Modeling fate and effects of priority chemicals within the Great Lakes - St. Lawrence region

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Great Lakes Binational Toxics Strategy
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ÉCOLE POLYTECHNIQUE MONTRÉAL

Great Lakes Commission des Grands Lacs

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Relations internationales Québec

Développement durable, Environnement et Parcs Québec

Outline

Project positioning within GLC reporting goals

Project objectives

Model relevance in LCA

Methodology

Results & interpretation

Conclusions of the study so far

Recommendations for the GLC

Next steps

INTRODUCTION

Great Lakes Toxic Air Emissions Inventory

More than 15 years of history

- Inspired by the:
  - Great Lakes Toxic Substances Control Agreement (1986)
  - Annex 15 of the Great Lakes Water Quality Agreement (1987)
  - Great Waters section of the Clean Air Act Amendments (1990)
  - Need for information on emissions to develop control strategies

- GLC has worked with 8 states and Ontario to:
  - Build capacity to estimate emissions
  - Create customized software and database tools
  - Compile regional inventories and reports
  - Outreach of project results

Challenge of reporting

Latest reports include:

- >200 pollutants
- From >2000 source classifications
- In >600 counties / districts

Result is 250,000,000 pollutant-source-county combinations to report on

Even more challenging is conveying:

- How data is produced
- Reasons for trends, discrepancies, etc.

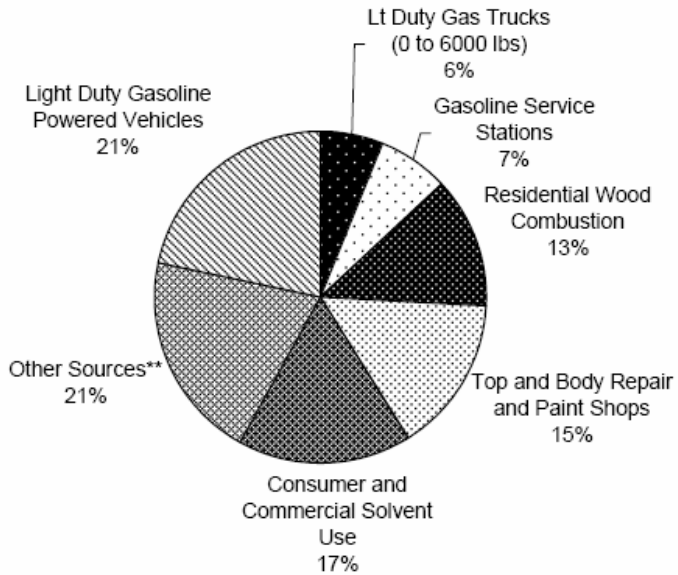
Getting People Interested is a Bigger Challenge

Reports show how much of a substance is released, where and by what.

But

It is difficult for audiences to interpret the importance of a pound of Naphthalene.

NAPHTHALENE
1997 Estimated Emissions* by Source Category for Point, Area, and Mobile Sources

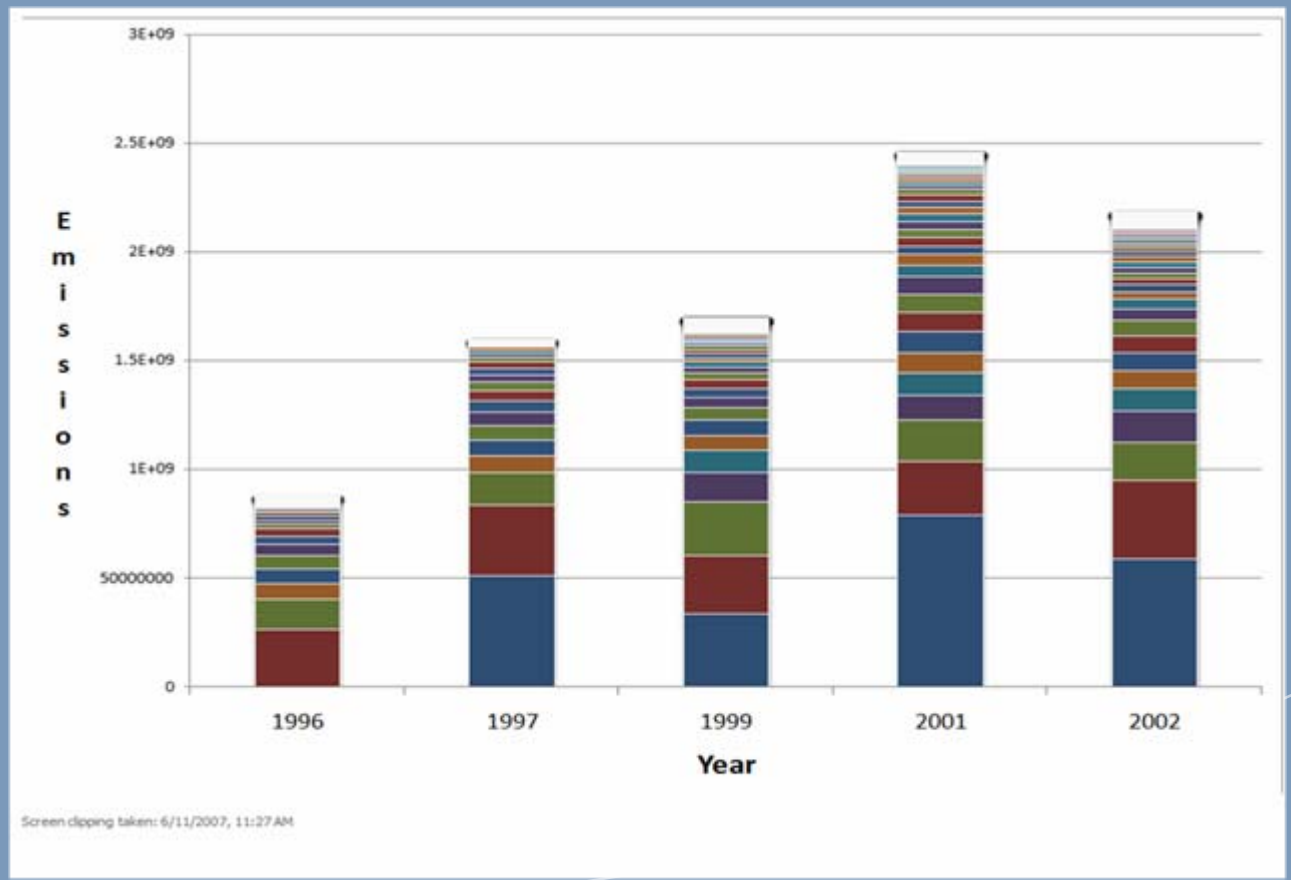


SIC	DESCRIPTION	EMISSIONS (LB)	IL	IN	MI	MN	NY	OH	ON	PA	WI
-------	Lt Duty Gas Trucks (0 to 6000 lbs)	828,916.67	x	x	x	x		x		x	x
5541	Gasoline Service Stations	952,947.71			x	x		x	x		x
-------	Residential Wood Combustion	1,723,881.78	x	x	x	x		x	x		x
7532	Top and Body Repair and Paint Shops	2,084,546.78	x	x	x	x		x		x	x
-------	Consumer and Commercial Solvent Use	2,292,406.95	x	x	x			x		x	x
-------	Other Sources**	2,795,143.56	x	x	x	x		x	x	x	x
-------	Light Duty Gasoline Powered Vehicles	2,931,569.04	x	x	x	x		x	x	x	x

Total Estimated Emissions: 13,609,412 lbs.

Are Things Getting Better?

A change in the combined emission of >200 pollutants is not very meaningful



Changes in methods make determining trends across years very difficult

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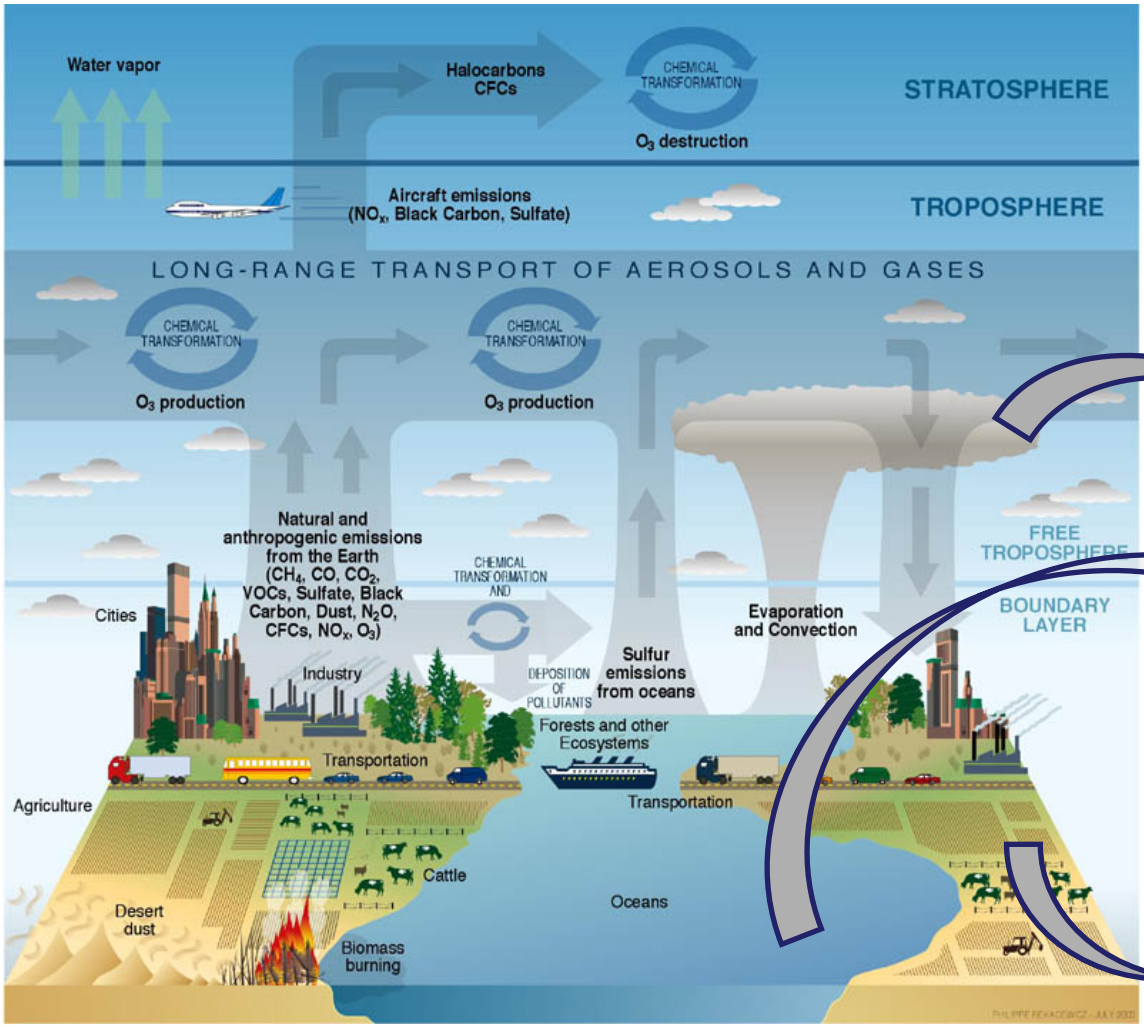
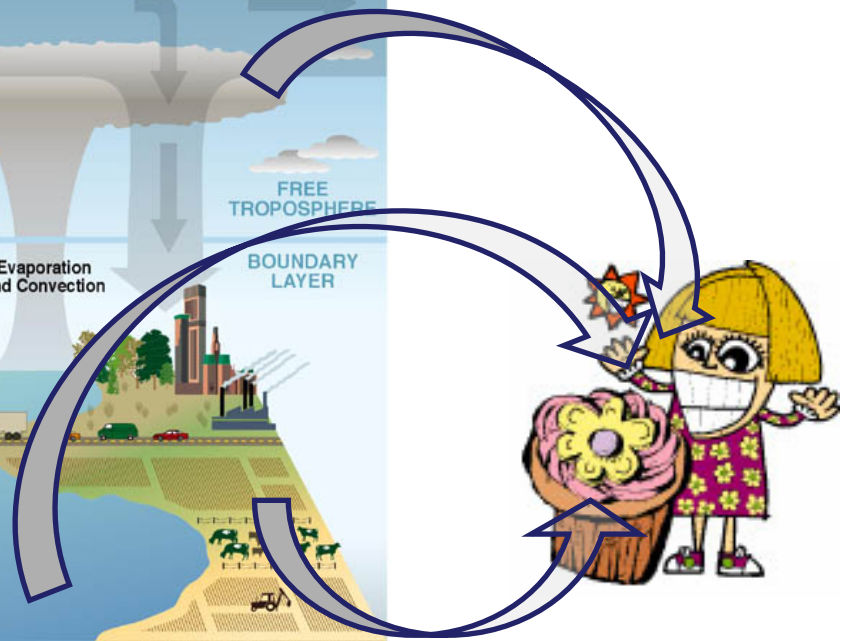
The Public wants to know about…





