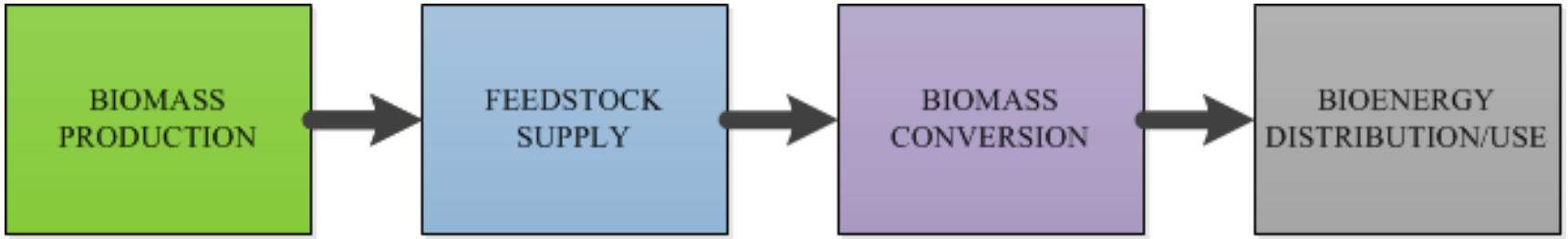
Integrated Biomass Supply and Logistics (IBSAL)



Dr. Shahab Sokhansanj, Dr. Mahmood Ebadian

Biomass and Bioenergy Research Group, UBC

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UBC biomass gasifier

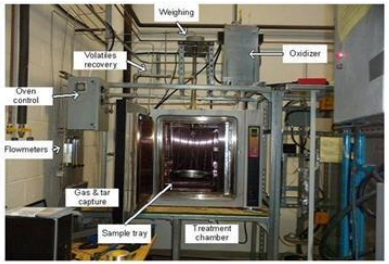
Biomass engineering lab

Figure 1- Appearance of raw material and pellets made in this study: (a) original Douglas fir woodchips, (b) SO_2-steam treated and dried woodchips, (c) pellets made from untreated particles, (d) Pellets made from SO_2-steam treated particles

Biomass logistics modeling

Pellet mill

Wood pellet storage



UBC-TGA system for drying and torrefaction of biomass

Biomass dryer

Hammer mill

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Woody and Herbaceous Pellet Samples at BBRG







Aspen


Douglas fir


Switchgrass


Corn Stover


Miscanthus


Wheat straw

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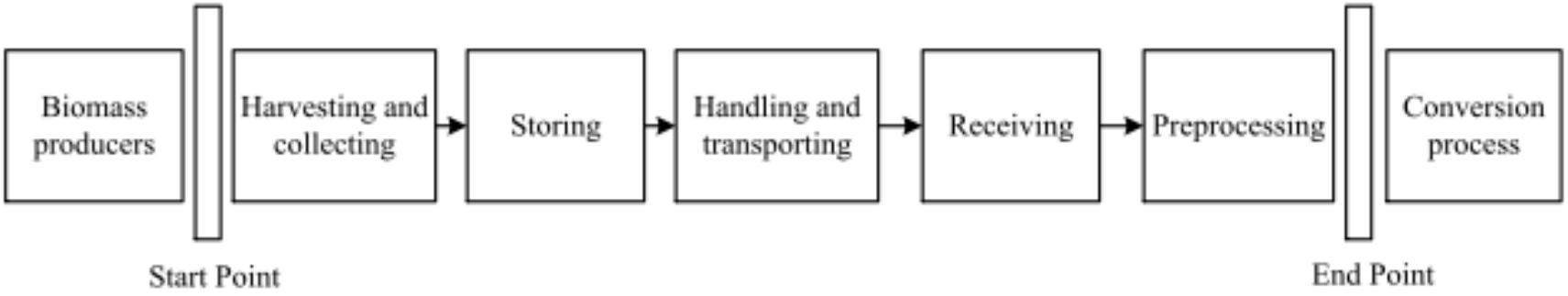
IBSAL

- **A decision-making support tool to understand the complexity and dynamics of the biomass supply chain**
  - **Harvest and collection**
  - **Storage**
  - **Transportation and handling**
  - **Preprocessing (e.g. densification, drying, grinding)**

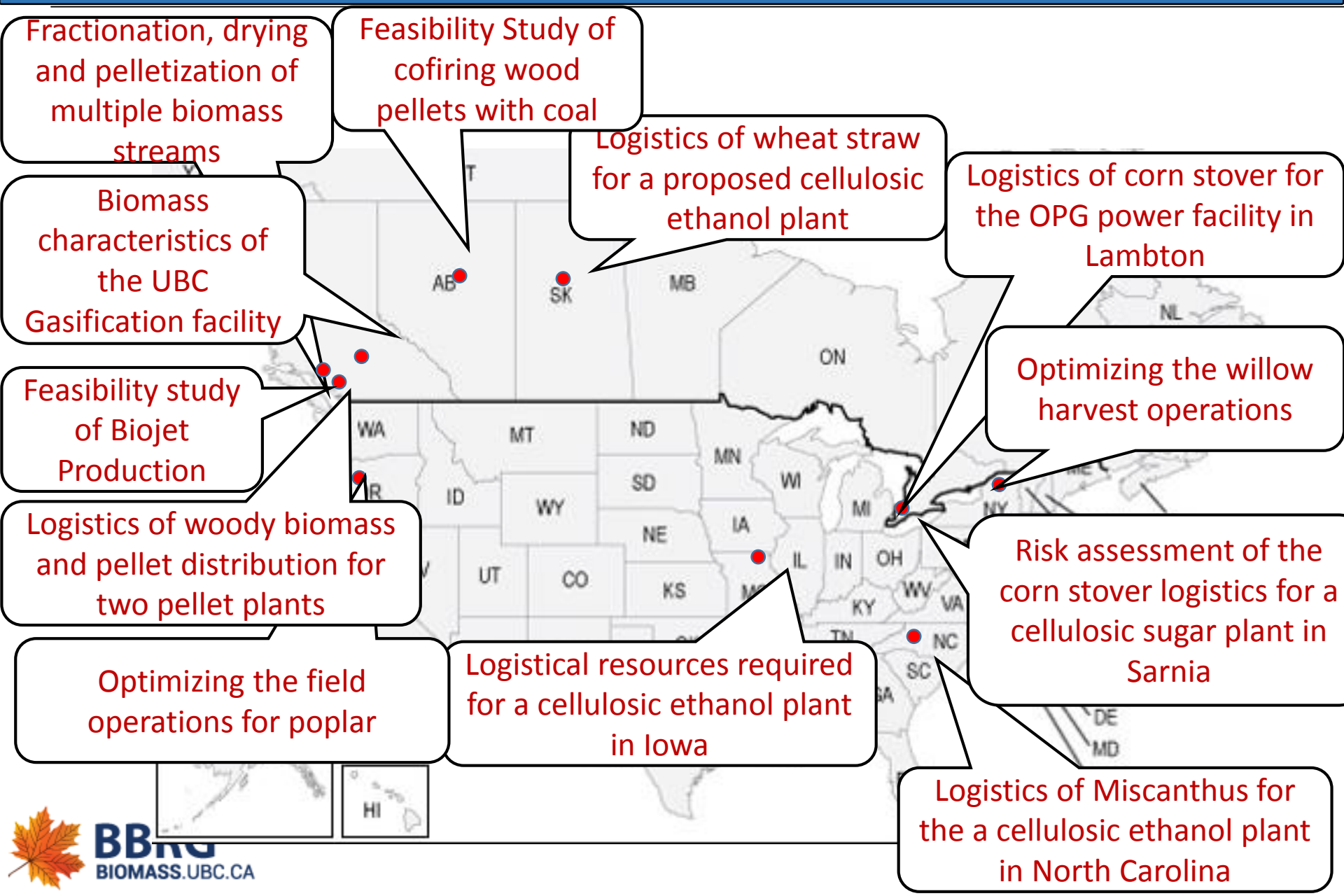


Meet **Quality**, **Quantity** and **Cost** specifications of the biorefinery

IBSAL strengths

- **Dynamic tool:** consideration of variability and uncertainty in the input parameters such as weather data, yield and moisture content
- **Development of engineering equations** (for design of unit operations and to monitor changes in the system such as moisture content, dry matter loss, field working condition and equipment performance): this strength enables IBSAL to provide accurate information on the performance of the entire biomass supply chain in terms of cost, quantity and quality.
- **Database: the IBSAL database has been developed gradually in the last 10 years and has detailed information on the equipment properties and their engineering economics:** harvest and collection equipment, handling equipment, transportation equipment, preprocessing equipment, conveyors and storage configurations

Recent Industrial Projects in USA and Canada



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IBSAL framework

Input Data (IBSAL- Excel file)

Daily Weather Data
- Average temperature
- Snow
- Rain
- Relative humidity
- Evaporation

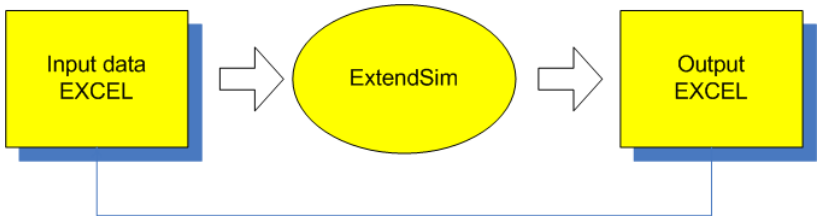
Harvest Schedule
Length of harvest window
Number of working days

Crop Data
- Historical biomass yield
- Yield to be deducted for conservation
- Harvest moisture content

Field Data
- Total crop supply area
- Distance to the side of farm

Equipment Data
- Equipment width
- Speed
- Horsepower
- Hourly cost of equipment

Storage Data
- Number and size of storage sites
- Distance from farm to storage
- Distance from storage to final destination



Simulation (IBSAL- ExtendSim file)

Simulating all operations required to deliver biomass from farm lands to the conversion plant

Mathematical equations calculating the operational performance of equipment

Mathematical equations calculating moisture content and dry matter loss

Flow of information to and from IBSAL

Outputs (IBSAL- Excel file)

Economic output:
- Custom Cost per ton of biomass
- Ownership Cost per ton of biomass

