Introduction to Electric Vehicles

ECI 189G: Lecture 1

Dan Sperling
Alan Jenn
Spring 2022

Class Logistics

Class Info

- Date/Time – Mondays and Wednesdays from 5-7pm
- Location – Hoagland Hall 113
- Office hours
  - Alan Jenn: Monday 10am-11am by Zoom (available to meet in-person, schedule by e-mail) (https://ucdavis.zoom.us/j/99856960120?pwd=WjNsMnc4ZVpjM3RrZHlOK1lBNUV3UT09)
  - Daniel Sperling:
- Contacts – Message via Canvas or ajenn@ucdavis.edu
- Holidays – May 30th (Memorial Day)

COVID Protocols

- Masking policy: official university policy allows for no masks as of March 19th. However, we will still be masking and highly recommend students to do so as well!
- Testing every 2 weeks is required, please make sure to test and fill out your daily symptom survey when you come to campus!
- **Don’t come to class if you are sick!**

Hybrid/Remote Teaching

- Lectures will *not* be hybrid mode (no remote attendance)
- …but lectures will be recorded and posted on Canvas and YouTube. If you miss a lecture or are unable to attend, you will be expected to watch these lectures to stay up to date with the class

Schedule Overview

Week	Date	Lecture	HW	Title
1	3/28/2022	1		Introduction to electric vehicles
	3/30/2022	2		History and market of EVs
2	4/4/2022	3	HW 1 assigned	Internal combustion vs electric vehicle drivetrains
	4/6/2022	4		Battery technology
3	4/11/2022	5		Vehicle efficiency
	4/13/2022	6	HW 1 due	Vehicle charging technology and electric vehicle supply equipment
4	4/18/2022	7	HW 2 assigned	Vehicle production costs and Total cost of ownership
	4/20/2022	8		Consumer preferences for EVs
5	4/25/2022	9		Travel behavior of EVs
	4/27/2022	10	HW 2 due	Charging behavior
6	5/2/2022	11	HW 3 assigned	Life cycle analysis of EVs and secondary battery life*
	5/4/2022	12		Electricity systems and use-phase emissions
7	5/9/2022	13		EVs and local air quality
	5/11/2022	14	HW 3 due	Medium and heavy-duty electric vehicles*
8	5/16/2022	15	HW 4 assigned	Zero Emissions Vehicle policy
	5/18/2022	16		Federal US policies on EVs
9	5/23/2022	17		State and local US policies on EVs, International EV policies
	5/25/2022	18	HW 4 due	Incentives and efficacy of subsidies
10	5/30/2022	19		Holiday (Memorial Day)
	6/1/2022	20		The future of EVs

Participation

- Free points as long as you show up for class
- We'll keep track of attendance by online polls at the beginning of each class
- Worth 20% of your grade

Homework

- Homework accounts for 50% of the final grade
- Each homework will consist of both a quantitative and qualitative section
- Four total homeworks throughout the quarter, 9 days per assignment
- Late homeworks will be accepted with a 5% deduction per day

Final Paper

- Final paper accounts for 30% of the final grade
- Two components for the project:
  - Project Proposal, due May 13th
  - Project Report, due June 8th
- More details will be forthcoming, but the paper will represent a deeper dive into any topic (or related topic) covered in this course—must include reviews of existing studies and policy recommendations
- Can work in groups of 2-3 people per project

Picnic Day – April 23, 2022

- Electric Vehicle Showcase!
- Community organized event with EV owners bringing in their personal vehicles to showcase
- More information will be forthcoming…
- Bonus points

