Assessment of Materials and Process Options within Cascaded Systems: A Case Study

Elizabeth Williams[1,2], Warren Mellor[1,2], Gary Stevens[1] Adisa Azapagic[2] & Roland Clift[2]

Polymer Research Centre[1] and School of Engineering in the Environment[2], University of Surrey, Guildford, Surrey. GU7 5XH

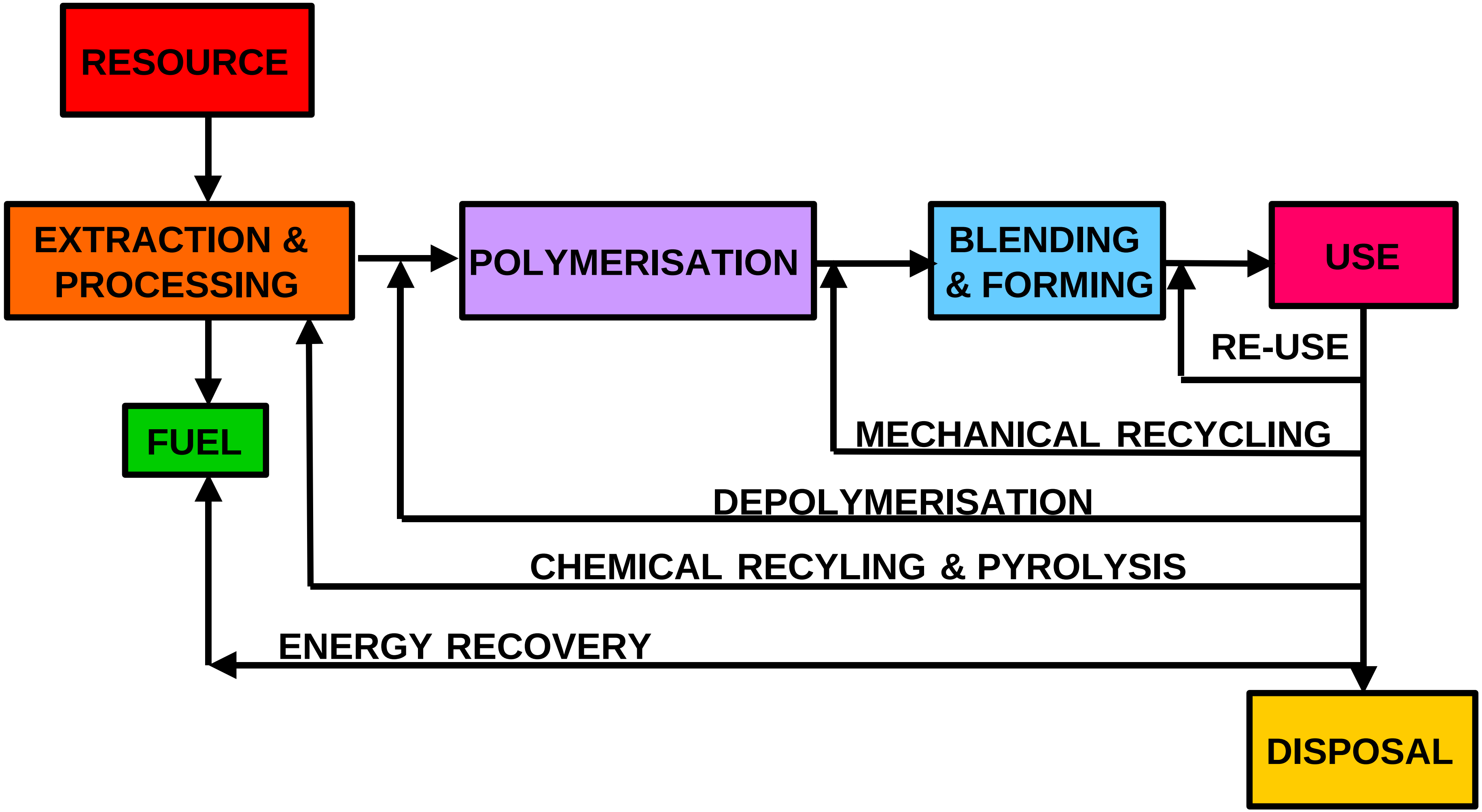
Background

- EC EOL vehicles directive may suggest recycle rates of 85% by 2005 and 95% by 2015
- Glass represents 4% by wt of a car and will be within the scope of this legislation.
- PVB is the interlayer used in laminated car windshields and currently there are no applications available for the recyclate.
- Imminent legislation is driving the research to look at alternative “recyclable” interlayers
- Decisions must be based on technical and economic grounds as well as environmental considerations.
- This highlights a need for a multi-attribute decision making tool

Methodology

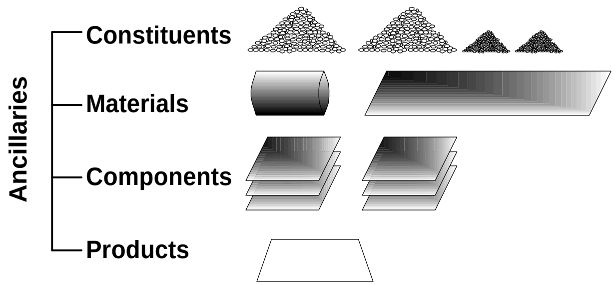
- The methodology has been developed under a UK EPSRC DTI-LINK Project
- The methodology will deliver a decision tool called CHAMP
- Prime objective is to identify optimum re-use and recycling routes for polymer materials
- Based on Life Cycle thinking but also addresses technical and economic criteria.
- This has been developed another stage further and focuses on Life Cycle Product Design (LCPD) and cascaded use of materials.
- Also offers the ability to optimise the available options.

Industrial Ecology of Polymers



Methodology

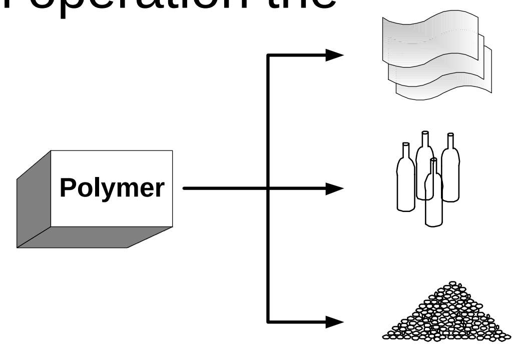
- **Approach:**
  - Model the flow of materials through a series of operations and processes throughout the life cycle of the material.
  - The methodology allows the existing process to be modelled explicitly and full logistics to be included.
- **Mass flows considered in this framework**
  - polymer
  - non-polymer



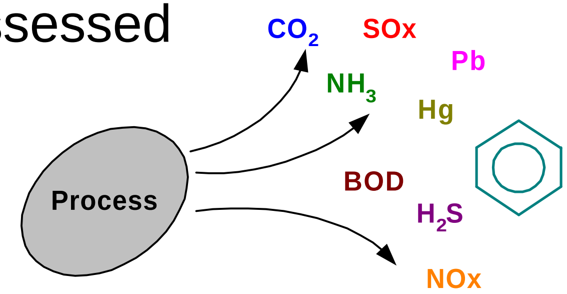
- **Cascaded Materials**
  - Opportunities for re-use and recycling can be identified
  - Suitable options are identified using several criteria
  - These options can be optimised

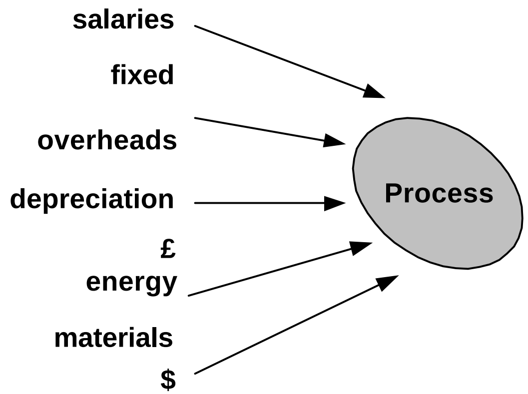
Methodology Overview

- **Utilities**
  - *u=(thickness, colour, impact strength, melting point, …,* u_n*)*
- **Operations & Processes**
  - As a mass flow member passes through an operation the utilities will be changed.
  - operation functions can be modelled and used to predict optimal cascade options.



