Life Cycle Assessment

- Life Cycle Assessment is the compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system during a product's lifetime.
- Life cycle analysis or assessment (LCA) is an examination of a product's total environmental impacts from raw materials extraction to waste management.
- **Life-cycle assessment** or **life cycle assessment** (**LCA**, also known as **life-cycle analysis**) is a methodology for assessing environmental impacts associated with all the stages of the life-cycle of a commercial product, process, or service.
- For instance, in the case of a manufactured product, environmental impacts are assessed from raw material extraction and processing (cradle), through the product's manufacture, distribution and use, to the recycling or final disposal of the materials composing it (grave).
- LCA study involves a thorough inventory of the energy and materials that are required across the industry value chain of the product, process or service, and calculates the corresponding emissions to the environment.
- LCA thus assesses cumulative potential environmental impacts. The aim is to document and improve the overall environmental profile of the product.
- It provides a systematic, holistic and multidisciplinary approach in quantification of environmental burdens and their potential impacts over the whole life cycle of a product, process or activity.

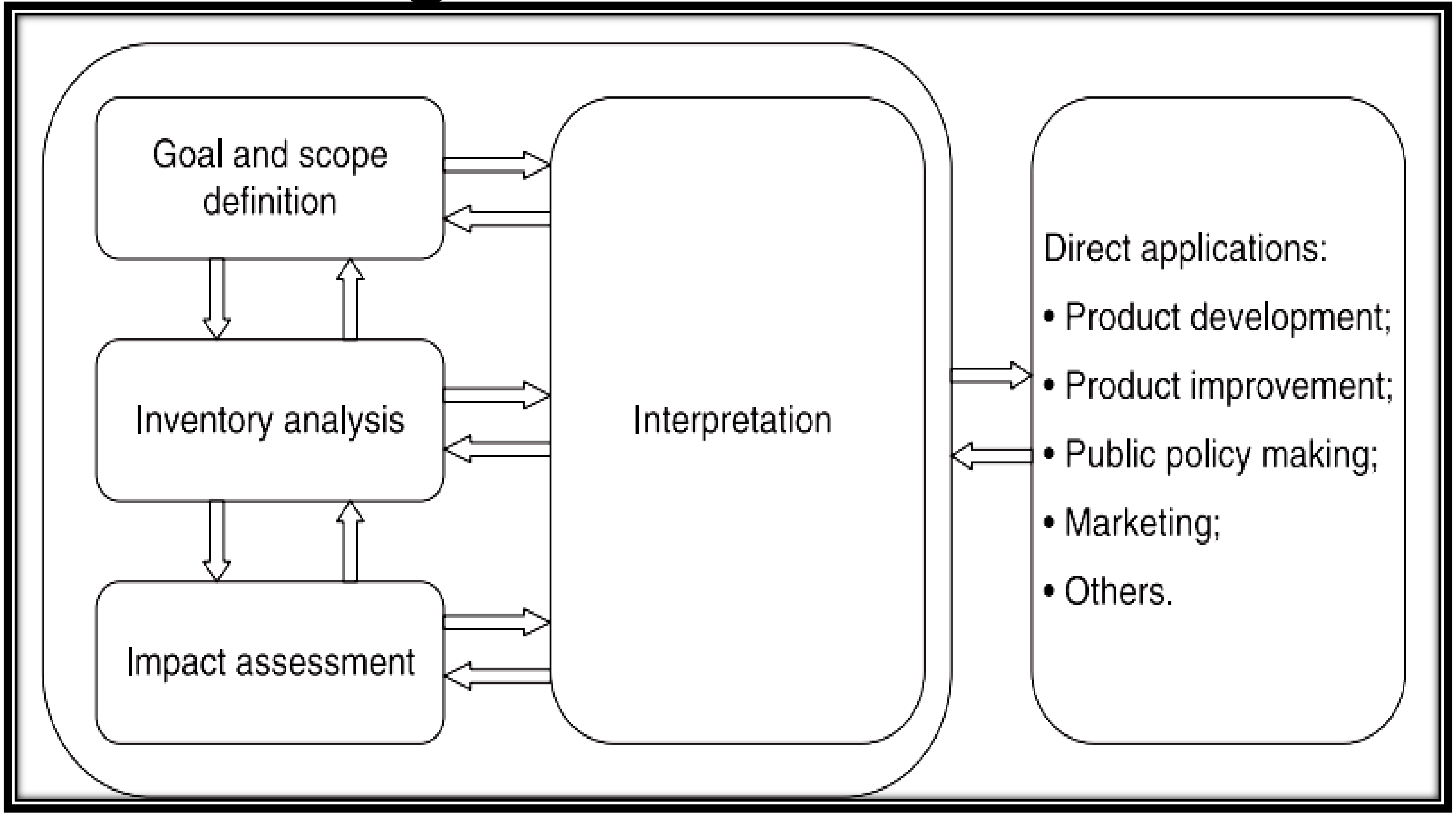
History of LCA

- The idea of LCA began in the 1960's as academics and practitioners became increasingly concerned about the adverse impacts of the growing use of energy and other resources.
- The early studies focuses on the risks of resource depletion in particular, the concern has shifted more recently to global climate change as a result of fossil fuel consumption.
- The study that set the foundation for LCA in the U.S. was a study for the Coca-Cola Company in 1969 that was carried out by Hunt *et al.* (1996).
- In the early 1970's, other companies began conducting similar studies on their products. In the U.S., Resource and Environmental Profile Analysis (REPA) became the process of analyzing resources used in various products in terms of energy and tracking potential impacts in the environment.
- Globally, the thought of LCA has been raised in 1992 - Earth Summit at Rio de Janeiro, in 1997 -Kyoto Protocol, 1998 - United Nations Environment Program and in 2002 - Earth Summit at Johannes burg.
- At this time, LCA methodology has become well recognized. This was facilitated by the introduction of the ISO 14040 series of standards in 1997, which provided a clear overview of the practice, applications and limitations of LCA to a broad range of potential users and stakeholders, including those with a limited knowledge of LCA.

Uses of life cycle assessment

- LCA is a tool for quantifying the environmental performance of products taking into account the complete life cycle, starting from the production of raw materials to the final disposal of the products, including material recycling if needed (ISO, 2006).
- LCA can contribute to cost savings through more efficient use of resources or energy, or by identifying alternative processes that lower overall production costs.
- LCA can also be used to identify improvements to products, processes and services.
- LCA is used to identify environmental impacts and hotspots associated with manufacturing of the products.

Methodological framework



General methodological framework of LCA, according to ISO 14040

Goal and Scope Definition

- Goal and scope definition is the first step in a Life Cycle Analysis process where the product to be assessed is defined, as well as the context of the assessment to be made.
- It has a great influence on the impact assessment step as many parameters are identified, such as the time and resources needed, the purpose of the study, the intended application, the system boundaries, the assessment methodology, and the general assumptions and limitations.
- Definition of the goal and scope guide the entire LCA process to ensure that the most relevant results are achieved (ISO 14041:1998)

Life Cycle Inventory (LCI)

- In the LCI phase, data are collected to quantify inputs and outputs of the system being studied to meet the goals of the defined study.
- The types of data include energy, raw materials, and other physical input; products, co-products, and wastes; releases to air, water, and soil; and other environmental aspects; output.
- The flow model shows the activities in the system (e.g., processes, transportation, and waste management) and the input and output flows among them throughout the life cycle. Input and output data (e.g., raw materials, energy, products, solid waste, emissions to air and water) are collected for all the processes in the system.

Life Cycle Impact Assessment

- The Life Cycle Impact Assessment (LCIA) identifies and evaluates the amount and significance of the potential environmental impacts arising from the LCI.
- The inputs and outputs are first assigned to impact categories and their potential impacts quantified according to characterization factors.

Life Cycle Assessment Interpretation

- In the interpretation phase, the results are checked and evaluated to see that they are consistent with the goal and scope definition and that the study is complete. This phase includes two primary steps:
  1. Identification of significant issues;
  2. Evaluation (described below).
- The life cycle interpretation is an iterative procedure both within the interpretation phase itself and with the other phases of the LCA. The roles and responsibilities of the various interested parties should be described and taken into account.
- The goal of the life cycle interpretation phase is to draw conclusions, identify limitations and make recommendations for the intended audience of the LCA.
- Identify the significant issues and hotspots.
- Evaluate the methodology and results for completeness, sensitivity and consistency; and
- Draw preliminary conclusions and check that these are consistent with the requirements of the goal and scope of the study.

Approaches to LCA

Cradle-to-gate

- Cradle-to-gate only assesses a product until it leaves the factory gates, before it is transported to the consumer. This means cutting out the use and disposal phase. *Cradle-to-gate* analysis can significantly reduce the complexity of an LCA and thus create insights faster, especially about internal processes.

Cradle-to-grave

- Cradle-to-grave is the full LCA from manufacturing or cradle to use phase and disposal phase, grave.

Cradle-to-cradle

- Cradle-to-cradle is a concept often referred to within the Circular Economy. It is a variation of cradle-to-grave, exchanging the waste stage with a recycling process that makes it reusable for another product, essentially “closing the loop”. This is why it is also referred to as closed loop recycling.

Gate-to-gate

- Gate-to-gate is sometimes used in product lifecycles with many value-adding processes in the middle. To reduce complexity in the assessment, only one value-added process in the production chain is assessed. These assessments can later be linked together to complete a larger level of life cycle assessment.

