Sustainable Energy For All:

Ensuring Health throughout the Energy Production and Use Life Cycle

Dan Greenbaum, President
Health Effects Institute (HEI)

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of New Energy Sources

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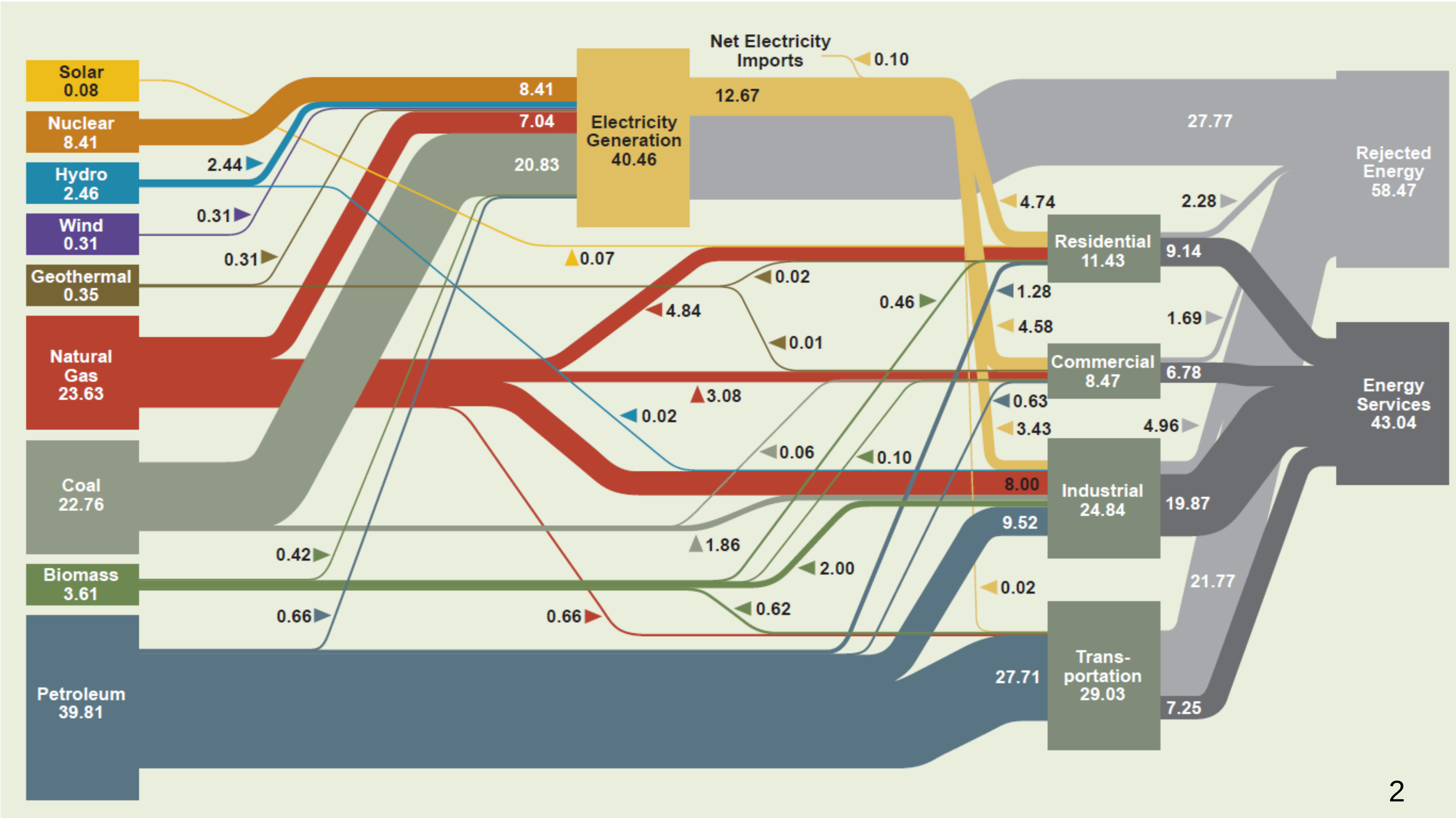
Energy Consumption in the United States (2007)

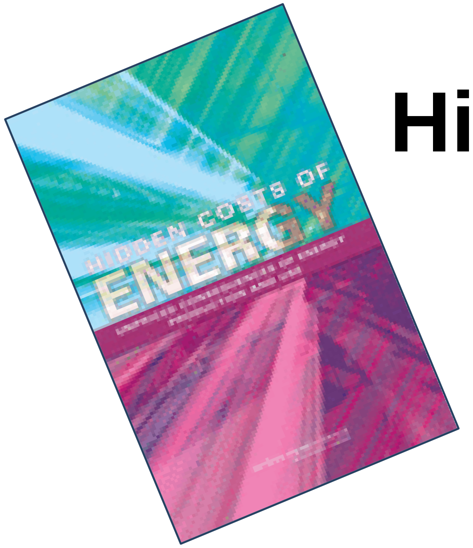
(in quadrillions of British thermal units (quads))



