Engineered Wood Products

Comparative Life Cycle Assessment:

Glue-Laminated Timber

vs.

Laminated Veneer Lumber

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Background

- Structural engineers like EWP
- Longer spans
- Better properties
- "Renewable" material
- Glulams, LVLs and PSLs common types
- Economical?

Background

- Engineered for performance
  - Creative use of lower grade woods/scrap
  - Organic resins bond wood together
  - Complicated processes
  - Common in residential & commercial
- Concerns
  - Environmentally better than real wood?
  - Global warming?
  - Formaldahyde? VOCs?

Literature Review

- CORRIM Phase I
  - Life Cycle Environmental Performance of Renewable Building Materials in the Context of Residential Construction, June 2005
- Other
  - 2002 Norway LCC/LCA Study for Glulams
  - AP-42 Chapter 10: Wood Products Industry
  - Canadian Wood Council (CWC)
  - Western Wood Products Association (WWPA)

Environmental Aspects

- Resource Consumption
  - Fossil-fuel use (non-renewables)
  - Biomass/Forestry (renewables)
  - Water use
- Energy Use
- Water Emissions
  - Manufacture of chemicals
  - Fertilizer
  - Not considered!
- Air Emissions
  - Global warming
  - Smog
  - Acidification
  - Human health
- Solid Waste
  - Forestry waste
  - Manufacturing waste
  - Construction & demolition waste
  - Recycling?
  - Not considered!

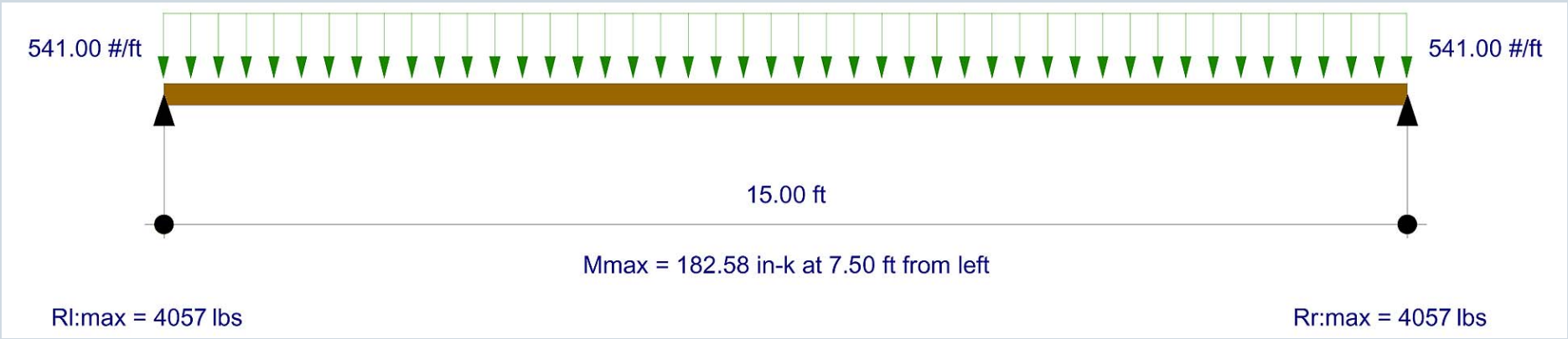
Process Alternatives

- Renewable Energy
  - More on-site biomass?
  - Hydro
- Chemical Processes
  - Inorganic resins?
- Fuels
  - Biodiesel (transport and manufacture)
- FSC Certification?

FSC FOREST STEWARDSHIP COUNCIL
Because forests matter

Goal & Scope

- Functional Unit
  - Nominal 4x12 EWP
  - 15 foot span
  - Indoor residential application
  - 75-year design life
  - 541 plf design load