Limitations of life cycle assessment

- The most apparent drawbacks are that full LCAs are relatively expensive, and that the results are uncertain and highly dependent on subjective methodological choices.
- LCA does not give adequate answers to other related questions, such as the following:
  - Finding the optimum mix of different competing options;
  - Selecting the best location for an investment (such as for a road or a factory);
  - Deciding if local environmental impacts are important; and
  - Deciding on the size and timing of an investment.
  - LCI can rarely, if ever, include every single process and capture every single input and output due to system boundaries, data gaps, cut-off criteria, etc.
  - LCI data collected contains uncertainty.
  - Characterization models are far from perfect.
  - Sensitivity and other uncertainty analyses are not fully developed.

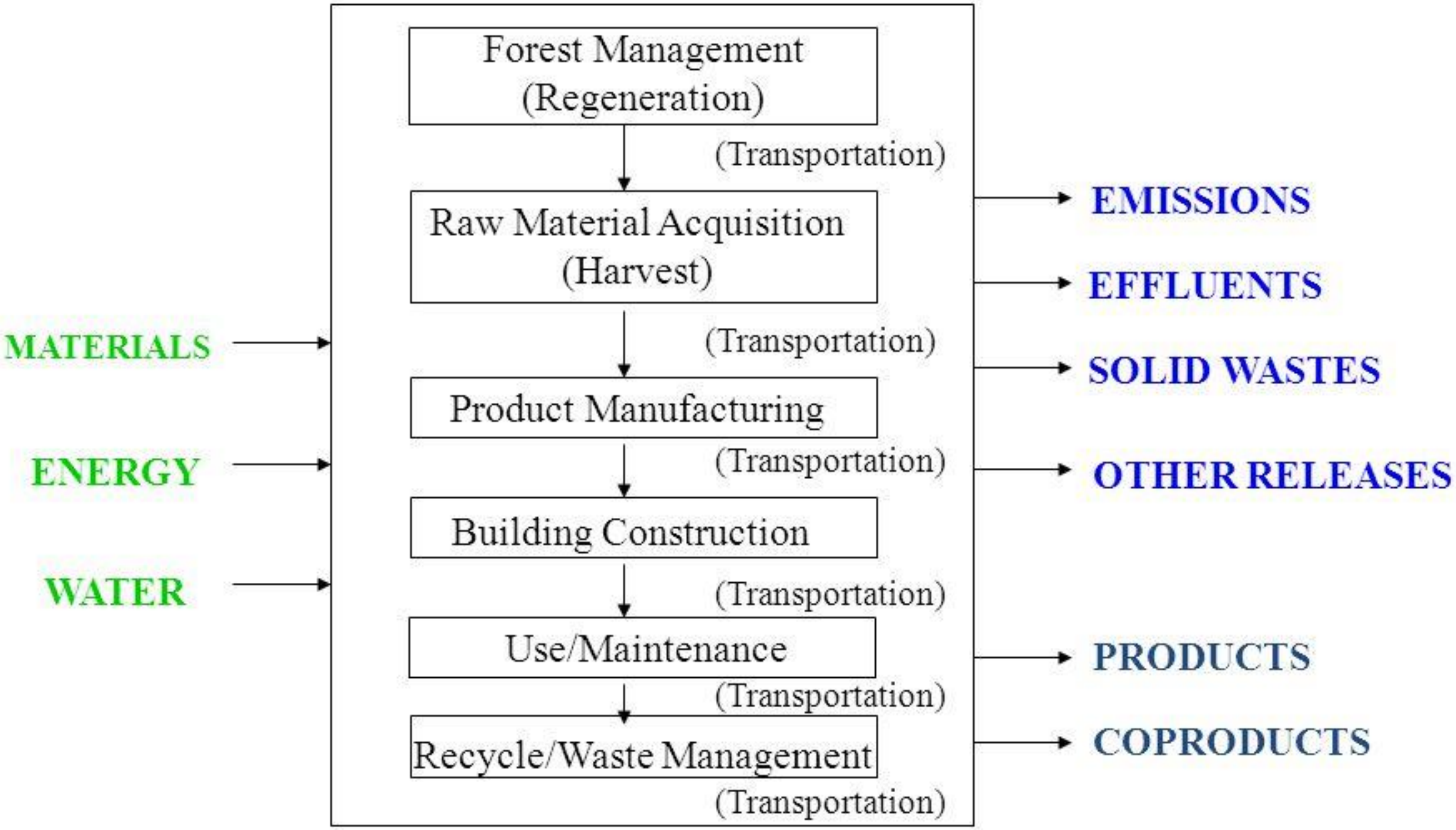
ISO standards for LCA

- According to the ISO standards on LCA, it can assist in:
  - Identifying opportunities to improve the environmental aspects of products at various points in their life cycle;
  - Decision making in industry, governmental or non-governmental organizations (e.g. strategic planning, priority setting, product and process design or redesign);
  - Selection of relevant indicators of environmental performance, including measurement techniques; and
  - Marketing (e.g., an environmental claim, eco-labeling scheme or environmental product declarations).

Case study 1: LCA on Timber Buildings

- Life cycle analysis (LCA) is a method of measuring the environmental impacts of building products over their whole life. The aim of a life cycle analysis is to identify, quantify and assess the impact of the energy and materials used and wastes released to the environment throughout the life of a building product.
- By providing a means of comparing various building products, a life cycle analysis can help building professionals to make informed decisions about building materials.
- The life cycle analysis of timber follows the piece of wood from harvesting, manufacture, construction and product life to recycling and disposal.
- Life cycle assessments of common alternative construction materials (like cement and aluminium) have shown that many other materials require larger energy inputs during manufacturing.
- This energy is typically sourced from non-renewable fossil fuels. In contrast, the manufacture of wood products typically requires far less energy.

Life Cycle Inventory Analysis for Wood Building Materials



MATERIALS

ENERGY

WATER

Forest Management (Regeneration)

(Transportation)

Raw Material Acquisition (Harvest)

(Transportation)

Product Manufacturing

(Transportation)

Building Construction

(Transportation)

Use/Maintenance

(Transportation)

Recycle/Waste Management

(Transportation)

EMISSIONS

EFFLUENTS

SOLID WASTES

OTHER RELEASES

PRODUCTS

COPRODUCTS

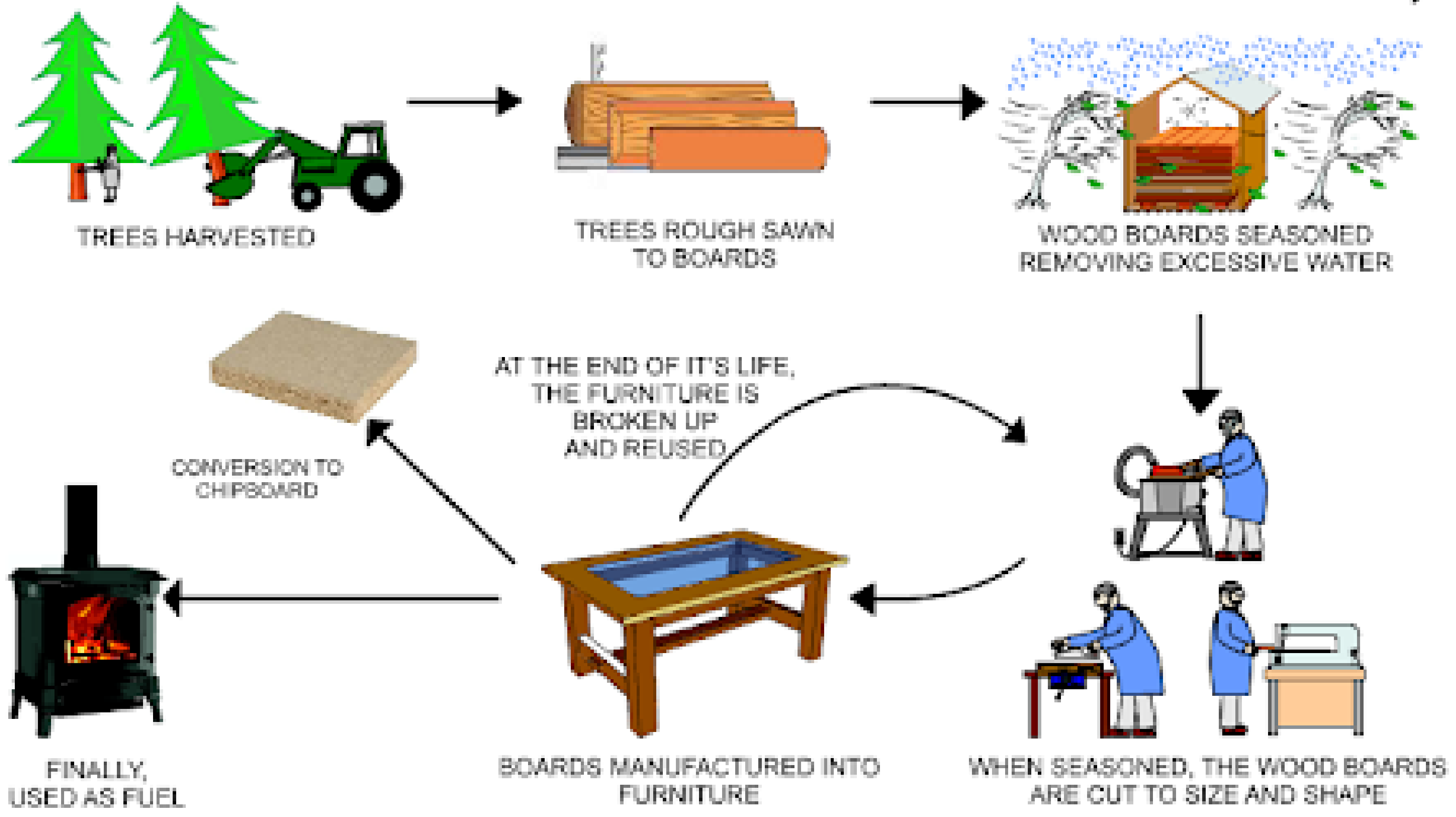
LCA for Building Products

- Analysis covers extraction or harvest of raw materials through eventual demolition and disposal or reuse.

