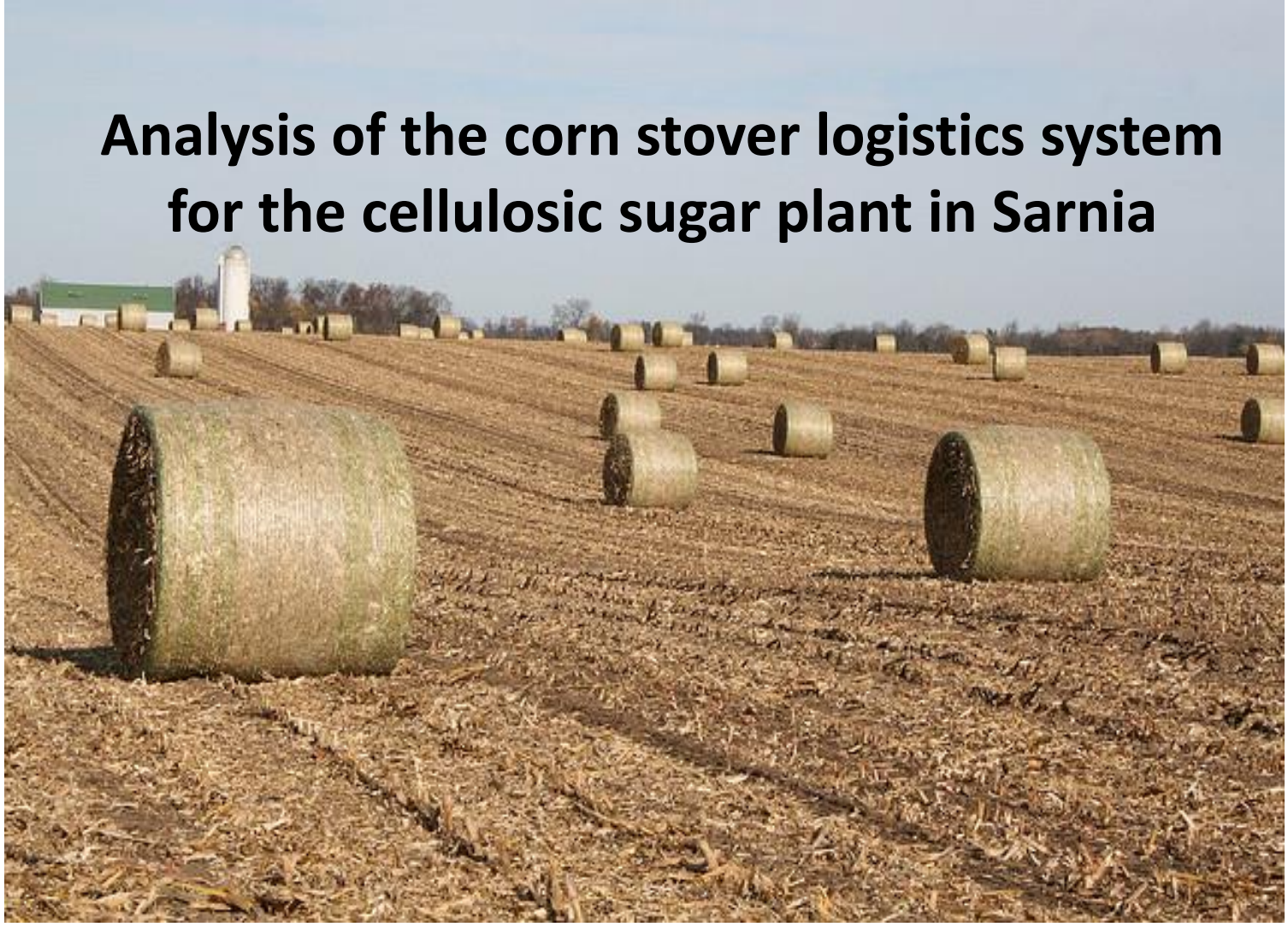
Analysis of the corn stover logistics system for the cellulosic sugar plant in Sarnia



Yu Wang, Mahmood Ebadian, Shahab Sokhansanj

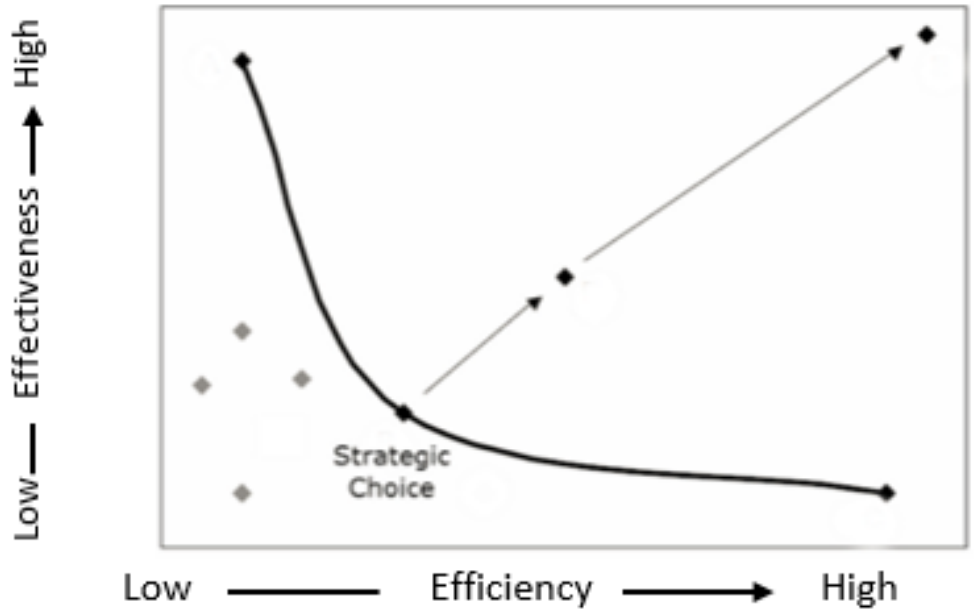
Biomass and Bioenergy Research Group
Chemical and Biological Engineering Department
The University of British Columbia

