Sustainable Mobility Technologies

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Notes prepared for the
UMD Study Abroad Program on "Sustainability & Infrastructure" 18-30 May 2024
Athens, Greece

We will also explore this at the end

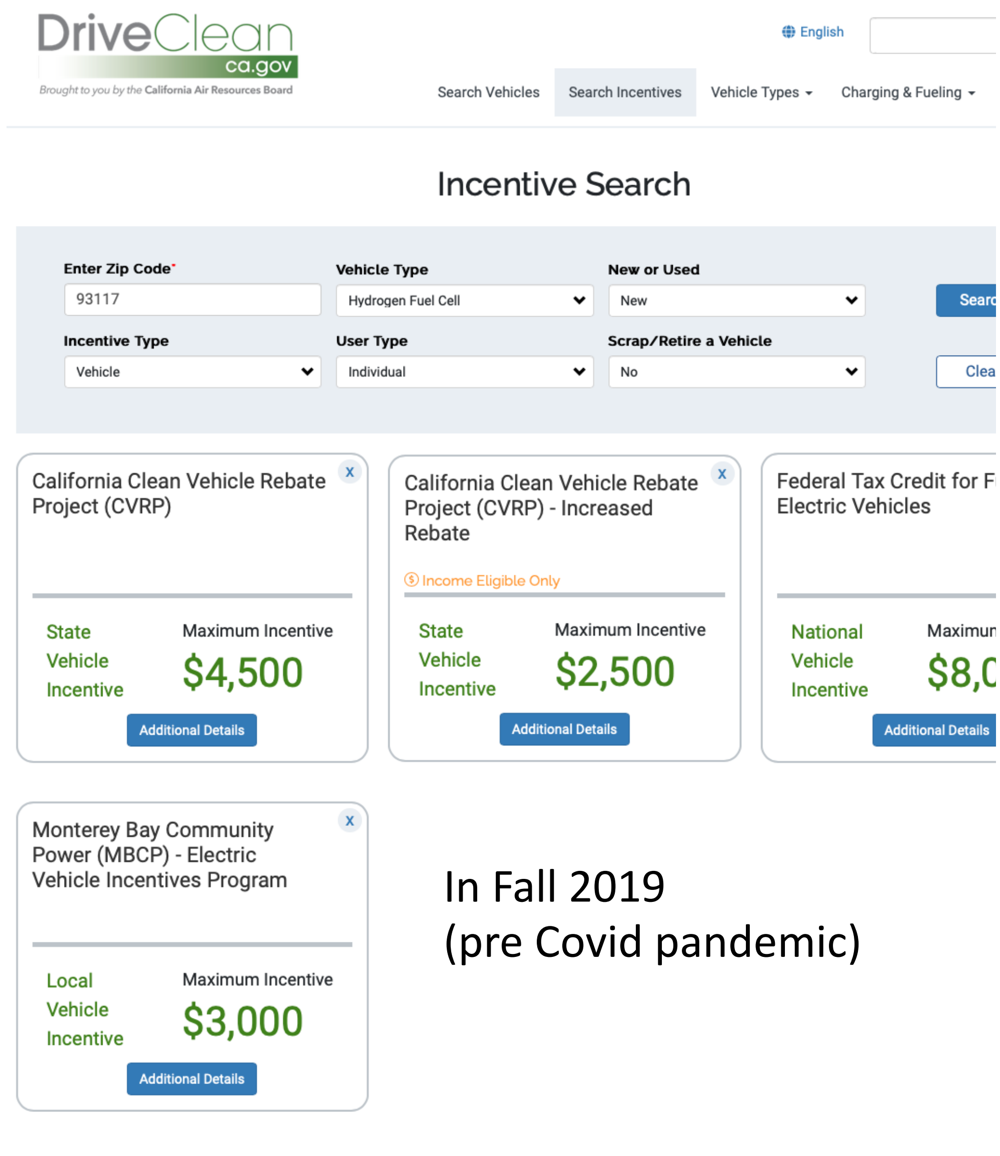
You want to buy an electric car

Question 1: Does the government (Federal and State) subsidize you?

Question 2: Why in this world would any government subsidize your car purchase?

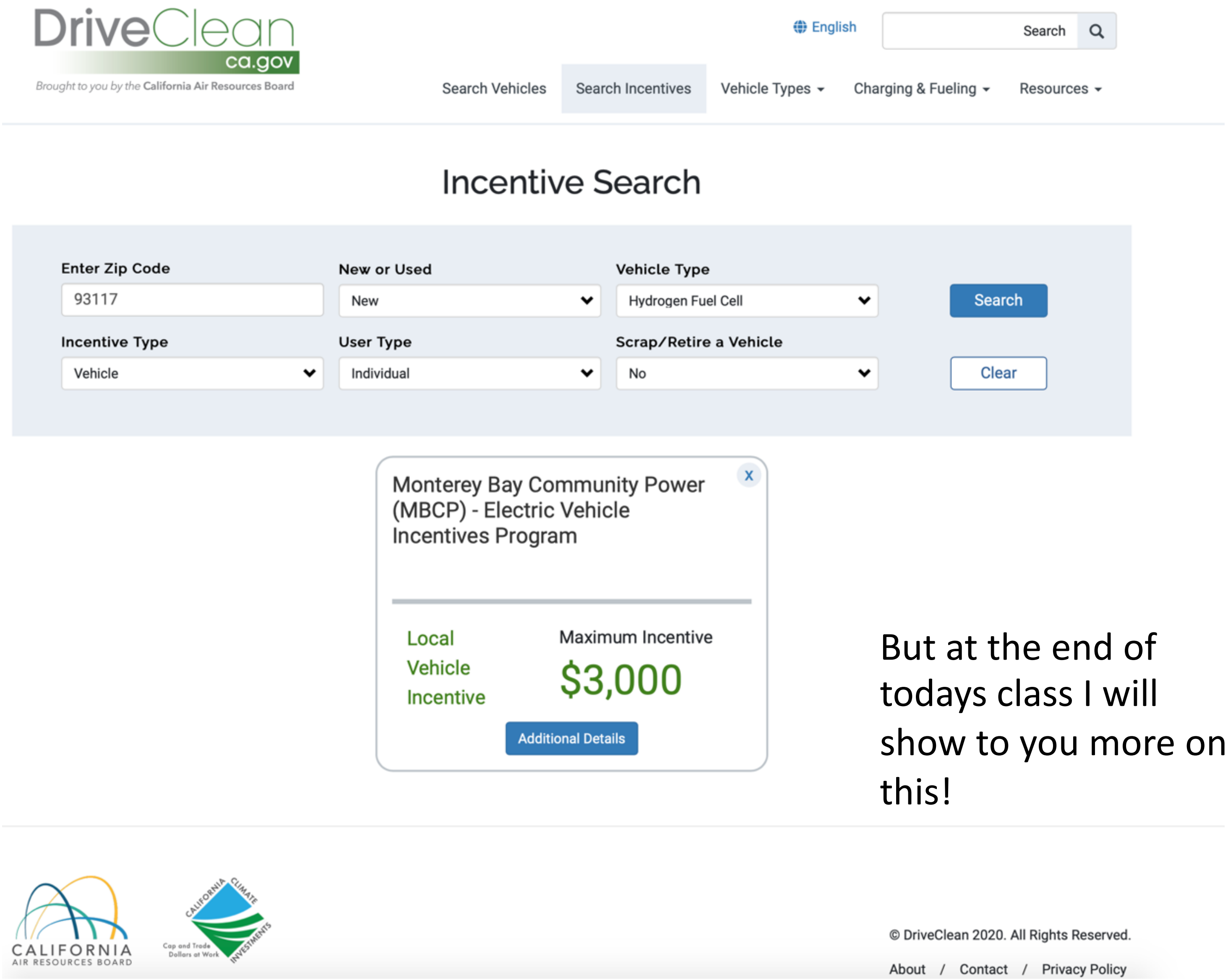
Check Options

- https://driveclean.ca.gov



In Fall 2019
(pre Covid pandemic)

In 2021

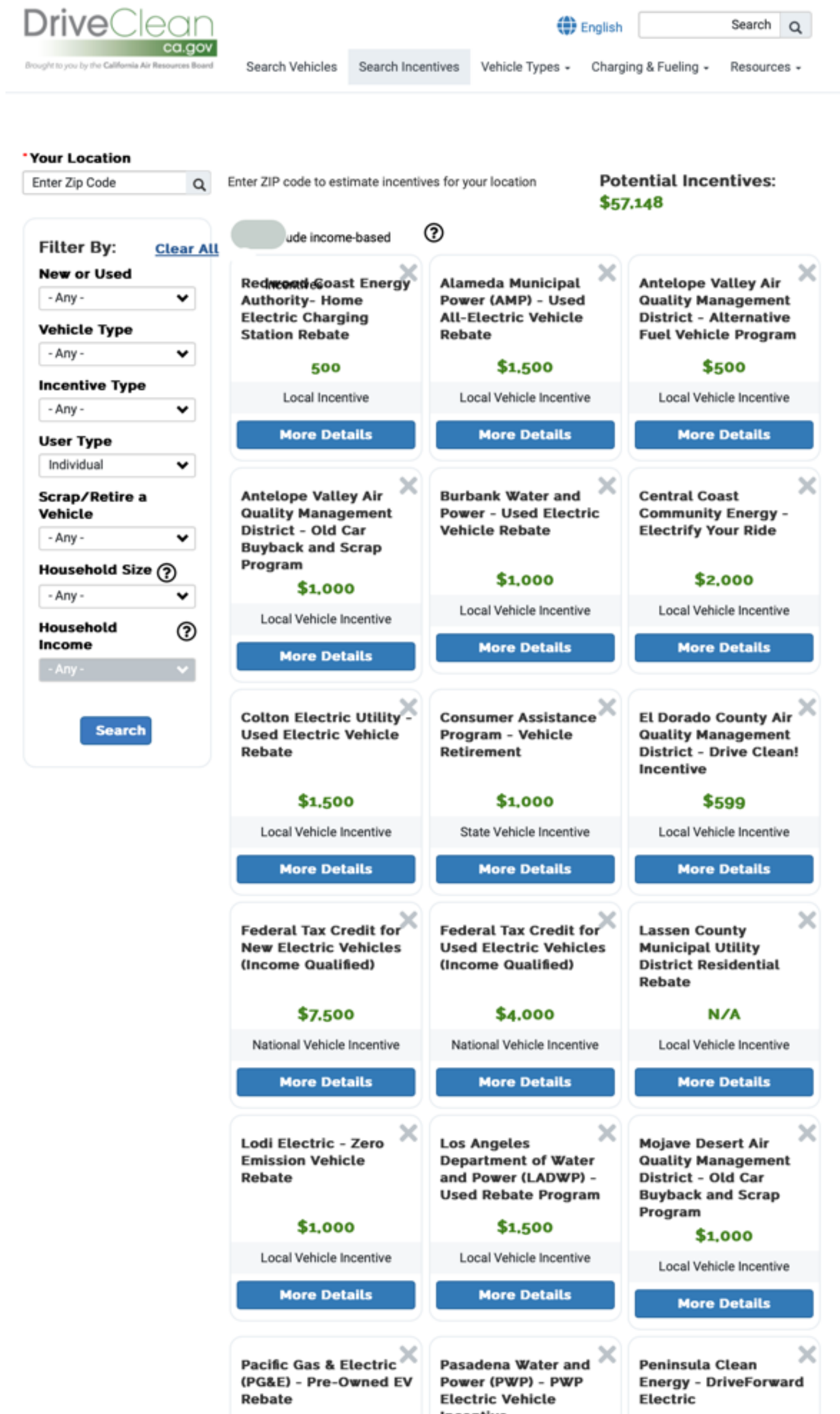


But at the end of todays class I will show to you more on this!

August 2022
Zipcode = 93117

Program	Level	Type	Incentive	Maximum Incentive
California Clean Fuel Reward	State	Vehicle	Incentive	$750
California Clean Vehicle Rebate Project (CVRP)	State	Vehicle	Incentive	$4,500
California Clean Vehicle Rebate Project (CVRP) - Increased Rebate (Income Eligible Only)	State	Vehicle	Incentive	$2,500
Consumer Assistance Program - Vehicle Retirement	State	Vehicle	Incentive	$1,500
Federal Tax Credit for Fuel Cell Electric Vehicles	National	Vehicle	Incentive	$8,000
Federal Tax Credit for Plug-in Electric Vehicles	National	Vehicle	Incentive	$7,500
Santa Barbara County Air Pollution Control District - Old Car Buyback and Scrap Program	Local	Vehicle	Incentive	$1,000
Southern California Edison Pre-Owned EV Rebate	Local	Vehicle	Incentive	$4,000
Alternative Fuel Infrastructure Tax Credit	National	Charging	Incentive	$1,000
Decal for High Occupancy Vehicle (HOV) lane exemption (DMV)	State	Decal	Incentive	HOV Access
Pacific Gas & Electric (PG&E) - Special EV Rate for Home Charging	Local	Utility Rate	Incentive	Discount
Southern California Edison (SCE) - Special EV Rate for Home Charging	Local	Utility Rate	Incentive	Discount
Farmers Insurance	State	Other	Incentive	Discount
Southern California Gas Company - CNG Home Refueling Rate	Local	Other	Incentive	Discount
Travelers Insurance - Car Insurance Discount	State	Other	Incentive	Discount

May 2024


DriveClean ca.gov
English
Search
Search Vehicles
Search Incentives
Vehicle Types
Charging & Fueling
Resources
*Your Location
Enter Zip Code
Enter ZIP code to estimate incentives for your location
Potential Incentives: $57,148
ude income-based
Filter By:
Clear All
New or Used
- Any -
Vehicle Type
- Any -
Incentive Type
- Any -
User Type
Individual
Scrap/Retire a Vehicle
- Any -
Household Size
- Any -
Household Income
- Any -
Search
Redwood Coast Energy Authority- Home Electric Charging Station Rebate
500
Local Incentive
More Details
Alameda Municipal Power (AMP) - Used All-Electric Vehicle Rebate
$1,500
Local Vehicle Incentive
More Details
Antelope Valley Air Quality Management District - Alternative Fuel Vehicle Program
$500
Local Vehicle Incentive
More Details
Antelope Valley Air Quality Management District - Old Car Buyback and Scrap Program
$1,000
Local Vehicle Incentive
More Details
Burbank Water and Power - Used Electric Vehicle Rebate
$1,000
Local Vehicle Incentive
More Details
Central Coast Community Energy - Electrify Your Ride
$2,000
Local Vehicle Incentive
More Details
Colton Electric Utility - Used Electric Vehicle Rebate
$1,500
Local Vehicle Incentive
More Details
Consumer Assistance Program - Vehicle Retirement
$1,000
State Vehicle Incentive
More Details
El Dorado County Air Quality Management District - Drive Clean! Incentive
$599
Local Vehicle Incentive
More Details
Federal Tax Credit for New Electric Vehicles (Income Qualified)
$7,500
National Vehicle Incentive
More Details
Federal Tax Credit for Used Electric Vehicles (Income Qualified)
$4,000
National Vehicle Incentive
More Details
Lassen County Municipal Utility District Residential Rebate
N/A
Local Vehicle Incentive
More Details
Lodi Electric - Zero Emission Vehicle Rebate
$1,000
Local Vehicle Incentive
More Details
Los Angeles Department of Water and Power (LADWP) - Used Rebate Program
$1,500
Local Vehicle Incentive
More Details
Mojave Desert Air Quality Management District - Old Car Buyback and Scrap Program
$1,000
Local Vehicle Incentive
More Details
Pacific Gas & Electric (PG&E) - Pre-Owned EV Rebate
Pasadena Water and Power (PWP) - PWP Electric Vehicle Incentive
Peninsula Clean Energy - DriveForward Electric

* Your Location

93117

Enter ZIP code to estimate incentives for your location

Potential Incentives:
$15,400

Include income-based incentives ?

Filter By: Clear All

New or Used
New

Vehicle Type
Battery-Electric

Incentive Type
- Any -

User Type
Individual

Scrap/Retire a Vehicle
- Any -

Household Size ?
1

Household Income ?
$58,321 or above

Search

Central Coast Community Energy - Electrify Your Ride
$2,000
Local Vehicle Incentive
More Details

Consumer Assistance Program - Vehicle Retirement
$1,000
State Vehicle Incentive
More Details

Federal Tax Credit for New Electric Vehicles (Income Qualified)
$7,500
National Vehicle Incentive
More Details

Santa Barbara County Air Pollution Control District - Old Car Buyback and Scrap Program
$1,000
Local Vehicle Incentive
More Details

Alternative Fuel Infrastructure Tax Credit
$1,000
National Charging Incentive
More Details

Central Coast Community Energy - Electrify Your Ride L2 Charger
$400
Local Charging Incentive
More Details

Pacific Gas & Electric (PG&E) - Empower EV Program
Income Eligible Only
$2,500
Local Charging Incentive
More Details

Sonoma Clean Power - GridSavvy
Free Charger
Local Charging Incentive
More Details

Decal for High Occupancy Vehicle (HOV) lane exemption (DMV)
HOV Access
State Decal Incentive
More Details

Pacific Gas & Electric (PG&E) - Special EV Rate for Home Charging
Discount
Local Utility Rate Incentive

Outline

- Part 1 – Establish a baseline and vocabulary
  - Pollutants and Internal Combustion Engines
  - Greenhouse Gas Emissions
  - Lifecycle Assessments
- Part 2 – Decarbonize with technology (if we have extra time)
  - Robocars + electric cars
  - Photovoltaics + electric cars

Air Quality?

