Prioritizing Climate Change Mitigation Technologies by Cost-Effectiveness:

How do transportation options compare with other sectors?

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Outline

- Background: U.S. climate mitigation
- Prioritizing GHG mitigation options
  - Climate change mitigation criteria
  - Cost-effectiveness “supply curves”
- Findings
  - Transportation sector
  - All economic sectors

Background: Mitigation Policy

- **Emission reduction targets**
  - e.g. to 1990 GHG level by 2020, 80% below 1990 GHG level by 2050
  - 17 states and 700+ cities (represent 53% of the U.S. population)
- **Emission mitigation planning**
  - State GHG inventories – 42 states (93% of U.S. GHG)
  - State "Climate Action Plans" – 30 states (53% of U.S. GHG)
  - Sector-specific actions (examples)
    - Renewable electricity portfolio targets (~half of U.S. elec. generation)
    - Vehicle GHG regulations (~half of U.S. auto sales)
- **Coordination – regional cooperation to establish emissions trading, common mitigation programs**
  - Northeastern states (RGGI, NEG/ECP pact)
  - Western states (WCG GWI, WCI)
  - Climate Registry – coordination on consistent GHG reporting guidelines
  - Cities – U.S. Mayor's Climate Protection Agreement

Background: Mitigation Areas

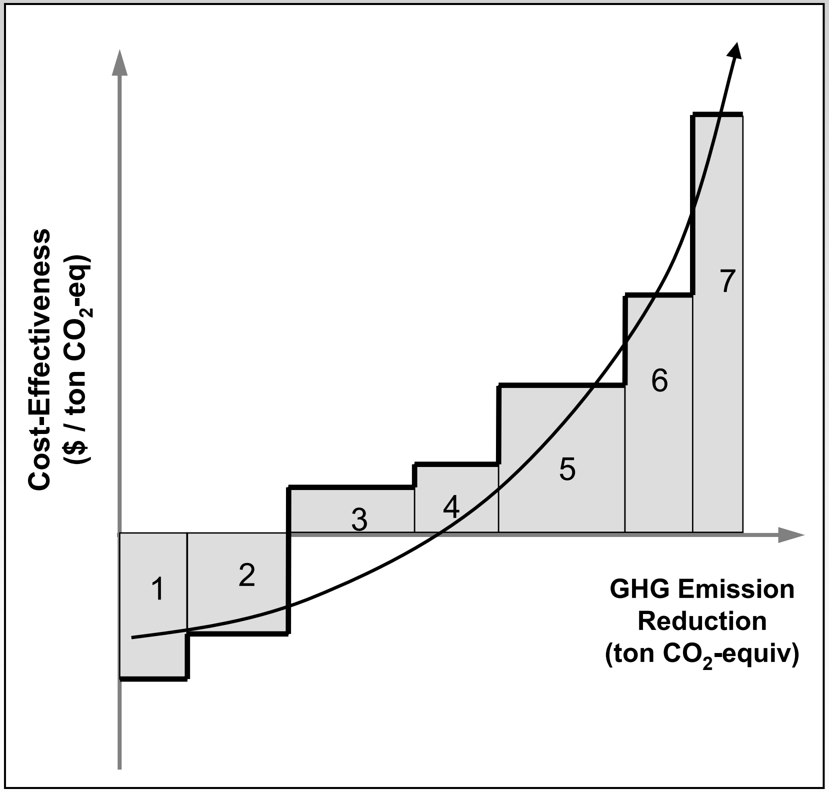
- Sector-specific GHG mitigation action areas:
  - Transportation:
    - Vehicle GHG regulation
    - Fuel standards, mandates, targets
    - VMT reduction measures
  - Electricity generation
    - Renewable electricity targets, standards
    - Energy efficiency resource standards
    - Fossil fuel efficiency (e.g. coal IGCC)
    - Carbon capture and storage (CCS) technology
  - Residential and commercial buildings
    - Appliance, lighting efficiency
    - Heating, cooling efficiency
    - Building codes
    - Distributed power generation
  - Industry (cement, paper/pulp, chemical, refrigerant, landfill)
  - Agriculture (forestry, soil carbon sequestration, N2O/CH4)

Background: Mitigation Criteria

- What criteria are most important in prioritizing mitigation actions?
- From state mitigation plans:
  - Individual action effects
    1.) GHG emission reduction potential
    2.) Implementation cost
    3.) Variable (lifetime) costs, benefits
    4.) Ancillary costs, benefits
  - Cumulative actions' effects
    5.) GHG emission reduction potential
    6.) Costs, benefits
    7.) Multi-sector equity (e.g. vehicles vs. electricity)

Evaluating GHG Mitigation Options

- **Cost-effectiveness "supply curve" approach:**
  - **Collect data for baseline and mitigation technology alternatives**
  - **Bundle cost, benefit, and emissions impact data in one variable**
    - **"Cost-effectiveness"**
    - **Cost-per-ton CO_2-equivalent reduced**
  - **Rank options by cost-effectiveness**
  - **Show cumulative impact at increasing cost**
  - **Highlights:**
    - **Actions under given $/ton cost**
    - **"No regrets" actions (net benefits > costs)**
    - **Total emission reduction goals (e.g., 1990 level by 2020)**



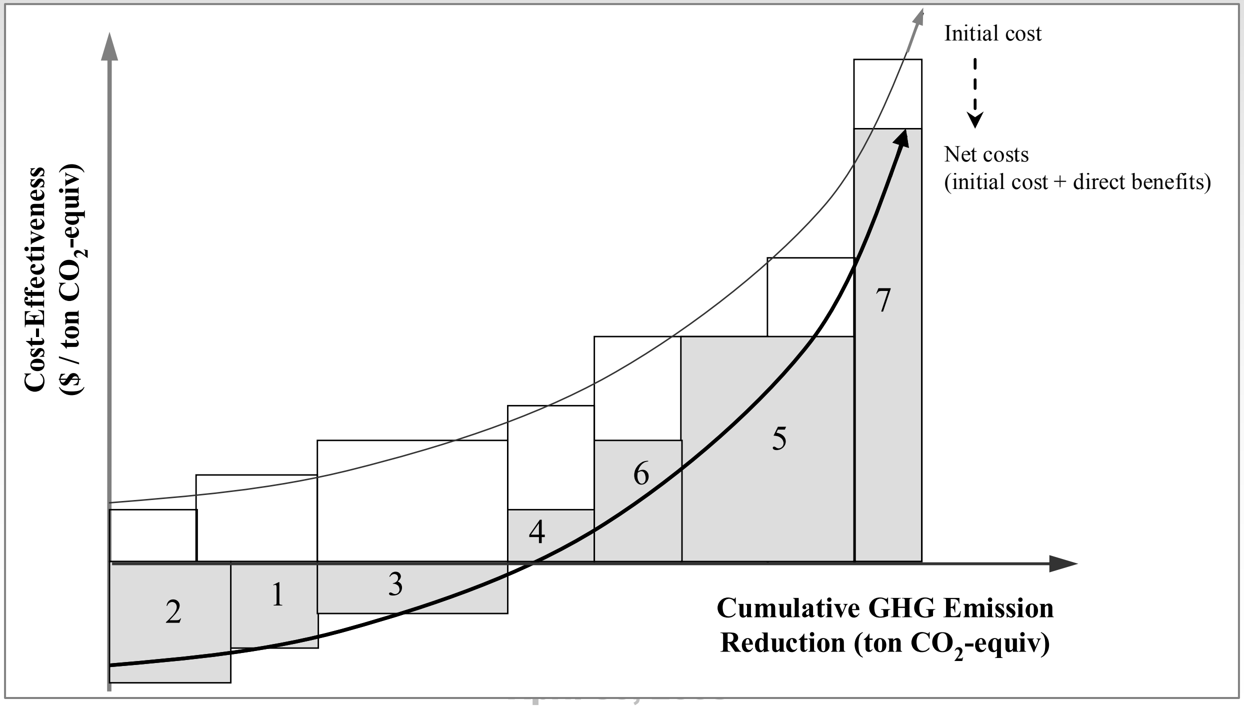
Cost-Effectiveness Curve Approach

- **Use in various forms**
  - **Initial costs only:**

$$\begin{pmatrix} Cost - Effectiveness \\ (\$ / tonne) \end{pmatrix} = \frac{\begin{pmatrix} Initial\ Technology \\ Cost \end{pmatrix}}{\begin{pmatrix} Greenhouse\ Emission \\ Reduction \end{pmatrix}}$$