BBRG
BIOMASS.UBC.CA

UBC

Biomass supply chains have a myriad of trade-offs

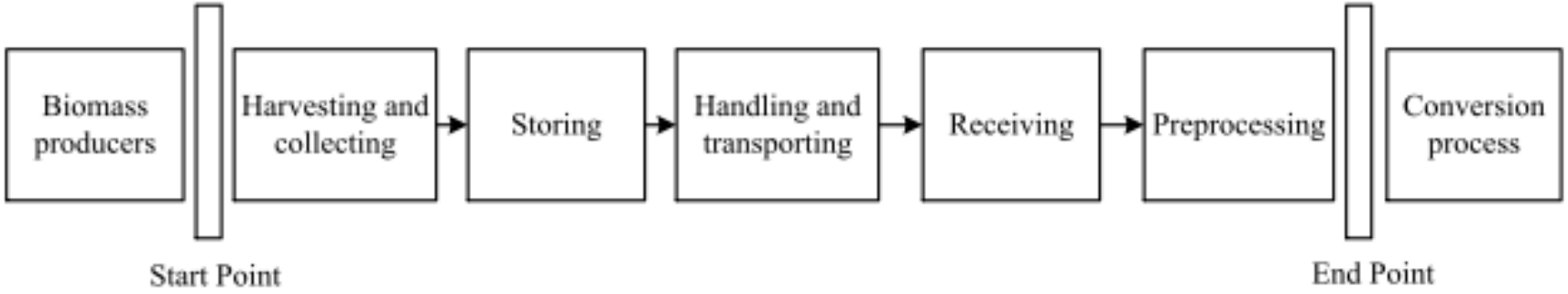
- **Majority of trade-offs stem from the physical properties and the chemical compositions of biomass (i.e. biomass characteristics).**
  - Type and size of logistics equipment
  - Onsite pre-processing and pre-treatment operations
  - Storage configuration
  - Size and location of the biorefinery
  - Biomass supply security and price stability



IBSAL- Integrated Biomass Supply Analysis and Logistics

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

- **An engineering and economic model**



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

IBSAL- Integrated Biomass Supply Analysis and Logistics

Input Data (IBSAL- Excel file)

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

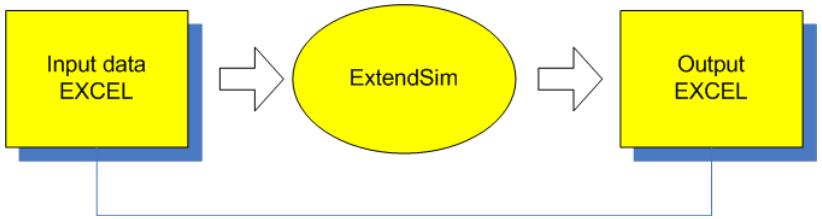
Harvest Schedule
- Harvest fraction decimal
- Moisture content fraction decimal

Crop Data
- Standard density of grain
- Standard grain moisture content
- Average biomass yield
- Yield to be deducted for conservation

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

Outputs (IBSAL- Excel file)