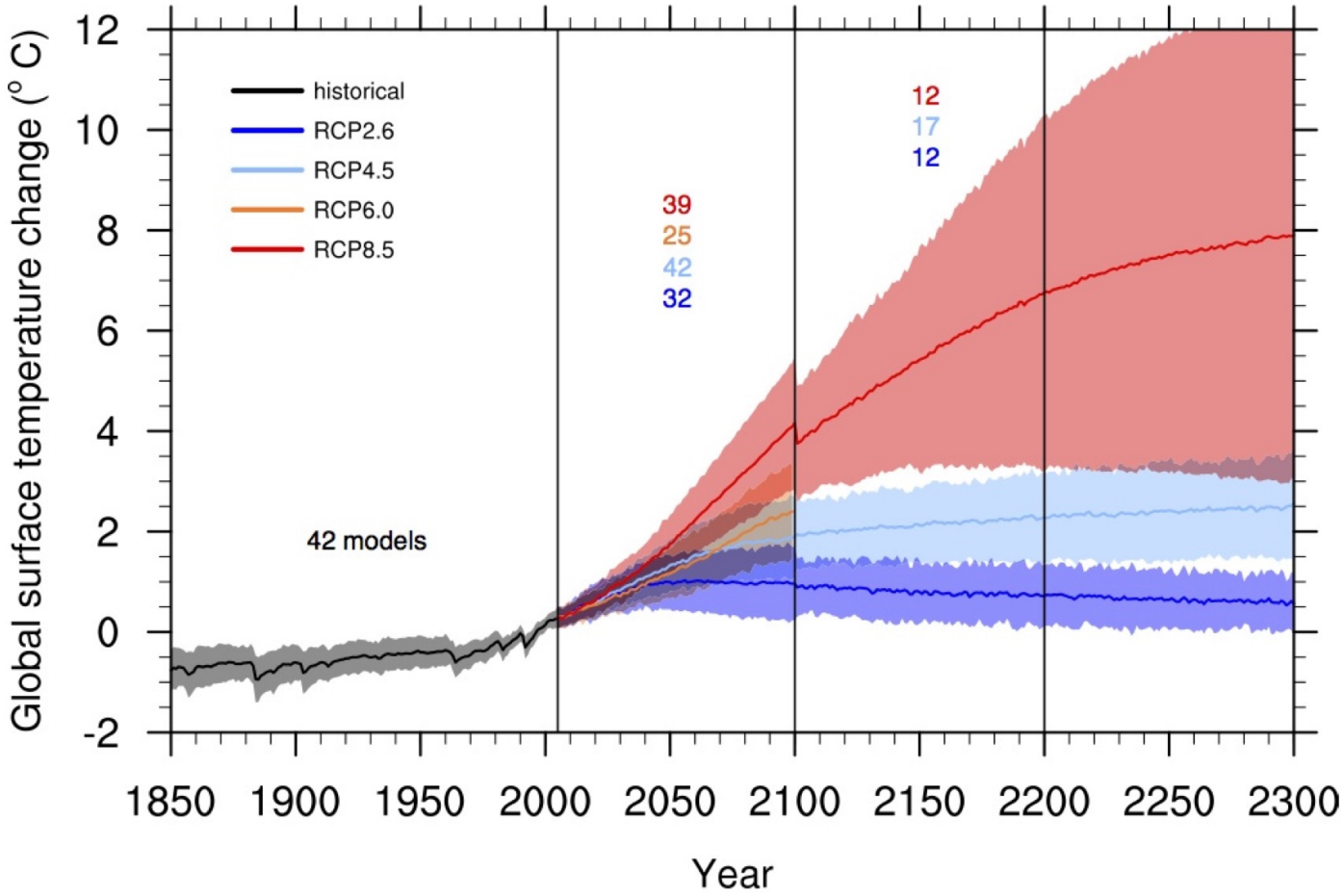
Internship Opportunity

- National Center for Sustainable Transportation summer research fellowship
- Details at https://ucdavis.infoready4.com/#competitionDetail/1859031

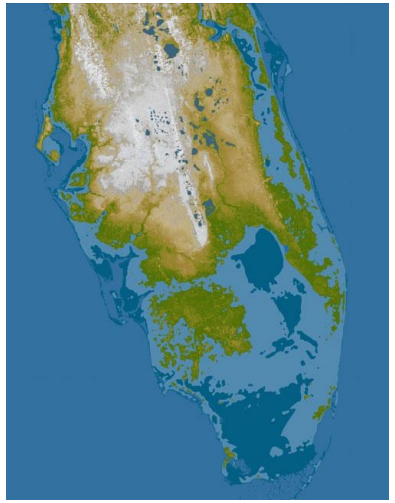
Why do we care about electric vehicles?

