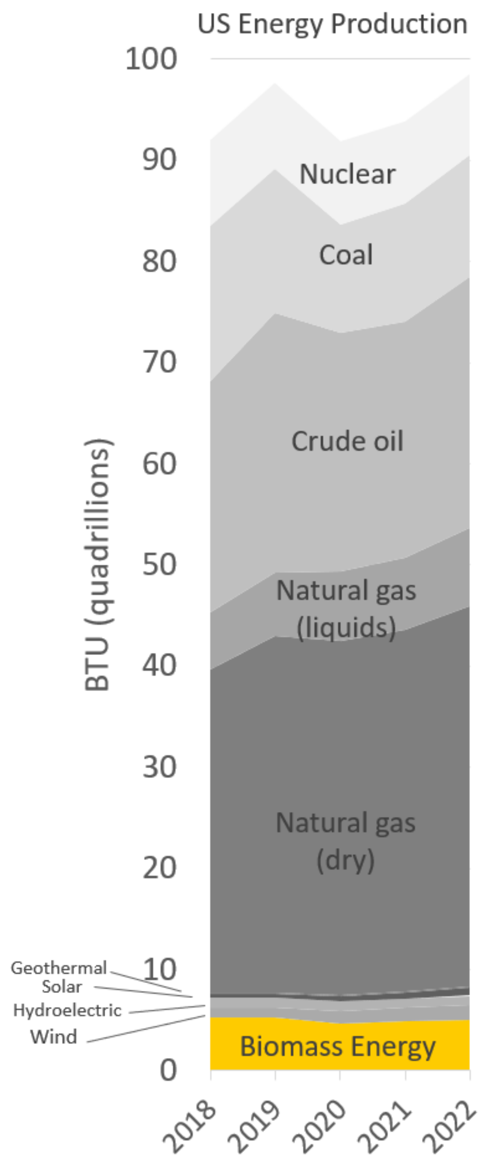
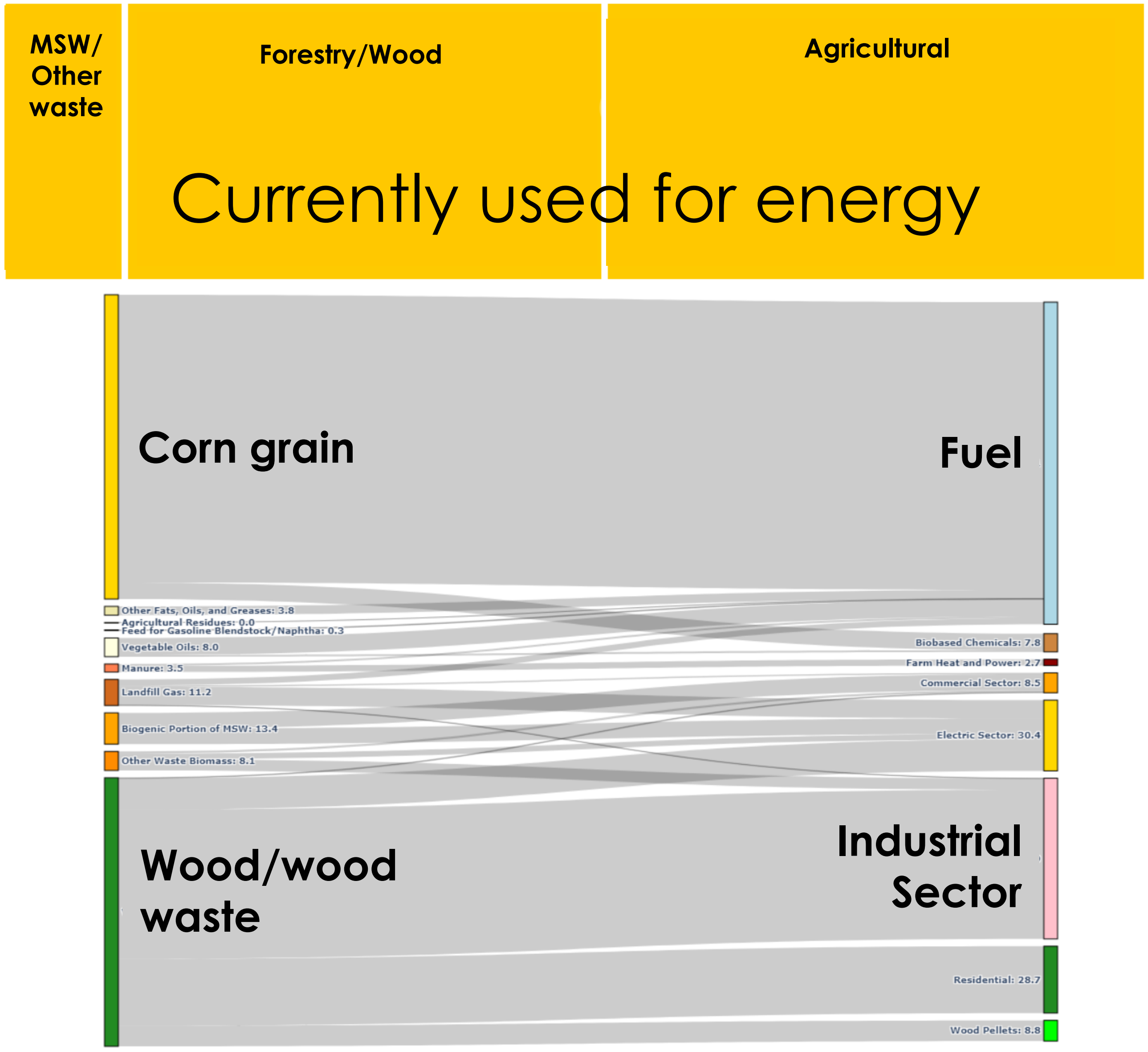
US currently uses ~350 million tons of biomass for fuel & power





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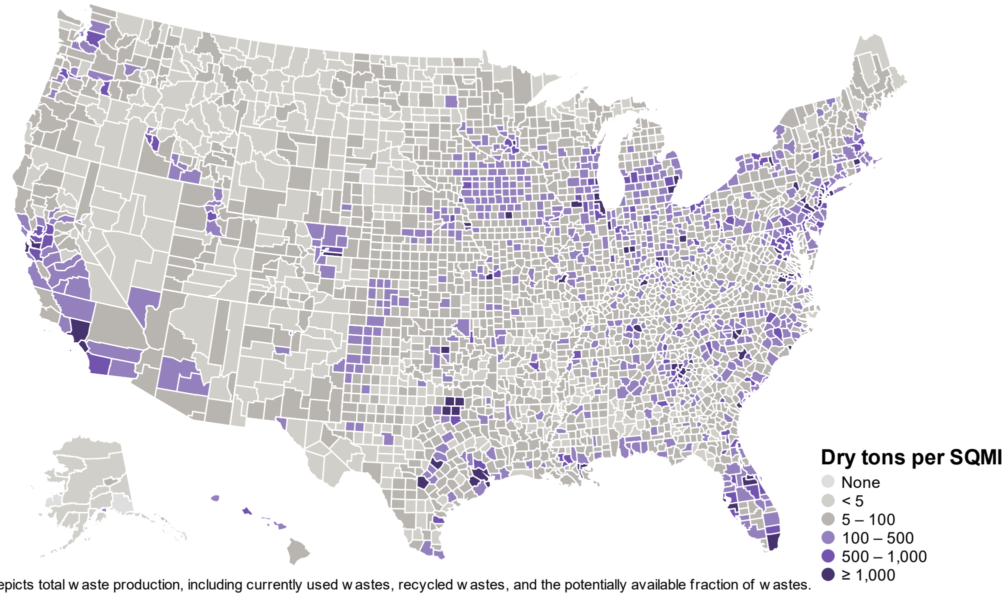
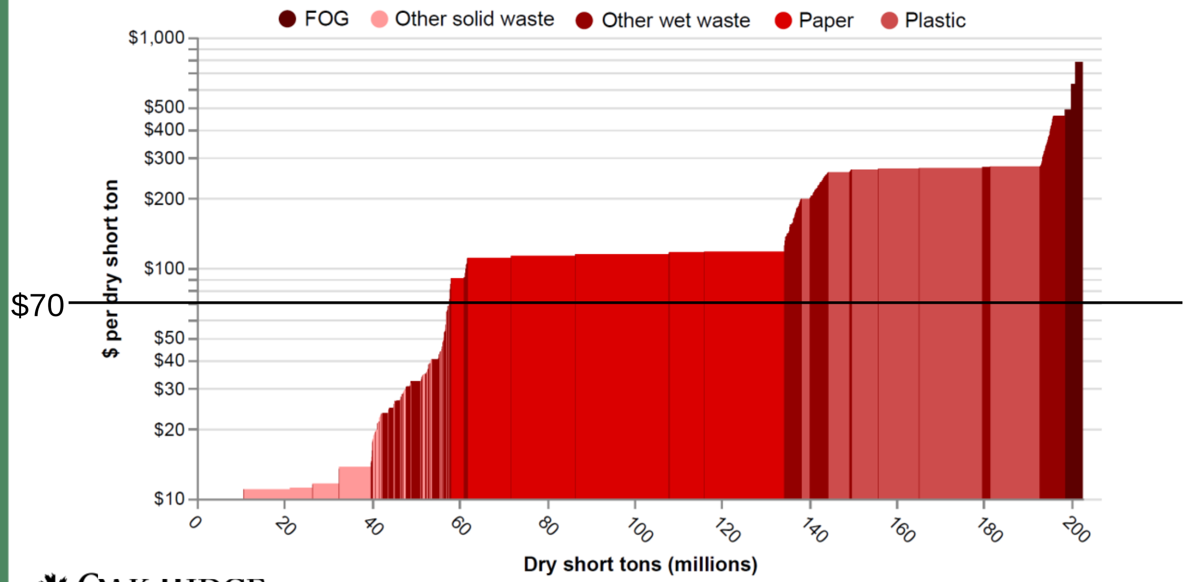
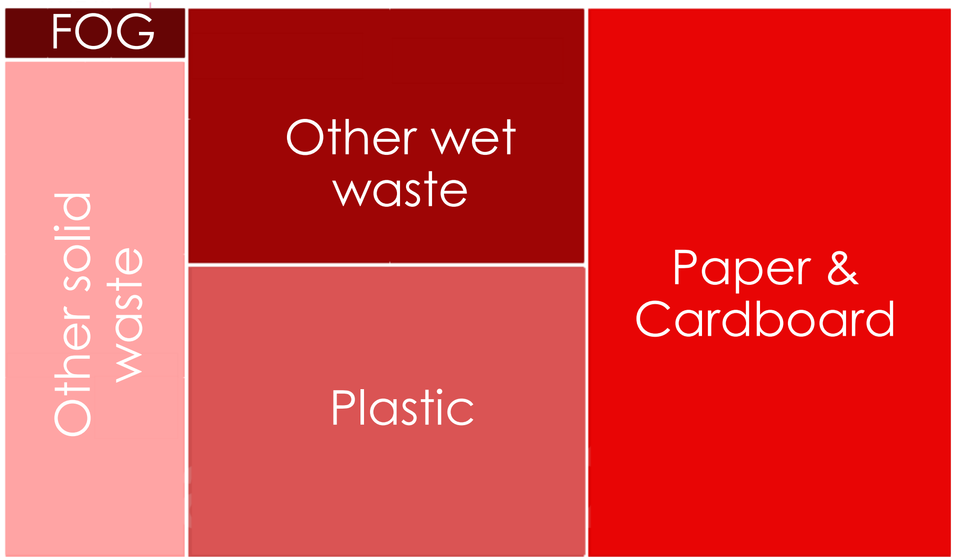
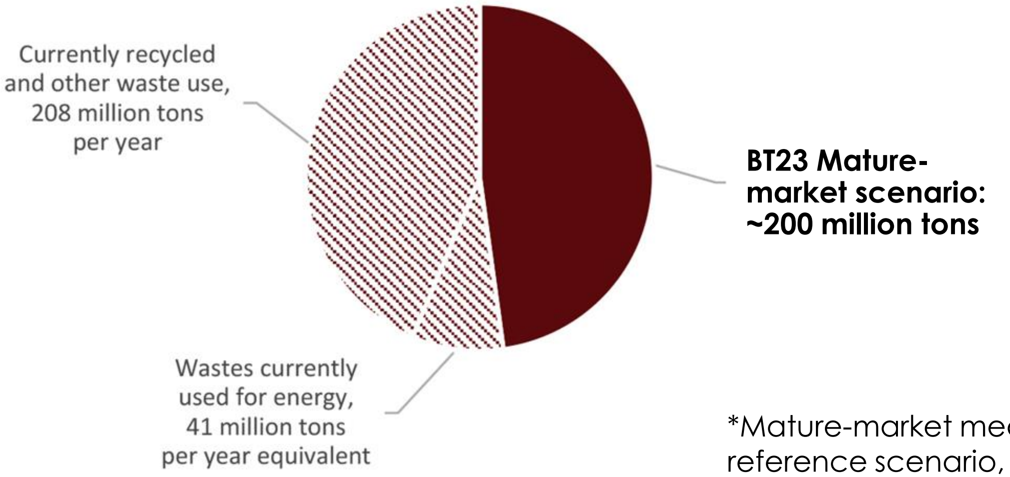
Waste & byproduct resources can provide ~200 million tons



Map depicts total waste production, including currently used wastes, recycled wastes, and the potentially available fraction of wastes. Purple colors indicate sufficient supply density to support >750,000 tons per year within a 50-mile radius.







*Mature-market medium, reference scenario, all prices

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Timberland is modeled with conventional forest products

Resource

Logging residues

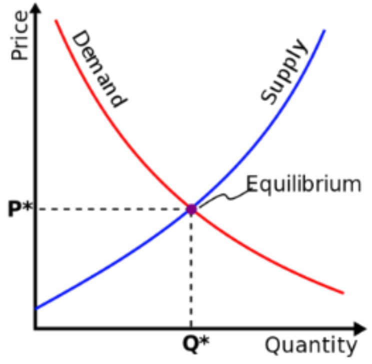
Forest thinnings

Plantations

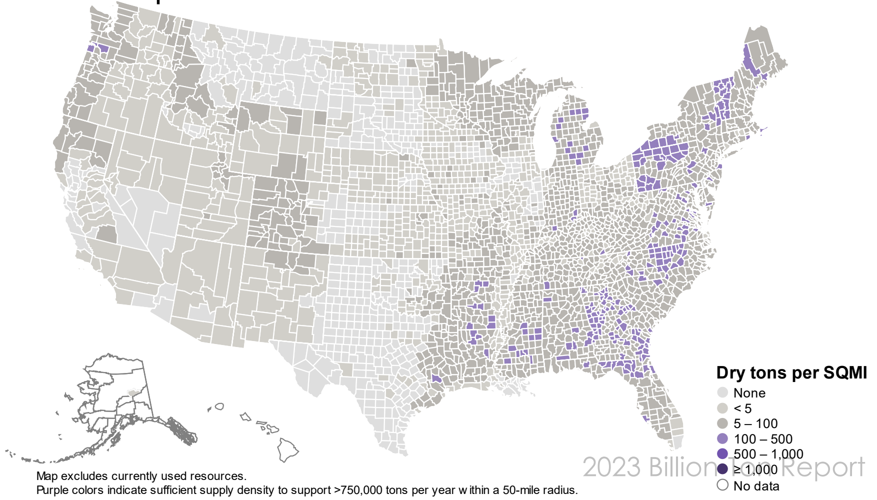
Collaboration	Analysis	Region
	Forest Sustainability and Economic Assessment Model (ForSEAM)	Conterminous US
	Subregional Timber Supply Model (SRTS)	SE US
	Bioregional Inventory Originated Simulation Under Management (BioSUM)	Western fire-prone forests

Inputs

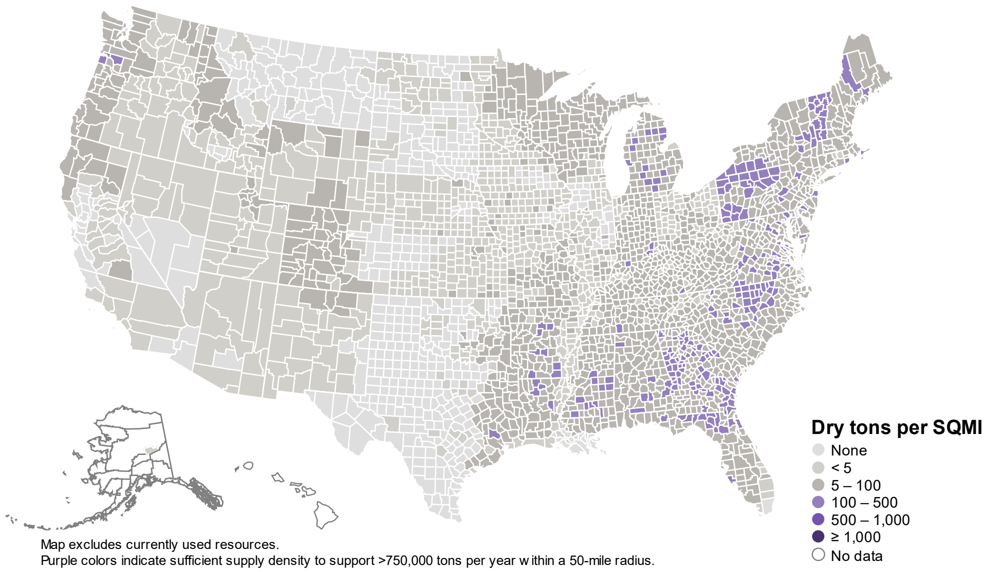
- Inventory from USFS Forest Inventory and Analysis (FIA) data
- Conventional demands (sawtimber and pulpwood) from Forest Resource Outlook Model
- Growth and yield data
- Operational costs