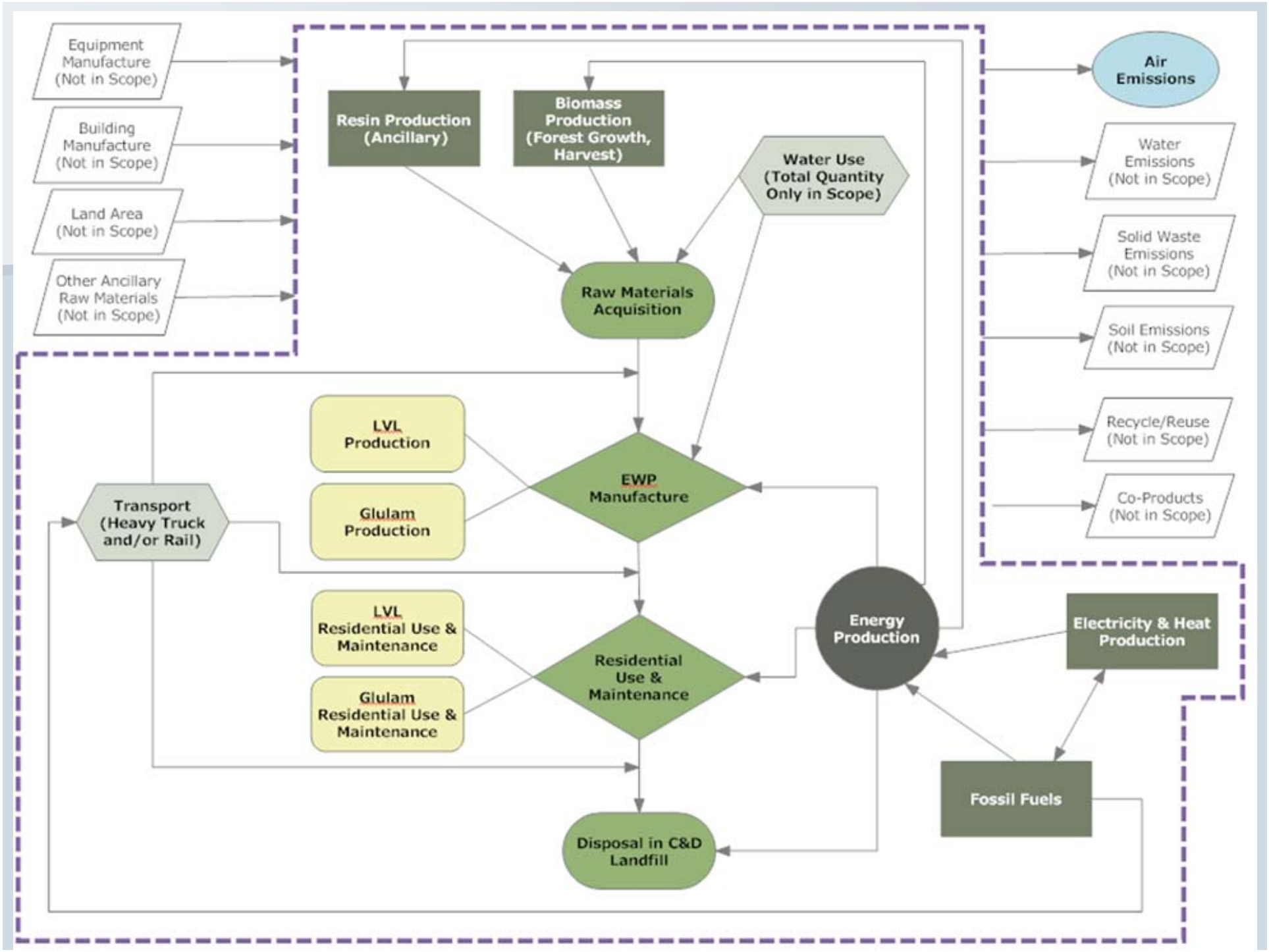


Goal & Scope

- Reference Flows
  - Study data collected was allocated by mass and outputs volume units
  - Easier to translate volume into engineering practice

Demand Vectors, f^T	**Unit**	**Total Flow**
3"x12"x15'0" Douglas Fir 26F-E/DF1M1	ft3/glulam	**3.75**
3.5"x11.875"x15'0" 1.8E Microllam LVL	ft3/LVL	**4.33**

- System Boundary


Equipment Manufacture (Not in Scope)
Building Manufacture (Not in Scope)
Land Area (Not in Scope)
Other Ancillary Raw Materials (Not in Scope)
Resin Production (Ancillary)
Biomass Production (Forest Growth, Harvest)
Water Use (Total Quantity Only in Scope)
Raw Materials Acquisition
LVL Production
Glulam Production
EWP Manufacture
Transport (Heavy Truck and/or Rail)
LVL Residential Use & Maintenance
Glulam Residential Use & Maintenance
Residential Use & Maintenance
Energy Production
Electricity & Heat Production
Fossil Fuels
Disposal in C&D Landfill
Air Emissions
Water Emissions (Not in Scope)
Solid Waste Emissions (Not in Scope)
Soil Emissions (Not in Scope)
Recycle/Reuse (Not in Scope)
Co-Products (Not in Scope)

Goal & Scope

- Allocation
  - Mass allocated, converted to volume (use and demolition)
  - Percentage of wood products in residence
- Impact Categories
  - Air Emissions Only
  - Forest to landfill life cycle
- Data
  - CORRIM & GREET
  - UWME Quality Scores