- Where the chemicals end up, and
- What harm they do

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OBJECTIVES

Provide a tool to assist decision makers with quantifying the impact on human health based on emissions (levels, source location & type)

Develop a spatial multimedia model for the Great Lakes region and demonstrate its validity on a small scale

Assess the best way forward to **weigh substances emissions**

BACKGROUND

Life Cycle Impact Assessment

Popcorn or Polystyrene?

Which packing material is most environmentally friendly?

Non renewable
Non biodegradable

Renewable
Biodegradable

Elementary flow	Popcorn	Polystyrene
Energy (MJ/kg)		
Non-renewable energy	7.2	81.3
Air emissions (g/kg)		
CO_2	620	5480
PM	0.2	1.3
CO	1.0	3.4
NH_3	3.1	0
Water emissions (g/kg)		
Nitrates	31	0

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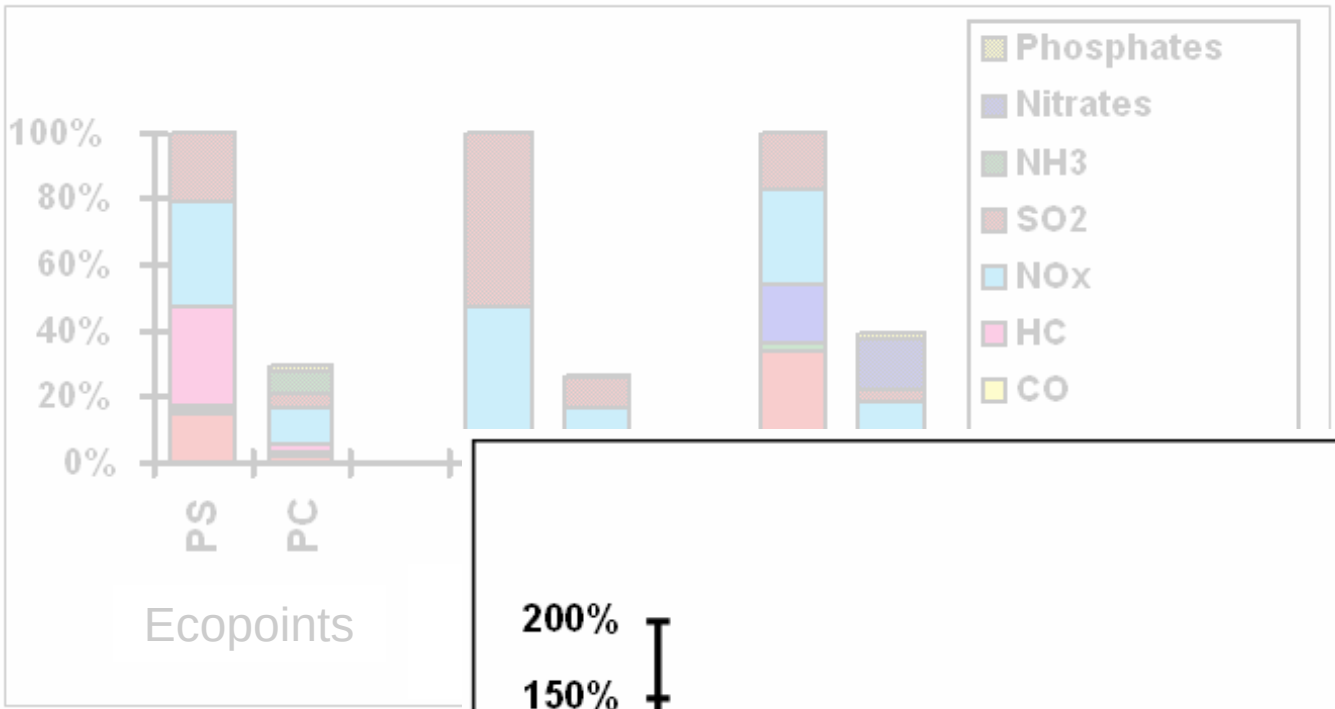
Impacts of packing materials

