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Valuation of Health Benefits from Mercury Pollution Control

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Panel on Human Health Effects of Pollutants

Air Pollution as Climate Forcing: A Second Workshop

East-West Center, Honolulu

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Economic Valuation of Human Health Benefits of Controlling Mercury Emissions from U.S. Coal-Fired Power Plants

February 2005

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Overview

- The report covers diverse areas of policy-relevant research including:
  - Mercury emissions (including changes from coal plants), atmospheric transport and fate, modeling of Hg deposition
  - Relationship between Hg deposition and methylmercury levels in fish, current and future exposures in humans to mercury in fish
  - Dose response functions, and finally, monetization of benefits

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Previous National Power Plant Mercury Studies

- Have not examined thoroughly relationship between dietary methylmercury intake and sources of consumable fish
- Ignored cardiovascular effects

What did this Report Monetize ?

- "Monetized two end points:
  - IQ of children born to mothers with high blood-Hg levels
  - Myocardial infarction and premature mortality among adults

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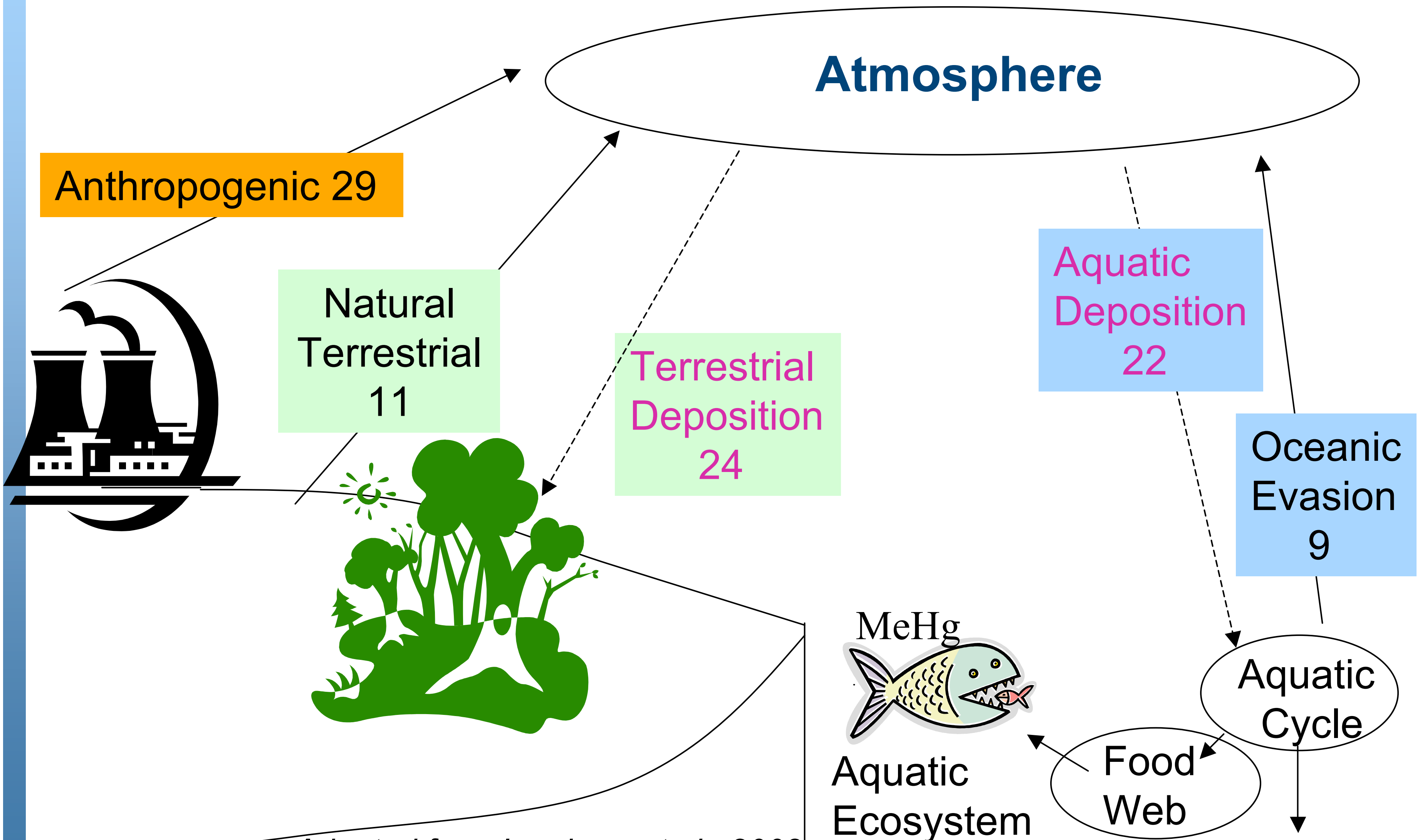
Global Mercury Cycle

Units: 100 tons/yr



Adapted from Lamborg et al., 2002

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Global Sources of Mercury to the Atmosphere (in metric tons per year)

Source	Seigneur et al. 2004	Bergan et al. 1999	Mason & Sheu 2002
Direct Anthropogenic	2143	2160	2400
Recycled Anthropogenic	2134	2000	2090
Total anthropogenic	4277	4160	4490
Natural	2134	1900	2110
Total (% of Anthropogenic Origin)	6411 (67%)	6060 (69%)	6600 (68%)

Most scientists agree on the total input of mercury to the atmosphere and the relative amount of this mercury that has come from anthropogenic sources (about two thirds of the total).

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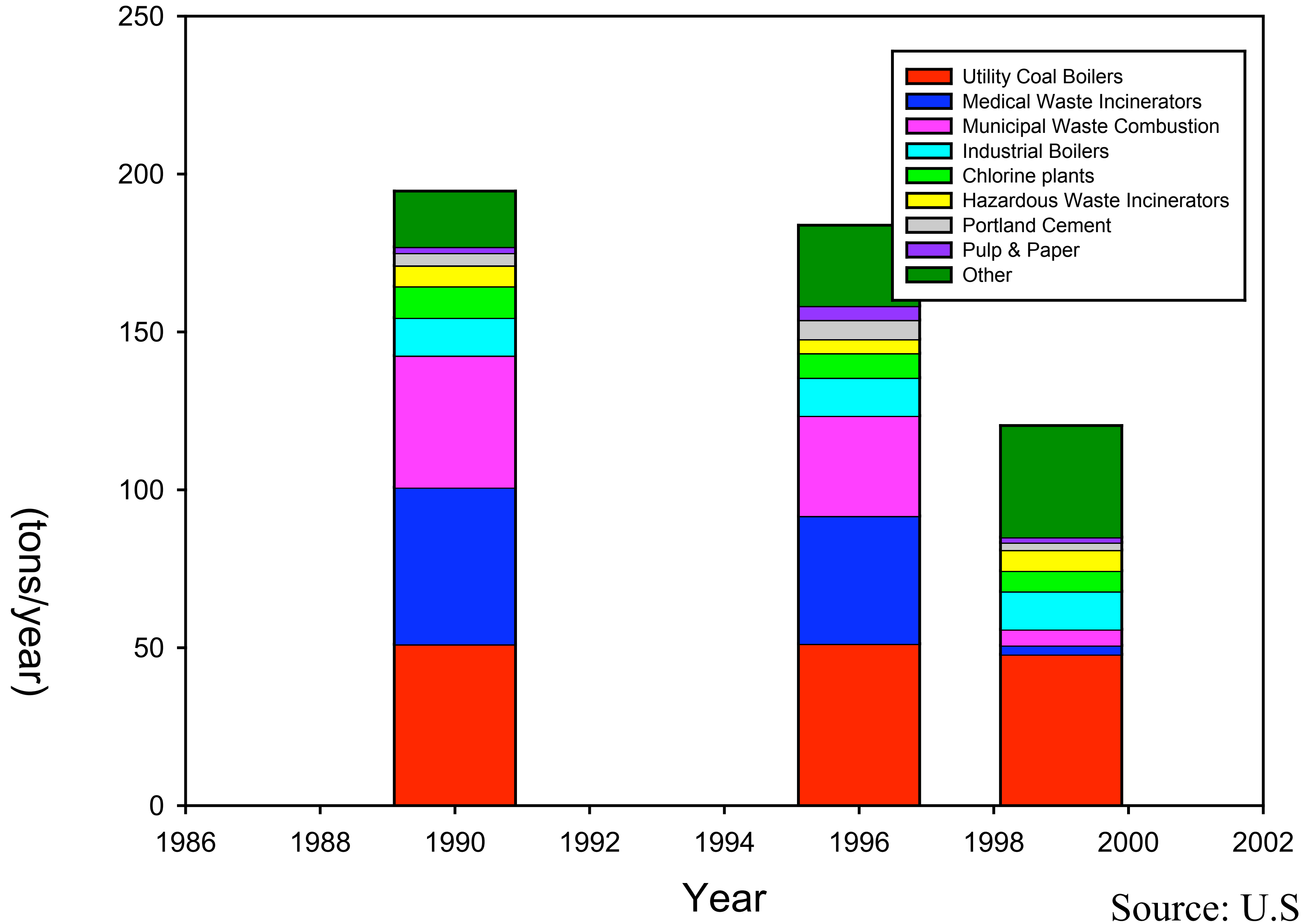
Total U.S. Mercury Emissions by Source Category