Goal & Scope

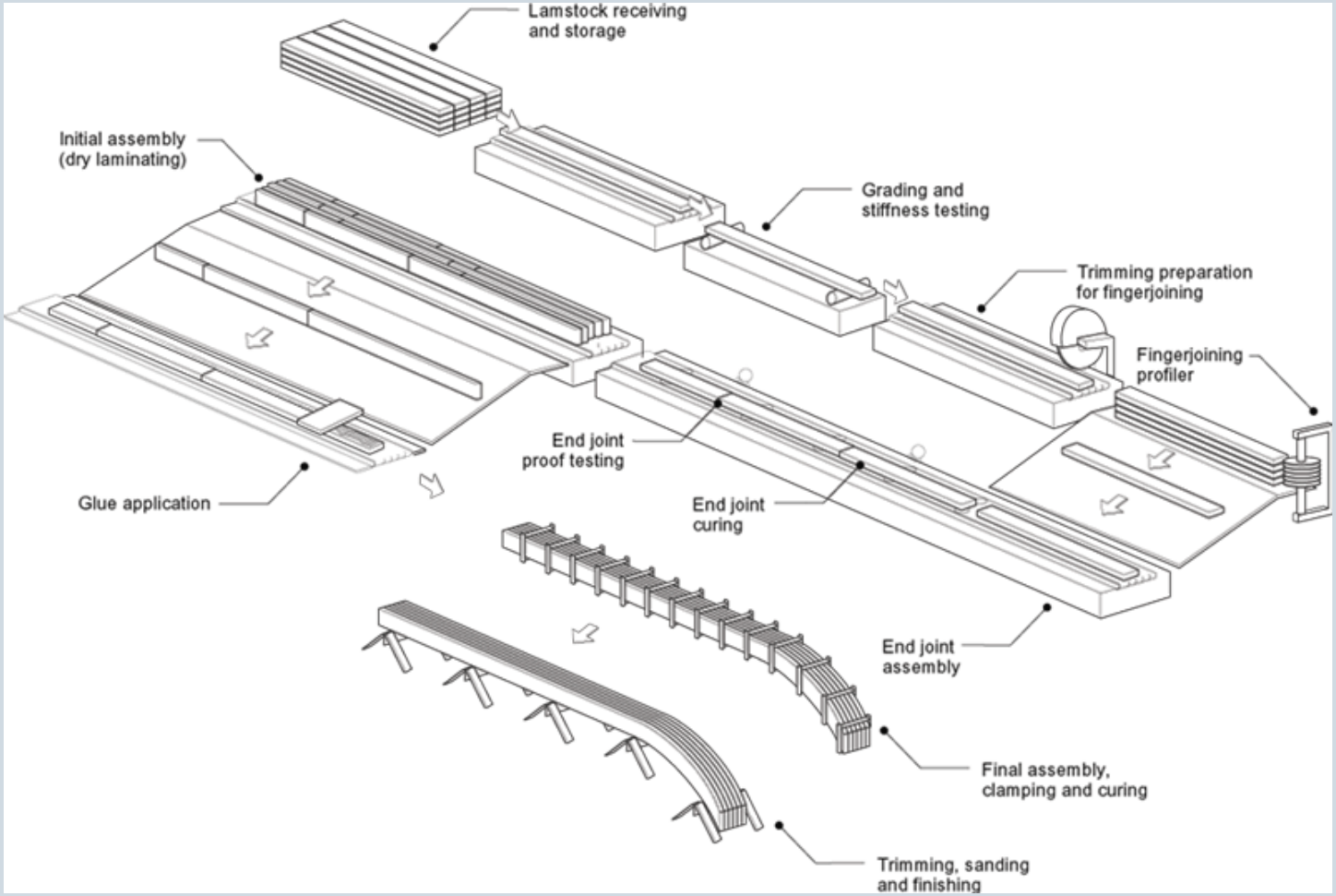
- Cutoff
  - Lubricants
  - Equipment & machinery
- Assumptions
  - Kerosene = No. 2 Diesel = Distillate Fuel Oil
  - Stationary grid electricity
- Limitations
  - Resins & lubricants
  - Non-local residential model

Life Cycle Inventory

- Unit Process Categories
  - Raw materials & biomass
  - Resin production
  - EWP production
  - Transport (empty backhaul)
  - Construction
    - Design-life implications
  - Demolition and Disposal
- 39 Unit Processes