Air is more “important” than water or food

- We breath, on average 22,000 times/day

- We breath approximately 2-3,000 gallons per day

- We can survive approximately 5 weeks with no food
- We can survive approximately 5 days with no water
- We can survive approximately 5 minutes without air

Note: all these numbers are approximate and depend on age, weight, lifestyle and so forth (see also https://www.lung.org/blog/how-your-lungs-work

Usual "Good" Air Composition (Clean Air):

78.09% Nitrogen by volume
20.94% Oxygen by volume

The Remaining 0.97% is made up by carbon dioxide, neon, helium, methane, krypton, hydrogen, xenon, nitrogen oxide, ozone, and other organic and inorganic compounds at extremely small quantities

Let’s define air pollution

Wisconsin's Definition:

"...the presence in the atmosphere of one or more contaminants in such **quantities** and of such **duration** as is or tends to be injurious to human health or welfare, animal or plant life, or property, or would unreasonably interfere with the enjoyment of life or property..."

Note: the air composition is changing continuously

Air Quality and Indicators

- US EPA uses six "criteria pollutants" as indicators of air quality, and has established for each of them a **maximum concentration** above which adverse effects on human health may occur. These threshold concentrations are called **National Ambient Air Quality Standards**.

- Europe also has similar criteria pollutants
- (https://www.eea.europa.eu/themes/air/country-fact-sheets/2023-country-fact-sheets/greece-air-pollution-country)

Pollutants

- Ozone (O_3)
- Carbon Monoxide (CO)
- Nitrogen Oxides (NO_x)
- Particulate Matter
- Lead (Pb)
- Oxides of Sulfur (SO_2)

- Ammonia (NH3)
- Volatile Organic Compounds (VOC)
- Mercury (Hg)
- Other Toxic Air Pollutants

+ CO2 that we will discuss separately!

WHY DO WE CARE ABOUT POLLUTANTS?

Pollutant	Effects on Health and the Environment
Ozone (O_3)	•Respiratory symptoms •Worsening of lung disease leading to premature death •Damage to lung tissue •Crop, forest and ecosystem damage •Damage to a variety of materials, including rubber, plastics, fabrics, paint and metals
PM2.5 (particulate matter less than 2.5 microns in aerodynamic diameter)	•Premature death •Hospitalization for worsening of cardiovascular disease •Hospitalization for respiratory disease •Asthma-related emergency room visits •Increased symptoms, increased inhaler usage
PM10 (particulate matter less than 10 microns in aerodynamic diameter)	•Premature death & hospitalization, primarily for worsening of respiratory disease •Reduced visibility and material soiling
Nitrogen Oxides (NO_x)	•Lung irritation •Enhanced allergic responses
Carbon Monoxide (CO)	•Chest pain in patients with heart disease •Headache •Light-headedness •Reduced mental alertness

Source: California Air Resources Board

Sulfur Oxides (SO_X)	•Worsening of asthma: increased symptoms, increased medication usage, and emergency room visits
Lead	•Impaired mental functioning in children •Learning disabilities in children •Brain and kidney damage
Hydrogen Sulfide (H_2S)	•Nuisance odor (rotten egg smell) •At high concentrations: headache & breathing difficulties
Sulfate	•Same as PM2.5, particularly worsening of asthma and other lung diseases •Reduces visibility
Vinyl Chloride	•Central nervous system effects, such as dizziness, drowsiness & headaches •Long-term exposure: liver damage & liver cancer
Visibility Reducing Particles	•Reduced airport safety, scenic enjoyment, road safety, and discourages tourism
Toxic Air Contaminants About 200 chemicals have been listed as toxic air contaminants	•Cancer •Reproductive and developmental effects •Neurological effects

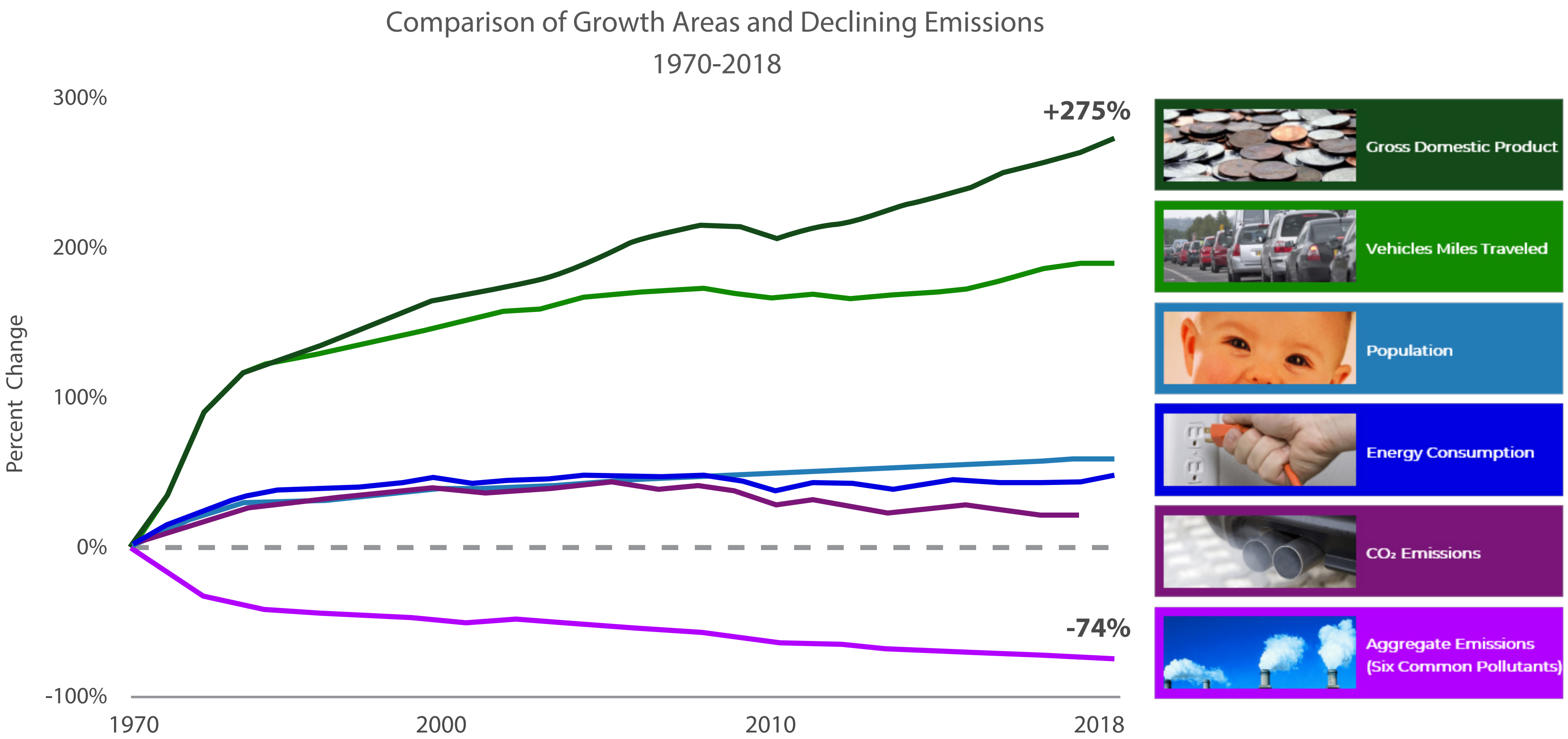
Source: California Air Resources Board

THE GOOD NEWS FIRST

https://gispub.epa.gov/air/trendsreport/2019/#home

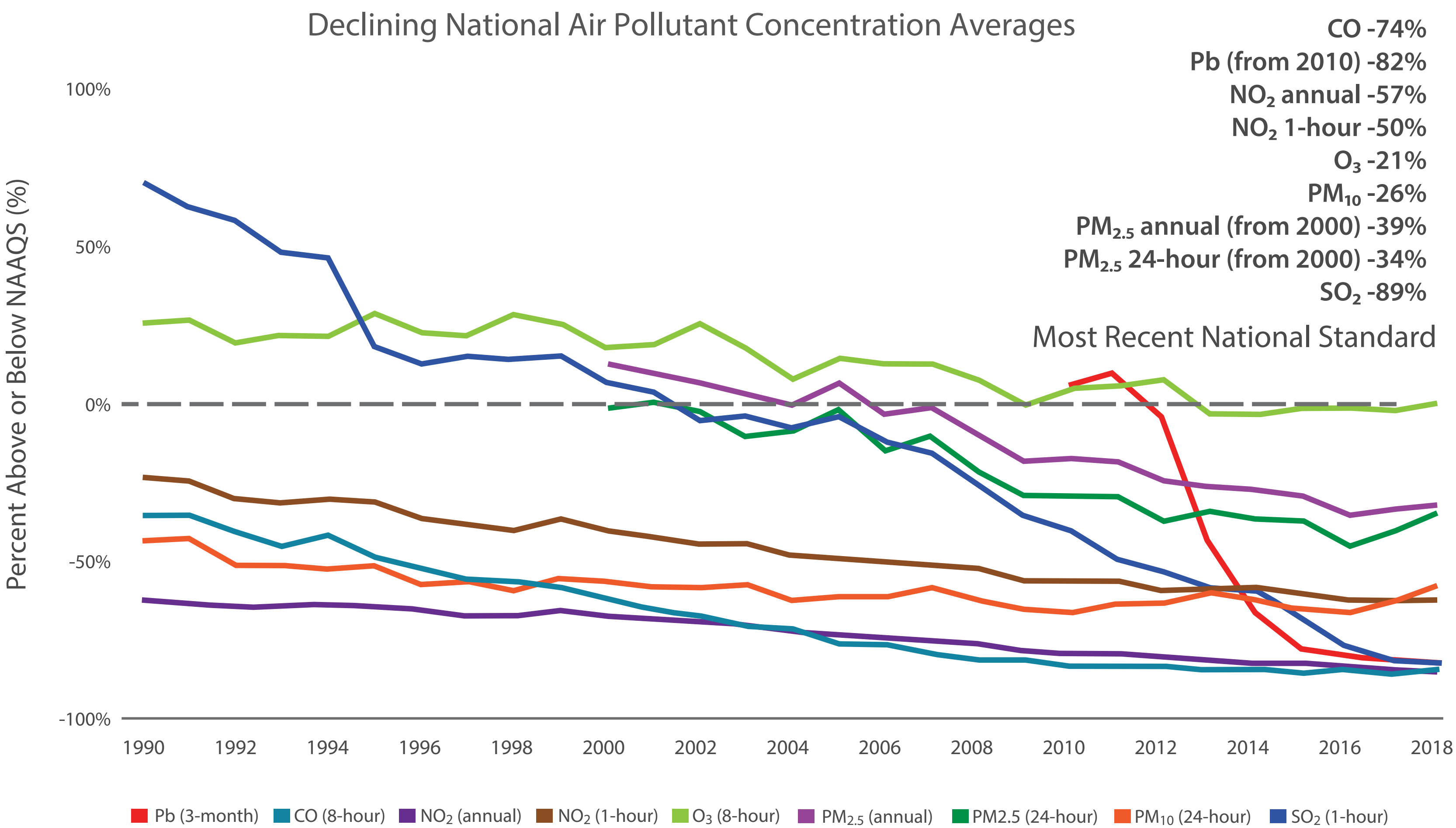
Economic Growth with Cleaner Air

Between 1970 and 2018, the combined emissions of the six common pollutants ($PM_{2.5}$ and PM_{10}, SO_2, NO_X, VOCs, CO and Pb) dropped by 74 percent. This progress occurred while the U.S. economy continued to grow, Americans drove more miles and population and energy use increased.



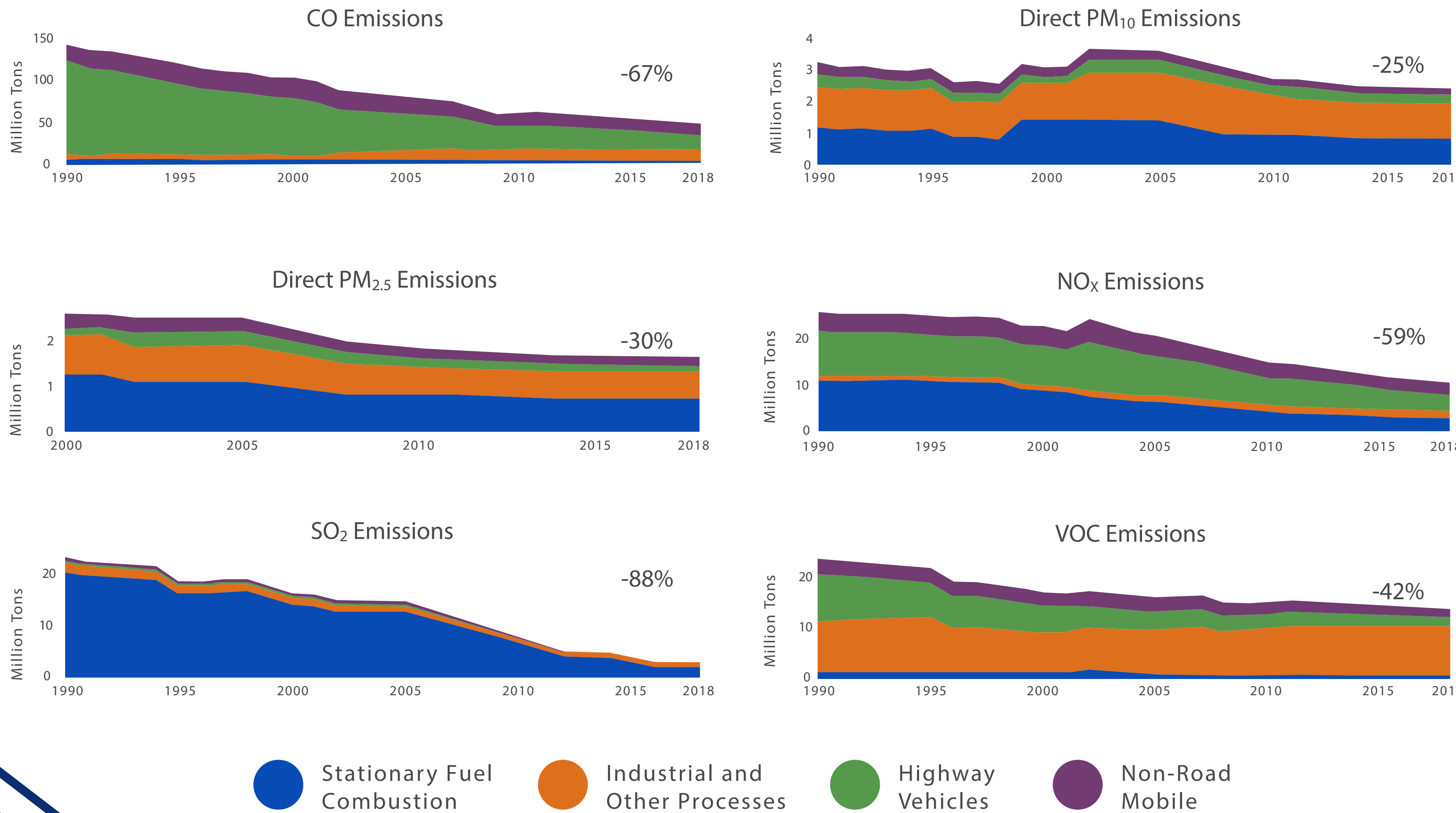
Air Quality Trends Show Clean Air Progress

While some pollutants continue to pose serious air quality problems in areas of the U.S., nationally, criteria air pollutant concentrations have dropped significantly since 1990 improving quality of life for many Americans. Air quality improves as America grows.

