Final Class Project

- Project proposal
  - Due May 13th at the end of the day
  - Worth 20% of the course project
  - Can work in groups of 2-3 people, only one submission required per group
  - Guidelines available on Canvas
- Contents:
  - Topic – What lecture's topic will you be examining?
  - Introduction – provide background information and motivation on the project topic
  - Research questions – what questions do you want to answer about your topic? Or what questions do you think need answering regarding your topic?
  - Related studies – provide a list of potential papers to review related to your topic

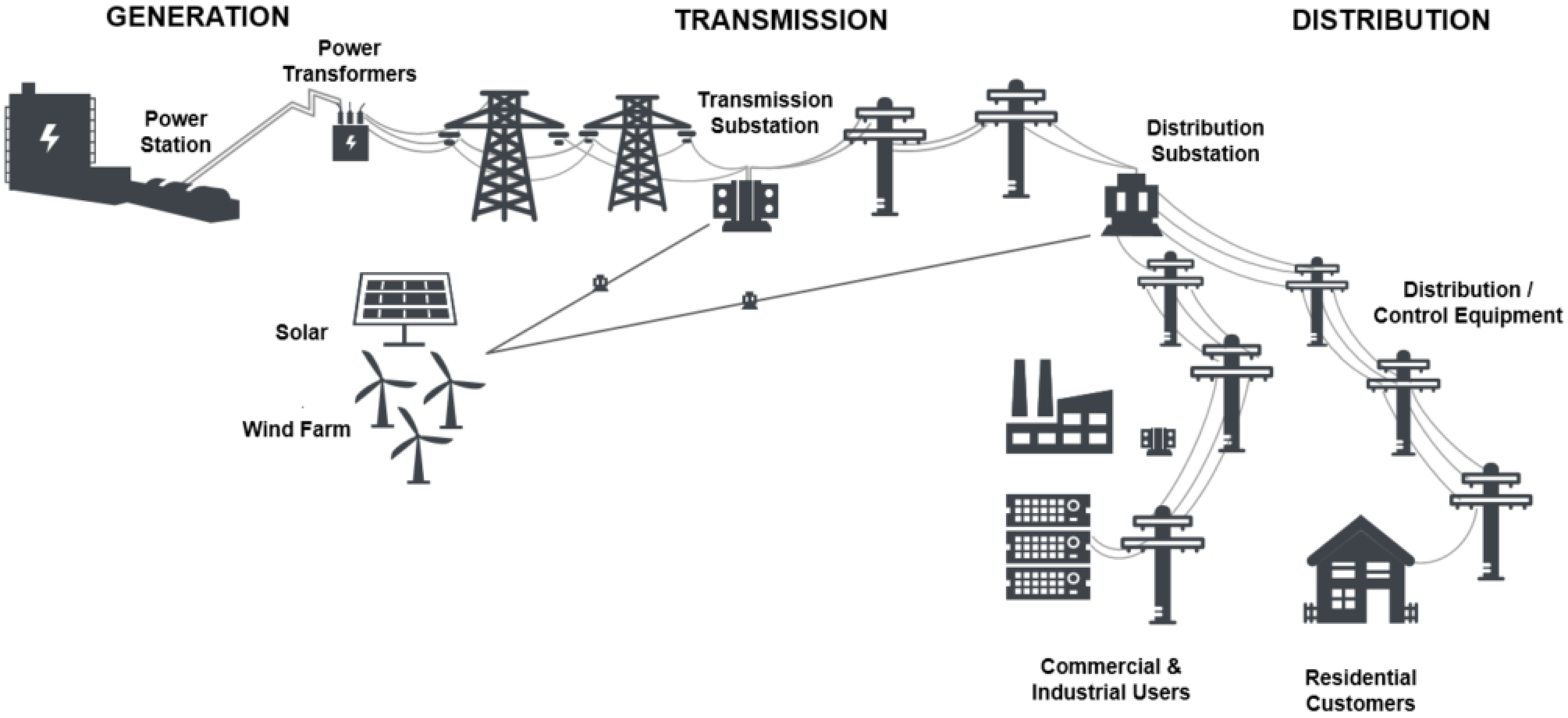
Electricity grid and use-phase emissions