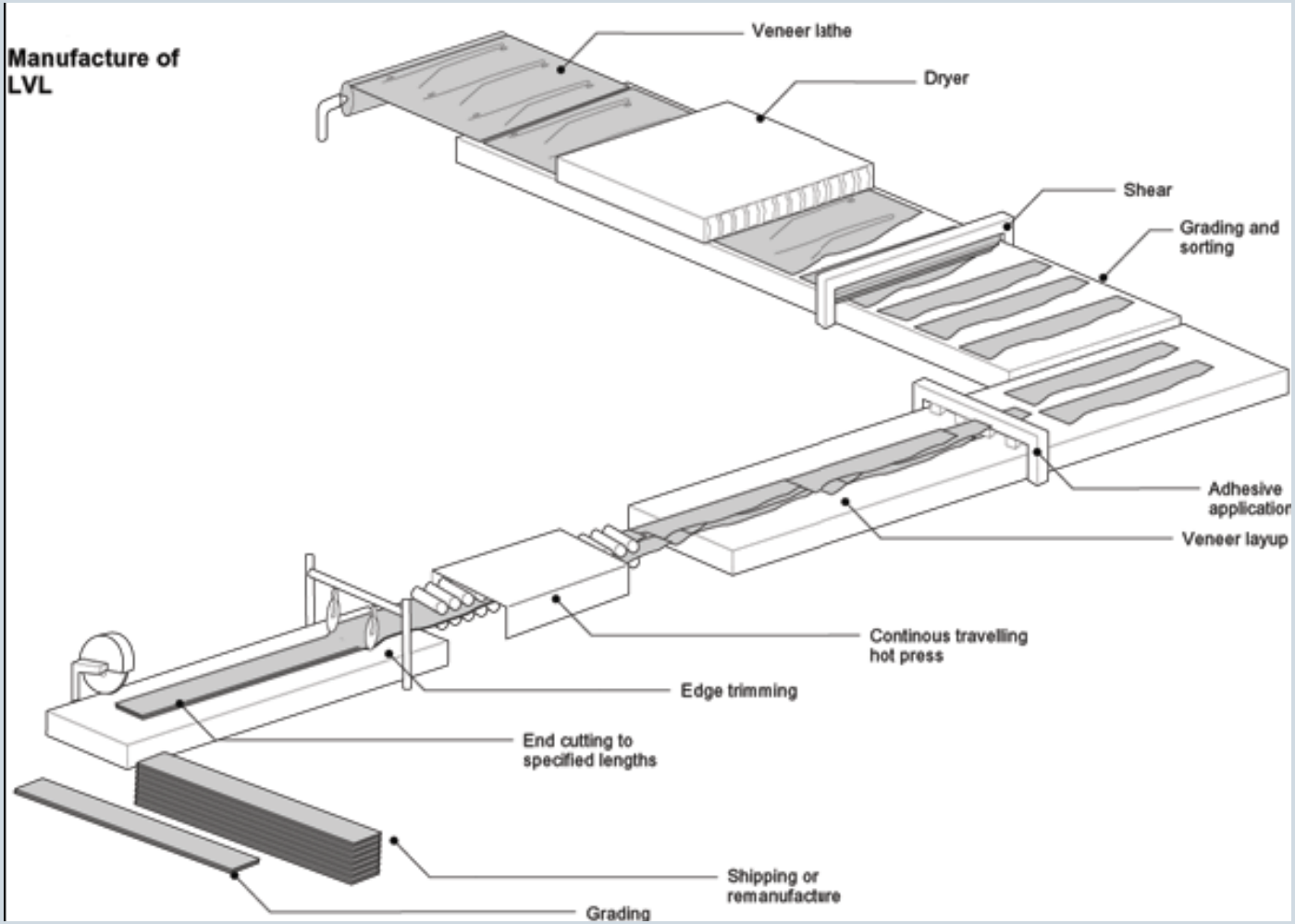
Life Cycle Inventory

- Glulam Manufacturing Process (Canadian Wood Council)