Source: Building Green With Wood www.naturallywood.com

MY PRODUCT'S LIFE CYCLE

My table has been designed so that materials can be recycled, when it cannot be used anymore. The table will eventually wear out but the materials will still be useful. The table is designed to be disassembled relatively easily, so that the parts can be used in the manufacture of a new piece of furniture. When the natural wood is completely worn out, it will become fuel for a wood burner, providing heat. Alternatively, this type of material can be processed and recycled into manmade boards, such as chipboard. This can be used in the construction industry and by furniture manufacturers.



TREES HARVESTED

TREES ROUGH SAWN
TO BOARDS

WOOD BOARDS SEASONED
REMOVING EXCESSIVE WATER

WHEN SEASONED, THE WOOD BOARDS
ARE CUT TO SIZE AND SHAPE

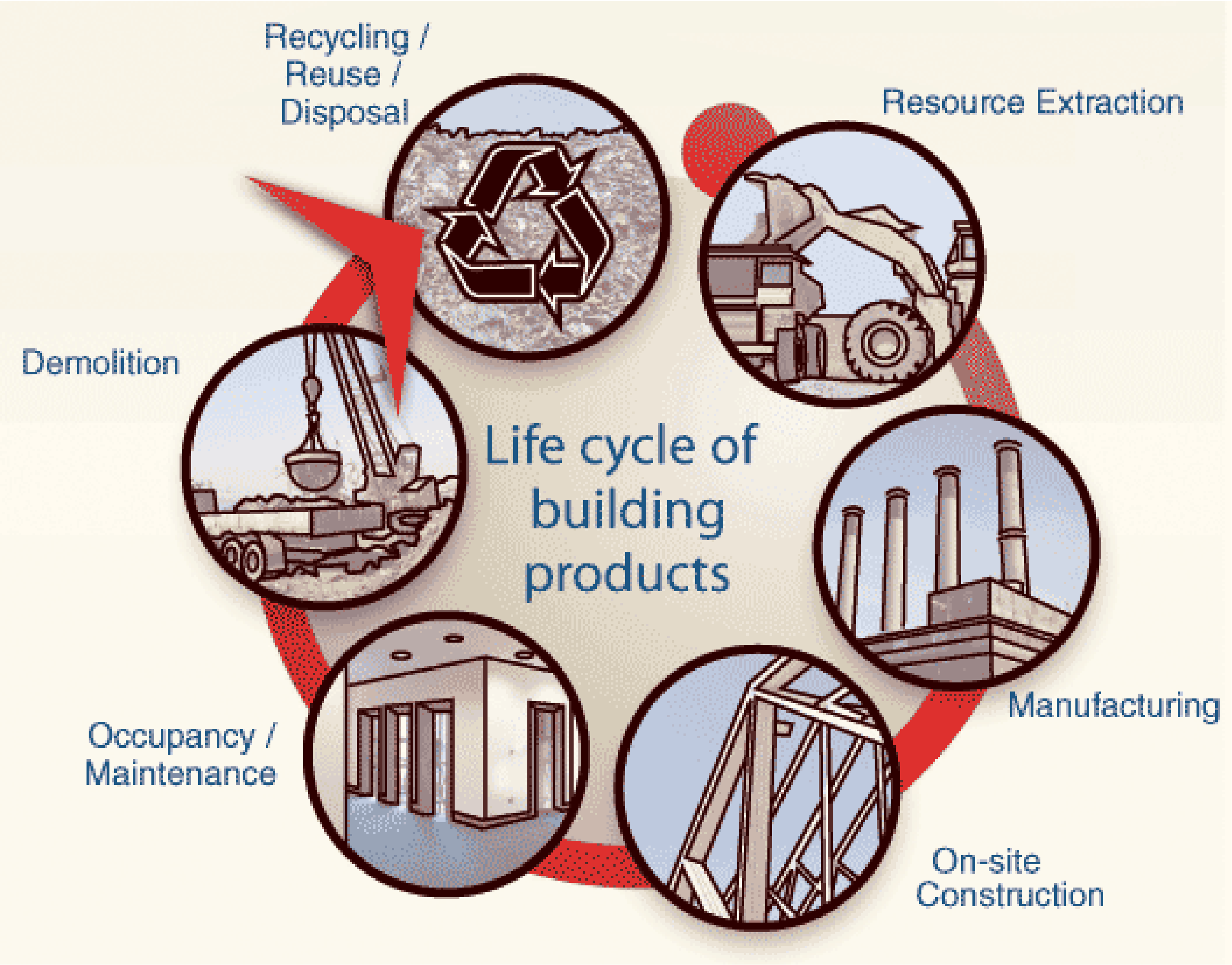
BOARDS MANUFACTURED INTO
FURNITURE

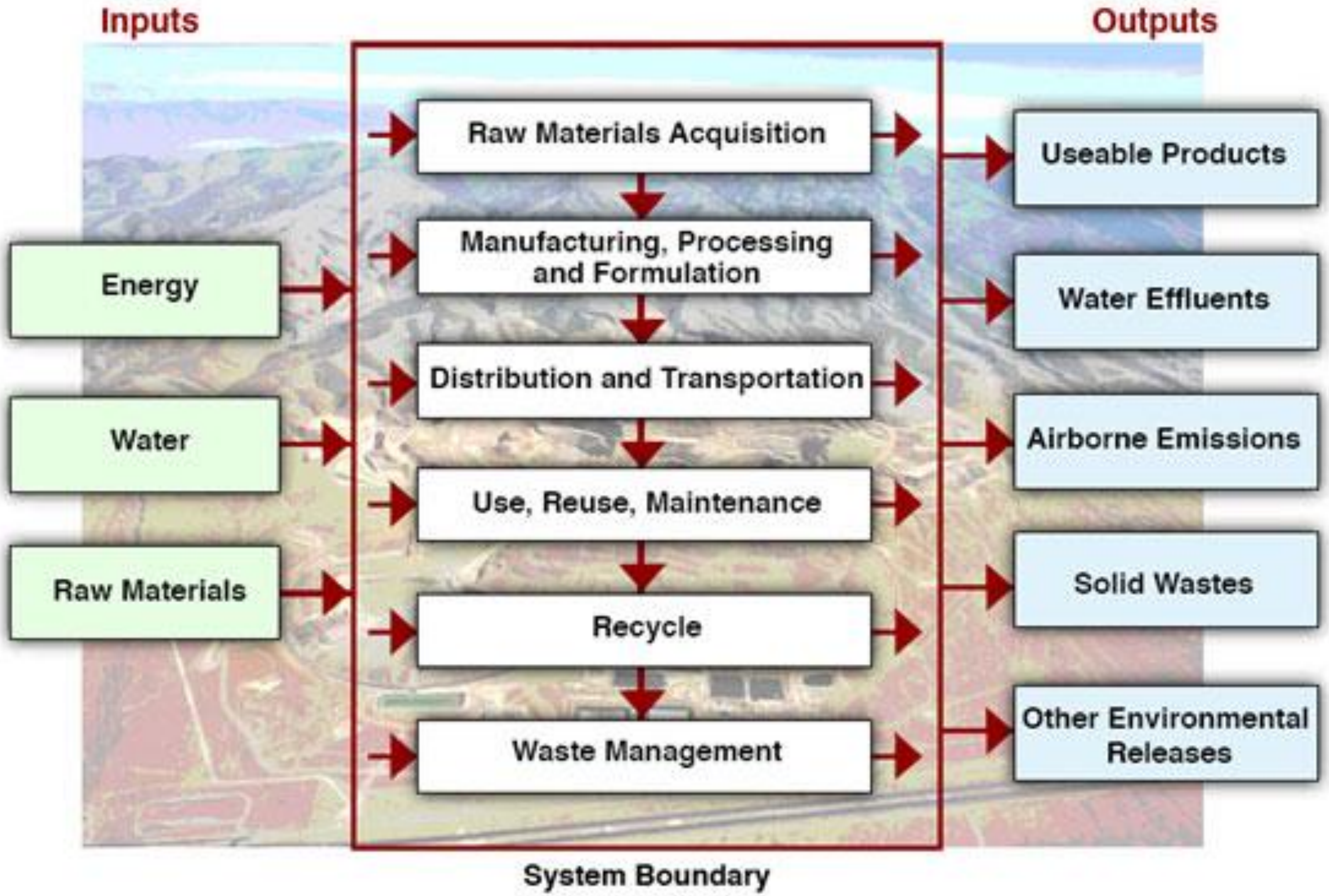
AT THE END OF IT'S LIFE,
THE FURNITURE IS
BROKEN UP
AND REUSED

CONVERSION TO
CHIPBOARD

FINALLY,
USED AS FUEL

NAME: PRODUCT LIFE CYCLE DATE:

Recycling / Reuse / Disposal
Resource Extraction
Demolition
Life cycle of building products
Manufacturing
Occupancy / Maintenance
On-site Construction



Inputs

- Energy
- Water
- Raw Materials

- Raw Materials Acquisition
- Manufacturing, Processing and Formulation
- Distribution and Transportation
- Use, Reuse, Maintenance
- Recycle
- Waste Management

System Boundary

Outputs

- Useable Products
- Water Effluents
- Airborne Emissions
- Solid Wastes
- Other Environmental Releases

Functional unit

- Functional unit reflect the function of the investigated product. For this study, material flows, fuel and electricity use, and emissions data were normalized to a per-production of one unit.