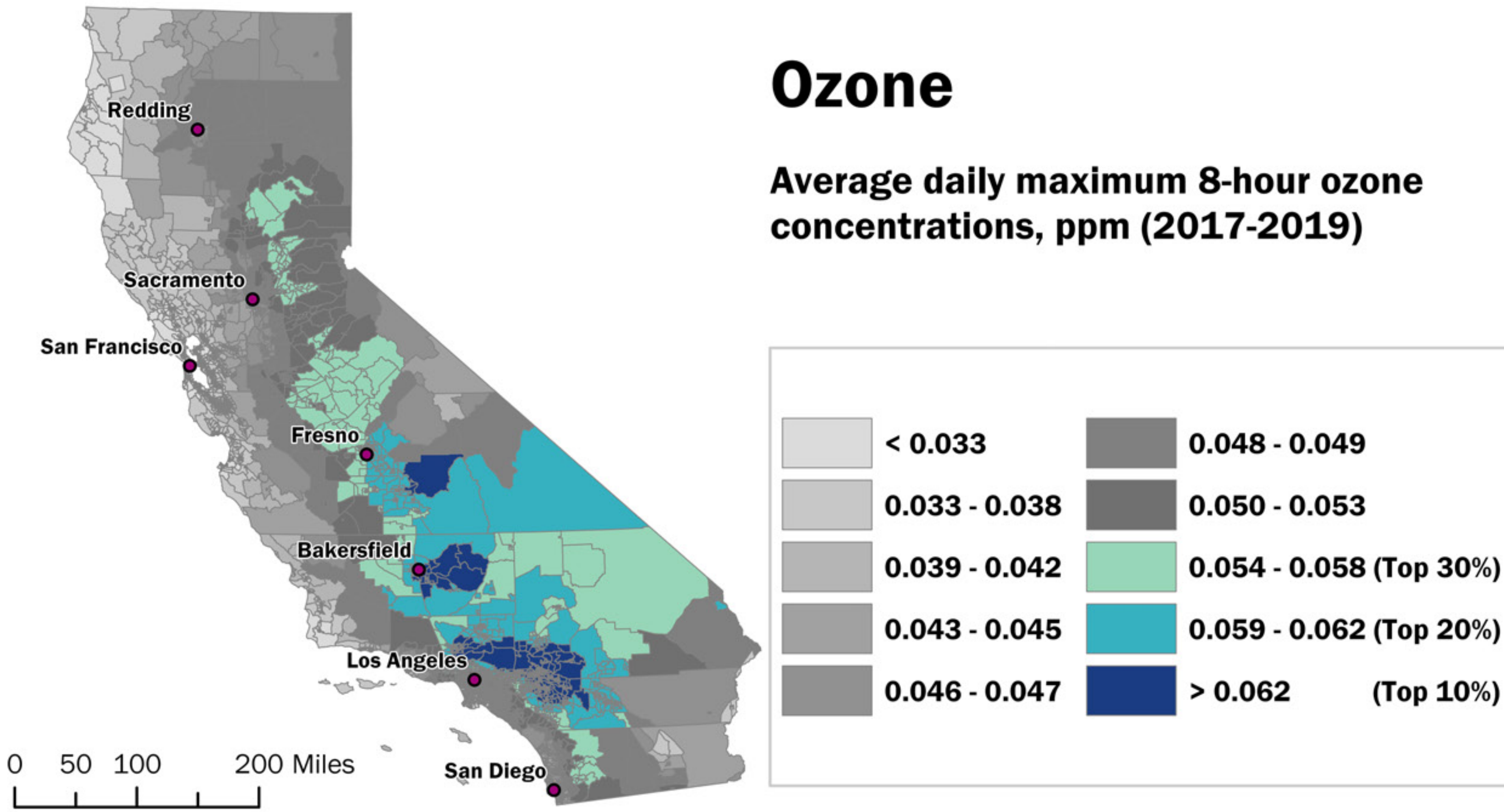


Air Pollutant Emissions Decreasing

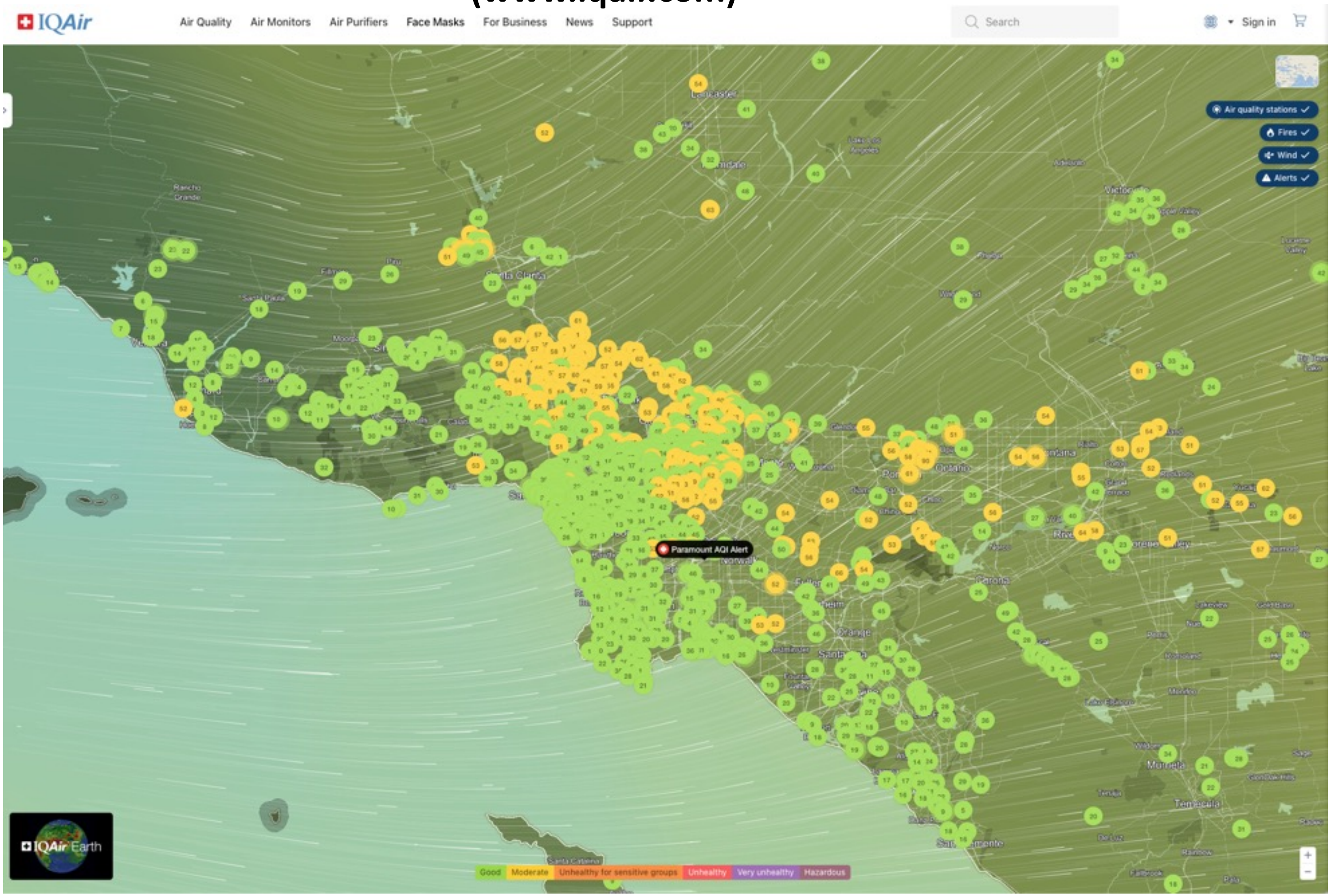
Emissions of key air pollutants continue to decline from 1990 levels. These reductions are driven by federal and state implementation of stationary and mobile source regulations.



Good News but not for All !!
Spatially Unequal Burden
(Calenviroscreen4.0)

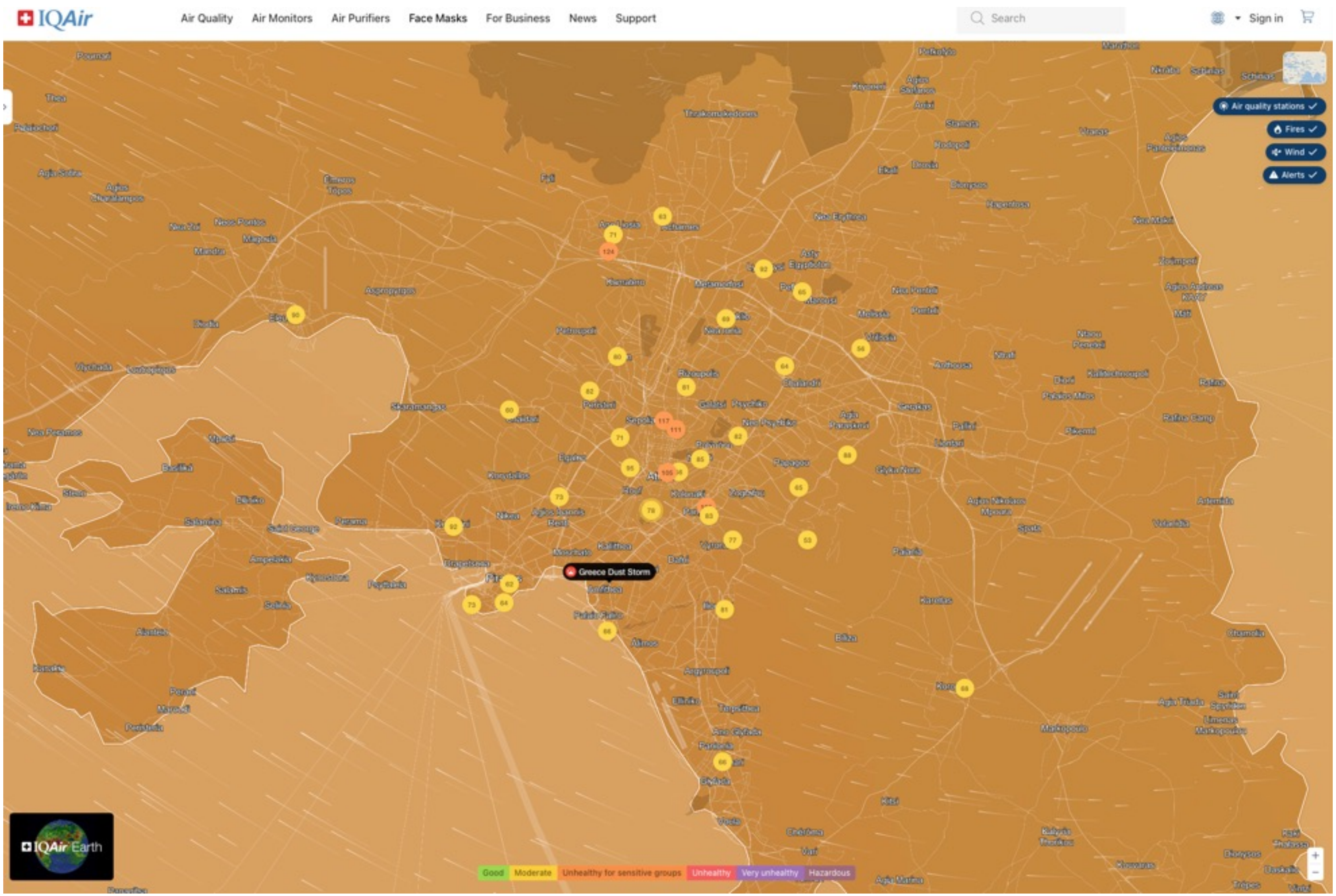


Good News but not for All !!
Spatially Unequal Burden
(www.iqair.com)



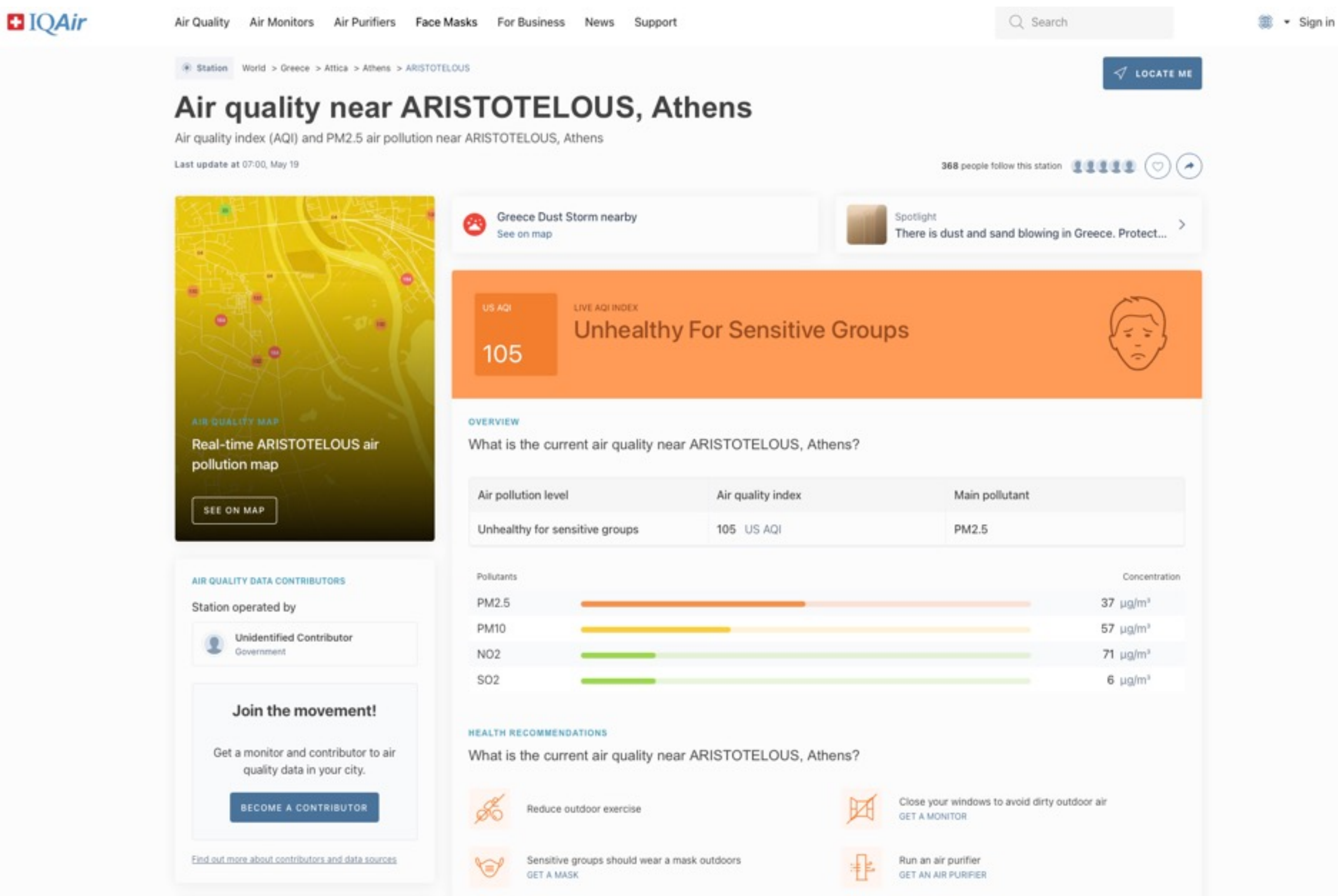
May 19, 2024 @ midnight

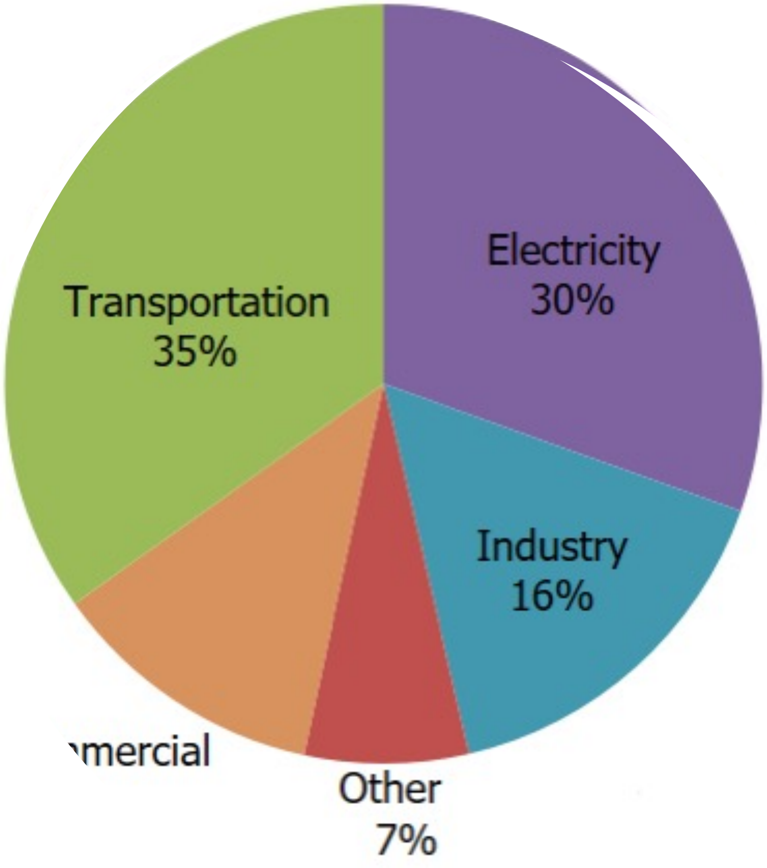
Not Uniform Air Quality and Often Sparsely Distributed Stations



May 19, 2024 @10:00 am

Source: https://www.iqair.com





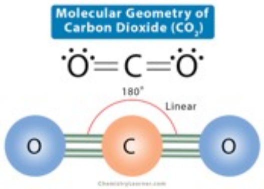
Greenhouse Gases == Gases that trap heat in the atmosphere

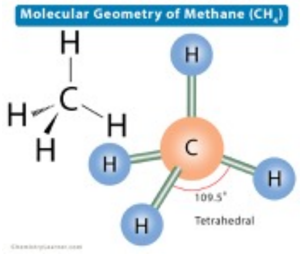
https://www.epa.gov/ghgemissions/overview-greenhouse-gases

Green House Gases

- **Water vapor (H_2O)**
- **Carbon Dioxide (**CO_2**)-** Anthropogenic emissions are small (~2%) but account for most of the observed accumulated CO_2 in the atmosphere
- **Methane (**CH_4**)–** Anthropogenic caused an increase of about 145% in atmospheric concentrations since the mid-1700s
- **Nitrous Oxide (**N_2O) - one third of global atmospheric N_2O from the application of nitrogenous fertilizers and the combustion of fossil fuels and wood.
- **Chlorofluorocarbons (CFC)**
- **Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6)** are up and coming and their projected growth could contribute substantially to radiative forcing soon.
- **Tropospheric ozone (O_3)**

+ **Black carbon** is a component of PM2.5 (not a gas but contributes to climate change)





From the California Air Resources Board
https://ww2.arb.ca.gov/ghg-descriptions-sources

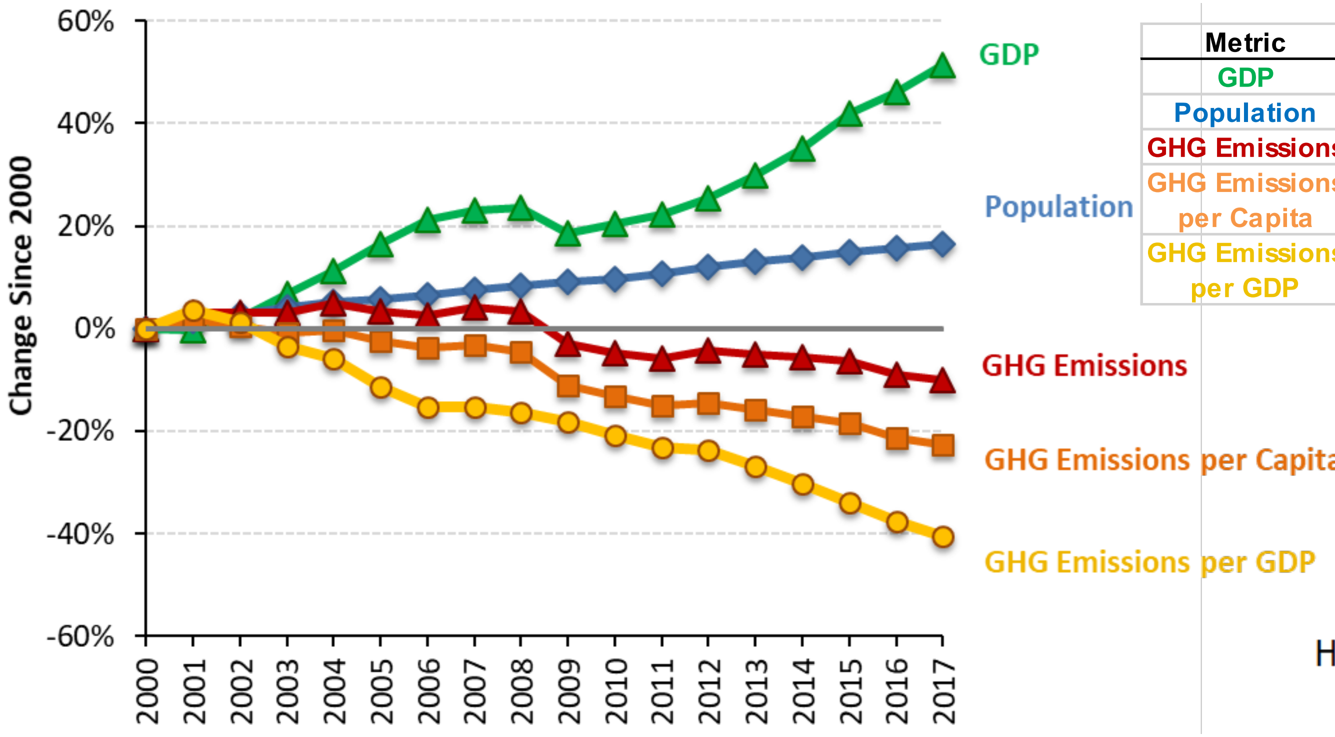
Greenhouse Gases

Health and Safety Code 38505 identifies seven greenhouse gases that ARB is responsible to monitor and regulate in order to reduce emissions:

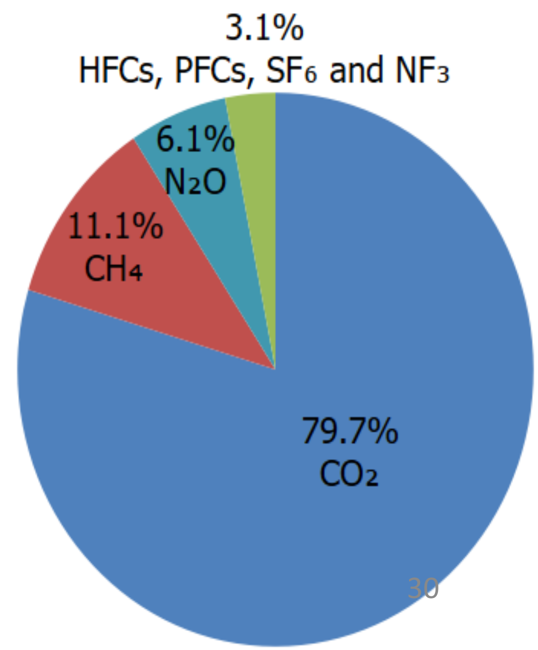
carbon dioxide (CO_2),
methane (CH_4),
nitrous oxide (N_2O),
sulfur hexafluoride (SF_6),
hydrofluorocarbons (HFCs),
perfluorocarbons (PFCs), and

nitrogen trifluoride (NF_3). The fluorinated gases are also referred to as "high global warming potential gases" in the 2008 Scoping Plan.

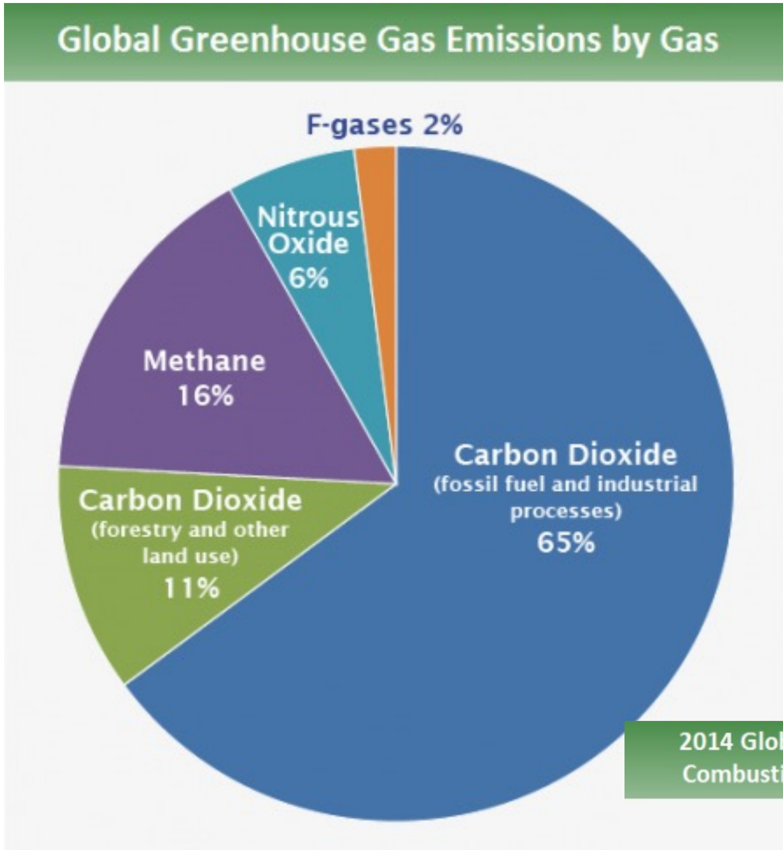
Figure 2a. Change in California GDP, Population, and GHG Emissions Since 2000

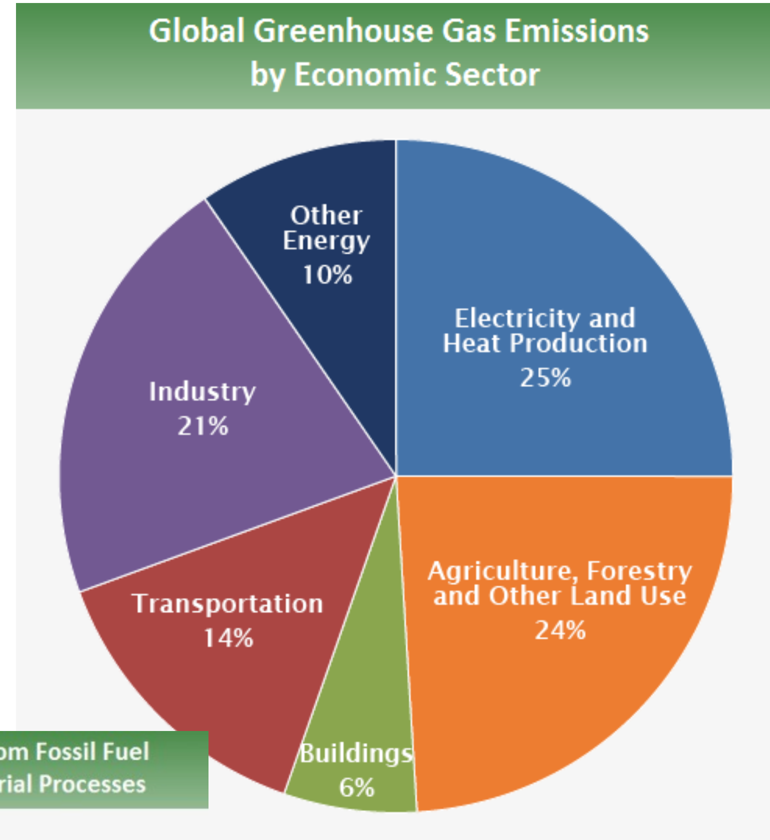


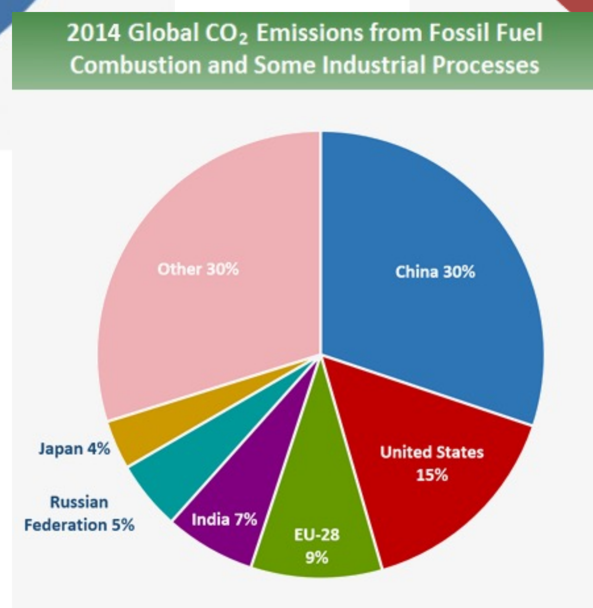
Metric	Associated 2017 Value
GDP	2.6 trillion (2012 $)
Population	39.6 million
GHG Emissions	424.1 $MMTCO_2e$
GHG Emissions per Capita	10.7 metric tons CO_2e per person
GHG Emissions per GDP	164 metric tons CO_2e per million dollars



Source: California Air Resources Board







https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data#Gas

Positives & Negatives

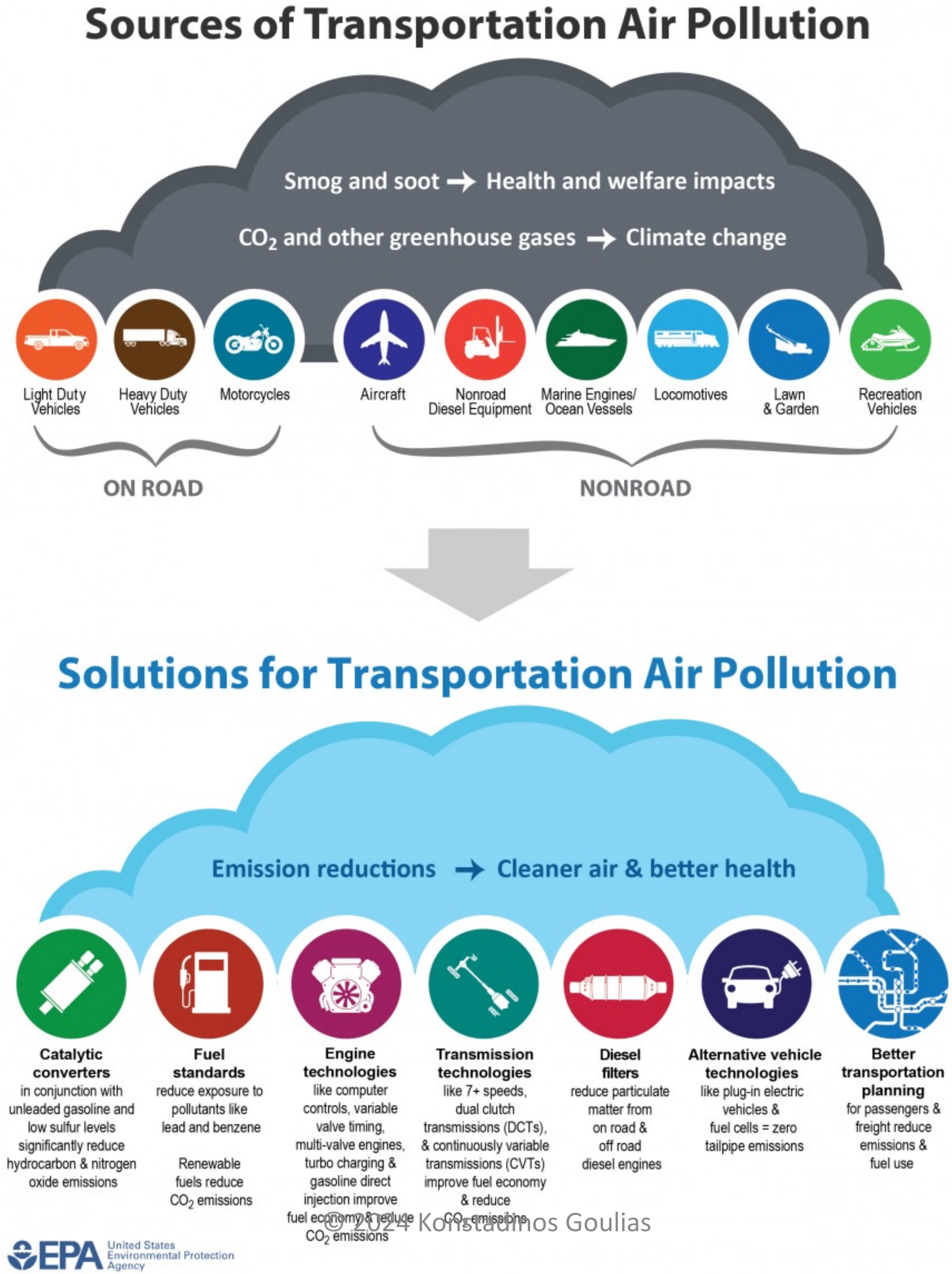
- More highways+cars lead to:

- Better access to opportunities and locations (accessibility)
- Stronger economies (goods to markets, labour options)
- Better (some aspects) quality of life such as comfort, independence, ability to live in nice suburbs

- More air pollution (urban smog – CO, NOx, VOC)
- Possible climate change (major input is CO2)
- Roadway Fatalities
- Congestion and lost time
- Energy dependency on fossil fuels
- Unequal pollution burden -> unequal health risks

Source: US DOE – 50 year perspective;
Calenviroscreen4.0

MORE ON INTERNAL COMBUSTION ENGINE (ICE) VEHICLES


Sources of Transportation Air Pollution
Smog and soot → Health and welfare impacts
CO_2 and other greenhouse gases → Climate change
Light Duty Vehicles
Heavy Duty Vehicles
Motorcycles
Aircraft
Nonroad Diesel Equipment
Marine Engines/ Ocean Vessels
Locomotives
Lawn & Garden
Recreation Vehicles
ON ROAD
NONROAD
Solutions for Transportation Air Pollution
Emission reductions → Cleaner air & better health
Catalytic converters in conjunction with unleaded gasoline and low sulfur levels significantly reduce hydrocarbon & nitrogen oxide emissions
Fuel standards reduce exposure to pollutants like lead and benzene
Renewable fuels reduce CO_2 emissions
Engine technologies like computer controls, variable valve timing, multi-valve engines, turbo charging & gasoline direct injection improve fuel economy & reduce CO_2 emissions
Transmission technologies like 7+ speeds, dual clutch transmissions (DCTs), & continuously variable transmissions (CVTs) improve fuel economy & reduce CO_2 emissions
Diesel filters reduce particulate matter from on road & off road diesel engines
Alternative vehicle technologies like plug-in electric vehicles & fuel cells = zero tailpipe emissions
Better transportation planning for passengers & freight reduce emissions & fuel use
EPA United States Environmental Protection Agency