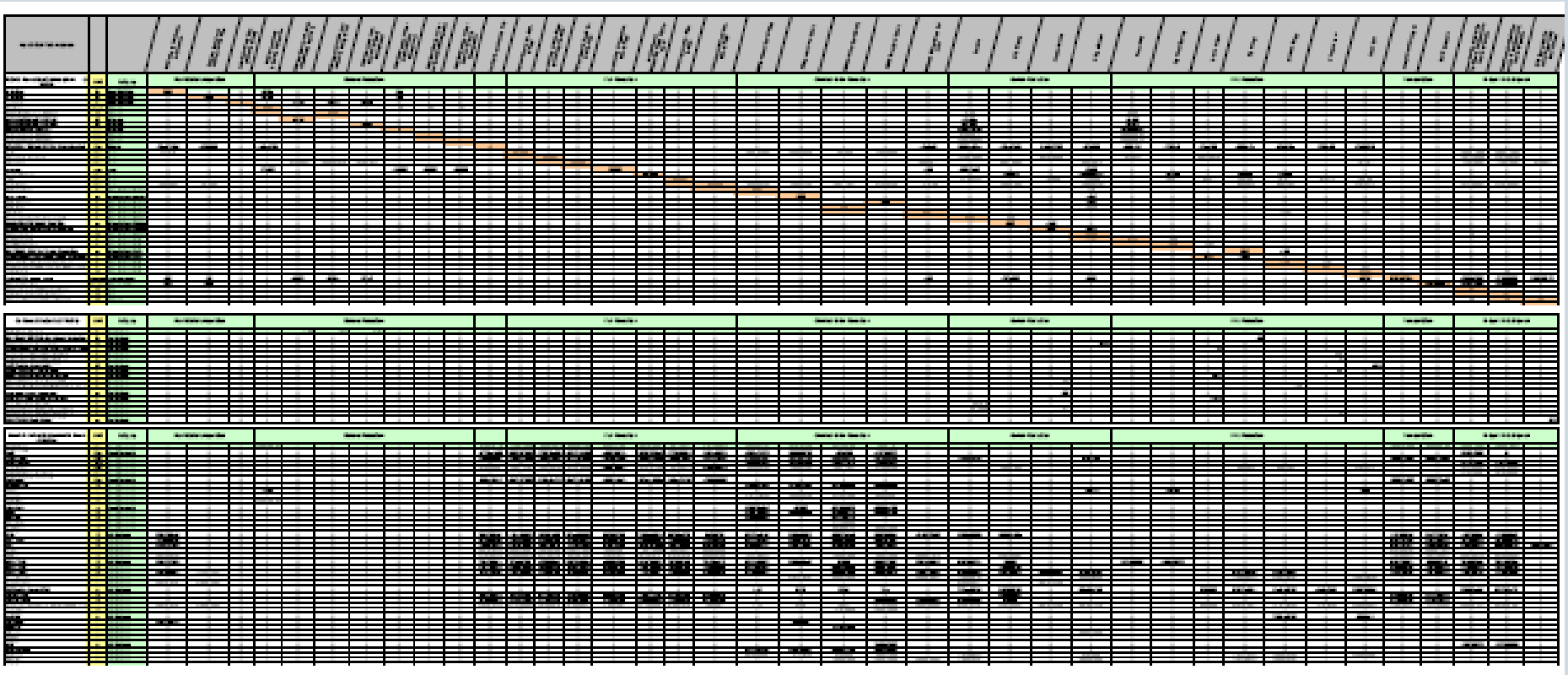
Life Cycle Inventory

- LVL Manufacturing Process (Canadian Wood Council)



Life Cycle Inventory

- 39 Technosphere Flows – 39 to A Matrix (39x39)
- 17 Co-Products (not considered)
- 82 Environmental Flows – 40 to B Matrix (40x39)



Life Cycle Inventory

- Calculations in MATLab

Scaling Matrix (s Matrix)	Glulam	LVL
PNW Nitrogen Fertilizer Production	**1.84E-08**	1.14E-08
PNW Phosphorous Fertilizer Production	**3.16E-09**	1.96E-09
Lubricant Production (Hollow Process)	**3.61E-05**	2.30E-05
PNW Greenhouse Seedling Production	**5.61E-07**	3.48E-07
PNW Harvest Acres - High Intensity Management	1.04E-07	**2.26E-07**
PNW Harvest Acres - Low Intensity Management	**6.91E-07**	1.23E-07
PNW Harvest Acres - Medium Intensity Management	**6.07E-07**	3.77E-07
PNW Reforested Acres - High Intensity Management	**1.04E-07**	6.46E-08
PNW Reforested Acres - Low Intensity Management	**6.91E-07**	4.29E-07
PNW Reforested Acres - Medium Intensity Management	**6.07E-07**	3.77E-07
Electricity - Stationary Grid	**1.09E+03**	8.62E+02
Production of Coal, Well-to-POU	**3.01E-04**	2.35E-09
Production of Non-Road Diesel, Well-to-POU	**1.06E-05**	1.01E-05
Production of Diesel Fuel, Well-to-POU	8.57E-05	**3.30E-04**
Production of Gasoline, Well-to-POU	**1.17E-05**	2.13E-07
Production of Hogfuel/Biomass, Well-to-POU	**4.47E-03**	1.74E-04
Production of LPG, Well-to-POU	**1.37E-04**	3.56E-05
Production of Natural Gas, Well-to-POU	**1.48E-03**	9.59E-04
MUF Hardener (for Glulam)	**6.83E-07**	0.00E+00
MUF Resin (for Glulam)	**6.15E-06**	0.00E+00

Scaling Matrix (s Matrix)	Glulam	LVL
PRF Hardener (for Glulam)	**3.29E-05**	0.00E+00
PRF Resin (for Glulam)	**5.81E-06**	0.00E+00
PF Resin Manufacture (for LVL)	0.00E+00	**9.36E-06**
Sawmill	**1.24E-04**	0.00E+00
Kiln Drying	**1.24E-04**	0.00E+00
Lumber Planer	**1.24E-04**	0.00E+00
Glulam Plant	**1.24E-04**	0.00E+00
Debarking	0.00E+00	**1.33E-04**
Log Conditioning	0.00E+00	**1.33E-04**
Green Veneer	0.00E+00	**1.33E-04**
Dry Veneer	0.00E+00	**1.33E-04**
Press & lay-up	0.00E+00	**1.33E-04**
Trim and saw	0.00E+00	**1.33E-04**
LVL Plant	0.00E+00	**1.33E-04**
Heavy Truck Transport	**5.52E+02**	1.85E+02
Rail Transport	**1.85E-02**	1.15E-02
Construction Installation of Glulam in Residence 75-Year Design Life	0.00E+00	0.00E+00
Construction Installation of LVL in Residence 75-Year Design Life	0.00E+00	0.00E+00
Disposal of EWP in Landfill (Including Demolition)	0.00E+00	0.00E+00

Life Cycle Inventory

Inventory Matrix (g Matrix)	Glulam	LVL	Inventory Matrix (g Matrix)	Glulam	LVL
Total Energy	**-1.77E+09**	-1.41E+09	N2O	**3.39E+03**	2.69E+03
Coal	**-1.22E+09**	-9.69E+08	NOx: Total	**2.60E+05**	2.07E+05
Fossil Fuels	**-1.71E+09**	-1.36E+09	SOx: Total	**5.72E+05**	4.54E+05
Hydro Energy	**-1.55E+01**	0.00E+00	VOC: Total	**2.14E+04**	1.70E+04
Natural Gas	**-3.95E+08**	-3.14E+08	Formaldehyde	1.25E-09	**1.50E-08**
Other (Nuclear, Undefined)	0.00E+00	0.00E+00	Dust	3.31E-08	2.94E-12
Petroleum	**-9.56E+07**	-7.59E+07	Particulates (unspecified)	**5.29E-05**	6.75E-08
Uranium Ore	**-8.75E-09**	0.00E+00	PM10: Total	**3.14E+05**	2.50E+05
Water	**-3.39E-02**	-5.11E-02	PM2.5: Total	**8.28E+04**	6.58E+04
Iron Ore	**-4.02E-09**	0.00E+00	Particulates Total (Dust, PM10, PM2.5, unsp.)	**3.97E+05**	3.15E+05
K-fertilizer	**-9.84E-11**	-6.11E-11	Aromatics	**2.03E-10**	0.00E+00
Limestone	**-3.23E-08**	0.00E+00	Acetone	0.00E+00	**1.52E-08**
NaCl	**-1.06E-06**	0.00E+00	Ammonia	**4.68E-10**	4.21E-12
Nitrogen	**-8.10E-08**	0.00E+00	Benzene	**1.57E-10**	0.00E+00
Phosphate	**-1.80E-09**	0.00E+00	Ethanol	**1.77E-08**	0.00E+00
Sulphur	**-2.85E-07**	0.00E+00	Floride	0.00E+00	0.00E+00
CH4	**3.21E+05**	2.55E+05	HCl	**1.85E-10**	0.00E+00
CO: Total	**6.35E+04**	5.04E+04	Hydrocarbons	**9.19E-08**	0.00E+00
CO_2	**2.39E+08**	1.89E+08	Methanol	**4.80E-08**	4.55E-08
GHGs	**2.47E+08**	1.96E+08	Phenol	**3.70E-08**	1.26E-08

Life Cycle Impact Assessment

- Factors from FRED
- 16 environmental flows considered
- Air emission impact categories
  - Global warming potential
  - Photochemical smog
  - Acidification
  - Eutrophication
  - Human health (± carcinogens)
  - Ecotoxicity

Life Cycle Impact Assessment

FRED Impact Equivalancy Factors (Q Matrix)	Unit	Category	GWP	Smog	Acid	Eutro	HH NC	HHC	Eco
CH4	g	Air Emission	21						
CO: Total	g	Air Emission		0.07					
CO_2	g	Air Emission	1						
N2O	g	Air Emission	310						
NOx: Total	g	Air Emission			0.7	0.13			
SOx: Total	g	Air Emission			1				
Formaldehyde	g	Air Emission		9.12			7	0.003	7.4
Aromatics	g	Air Emission		3.93					
Acetone	g	Air Emission		0.48					
Ammonia	g	Air Emission			1.9	0.33	3.2		
Benzene	g	Air Emission							
Ethanol	g	Air Emission		1.92					
Floride	g	Air Emission							7.3
HCl	g	Air Emission			0.087				11
Methanol	g	Air Emission		0.99					
Phenol	g	Air Emission		1.86			0.045		

Life Cycle Impact Assessment

- Calculations in MATLab

Total Environmental Impact (h Matrix)	Glulam	LVL
Global Warming Potential	***2.46E+08***	1.96E+08
Photochemical Smog	***4.44E+03***	3.53E+03
Acidification	***7.55E+05***	5.99E+05
Eutrophication	***3.38E+04***	2.69E+04
Human Health (Non-Carcinogen)	1.19E-08	***1.06E-07***
Human Health (Carcinogen)	3.75E-12	***4.51E-11***
Ecotoxity	1.13E-08	***1.11E-07***

Life Cycle Impact Assessment

- Normalization Results for Key Issues
  - Current U.S. Population = 303,616,968
  - (http://www.census.gov/)
  - Class notes for normalization factors

Normalization Factors: AS PERCENT OF THE US TOTAL

Climate change	2.192E+04 kg CO2 equivalents/capita
Acidification	2.187E+04 kg H+ equivalents/capita

