Modeling the Carbon Footprint of Wood Pallet Logistics

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ABOUT ANDRES....

- Education
  - Universidad Catolica, Venezuela (B.S)
  - North Carolina State University (M.Sc., Ph.D.)

- Work experience
  - Rochester Institute of Technology (13 years)
  - Visiting professor
    - Kanazawa Institute of Technology, Japan
    - Yeditepe University, Turkey
  - Toyota Production Systems Lab (Director 2006-2013)
  - Starting at Auburn University in 3 days!

- Research Interests:
  - Manufacturing processes and systems.
  - Surface metrology and engineering.
  - Sustainable product design
  - Material Handling (proud CICMHE member!)
WORKSHOP OBJECTIVES

By the end of the session, the participants will (hopefully!) have:

- Developed a fundamental understanding of pallet anatomy, pallet logistics and pallet life cycle.
- Developed a basic understanding of the concepts of embodied energy, CO\textsubscript{2} impacts, functional units and LCA.
- Performed CO\textsubscript{2} calculations for (at least) one transportation leg and one process related to pallets.
- Been exposed to a demo of an educational excel-based tool that can be incorporated in their classroom.

AGENDA

- Part A: Motivation.
- Part B: Fundamentals of LCA.
- Part C: Carbon footprint of wood pallet logistics.
- Part D: Demo of a teaching Excel tool.
PALLETS ACTIVITY AND IMPACTS

2 billion pallets in use everyday.

8.8 million trucks traveled 263 billion miles in 2006 consuming 16.8 billion gallons of fuel (3).

Transportation / SC represent 10% U.S. GDP and produces 2/3 CO emissions nationwide (3,4)

About 500 MM Tons of carbon equivalent emissions.

80% of U.S. trade is carried on pallets (5)

700 million new pallets/year (1)

Resource consumption: 70 million of dry tons of wood fibers (7)

1 Robert J. Bush & Araman (2009); 2 NWPCA (2000); 3 DTS (2009); 4 EPA; 5 Raballan & Aldaz-Carrol (2005); 6 DC Velocity (2008); (7) Dr. M. White, Va Tech.
As companies strive to become more sustainable, a thorough understanding of the environmental impacts of all aspects of the supply chain operations becomes critical.

**BREAKDOWN OF PALLETs BY MATERIAL**

- **Wood (441 million)**: 88.2%
- **Plastic (8.3 million)**: 9.9%
- **Metal (1.1 million)**: 0.2%
- **Plastic (17.4 million)**: 1.7%
- **Other (49.6 million)**

1 Source: Mazeika, A. (2010).
PART B: Fundamentals of Life Cycle Assessment

- Life cycle of products
- Embodied energy
- CO\textsubscript{2} equivalent emissions.
- Functional unit
- LCA Techniques and Eco audits

THE PRODUCT LIFE-CYCLE

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TYPICAL LCA OUTPUT
(the good, the bad and the ugly)

Typical LCA output

Aluminum cans, per 1000 units
- Bauxite: 59 kg
- Oil fuels: 148 MJ
- Electricity: 1572 MJ
- Energy in feedstock: 512 MJ
- Water use: 1149 kg
- Emissions: CO₂: 211 kg
- Emissions: CO: 0.2 kg
- Emissions: NOₓ: 1.1 kg
- Emissions: SO₂: 1.8 kg
- Particulates: 2.47 kg
- Ozone depletion potential: 0.2 x 10⁻³
- Global warming potential: 1.1 x 10⁻³
- Acidification potential: 0.8 x 10⁻³
- Human toxicity potential: 0.3 x 10⁻³

Roll up into an "eco-indicator"?

EMBODIED ENERGY OF MATERIALS

Generic data
- Material energy MJ / kg
- Database of embodied energies for materials
- Process energy MJ / kg
- Database of processing energies for materials

Transport, MJ / tonne.km
- Sea freight: 0.11 – 0.15
- Barge (river): 0.75 – 0.85
- Rail freight: 0.80 – 0.9
- Truck: 0.9 – 1.5
- Air freight: 8.3 – 15

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(Cambridge University)
DRINK CONTAINER

Materials
- PET body: 38 g
- PP cap: 5 g

Material energy MJ / kg
- Embodied energy, PET: 85
- Energy to blow mould: 11

Manufacture
- PET body molded: 38 g
- PP cap molded: 5 g

Transport, MJ / tonne.km
- Sea freight: 0.11
- Truck: 1.3

Use
- Refrigeration: 5 days
- Transport: 200 km

Disposal
- Recycling: Yes
- Transport: 15,000 km

Refrigeration, MJ / m³.day
- Refrigeration (4°C): 10.5
- Freezing (-5°C): 13.0

ENERGY BREAKDOWN FOR PET BOTTLE

What would the CO2 graph look like?

What would it depend upon?

