Techno-Economic and Life Cycle Analyses of Biomass Utilization for Bioenergy Products

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USDA United States Department of Agriculture National Institute of Food and Agriculture

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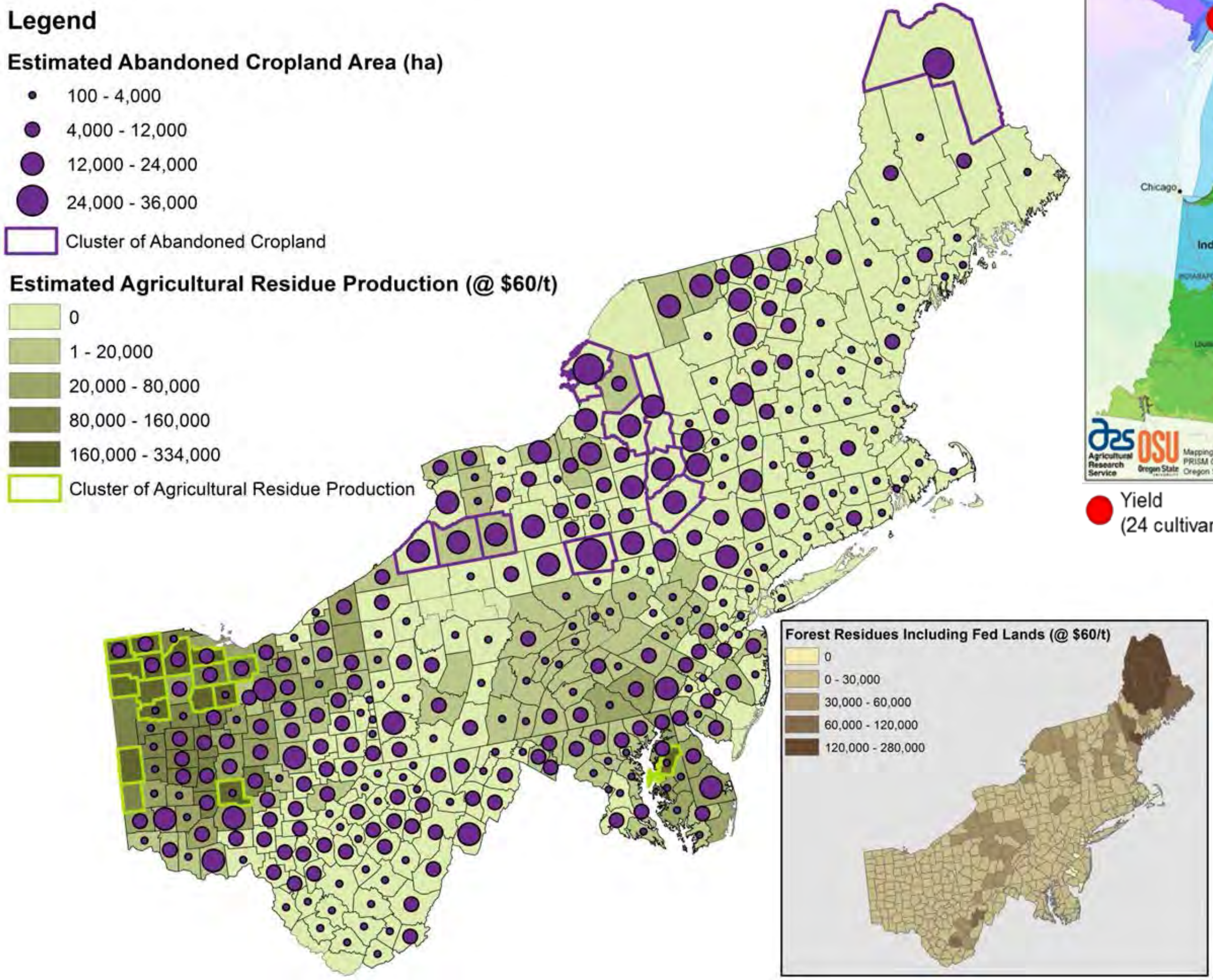
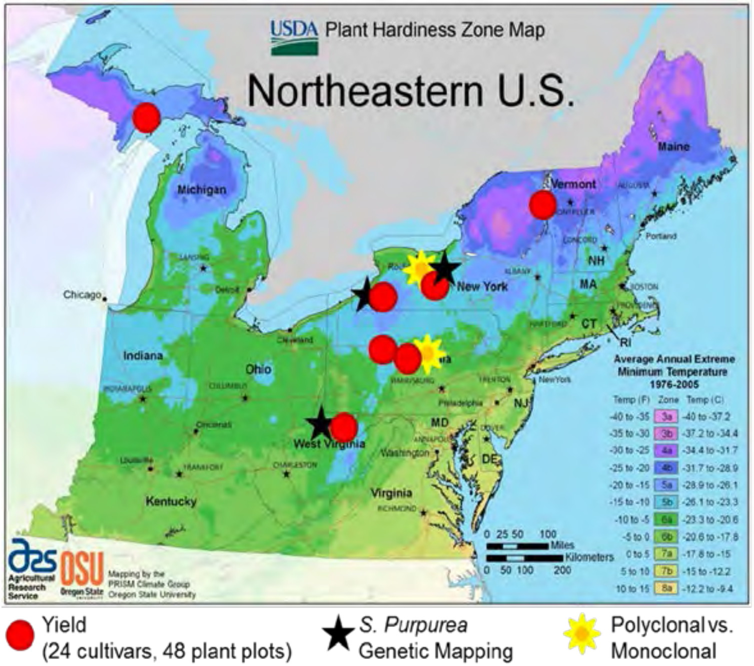
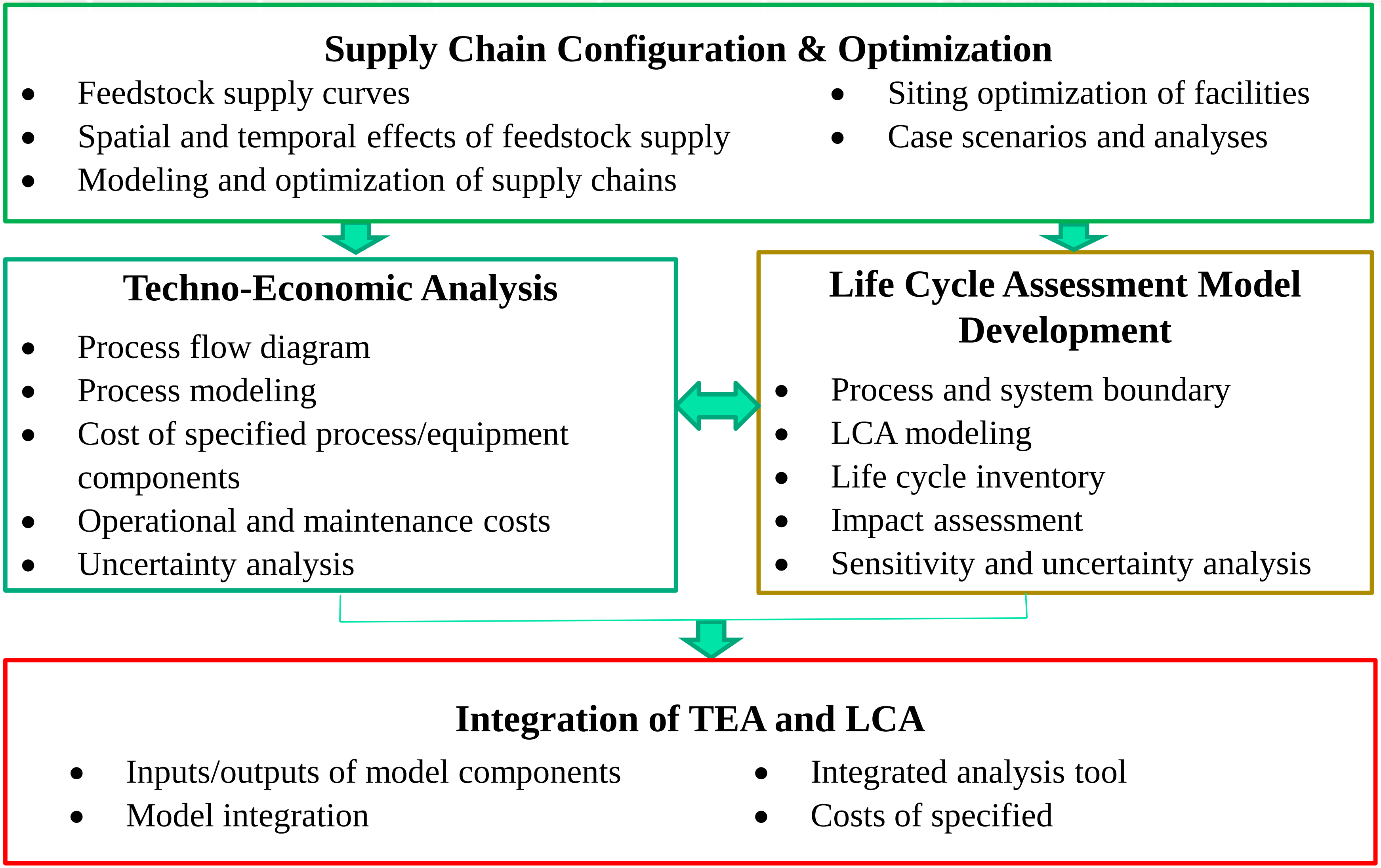
Biomass Production Potential