ECI 189G: Lecture 11

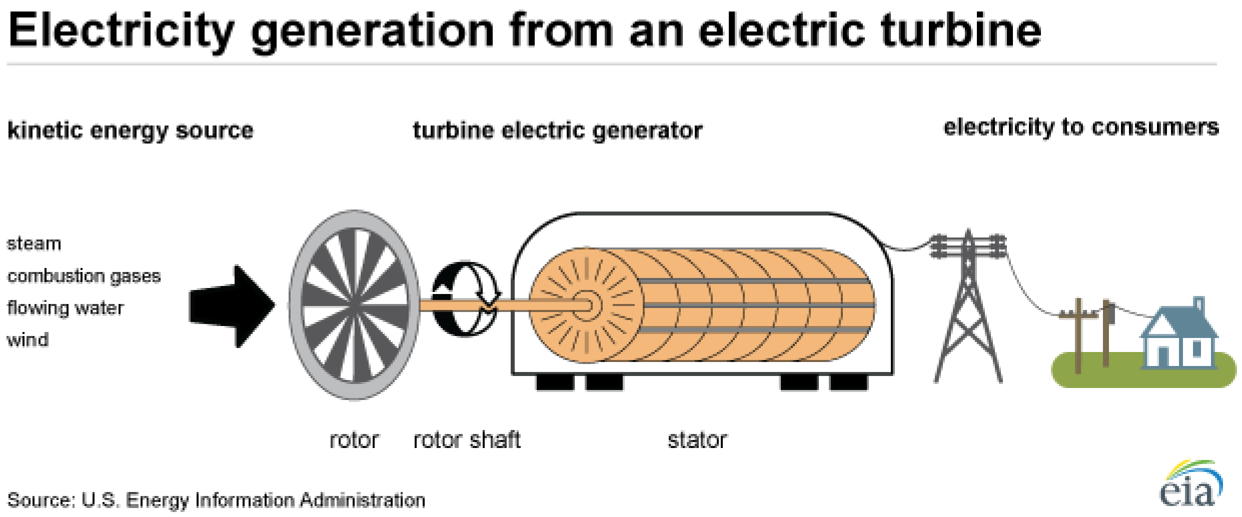
Dan Sperling
Alan Jenn
Spring 2022

What happens when you plug in an electric vehicle?