Source: America's Energy Future, NAS 2009

Systems Thinking

- America’s production and use of energy results from a complex system of supply and demand
- It also creates a complex web of potential health, environmental, and other effects throughout the lifecycle
- Any one component of the system (e.g. shale gas hydraulic fracturing) must be placed in the context of the whole system
  - Evaluating effects throughout the system, and
  - Comparing effects, as much as possible, on an “apples-to-apples” basis across different energy sources and uses.
- One example: the recent NRC report on “The Hidden Costs of Energy”



Hidden Costs of Energy:

Unpriced Consequences of Energy Production and Use

National Research Council Report
Published 2009

Congress Requested this study in the Energy Policy Act of 2005.

Study Task:

> "Define and evaluate key *external costs and benefits* – related to health, environment, security, and infrastructure – that are *associated with the production, distribution, and use of energy* but *not reflected in the market price of energy or fully addressed by current government policy*."

What the Study Committee Found

- There are many external effects related to energy production and use in the U.S.
- The Committee was able to monetize a wide range of damages, although many other external effects were not monetized because of insufficient data or other reasons.
- Monetized damages from energy production and use in the U.S. added up to more than $120 Billion in 2005, not including climate change damages.

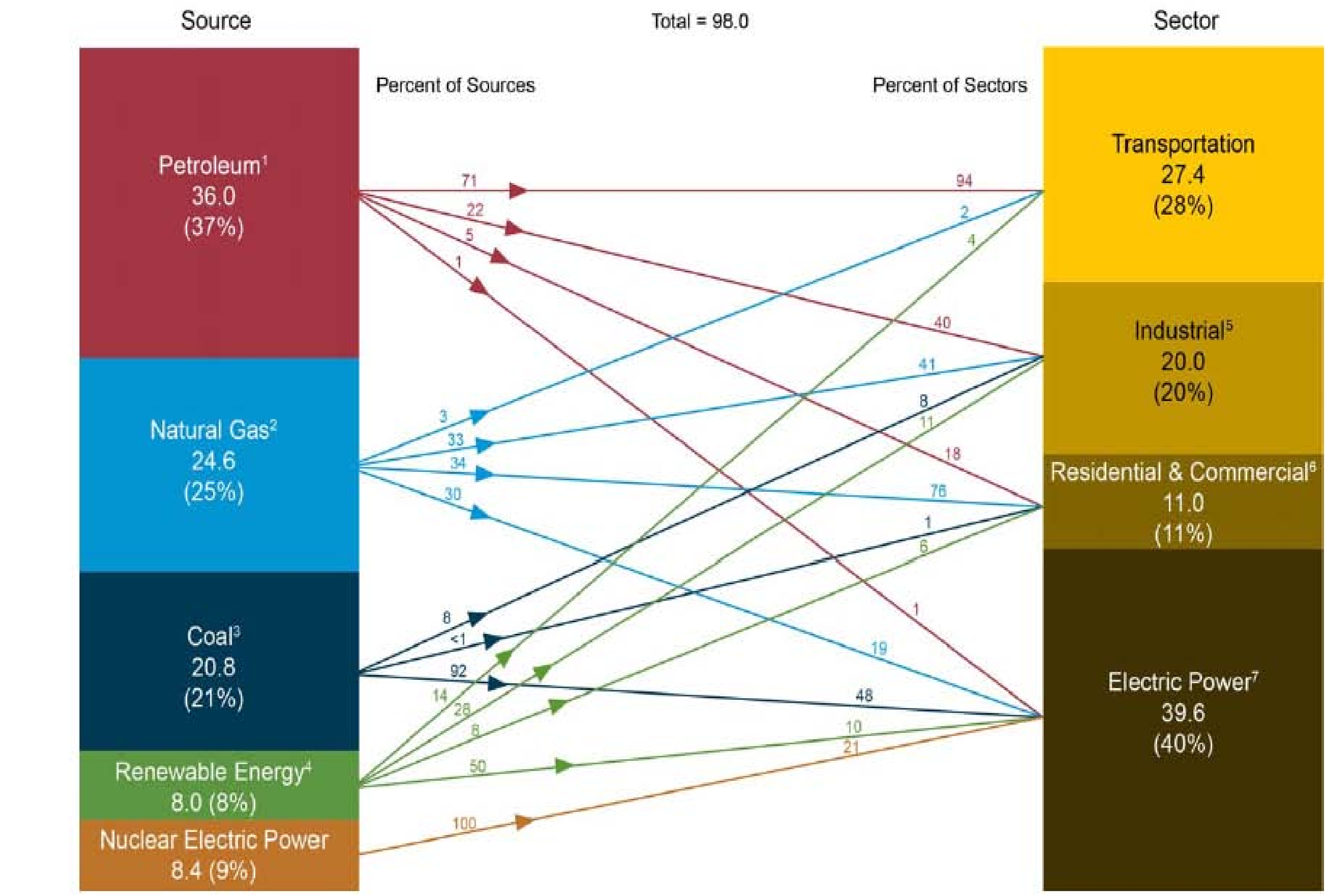
Committee Roster

Jared Cohon (Chair)	Carnegie Mellon University
Maureen Cropper (Vice Chair)	University of Maryland, College Park
Mark Cullen	Stanford University School of Medicine
Elisabeth Drake	Massachusetts Institute of Technology (retired)
Mary English	University of Tennessee, Knoxville
Christopher Field	Carnegie Institution of Washington
Daniel Greenbaum	Health Effects Institute
James Hammitt	Harvard University Center for Risk Analysis
Rogene Henderson	Lovelace Respiratory Research Institute
Catherine Kling	Iowa State University
Alan Krupnick	Resources for the Future
Russell Lee	Oak Ridge National Laboratory
H. Scott Matthews	Carnegie Mellon University