Source: U.S. EPA

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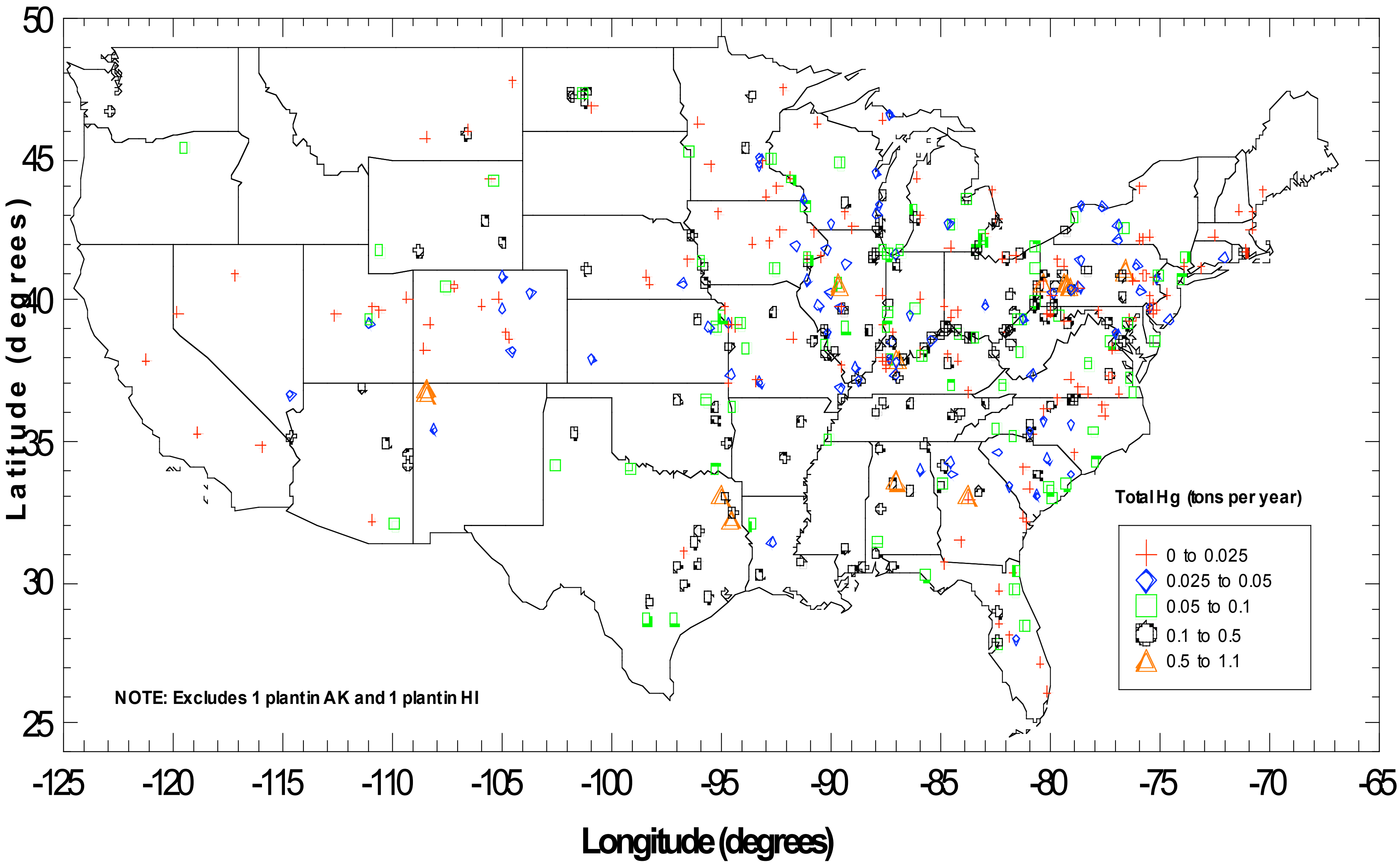
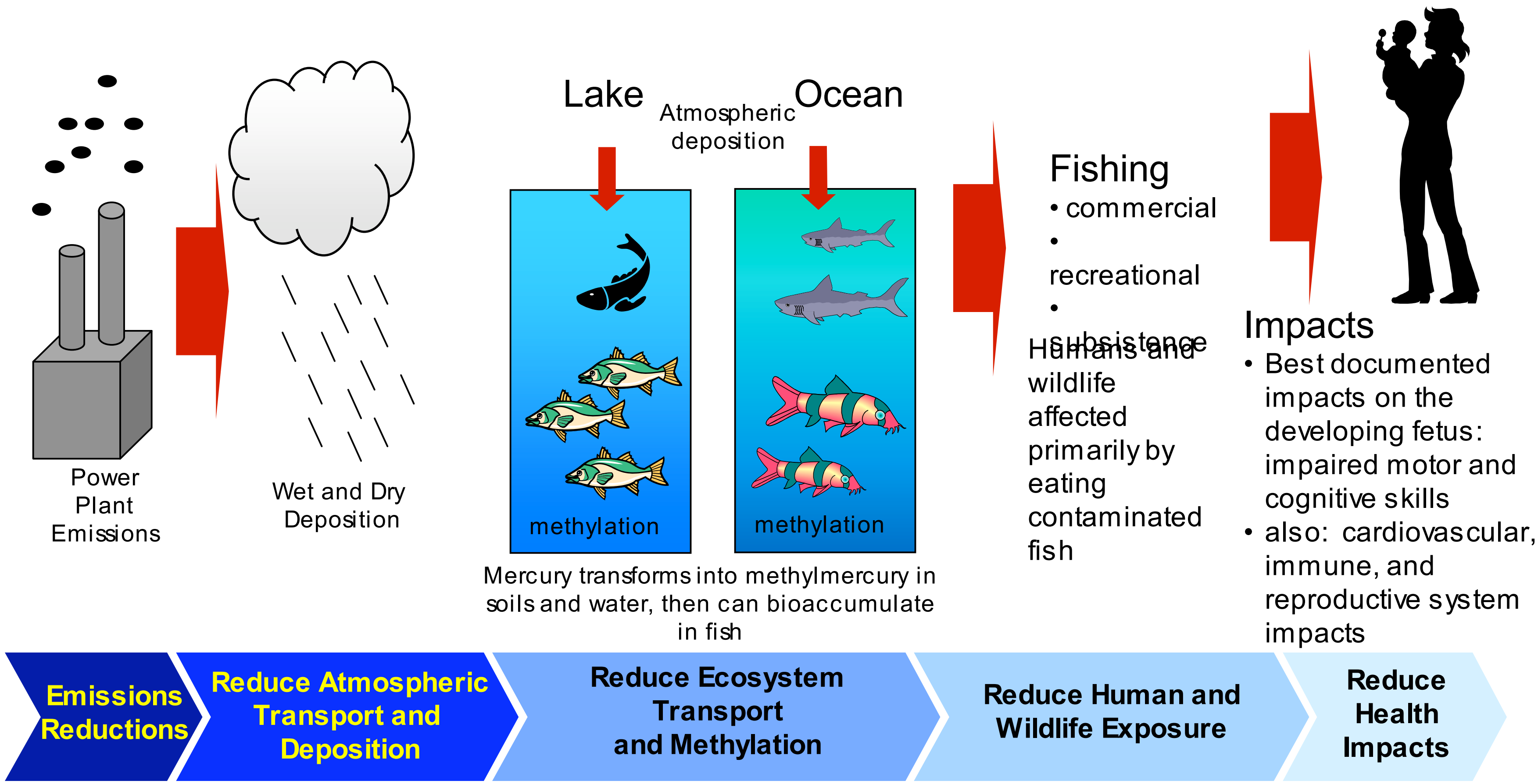
Total Hg Emissions for the 1999 ICR Plants



Mercury Emissions from Power Plants Cause Human Exposure to Mercury



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Blood Methylmercury Concentrations (µg/L) in U.S. Women 16 to 49 Years of Age

Fish Meals prior month[a]	n	50[b]	75	90	95
0	480	--	0.4	1.1	1.6
1-4	780	0.6	1.3	2.9	4.7
5-8	230	1.3	3.3	6.1[c]	9.9
>8	153	2.8	5.2	11	12
Total	1707	0.6	1.7	4.4	6.7

Source: Mahaffey et al., 2004

[a] Fish meal - self-reported number of finfish and shellfish meals in prior 30 days.