- **Environmental & Economic**
  - both criteria assessed

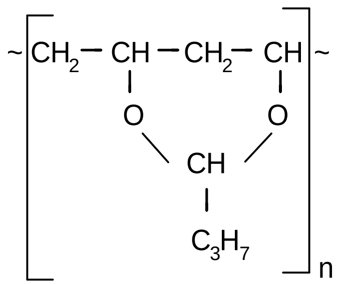




The Case Study

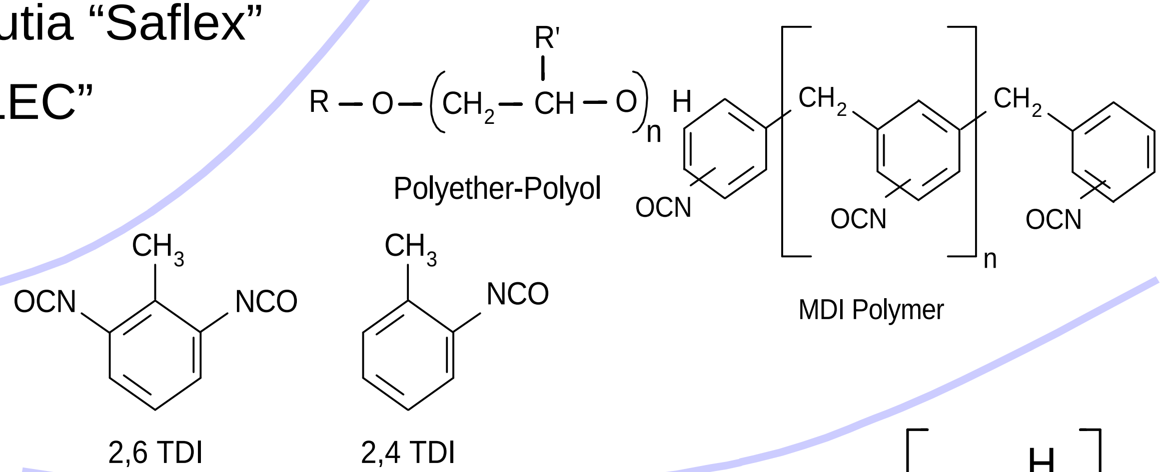
- **Purpose: To develop and improve the CHAMP methodology**
- **Looked at the existing windshield manufacturing process and waste disposal methods**
- **Looked at four different polymers and compared any changes in environmental, technical and economic performance in the first life cycle**
- **The study has moved onto focus on cascaded use.**
- **First case study of a series of six which will be used to refine and develop the methodology. Other case studies include:**
  - Fibre optic & copper datacom cables
  - Bottles & packaging waste
  - Electronic equipment and components

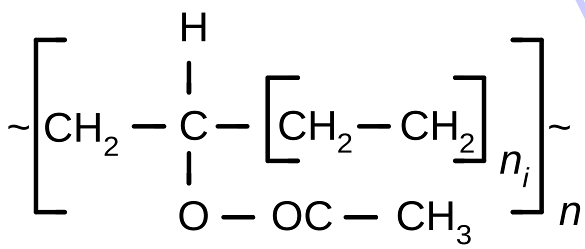
Polymers Under Analysis



Poly Vinyl Butyral: DuPont "Butacite", Solutia "Saflex" or Sekisui "S-LEC"

Polyurethane: Morton "PE192"



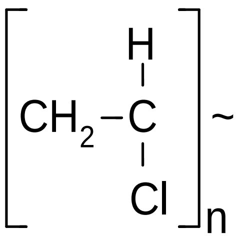


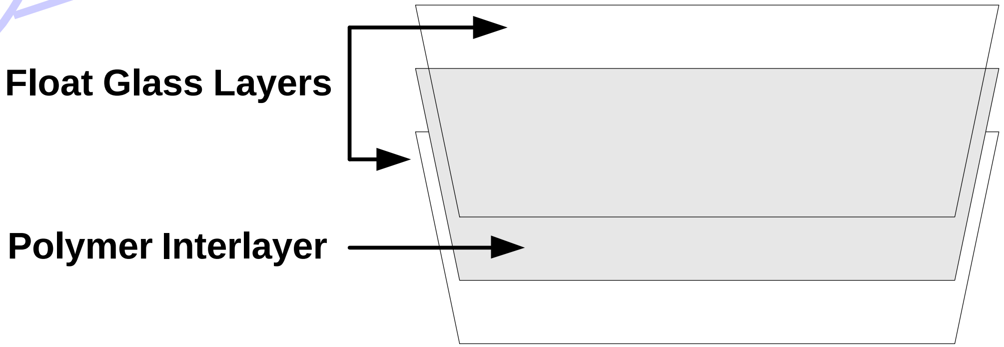
Ethylene Vinyl Acetate

where n_i = approx 140

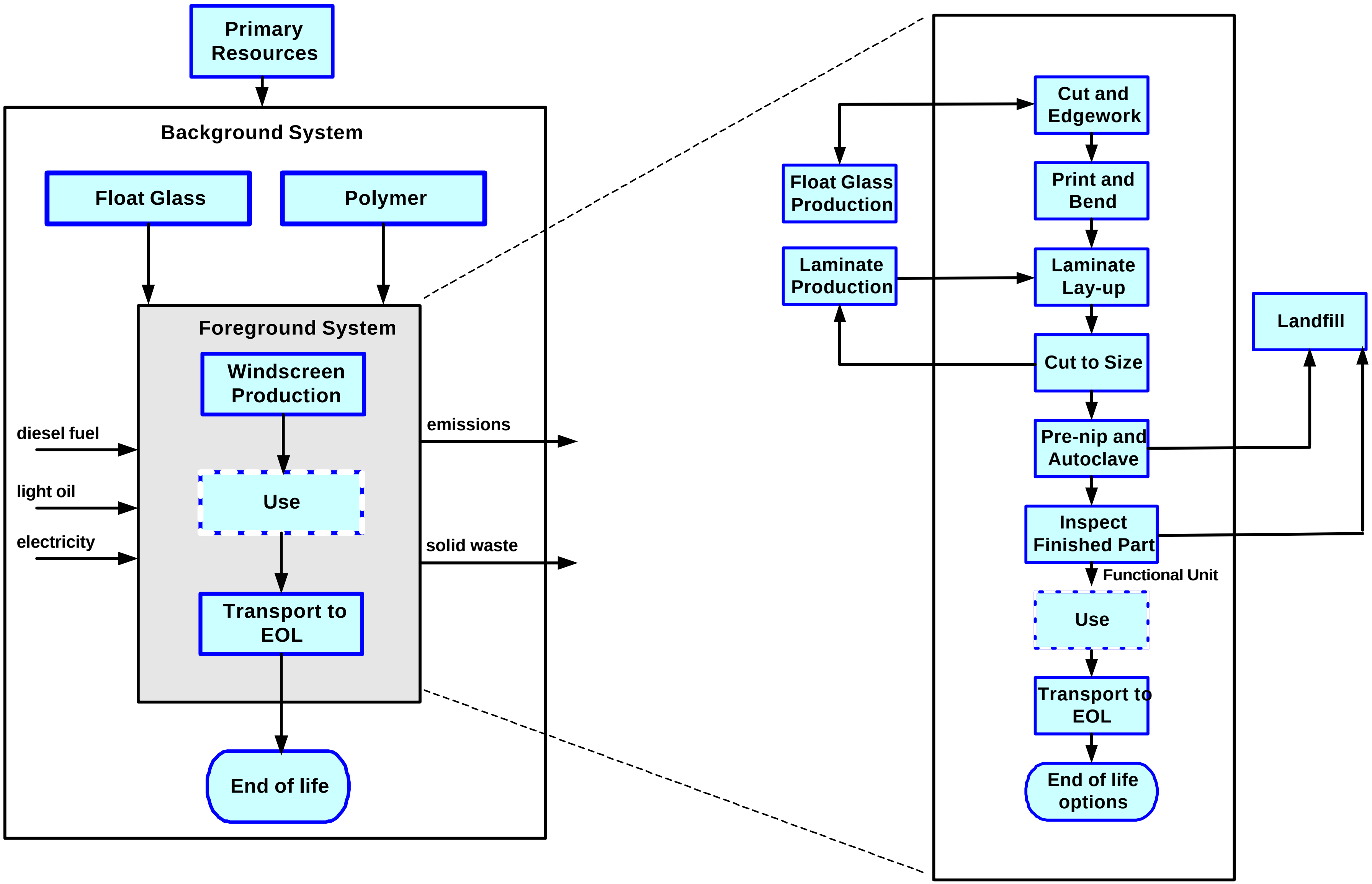
Ethylene Vinyl Acetate: Bridgestone "EVASafe"