What about “other” emissions?

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ENERGY CONSUMPTION OF PRODUCTS

Which phase dominates? Material - Manufacturing - Use - Disposal
(Approximate breakdown: Bey, 2000, Allwood, 2006)

Aircraft
Automobile
Appliance (refrigerator)

Multi-level parking deck
Family home
Carpet

EMBODIED ENERGY OF MATERIALS PER KG

Used with permission from Dr. M. Ashby
(Cambridge University)
EMBODIED ENERGY OF MATERIALS PER M³

FUNCTIONAL UNIT EXAMPLE
## EMBODIED ENERGY PER UNIT OF FUNCTION

Function: to contain 1 liter of fluid

<table>
<thead>
<tr>
<th>Material</th>
<th>Mass (g)</th>
<th>Mass/liter (g/liter)</th>
<th>Emb. energy (MJ/kg)</th>
<th>Energy/liter (MJ/liter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>325</td>
<td>433</td>
<td>14</td>
<td>6.1</td>
</tr>
<tr>
<td>PE</td>
<td>38</td>
<td>38</td>
<td>80</td>
<td>3.1</td>
</tr>
<tr>
<td>PET</td>
<td>25</td>
<td>62</td>
<td>84</td>
<td>5.4</td>
</tr>
<tr>
<td>Aluminum</td>
<td>20</td>
<td>45</td>
<td>200</td>
<td>9.0</td>
</tr>
<tr>
<td>Steel</td>
<td>45</td>
<td>102</td>
<td>23</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Used with permission from Dr. M. Ashby (Cambridge University)

### PART C: Carbon Footprint of Wood Pallet Logistics
PALLET LIFE CYCLE

Legend:
- EOL
- Shipping
- : Inventory
- : Facility

Materials and Manufacturing stage

Use and transportation stage

Repair, Recycling and End-of-life stage
PALLET LIFE CYCLE (MATERIALS)

CO2 LCA ASSESSMENT - PALLETS

CO2 Emissions Profile

<table>
<thead>
<tr>
<th>Lifecycle Stage</th>
<th>CO2 Emissions (kg CO2 Eq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Elements</td>
<td>25%</td>
</tr>
<tr>
<td>Manufacturing Processes</td>
<td>7%</td>
</tr>
<tr>
<td>Repair/Recycling</td>
<td>18%</td>
</tr>
<tr>
<td>Transportation (Use Stage)</td>
<td>44%</td>
</tr>
<tr>
<td>End of Life</td>
<td>6%</td>
</tr>
<tr>
<td>Total System Footprint</td>
<td>14.94</td>
</tr>
</tbody>
</table>
SCOPE

48' x 40” Stringer
13.5 board feet

48' x 40” Block
20.1 board feet

<table>
<thead>
<tr>
<th>Material</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>High density eastern hardwoods</td>
<td>60%</td>
</tr>
<tr>
<td>Medium density eastern hardwoods</td>
<td>10%</td>
</tr>
<tr>
<td>Eastern oaks</td>
<td>30%</td>
</tr>
<tr>
<td>Helically threaded nails</td>
<td>84</td>
</tr>
<tr>
<td>High density eastern hardwoods</td>
<td>39%</td>
</tr>
<tr>
<td>Southern yellow pine</td>
<td>61%</td>
</tr>
<tr>
<td>Annularly threaded nails (2 different lengths)</td>
<td>102</td>
</tr>
</tbody>
</table>

RAW MATERIALS

Lumber
- Timber extraction
- Logs transported to the lumber mill
- Logs debarked and rip sawn

Nails
- Steel production
- Manufacture from steel
- Transportation
LUMBER MILLS *(chamfered boards)*

(3:00 minutes)

Joudelia: lumber production to board feet  
http://www.youtube.com/watch?v=tQTA7jB4t_k

EMISSIONS MODEL FOR MATERIALS PHASE

Total CO2 Equivalent Emissions Derived from Material Inputs

- Emissions associated with material for new Stringer Pallets
  - Emissions from 1 new stringer pallet
    - Multiplied by number of pallets

- Emissions associated with material for new Block Pallets
  - Emissions from 1 new block pallet
    - Multiplied by number of pallets

- Emissions from sourcing 1 board foot of hardwood
  - Multiplied by number of pieces in a stringer pallet

- Emissions associated with fasteners (threaded nails)
  - Multiplied by number of nails

- Emissions from finishing and transportation

- Emissions from primary manufacture

- Emissions from secondary manufacture

- Emissions from finishing and transportation
MANUFACTURING

- Assembly of pallets (nailers)
- Treatments
  - Kiln drying (19% EMC)
  - Phytosanitation
    - Heat treatment (HT - 133°F, 30 min)
    - Fumigation (MB - methyl bromide)
  - Mold dipping
    - PQ80, USDA approved, 3 months

