

Health and Economic Consequences of Mercury Pollution in America

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The Mercury Cycle

- Ubiquitous environmental toxicant
 - Volcanoes and other natural sources release some elemental mercury to the environment
 - Anthropogenic emissions now account for approximately 70% of the 5500 metric tons of mercury that are released into the earth's atmosphere each year
 - Coal-fired power plants, chlorine plants, incinerators
- Three forms: the metallic element, inorganic salts, and organic compounds (methylmercury, ethylmercury and phenylmercury)
 - each possesses different bioavailability and toxicity

Mercury in the Environment

- Elemental mercury readily aerosolized
- Once airborne deposits into soil and water
- Transformed within microorganisms into methylmercury
- Microorganisms subsequently consumed by fish, which are in turn eaten by larger fish
- Methylmercury reaches very high concentrations in predatory fish such as swordfish, tuna, king mackerel and shark
- *Consumption of contaminated fish is the major route of human exposure to methylmercury.*

Evidence for Methylmercury Toxicity in American children

- Strongest evidence for cognitive impacts
- New Zealand: three-point IQ loss in Wechsler full-scale IQ among children born to women with maternal hair Hg > 6 $\mu\text{g/g}$ (Kjellstrom et al 1986 and 1989)
- Seychelles: only adverse association with performance on grooved pegboard test with nonpreferred hand (one of few measures not confounded by language/cultural translation) (Myers et al 2003, Landrigan and Goldman 2003)
- Faroe Islands: dose-related, adverse associations with wide range of memory, attention, language and visual-spatial tests (even when controlled for PCBs) (Grandjean et al 1997)

NAS report: *Toxicological Effects of Methylmercury*

- Strong evidence for fetal neurotoxicity of methylmercury, even at low concentrations of exposure
- All three studies credible, but not deterred by negative findings of Seychelles (50% statistical power for range of exposures in which effects occur)
- NAS chose to base recommended safety threshold for methylmercury on Faroe Islands

(NRC 2000)

NAS recommendation

- Recommended to EPA choice of a benchmark cord blood mercury concentration of 58 $\mu\text{g/L}$
 - Level corresponds to doubling of clinically subnormal scores for Boston Naming Test
- Faroes and New Zealand studies support conclusion that effects occur as low as 1 ppm hair Hg (5.8 $\mu\text{g/L}$ cord blood) (Grandjean et al 1997; Kjellstrom et al 1986 and 1989)
 - Delays in brainstem auditory responses occur at much lower concentrations (Murata et al 2004)

Exposure to MeHg in US children

- 1999-2000 NHANES:
 - 7.8% of women of childbearing age with total blood mercury concentration $\geq 5.8 \mu\text{g/L}$ (Mahaffey et al 2004)
- Recent metaanalysis suggests cord/maternal blood mercury ratio = 1.7 (CI 1.0-3.4) (Stern and Smith 2004)
 - $5.8/1.4 = 3.41 \mu\text{g/L}$
 - 15.7% of women of childbearing age with total blood mercury concentration $\geq 3.5 \mu\text{g/L}$ (Mahaffey et al 2004)

Previous Work

- Estimated IQ decrements resulting from children born with cord blood $\geq 5.8 \mu\text{g/L}$ in 2000 US birth cohort
 - Base case assumptions: 1.5 IQ point decrease/doubling, 1.7 cord/maternal blood concentration, 70% attributable to anthropogenic emissions
 - Used published percentiles of total mercury concentrations $\geq 3.5 \mu\text{g/L}$ (Mahaffey et al 2004)

Previous Work

- Converted to cost of loss economic productivity using preexisting relationships between loss in IQ and lost lifetime economic productivity
 - 1.931% in men, 3.225% in women (Salkever 1995; Schwartz et al 1985)
 - Lifetime income of boy born in 2000 \$1,032,002; lifetime income of girl \$763,468 (Max et al 2002)

Results

Table 1. Cost of anthropogenic mercury (Hg) exposure using a logarithmic model.