Polyvinyl Chloride: Sekisui "Neomute"

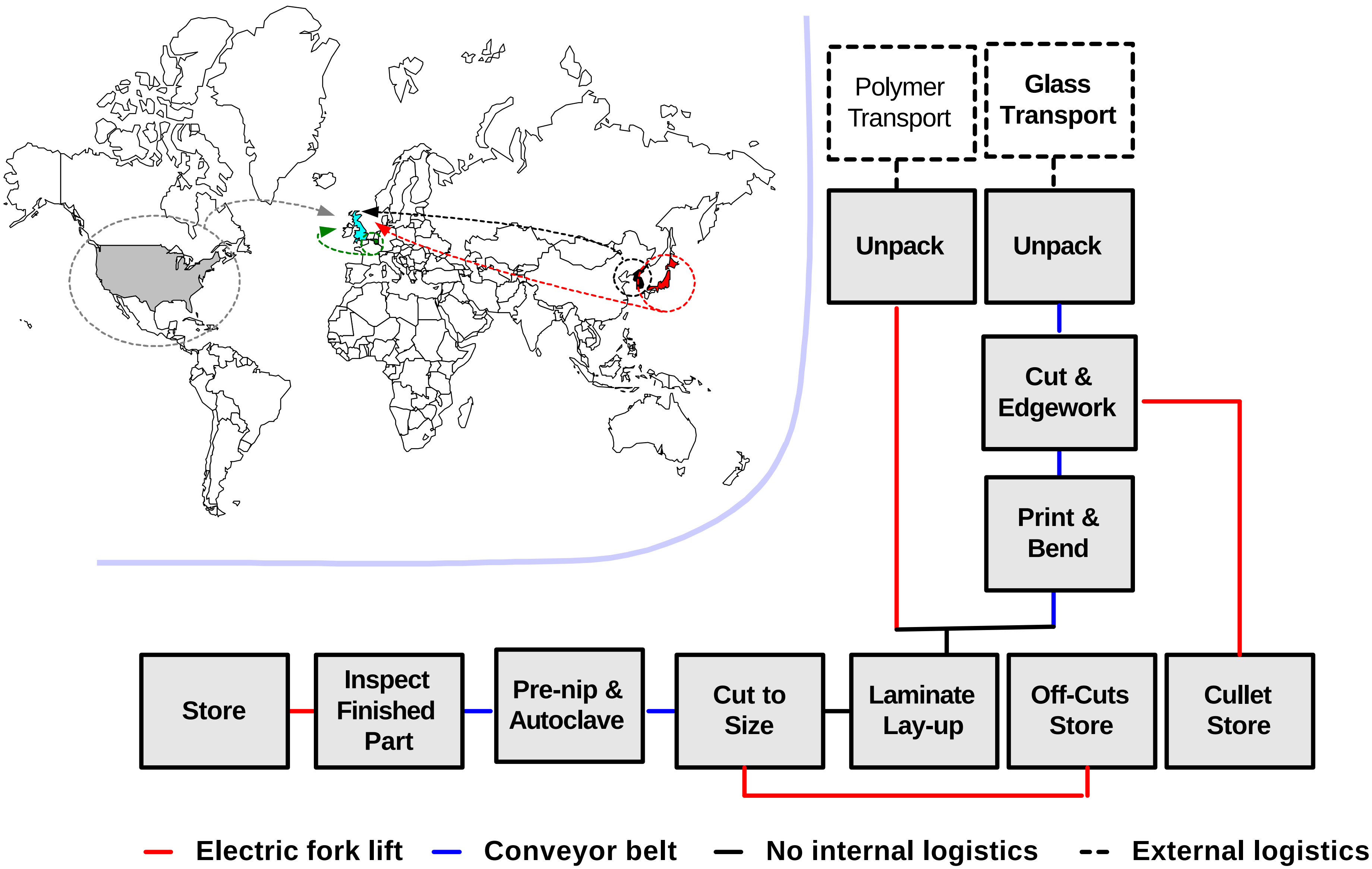




Background & Foreground



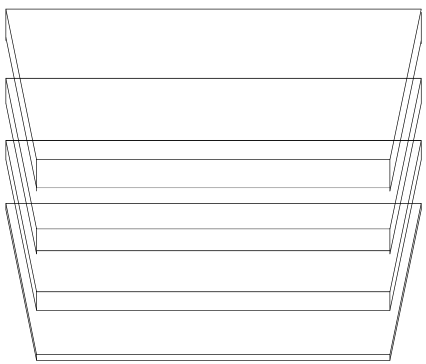
Logistics



Polymer Transport
Glass Transport
Unpack
Unpack
Cut & Edgework
Print & Bend
Store
Inspect Finished Part
Pre-nip & Autoclave
Cut to Size
Laminate Lay-up
Off-Cuts Store
Cullet Store
Electric fork lift
Conveyor belt
No internal logistics
External logistics

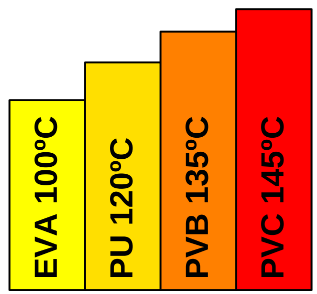
Technical Analysis

- **Utilities and Key Utilities**
- **Utilities which the polymer needs to possess:**
  - haze
  - brittle point
  - glass-plastic adhesion
  - UV stability
  - Penetration resistance
- **All four polymers meet these requirements**
- **Differences - thickness & energy input**