Thomas McKone	Lawrence Berkeley National Laboratory
Gilbert Metcalf	Tufts University
Richard Newell *	Duke University
Richard Revesz	New York University School of Law
Ian Sue Wing	Boston University
Terrance Surles	University of Hawaii at Manoa

***** Resigned August 2, 2009 to accept appointment as Administrator of the U.S. Energy Information Administration.

US Energy Flows 2010

(Source: EIA)



Study Approach – Non-Climate Damages

- Selected Areas
    - Electricity Generation (40 %)
    - Transportation (27%)
    - Heat for Buildings and Industrial Processes (11%)
    - Climate Change
    - Infrastructure and National Security

- Considered full life-cycle

- 2005 and 2030 reference years

- Emissions>>Ambient Concentration>>Exposure>>Effect>>Monetized Damages

    - Effects of air pollution on human health, grain crop and timber yields, building materials, recreation, and visibility of outdoor vistas.

    - Modeling used to estimate damages-- based primarily on SO_2, NO_x, and PM emissions across the 48 contiguous states.
        – Non-quantifiable damages are described in detail

    - Most of the damages are associated with human mortality.

Electricity: Coal

406 coal-fired power-plants

<u>Aggregate non-climate damages (2005):</u> $62 billion

- 10% of plants with the highest damages--which produced 25% of net generation--accounted for 43% of the damages.
- Variation in damages primarily due to variation in tons of pollutants emitted.

<u>Average damages per kilowatt hour (kWh):</u>

2005: 3.2 cents/kWh
2030: 1.7 cents/kWh

- Fall in damages per kWh in 2030 due to assumption that pounds of SO_2 per kWh hour will fall by 64% and that NO_x emissions per kWh will fall by 50%.

Electricity: Natural Gas
498 Natural Gas-Fired Plants

Aggregate non-climate damages (2005): **≈ $740 million**

- From plants that account for 71% of net generation from gas
- 10% of plants with largest damages accounted for 65% of damages.

Average damages per kilowatt hour:
2005: 0.16 cents/kWh
2030: 0.11 cents/kWh

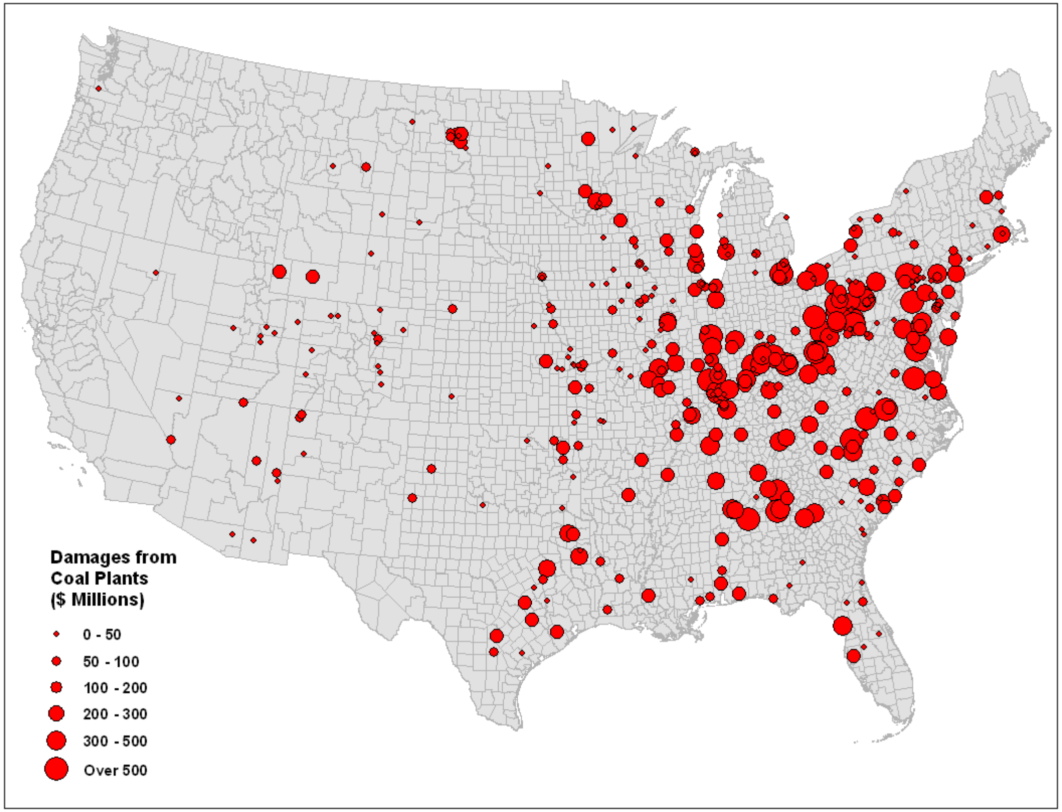
Fall in damages per kWh in 2030 explained by an expected19% fall in NO_x emissions per kWh hour and 32% fall in $PM_{2.5}$ emissions per kWh.

