An Introduction to Input-Output LCA Theory and Methodology, its Strengths and Weaknesses and a Comparison between Input-Output LCA and Process LCA

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My Assumptions

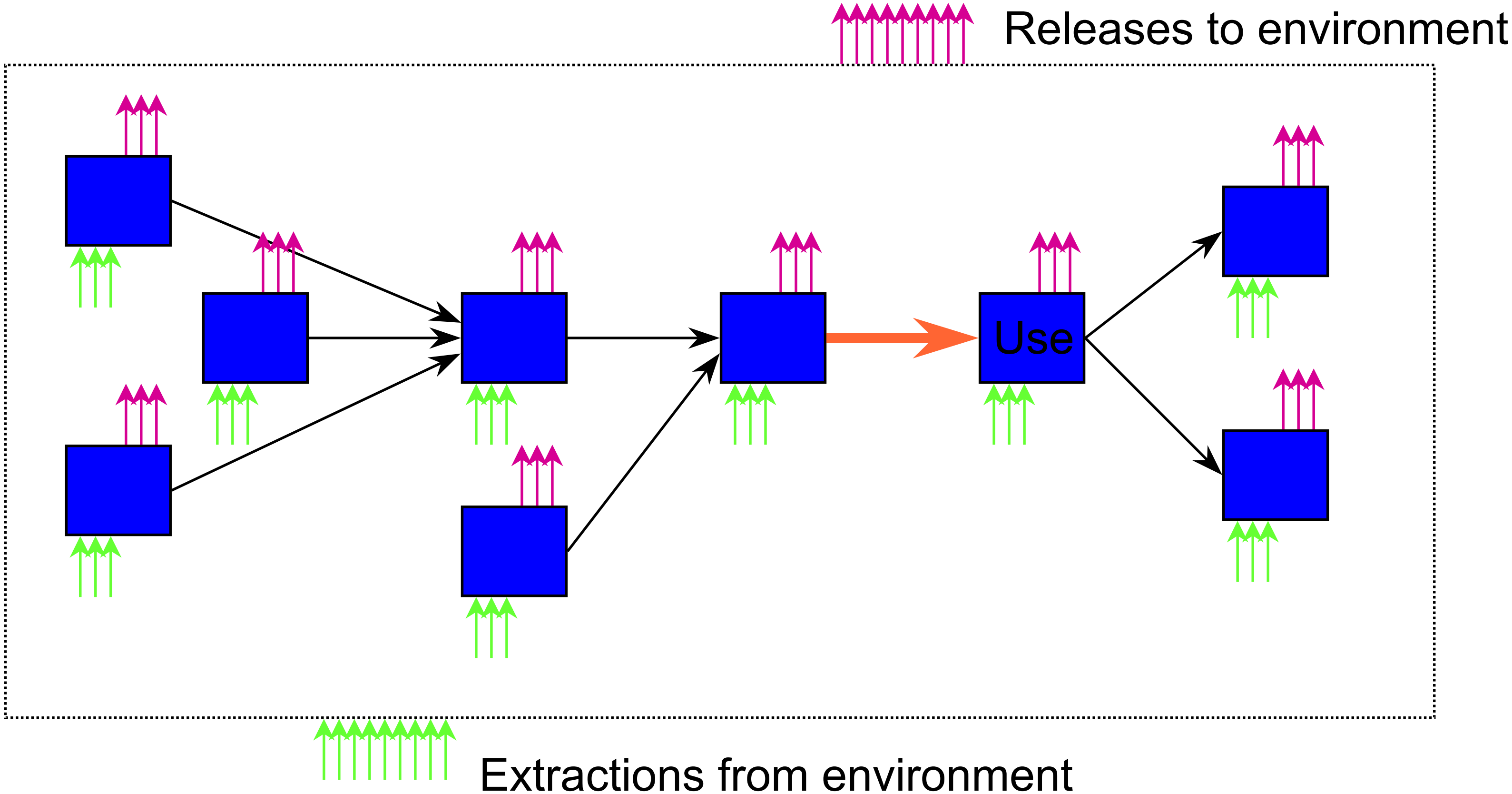
- Know Process LCI
- Know enough about IO-LCI to be interested

- “How do PLCI and IO-LCI *‘inputs’* differ?”
  - Methods
  - Data sources
  - Assumptions
- “How does IO-LCI work?”
- “How do PLCA and IO-LCI *‘outputs’* differ?”
  - Results, conclusions, uncertainties
  - Applications

Outline

- Product LCI Reconsidered
  - Essentials
  - Matrix framing
- IO-LCI vis-à-vis Product LCI
- Differences
  - Data
  - Outcomes
- My Purposes:
  - Strip away misconceptions about differences
  - Focus on true remaining differences

Life Cycle Inventory Analysis



Unit Process defined

- ISO 14040: The level of detail at which life cycle inventory data are gathered.
  - Boiler
  - Coal steam power plant
- Note that PLCI databases usually report average data across a sample
  - Oil-fired industrial boilers
  - US coal steam power plants

Unit Process, PLCI

Data

PRODUCTS

Known outputs to technosphere. Products and co-products

Name	Amount	Unit

Known outputs to technosphere. Avoided products

Name	Amount	Unit

INPUTS

Known inputs from nature (resources)

Name	Amount	Unit

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit

OUTPUTS

Emissions to air

Name	Amount	Unit

Emissions to water

Name	Amount	Unit

Emissions to soil

Name	Amount	Unit

Solid emissions

Name	Amount	Unit

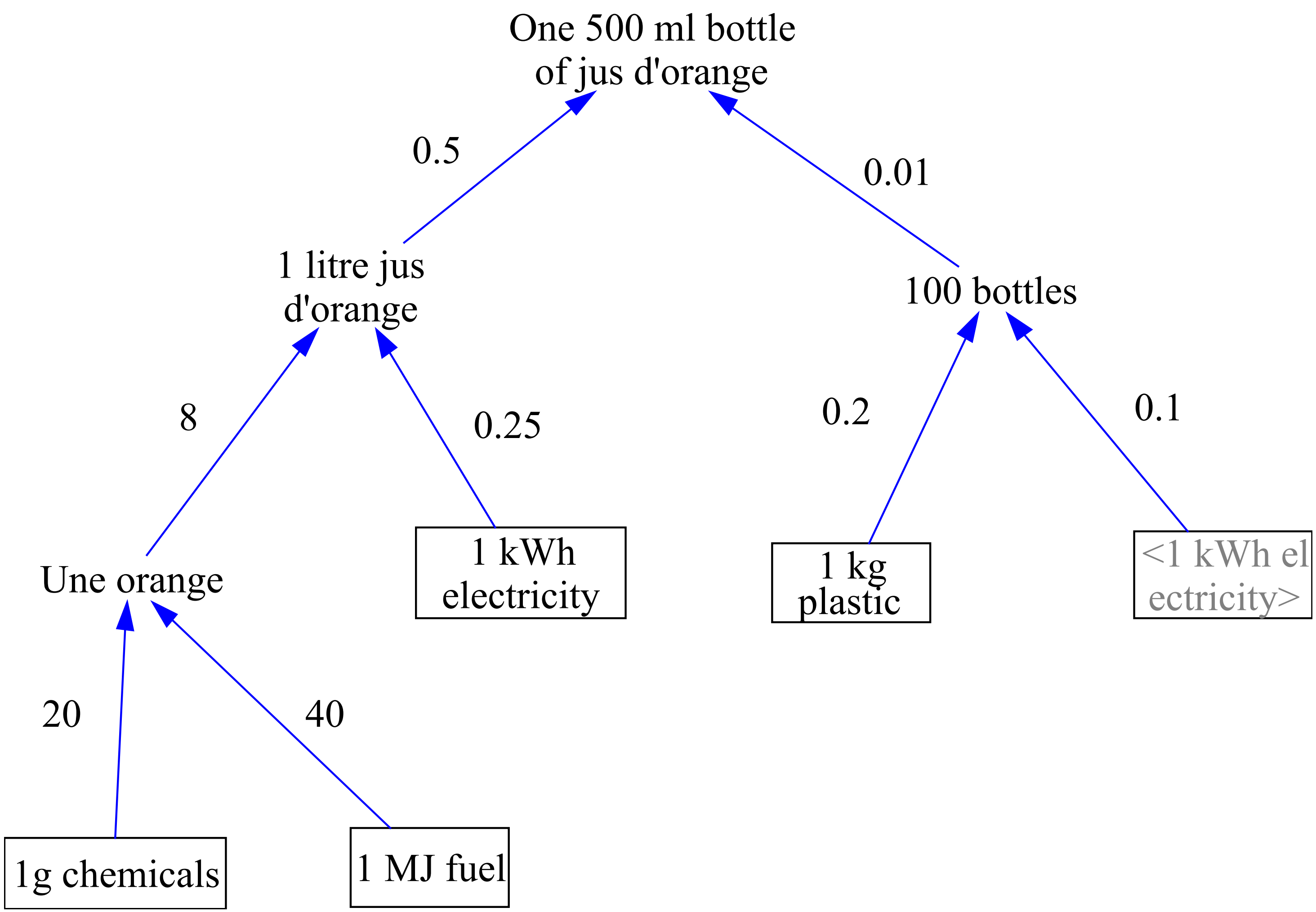
Non material emissions

Name	Amount	Unit

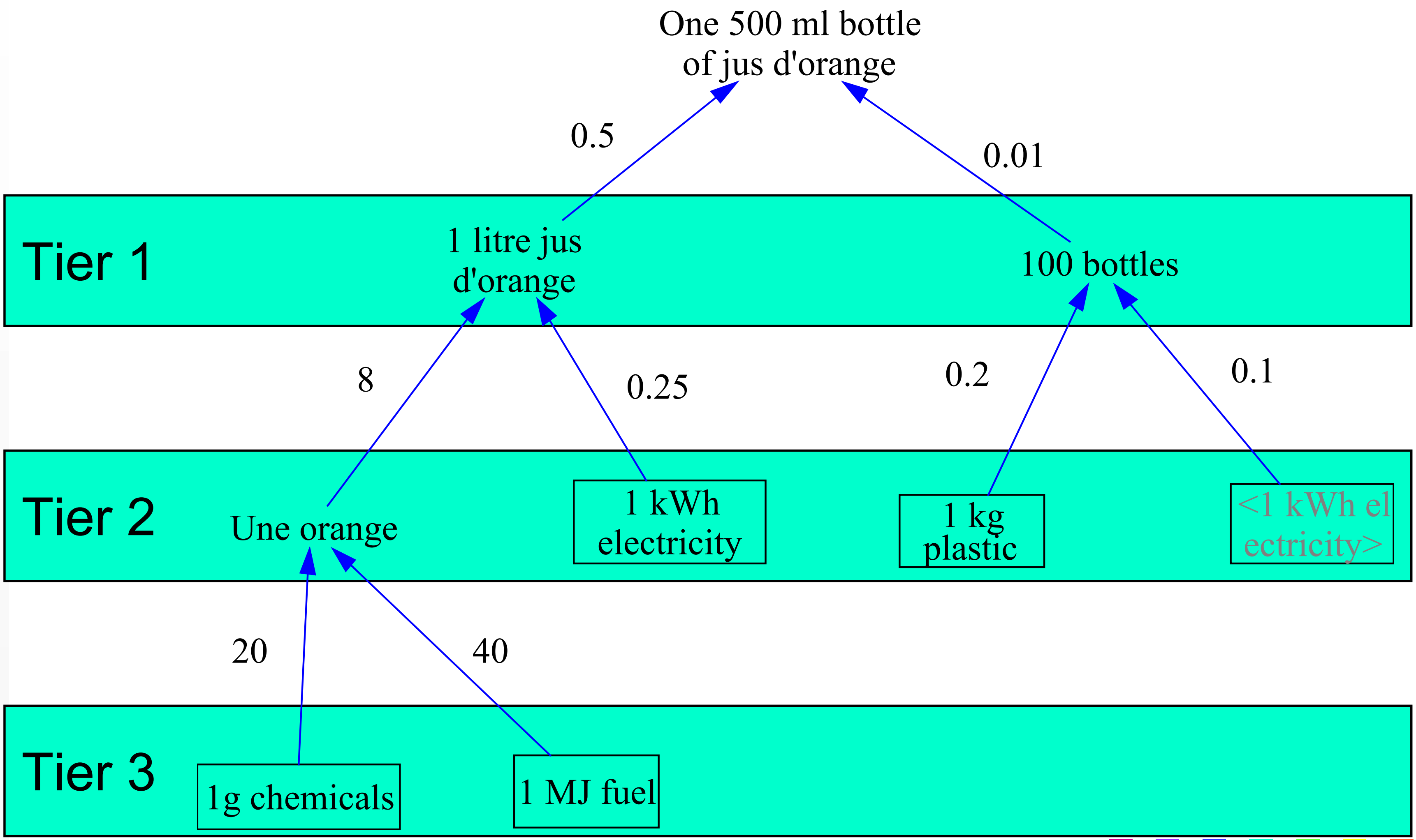
Known outputs to technosphere. Waste and emissions to treatment

Name	Amount	Unit

PLCI “Process Tree”



PLCI “Process Tree”



Assume for simplicity that each process has unit emissions of 1 kg / specified output.

We can solve for the LCI using a matrix formulation of the problem

$A =$

Result - Ind by Ind Direct Requirements

Mid Value of Ind by Ind Direct Requirements

Supplying Inds ☐ Totals

Using Inds ☐ Totals

	1 500ml bottle juice	1 liter juice	100 bottles	1 orange	1 kg plastic	1 g chemicals	1 kWh electricity	1 MJ fuel
1 500ml bottle juice	0	0	0	0	0	0	0	0
1 liter juice	0.5	0	0	0	0	0	0	0
100 bottles	0.01	0	0	0	0	0	0	0
1 orange	0	8	0	0	0	0	0	0
1 kg plastic	0	0	0.2	0	0	0	0	0
1 g chemicals	0	0	0	20	0	0	0	0
1 kWh electricity	0	0.25	0.1	0	0	0	0	0
1 MJ fuel	0	0	0	40	0	0	0	0

$$y = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Tier 1 output = Ay

Tier 2 output = $A(Ay) = A^2y$

Tier 3 output = $A(A(Ay)) = A^3y$

…

Total output $x = y + Ay + A^2y + A^3y + \ldots$

$x = (I+A+A^2+A^3+A^4+\ldots)x = (I-A)^{-1}y$

Also via: $x = Ax + y \rightarrow (I-A)x = y$

Output results

Result - Tierwise Reqts

mid

Mid Value of Tierwise Reqts

Supplying Inds ☐ Totals

Tier ☑ Totals

	0	1	2	3	4	5	6	Totals
1 500ml bottle juice	1	0	0	0	0	0	0	1
1 liter juice	0	0.5	0	0	0	0	0	0.5
100 bottles	0	0.01	0	0	0	0	0	0.01
1 orange	0	0	4	0	0	0	0	4
1 kg plastic	0	0	2m	0	0	0	0	2m
1 g chemicals	0	0	0	80	0	0	0	80
1 kWh electricity	0	0	0.126	0	0	0	0	0.126
1 MJ fuel	0	0	0	160	0	0	0	160