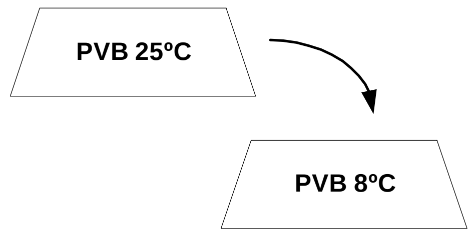


] EVA	1.00mm	0.93kg
] PVC	0.76mm	1.03kg
] PVB	0.76mm	0.84kg
] PU	0.45mm	0.50kg

- Autoclave



- Refrigeration



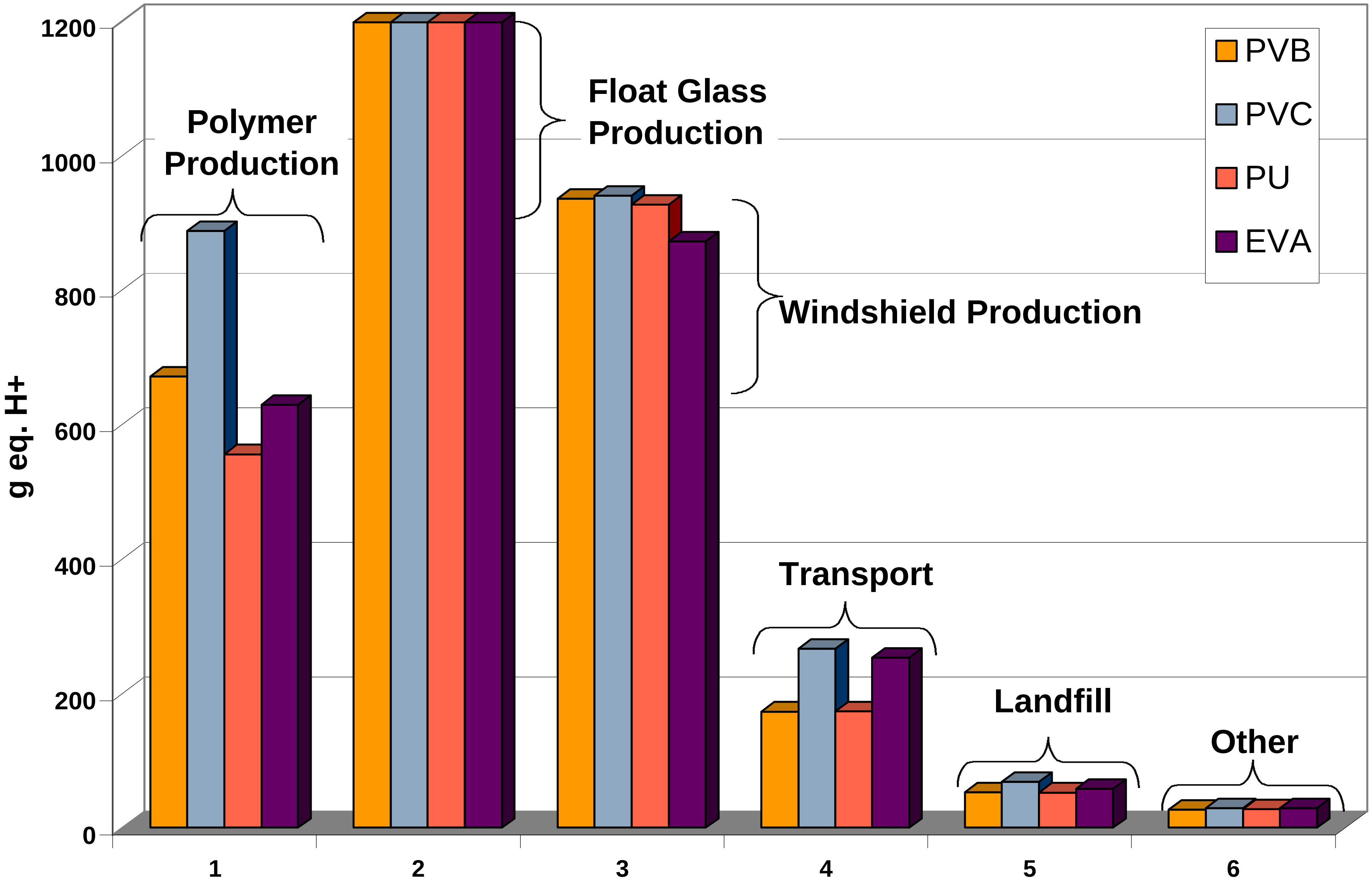
Life Cycle & Impact Assessment

- **Carried out a LCA from Cradle to Grave on all polymer interlayers within the existing system in addition to the glass.**

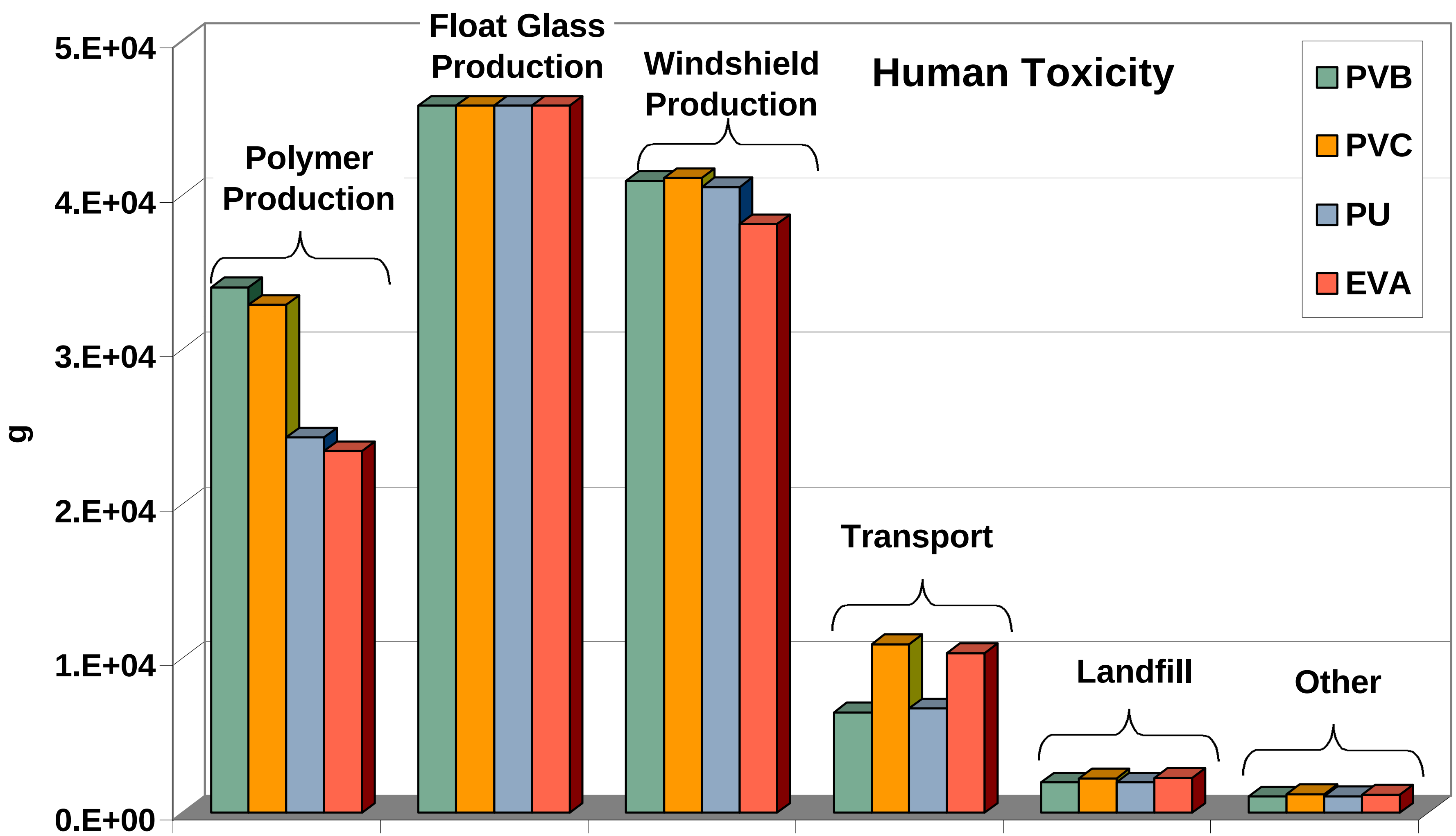
- **Assumptions**
  - Energy input is a UK mix for windshield manufacture.
  - 30% waste glass & polymer is produced during cutting and is recycled internally.
  - 2% of finished product rejected after inspection.
  - Changes in operating conditions were within the specification of the machinery.
  - Logistics of the dismantlers, landfill site & recyclers are equal.

