URBAN PLANNING, LAND USE POLICY, & VEHICLE TECHNOLOGIES TO REDUCE GHG EMISSIONS IN CITIES

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Key, Connected Topics

- **Land Use Policies**
  - Example: Parking policies

- **Transportation Policies**
  - Example: Plug-in vehicles

- **Transportation Technologies**
I. Land Use Policies

*Denser* Development (more persons & jobs per acre)

*More Accessible* Regions & Neighborhoods

*More Mix & Balance* of Complementary Use Types

*Transit-Oriented* Designs

*More Connected* Networks

*Urban Growth Boundaries*

*Parking Maxima* (per dwelling unit, job, m²)

→ Various co-benefits, but driving distances & GHGs do not fall as much as we would like.
How helpful are these?

10% increase in the following values, with 1% of U.S. households affected ...

- % of 4-way intersections: 0.40 M tons/yr
- Net (jobs + population) density: 0.32
- Population density: 0.07 to 0.30
- Accessibility: 0.27
- Land use mixing: 0.18
- Walking quality: 0.14
- Vertical mixing: 0.095
- Population centrality: 0.030

Note: Values assume no vehicle type/fuel economy changes.
Car Distances vs. Density

3 Austin, Texas Scenarios

**Base Scenario:** Business as usual/Trend

**Road Pricing:** Congestion pricing (on freeways) + Carbon tax (4.5¢ per mile)

**Urban Growth Boundary:** Zones with 3+ person-equivalents per developable acre, plus adjacent zones
Forecast Comparisons
Job Densities in 2030

Base Case

Road Pricing

UGB
Forecast Comparisons
Population Densities in 2030

Base Case

Road Pricing

UGB
Scenario Comparisons

Jobs, Households, & Traffic Patterns

<table>
<thead>
<tr>
<th></th>
<th>Accessibility (of CBD)</th>
<th>Reg. Density (per sq.mi.)</th>
<th>Avg. Speed (mph)</th>
<th>VMT (10^6 /day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HHs (10^6/day)</td>
<td>Jobs (10^6/day)</td>
<td>HHs</td>
<td>Jobs</td>
</tr>
<tr>
<td>Base Case</td>
<td>1.81</td>
<td>6.29</td>
<td>1483</td>
<td>7995</td>
</tr>
<tr>
<td>Road Pricing</td>
<td>1.53</td>
<td>6.32</td>
<td>1477</td>
<td>8047</td>
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<tr>
<td>UGB</td>
<td>3.74</td>
<td>6.93</td>
<td>29,696</td>
<td>22,581</td>
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</tbody>
</table>

\[
\text{Accessibility} = \sum_i \frac{\text{Count}_i}{\text{DistToCBD}_i}
\]
More Traffic Comparisons

<table>
<thead>
<tr>
<th></th>
<th>Average Speed</th>
<th>Average Max. VOC</th>
<th>Total Flow ($\times 10^6$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AM</td>
<td>PM</td>
<td>AM</td>
</tr>
<tr>
<td>Base Scenario</td>
<td>43.4</td>
<td>45.5</td>
<td>0.556</td>
</tr>
<tr>
<td>Congestion Pricing</td>
<td>44.0</td>
<td>46.2</td>
<td>0.491</td>
</tr>
<tr>
<td>Density Floor</td>
<td>43.3</td>
<td>45.3</td>
<td>0.554</td>
</tr>
<tr>
<td>Urban Growth Boundary</td>
<td>44.0</td>
<td>45.5</td>
<td>0.495</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Vehicle Miles Traveled</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AM</td>
</tr>
<tr>
<td>Base Scenario</td>
<td>17,010</td>
</tr>
<tr>
<td>Congestion Pricing</td>
<td>14,636</td>
</tr>
<tr>
<td>Density Floor</td>
<td>16,913</td>
</tr>
<tr>
<td>Urban Growth Boundary</td>
<td>14,205</td>
</tr>
</tbody>
</table>
A Word of Caution: Low Speeds from Higher Densities?

- Maximum fuel economy at higher speeds (30 to 60 mph).
- Reduce/enforce freeway speed limits.
- Increase urban speeds (via road pricing & design).

Source: ORNL (1997)

Based on 8 vehicles (5 PCs & 3 LDTs)
II. Transportation Policies

Pricing (by vehicle type, location & time of day)...

• ... of Parking & Road Use

• ... of Vehicles & Fuels (via Feebates, Fees & Taxes)

Fuel Economy Standards

Resource Sharing (carsharing, bikesharing, dynamic ride-sharing, transit provision, mixed parking lot uses)

Information Provision (to car buyers, drivers, transit users, sluggers, via Smartphones & Smartmeters, ...)

Fuel Economy & Pricing Policies

- **Gas Taxes** (relatively low impact)
- **Vehicle Registration Fees** (significant in Asia)
- **Fuel Economy Standards** (common & meaningful)
- **Feebates** (may emerge in US)
- **GHG Emissions Standards** (present in EU)
- **Road Pricing** (controversial & targets congestion)
- **Paying More for Parking** (effective & underutilized in many locations)
- **Subsidy of Alternative Modes** (negative benefit-cost ratios in many contexts)
What does a 1% Mode Shift buy us, vs. Drive Alone? (At Average Occupancies, Trips <50 miles)
1% Local Travel Mode Shift
(Alternative Modes at *Full Occupancy*)

Notes:
- Modal options sub for local VMT (trips under 50 mi).
- Average HBW occupancy is 1.1.
- Average driving occupancy is 1.6.
- “Marginal shift” signifies use of unused capacity in a carpool or transit vehicle.
Example: Credit-Based Congestion Pricing

Speeds rise & most travelers benefit.
Miles-driven & emissions fall just 7% if charge marginal delay cost.
III. Transportation *Technologies*

**Plug-in Electric Vehicles (PEVs)**
- **BEVs** (ex. Leaf & Roadster) + **PHEVs** (ex. Volt)
- **Tax credits** → **Owner savings under moderate energy prices** (offset by uncertainty & myopia?)
- **Battery advances**
- **Cleaner power** (offshore wind fields, solar films, algae-based fuels, carbon sequestration, & more affordable energy storage)
- **Smart Charging & V2G Opportunities**

**Vehicle Safety** (stronger, lighter-weight materials; electronic stability control; obstacle detection & lane-departure warnings; GPS navigation)
**PEVs: Plug-in Hybrids & BEVs**

**Electrification of miles...**
- Maximizes efficiency of electric motors.
- Allows substitution of lower GHG “fuels”.
- Centralizes emissions (opportunity for CCS).
- Charging schedules can exploit excess off-peak capacity & wind’s peak generation times.
- Does best for those with stable driving patterns (e.g., suburban commuters).
- Key markets: High gas prices, 220 V outlets, & reasonable alternatives for long-distance trip-making.

**Issues**
- Battery cost, weight, range, durability & supply.
- Emissions of power grid (GHGs & other pollutants).
- Possibly no improvement over improved HEVs (given cost).
## Some PEV Examples

<table>
<thead>
<tr>
<th>BEVs</th>
<th>eREVs</th>
<th>PHEVs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Battery size</strong></td>
<td>24-85 kWh</td>
<td>14-16 kWh</td>
</tr>
<tr>
<td><strong>AER</strong></td>
<td>60-300 miles</td>
<td>25-50 miles</td>
</tr>
<tr>
<td><strong>Price</strong></td>
<td>~$30,000 – $100,000</td>
<td>~$40,000</td>
</tr>
<tr>
<td><strong>Gasoline</strong></td>
<td>None</td>
<td>Conventional</td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
<td>No internal combustion engine. No Tailpipe emissions.</td>
<td>No range limitation. Reduced tailpipe emissions. Acts as a BEV for shorter trips.</td>
</tr>
</tbody>
</table>

*Slide Contents: Dave Tuttle*
<table>
<thead>
<tr>
<th>Make &amp; Model</th>
<th>Release Date</th>
<th>Estimated Retail Price (after rebate)</th>
<th>Body Type</th>
<th>Battery Size (kWh)</th>
<th>Estimated State of Charge Window</th>
<th>All Electric Range (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Range-Extended PEVs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chevy Volt eREV</td>
<td>2010</td>
<td>$33,500</td>
<td>4-door sedan</td>
<td>16</td>
<td>65%</td>
<td>25-50</td>
</tr>
<tr>
<td>Ford CMAX Energi PHEV</td>
<td>2012</td>
<td>TBA</td>
<td>4-door CUV</td>
<td>10</td>
<td>TBA</td>
<td>TBA</td>
</tr>
<tr>
<td>Toyota Prius PHEV</td>
<td>2012</td>
<td>TBA</td>
<td>4-door sedan</td>
<td>5.3</td>
<td>Est 50%</td>
<td>13 (at limited speeds)</td>
</tr>
<tr>
<td><strong>Non-Range-Extended (BEVs)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tesla Roadster</td>
<td>2009</td>
<td>$101,500</td>
<td>2-door sports car</td>
<td>53</td>
<td>80%+</td>
<td>240</td>
</tr>
<tr>
<td>Nissan Leaf</td>
<td>2010</td>
<td>$25,250</td>
<td>4-door sedan</td>
<td>24</td>
<td>90%+</td>
<td>100</td>
</tr>
<tr>
<td>Ford Focus</td>
<td>2012</td>
<td>TBA</td>
<td>4-door sedan</td>
<td>23</td>
<td>TBA</td>
<td>100</td>
</tr>
<tr>
<td>Tesla Model S</td>
<td>2012</td>
<td>$49,900 base</td>
<td>4-door sedan</td>
<td>42 (also 65 &amp; 85kWh options)</td>
<td>80%+</td>
<td>160 (also 230 &amp; 300 options)</td>
</tr>
<tr>
<td>Mitsubishi iMiEV</td>
<td>2011</td>
<td>TBA</td>
<td>4-door sedan</td>
<td>16</td>
<td>TBA</td>
<td>100</td>
</tr>
<tr>
<td>Mercedes Smart Car</td>
<td>2012</td>
<td>TBA</td>
<td>2-door sedan</td>
<td>TBA</td>
<td>TBA</td>
<td>90</td>
</tr>
</tbody>
</table>

How might day-to-day variability in driving affect PEV adoption & use opportunities?

We find that the market offers great potential for heavy adoption, with very moderate household adjustment.
Analysis Framework

Household

Single-vehicle household
- Switch to a BEV (Case 1)
  - What percentage of days are covered?

Switch to a PHEV (Case 2)
  - What percentage of miles are electrified?

Multiple-vehicle household
- Switch a vehicle to a BEV
  - Which vehicle to switch?
    - The vehicle that travels less on average (Case 3)
      - What percentage of days are covered?
    - The vehicle that travels less on any given day (Case 4)
      - What percentage of days are covered?

- Switch a vehicle to a PHEV
  - Which vehicle to switch?
    - The vehicle that travels more on average (Case 5)
      - What percentage of miles are electrified?
    - The vehicle that travels more on any given day (Case 6)
      - What percentage of miles are electrified?
Adoption Rates: 1-BEV Households
Electrified Miles: 1-PHEV Households

- Households averaging ≤ 15 VMT/day
- Between 15 and 30 VMT/day
- Over 30 VMT/day

All Electric Range (AER), in Miles
Maximum Possible Multiple-vehicle Household BEV Adoption Rates in Seattle, with BEV Replacing the Lower Overall-VMT Vehicle (Case 3)
Electrified VMT: Multi-vehicle HHs

Average Shares of Household Miles Electrified (with Standard Deviations) using PHEVs in Multiple-vehicle Seattle Households
PHEV, HEV & SmartCar shares peak under FEEBATE2+GAS$5 scenarios (16.4% of fleet) & GASPRICE$7 scenario (16.3% market share), while total miles-traveled fall about 30%.

HI-DENSITY scenario shows average vehicle ownership falling 7% (to 1.72 veh per household, vs. 1.85 under TRENDS).
Power + Transport ≈ 62% of U.S. GHGs → Key to Emissions Abatement

Source: EIA (2008)
Timing of Travel

VMT by time of day (using NHTS 2009 data).
Best Options for Sustainable Cities

- PHEVs with Clean Grid (renewables, nuke & CCS)
- Non-motorized Modes (biking & walking)
- Shared Cars & Buses running Full (via real-time carpooling?)
- Parking Charges + Fuel Pricing
- Urban Growth Boundaries (controlled release of land to development)
Other Findings

• **HEVs are a very cost-effective technology.** (We need more HEV vehicle-body options, & U.S. needs smaller vehicles.)

• **Reducing Coal-fired Power Generation is Key.** (offering greater savings than *any* single transportation or land use option)

• **Advertising Societal Benefits** of New Technologies & **Lifetime Fuel Savings** (via vehicle stickering & online) is cheap yet powerful!

• And how about **tradable carbon credits** at level of households? (for home energy + vehicle odometer readings + air travel)
The Rankings of 1% Adoption Strategies...

<table>
<thead>
<tr>
<th>Reduction Strategy (1% Adoption)</th>
<th>% U.S. Total GHG Emissions</th>
<th>Reduction Strategy (1% Adoptions)</th>
<th>% U.S. Total GHG Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1% Shift to Renewables – 2050</td>
<td>0.450</td>
<td>1% HHs Switch to Heat Pump</td>
<td>0.031</td>
</tr>
<tr>
<td>1% Shift to Renewables – 2030</td>
<td>0.380</td>
<td>Downsize Home: 2400 to 2000 sq ft</td>
<td>0.005 - 0.026</td>
</tr>
<tr>
<td>1% Shift to Renewables - 2006</td>
<td>0.330</td>
<td>Parking to Rear Lot</td>
<td>0.021</td>
</tr>
<tr>
<td>Conv. Improv. + 10% Lightweighting + Cellulosic Ethanol Fuel</td>
<td>0.208</td>
<td>Warmest Climates Reduce A/C Operation by 1 hour/day</td>
<td>0.018</td>
</tr>
<tr>
<td>Cellulosic Ethanol</td>
<td>0.161</td>
<td>Clothes Washing in Cold Water (versus hot)</td>
<td>0.016</td>
</tr>
<tr>
<td>Conv. Improv. + 10% Lightweighting + Biodiesel Fuel</td>
<td>0.160</td>
<td>HHs Reduce Water Heater Temp from 140 to 120°F</td>
<td>0.013</td>
</tr>
<tr>
<td>PHEV 30 (2030, renewable energy)</td>
<td>0.160</td>
<td>Insulation: from 90 to 500 mm</td>
<td>0.013</td>
</tr>
<tr>
<td>PHEV 30 (2030, projected ave grid)</td>
<td>0.134</td>
<td>10% Lightweighting</td>
<td>0.012</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>0.119</td>
<td>Front &amp; Side Parking</td>
<td>0.010</td>
</tr>
<tr>
<td>Subway/Rapid Rail - avg occupancy</td>
<td>0.096</td>
<td>Paid employee parking</td>
<td>0.002 – 0.010</td>
</tr>
<tr>
<td>SFDU to MFDU</td>
<td>0.026 – 0.078</td>
<td>Four-way Intersections</td>
<td>0.005</td>
</tr>
<tr>
<td>Conventional Improvements</td>
<td>0.045</td>
<td>HDT Idle Reduction (APU)</td>
<td>0.005</td>
</tr>
<tr>
<td>$50/month Residential Parking</td>
<td>0.041</td>
<td>Increase Population Density 10%</td>
<td>0.001 – 0.003</td>
</tr>
<tr>
<td>Rail Mode Shift</td>
<td>0.039</td>
<td>Bus Mode Shift - full occupancy (average occupancy)</td>
<td>0.137 (-0.060)</td>
</tr>
</tbody>
</table>

HHs = Households
Important Tools & Challenges

Simulation (of human behavior, for uncertainty in inputs & parameters, & for model estimation)

... yet land use change remains very difficult to mimic.

Discrete choice models (to forecast land use types, buy/sell decisions, vehicle choices, destinations & modes & routes, vehicle allocation to household members, ...)

Spatial relationships (heavy use of GIS databases, spatial econometrics for autocorrelation in location factors & behavioral processes)
Thank you for your time!

Papers available at
www.ce.utexas.edu/prof/kockelman.
Air Travel (Passenger)

- 6.5% U.S. transp. GHG emissions come from commercial air travel.
- Emissions per passenger-mile depend on aircraft occupancy, trip length, & design:
  - Short trip (200 mi): 0.53 lb/pax-mi (WRI 2006)
  - Med. trip (700 mi): 0.42
  - Long trip (1500 mi): 0.40

vs. 20 mpg LDV...
  - Solo driver: 1.3 lb/paxmi
  - 4-persons Carpool: 0.32
Home Design: CO₂ Savings

- Double vs. Single Pane: 1,000-7,000 lbs/year/home
  (0.30-2.5 million tons for 1% of homes)
- Triple vs. Double Pane: 6,000-10,000 lbs (3.2-5.4)
- Update the A/C unit: 1,000 lbs (0.54)
- Upgrade R21 insulation to R60: 1,000-34k lbs (0.54-3.65)
- Replace incandescent bulbs with CFLs: 1,550 lbs (0.84)

(X) = Millions of Tons CO₂e per year for 1% of households
(vs. 6 B = U.S. total)
Estimates of CO$_2$ Savings from Home Design Changes

- Install double-pane windows: 2,240 lbs/year/home
- Replace incandescent bulbs with CFLS: 1,550 lbs
- Update the A/C unit: 1,000 lbs
- Upgrade R15 insulation to R21: 750-1450 lbs
- A/C savings from downsizing home 250 sf: 450 lbs

- All together: > 6,000 lbs/yr/home (>20% average home energy demand)

Still to come: More calculations on building materials & insulation, & commercial heating loads.

CO$_2$ Emissions per Household, 1997

- Space Heating: 8,829 lbs CO$_2$
- Lighting: 2,145 lbs CO$_2$
- Refrigerators & Freezers: 2,007 lbs CO$_2$
- Water Heating: 3,558 lbs CO$_2$
- Air Conditioning: 1,882 lbs CO$_2$
- Cooking: 825 lbs CO$_2$
- Other Appliances: 6,182 lbs CO$_2$
Home Design (2)

- Downsize home ~20% (2400 to 2000 sf):
  450 lbs/year/average home from A/C (.25)
  plus 1,000-2,000 lbs from heating (0.54-1.1)

- Move from 2400 sf SFDU to MFDU:
  3,000-20,000 lbs (1.6-12)

(X) = Millions of Tons CO$_2$e per year for 1% of households
Parking Policies

- **$50/month** for **Residential** parking: **5,560 lbs** per household per year (stemming from reduced vehicle ownership) (3.5 M tons/yr)

- **Downtown Employees Pay** market rates for parking: **300-1400 lbs** per worker (due to reduced SOV mode share) (.18-0.85)

- **Market-priced Curb Parking**: **230 lbs** per year per parking space (.15) (from reduced cruising)

