



Two Hybrid Life Cycle Assessments for Construction

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Outline

- Life Cycle Assessment (LCA) Basics
 - ◆ Process
 - ◆ Input-Output
 - ◆ Hybrid
- Construction
 - ◆ Building Life Cycle
 - Design and Construction - Missing Stages?
 - ◆ Hybrid LCAs for Construction Processes
 - Augmented Process-Based
 - Input-Output-Based
- Future Work

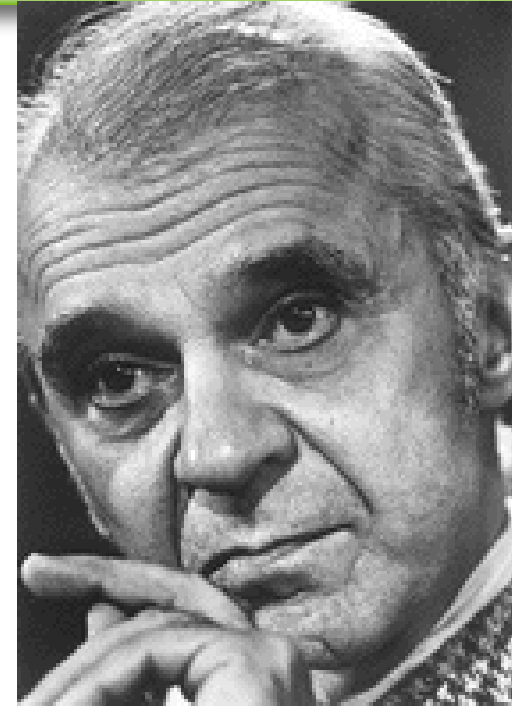
Building Industry Process LCA Tools

- **BEES**
 - ◆ NIST (U.S.)
- **SimaPro**
 - ◆ Netherlands
- **GaBi**
 - ◆ Germany
- **Athena**
 - ◆ Canada



Input-Output

- Wassily Leontief (1930s)
 - ◆ Matrix-based economic analysis
 - ◆ Nobel Prize in Economics (1973)
- I-O for LCA
 - ◆ Associates sector-level environmental data with economic data
 - Resource / energy use
 - Environmental emissions
 - ◆ Change in economic demand quantified in environmental or resource terms (linear)
- Economic Input-Output Life Cycle Assessment model (EIO-LCA)
 - ◆ Developed by Carnegie Mellon University (1995)
 - ◆ Web-based since 1999
 - www.eiolca.net
 - ◆ U.S. economy represented by 500 sectors
- Direct and indirect impacts (supply chain)
 - ◆ Economic
 - ◆ Environmental



