CEMAC
Clean Energy Manufacturing Analysis Center

DOE Bioenergy Technologies Office (BETO) 2019 Project Peer Review

Wednesday, March 6th, 2019

CEMAC: Evaluation of Agricultural Equipment Manufacturing for a Bio-based Economy

WBS NREL 6.3.0.8, INL 6.3.0.10, ORNL 6.3.0.9

NL0030036

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Goal Statement of Project

GOAL: To evaluate the feedstock supply chain and manufacturing of agricultural and preprocessing equipment to support feedstock supply for a large-scale biofuel and bio-products industry by quantifying the number of agricultural equipment and pre-processing equipment required to utilize the potential biomass resource projections outlined in the 2016 Billion Ton study (BT16).

RELEVANCE: Assess feedstock supply chain needs for the emerging bioeconomy and the benefits it could create for the agricultural industry and rural communities in terms of jobs and gross domestic product (GDP).

OUTCOME: Analyses and quantification of feedstock equipment manufacturing logistics show potential economic and manufacturing impacts of:

- 240 (short term) to 358 (long term) biorefineries
- 280,000 (short term) to 380,000 (long term) pieces of agricultural equipment
- $36 billion (short term) to $47 billion (long term) in market value of required equipment
- $20 billion (short term) to $27 billion (long term) in additional GDP
- 150,000 (short term) to 200,000 (long term) FTE job years

Quad Chart Overview

Timeline

- Start Date: October 1, 2016
- End Date: March 31, 2018
- Completed: 100%

	Total Costs Pre FY17**	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY 19-Project End Date)
DOE Funded	$0	$400k	$0	$0

Partners:

- **INL $275k (69%)**
- **ORNL $75k (19%)**
- **NREL $50k (12%)**

Barriers addressed

Ft-E: Terrestrial Feedstock Quality, Monitoring and Impact on Conversion Performance

Ft-H: Biomass Material Handling and Transportation

Ft-I: Overall Integration and Scale-Up

Objective

Evaluate the feedstock supply chain and manufacturing of agricultural and preprocessing equipment to support feedstock supply projections in 2016 Billion Ton study.

End of Project Goal

Analyses and quantification of feedstock equipment manufacturing logistics show potential economic and manufacturing impacts.

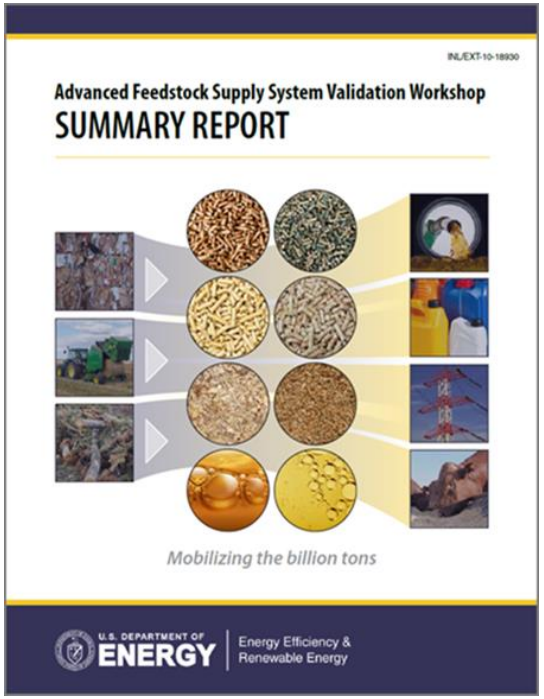
Drivers and Barriers to Transition

Advanced Feedstock Supply Systems (AFSS) are expected to meet DOE goals of producing high volumes of biofuels, requiring **the sustainable and cost effective supply of high volumes of quality feedstocks to future biorefineries**.

BETO-sponsored AFSS Validation Workshop held in February 2015:

- **Transition strategy** will be necessary to move from conventional feedstock supply systems (CFSS) to AFSS
- Equipment manufacturers may also require several years to modify existing equipment or develop new technologies to improve the efficiency in harvesting, transportation, and storing large volume of commodity-based biomass feedstock.

What are the drivers and barriers to this transition?



*The fundamental idea of Advanced Feedstock Supply System technologies is that there are **two independently viable industries** (i.e., a feedstock industry and a conversion industry) for advancing the cellulosic biofuels industry.*

Feedstocks to Fuels – Biomass Availability

Logistically, what is required to collect and transport all this biomass to biorefineries? How do we get there?

Each feedstock will require its own production route and agricultural equipment needs

Feedstocks in red, and their agricultural equipment requirements, were considered for this study.

"Short term" = 2022
"Long term" = 2040

Biomass type	Year			
	2017	2022	2030	2040
Crop Residues (million tons)				
Corn stover	102	119	142	166
Wheat straw	15	17	19	20
Orchard and vineyard prunings	5.5	5.6	5.8	6.0
Rice straw	4.9	5.2	5.4	5.6
Rice hulls	1.4	1.5	1.5	1.6
Other residues and trash	5.2	7.0	7.3	8.4
Energy Crops (million tons)				
Switchgrass	0	71	100	137
Miscanthus	0	104	203	293
Biomass sorghum	0	1	18	58
Energy Cane	0	0	1	2
Non-Coppice	0	0	34	41
Coppice	0	10	19	15

Potential availability of agricultural residues (≤$80/dry ton) agricultural wastes (≤$60/dry ton), and energy crops (≤$80/dry ton) from agricultural lands in the United States, base-case scenario (1% annual growth) (*Billion Ton Study,* US DOE, 2016, Tables 4.7, Table 5.1, and Table 4.8, respectively)

Project Overview

DETAILED GOALS:

Develop analyses and methodologies:

1. To understand ***transitional needs in agricultural equipment manufacturing*** by identifying and quantifying the number of agricultural and pre-processing equipment that would be necessary to ***enable conversion of lignocellulosic biomass to fuels to support the mobilization of the 2016 Billion Ton (BT16) study projections.***

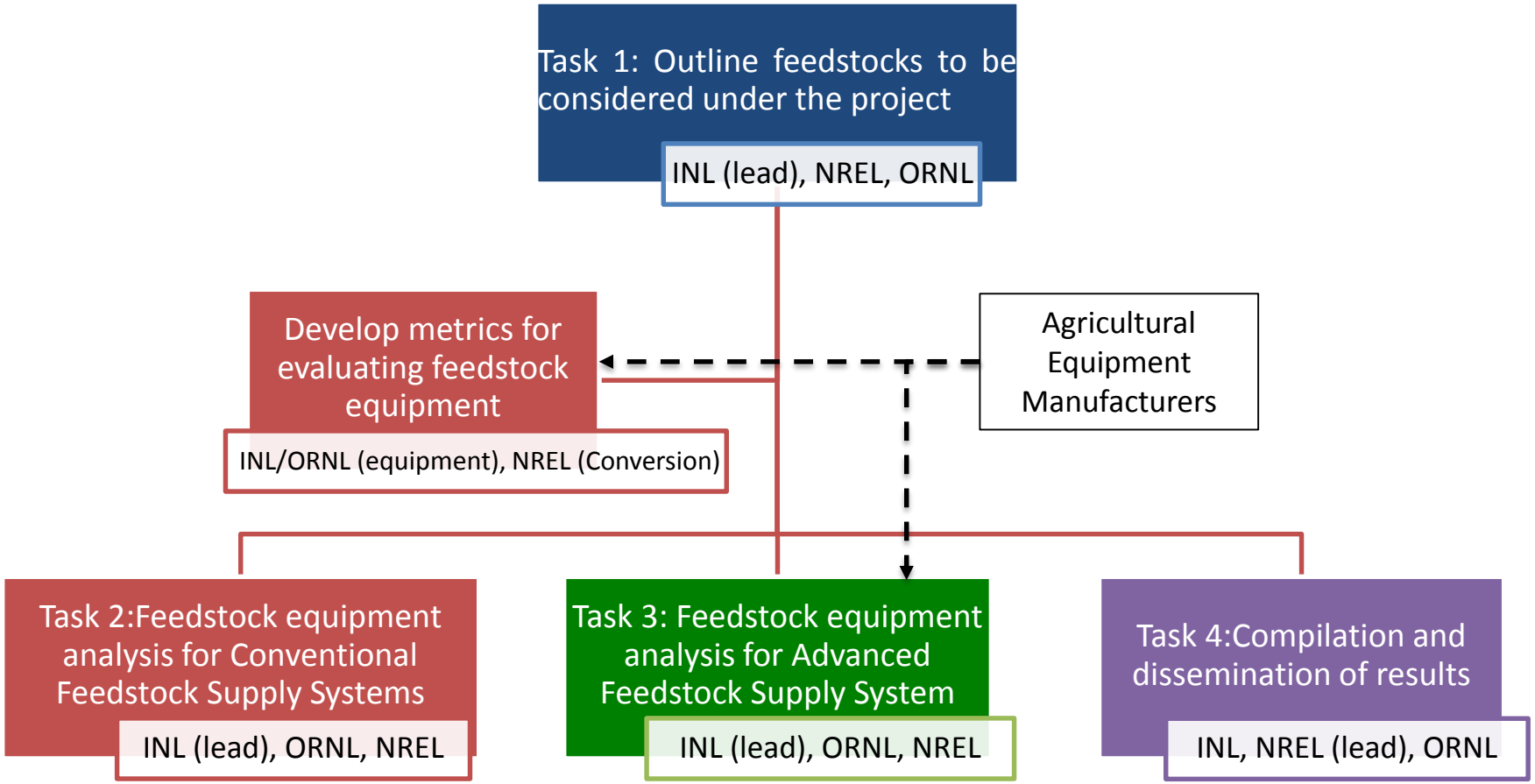
CEMAC Clean Energy Manufacturing Analysis Center