| Variable | Segment of population (percentile) | | | |
|--|------------------------------------|---------------|----------------|---------------|
| | 90–92.1 Hg | 92.2–94.9 Hg | 95–99.3 Hg | ≥ 99.4 Hg |
| Range of maternal total Hg concentration | 4.84–5.8 µg/L | 5.8–7.13 µg/L | 7.13–15.0 µg/L | > 15.0 µg/L |
| Assumed maternal total Hg concentration | 4.84 | 5.8 | 7.13 | 15 |
| No effect concentration (maternal total Hg) | 3.41 | 3.41 | 3.41 | 3.41 |
| IQ points lost at assumed concentration | 0.76 | 1.15 | 1.60 | 3.21 |
| Loss of 1 IQ points = decrease in lifetime earnings | | | | |
| For boys, lifetime earnings (1.931% decrease) | | | \$1,032,002 | |
| For girls, lifetime earnings (3.225% decrease) | | | \$763,468 | |
| No. of boys in birth cohort affected | 45,693 | 58,155 | 91,387 | 12,462 |
| No. of girls in birth cohort affected | 43,601 | 55,492 | 87,201 | 11,891 |
| Lost income | \$1.1 billion | \$2.0 billion | \$4.4 billion | \$1.2 billion |
| Total cost = \$8.7 billion in each year's birth cohort | | | | |

Assumptions: EAF = 70%, main consequence = loss of IQ over lifetime.

Sensitivity Analysis

Table 2. Sensitivity analysis: cost of anthropogenic methyl mercury exposure.

| Variable | Base-case cost estimate (range)* |
|---|--------------------------------------|
| Children born to women with Hg > 4.84 µg/L, effect > 3.5 µg/L | |
| Logarithmic model | \$8.7 billion (\$4.9–13.9 billion) |
| Linear model, cord:maternal Hg ratio = 1.7 | \$32.9 billion (\$20.9–43.8 billion) |
| Linear model, cord:maternal Hg ratio = 1 | \$19.3 billion (\$12.3–25.8 billion) |
| Children born to women with > 5.8 µg/L, effect > 4.84 µg/L | |
| Logarithmic model | \$3.9 billion (\$2.2–6.3 billion) |
| Linear model, cord:maternal Hg ratio = 1.7 | \$18.7 billion (\$11.9–24.9 billion) |
| Linear model, cord:maternal Hg ratio = 1 | \$11.0 billion (\$7.0–14.6 billion) |
| Range of estimates | |
| Logarithmic model | \$2.2–13.9 billion |
| Linear model | \$7.0–43.8 billion |

Assumptions: EAF = 70%, main consequence = loss of IQ over lifetime.

*Based on range of possible IQ decrement:increase cord blood mercury.

Cost of anthropogenic Hg exposure:

\$2.2-43.8 billion

- Varied IQ impact from .85-2.4 points/doubling
- Applied linear model used by NAS (.59-1.24 IQ points per µg/L increase)
- Varied cord/maternal blood Hg ratio from 1-1.7

What is Attributable to American Sources?

In 1995, 158 tons of mercury were emitted to the atmosphere by American anthropogenic sources.

- Fifty-two (33%) of those tons were deposited in the lower 48 states.
- An additional 35 tons of mercury from the global reservoir were deposited in the United States.
- Therefore, a total of 87 total tons of mercury were deposited in the United States in that year, of which 60% (52 of 87) would have been available to bioaccumulate in the marine and aquatic food chains and to enter American freshwater and saltwater fish. (U.S. EPA 2004)

Of the 10.4 billion pounds of edible fish supplied in the United States in 2002, 4.4 billion (42%) are imported from sources outside of the United States (National Marine Fisheries Service 2002).

- In the remaining 58% of fish consumed in the United States, we calculate that 60% of the mercury content comes from American anthropogenic sources.

Imported Fish Mercury Content

158 tons of American emissions –

52 tons of American mercury deposited on American soil = 106

106 tons of American mercury available to contaminate imported fish = _____

5,413

5,500 tons emitted globally –

87 tons deposited on American soil

= 5,413 tons of mercury from all sources to contaminate imported fish

= 0.02, or 2% of mercury in imported fish of American origin

American Fish Mercury Content

We therefore applied a 36% factor (the weighted average of American sources of mercury content in fish, or $0.6 \times 0.58 + 0.02 \times 0.42$) to calculate the economic costs of anthropogenic methyl mercury exposure attributable to American sources.