PALLET ASSEMBLY (*semi-automated*)

(1:45 minutes)

http://www.youtube.com/watch?v=Efmy_aVQ1E
**Pallet Assembly (manual)**

(1:00 minute)

CMS Scarpari: Block Pallet manufacturing.

http://www.youtube.com/watch?v=Eh0CI9FvFlo

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**Emissions Model for Manufacturing Phase**

Emissions associated with manufacturing new stringer panels

- Emissions from molding process on mold and die
  - Multiplied by total number of stringer panels

- Emissions from heat treating one stringer panel
  - Multiplied by % of pallets that require heat treating

- Emissions from kiln drying one stringer panel
  - Multiplied by % of pallets that require kiln drying

- Emissions from mold dipping one stringer panel
  - Multiplied by % of pallets that require mold dipping

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Total CO2 Equivalent Emissions Derived from Manufacturing Process

- Emissions associated with manufacturing new block pallets
  - Emissions from molding process on mold and die
    - Multiplied by total number of block pallets
  - Emissions from heat treating one block pallet
    - Multiplied by % of pallets that require heat treating
  - Emissions from kiln drying one block pallet
    - Multiplied by % of pallets that require kiln drying
  - Emissions from mold dipping one block pallet
    - Multiplied by % of pallets that require mold dipping
EXERCISE
CALCULATION OF CO₂ FOOTPRINT OF MANUFACTURING PHASE

**CARBON FOOTPRINT EXERCISE**

*Neruda Pallets S.A* wants to manufacture 500 stringer pallets and 700 block pallets, for their next month’s order from *Lider* Supermarkets.

- **Transportation Distances**
  - Wood supplier to pallet manufacturer 480 km by truck
  - Nail supplier to pallet manufacturer 7,322 km by ship and 800 km by train
  - Pallet manufacturer to customer 400 km by truck

- **Pallet treatment and conditioning**
  - Heat Treatment
    - 30% Stringer pallets
    - 60% Block pallets
  - Kiln Dried (19% EMC)
    - 30% Stringer pallets

*Example Data References: SimaPro Software (Eco Invent Database) & CES Cambridge Engineering Selector*
**EMISSIONS BY ENERGY SOURCE**

<table>
<thead>
<tr>
<th>Source</th>
<th>kg CO2/kwh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>1.190</td>
</tr>
<tr>
<td>Oil</td>
<td>0.885</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>0.684</td>
</tr>
<tr>
<td>Other</td>
<td>0.138</td>
</tr>
<tr>
<td>Solar</td>
<td>0.047</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.013</td>
</tr>
<tr>
<td>Wind</td>
<td>0.012</td>
</tr>
<tr>
<td>Hydroelectrical</td>
<td>0.004</td>
</tr>
</tbody>
</table>

*Source: SimaPro Software (Eco invent Database)*

**ENERGY MIX**

<table>
<thead>
<tr>
<th>Units</th>
<th>Non-Renewable Sources</th>
<th>Renewable Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coal</td>
<td>Natural Gas</td>
</tr>
<tr>
<td>CO2 kg/kwh</td>
<td>1.19</td>
<td>0.684</td>
</tr>
<tr>
<td>Percentage of U.S. Grid</td>
<td>50%</td>
<td>18%</td>
</tr>
</tbody>
</table>

*Total Average U.S. Grid kg CO2/kwh 0.749*

**Inputs**

### 48' x 40'' Stringer

- **Wood**
  - 13.5 board feet (green wood)
  - Unit weight: 1.7006 kg/boardfoot
- **High density eastern hardwoods**: 60%
- **Medium density eastern hardwoods**: 10%
- **Eastern oaks**: 30%
- **Steel**
  - 84 Helically threaded nails
  - Unit weight: 0.0035 kg/nail

### 48' x 40'' Block

- **Wood**
  - 20.1 board feet (air dried ~30% EMC)
  - Unit weight: 1.7050 kg/boardfoot
- **High density eastern hardwoods**: 39%
- **Southern yellow pine**: 61%
- **Steel**
  - 54 Annularly threaded nails (short - 1.25’’)
  - Unit weight: 0.0017 kg/nail
  - 48 Annularly threaded nails (long - 3’’)
  - Unit weight: 0.0046 kg/nail
**Pallet Flow Diagram**

**Inputs**

- 48' x 40" Stringer
  - Assembly time: 1 minute

- 48' x 40" Block
  - Assembly time: 2 minutes

Electric Nail Gun Power Consumption: XXXX kwh
Power source: local grid

- Heat Treatment: 1.5 hours with energy consumption of 850,000 btu/hr
- Kiln Drying: 96 hours with energy consumption 83,840 btu/hr.

Both heat treatment and kiln drying are powered using natural gas and use a chamber that has a 600 pallet maximum capacity.