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

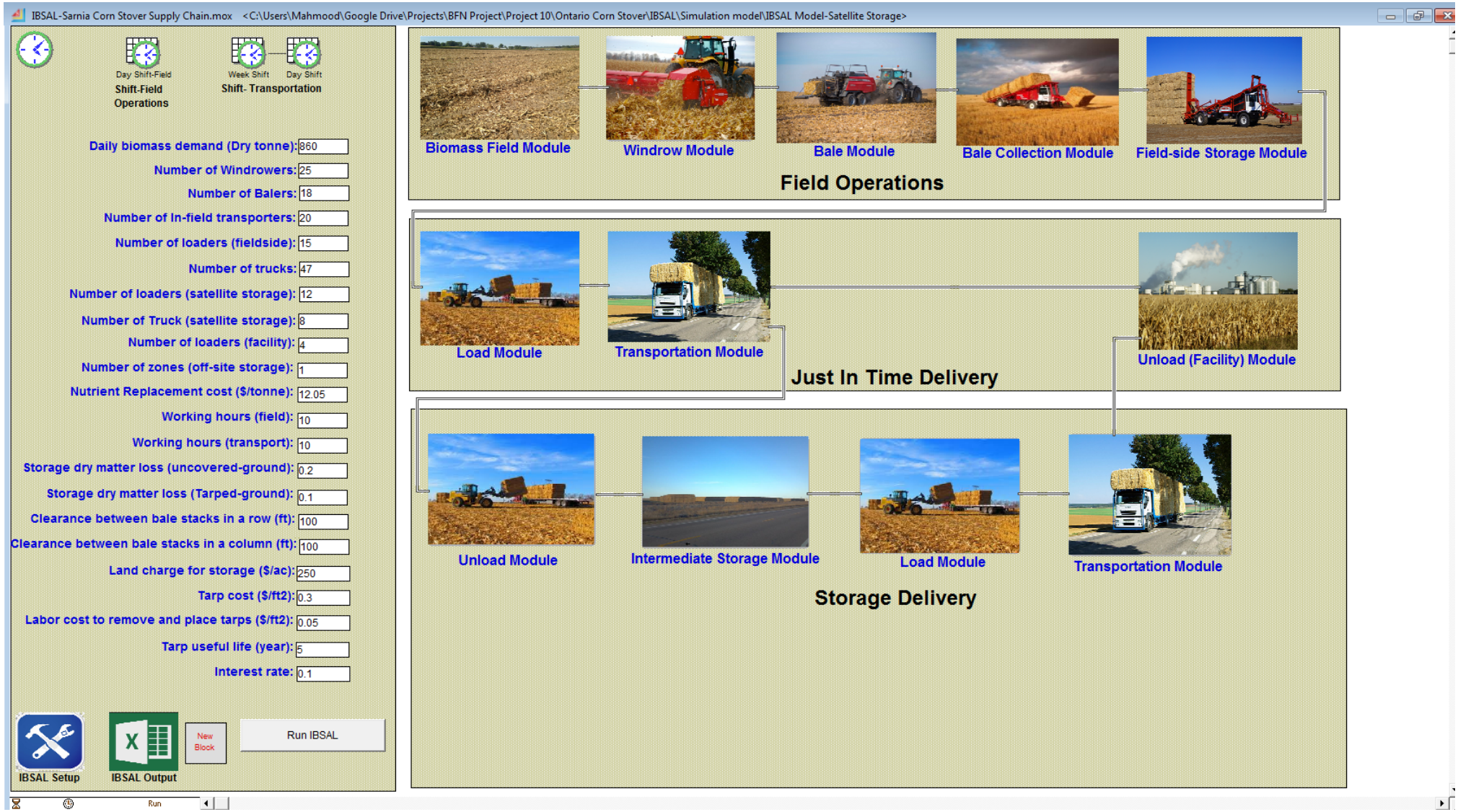
Energetic and environment output:
- Energy Input
- CO_2 Emission

Biomass recovery:
- Dry matter loss
- Net collected yield

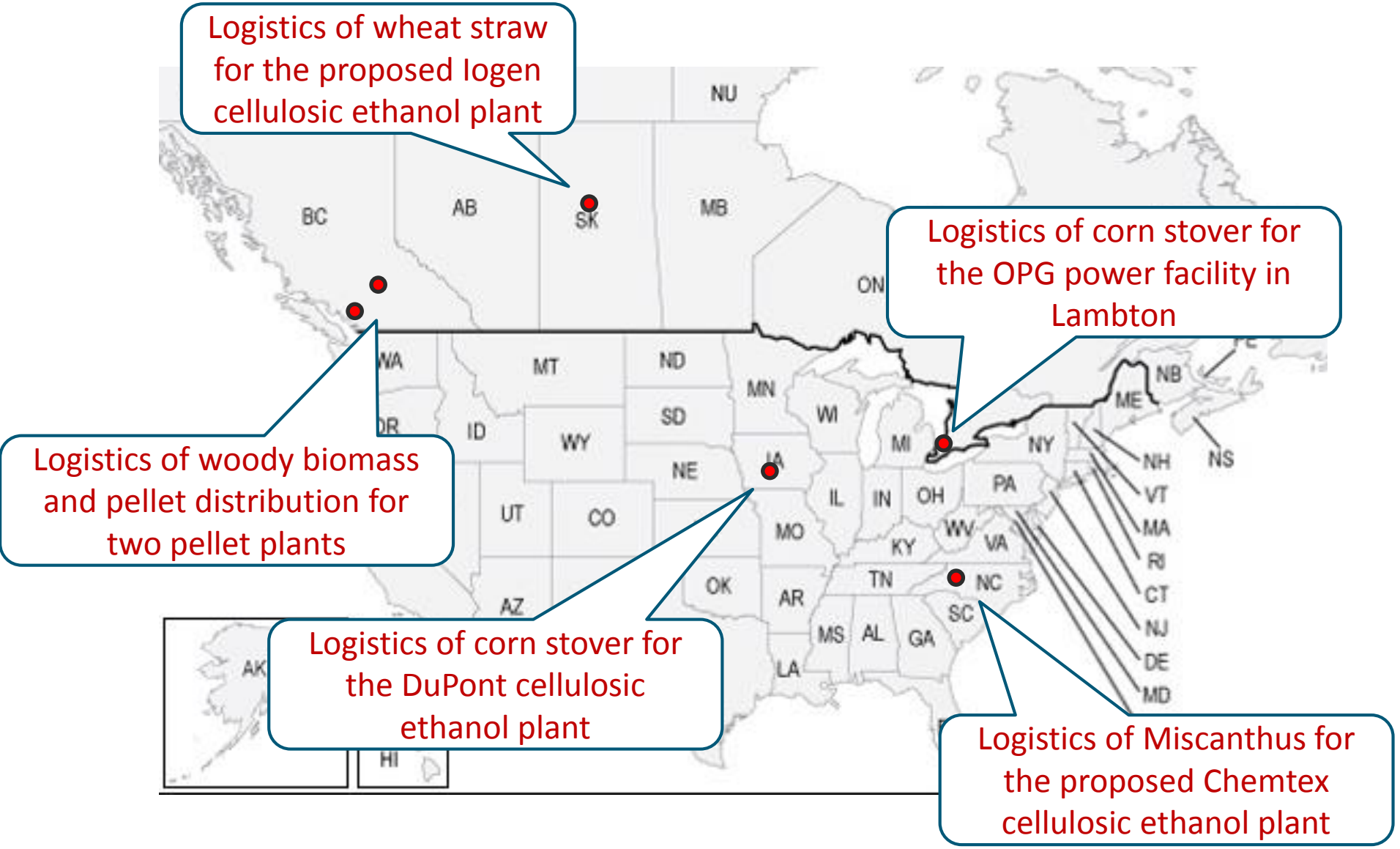
Resource output:
- Number of days to complete each operation
- Number of required machines
- Utilization rate for machineries
- The harvested area