- **Concentrated on the following indexes**
  - Air Acidification
  - Toxicity - Aquatic, Human and Terrestrial
  - Eutrophication - Total and Water
  - Greenhouse Effect
  - Depletion of Non-Renewable Resources
  - Ozone Layer Depletion

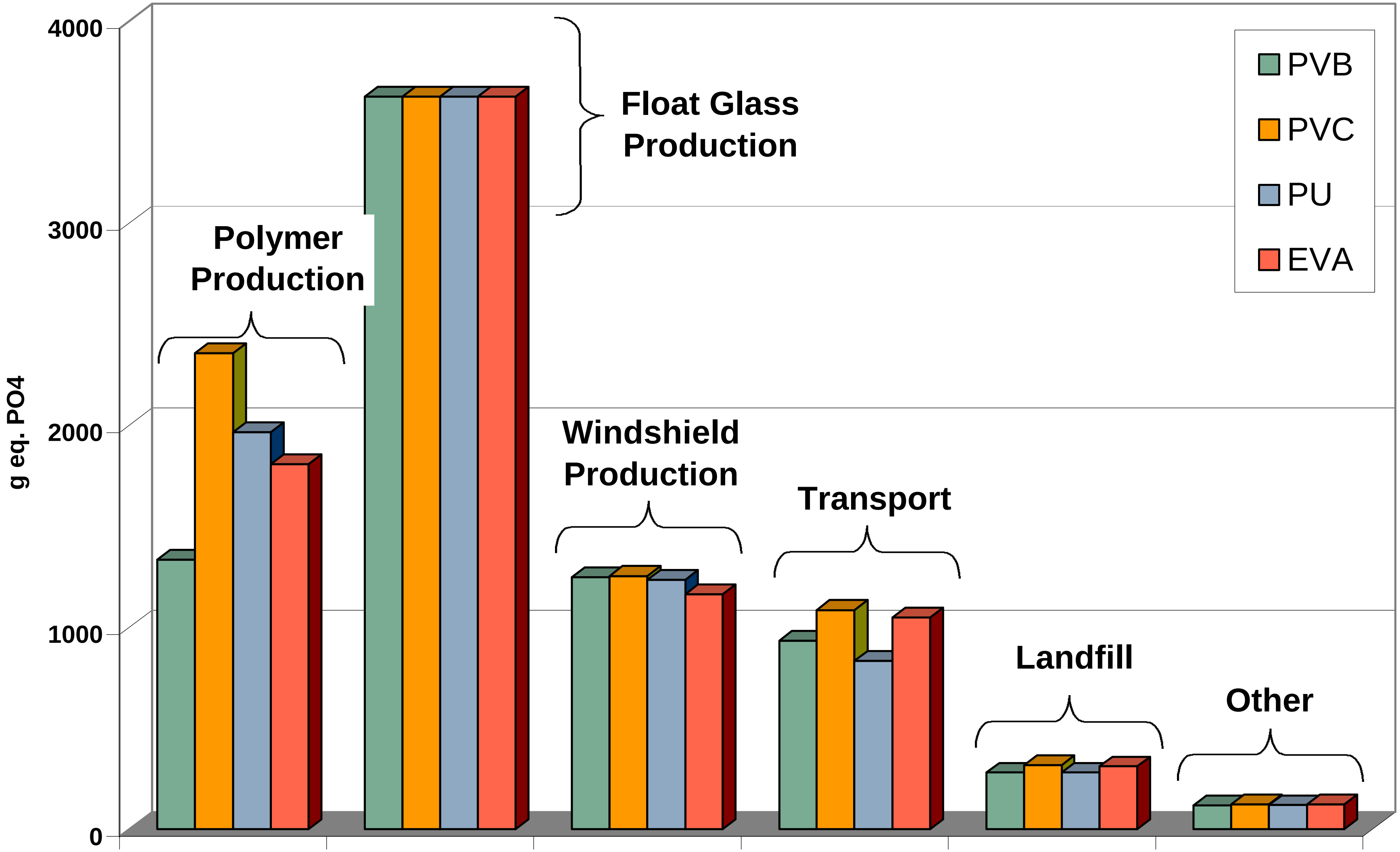
Air Acidification



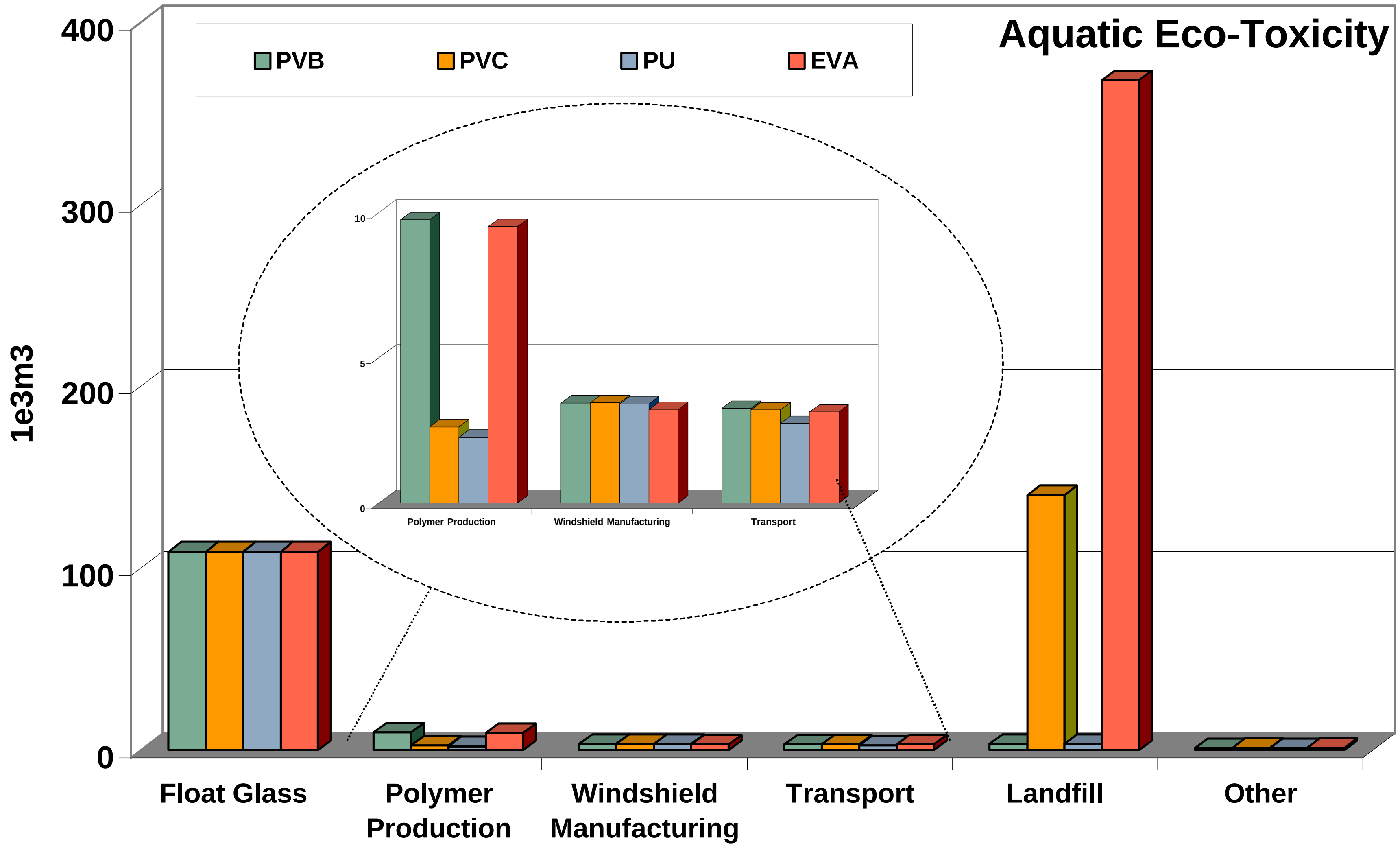
Human Toxicity