MOBILE SOURCES OF AIR POLLUTION

On-road vehicles include:

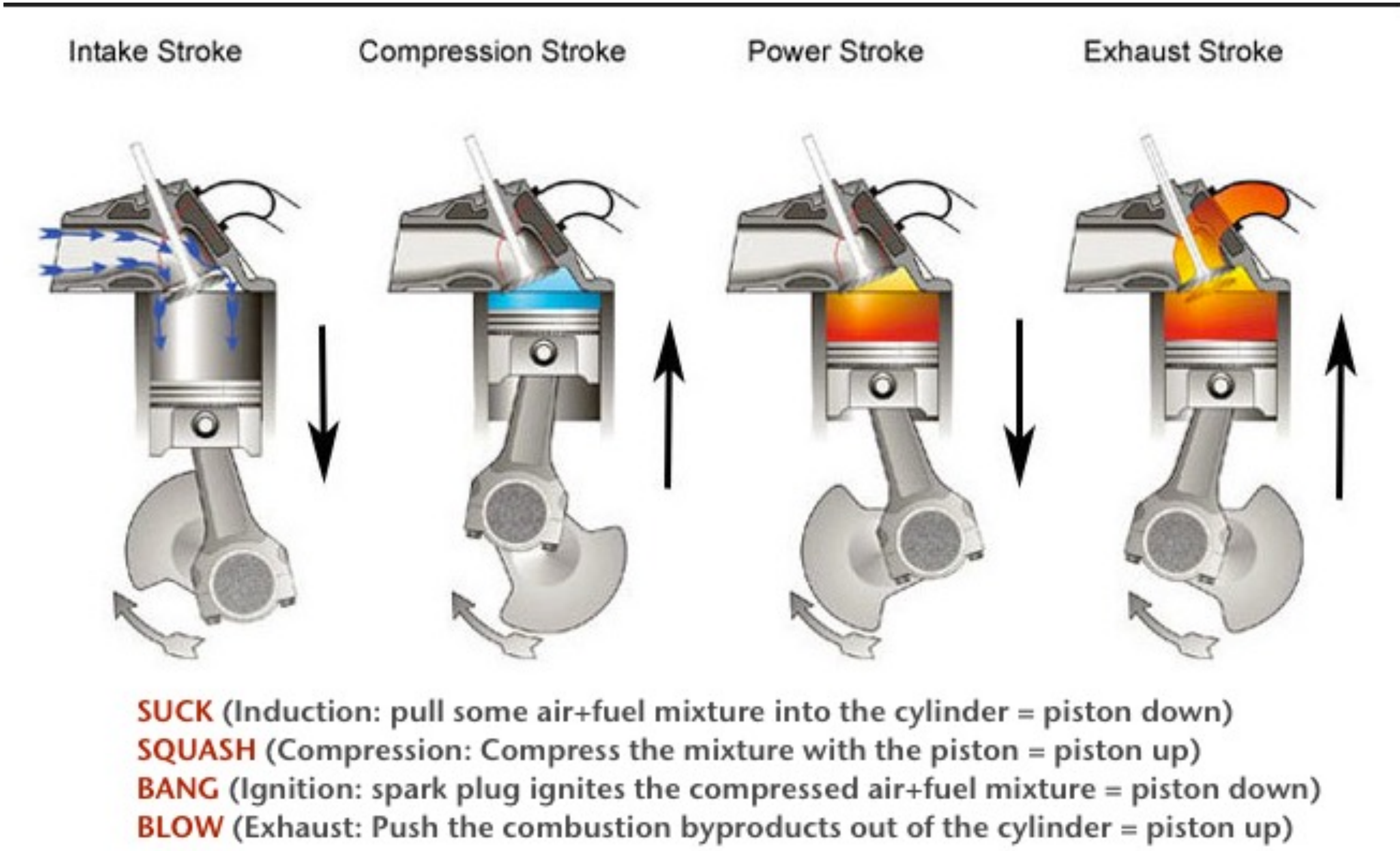
- Motorcycles;
- Passenger cars and trucks; and
- Commercial trucks and buses.

Nonroad vehicles and engines include:

- Aircraft;
- Heavy equipment;
- Locomotives;
- Marine vessels;
- Recreation vehicles (snowmobiles, all-terrain vehicles, etc.); and
- Small engines and tools (lawnmowers, etc.).

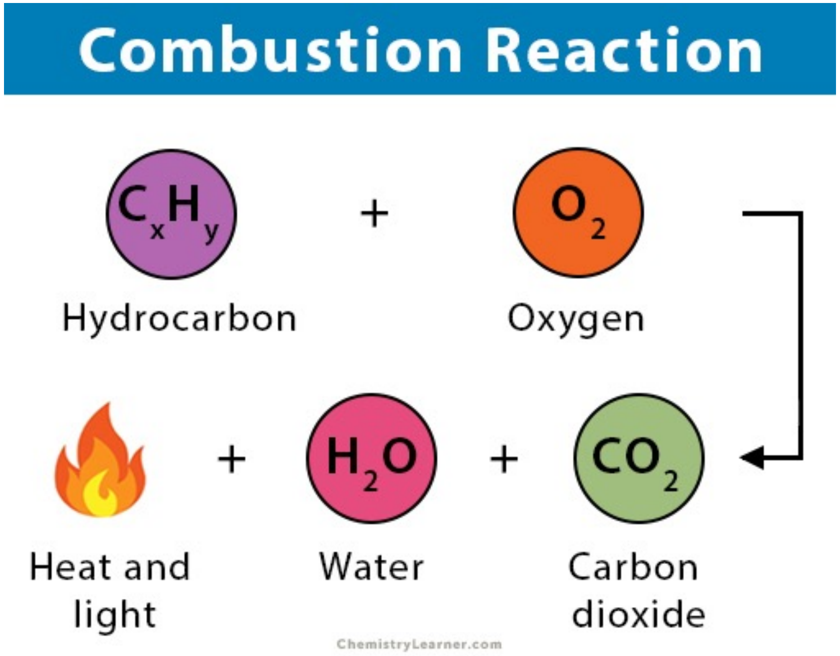
Source: US EPA

Four stroke internal combustion engines



•Four strokes: intake-compression-combustion-exhaust (Otto cycle)

Ideally



In reality: In engines we burn (the combustion) fuel by combining Fules (Hydrocarbons plus other molecules) with Air (O2 plus large portion of N) -> Exhaust produces unburned Hydrocarbons, NOX, CO, and CO2 plus all kinds of toxic matter present in the fules with the Hydrocarbons

EV, HEV, PHEV, FCEV versus ICE

Types of technology: ICE, Hybrids (HEV), Plugin Hybrids (PHEV), Purely Battery Electric Vehicles (EV), Fuel Cell Evs (FCEV)

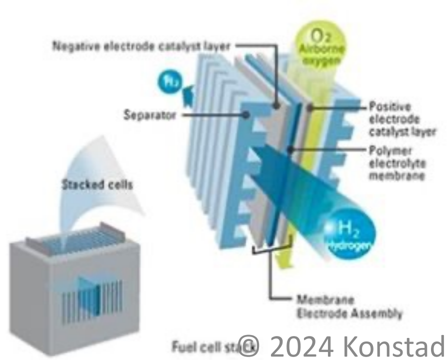
They have different powertrains = the components that generate moving power and deliver it to the wheels to move the car.

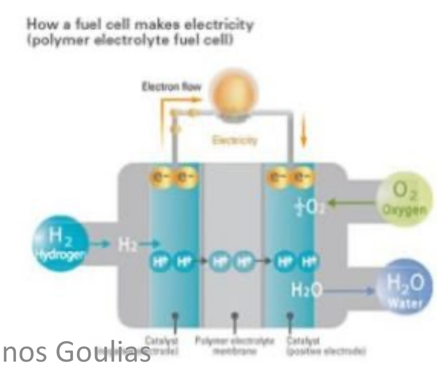
•ICE vehicles burn fuel (usually petrol/gasoline or fuel oils/diesel) that releases heat to move parts of the engine and other components that deliver power to the wheels. The ignition starts this combustion process.

•BEVs use power stored as electricity in rechargeable batteries and deliver it via one or more electric motors to the wheels.

•Hybrids and PHEVs PHEVs have both ICE and electric components, along with controls that manage the balance of electric and ICE power used while driving.

•FCEVs use **electrochemical reaction in a fuel cell catalyst** with Hydrogen to the anode and oxygen (from air) to the cathode. The hydrogen molecules break apart into protons and electrons. Protons then travel through the membrane to the cathode and electrons are force to travel through an external circuits producing work (very cool !!).





How they work

Typical ICE use ignition and combustion of a 15:1 air-fuel mix,

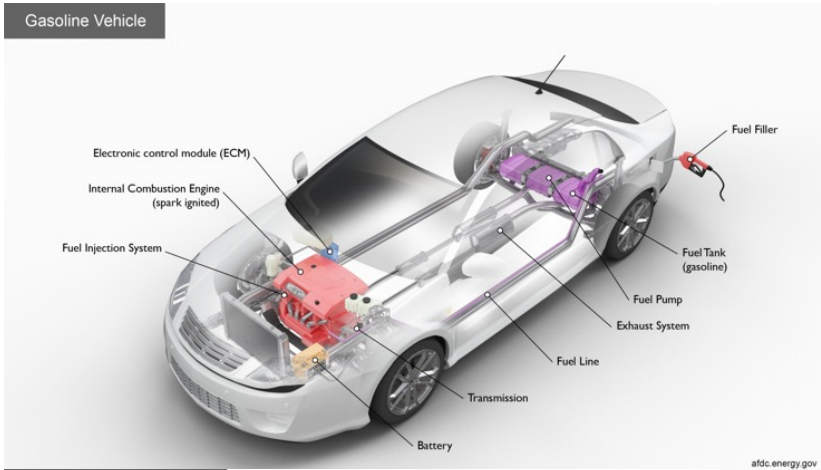
ICE engine converts **thermal energy into mechanical energy** and emits **waste exhaust gases** in the process. Basic functions did not change much in the past 100 years but efficiency better than in the past (Miles per gallon).

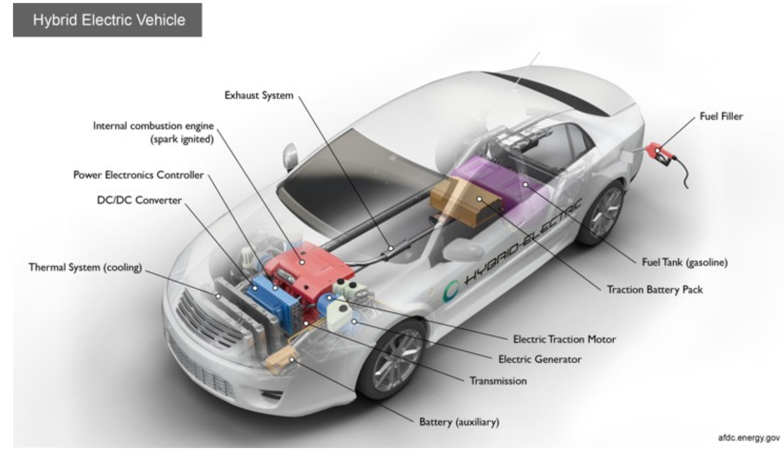
ICE have **hundreds of moving parts** in their mechanical and hydraulic systems with tight tolerances that must work together to keep the combustion engine running.

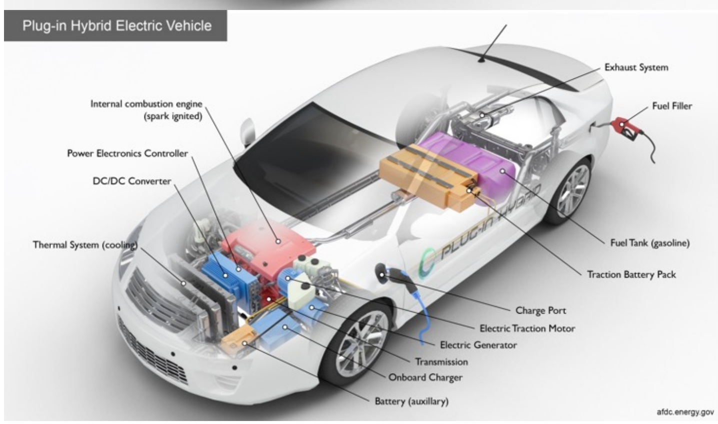
Electrical powertrains convert **electrical energy (stored in the battery) into mechanical energy.** EVs have 90% fewer moving parts than ICE vehicles.

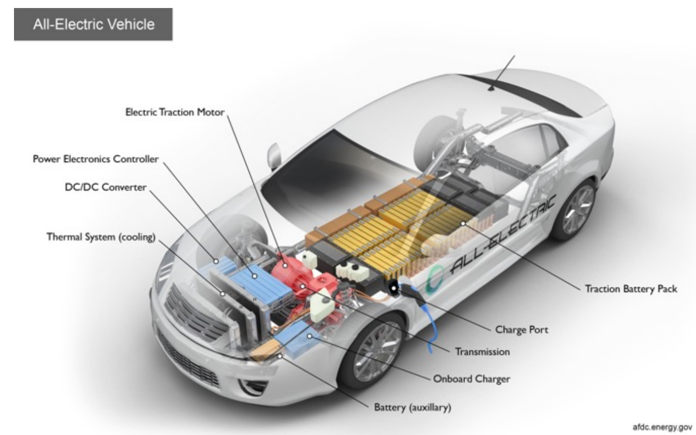
FCEV powertrains also convert **electrical energy (produced by the Hydrogen fuel cells) into mechanical energy.**

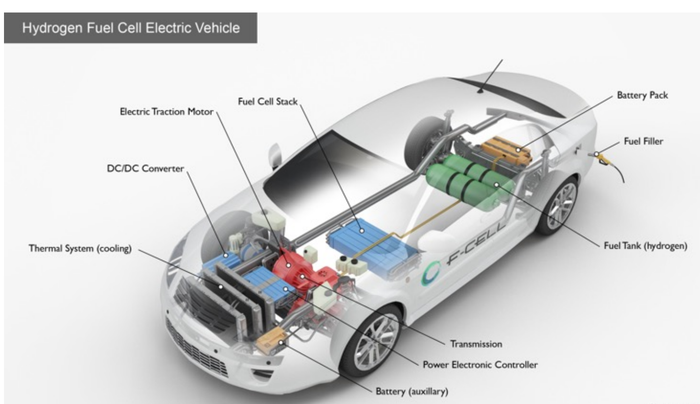
From the US DOE

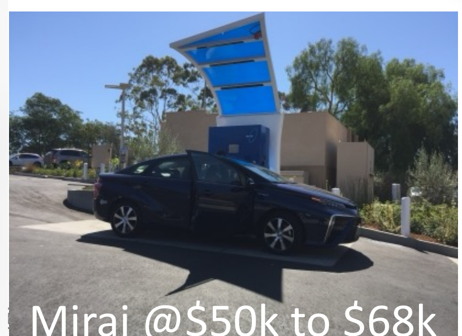




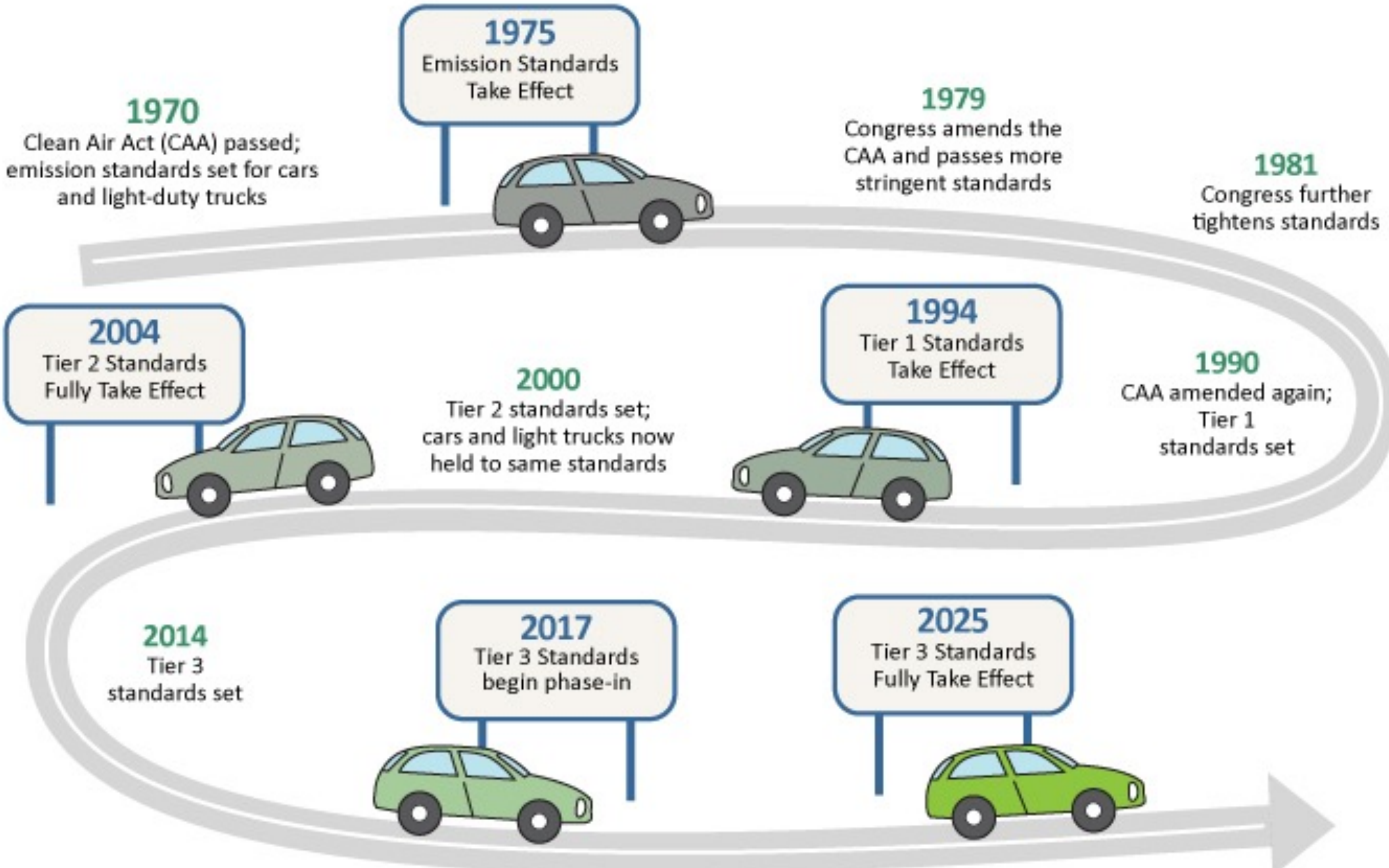








The Road to Cleaner Cars...