(Courtesy to Dr. Tom Richard of Penn State Univ. and Dr. Larry Smart of Cornell Univ. for this slide.)

Integration of LCA and TEA



Supply Chain Configuration & Optimization

- Feedstock supply curves
- Spatial and temporal effects of feedstock supply
- Modeling and optimization of supply chains
- Siting optimization of facilities
- Case scenarios and analyses

Techno-Economic Analysis

- Process flow diagram
- Process modeling
- Cost of specified process/equipment components
- Operational and maintenance costs
- Uncertainty analysis

Life Cycle Assessment Model Development

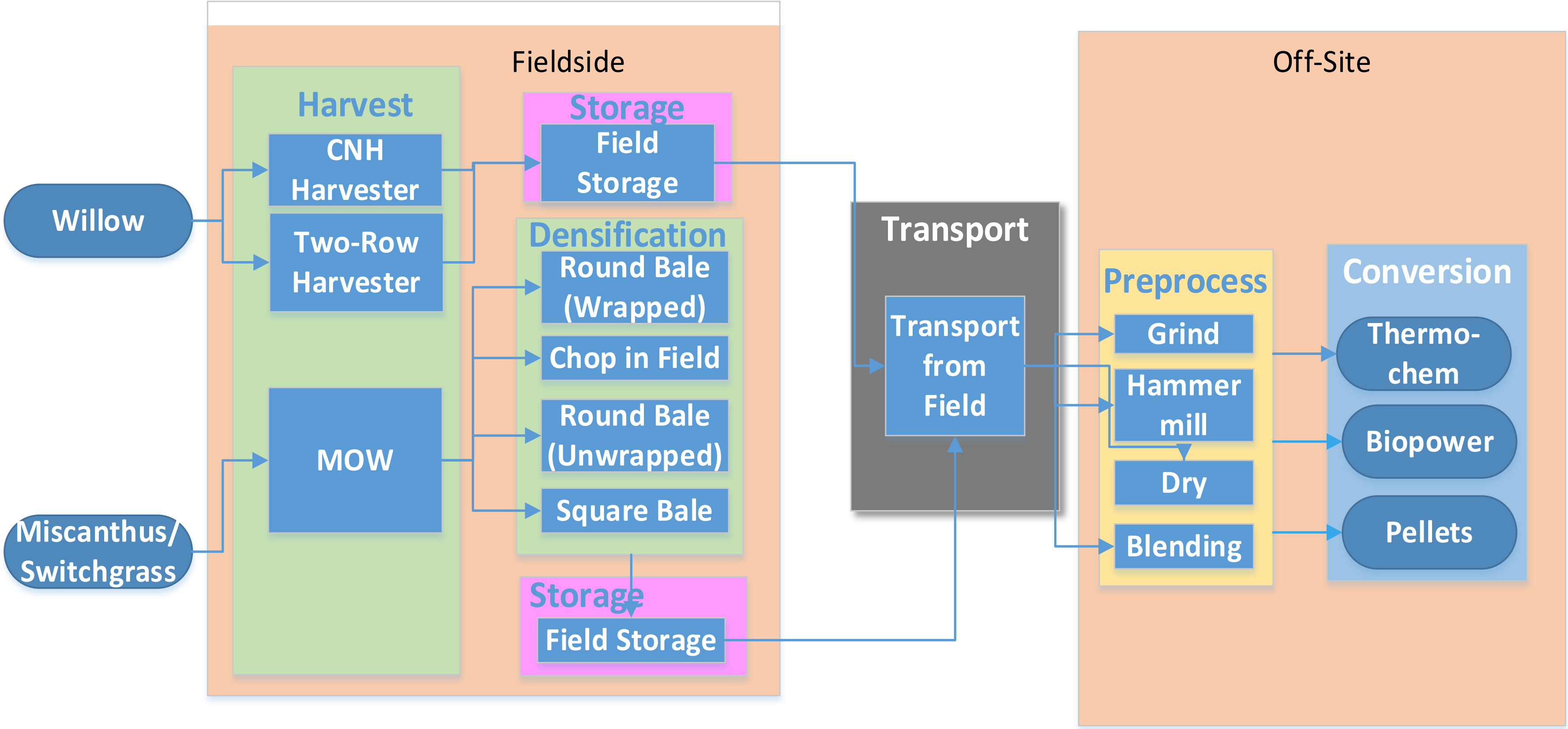
- Process and system boundary
- LCA modeling
- Life cycle inventory
- Impact assessment
- Sensitivity and uncertainty analysis

Integration of TEA and LCA

- Inputs/outputs of model components
- Model integration
- Integrated analysis tool
- Costs of specified

Processes of Biomass Supply Chain

Feedsotck → ***Process 1: Harvesting*** → ***Process 2: Densification, Storage and Transportation*** → ***Process 3: Preprocessing*** → ***Process 4: Conversion*** → **Products**



TEA Modeling

Logistic Model:

$$\boldsymbol{Min\ \psi = f + \eta + \tau + p + \mu}$$

$$= \sum^{T}\sum^{J}\sum^{I}\sum^{M}\left[x_{mijt} \times pc_m\right] + \sum^{T}\sum^{J}\sum^{I}\sum^{M}\left[x_{mijt} \times hc_m\right]$$

$$+ \sum^{T}\sum^{J}\sum^{I}\sum^{M} x_{mijt} \times tc_m \times d_{ij} + \sum^{T}\sum^{J}\sum^{M} xs_{mjt} \times prec_m$$

$$+ \sum^{T}\sum^{J}\sum^{M} xs_{mjt} \times sc_m$$

(1) Biomass feedstock establishment (f), (2) harvest (η), (3) transport (τ), (4) process (p) and (5) storage (μ) were considered as cost components in the logistic model. The objective is to minimize the total delivered cost (ψ).

CAPEX & OPEX:

Fast pyrolysis – Wright et al. 2010;
Power plant – The International Renewable Energy Agency (IRENA) 2012;
Pellet mill – Sultana et al. 2010.