Operated by the Joint Institute for Strategic Energy Analysis

2. To understand ***the impact of this transition on the U.S. economy*** by quantifying the growth potential of the agricultural and manufacturing industries to support the bioeconomy.

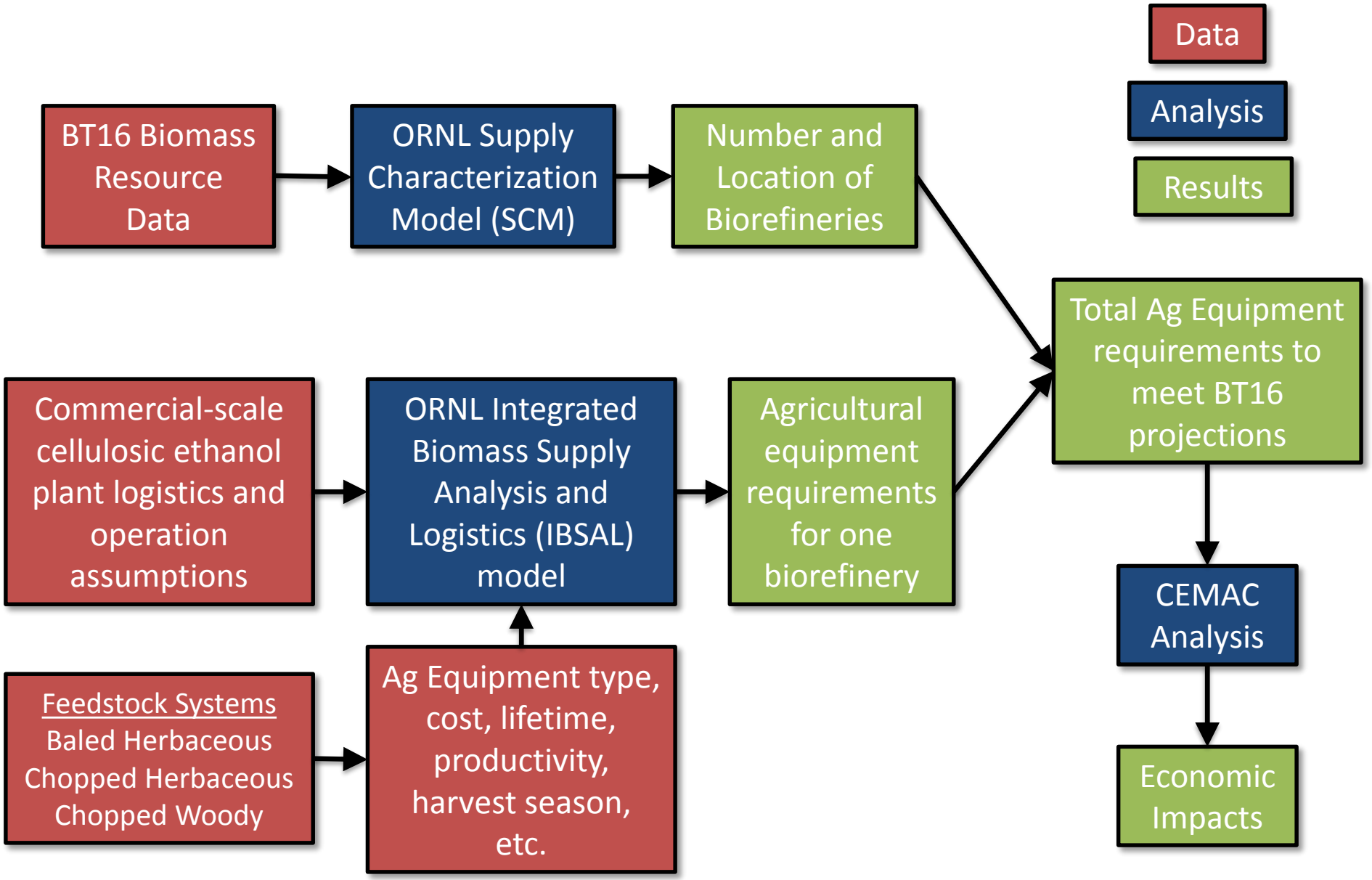
3. To identify ***the drivers and barriers*** to transitioning to the equipment and advanced feedstock supply system necessary for supporting a large-scale biofuel and bioproducts industry through discussions with agricultural equipment manufacturers.

Approach: Management



- Monthly calls with entire team (including DOE) to discuss progress and next steps.
- Clear timeline on tasks/due date of deliverables and clear definition of responsibility.
- Yearly meeting with entire CEMAC team and external advisory board.
- Yearly CEMAC analyst day held at DOE to review project details.