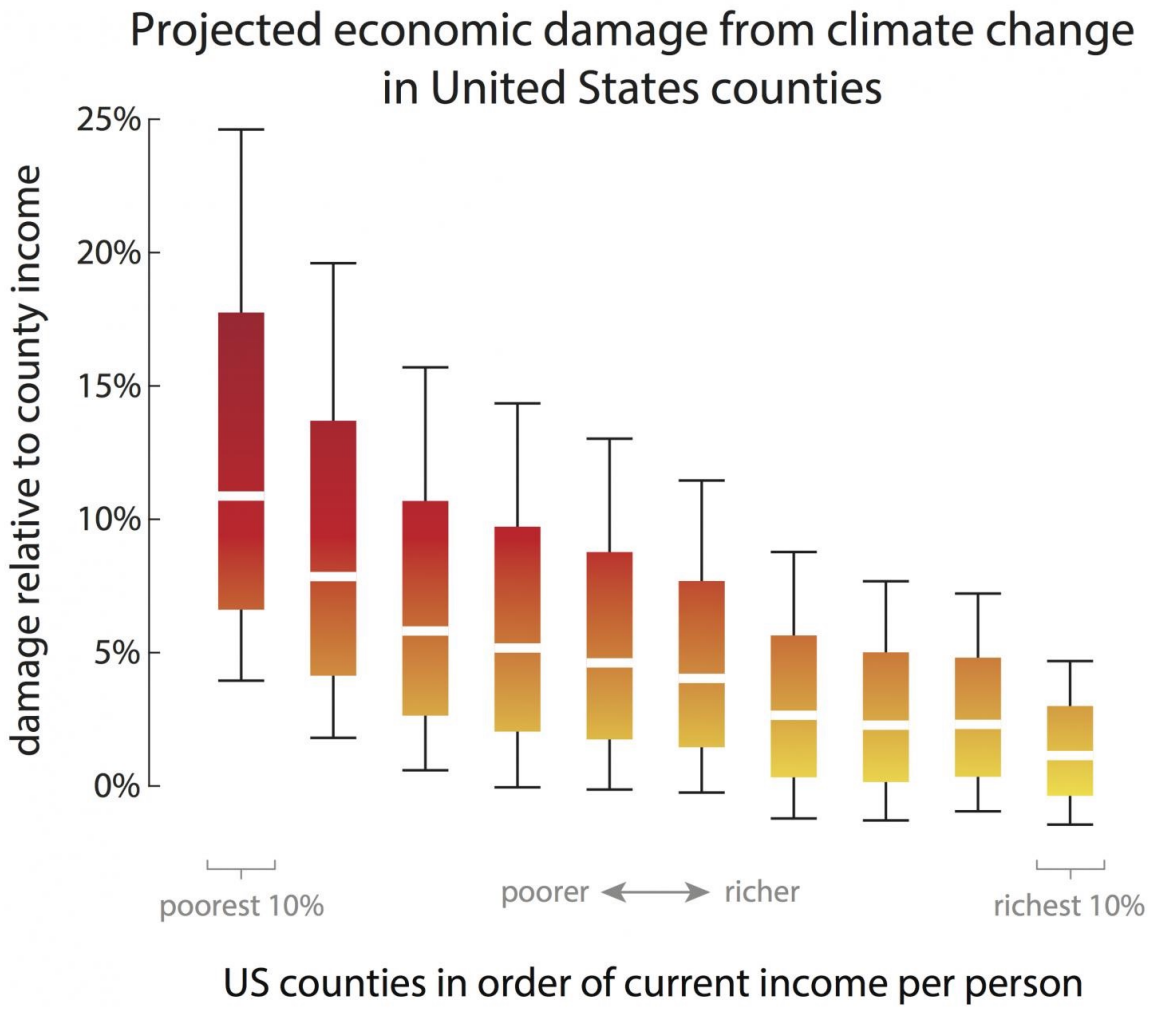
Emissions and climate change

- Anthropogenic emissions of greenhouse gases are leading to global warming and other climate change issues
- Emissions must be lowered to mitigate the effects of climate change



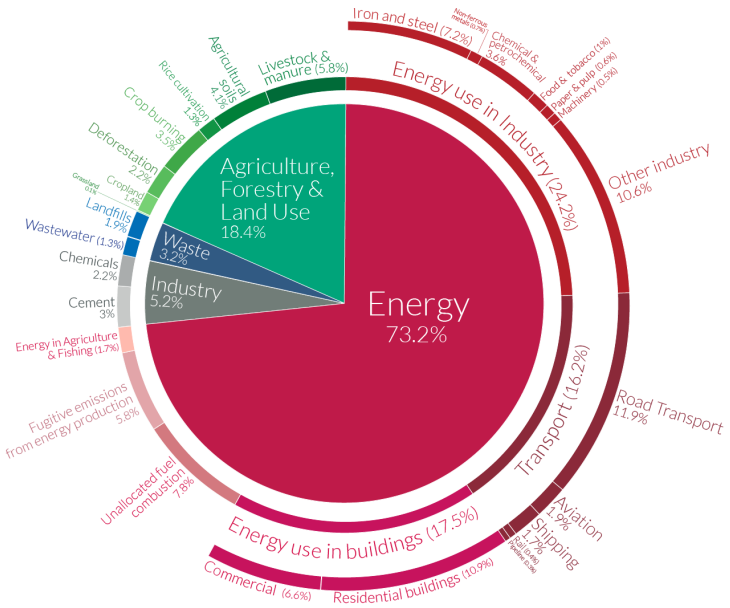
Damages from climate change



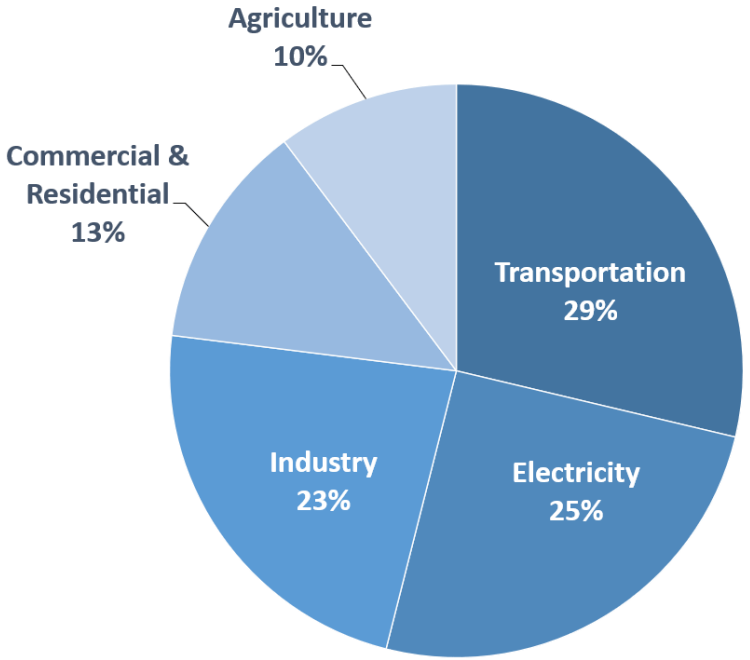


Hsiang, Kopp, Jina, Rising, et al. (2017)