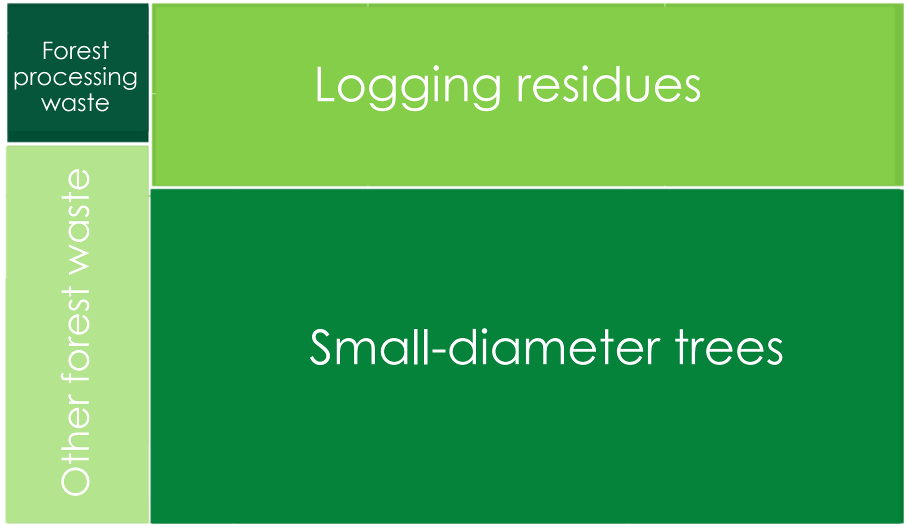


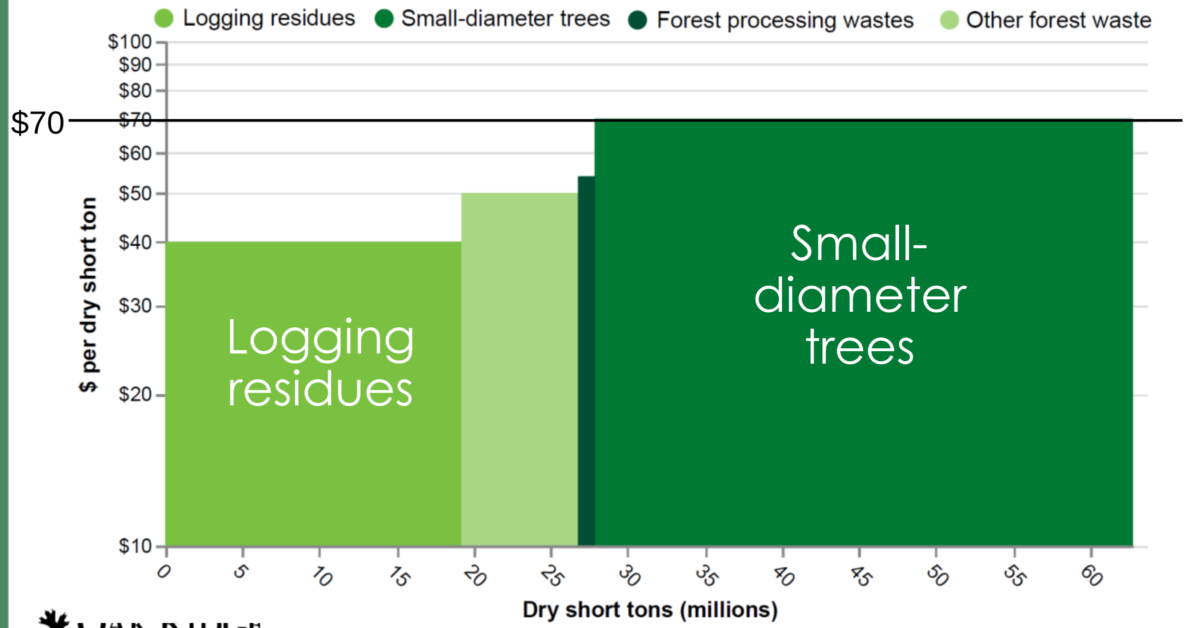
Outputs: County-level supply curves

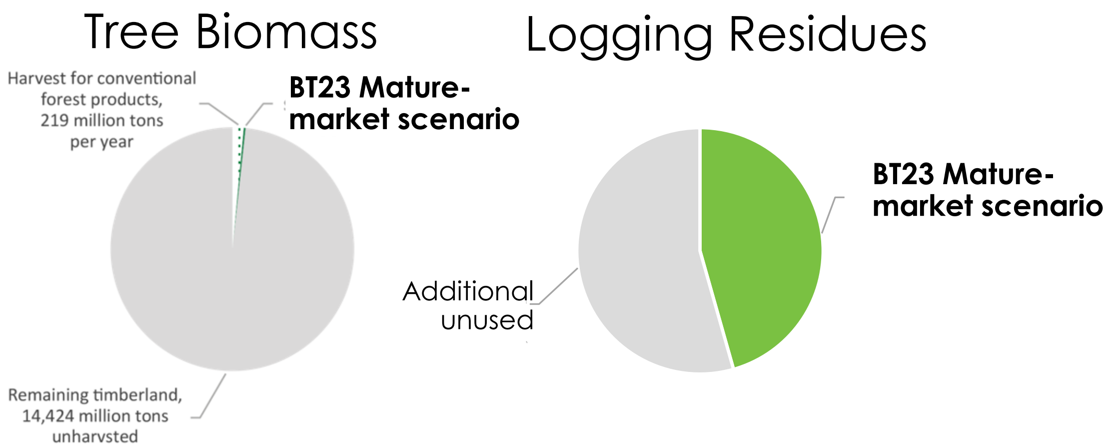


Timberland resources can provide ~50 million tons









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Agriculture is modeled with conventional crops

Resource

Crop residues

Switchgrass

Willow

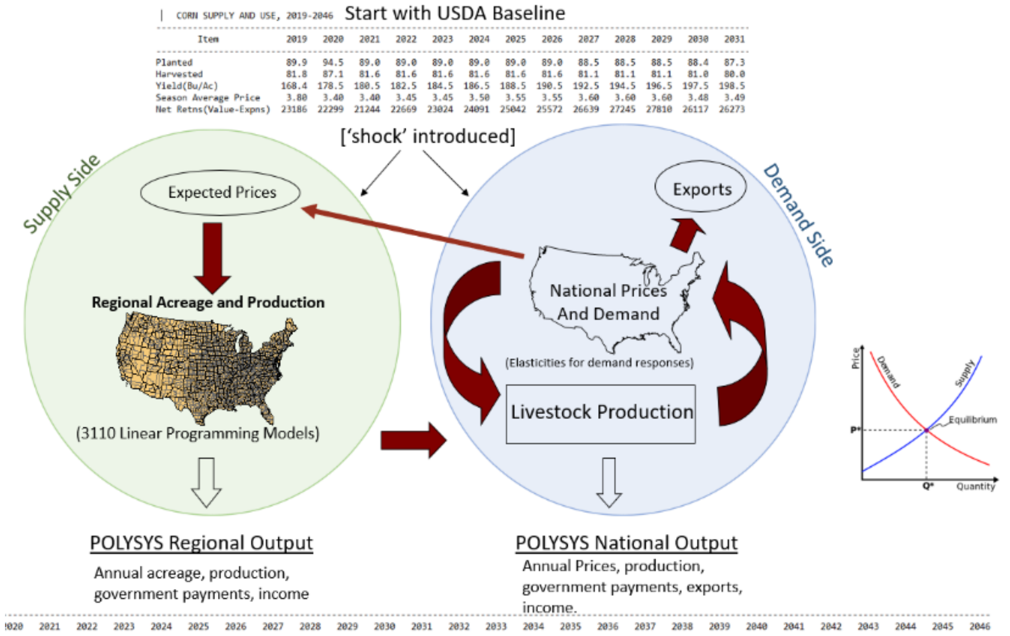
Oil seeds

Analysis:

Model: Policy Analysis System (POLYSYS)

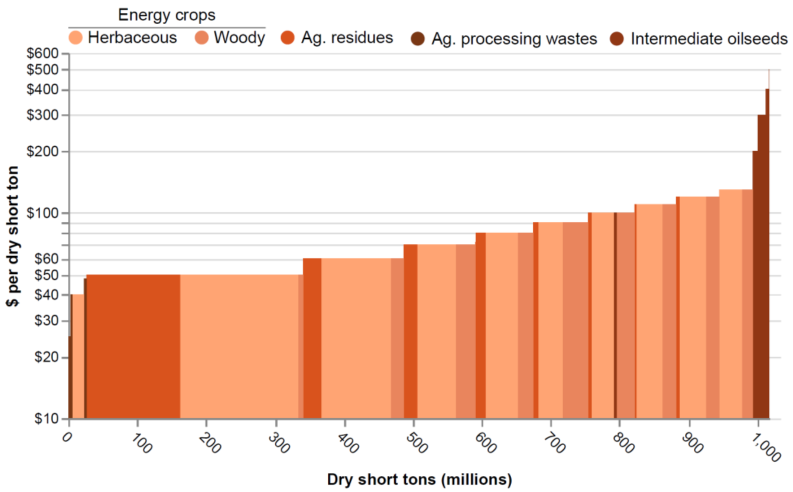
Inputs:

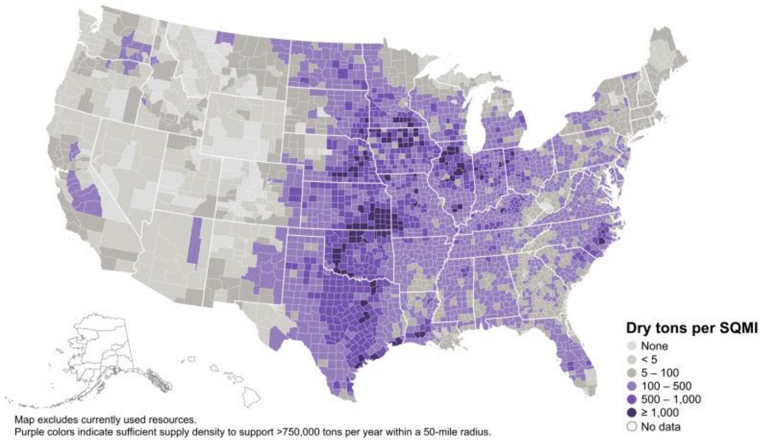
- Conventional (food, feed, fiber, export) demands from 2023 USDA Baseline Projection
- Crop yields (tons/acre/year) from SunGrant Regional Feedstock Partnership and PRISM model
- Updated crop production budgets
- 30-meter cropland resolution (2022 Cropland Data Layer)



Item	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Planted	89.9	94.5	89.0	89.0	89.0	89.0	89.0	89.0	88.5	88.5	88.5	88.4	87.3
Harvested	81.8	87.1	81.6	81.6	81.6	81.6	81.6	81.6	81.1	81.1	81.1	81.0	80.0
Yield(Bu/Ac)	168.4	178.5	180.5	182.5	184.5	186.5	188.5	190.5	192.5	194.5	196.5	197.5	198.5
Season Average Price	3.80	3.40	3.40	3.45	3.45	3.50	3.55	3.55	3.60	3.60	3.60	3.48	3.49
Net Retns(Value-Expns)	23186	22299	21244	22669	23024	24091	25042	25572	26639	27245	27810	26117	26273

Outputs:





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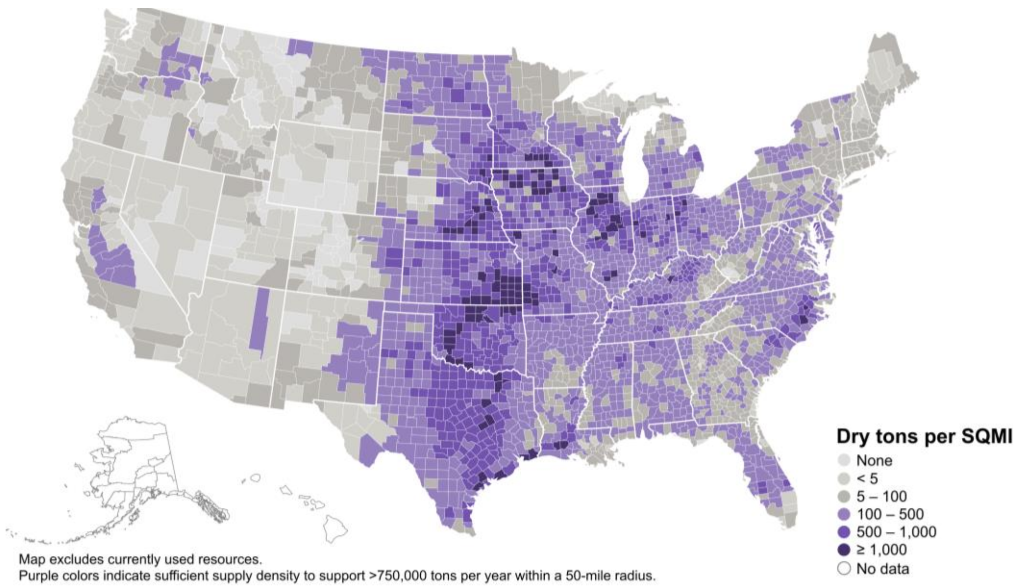
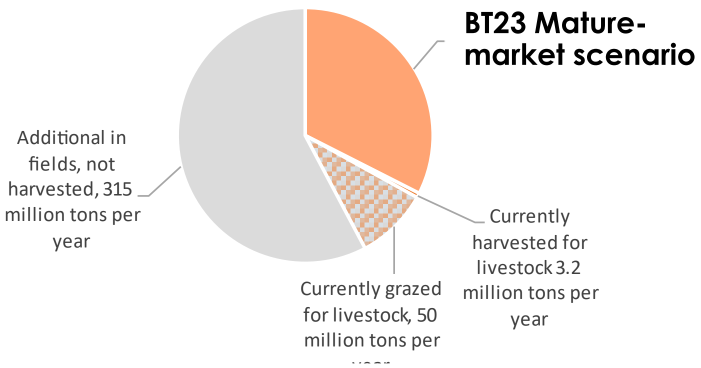
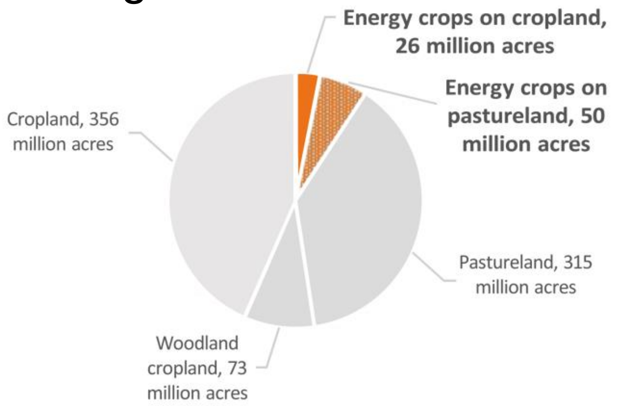
Agricultural resources can provide ~200-800 million tons



Ag lands can be used to grow 300-600 million tons of cellulosic energy crops. Intermediate oil seeds can provide another 28 million tons.





*Mature-market medium, reference scenario, up to $70 per ton

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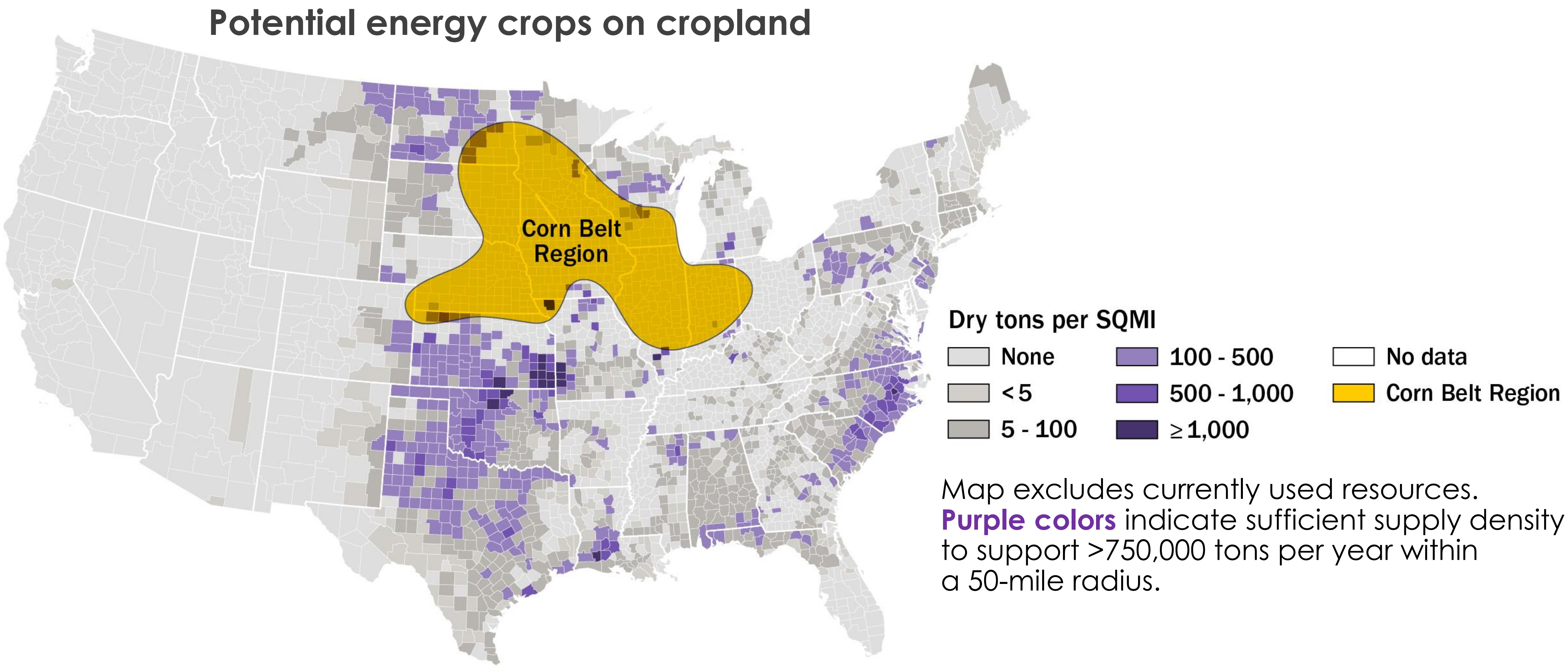
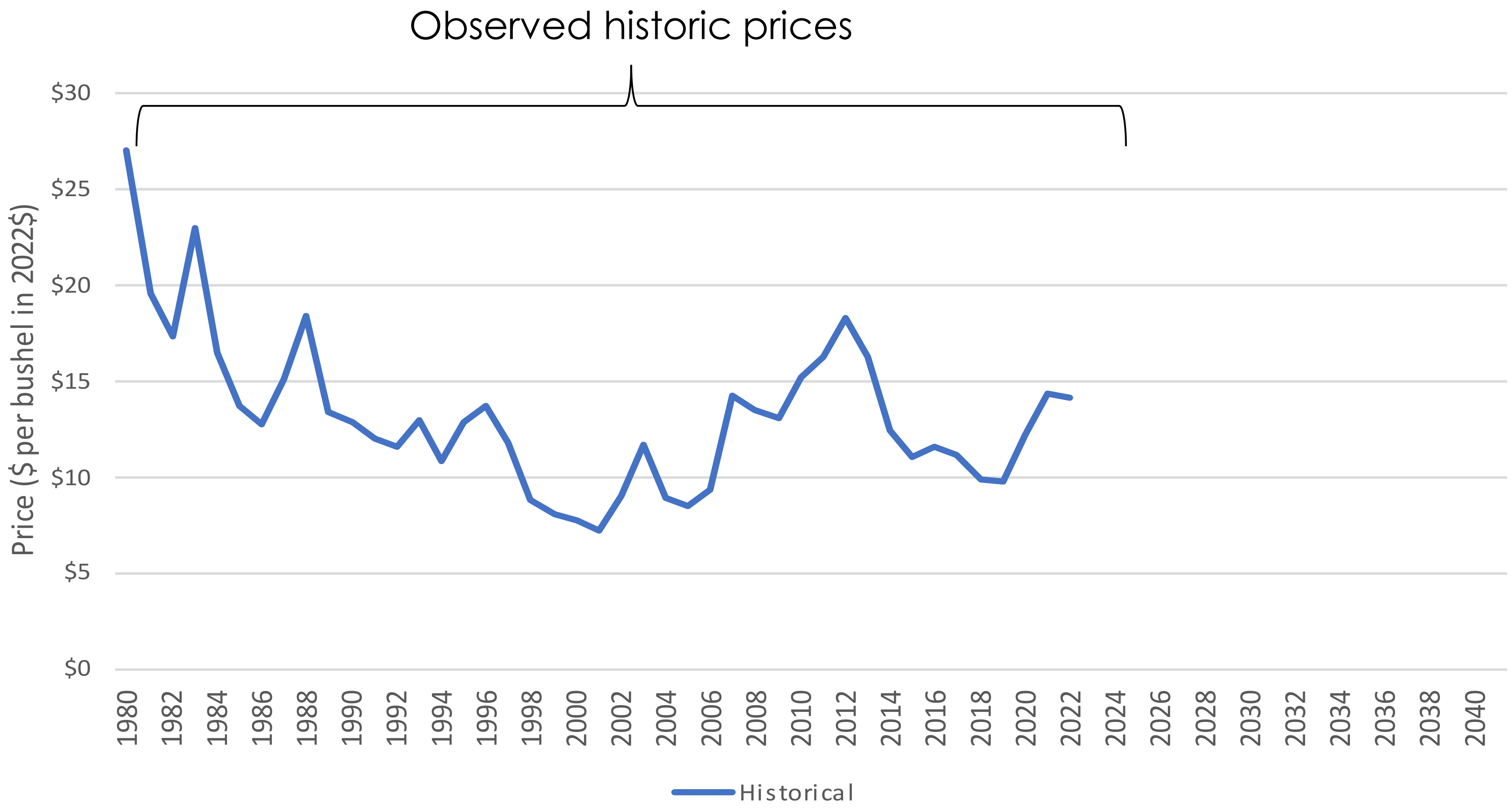
Energy crops results on cropland are outside the corn belt

