A Life Cycle Assessment Approach for Evaluating Future Nanotechnology Applications

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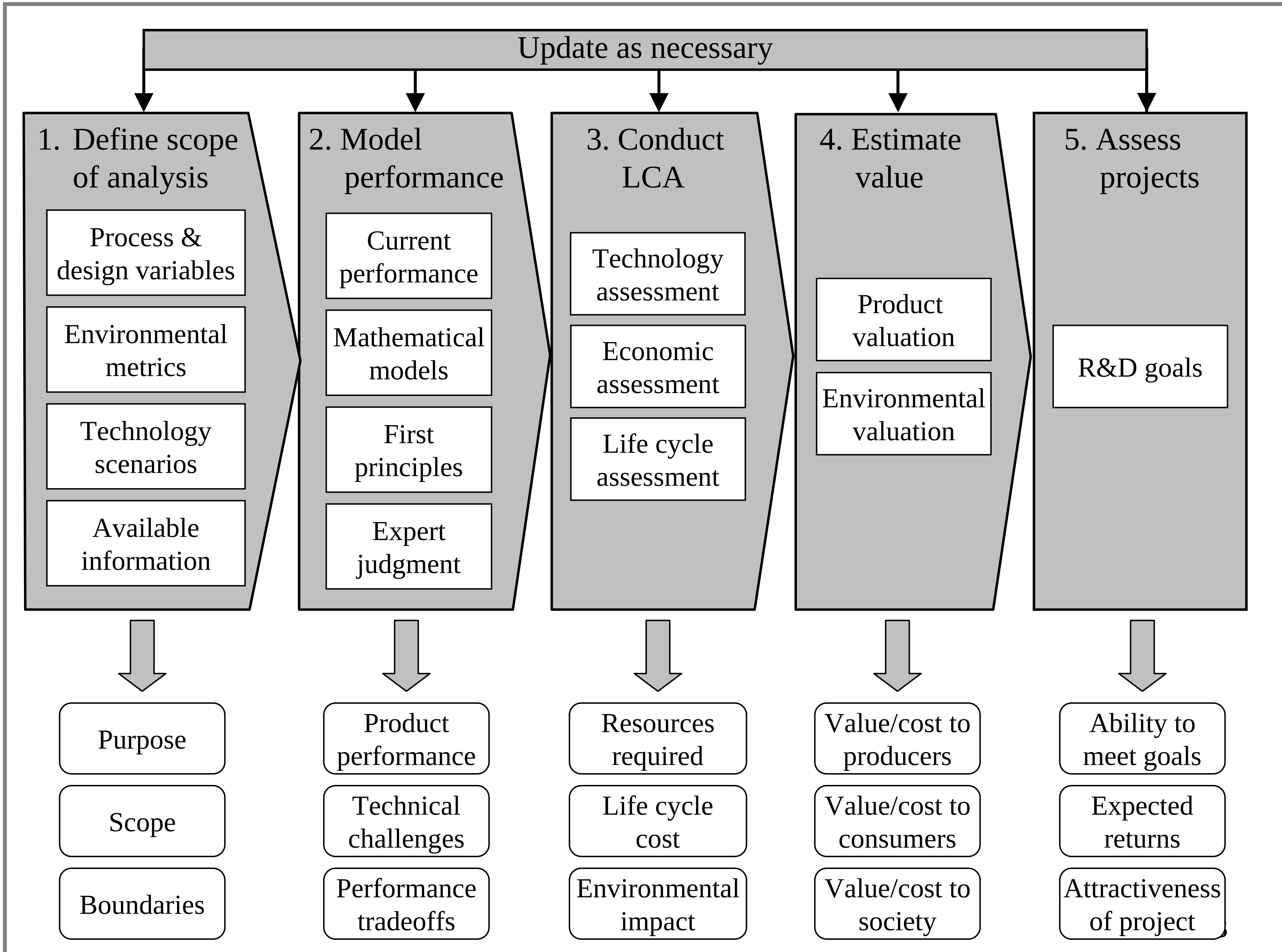
Motivation for Applying LCA

- Reduce material and energy consumption
- Reduce environmental discharge
- Use LCD early in product life cycle
- Optimize economic and social value
- Identify regulatory needs
- Address public concerns


Update as necessary
1. Define scope of analysis
Process & design variables
Environmental metrics
Technology scenarios
Available information
2. Model performance
Current performance
Mathematical models
First principles
Expert judgment
3. Conduct LCA
Technology assessment
Economic assessment
Life cycle assessment
4. Estimate value
Product valuation
Environmental valuation
5. Assess projects
R&D goals
Purpose
Scope
Boundaries
Product performance
Technical challenges
Performance tradeoffs
Resources required
Life cycle cost
Environmental impact
Value/cost to producers
Value/cost to consumers
Value/cost to society
Ability to meet goals
Expected returns
Attractiveness of project