<table>
<thead>
<tr>
<th>Pallet</th>
<th>Manufacturing</th>
<th>25% MC</th>
<th>19% MC</th>
<th>15% MC</th>
<th>12% MC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stringer</td>
<td>23.3</td>
<td>20.0</td>
<td>19.1</td>
<td>18.2</td>
<td>17.7</td>
</tr>
<tr>
<td>Block</td>
<td>34.8</td>
<td></td>
<td>23.6</td>
<td>22.7</td>
<td>22.3</td>
</tr>
</tbody>
</table>
**Pallet Flow Diagram**

- **2448 kg CO2** from Lumber Mill to Boardfeet.
- **1021 kg CO2** from Boardfeet to Heat/Kiln Treatment.
- **1 kg CO2** from Heat/Kiln Treatment to Pallet Manufacturer.
- **845 kg CO2** from Pallet Manufacturer to Product Manufacturer (Pallet User).
- **1868 kg CO2** from Product Manufacturer to Wood Scrap.
- **33 kg CO2** from Wood Scrap to China's Nail Manufacturer.
- **1240 kg CO2** from China's Nail Manufacturer to Annularly Threaded Nail.
- **3 kg CO2** from Annularly Threaded Nail to Use/Transportation.

**Total Carbon Footprint Summary**

- **Materials**: 3688 kg CO2
- **Mfg**: 3768 kg CO2
- **Use/Transportation**: ?
- **Repair**: ?
- **End of Life**: ?

<table>
<thead>
<tr>
<th>Process</th>
<th>kg CO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embodied Energy: Wood</td>
<td>2448</td>
</tr>
<tr>
<td>Embodied Energy: Nails</td>
<td>1240</td>
</tr>
<tr>
<td>Total</td>
<td>3688</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process</th>
<th>kg CO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation Emissions: Wood</td>
<td>1021</td>
</tr>
<tr>
<td>Transportation Emissions: Nails</td>
<td>33</td>
</tr>
<tr>
<td>Assembly</td>
<td>1</td>
</tr>
<tr>
<td>Drying</td>
<td>1888</td>
</tr>
<tr>
<td>Transportation Emissions: Final Product</td>
<td>845</td>
</tr>
<tr>
<td>Total</td>
<td>3768</td>
</tr>
</tbody>
</table>
USE AND TRANSPORTATION

Emissions based on:
- Mode
- Type of pallet
- Kiln treatment
  - Weight (as a function of EMC)

![Graph showing pallet weight by EMC]

PALLET RETURN

- Classic mix at warehouse stores

![Image showing pallets with goods]
REPAIR AND RECYCLING

- Not a glamorous business!
- Dock sweeping and pallet recovery
  - Pallet recyclers or “pallet gypsies”
- Transportation
- Pallet sortation
  - No touch (resale or “crossdocking”)
  - Leased pool (CHEP, Peco, etc)
  - Repair (core) pallets
  - Donor (tear down) pallets
  - EOL disposal pallets

PALLET DAMAGE
REPAIR AND RECYCLING

- Characterization of pallet damage

- NWPCA Uniform standard for wood pallets (2011)
  - Class I (A): plate repairs OK but no companion stringers
  - Class II (B): 1-2 repaired stringers with long companions
  - Class III (C): otherwise

REPAIR AND RECYCLING

Characterization of the repair process (New and “A”)

<table>
<thead>
<tr>
<th>Stringer Position</th>
<th>Light foot- Good handling</th>
<th>Number of Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Pallet Cycle 9</td>
<td>10</td>
<td>15 17 18 24</td>
</tr>
<tr>
<td>A Pallet</td>
<td></td>
<td>26 26</td>
</tr>
<tr>
<td>Repair of boards – NB</td>
<td>Repair of stringers – NB</td>
<td>Replace of boards – BB</td>
</tr>
</tbody>
</table>

- Damage pattern depends on service environment (handling) and weight of load
- CO2 includes emissions from transportation, repair processes, and materials (nails and plates).
END OF LIFE

- End of life disposal
- Transportation
- Scenarios

<table>
<thead>
<tr>
<th>Application by region</th>
<th>NE</th>
<th>SW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landscaping</td>
<td>60%</td>
<td>-</td>
</tr>
<tr>
<td>Animal Bedding</td>
<td>4%</td>
<td>10%</td>
</tr>
<tr>
<td>Biofuel</td>
<td>35%</td>
<td>80%</td>
</tr>
<tr>
<td>Municipal Waste</td>
<td>1%</td>
<td>10%</td>
</tr>
</tbody>
</table>
LCA ANALYSIS

Single Cycle Distance: 100 Miles by Train
End of Life: 100% Incineration (with energy recovery), 10% mulched, 75% Landfilling

PART D: Excel based calculator demo
This project is funded by Material Industry of America (MHIA) Research Grant #11100576