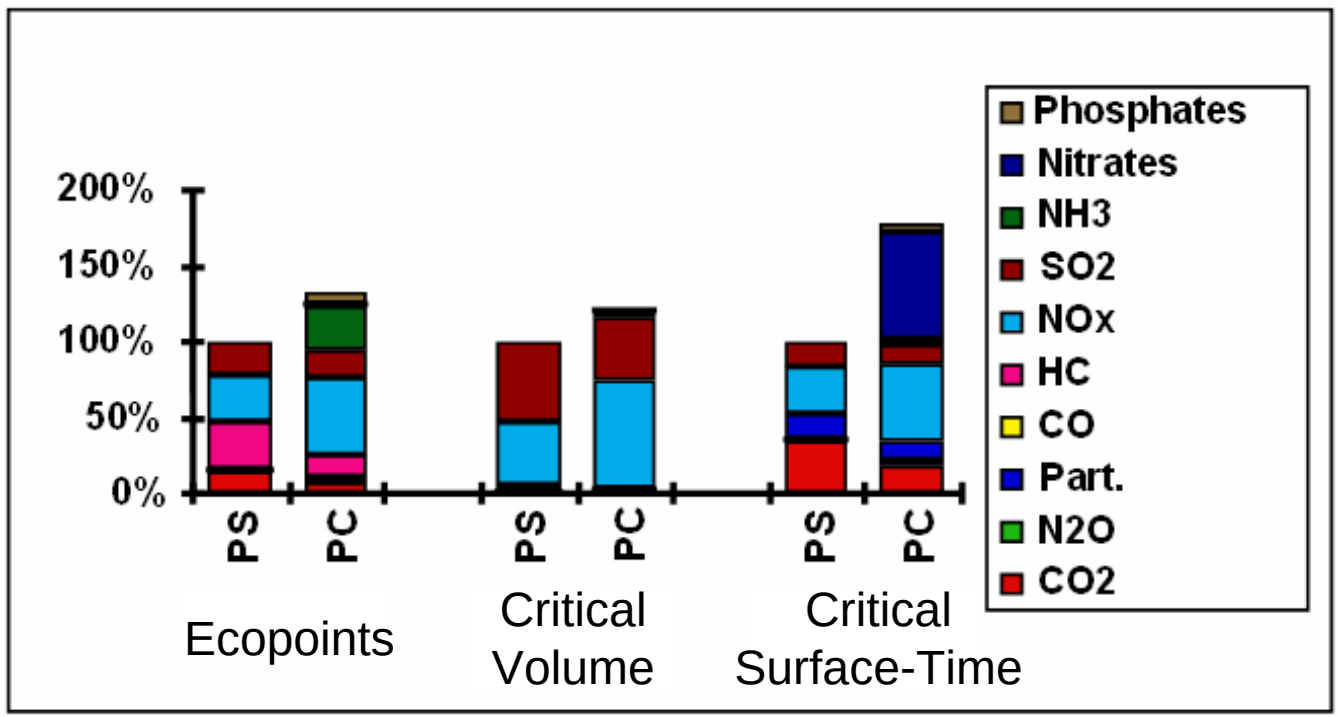


Per kg

PS: Polystyrene

PC: Pop Corn

Per m^3



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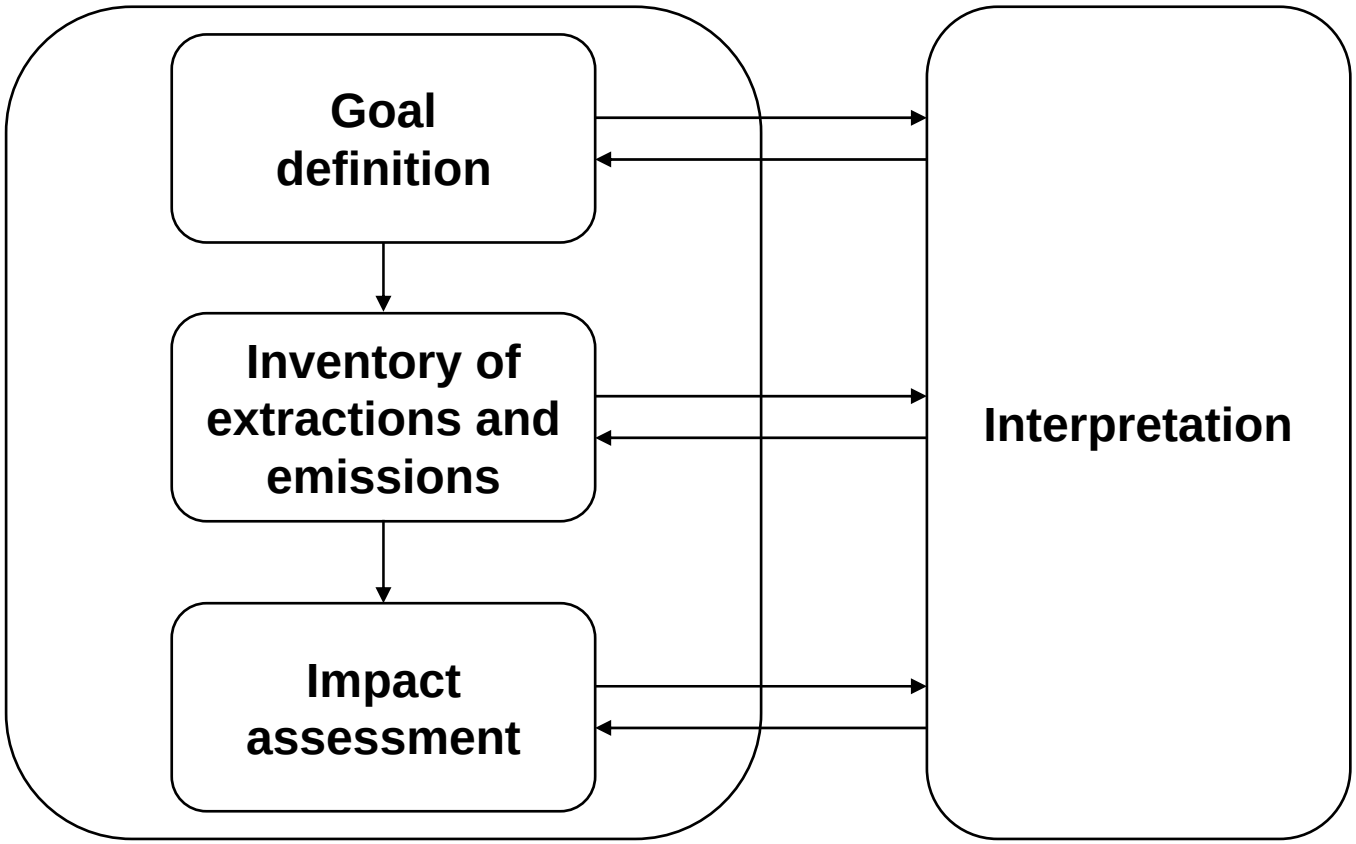
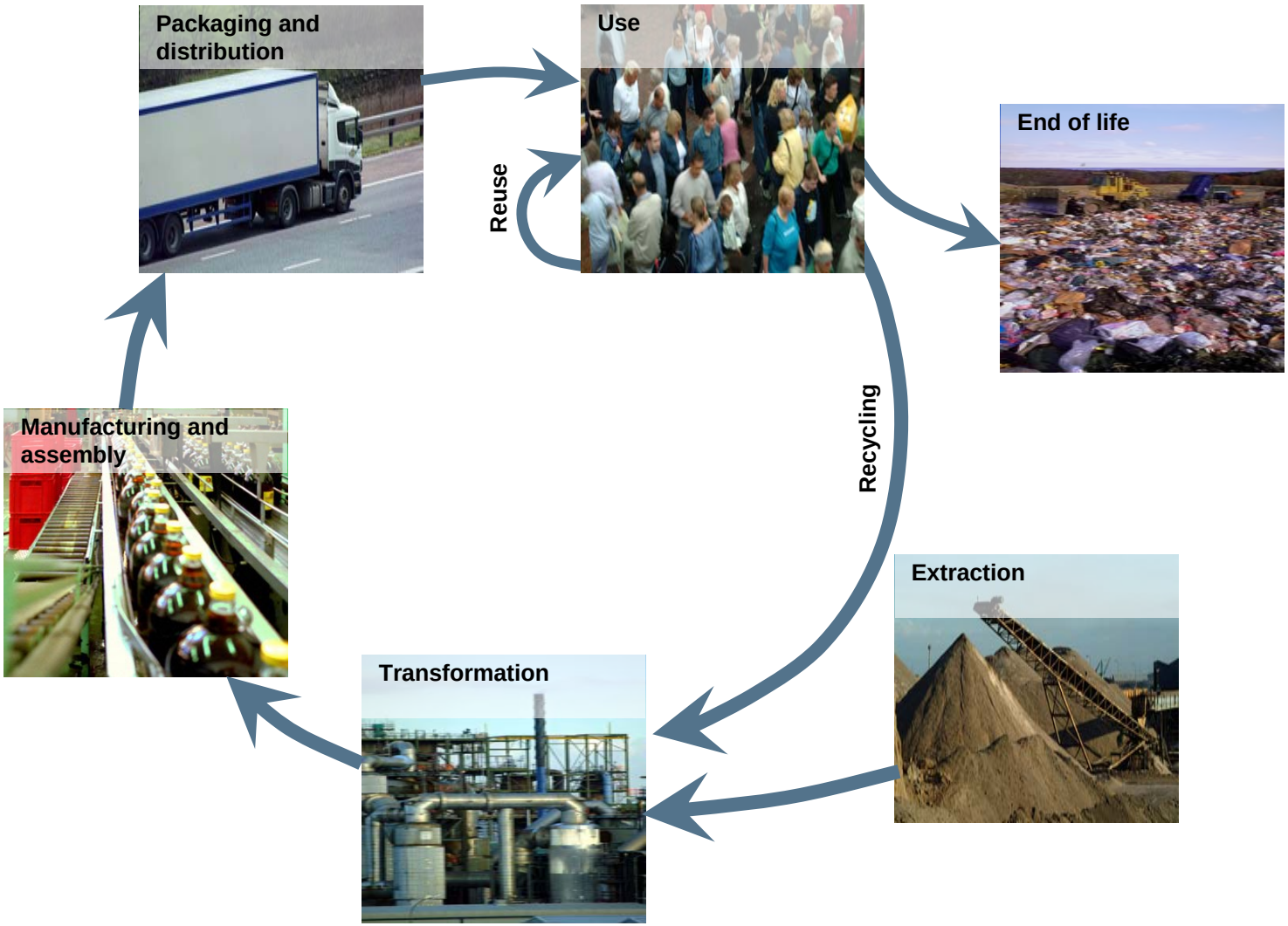
Life Cycle Assessment (LCA)

- ISO 14040 series
- Decision making tool



Life cycle of a product



+ Transport at each step!

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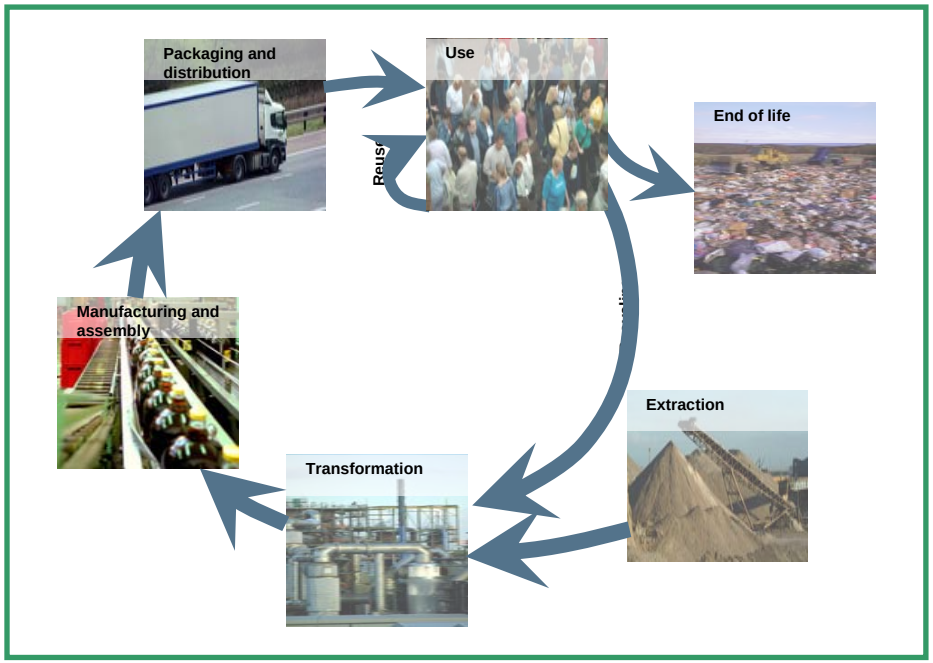
Life Cycle Inventory (LCI)