LCA Modeling

LCA– Goal and Scope

Cradle to grave

Functional unit: 1,000 MJ.

LCA – Life cycle inventory

- Front-ground dataset:
  - Feedstock plantation and harvest – Field measurement;
  - Transportation – Model simulation and US EI;
  - Storage and Preprocessing – Lab measurement and research papers;
  - Energy conversion, distribution, and end-use – Research papers;
- Back-ground dataset:
  - Ecoinvent 2.2 - Other

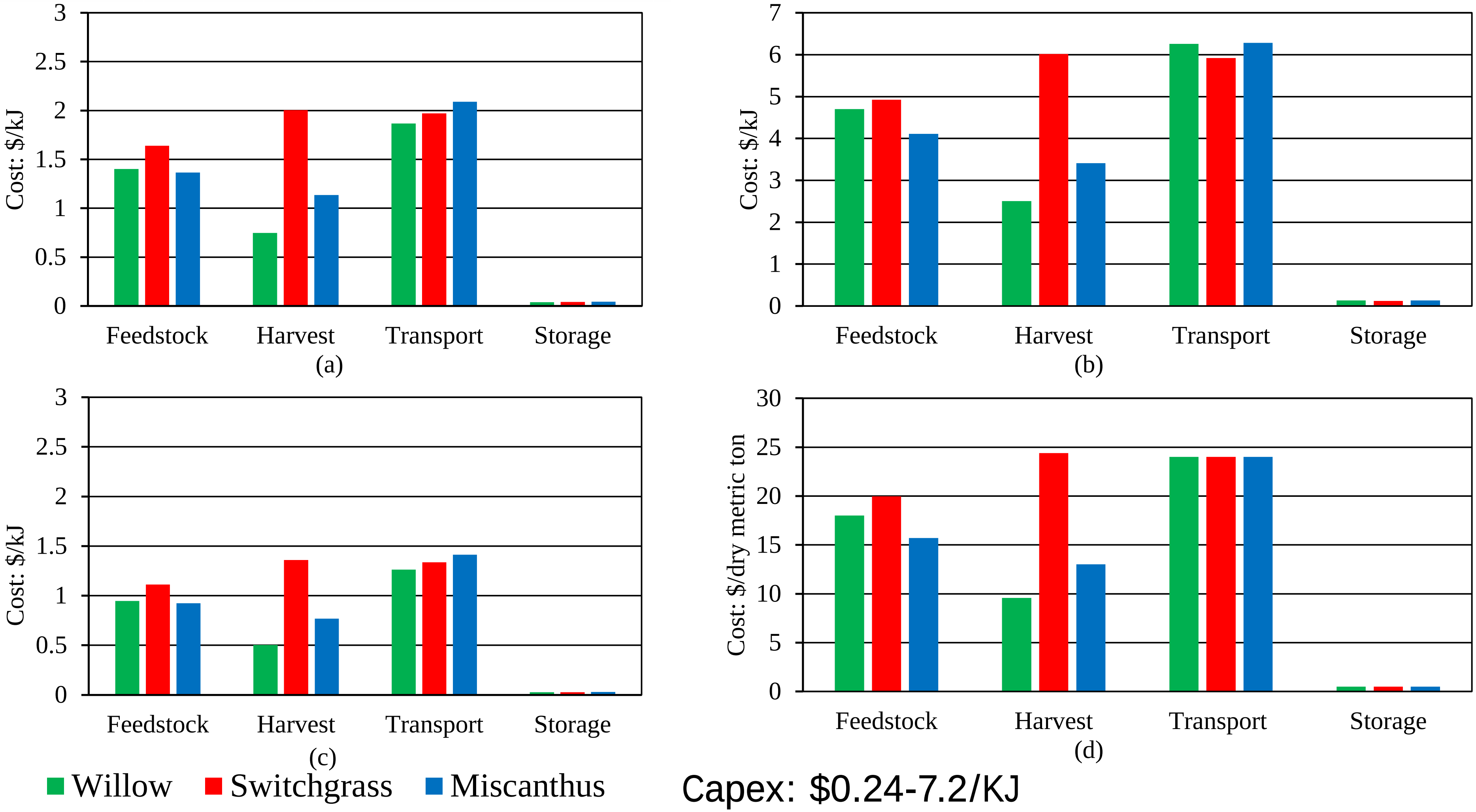
LCA – Impact assessment

- Model development
  - SimaPro 8.
- Impacts
  - GHG emissions;
  - Carcinogenics;
  - Blue water consumption;
  - Respiratory effects;
  - Fossil energy usage;
  - Human toxicity;
  - Ozone depletion

