Prioritizing Climate Change Mitigation Technologies by Cost-Effectiveness:

How do transportation options compare with other sectors?

Nic Lutsey
Ph.D. Candidate
Institute of Transportation Studies
University of California at Davis

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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 CO₂-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:
  - Include costs and direct benefits:
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-CO₂ GHGs:**
  - Air conditioning (HFC-134a)
  - Nitrous oxide (N₂O), Methane (CH₄)
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:

- Incremental efficiency (-20% by 2020)
- Improved "on-road" efficiency shortfall (from 20% to 10%)
- Cellulosic ethanol (21% by 2030)
- Hybrid-electric vehicles (50% sales by 2025)
- A/C refrigerant (HFC-134a to CO2)

Cost effectiveness ($2008/tonne CO2e)

Cumulative GHG reduction in 2030 (million tonne CO2e/yr)
Transportation

Light duty vehicle GHG-reductions through 2030:

<table>
<thead>
<tr>
<th>Year</th>
<th>Light duty vehicle GHG emissions (million tonne CO2e/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>Reference</td>
</tr>
<tr>
<td>1995</td>
<td>Incremental fuel consumption improvement (-20% by 2020)</td>
</tr>
<tr>
<td>2000</td>
<td>'On-road' fuel consumption factor improvement (20% to 10% by 2020)</td>
</tr>
<tr>
<td>2005</td>
<td>Cellulosic ethanol increase (21% motor fuel by 2030)</td>
</tr>
<tr>
<td>2010</td>
<td>Alternative air-conditioning refrigerant (HFC-134a to CO2)</td>
</tr>
<tr>
<td>2015</td>
<td>Hybrid gasoline-electric vehicles (50% sales by 2025)</td>
</tr>
<tr>
<td>2020</td>
<td>U.S. 1990 GHG emission level</td>
</tr>
<tr>
<td>2025</td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
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</tbody>
</table>
Transportation

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

- Biodiesel (B5 by 2020)
- Cellulosic ethanol (21% by 2030)

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)

![Graph showing Building Sector GHG reductions in 2030](image)

![Graph showing Building GHG emissions](image)
Electricity Generation

Electricity generation GHG-reductions:

- Coal-to-gas shift
- Nuclear
- Wind
- Coal IGCC
- Biomass
- Coal CCS
- Natural gas CCS
- Solar thermal
- Solar photovoltaic

GHG reduction in 2030
(million tonne CO$_2$e/year)

Cost effectiveness
(2008$/tonne CO$_2$e)

Lifetime cost accounting
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 CH₄)
- N₂O-related soil management strategies

![Graph showing GHG reduction in 2030 (million tonne CO₂e/yr) vs. Cost effectiveness ($/tonne CO₂ e)](chart.png)
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
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

GHG reductions in 2030, all sectors (million tonne CO$_2$e/year)
Multi-Sector GHG Abatement

What is the impact of the lower cost mitigation measures?

Synthesis of all sectors’ technologies <$50/tonne CO₂e:

- 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):

- HD truck (Class 7-8) efficiency
- LDV incremental efficiency
- LDV "on-road" efficiency
- MD truck (Class 3-6) efficiency
- Cellulosic ethanol
- LDV HEV efficiency
- A/C refrigerant

GHG reductions in 2030, all sectors (million tonne CO2e/year)

Reductions to reach 10% below 1990 GHG level
Transportation GHG Abatement

Transportation GHG-reduction through 2050:

Reference
- With LDV incremental efficiency reductions
- With LDV "on-road" efficiency (and above) reductions
- With cellulosic ethanol (and above) reductions
- With A/C refrigerant replacement (and above) reductions
- With LDV hybrid efficiency (and above) reductions
- With HDV efficiency (and above) reductions
- With aircraft efficiency (and above) reductions
- Path to achieve 80% below 1990 by 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 < $50-per-tonne CO$_2$e
    • 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
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  – Dissertation committee members: Dan Sperling, Joan Ogden, and Tim Lipman

• Contact
  – nplutsey@ucdavis.edu

• Questions?
Comparison with Other Studies


![Graph showing GHG reduction and cost effectiveness comparison](chart.png)
Other Benefits of GHG Mitigation Actions

With inclusion of generic $25/tonne CO₂e co-benefit:

GHG reductions in 2030, all sectors
(million tonne CO₂e/year)

Cost effectiveness ($2008/tonne CO₂e)

-150 -100 -50 0 50 100 150 200 250 300 350 400 450 500

Initial cost accounting
Lifetime cost accounting
Hypothetical ancillary cost accounting

Reductions to reach 1990 level of GHG emissions