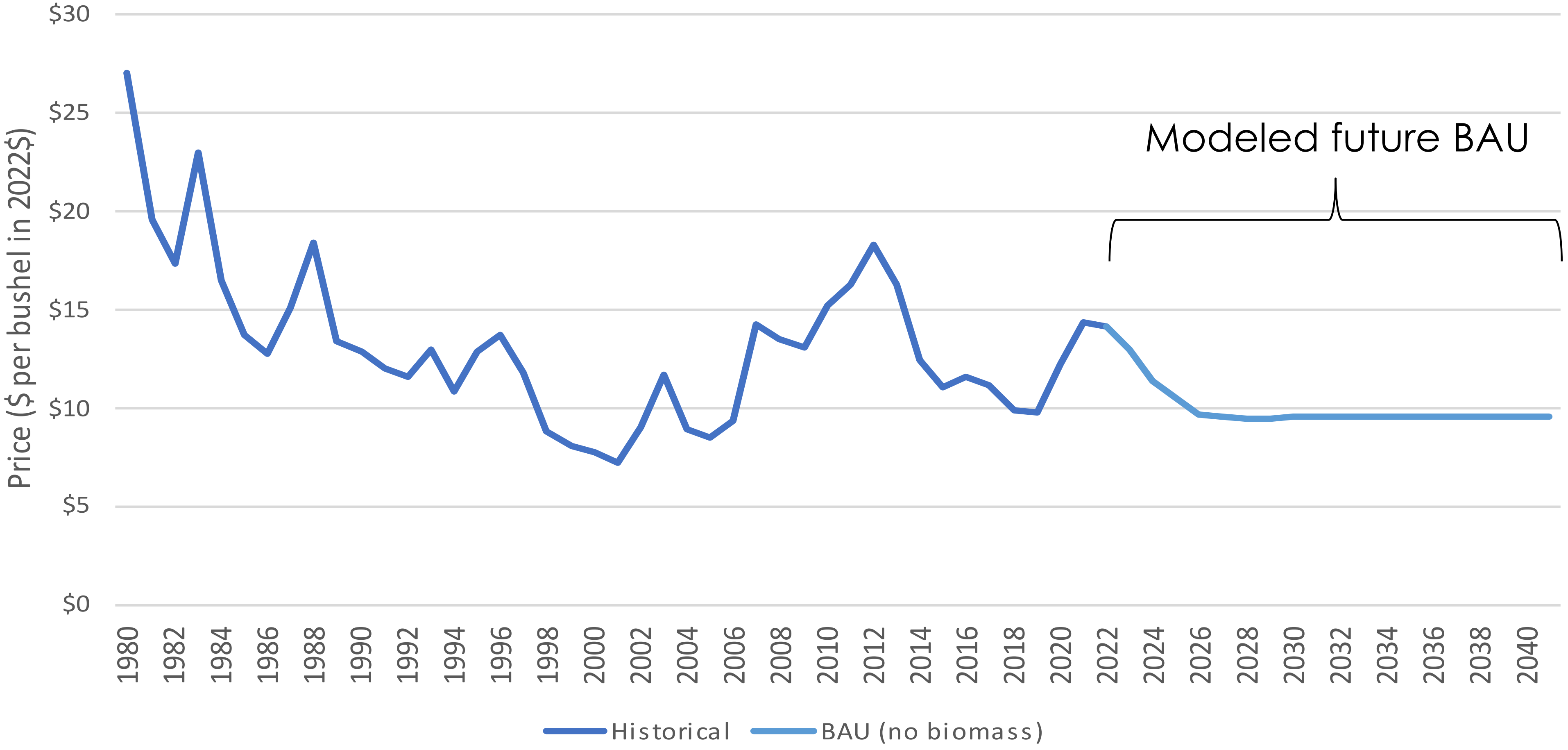


Map excludes currently used resources. **Purple colors** indicate sufficient supply density to support >750,000 tons per year within a 50-mile radius.

Commodity price impacts: Soy



Commodity price impacts: Soy



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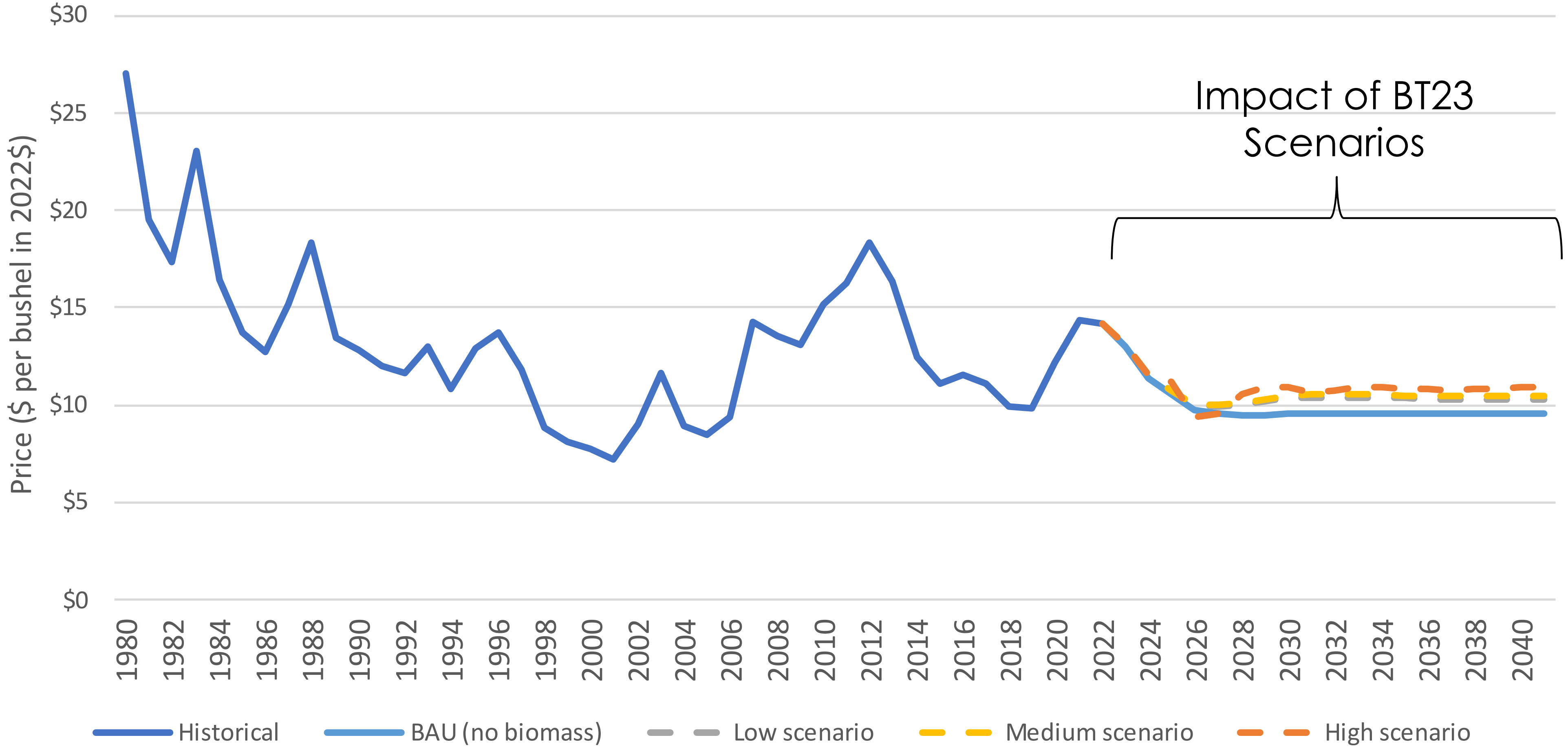
Commodity price impacts: Soy



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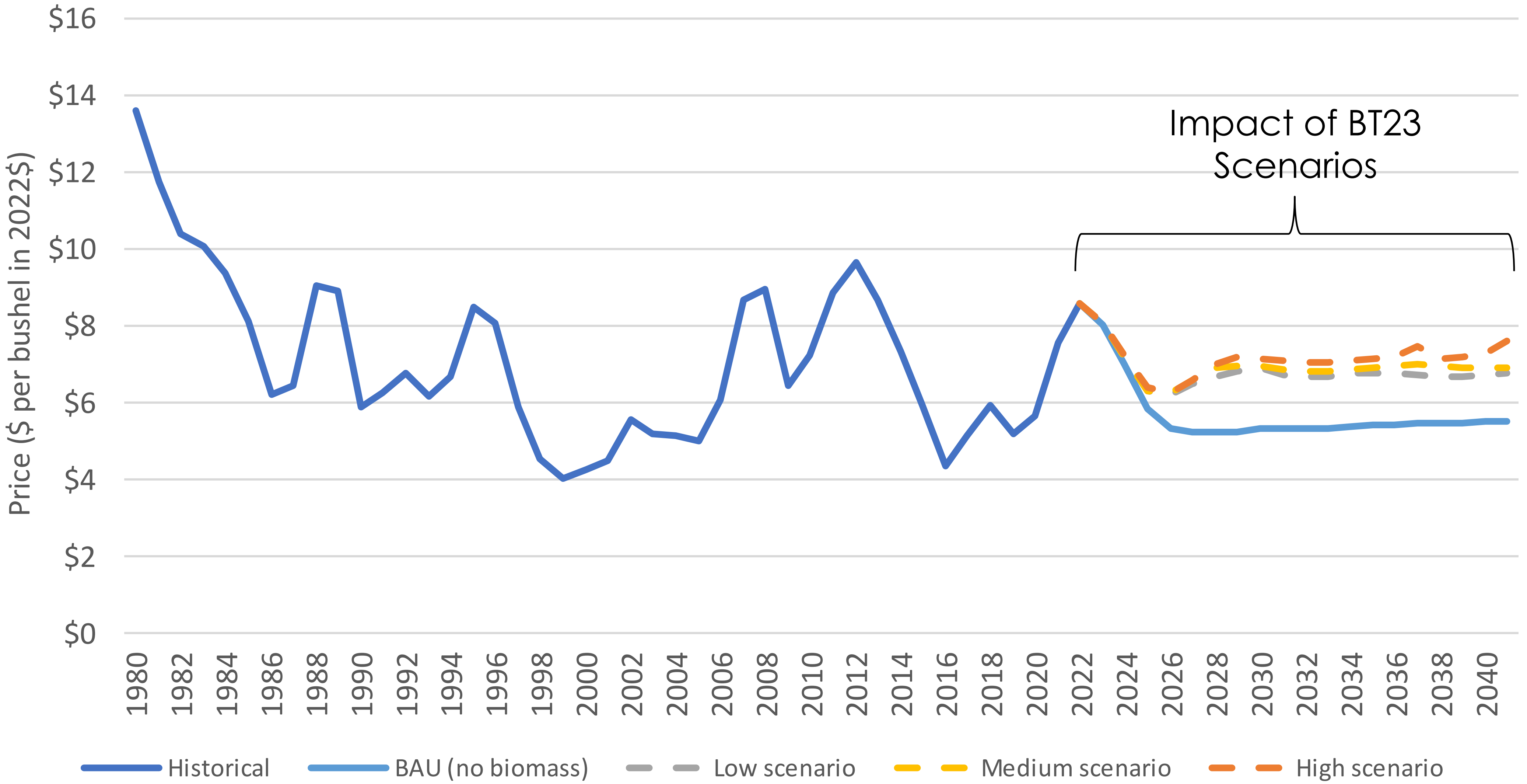
Commodity price impacts: Wheat



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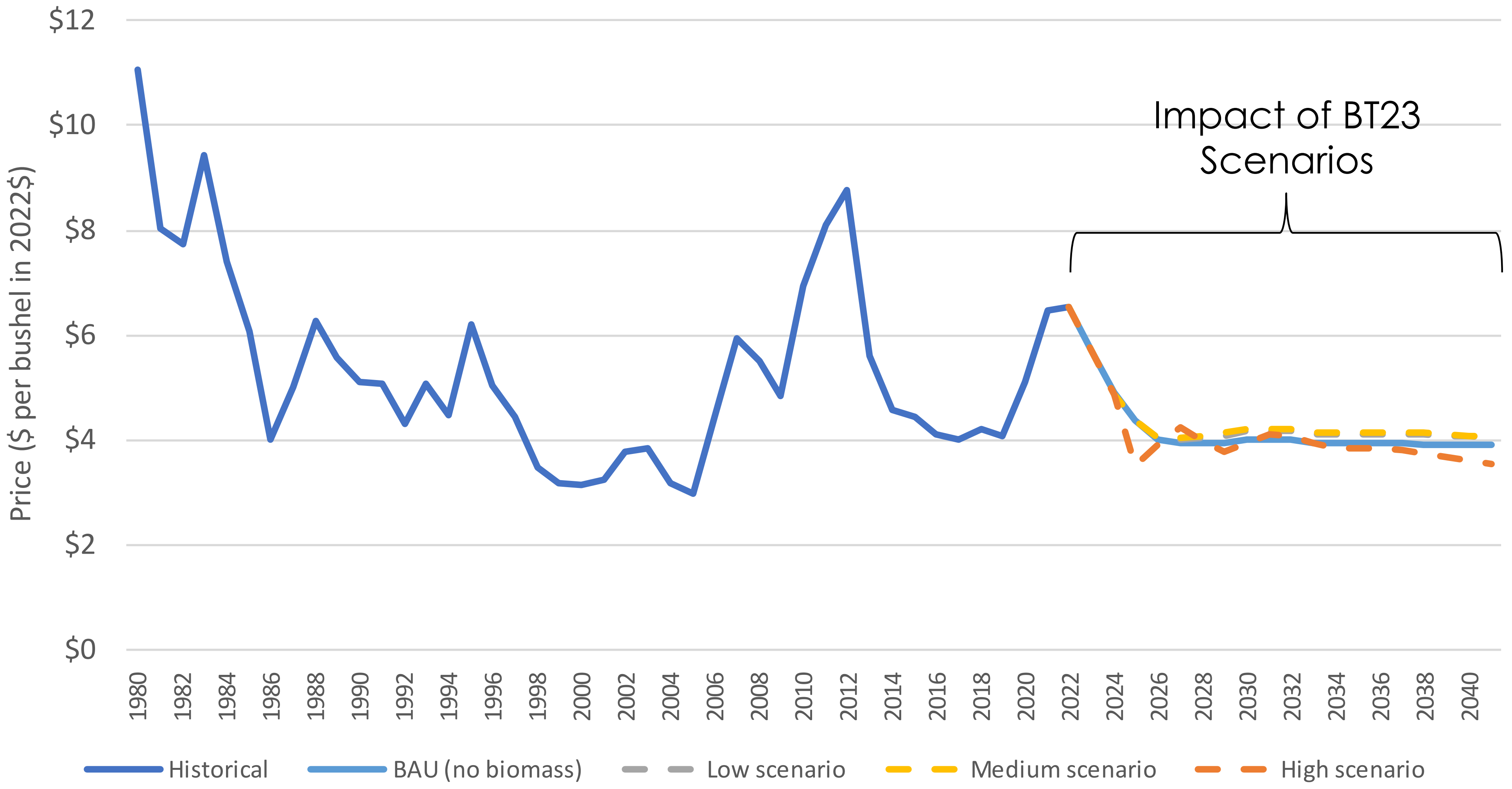
Commodity price impacts: Corn