Electricity: Coal

Aggregate non-climate damages (2005): **$62 billion**

Location of Sources of Damages

Damage Estimates based on SO_2, NO_x, and PM emissions



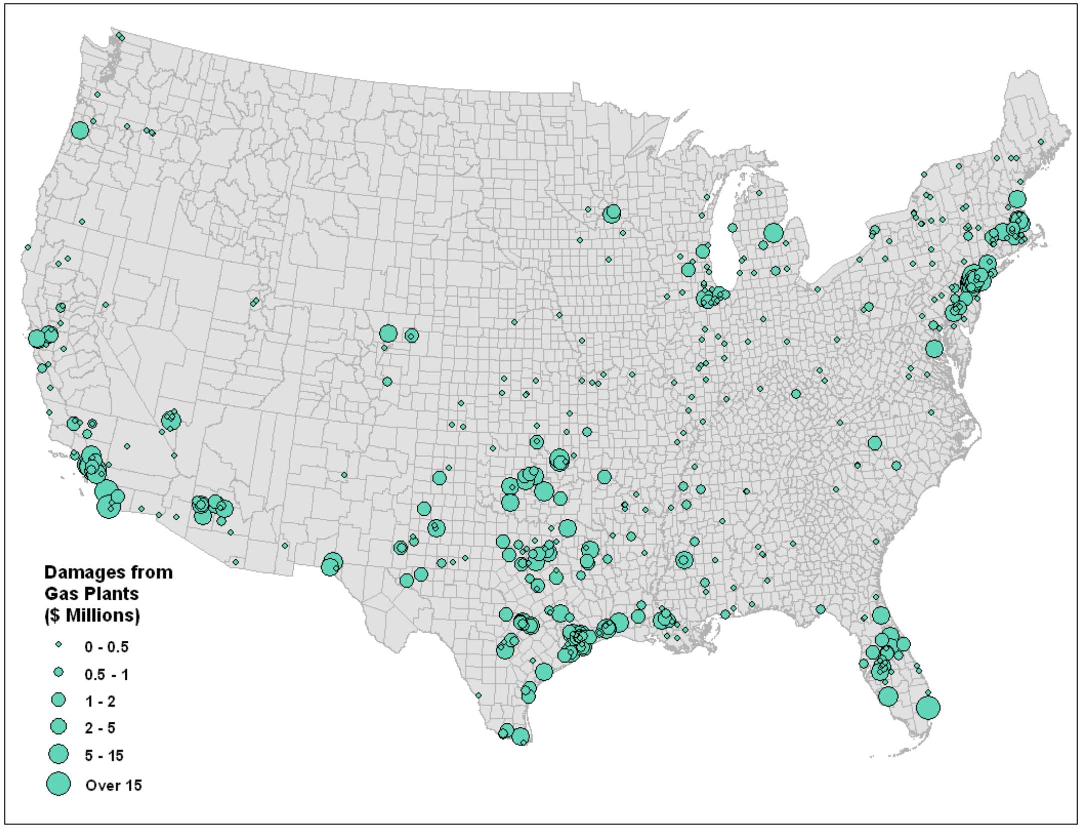
- Air Pollution Damages from Coal Generation for 406 plants, 2005
- Damages related to climate-change effects are not included

Electricity: Natural Gas

Aggregate non-climate damages (2005): **≈ $740 million**

Location of Sources of Damages

Damage Estimates based on SO_2, NO_x, and PM emissions



- Air Pollution Damages from Natural Gas Generation for 498 plants, 2005.
- Damages related to climate-change effects are not included.