The electric power grid

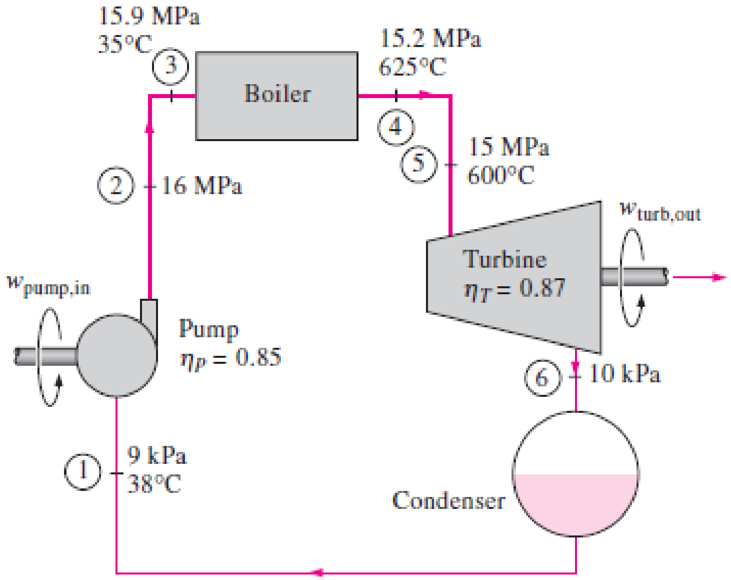


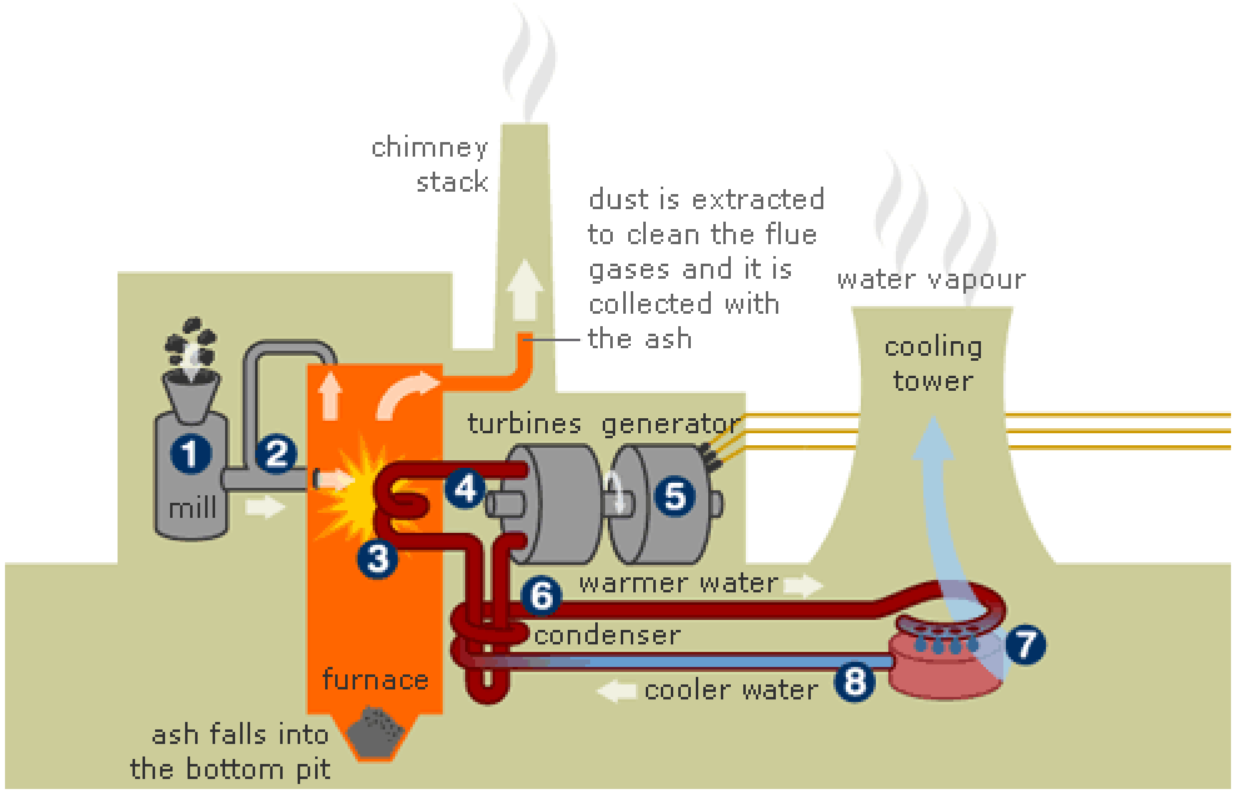
Electricity from turbines



- Remember how we generate electricity? Translating kinetic energy from spinning a turbine to produce electricity
- Nearly all electricity in the world is produced this way—whether the source is coal, natural gas, nuclear, wind, hydro (okay, not solar…)

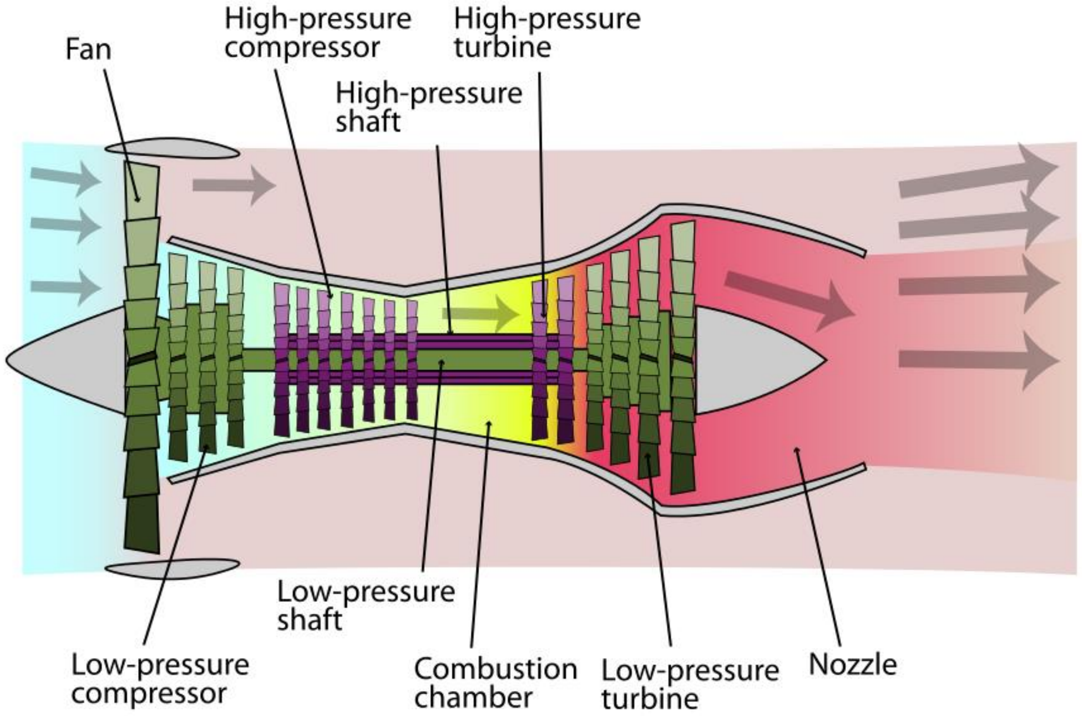
Steam turbines

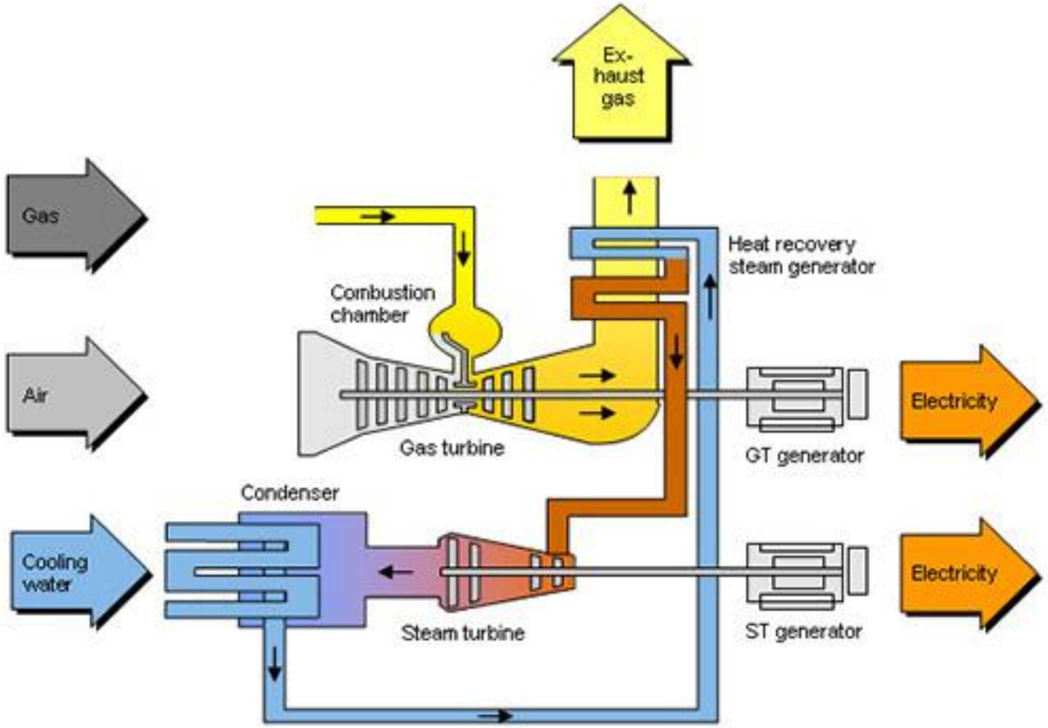




- Coal is combusted to heat water—as steam it spins a turbine to produce electricity
- The thermodynamic cycle for a steam turbine is known as a Rankine Cycle (about 35% efficient in practice)

Gas turbines and combined cycle

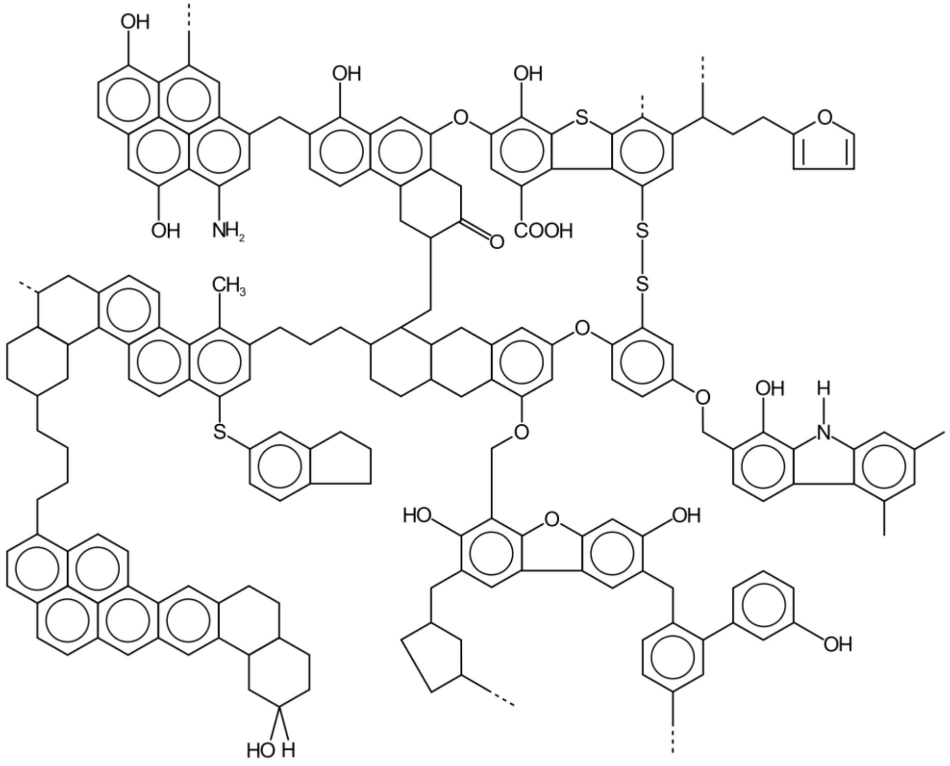




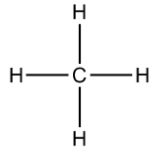
- Natural gas turbines combust the gas directly in the turbine to cause it to spin—thermodynamic cycle is called the Brayton Cycle (about 40% efficient)
- Heat from the Brayton Cycle can be combined with a steam turbine to increase efficiency (known as a combined cycle plant)

Fuels for combustion

Coal



Natural Gas



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*Impurities include: carbon dioxide, hydrogen sulfide, water vapor, oil, nitrogen, hydrates, hydrocarbons (ethane, propane, butane, pentane)

Fossil fuel combustion

$$C_nH_m + \left(n + \frac{m}{4}\right)O_2 \rightarrow nCO_2 + \left(\frac{m}{2}\right)H_2O$$

- Natural gas combustion is fairly straightforward:

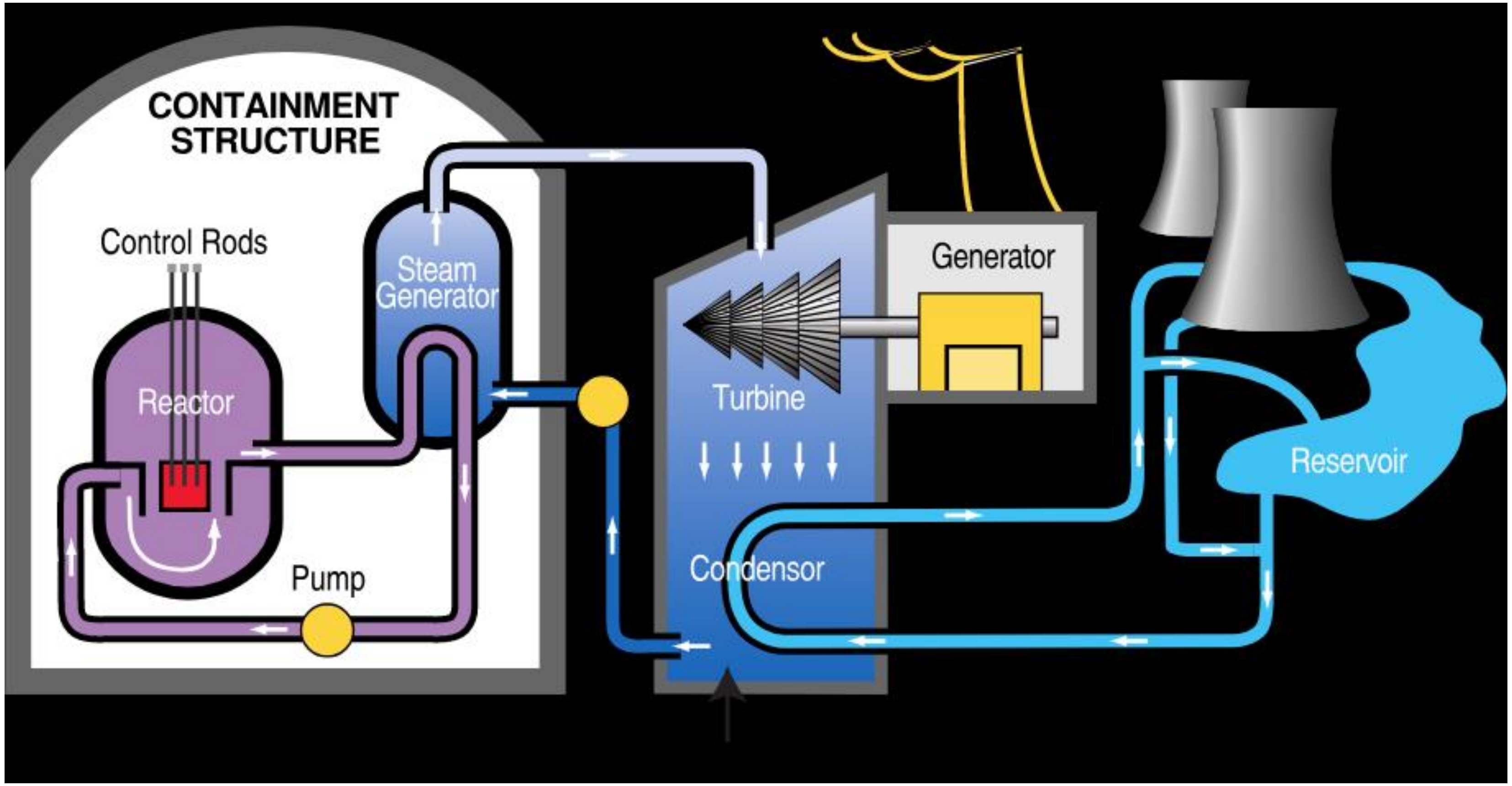
$$CH_4 + 2O_2 \rightarrow CO_2 + H_2O$$

  But impurities release nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), volatile organic compounds (VOCs), and trace amounts of sulfur dioxide (SO_2) and particulate matter (PM)

- Coal combustion is the opposite of straightforward.

  Impurities include solids: fly ash, flue-gas desulfurization materials, bottom ash, and boiler slag and gases: all of the compounds as seen in natural gas combustion with significantly higher sulfur dioxide, also contains mercury, arsenic, and heavy metals

Nuclear plant



- Mostly the same as coal plants, except water is heated via nuclear fission reactions within a reactor

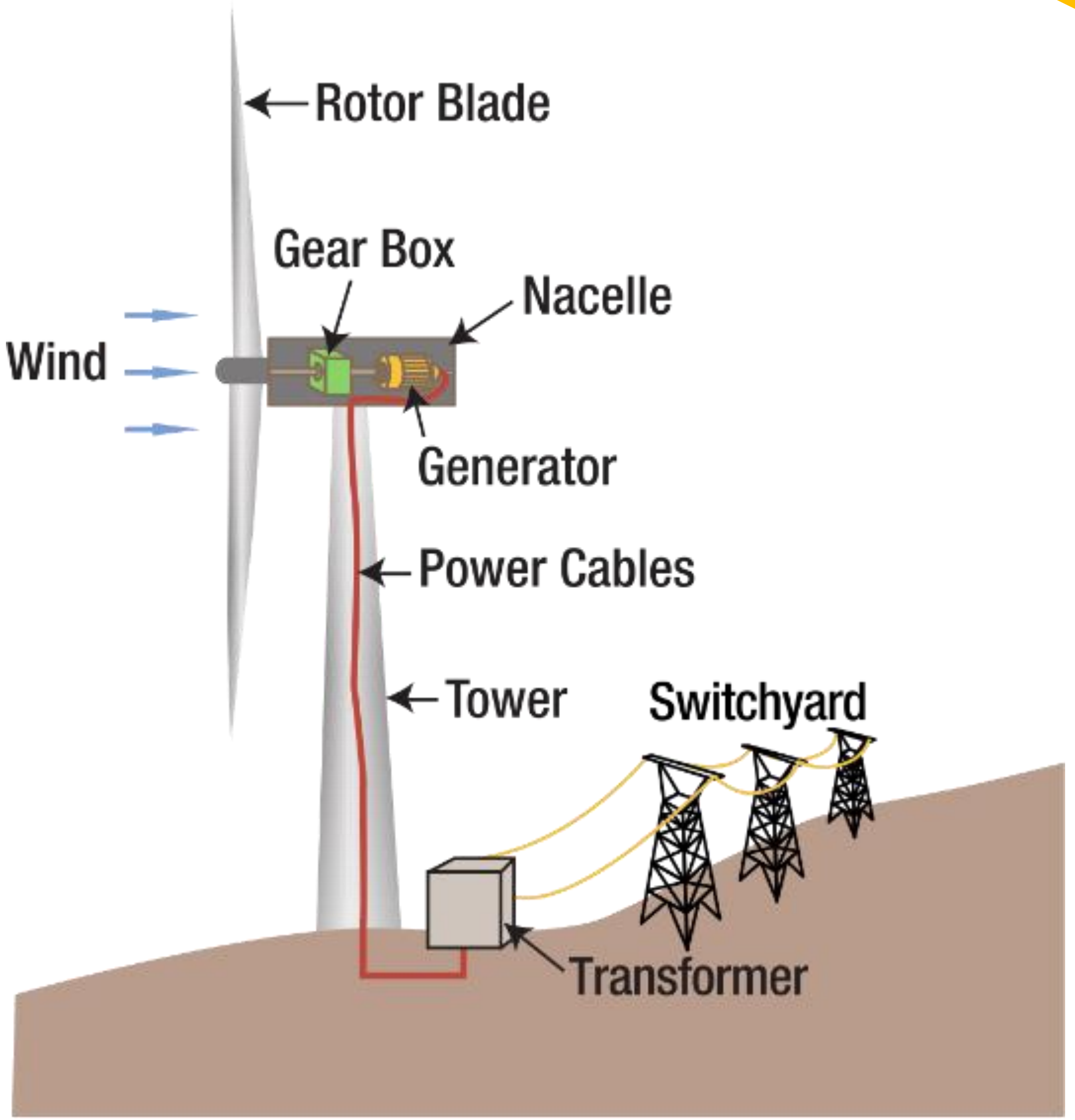
Nuclear fission

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{139}_{56}Ba + ^{94}_{36}Kr + 3^{1}_{0}n$$