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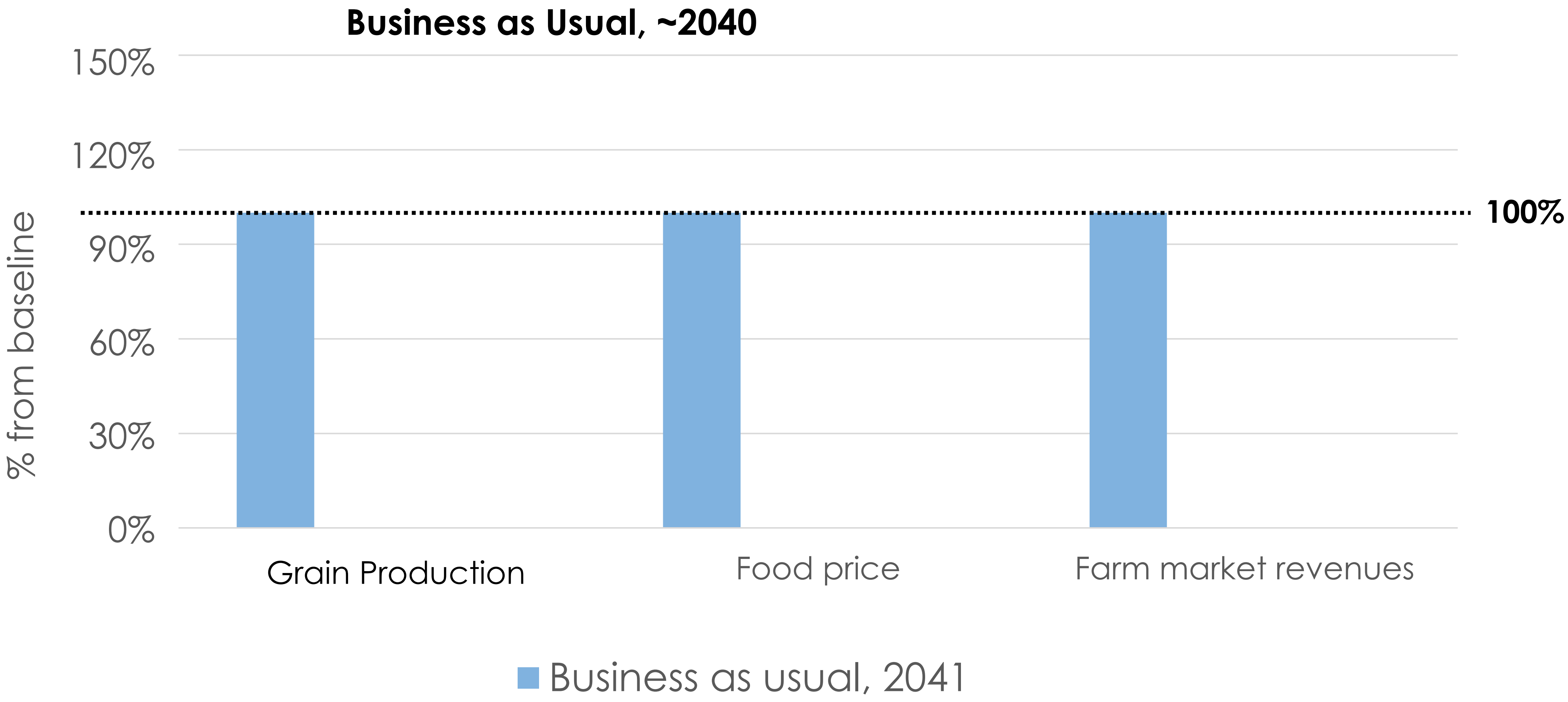
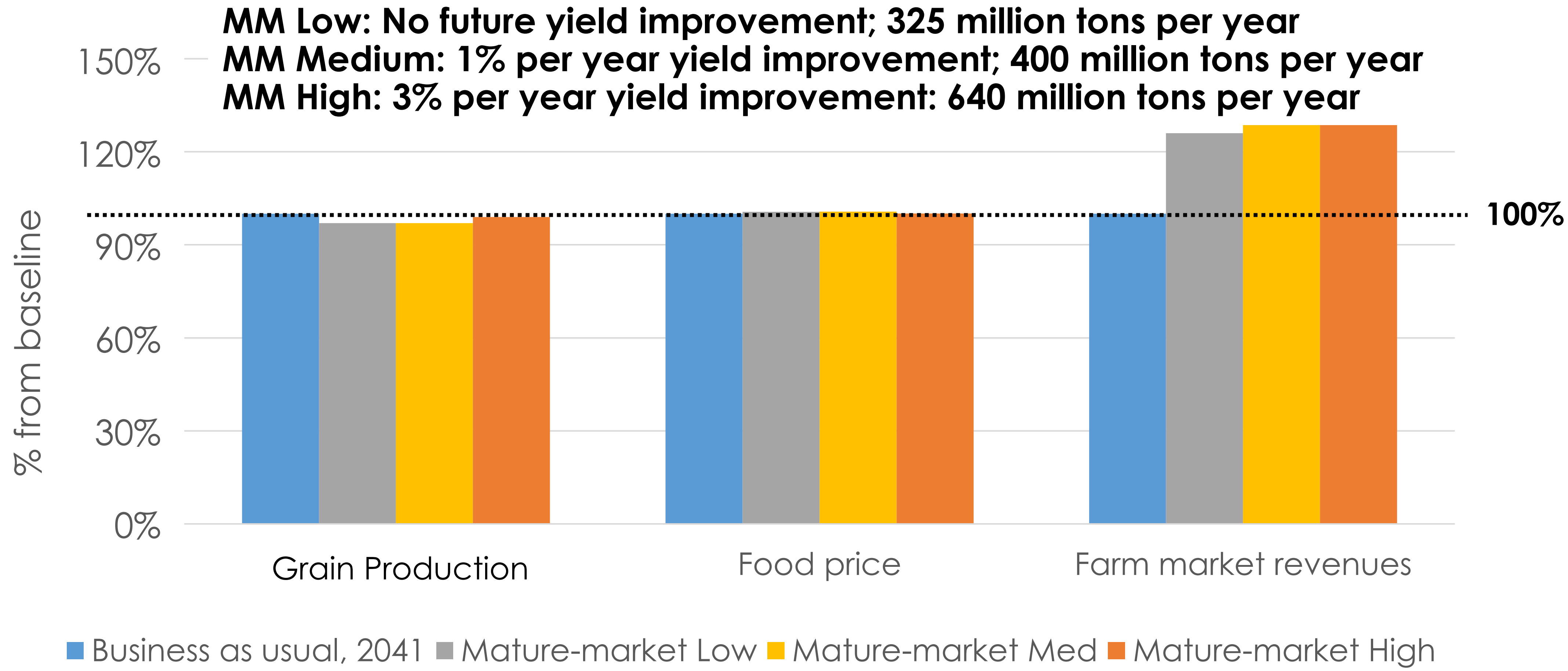
Energy crops could have nominal impacts on food production



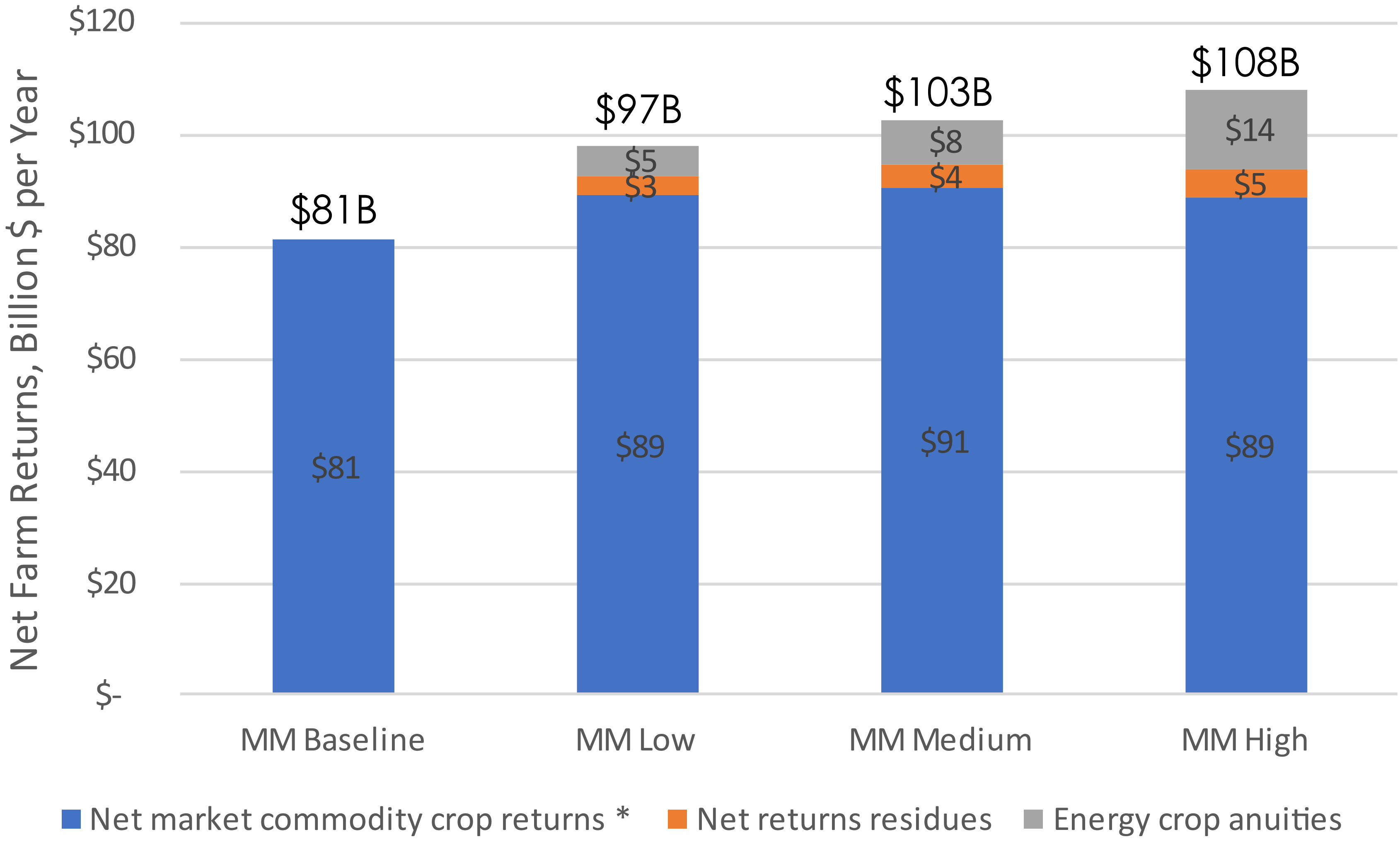
Modeled impacts of energy crop scenarios on US commodity crop production, food prices, and farm revenues. Future yield improvements simulated in the MM High scenario mitigate impacts on conventional production and increase biomass production.

Energy crops can impact commodity crop production and rural incomes

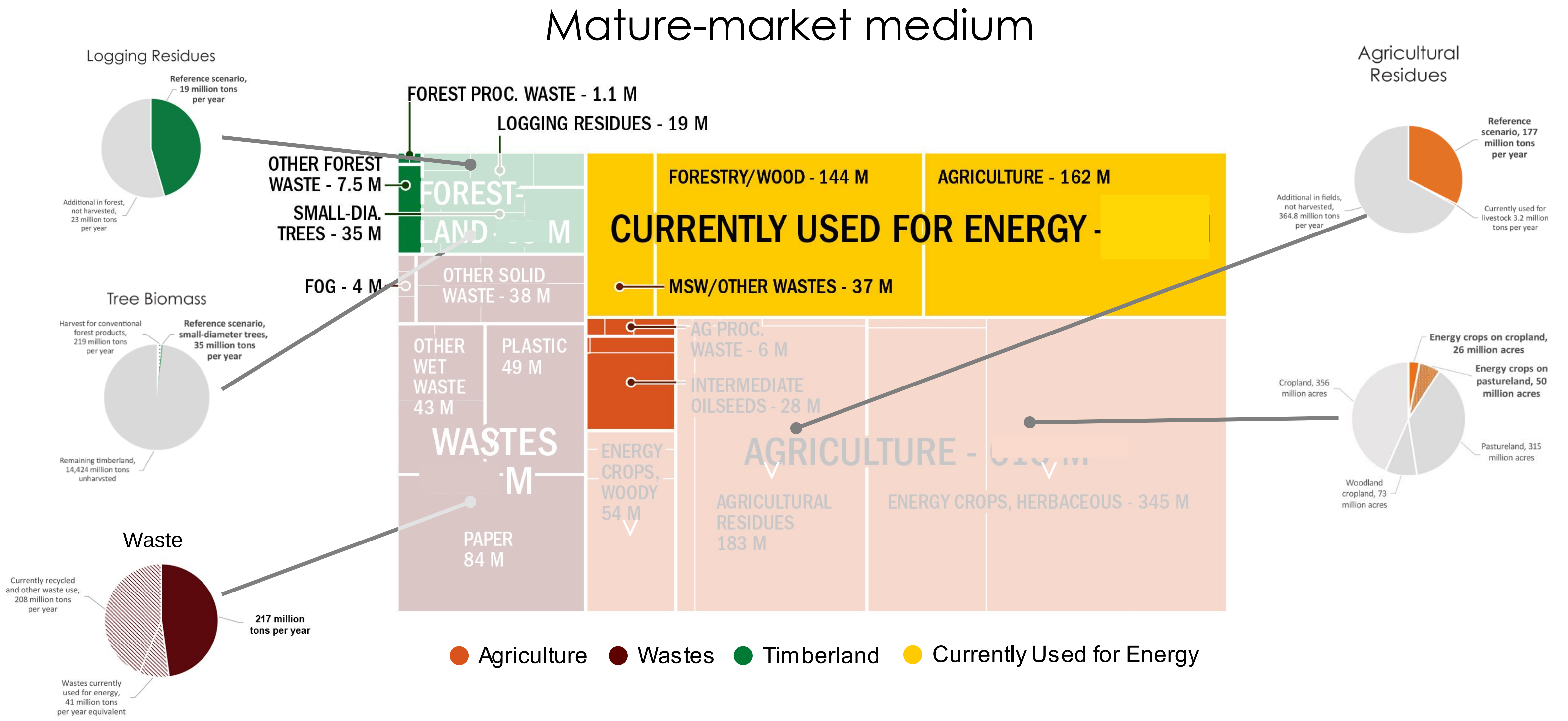


Modeled impacts of energy crop scenarios on US commodity crop production, food prices, and farm revenues. Future yield improvements simulated in the MM High scenario mitigate impacts on conventional production and increase biomass production.

Farm net returns increase $17-$27 Billion per year



Uncertainties



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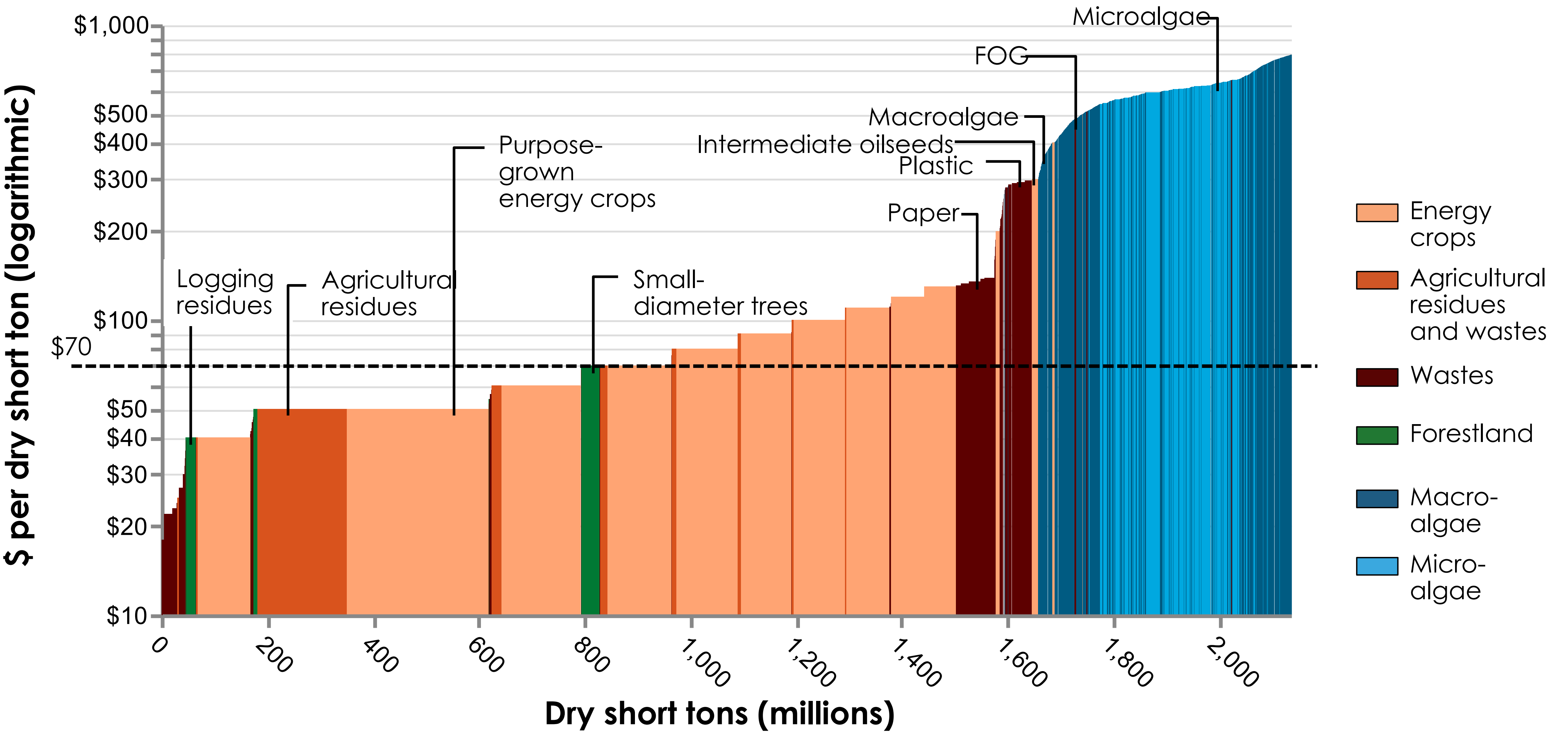
Potential biomass depends on price (MMH+Emerging scenario)



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Biomass Carbon Removal and Storage (BiCRS)

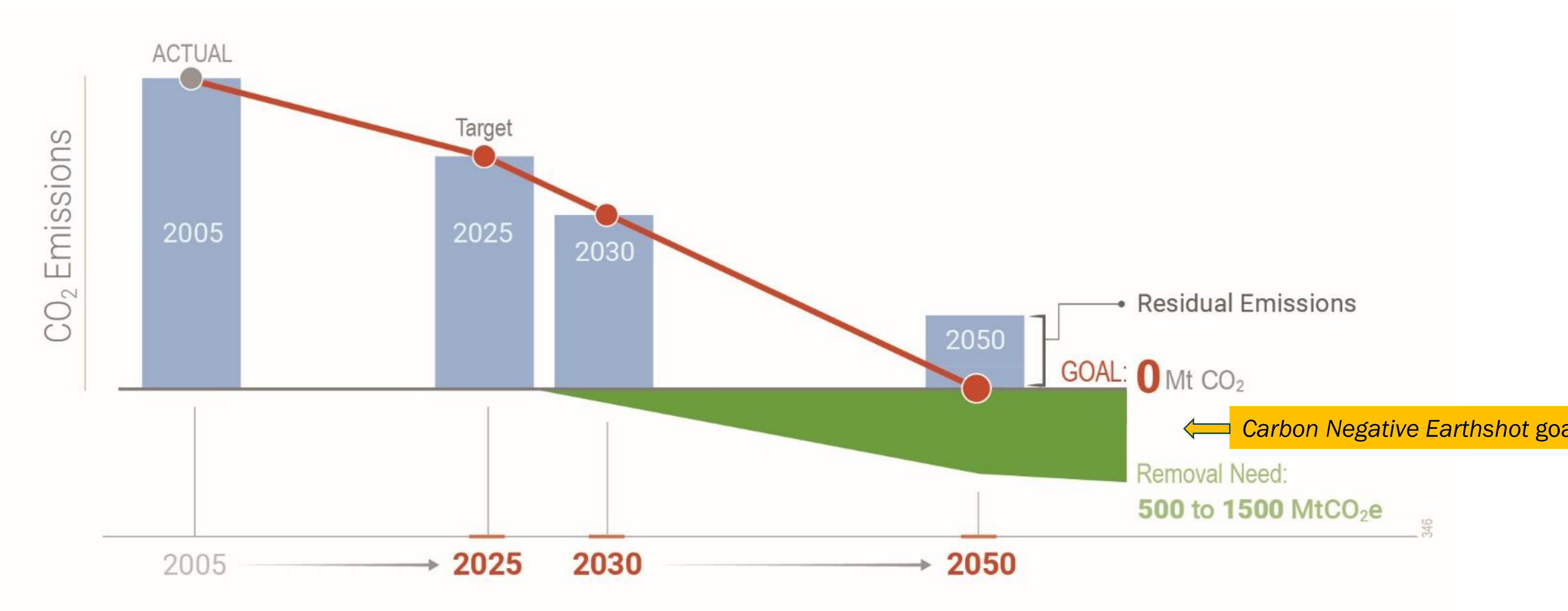
Sarah Baker

Wenqin Li, Alvina Aui, Allegra Mayer, Kim Mayfield, Hannah Goldstein, Corinne Scown, Whitney Kirkendall, Joe Sagues, Matthew Langholtz, Chad Hellwinckel, Ingrid Busch, Mark Wright, Jerome Dumortier, Phil Robertson, Bruno Basso, Sinead Crotty, Jennifer Pett-Ridge