Energetic and environment output:
- Energy Input
- CO_2 Emission

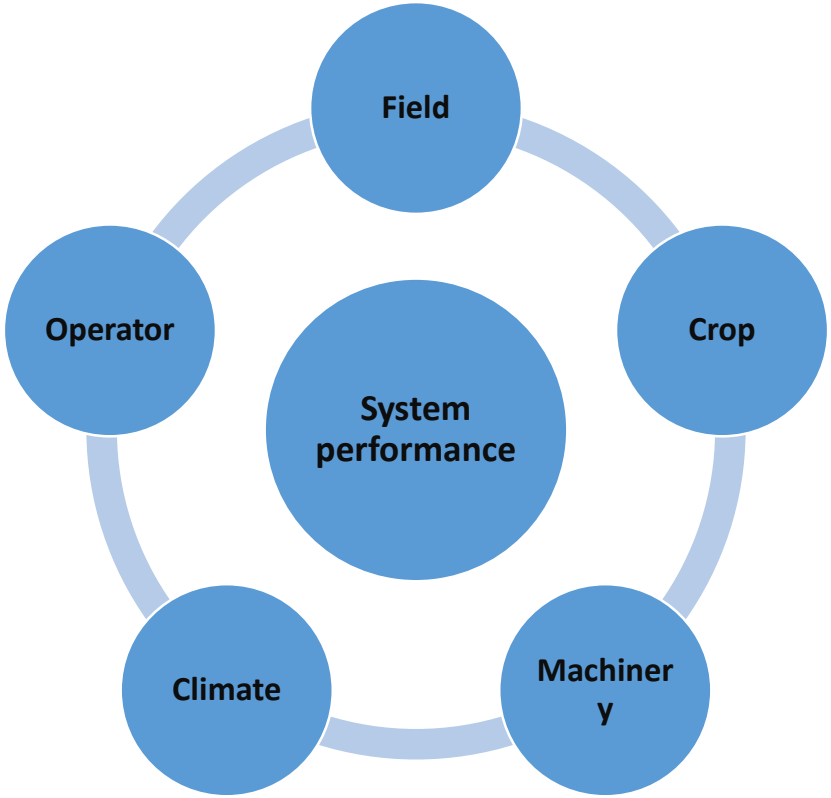
Biomass recovery:
- Dry matter loss
- Net collected yield

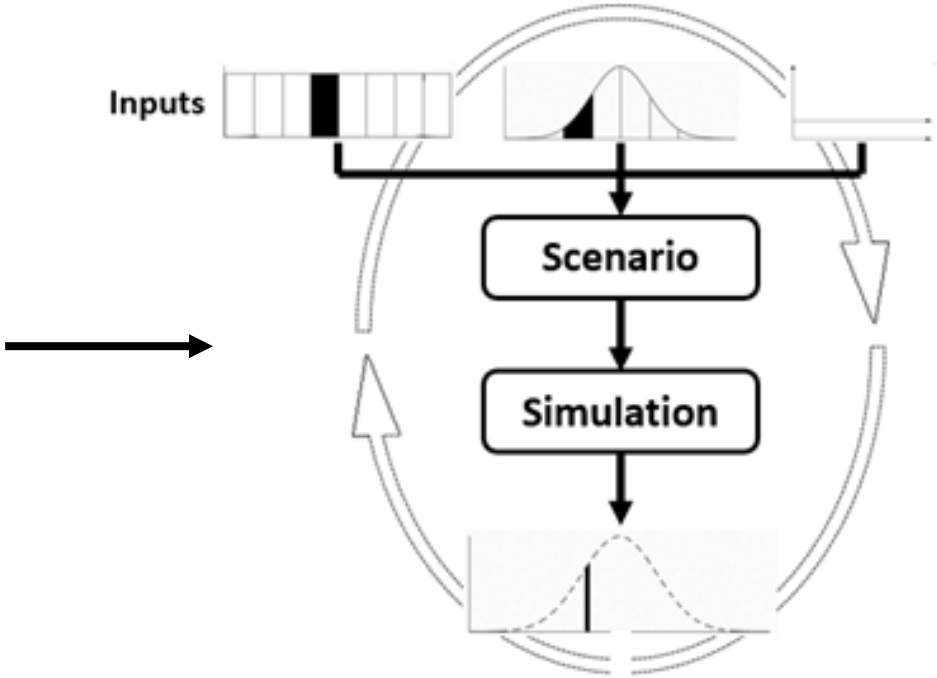
Resource output:
- Number of days to complete each operation
- Number of required machines and workforce
- Utilization rate for machineries
- The harvested area

Why simulation in IBSAL?

Given the dynamics, stochastic and complex nature of biomass supply chains, the main concern is the ***robustness*** of the supply chain instead of optimality.

To Develop a robust supply chain, sources of variability are first identified, their impacts are quantified and the elements of supply chain are designed and planned according to the magnitude of variability in the entire system.





IBSAL- Baling and chopping scenarios

- **Two existing scenarios to harvest and collect agricultural biomass are modeled in IBSAL including baling and chopping.**
- **The following decisions are made in IBAL for both baling and chopping scenarios:**
  - **Location of bio-processing facility**
  - **Location of storage sites**
  - **Number of biomass suppliers to contract and their location**
  - **Ownership and custom operating costs ($/dry tonne)**
  - **Biomass inventory planning**
  - **Truck planning and scheduling**
  - **Number of required logistics equipment**
  - **Daily flow of biomass in the entire biomass supply chain**
  - **Dry matter loss monitoring**
  - **Moisture content monitoring**
  - **Biomass delivered cost ($/dry tonne)**
  - **Equipment energy consumption and its associated CO_2 emissions**

Baling scenario modeled in IBSAL

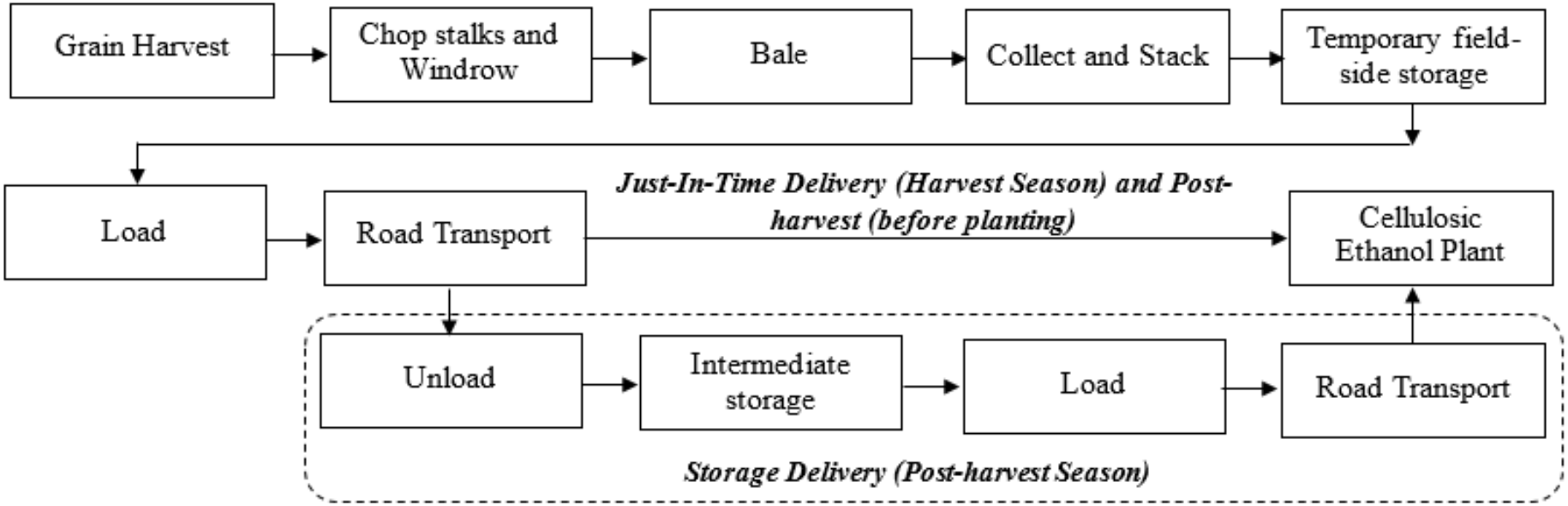


Figure 1. Base case biomass logistics system- bale scenario.

- **The bale scenario is developed based on the existing agricultural machinery used in the three pioneering cellulosic ethanol projects in the USA.**
- **This scenario is considered for corn stover, wheat straw, miscanthus and switchgrass**

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Equipment used in baling scenario

Corn stover chopper/shredder

Self-propelled windrower-Miscanthus and switchgrass

Baler

Tractor (180-220hp)

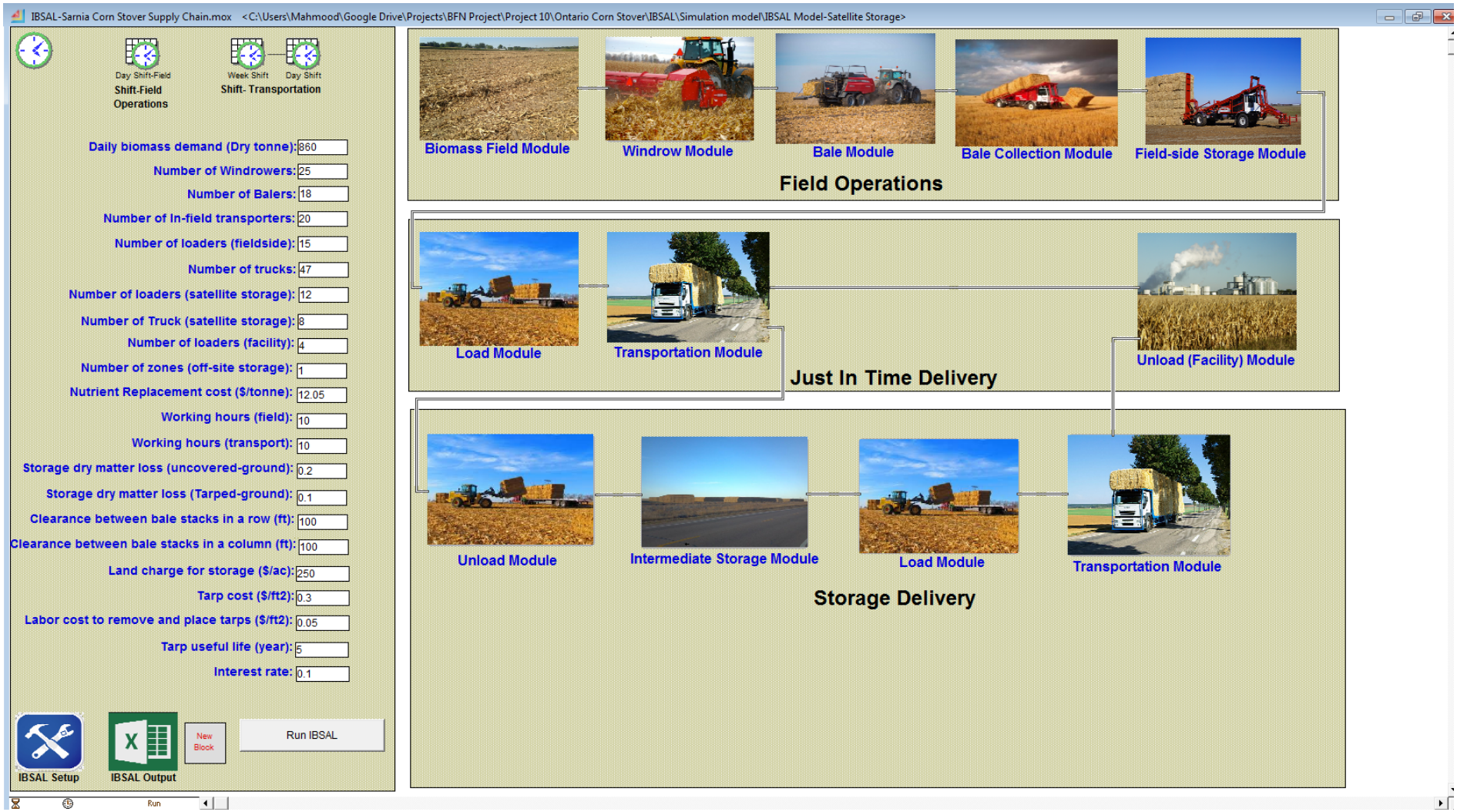
Truck and flatbed trailer

Bale collector /stacker

Telescopic loader

Sources: Stinger Inc., 2016; Morris-industries, 2014; Shah, 2013; Gutesa, 2013; AGCO, 2015.