Approach: Technical



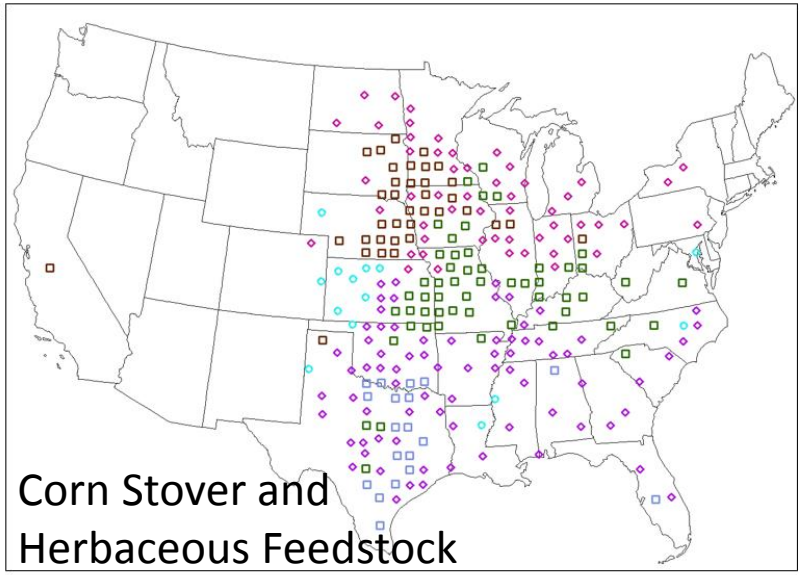
Approach: Technical

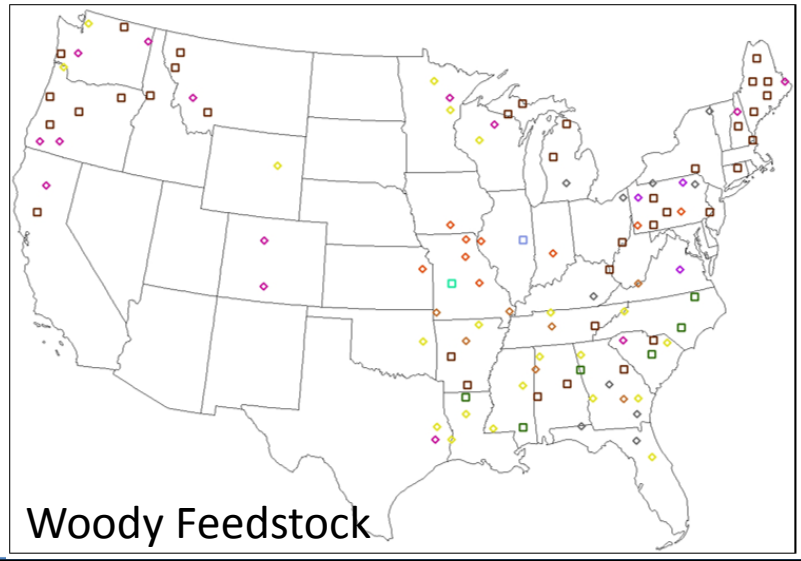
- Critical Success Factors: Transition and adoption
  - The adoption of a transition will be self-sustaining if the transition creates a net gain for all the stakeholders of the supply chain
  - Farmers need to face the right signals for the adoption of appropriate technologies. Farmers will consider, invest in and implement new technologies if they expect the investment will be profitable, if they have the right education, information and motivation, and if government policies set clear goals
- Challenges
  - Quantifying and demonstrating benefits of transition to a large-scale biofuel and bio-products industry to all stakeholders
  - Successful commercial biorefinery operation is needed to truly understand the requirement of an advanced feedstock supply and preprocessing system

Estimated Number of Potential Biorefineries

- ORNL Supply Characterization Model (SCM): Determines number and location of biorefineries based on the availability and distribution of biomass in a region, the road network and the target biomass delivered cost
- Biomass feedstocks can support 240 (short term) to 358 (long term) biorefineries
- Majority of biorefineries are located in Northeast, Southeast and Northwest regions of the United States

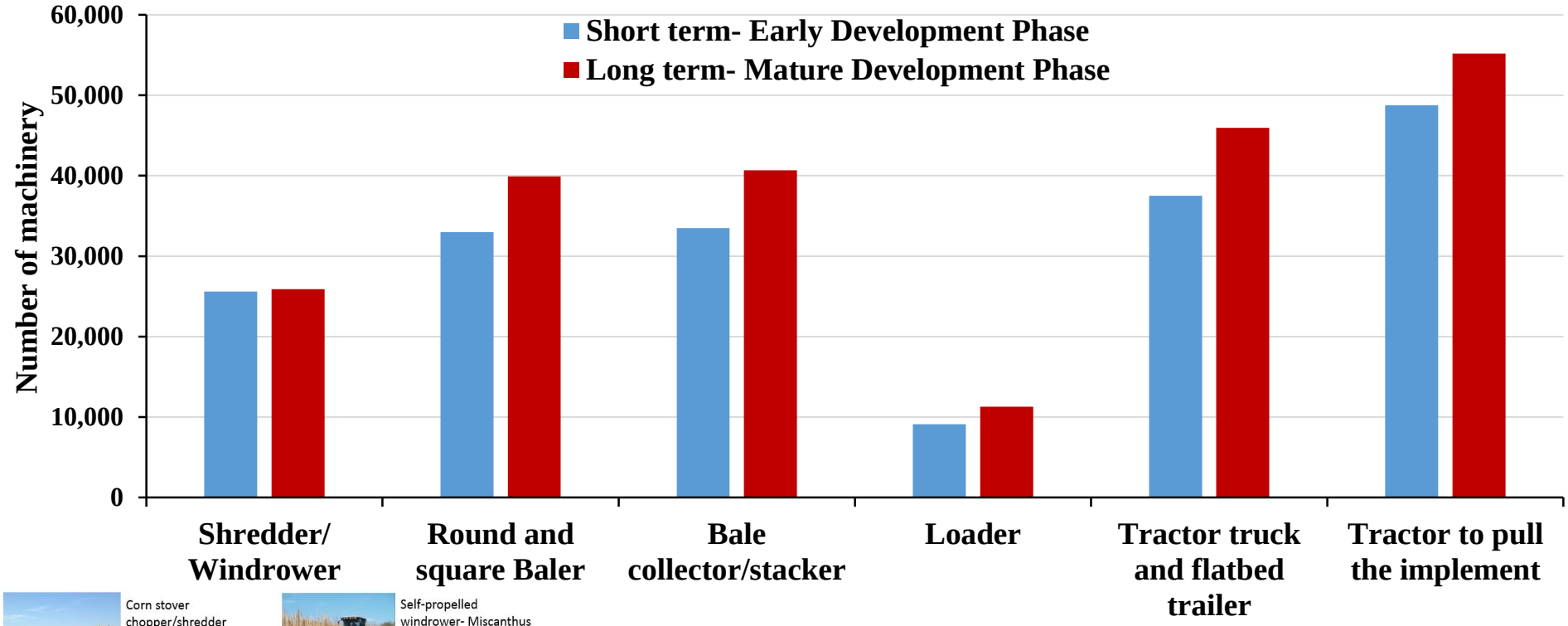
Biorefinery Locations





Assumes annual biorefinery demand of 800,000 tons/year (Argo et al., 2013; Muth et al. 2014)

Ag Equipment Requirements: Baling Scenario




Corn stover chopper/shredder


Self-propelled windrower- Miscanthus and switchgrass


Square and round balers and tractor to pull them


Truck and flatbed trailer


Bale collector /stacker


Telescopic loader

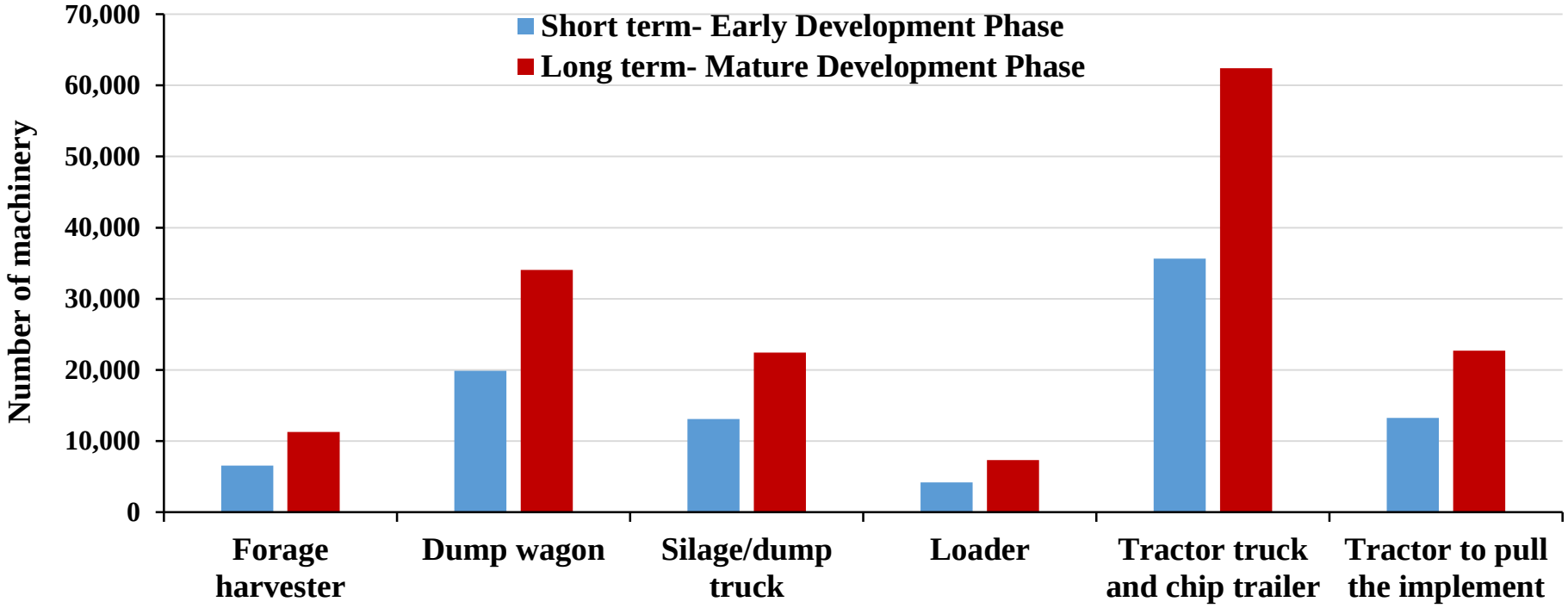
Agricultural equipment requirements are significant:

- 187,000 machines short term
- 219,000 machines long term

High-end estimate:

- Assumes each biorefinery owns its own equipment
- Does not consider dual-use of equipment

Ag Equipment Requirements: Chopping Scenario





Forage harvester



Cane/Dump Wagon


Dump Truck/ Silage truck


Agricultural telehandler/Wheel loader


18-wheeled chips truck and trailer

Agricultural equipment requirements are significant:

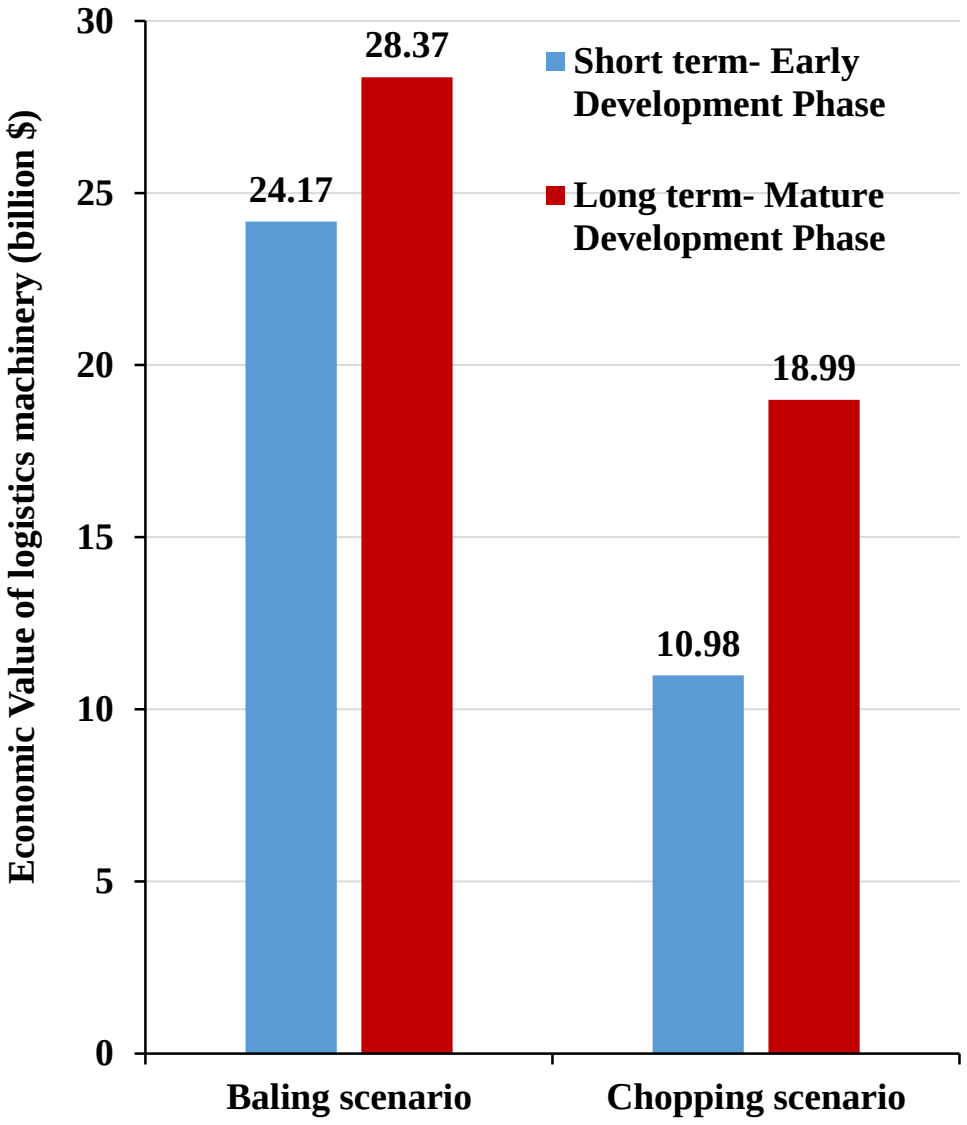
- 93,000 machines short term
- 160,000 machines long term

High-end estimate:

- Assumes each biorefinery owns its own equipment
- Does not consider dual-use of equipment

Economic Impacts – Equipment Value of Billions of US$

- Total combined estimated market value of agricultural machinery in baling and chopping scenarios:
  - Short term: $36 billion
  - Long term: $47 billion
- About 15% and 19% of current market value of all farm machinery and equipment in operations, respectively



Why is the difference between short and long term so small in baling scenario?

- Increase in biomass availability is relatively small. See Biomass Availability table

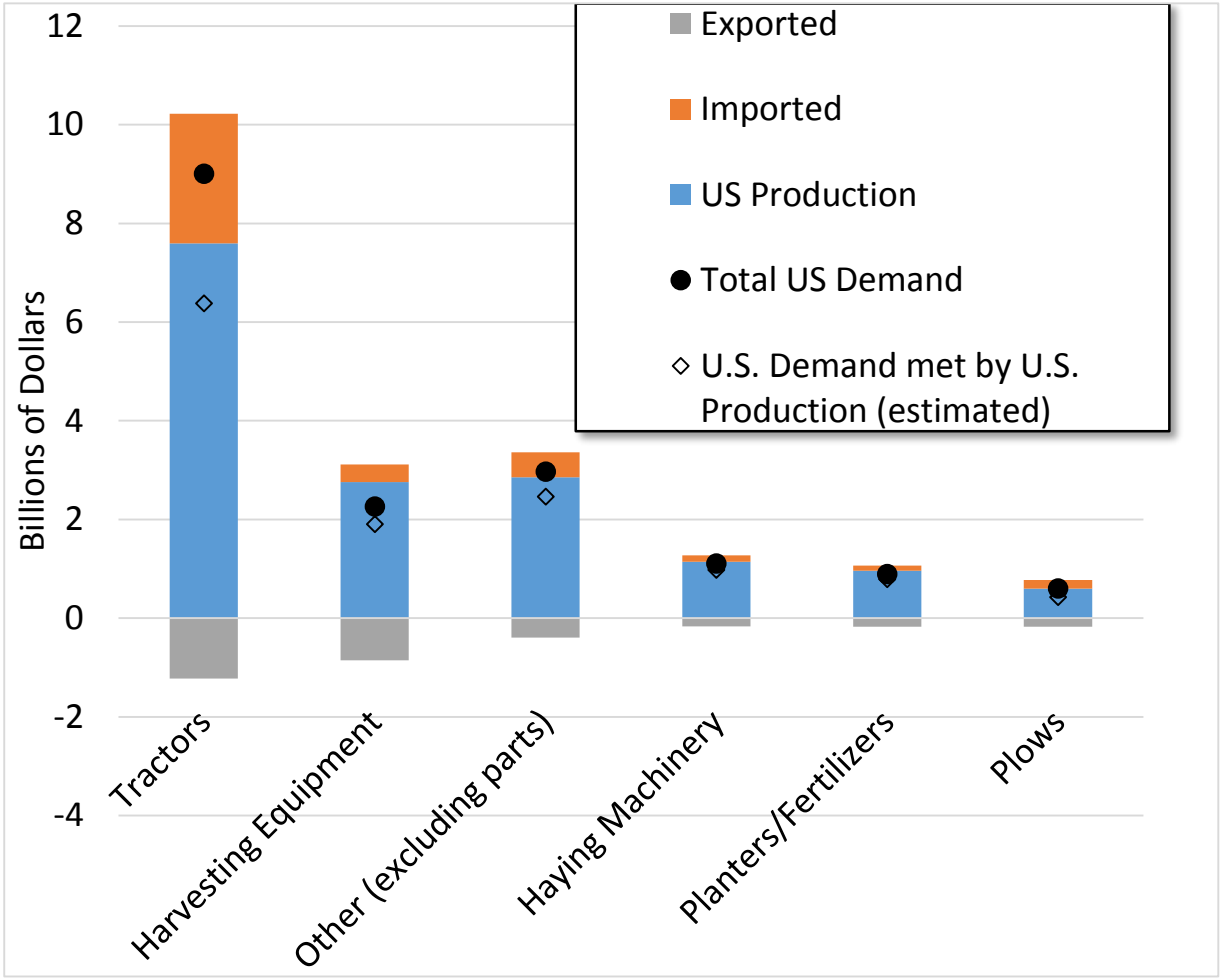
Economic Impacts – Manufacturing in the United States

Where will this equipment come from?