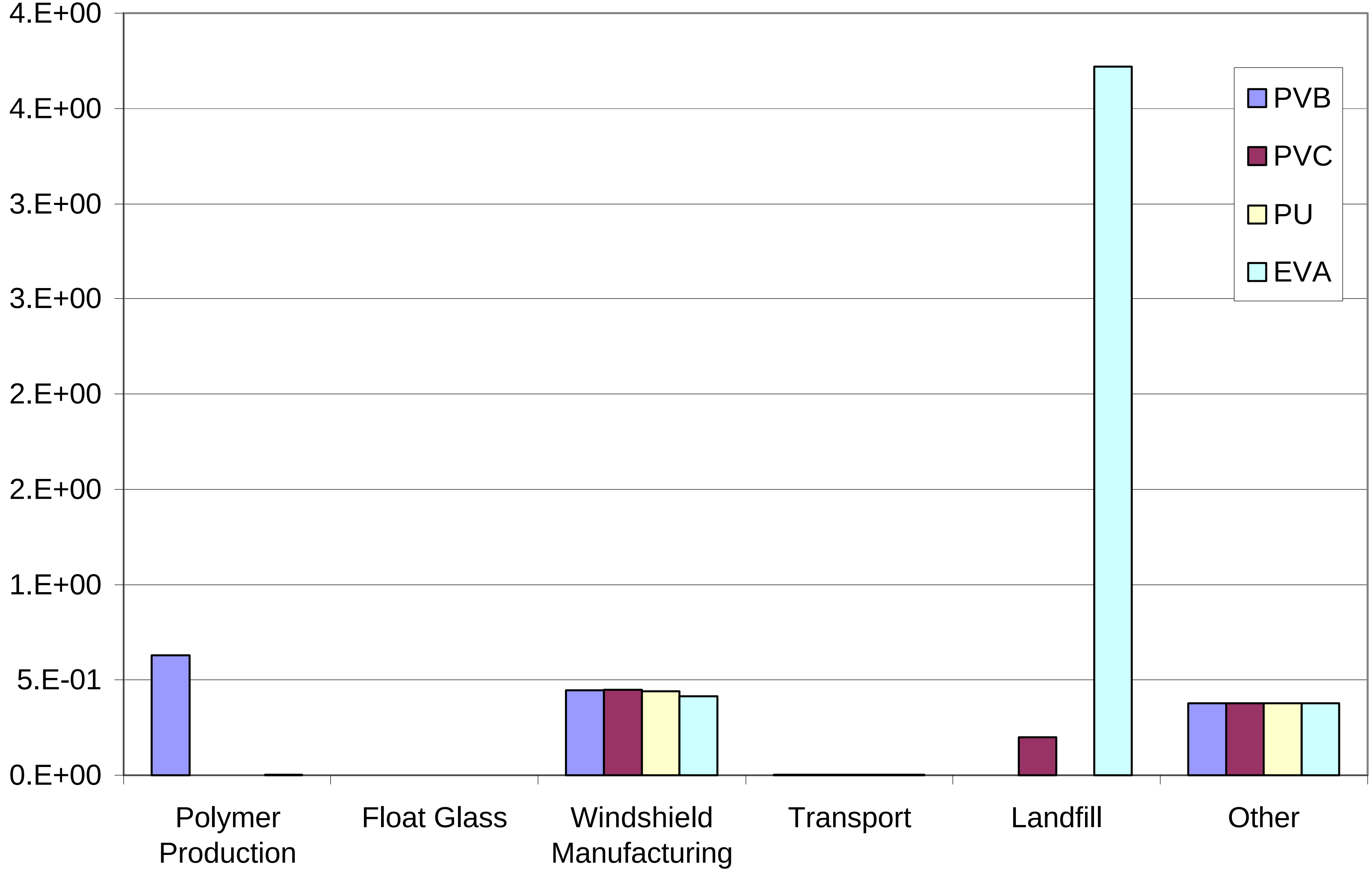
Eutrophication



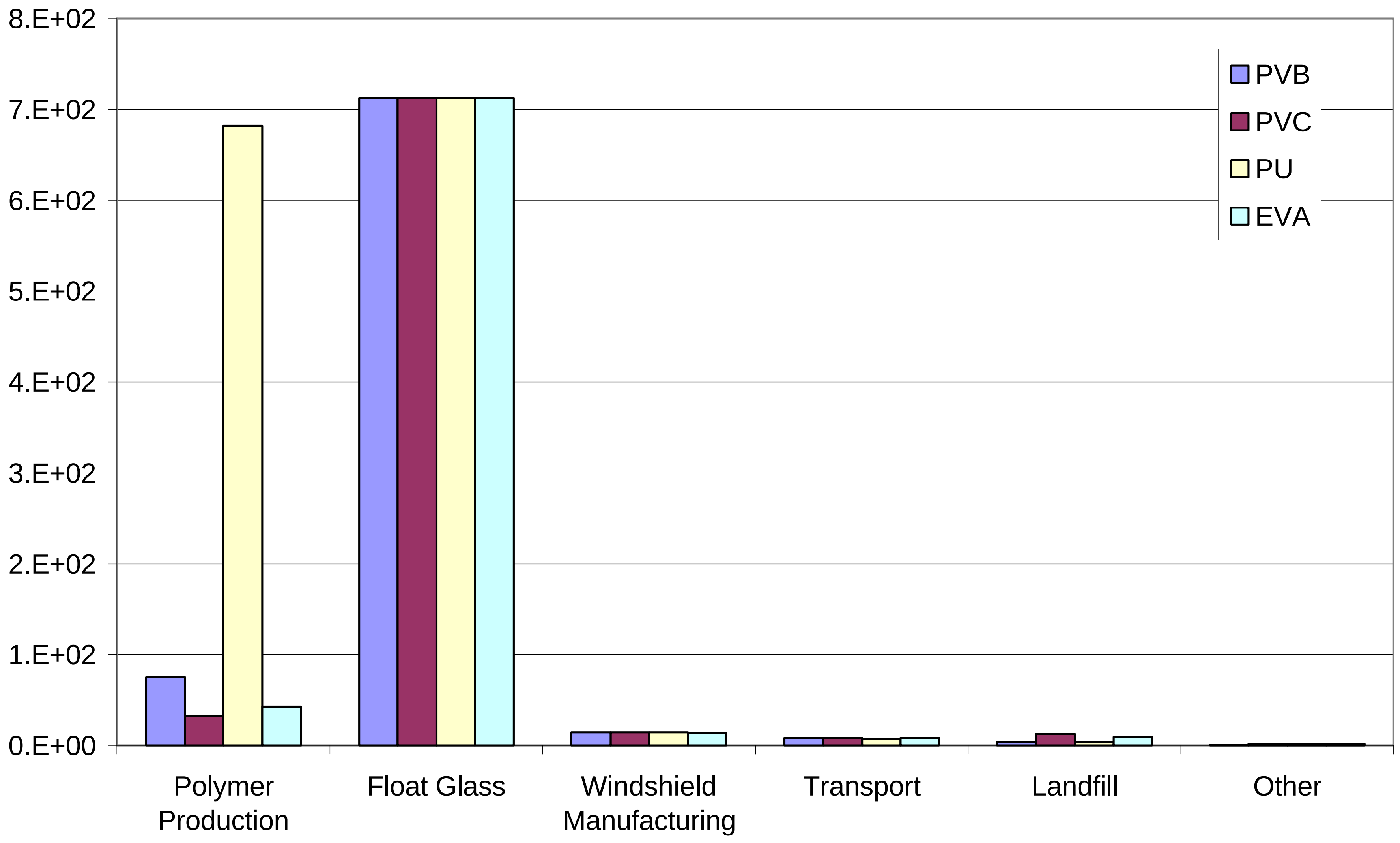
Aquatic Eco-toxicity



Terrestrial Eco-toxicity

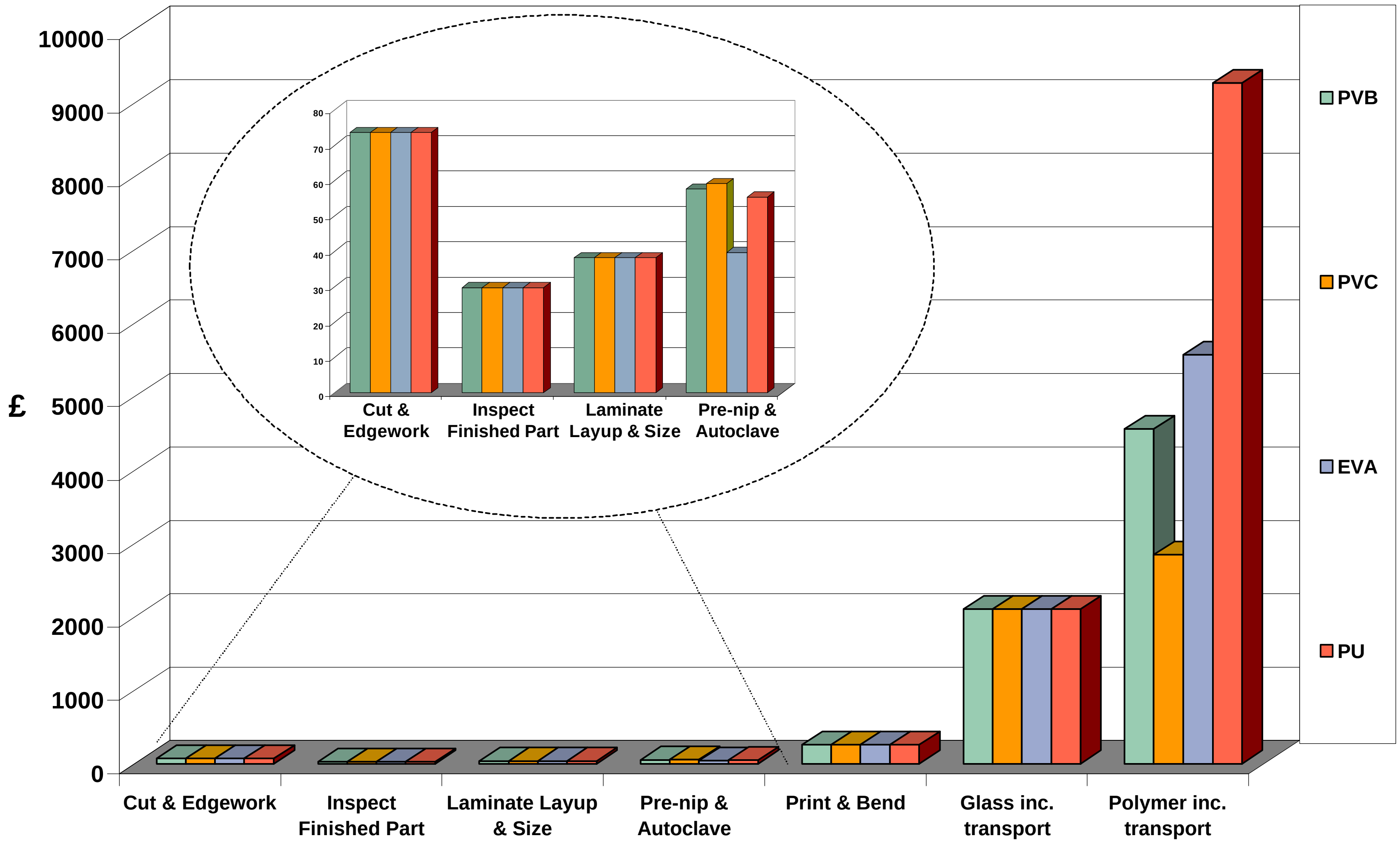


Eutrophication (Water)



Economic Analysis

- Costs of energy into foreground operations plus material costs.
- Polymer cost is the most significant
- Transport is an important contributor to cost