Modeling supported by the Electric Power Resource Institute (EPRI) estimates that 70% of the mercury deposited in the United States comes from foreign sources

In this model, U.S. sources are responsible for > 60% of mercury deposition in the Boston–Washington, D.C. corridor.

In one of the model's selected receptor areas — Pines Lake, New Jersey — **80%** of the deposition originated from U.S. sources, showing that regional deposition can be higher than the 60% number we use in our base case analysis.

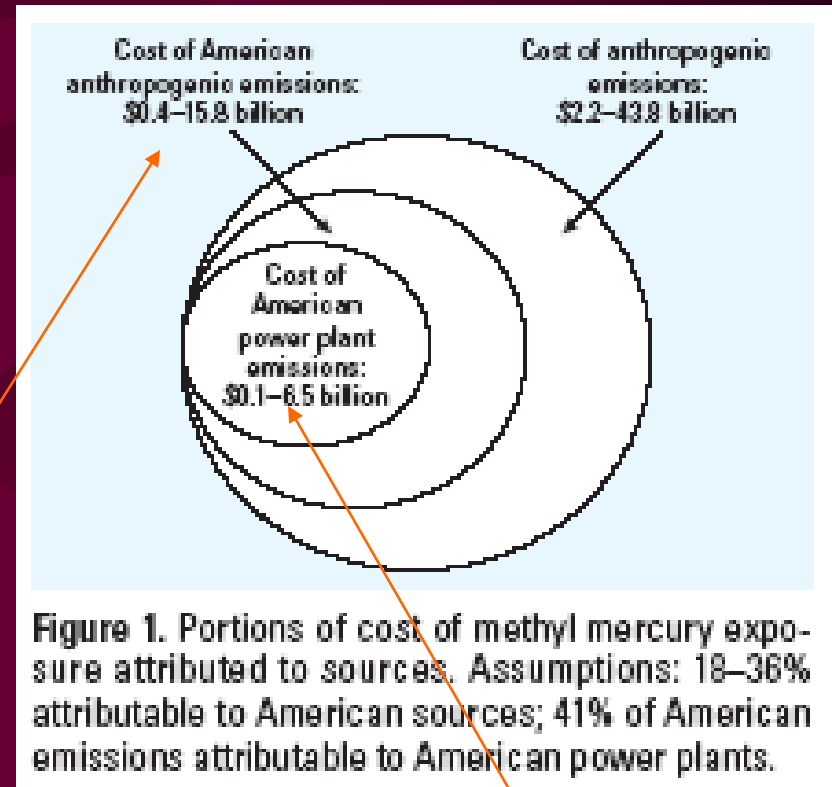
(Seigneur et al. 2004)

In our sensitivity analysis, we varied the factor used to convert the economic cost of anthropogenic methyl mercury exposure to the economic cost attributable to American sources from 18% ($0.3 \times 0.58 + 0.02 \times 0.42$, using EPRI's modeling) to 36% (using federal data on mercury deposition).