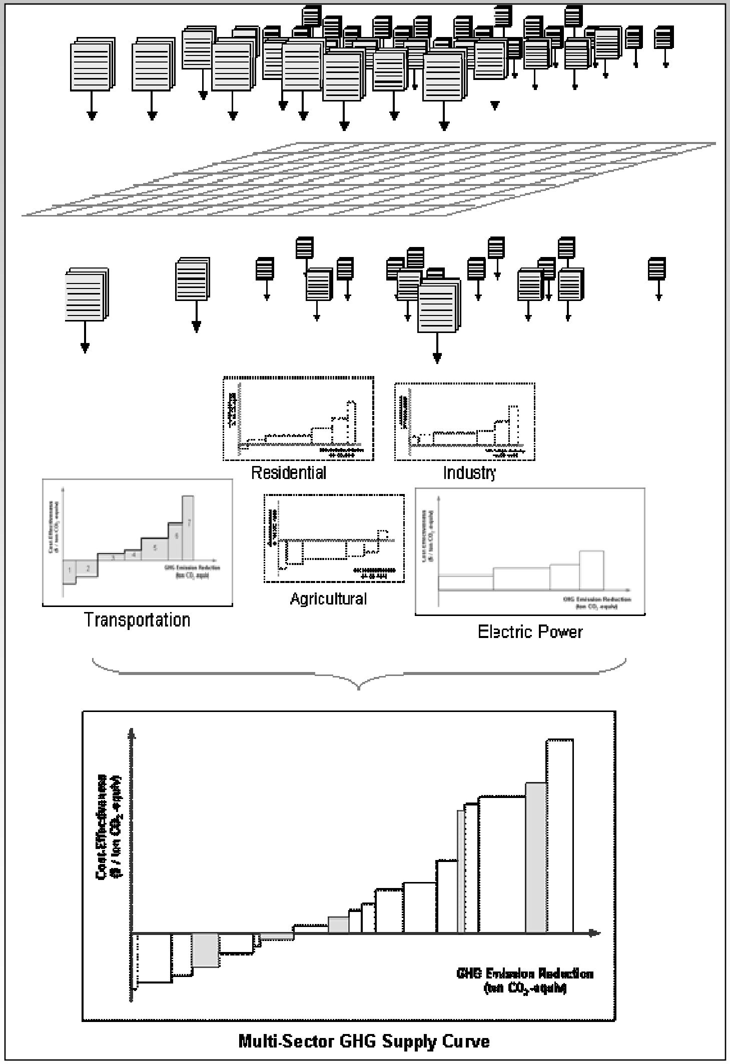
  - **Include costs and direct benefits:**

$$\begin{pmatrix} Cost - Effectiveness \\ (\$ / tonne) \end{pmatrix} = \frac{\begin{pmatrix} Initial\ Technology \\ Cost \end{pmatrix} + \begin{pmatrix} Lifetime\ Fuel \\ Cost\ Impact \end{pmatrix}}{\begin{pmatrix} Greenhouse\ Emission \\ Reduction \end{pmatrix}}$$



Cost-Effectiveness Curve Approach

- **Methodological Steps**
  - **Literature search and screening –**
    - **Assess/screen technologies**
      - **Available data (GHG, cost, benefit)**
      - **Technology-based**
      - **Timeframe: GHG technologies to be deployed from 2010-2025**
  - **Cost-effectiveness curve development**
    - **Estimation and accumulation of cost, GHG-reduction data**
    - **Assume US EIA fuel prices (at 7% discount rate)**
    - **Develop sector-specific curves**
    - **Combine in multi-sector curve**
  - **Multi-Sector Assessment –**
    - **Synthesis various economic sectors' GHG mitigation strategies and their contribution to overall US GHG emissions reductions**



Technology Areas

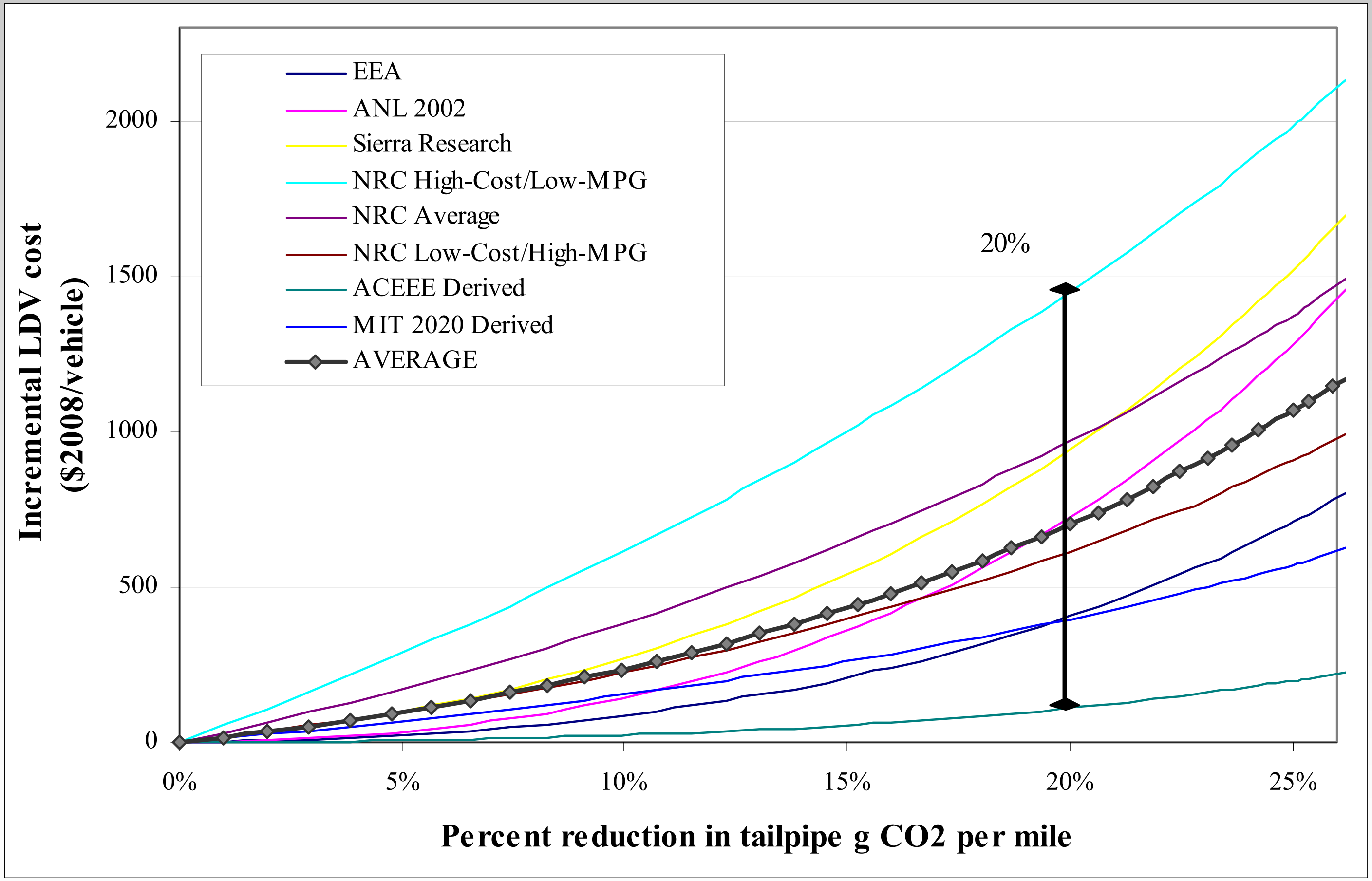
- Sector-specific areas to analyze for GHG reductions
  - Transportation
    - Light duty vehicle efficiency (rated incremental, “on-road”, HEV)
    - Commercial truck efficiency
    - Biofuels (ethanol, biodiesel)
    - Aircraft
  - Residential and commercial buildings
    - Appliances
    - Lighting
    - Heating, ventilation, and air-conditioning (HVAC)
    - Distributed power
  - Electric power sector
    - Fossil-fuel switching (coal – to natural gas)
    - Carbon capture and sequestration (CCS)
    - Renewable (wind, solar, biomass)
    - Nuclear
  - Industry (cement, paper/pulp, chemical, refrigerant, landfill)
  - Agriculture (forestry, soil carbon sequestration, N2O/CH4)

Vehicle Technology Options

- **Incremental vehicle efficiency**
  - Engine (gasoline direct injection, variable displacement)
  - Transmission (5 and 6-speed auto, continuously variable)
  - Body, road load reduction (light-weighting, aerodynamics)
- **"On-road" fuel efficiency improvements**
  - Tire inflation, rolling resistance
  - Maintenance, low-friction oil
  - Efficient accessories, alternator
- **Advanced drivetrain technology**
  - Electrified drivetrain (HEV, PHEV, EV)
  - Fuel cell electric (hydrogen or other fuel)
- **Reducing other non-CO_2 GHGs:**
  - Air conditioning (HFC-134a)
  - Nitrous oxide (N_2O), Methane (CH_4)

Transportation

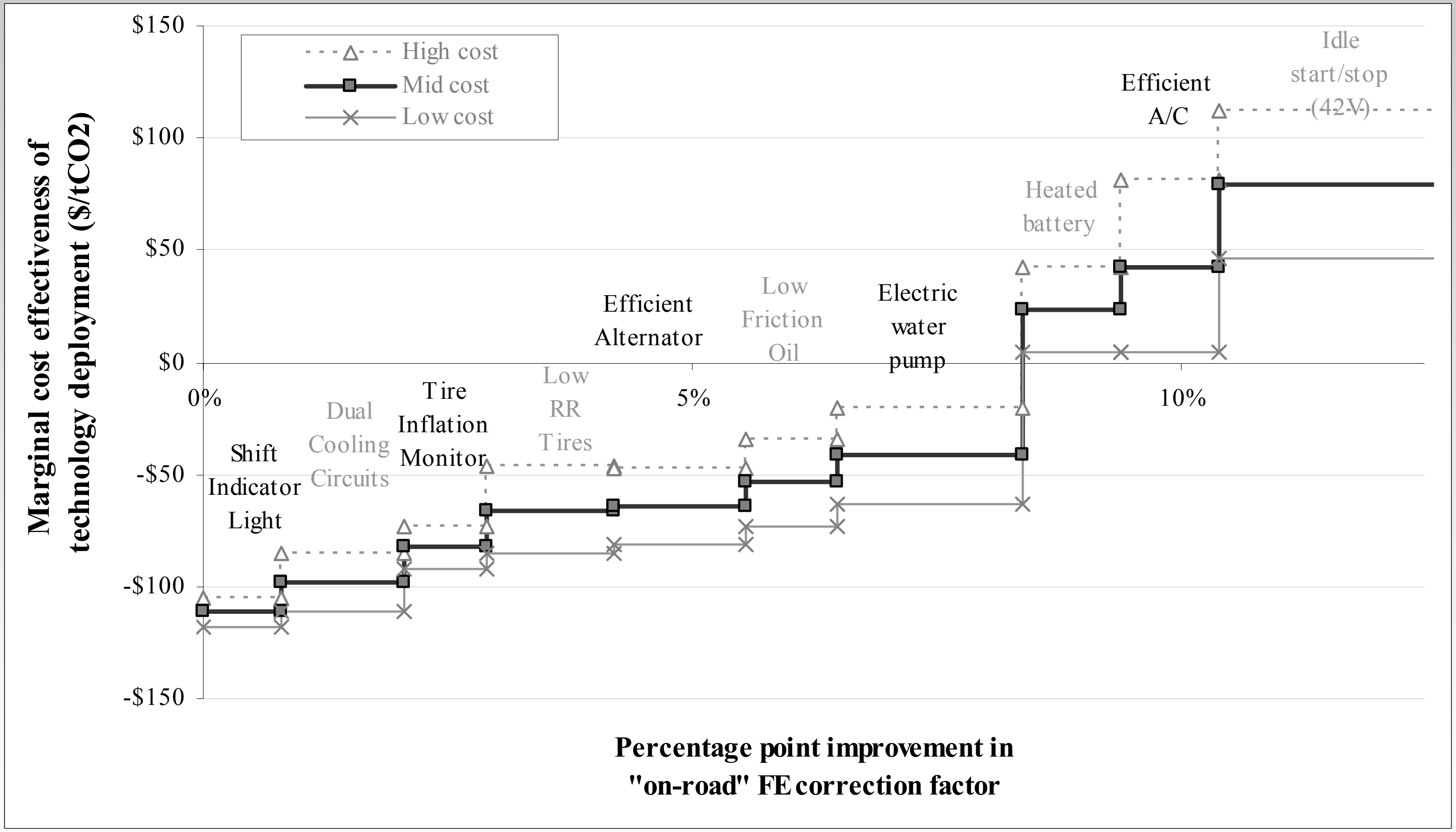
Incremental efficiency technology for light-duty vehicles:



Assumptions: vehicle life of 189k, 17 years; ~$2.35/gallon gasoline (U.S. EIA, 2007); 7% discount factor for future fuel savings. Sources: Austin, et al, 1999 (Sierra); DeCicco et al, 2001 (ACEEE); EEA, 1995; NRC 2002; Plotkin et al, 2002; Weiss, M.A., et al., 2000 (MIT)

Transportation

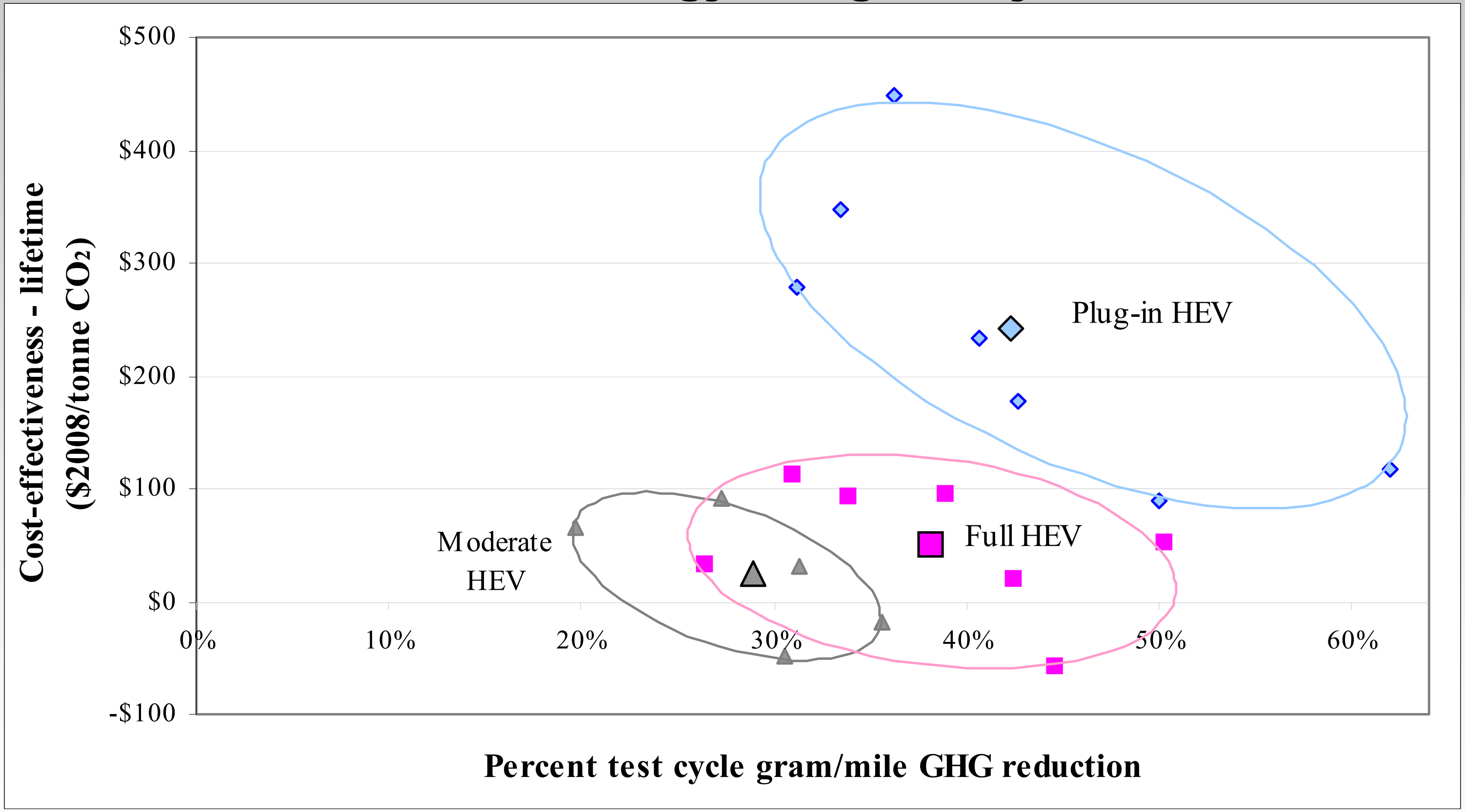
"On-road" efficiency technology for light-duty vehicles:



Assumptions: vehicle life of 189k, 17 years; ~$2.35/gallon gasoline (U.S. EIA, 2007); 7% discount factor for future fuel savings. Based on IEA and ECMT, 2006

Transportation

Hybrid electric vehicle technology for light-duty vehicles:

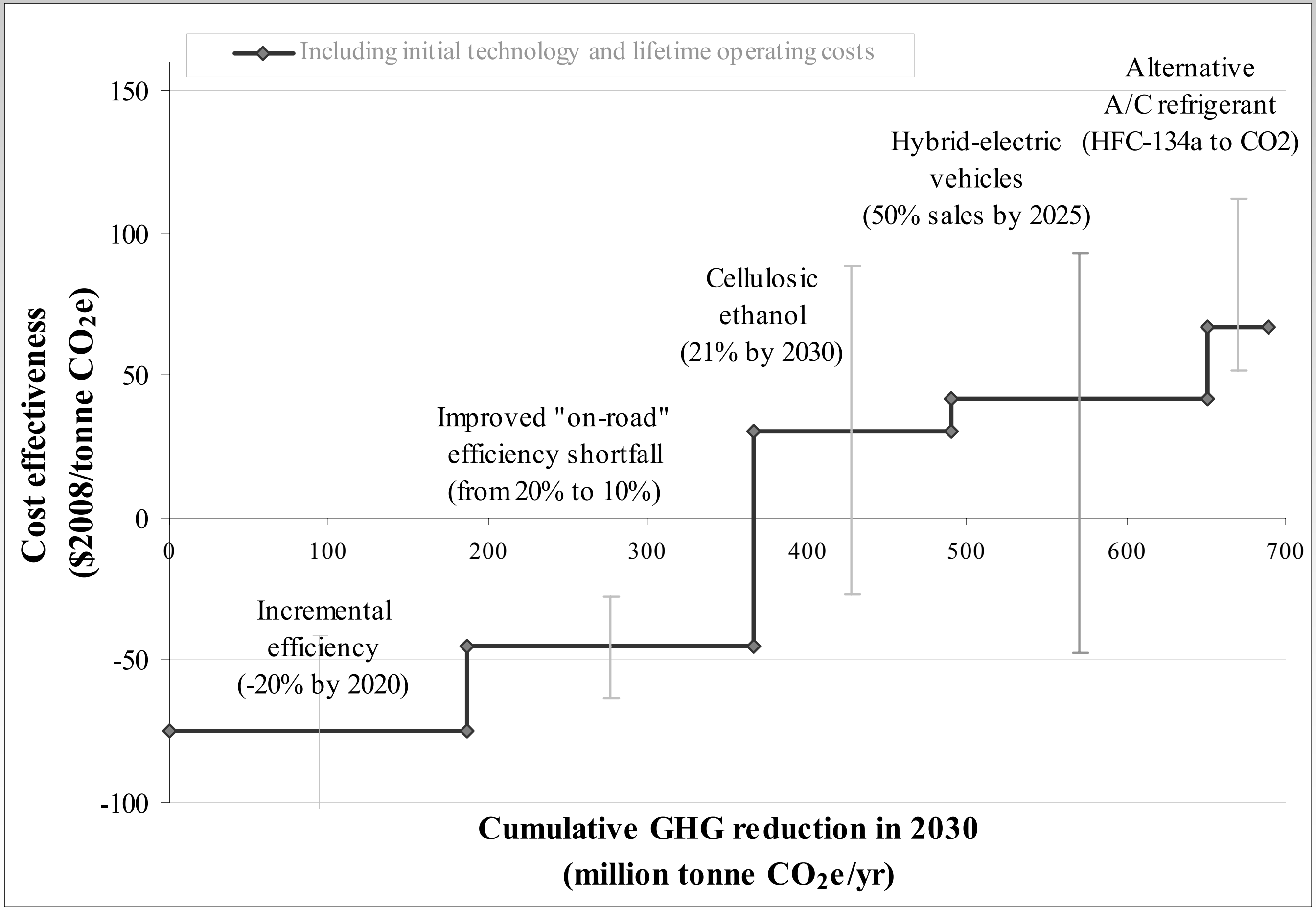


Assumptions: vehicle life of 189k, 17 years; ~$2.35/gallon gasoline (U.S. EIA, 2008); 7% discount factor for future fuel savings; 0.8 on-road fuel economy degradation factor; U.S. electricity mix