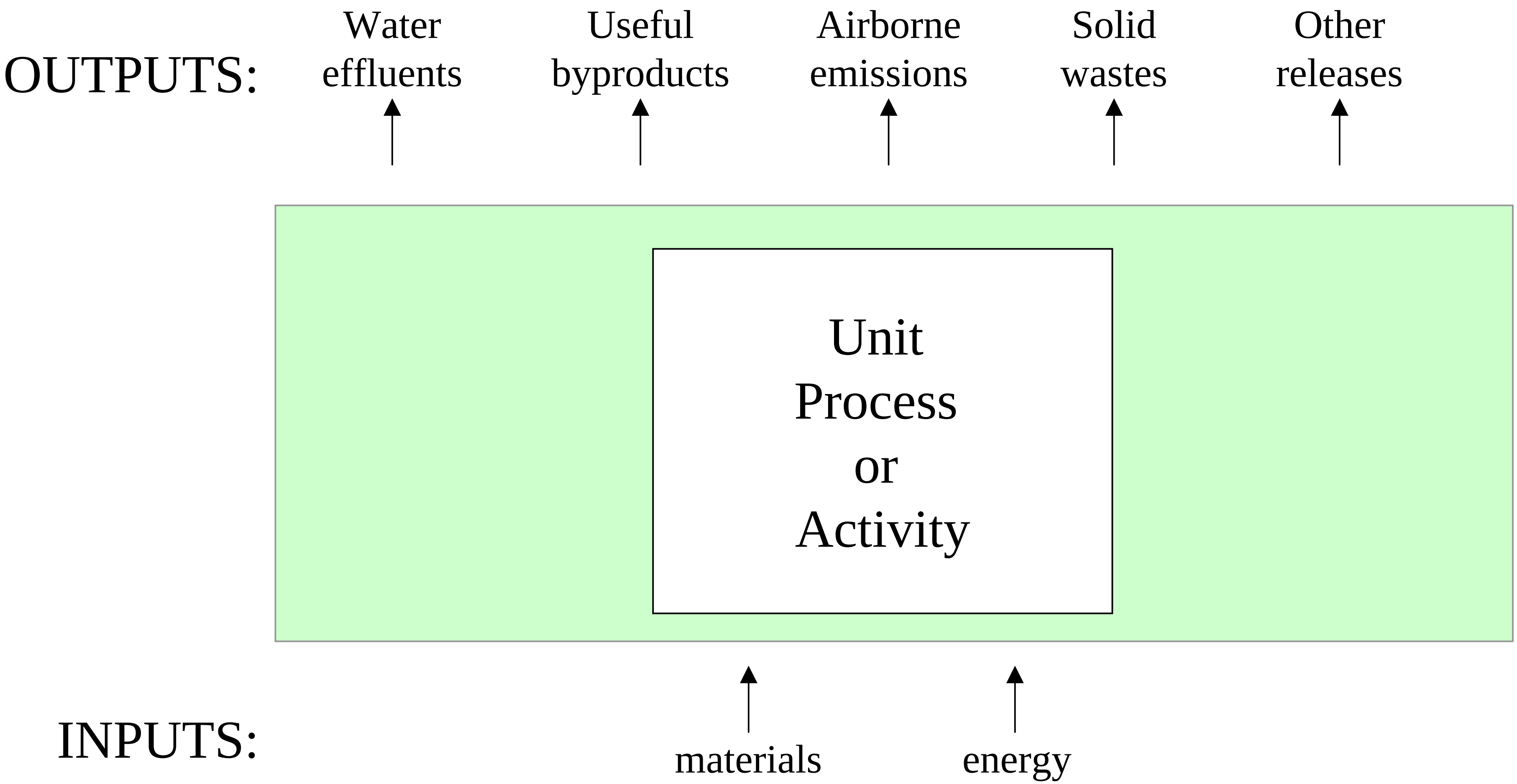
LCA Methods Used

- Process-based
  - developed by SETAC, U.S. EPA and ISO
  - quantifies physical flows of energy, resources and environmental effects
  - Captures direct effects

- Streamlined software

- EIO-LCA
  - developed by CMU’s Green Design Initiative
  - driven by the interrelationships among 491 sectors of the US economy
  - quantifies inputs and effects by relating economic activity to public datasets
  - captures direct and indirect effects