Transportation

- Committee focused on highway vehicles
  - they account for more than 75% of transportation-energy consumption in the U.S.

- Energy Sources: oil (petroleum/diesel), natural gas, biomass, electricity, and others

- Four life-cycle stages (well-to-wheel) were considered:

  (1) Feedstock: fuel extraction and transport to refinery

  (2) Fuel: fuel refining/conversion and transport to the pump

  (3) Vehicle: emissions from production/manufacturing of the vehicle

  (4) Operation: tailpipe and evaporative emissions

Transportation

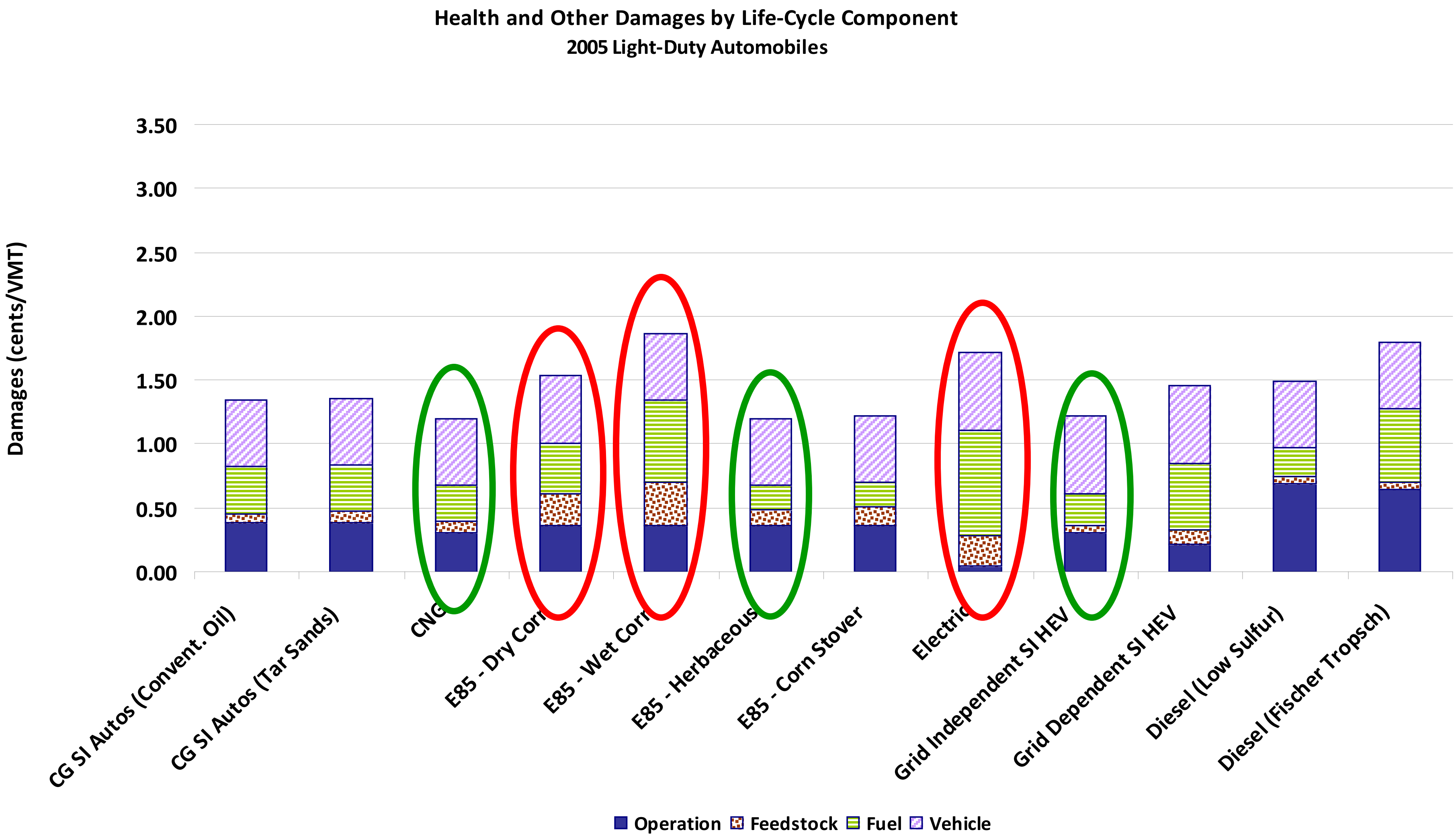
<u>Aggregate 2005 non-climate damages</u>: ≈ $ 56 billion