$$e \equiv \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$$

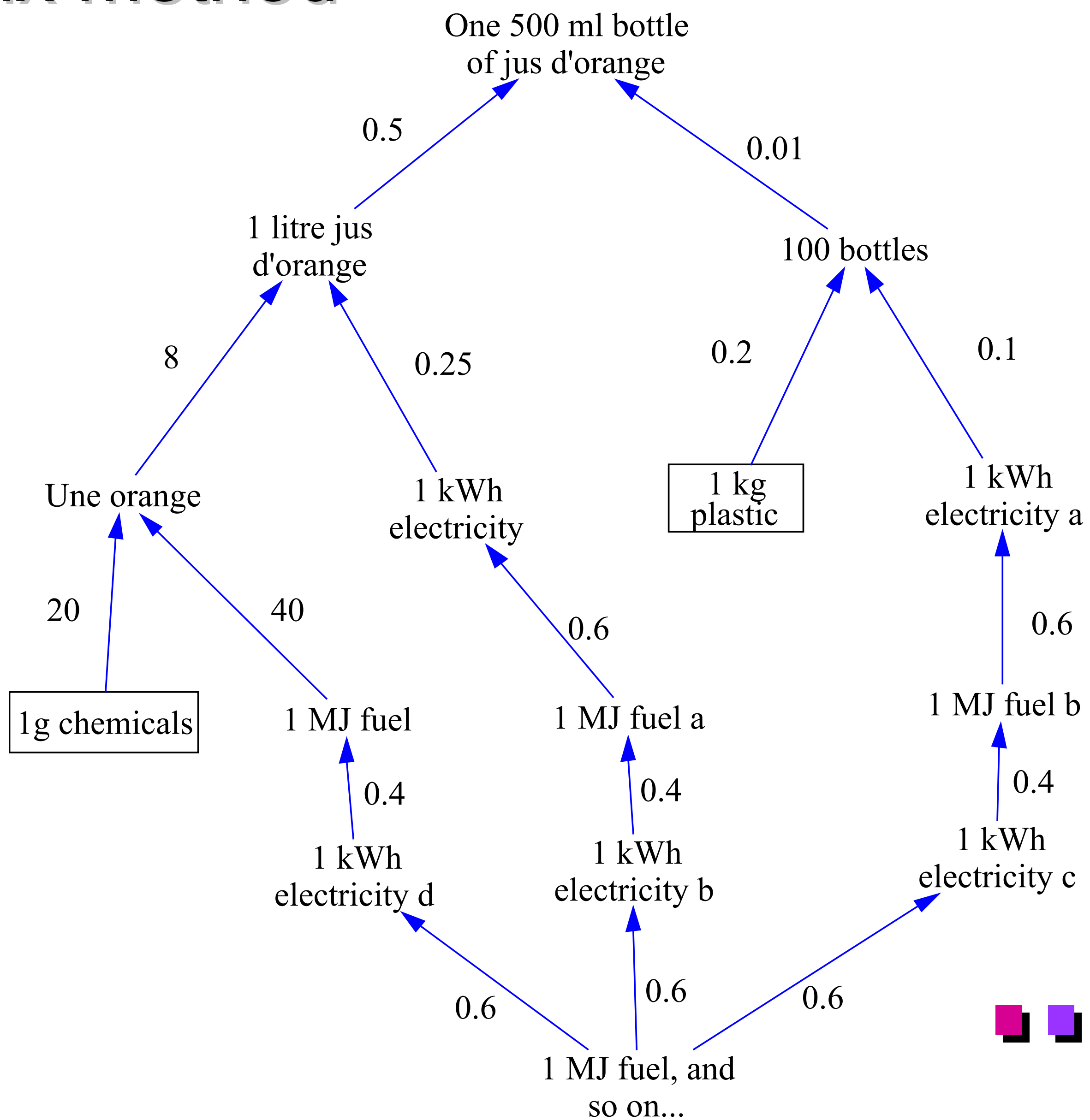
Tier 1 inventory = $e^T[Ay]$

Tier 2 inventory = $e^T[A(Ay)] = e^T[A^2y]$

…

Total inventory = $e^Tx = e^T(I-A)^{-1}y$

Process tree with loops… no difficulty for matrix method



$A =$

Edit Table - Ind by Ind Direct Requirements

Edit Table of Ind by Ind Direct Requirements

Supplying Inds

Using Inds

	1 500ml bottle juice	1 liter juice	100 bottles	1 orange	1 kg plastic	1 g chemicals	1 kWh electricity	1 MJ fuel
1 500ml bottle juice	0	0	0	0	0	0	0	0
1 liter juice	0.5	0	0	0	0	0	0	0
100 bottles	0.01	0	0	0	0	0	0	0
1 orange	0	8	0	0	0	0	0	0
1 kg plastic	0	0	0.2	0	0	0	0	0
1 g chemicals	0	0	0	20	0	0	0	0
1 kWh electricity	0	0.25	0.1	0	0	0	0	0.4
1 MJ fuel	0	0	0	40	0	0	0.6	0