Flow of information to and from IBSAL

Snapshot of the IBSAL model



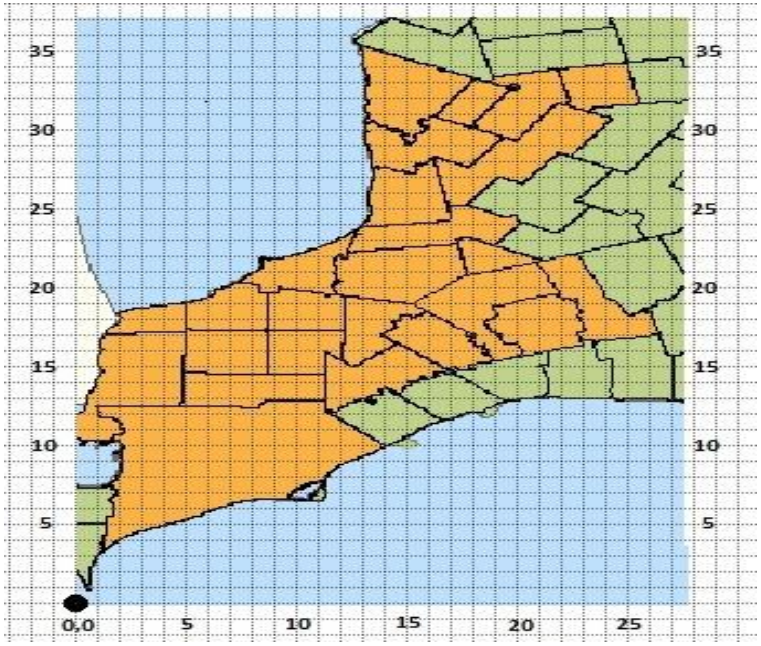
Applications in commercial cases



Corn Stover Supply Area

- **The corn stover supply area includes four counties of Lambton, Middlesex, Huron and Kent in Southwestern Ontario.**

Counties in Southwestern Ontario. Lambton, Middlesex, Huron and Kent are the major corn growing counties in this region. These counties make up the corn stover supply area in this study.



Corn stover supply area (in orange). Each polygon represents a township.

Assumptions- Base case scenario

- **Harvest Schedule**: 100% of the corn stover harvest takes place in fall (fall harvest). Fall harvest would commence on October 15, up to 90 days.
- **Facility Size**: the logistics system for two facility sizes will be evaluated including 175 dry tonnes/day and 860 dry tonnes/day.
- **Location of the cellulosic sugar plant:** The plant will be in the TransAlta Energy Park, Sarnia, ON.
- **Corn Yield:** Only high-yield corn fields (180+ bu/ac) are considered to supply stover to the cellulosic sugar plant. This would assure the sustainable removal of stover.
- **Removal rate**: The harvestable stover within the supply radius is estimated based on the amount of stover that is left behind in the field to maintain the soil organic carbon and mitigate the soil erosion.
- **Farm participation rate:** 100% participation rate of corn growers within the supply radius.
- **On-site and off-site storage sites**: three off-site and one on-site storage sites are considered to meet the daily demand of the cellulosic sugar plant throughout the year. The location of these storage sites are pre-determined by BIC.
- **Configuration of storage sites**: Stack configuration in each storage site is 6 bale high (18 foot), 6 bale wide (48 foot) and 60 bale long (240 foot). the clearance between stacks is assumed to be 100 ft.
- **Field-side storage**: The collected bales in each field are stored temporarily at the fieldside and then transported to the intermediate storage sites (off-site storage sites) within one week.
- **Type of delivered bales**: compacted square bales (3*4*8) based on AGCO data.
- **Working hours**: all logistics operations run for 10 hours in a day.
- **Variable input parameters**: Corn yield; number, size and location of corn fields; field efficiency and machine efficiency of logistics equipment; bale density; and initial moisture content of corn stover.