Natural Resources

- Ore
- Crude oil
- Water
- Wood
- Land area



Emissions

-To air

CO_2, SO_x, PM, VOC

-To water

PO_4, NO_3

-To soil

Pesticides, metals

Others

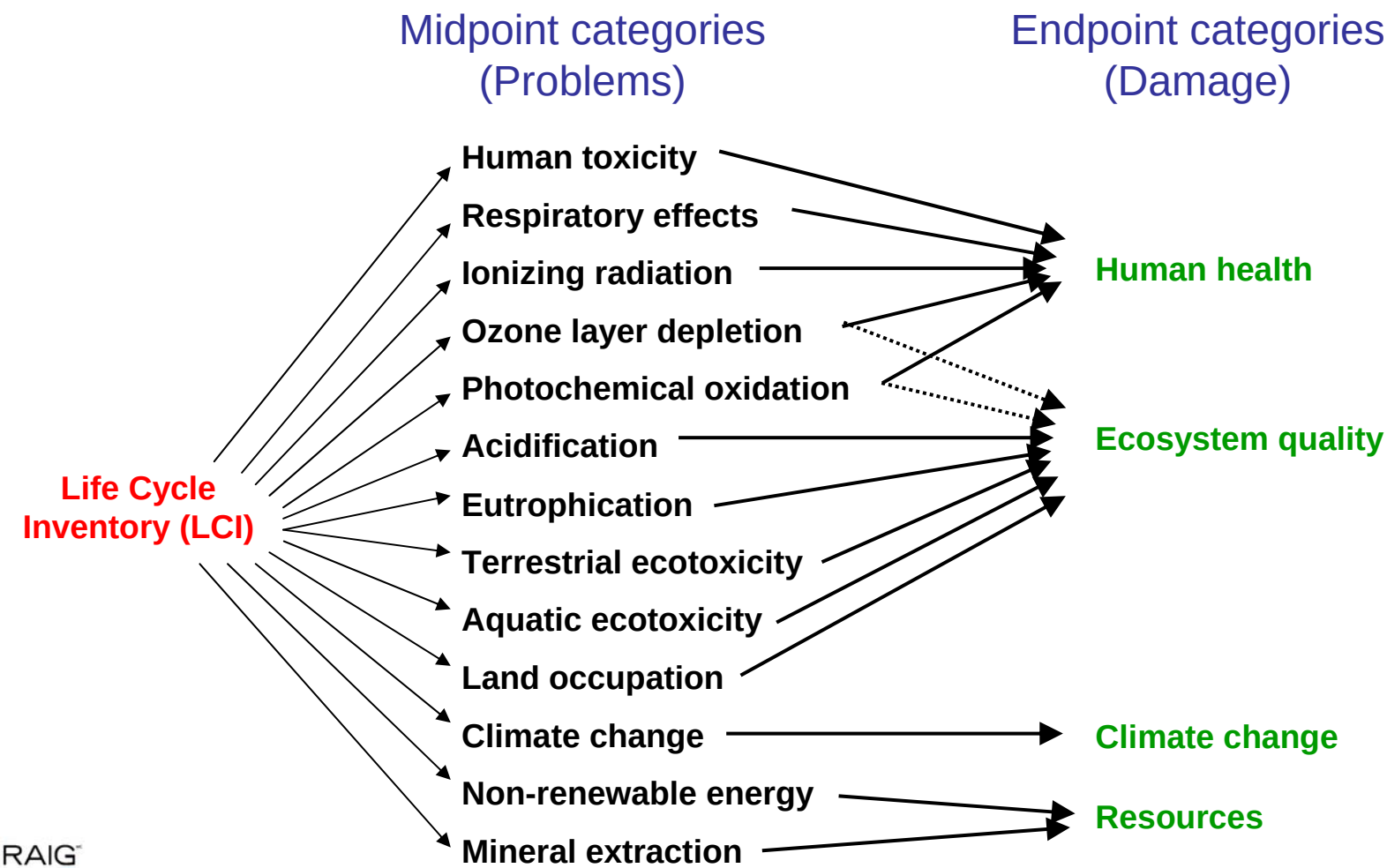
Radiation

Heat

Noise

Life Cycle Assessment (LCA)

- Environmental evaluation of impacts from cradle to grave based on all inputs from and emissions to the environment



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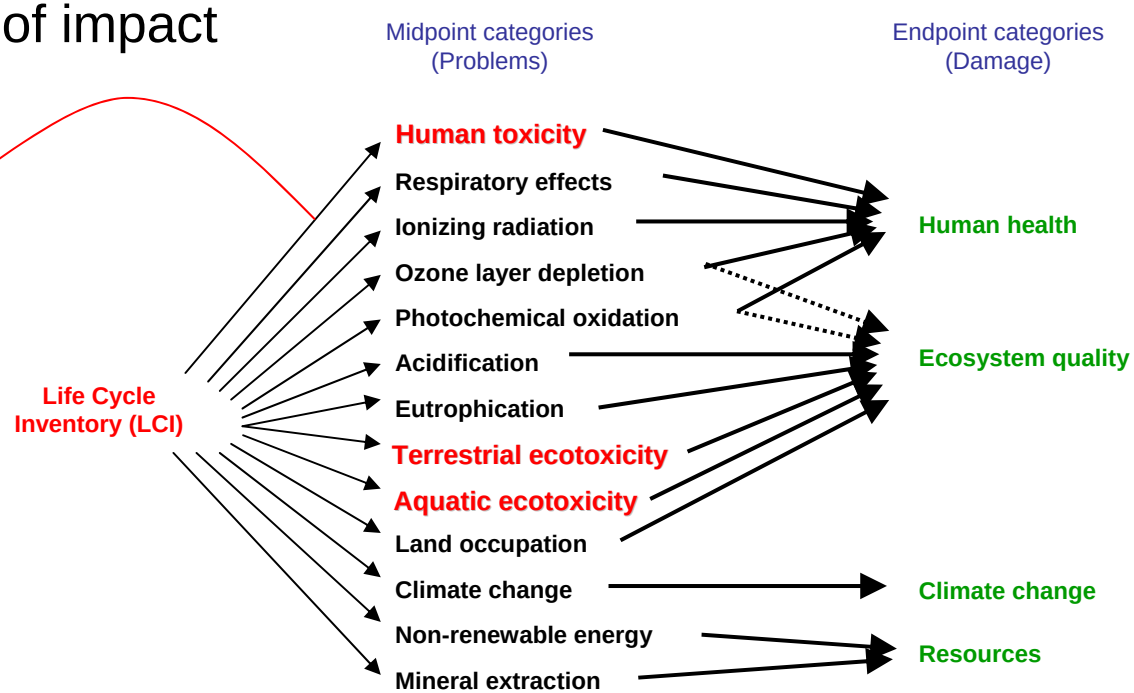
IMPACT2002 in the context of LCA

- IMPACT2002+ is an evaluation method of the impacts

- IMPACT2002 is a model which determines the “conversion” of inventory results into a quantity of impact

Characterisation Factor
- Per substance
- Calculated by a model
- Function of location and model resolution



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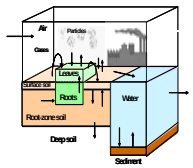
IMPACT2002: Established modeling



Emission | **Concentration** | **Intake** | **Incidence** | **Damage**

$\vec{\dot{S}}$ | $\vec{M}$ | $\vec{\dot{I}}$ | $\vec{\dot{N}}$ | $\vec{\dot{D}}$

Emission flow [$kg_{emitted}/day$] | **Mass in env.** [kg] | **Intake flow** [kg_{intake}/day] | **Risk flow** [$cases/day$] | **Damage flow** [$years/day$]

$\overline{FF}$ [day] **Fate** | $\overline{XF}$ [$1/day$] **Exposure** | $\overline{EF}$ [$cases/kg_{intake}$] **Dose-Response** | $\overline{DF}$ [$years/case$] **Severity**

$$\overline{iF_{xr}} = \overline{XF} \cdot \overline{FF}$$

$[kg_{intake}/kg_{emitted}]$

$$iF = \frac{\sum_{people,time} \text{mass intake by an individual}}{\text{mass released into the environment}}$$

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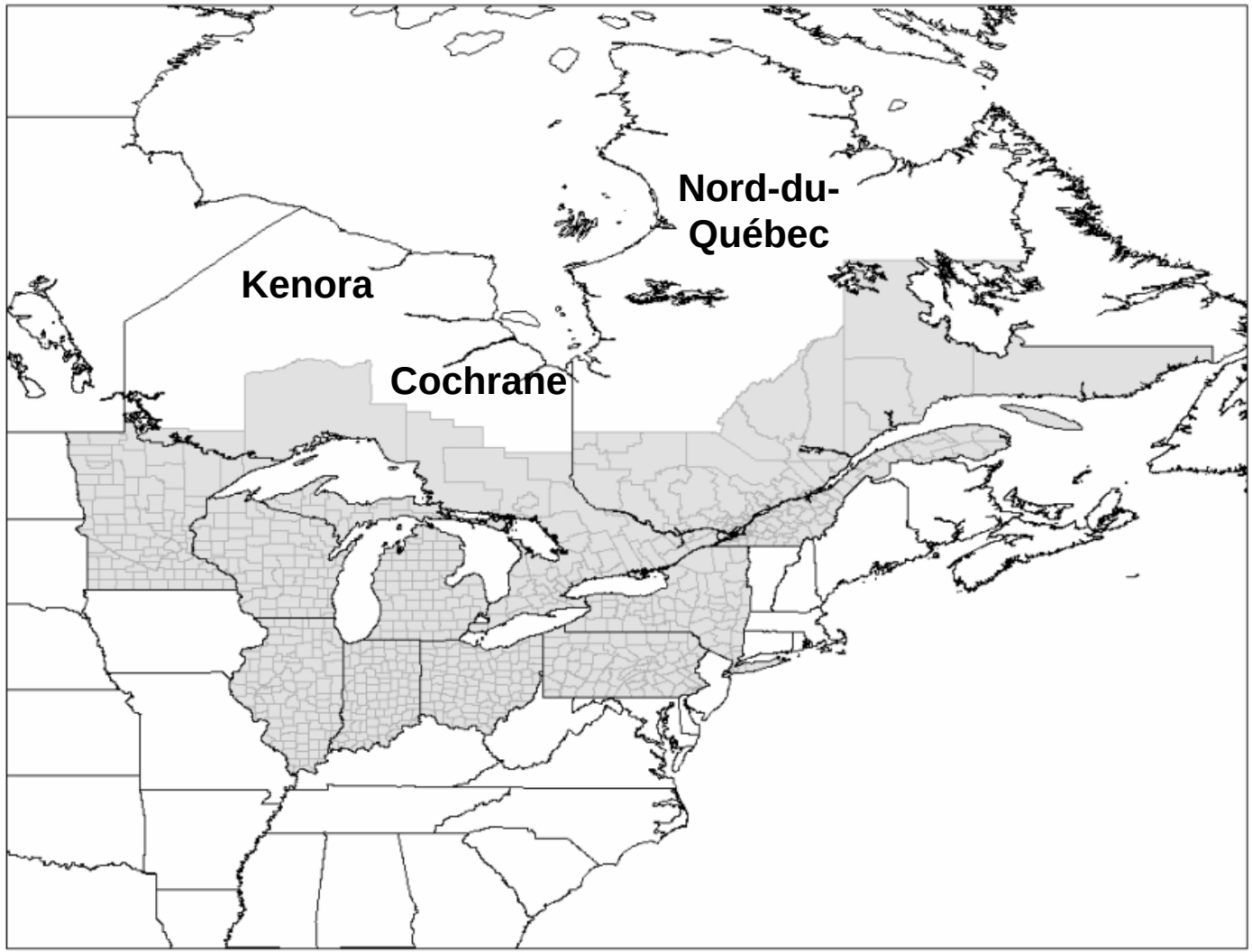
METHODOLOGY