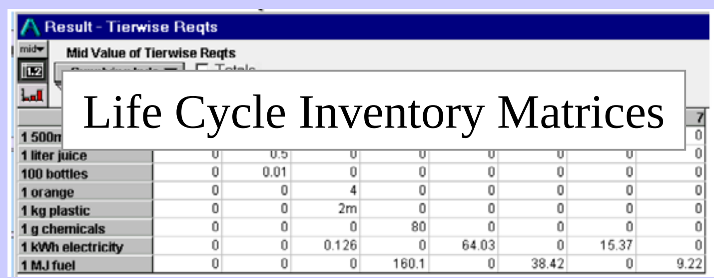
Process-based LCA



Streamlined Software

INPUTS:
- Bill of materials
- Process details
- Product output

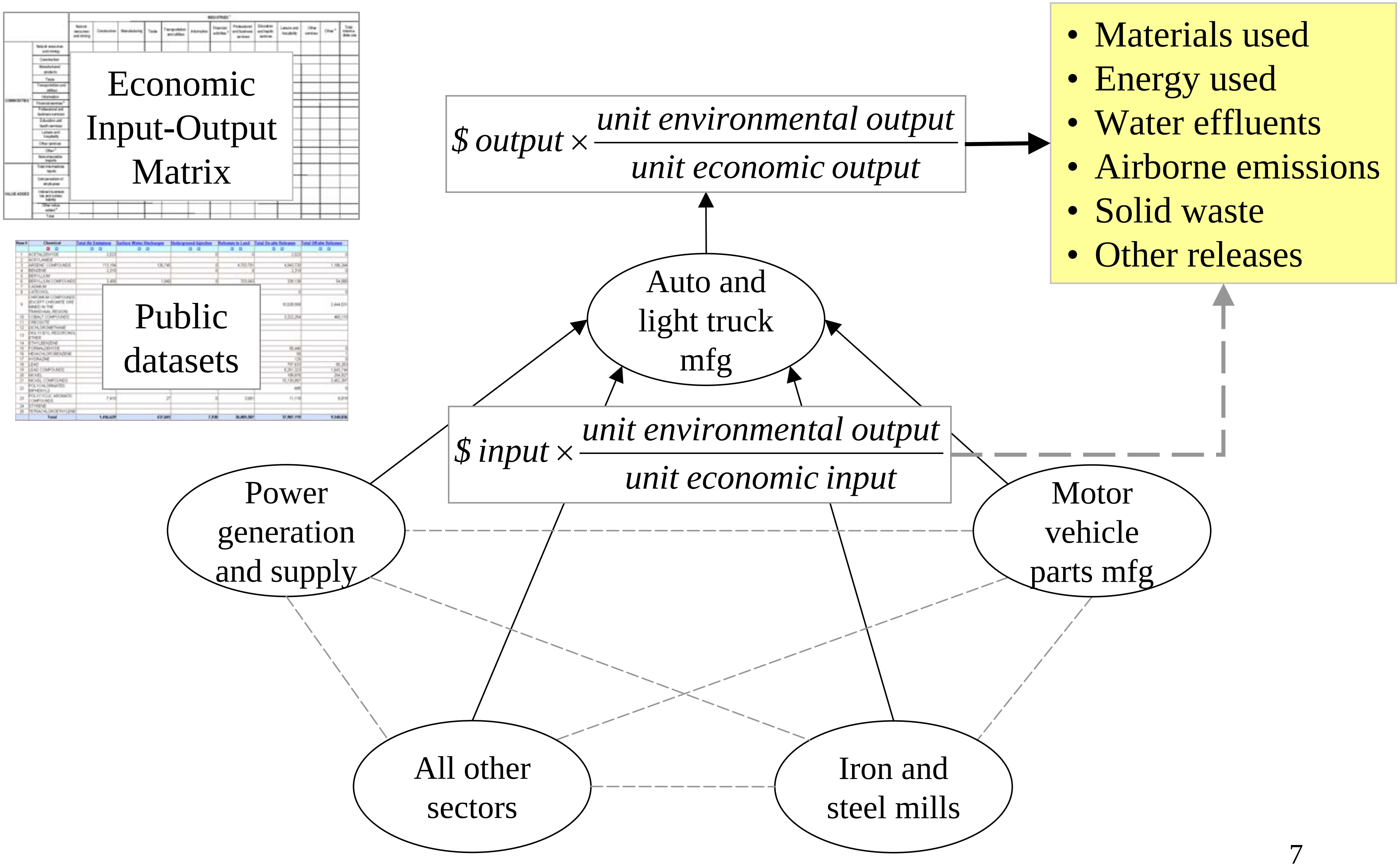
