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Biorefinery Siting in the Western Montana Corridor

Natalie Martinkus, PE, PhD candidate

Washington State University

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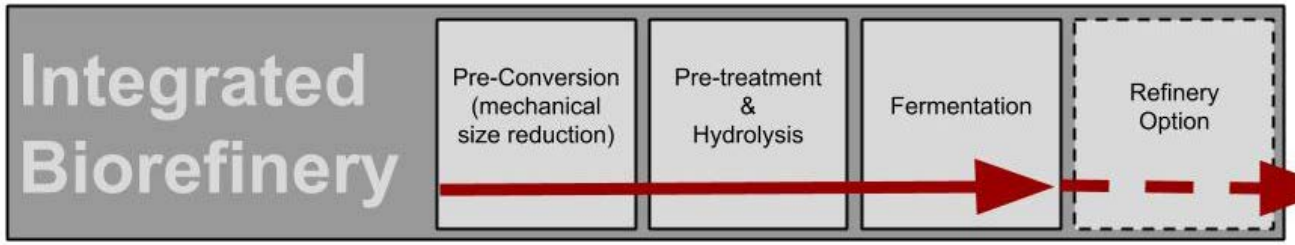
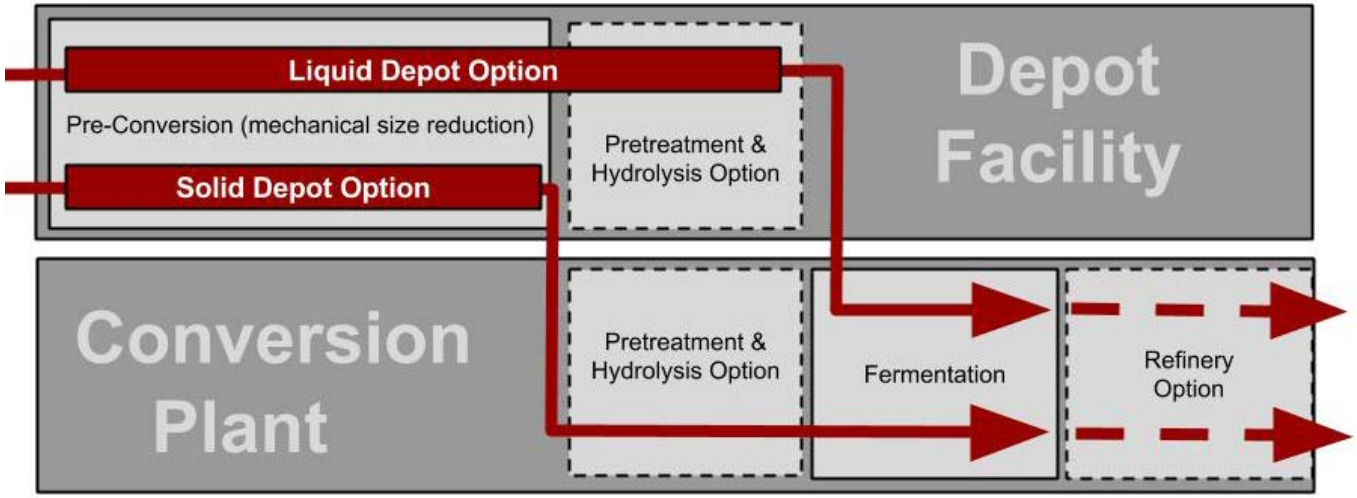
Northwest Advanced Renewables Alliance

NARA Conversion Scenarios

Option #1: Centralized Production



Option #2: Distributed Production



Source: NARA. Preliminary Scoping: Northwest Wood-Based Biofuels. IDX Studio – Fall 2014.

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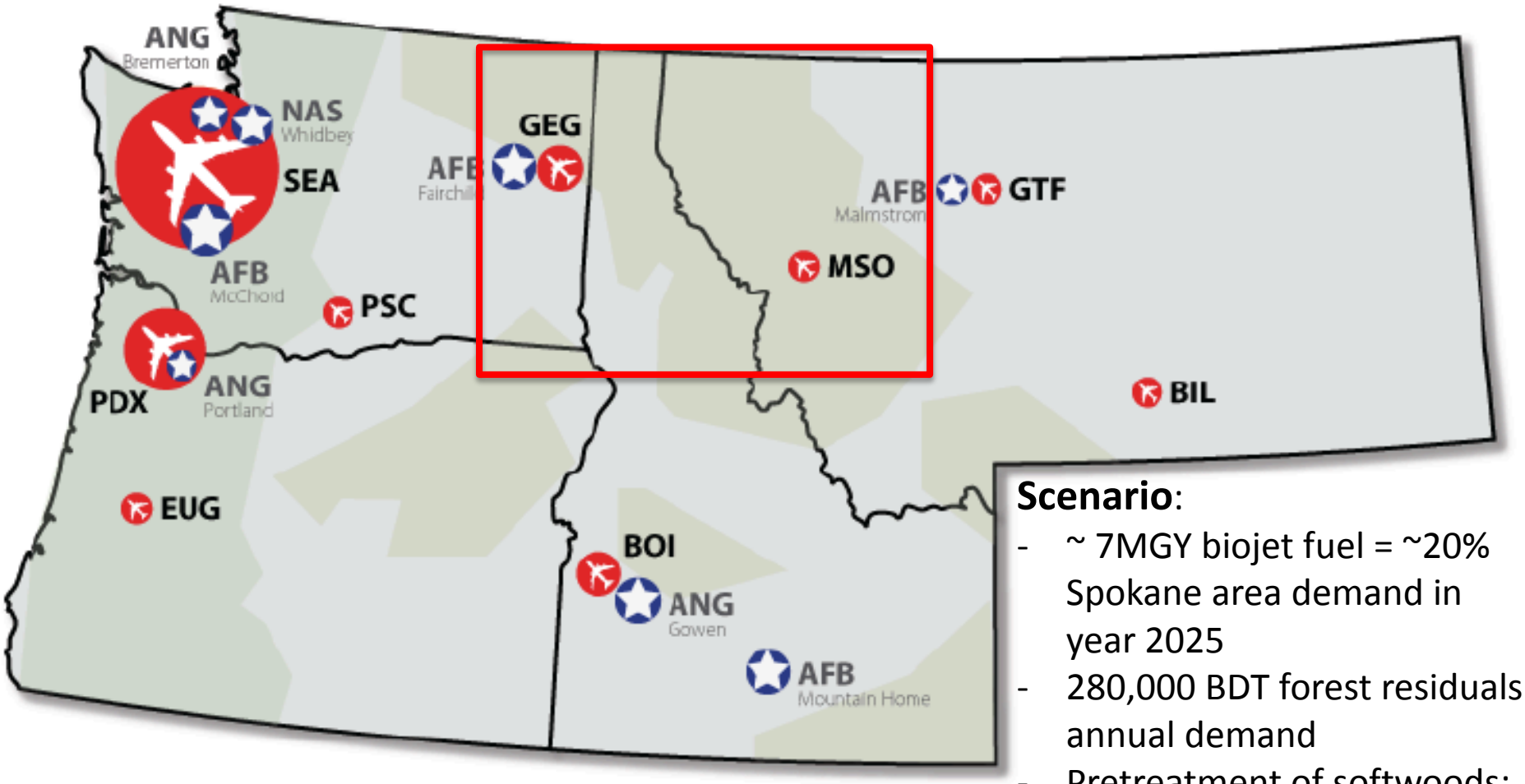
Study Region: Western Montana Corridor (WMC)



Scenario:

- ~ 7MGY biojet fuel = ~20% Spokane area demand in year 2025
- 280,000 BDT forest residuals annual demand
- Pretreatment of softwoods: micronized wood
- Depot Model – 1 large and 2 small depots

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Forest Residuals-to Biorefinery Supply Chain

Timber Harvest

Slash Pile Storage

Ground Slash

Sawmill (Depot)

Isobutanol Biorefinery

End User

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NARA Siting Philosophy

Retrofit existing industrial facilities around existing assets

Benefits:

- Reuse existing equipment and infrastructure
- Skilled workforce is in place or nearby = jobs saved and created
- Environmental (air, water) permits and water rights may exist = less start-up time delays
- Plant is set up for receiving raw wood via trucks and rail

Existing Facilities in WMC

Greenfield
Spokane, WA

Active Pulp Mill
Lewiston, ID

Decommissioned Pulp Mill
Frenchtown, MT

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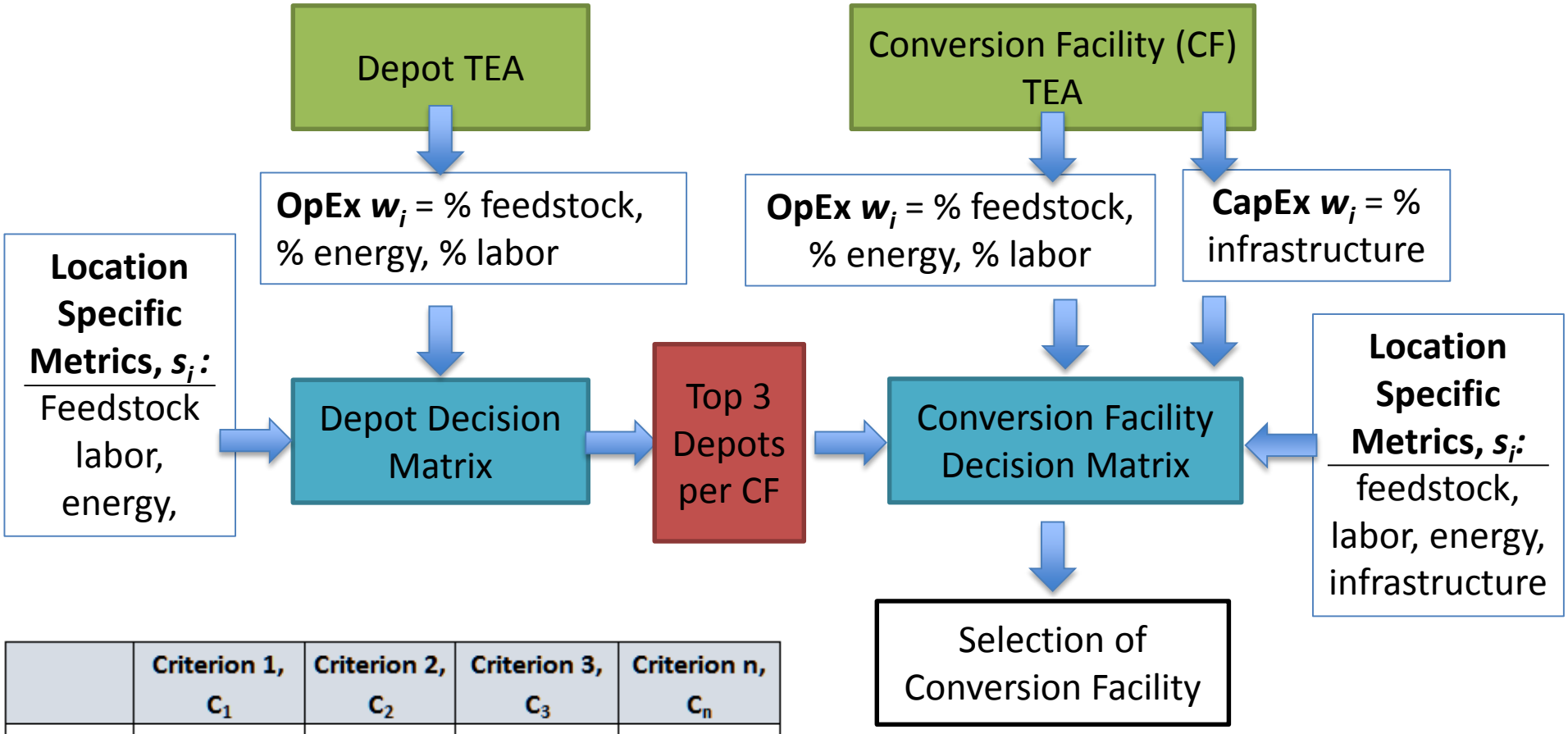
Framework for Facility Assessment



	Criterion 1, C_1	Criterion 2, C_2	Criterion 3, C_3	Criterion n, C_n
Scale, s				
5	a_{min}	b_{min}	c_{min}	n_{min}
4	$a_{min} + B_1$	$b_{min} + B_2$	$c_{min} + B_3$	$n_{min} + B_n$
3	$a_{min} + 2B_1$	$b_{min} + 2B_2$	$c_{min} + 2B_3$	$n_{min} + 2B_n$
2	$a_{min} + 3B_1$	$b_{min} + 3B_2$	$c_{min} + 3B_3$	$n_{min} + 3B_n$
1	$a_{min} + 4B_1$	$b_{min} + 4B_2$	$c_{min} + 4B_3$	$n_{min} + 4B_n$
weight	w_1	w_2	w_3	w_n

Decision Matrix Facility Score

$$F = \sum_{i=1}^{n} w_i \cdot s_i$$

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Depot Assumptions and Criteria

Assumptions and Criteria

1. Co-located with the mill
2. Onsite rail spur
3. At least 10 acres of unutilized land for depot
4. Access to natural gas
5. Where multiple mills were located in the same town, one representative mill was selected.

Depot Decision Matrix				
	Forest-2-CF Delivered Cost ($/BDT)	Electricity ($/kWh)	Natural Gas ($/k.c.f.)	Labor: % Less than H.S. diploma
Scale				
5	$48	0.02	5.5	0.0
4	$62	0.05	6.2	12.8
3	$77	0.07	6.9	25.6
2	$92	0.09	7.6	38.4
1	$106	0.11	8.3	51.2
weights	*8.5*	*7.0*	*2.6*	*1.9*

Weight Development from TEA		
Operating Expenditure Component	% of OpEx Cost	Normalized to 20
Feedstock	42%	8.5
Electricity	35%	7.0
Natural Gas	13%	2.6
Labor	10%	1.9

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Costs along the Supply Chain

Total Transport Cost, C_{ij}

$$C_{ij} = F_i + V_{ij}$$

C_{ij} = *total transport cost ($/BDT) between pts i and j*
F = *Fixed cost at pt i*
V = *Variable transport cost between pts i and j*

Supply Chain Link	Truck type	Transport Material	Fixed Cost, F_i ($/BDT)	Variable Transport Cost, V_{ij} ($/BDT-min, $/BDT-hr, $/BDT-mi)
Forest (FIA) - Depot	45' chip van	wood chips	38.8	$0.233\sum_{p=1}^{N} d_p + 0.175\sum_{g=1}^{N} d_g + 0.166\sum_{d=1}^{N} d_d$
Depot - Conversion Facility	8,000 gal tanker	micronized wood	7.74	$2\left[1.80\sum_{t=1}^{N} x_t + 0.073\sum_{d=1}^{N} x_d\right]$
Conversion Facility - Terminal	8,000 gal tanker	biojet fuel (IPK)	0.59	$2\left[0.11\sum_{t=1}^{N} y_t + 0.004\sum_{d=1}^{N} y_d\right]$

d_p = *dist. along paved road (mi)*
d_g = *dist. along gravel road (mi)*
d_d = *dist. along dirt road (mi)*

N = *total no. of road segments*
x_t, y_t = *time along road segment x, y (hr)*
x_d, y_d = *dist. along road segment x, y (mi)*

Fixed and Variable Cost and Equation Sources

Zamora-Cristales, R., et al. "Economic Impact of Truck- Machine Interference in Forest Biomass Recovery Operations on Steep Terrain." *For. Prod. J.* 63.5-6 (2013): 162-73. Print.

Parker, Nathan, et al. *Strategic Assessment of Bioenergy Development in the West: Spatial Analysis and Supply Curve Development*: The University of California, Davis, 2008. Print.

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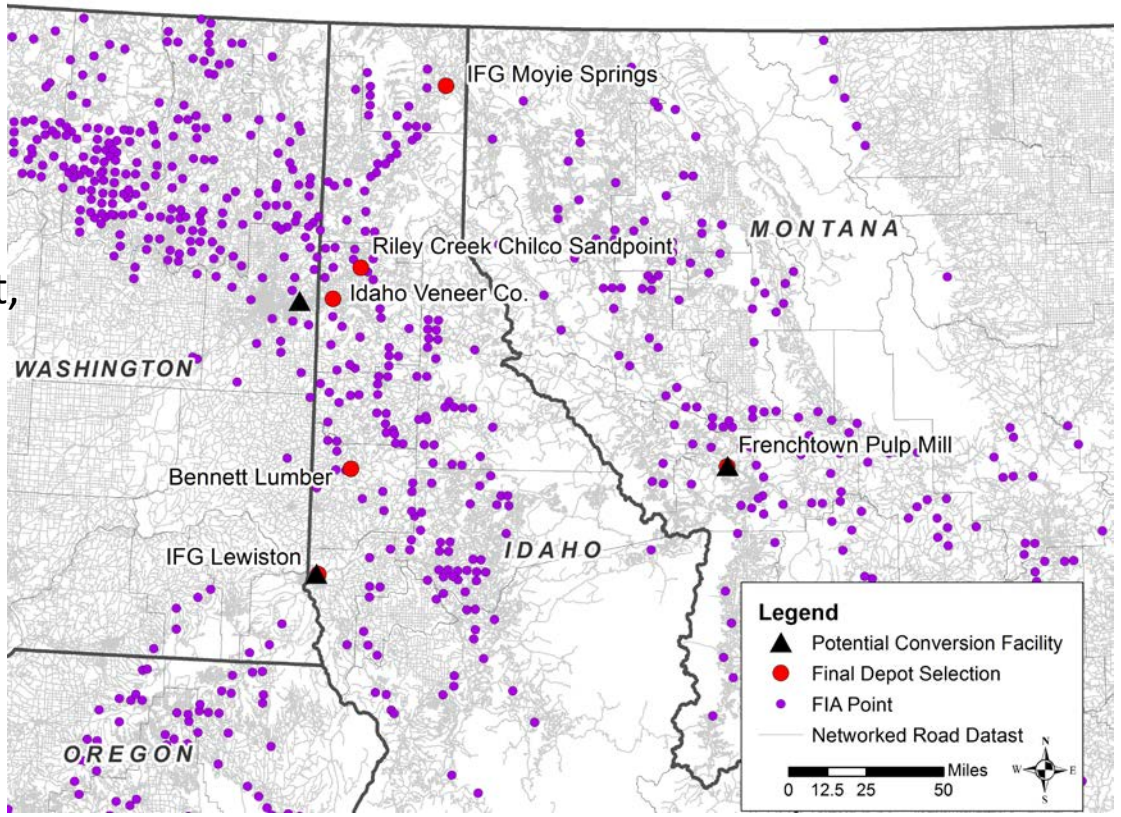
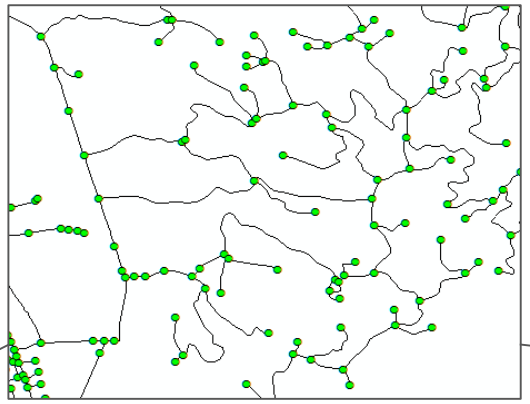
Delivered Feedstock Cost Estimation

<u>Forest Residue Estimation Datasets</u>

1. 30-year average annual forest residual volume (BDT) for each FIA point on State and Private lands.
2. Fixed and variable costs for harvest, comminution and transportation
3. Networked road shapefile





PNW_roads_ESRI_1

FULLNAME	Length_mi	Sessions_Speed	Time_min	FIA-2-Depot	Depot-to-CF	CF-2-Terminal
Slaughterhouse Creek Rd	0.678797	45	0.905062	0.210879	0.15368	0.009292
Slaughterhouse Creek Rd	2.578026	45	3.437368	0.800907	0.583665	0.03529
Slaughterhouse Creek Rd	0.329112	45	0.438817	0.102244	0.074511	0.004505
Nfd 115 Rd	0.752583	45	1.003444	0.233803	0.170385	0.010302
Nfd 115 Rd	0.960881	45	1.281175	0.298514	0.217543	0.013153
Nfd 115 Rd	0.69398	45	0.925307	0.215597	0.157117	0.0095

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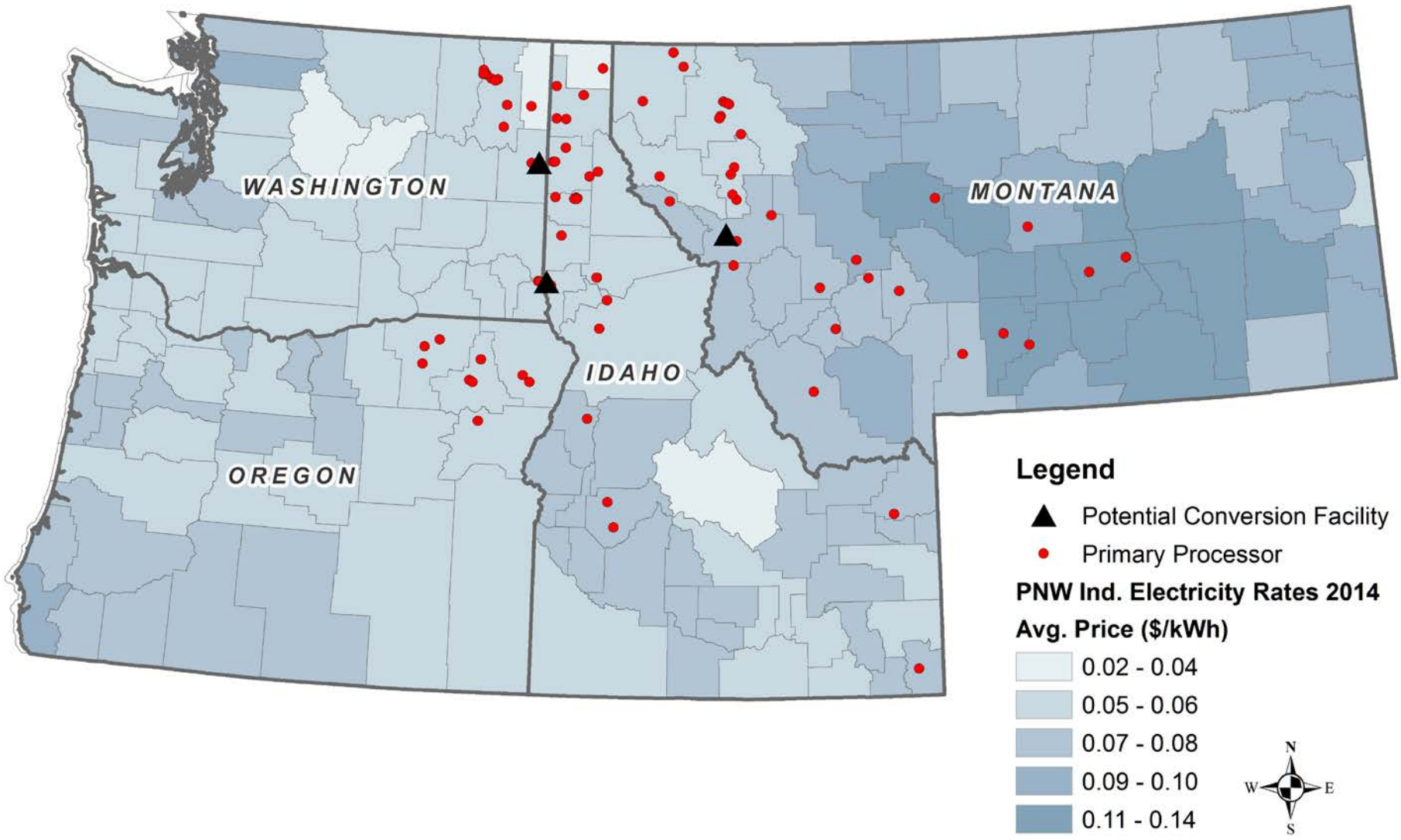
Industrial Electricity Rates in PNW



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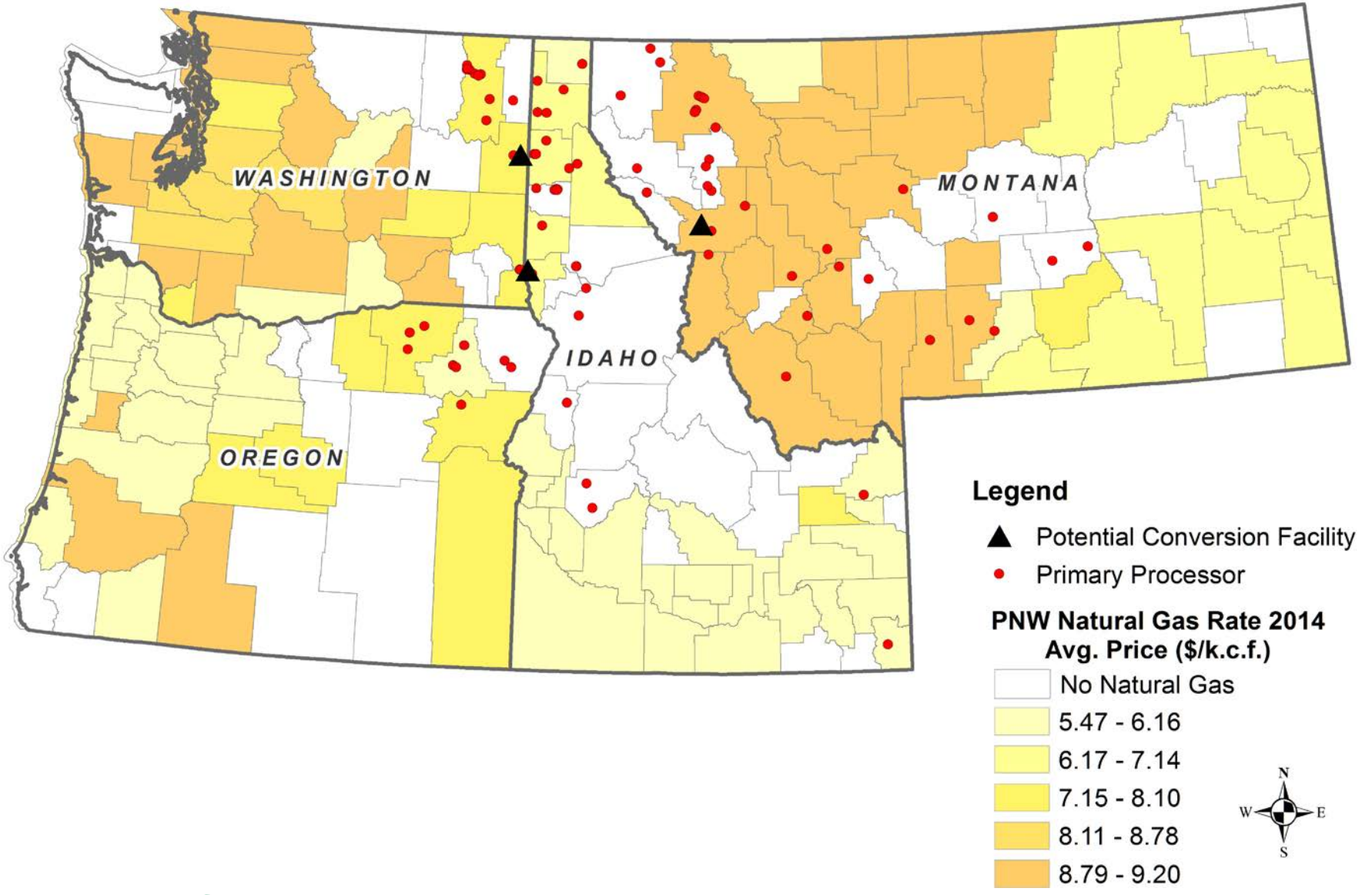
Industrial Natural Gas Rates in PNW



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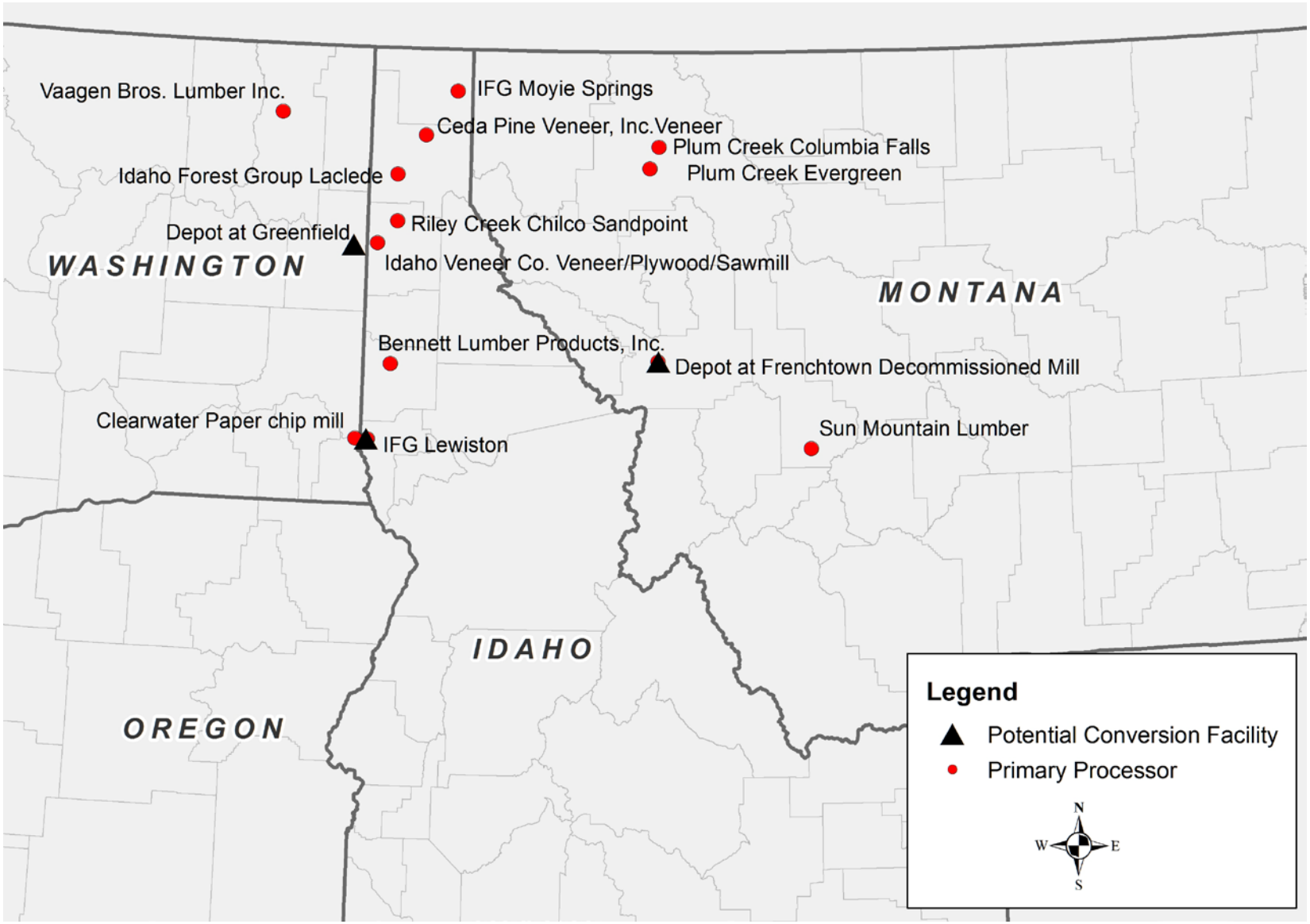
Final Depot Map



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Final Depots to Conversion Facility Sites

Assume 1 large depot at conversion facility site
2 smaller satellite depots

Final Depot Ranking for Spokane	Score
Riley Creek Chilco Sandpoint	93.6
Spokane Greenfield	91.7
Bennett Lumber Products, Inc.	85.1
Ceda Pine Veneer, Inc.Veneer	85.1
Vaagen Bros. Lumber Inc.	83.2

Final Depot Ranking for Frenchtown	Score
Former SmurfitStone	75.8
Idaho Forest Group Moyie Springs	72.6
Riley Creek Chilco Sandpoint	70.9
Ceda Pine Veneer, Inc.Veneer	70.9
Idaho Veneer Co. Veneer/Plywood/Sawmill	70.9

Final Depot Score for Lewiston	Score
IFG Lewiston	87.5
Bennett Lumber Products, Inc.	79.0
Idaho Forest Group Moyie Springs	72.1
Ceda Pine Veneer, Inc.Veneer	70.5
Idaho Veneer Co. Veneer/Plywood/Sawmill	70.5

Conversion Facility Siting Decision Matrix

Assumptions and Criteria

1. Site size at least 100 acres
2. Onsite rail spur (for existing facilities)
3. Active/decommissioned wood-using facility or greenfield
4. Access to natural gas

Conversion Facility Decision Matrix					
	Total Milled Wood + IPK Transport Cost ($/BDT)	Electricity ($/kWh)	Natural Gas ($/k.c.f.)	Infrastructure: % reduction from Greenfield Cost	Labor: % less than H.S. Diploma
Scale					
5	223.0	0.02	5.5	33%	0.0
4	227.5	0.05	6.2	26%	12.8
3	232.0	0.07	6.9	20%	25.6
2	236.5	0.09	7.6	13%	38.4
1	241.0	0.11	8.3	7%	51.2
weights	*13.3*	*2.5*	*2.0*	*1.4*	*0.8*

Weight Development from TEA		
Operating Expenditure Component	% of OpEx Cost	Normalized to 20
Feedstock	67%	13.3
Electricity	12%	2.5
Natural Gas	10%	2.0
Labor	4%	0.8
Annualized Infrastructure	7%	1.4

Preliminary Results – Do Not Cite

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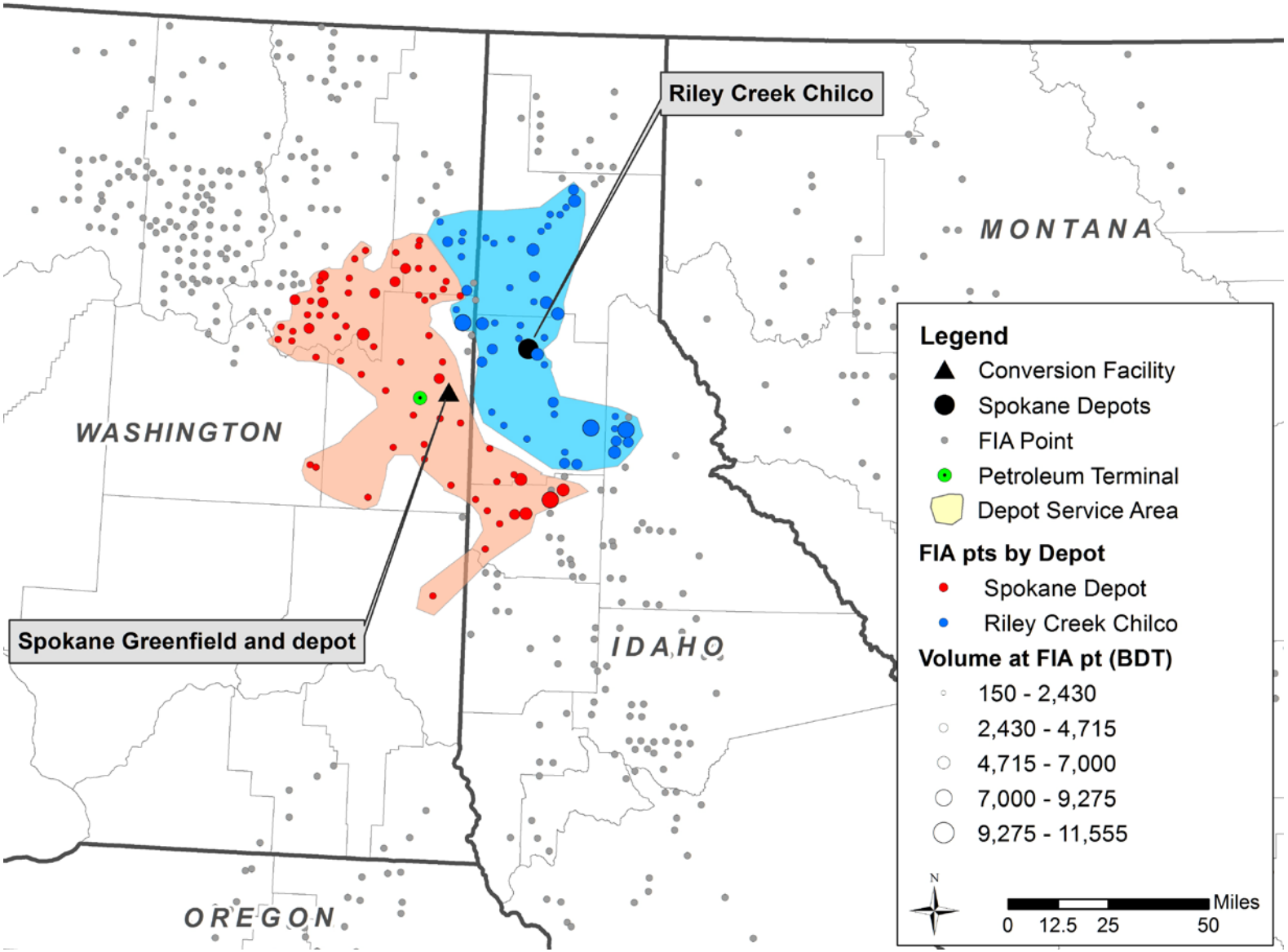
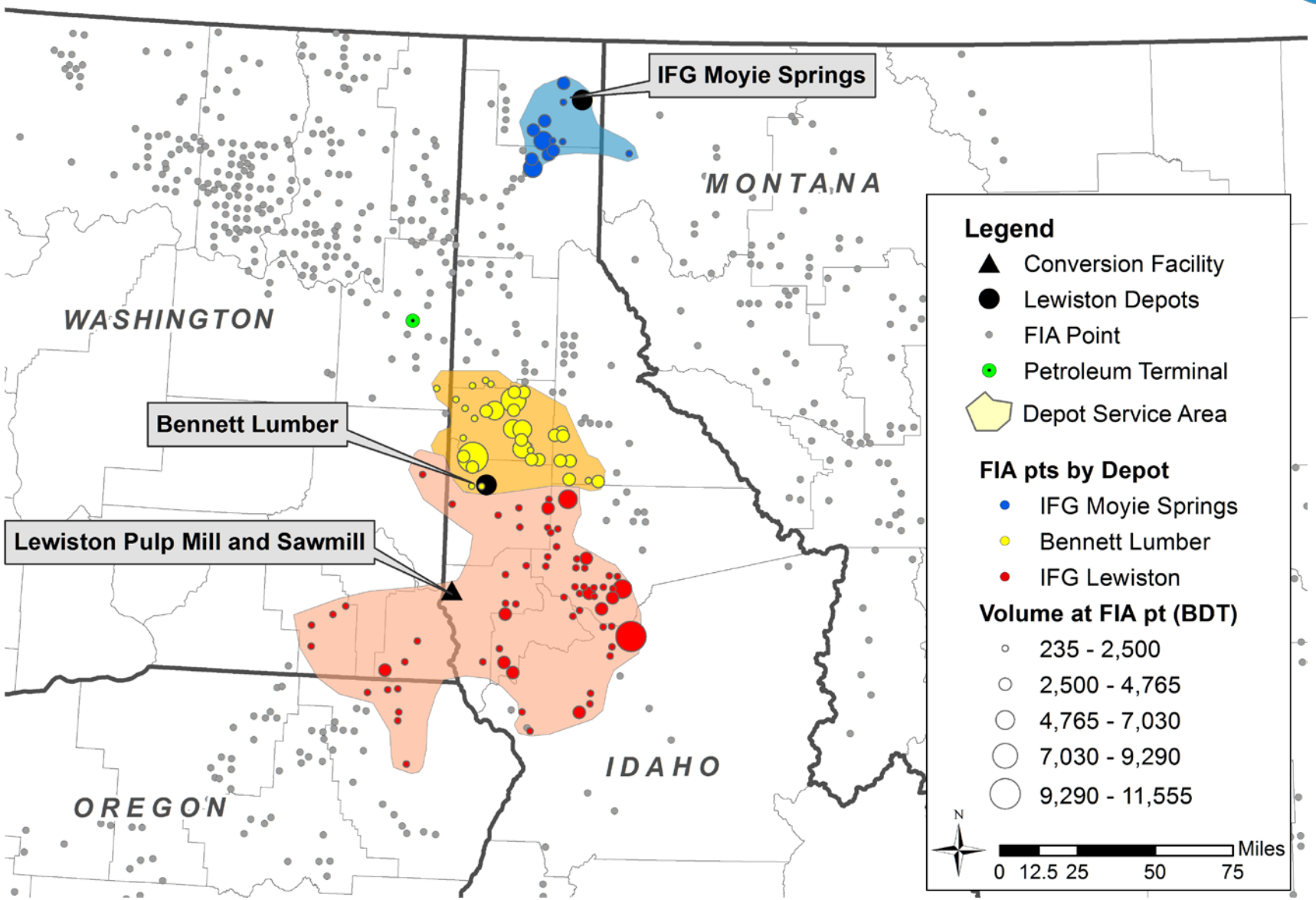
Delivered Cost to Terminal – Spokane Conversion Facility



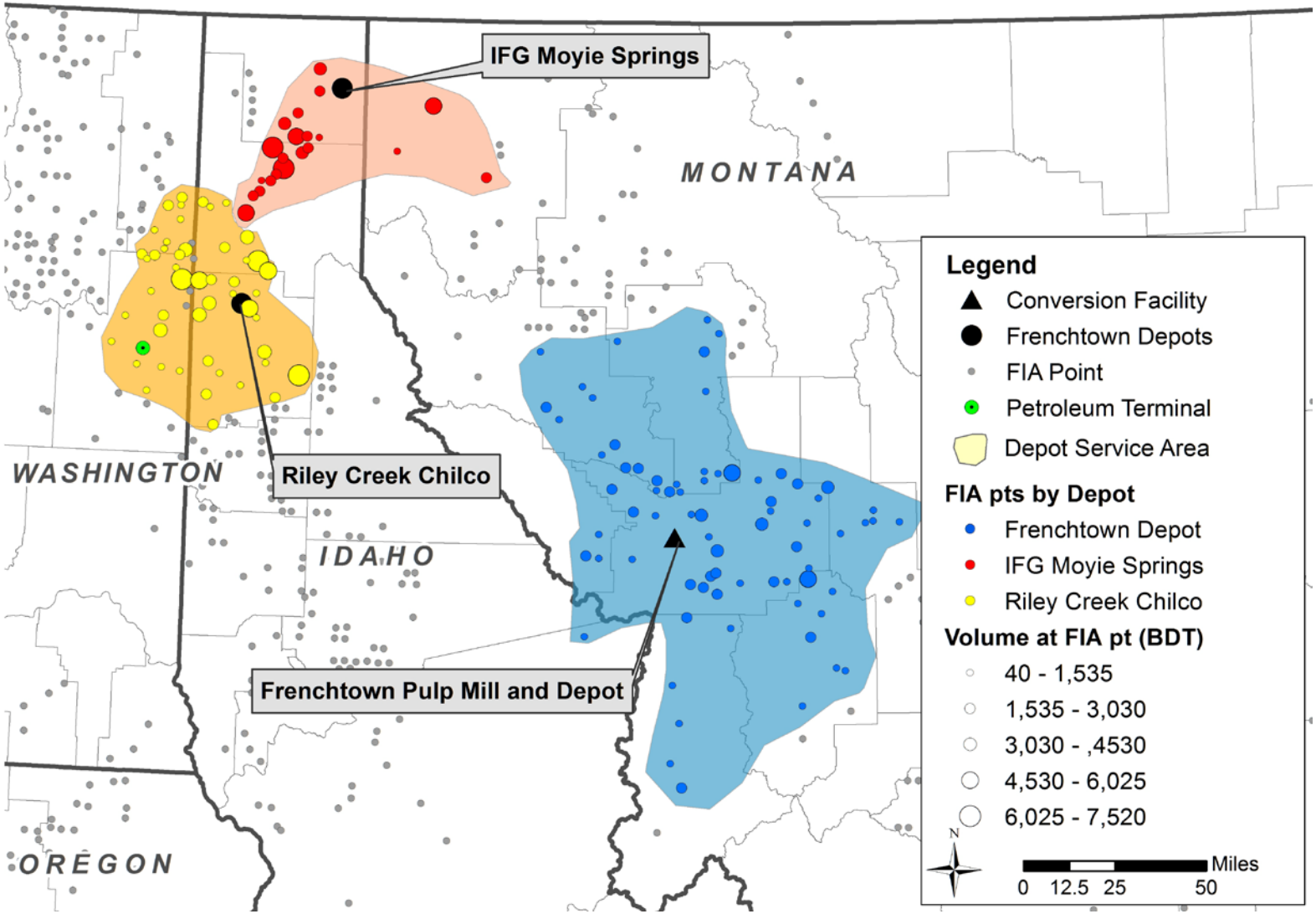
Preliminary Results – Do Not Cite

Delivered Cost to Terminal – Lewiston Conversion Facility



Preliminary Results – Do Not Cite

Delivered Cost to Terminal – Frenchtown Conversion Facility



Preliminary Results – Do Not Cite

Biorefinery Siting Decision Matrix

Assumptions and Criteria

1. Site size at least 100 acres
2. Onsite rail spur (for existing facilities)
3. Active/decommissioned wood-using facility or greenfield
4. Access to natural gas

Conversion Facility Decision Matrix					
	Total Milled Wood + IPK Transport Cost ($/BDT)	Electricity ($/kWh)	Natural Gas ($/k.c.f.)	Infrastructure: % reduction from Greenfield Cost	Labor: % less than H.S. Diploma
Scale					
5	223.0	0.02	5.5	33%	0.0
4	227.5	0.05	6.2	26%	12.8
3	232.0	0.07	6.9	20%	25.6
2	236.5	0.09	7.6	13%	38.4
1	241.0	0.11	8.3	7%	51.2
weights	*13.3*	*2.5*	*2.0*	*1.4*	*0.8*

Operating Expenditure Component	% of OpEx Cost	Normalized to 20
Feedstock	67%	13.4
Electricity	14%	2.9
Natural Gas	9%	1.7
Labor	4%	0.7
Annualized Infrastructure	6%	1.3

Preliminary Results – Do Not Cite

Infrastructure Assessment – reductions in CapEx

Table 6-9, Peters et al. ($1MM-$100MM)

GREENFIELD SCENARIO	Solids Processing Plant	Solids-Fluids Processing Plant	Fluids Processing Plant
Delivered cost of process equipment	100	100	100
Installation	45	39	47
Instrumentation and control	18	26	36
piping	16	31	68
electrical	10	10	11
buildings (including services)	68	47	45
yard improvements	15	12	10
service facilities	40	55	70
Total Direct Plant Costs	**312**	**320**	**387**
engineering and supervision	33	32	33
construction expenses	39	34	41
Total and Indirect Plant Costs	**384**	**386**	**461**
contractor's fee and legal expenses	21	23	26
contingency	35	37	44
Fixed Capital Investment	**440**	**446**	**531**
Lang Factor (FCI)	4.4	4.46	5.31
working capital (17.6% of FCI)	77	78	93
Total capital investment	**517**	**524**	**624**
Lang Factor (TCI)	**5.17**	**5.24**	**6.24**

Solid Plant: coal briquetting plant
Solid-Fluid Plant: oil extraction plant
Fluid Plant: Petroleum Refinery

Service Facilities	Low % of PEC	Typical % of PEC	High % of PEC
steam generation	9.63	12.0	24.0
steam distribution	0.74	4.0	8.0
water supply, cooling and pumping	1.48	7.2	14.8
water treatment	1.85	5.2	8.4
water distribution	0.37	3.2	8.0
electrical substation	3.33	5.2	10.4
electrical distribution	1.48	4.0	8.4
gas supply and distribution	0.74	1.2	1.6
air compression and distribution	0.74	4.0	12.0
refrigeration including distribution	1.85	4.0	8.0
process waste disposal	2.22	6.0	9.6
sanitary waste disposal	0.74	1.6	2.4
communications	0.37	0.8	1.2
raw material storage	1.11	2.0	12.8
finished product storage	2.59	6.0	9.6
fire protection system	1.11	2.0	4.0
safety installations	0.74	1.6	2.4

Total Capital Investment accuracy: +/- 30%

Timmerhaus, Klaus D., Ronald E. West, and Max S. Peters. *Plant Design and Economics for Chemical Engineers*. 5th ed. New York: McGraw-Hill, 2003. Print.

Infrastructure Assessment

Cost Items	Spokane Greenfield	Lewiston Pulp Mill	Frenchtown Decommissioned Mill
Delivered cost of process equipment (TDEC)	100	53.3	100
Installation	39	39	39
Instrumentation and control	26	26	26
Piping	31	31	31
Electrical	10	10	10
Buildings (including	47	7	29
Yard improvements	12	0	0
Service facilities	81.7	28.4	81.7
Total Direct Plant Costs	**347**	**195**	**317**
Engineering and supervision	32	32	32
Construction expenses	34	34	34
Total and Indirect Plant	**413**	**261**	**383**
Contractor's fee and legal expenses	23	23	23
Contingency	37	37	37
Fixed Capital Investment	**473**	**321**	**443**
Lang Factor (FCI)	**4.73**	**3.21**	**4.43**

		yes(0) / no(1) analysis	
Capital Cost Component	% of TDEC	Lewiston	Frenchtown
Enzymatic Hydrolysis	4.8	4.8	4.8
Fermentation, Separation & Alcohol-to-Jet	27.0	27.0	27.0
Pellet Mill	21.5	21.5	21.5
Wastewater Treatment	46.7	0.0	46.7
Total	**100.0**	**53.3**	**100.0**

Infrastructure Assessment

Cost Items	Spokane Greenfield	Lewiston Pulp Mill	Frenchtown Decommissioned Mill
Delivered cost of process equipment (TDEC)	100	53.3	100
Installation	39	39	39
Instrumentation and control	26	26	26
Piping	31	31	31
Electrical	10	10	10
Buildings (including	47	7	29
Yard improvements	12	0	0
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Total Direct Plant Costs	**347**	**195**	**317**
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Total and Indirect Plant	**413**	**261**	**383**
Contractor's fee and legal expenses	23	23	23
Contingency	37	37	37
Fixed Capital Investment	**473**	**321**	**443**
Lang Factor (FCI)	**4.73**	**3.21**	**4.43**
% Reduction from greenfield		33%	6%

		yes(0) / no(1) analysis	
Service Facilities	% of TDEC	Lewiston	Frenchtown
water supply, cooling and pumping	7.9	0.0	7.9
water distribution	3.5	0.0	3.5
electrical substation	5.7	5.7	5.7
electrical distribution	4.4	0.0	4.4
gas supply and distribution	1.3	0.0	1.3
air compression and distribution	0.8	0.0	0.8
refrigeration including distribution	2.0	2.0	2.0
sanitary waste disposal	0.8	0.0	0.8
communications	0.9	0.0	0.9
raw material storage	14.1	14.1	14.1
finished product storage	6.6	6.6	6.6
fire protection system	2.2	0.0	2.2
safety installations	1.8	0.0	1.8
steam generation	26.4	0.0	26.4
steam distribution	0.8	0.0	0.8
process waste disposal	2.4	0.0	2.4
Total	**81.7**	**28.4**	**81.7**

Preliminary Results – Do Not Cite

Final Site Selection

Conversion Facility Decision Matrix					
	Total Milled Wood + IPK Transport Cost ($/BDT)	Electricity ($/kWh)	Natural Gas ($/k.c.f.)	Infrastructure: % reduction from Greenfield Cost	Labor: % less than H.S. Diploma
Scale					
5	223.0	0.02	5.5	33%	0.0
4	227.5	0.05	6.2	26%	12.8
3	232.0	0.07	6.9	20%	25.6
2	236.5	0.09	7.6	13%	38.4
1	241.0	0.11	8.3	7%	51.2
weights	*13.3*	*2.5*	*2.0*	*1.4*	*0.8*

Location Specific Values

Facility	Total Milled Wood + IPK Transport Cost ($/BDT)	Electricity Rate ($/kWh)	Natural Gas ($/k.c.f.)	Infrastructure: % reduction from Greenfield Cost	Labor: % less than H.S. Diploma
Frenchtown	246.8	0.07	9.2	6	6.1
Lewiston	237.3	0.05	7.1	33	9.6
Spokane	223.7	0.05	7.9	0	7.8

Scaled Values with Facility Scores

Facility	Total Milled Wood + IPK Transport Cost ($/BDT)	Electricity Rate ($/kWh)	Natural Gas ($/k.c.f.)	Infrastructure: % reduction from Greenfield Cost	Labor: % less than H.S. Diploma	Score
Frenchtown	1	3	1	2	5	29.6
Lewiston	3	4	3	5	5	66.9
Spokane	5	4	2	1	5	85.9

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Future Work

- Incorporate Conversion Facility processing costs into decision matrix

- Run optimization model on all Depots to Conversion Facilities to compare against Depot Decision Matrix Results

THANK YOU

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