Case Scenarios and Uncertainty Analysis

Parameter	Base Case	LCA Sensitivity	TEA Sensitivity	Notes
Willow – Yield	12.4 ton/ha	10.7 - 14.1 odt/ha	10.7 - 14.1 odt/ha	Yield increases from minimum to maximum yield by 10% of their difference.
Switchgrass – Yield	9.6 ton/ha	6.6-12.6 odt/ha	6.6-12.6 odt/ha	
Miscanthus - Yield	17.8 ton/ha	10.9-24.7odt/ha	10.9-24.7odt/ha	
Transportation	50 miles (80 Km)	10 – 100 miles (16-160 Km)	10 – 100 miles (16-160 Km)	The distance increases by 10 miles (16Km) each time.
Bio-fuel - Conversion rate	0.39 tons feedstock/bbl of fuel	0.33-0.45 odt feedstock/bbl of fuel	0.33-0.45 odt feedstock/bbl of fuel	Amount of feedstock demand increases from minimum to maximum yield by 10% of their difference.
Bio-power – Conversion rate	0.84 tons feedstock/MWh of bio-power	0.63-1.05 odt feedstock/ MWh of bio-power	0.63-1.05 odt feedstock/ MWh of bio-power	
Pellet – Conversion Rate	1 ton feedstock/ton of pellet	-	-	No Waste was assumed to produce pellet.
Pretreatment	Dry	Dry / Torrefaction		
Bio-fuel – Capacity	1,000 bbl/day	-	-20% and +20%	The change of capacity will be 20% lower and higher than the base case.
Bio-power – Capacity	20 MW	-		
Pellet – Capacity	200,000 dry metric tons/year	-		
IRR	15%	-	10% and 20%	

Results - Costs



(a) Biofuel (b) Bio-power

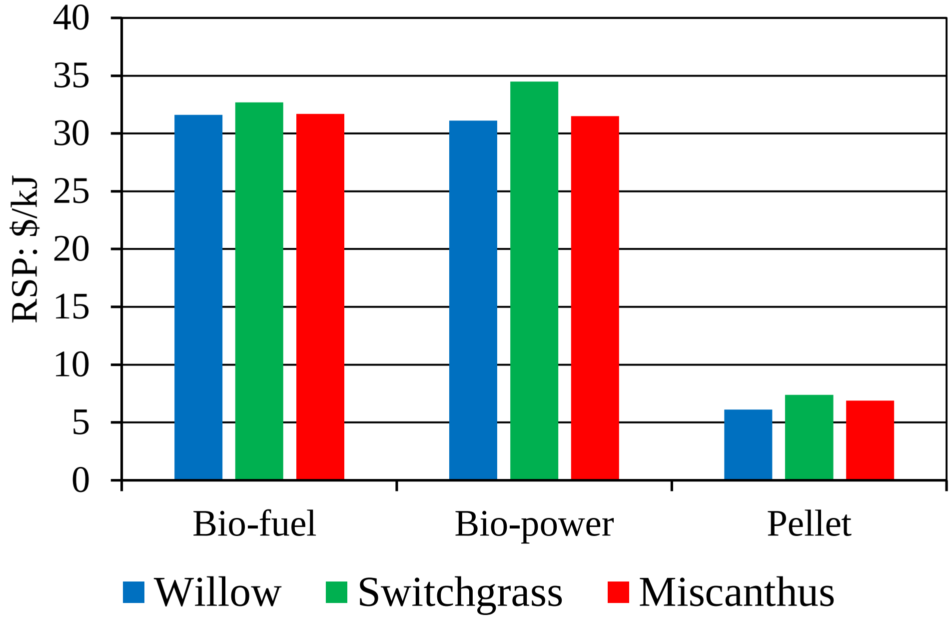
(c) Pellet (d) Biomass cost

Capex: $0.24-7.2/KJ

Opex: $2.26-7.0/KJ

Total biomass delivered cost: $52-68/dry ton

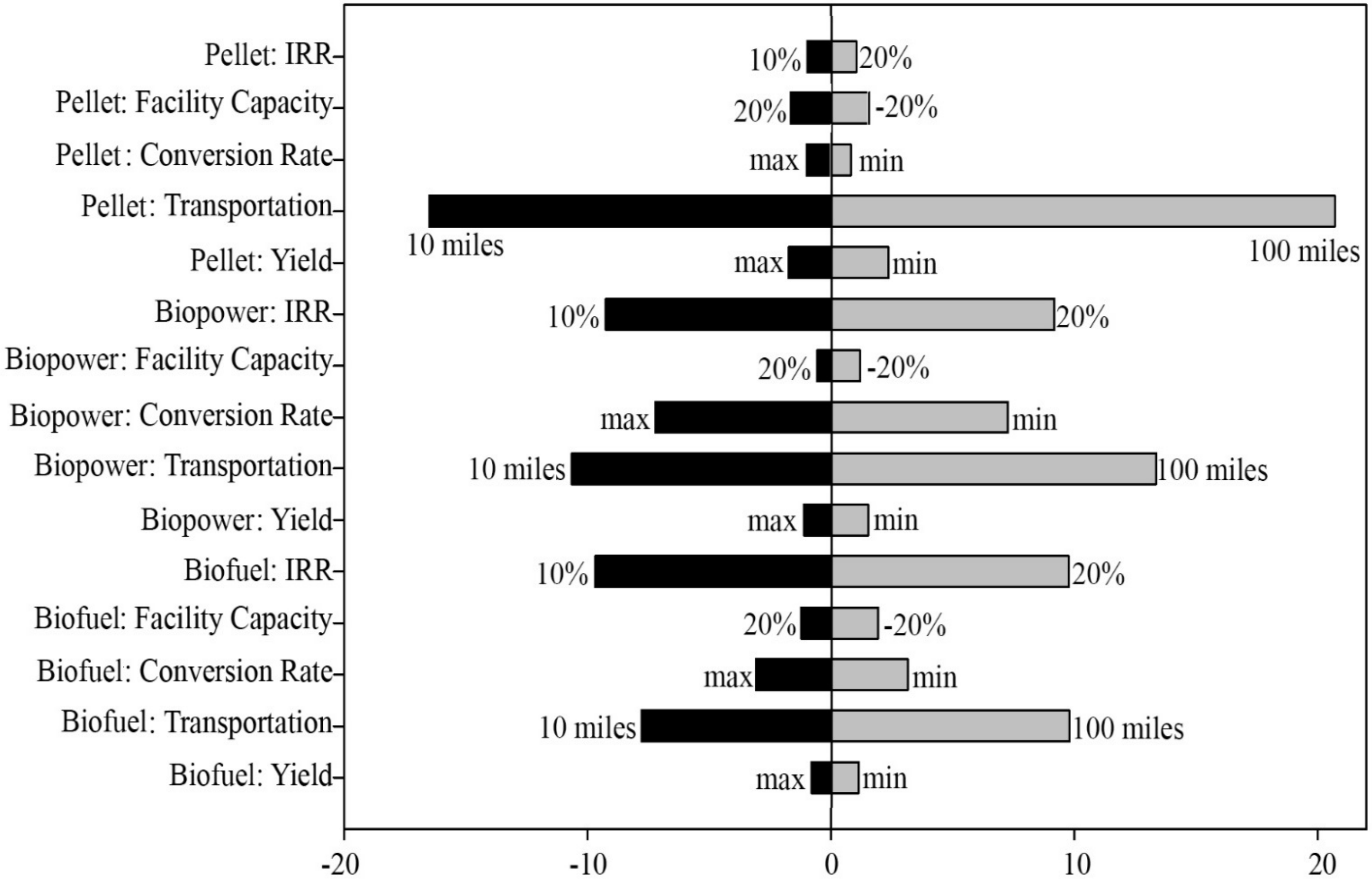
Results - RSP



Crops	Bio-fuel: $/bbl	Bio-power: $/MWh	Pellet: $/ton
Willow	158.99	112.2	116.1
Switchgrass	164.66	124.4	132.9
Miscanthus	159.48	113.3	117.2

- RSPs $31.6-32.7/KJ for biofuel; $31.1-34.5/KJ for biopower; $6.1-7.4/KJ.
- RSPs: $/*bbl* for bio-fuel, $/*MWh* for bio-power, and $/dry *ton* for pellet fuel.
- For the same bioenergy product, the RSPs using willow were 0.5-5.8% lower than the other two crops.
- The RSP was higher for the production of biofuel.

Sensitivity Analyses of RSP



Percentage change of RSP based on the base case for willow: %

Sensitive Factors:

Pellet
- Transportation

Biopower
- Transportation
- IRR
- Conversion rate

Biofuel
- IRR
- Transportation

Impacts of LCA

LCA Results:

Pellet

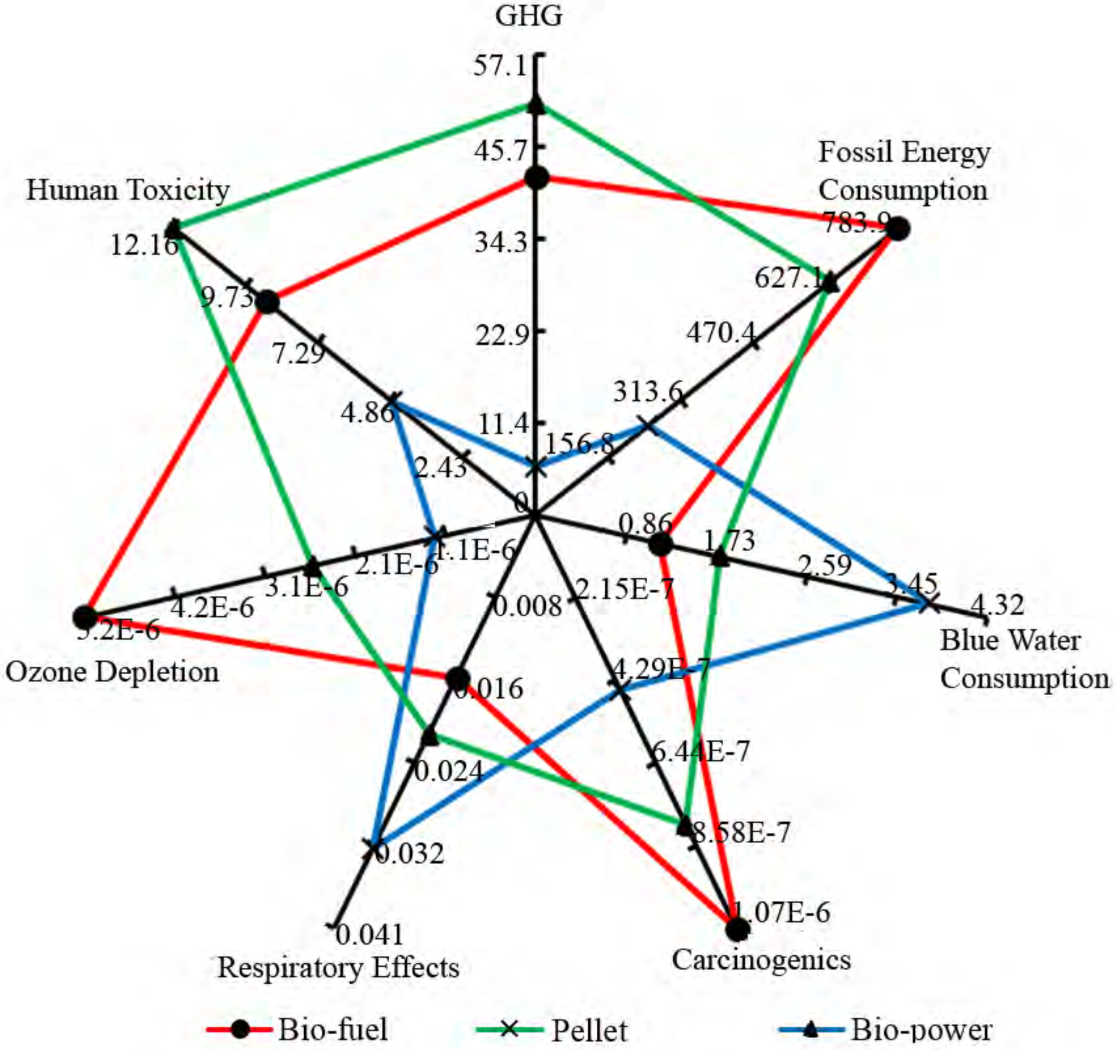
- GHG emissions (51.15 kg CO_2 eq);
- Human toxicity (12.15 kg 1,4-DB eq);

Bio-fuel

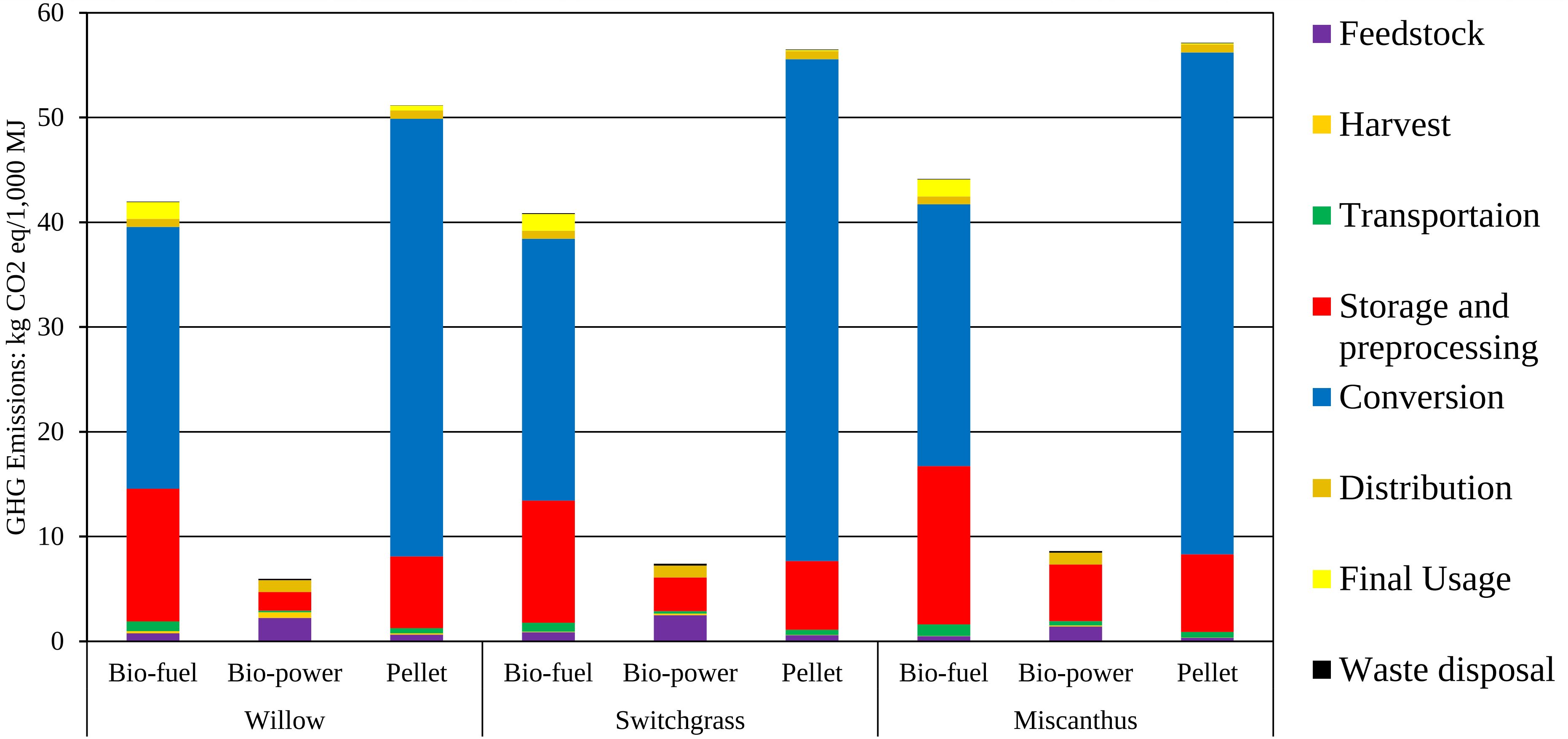
- FEC (783.93 MJ);
- Carcinogenics (1.07E-6 CTUh);
- Ozone depletion (5.21E-6 kg CFC-11 eq);