LCA Software



Life Cycle Inventory Matrices

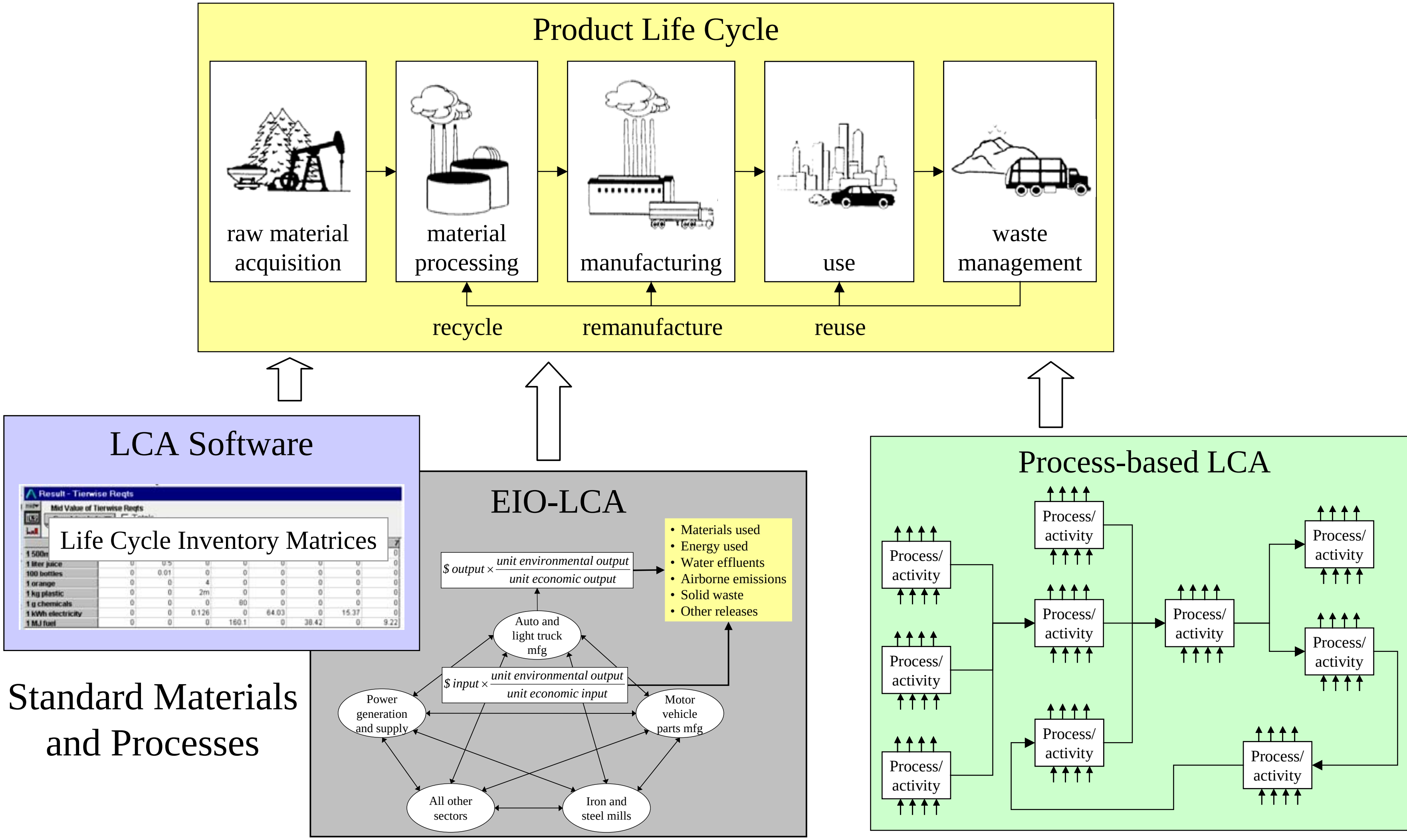
OUTPUTS:
- Materials used
- Energy used
- Water effluents
- Airborne emissions
- Solid waste
- Other releases

EIO-LCA



Economic Input-Output Matrix
Public datasets
$\$ \, output \times \frac{unit\ environmental\ output}{unit\ economic\ output}$
Materials used
Energy used
Water effluents
Airborne emissions
Solid waste
Other releases
Auto and light truck mfg
$\$ \, input \times \frac{unit\ environmental\ output}{unit\ economic\ input}$
Power generation and supply
Motor vehicle parts mfg
All other sectors
Iron and steel mills

Hybrid LCA



Unique Materials and Processes

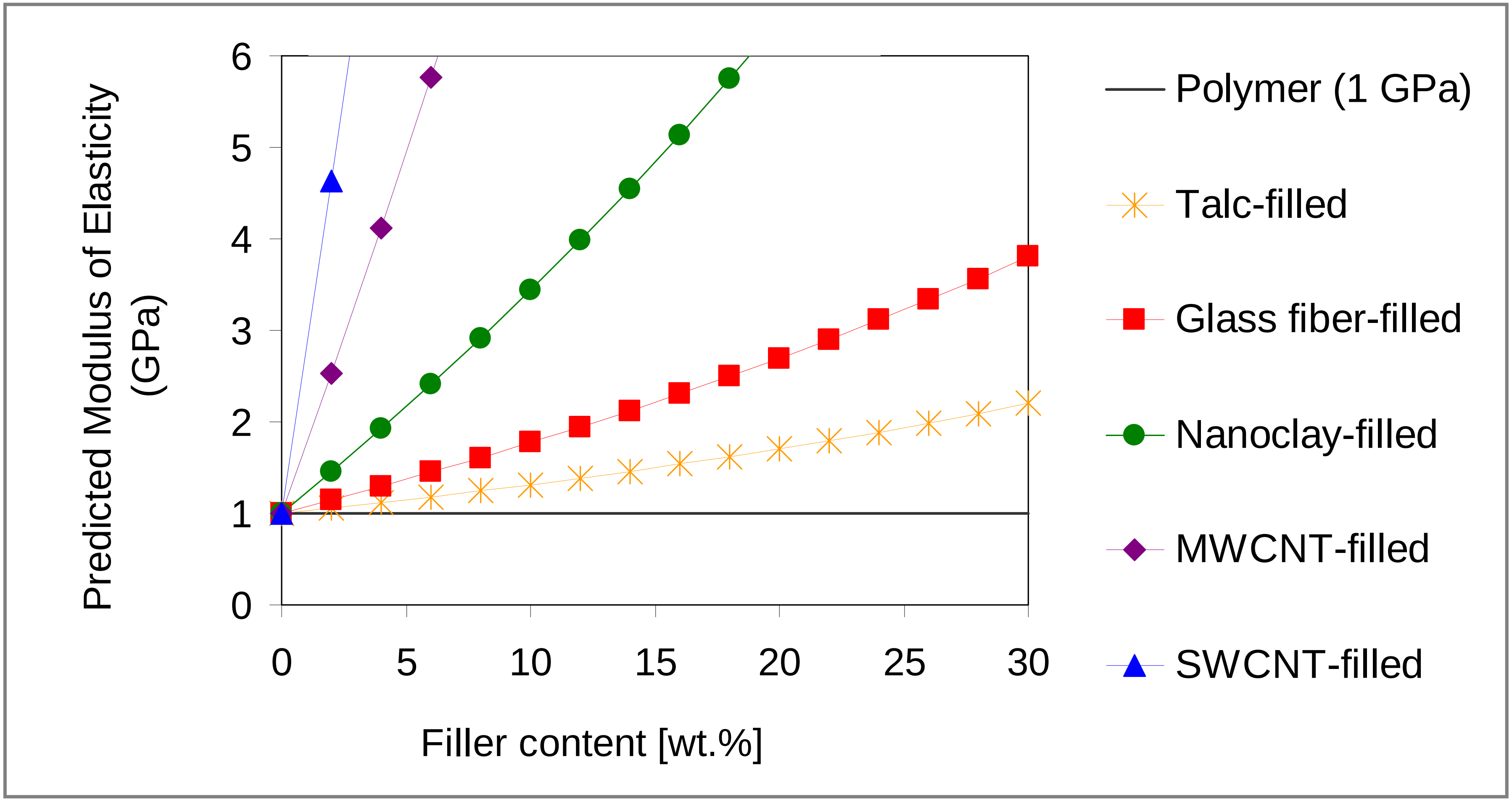
Applications

- Life Cycle Implications of Using Nanocomposites for Automotive Body Panel Weight Reduction
- Life Cycle Implications of Using Nanofabrication to Position and Stabilize Nanoscale PGM Particles in Automotive Catalysts

Life Cycle Implications of Using Nanocomposites for Automotive Body Panel Weight Reduction

- Example Results -

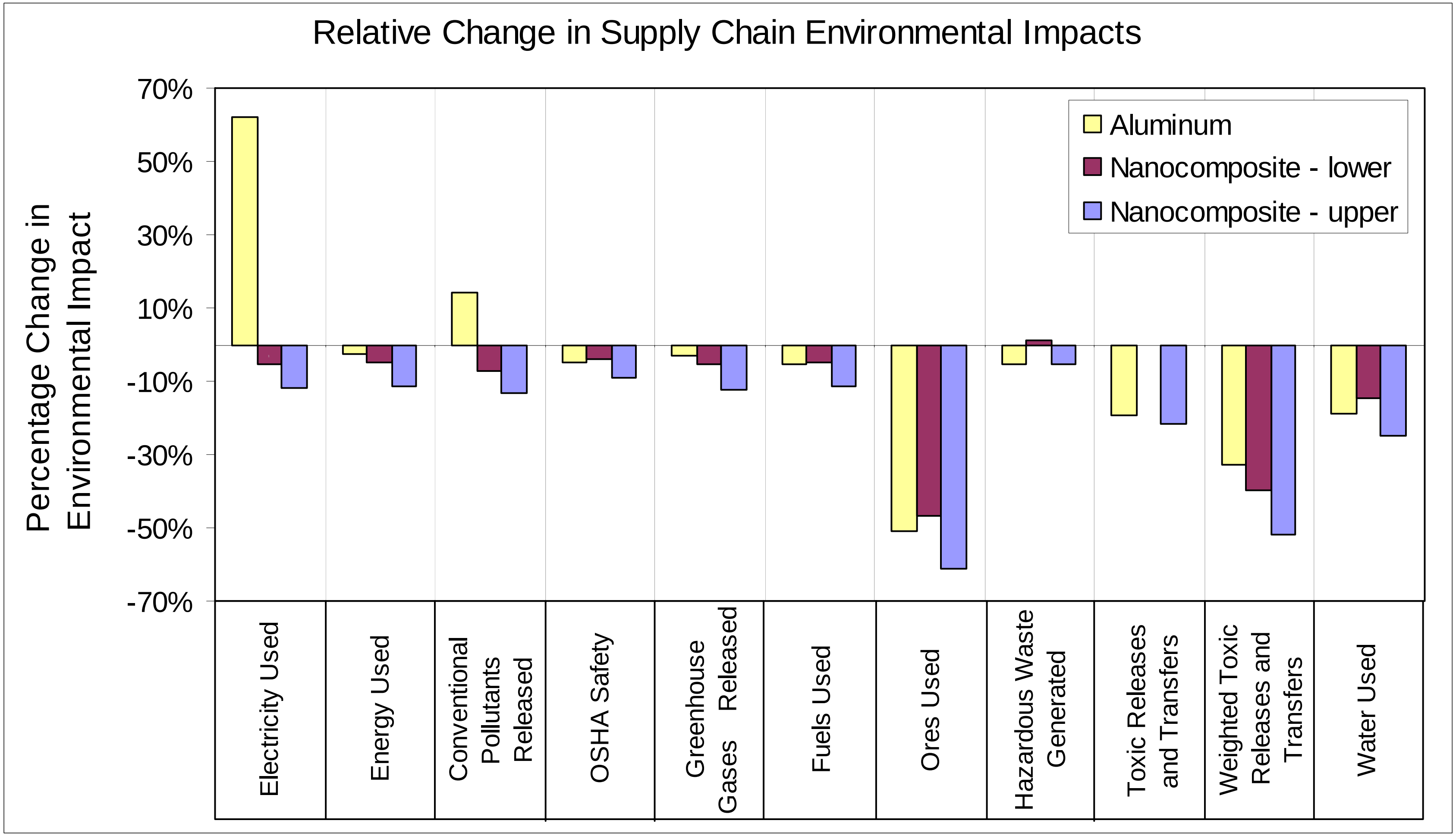
Modeled Product Performance



Predicted elastic modulus vs. filler content based on general Halpin-Tsai model

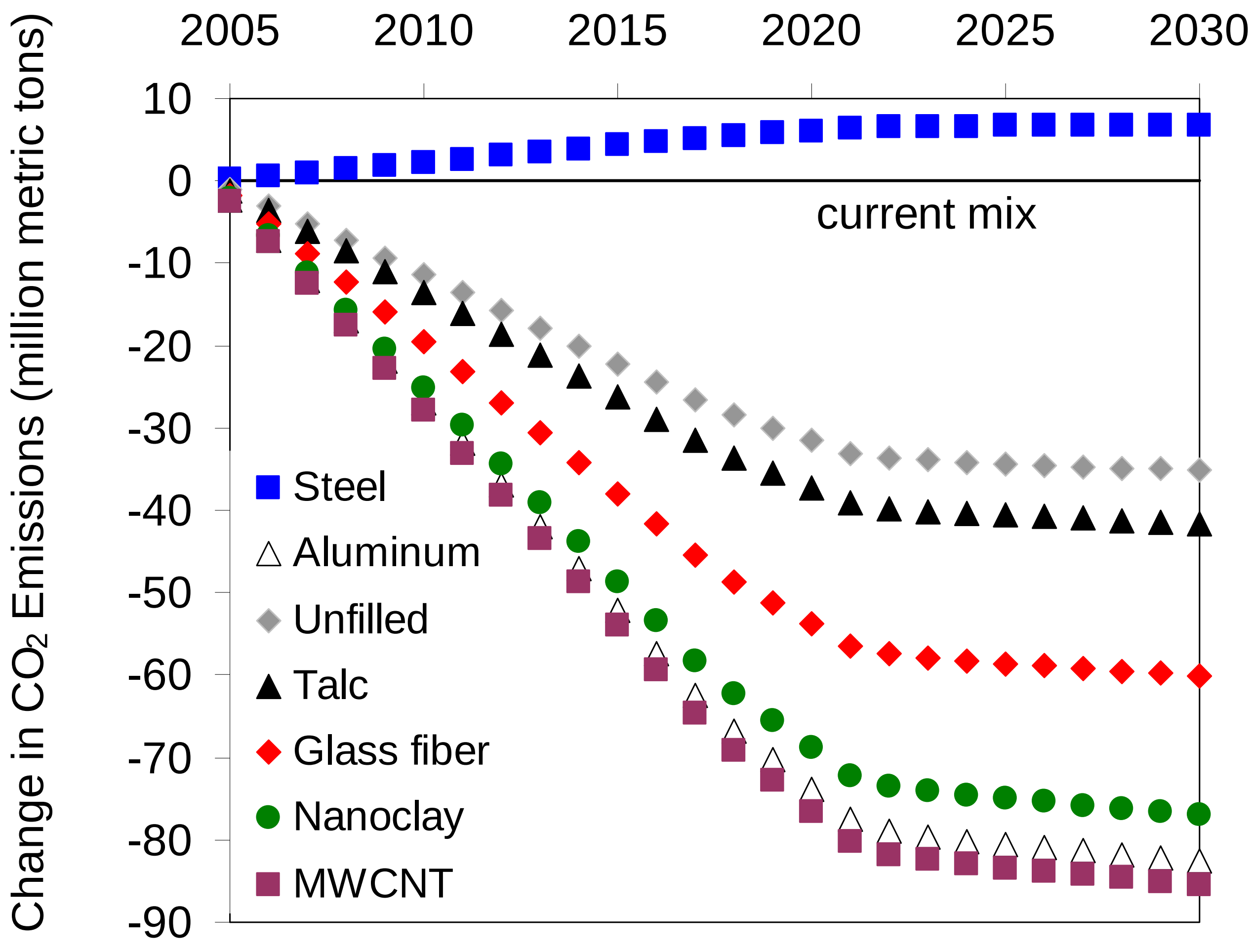
Life Cycle Supply Chain Effects

(one year's fleet of vehicles)