Harvest area (ac) and recovered corn stover (DT)

- Average harvestable stover yield in both scenarios is estimated to be 1.72 DT/ac.
- In 175 DT/day scenario, farms are located within a supply radius range of 55-66 km. This range is 114-140 km in 860 DT/day scenario.
- Maximum required area is estimated to be 43,674 and 216,159 acres in 175 and 860 DT/day scenarios, respectively. In these areas, about 75,120 and 371,800 DT of corn stover would be harvested.
- 12-15% of this volume would be lost during harvesting, collection, handling and storage operations. 27-33% of the dry matter loss would take place during storage time at storage sites.

Required Harvest Area (ac)

Harvest Area	175 DT/day	860 DT/day
Maximum	43,674	216,159
Average	41,889	214,961
Minimum	41,010	194,003

Delivered Cost ($/DT)

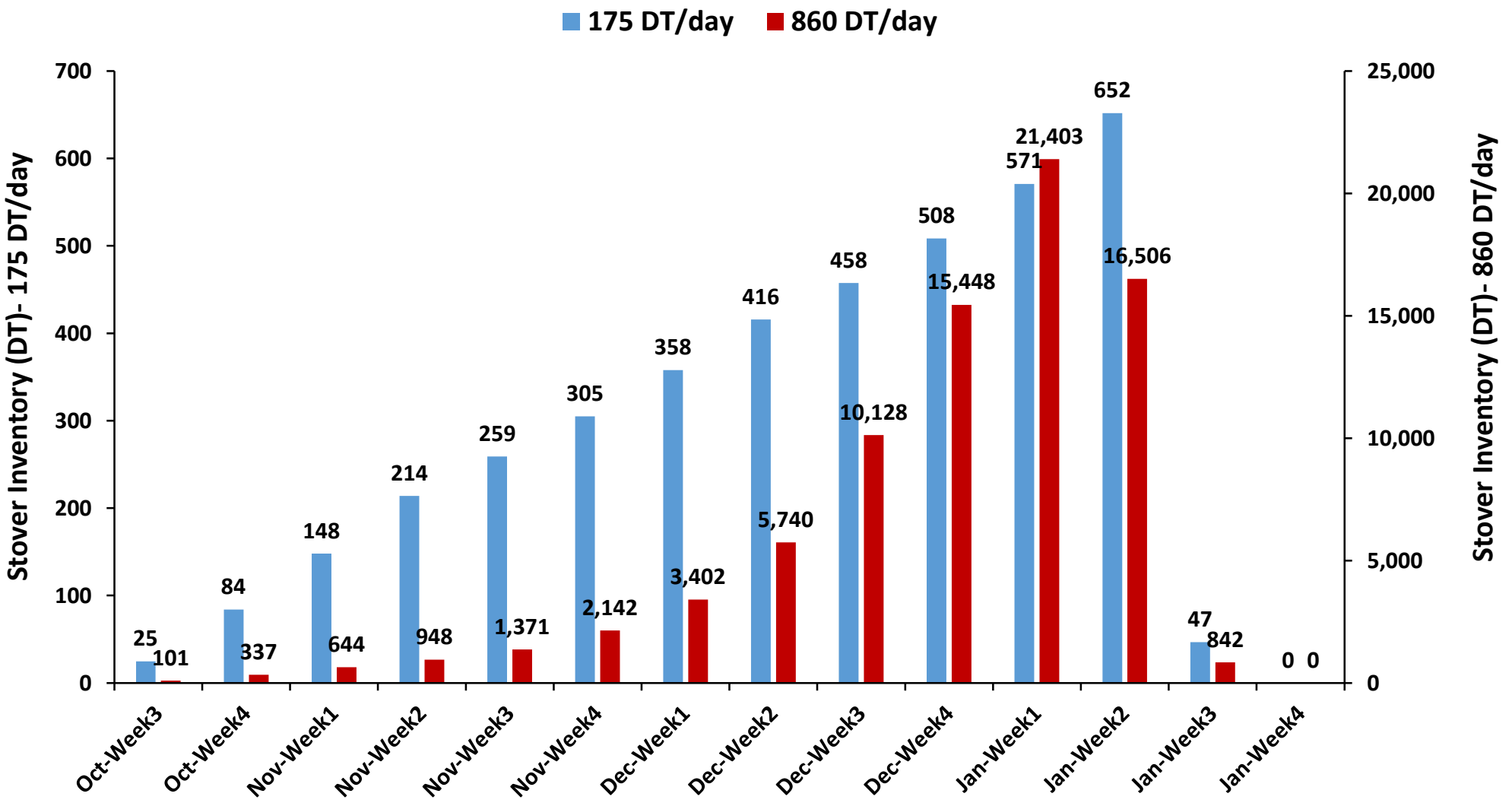
- **Delivered cost at the gate of the cellulosic sugar plant is estimated to be 73.33±1.66 $/DT in 175 DT/day scenario.**
- **Delivered cost at the gate of the cellulosic sugar plant is estimated to be 82.30±2.47 $/DT in 860 DT/day scenario.**