- Historical data suggests **~75%** of farm machinery and equipment demand in the United States supplied by U.S. manufacturers
- Results are in good agreement with other reports (IHS Markit, 2017) and conversations with manufacturers

→ Agricultural equipment used in the U.S. is mostly made in the U.S.

2016 U.S. Agricultural Equipment Production and Trade Data



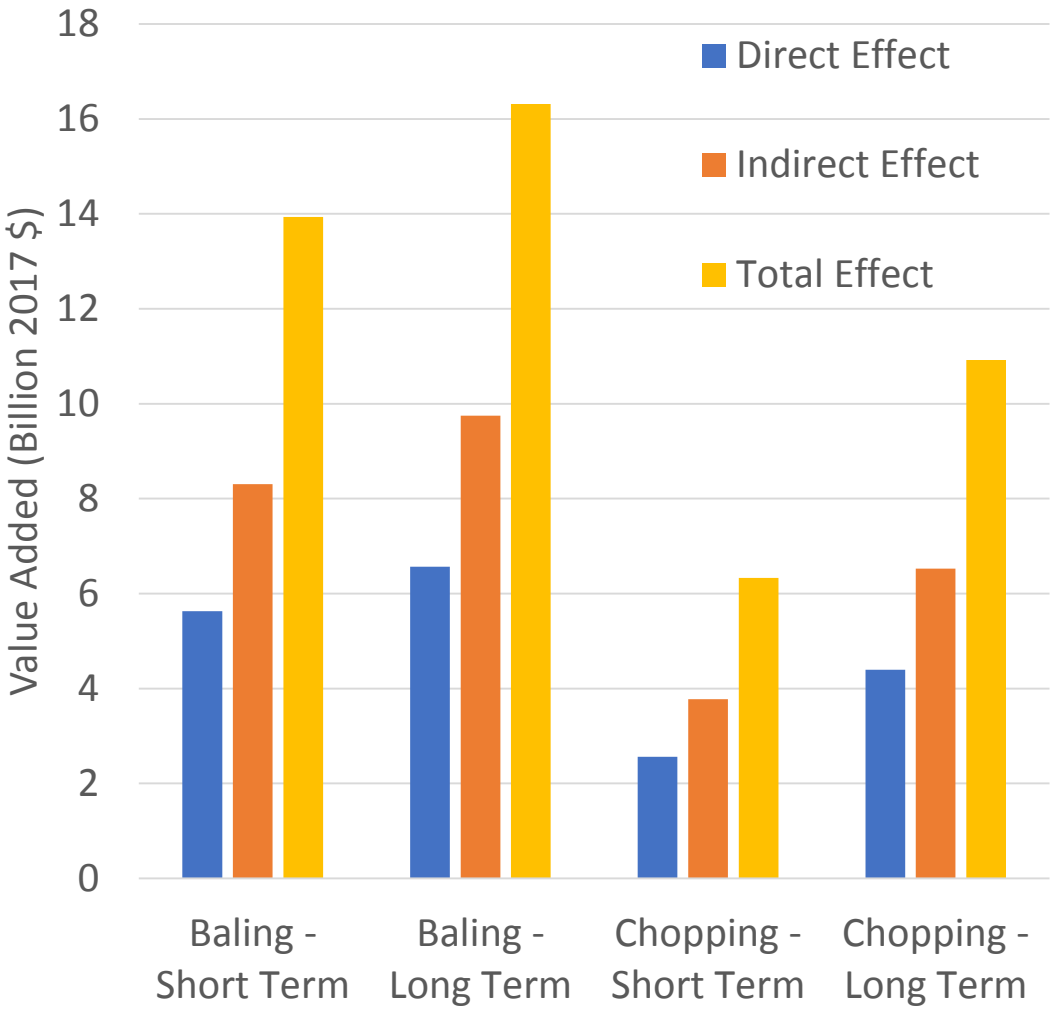
U.S. Demand = Production + Imports - Exports

U.S. Demand met by U.S. Production = U.S. Production - Exports

Economic Impacts – Gross Domestic Profit (GDP)

Value added (contribution to GDP) impacts, in US$(2017) billion, from market value of baling and chopping scenarios in short and long term.

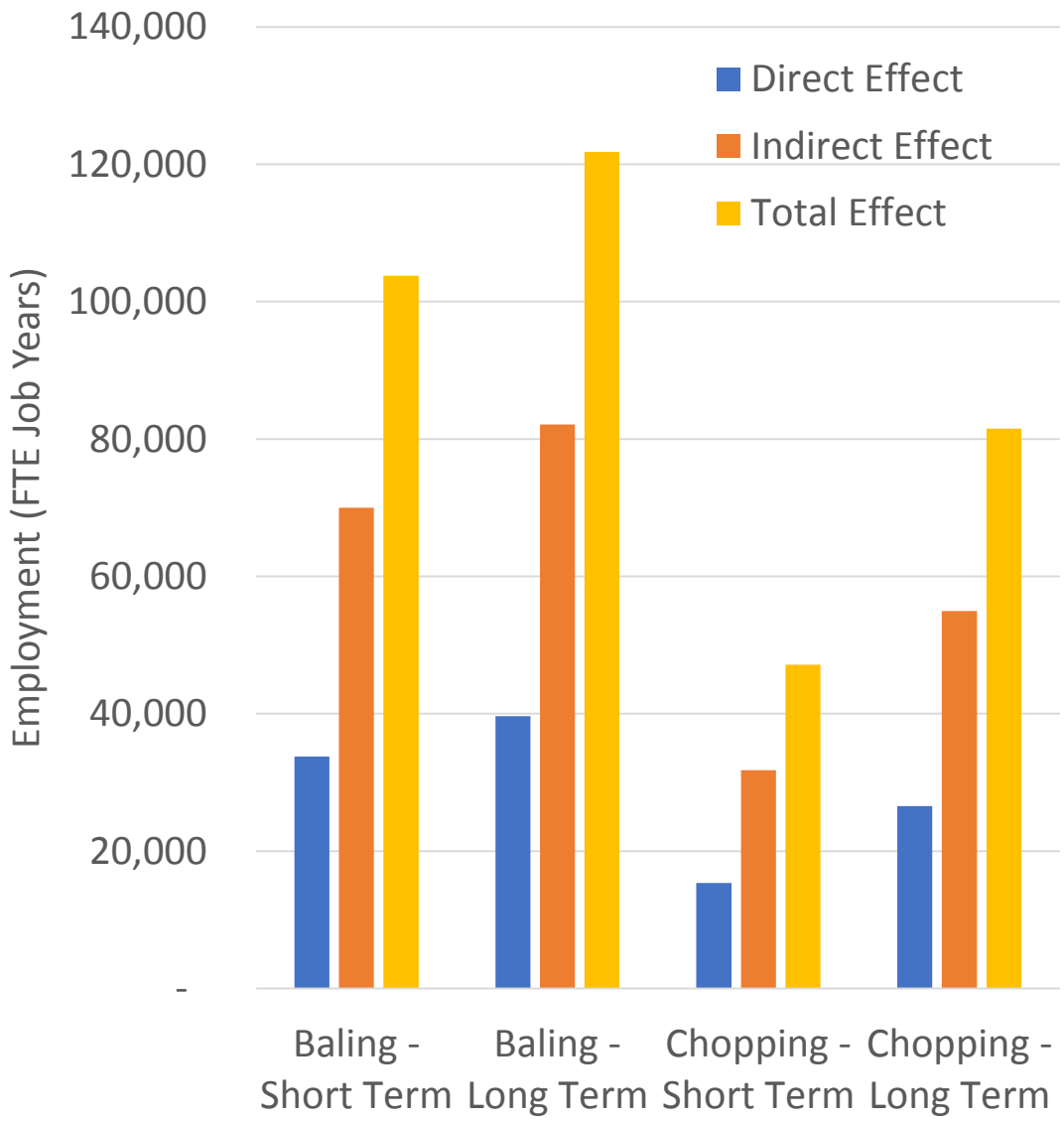
- Impacts calculated using the Economic Impact Analysis for Planning (IMPLAN) model
- Assumes full agricultural equipment logistical requirements are newly manufactured (i.e., high-end estimate) and 75% of equipment is manufactured domestically