(X) = Millions of Tons CO₂e per year for 1% of households or 1% of workers or 1% of CBD parking spaces.
Ranking of Home Design Changes & Parking Policies

If applied to 1% US households:

- Double to **triple pane** glass: 3.2-5.4 M tons/yr
- Residential parking at $50/month: 3.5
- Move from 2400 sq ft SFDU to MFDU: 1.6 to 12
- Replace **R15** Insulation with **R60**: 0.54 to 3.6
- Single to **double pane** glass: 0.3 to 2.5
- Reduce average home size to 2000 sf: 0.25 cooling & 0.54 to 1.05 heating
- Move to **CFL** Lighting: 0.84
- Reduce **A/C oper. 1 hr/day** during hot months: 0.64
- Update **A/C unit**: 0.54
- Paid **employee parking**: 0.18 to 0.54
Land Use: **Design**

- **SOV mode reduction due to 10% change in:**
  - Increase Walking Quality: 267 lbs/HH (.286 B/yr)
  - Increase Land use mixing: 350 lbs/HH (.371)

- **CO₂ reduction due to 10% increase:**
  - Vertical Mixing: 178 lbs/HH (.190)
  - Four-way intersections: 750 lbs/HH (.800)
Reducing **Braking & Inertial Forces**

Reduce Vehicle Weights

- 10% *Mass reduction* ☞ 6% FE improvement (IEA 2007)
  - FE improvement can reach 10% if engine downsized to match lighter vehicle body.

Ways to lightweight:

- Replace heavy materials with lighter weight materials – already being done
- **Downsize** vehicle – decreases utility of vehicle
- Improved packaging, *unit body* construction (body panels are load bearing), parts consolidation, ...

Most alternative materials are cost effective, based on lifetime fuel savings.

Safety: Design is more important than mass.
Current U.S. Power Generation Sources

- Coal: 49.07%
- Natural Gas: 20.04%
- Petroleum: 1.59%
- Nuclear: 19.40%
- Other Gases: 0.40%
- Hydroelectric: 7.13%
- Biomass: 1.35%
- Solar/PV: 0.36%
- Wind: 0.66%
- Geothermal: 0.01%

Source: EIA (2008)
1% Adoption of Various Power Technologies

Notes:
• Shows reduction from 1% of electricity demand being met by respective power generation technology
• Expanded Nuclear & Renewables = grid mix with 35% coal, 15% natural gas, & 50% nuclear/renewable.
# Power Generation Policy Barriers

<table>
<thead>
<tr>
<th>Technology</th>
<th>Transmission &amp; Distribution</th>
<th>Intermittence</th>
<th>Supply Uncertainty</th>
<th>Other Barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear</td>
<td></td>
<td>X</td>
<td></td>
<td>Security &amp; waste storage</td>
</tr>
<tr>
<td>Geothermal</td>
<td></td>
<td></td>
<td></td>
<td>Advanced tech. undemonstrated</td>
</tr>
<tr>
<td>Solar: Photovoltaics</td>
<td></td>
<td>X</td>
<td>X</td>
<td>Grid not designed for distributed generation</td>
</tr>
<tr>
<td>Solar: Concentrated Solar Power</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Biomass</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Coal w/CCS</td>
<td></td>
<td></td>
<td></td>
<td>Undemonstrated</td>
</tr>
</tbody>
</table>

*Note: Hydroelectric excluded due to limited new sites/capacity.*
1% Adoption of Alternative Fuels

Notes:
- Ethanol sub for gasoline.
- Biodiesel sub for diesel.
- Chart based on total annual fuel consumption by transportation.
1% Adoption of Freight Mode Shifts & Trucking Technologies

Notes:
- Options sub for 1% of truck ton-miles.
- Reduced Empty Miles is a 1% reduction in the estimated 15,000 miles driven empty per year per truck. Has negligible impact.
Winning Strategies: **Mode Shifting**