Light-duty vehicles: $36 billion

Heavy-duty vehicles: $20 billion

- Damages per vehicle-mile traveled (VMT) ranged from 1.2 cents to 1.7 cents.
  - 23-38 cents/ gasoline gallon equivalent
- ***Damage estimates did not vary significantly across fuels and technologies***; caution is needed for interpreting small differences.
  - Some (electric, corn ethanol) had higher lifecycle damages
  - Others (cellulosic ethanol, CNG) had lower lifecycle damages

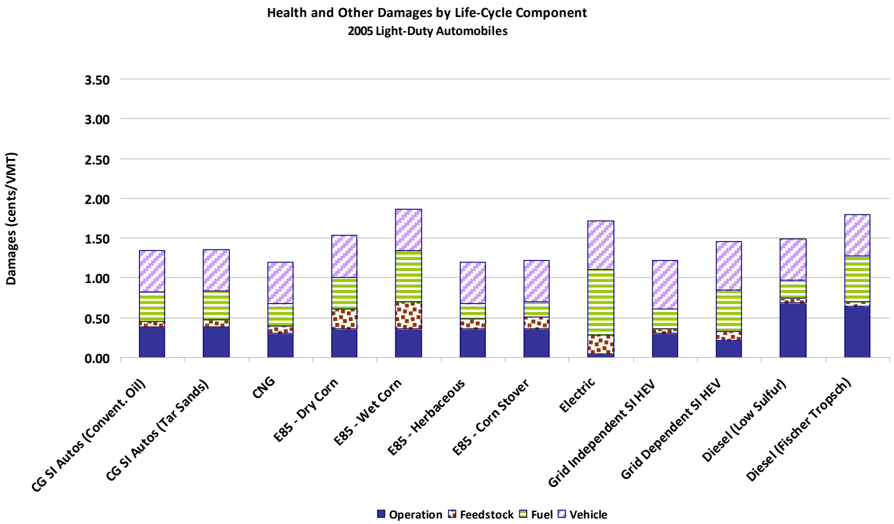
Light-Duty Vehicles
Non-Climate Damages in 2005

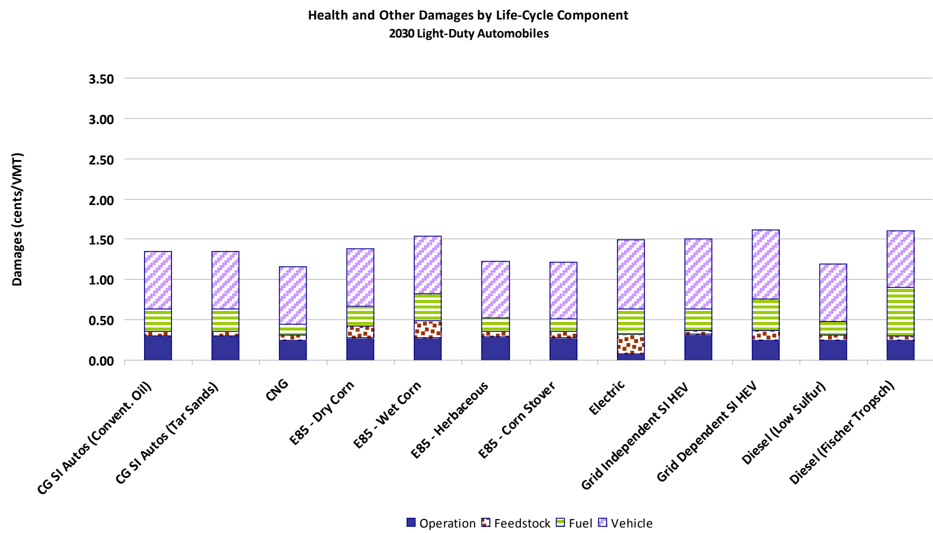


Light-Duty Vehicles: Non-Climate Damages: 2005 and 2030

Damages in 2030 are similar to 2005, despite population and income growth

Fuel economy (CAFE) and diesel emission rules reduce 2030 damages





CG SI = Conventional Gasoline Spark Ignition

- Damages are not spread equally among the different lifecycle components.
  - ***Vehicle operation*** accounted in most cases for ***less than one-third of the total damage***
  - Other components of the life cycle contributed the rest
  - ***Vehicle manufacturing*** is ***a significant contributor*** to damages

Study Approach: Climate Change Damages

- Energy production and use is a major source of GHG emissions, principally CO_2 and methane.
- The committee estimated GHG emissions but did not attempt estimate specific climate damages
- Rather,
  - reviewed existing Integrated Assessment Models (IAMs) and the associated climate-change literature on the "social cost" of carbon.
  - Sought to explain why estimates of damage per ton of CO_2-eq vary across IAMs
    - Did not endorse a single point estimate
    - Range of estimates: $1 - $100/ton CO_2-eq
  - **Key factors in IAMs that drive damage from a ton of CO_2-eq:**
    - Rate at which future damages are discounted
    - How fast damages (as a % of GDP) increase with temperature (gradual or steep)