Snapshot of baling scenario in IBSAL



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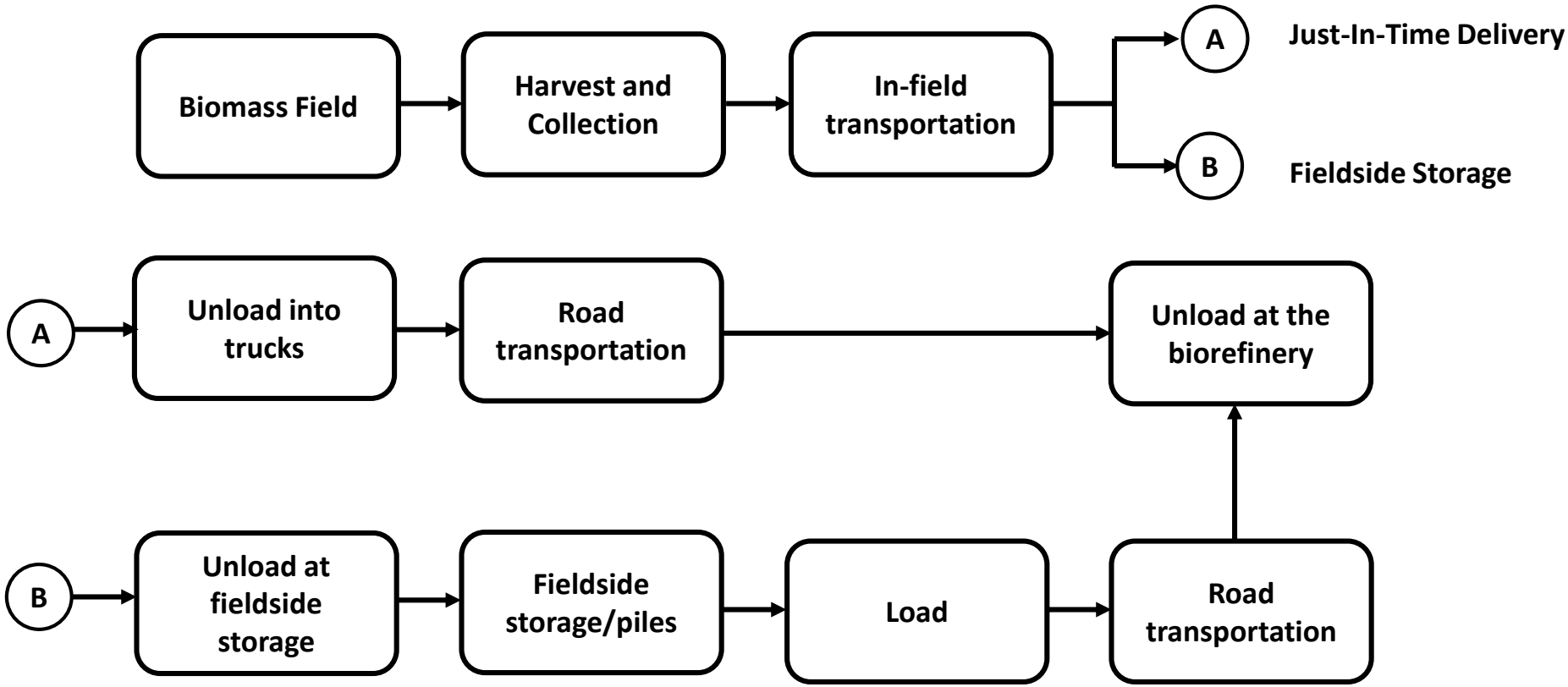
Chopping scenario modeled in IBSAL



- The chop scenario is developed based on the existing agricultural machinery used to harvest biomass crops and forage crops.
- This scenario is considered for miscanthus, switchgrass, willow and poplar.

Equipment used in chopping scenario

Forage harvester

Dump Wagon

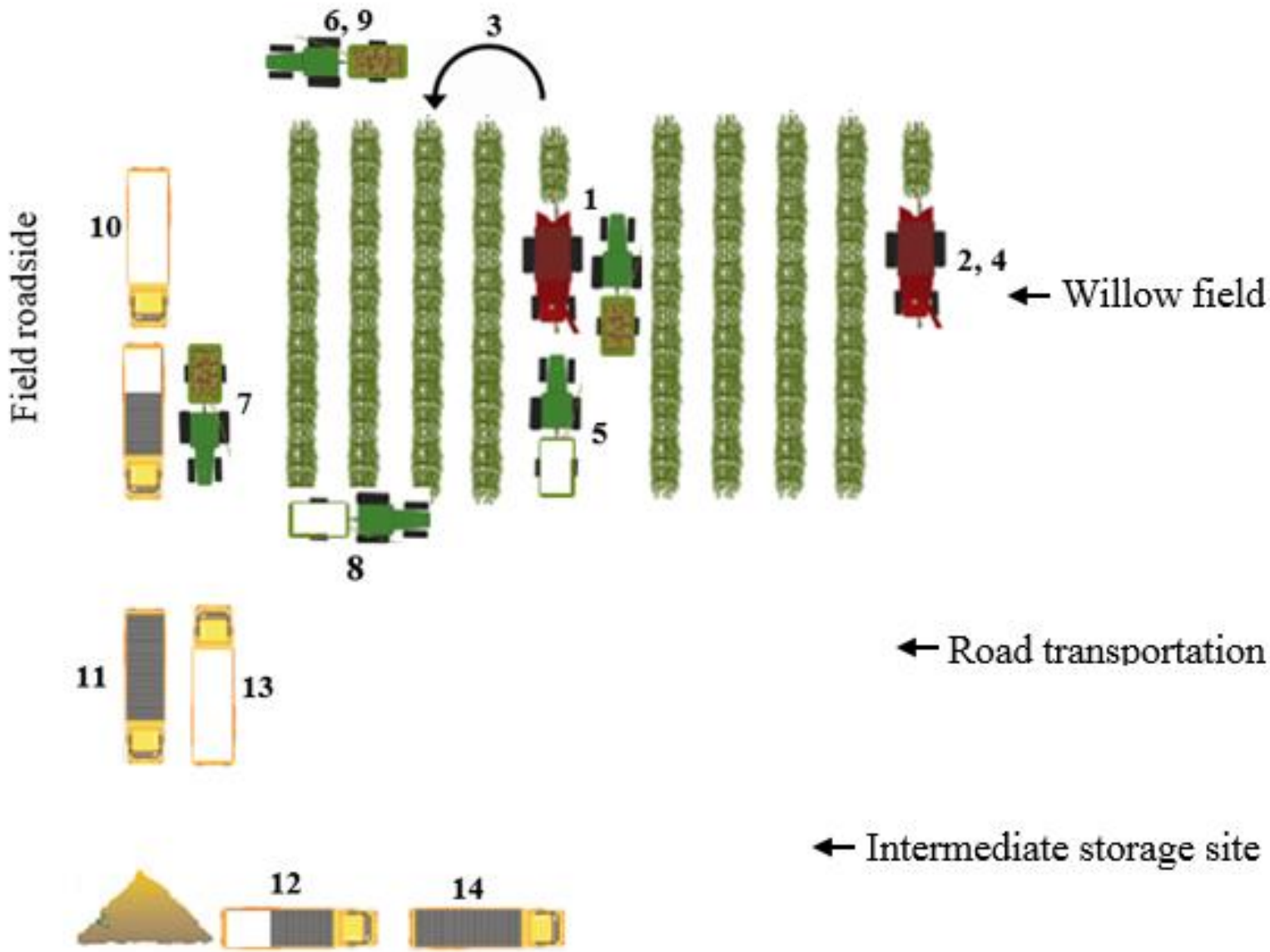
Dump Truck/
Silage truck

Tractor (180-220hp)

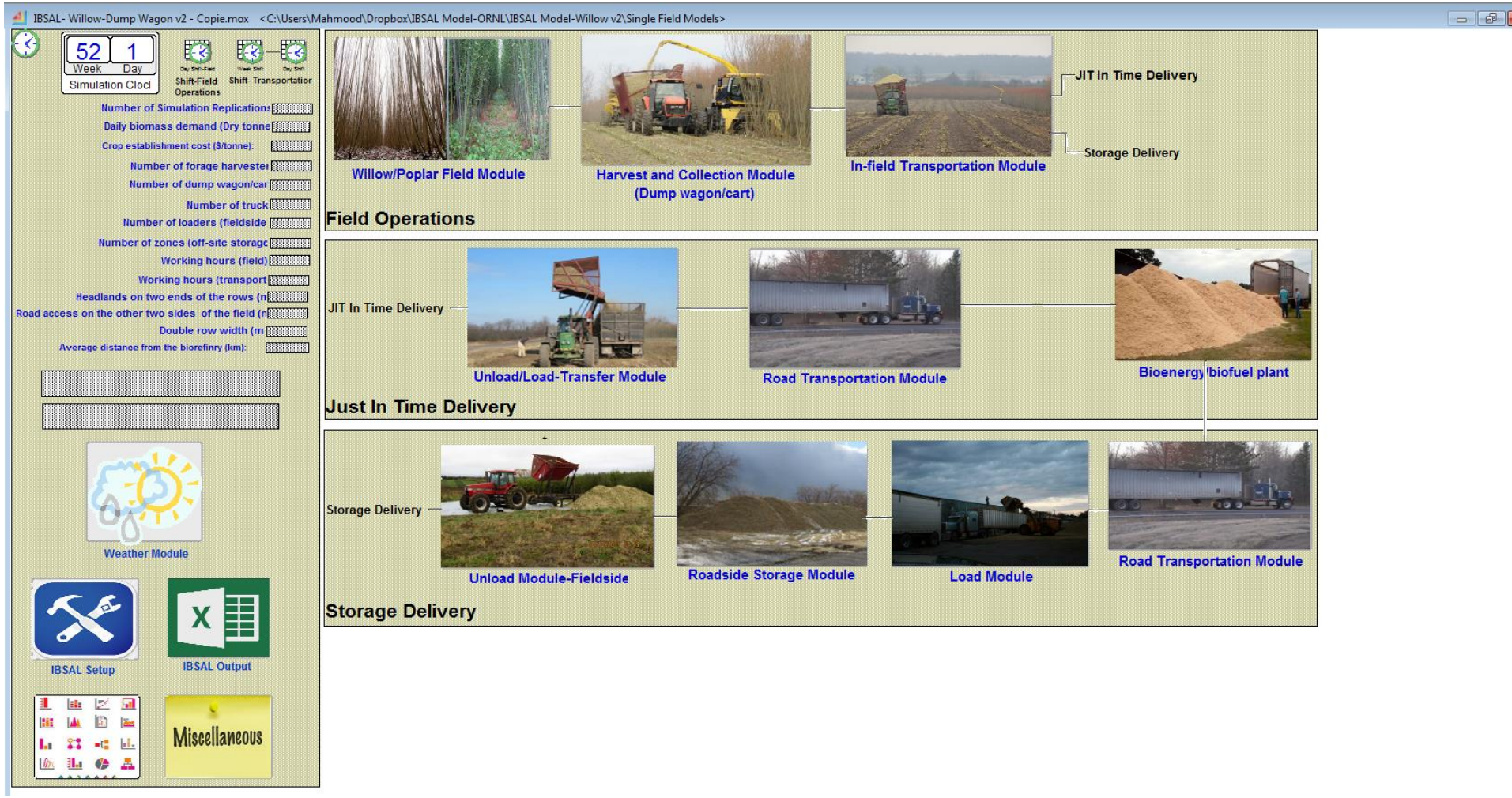
Agricultural telehandler/Wheel loader

18-wheeled chips truck and trailer

Example of chopping harvest system in IBSAL



Snapshot of chopping scenario in IBSAL



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Examples of modules developed in IBSAL