- Heavy Duty Truck to Rail Shift
- Avg. Occ. Drive to HSR, Diesel
- Avg. Occ. Drive to 4 Person Carpool
- Avg. Occ. Drive to Full Occ. Bus, Diesel
- Avg. Occ. Drive to Full Occ. LRT, "Clean Grid" w/ CCS, Electric
- Avg. Occ. Drive to Full Occ. LRT, Electric
- Avg. Occ. Drive to Avg. Occ. LRT, "Clean Grid" w/ CCS, Electric
- Avg. Occ. Drive to Avg. Occ. LRT, Electric
- Avg. Occ. Drive to Full Occ. HRT, "Clean Grid" w/ CCS, Electric
- Avg. Occ. Drive to Full Occ. HRT, Electric
- Avg. Occ. Drive to Avg. Occ. HRT, "Clean Grid" w/ CCS, Electric
- Avg. Occ. Drive to Avg. Occ. HRT, Electric
- Avg. Occ. Drive to Full Occ. Bus, Diesel
- Avg. Occ. Drive to Full Occ. Bus, Diesel
- Avg. Occ. Drive to 4 Person Carpool

Percent of an 80% Reduction Target (vs. 2000 U.S. GHG Emission Levels)
80% of 2000 Levels

Fraction of 80 Percent Reduction Target =

1% Adoption Savings (2006 “Feasible Market”)

\[
\frac{\text{2006 GHG Emissions} - 0.2 \times \text{2000 GHG Emissions}}{\text{2006 GHG Emissions} - 0.2 \times \text{2000 GHG Emissions}}
\]
1% Adoption of Vehicle Technologies

Notes:
- Vehicles sub for average existing vehicle (20.5 mpg) or average new vehicle (26.7 mpg in 2007 MY).
- Based on total number of passenger vehicles at average annual VMT.
- “Conventional Technologies” include engine, transmission, & vehicle body changes.
1% Long Distance Travel Mode Shift
(At Average Occupancies)

Notes:
• Options sub for trips over 50 mi.
• Basis for comparison is SOV.
• Average driving occup. is 1.6 pass.
• “Marginal shift” signifies use of unused capacity in a carpool or transit vehicle.
1% Long Distance Travel Mode Shift
(Alternative Modes at **Full Occupancy**)

**Notes:**
- Options sub for trips over 50 mi.
- Basis for comparison is SOV.
- Average work trip occup. is 1.6.
- “Marginal shift” signifies use of unused capacity in a carpool or transit vehicle.
Overall Vehicle & Power Winners

Percent of an 80 Percent Reduction Target (vs. 2000 U.S. GHG Emission Levels)

* = Local Travel

- PHEV-60, Average Grid
- Avg. Occ. Drive to Avg. Occ. LRT, "Clean Grid" w/ CCS
- Avg. Occ. Drive to Full Occ. HRT, Electric*
- Avg. Occ. Drive to Avg. Occ. HRT, "Clean Grid" w/ CCS
- PHEV-60, Clean Grid
- PHEV-60, Average Grid, E85 Cellulosic
- PHEV-60, "Clean Grid," E85 Cellulosic
- PHEV-60, Clean Grid w/ CCS
- Gasoline to E85 Cellulosic Ethanol
- Pass. Car, Al. Conv. Improvmts., E85 Cellulosic
- HEV w/ Al. Conv. Improvmts., E85 Cellulosic
- PHEV-60, "Clean Grid" w/ CCS & E85 Cellulosic
- CCS Coal Electricity Generation (vs. Grid Avg.)
- "Clean Grid" w/ CCS Electricity Generation (vs. Grid Avg.)
- Renewable Electricity Generation (vs. Grid Avg.)
Top Strategies: Power Generation, Fuels, & Vehicle Technologies

"Clean Grid" = 50% Renewable/Nuclear, 35% Coal, 15% Natural Gas

Percent of an 80% Reduction Target (vs. Year 2000 U.S. GHG Emissions Levels)