Bio-power

- BWC (3.75 m^3);
- Respiratory effects (0.03 kg PM2.5 eq);

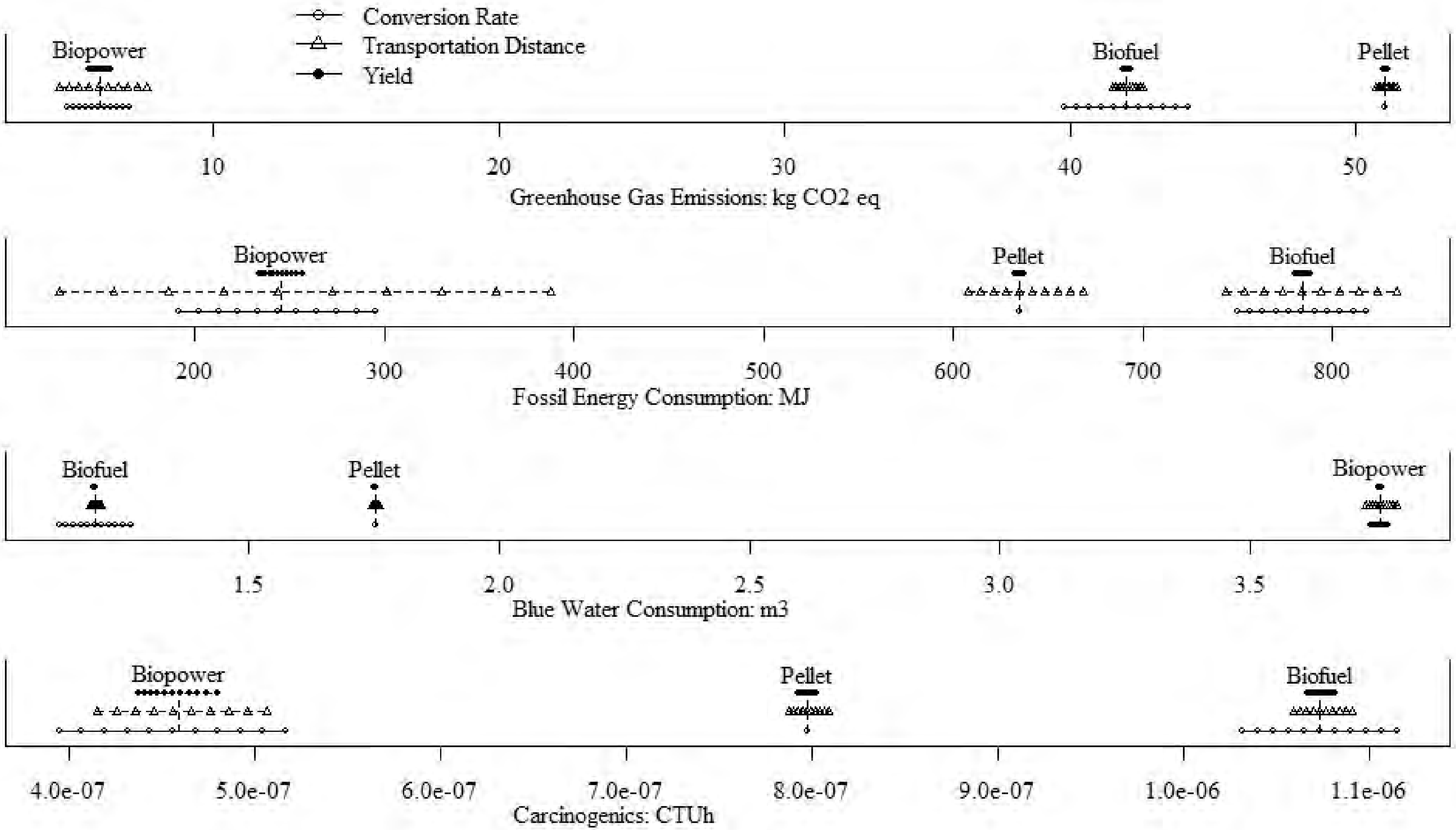


GHG Emissions



- The most emissions occurred in the “Preprocessing” and “Conversion” processes.
- The bio-power production presented the lowest GHG emission among the bioenergy products.
- Using willow shrub for bio-power generation demonstrated the lowest emission whereas miscanthus for pellets presented the highest emission.

Sensitivity Analyses of LCA



Sensitivity of Environmental impacts for willow

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Summary

- Integrated analyses can simulate pathways under uncertainty from feedstock land prep to point of energy product departure.
- Uncertainty analysis can be employed to increase the realism of bioenergy product pathways.
- Future analyses should focus on generating additional data for factors that affect cash flow variability the most.
- Work with our stakeholders for real case studies, Greene Team Pellet Fuel, ReEnergy, and Rematix.

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