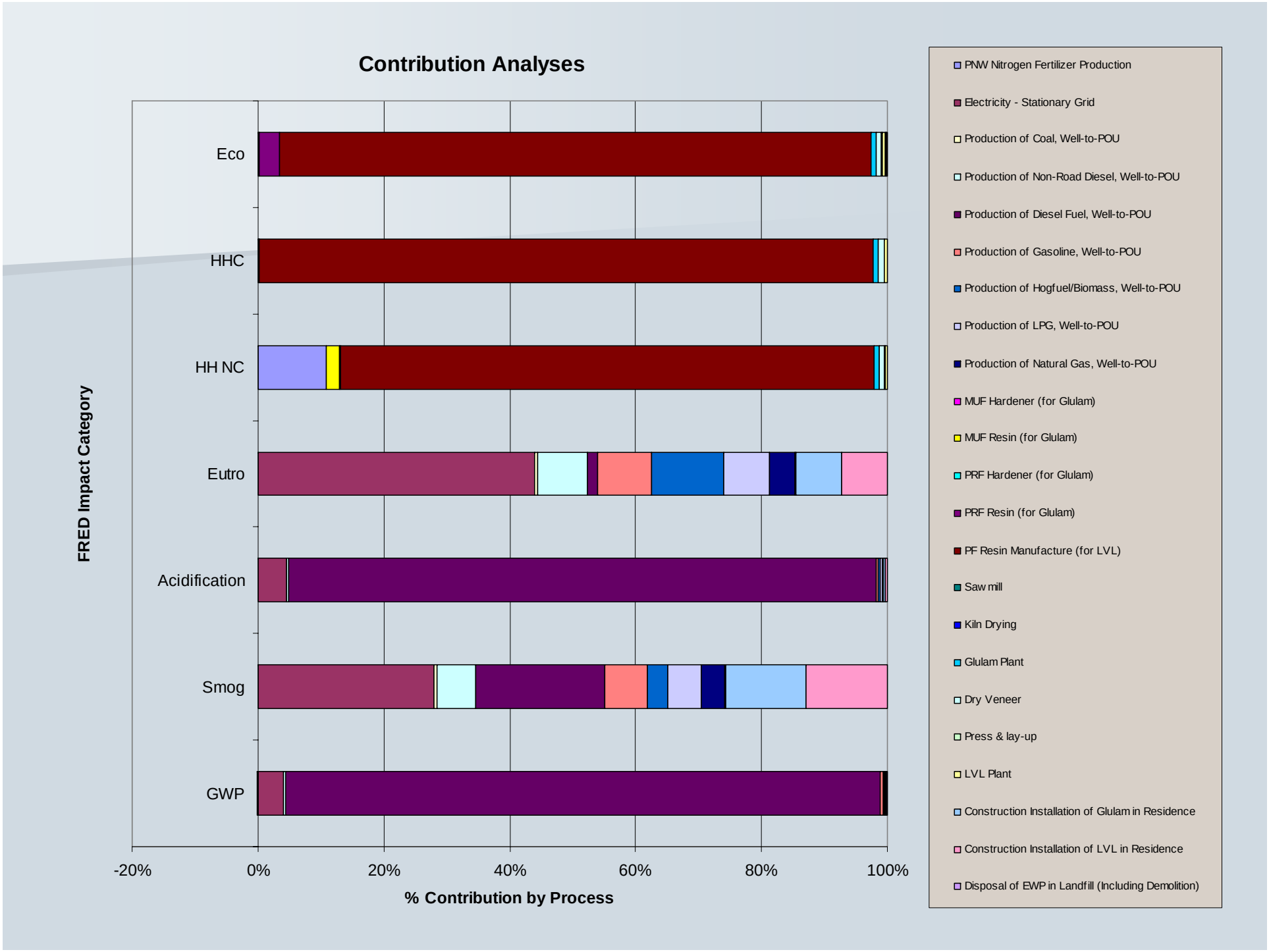
Normalized Impacts (h Matrix)	Glulam	LVL
Global Warming Potential	**0.0037%**	0.0029%
Acidification	**0.000011%**	0.000009%

Interpretation

- Contribution Analyses

	Worst Process Contributors	% Impact	Beam
Global Warming	Well to POU Diesel	**94.6%**	Both
Smog	Production of Electricity	**28.0%**	Both
Acidification	Well to POU Diesel	**93.4%**	Both
Eutrophication	Production of Electricity	**43.9%**	Both
Human Health NC	PF Resin Manufacture for LVL	**84.9%**	LVL
Human Health C	PF Resin Manufacture for LVL	**97.6%**	LVL
Ecotoxicity	PF Resin Manufacture for LVL	**94.0%**	LVL

- 16 of 39 processes have no associated impact!
  - None for forest management?
  - Hmmm….