Sources: Graham et al 2001 (EPRI); Plotkin et al 2001 (ANL); Lipman and Delucchi, 2003; Weiss et al 2001 (MIT); An et al 2001; Markel et al (NREL), 2006

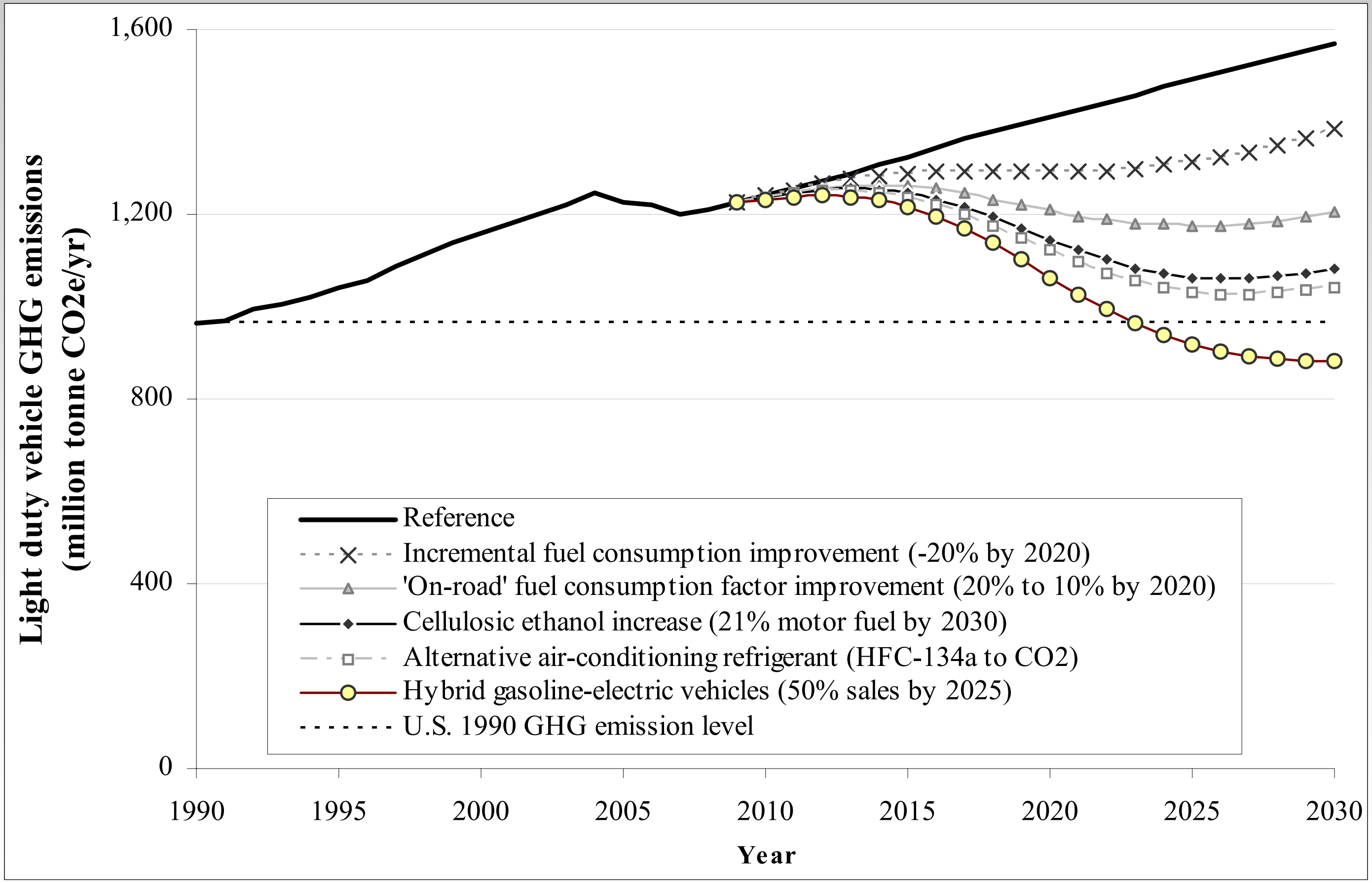
Transportation

Light-duty vehicles GHG cost-effectiveness curve:



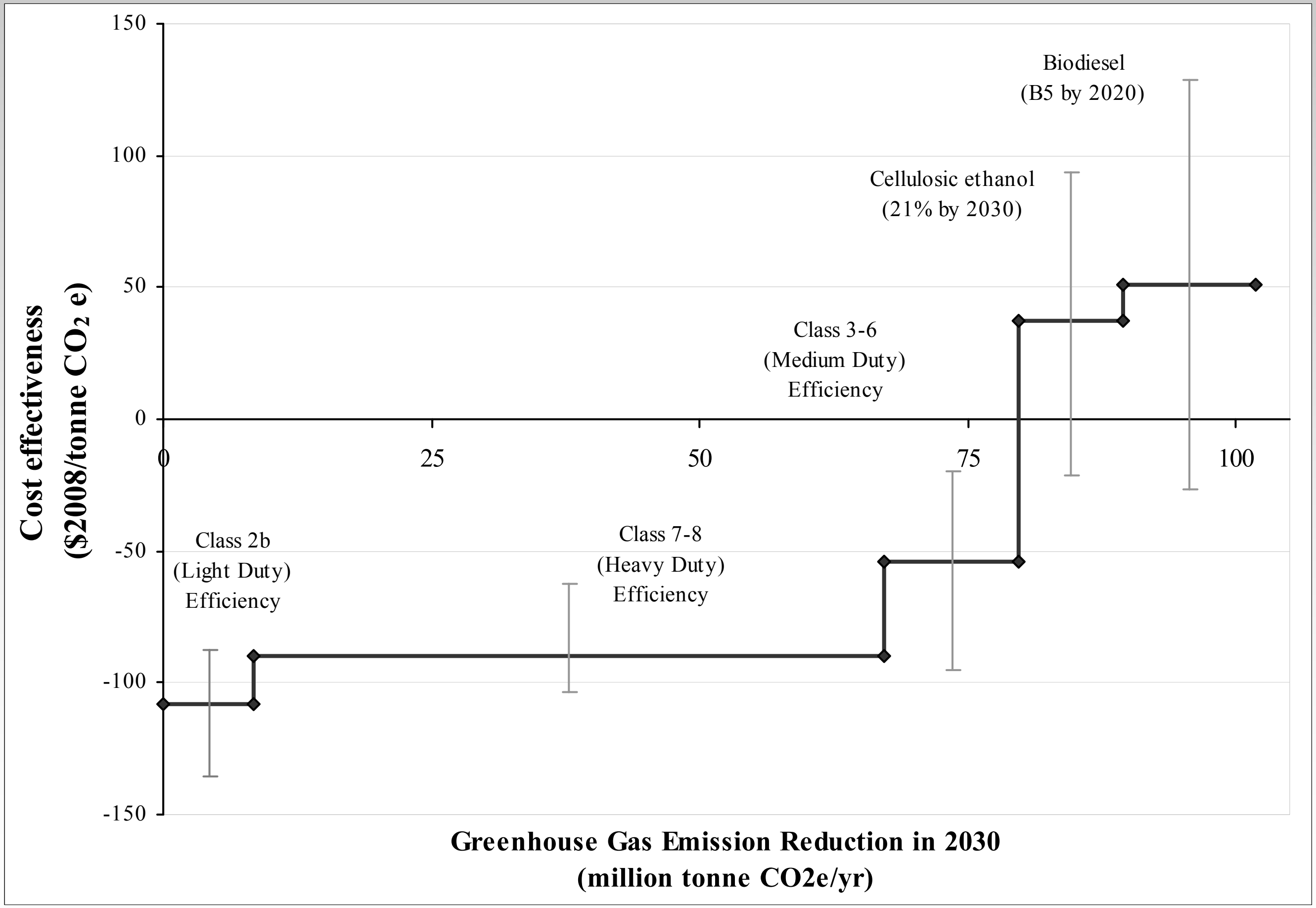
Transportation

Light duty vehicle GHG-reductions through 2030:



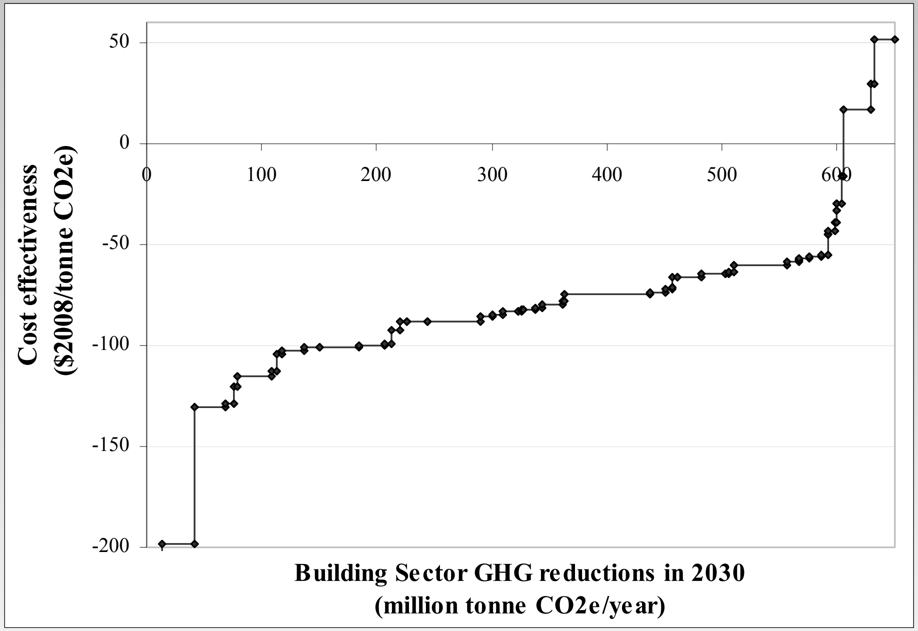
Transportation

Commercial truck (Class 2b, Class 3-6, Class 8) GHG-reduction:



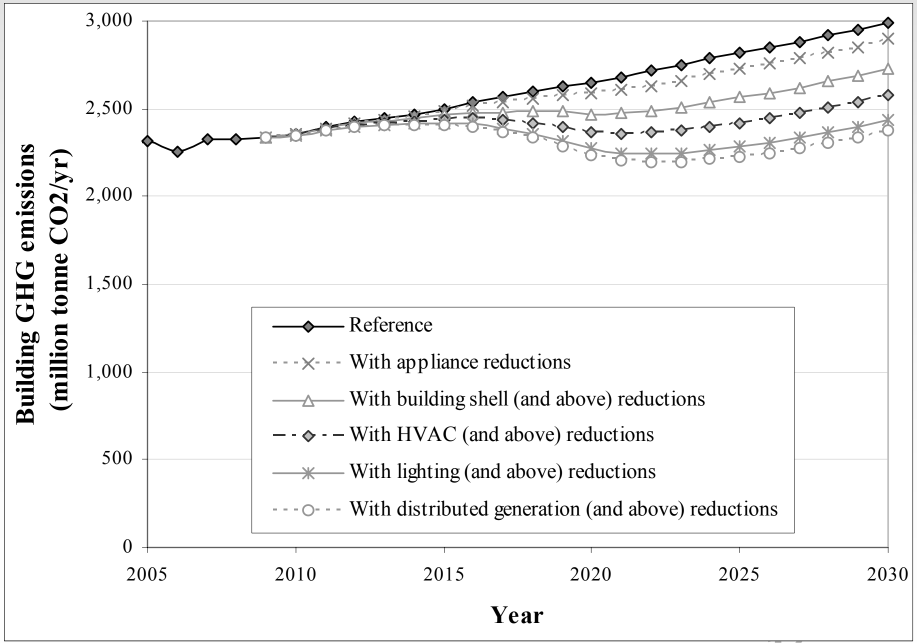
Based on An et al 2000; Langer, 2004; Vyas et al 2002; Schaefer and Jacoby, 2006; Muster, 2001; Lovins et al, 2004

Building Sector



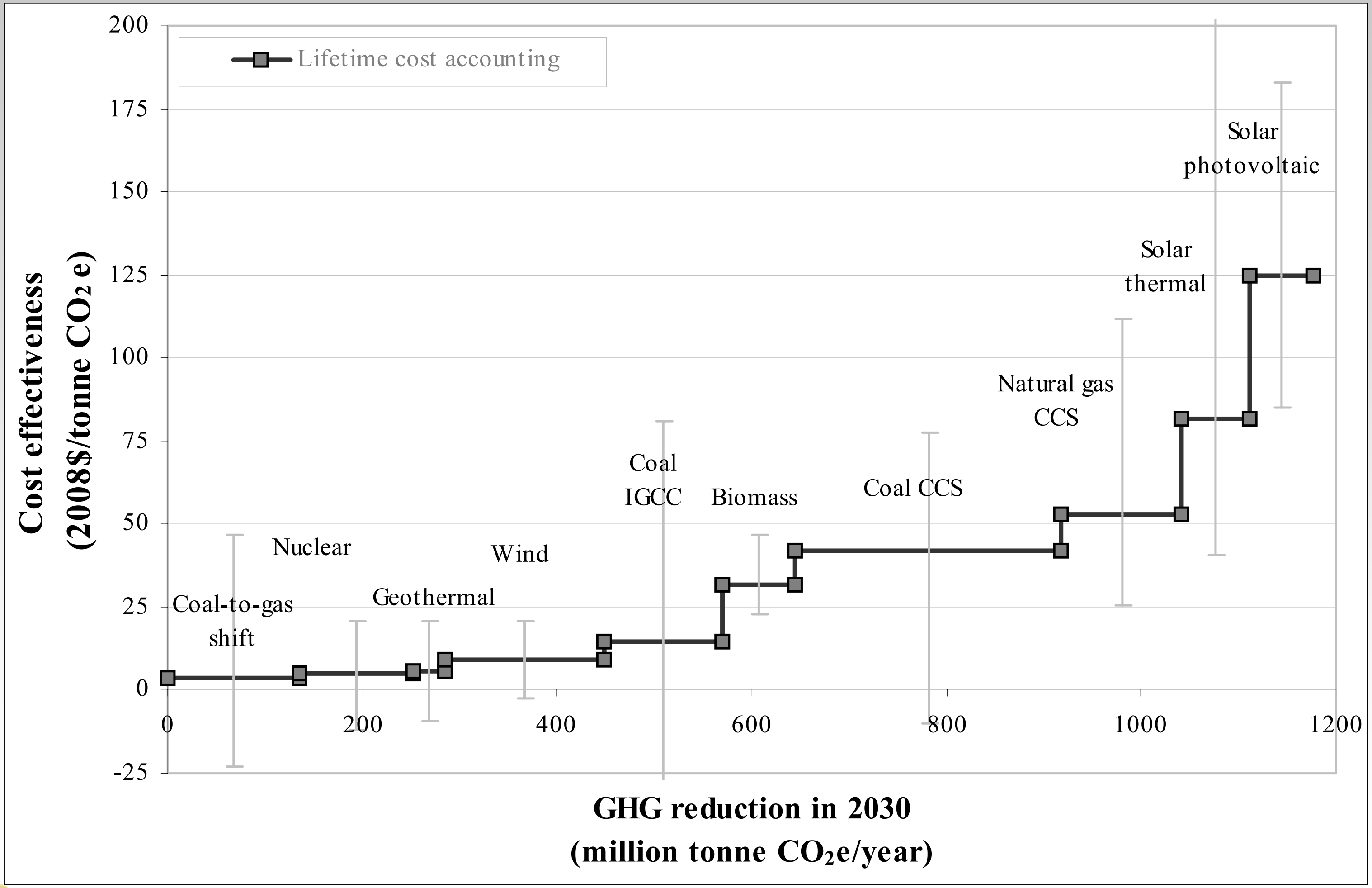
Technology areas in residential and commercial buildings:

- Appliance efficiency (18 technologies)
- Building shell efficiency (13 technologies)
- HVAC efficiency (10 technologies)
- Lighting efficiency (10 technologies)
- Distributed power (2 technologies)



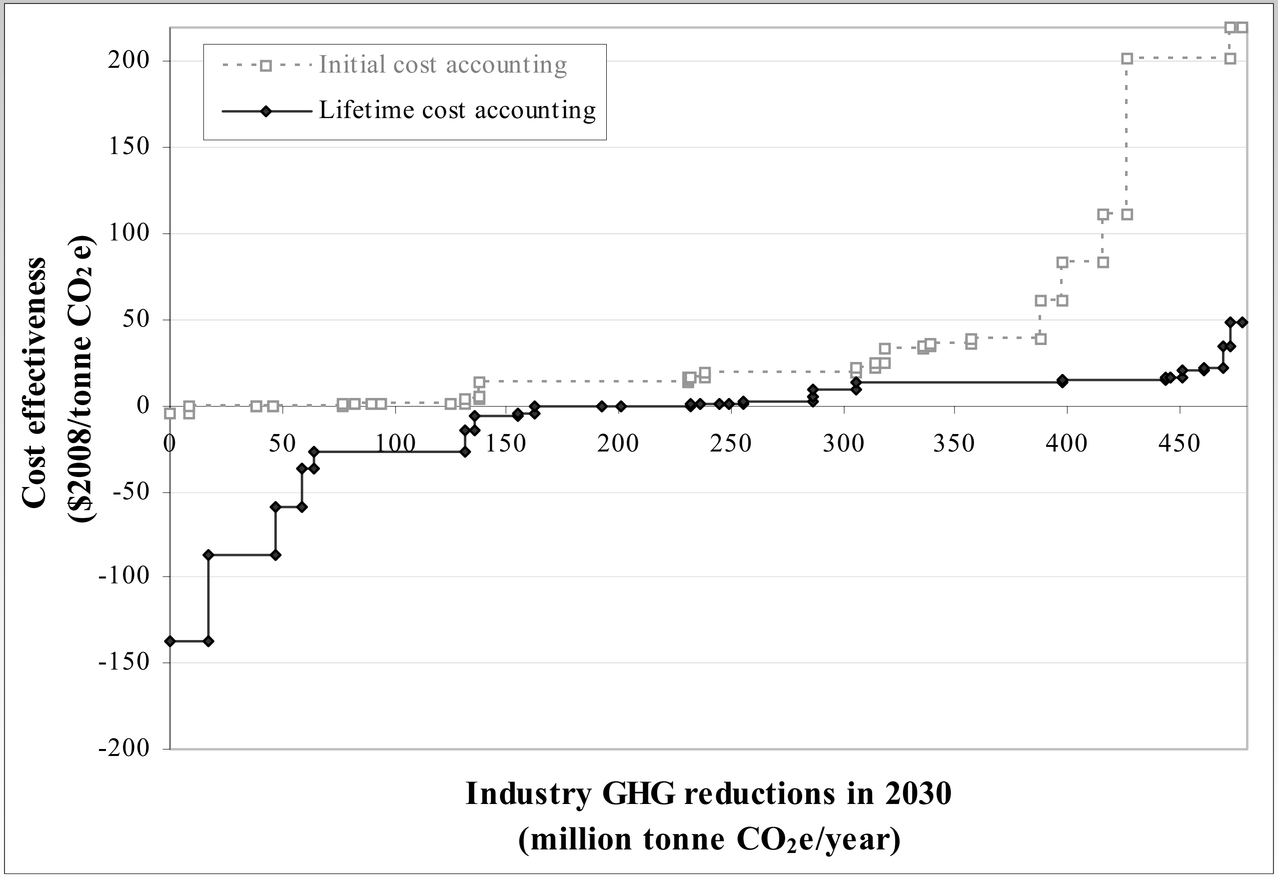
Electricity Generation

Electricity generation GHG-reductions:



Industry Sector

GHG abatement in other industrial sectors:

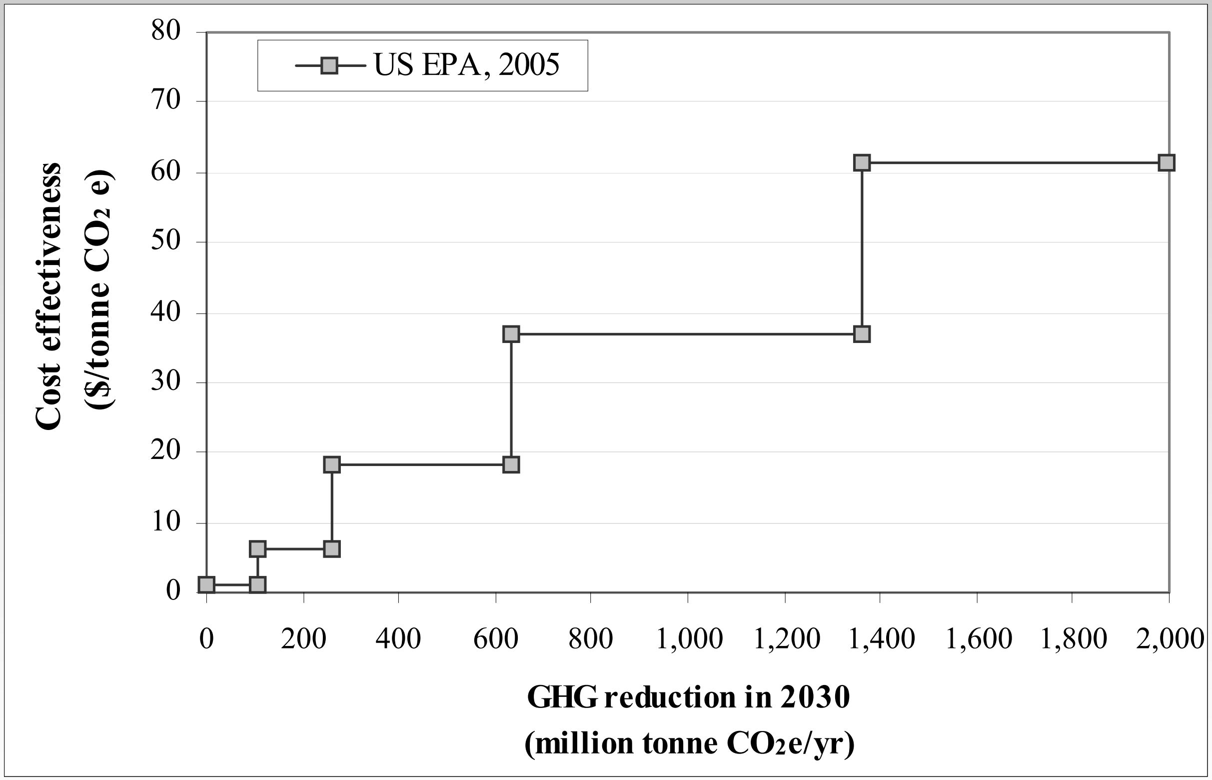


Technology Areas:

- High-GWP "F gases"
- Steel and iron
- Cement
- Combined heat and power (CHP)
- Landfill gas management
- Paper and pulp

Agricultural Sector

GHG abatement in agriculture and forestry:



Areas included:

- Afforestation
- Forest management
- Soil carbon sequestration
- Biofuel offsets (biomass for transp. Fuels, power plants)
- Reduced fossil fuel inputs
- Livestock manure management (enteric ferm. and manure CH_4)
- N_2O-related soil management strategies

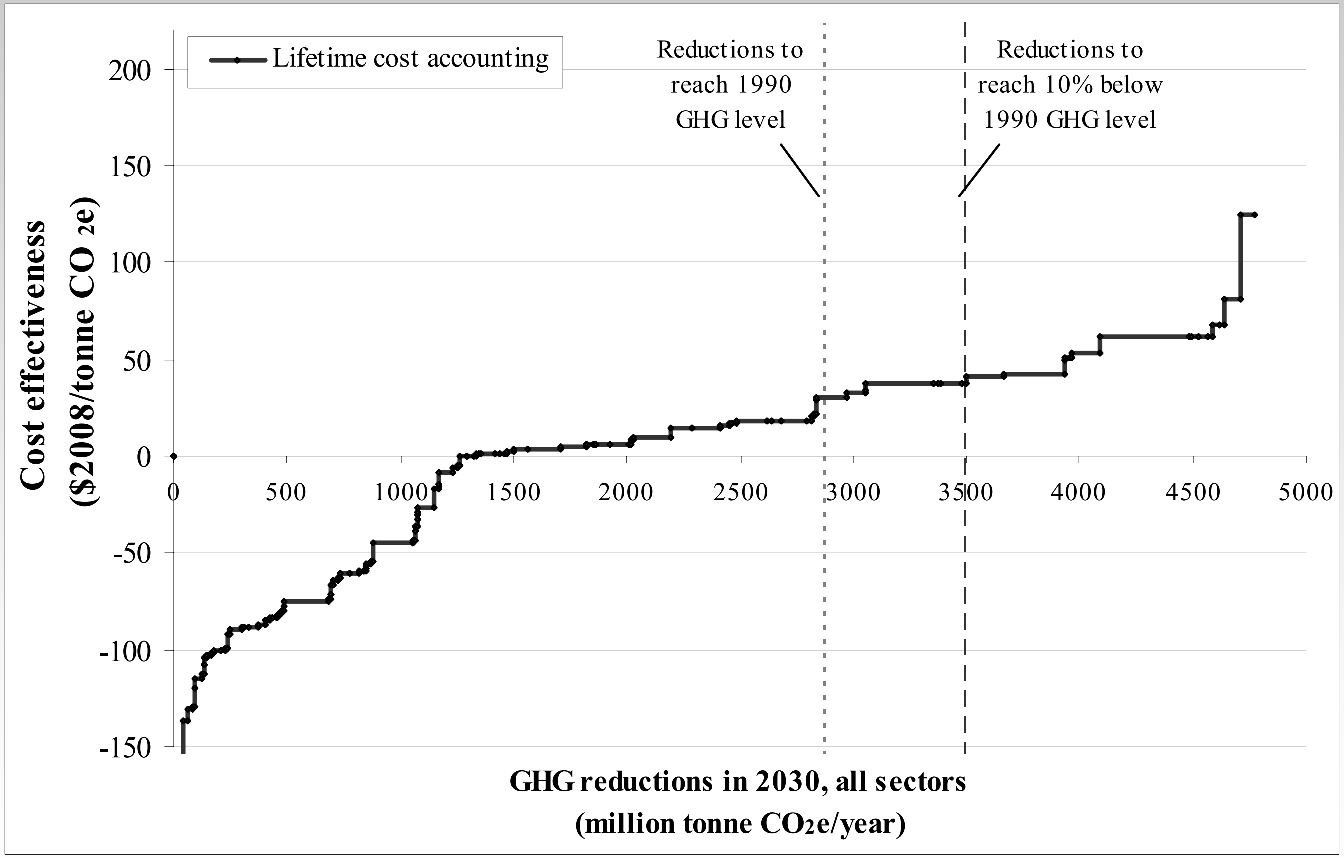
Multi-Sector GHG Abatement

- Issues in integrating GHG abatement measures
  - Interaction effects, or "double counting"
  - Cross-sector linkages
    - Building sector efficiency – electricity generation technologies
    - Agriculture sector biomass production – transportation/electricity biomass usage

- Handling of data
  - Choose mutually exclusive GHG-reduction measures
  - Adjust baseline emissions characteristics for measures that interact (and recalculate GHG emission reductions and cost effectiveness ratios)
  - Selection of studies and technologies to be consistent across sectors

Multi-Sector GHG Abatement

Synthesis of all sectors' GHG cost-effectiveness curves:



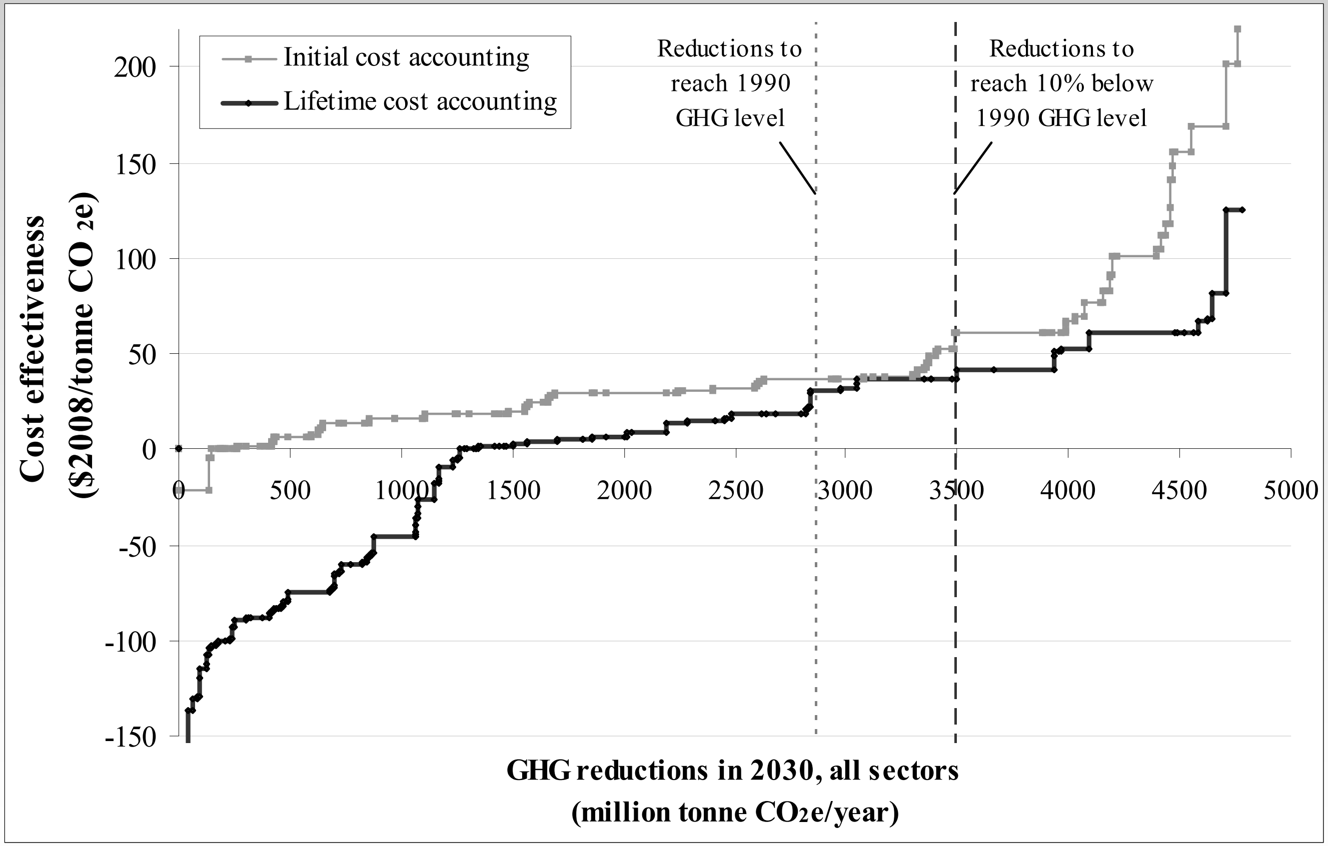
Technologies included:

- Automobile efficiency
- Truck efficiency
- Biofuels
- Aircraft efficiency
- Renewable electricity
- Carbon capture and storage
- Nuclear power
- "Clean coal" IGCC
- Appliance
- Building shell
- HVAC efficiency
- Distributed power
- Livestock management
- Landfill gas-to-energy
- Hydrofluorocarbon

Multi-Sector GHG Abatement

Impact of energy savings in GHG cost-effectiveness curves

(Why aren't "no regrets" technologies more widely adopted?):



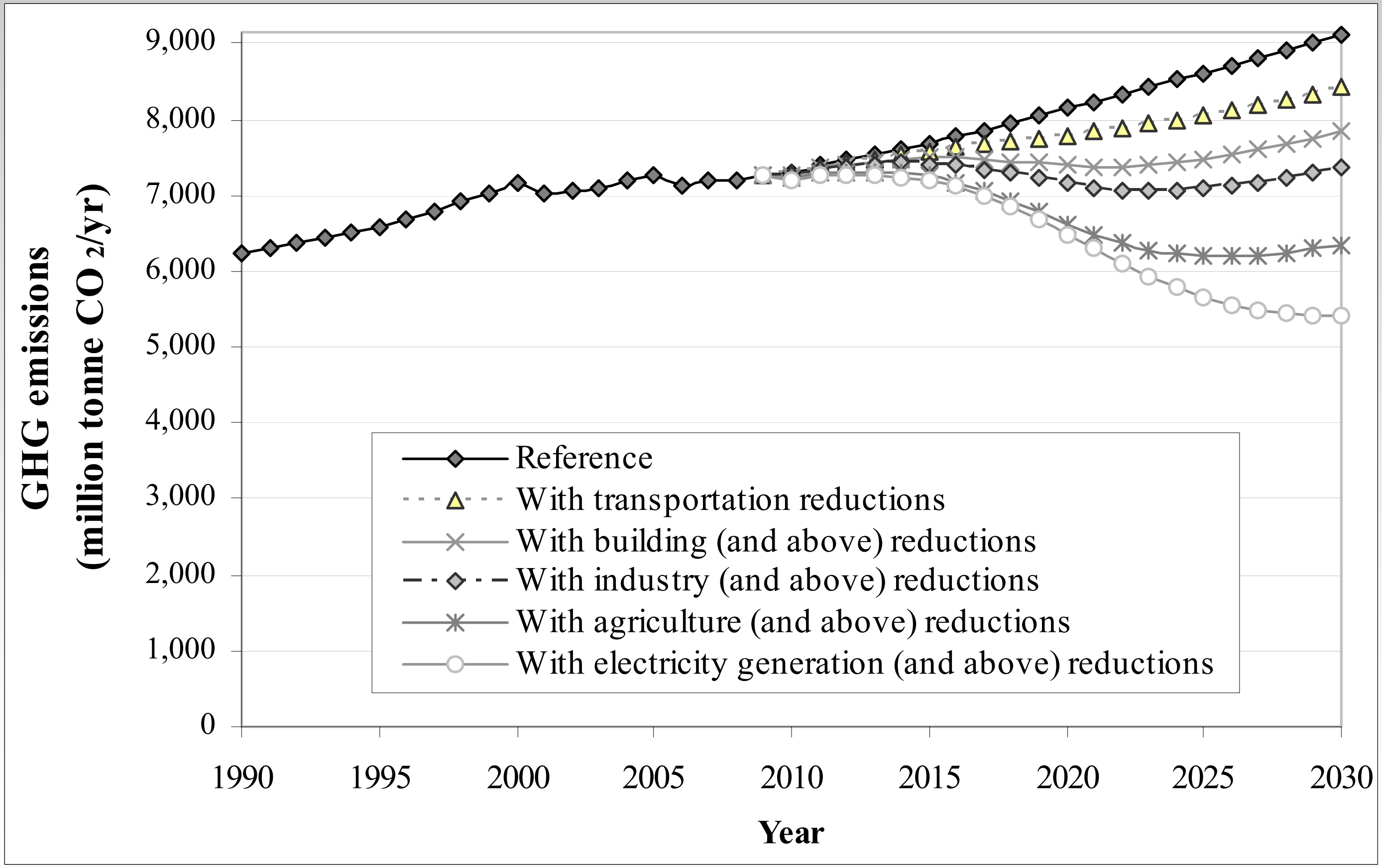
"Efficiency gap" factors:

- **Slow diffusion of technologies**
- **Information availability**
- **Consumers do not value or consider future energy savings**
- **Principal-agent problem (purchaser ≠ energy-saver)**
- **Other technology costs/limitations that are not included**
- **Institutional barriers**

Multi-Sector GHG Abatement

What is the impact of the lower cost mitigation measures?

Synthesis of all sectors' technologies <$50/tonne CO_2e:

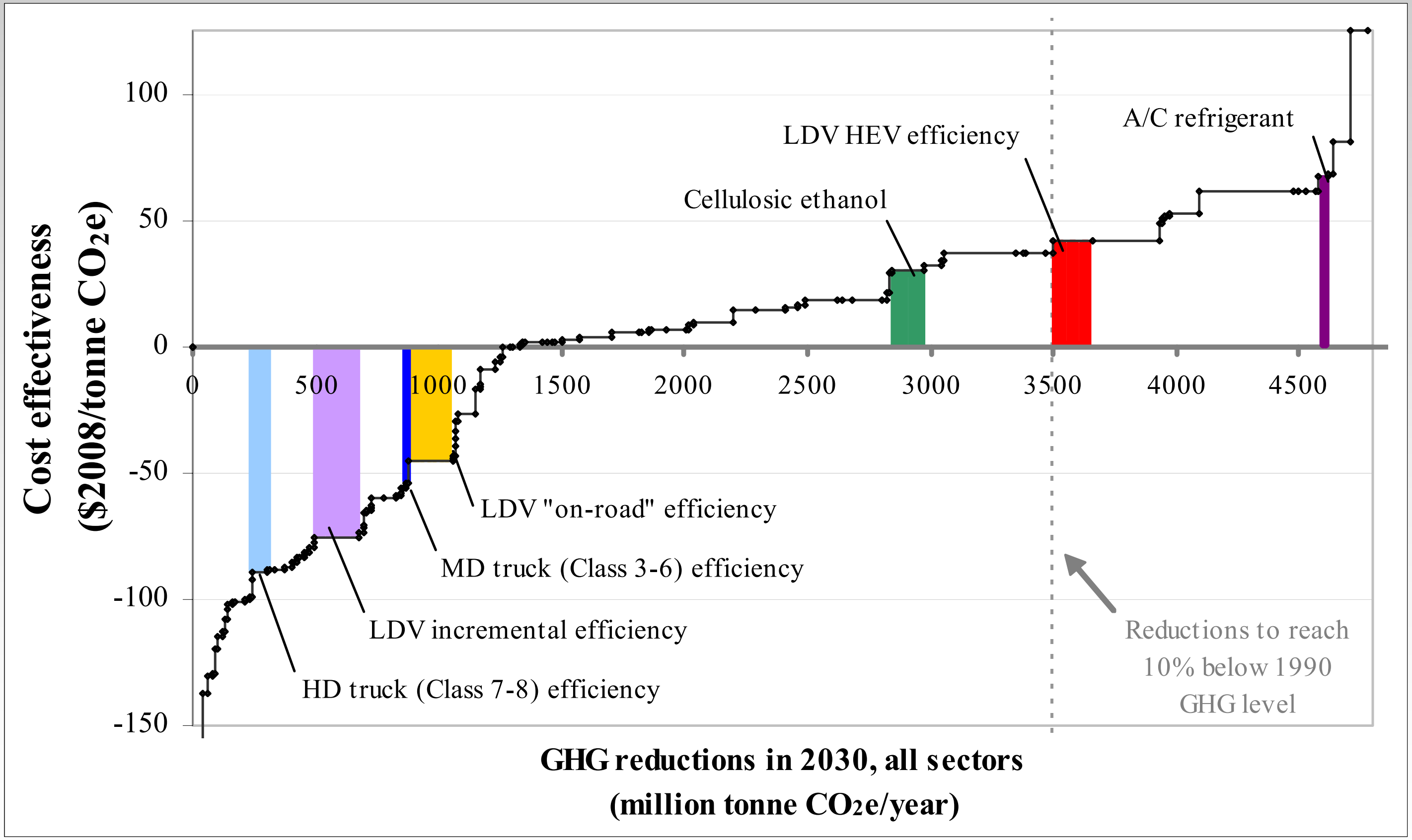


43% below 2030 baseline

16% below 1990 level in 2030

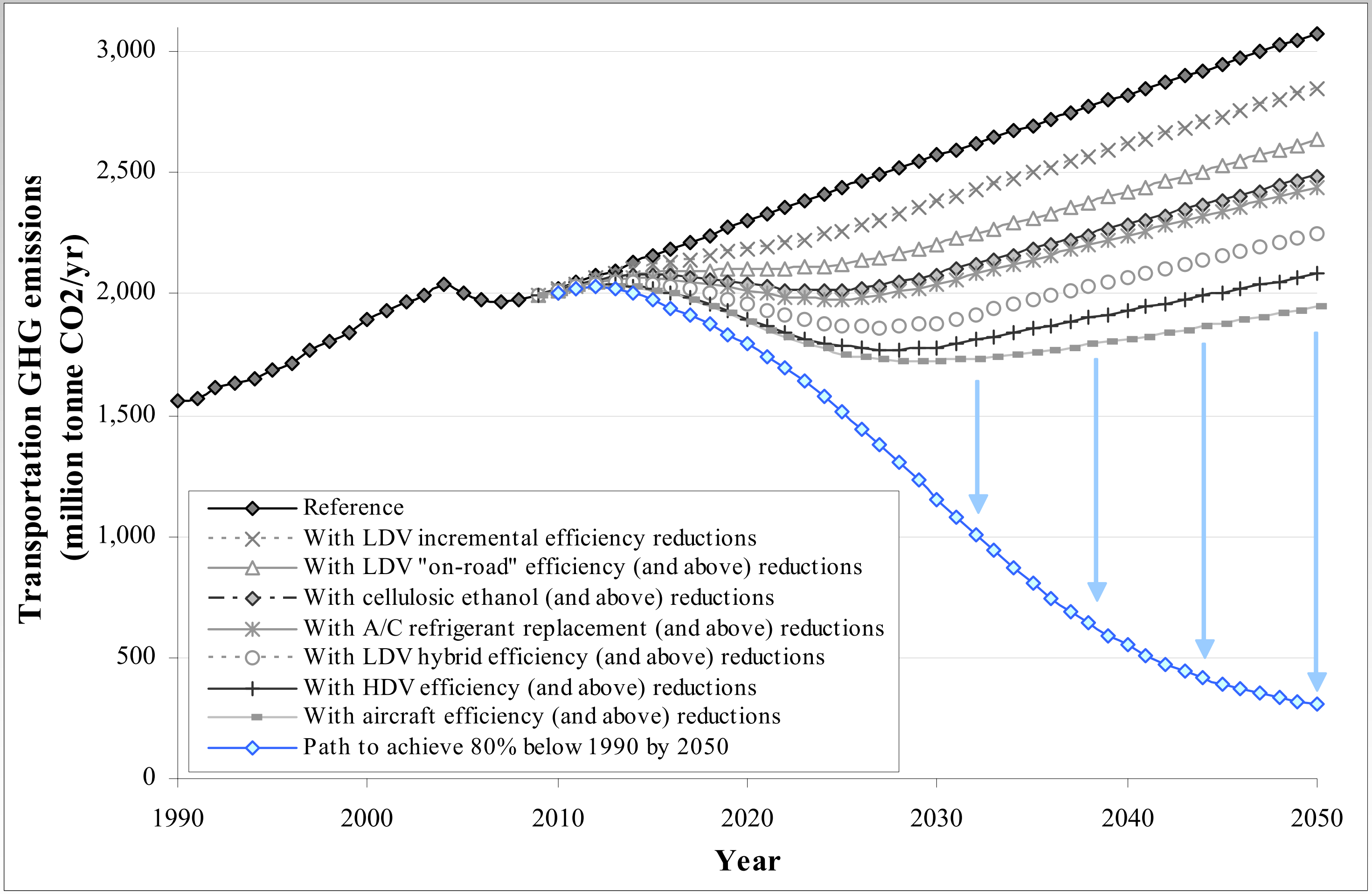
Multi-Sector GHG Abatement

Synthesis of all sectors' GHG cost-effectiveness curves (selected transportation measures highlighted):



Transportation GHG Abatement

Transportation GHG-reduction through 2050:



Conclusions

- **Transportation**
  - Energy savings makes vehicle efficiency options very attractive
  - Many available technologies are cost-effective contributors to overall GHG mitigation targets through 2030
  - Near-zero GHG emission vehicles and/or substantial VMT reductions required for deeper 2050 GHG reductions

- **All economic sectors**
  - On achieving the target of 1990 GHG emission level in 2020-2030 time period (40% reduction from baseline) . . .
    - Feasible with known technologies
    - Feasible with measures at cost < $50-per-tonne CO_2e
    - Many technologies in many economic sectors will be required
    - Many "no regrets" actions with net economic benefits to operators of efficiency technologies (e.g. appliance, lighting, buildings, and vehicles)

Conclusions

- **Acknowledgements**

  - Dissertation fellowship from ITS-Davis' Sustainable Transportation Center (STC), with funding from Caltrans and U.S. DOT
  - Dissertation committee members: Dan Sperling, Joan Ogden, and Tim Lipman

- **Contact**

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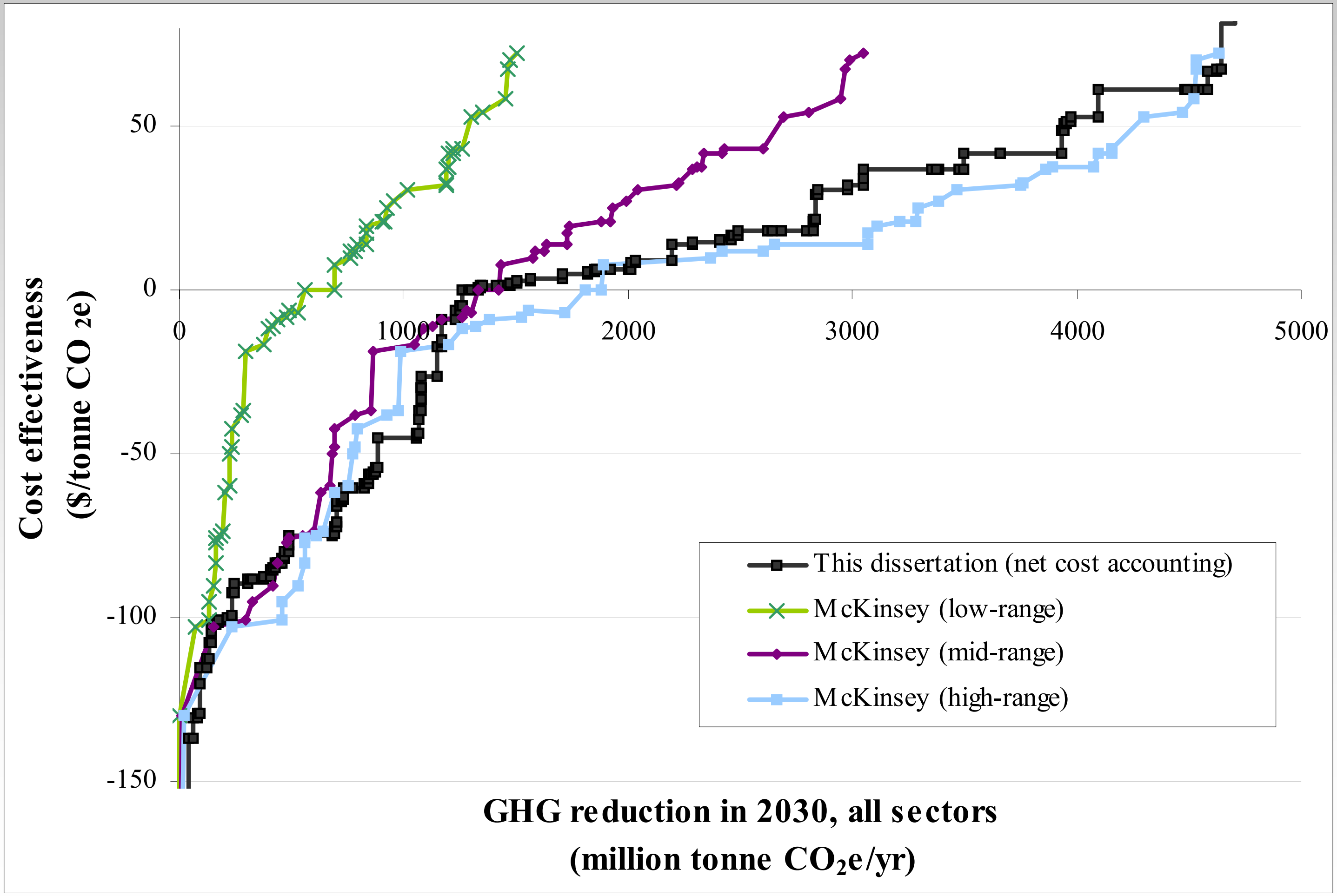
- **Questions?**

Comparison with Other Studies

- **As compared to McKinsey study, *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost* (Creyts et al, 2007)**



Other Benefits of GHG Mitigation Actions

With inclusion of generic $25/tonne CO_2e co-benefit: