An analysis of transportation options for meeting California's long-term greenhouse gas emissions reductions goals

Dr. Christopher Yang, David McCollum, Ryan McCarthy, Wayne Leighty
Institute of Transportation Studies, University of California, Davis
http://steps.ucdavis.edu

Scenario 1: Technological Optimism, Social Stagnation

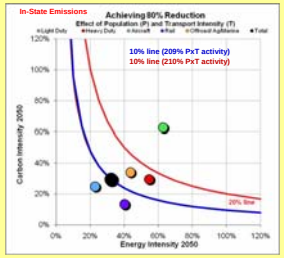
GHG Emissions Reductions (1990 to 2050)

In-State 80% ↓ **Overall** 63% ↓

Scenario Characteristics

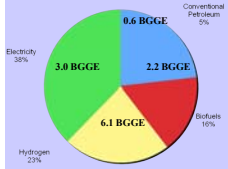
- Technological Drivers
  - Vehicle efficiencies are optimistic, but not pushed to the limits
  - Hydrogen fuel cell and/or battery electric vehicles gain substantial LDV, HDV, Bus, and Rail market shares
    - Significant penetration into Marine, Ag, and Off-road sectors as well
  - Low-carbon H2 and electricity production
    - H2 = ~30% of 1990 gasoline (g-CO2/MJ); Electricity = ~12% of 1990 grid mix
    - Carbon capture and storage (CCS) is successful and utilized wherever possible
  - Biofuels replace gasoline and diesel in Aircraft, Marine, Ag, and Off-road
- Social Drivers
  - No change in light-duty vehicle per-capita VMT and PMT from 1990
    - No mode-switching; no carpooling
    - Public transit not successful (light-rail, heavy-rail, buses)
    - Low-density land uses (sprawl) still common
  - Air travel continues to increase at rapid rate
    - Planes preferred over Buses, Rail, LDVs for long-distance transport
    - High-speed rail and intercity buses not successful
  - Public acceptance of coal, nuclear, CCS

Large increases in transport activity (P x T = 2.10) require larger technology advances for 80% reduction
- 90% reduction in carbon per unit mile (E x C) across all sectors
- LDV, Rail are least carbon-intensive
- Carbon reduction potential lower for Aircraft



Resource and Fuels Usage

	Total Energy (PJ)	% of 1990 usage
Natural gas	577	24%
Biomass	494	1190%
Renewables	182	106%
Nuclear	73	62%
Coal	561	908%
Petroleum	77	4%
Total Electricity	363	37%



- **Fuels composition**
  - Biofuels: 100% cellulosic technologies **(C: -82% from 1990 gasoline)**
  - H_2: 30% NG (w/CCS), 20% biomass, 40% coal (w/CCS) **(C: 3,414 gCO$_2$/kg; -70% from 1990 gasoline)**
  - Electricity: 30% NG (w/CCS), 20% nuclear, 35% renewables, 10% coal (w/CCS) **(C: -88% from 1990 electricity, -85% from 1990 gasoline)**

Scenario 2: Technological Evolution, Social Consistency

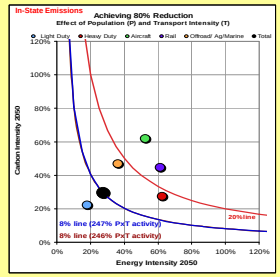
GHG Emissions Reductions (1990 to 2050)

In-State 80% ↓ **Overall** 66% ↓

Scenario Characteristics

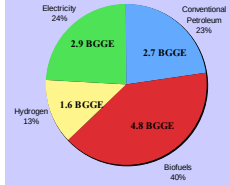
- Technological Drivers
  - Optimistic vehicle efficiencies
  - No dominant LDV technology (equal distribution, 25%, among PHEVs, biofuel PHEVs, FCVs and BEVs)
  - No penetration of hydrogen or electricity in HDV, air, marine, or off-road vehicle applications
  - HDV, marine, off-road 70% biofuels, 30% diesel
  - Air 50% biofuels, 20% gasoline, 30% kerosene
  - Electricity supply largely decarbonized (94% of 1990 levels)
  - No coal
- Social Drivers
  - No reduction in LDV VMT (grows at expected rate, passengers-per-vehicle constant at 1990 levels)
  - No reduction in air travel compared to reference case

Large increases in transport activity (P x T = 2.46) require larger technology advances for 80% reduction
- 92% reduction in carbon per unit mile (E x C) across all sectors
- LDV is least carbon-intensive



Resource and Fuels Usage

	Total Energy (PJ)	% of 1990 usage
Natural gas	122	5%
Biomass	891	2145%
Renewables	272	159%
Nuclear	103	88%
Coal	0	0%
Petroleum	327	15%
Total Electricity	345	35%