Case study 1: LCA on Timber Buildings

- The life cycle cost of a specific building to be minimized, it is important to determine “during its design and construction stage” the subsystems that affect its life cycle cost with the view of taking optimal design decisions. In general, the following subsystems have a considerable impact on the life cycle cost of a building:
  - Building Envelope (insulation profiles, shading systems, glazing, roofing, etc.)
  - Mechanical and Energy Systems (use of photovoltaic panels or alternative sources of energy, ventilation systems, water distribution systems, etc.)
  - Structural Systems (selection of appropriate frame materials, sizing of the frame components)
  - Siting (landscaping and irrigation-related design decisions).
  - Electrical Systems (lighting sources and control, distribution)

- It is also necessary to consider the average life cycle of the timber buildings in order to predict.
- Any potential replacements that may occur during the examined life cycle period. The maintenance processes affect the life cycle of the examined system, both in environmental and in economic terms. Their estimated service life provides useful guidelines regarding their potential replacement or repair.
- The average life cycle of “frequently used” building materials and subsystems is as follows:
  - Building Exteriors, Doors, and Windows: 80 years (lifetime)
  - Timber structural systems: 50 years (lifetime)
  - Mineral wool insulation profiles: 50 years
  - Photovoltaic panels: 25 years
  - HVAC systems: 15-20 years
  - Gypsum boards: 75 years

- The LCA evidently influenced the main considerations regarding the life cycle costs of the examined subsystems that were later on introduced in the optimization processes. The main assumptions are the following:
    - The mineral wool wall insulation profile is expected to end up in a landfill despite the fact that most of it can be recycled at the end of its useful life.
    - The PV array requires (usually twice a year) periodic removal of the dust -concentrated on the panels- that affects its performance but this cost is negligible. Another cost that needs to be taken into account is the replacement of the inverter (information about the useful life of the inverter is provided by the guarantee, however excepting that its replacement would take place every 5-10 years is a legitimate assumption).
    - The timber building envelope walls require some degree of regular maintenance in order for water penetration to the shell to be prevented. Two scenarios (A & B) for the management of the structural elements at the end of the building's life cycle are examined: deconstruction and reuse (A) or recycling (B) of the frame components.
    - The gypsum boards are assumed that will end up in a landfill, despite the fact that they could be recyclable to some extent at the end of their useful life. Some degree of protection and maintenance is required.

Structural Optimization of the Timber Frame

- The beams are checked according to Eurocode 5 for bending, shear and deflection. Similarly, each column is checked for compression, buckling and combined compression and bending.
- The optimization aims to the minimization of the cost of each timber structural element and takes place through the use of genetic algorithms and simulated annealing.

Energy Performance Optimization Results

- It seems to be a cost-effective decision to use window panels with very low g values.
- In no optimization scenario the decision to cover part of the electricity needs for heating and cooling through a PV system of any size was a cost-effective decision.
- The heating and cooling requirements of the office building can be covered with a 9000 Btu, A/C system of very high energy efficiency (falling into the energy class category A+++).
- A change in the design internal building temperature of the building (within the acceptable limits), slightly affects the optimal solution, but not to a great extent. Nevertheless, in larger buildings, a greater degree of precision in the selection of the design temperature could lead to considerable cost savings.

Economic Implications of the Management of the Structural Elements at the End of the Building's Life Cycle

- There are two scenario:
- Scenario A (deconstruction and reuse of the structural members that constitute the building’s frame) assumes that 80% of the structural elements of the building will be recovered and reused.
- Scenario B (deconstruction and recycling of the structural members that constitute the building’s frame) assumes that 80% the timber material that constitutes the frames of the building can be recovered.

Case study 2: LCA on furniture making

- LCA is a powerful tool for designers, product developers, manufactures, and consumers to compare the environmental credentials of similar products and services.

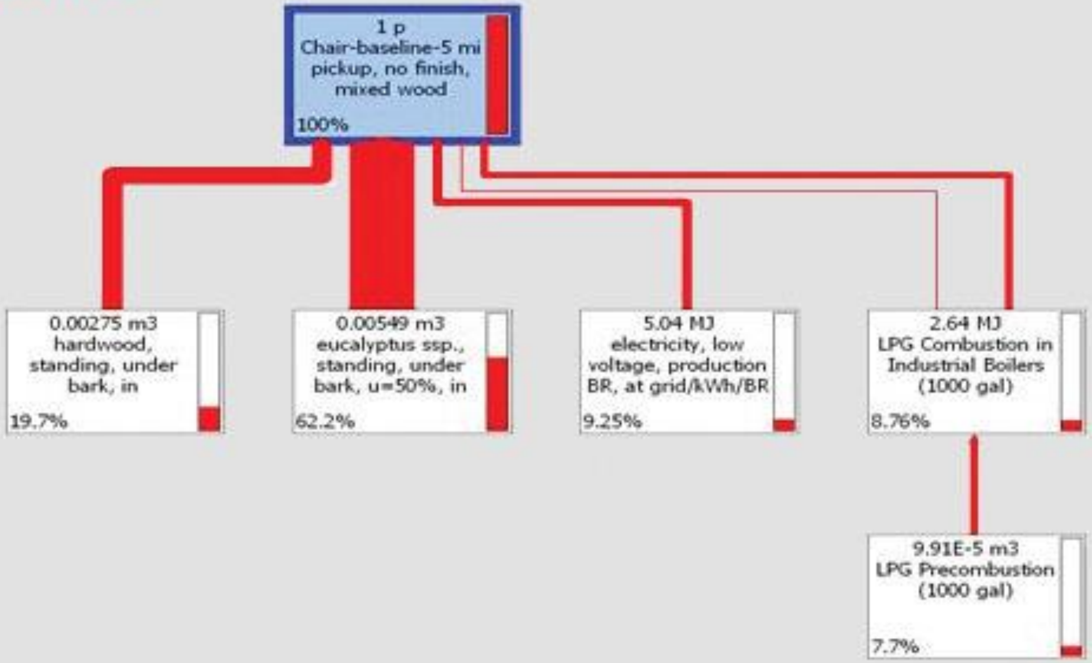
Growing harvesting raw material

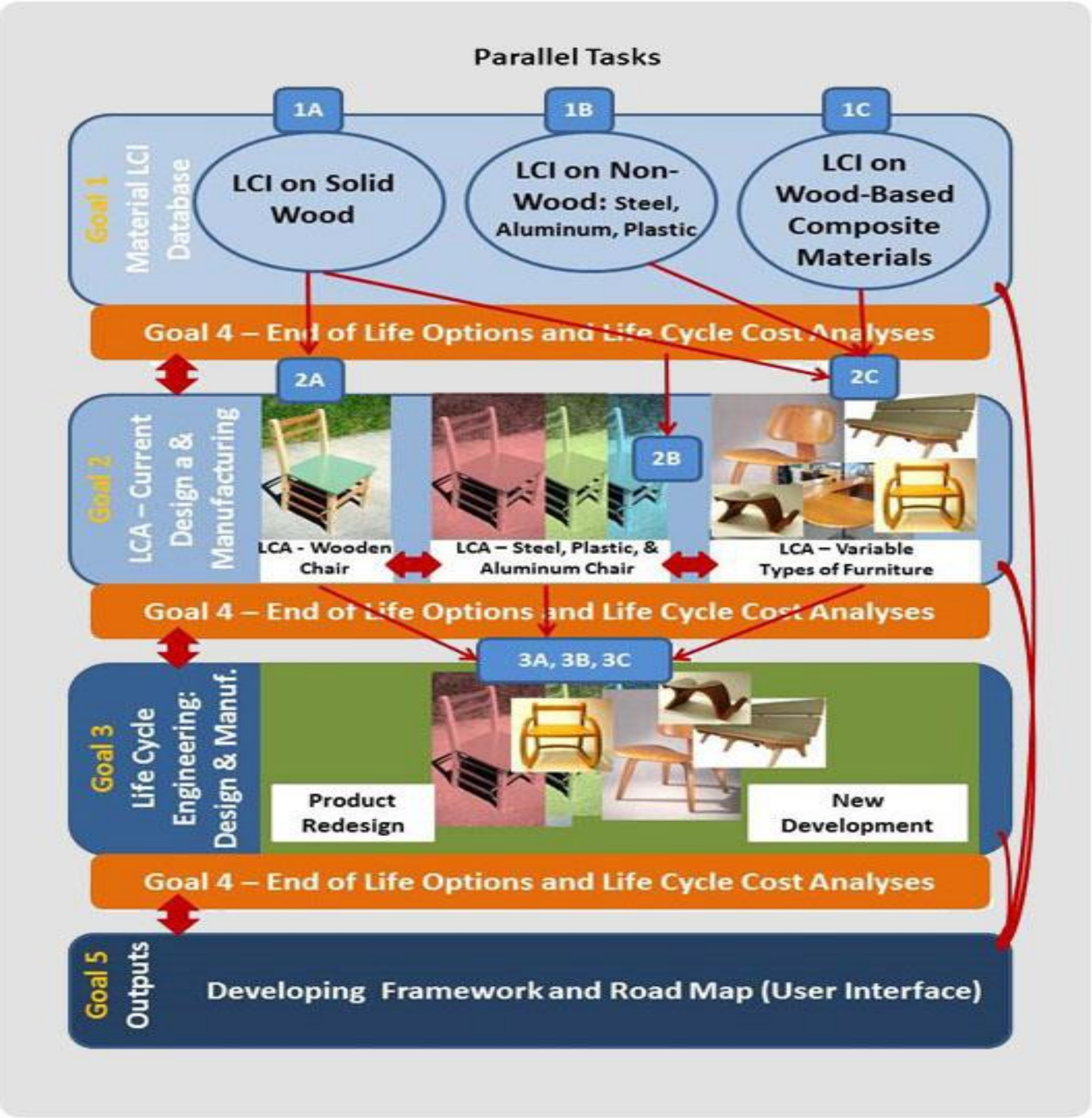
Processing

Transport

Use and maintenance

Use, reuse recycling or disposal





Parallel Tasks

Goal 1 Material LCI Database

1A LCI on Solid Wood

1B LCI on Non-Wood: Steel, Aluminum, Plastic

1C LCI on Wood-Based Composite Materials

Goal 4 – End of Life Options and Life Cycle Cost Analyses

Goal 2 LCA – Current Design a & Manufacturing

2A LCA - Wooden Chair

2B LCA – Steel, Plastic, & Aluminum Chair

2C LCA – Variable Types of Furniture

Goal 4 – End of Life Options and Life Cycle Cost Analyses

Goal 3 Life Cycle Engineering: Design & Manuf.

3A, 3B, 3C

Product Redesign

New Development

Goal 4 – End of Life Options and Life Cycle Cost Analyses

Goal 5 Outputs

Developing Framework and Road Map (User Interface)

Furniture Industry Sustainable Supply Chain Management Best Practices

Design and Engineering	Product and Business Development	Material Inputs	Manufacturing	Distribution and Logistics	Use	End of Life
• Design for the Environment (DfE)	• Green Chemistry • Life Cycle Analysis (LCA) • Clean Technologies	• Resource Management • Sustainable Purchasing • Renewable Resources • Fair Trade	• Resource Conservation and Efficiency e.g. water and energy • Sustainable manufacturing • Waste Minimization • Environmental Management Systems (EMS) eg ISO 14001 • Employee Health and Safety (EHS) • Pollution Prevention (P2) • GHG Emission Mitigation and Adaptation • Environmental Impact Reduction	• Sustainable Transportation • Sustainable Packaging	• Sustainability Standards and Certifications • Education and Training • Product: Return, Re-use, Re-Manufacture	• Disposal

GRAND VALLEY STATE UNIVERSITY
SUSTAINABLE COMMUNITY DEVELOPMENT INITIATIVE

The life cycle stages considered for this study include:

- Raw material production
- Furniture manufacture
- Furniture transportation
- Use of furniture
- Used furniture management (Reuse/ Recycle/Disposal)

The modes of disposal studied include incineration and landfill.

Human health

- The damage category, ‘Human health’, indicates the adverse impact on human health due to the release of pollutants into the environment. The impact categories included within this damage category are:
    - Carcinogens
    - Respirable organics
    - Respirable inorganics
    - Climate change
    - Radiation
    - Ozone layer

Ecosystem quality

- Ecosystem quality indicates the adverse impact on ecosystem quality due to the release of pollutants into the environment. The impact categories included within Ecosystem quality are:
    - Ecotoxicity
    - Acidification / Eutrophication
    - Land use

Resources

Resources indicate the adverse impact of consumption of material during the life cycle of the product that lead to depletion of resources. The impact categories included within Resources are:

- Minerals
- Fossil fuels

Wooden furniture:

- Wooden furniture during its life cycle has an impact on Respirable organics and inorganics, Climate change, Acidification/Eutrophication, Land use and Fossil fuels. However the impact on Fossil fuels, Climate change and Land use is relatively high.
- As compared to PP furniture, wooden furniture have a lower impact on Resources but a higher impact on Human health and Ecosystem quality. Wood being a renewable resource does not have a major impact on resources.
- The impact during the manufacturing stage is primarily due to logging, transportation and incineration.
- Also, as compared to PP furniture, wooden furniture has lesser life resulting in higher environmental load during its life cycle.
- The other important aspect which has a major bearing on the final result is the release of Carbon dioxide during the manufacturing stage (cultivation to manufacturing of furniture). Non recyclability is a disadvantage that wooden furniture have vis-à-vis PP furniture.

Steel furniture

- Steel furniture during its life cycle affects eight categories. Steel furniture have a relatively high impact on Respirable inorganics, Fossil fuels and Climate change while the impact on Minerals, Carcinogens and Respirable organics is low.
- As compared to PP furniture, steel furniture have a higher impact across all the three damage categories. The steel manufacturing process is resource intensive and the energy consumption during the transportation stage is also high. Steel manufacturing process involves the use of iron ore as a raw material, which is a non renewable resource.
- All these factors, combined together, result in a comparatively high score for the 'Resources' damage category. The steel manufacturing process also has a high impact on climate change, respiratory organics and carcinogens. The metal emissions during the steel manufacturing process results in high impact on ecosystem quality.

PP furniture

- PP furniture during its life cycle impacts Carcinogens, Respirable organics and inorganics, Climate change, Acidification/ Eutrophication and Ecotoxicity.
- The impact on Fossil fuel, Climate change and Respirable organics is comparatively higher than the other categories.
- As compared to the impact on Human health and Ecosystem quality, Polypropylene chairs, have a higher impact on the category ‘Resources’. The impact on Resources is primarily due to the use of crude oil as a raw material and its use as a source of energy during the life cycle. However, impact due to the contribution of the actual energy consumption is lower in comparison to the impact due to its use as a raw material.
- Recycling of PP however, results in lowering the impact on resources. The PP Chair during its life cycle also results in high impact on respirable inorganics and acidification and eutrophication. PP being lighter than steel and wooden furniture also has a lower impact during the transportation stage.

- Lifecycle impact analysis for a wooden chair

Impact category

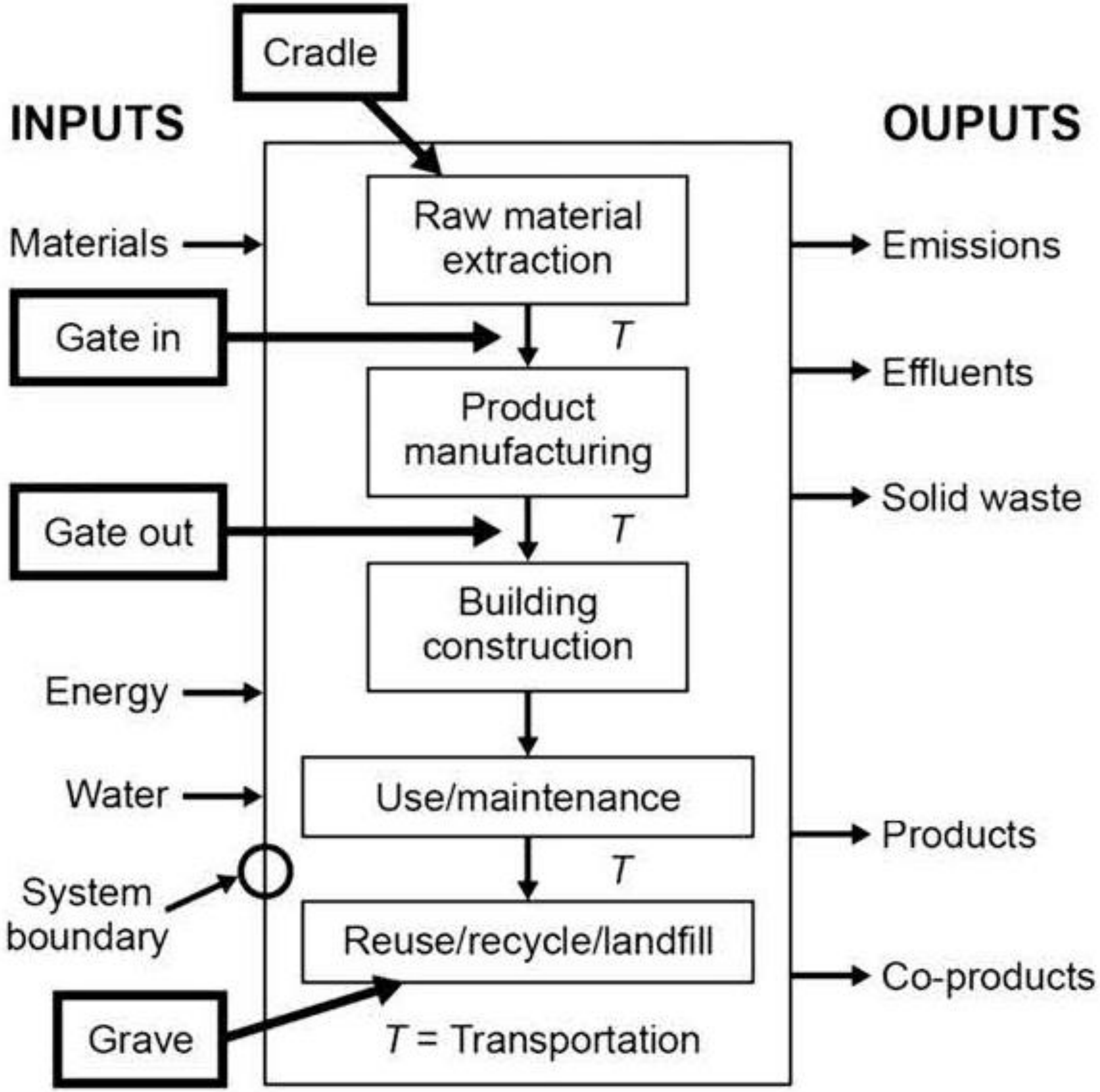
  - Acidification
  - Carcinogenics
  - Ecotoxicity
  - Eutrophication
  - Fossil fuel depletion
  - Global warming
  - Non carcinogenics
  - Ozone depletion
  - Respiratory effects
  - Smog

Operation times and energy consumption of each machine for producing a single chair.

Machine	Cutting Time (s)	Idle Time (s)	Energy (kwh)
• Band Saw	87	40	0.045
• Radial Arm Saw	28	21	0.024
• Jointer	65	65	0.040
• Planer	34	0	0.071
• Table Saw	82	52	0.112
• Drill Press	600	792	0.103
• Tenon Machine	240	139	0.048
• Bent saw - trim	200	152	0.114
• Orbital Sander	30	0	0.002
• Hand Router	150	0	0.009
• Dust Collector	150	198	1.032
		Total	**1.6**

Case study 3: LCA on panel wood production

- The manufacture of building products such as wood panels impacts the environment, including contributing to climate change.
- Evaluating these impacts would help in identifying environmental "hot spots" and producing building products with lower environmental impacts.
- LCA is an internationally accepted and standardized method for evaluating the environmental impacts of products.
- With LCA, holistic environmental impacts were calculated based on survey data from mills on emissions to air and water, solid waste, energy consumption, and resource use.
- The LCIA use LCI flows to examine impacts for four areas: human health, social health, resource depletion, and ecosystem function.


Cradle
INPUTS
OUPUTS
Materials
Gate in
Gate out
Energy
Water
System boundary
Grave
Raw material extraction
T
Product manufacturing
T
Building construction
Use/maintenance
T
Reuse/recycle/landfill
T = Transportation
Emissions
Effluents
Solid waste
Products
Co-products

Manufacturing process

- For most wood panels, woody biomass residues that were historically burned for energy or were sent to landfills for disposal as waste material are now used in the manufacturing of the panels.
- During the last several decades, these wood panel products have evolved into highly engineered products designed to meet specific end-use requirements.
- The production of wood panels falls into the North American Industry Classification System Code 321219-reconstituted wood products, which include other wood composite products such as cellulosic fiberboard, medium-density fiberboard, particleboard, and OSB (USCB 2012).
- Manufacturing engineered wood products such as wood panels requires electricity for breaking down wood raw material (i.e. feedstock) and thermal energy to dry wood raw material and set resins.
- These inputs are primarily responsible for most of the greenhouse gas (GHG) emissions released to the atmosphere during wood product manufacturing.

- Amount and type of thermal energy depends on the panel product’s manufacturing process, whereas the electricity profile depends on the location of the plants and the associated energy sources.

Oriented strandboard

OSB is an engineered structural panel produced from wood strands and bounded with resin.

Softwood plywood

Softwood plywood is manufactured of cross-directional layers of peeled veneer and glued together with resin.

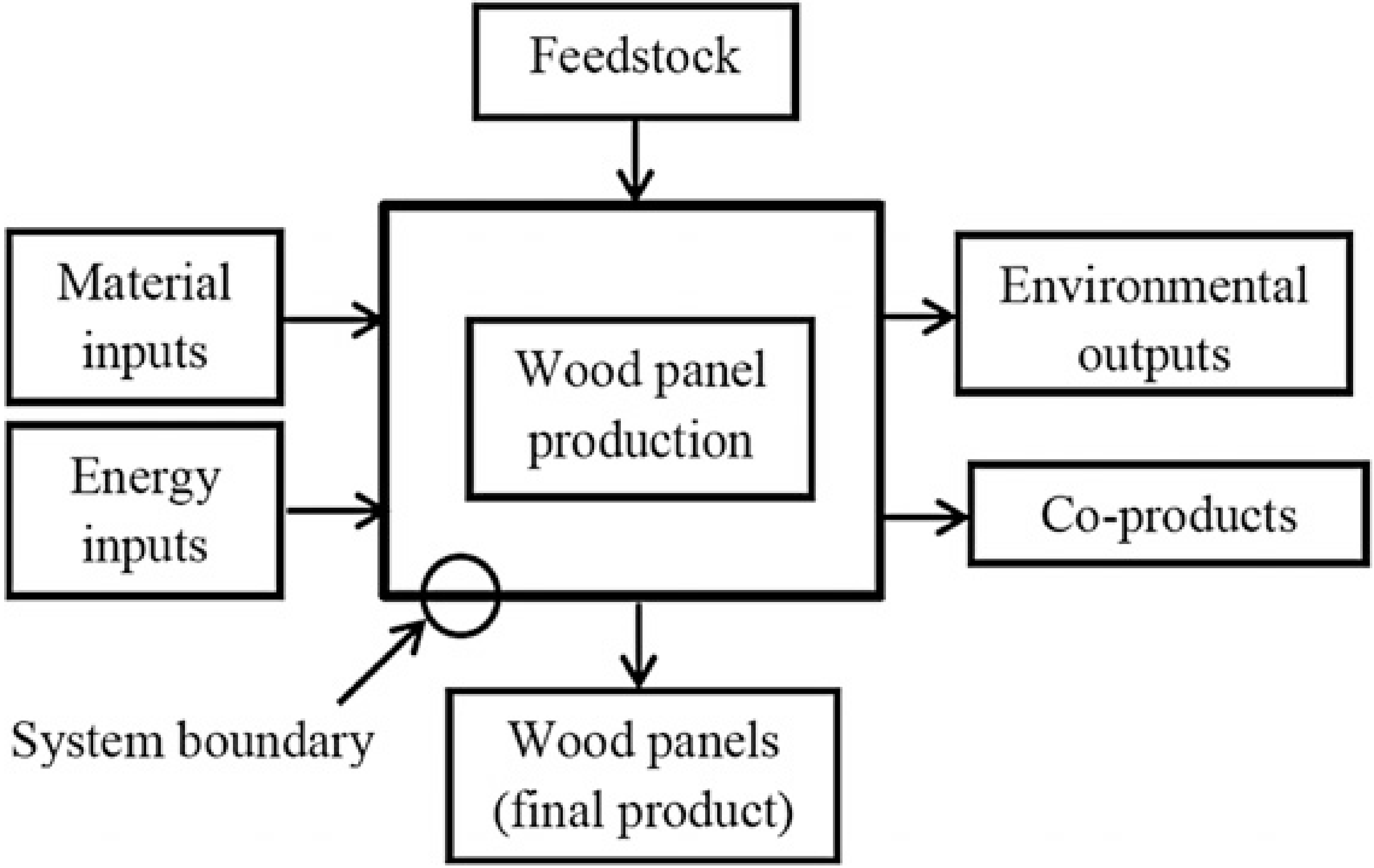
Hardboard

Manufacturing hardboard in North America currently uses either a wet or dry process to create high-density wood composition panels.

Cellulosic fiberboard

Cellulosic fiberboard is produced from industrial wood residues (such as shavings, sawdust, and chips from primary log breakdown), from whole-tree chips, and from mixed paper and construction waste.