Harvest and collection

Input data

- Harvest season
- Working hours
- Daily biomass demand
- Moisture content
- Biomass removal rate
- Farm size
- Supply radius
- Weather condition
- Equipment data

Output data

- Baling cost ($/dt)
- Number of equipment
- Number of bales and bale density
- Utilization rate
- Dry matter loss
- Energy input and the associated emission

Baling module in IBSAL

Photo: http://www.us.all.biz/large-square-balers-hesston-2100-series-g84883#.Vfc0IxHBzRY

Storage

Input data

- Location of farms and the biorefinery
- Annual biomass demand
- Moisture content
- Fire code
- Bale type and size
- Quality specification
- Weather condition

Output data

- Storage cost ($/dt)
- Number and size of storage sites
- Storage configuration
- Utilization rate
- Dry matter loss
- Inventory planning and scheduling

Storage module in IBSAL

Photo: http://vitalbypoet.com/stories/it-all-starts-with-biomass

Transportation

Input data

Location of storage sites and the biorefinery →

Daily biomass demand →

Moisture content →

Truck configuration →

Road class →

Output data

→ Transportation cost ($/dt)

→ Number of trucks

→ Truck scheduling

→ Utilization rate

→ Energy input and the associated emission

Transportation module in IBSAL

Photo: www.visualphotos.com

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Pre-processing

Input data

Quality specification of the conversion reactor

Quality of delivered biomass (moisture content, particle size, ash content,..)

Output data

Pre-processing cost ($/dt)

Type of preprocessing (grinding, drying,…)

Utilization rate

Dry matter loss

Energy input and the associated emission

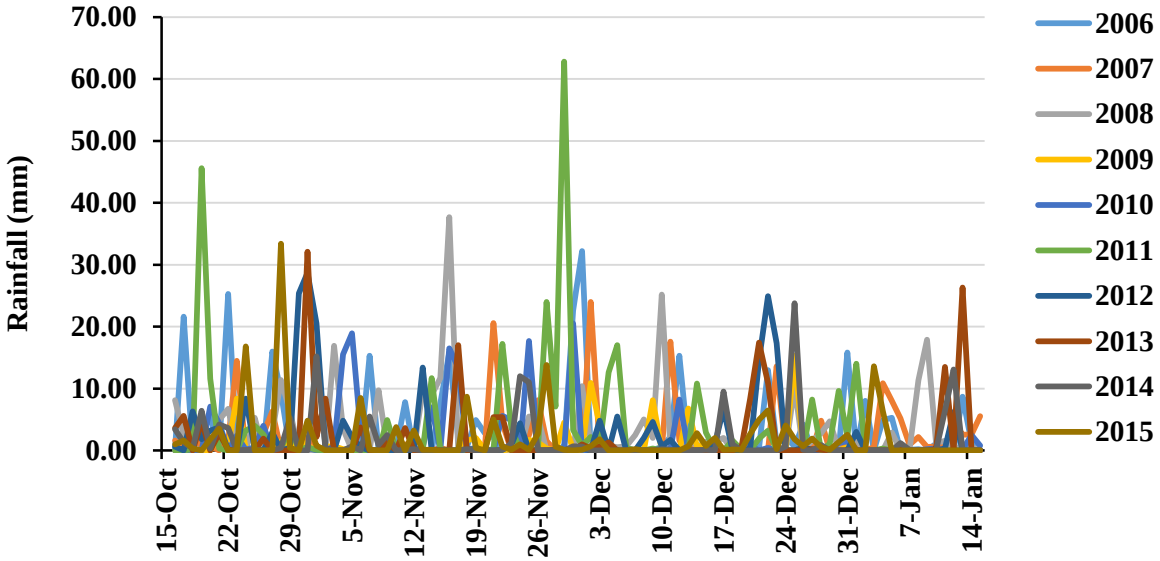
Pre-processing module in IBSAL

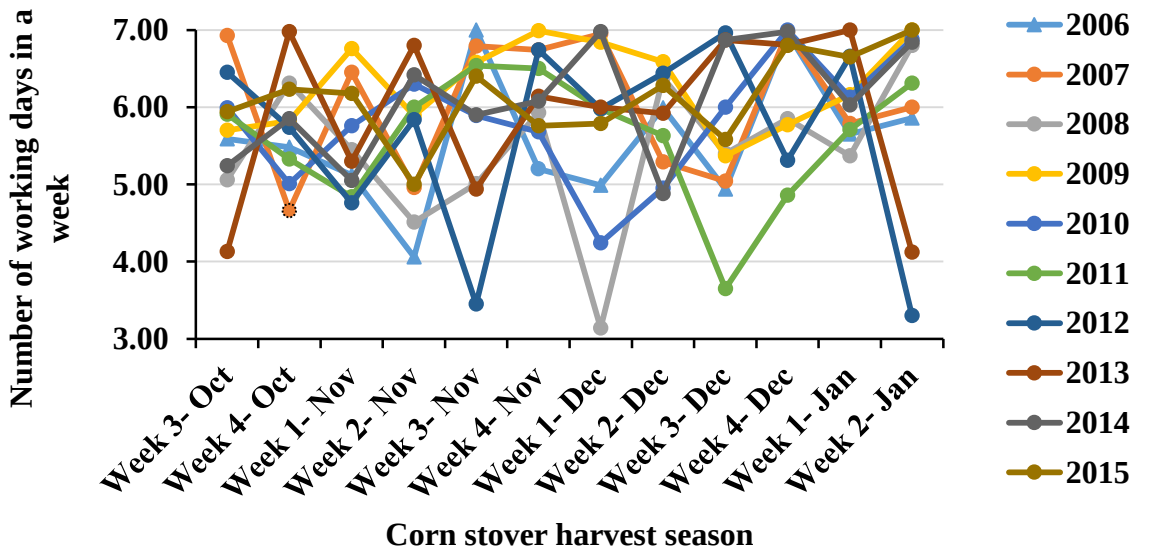
Photo: Sokhansanj, 2015- Pricing INL-PDU operations

Examples of input data in IBSAL

Examples of Variable Input Parameters

- biomass yield
- harvest window
- harvest moisture content
- bale bulk density
- farm participation rate
- dry matter loss
- equipment capacity and efficiency
- machine breakdown and repair times
- winding factor and road transportation timel





Variability in logistics data

Parameter	Value
Moisture content	Ave.: 44.4, S.D.: 2.2
Bulk density-willow chips (kg/m3)	[170,260]
Failure interval time (h) Repair interval time (h)	Exp (10h) Exp (1h)
Biomass no collected and left on the field (% of standing biomass)	[4,9]
Turn time at headlands (min)	[0.5,4.5+]
Percentage of total unplanted area in a parcel (%)	[13,28]
Harvester field speed (km/h)	[2,9]
Travel speed (km/h)- collection equipment	Cane wagon: Ave. 5.8, S.D. 2.4 Dump cart: Ave. 3.9, S.D.: 1.2 Forage wagon: Ave. 5.8, 2.4 Silage truck: Ave.: 14.6, 3.1 18-wheeled truck: Ave. 64.3, S.D. 28.1

Input Data- Harvester

Equipment characteristics	Value
Purchase price (US$)	480,000 (harvester + 130 FB coppice header)
Economic life (yr)	7
Power (kW)	510
Operational width (m)	2.29
Field speed (km/h)	[2, 9]
Biomass no collected and left on the field after harvesting operations (% of standing biomass)	[4, 9]
Turn time at headlands (min)	[0.5, 4.5+]
Set time to failure Set time to repair	Exp (10h) Exp (1h)
Willow chips- moisture content at harvest time (wet basis, %)	Ave.: 44.4 S.D.: 2.2
Bulk density of harvested wood chips (kg/m^3)	[170, 260]
Percentage of total unplanted area in a parcel (%) (headlands, road access, un-cleared obstructions, failed establishment, wet areas, ditches etc.)	[13,28]

Input Data- Collection and transportation equipment

Equipment data	Collection and transportation equipment				
	Cane wagon + tractor	Dump cart + tractor	Forage wagon + tractor	Silage truck	18-wheeled chip trailer + truck
Purchase price (US$)	Wagon: 40,500 Tractor: 115,000	Wagon: 23,000 Tractor: 65,000	Wagon: 31,500 Tractor: 95,000	70,000	Trailer: 72,000 Truck tractor: 120,000
Economic life (yr)	Wagon: 5 Tractor: 12	Wagon: 5 Tractor: 12	Wagon: 5 Tractor: 12	8	Trailer: 8 Tractor: 12
Tractor power (hp)	105	78	97	261	336
Load volume (m^3)	34	13	21	51	89
Travel speed-full (km/h)*	Ave.: 5.8 S.D.: 2.4	Ave.: 3.9 S.D.: 1.2	Ave.: 5.8 S.D.: 2.4	In-field transportation: Ave.: 14.6 S.D.: 3.1 Road transportation Ave.: 47 S.D.: 15.1	Ave.: 64.3 S.D.: 28.1

Input Data- Collection and transportation equipment

Equipment data	Collection and transportation equipment				
	Cane wagon + tractor	Dump cart + tractor	Forage wagon + tractor	Silage truck	18-wheeled chip trailer + truck
Travel speed-empty (km/h)*	Ave.: 8.2 S.D.: 2.7	Ave.: 6.3 S.D.: 2.2	Ave.: 8.2 S.D.: 2.7	In-field transportation: Ave.: 15.7 S.D.: 5.2 Road transportation Ave.: 51 S.D.: 16.3	Ave.: 76 S.D.: 28
Unload time (min)	[2.5,4]	[2.5,4]	[2.5,4]	[1.25,6.25]	[15,20]
Dry matter loss (%)	[0, 2]	[0, 2]	[0, 2]	[0, 2]	Negligible
Winding factor	[1, 1.2]	[1, 1.2]	[1, 1.2]	[1, 1.5]	[1, 1.5]
Set time to failure Set time to repair	Exp (10h) Exp (0.25hr)	Exp (10h) Exp (0.25hr	Exp (10h) Exp (0.25hr	Exp (10h) Exp (0.25hr	Exp (10h) Exp (0.25hr

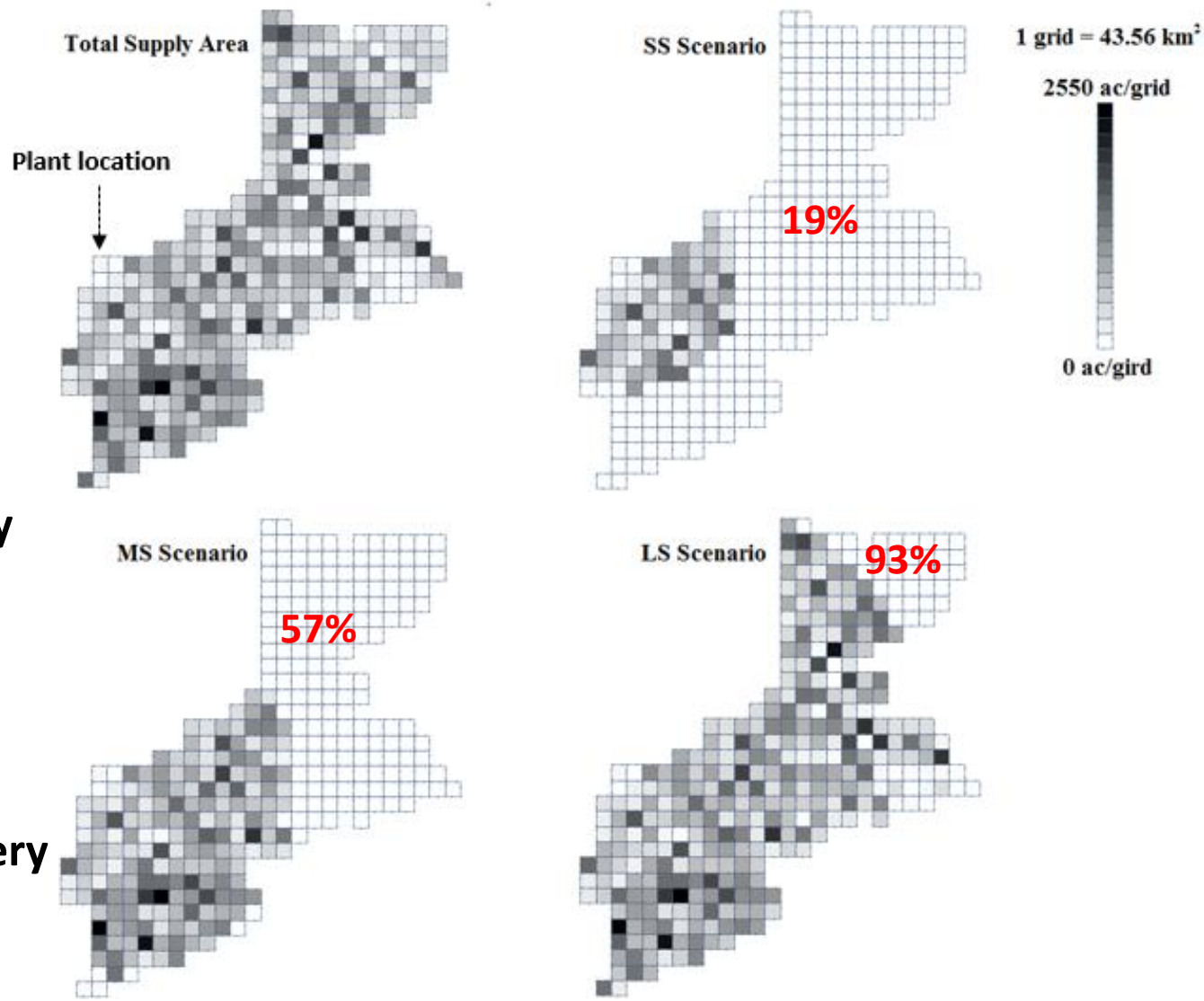
Examples: Outputs of IBSAL

Harvest area (ac) based on the size of the biorefinery

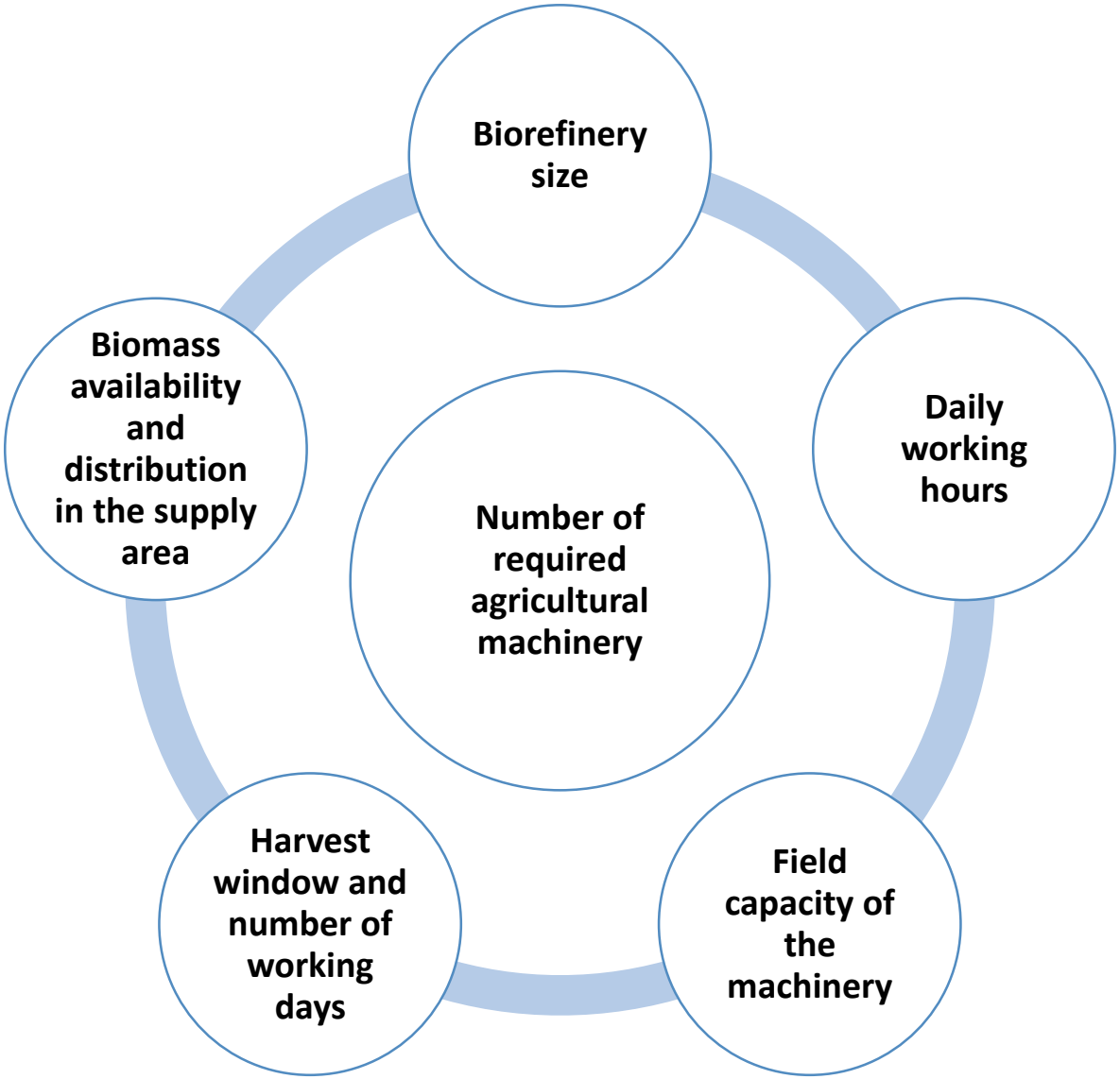
Small-scale biorefinery scenario (175 dry tonne/day)

Mid-scale biorefinery scenario (520 dry tonne/day)

Large-scale biorefinery scenario (860 dry tonne/day)



Major factors impacting the number of agricultural machinery to mobilize biomass in commercial quantities

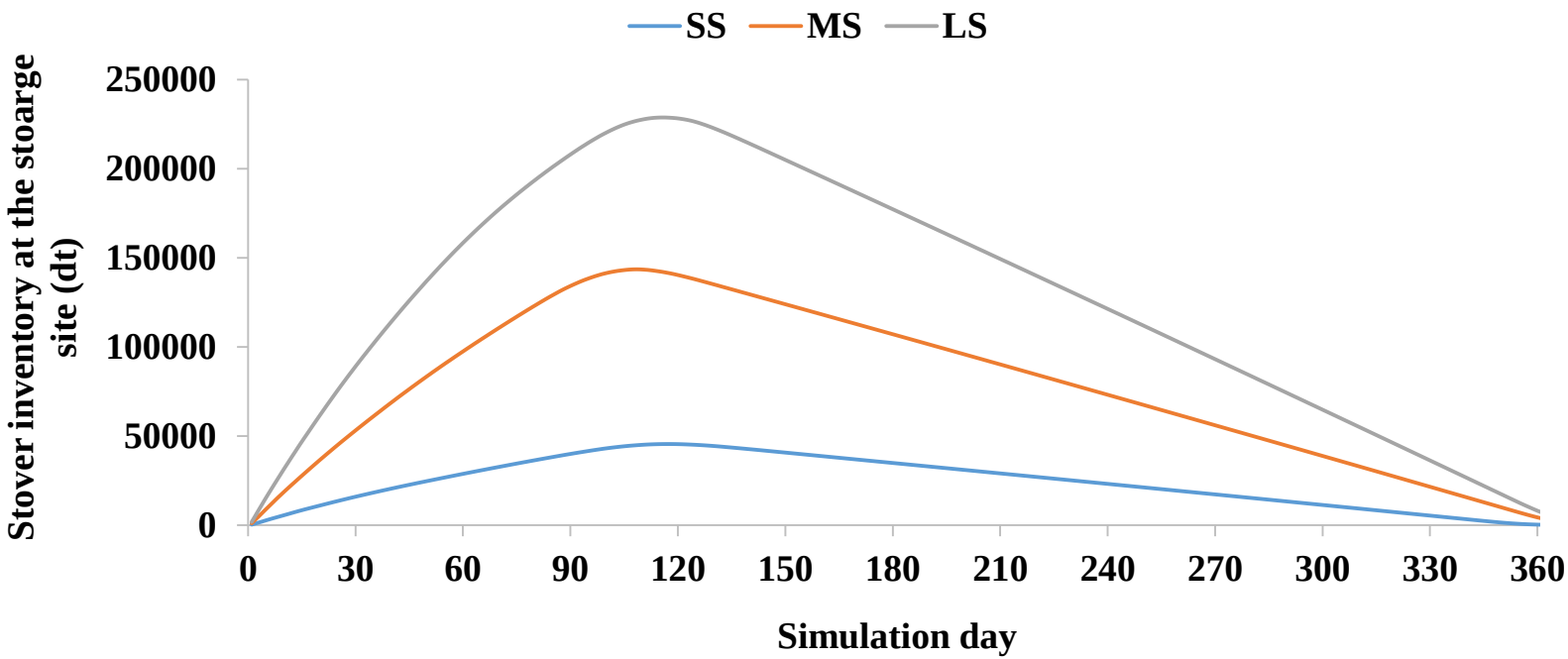


Number of logistics equipment and workforce

Equipment	Small-scale biorefinery scenario (175 dry tonne/day)			Mid-scale biorefinery scenario (520 dry tonne/day)			Large-scale biorefinery scenario (860 dry tonne/day)		
	Number of machines	Economic value ($)	Number of operators	Number of machines	Economic value ($)	Number of operators	Number of machines	Economic value ($)	Number of operators
Cornstalk shredder	7	245,000	-	23	805,000	-	38	1,330,000	-
Square baler	7	980,000	-	22	3,080,000	-	36	5,040,000	-
Bale collector/stacker	7	1,750,000	7	23	5,750,000	23	38	9,500,000	38
Tractor (185-220 hp)	14	2,800,000	14	45	9,000,000	45	74	14,800,000	74
Telescopic bale loader-roadside of corn fields	3	-	3	16	-	16	28	-	28
53-ft flatbed trailer truck- roadside of corn fields	9	-	9	36	-	36	65	-	65
Telescopic bale loader-intermediate storage site	3	27,0000	3	13	1,170,000	13	26	2,340,000	26
53ft-flatbed truck-intermediate storage site	3	58,5000	3	9	1,755,000	9	12	2,340,000	12
Telescopic bale loader-Cellulosic sugar facility	1	90,000	1	3	270,000	3	4	360,000	4
Total	54	6,720,000	37	190	21,830,000	136	321	35,710,000	235