Economic Impacts – Gross Manufacturing Jobs

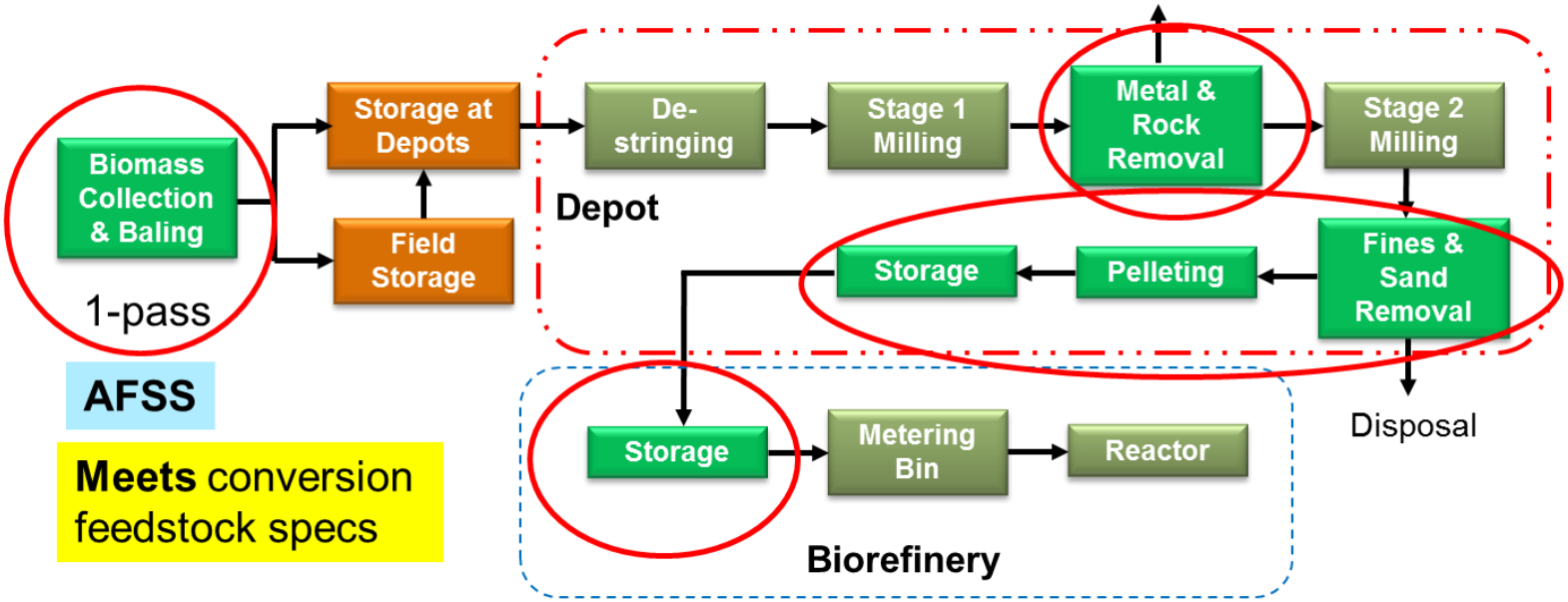
Employment impacts (in FTE job years) from market value of baling and chopping scenarios in short and long term

- Impacts calculated using IMPLAN model
- Assumes full agricultural equipment logistical requirements are newly manufactured (i.e., high-end estimate) and 75% of equipment is manufactured domestically



Transition from Conventional to Advanced Feedstock Preprocessing System

- All three pioneer biorefineries built in the U.S. used bale supply logistics and conventional preprocessing methods. This led to long start-up time, low plant throughput, and low product yield. These challenges confirm that the baling logistics and conventional preprocessing systems have not met the requirements of the biorefineries.
- Preliminary evaluation indicates that the chopping logistics and advanced preprocessing system can meet conversion feedstock specifications and should provide the backbone of a robust feedstock supply system required for successfully starting a large-scale biofuels and bioproducts industry.



Drivers and Barriers: Recent Transitions in Ag Equipment

Krone Mobile pellet harvester

Vermeer ZR5 self-propelled baler

John Deere Plus2 round bale accumulator

Autonomous Tractor corporation (ATC)

Kinze harvest system: autonomous grain cart system

→Five recent technology developments identified

→These companies interviewed to discuss drivers and barriers to new technologies

Industry Survey- Contacted Companies

Manufacturer	Points of contact
Krone, Germany	Felix Reuver- Sales Export Manager Richard Shelton- National Sales Manager
Vermeer, USA	Jay Van Roekel- Biomass Business Unit Manager Josh Vrieze- Product Manager
John Deere, USA	John Deere website
Kinze Manufacturing, USA	Brian A. McKown- Executive Vice-President and COO
Autonomous Tractor Corporation (ATC), USA	Kraig Schulz- CEO

The CEMAC also organized an industry panel discussion in the Agricultural Equipment Technology Conference (AETC) in Louisville, 2017 inviting four major OEMs to participate in the discussion including John Deere, AGCO, CNH and Vermeer.

Drivers and Barriers: Results of Industry Survey

Motivation/Market drivers

- Improve the field efficiency of harvest and collection operations
- Eliminate the need for skilled operators/ no need for operators at all
- Reduce wheel traffic and the damage that excessive wheel traffic causes to growth of the next crop
- Reduce operator fatigue
- Reduce equipment costs and increase the service life of existing fleet
- Reduce emission
- Improve implement control
- Realization of the autonomous technology in other industries
- Downsize field equipment

Barriers/Challenges

- Resistance from the existing farm machinery industry and their dealers
- Lack of availability of parts suppliers in some regions of the country
- Lack of strong service/support capabilities in the existing distribution and dealer network
- High costs of new technologies
- Organizational conflicts

Goal (re-)Statement of Project

GOAL: Develop analyses and methodologies:

- To understand any ***transitional needs in agricultural equipment manufacturing*** that would be necessary to ***enable conversion of lignocellulosic biomass to fuels to support the mobilization of the 2016 Billion Ton (BT16) study projections.***
- To investigate ***the pinch points and barriers*** of the current state of the industry that limit the ability to meet a billion-ton bioeconomy.
- That can be ***leveraged by decision-makers to inform investment strategies, policy, and other decisions*** to promote economic growth and competitiveness in the transition to a clean energy economy.

Support BETO Strategic Goals

1. Better Understand the Benefits of Bioenergy to Rural Communities
   - *Estimates show bioeconomy could impact expansion of the US economy and jobs in equipment manufacturing and the farm belt*
2. Optimization of Supply Chain Interfaces and Cross-System Integration
   - *Quantifies supply chain needs in both collection and pre-processing of biomass.*
   - *Links supply chain needs to equipment manufacturing.*
3. Conduct Supply Chain Analyses of Current and Alternative Supply and Logistics Systems for Identification of Benefits/Limitations
   - *Identifies equipment needs in conventional feedstock supply system.*
   - *Identifies drivers and barriers to transition to advanced feedstock supply system.*

Summary

Approach

- Multi-lab collaborative project to evaluate the manufacturing of agricultural equipment that would be necessary to enable the transition from the current state of the industry to a future commodity-based feedstock supply system.
- Working with industry to support evaluations and to provide input into analysis methodology and data.

Relevance

- Directly aligns with BETO Strategic Goals to "Conduct Supply Chain Analyses of Current and Alternative Supply and Logistics Systems for Identification of Benefits/Limitations".

Results

- Quantification of following for conversion of lignocellulosic biomass to fuels to support the mobilization of the 2016 Billion Ton (BT16) study projections:
  - 240 (short term) to 358 (long term) biorefineries needed
  - 280,000 (short term) to 380,000 (long term) pieces of agricultural equipment
  - $36 billion (short term) to $47 billion (long term) in market value of required equipment
  - $20 billion (short term) to $27 billion (long term) in additional GDP
  - 150,000 (short term) to 200,000 (long term) FTE job years
- Identified drivers and barriers in transition in agricultural and preprocessing equipment.

Acknowledgements

Thank you to..

- DOE Bioenergy Technologies Office
  - Jay Fitzgerald, Alison Goss-Eng, Alicia Lindauer, Steve Thomas
- DOE Clean Energy Manufacturing Initiative
  - Brian Walker
- Project partners
  - Quang Nguyen (INL)
  - Shahab Sokhansanj, Mahmood Ebadian, Erin Webb(ORNL)

V Back Up Slides

Economic Impacts - Manufacturing

NAICS-based Code	Description	Total U.S. Demand (2015)	% Supplied by U.S. Production
3331111	Tractors	$11,944,949	75%
3331119	Harvesting Equipment	$3,312,046	90%
333111J	Turf/Grounds Equipment	$3,083,553	94%
333111G	Other (excluding parts)	$2,960,393	84%
333111C	Parts - for sale separately	$3,587,832	9%
3331114	Dairy, sprayers, dusters, blowers	$1,564,819	90%
333111A	Haying Machinery	$1,522,325	87%
3331117	Planters/Fertilizers	$1,227,826	90%
333111E	Plows	$750,106	74%

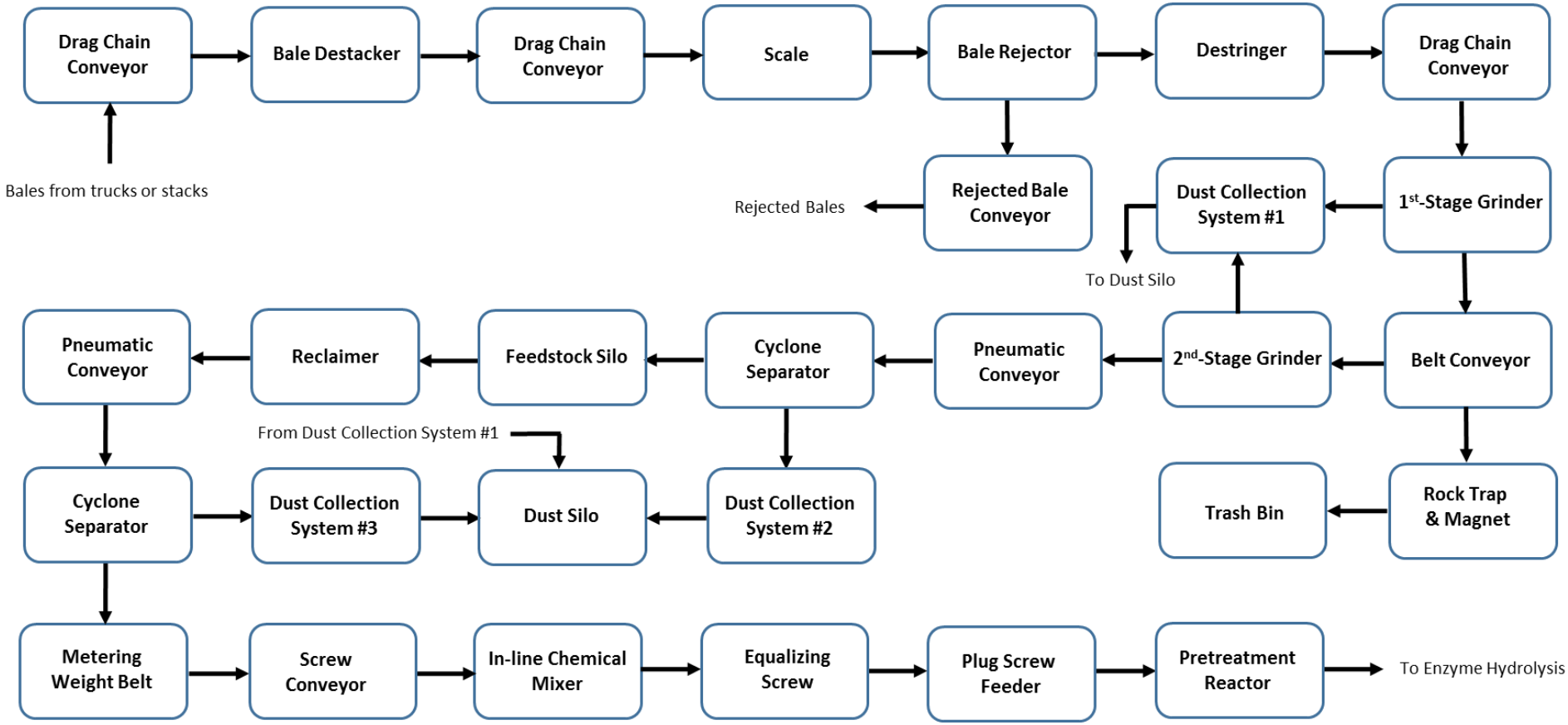
- About 75% of farm machinery and equipment demand in the United States was supplied by U.S. manufacturers annually
- Results in good agreement with other reports that state that approximately 30% of U.S. agricultural equipment production is intended for export (IHS Markit, 2017)
- Represents significant agricultural equipment manufacturing opportunity for U.S. market

Summary

Descriptions	Early Development Phase	Mature Development Phase
Total harvestable biomass (million tons)	304	652
Potential number of biorefineries (800,000 dry tons/year)	240	358
Estimated number of required agricultural equipment: Baling scenario Chopping scenario	 187,442 92,581	 218,946 160,147
Estimated market value of agricultural equipment ($Billions) Baling scenario Chopping scenario	 24.17 10.98	 28.37 18.99
Estimated number of operators to run agricultural equipment: Baling scenario Chopping scenario	 49,761 26,444	 57,773 45,815
Estimated number of participating farmers	123,928	162,315
Estimated net annual income of participating farmers ($Billion/year)	2.48	3.25

Equipment Requirements for Baled Herbaceous System

- This project also estimated the type and number of equipment for a preprocessing system that would be required for the projected number of biorefineries.
- The system below assumes a baled herbaceous feedstock



Equipment Requirements for Baled Herbaceous System

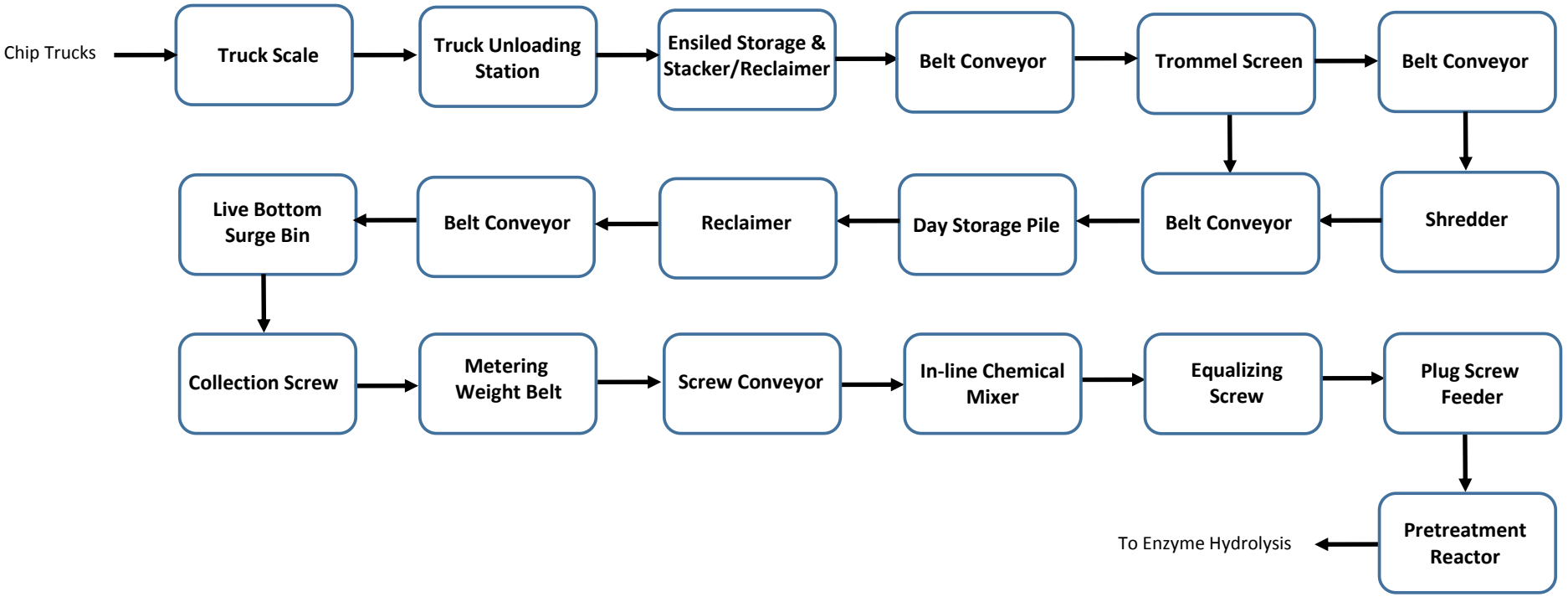
Estimated Number of Major Equipment and Turnkey Systems for a Baled Herbaceous Preprocessing System (800,000 Dry Tons/Year per Biorefinery)