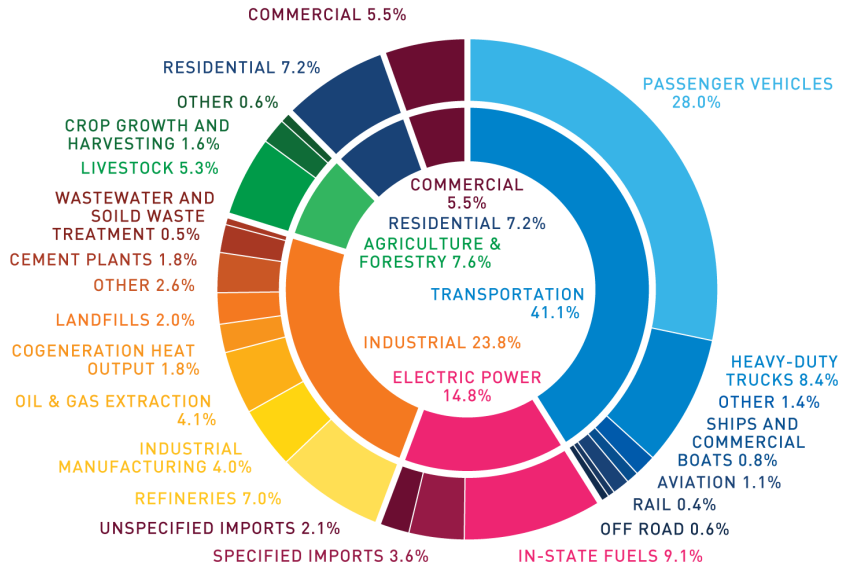
Emissions by sector



OurWorldinData.org – Research and data to make progress against the world's largest problems.
Source: Climate Watch, the World Resources Institute (2020). Licensed under CC-BY by the author Hannah Ritchie (2020).



U.S. Environmental Protection Agency (2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019



NEXT 10 CALIFORNIA GREEN INNOVATION INDEX. Data Source: California Air Resources Board, California Greenhouse Gas Inventory – by Sector and Activity. NEXT 10 / SF · CA · USA

Energy and Power

What is energy?

- Energy is the ability to perform work on (moving something) or heat an object
- What are the main forms of energy?
  - Kinetic, chemical, heat, electrical, electromagnetic, elastic, nuclear, gravitational

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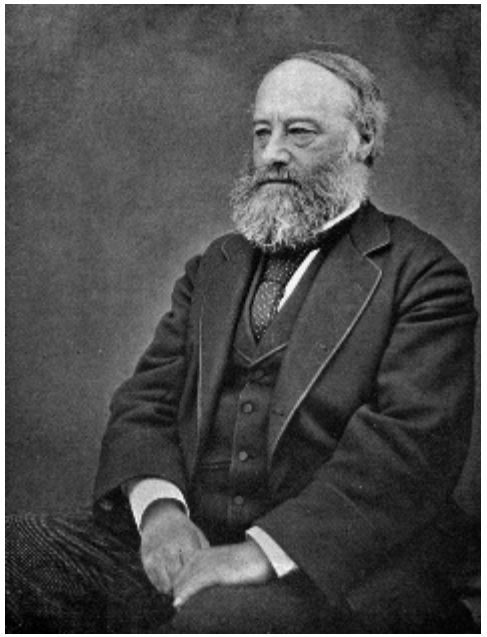
Energy – Joules (J)

- The gold standard (SI unit for energy), used across a wide variety of applications and fields
- 1 Joule can:
  - Heat 1 gram of water by 0.24°C
  - Move 1 kg a distance of 1 m at 1 ms^2



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What is power?

- Power is the *rate* of doing work, or energy/time
- Units of power:
  - Watt (W)
  - Horsepower (hp)

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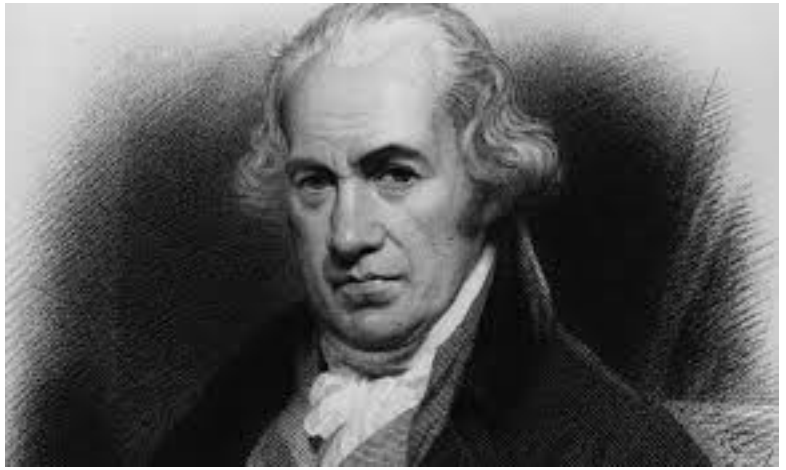
Power – Watts (W)

- The SI unit for power, 1 W = 1 J/s
- Commonly used in electricity to describe the capacity of a power plant (e.g. if a plant has an installed capacity of 10 MW, it is physically able to produce up to 10 MW of instantaneous power)



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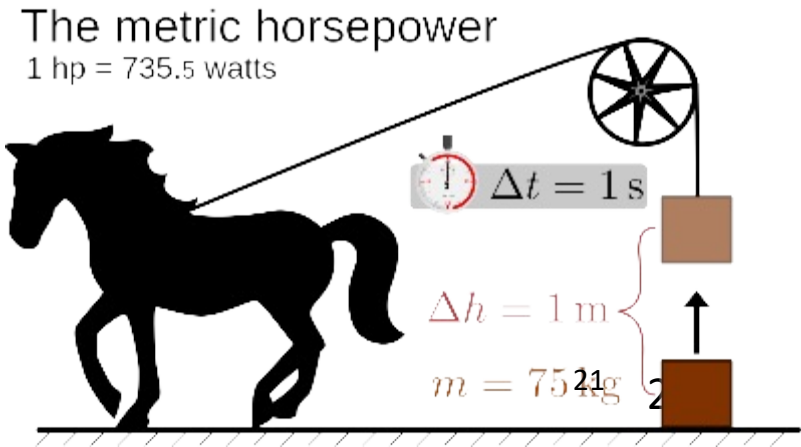
Power – Horsepower (HP)

- Commonly used to describe power for engines (and mechanical power)
- 1 hp can lift 75 kg one meter in 1 second
- 1 hp (imperial) = 745.7 W
- 1 hp (metric) = 735.5 W
- The peak power production of a horse is…about 15 horsepower



Energy – kilowatt-hours (kWh)

- Most commonly used in electricity
- The amount of energy used at a constant power rate over a period of time
- 1 Wh = 3.6 kJ
- Consumption of electricity at the residential level is often measured in kilowatt-hours (kWh)

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Battery Energy and Vehicle Range

Toyota Camry
15.8 gallon tank
537 mile range

Tesla Model Y
75 kWh battery
303 mile range

Ford Mustang Mach-E
68 kWh battery
211 mile range

Chevrolet Bolt
60 kWh battery
238 mile range

Nissan Leaf
40 kWh battery
150 mile range

Vehicle Efficiency

Toyota Camry
15.8 gallon tank
537 mile range
34 MPG

Tesla Model Y
75 kWh battery
303 mile range
4.0 mi/kWh or .25 kWh/mi

Ford Mustang Mach-E
68 kWh battery
211 mile range
3.1 mi/kWh or .32 kWh/mi

Chevrolet Bolt
60 kWh battery
238 mile range
4.0 mi/kWh or .25 kWh/mi

Nissan Leaf
40 kWh battery
150 mile range
3.75 mi/kWh or .27 kWh/mi

Charging Power

Consider a 75 kWh battery: ~300 miles….

~1 kW (Level 1): ~75 hours

~50 kW (DCFC): ~1.5 hours

~120 kW (Tesla Supercharger): ~40 min

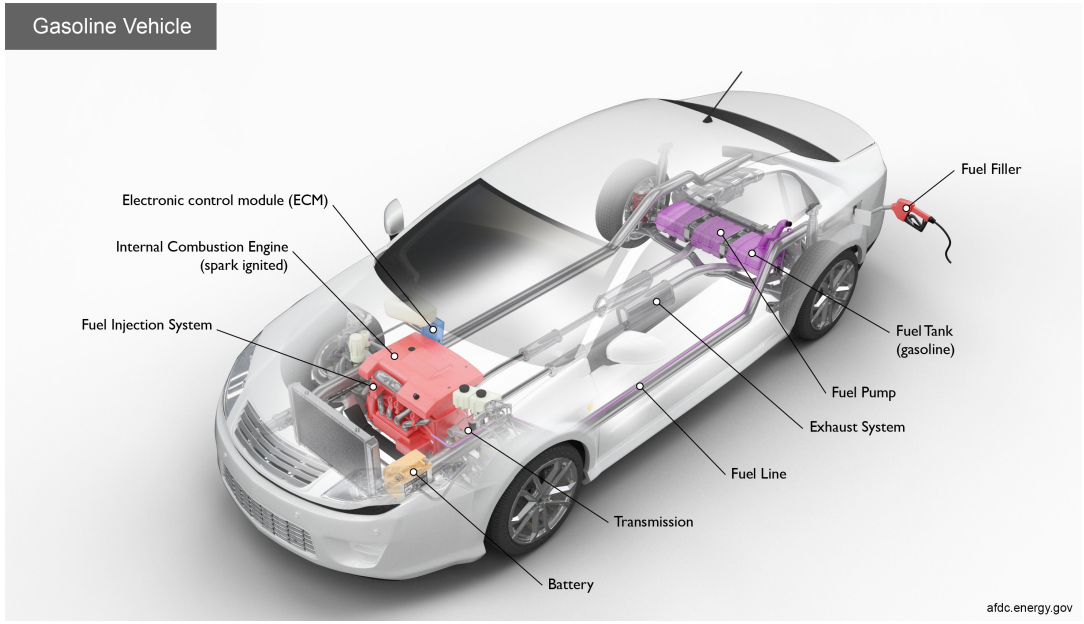
~7 kW (Level 2): ~10 hours

~270 kW (XFC): ~15 min

Electric Vehicle Basics

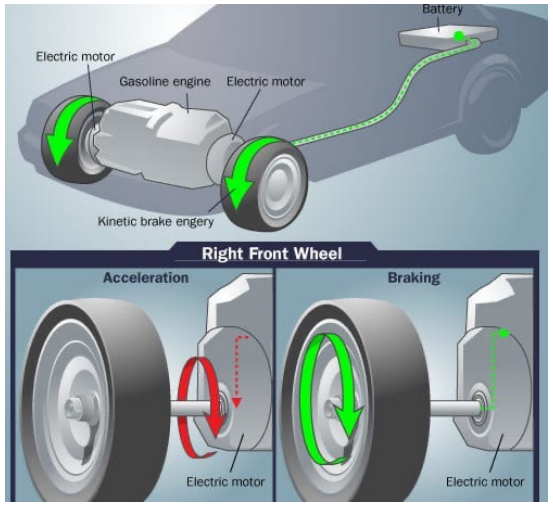
Internal Combustion Engine (ICE/ICV)

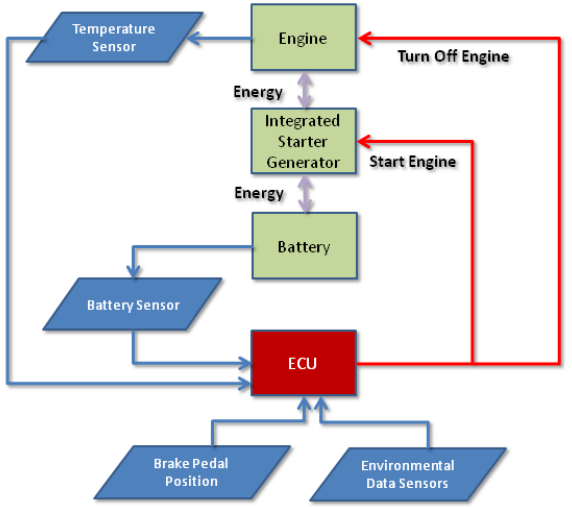
- Vehicle drivetrain is powered by the combustion of fuel
- Most common fuels are fossil fuels such as gasoline and diesel, less common fuels include natural gas and ethanol (E85)



Hybrid Electric Vehicle (HEV)

- Hybrid vehicles are actually ICVs and not traditionally considered to be true electric vehicles
- Drivetrain is still powered by gasoline/diesel, but have several features that improve fuel efficiency:
  - Regenerative braking (energy from motion stored to a battery)
  - Reduce idling emissions by shutting down engine when idling (start-stop system)