[b] percentiles of total blood methylmercury concentration

[C] Shaded values exceed US EPA's methylmercury RfD (5.9 µg/L)

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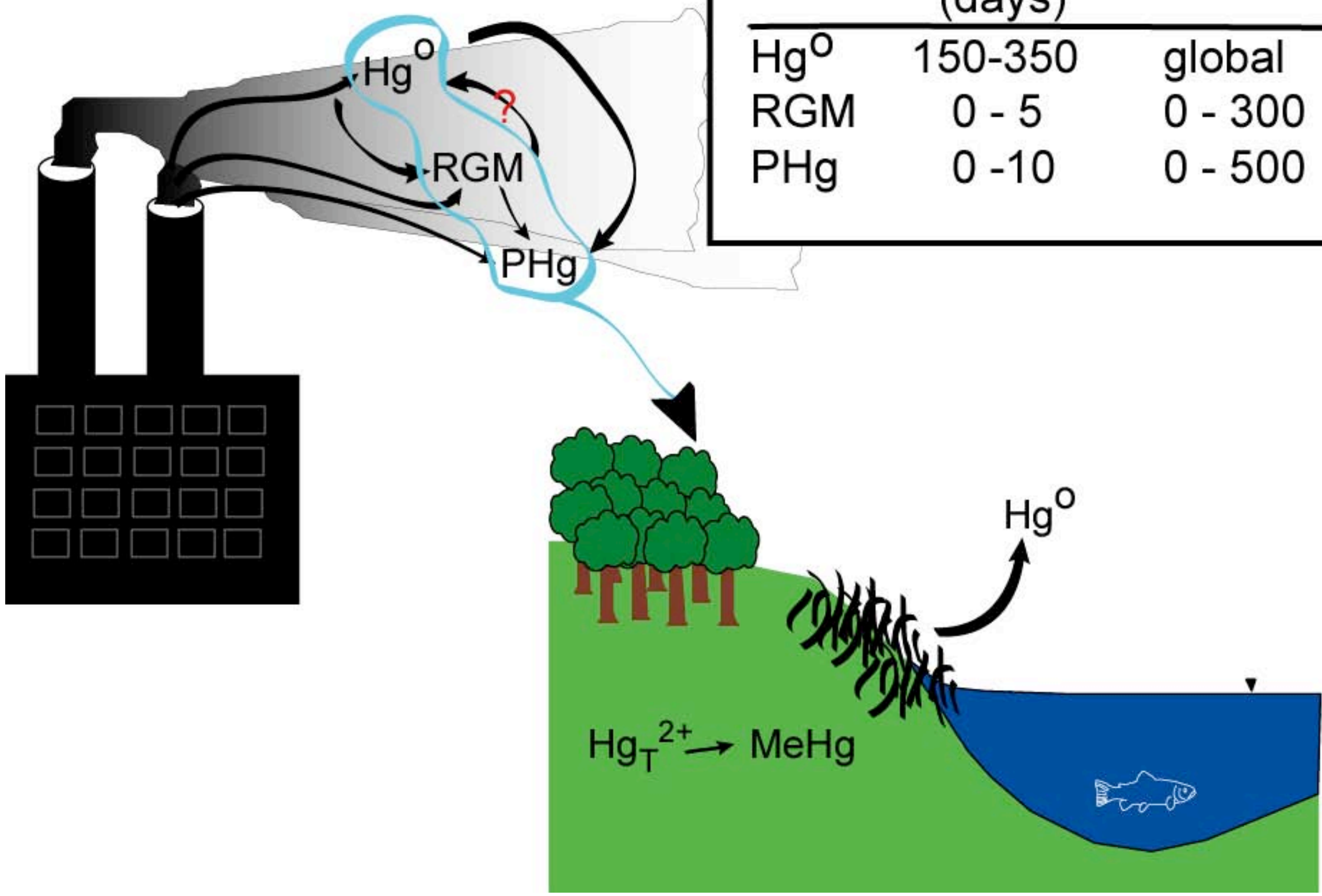
Key Assumptions

- **Equilibria exist between**
  - Mercury deposition rates
  - Fish methylmercury levels
  - Human fish consumption patterns
- **Proportional relationship**
  - Methylmercury concentrations and mercury deposition
- **Hold constant**
  - Emissions from other sources
  - Source waters where fish caught for consumption
  - Types and rates of fish consumed
- **No environmental lag time**
- **Change in methylmercury intake as consequence of change in deposition at location where fish is caught**

Simplified Mercury Cycle

	residence time (days)	distance (km)
Hg^o	150-350	global
RGM	0 - 5	0 - 300
PHg	0 -10	0 - 500



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Speciation of Power Plant Mercury Emissions

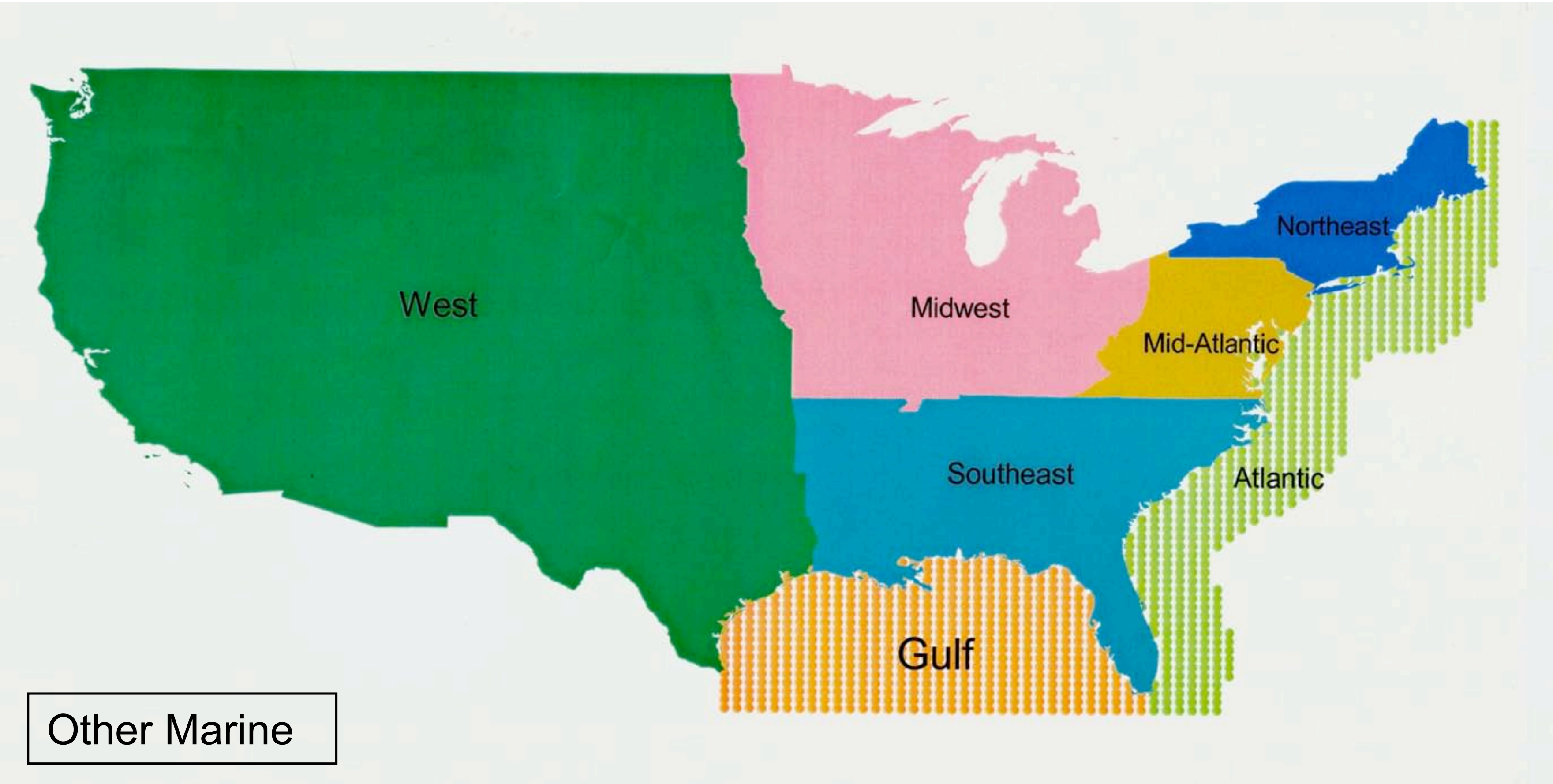
Elemental mercury	5-95%
RGM	5-95%

Use of an average species distribution does not accurately reflect actual variability.