Great Lakes region and St-Lawrence Basin

Two provinces:
- Québec
- Ontario

Eight states:
- Wisconsin
- Minnesota
- Michigan
- Illinois
- Indiana
- Ohio
- Pennsylvania
- New York

Regions not considered:
- Low population density
- Large areas



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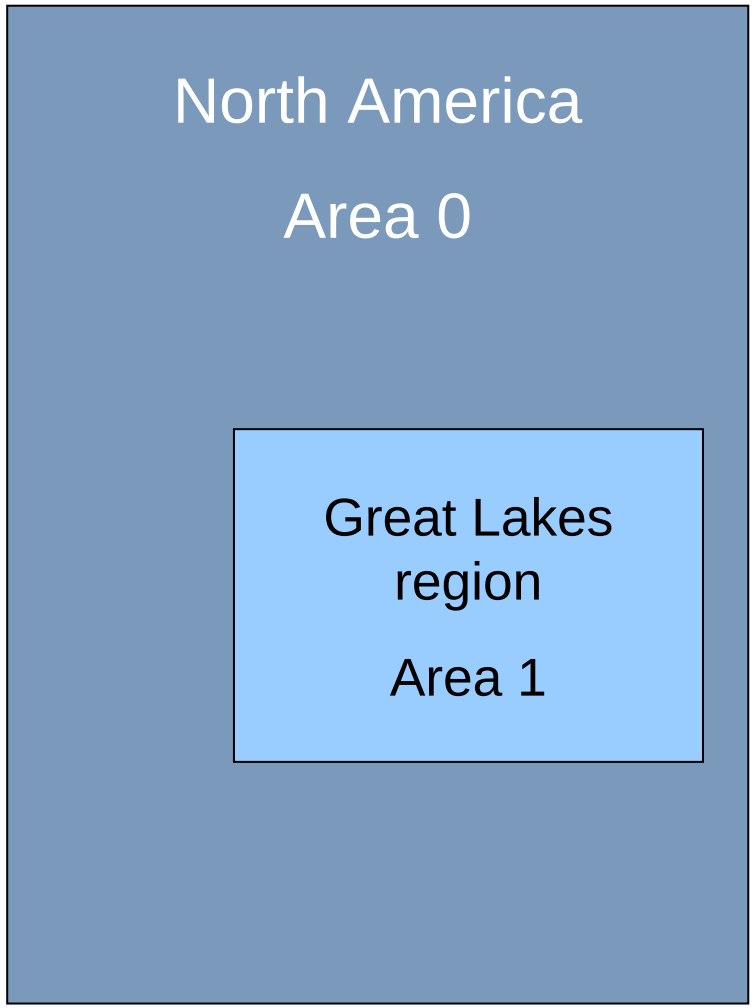
Representation of the non-spatial model

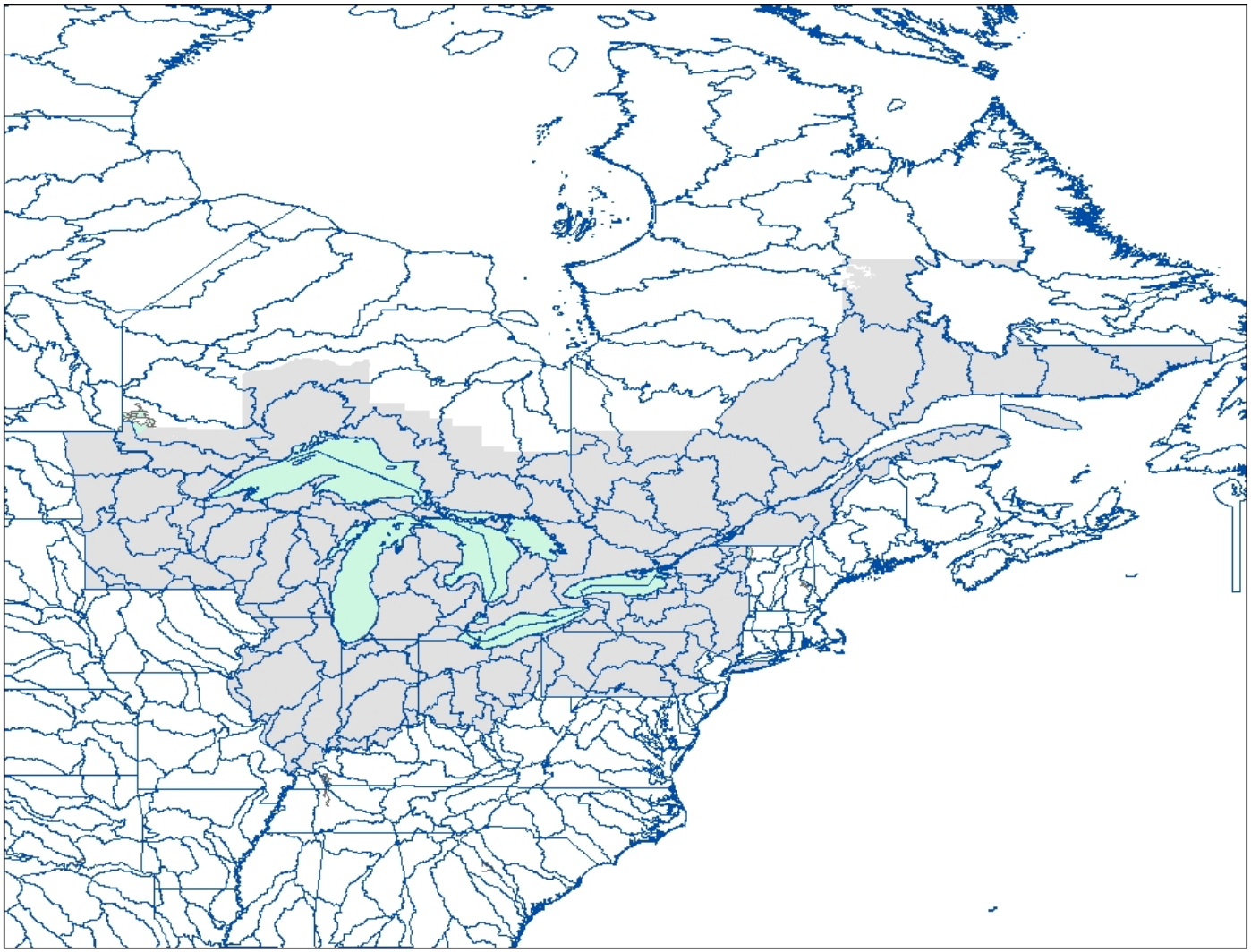
As simple as possible, as complex as necessary.

Area division

- **Watershed**
  - Water
  - Soil
- **Oceanic region**
  - St-Lawrence
- **Air**



Spatially resolved model



Validation with benzo[a]pyrene

GL-BTS

- Great Lakes Binational Toxic Strategy
- Level 1 substance (1997)

Known and studied PAH

Measured

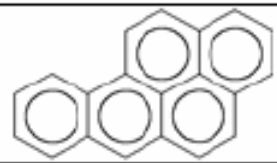
Highly carcinogenic

Higher exposure by food ingestion than by inhalation

Known and quantified sources:

- Fireplaces and woodstoves
- Fluidized bed catalytic cracking units (refineries)
- Metal production (Aluminium)
- Open burning (controlled and wild fires)
- Mobile sources (engine combustion)

Chemical profile of B[a]P

Chemical profile of benzo(a)pyrene	
Chemical Abstract Service (CAS) number	50-32-8
Chemical structure	
Chemical formula	$C_{20}H_{12}$
Molecular weight	252.30
Melting point	175° C
Boiling point	>360° C
Log K_{OW}	6.04
Log K_{OA}	10.77
Degradation rate in air (half life)	5 to 170 hours
Degradation rate in water (half life)	940 to 1700 hours
Degradation rate in sediments (half life)	4700 to 55,000 hours

Parameterization

Regional parameters

- Geographic
  - Surfaces: water, soil, …
  - Average lake depth
  - …
- Annual consumption of agricultural products
  - Meat
  - Cereals
  - …
- Population data

Data Sources → Governmental

- Canada
  - Statistics Canada
  - Fisheries and Ocean Canada
- US
  - USDA
  - USGS

Emissions and concentration data

Emission data

- National Emissions Inventory (NEI) – US
- Environment Canada (EC) – Canada
- National Pollutant Release Inventory (NPRI) – Canada
- Great Lakes Commission's regional inventory – US and Canada

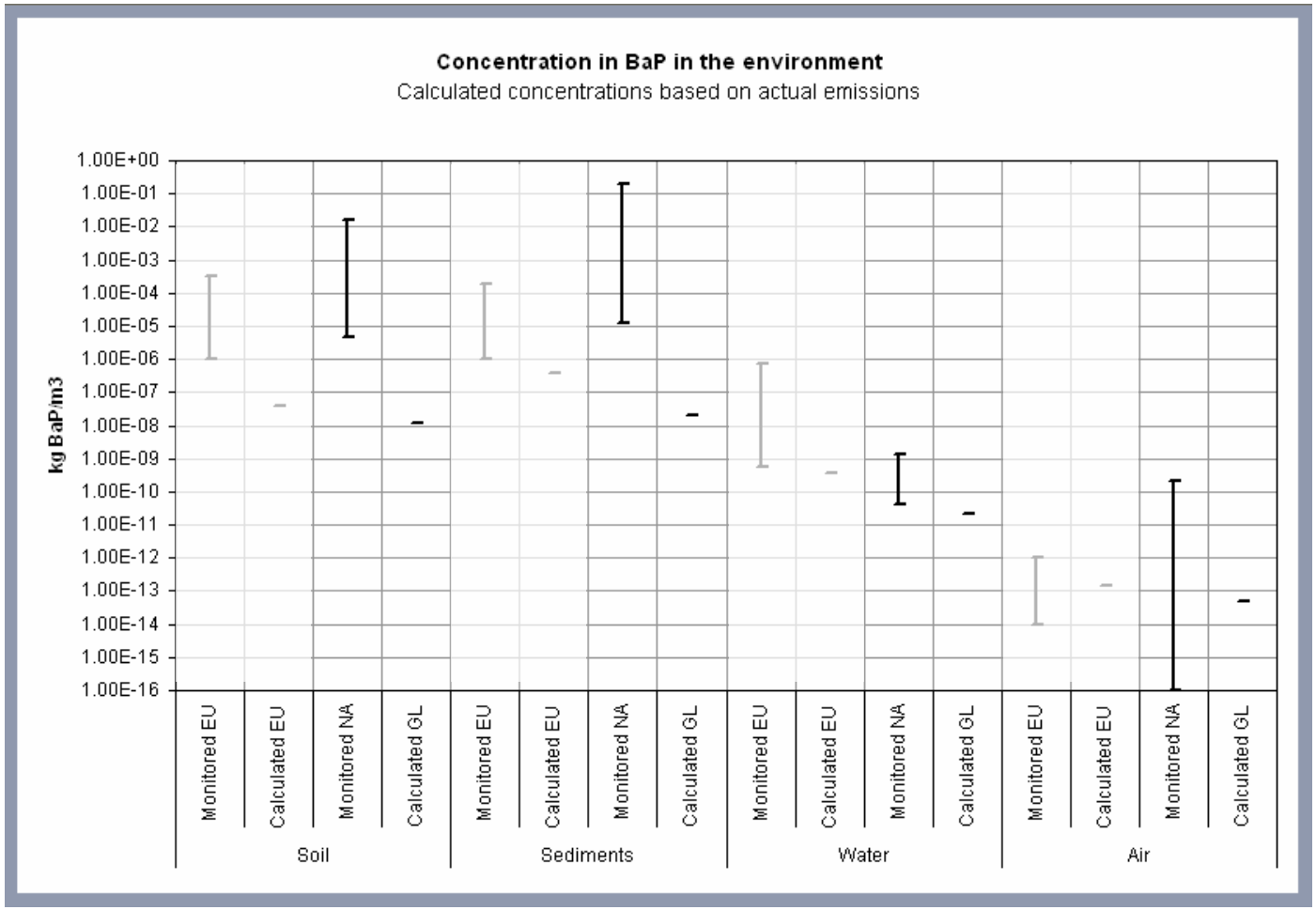
Concentration data

- Articles : data on GL and US
- Ministère du développement durable, de l'environnement et des parcs du Québec (MDDEP)
- Environment Canada (EC)
- Integrated Atmospheric Deposition Network (IADN) – GL basin, Ontario included

RESULTS

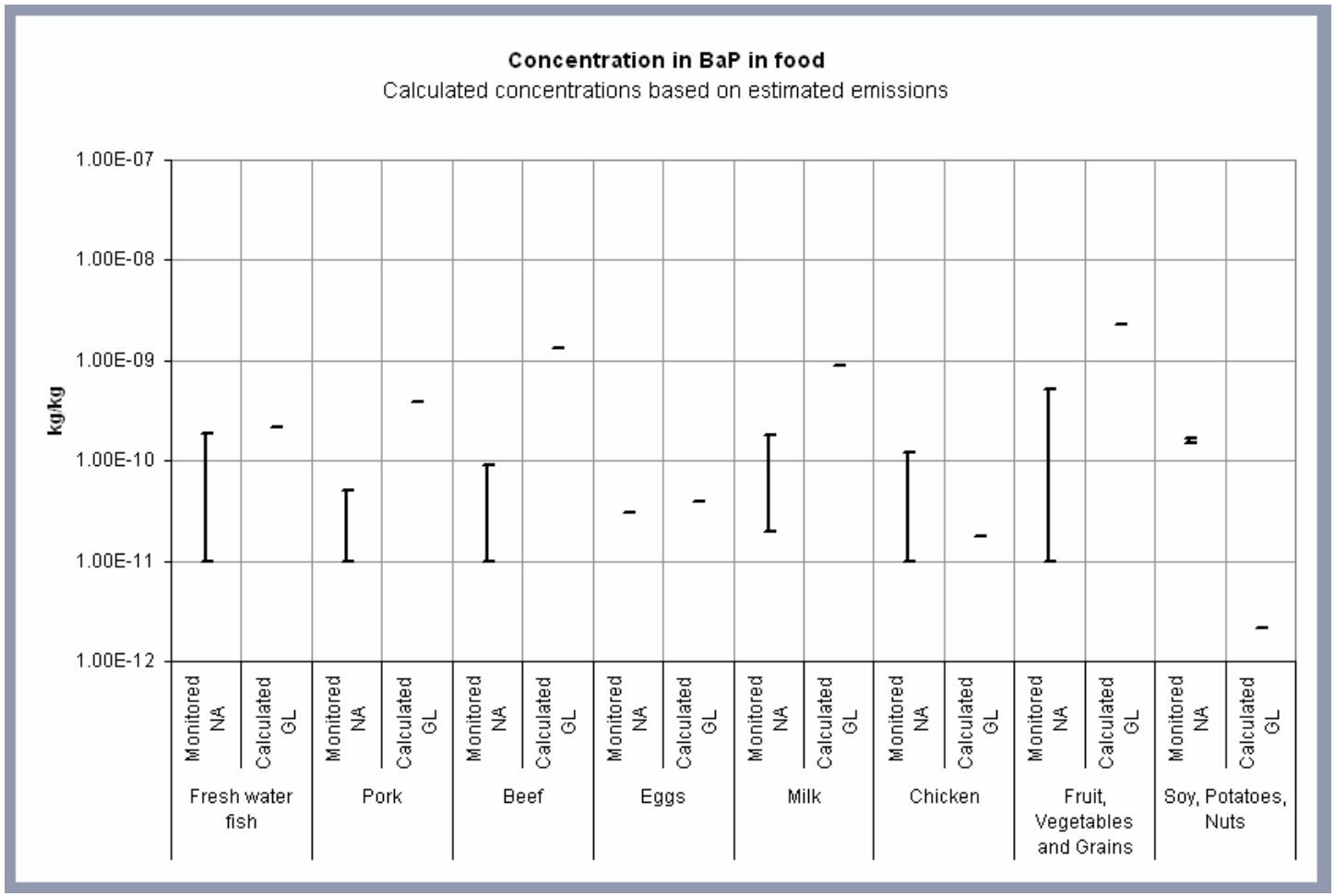
Concentration in B[a]P in the environment

- Correlation between calculated and monitored concentrations similar in GL and Europe



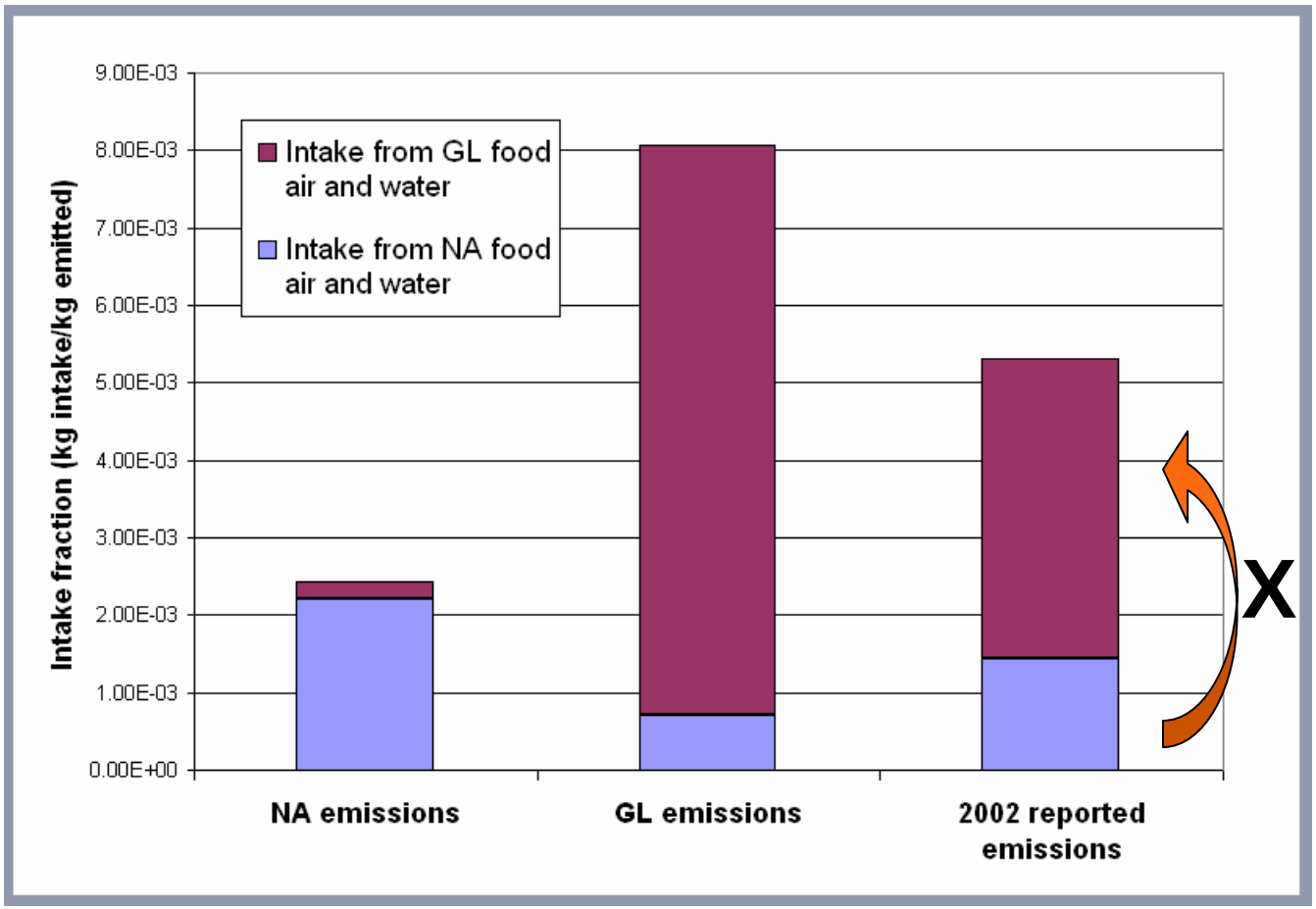
Concentration in B[a]P in food

- Calculated concentrations in food and intake fraction overestimated by one order of magnitude



Intake fraction of B[a]P

- Exposure from GL emissions is 3x higher than from NA emissions



- Rest of NA has 4 times the population of the GL
  → Intake implications

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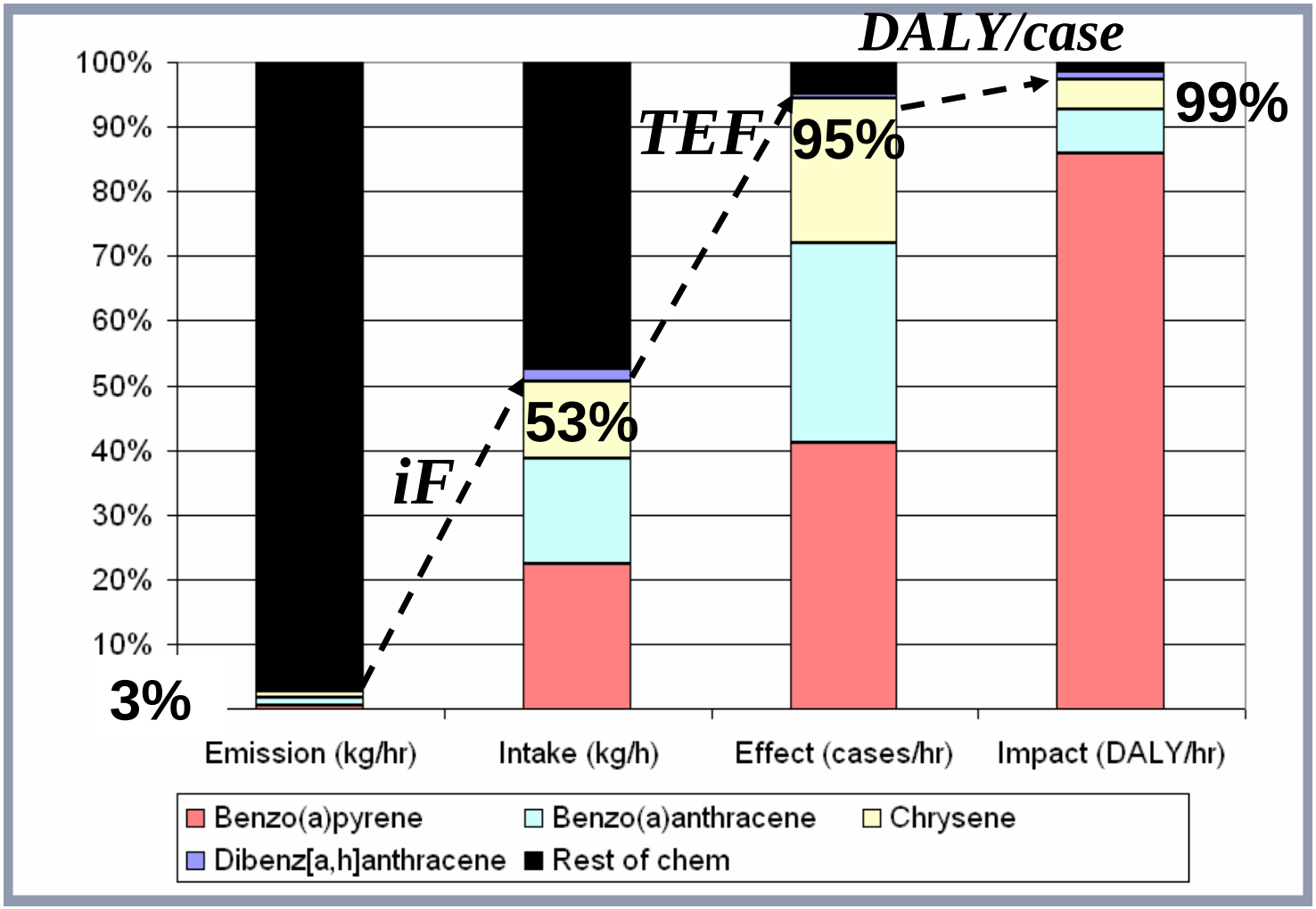
Impact of PAH-16 emissions

- 3% emissions correspond to 53% intake which account for 99% impact



Emission Equivalent Factors

Intake Fraction (iF)

- Emission to dose
- Regional

Toxic Equivalent Factors (TEF)

- Dose to toxicity

Emission Equivalent Factors

- Emissions to toxicity
- Regional

$$EEF = iF \times TEF$$

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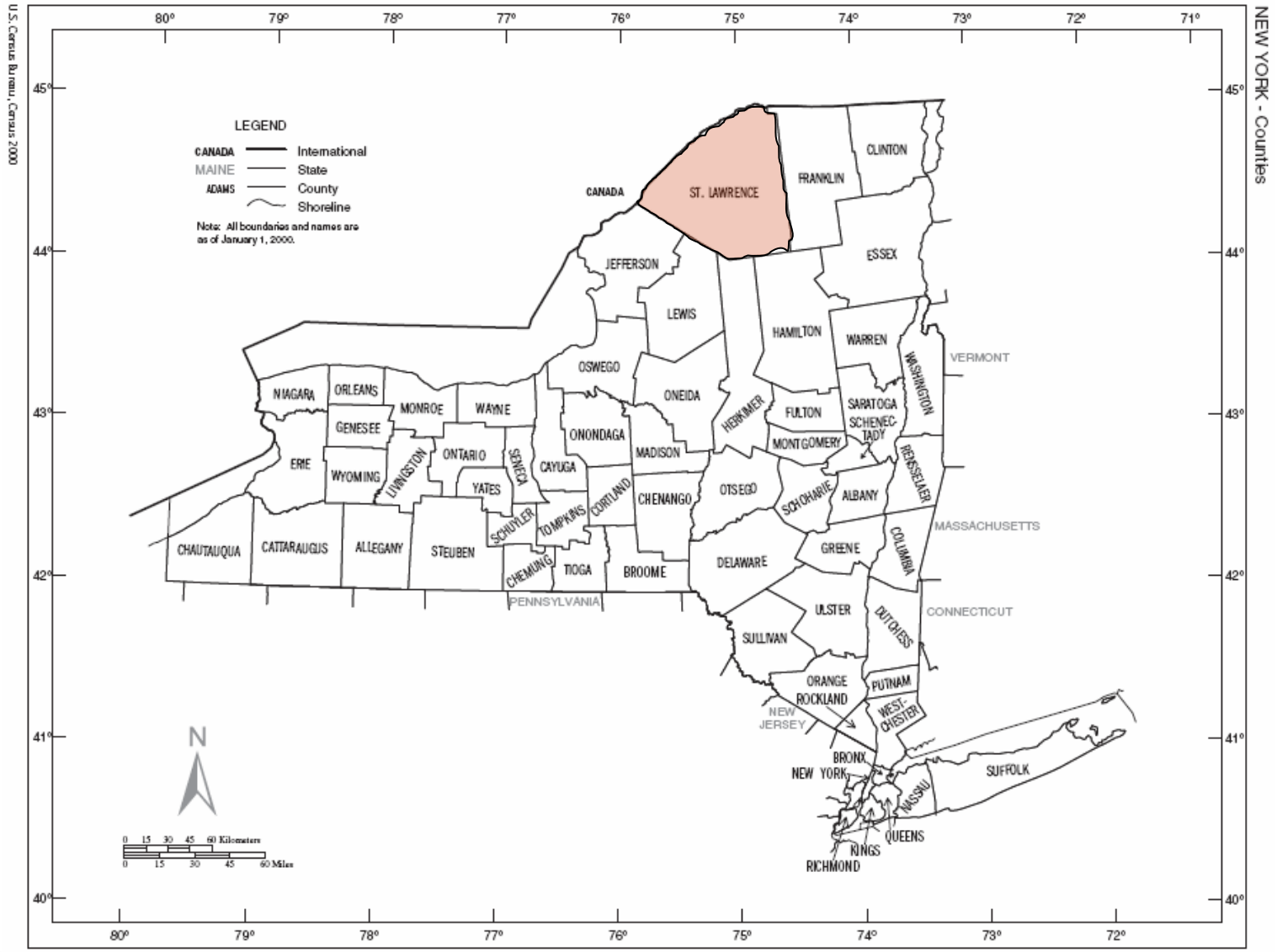
An example: St-Lawrence County, NY



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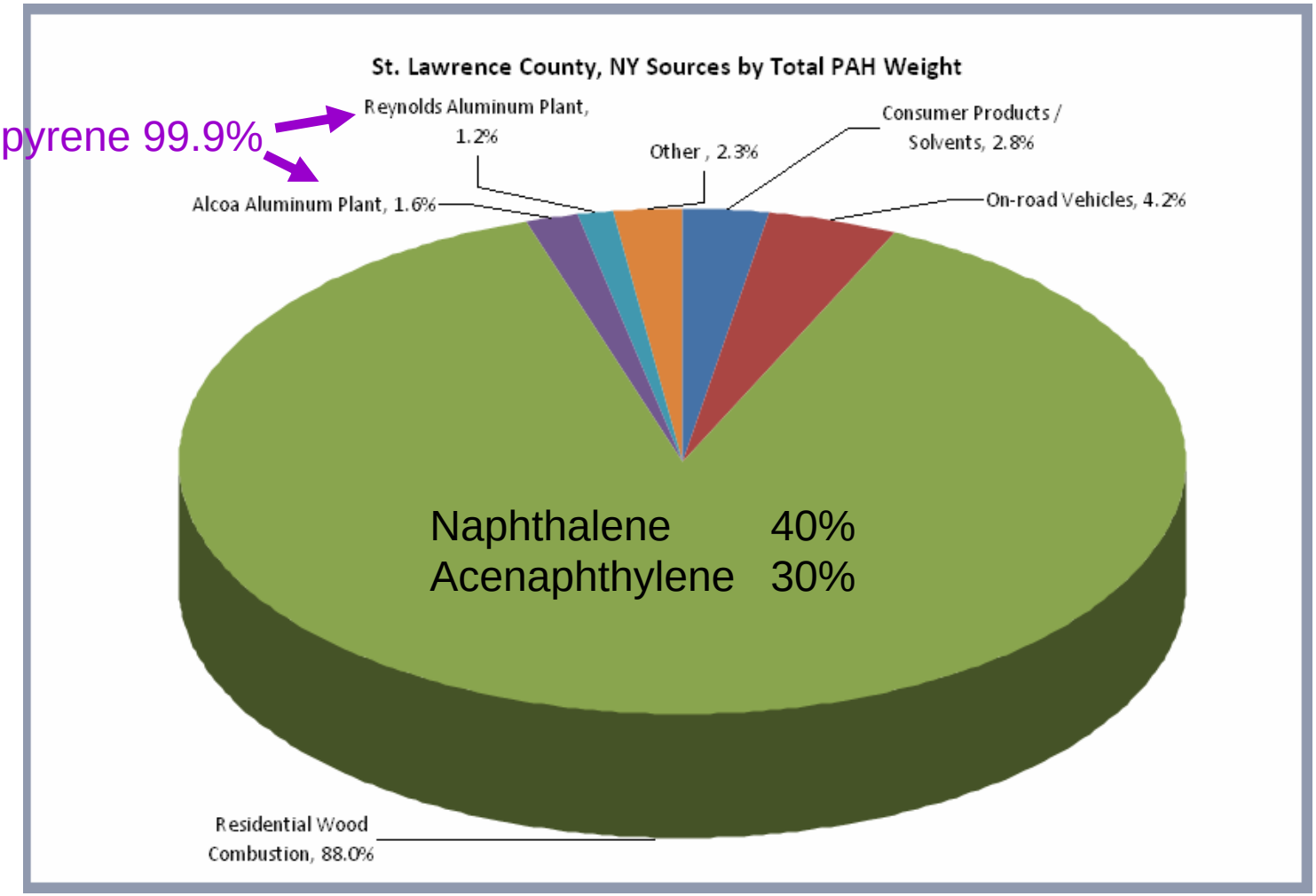
Sources by total PAH weight

- 88% PAH are emitted by Residential Wood Combustion



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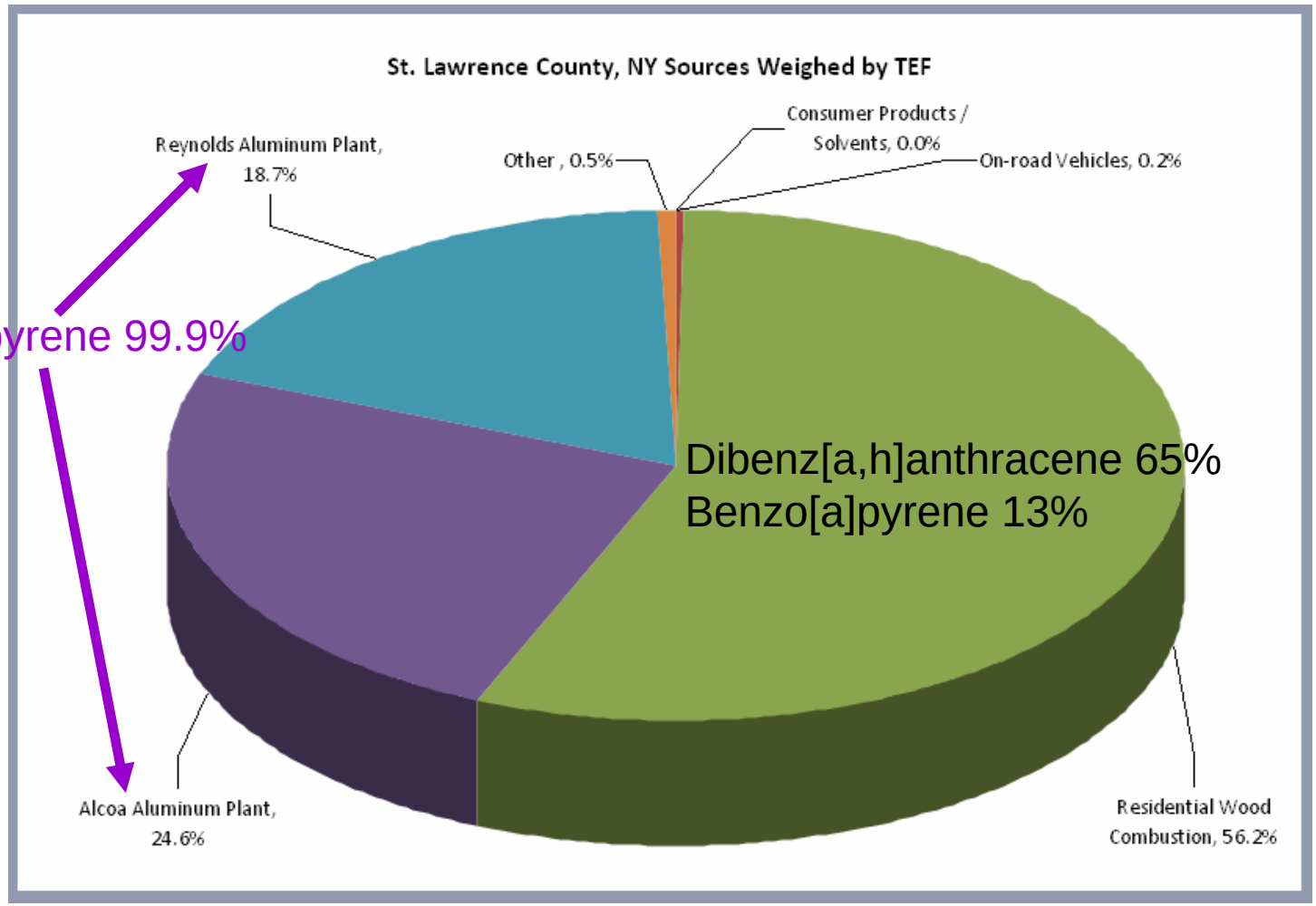
TEF weighed sources

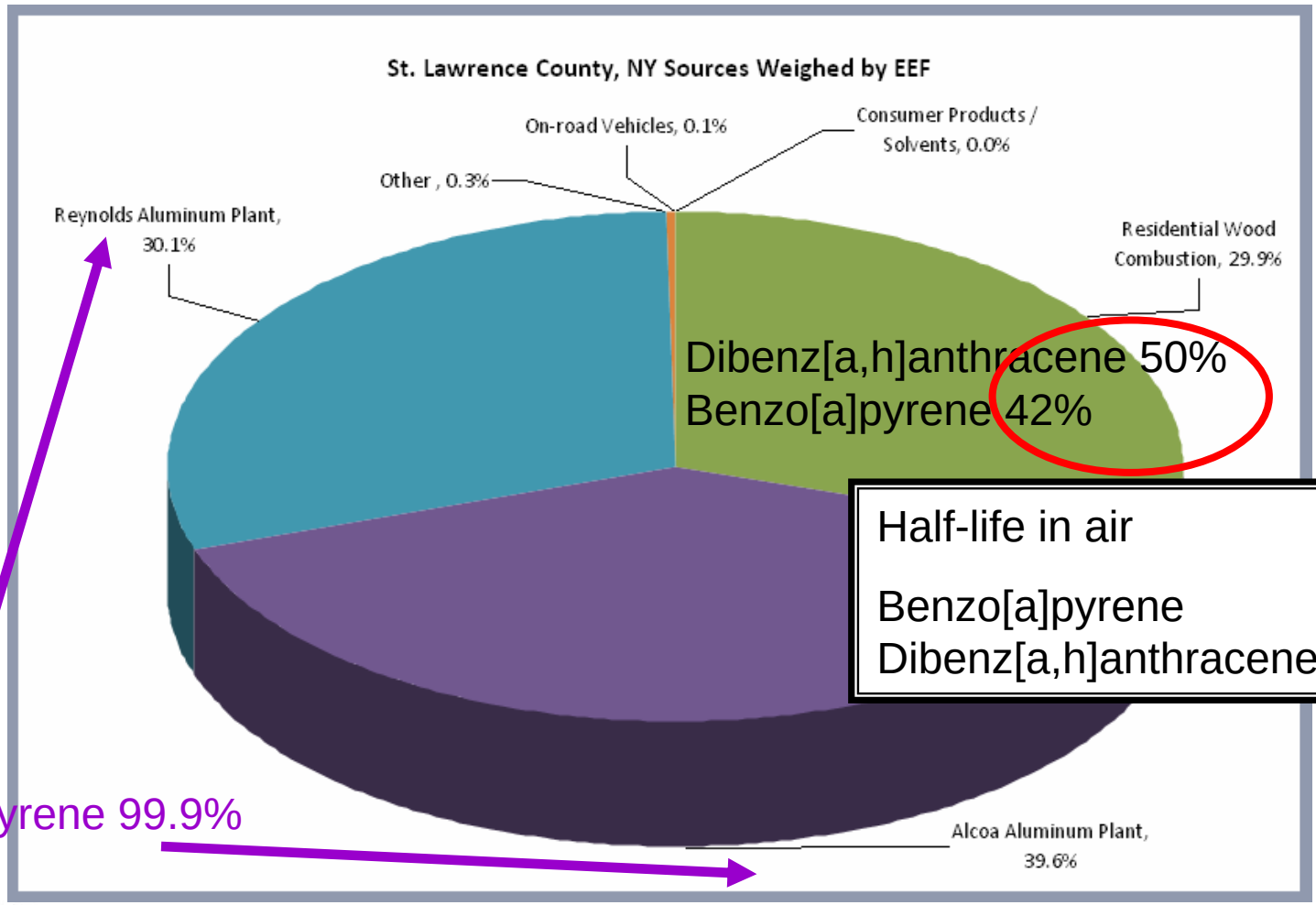
- The importance of Al plants increases in the TEF weighed inventory



Benzo[a]pyrene 99.9%

EEF weighed sources

- Residential Wood Combustion is no longer the most important activity in a EEF weighed inventory



Half-life in air

Benzo[a]pyrene	170h
Dibenz[a,h]anthracene	8h

Benzo[a]pyrene 99.9%

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Identifying hotspots for targeted action

- Develop tailored measures to reduce emissions at hotspots
- Maximum environmental benefit for the effort invested

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CONCLUSIONS & RECOMMENDATIONS

Conclusions

Substances impact is dependent on toxicity and intake fraction

- Six orders of magnitude variation between B[a]P and Acenaphtene in DALY/hr based on reported emissions
- 4 PAH account for only 3% of emissions, but contribute to approx. 99% of human health impact of PAH-16

Location of emission is a determining factor of exposure

Recommendations

Measure PAHs emission reduction based on modeled impacts

- ➔ iF x TEF
- ➔ NOT quantity of emission
- ➔ NOT TEF weighted emissions

Apply Life-Cycle approach the emissions inventory

- ➔ A way to report out the impact of the inventory
- ➔ Set reduction goals based on combined impact of multiple chemicals

Next steps

Non spatially resolved model→ Next 2 months

- Improve model fit (calculated vs. monitored concentrations)

Spatially resolved model → Next 6 months

- Parameterization
- Results analysis
- Applications

Thank you for your attention!

Questions?

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