Lawrence Livermore National Laboratory

March 2024

BOTH Decarbonization AND CO2 removal are needed



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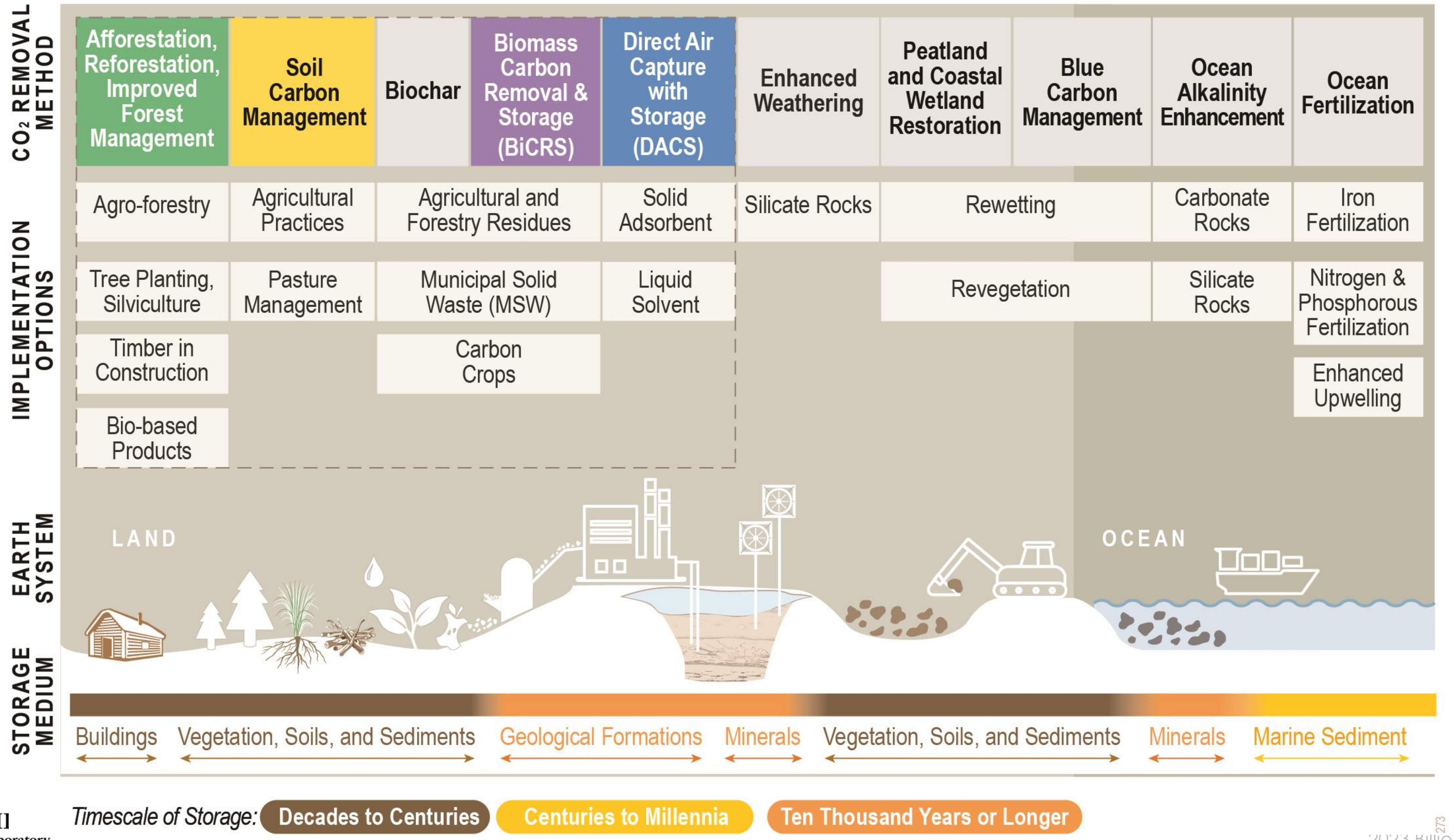
Five carbon removal strategies



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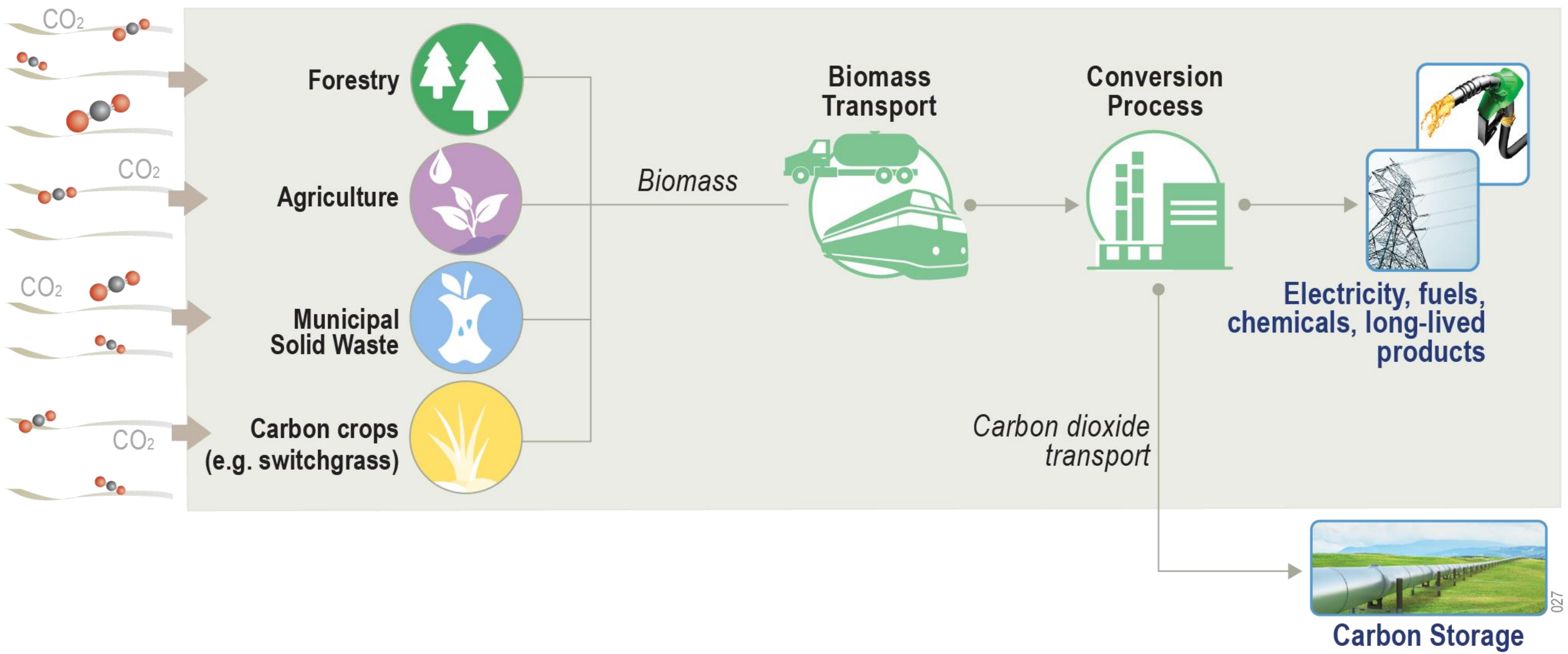
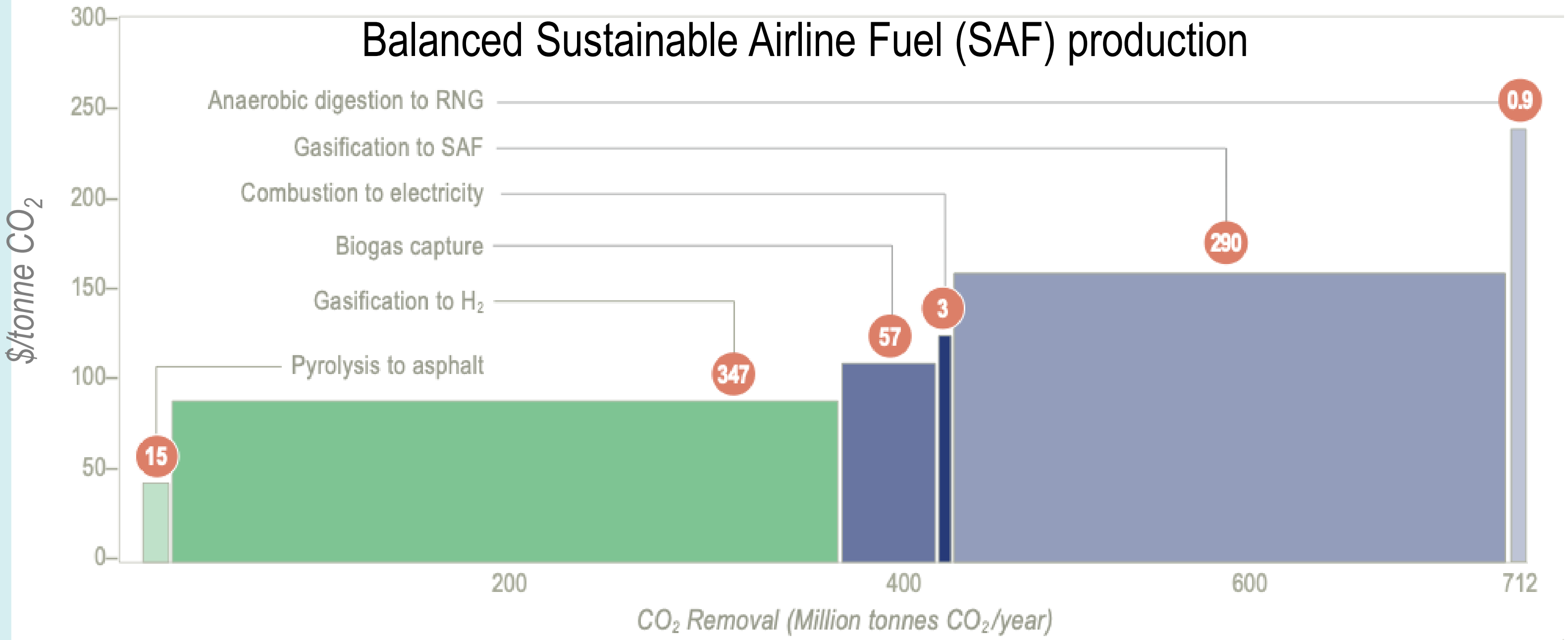
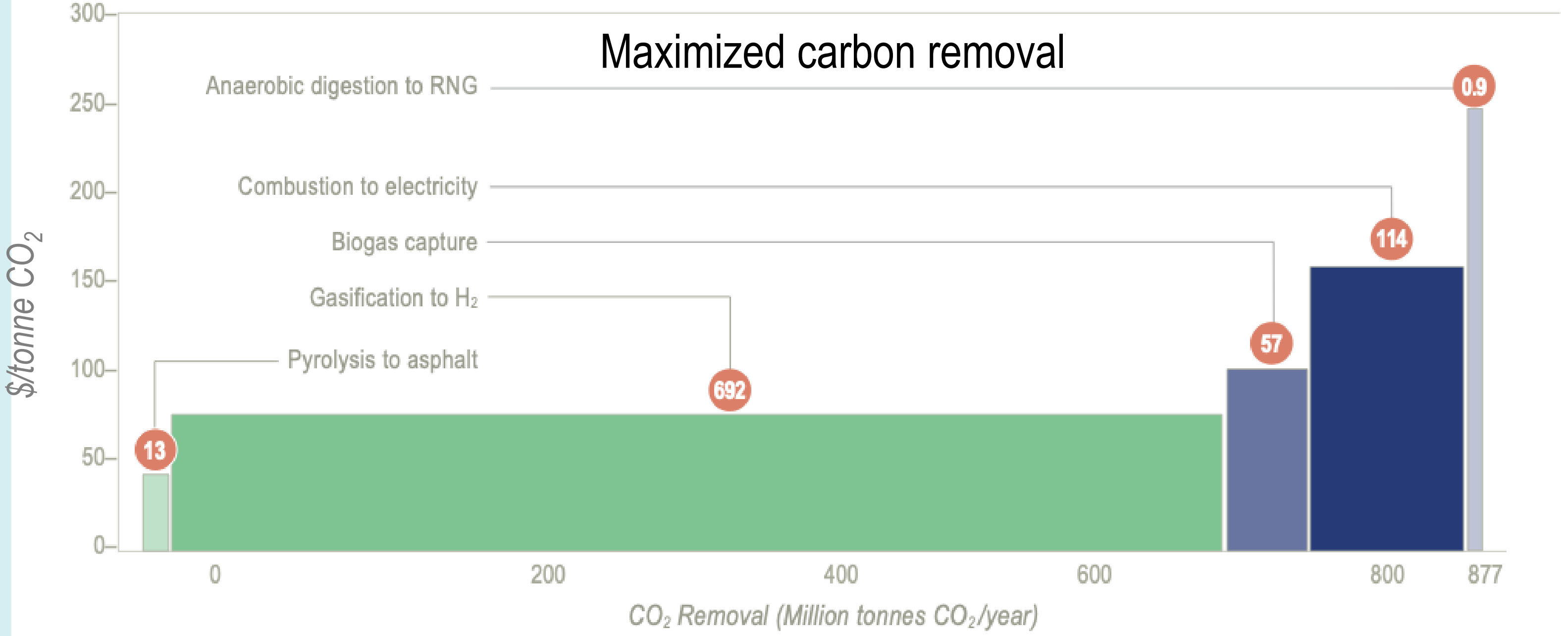
Biomass Carbon Removal and Storage (BiCRS):



BiCRS* can be customized to prioritize essential products OR to maximize carbon removal



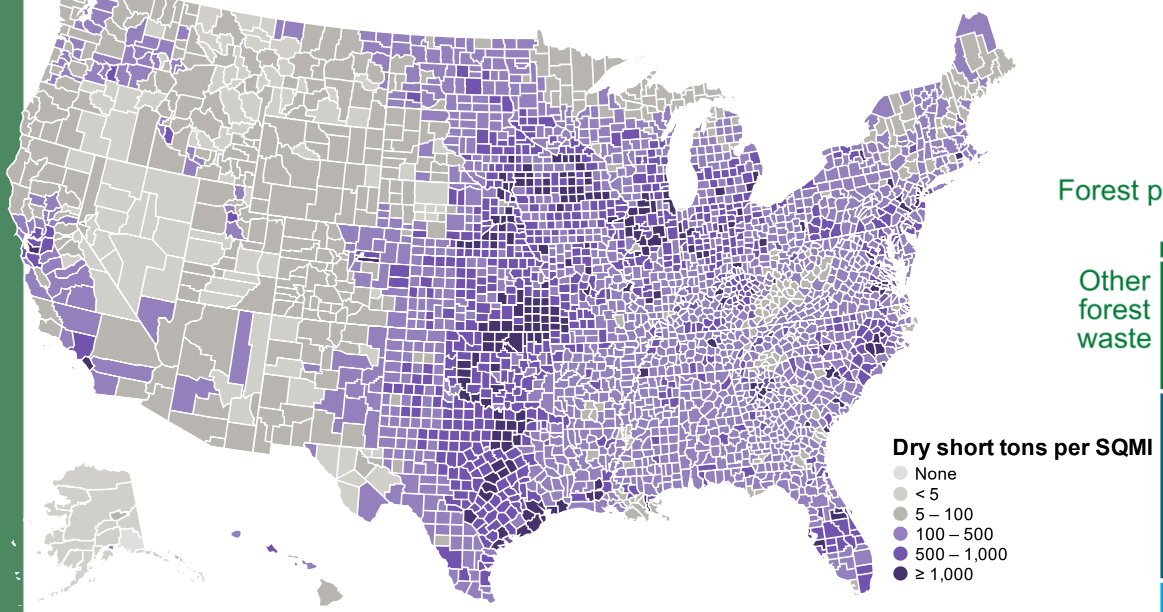


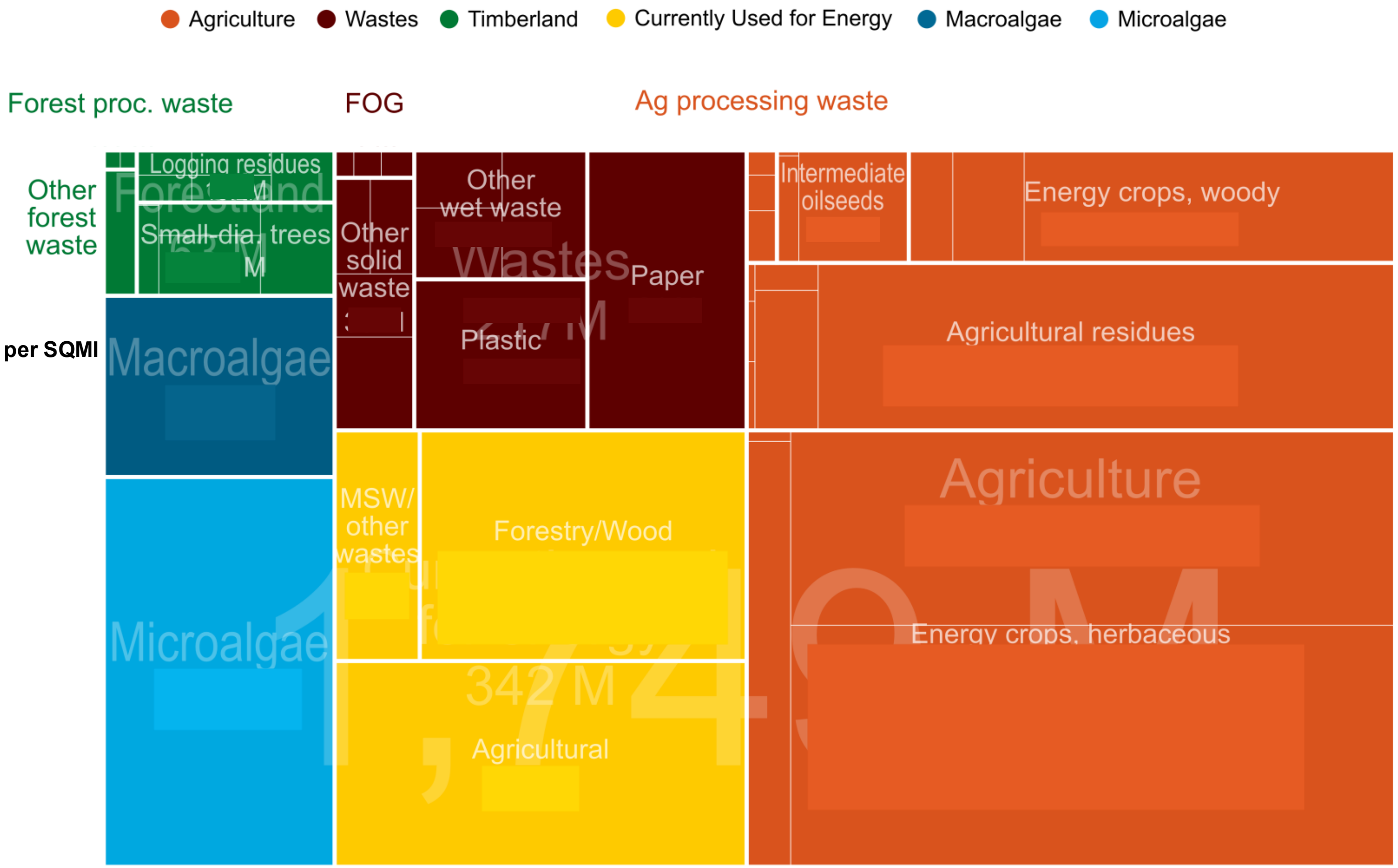
2023 Billion-Ton Report

*BiCRS = Biomass Carbon Removal and Storage

BT23 Emerging Scenario

- 57 resources, 6 analysis classes





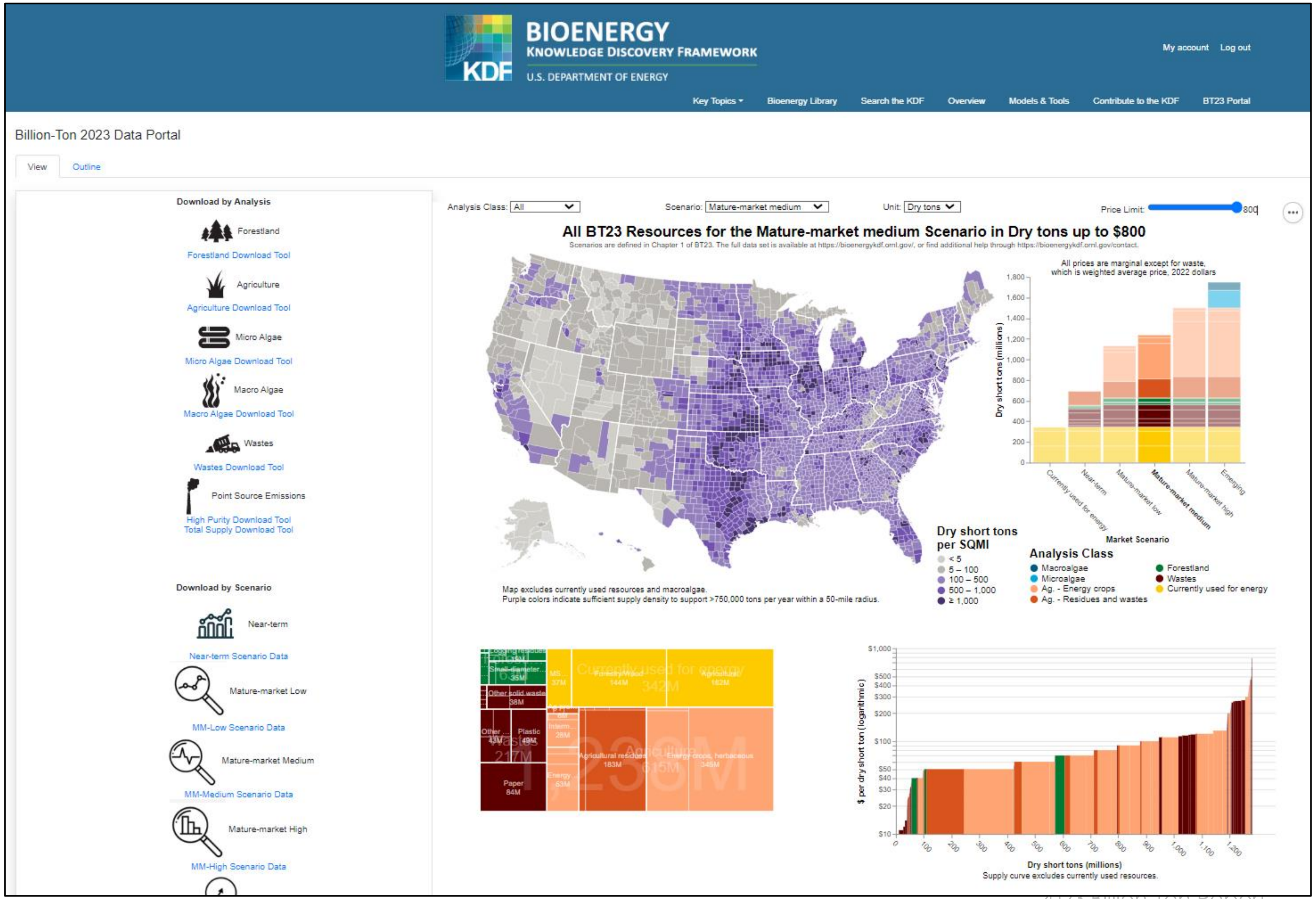
Map excludes currently used resources. Purple colors indicate sufficient supply density to support >750,000 tons per year within a 50-mile radius.

bioenergy KDF

Data portal available March 15th 2024:
https://bioenergykdf.ornl.gov/bt23-data-portal

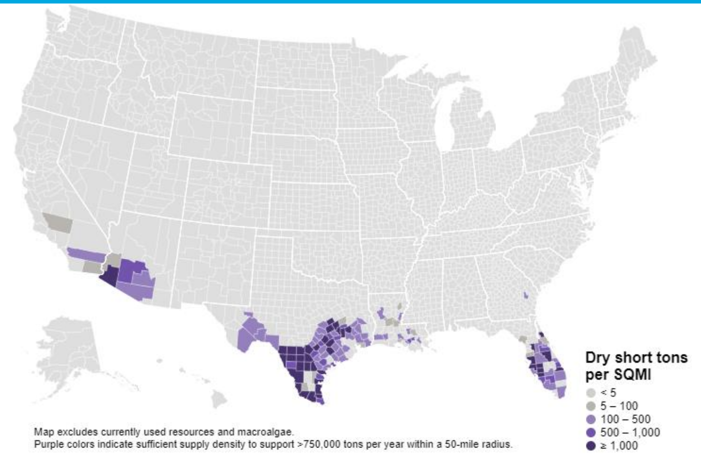
Thank you

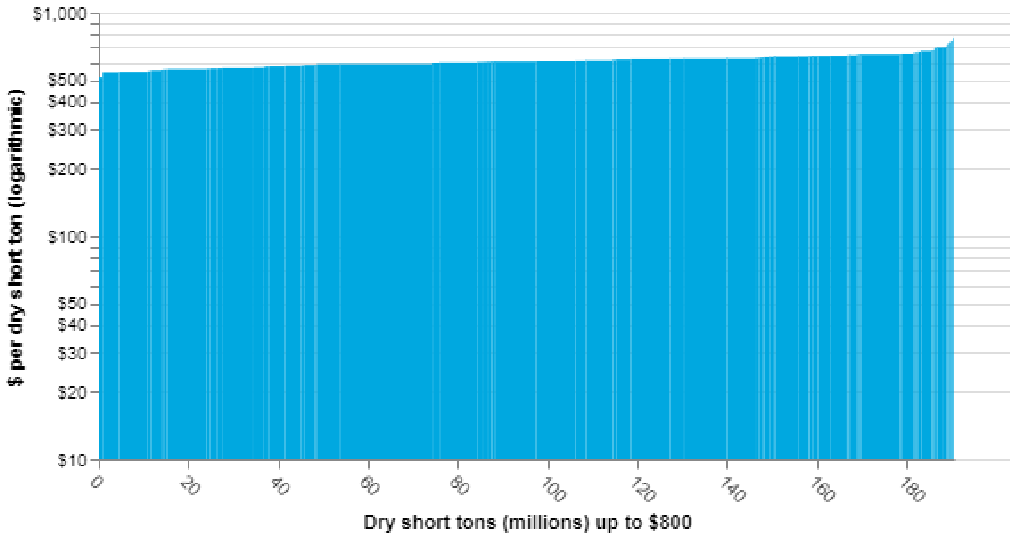
Matt Langholtz
langholtzmh@ornl.gov



Emerging resources can provide 250+ million tons in future

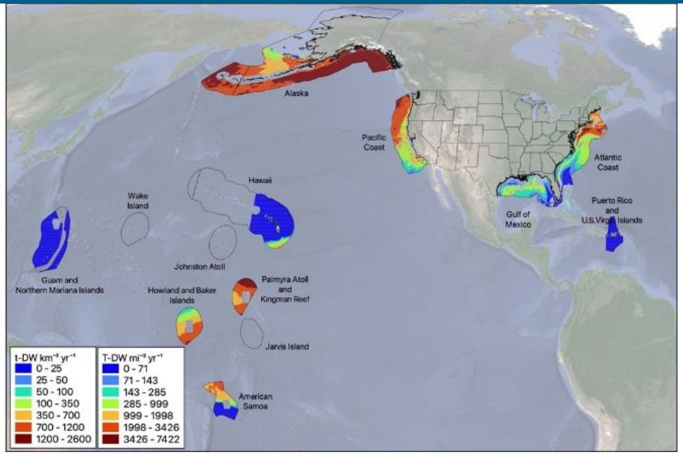
Microalgae

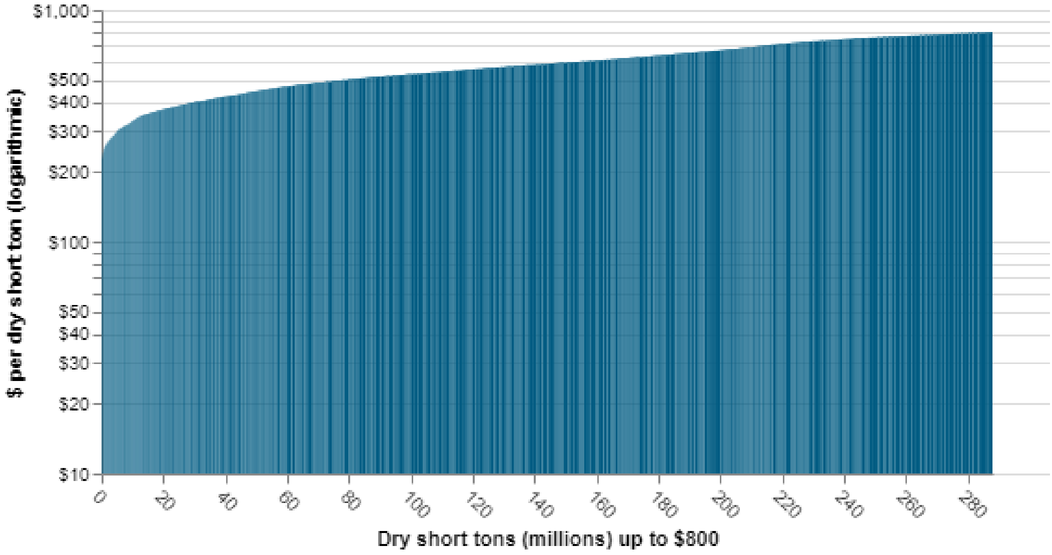




Microalgae supply curve based on weighted average cost of individual sites by county.

Macroalgae





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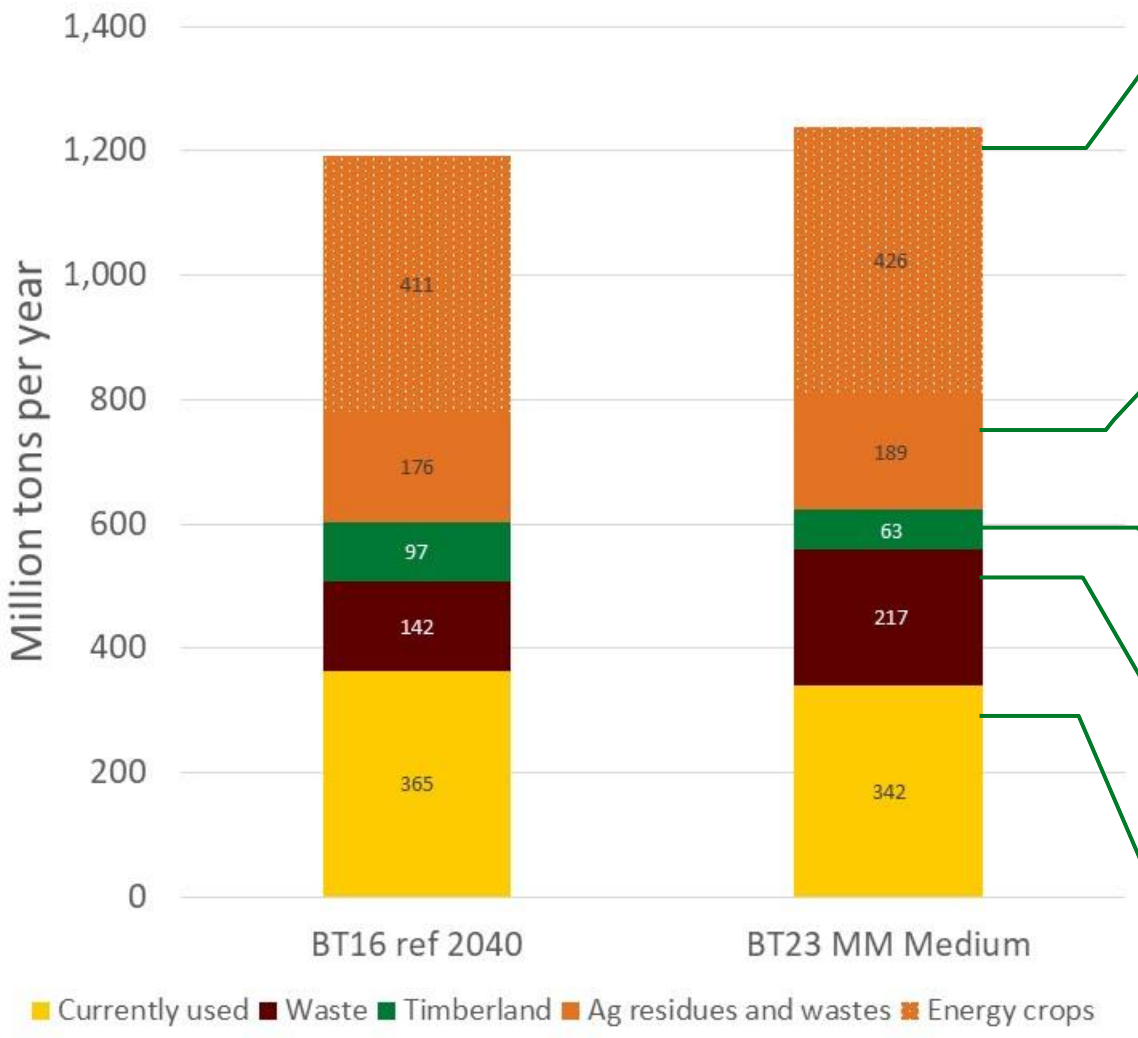
Extended Presentation: Methods & Interpretation

Notable changes

- Data updates
  - 2023 USDA Baseline Projection for conventional food crop demands
  - Projected forest products demands (e.g. paper, lumber) from FOrest Resource Outlook Model (FOROM) 2023
  - Costs (e.g. crop budgets and prices) to 2022 dollars
- Additions
  - Intermediate (i.e. off-season) oilseed cover crops (e.g. pennycress)
  - Macroalgae (i.e. seaweed)
  - Sensitivity analysis to relaxing sustainability constraints
- Key interpretations
  - Resource availability is contingent upon market maturity
  - Results show sustainable commercial production capacity, rather than maximum production potential
  - Reported availabilities are less than in-field quantities (e.g. ~1/2 of wastes, ~1/3 of ag residues, <1% of timberland biomass)
  - Deviation from modeled constraints results in more biomass production

Base-case comparison with BT16



Energy crops @ $70/ton. Cellulosics reduced to ~400 million tons by 2023 USDA Baseline Projection, but ~28 million tons intermediate oilseeds added at $400/ton

Ag residues @ $70/ton. Includes 13 million tons of ag processing wastes

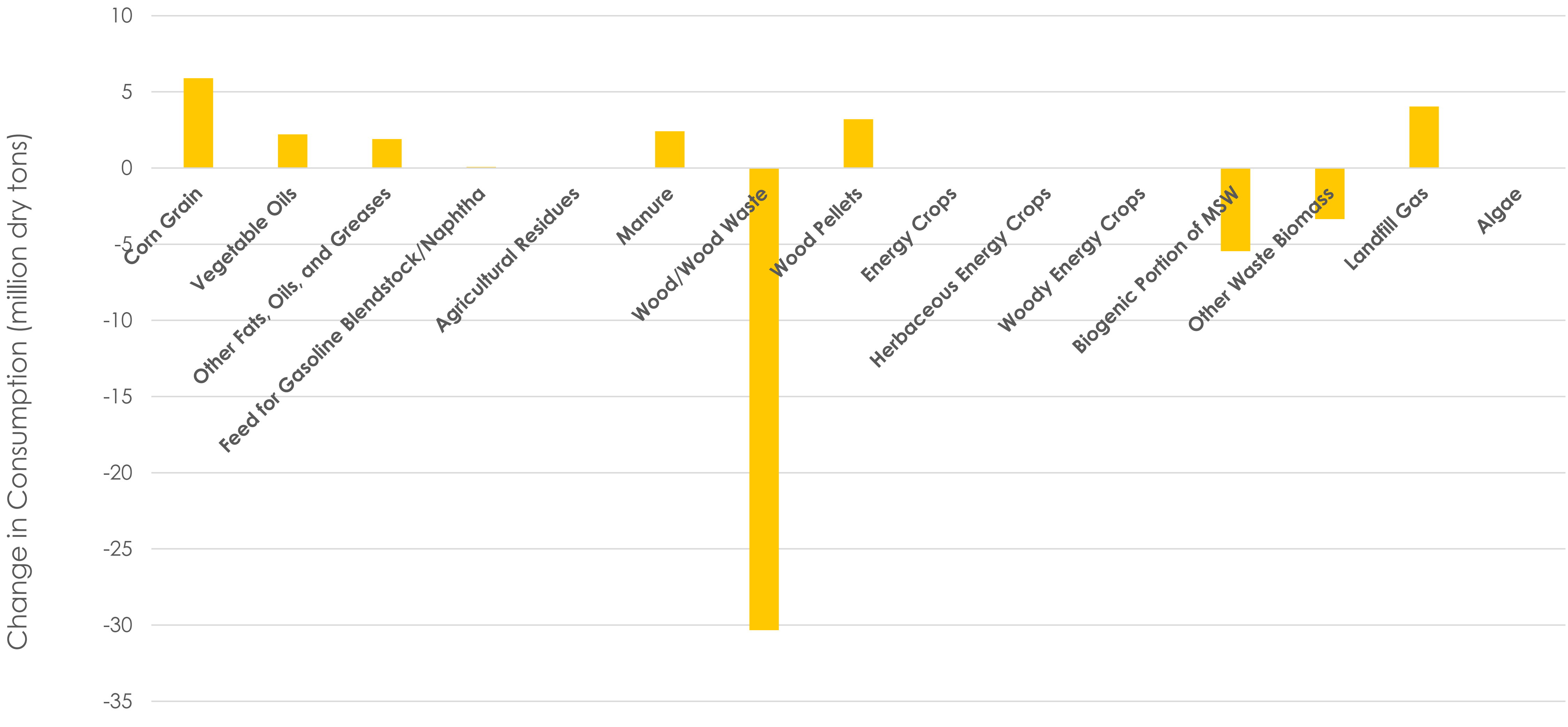
Forestry is now constrained to <$70/ton price vs cost

Wastes now included at all prices, e.g. plastics, paper, and FOGs

Net decrease of 23 million tons, primarily due to sawmill closures

Currently Used for Energy and Coproducts

Differences in Currently Used for Energy (BT23 vs BT16)