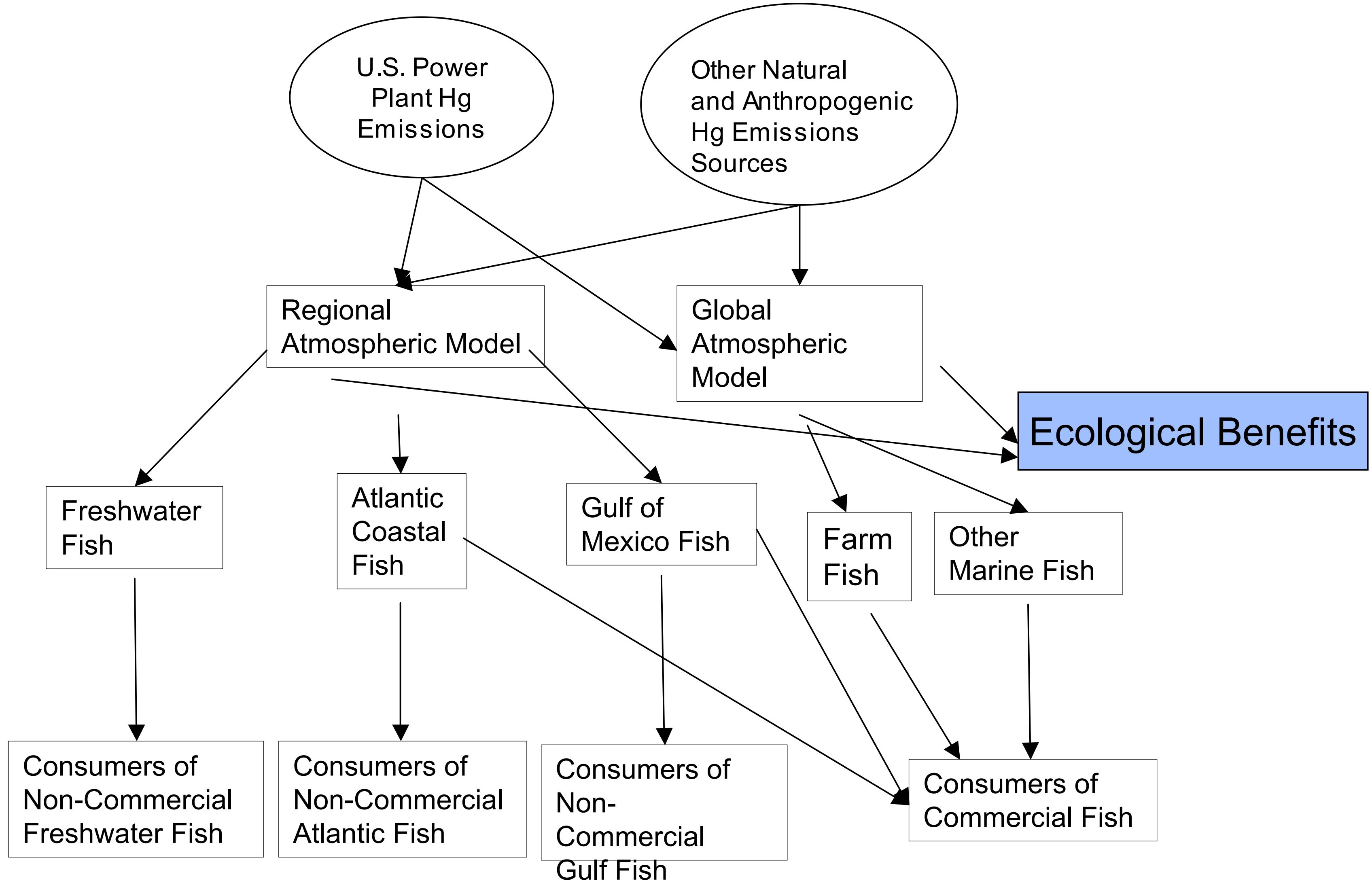
Actual distribution depends on:

- Coal type
- Operating conditions
- Control technology

8 Regions

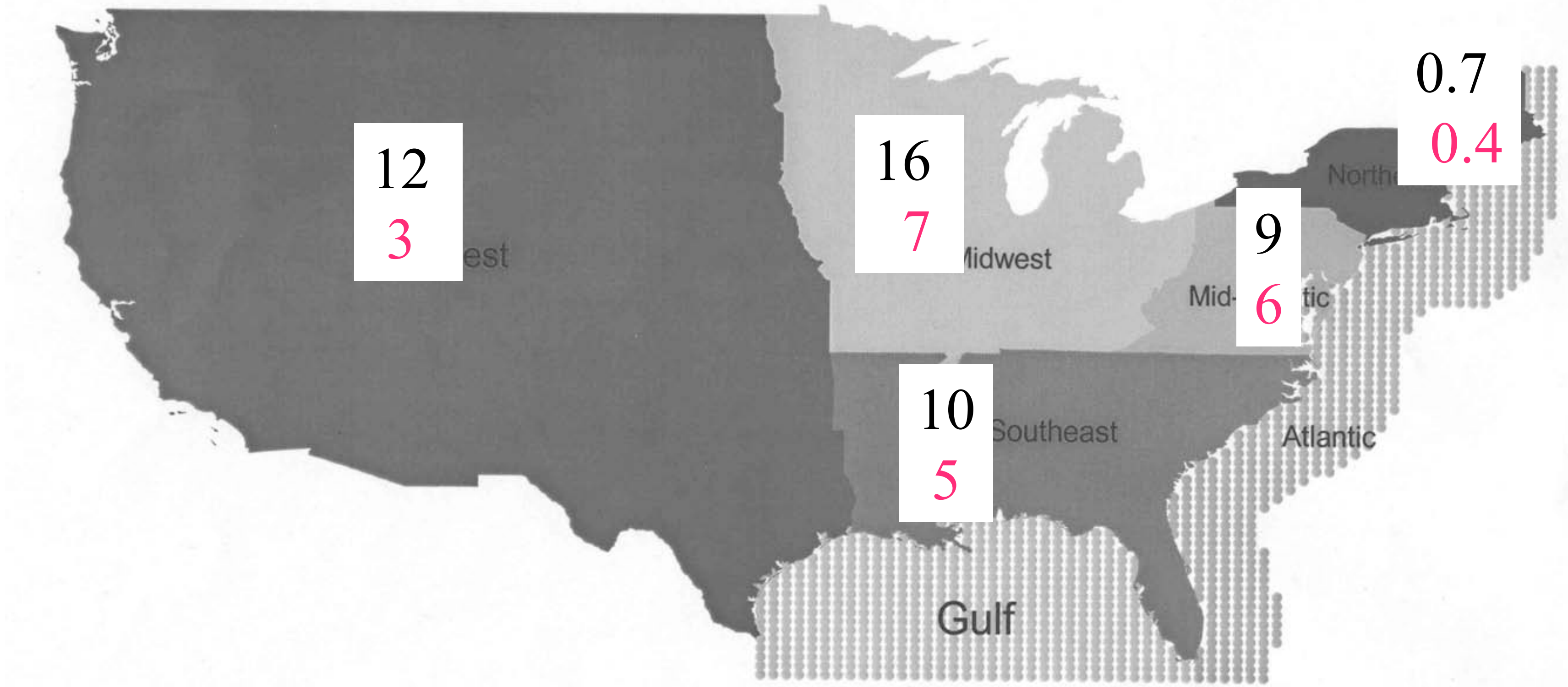

West
Midwest
Northeast
Mid-Atlantic
Southeast
Atlantic
Gulf
Other Marine

Conceptual Model of US Mercury Intake



Source of fish affects ability to reduce methylmercury intakes via emissions controls

Distribution of Power Plant Mercury Emissions by US Region (tons/year): Total VS Hg^{++} and Hg_P



Total Power Plant Mercury Emissions (tons/year)
Power Plant Hg^{++} and Hg_P Emissions (tons/year)

Source: EPA, 2001

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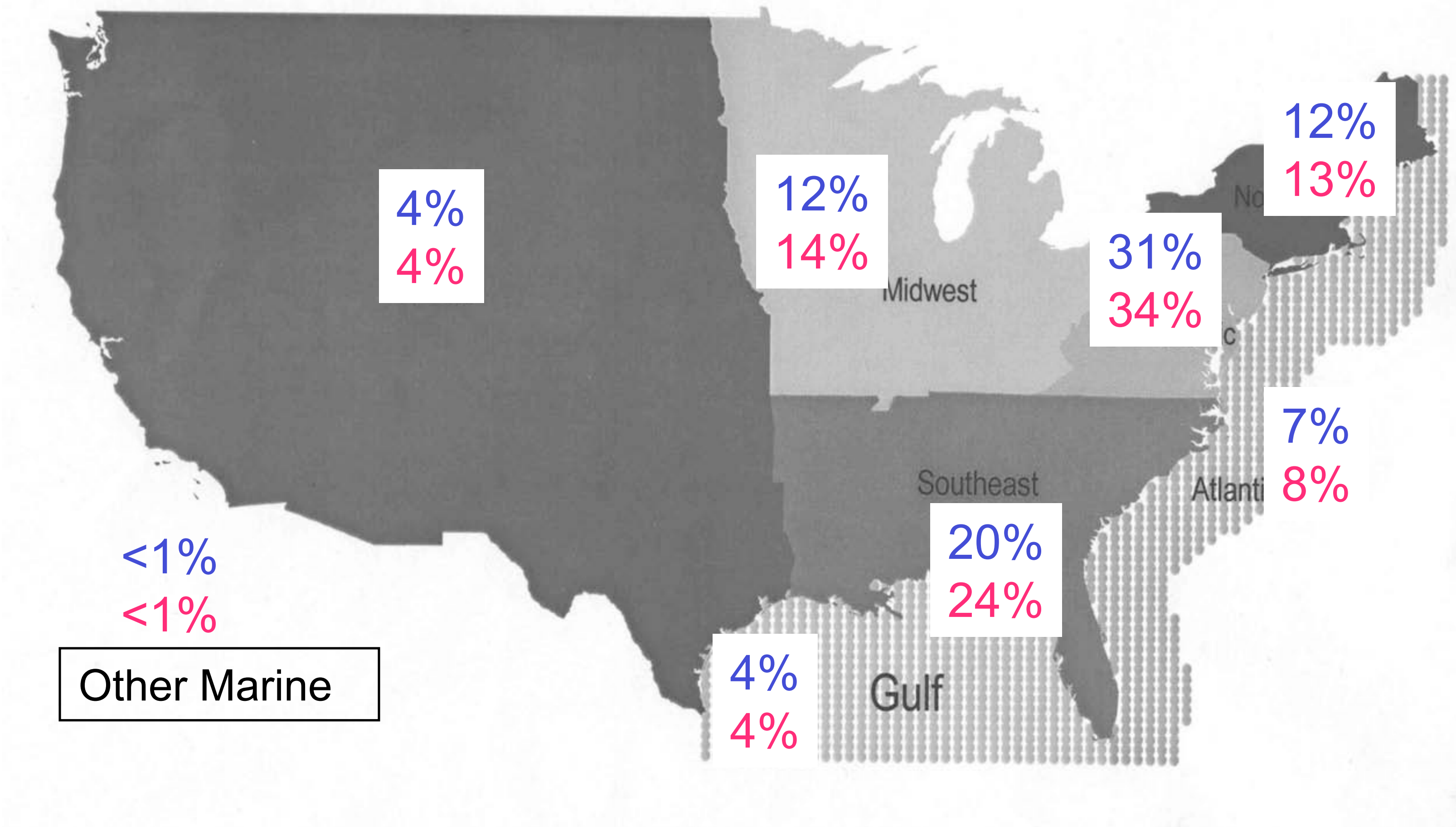
Nationwide Estimates of Changes in Mercury Deposition

- REMSAD model output (EPA, 2003)
- Model inputs include changes in mercury emissions from other sectors
- Power plant responses to regulations, changes in demand, etc. using IPM
- Power plant mercury emissions
  - 49 tons/year (Base case, 2001)
  - 26 tons/year (Clear Skies Act, 2010, Scenario 1)
  - 18 tons/year (Clear Skies Act, 2020, Scenario 2)

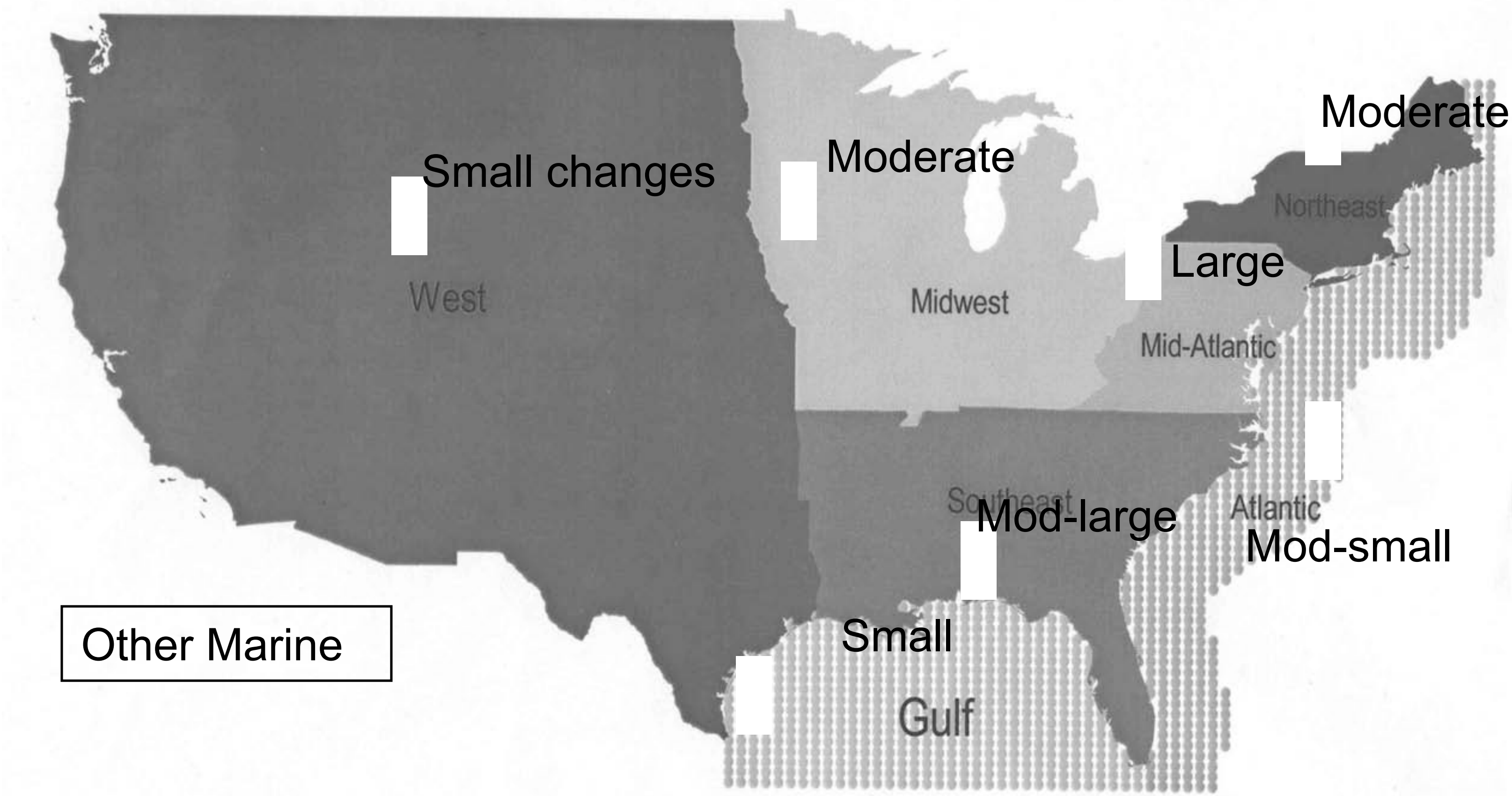
Reducing Annual Power Plant Emissions to 26 tons and 18 tons results in Mercury Deposition Rate Decreases:



Regions Considered in Model

Source: U.S. EPA 2003

Assume: Reducing Mercury Emissions Has Relatively Small Effect on Pacific Deposition, Larger Effect in the East.



Prevalent West-to-East wind patterns

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Predicted Percent Decreases in Mercury Deposition in the Five Freshwater Regions Relative to Current Emissions

	Baseline1	Scenario 1	Baseline 2	Scenario 2
Northeast	Current deposition rate: 12.6 μg/m^2/yr (199 Receptors)			
Average Decrease	9%	12%	9%	13%
Standard deviation	9%	9%	9%	9%
Mid-Atlantic	Current deposition rate: 14.1 μg/m^2/yr (201 Receptors)			
Average Decrease	22%	31%	24%	34%
Standard deviation	12%	12%	12%	12%
Southeast	Current deposition rate: 10.2 μg/m^2/yr (661 Receptors)			
Average Decrease	17%	20%	18%	24%
Standard deviation	12%	12%	13%	12%
Midwest	Current deposition rate: 12.5 μg/m^2/yr (841 Receptors)			
Average Decrease	9%	12%	9%	14%
Standard deviation	7%	9%	8%	10%
West	Current deposition rate: 6.5 μg/m^2/yr (3001 Receptors)			
Average Decrease	3%	4%	3%	4%
Standard deviation	5%	5%	5%	6%

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Predicted Percent Decreases in Mercury Deposition to the Coastal Atlantic Ocean Region, the Gulf of Mexico Region, and All Other Water Regions Under CSI

	Coastal Atlantic Ocean	Gulf of Mexico	All Other Waters
Current Deposition Rate (μg/m^2/yr)	22.6	22.1	NA
Baseline 1	5.87%	3.52%	0.6%
Scenario 1	7.04%	3.89%	1%
Baseline 2	6.00%	3.54%	0.6%
Scenario 2	7.53%	4.29%	1.2%

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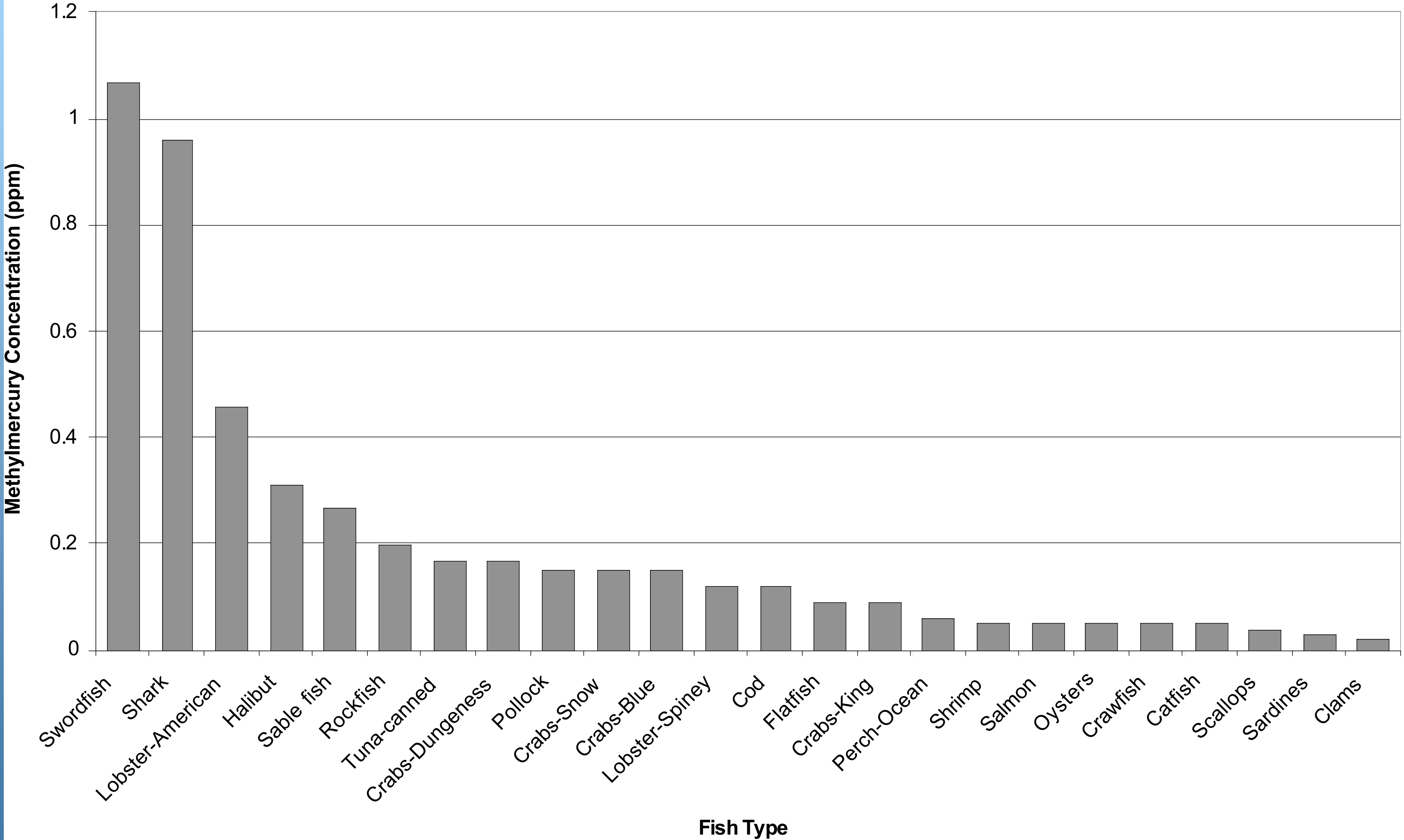
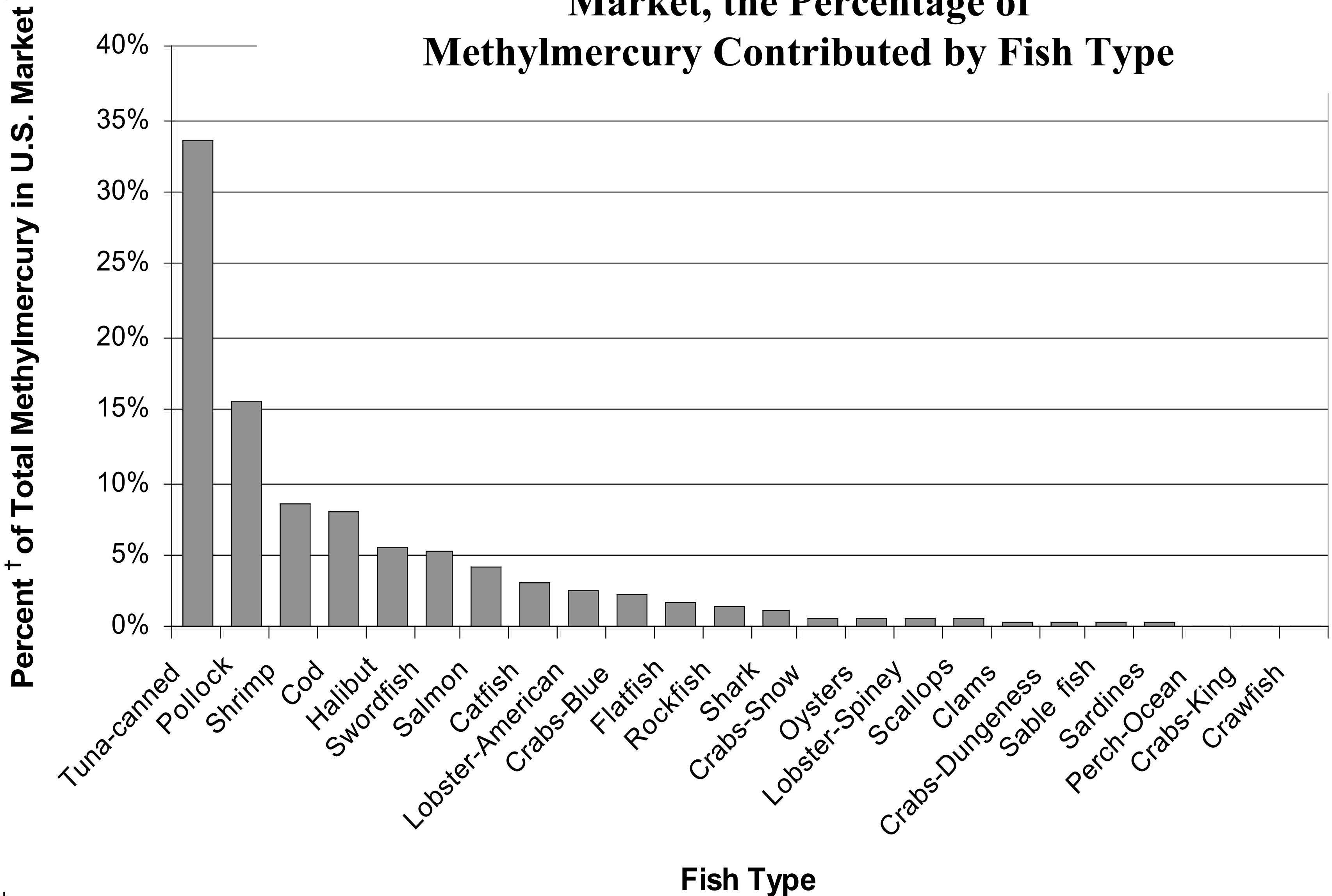
Methylmercury Intake via Commercial Fish Consumption

- Weighted mean methylmercury concentration: commercial fish
  - weighted by per capita consumption (Carrington and Bolger, 2002)
  - weighted by proportion of fish caught in each source water (NMFS, 2002)
- Predicted mercury deposition decreases used to estimate decrease in mean methylmercury concentration by fish type and source water
- Approach assumes commercial fish consumers diet well mixed
  - eat variety of commercial fish (reflected by per capita data)
  - eat fish from a variety of source waters (reflect NMFS, 2002)
- Assume NHANES blood methylmercury concentration distribution in U.S. females of reproductive age is reasonable surrogate for oral intake
  - (methylmercury 1-compartment toxicokinetic model)
  - (NHANES data as reported in Mahaffey et al., 2003)

Average Methylmercury Concentrations for "Top 24" Types of Fish Consumed in the U.S. Commercial Seafood Market



For "Top 24" Types of Fish in U.S. Commercial Seafood Market, the Percentage of Methylmercury Contributed by Fish Type



† Estimate based on the product of per capita fish consumption rates and mean methylmercury concentrations of each type of fish (Carrington and Bolger, 2002)

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Methylmercury Intake via Non-Commercial Freshwater Fish Consumption cont.

- Fish consumption rate Distributions for composite freshwater fish consumers
  - (EPA, 1997)
- Implemented through Monte Carlo Approach
- Size of freshwater fish consuming population based on U.S. FWS
- Allocation of freshwater fishers to regions
  - days fished in each State
  - aggregate by region

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Methylmercury intake via Non-Commercial Marine Fish

- Step 1: Derive Weighted Mean methylmercury concentration for typical fish
    - Atlantic Ocean
    - Gulf of Mexico
        - Weighted by recreational catch mass by fish type (NMFS, 2002)
        - Mean fish methylmercury concentrations (EPA, 2003)
    - Assume reasonable for non-commercial fish

- Step 2: Calculate future fish methylmercury concentrations
  - Current mean concentrations
  - ratio of present and future deposition rates
    - Assume
      - mercury depositing in these waters is well-mixed
      - non-commercial fish consumers diet well mixed

- Step 3: Fish consumption rates for angler populations (EPA, 1997)

- Step 4: Estimated population sizes (NMFS and FWS)

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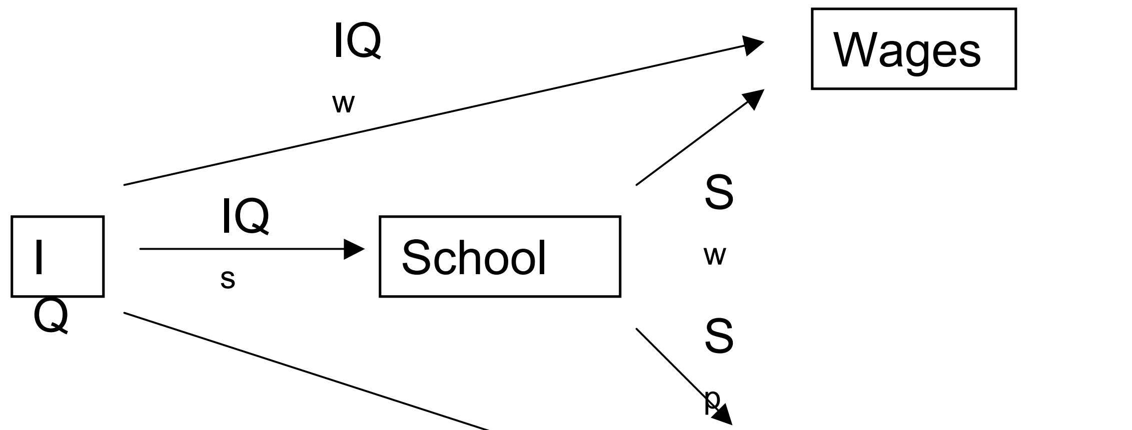
Additional Comments on Non-Commercial Consumers

- 80% of anglers consume their catch
  - EPA, 1997
- On average anglers share catch with 1.5 others
  - EPA, 1997

Persistent IQ Decreases via *in utero* Exposures COI (2000$)

- ΔIQ = -0.5 IQ points/ 1 ppm hair mercury (New Zealand)
- With and Without Threshold of 0.1 μg/kg/day
- Cost-of-Illness Approach: $16,500/ IQ point (2000$)



Key:

IQ_W	effect of IQ on wage
IQ_S	effect of IQ on scholastic achievement
IQ_P	effect of IQ on work force participation
S_W	effect of scholastic achievement on wages
S_P	effect of schooling on participation

-Adapted from Salkever, 1995; Schwartz, 1994

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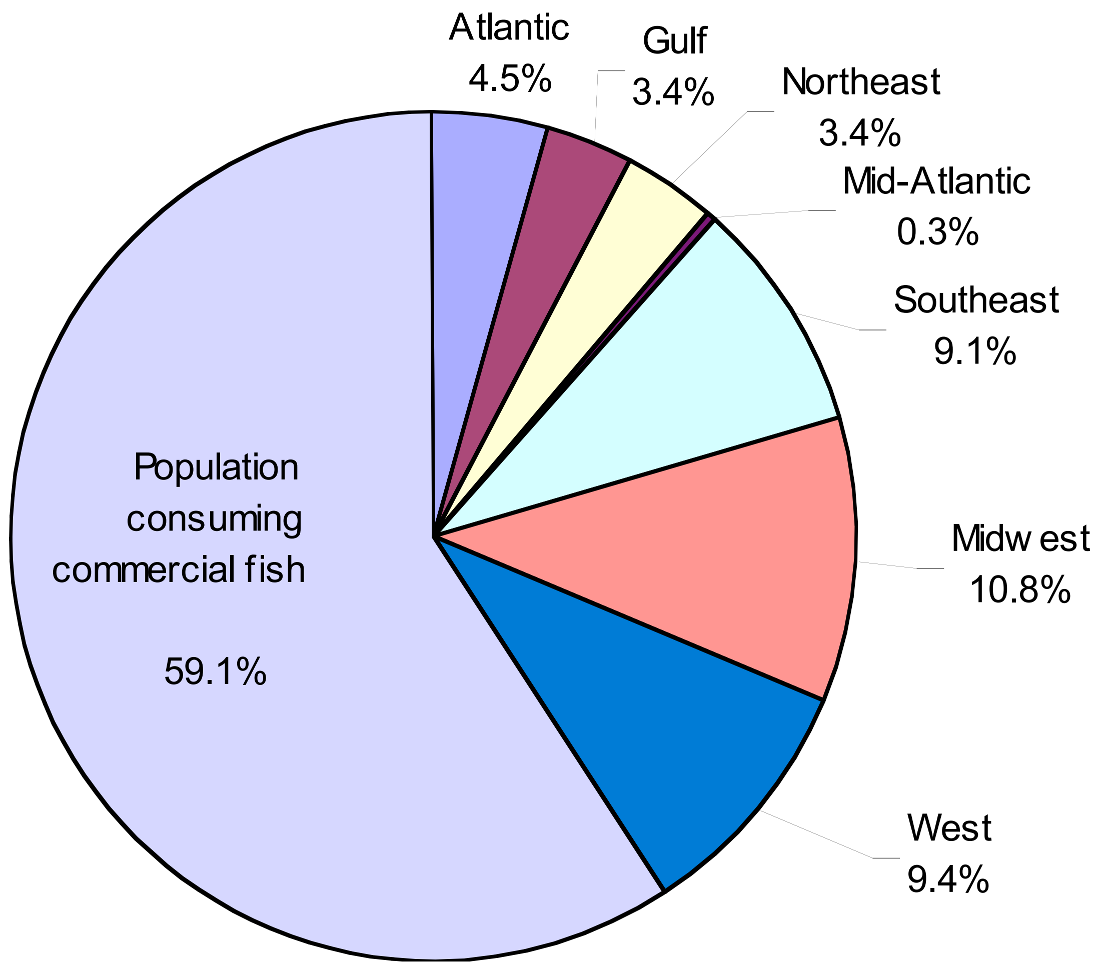
Fractional Contribution of Consumers of Non-Commercial Fish in Each Region and Commercial Fish to Total IQ Point Loss, Assuming No Neurotoxicity Threshold



EPA Methylmercury RfD

- EPA's Position (general scientific consensus) low-dose fetal neurotoxicity is a credible effect
- Outcome: neurological impairment in 7 year-olds
  - Faroe Islands and New Zealand studies
  - Faroe study: 1 change persists in 14 year-olds
- Exposure: Intrauterine methylmercury
- Central tendency
  - $BMDL_{05}$ = 0.6 µg/kg day ⟶ 1 µg/kg day
- Composite Uncertainty Factor = 10
- RfD = 1E-4 mg/kg/day

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Methylmercury Threshold

- Functional form

$D \leq T$,	$P(D) = 0$
$D > T$,	$P(D) = m \times (D - T)$

Where:

P(D)	Probability of effect at dose D
T	Population toxicity threshold (µg/kg/day)
D	average dose (µg/kg/day)
m(*)	slope dose-response function for (per µg/kg/day)

- Threshold may be between 0 and 1 µg/kg/day Illustrate assuming threshold of 0.1 µg/kg/day (RfD)

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Mercury Cardiovascular Toxicity

Salonen, 1995

- n = 1833 Male Finns, aged 42-60 years
- Estimated mean hair concentrations = 1.9 ppm, included 7 year follow-up
- Freshwater fish: high methylmercury and low polyunsaturated fatty acids concentrations

Rissanen 2000 - methylmercury intake may attenuate benefits of polyunsaturated fatty acids

Salonen 2000 - methylmercury may promote progression of arteriosclerosis (carotid thickening)

Salonen	Fatal and Nonfatal AMI			All Cause Mortality		
Model	RR	p value	95% CI	RR	p value	95% CI
Hair Mercury (ppm)	1.07	0.18	0.97, 1.2	1.09	0.04	>1.00, 1.19
Hair Mercury (>2 ppm)	1.69	0.04	1.03, 2.76	1.93	0.01	1.2, 3.1

Difficult to separate cardioprotective components from potentially harmful components in epidemiology studies.

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Relative Risk of Acute Coronary Events Based on Serum Fatty Acid Composition, Stratified by Hair Mercury Levels

	Quintiles, by Proportion of Serum Fatty Acids comprised of DHA and DPA				
Hair mercury concentration	<2.4%	2.4%-2.7%	2.7%-3.1%	3.1%-3.6%	>3.6%
< 2 ppm	0.9	0.5	0.5	0.4	0.3
> 2 ppm	1.0	0.8	0.6	0.8	0.8

DHA = Docosahexaenoic Acid
DPA = Docosapentanoic Acid
DHA and DPA are fish-derived fatty acids

Source Rissanen, 2000

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Spectrum of Health Effect Weight-of-Evidence

- Persistent IQ deficits from fetal exposures above MeHg RfD
- Persistent IQ deficits in all children from fetal MeHg exposures
- Cardiovascular effects and premature mortality in male consumers of non-fatty freshwater fish with high MeHg levels
- Cardiovascular effects and premature mortality in male fish consumers
- Cardiovascular effects and premature mortality in all fish consumers

Decreasing Weight-of-Evidence →

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Summary of Cost-of-Illness and Value-of-Statistical Life Approaches for Neurotoxicity and Cardiovascular Toxicity

	Neurotoxicity Threshold	No Neurotoxicity Threshold	Costs AMI+ ACM (VSL) Male Pike Consumers	Costs AMI+ ACM (COI)	Costs AMI+ ACM (VSL)
Scenario 1	$75,311,000	$193,940,000	$48,436,000	$154,814,000	$3,286,000,000
Scenario 2	$119,002,000	$288,247,000	$86,713,000	$231,244,000	$4,907,000,000
Scenario 1 Summary of neurotoxicity costs and cardiovascular toxicity costs (no threshold)			$242,376,000	$348,754,000	$3,480,000,000
Scenario 2 Summary neurotoxicity costs and cardiovascular toxicity costs (no threshold)			$374,959,000	$519,491,000	$5,195,000,000

Spectrum of Health Effect Certainty

	Persistent IQ deficits from fetal exposures above MeHg RfD	Persistent IQ deficits in all children from fetal MeHg exposures	Cardiovascular effects and premature mortality in male consumers of non -fatty freshwater fish with high MeHg levels	Cardiovascular effects and premature mortality in male fish consumers	Cardiovascular effects and premature mortality in all fish consumers
Scenario 1 (26 TPY)	$75M	$194M	$48M	$1.5B	$3.3B
Scenario 2 (18 TPY)	$119M	$288M	$86M	$2.3B	$4.9B

Decreasing Certainty

→

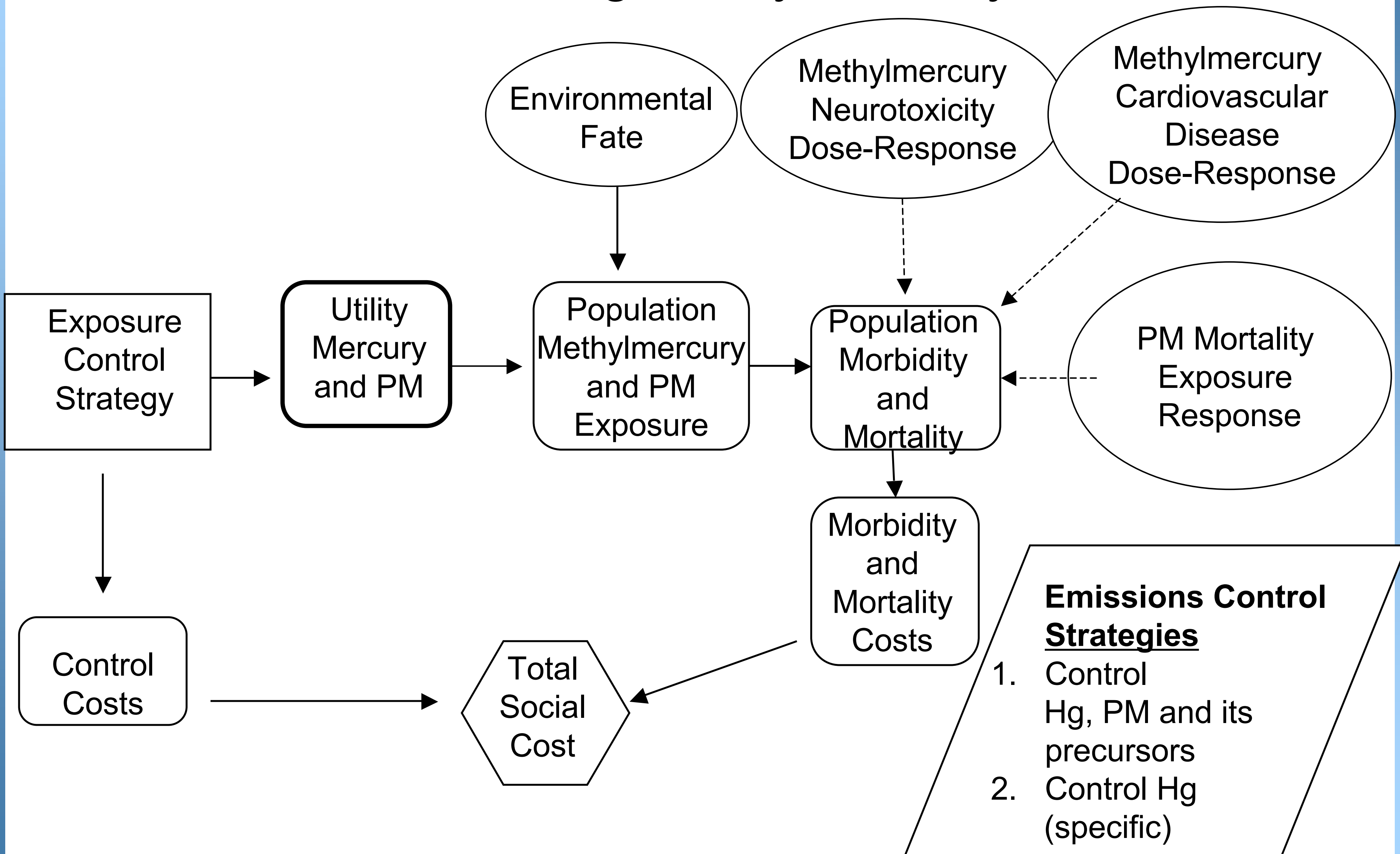
Increasing Benefit

Spectrum of Certainty of Causal Association of Health Effect with Mercury Exposure with Estimated Benefit Overlay in Millions ($M) and Billions ($B) of Dollars (2000$)

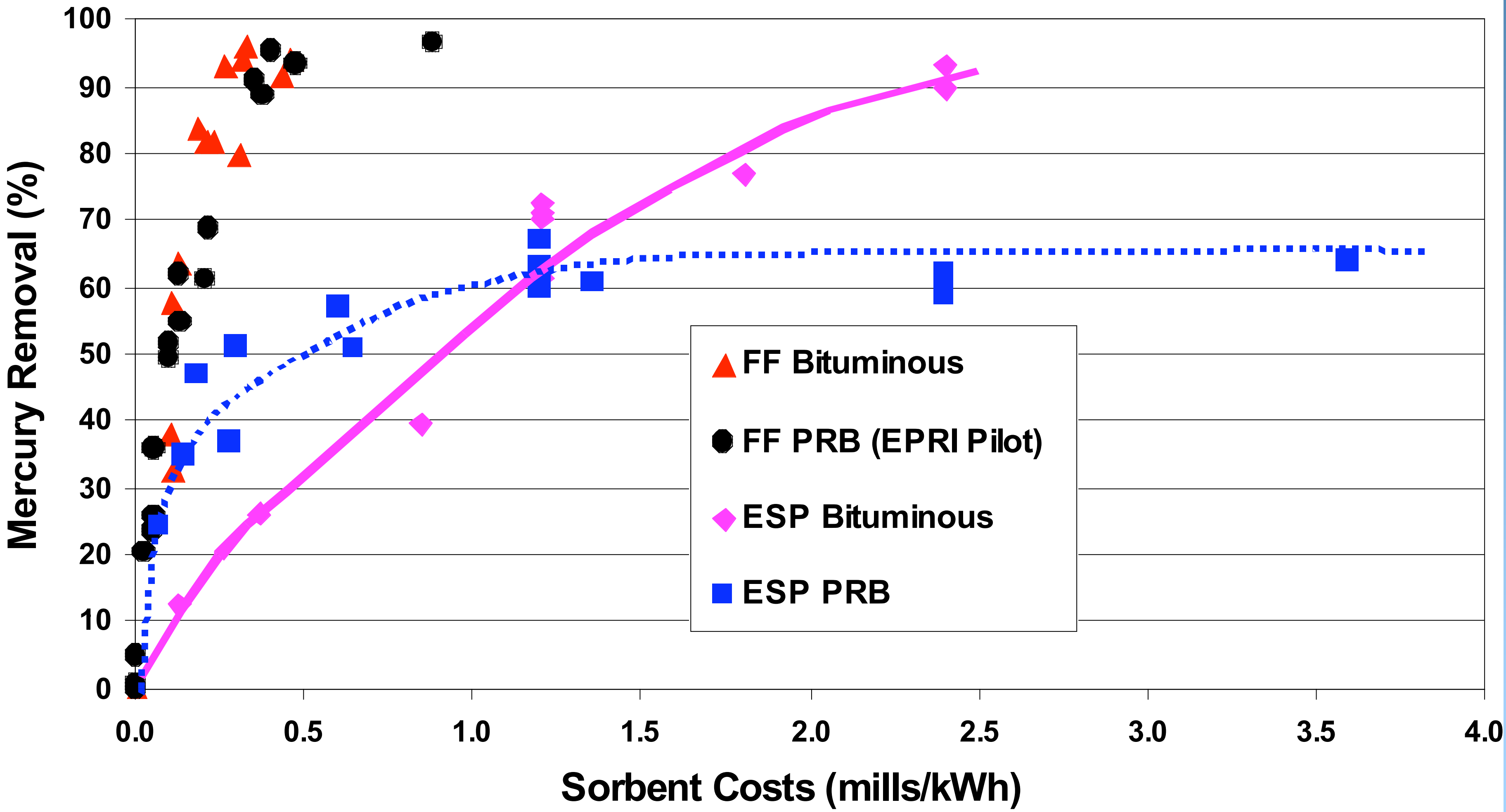
Value of Monetized Benefits for about 70 percent control

- Annual Benefits: 100 to 300 million dollars for IQ gain
- Annual benefits: 3 to 5 Billion dollars for avoided mortality and avoided non-fatal CHD

Moving Forward…Influence Diagram for Controlling Methylmercury Intake



Cost and Performance of Sorbent-Based Mercury Control



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Some Observations on Policy

- Many states in the U.S. are moving at a faster and a more certain pace than the federal regulation, based on the assumption that environmental regulation drives technology innovation and implementation
- Hg Control technologies are now commercially available; new technologies are rapidly emerging; 90% and higher control is feasible
- Cost effectiveness of Hg control is quite comparable to, and more attractive than, the cost effectiveness of SO_2 and NOx controls from power plants ($Hg:SO_2:NOx$:1 to 3 mills/kwhr: 3-5 mills/kwhr: 2-3 mills/kwhr)

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Some Observations: Effect on Global Climate Change

- "Hg co-benefits" through control of SO_2 with wet and dry scrubbers has substantial effect on sulfate aerosols (40 percent of fine PM mass in the U.S.)
- Application of bag houses (fabric filters) instead of or in addition to ESPs to control Hg results in large reductions in primary PM emissions