Average cost of logistics operations

Cost Component	175 DT/day	860 DT/day
	$/DT	$/DT
Fertilizer replacement	12.05	12.05
Chop and Windrow	6.59	6.64
Bale	14.03	14.10
In-field transportation	6.68	6.83
Load (Field-side)	2.61	2.61
Road Transportation	22.1	30.17
Unload/Load at Intermediate storage	2.04	2.02
Intermediate storage	5.91	6.48
Unload at the facility	1.39	1.40
Total logistics system	73.40	82.30

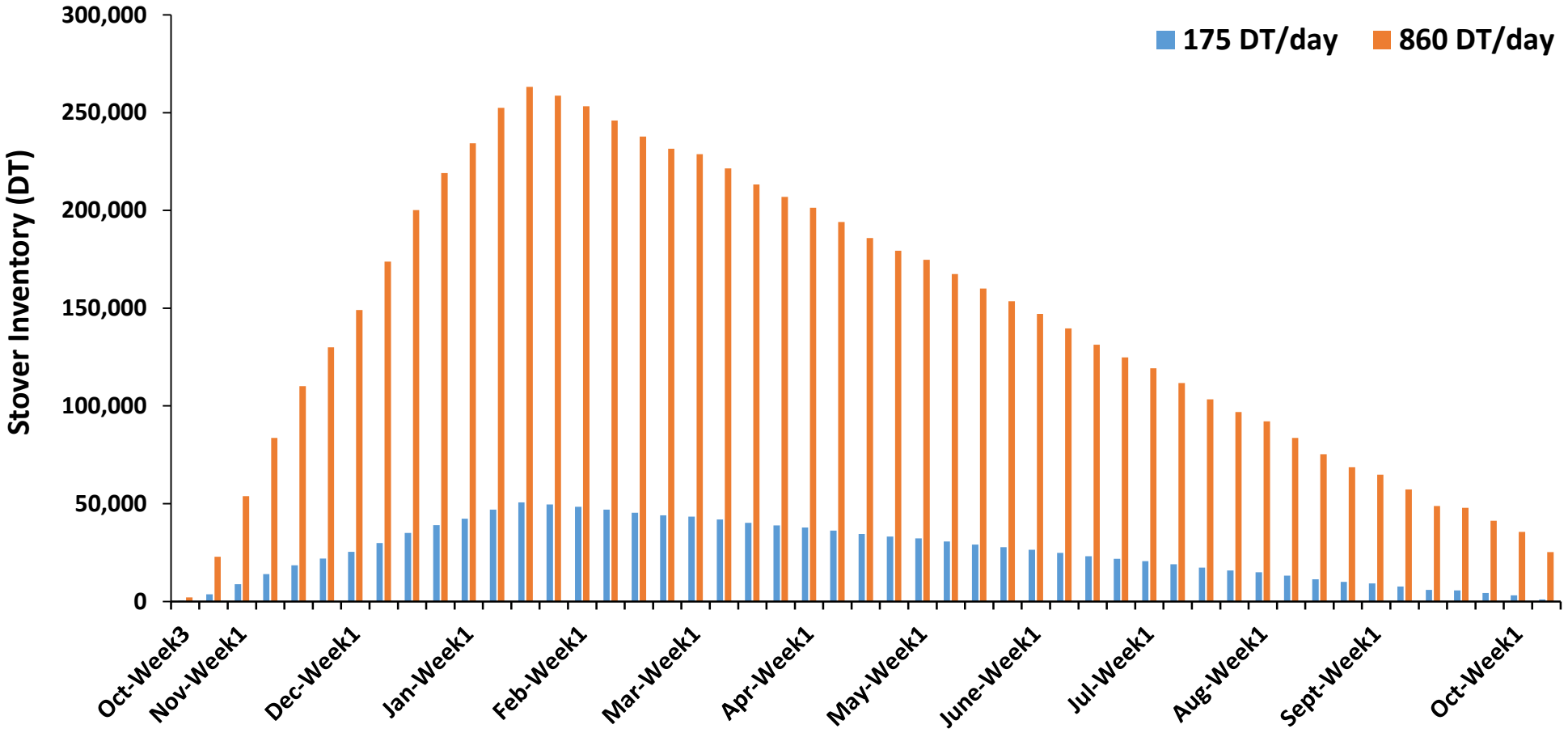
Note: road transportation includes transportation of bales from corn fields to the facility, from corn fields to the off-site storage sites and from the storage sites to the facility.

