

Introduction and Research Goals:

California's greenhouse gas emissions reduction targets are among the most ambitious by a major world economy:

- Reducing emissions to 2000 levels by 2010,
- Achieving 1990 levels by 2020 and
- Reaching an 80% reduction below 1990 levels by 2050.

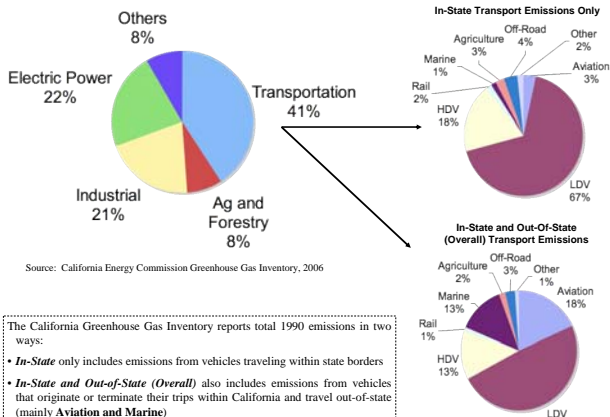
Given the expected growth in population and energy service demand in the State, meeting these targets, especially the 80% reduction by 2050, will be quite challenging. This study focuses on how the state could meet the 80% target in the transportation sector by 2050.

The goal of this study is to identify technology and other potential options for meeting this ambitious, long-term goal in the transportation sector, including light-duty, heavy-duty, rail, aircraft, agriculture, marine, and off-road vehicles. Our analysis focuses on three main areas:

- Travel demand
- Fuel efficiency
- Fuel carbon intensity

The study highlights the various options that could be used to meet the emission reduction targets and creates "snapshots" of option combinations that allow the State to meet the targets across the various transportation modes.

California's Historical Greenhouse Gas Emissions & Future Goals:

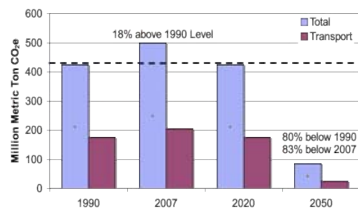


Source: California Energy Commission Greenhouse Gas Inventory, 2006

The California Greenhouse Gas Inventory reports total 1990 emissions in two ways:

- **In-State** only includes emissions from vehicles traveling within state borders
- **In-State and Out-of-State (Overall)** also includes emissions from vehicles that originate or terminate their trips within California and travel out-of-state (mainly **Aviation and Marine**)

GHG Emissions Goals - CA AB32



Emissions Analysis Framework:

$$CO_{2,Transport} = \left(Population \right) \left(\frac{Transport}{Person} \right) \left(\frac{Energy}{Transport} \right) \left(\frac{Carbon}{Energy} \right)$$

$$= P \times T \times E \times C$$

Population (California pop.) Transport intensity (e.g., VMT/capita) Energy Intensity (e.g., MJ/mile) Carbon Intensity (e.g. gCO₂-eq/MJ)

- Each transport sector's GHG emissions can be decomposed using the equation above; each of the parameters influences emissions.
- The analysis reviewed the literature to assess the potential for changes in each parameter by 2050.
- We analyze various vehicle technology, fuel and policy options for reducing the individual **T**, **E** and **C** parameters for each transport sector.

Social or Activity Parameters (P and T)

• P - Population

• T - Transport Intensity

- Level of transport activity *per capita*
 - e.g. VMT/capita, PMT/capita, freight ton miles/capita
- Reduction options
 - Conservation, increasing cost of travel or fuel
 - Land use patterns, smart growth to reduce travel distances and vehicle trips
 - Carpooling, ridesharing
 - Shifting to non-motorized travel

Technology Parameters (E and C)

• E - Energy Intensity

- Energy required per unit of transport activity
 - e.g. MJ per mile, BTU per passenger mile, BTU per ton-mile
- Reduction options
 - Mode shift - change to lower energy intensive modes
 - Increasing passenger occupancy in vehicles
 - Increasing vehicle efficiency

• C - Carbon Intensity

- Carbon per unit energy - e.g. grams CO₂e/MJ
- Reduction options
 - Fuel switching to lower carbon content fuels or feedstocks
 - Change in fuel production methods (e.g. CCS or higher efficiency)

Project Goals

- Provide snapshots of what 80% reduction in transport could look like
 - To start dialogue of whether this reduction is possible
 - To discuss the best options to achieve deep reductions
- Provide a very simple tool (emissions calculator)
 - LEVERS model
 - To determine the most important areas to target
 - To see the results and tradeoffs resulting from specific assumptions
 - To see what role technology can play and how much reductions in transport activity will be needed
- Issue project report, policy report, and journal article

Options for Reducing Transportation Greenhouse Gas Emissions

Transport Sector	Greenhouse Gas Reduction Options
Light-Duty Vehicles	T <ul style="list-style-type: none"> • Mode switching • Carpooling • Land use changes and telecommuting
	E <ul style="list-style-type: none"> • Hybridization and electrification • High efficiency propulsion system (Fuel cell, advanced engines, diesels) • Improved aerodynamics • Weight reduction
	C <ul style="list-style-type: none"> • Switching to lower-carbon fuels (biofuels, H₂, electricity, natural gas, syngas w/ CCS)
Heavy-Duty Vehicles	T <ul style="list-style-type: none"> • Greater use of efficient public transit bus systems • Increased size (weight, length and combinations) of truck trailers
	E <ul style="list-style-type: none"> • Higher efficiency propulsion systems (Hybrids, Fuel cells, advanced diesels, combined cycle) • Improved aerodynamics • Low rolling resistance tires • Operational control (Low speed operation and reducing idle)
	C <ul style="list-style-type: none"> • Switching to lower-carbon fuels (NG, H₂, biofuels, syngas w/ CCS)
Aviation	T <ul style="list-style-type: none"> • Improved air traffic management systems • Larger planes (more passengers/plane) • Increase airplane load factors
	E <ul style="list-style-type: none"> • Improved aerodynamics • Reduced aircraft weight • Higher efficiency propulsion systems (advanced engine designs) • Use of auxiliary power units for auxiliary in-flight electric loads
	C <ul style="list-style-type: none"> • Switching to lower-carbon fuels (biofuels, syngas w/ CCS)
Rail	T <ul style="list-style-type: none"> • Greater use of efficient public transit rail systems (light, heavy, commuter, and intercity rail) • Improved aerodynamics and reduced rolling resistance • Reduced weight through lightweight materials
	E <ul style="list-style-type: none"> • Regenerative braking • Higher efficiency propulsion systems (advanced diesels, Fuel cells, electrified railways) • Advanced traffic management and control systems
	C <ul style="list-style-type: none"> • Switching to lower-carbon fuels (biofuels, electricity, H₂, syngas w/ CCS)
Marine	T <ul style="list-style-type: none"> • Reduce transport (freight, personal watercraft) demand
	E <ul style="list-style-type: none"> • Improved hull shape (hydrodynamics) • Improved propeller efficiency • Operational control (lower speed, improved routing) • Engine and powerplant efficiency (hybrid, combined cycle)
	C <ul style="list-style-type: none"> • Switching to lower-carbon fuels (biofuels, syngas w/ CCS)
Agriculture and Off-Road	T <ul style="list-style-type: none"> • Reduce transport demand
	E <ul style="list-style-type: none"> • Improved engine efficiency (advanced engines)
	C <ul style="list-style-type: none"> • Switching to lower-carbon fuels (biofuels, syngas w/ CCS)

Long-term Evaluation of Vehicle Emission Reduction Strategies (LEVERS) Model

- Excel based modeling tool to organize parameters into scenarios and calculate GHG reductions
- Normalize 1990 Kaya parameter values at 1
 - The $P \times T \times E \times C$ identity is used to calculate whether 2050 emissions meet the target
 - $CO_{2,1990} = 1 \times 1 \times 1 \times 1 = 1$ $CO_{2,2050} = 2 \times 1 \times 4 \times 5 = 0.4$

LDVs	2.00	0.61	0.18	0.30	7%
Total LDVs	2.00	0.61	0.18	0.30	7%
HDVs					
Buses	2.00	3.86	0.43	0.29	0.94
Heavy Trucks	2.00	1.55	0.53	0.40	0.65
Total HDV	2.00	2.88	0.34	0.36	71%
Aircraft					
Passenger Aviation	2.00	0.48	0.50	0.66	0.32
Freight	2.00	7.01	0.33	0.66	3.10
General Aviation	2.00	1.05	0.84	0.66	1.16
Total Aircraft	2.00	1.16	0.40	0.66	61%

Acknowledgements:

- Sustainable Transportation Energy Pathways (STEPS) Program, Institute of Transportation Studies, University of California-Davis

Contacting the Authors:

Dr. Christopher Yang (ccyang@ucdavis.edu), David McCollum (dmmccollum@ucdavis.edu), Ryan McCarthy (rvmccarthy@ucdavis.edu), Wayne Leighty (wwleighty@ucdavis.edu)