Tier-wise output =

Result - Tierwise Reqts

Mid Value of Tierwise Reqts

Supplying Inds ☐ Totals

Tier ☐ Totals

	0	1	2	3	4	5	6	7
1 500ml bottle juice	1	0	0	0	0	0	0	0
1 liter juice	0	0.5	0	0	0	0	0	0
100 bottles	0	0.01	0	0	0	0	0	0
1 orange	0	0	4	0	0	0	0	0
1 kg plastic	0	0	2m	0	0	0	0	0
1 g chemicals	0	0	0	80	0	0	0	0
1 kWh electricity	0	0	0.126	0	64.03	0	15.37	0
1 MJ fuel	0	0	0	160.1	0	38.42	0	9.22

$x = (I-A)^{-1}y =$

Result - Vector of Total Requirements

Mid Value of Vector of Total Requirements

Supplying Inds ☐ Totals

1 500ml bottle juice	1
1 liter juice	0.5
100 bottles	0.01
1 orange	4
1 kg plastic	2m
1 g chemicals	80
1 kWh electricity	84.38
1 MJ fuel	210.6

Subsequent slides:

- How do we develop the PLCI data?
- IO-LCA Data basis
- IO-LCA matrix model form and example
- If PLCA and IO-LCA are mathematically equivalent, why is IO-LCA interesting?
  - Data
    - Already collected
    - Comprehensive on inputs
    - Comprehensive on products
- Strengths, weaknesses of each
- Examples of boundary truncation analysis with IO LCA

Flexibility in Scope of Input Type

- Material / Energy inputs - major
- Equipment, capital, infrastructure - major
- Material / Energy inputs - minor
- Overhead inputs (building, site, etc.)
- Service inputs
- Personnel-related expenses (travel, hotels…)
- Work-related employee expenditures (car,…)
- Delta-consumption due to employment demand
- (X) Total consumption of employees
- Profits (spending / re-investment)
- Taxes (spent by government)

Some slides which may also be used, follow…

Adding Pollution (or any impact): Basic Approach

x_i = sector *i* economic output ($/yr)

p_{ij} = sector *i* pollutant *j* release (kg/yr)

$$\frac{p_{ij}}{y_i} = e_{ij} = \text{sector } i \text{ pollution intensity (kg/\$)}$$

Data Discussion - USA

- Economic I/O Data
- Energy-related Air Emissions
- Toxic Release Inventory

The “Work Files”

- US Department of Commerce’s Bureau of Economic Analysis (BEA)
- BEA creates the I/O tables from establishment-level Census data
- Work files are an unpublished, intermediate data product
- Most recently published: 1992
- 1997 data projected for 2001
- “Transactions” table: 1000 x 7000 detailed “Use” matrix (use of 7K items by 1K industries)

Energy-related Air Emissions

- CO_2, { CO, NO_x, SO_2, Particulates, VOCs }
- Approaches for estimating P_{ij} (kg/year, each sector, flow)
  - Carnegie-Mellon University approach:
    $ fuel per year → kg or litres fuel per year → kg pollutant
  - Sylvatica approach:
    - CO2: Department of Energy data on fuel *combusted per year*
    - {"Criteria air pollutants"}: US EPA emissions inventories (kg/yr, each sector, each flow)
  - Needed: comparison of results; estimates of uncertainties;
  - Advantages of latter approaches:
    - More recent (1996 vs. 1992)
    - Continual improvement, millions of man-hours at state level
    - Capture non-energy-related process emissions (e.g., VOCs)
    - Avoid allocating combustion to feedstock uses
    - Avoid sectoral price difference impacts
- Main message: data selection and integration = model design

Toxic Release Inventory

- US EPA: Required plant-level annual reporting
- Manufacturing sectors, ~ 300 pollutants
- Need to characterize uncertainties due to:
  - Reporting/measurement/estimation error
  - Non-reporting
    - Non-reporting sectors
    - Non-reporting establishments within reporting sectors
    - Non-reported chemicals from reporting establishments
- Need to create adjusted e_{ij} intensities (kg/$)