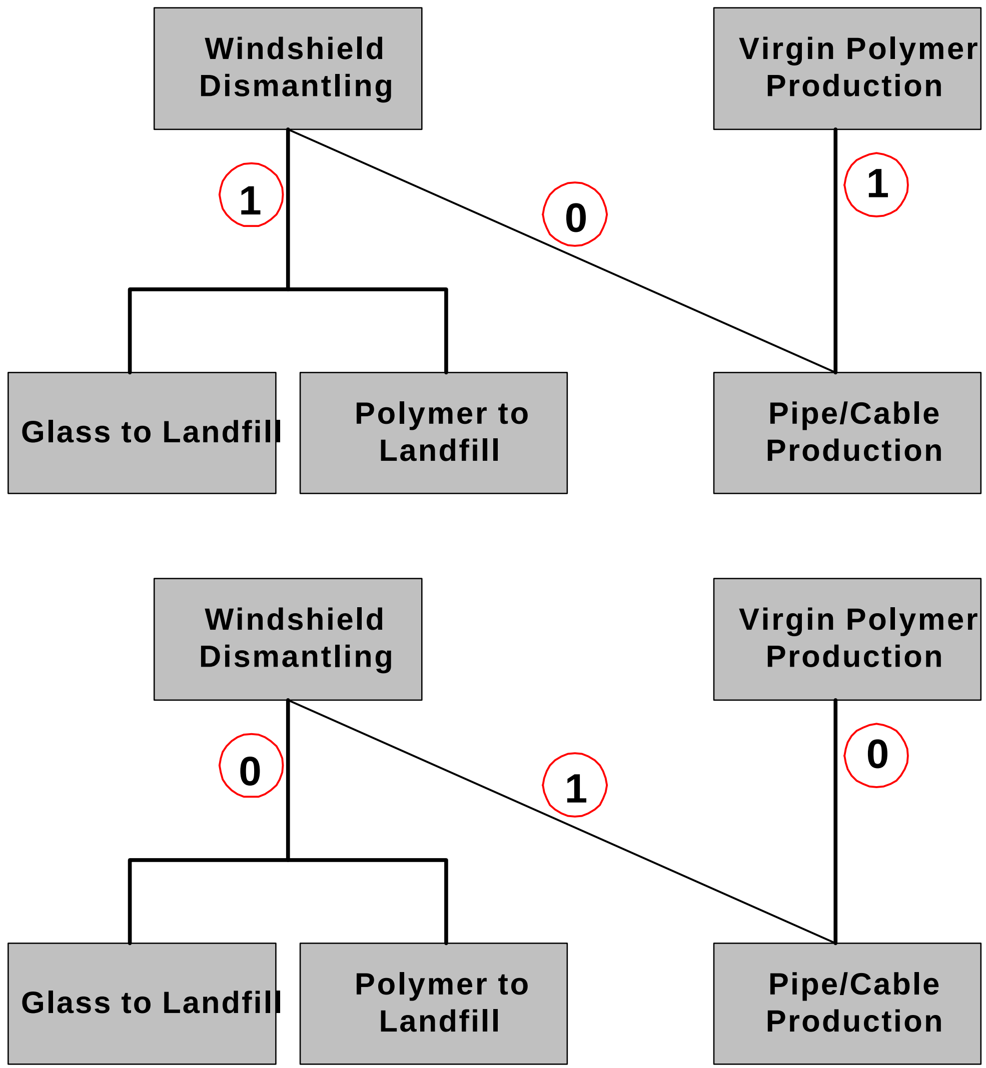
Cascaded Systems

- **Specification from the windshield dismantler**
  - energy requirements to dismantle
  - % purity => utilities

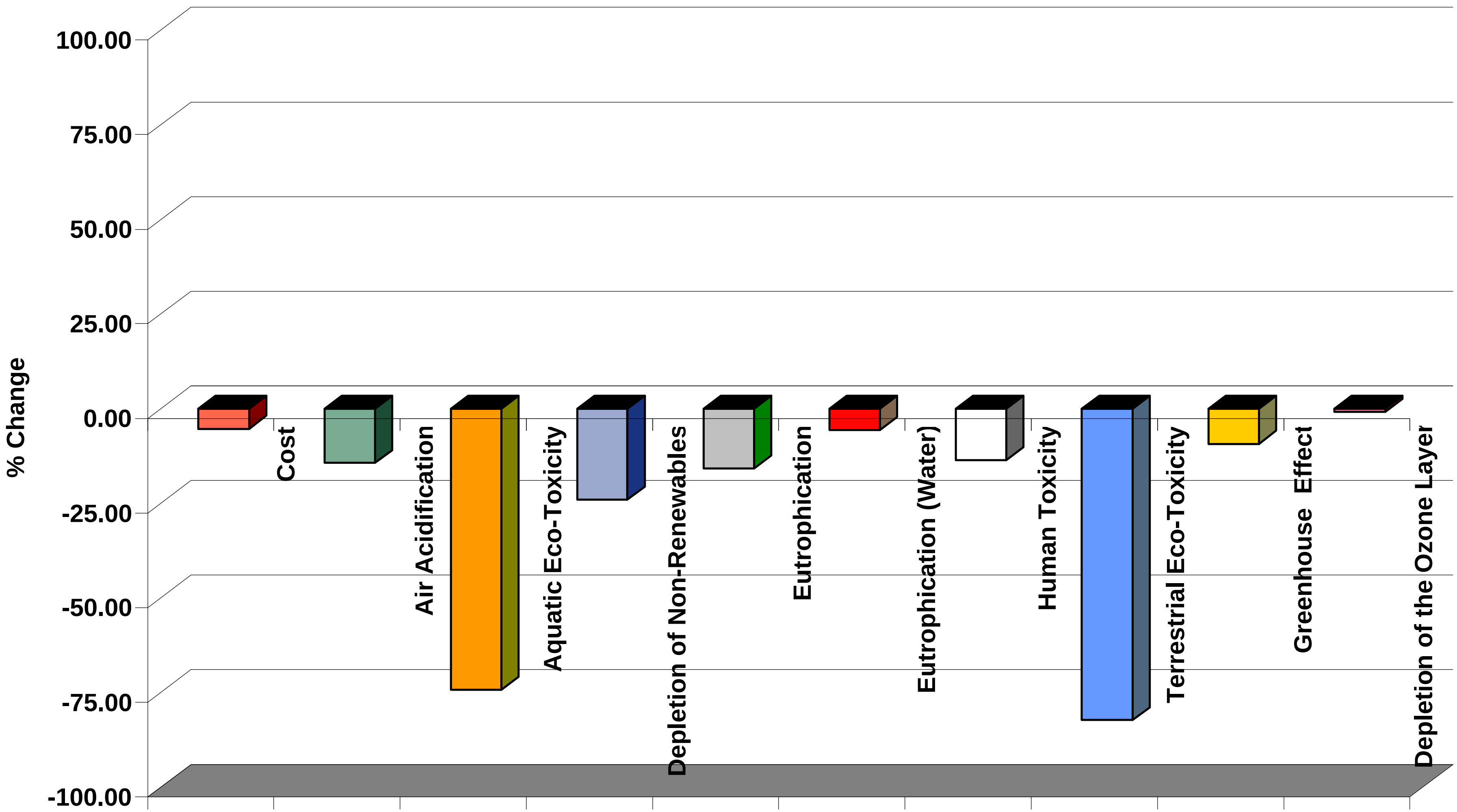
- **Compare these utilities with specifications for other applications**
  - PVC pipes
  - EVA cable jacketing
  - PVB and PU not matched