eiolca.net

Hybrid LCA

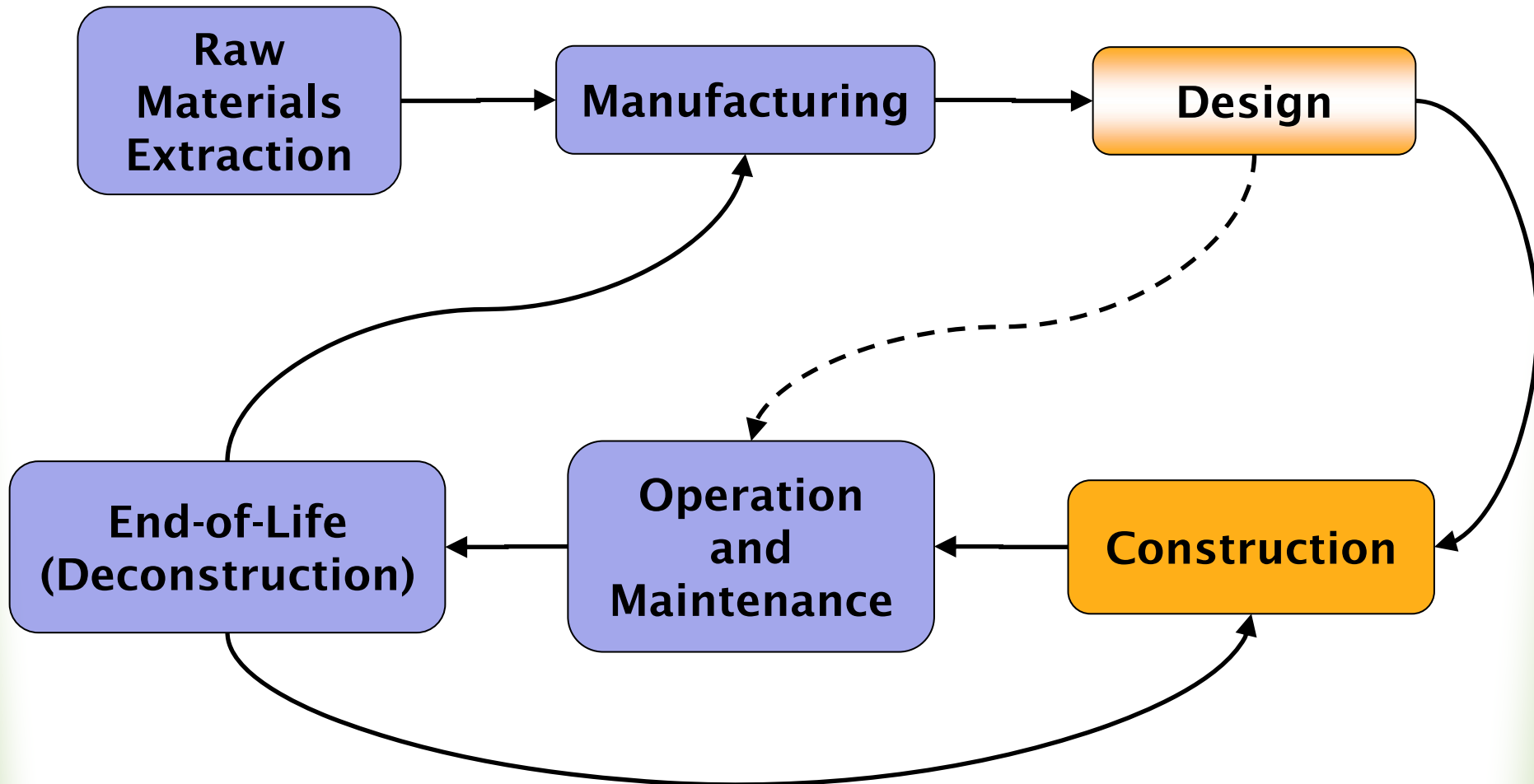
- Combination of process and I-O LCA methods
 - ◆ Lots of types
- For construction
 - ◆ Two hybrid models of focus
 - “Augmented” process-based
 - Self-named
 - Input-output-based hybrid
 - S. Joshi
 - ◆ Difficult due to a variety of factors
 - Many innate to industry

Past “Construction” LCAs

- Modeling construction is challenging
 - ◆ Dispersed
 - Operationally
 - Subcontractors
 - Nature of “product”
 - ◆ Spatially
 - Construction sites
 - Resource suppliers
 - Labor pool
- Existing research and LCAs
 - ◆ Construction “glossed over” or ignored



Life Cycle of Infrastructure

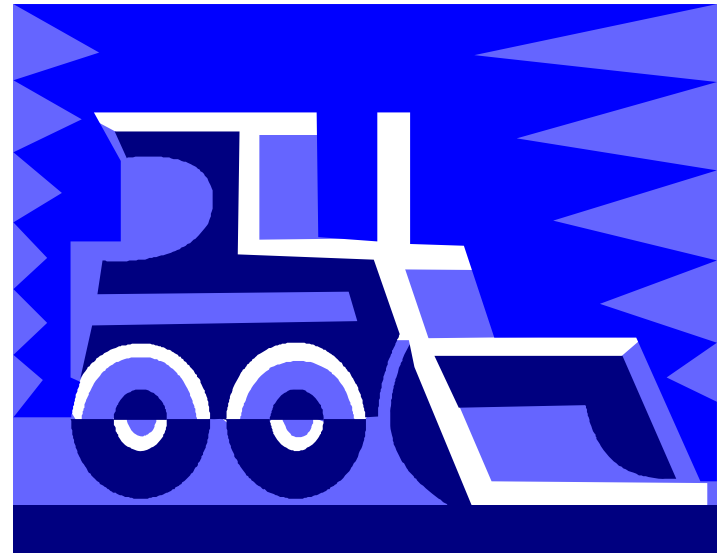
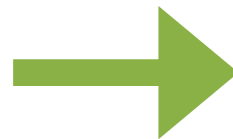


Life Cycle of Construction?

- Past and present building research
 - ◆ Material selection
 - ◆ Building energy use
 - ◆ Indoor environmental quality
 - ◆ End-of-life
- Construction industry *is* responsible for many environmental impacts
 - ◆ To understand *entire* life cycle of a building . . .
 - ◆ Construction phase *must* be adequately quantified



Input-Output Based Hybrid for Construction



EIO-LCA Construction Sectors

IO #	I-O Title
2301	New residential construction
230110	New residential 1-unit structures, nonfarm
230120	New multifamily housing structures, nonfarm
230130	New residential additions and alterations, nonfarm
230140	New farm housing units and additions and alterations
2302	New nonresidential construction
230210	Manufacturing and industrial buildings
230220	Commercial and institutional buildings
230230	Highway, street, bridge, and tunnel construction
230240	Water, sewer, and pipeline construction
230250	Other new construction
2303	Maintenance and repair construction
230310	Maintenance and repair of farm and nonfarm residential structures
230320	Maintenance and repair of nonresidential buildings
230330	Maintenance and repair of highways, streets, bridges, and tunnels
230340	Other maintenance and repair construction

NAICS Industries

- **Building, Developing, and General Contracting Industries**
 - ◆ Land subdivision & land development
 - ◆ Single-family housing construction
 - ◆ Multifamily housing construction
 - ◆ Manufacturing & industrial building construction
 - ◆ Commercial & institutional building construction
- **Heavy Construction Industries**
 - ◆ Highway & street construction
 - ◆ Bridge & tunnel construction
 - ◆ Water, sewer, & pipeline construction
 - ◆ Power & communication transmission line construction
 - ◆ Industrial nonbuilding structure construction
 - ◆ All other heavy construction
- **Special Trade Industries**
 - ◆ Plumbing, heating, & air-conditioning contractors
 - ◆ Painting & wall covering contractors
 - ◆ Electrical contractors
 - ◆ Masonry & stone contractors
 - ◆ Drywall, plastering, acoustical, & insulation contractors
 - ◆ Tile, marble, terrazzo, & mosaic contractors
 - ◆ Carpentry contractors
 - ◆ Floor laying & other floor contractors
 - ◆ Roofing, siding, & sheet metal contractors
 - ◆ Concrete contractors
 - ◆ Water well drilling contractors
 - ◆ Structural steel erection contractor
 - ◆ Glass & glazing contractors
 - ◆ Excavation contractors
 - ◆ Wrecking & demolition contractors
 - ◆ Building equipment & other machinery installation contractors
 - ◆ All other special trade contractors

Existing IO Sector / NAICS “Map”

IO #	I-O Title	NAICS Codes
2301	New residential construction	
230110	New residential 1-unit structures, nonfarm	23*
230120	New multifamily housing structures, nonfarm	23*
230130	New residential additions and alterations, nonfarm	23*
230140	New farm housing units and additions and alterations	23*
2302	New nonresidential construction	
230210	Manufacturing and industrial buildings	23*
230220	Commercial and institutional buildings	23*
230230	Highway, street, bridge, and tunnel construction	23*
230240	Water, sewer, and pipeline construction	23*
230250	Other new construction	23*
2303	Maintenance and repair construction	
230310	Maintenance and repair of farm and nonfarm residential structures	23*
230320	Maintenance and repair of nonresidential buildings	23*
230330	Maintenance and repair of highways, streets, bridges, and tunnels	23*
230340	Other maintenance and repair construction	23*

Construction Mapping

IO Code	IO Sector Name	Corresponding NAICS Industries in CSM Model		
		NAICS Code	Description	% of NAICS Industry in IO Sector
230110	New residential 1-unit structures, nonfarm	2331	Land subdivision & land development	60
		23321	Single-family housing construction	72
		2351	Plumbing, heating, & air-conditioning contractors	27
		2352	Painting & wall covering contractors	27
		2353	Electrical contractors	26
		23541	Masonry & stone contractors	38
		23542	Drywall, plastering, acoustical, & insulation contractors	27
		23543	Tile, marble, terrazzo, & mosaic contractors	38
		23551	Carpentry contractors	38
		23552	Floor laying & other floor contractors	38
		2356	Roofing, siding, & sheet metal contractors	38
		23592	Glass & glazing contractors	27
		23593	Excavation contractors	37

Old Energy Vector

I-O #	Electricity	Coal	Natural Gas	LPG	Motor Gasoline	Distillate fuel	Kerosene	Jet fuel	Residual fuel
230110	0.07	0	0.21	0.05	0.03	0.37	0	0.01	0
230120	0.08	0	0.22	0.20	0.07	1.61	0	0.05	0.00
230130	0.06	0	0.18	0	0	0	0	0	0
230140	0.06	0	0.20	0	0	0	0	0	0
230210	0.07	0	0.23	0.30	0.08	2.45	0	0.08	0
230220	0.08	0	0.23	0.31	0.02	2.54	0	0.08	0
230230	0.08	0	0.71	1.10	0.06	9.00	0	0.40	0
230240	0.05	0	0.14	0.58	0.06	4.74	0	0.21	0
230250	0.05	0	0.14	0.33	0.48	2.73	0	0.10	0.00
230310	0.04	0	0.11	0	0	0	0	0	0
230320	0.08	0	0.24	0	0	0	0	0	0
230330	0.08	0	0.82	0	0	0	0	0	0
230340	0.05	0	0.12	0.52	0.45	4.17	0	0.15	0

Note: All Units in TJ / Million \$ except for Electricity, which is MkWh / Million \$

Revised Energy Vector

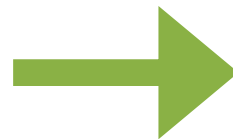
I-O #	Electricity	Coal	Natural Gas	LPG	Motor Gasoline	Distillate fuel	Kerosene	Jet fuel	Residual fuel
230110	0.03	0	0.08	0.03	0.19	0.65	0	0	0
230120	0.06	0	0.20	0.12	0.73	2.46	0	0	0
230130	0.06	0	0.20	0.09	0.53	1.80	0	0	0
230140	0.81	0	2.58	0.99	6.27	21.10	0	0	0
230210	0.04	0	0.14	0.08	0.41	1.38	0	0	0
230220	0.03	0	0.07	0.04	0.19	0.64	0	0	0
230230	0.06	0	0.71	0.49	1.41	4.73	0	0	0
230240	0.06	0	0.14	0.52	1.67	5.63	0	0	0
230250	0.02	0	0.06	0.07	0.31	1.05	0	0	0
230310	0.10	0	0.31	0.13	0.82	2.77	0	0	0
230320	0.05	0	0.15	0.08	0.45	1.53	0	0	0
230330	0.20	0	2.02	1.53	4.50	15.14	0	0	0
230340	0.10	0	0.31	0.38	1.66	5.57	0	0	0

Note: All Units in TJ / Million \$ except for Electricity, which is MkWh / Million \$

Hybrid EIO-LCA Feature

316900	Other leather product manufacturing	0.008000	0.008000
321113	Sawmills	5.744000	5.744000
321114	Wood preservation	2.737000	2.737000
321219	Reconstituted wood product manufacturing	1.290000	1.290000
32121A	Veneer and plywood manufacturing	3.922000	3.922000
32121B	Engineered wood member and truss manufacturing	3.253000	3.253000
321911	Wood windows and door manufacturing	6.704000	6.704000
321912	Cut stock, resawing lumber, and planing	1.494000	1.494000
321918	Other millwork, including flooring	3.973000	3.973000
321920	Wood container and pallet manufacturing	0.048000	0.048000
321991	Manufactured home, mobile home, manufacturing	0.000000	0.000000
321992	Prefabricated wood building manufacturing	4.688000	4.688000
321999	Miscellaneous wood product manufacturing	0.340000	0.340000
322110	Pulp mills	0.007000	0.007000
3221A0	Paper and paperboard mills	0.603000	0.603000
322210	Paperboard container manufacturing	0.784000	0.784000
322225	Flexible packaging foil manufacturing	0.011000	0.011000
322226	Surface-coated paperboard manufacturing	0.001000	0.001000
32222A	Coated and laminated paper and packaging materials	0.535000	0.535000
32222B	Coated and uncoated paper bag manufacturing	0.026000	0.026000
322231	Die-cut paper office supplies manufacturing	0.014000	0.014000
322232	Envelope manufacturing	0.020000	0.020000
322233	Stationery and related product manufacturing	0.023000	0.023000
322291	Sanitary paper product manufacturing	0.019000	0.019000
322299	All other converted paper product manufacturing	0.251000	0.251000
323116	Manifold business forms printing	0.059000	0.059000
323117	Books printing	0.000000	0.000000