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Forestland Resources

BT23 general approach for modeling sustainability

Start with total resource

Account for competing demands (food, feed, fiber, exports, conventional forest products, reducing the amount bioenergy)

Reducing for environmental constraints (wind erosion, water erosion, sustained yield, soil organic carbon)
Deviation from these constraints would result in more supply and possibly undesirable effects

Agricultural and Forestry resources modeled as free market rather than pre-determined

Price impacts on conventional markets are quantified
Modeled food price increase up to 0.7%
Cropland net revenues up ~25%

Guardrails (e.g., BMPs) may be needed to avoid unsustainable production

Modeling limitations

- Ag and forestry: Sustainability constraints
- Sustainability analysis

Timberlands constraints for ForSEAM

GROWTH EXCEEDS HARVESTS OF CONVENTIONAL AND BIOMASS HARVESTS (STATE LEVEL)

COSTS ASSUME BEST MANAGEMENT PRACTICES

LEAVE AT LEAST 30% OF LOGGING RESIDUES

ALL BIOMASS HARVESTS WITHIN ½ MILE OF ROADS

NO LOGGING RESIDUES REMOVED ON SLOPES >40%

NO BIOMASS REMOVAL IN WET AREAS TO AVOID SOIL COMPACTION

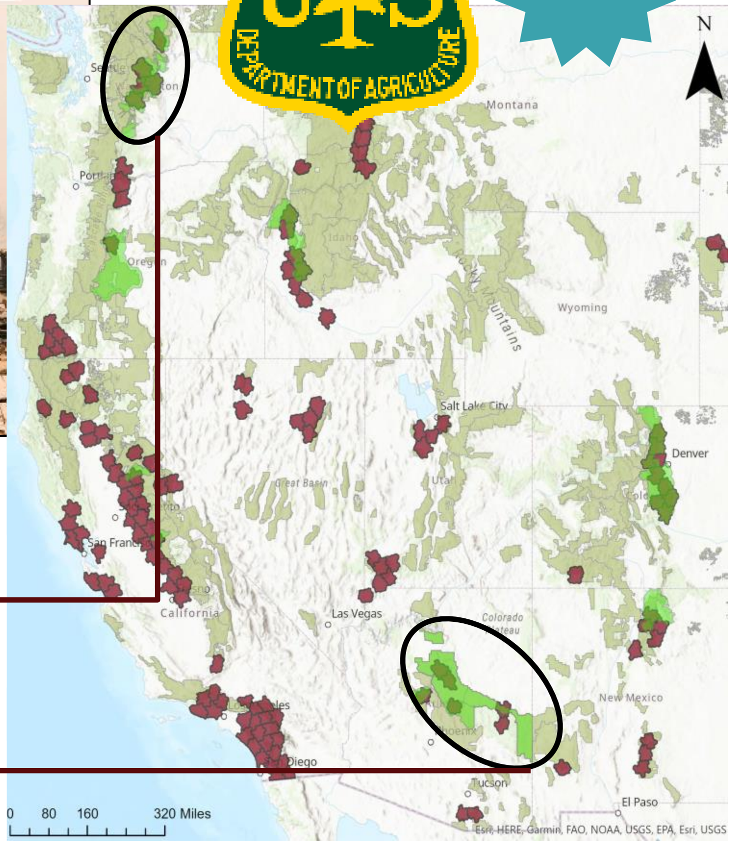
NO PRODUCTION IN ADMINISTRATIVELY RESERVED FORESTLANDS, SUCH AS WILDERNESS AREAS AND NATIONAL PARKS

FRAGILE, RESERVED, PROTECTED, AND ENVIRONMENTALLY SENSITIVE FORESTLAND EXCLUDED

Biomass from fire reduction treatments with USFS

- National Wildfire Crisis Strategy: Enhance fire resistance of 50 million ac.
- Biomass from forest fuel reductions
- ~16 million acres of forest/wildland
- High cost, with externality benefits

NEW



10 initial areas
Priority firesides
NFS lands

Central Washington Initiative

Four Forest Restoration Initiative

Agricultural Land Resources

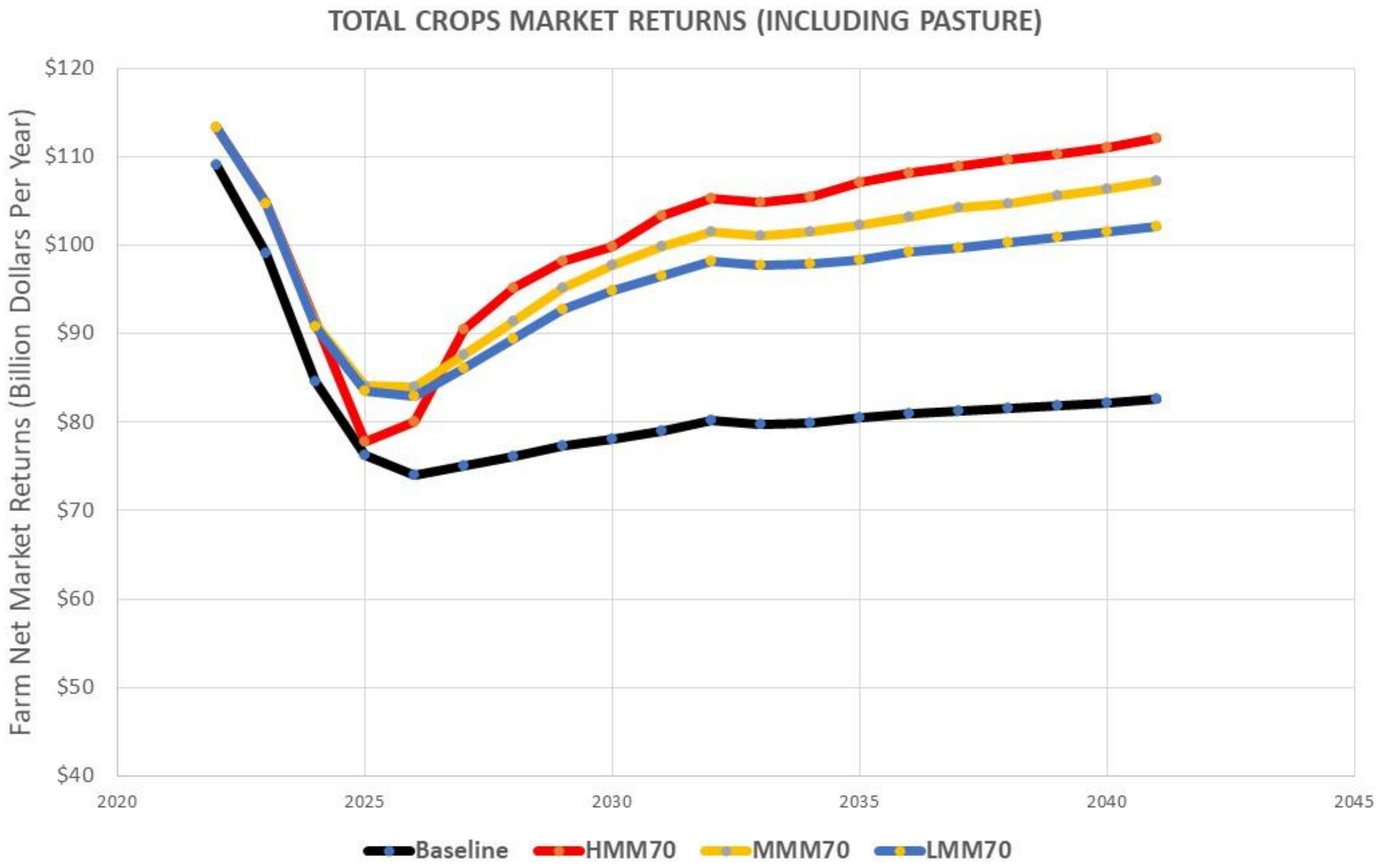
Constraints: Agricultural lands

- Agricultural residues
  - Revised Universal Soil Loss Equation (RUSL2)
  - Wind Erosion Equation (WEQ)
  - Operational efficiency increasing with time (50% to 90%)
  - Result: ~1/3 of ag residues available
- Energy crops
  - Solve for food, feed, fiber, and exports with added biomass demand
  - Irrigated cropland or pasture excluded
  - No transition of non-agricultural lands to energy crops

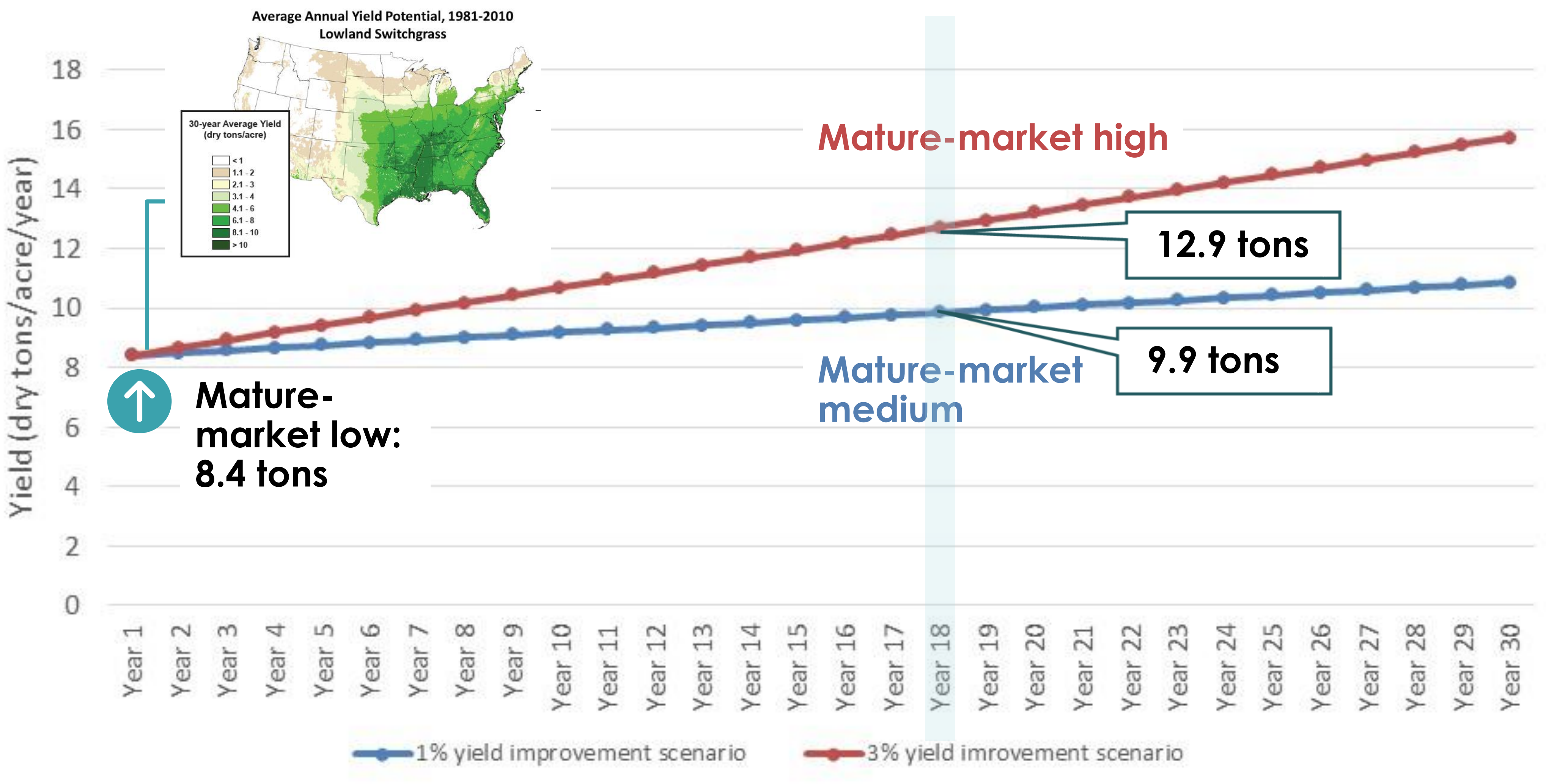
Agriculture land resource scenario assumptions

Mature-market scenarios	Assumptions	
Near-term	Near team (simulated as 7 years after 2023)	Only crop residues (corn, wheat, sorghum, barley, and oat) No harvest technology improvements
Low	Mature-market (simulated as 18 years after 2023) No dedicated biomass crop yield improvements	Conventional crop yield improvements assume USDA baseline No harvest technology improvements
Medium	Mature-market (simulated as 18 years after 2023) 1% per year dedicated biomass yield improvements	Conventional crop yield improvements assume USDA baseline Harvest technology improves from 50% to 90% efficiency
High	Mature-market (simulated as 18 years after 2023) 3% per year dedicated biomass yield improvements	Conventional crop yields improve 1.5 times the USDA trend Harvest technology improves from 50% to 90% efficiency

Farm net returns increase over the baseline



Impact of R&D on yields



*Example of switchgrass yield from Crittenden County, KY; 2009 High-Yield Scenario Workshop Series Report

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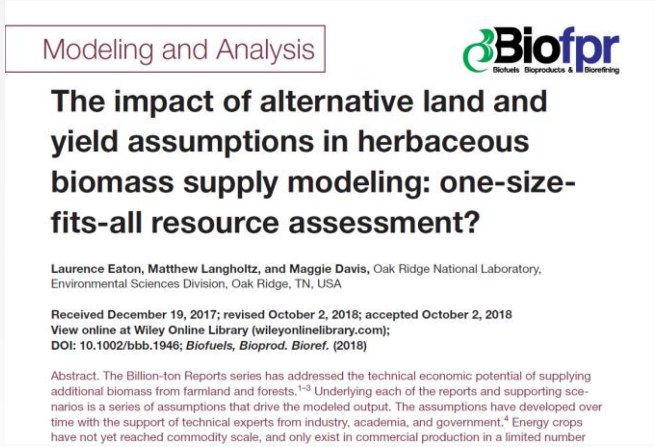
Assumptions matter

Yield assumptions



Modeling and Analysis

The impact of alternative land and yield assumptions in herbaceous biomass supply modeling: one-size-fits-all resource assessment?

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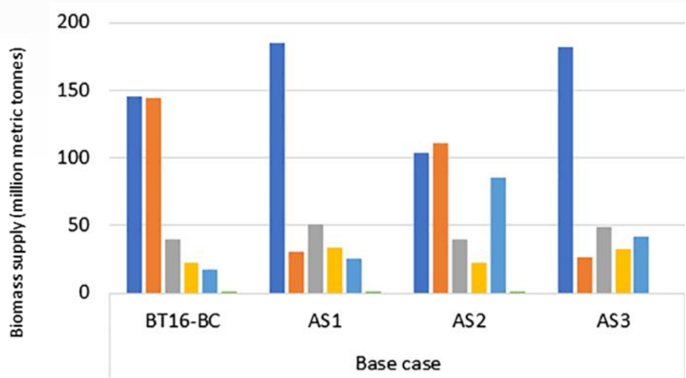
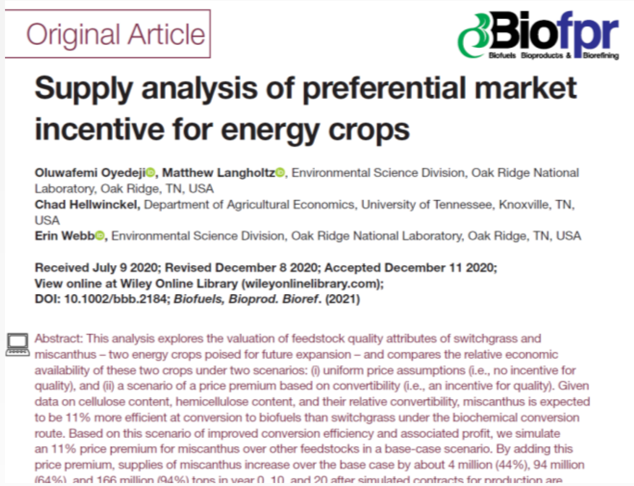
View online at Wiley Online Library (wileyonlinelibrary.com);
DOI: 10.1002/bbb.1946; *Biofuels, Bioprod. Bioref.* (2018)

Abstract. The Billion-ton Reports series has addressed the technical economic potential of supplying additional biomass from farmland and forests.[1–3] Underlying each of the reports and supporting scenarios is a series of assumptions that drive the modeled output. The assumptions have developed over time with the support of technical experts from industry, academia, and government.[4] Energy crops have not yet reached commodity scale, and only exist in commercial production in a limited number



Market assumptions



Original Article

Supply analysis of preferential market incentive for energy crops

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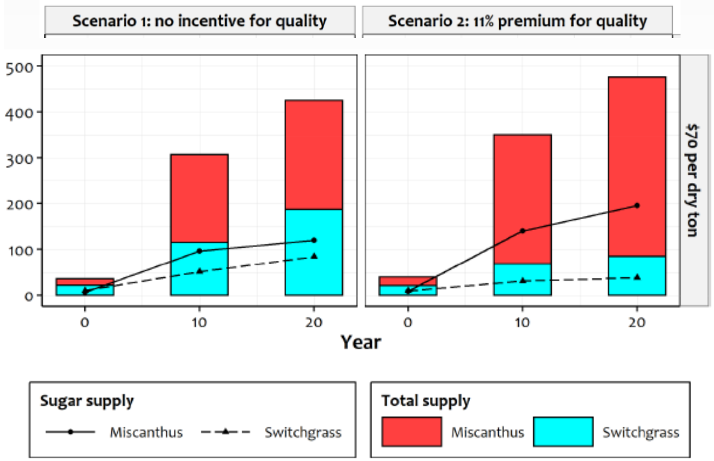
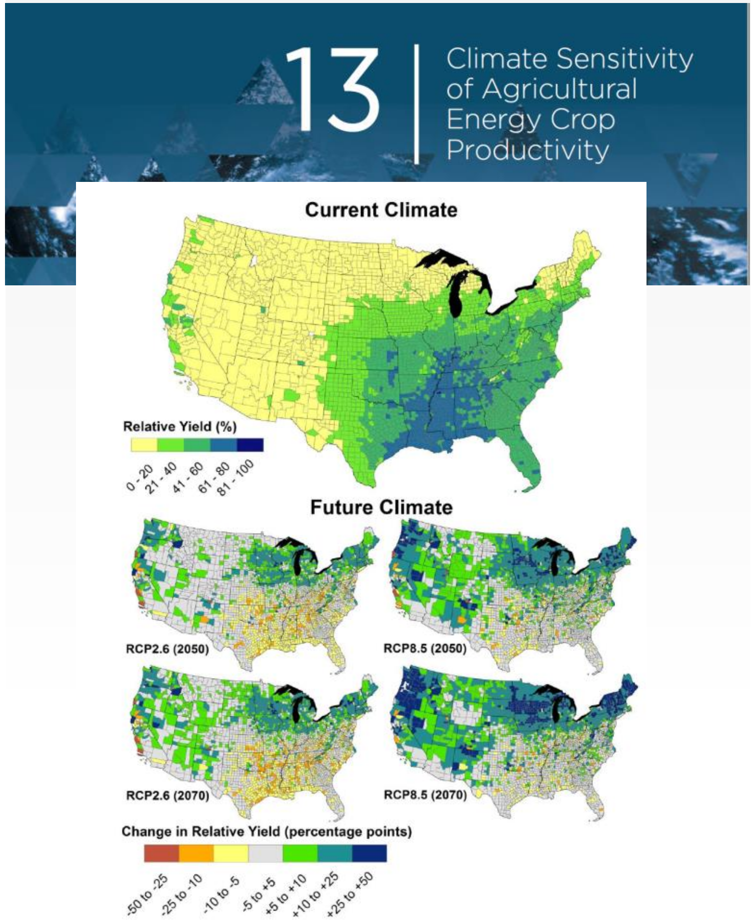
Received July 9 2020; Revised December 8 2020; Accepted December 11 2020;
View online at Wiley Online Library (wileyonlinelibrary.com);
DOI: 10.1002/bbb.2184; *Biofuels, Bioprod. Bioref.* (2021)