- **Re-run LCA and economic analysis comparing cascaded use vs. virgin polymer**

Cascaded System Assessed



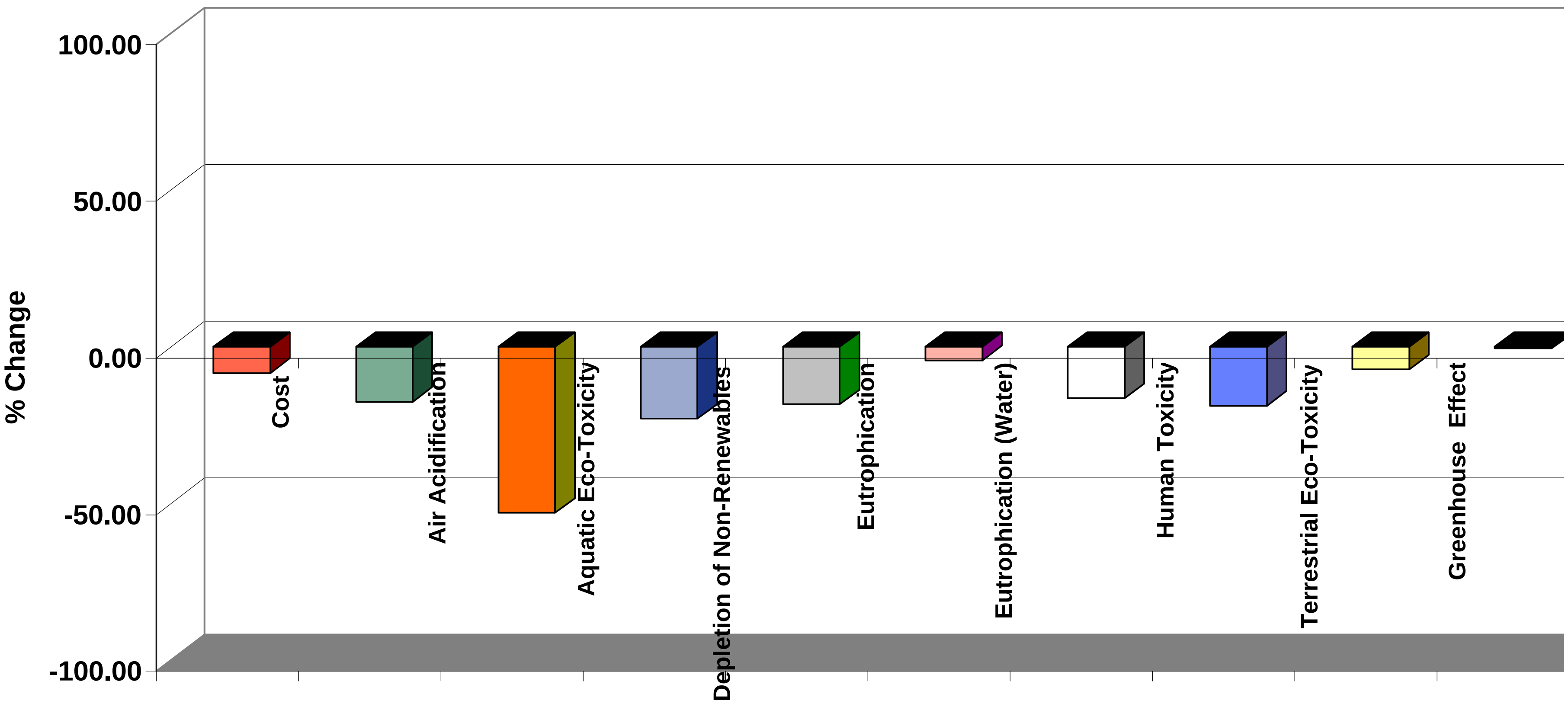
Impacts of Cascaded Use - EVA



Impacts of Cascaded Use - EVA

	Virgin Polymer	Cascaded Use	% Change
Cost (£)	8780.17	8315.17	-5.30
Air Acidification (g eq. H+)	3531.67	3024.61	-14.36
Aquatic Eco-toxicity (1e3m3)	503.73	129.68	-74.26
Depletion of non renewable resources (frac. of reserves)	4.19E-11	3.19E-11	-24.03
Eutrophication (g eq. PO4)	9471.09	7973.89	-15.81
Eutrophication (water) (g eq. PO4)	828.49	781.82	-5.63
Human Toxicity (g)	1.39E+05	1.20E+05	-13.60
Terrestrial Eco-toxicity (t)	4.52	0.80	-82.34
Greenhouse effect (direct, 100 years) (g eq. CO2)	2.86E+07	2.59E+07	-9.30
Depletion of the ozone layer (average) g eq. CFC-11	2.01	1.99	-0.84

Impacts of Cascaded Use - PVC



Impacts of Cascaded Use - PVC

Impact Category	Virgin PVC	Cascaded Use	% Change
Cost (£)	6148.32	5633.32	-8.38
Air Acidification g eq. H+	4413	3636	-17.60
Aquatic Eco-toxicity (1e3m3)	263	124	-52.98
Depletion of non renewable resources (fraction of reserves)	4.78E-11	3.68E-11	-23.01
Eutrophication (g eq. PO4)	11221	9151	-18.45
Eutrophication (water) (g eq. PO4)	810	775	-4.32
Human Toxicity (g)	1.72E+05	1.44E+05	-16.46
Odour (air) (m3)	3.31E+05	3.31E+05	0.00
Terrestrial Eco-toxicity (t)	1.07	0.87	-18.74
Greenhouse effect (direct, 100 years) g eq. CO2	2.87E+07	2.66E+07	-7.23
Depletion of the ozone layer (average) g eq. CFC-11	2.07	2.05	-0.60

Overall Conclusions

- All polymers have a high impact on the environment in one or more categories.
- Glass is a significant contributor.
- PVC shows less economic impact than other interlayers.
- PVC and EVA both show a greater potential for recycling within the first cascade.
- Expect differences in multiple recycles - future work will focus on the maximum achievable cycles.
- Optimisation of all materials and criteria will increase decision making ability
- Case study illustrates the potential of the methodology to assess technical, economic and environmental impacts together.