Storage size and inventory level

Biorefinery scenario	Small-scale biorefinery scenario (175 dry tonne/day)	Mid-scale biorefinery scenario (520 dry tonne/day)	Large-scale biorefinery scenario (860 dry tonne/day)
Maximum inventory (dt)	45,563	143,564	228,759
Number of stored bales	92,596	291,763	464,903
Stack configuration (bales)	6 high, 6 wide and 60 long		
Number of stacks	47	136	216
Clearance between stacks (m)	30.5		
Total storage footprint (ac)	42.6	144.4	233.5



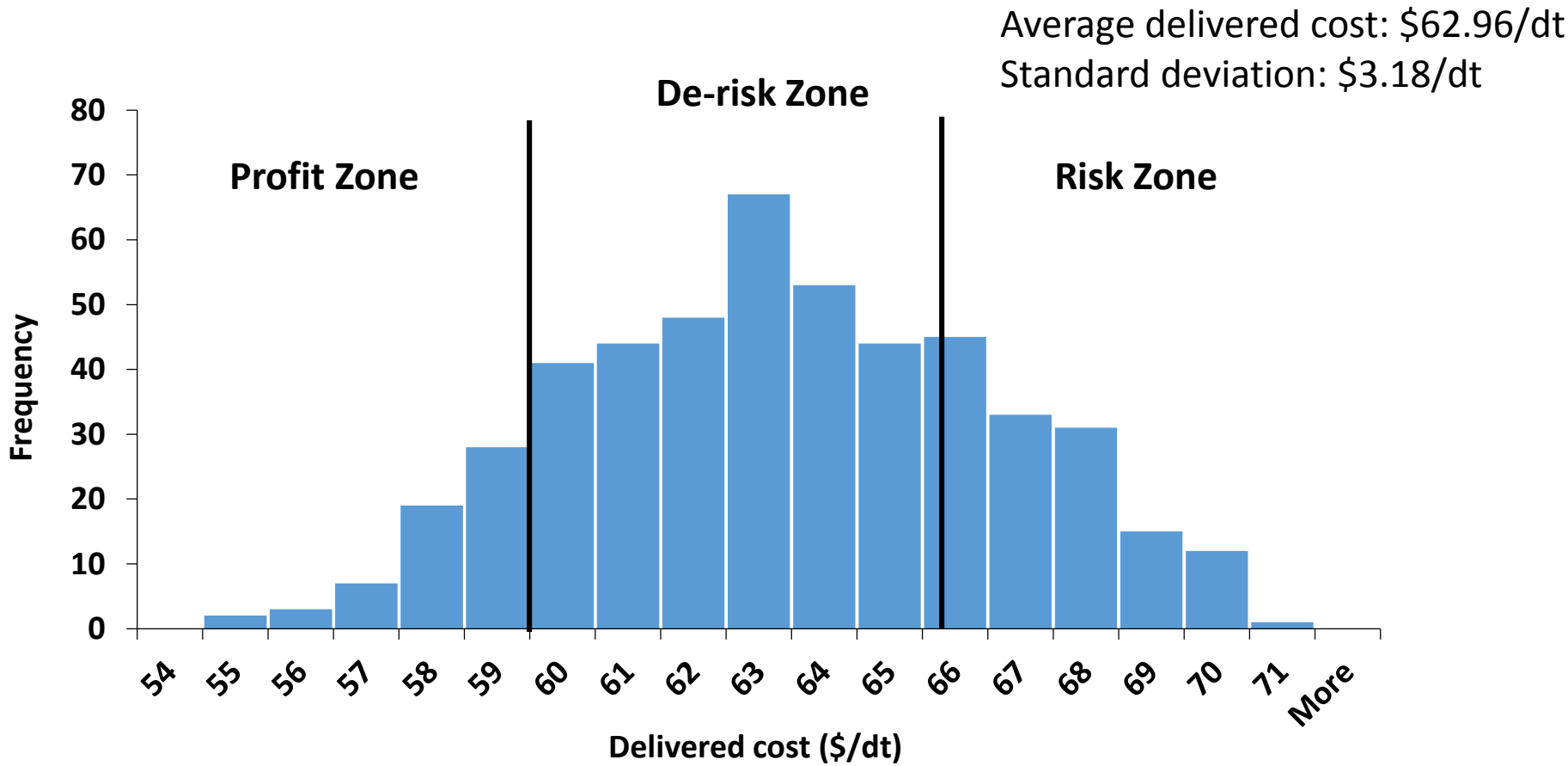
Biomass delivered costs- Average values

Cost component ($/dt)	Small-scale biorefinery scenario (175 dry tonne/day)	Mid-scale biorefinery scenario (520 dry tonne/day)	Large-scale biorefinery scenario (860 dry tonne/day)
Nutrient replacement	12.05	12.05	12.05
Shred and windrow	7.42	7.59	7.77
Bale	17.36	17.66	17.68
Bale collection/stack at the roadside	8.66	8.92	8.98
Load at the roadside	2.11	2.28	2.30
Transportation to the intermediate storage	26.62	34.39	42.81
Load & unload at the intermediate storage	1.66	1.70	1.77
Intermediate storage	9.09	9.37	9.80
Transportation to the bio-conversion facility	14.32	14.12	14.04
Unload at the facility	1.10	1.08	1.06
Total delivered cost	82.09	87.49	93.75

Biomass delivered costs

Biorefinery scenario	Small-scale biorefinery scenario (175 dry tonne/day)	Mid-scale biorefinery scenario (520 dry tonne/day)	Large-scale biorefinery scenario (860 dry tonne/day)
Maximum observed value ($/dt)	92.38	101.08	107.79
Average observed value ($/dt)	82.09	87.49	93.75
Minimum observed value ($/dt)	72.76	77.24	79.19
Standard deviation ($/dt)	3.97	4.56	5.18
Confidence interval	90%	90%	90%
Probability of achieving the target delivered cost	45.5%	9.2%	0.3%

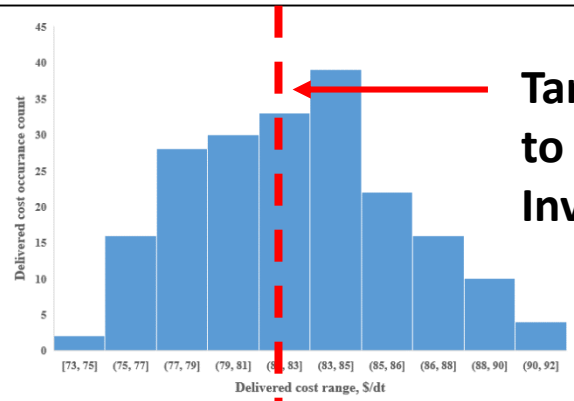
Biomass delivered costs distribution ($/ dry tonne)



- **In addition to the average costs, other information that can be extracted from the IBSAL are the standard deviation, percentiles to quantity the deviation from the target delivered cost and worse and best delivered costs.**

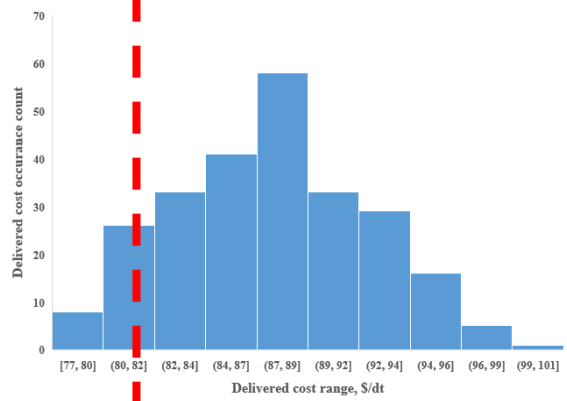
Biomass delivered costs

Small-scale biorefinery scenario (175 dry tonne/day)

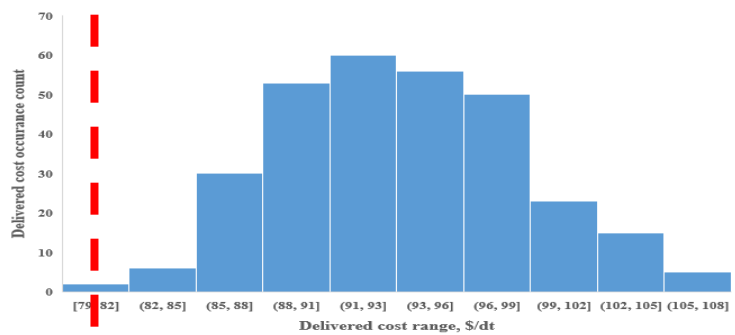


Target delivered cost ($81.33/dt) to meet the expected Return on Investment of 15%