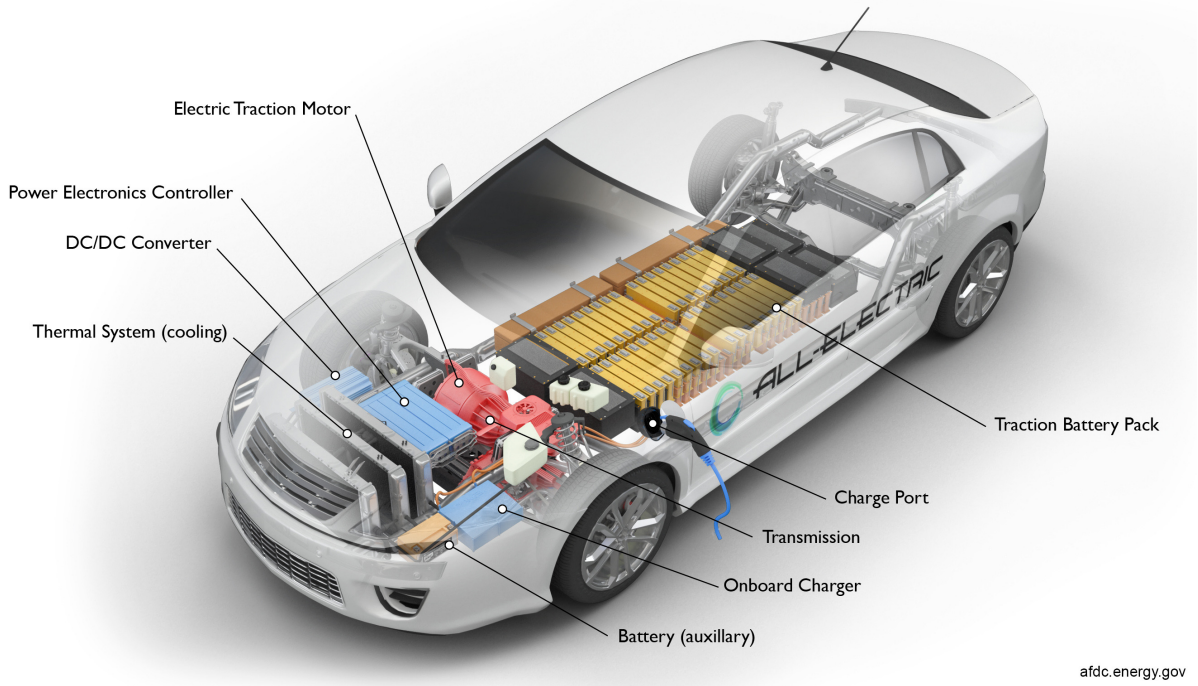
Electric Vehicle (EV) and Plug-in Electric Vehicle (PEV)

- Electric vehicles are vehicles whose propulsion is powered by electricity rather than through the combustion of fuel
  - The most common is via a battery, but fuel cells are also considered EVs
- Plug-in electric vehicles are a *subset* of electric vehicles (all PEVs are EVs, not all EVs are PEVs!)
  - PEVs have batteries that are charged by plugging into a charger

Battery Electric Vehicle (BEV)

- A BEV's powertrain operates on electricity powered solely by an onboard battery
- The battery powers a motor to translate electricity into motion
- Very few moving parts compared to an ICV!