Equipment	Quantity per Biorefinery	Short-Term Total Quantity	Long-Term Total Quantity
Truck scale	2	268	352
Telehandler	4	536	704
Front-end loader	2	268	352
Bale destacker	4	536	704
Drag chain conveyor	9	1,206	1,584
Destringer	4	536	704
Grinder	8	1,072	1,408
Dust collection system	12	1,608	2,112
Fire and dust explosion suppression	12	1,608	2,112

Equipment	Quantity per Biorefinery	Short-Term Total Quantity	Long-Term Total Quantity
Pneumatic conveyor	8	1,072	1,408
Cyclone separator	8	1,072	1,408
Belt conveyor	4	536	704
Feedstock silo	4	536	704
Feedstock reclaimer	4	536	704
Dust silo	1	134	176
Metering weight belt	4	536	704
Screw conveyor	8	1,072	1,408
Plug screw feeder	8	1,072	1,408

Equipment Requirements for Chopped Herbaceous System

- This project also estimated the type and number of equipment for a preprocessing system that would be required for the projected number of biorefineries.
- The system below assumes a chopped herbaceous feedstock



Equipment Requirements for Chopped Herbaceous System

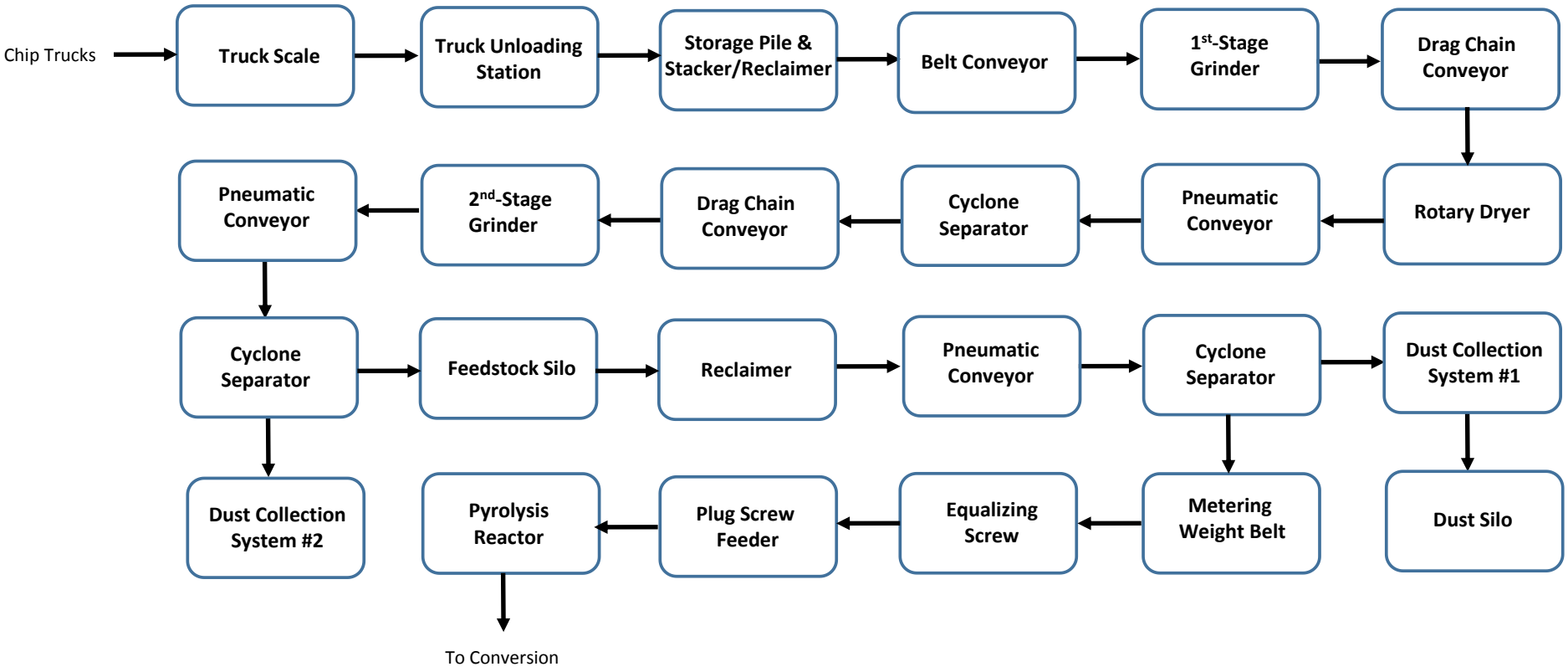
Estimated Number of Major Equipment and Turnkey Systems for Chopped Herbaceous Preprocessing Systems (800,000 Dry Tons/Year per Biorefinery)

Equipment	Qty per Biorefinery	Short-Term Total Quantity	Long-Term Total Quantity
Truck scale	2	164	252
Front-end loader	2	164	252
Pile compactor	4	328	504
Truck unloading system	2	164	252
Ensiled storage and stacker/ reclaimer	2	164	252
Belt conveyor	16	1,312	2,016
Trommel screen	4	328	504
Shredder	4	328	504

Equipment	Qty per Biorefinery	Short-Term Total Quantity	Long-Term Total Quantity
Shredder	4	328	504
Day storage pile and reclaimer	2	164	252
Live bottom surge bin	4	328	504
Screw conveyor	12	984	1,512
Metering weight belt	4	328	504
Plug screw feeder	4	328	504

Equipment Requirements for Chopped Woody Biomass System

- This project also estimated the type and number of equipment for a preprocessing system that would be required for the projected number of biorefineries.
- The system below assumes a chopped woody biomass feedstock



Equipment Requirements for Chopped Woody Biomass System

Estimated Number of Major Equipment and Turnkey Systems for Chopped Woody Biomass Preprocessing Systems (800,000 Dry Tons/Year per Biorefinery)

Equipment	Quantity per Biorefinery	Short-Term Total Quantity	Long-Term Total Quantity
Truck scale	2	48	112
Front-end loader	2	48	112
Truck unloading system	2	48	112
Storage and stacker/reclaimer system	2	48	112
Belt conveyor	4	96	224
Grinder	8	192	448
Drag chain conveyor	8	192	448
Rotary dryer	4	96	224
Storage silo and reclaimer	4	96	224

Equipment	Quantity per Biorefinery	Short-Term Total Quantity	Long-Term Total Quantity
Pneumatic conveyor	12	288	672
Dust collection system	8	192	448
Dust silo	1	24	56
Fire and dust explosion suppression system	8	192	448
Screw conveyor	4	96	224
Metering weight belt	4	96	224
Plug screw feeder	4	96	224