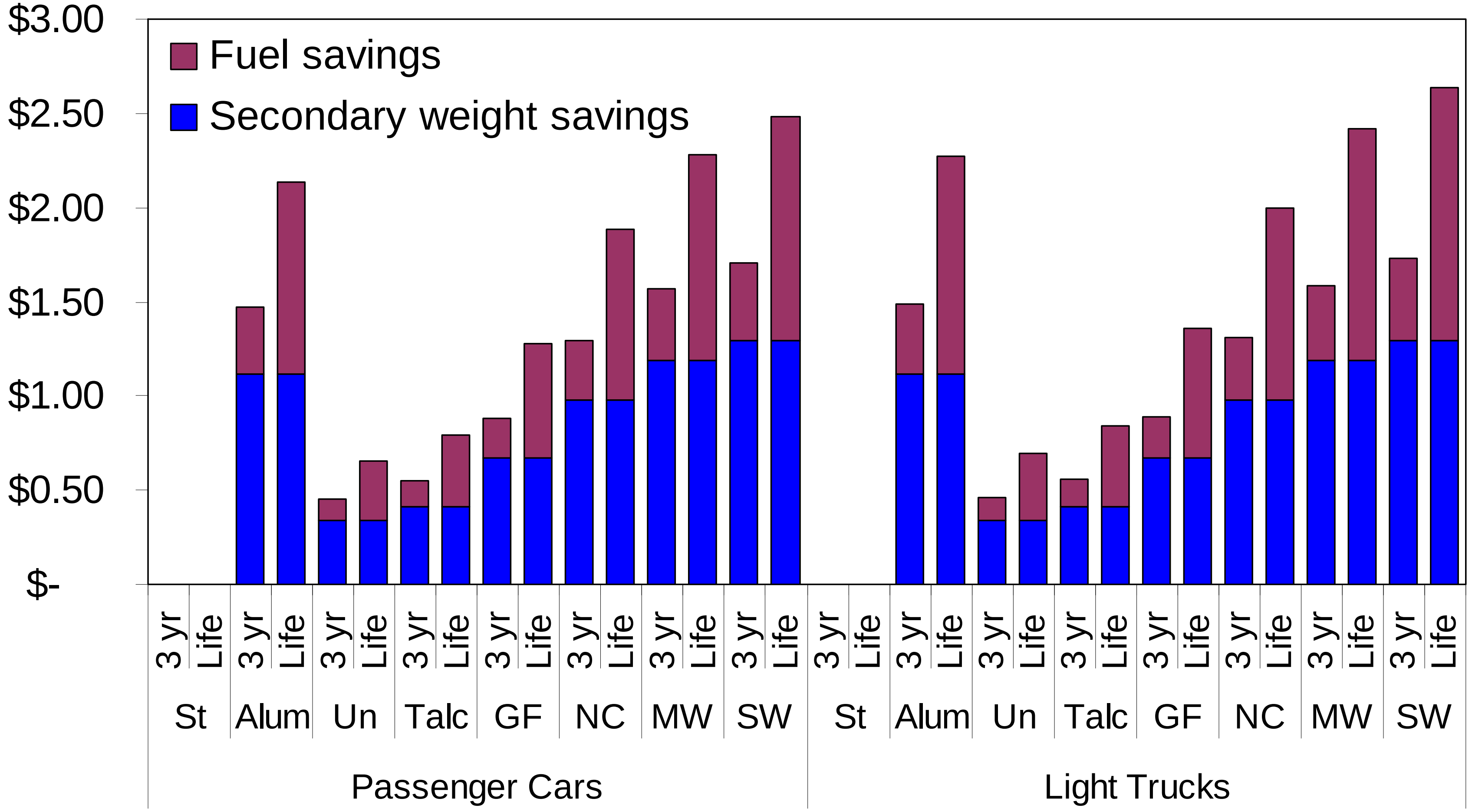


Source: Lloyd and Lave, ES&T, Vol. 37, No. 15, pp. 3458-3466, 2003

Petroleum Production & Combustion

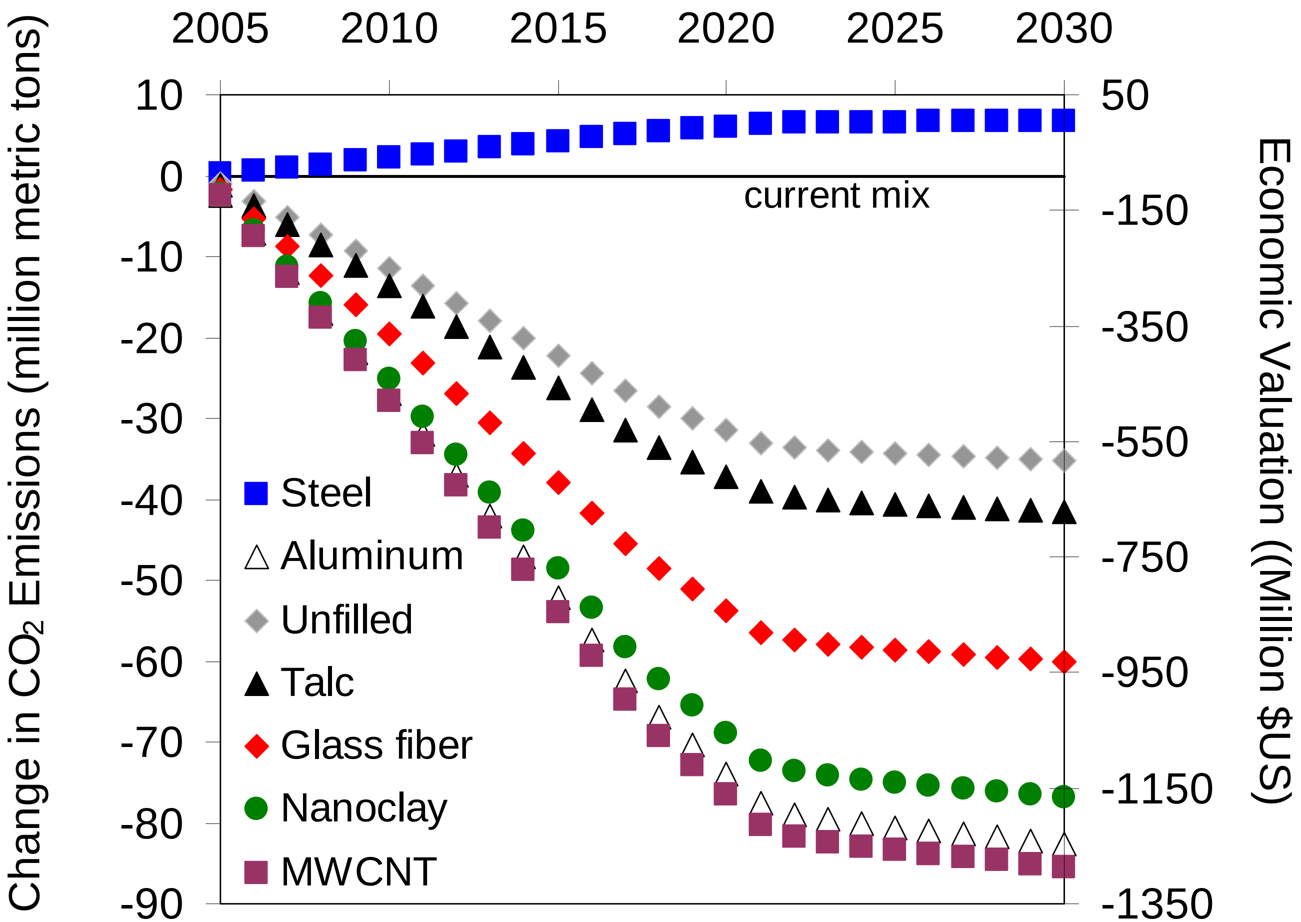


Value to Producers/Consumers



Social Value

(using $15/tC)



Assessment of LCA Framework

Incorporated:

- multiple LCA models.
- technology forecasting to extend beyond current products.
- valuation techniques to extend beyond environmental inventories.
- expert elicitation to characterize expected impacts.