- **Fuels composition**
  - Biofuels: 100% cellulosic technologies **(C: -82% from 1990 gasoline)**
  - H_2: 20% NG, 20% biomass, 60% renewable electrolysis **(C: 1,670 gCO$_2$/kgH2; -85% from 1990 gasoline)**
  - Electricity: 10% NG (w/CCS), 30% nuclear, 30% biomass, 30% renewables **(C: -94% from 1990 electricity)**

Scenario 3: Very High Energy Prices with Good Planning

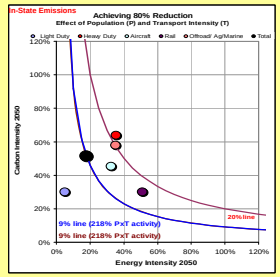
GHG Emissions Reductions (1990 to 2050)

In-State 80% ↓ **Overall** 71.1% ↓

Scenario Characteristics: economic drivers motivate change

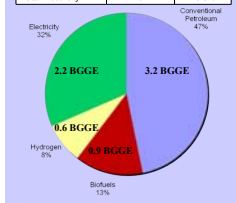
- Technological Drivers
  - High fuel cost motivates optimistic vehicle efficiency (e.g., 1.7% annually for LDV) from technology and reduced performance
  - Evolutionary LDV technology (50% gasoline PHEV, 30% diesel PHEV, 10% FCVs and 10% BEVs)
  - 10% hydrogen for surface transportation, electrification of light and medium rail.
  - Biofuels used for blending (20%), marine, heavy-duty, and extensively in air sector only (70%).
  - Electricity supply largely decarbonized (90% from 1990 levels)
- Social Drivers
  - Reduced VMT in response to high fuel cost
  - LDV PMT per capita down 20% from projected growth (down 3% from 1990 levels)
  - HDV miles per person down 20% from projected growth (up 24% from 1990 levels)
  - Commercial air down 10% from projected growth; general aviation down 50%
  - Personal boats down 50% from projected growth.

Mitigated increases in transport activity (P x T = 2.18) require less technological innovation for 80% reduction
- 91% reduction in carbon per unit mile (E x C) across all sectors, but more from E (82%) than from C (49%).
- LDV is least carbon-intensive and most efficient



Resource and Fuels Usage

	Total Energy (PJ)	% of 1990 usage
Natural gas	123	5.08%
Biomass	122	294%
Renewables	164	96%
Nuclear	78	67%
Coal	68	110%
Petroleum	387	18%
Total Electricity	261	26.8%



- **Fuels composition**
  - Biofuels: 100% cellulosic technologies **(C: -82% from 1990 gasoline)**
  - H_2: 20% NG, 10% biomass, 60% renewable electrolysis, 10% coal with CCS **(C: 2,010 gCO$_2$/kg; -82% from 1990 gasoline)**
  - Electricity: 20% NG (w/CCS), 30% nuclear, 40% renewables, 10% coal (w/CCS) **(C: -90% from 1990 electricity)**

Normalized Kaya Parameters (2050-to-1990) for Various Scenarios

	Reference Case Scenario (Baseline efficiency, BAU values for T, No change in C) +63% increase (instate), +71% increase (overall)					Technological Optimism, Social Stagnation 80% reduction (instate), 63% reduction (overall)					Technological Evolution, Social Consistency 80% reduction (instate), 66% reduction (overall)					Very High Energy Prices with Good Planning 80% reduction (instate), 71% reduction (overall)				
	P	T	E	C	Product	P	T	E	C	Product	P	T	E	C	Product	P	T	E	C	Product
LDV	2.00	1.21	0.53	1.00	1.27	2.00	1.00	0.23	0.25	0.11	2.00	1.21	0.18	0.22	0.10	2.00	0.97	0.05	0.30	0.03
HDV	2.00	1.09	1.33	1.06	3.06	2.00	1.09	0.55	0.30	0.35	2.00	1.09	0.63	0.32	0.43	2.00	1.67	0.35	0.64	0.75
Aircraft	2.00	2.38	0.84	1.05	4.21	2.00	2.38	0.63	0.63	1.88	2.00	1.97	0.34	0.62	0.83	2.00	2.10	0.32	0.45	0.62
Rail	2.00	1.46	0.86	0.74	1.84	2.00	1.46	0.40	0.13	0.16	2.00	1.55	0.60	0.43	0.80	2.00	3.38	0.51	0.30	1.04
Ag/Marine/Other	2.00	1.43	0.51	1.06	1.55	2.00	1.43	0.44	0.34	0.42	2.00	1.43	0.36	0.50	0.51	2.00	1.26	0.35	0.58	0.51
Total	2.00	1.05	0.27	1.01	1.62	2.00	1.05	0.27	0.29	0.20	2.00	1.23	0.27	0.30	0.20	2.00	1.09	0.18	0.51	0.20

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Contacting the Authors:
Dr. Christopher Yang (ccyang@ucdavis.edu), David McCollum (dlmccollum@ucdavis.edu),
Ryan McCarthy (rwmccarthy@ucdavis.edu), Wayne Leighty (wwleighty@ucdavis.edu)