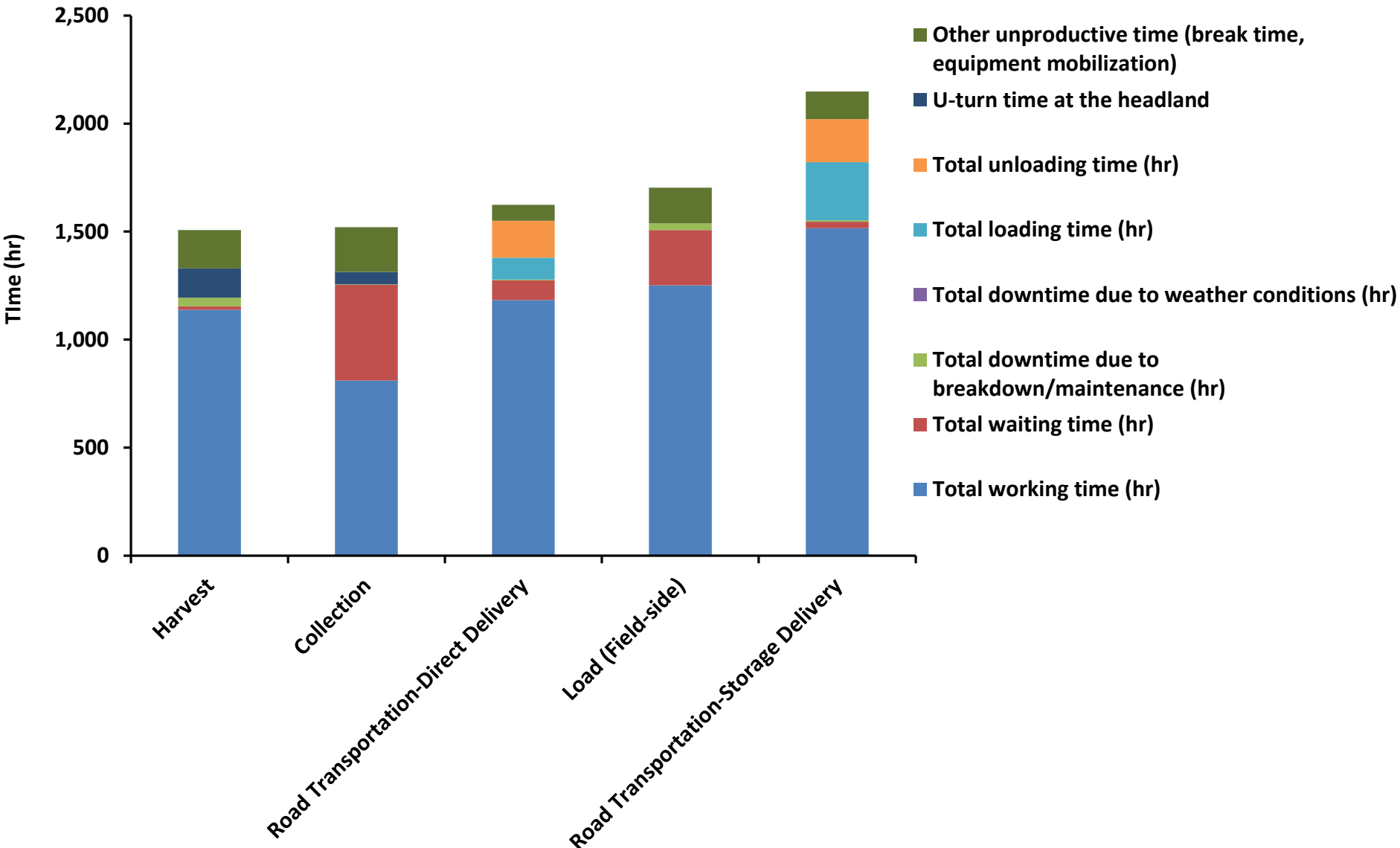
Mid-scale biorefinery scenario (520 dry tonne/day)



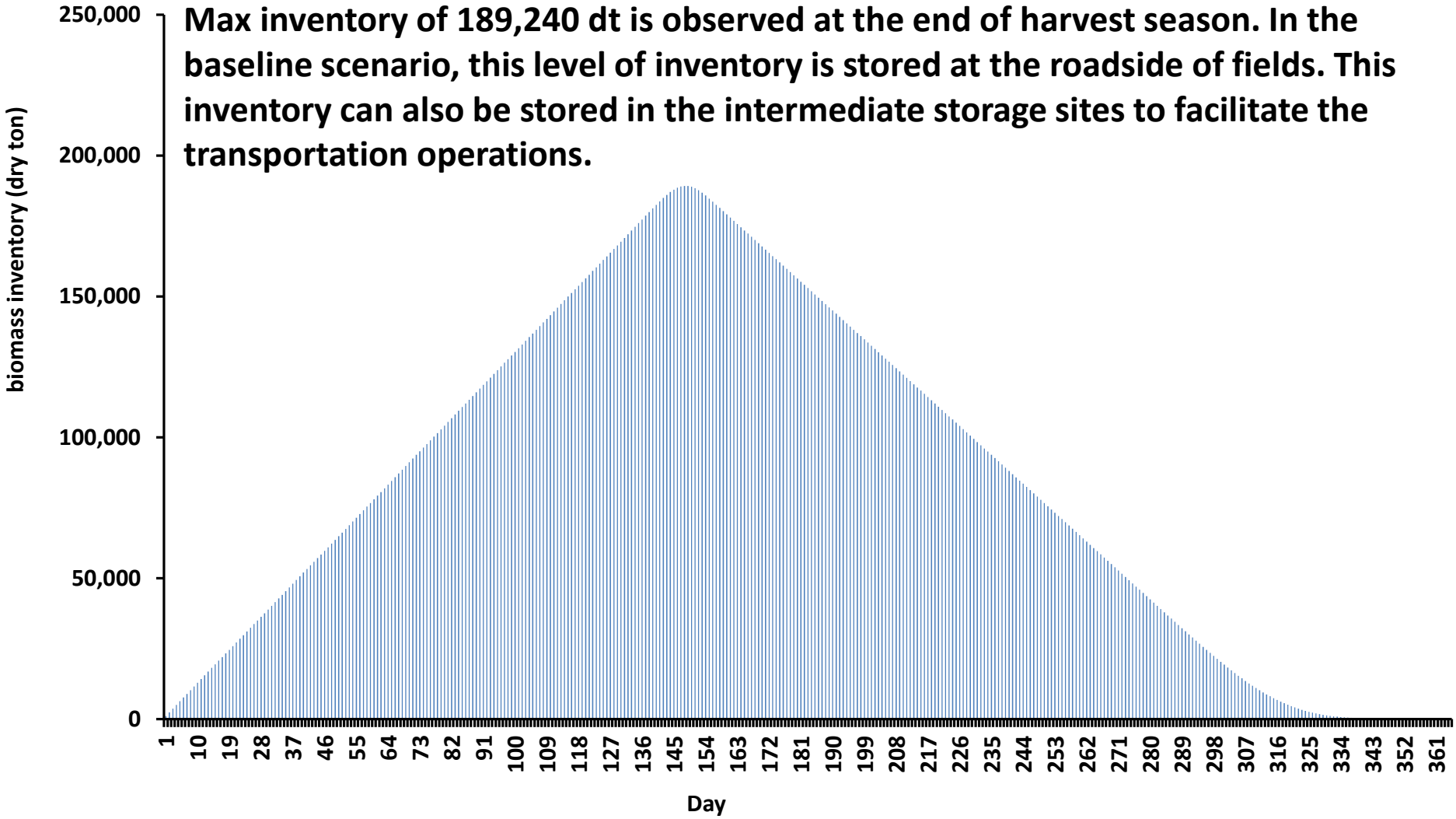
Large-scale biorefinery scenario (860 dry tonne/day)