Contribution Analyses
FRED Impact Category
Eco
HHC
HH NC
Eutro
Acidification
Smog
GWP
-20%
0%
20%
40%
60%
80%
100%
% Contribution by Process
PNW Nitrogen Fertilizer Production
Electricity - Stationary Grid
Production of Coal, Well-to-POU
Production of Non-Road Diesel, Well-to-POU
Production of Diesel Fuel, Well-to-POU
Production of Gasoline, Well-to-POU
Production of Hogfuel/Biomass, Well-to-POU
Production of LPG, Well-to-POU
Production of Natural Gas, Well-to-POU
MUF Hardener (for Glulam)
MUF Resin (for Glulam)
PRF Hardener (for Glulam)
PRF Resin (for Glulam)
PF Resin Manufacture (for LVL)
Saw mill
Kiln Drying
Glulam Plant
Dry Veneer
Press & lay-up
LVL Plant
Construction Installation of Glulam in Residence
Construction Installation of LVL in Residence
Disposal of EWP in Landfill (Including Demolition)

Interpretation

- Data Quality Score = 1.22

Discrepancy Matrix (d Matrix)	Glulam	LVL
PNW Nitrogen Fertilizer Production	**-2.08E-15**	**2.00E-17**
PNW Phosphorous Fertilizer Production	**1.13E-14**	**4.92E-17**
Lubricant Production (Hollow Process)	**9.83E-20**	**8.30E-20**
PNW Greenhouse Seedling Production	**5.92E-15**	**2.22E-16**
PNW Harvest Acres - High Intensity Management	0.00E+00	**2.17E-19**
PNW Harvest Acres - Low Intensity Management	**-7.16E-18**	**-1.82E-17**
PNW Harvest Acres - Medium Intensity Management	**-5.20E-18**	**3.47E-18**
PNW Reforested Acres - High Intensity Management	**-1.36E-21**	**-5.77E-21**
PNW Reforested Acres - Low Intensity Management	**2.01E-20**	**5.40E-21**
PNW Reforested Acres - Medium Intensity Management	0.00E+00	**5.29E-23**
Electricity - Stationary Grid	**-9.09E-13**	0.00E+00
Production of Coal, Well-to-POU	**-4.26E-14**	**-6.80E-15**
Production of Non-Road Diesel, Well-to-POU	**-8.88E-16**	**-2.66E-15**
Production of Diesel Fuel, Well-to-POU	**1.28E-13**	**-3.55E-15**
Production of Gasoline, Well-to-POU	**3.50E-13**	**9.33E-14**
Production of Hogfuel/Biomass, Well-to-POU	0.00E+00	**5.33E-14**
Production of LPG, Well-to-POU	0.00E+00	**-7.11E-15**
Production of Natural Gas, Well-to-POU	**-1.48E-11**	**-1.02E-12**
MUF Hardener (for Glulam)	**-1.08E-19**	0.00E+00
MUF Resin (for Glulam)	0.00E+00	0.00E+00

Discrepancy Matrix (d Matrix)	Glulam	LVL
PRF Hardener (for Glulam)	**-8.67E-19**	0.00E+00
PRF Resin (for Glulam)	**6.94E-18**	0.00E+00
PF Resin Manufacture (for LVL)	0.00E+00	0.00E+00
Sawmill	0.00E+00	0.00E+00
Kiln Drying	0.00E+00	0.00E+00
Lumber Planer	0.00E+00	0.00E+00
Glulam Plant	0.00E+00	0.00E+00
Debarking	0.00E+00	0.00E+00
Log Conditioning	0.00E+00	0.00E+00
Green Veneer	0.00E+00	0.00E+00
Dry Veneer	0.00E+00	0.00E+00
Press & lay-up	0.00E+00	0.00E+00
Trim and saw	0.00E+00	0.00E+00
LVL Plant	0.00E+00	**-8.88E-16**
Heavy Truck Transport	**-1.11E-16**	**1.11E-16**
Rail Transport	**-6.83E-16**	**-4.66E-16**
Construction Installation of Glulam in Residence 75-Year Design Life	0.00E+00	0.00E+00
Construction Installation of LVL in Residence 75-Year Design Life	0.00E+00	0.00E+00
Disposal of EWP in Landfill (Including Demolition)	0.00E+00	0.00E+00

Interpretation

- MATLab to the rescue again…
- Condition number
  - Upper bound for uncertainties…
  - $\kappa = 2.18 \times 10^{13}$!!
- Sensitivity/Perturbation Analyses
  - Fossil fuel and resource use processes and related environmental flows are most influenced by small perturbations
  - Some values approach |1| but none exceed
  - Possibly due to data gaps

Summary

- Glulam appears more environmentally detrimental than LVL
- LVL loses for human health and ecotoxicity impacts
  - More data was available on glulam resin production than for LVL
  - Glulam has less volume of wood in final product!
  - LVL process was black-boxed by CORRIM

Recommendations

- Gather more primary data
  - Resin manufacture (though proprietary)
  - Lubricants
  - CO_2 emissions reporting from wood manufacturers
  - C&D data for components
  - Update existing information
- Refine model to be local or regional
- Compare with dimension lumber
- Consider recycling, co-products, other emissions
- Try other transportation models
  - Consider backhaul
- Pursue cost analysis on smaller scale
  - CORRIM performed but not for individual components

Sources

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