American Sources and Coal-Fired Power Plants

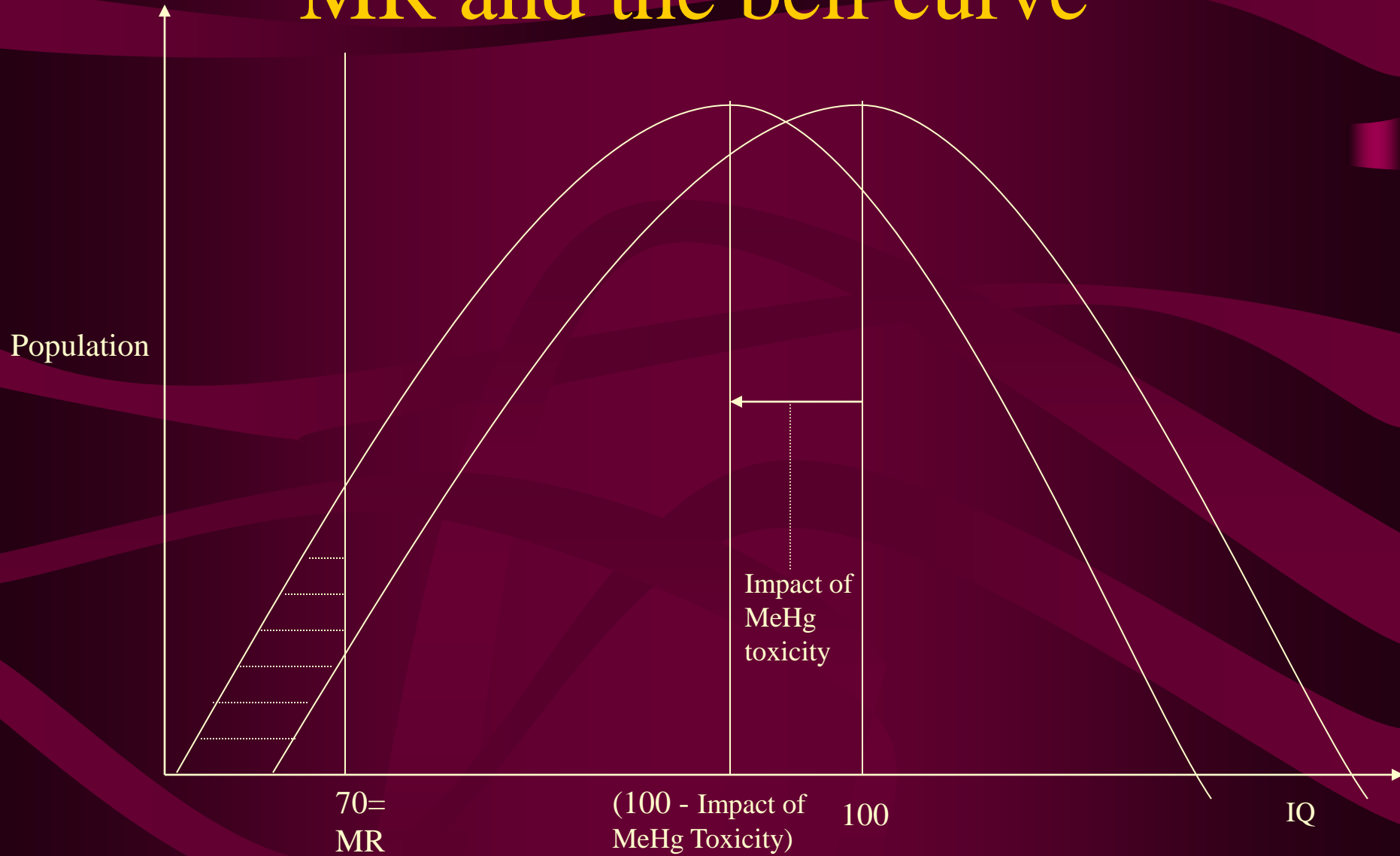
In 1999, the most recent year for which data on American mercury emissions are available, 48 (41%) of the 117 tons of mercury emissions from anthropogenic sources in the United States were emitted by electric power generation facilities (U.S. EPA 2003a).

Base case: \$3.1 billion



Base case: \$1.3 billion

MR and the bell curve



Mental Retardation

- This analysis did not include the cost of cases of mental retardation that can result from loss of cognition, especially those children who are most highly exposed to methylmercury from anthropogenic sources.
- To further assess the costs that may result from exposure of the developing brain to methylmercury, we estimated the burden and cost of mental retardation associated with anthropogenic methylmercury exposure in the 2000 U.S. birth cohort.

Methods

- Applied same model that we used to calculate costs of lost economic productivity in our previous analysis
- Assumed that MeHg exposure is not correlated with native intelligence
 - Normally distributed with SD 15
- Relied upon previously published per case cost estimates for MR (Honeycutt et al 2000)
 - After applying a 3% discount rate to extrapolate to the cost per case of mental retardation in 2000
 - Used a cost per case of \$1,248,648 in 2000 dollars (excluding lost economic productivity)

Results

- At least 316,588 (7.8%) children are born in the U.S. with cord blood Hg levels $>5.8 \mu\text{g/L}$, and suffer loss of IQ ranging from 0.22-24.4 points (base case log model .76-3.21)
- This IQ loss is associated with:
 - 1566 (range 376 and 14293) cases of MR
 - Health care, special education and other costs amounting to \$2.0 billion (range \$.5-17.9) each year
- This analysis suggests that 3.2% (range .8-29.2%) of MR is attributable to MeHg exposure from all anthropogenic emissions.

(Trasande et al Am J Ind Med 2006)

American Sources and Coal-Fired Power Plants

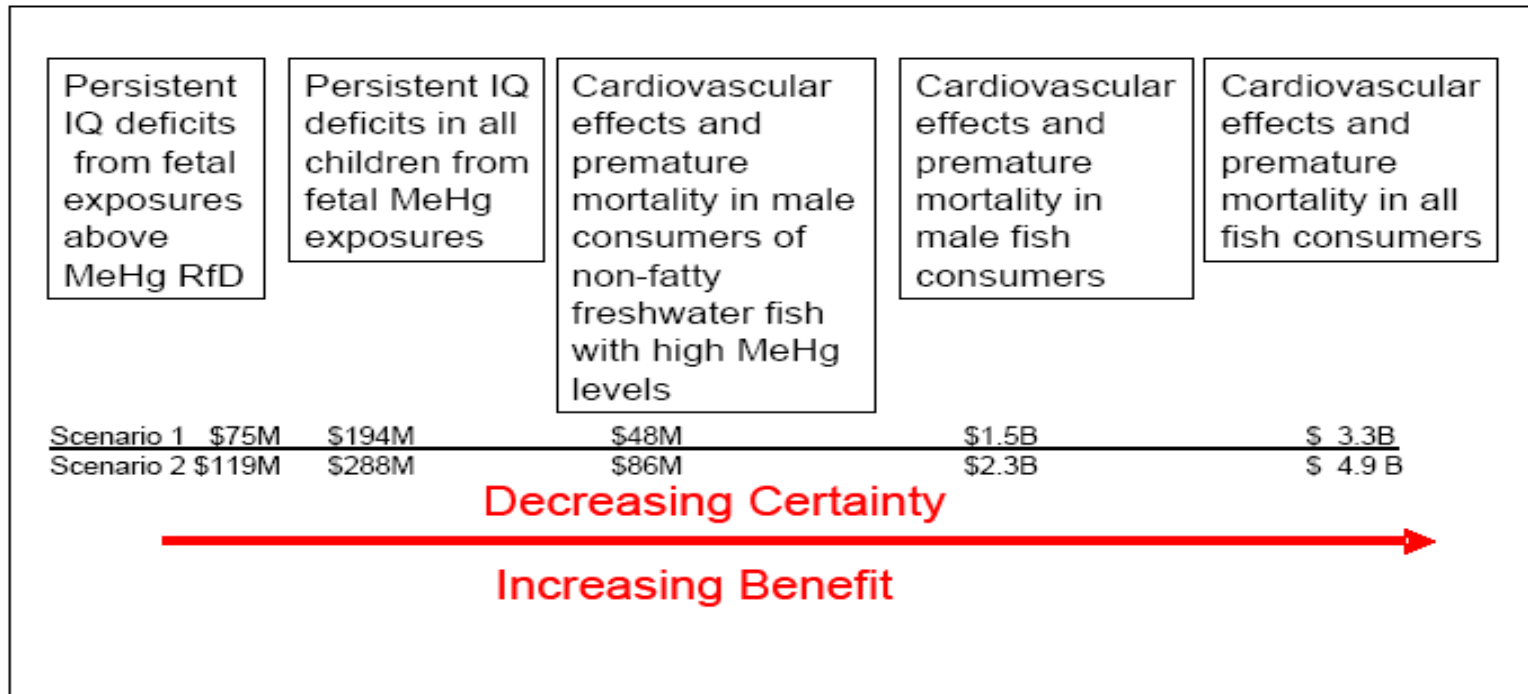
- Mercury from American coal fired power plants is associated with 231 cases of MR each year, which cost \$289 million (range 28-2109 cases, \$35M-2.6B/yr).
 - This analysis suggests that .4% of cases of MR (range .06-4.3%) may be attributable to American coal-fired power plants.

Next Steps

- Comparing costs of mercury pollution control proposals
 - Existing protections under the Clean Air Act will limit mercury emissions from coal-fired power plants to five tons per year by 2008. (US EPA 2004)
 - Proposed “Clear Skies Initiative” would allow these releases to remain as high as twenty-six tons per year through 2010. (US EPA 2004)
 - Other legislative proposals: Sen. Jeffords (S. 150), Sen. Carper (S. 843 – 108th Congress)

Benefits of Clear Skies

Spectrum of Health Effect Certainty



Clean Air Act?

- Harvard/NESCAUM analysis only hypothesized economic benefits of Clear Skies
 - Did not include assumptions based on implementation of Clean Air Act, or alternative proposals

Preliminary C/E

| Policy Options | 2010 | 2013 | 2015 | 2020 | Marginal Cost Compared with Base Case CAIR | Marginal Cost Compared with Old Base Case |
|----------------|------|-------|------|------|--|---|
| Old Base Case | 46.6 | 46.6* | 45 | 46.2 | | |
| Base Case CAIR | 38 | 38* | 34.4 | 34 | | \$41,100,000,000 |
| CAMR | 31.3 | 31.3* | 27.9 | 24.3 | \$3,900,000,000 | \$45,000,000,000 |
| EPA 24/15 | 31.1 | 31.1* | 27.4 | 21.1 | \$5,200,000,000 | \$46,300,000,000 |
| EPA 15/15 | 30.9 | 30.9* | 25.7 | 20.1 | \$6,000,000,000 | \$47,100,000,000 |
| Carper | 24 | 10 | 10 | 10 | \$19,153,800,000 | \$60,253,800,000 |
| Jeffords | 5** | 5** | 5** | 5** | \$26,512,800,000 | \$67,612,800,000 |

* = estimates (assuming equal reductions in intervening period)

** = estimates assume no reductions until 2010; Jeffords proposal reduces as of 2008

Source for Costs and all Emissions Estimates Except Carper/Jeffords:

EPA 2005 COST AND ENERGY IMPACTS – Technical Support Document

Sources for Carper/Jeffords Emissions: S. 150 – 109th Congress; S. 843 – 108th Congress

Preliminary C/E

| Net Difference (Base) | Lost IQ points | Cases MR | Total economic costs (|
|------------------------------|-----------------------|-----------------|-------------------------------|
| CAIR-Old Base | -458,441 | -1,967 | -\$5,497,774,811 |
| CAMR-CAIR | -346,580 | -1,475 | -\$4,132,901,363 |
| EPA24/15-CAMR | -64,901 | -274 | -\$699,436,953 |
| EPA 15/15-CAMR | -109,087 | -461 | -\$1,214,457,096 |
| Jeffords-CAMR | -1,059,571 | -4,450 | -\$13,077,778,596 |
| Carper-CAMR | -695,385 | -2,929 | -\$8,359,129,472 |
| Jeffords-CAIR | -1,406,151 | -5,925 | -\$17,210,679,959 |
| Carper-CAIR | -1,041,965 | -4,404 | -\$12,492,030,835 |
| Net Max Difference | Lost IQ points | Cases MR | Total costs (anth) |
| CAIR-Old Base | -2,935,982 | -28,349 | -\$46,508,558,873 |
| CAMR-CAIR | -2,155,136 | -20,068 | -\$33,519,303,472 |
| EPA24/15-CAMR | -393,894 | -3,558 | -\$5,472,487,586 |
| EPA 15/15-CAMR | -662,852 | -5,997 | -\$9,521,678,731 |
| Jeffords-CAMR | -6,278,004 | -55,052 | -\$98,828,153,956 |
| Carper-CAMR | -4,161,043 | -36,938 | -\$64,110,282,448 |
| Jeffords-CAIR | -8,433,140 | -75,120 | -\$132,347,457,428 |
| Carper-CAIR | -6,316,179 | -57,006 | -\$97,629,585,920 |
| Net Min Difference | Lost IQ points | Cases MR | Total costs (anth) |
| CAIR-Old Base | -101,980 | -389 | -\$1,188,545,744 |
| CAMR-CAIR | -75,967 | -289 | -\$881,981,302 |
| EPA24/15-CAMR | -14,052 | -53 | -\$147,599,481 |
| EPA 15/15-CAMR | -23,633 | -90 | -\$256,446,307 |
| Jeffords-CAMR | -226,567 | -860 | -\$2,728,994,820 |
| Carper-CAMR | -149,458 | -567 | -\$1,752,696,859 |
| Jeffords-CAIR | -302,534 | -1,149 | -\$3,610,976,121 |
| Carper-CAIR | -225,425 | -857 | -\$2,634,678,160 |

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