Established a framework that can be used to:

- make more informed decisions throughout R&D.
- compare current products to those expected from emerging technologies.
- help address public concerns about emerging technologies.

Contributed:

- a new approach for performing anticipatory LCA.

Assessment of LCA Framework

Available Information

- General LCA Modeling
- Prospective LCA Modeling
- Nanotechnology LCA Modeling

Available Information

General LCA Challenges

- Data management and access
- Uncertainty in deterministic LCA
- Transparency
- Time requirements
- Incorporating into nanotechnology risk analysis
- Collaborative design
- Spatial considerations
- Linear relationship
- Occupational safety and health

Available Information

Prospective LCA Challenges

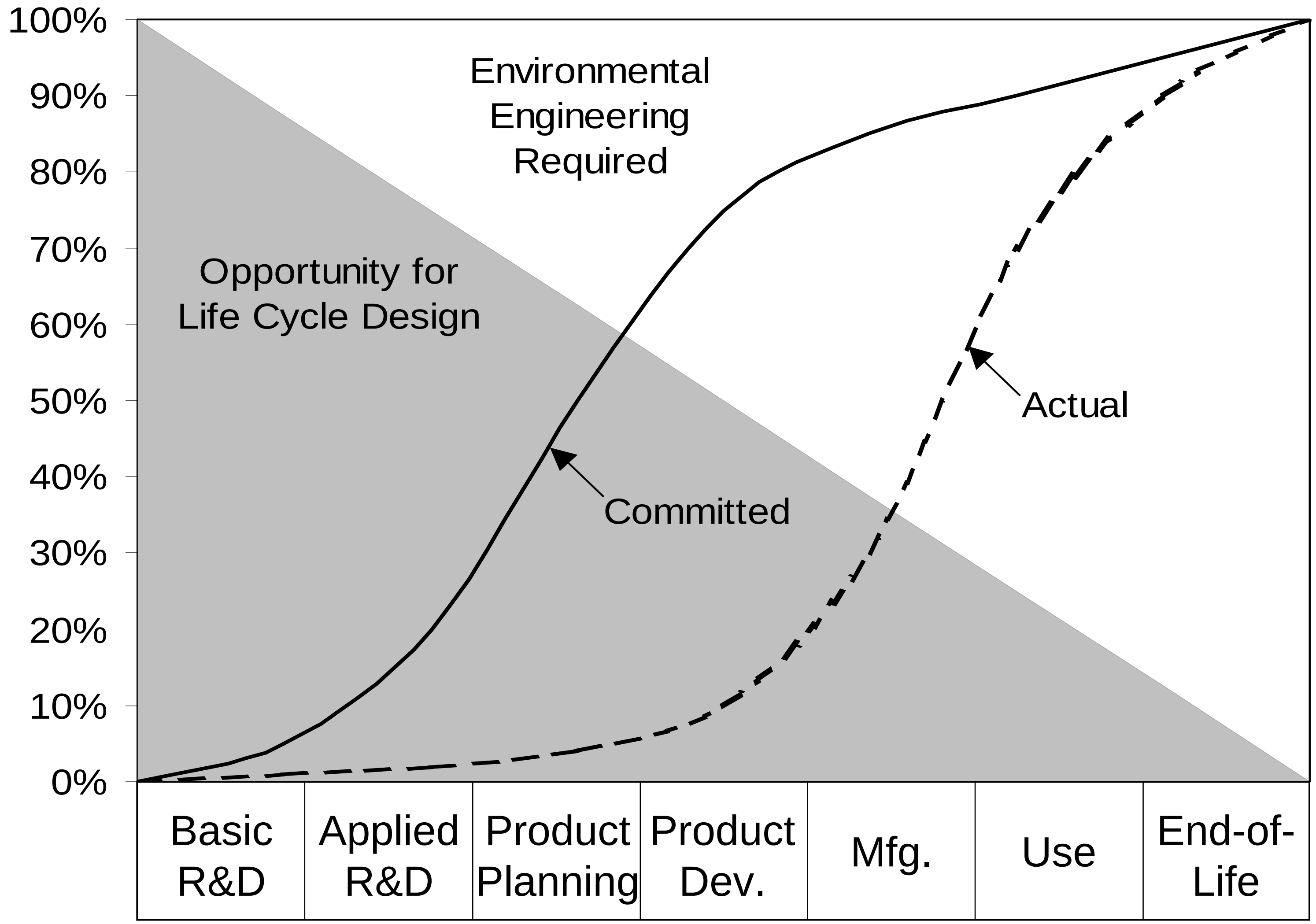
- Defining relevant future states
- Incorporating learning curves
- Technology adoption
- Technology interactions
- Forecasting life cycle processes and activities
- Radically different technologies
- Gap between scientific knowledge and understanding of environmental and human

Available Information

Nanotechnology LCA Challenges

- Establishing an inventory for nanomaterials and nanoprocesses
- Determine if risks are qualitatively/quantitatively different

Incorporating LCA product life cycle



Incorporating LCA in nanotechnology risk assessment