Electricity:
GHG Emission Estimates
(Downstream emissions)

Coal-fired plants:

- 2005 Average Emissions: 1 ton of CO_2/MWh of power generated

Natural gas fired plants:

- 2005 Average Emissions: 0.5 ton of CO_2/MWh of power generated

Other energy sources:

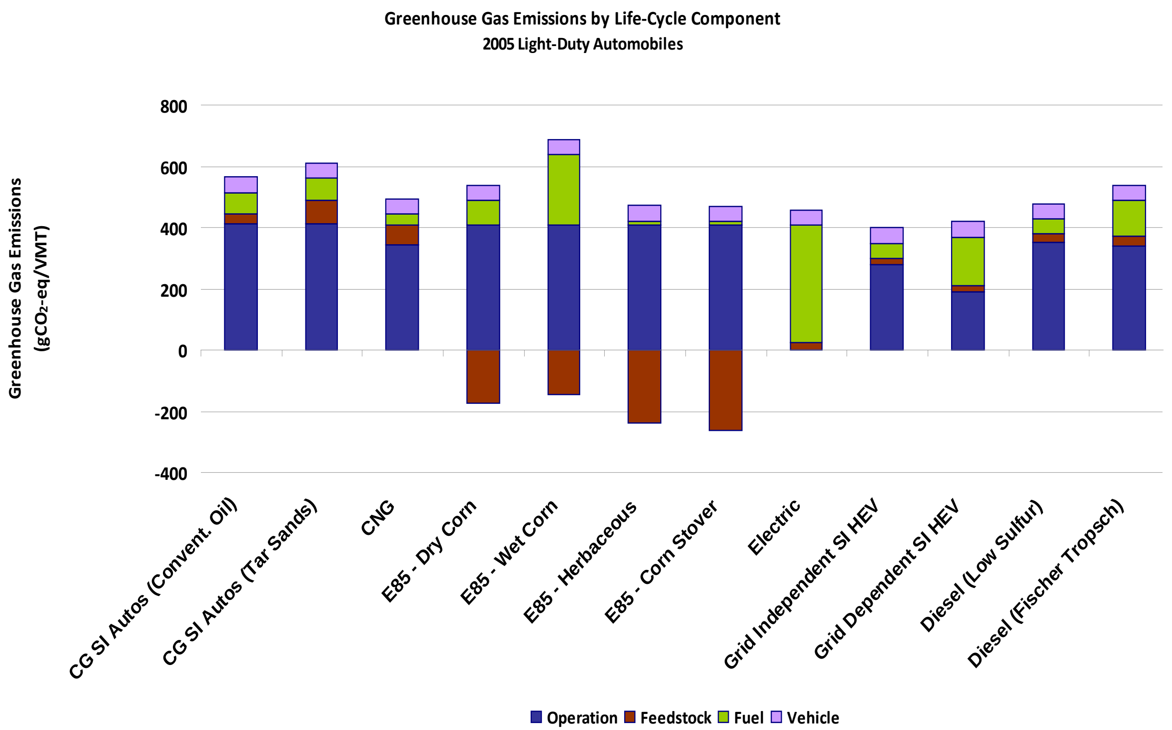
- Life-cycle emissions of GHGs from nuclear, wind, solar, and biomass appear so small as to be negligible compared to those from fossil fuel generated electricity

Transportation GHG Emissions in 2005

Light-Duty Vehicles

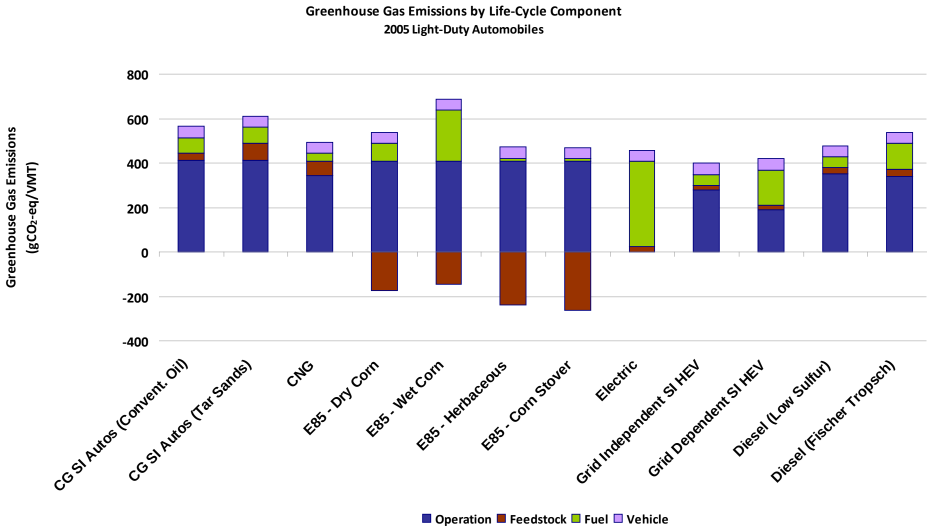
GHG lifecycle emissions did not vary significantly across fuels and technologies
(*caution is needed for interpreting small differences*).