Augmented Process-Based Hybrid for Construction



Case Study - Initial Findings

- **NO_x emissions**
 - ◆ Transportation
 - ◆ Equipment Fuel Combustion
- **EPA Nonroad Rule**
 - ◆ Reduce PM and NO_x by 90% by 2015
 - ◆ Considerable future reductions from on-site equipment
- **Service Sectors**
 - ◆ Ignored by many process LCAs
 - Most CO emissions
 - If excluded, GWP would be ~ 20% lower for entire construction process
- **Transportation**
 - ◆ Highest air emissions in all categories except one
 - ◆ *LEED* “Local” materials



Hybrid Process Model Explanation

- Construction is modeled with Analytica
- Analytica is a visual tool for creating, analyzing, and communicating decision models.
- Search for the best perceived data...
- Various data sources:
 - ◆ EIO-LCA
 - ◆ SimaPro Processes
 - ◆ Nonroad
 - ◆ Concrete washout water laboratory data
 - ◆ R.S. Means

Hybrid Process Model

Hybrid Construction LCA -- Analytica® Educational Professional -- C:\Documents and Settings\Wmblec\M - [Diagram - Hybrid Construction LCA]

File Edit Object Definition Result Diagram Window Help



Enter Dollar Value of Construction (\$M)

Enter VMT Unpaved Roads

Enter VMT Paved Roads

Percentage of Diesel to Gasoline Equipment

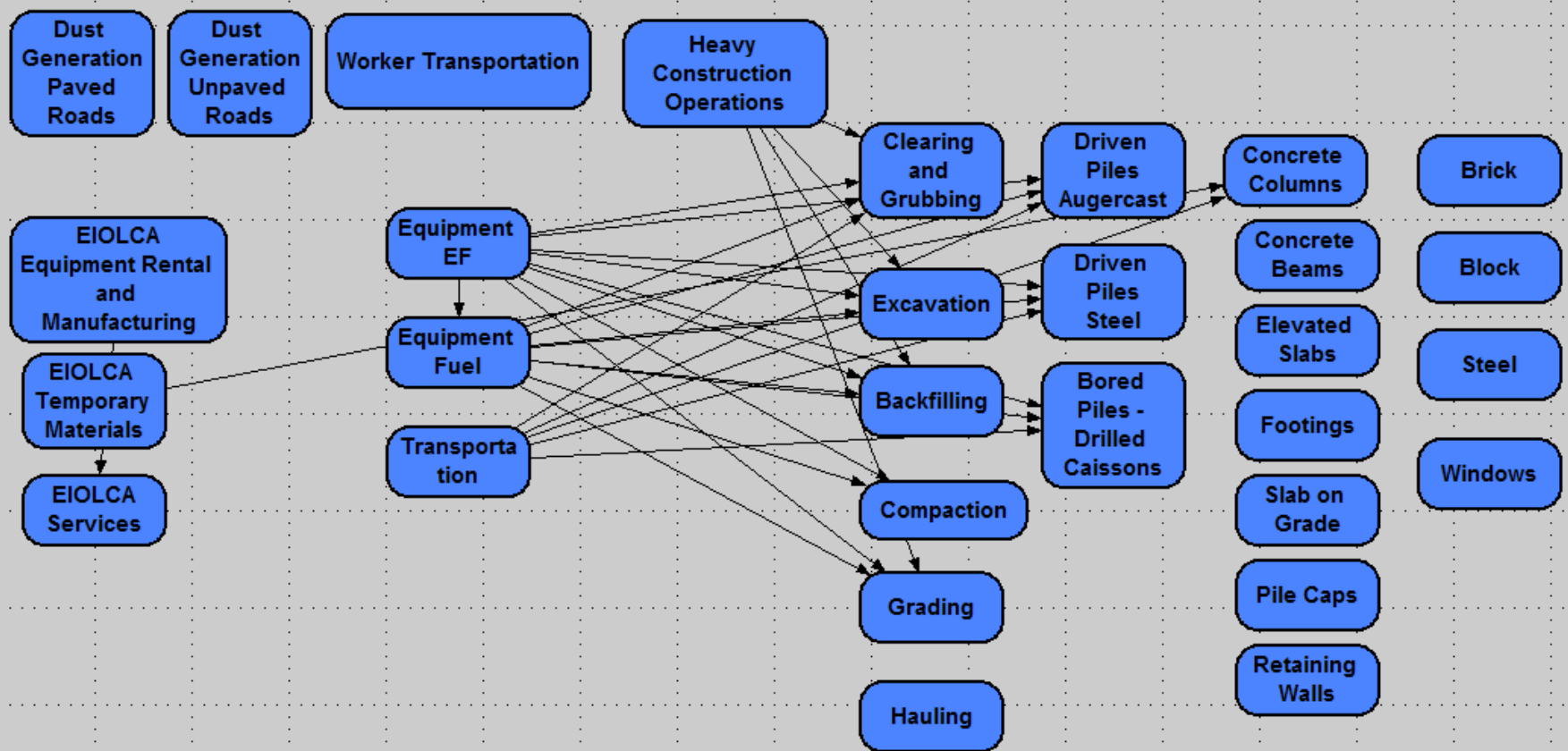
Percentage of Diesel to Gasoline Transportation