Source: US EPA

Average Emissions and Fuel Consumption for Passenger Cars*

Pollutant/Fuel	Emission & Fuel Consumption Rates (per mile driven)	Calculation	Annual Emission & Fuel Consumption
VOC	1.034 grams (g)	(1.034 g/mi) x (12,000 mi/yr) x (1 lb/454 g)	27.33 lb
THC	1.077 g	(1.077 g/mi) x (12,000 mi/yr) x (1 lb/454 g)	28.47 lb
CO	9.400 g	(9.400 g/mi) x (12,000 mi/yr) x (1 lb/454 g)	248.46 lb
NOx	0.693 g	(0.693 g/mi) x (12,000 mi/yr) x (1 lb/454 g)	18.32 lb
PM_{10}	0.0044 g	(0.0044 g/mi) x (12,000 mi/yr) x (1 lb/454 g)	0.12 lb
$PM_{2.5}$	0.0041 g	(0.0041 g/mi) x (12,000 mi/yr) x (1 lb/454 g)	0.11 lb
CO_2	368.4 g	(368.4 g/mi) x (12,000 mi/yr) x (1 lb/454 g)	9,737.44 lb
Gasoline Consumption	0.04149 gallons (gal)	(12,000 mi/yr) / (24.1 mi/gal)	497.93 gal

1. Figures presented above are averages only. Individual vehicles can differ substantially in terms of both annual miles traveled and pollution emitted per mile from values indicated here. Values shown may differ slightly from original sources due to rounding.

2. These emission factors and fuel consumption rates are averages for the entire in-use fleet as of July 2008. Newer vehicles generally emit less pollution and use less gasoline, while older vehicles generally emit more pollution and use more gasoline. This is due to several factors, including the increasing stringency of emission standards over time and the deterioration (degradation) in the performance of emission control technology (e.g., catalytic converters) with increasing age and accumulated mileage.

Source: Old EPA publication

Average Emissions and Fuel Consumption for Light-Duty Trucks*

(most pick-uptrucks, SUVs, etc.)

Pollutant/Fuel	Emission & Fuel Consumption Rates (per mile driven)	Calculation	Annual Emission & Fuel Consumption
VOC	1.224 grams (g)	(1.224 g/mi) x (15,000 mi/yr) x (1 lb/454 g)	32.35 lb
THC	1.289 g	(1.289 g/mi) x (15,000 mi/yr) x (1 lb/454 g)	34.07 lb
CO	11.84 g	(11.84 g/mi) x (15,000 mi/yr) x (1 lb/454 g)	312.95 lb
NOx	0.95 g	(0.95 g/mi) x (15,000 mi/yr) x (1 lb/454 g)	25.11 lb
PM_{10}	0.0049 g	(0.0049 g/mi) x (15,000 mi/yr) x (1 lb/454 g)	0.13 lb
$PM_{2.5}$	0.0045 g	(0.0045 g/mi) x (15,000 mi/yr) x (1 lb/454 g)	0.12 lb
CO_2	513.5 g	(513.5 g/mi) x (15,000 mi/yr) x (1 lb/454 g)	13,572.69 lb
Gasoline Consumption	0.05780 gallons (gal)	(15,000 mi/yr) / (17.3 mi/gal)	693.64 gal

Source: Old EPA publication

US Standards Today

(https://www.epa.gov/greenvehicles/smog-vehicle-emissions#standards)

Notes:
Automakers choose to certify each car model to one of EPA's smog rating standards, also known as "bins," but the automaker's fleet as a whole must meet a specified average. Vehicles certified to a specific bin cannot exceed the amount of pollution specified for that bin. For example, if a vehicle is certified to Bin 50, it cannot emit more than 0.05 grams of NOx + NMOG, 1.7 grams of CO, 0.003 grams of PM, and 0.004 grams of HCHO per every mile it drives.

- **An automaker's fleet (i.e., all the cars they produce in a given model year) must meet a specified NMOG + NOx average annually**. The fleet average limit is lowered each year until MY 2025. The noted fleet average is for the end goal of the regulation (MY 2025).
- A certain percentage of an automaker's fleet must achieve the set PM emission limit (0.003 g/mi) each year; this percentage increases every year until reaching 100% in MY 2021.
- There is no mandated fleet average for CO or HCHO.

NMOG = non-methane organic gas
HCHO = Formaldehyde = a lung irritant and carcinogen.

Current Emission Standards (Tier 3)

Standard	Emission Limits (grams/mile)			
	NOx + NMOG	CO	PM	HCHO
Bin 1	0	0	0	0
Bin 20	0.02	1	0.003	0.004
Bin 30	0.03	1	0.003	0.004
Bin 50	0.05	1.7	0.003	0.004
Bin 70	0.07	1.7	0.003	0.004
Bin 125	0.125	2.1	0.003	0.004
Bin 160	0.16	4.2	0.003	0.004
Fleet Average	0.03	--	--	--

European emissions standards

Strangely a good source for past Euro standards is https://en.wikipedia.org/wiki/European_emission_standards)

Euro 7 in https://theicct.org/wp-content/uploads/2024/03/ID-116-–-Euro-7-standard_final.pdf

European emission standards for passenger cars (Category M),[a] g/km

Tier	Date (type approval)	Date (first registration)	CO	THC	NMHC	NH_3	NO_x	$HC+NO_x$	PM
Diesel									
Euro 1[c]	July 1992	January 1993	2.72 (3.16)	–	–	–	–	0.97 (1.13)	0.14 (0.18)
Euro 2	January 1996	January 1997	1.0	–	–	–	–	0.7	0.08
Euro 3	January 2000	January 2001	0.66	–	–	–	0.500	0.56	0.05
Euro 4	January 2005	January 2006	0.50	–	–	–	0.250	0.30	0.025
Euro 5a	September 2009	January 2011	0.50	–	–	–	0.180	0.230	0.005
Euro 5b	September 2011	January 2013	0.50	–	–	–	0.180	0.230	0.0045
Euro 6b	September 2014	September 2015	0.50	–	–	–	0.080	0.170	0.0045
Euro 6c	–	September 2018	0.50	–	–	–	0.080	0.170	0.0045
Euro 6d-Temp	September 2017	September 2019	0.50	–	–	–	0.080	0.170	0.0045
Euro 6d	January 2020	January 2021	0.50	–	–	–	0.080	0.170	0.0045
Euro 6e	September 2023	September 2024	0.50	–	–	–	0.080	0.170	0.0045
Petrol									
Euro 1[c]	July 1992	January 1993	2.72 (3.16)	–	–	–	–	0.97 (1.13)	–
Euro 2	January 1996	January 1997	2.2	–	–	–	–	0.5	–
Euro 3	January 2000	January 2001	2.3	0.20	–	–	0.150	–	–
Euro 4	January 2005	January 2006	1.0	0.10	–	–	0.080	–	–
Euro 5a	September 2009	January 2011	1.0	0.10	0.068	–	0.060	–	0.005[d]
Euro 5b	September 2011	January 2013	1.0	0.10	0.068	–	0.060	–	0.0045[
Euro 6b	September 2014	September 2015	1.0	0.10	0.068	–	0.060	–	0.0045[
Euro 6c	–	September 2018	1.0	0.10	0.068	–	0.060	–	0.0045[
Euro 6d-Temp	September 2017	September 2019	1.0	0.10	0.068	–	0.060	–	0.0045[
Euro 6d	January 2020	January 2021	1.0	0.10	0.068	–	0.060	–	0.0045[
Euro 6e	September 2023	September 2024	1.0	0.10	0.068	–	0.060	–	0.0045[

a. ^ Before Euro 5, passenger vehicles > 2,500 kg were type approved as light commercial vehicles N_1 Class I
b. ^ Brake particle emissions (PM_{10}). Only regulated for M1, N1 vehicles and only as PM - not PN. After 2035 the limit drops to 0.00
to brake particle emissions regulation even after 2035.
c. ^ a b Values in parentheses are conformity of production (COP) limits
d. ^ a b c d e f g Applies only to vehicles with direct injection engines
e. ^ 6×10^{12}/km within first three years from Euro 6b effective dates

European CO2 emissions standards

(https://climate.ec.europa.eu/eu-action/transport

2020 to 2024

•Cars: 95 g CO_2/km

•Vans: 147 g CO_2/km

These target levels refer to the NEDC emission test procedure.

2025 to 2034

The targets that will apply from 2025 onwards are based on the WLTP (Worldwide harmonized Light vehicles Test Procedure) and were set out in Commission Implementing Decision (EU) 2023/1623:

•Cars: 93,6 g CO_2/km (2025-2029) and 49,5 g CO_2/km (2030-2034)

•Vans: 153,9 g CO_2/km (2025-2029) and 90,6 g CO_2/km (2030-2034)

From **2035 onwards**, the EU fleet-wide CO_2 emission target for both cars and vans is **0 g CO_2/km**, corresponding to a 100% reduction.

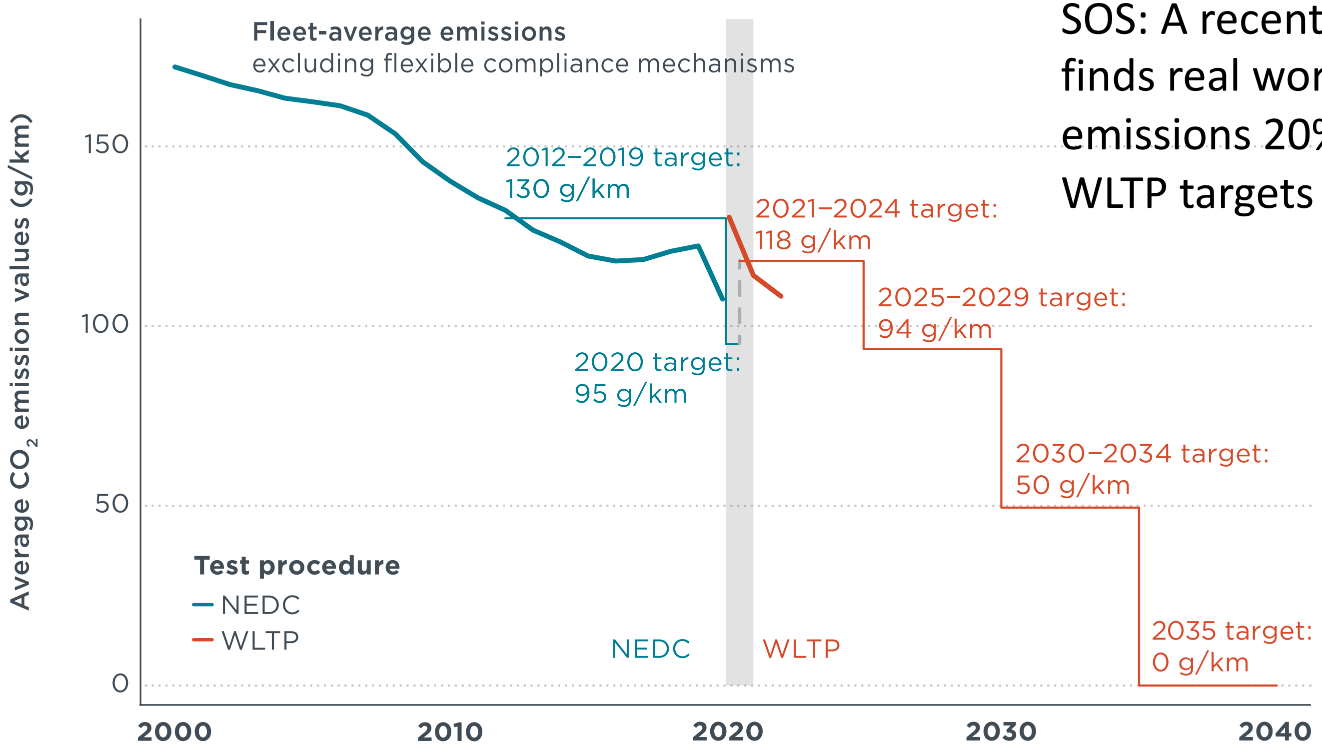


Figure 1. Historical average NEDC and WLTP CO_2 emission values and targets of new passenger cars without flexible compliance mechanisms. The 2021–2024 line corresponds to the WLTP specific emissions reference target for 2021, calculated as the average of the WLTP specific emissions reference targets of all manufacturers.

SOS: A recent EU report finds real world CO2 emissions 20% higher than WLTP targets

The report below contains market share of cars in 2022 by country and type of car/fuel

https://theicct.org/wp-content/uploads/2024/02/ID-102-–-EEA-OEM-briefing_final.pdf

Get the fleet and pollutant emissions about Greece at the report below.

https://ypen.gov.gr/wp-content/uploads/2023/05/2023_NIR_Greece-1.pdf

CARBON FOOTPRINT

Carbon Footprint

The carbon footprint measures a vehicle's impact on climate change in tons of carbon dioxide (CO_2) emitted annually. The following three tables show the carbon footprint for various vehicle classes. The sales-weighted average fuel economy rating for each vehicle class, based on 45% highway and 55% city driving, is used to determine the average annual carbon footprint for vehicles in the class. An estimate of 15,000 annual miles is used for each vehicle class and for each year in the series.

$$CarbonFootprint = \left(CO_2 \times LHV \times \frac{AnnualMiles}{CombinedMPG} \right) + \left(CH_4 + N_2O \right) \times AnnualMiles$$

where:

CO_2 = (Tailpipe CO_2 + Upstream Greenhouse Gases) in grams per million Btu

Upstream = production & processing

LHV = Lower (or net) Heating Value in million Btu <u>per gallon</u>

Heating values describe the amount of energy released when a fuel is burned completely https://world-nuclear.org/information-library/facts-and-figures/heat-values-of-various-fuels

CH_4 = Tailpipe <u>CO_2 equivalent</u> methane in grams per mile

N_2O = Tailpipe <u>CO_2 equivalent</u> nitrous oxide in grams per mile

> **Note:** The Environmental Protection Agency publishes tailpipe emissions in terms of grams of CO_2 per mile in the *Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 through 2017*, www.epa.gov/fueleconomy/trends-report.

Between 1975 and 2020, the production-weighted average annual carbon footprint for new light vehicles dropped dramatically. Total new cars experienced a decrease of 56.9% while the carbon footprint for light trucks decreased by 48.3%.

Table 12.11
Average Annual Carbon Footprint of New Vehicles by Vehicle Classification, Model Years 1975 and 2020[a]
(metric tons of CO_2)

	Production share		Carbon footprint		
Vehicle class	Model year 1975	Model year 2020	Model year 1975	Model year 2020	Percent change 1975 - 2020
Cars					
Car	80.6%	33.3%	12.6	5.3	-57.7%
Car SUV[b]	0.1%	9.5%	15.2	5.8	-62.1%
Total cars	80.7%	42.8%	12.6	5.4	-56.9%
Light trucks					
Van	4.5%	2.6%	15.2	7.4	-51.6%
Truck SUV[b]	1.7%	40.8%	15.3	7.1	-53.6%
Pickup	13.1%	13.7%	14.2	8.7	-38.6%
Total light trucks	19.3%	57.2%	14.5	7.5	-48.3%

Note: Light truck data include pickups, vans, and truck SUVs less than 8,500 lb. Beginning with 2011, SUV and passenger vans up to 10,000 lb were also included.

Source:
Calculated using fuel economy from the U.S. Environmental Protection Agency, *The 2020 EPA Automotive Trends Report*, EPA-420-R-21-003, January 2021. See TEDB page 12-15 for details. (Additional resources: https://www.epa.gov/automotive-trends)

[a] Annual carbon footprint is based on 15,000 miles of annual driving. Includes tailpipe and upstream emissions.