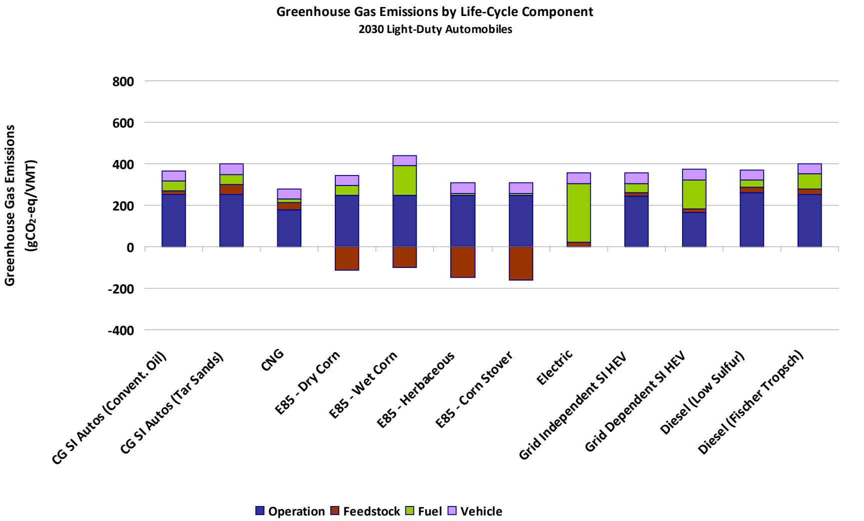
- Some – cellulosic ethanol – were lower
- Others – tars sands petroleum and Fischer Tropsch diesel – were higher



Vehicle operation is in most cases a substantial relative contributor to total lifecycle GHG emissions.

Light-Duty Vehicles: GHG Emissions
2005 and 2030



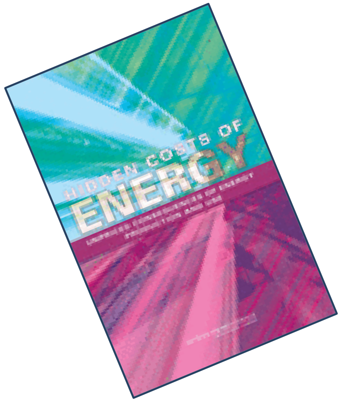


CG SI = Conventional Gasoline Spark Ignition; 1lb = 454 g

Substantial improvements in fuel efficiency in 2030 result in most technologies becoming much closer to each other in per VMT lifecycle greenhouse gas emissions.

Combining Non-Climate and Climate Change Damage Estimates (2005)

Energy-Related Activity (fuel type)	Non-climate damage	Climate Damages (per ton CO_2-eq)		
		@$10	@ $30	@ $100
Electricity Generation (coal)	**3.2 cts/kWh**	**1 cts/kWh**	**3 cts/kWh**	**10 cts/kWh**
Electricity Generation (natural gas)	**0.16 cts/kWh**	**0.5 cts/kWh**	**1.5 cts/kWh**	**5 cts/kWh**
Transportation	**1.1 to ~1.7 cts/VMT**	**0.15 to ~0.65 cts/VMT**	**0.45 to ~2 cts/VMT**	**1.5 to ~6 cts/VMT**
Heat production (natural gas)	**11 cts/MCF**	**70 cts/MCF**	**210 cts/MCF**	**700 cts/MCF**



Conclusions

- Non-climate damages from electricity generation and transportation exceed $120 billion for the year 2005.
  - These damages are principally related to emissions of NO_x, SO_2, and PM.
- The above total is a substantial underestimate because it does not include damages related to climate change, health effects of hazardous pollutants, ecosystem effects, or infrastructure and security.
- How much a burden should be reduced depends on its magnitude ***and*** the cost of reducing it.
- Reducing emissions, improving energy efficiency, or shifting to cleaner methods of generating electricity could substantially reduce damages.

Systems Thinking

- Important to place natural gas in its larger, and life cycle, context
- Overall, natural gas came out quite favorably in these non-climate and climate effects analyses
- Major information and data needs remain, e.g.
  - Could not fully quantify upstream effects of gas *or* coal for electricity usage (for both air pollution and GHGs)
  - Could not quantify many environmental effects on a national scale (e.g. biofuels and water)

- HOWEVER, systems approaches to these questions are the only way we can make fully informed decisions going forward.

Thank You!

Dan Greenbaum
dgreenbaum@healtheffects.org

Hidden Costs report available at:
http://www.nap.edu/catalog.php?record_id=12794