Project Duration(Days)

Average Construction Workers/Day

Average Commute Distance (One-Way) (km)

Master Inventory List



Hybrid Process Model Drill Down

Hybrid Construction LCA -- Analytica® Educational Professional -- C:\Documents and Settings\Mbilec\M - [Diagram - Clearing and Grubbing]

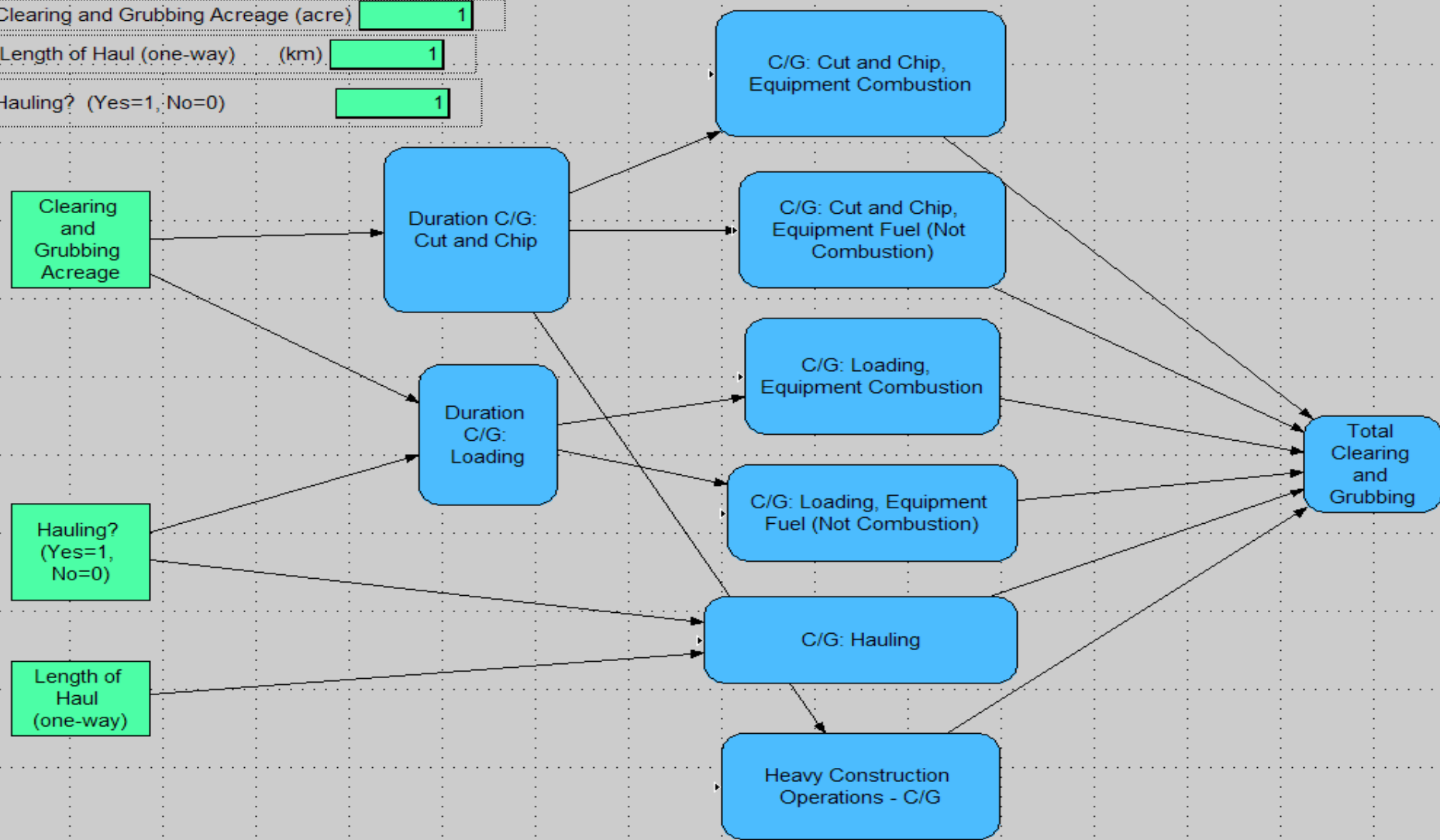
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Clearing and Grubbing Acreage (acre)