Abstract: This analysis explores the valuation of feedstock quality attributes of switchgrass and miscanthus – two energy crops poised for future expansion – and compares the relative economic availability of these two crops under two scenarios: (i) uniform price assumptions (i.e., no incentive for quality), and (ii) a scenario of a price premium based on convertibility (i.e., an incentive for quality). Given data on cellulose content, hemicellulose content, and their relative convertibility, miscanthus is expected to be 11% more efficient at conversion to biofuels than switchgrass under the biochemical conversion route. Based on this scenario of improved conversion efficiency and associated profit, we simulate an 11% price premium for miscanthus over other feedstocks in a base-case scenario. By adding this price premium, supplies of miscanthus increase over the base case by about 4 million (44%), 94 million



Climate change



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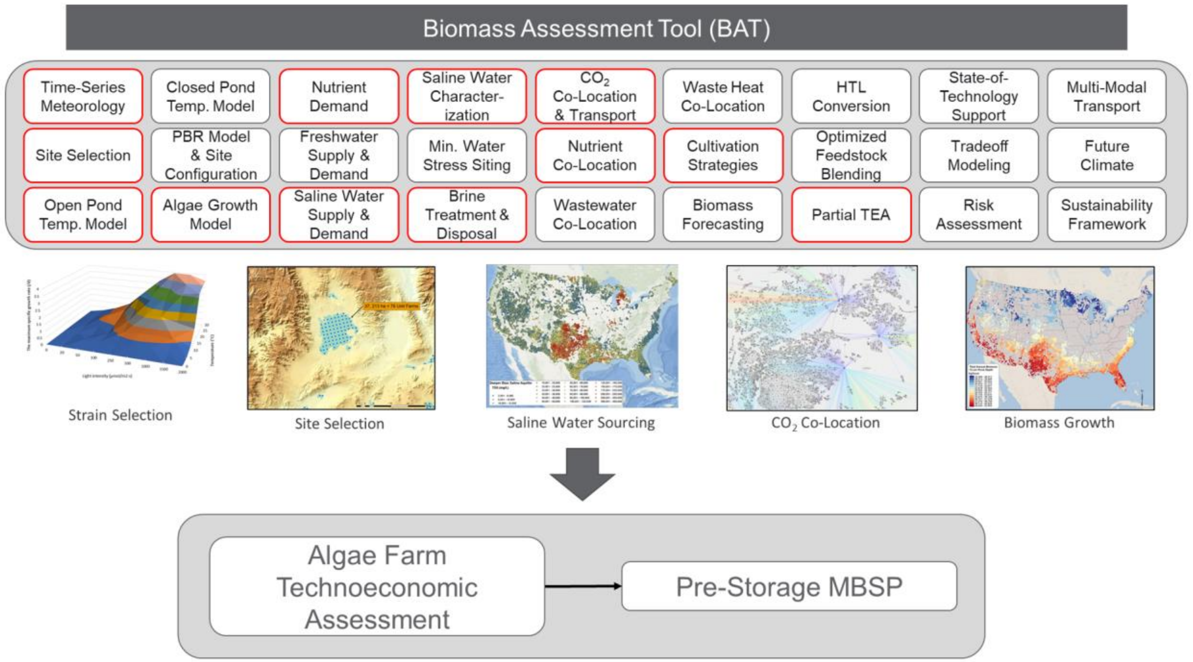
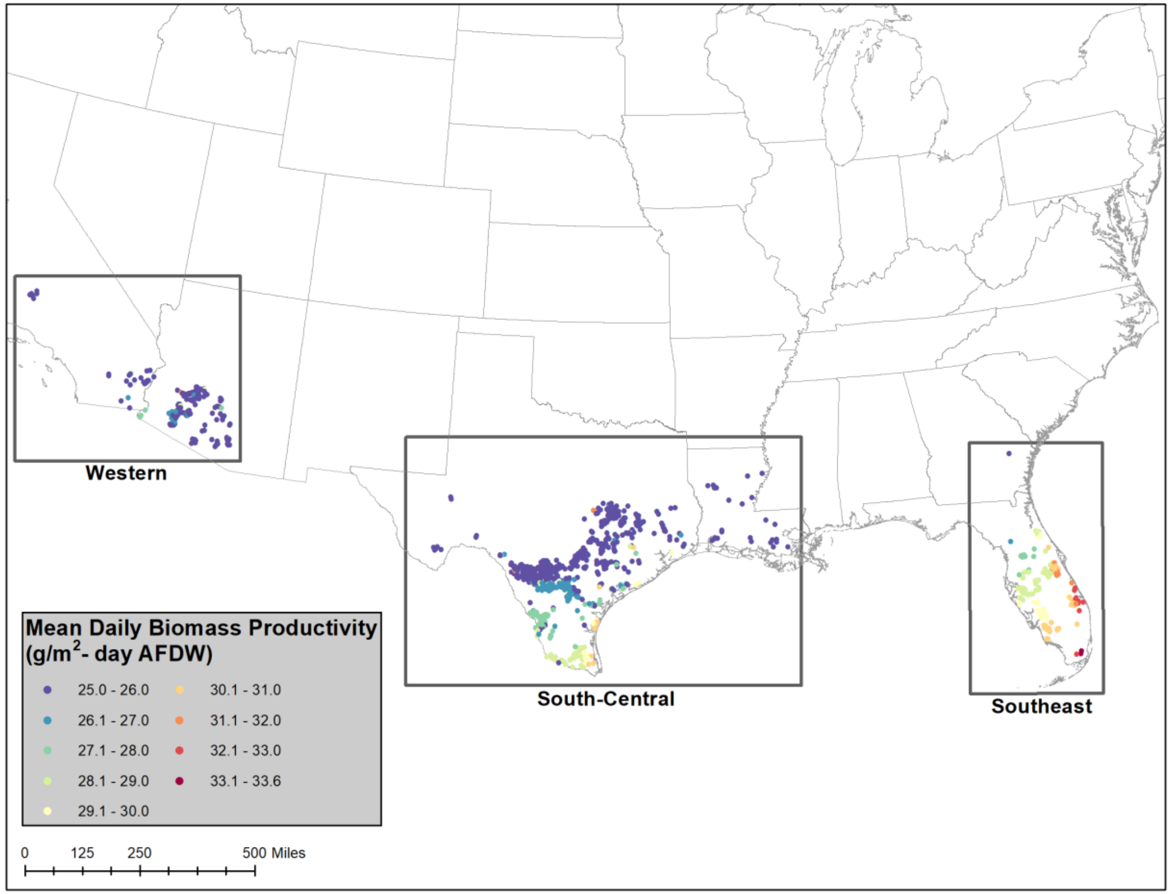
Emerging Resources

Microalgae

- 2022 Algae Harmonization Update
- Land screening model to identify sites
- Biomass Assessment Tool (BAT to identify yields and costs)





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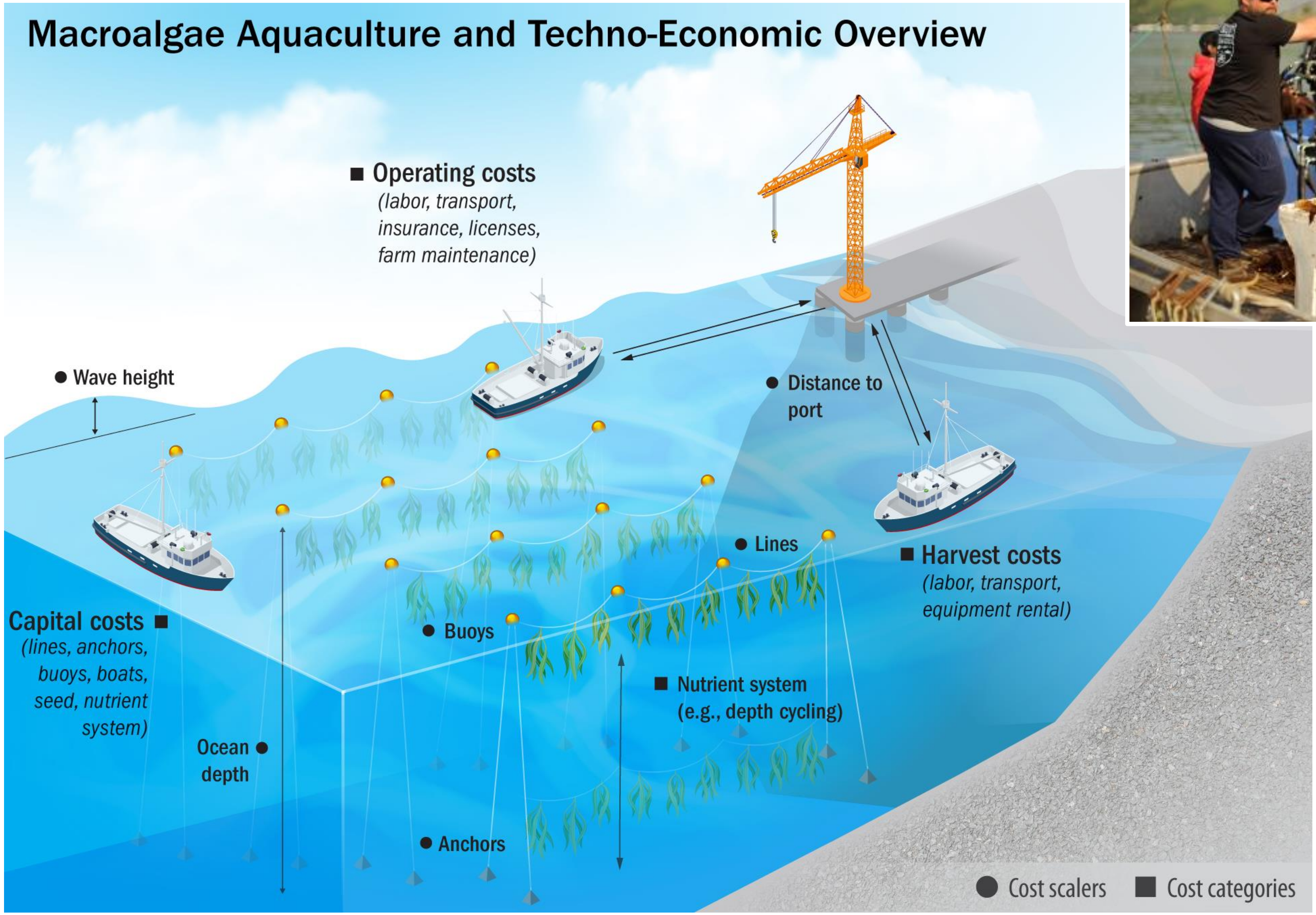
Macroalgae



Screening tool:

OceanReports
A BOEM/NOAA PARTNERSHIP

MarineCadastre.gov

Biophysical Model:

MACMODS
MacroAlgae Cultivation MODeling System

Macroalgae Techno-Economic Model: DeAngelo et al. (2023)

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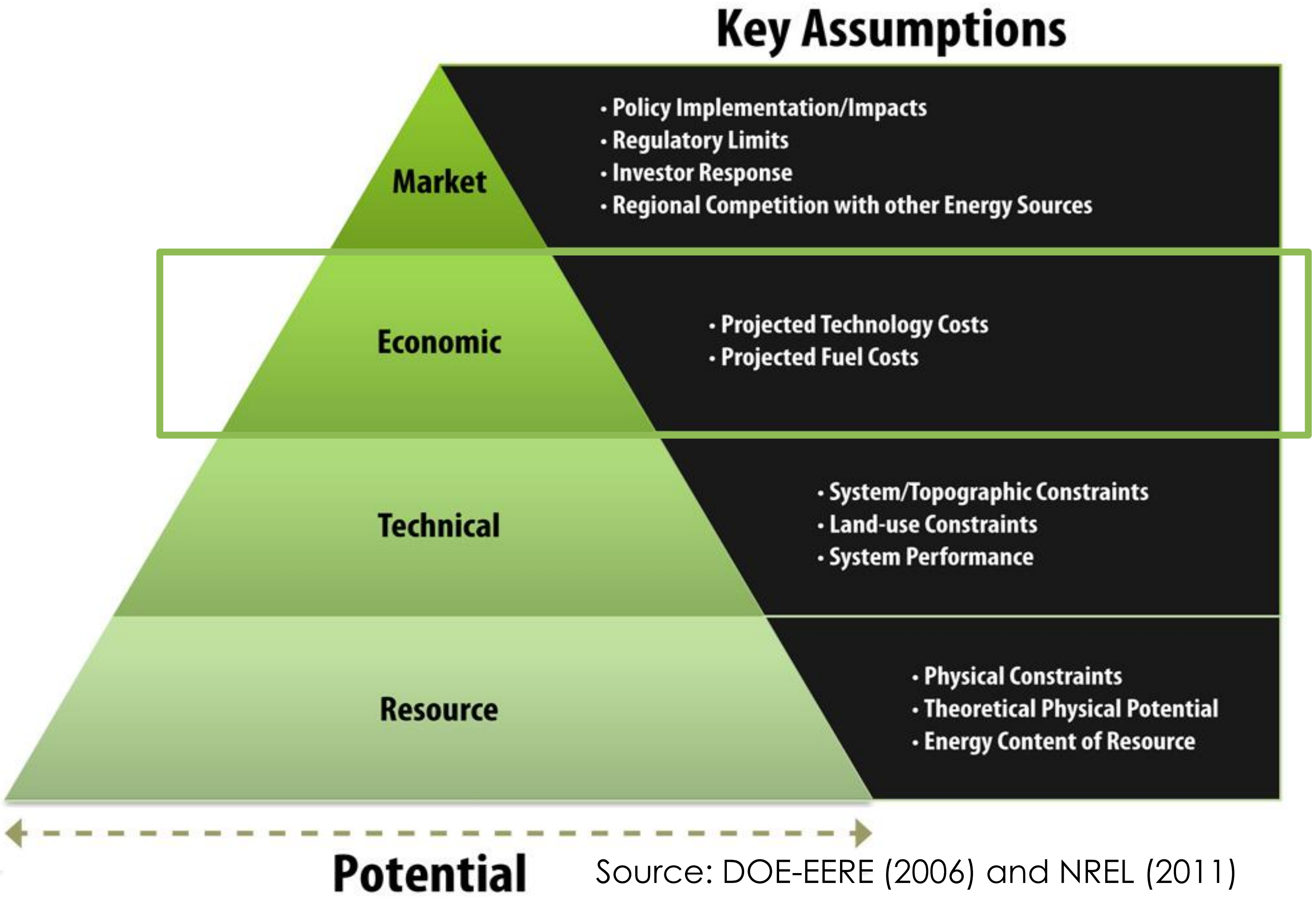
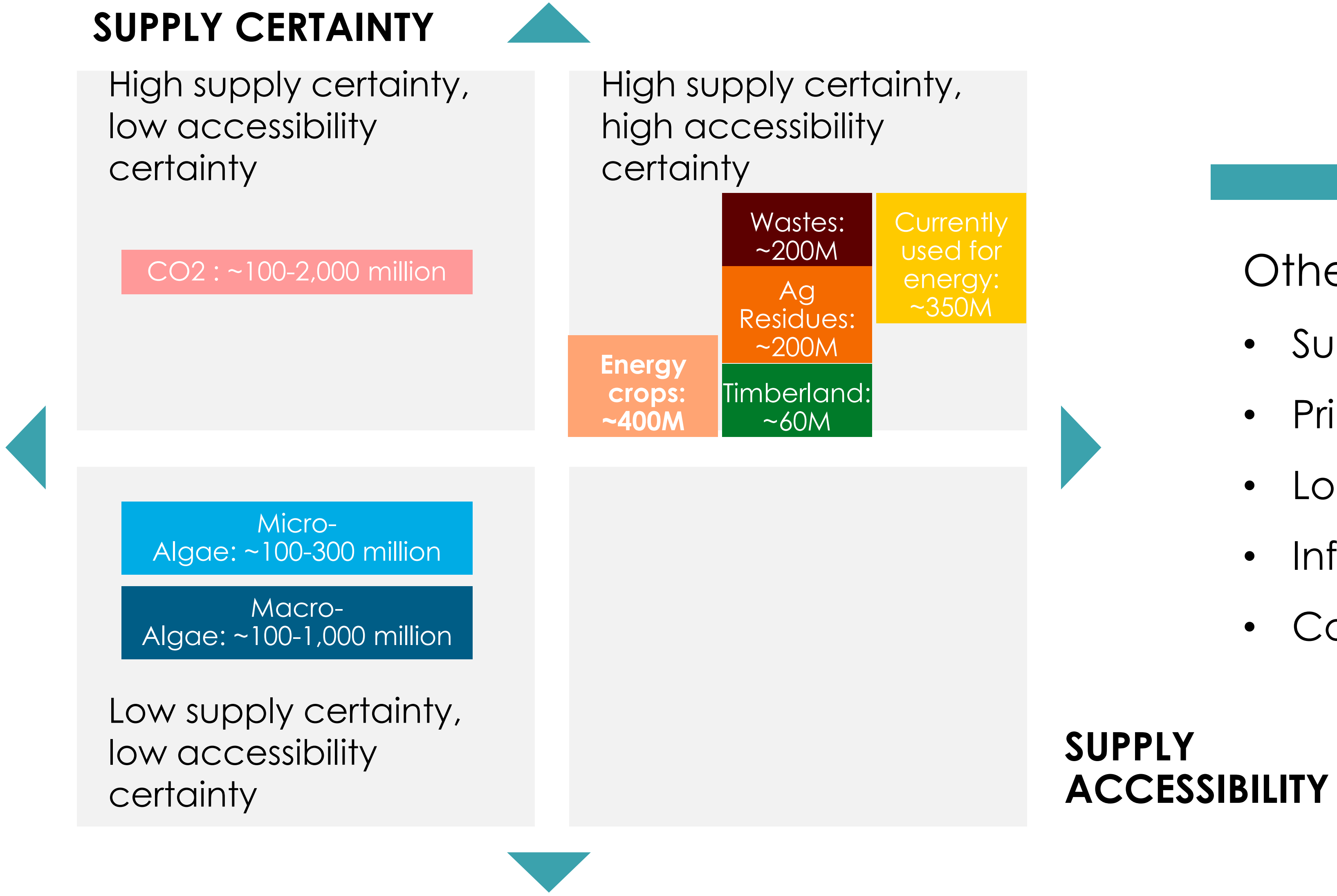
Economic availability



Source: DOE-EERE (2006) and NREL (2011)

Deployability characterization



Other potential attributes:

- Supply control
- Price
- Logistics
- Infrastructure
- Convertibility