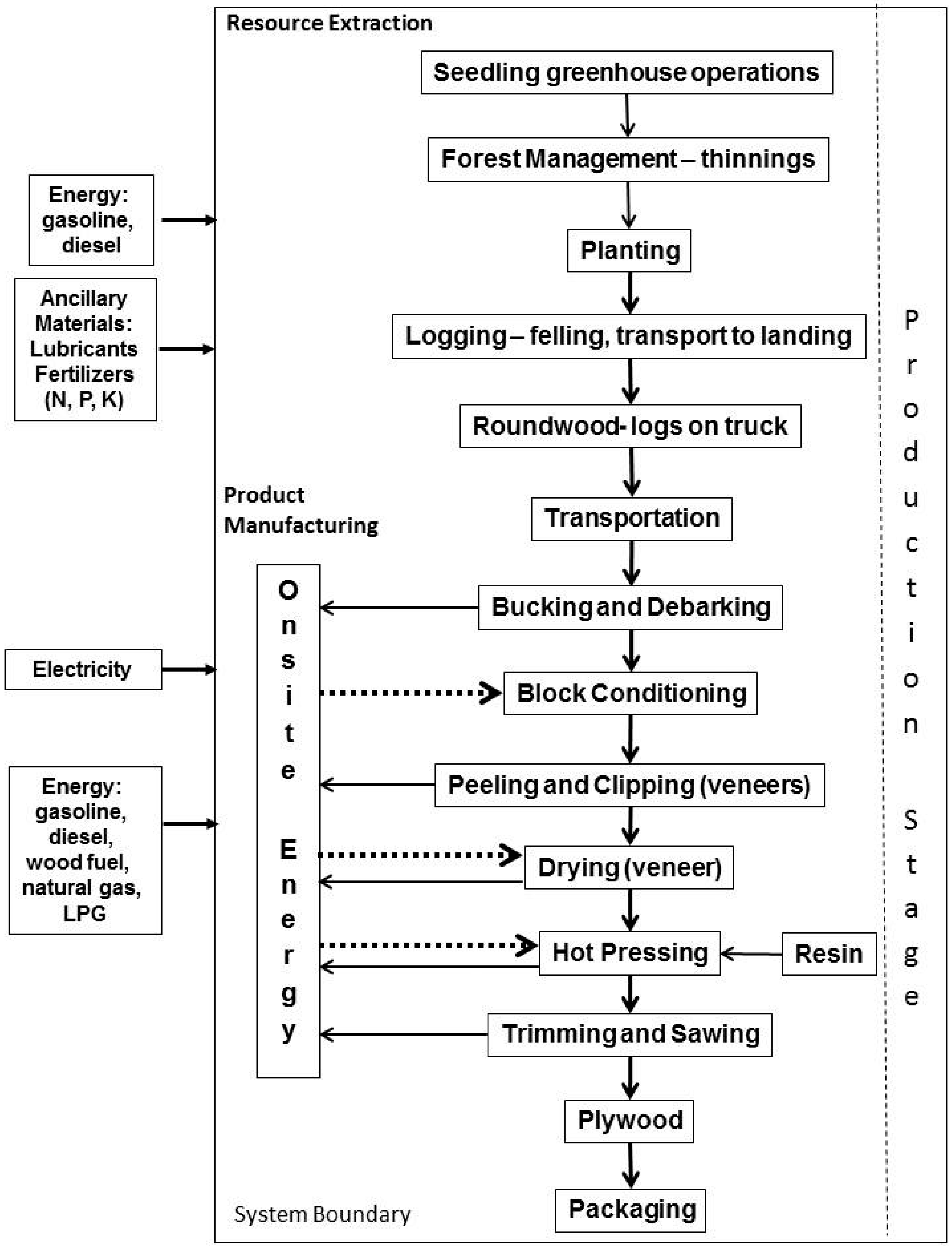
Manufacturing cellulosic fiberboard uses a wet process that produces a low-density wood composition panel and is often referred to as insulation board.


Feedstock
Material inputs
Energy inputs
Wood panel production
Environmental outputs
Co-products
System boundary
Wood panels (final product)

- The hazardous air pollutants specific to their wood products manufacturing process were include formaldehyde, methanol, acrolein, acetaldehyde, phenol, and propionaldehyde (propanal).
- Hardboard had the greatest environmental impacts relative to the other wood panels for all life cycle impacts except for the following categories: 1) other renewable sources (cellulosic fiberboard) and 2) solid waste (PNW softwood plywood).
- Cellulosic fiberboard consumed the lowest percentage of renewable biomass. This was primarily because of cellulosic fiber- board production can use low-quality feedstock that other wood panel products would use as fuel for boilers.
- More fossil fuels were consumed during cellulosic fiberboard production.
- As for cellulosic fiberboard and hardboard, the wood panel carbon was 42% and 51% of their respective manufacturing GHG emissions.
- One reason for the large variation was that cellulosic fiberboard was able to consume raw materials of lower quality, whereas hard board production consumed large amounts of electricity (654kWh/m3) especially during the refining process compared with the other panel products.

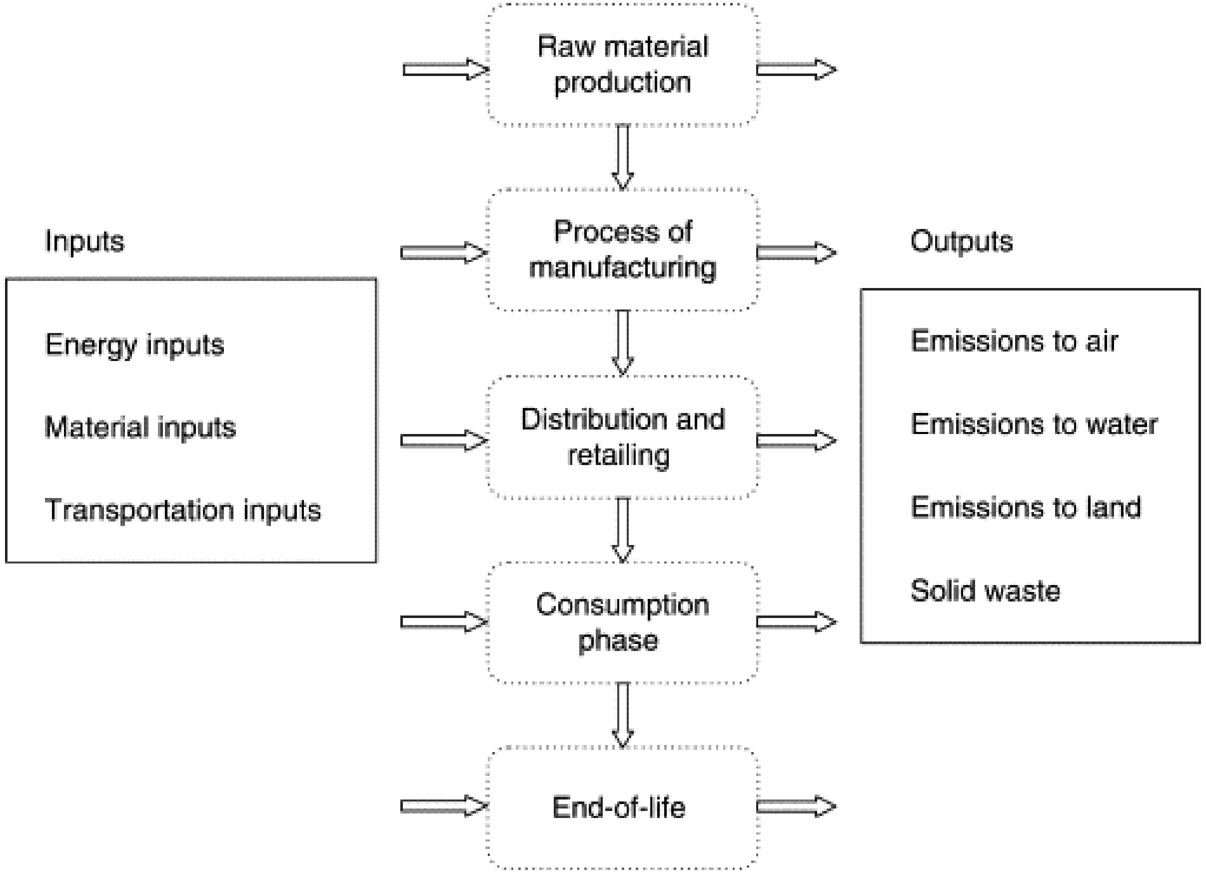
- For most wood panels, hog fuel, a mixture of residues generated during product production, is readily available except for cellulosic fiberboard production.
- However, what most wood panel products would consider hog fuel at their production facility to be burned in a boiler for thermal energy, a cellulosic fiberboard production facility could use as a feedstock.
- For cellulosic fiberboard production, its use of woody biomass for on-site energy is limited unless a large source of underutilized wood is available nearby.
- Companies and other stakeholders have to decide if greater material use or lower GHG emissions are the most important outcome during product production.
- Densities and panel thicknesses have the greatest impacts on converting from a cubic meter to a square meter basis for the various life cycle impacts evaluated.
- Using woody biomass energy for panel production decreases their impact on climate change.

- The release of GHG emissions is especially great when fossil fuels are consumed to generate steam (i.e. thermal energy) for the drying process.
- Using woody biomass instead of fossil fuels would lower the GWI (Global Warming Impacts) of the various wood panel products produced.
- The carbon stored in the wood panels substantially offset these GHG emissions and in most cases, the carbon stored was greater than the gate-to-gate manufacturing GHG emissions released during manufacturing.