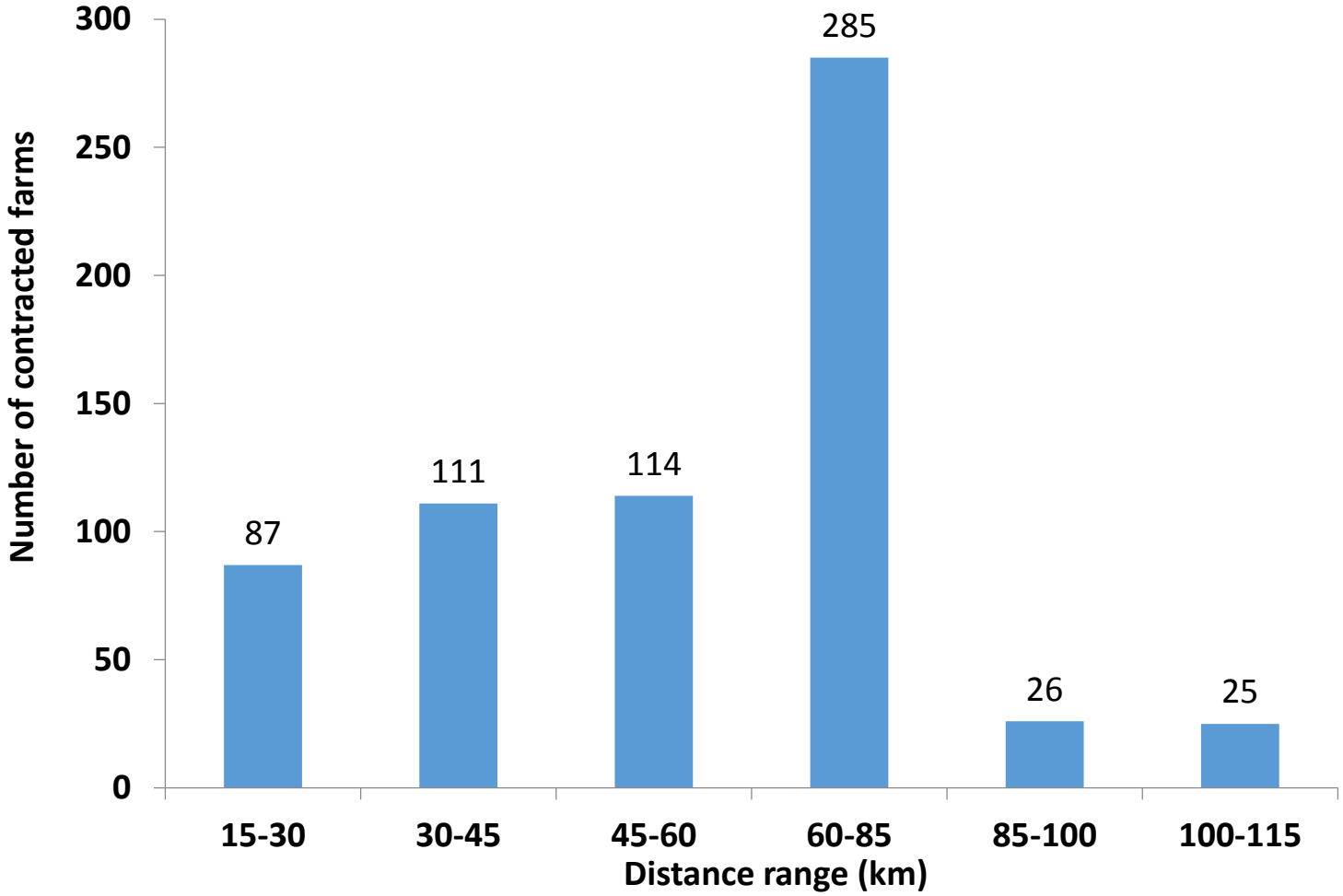
Equipment utilization



Daily biomass inventory trend



Number of contracted farms



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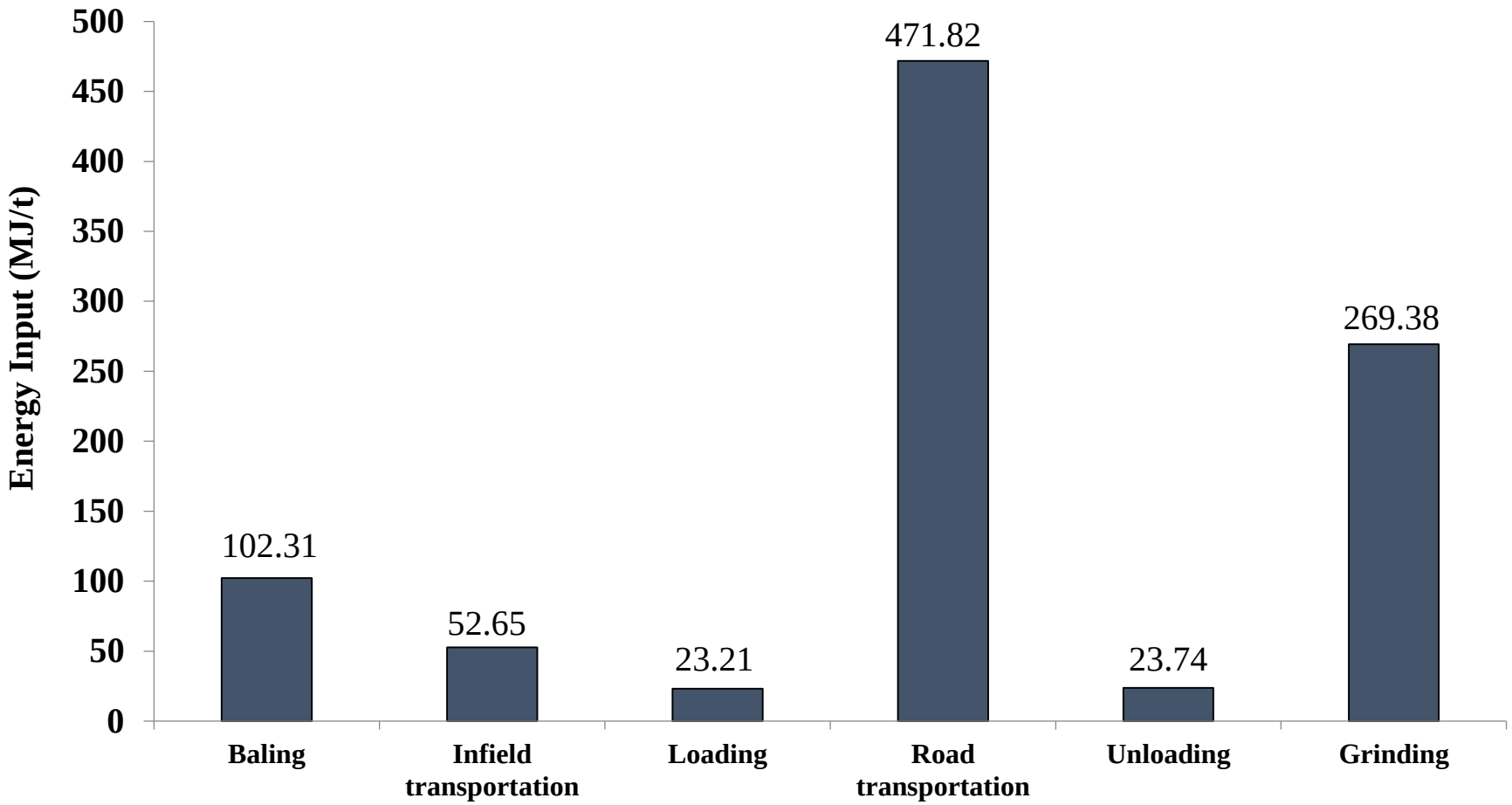
Energy Input (MJ/dt)- Logistics operations



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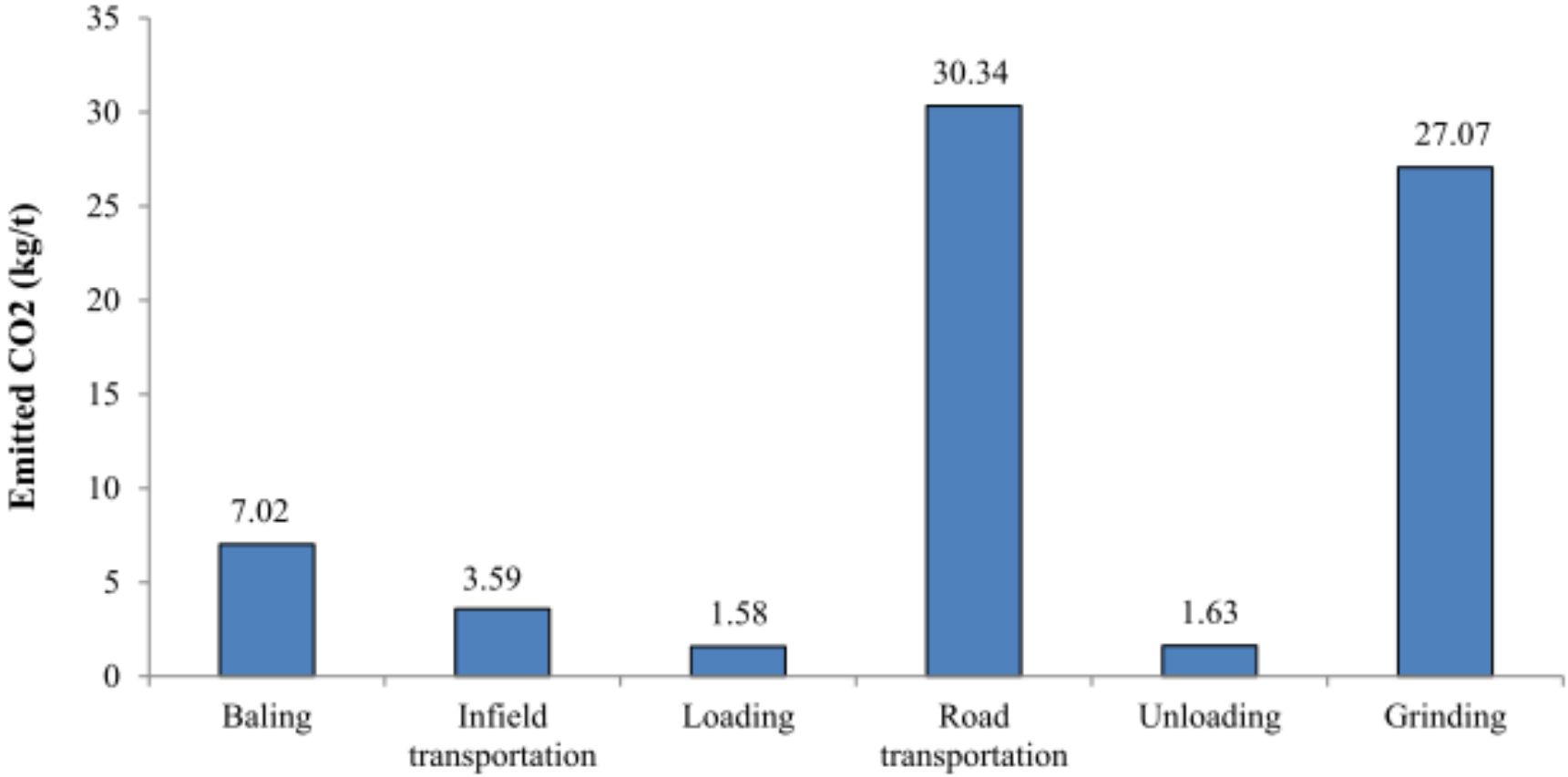
CO2 emissions (kg/dt)- Logistics operations



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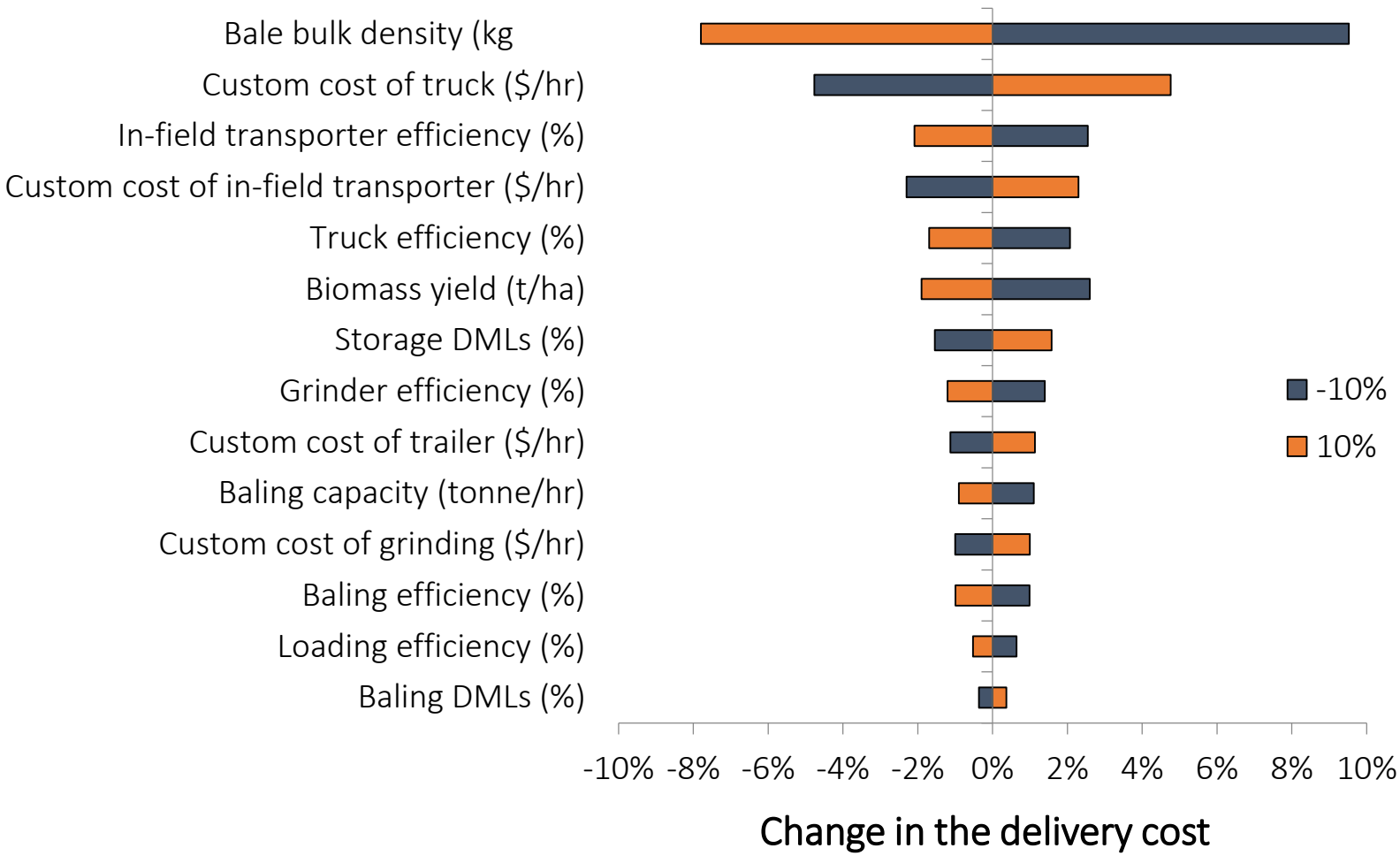
Sensitivity analysis



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