[b] Car SUV category is defined in Table 4.10. Truck SUV category includes all SUVs not in the Car SUV category.

Source: Transportation Energy Databook 40

Wells-to-**wheels** emissions take into account the production and distribution of the fuel. It is a type of analysis that allows individuals to compare emissions over the entire life cycle of a vehicle —from the energy and materials used to power a vehicle, to the direct tailpipe emissions.

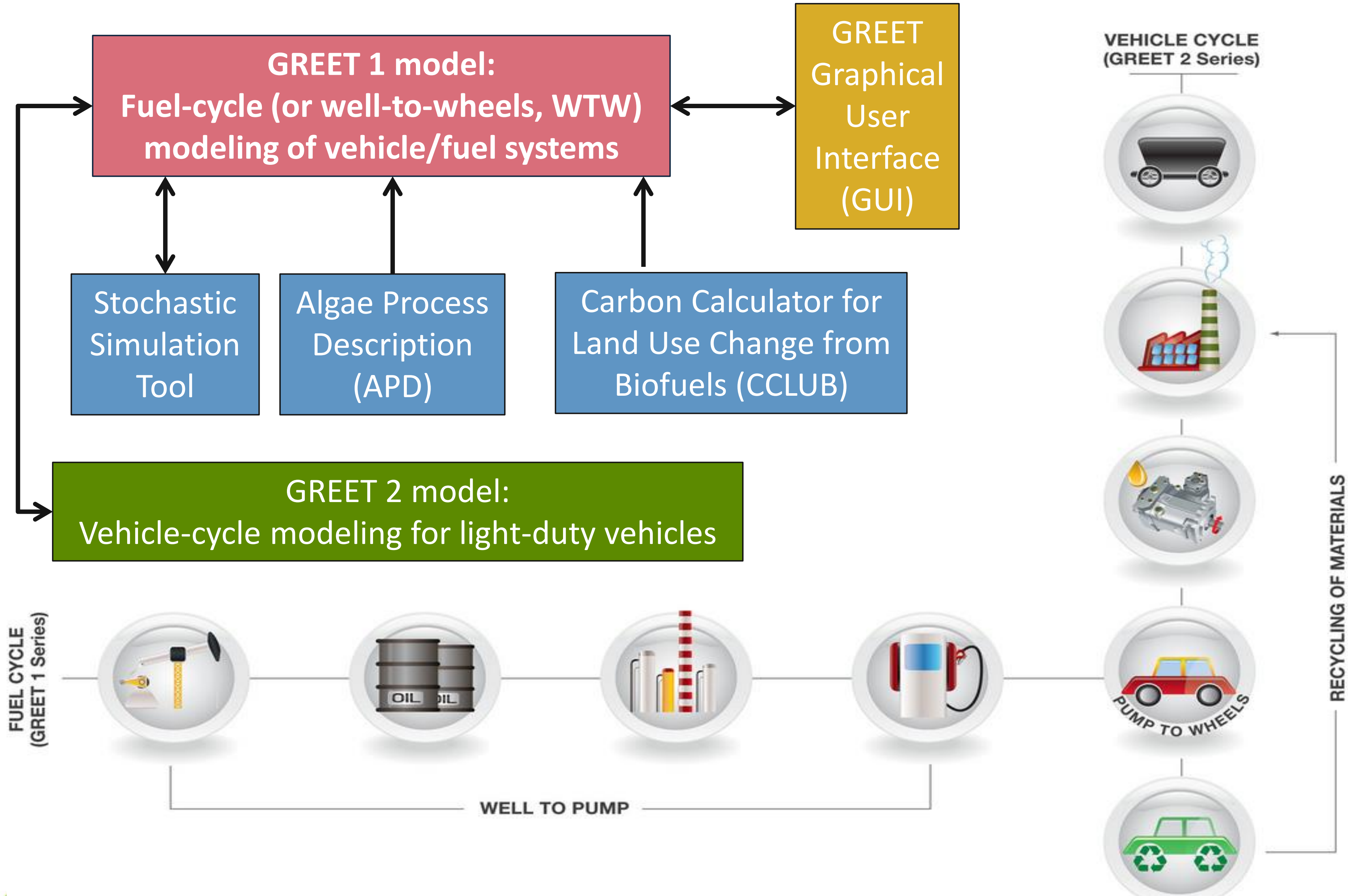
LIFE CYCLE ANALYSIS (FOR CARS: WELLS-TO-WHEELS)

The GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) Model

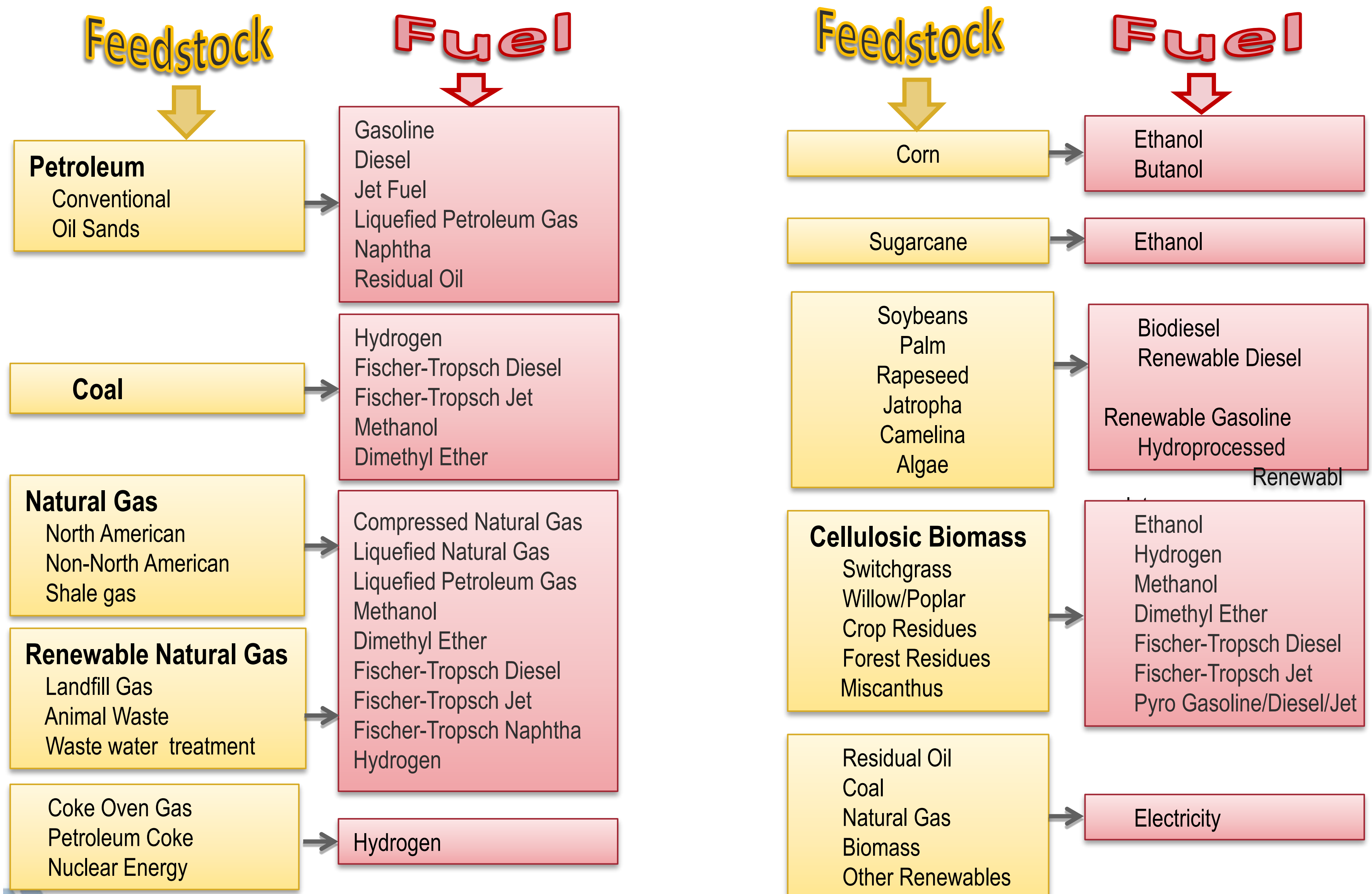
ARGONNE NATIONAL LAB

Video from Argonne: Checked May 2024 (4.32 minutes – show to class)

HTTPS://YOUTU.BE/X3LZLWBKRCM?LIST=PLLT1SPOEVQQXWROFTABWU_IBYLSPS18PO

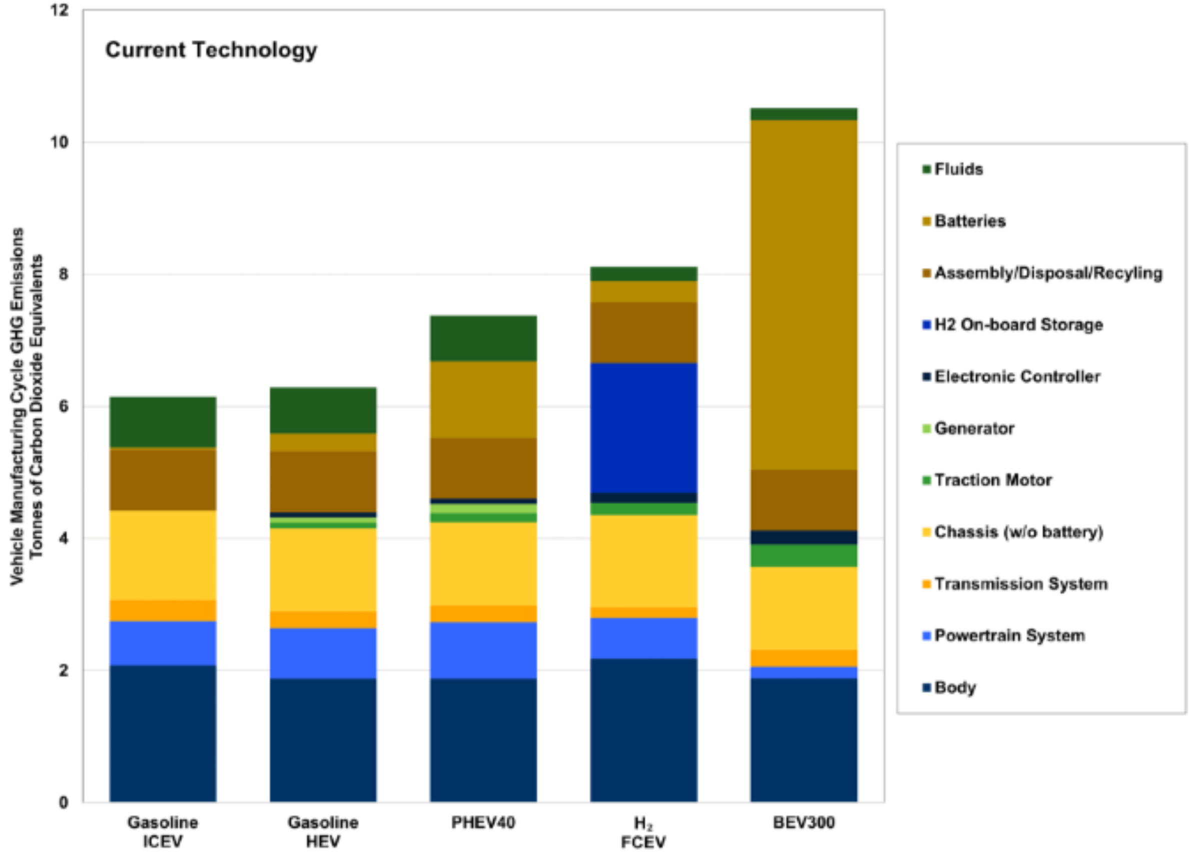

GREET 1 model:
Fuel-cycle (or well-to-wheels, WTW) modeling of vehicle/fuel systems
GREET Graphical User Interface (GUI)
Stochastic Simulation Tool
Algae Process Description (APD)
Carbon Calculator for Land Use Change from Biofuels (CCLUB)
GREET 2 model:
Vehicle-cycle modeling for light-duty vehicles
VEHICLE CYCLE (GREET 2 Series)
FUEL CYCLE (GREET 1 Series)
OIL
OIL
PUMP TO WHEELS
WELL TO PUMP
RECYCLING OF MATERIALS

GREET includes more than 100 fuel production pathways from various energy feedstock sources



Greenhouse gas emissions associated with vehicle manufacturing (current technology) were estimated using the GREET model. Emissions from manufacturing the vehicle body are about two tonnes of carbon dioxide equivalent for each of the vehicle types. Emissions from the manufacture of the hydrogen on-board storage cause the total emissions associated with the manufacture of a hydrogen fuel cell vehicle to be higher than the other vehicle types. Emissions from the manufacture of batteries cause BEV300 vehicles to have the highest total emissions.

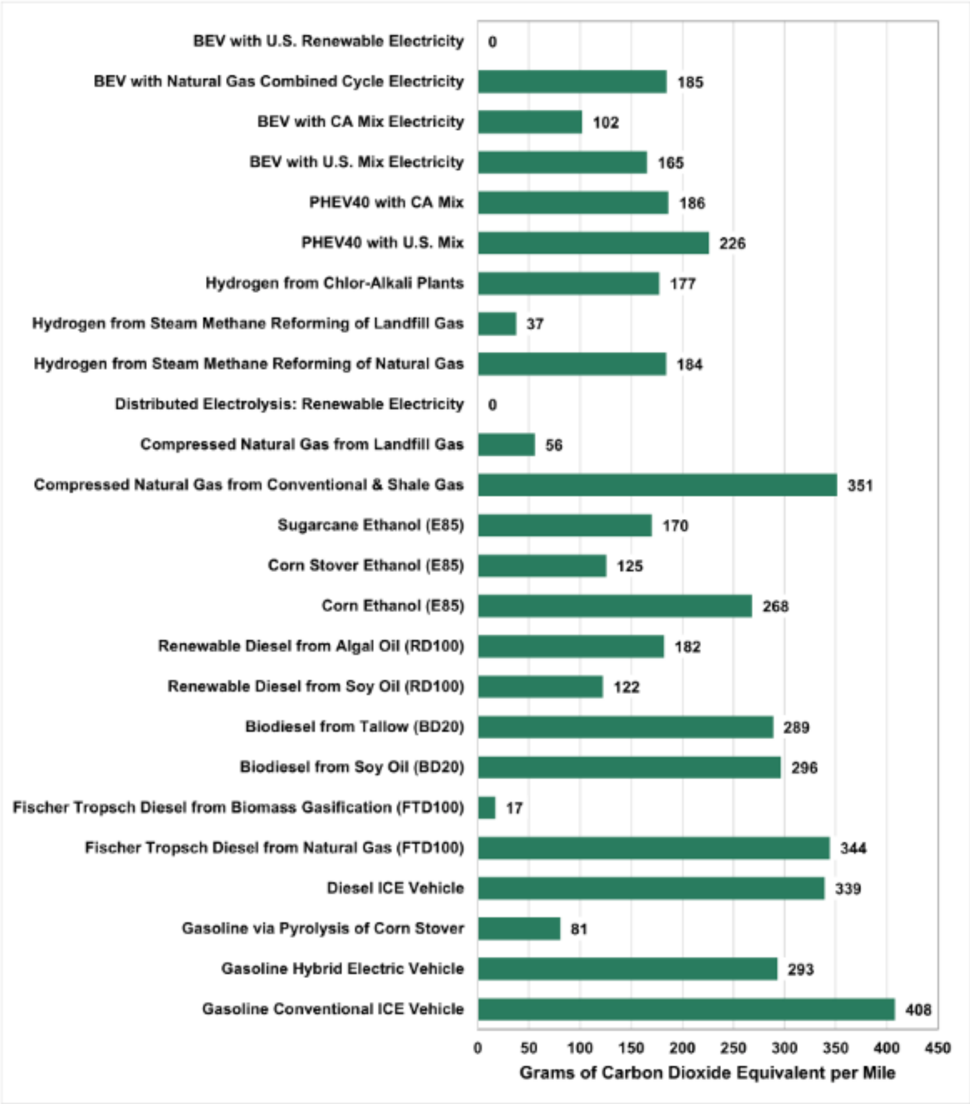
Figure 12.5. Vehicle Manufacturing Cycle Greenhouse Gas Emissions by Vehicle Component



Note: GHG = greenhouse gases. ICEV = internal combustion engine vehicle. CNG = compressed natural gas. HEV = hybrid-electric vehicle. PHEV40 = Plug-in hybrid electric vehicle with 40-mile electric range. H_2FCEV = Hydrogen fuel cell electric vehicle. BEV100 = Battery-electric vehicle with a 100-mile range. BEV300 = Battery-electric vehicle with a 300-mile range.

Results from the GREET 1 2021 model on emissions of carbon dioxide equivalents per mile are shown for various fuels and vehicle technologies. A full description of the model is on the preceding pages.