Temporary stover inventory at the roadside of corn fields



Stover inventory at off-site storage sites

- **Maximum observed inventory in 175 DT/day case was 50,672 DT (96,972 bales). The footprint of this amount of inventory is estimated to be about 45 acres.**
- **Maximum observed inventory in 860 DT/day case was 263,133 DT (503,566 bales). The footprint of this amount of inventory is estimated to be about 254 acres.**



Storage configuration and costs- off-sit storage sites

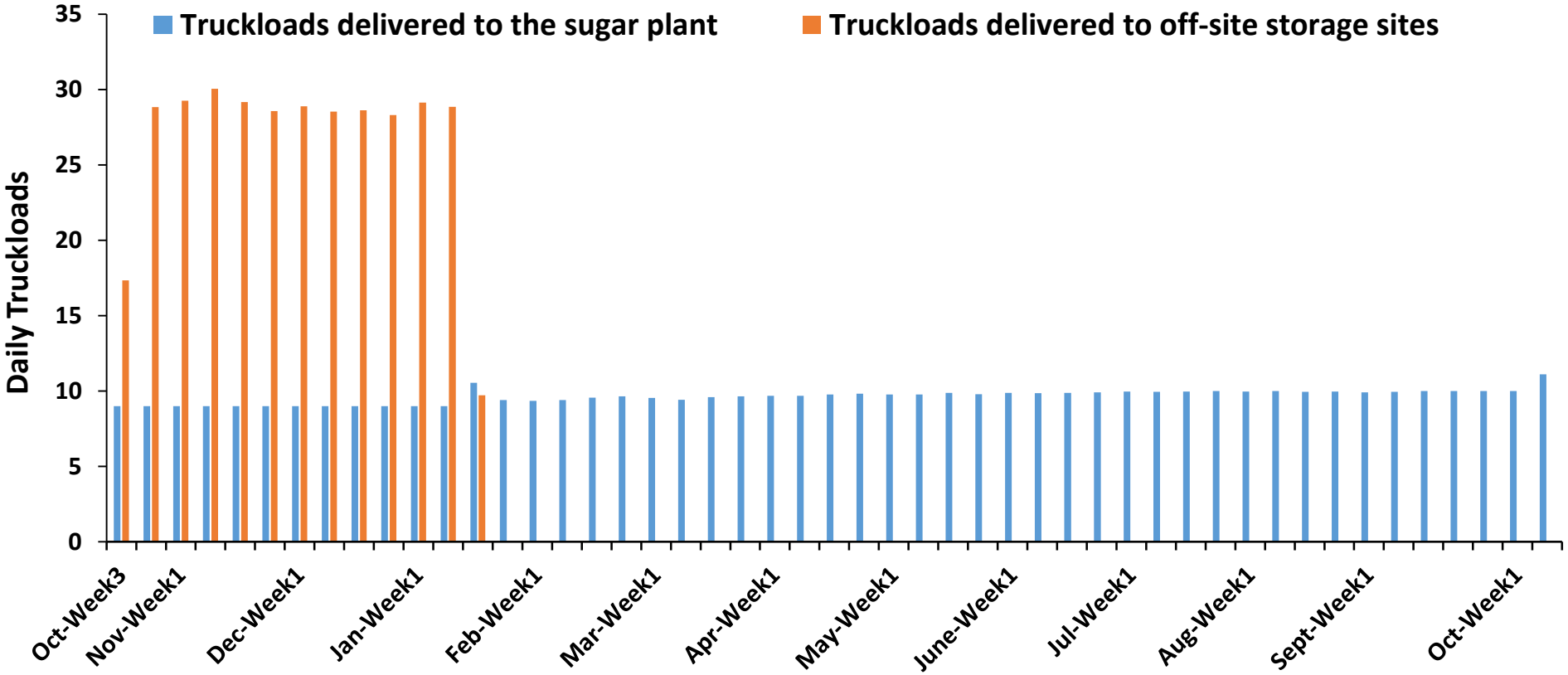
Storage configuration and cost components

Storage configuration	170 DT/day	860 DT/day
Maximum inventory (DT)	50,672	263,133
Number of stored bales	96,972	503,566
Stack width (bale)	6	6
Stack height (bale)	6	6
Stack length (bale)	60	60
Number of bales in each stack	2,160	2,160
Number of stacks	45	234
Clearance between stacks (ft)	100	100
Storage footprint (ac)	45	254
Cost components		
Land rental ($/DT)	0.22	0.24
Tarp cost ($/DT)- tarp and labour	2.51	2.51
Dry matter loss cost ($/DT)	3.18	3.73
Total storage cost ($/DT)	5.91	6.48

Note: The cost associated with land preparation such as grade, roads, drainage and fire detection are not considered in the base case scenario.