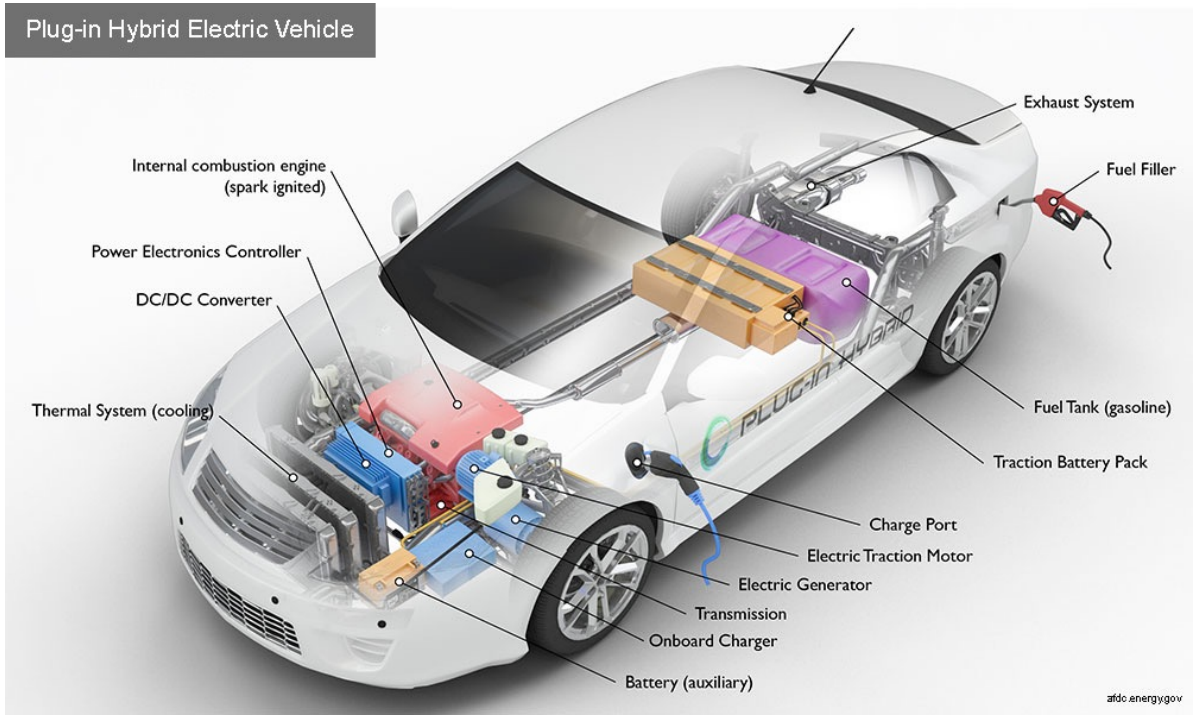
All-Electric Vehicle



afdc.energy.gov

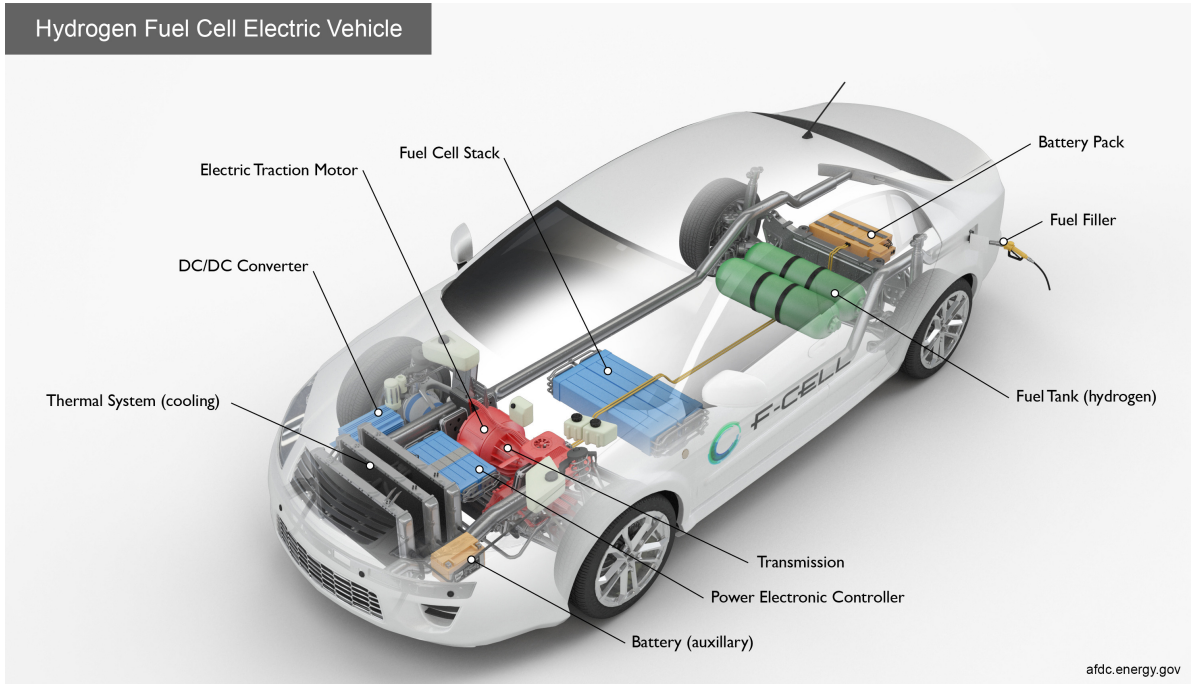
Plug-in Hybrid Electric Vehicle (PHEV)

- A PHEV contains both drivetrains of an ICV and a BEV: engine, gas tank, motor, and battery
- Unlike HEVs, PHEVs can operate *solely* on electric power and without the engine turning on
- PHEVs can vary substantially in configuration (parallel, series, parallel-series) and operation



Fuel Cell Vehicle (FCV)

- FCVs employ a fuel cell to oxidize a fuel to generate electricity (as opposed to heat in combustion)
- The most common is a hydrogen fuel cell though other types exist such as natural gas
- Modern hydrogen FCVs have a battery as well, allowing for more efficient operation (e.g. regenerative braking)



Zero-Emission Vehicle (ZEV)

- A zero-emission vehicle is considered a vehicle that has no “tailpipe” emissions
- BEVs and FCVs are both ZEVs but not all EVs/PEVs are ZEVs since a PHEV is not a pure ZEV

Classifications

ICV

Toyota Camry

Toyota Prius

HEV

PEV

Tesla Model Y

Chevrolet Bolt

Nissan Leaf

Mustang Mach E

Ford F-150 Lightning

BEV (ZEV)

Chevrolet Volt

Toyota Rav4 Prime

Toyota Prius Prime

PHEV

EV

Toyota Mirai

Hyundai Nexo

FCV (ZEV)

Nomenclature (Reference Slide)

- ICV/ICE (Internal combustion engine vehicle) – *usually* refers to traditional gasoline car
  - HEV (Hybrid Electric Vehicle) – highly efficient gas car (start/stop technology, regenerative braking, etc)
- EV/ZEV (Electric Vehicle/Zero Emission Vehicle) – vehicles whose drivetrain is powered by electricity, often considered to be “zero” emission (at the tailpipe)
  - PEV (Plug-in Electric Vehicle) – vehicle that charges its battery (to power drivetrain) by plugging it in
    - BEV (Battery Electric Vehicle) – vehicle with only a battery to power its drivetrain
    - PHEV (Plug-in Hybrid Electric Vehicle) – vehicle with both a battery and a combustion engine (not a full ZEV) to power its drivetrain
  - FCV (Fuel Cell Vehicle) – electricity generated from a fuel cell (usually through hydrogen oxidation) to power the drivetrain