Figure 12.4. Well-to-Wheel Emissions for Various Fuels and Vehicle Technologies



Note: BEV = Battery-electric vehicle. PHEV40 = Plug-in hybrid electric vehicle with 40-mile electric range.

Electric Vehicle Research Findings

Mostly from GeoTrans & National Renewable Energy Laboratory

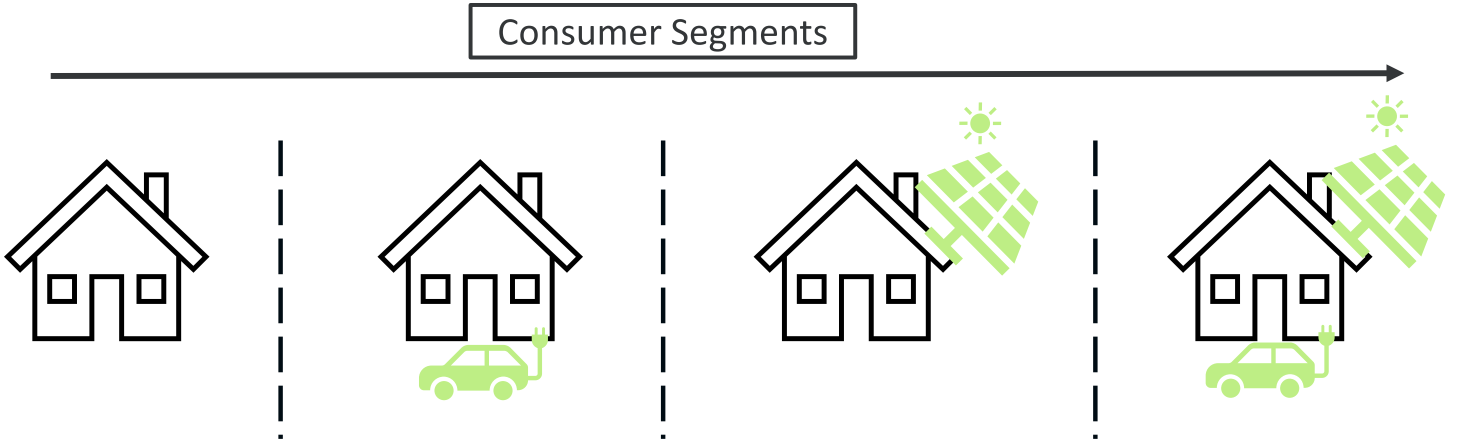
Is the Adoption of Electric Vehicles (EVs) and Solar Photovoltaics (PVs) Interdependent or Independent? An Integrated EVs-PVs Modeling Framework

Shivam Sharda[1],Venu M. Garikapati[1],Konstadinos Goulias[2],Janet L. Reyna[1], Bingrong Sun[1],C. Anna Spurlock[3],and Zachary Needell[3]

[1]National Renewable Energy Laboratory,[2]University of California Santa Barbara,[3]Lawrence Berkeley National Laboratory

Behavior, Energy, and Climate Change Conference (BECC), 2022
November 13-16, Washington DC

Pathways to Decarbonize Household Energy Footprint



Research Questions

Is the adoption behavior of EV and PV **interdependent or independent**?

What are the role of **attitudes, values, and perceptions** in adoption patterns of EVs and PVs?

Who are **adopting** EVs and/or PVs?

Literature on EV, and PV Ownership

Electric Vehicles (EVs)

- EVs are owned by individuals who are **older**, have higher income, and reside in **urban areas**
- EV owners prefer **home** charging followed by **work and public** charging locations
- In the U.S., there is a proposed **federal tax credit** of up to $4,000 on used EVs and $7,500 on new EVs; in India, **tax exemptions** are provided to EV owners

Solar Photovoltaics (PVs)

- PVs are owned by individuals who are **middle-aged**, have higher income, and reside in **rural areas**
- Charing EVs through **residential solar** can nearly double the cost savings compared to dynamic **electric tariff** strategies
- In the U.S., 30 percent of total PV installation cost can be claimed as a **federal tax credit**; in India, a 40 percent **subsidy** is provided to install solar panels

Integrated Assessment of EVs and PVs

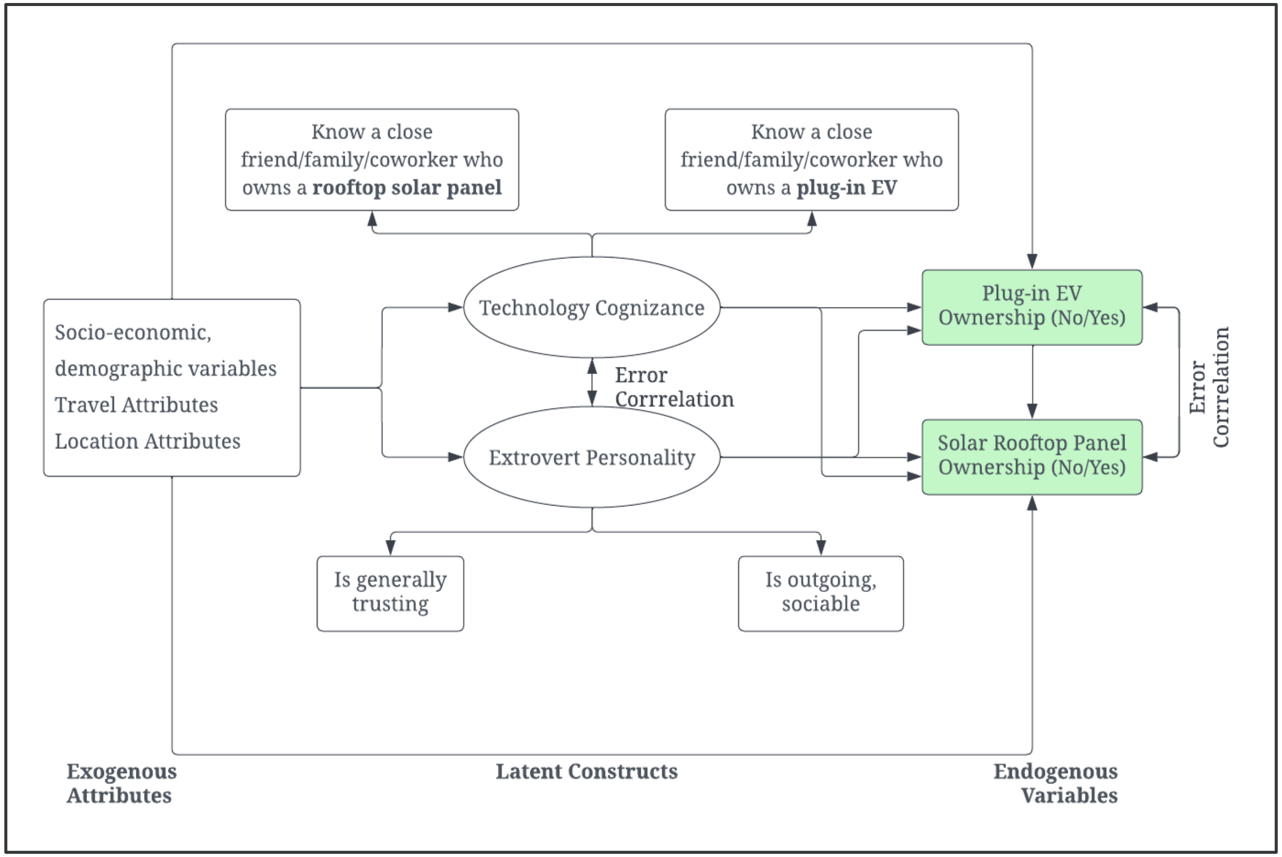
- A study from **Swiss residents** reported significant increase in the intention to adopt EVs when consumers were offered charging services **bundled with EV purchase**
- A survey from **German consumers** reported that willingness to buy community solar panels and electric vehicles was higher than buying an **EV alone**
- Integrating **photovoltaics in electric vehicles** was found to cover up to 35 percent of driving range per year
- Sheperoa et al (2018) concluded that there is a need to develop advanced **spatio-temporal** and integrated EV-PV modeling frameworks

A scan of **EV, PV, and EV-PV literature** reveals a clear gap re: absence of a joint adoption modeling framework that explicitly considers the **inter-relationship** in **adoption behaviors** of EVs and PVs

Dataset

- **WholeTraveler Transport Behavior Study Survey**
  – Year: 2018
  – Sample: San Francisco Bay Area
  – Sample size: 869 respondents
  – Exogenous Variables
    (a) Socio-demographic characteristics
    (b) Travel and location attributes
    (b) Attitudes/perceptions towards sustainable technologies
  – Endogenous Variables
    (a) Own a plug-in electric vehicle(s)
    (b) Own a rooftop solar panel(s)

Integrated EV-PV Modeling Framework



Measurement Model for **Latent Psychological Factors**

$$z_j^* = w_j\alpha_j + \eta_j$$

Structural Equation Model for **Observed Endogenous Variables**

$$y_i = x_i\beta_i + z^*\gamma_i + \varepsilon_i.$$

Discussion

*Is the adoption behavior of EV and PV **Interdependent or Independent**?*

Owning EVs had a **positive and statistically significant** impact on owning PVs (EV→ PV), suggesting **interdependency**

*What are the role of **attitudes, values, and perceptions** in adoption of EVs and PVs?*

Those who are **technology cognizant** are less likely to own EVs but more likely to own PVs

*Who are **adopting** EVs and/or PVs?*

Younger individuals are less likely to **own EVs**, while **older adults** are more likely to **own PVs**

Highly educated and higher income individuals are more likely to own EVs, while **larger households** are more likely to own PVs

Telecommuters are more likely to own PVs, while individuals who reside in densely populated areas are less likely to own PVs

Sharda, S., Garikapati, V. M., Goulias, K. G., Reyna, J. L., Sun, B., Spurlock, C. A., & Needell, Z. (2024). The electric vehicles-solar photovoltaics Nexus: Driving cross-sectoral adoption of sustainable technologies. *Renewable and Sustainable Energy Reviews*, *191*(C).

Study Conclusions and Implications

- This research effort presents an **integrated model system** that explicitly accounts for the **interdependencies** in the adoption of EVs and PVs
- Latent attitudinal constructs are influence by socio-demographic characteristics, travel attributes, and location information
- Major finding of this research effort is that ***'owning an EV had a positive and statistically significant impact on owning PVs'***
- The integrated EV-PV modeling framework can help strategize long-term planning investments that drive ***'bundled adoption'*** of sustainable technologies
- The study highlights the need to bring '**transport and building energy consumption**' research into a ***single integrated structure***

Sharda, S., Garikapati, V. M., Goulias, K. G., Reyna, J. L., Sun, B., Spurlock, C. A., & Needell, Z. (2024). The electric vehicles-solar photovoltaics Nexus: Driving cross-sectoral adoption of sustainable technologies. *Renewable and Sustainable Energy Reviews*, *191*(C).

Combine Autonomous with Electric Mobility

SAE **J3016**™ LEVELS OF DRIVING AUTOMATION™

Learn more here: sae.org/standards/content/j3016_202104

	SAE LEVEL 0™	SAE LEVEL 1™	SAE LEVEL 2™	SAE LEVEL 3™	SAE LEVEL 4™	SAE LEVEL 5™
What does the human in the driver's seat have to do?	**You are driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			**You are not driving** when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			**These are automated driving features**		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering **OR** brake/ acceleration support to the driver	These features provide steering **AND** brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering **OR** • adaptive cruise control	• lane centering **AND** • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

We want to understand who will buy and/rent autonomous vehicles and if these persons and their households are and will be EV users.

Household = group of people living together

Data: 2019 California Vehicle Survey (CVS)

Model: A complex structural equation model (SEM).

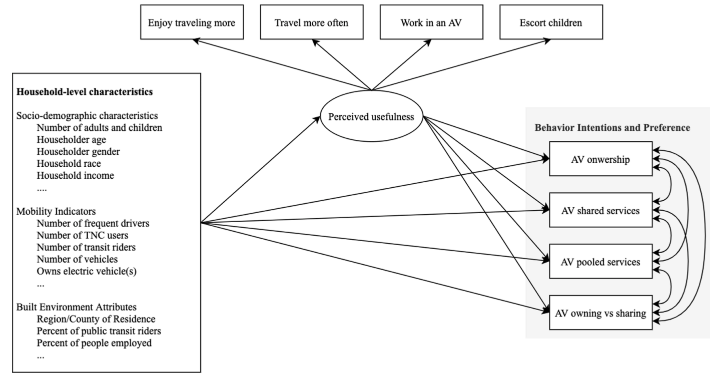


Fig. 3. The Proposed Conceptual Model.

Findings:
1) **Perceived usefulness** is an important determinant of behavioral **intention**.
2) Young, high-educated, and males perceive higher usefulness of AVs.
3) Households that have telecommuters, transit riders, transportation network company (TNC; e.g., Uber & Lyft) riders, and **electric vehicles (EVs) owners**, and households that own or plan to install **photovoltaic cell (solar) panels** also anticipate high benefits of AVs.
4) Living or working at places with access to infrastructure such as EV charging stations and hydrogen fueling stations also add to positive perception of AVs' advantages.

5) Households having higher annual income and EVs express a stronger interest in **buying an AV** but not in ridesharing.
6) Young educated households with more TNC riders show a greater propensity to AV sharing services but not for owning AVs.

Source: Xiao, J., & Goulias, K. G. (2022). Perceived usefulness and intentions to adopt autonomous vehicles. *Transportation Research Part A: Policy and Practice*, *161*.

What do we gain by combining EV with AV?

Prior to the market uptake of autonomous vehicles (AVs), it is critical to understand the consumer segments of AV adopters and quantify the impact of AV adoption on transportation systems and the environment, such as annual vehicle miles travelled (VMT) and greenhouse gas (GHG) emission.

Microsimulation using:

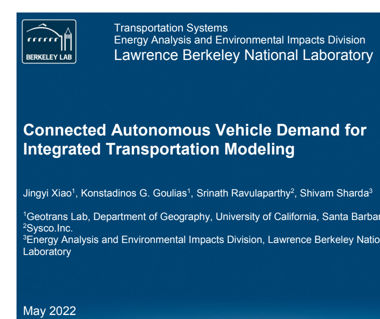
1) Data from the 2019 California Vehicle Survey (CVS);
2) Statistical models correlating people's intention to buy an AV and their socioeconomic and built environment attributes at the household; and
3) A sensitivity correlational analysis to understand the importance of factors impacting AV adoption.

Then microsimulation (we enumerate every car in the area) is used with scenarios for the entire San Francisco Bay Area region to assess how the annual vehicle miles traveled (VMT) and tailpipe Carbon Dioxide (CO_2) emissions associated with driver behavior, vehicle usage, and scenarios of replacement.

Findings

1) Adopting electric AVs can potentially reduce more than 5 megatons of CO_2 yearly !!
2) This is approximately 30% of the total CO_2 emitted by internal combustion engine cars in the regional resident population.

3) Bottom line: EV with AV is the right policy direction, especially in heavily congested places like the SF Bay Area.


Transportation Systems
Energy Analysis and Environmental Impacts Division
Lawrence Berkeley National Laboratory

Connected Autonomous Vehicle Demand for Integrated Transportation Modeling

Jingyi Xiao[1], Konstadinos G. Goulias[1], Srinath Ravulaparthy[2], Shivam Sharda[3]

[1]Geotrans Lab, Department of Geography, University of California, Santa Barbara
[2]Sysco.Inc.
[3]Energy Analysis and Environmental Impacts Division, Lawrence Berkeley National Laboratory

May 2022

Commercial Fleets in California

- Use the California Energy Commission's California Vehicle Survey (CVS) of 2019
- Explore if there are specific commercial fleet vehicles that are more likely to be replaced by electric vehicles
- Explore if these vehicles will be replaced by ride hailing services for passengers and goods.
- Note: Contract services can function as substitutes of fleet vehicle purchase and may be viewed as services provided by transportation fleets to other industries.

Pacific Southwest Research Transportation Center Funded Project with Hui Shi at UCSB

Data & Methods

- The analysis uses data collected on **5,320** randomly selected vehicles from **2,301** recruited commercial fleets for which specific questions about substitution were asked by pinpointing vehicle considered in each fleet.
- **Factor Analysis with Mixed Data**
  - Continuous and categorical variables
- **Multilevel Multinomial Logit**
  - Vehicles within fleets
  - Fleets = spokesperson in survey

Summary of Findings

The majority of **fleet vehicles** can be replaced by electric vehicles !!!

Vehicle **replacement propensity** is a function of the utilization type of the vehicle, vehicle efficiency, vehicle age, size, fleet size, and the type of business of the owner firm of the fleet.

Contract and ride hailing services can be a major competitor of ICE vehicles in fleets.

UBER green figured this already!

Overall Research Findings

- EVs and PVs are popular in different population segments with some overlap
- EVs and AVs are also popular in different segments but an overlapping segment are early adopters who are wealthy, males, technophiles
- Remote Workers is a good target segment for all of the above
- Commercial Fleets & Early Adopters will create a used vehicle market that will give MAJOR positive impacts

Back to the original but modified questions

You want to buy an electric car

Question 1: Should the government (Federal and State) subsidize you?

Question 2: How should the subsidy be structured?

The End!
Thank you!