Resource Extraction
Seedling greenhouse operations
Forest Management – thinnings
Planting
Logging – felling, transport to landing
Roundwood- logs on truck
Transportation
Product Manufacturing
Bucking and Debarking
Block Conditioning
Peeling and Clipping (veneers)
Drying (veneer)
Hot Pressing
Resin
Trimming and Sawing
Plywood
Packaging
Onsite Energy
Production Stage
System Boundary
Energy: gasoline, diesel
Ancillary Materials: Lubricants Fertilizers (N, P, K)
Electricity
Energy: gasoline, diesel, wood fuel, natural gas, LPG

LCA in Plywood Industry

- Plywood industry producing large amount of GHGs due to energy inputs, material inputs, transport inputs, and burning of wastes for energy generation.
- **Life Cycle Inventory** (LCI) is the **inventory** of the total energy use, raw **material** use, air and water emissions, and the total solid waste produced from the cradle-to-grave (grave being the ultimate disposal)



Goal and Scope definition

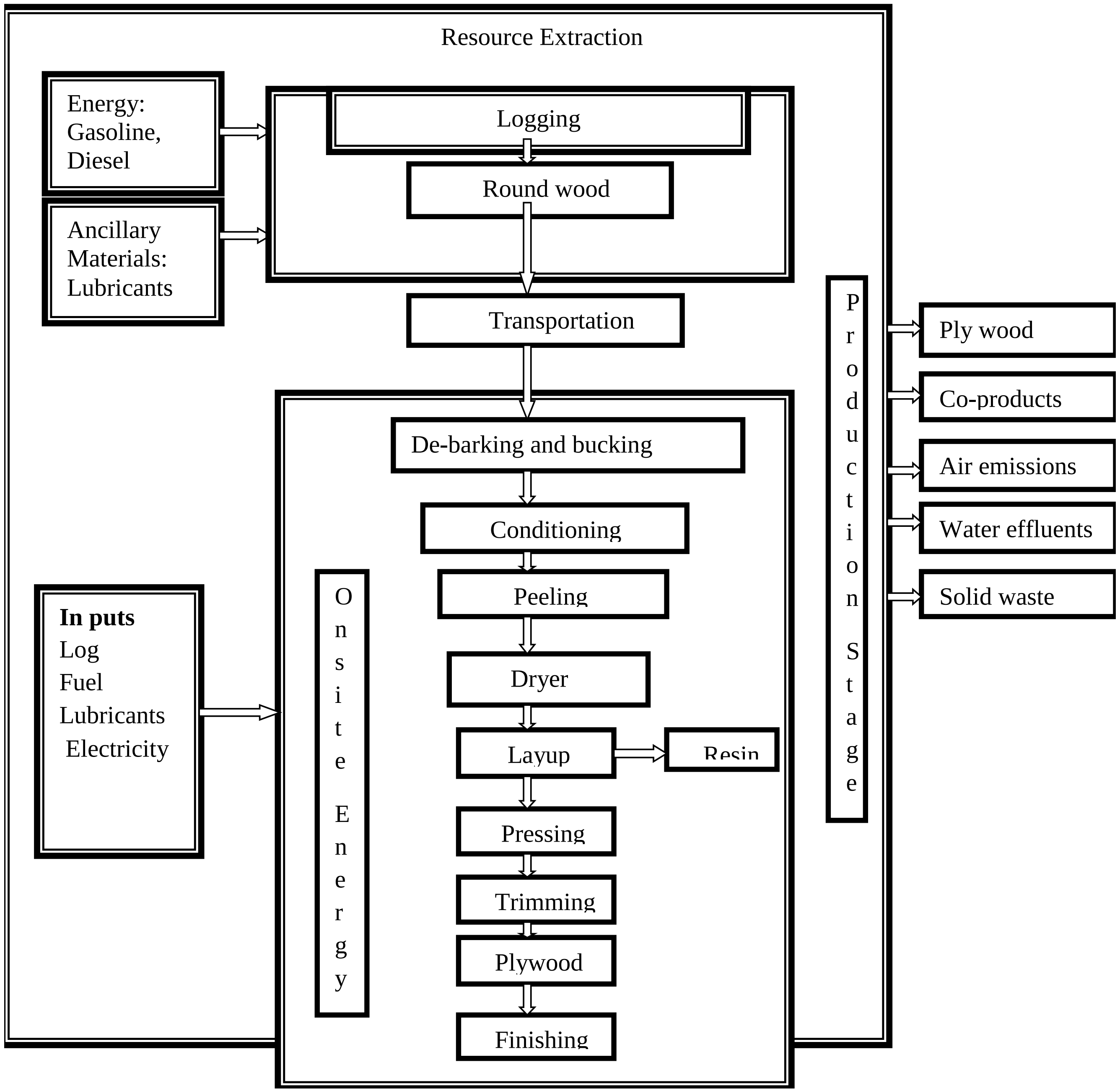
- The LCA procedure comprises four phases: goal and scope definition, inventory analysis, impact assessment, and interpretation of results.
- The scope of this study describes the functional unit of the studied product, the product system and its boundaries, data collection and processing procedures, and environmental impact categories considered.
- The inventory analysis phase quantifies the natural resources and other inputs and the environmental emissions and other outputs for each process in the product system.
- The impact assessment phase translates the natural resource inputs and environmental emissions into their contributions to a range of selected impact categories.
- The final phase, i.e. interpretation, interprets the results from the preceding phases of the LCA.

Functional unit

- Functional unit must reflect the function of the investigated product.
- For plywood, material flows, fuel and electricity use, and emissions data were normalized to a per-production of one unit plywood. The functional unit for plywood is one cubic meter (1.0 m^3) or 92.90304 square meters.

System boundary

- It cover the manufacturing life cycle of plywood from harvesting to factory gate perspective and ignored background data for raw materials (internal) and data on products sales (external).
- The product system is detailed in the Figure and includes the following main stages: raw material and energy production, transport, plywood production, and waste disposal.
- Boundary setting facilitated material tracking and cross-boundary energy flows.
- The system boundaries in this study included what occurred during production on-site along with off-site measurements, such as resources consumed in energy production, raw material production, additives and transport, and electricity generation; these features were partially collected and analyzed.
- The production process system boundary begins with the logging, debarking, backing conditioning, peeling drying, layup, pressing, trimming and finishing.


Resource Extraction
Energy: Gasoline, Diesel
Ancillary Materials: Lubricants
Logging
Round wood
Transportation
De-barking and bucking
Conditioning
Peeling
Dryer
Layup
Resin
Pressing
Trimming
Plywood
Finishing
Onsite Energy
In puts
Log
Fuel
Lubricants
Electricity
Production Stage
Ply wood
Co-products
Air emissions
Water effluents
Solid waste

Life cycle inventory

- The LCI result contained emissions both due to the production process of plywood and all inputs (raw materials, fuels and energy sources) used in the system boundary to produce one cubic meter of plywood in the plywood industry.

Key points

- LCA is used to identify environmental impacts and hotspots associated with plywood manufacturing.
- To improve environmental performance of plywood, advanced technologies and green materials can be used.
- The environmental performance of products and processes has become key issue, which is why some companies are investigating ways to minimize their effects on the environment. It is advantageous to explore ways of moving beyond compliance using pollution prevention strategies and environmental management systems to improve their environmental performance.

- The plywood manufacturing process has some onsite emissions from drying veneers and pressing the panels with the resins.
- The CO_2 emissions associated with plywood production, logs and resin used. The formaldehyde resin contributed a high percentage towards the overall CO_2 emissions for the plywood.
- Analysis of abiotic depletion (ADP), effect of Acidification Potential (AP), primary energy depletion (PED), freshwater eutrophication (EP), global warming potential (GWP), and particulate matter (RI) are responsible for environmental impact.
- The analysis of these factors serve as decision-making indicators to help the plywood industry develop and introduce alternatives in plywood processing to improve the environmental performance of production.
- In the process of plywood production, manufacturing of veneers in all raw materials has the greatest impact on the environment, mainly attributed to the drying stage of the veneer manufacturing process.

Impact categories

Global Warming Potential (GWP)

- Global Warming Potential, or GWP, has been developed to characterize the change in the greenhouse effect due to emissions and absorptions attributable to humans.
- The unit for measurement is grams equivalent of CO_2 per functional unit of product (note that other greenhouse gases, such as methane, are included in this category, thus the term “CO_2 equivalent” is an impact and not an emission).

Acidification Potential (AP)

- Acidifying compounds emitted in a gaseous state either dissolve in atmospheric water or fixed on solid particles.
- They reach ecosystems through dissolution in rain. The two compounds principally involved in acidification are sulfur and nitrogen compounds. The unit of measurement is grams of hydrogen ions per functional unit of product.

Eutrophication Potential (EP)

- Eutrophication is the addition of undesired mineral nutrients to the soil or water. The addition of large quantities of mineral nutrients such as nitrogen and phosphorous results in undesirable shifts in the number of species in ecosystems and reduction in ecological diversity.
- Excess nutrient in water leads to increased biological oxygen demand from the dramatic increase in flora that feed on these nutrients, a following reduction in dissolved oxygen levels, and the collapse of fish and other aquatic species.
- The unit of measurement is grams of nitrogen per functional unit of product.

Fossil Fuel Depletion

- This impact addresses only the depletion aspect of fossil fuel extraction, not the fact that the extraction itself may generate impacts.
- The unit for measurement is mega joules (MJ) of fossil-based energy per functional unit of the product.

Smog Formation Potential

- Under certain climatic conditions, air emissions from industry and fossil-fueled transportation can be trapped at ground level, where they react with sunlight to produce photochemical smog.
- The contribution of a product or system to smog formation is quantified by this category. The unit of measurement is grams of nitrogen oxide per functional unit of product.

Ozone Depletion Potential

- Emissions from some processes may result in the thinning of the ozone layer, which protects the earth from certain parts of the solar radiation spectrum. Ozone depletion potential measures the extent of this impact for a product or system. The unit of measurement is CFC-11 per functional unit of the product.

Ecological Toxicity

- The ecological toxicity impact measures the potential of a chemical released into the environment to harm terrestrial and aquatic ecosystems.
- The unit of measurement is grams of 2, 4-dichlorophenoxy-acetic acid per functional unit of product.