Length of Haul (one-way) (km)

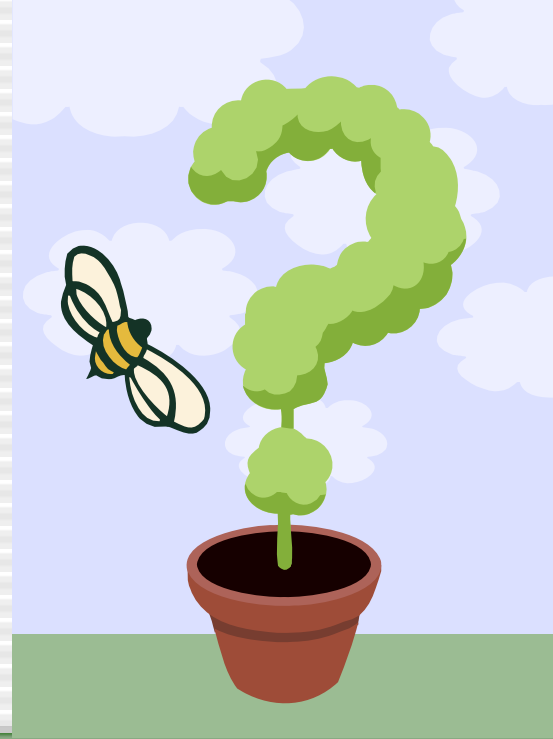
Hauling? (Yes=1, No=0)



Ongoing Research

- Two Hybrids
 - ◆ Augmented process-based
 - ◆ Input-output-based
 - EIO-LCA improvements
- Better estimations of construction's environmental impacts
- Case Studies
 - ◆ Majority of sectors
 - Residential
 - Ochoa
 - Commercial
 - CMU
 - RAND
 - Highway
 - PA Turnpike
 - PA DOT
 - VA DOT
- Hybrid Hybrid?

QUESTIONS ?



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Topic	Issue	Process LCA	Input-Output LCA
Boundary	Analysis Limits	Subjectively determined based on data availability	Entire U.S. economy (industries, services, etc.)
	Imports & Exports	Can be considered if data is gathered	Must be considered as U.S. products
	Direct & Indirect Impacts	Must be iteratively determined	Automatically included
Data	Type	Public, private, and sometimes proprietary	Public
	Comprehensive?	Can be an issue	Entire economy
	Specificity	Can do specific products	All commodities included, though highly aggregated in some sectors
	Units	Mostly physical	Dollar; difficult to link to physical units
Life Cycle Phases	Use / Operation	If data gathered	Not included
	End-of-Life	If data gathered	Not included
	Reproducible?	If public data	Yes
	Product / Process Comparisons	Possible	Impossible if in same sector
	Process Improvements	Can be targeted	Determinable on sector level only
Investment	Time	High	Low
	Cost	High	Low

Research Objective

- **Research Objective**
 - ◆ Develop a hybrid life cycle assessment tool to better assess the impacts of construction
- **Relevance**
 - ◆ USGBC
 - In revisions to LEED
 - ◆ Government agencies
 - EPA, DOE, DOT
 - ◆ Hybrid framework can be applied
 - Whole building LCAs
 - Future LCAs or model
 - Other industries