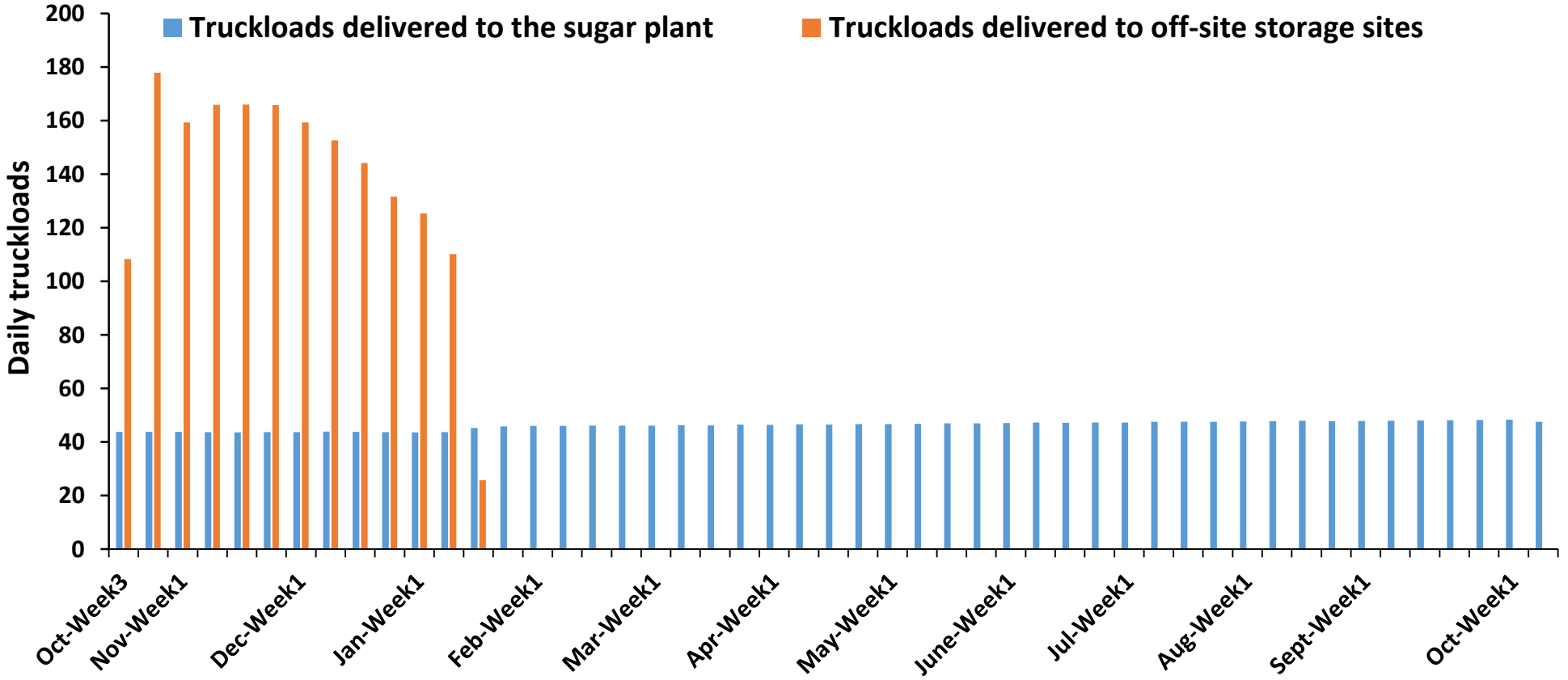
Number of truckloads- 175 DT/day scenario

- Average daily truckloads delivered to the sugar plant and off-site storage sites are estimated to be 10 and 27, respectively.
- Annual truckloads delivered to the sugar plant and off-site storage sites are estimated to be 473 and 345, respectively.
- Number of trucks during the harvest season (Oct. 15th – January 15th) and the post-harvest season is estimated to be 12 and 2, respectively.



Number of truckloads- 860 DT/day scenario

- Average daily truckloads delivered to the sugar plant and off-site storage sites are estimated to be 47 and 138, respectively.
- Annual truckloads delivered to the sugar plant and off-site storage sites are estimated to be 2,266 and 1,793, respectively.
- Number of trucks during harvest season (Oct., 15th – January 15th) and the post-harvest season would be 70 and 10, respectively.



Logistics Equipment Pool

- Number of required machinery for each logistics operation is estimated based on five factors: 1) Daily feedstock demand of the cellulosic sugar plant; 2) Length of the harvest season; 3) Maximum time that collected bales can be temporarily stored at the roadside of corn fields; 4) Daily working hours and 5) Time to mobilize logistics equipment between corn fields.

Number of machinery- field operations

Equipment	175 DT/day	860 DT/day
Chopper	5	24
Square Baler	4	18
Wagon-baler collector	3	21
Self-propelled Stacker	3	21
Tractors (185-225 hp)	12	63

Number of machinery- handling and transportation

Equipment	175 DT/day	860 DT/day
Telescopic loader- roadside of corn fields	4	18
53’ flatbed trailer truck- harvest season	12	70
Telescopic loader- off-site storage sites	1	14
53’ flatbed truck- off-site storage sites	2	10
Telescopic loader- Sugar plant	1	4

Capital and workforce requirement to run field operations

Equipment pool		175 DT/day			860 DT/day		
Machine	Purchase price ($)	Number of machines	Capital (Million $)	Number of operators	Number of machines	Capital (Million $)	Number of operators
Chopper	35,000	5	0.18	-	24	0.84	-
Square Baler	140,000	4	0.56	-	18	2.52	-
Wagon	80,000	3	0.24	-	21	1.68	-
Bale Stacker	250,000	3	0.75	3	21	5.25	21
Tractors (185-225 hp)	200,000	12	2.4	12	63	12.6	63
Total	-	-	4.12	15	-	22.89	84

Future works

- **Sensitivity analysis**
  - **Harvest length**
  - **Temporary storage at the roadside of corn fields**
  - **Farmer participation rate**
  - **Corn yield**
- **Estimation of dry matter losses in storage based on the weather conditions**
- **Assessment of the soil compaction issue during the harvest season**

Acknowledgment

Cellulosic Sugar Producers Co-op

This research is funded by BioFuelNet Canada, a network focusing on the development of advanced biofuels. BioFuelNet is a member of the Networks of Centres of Excellence of Canada program. Website: www.biofuelnet.ca".