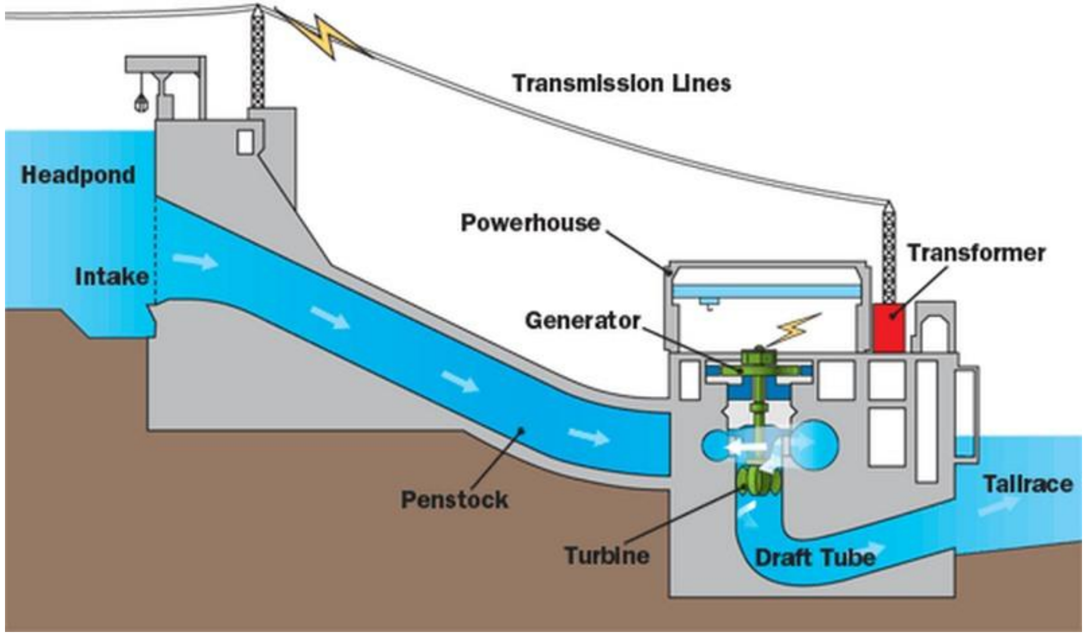
- Uranium-235 can be bombarded with neutrons to produce the above nuclear fission (splitting) reaction
- The reaction produces a tremendous amount of energy and 3 more neutrons—which can be used to produce a chain reaction
- 1 kg of Ur-235 can produce 24 GWh of energy! (Several million times more energy dense than coal)

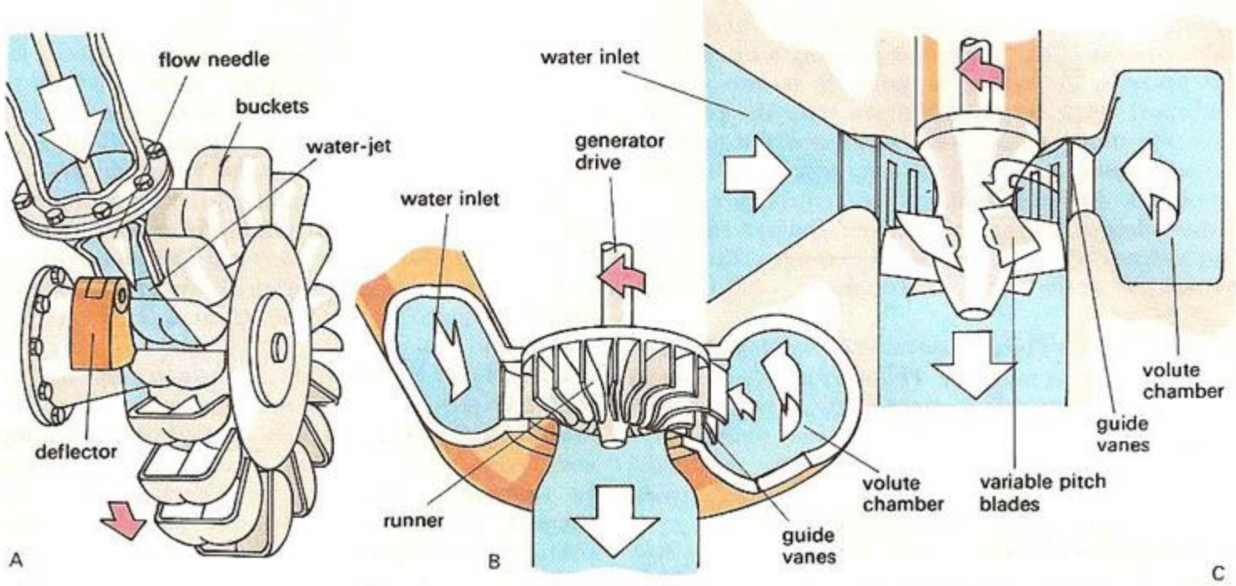
Wind turbines

- Maximum theoretical efficiency (Betz's Law): 59.3%
- Average efficiency: 35%-45%
- Height of turbine needed because wind speed is higher at greater elevation from the ground
- Diameter of modern-day turbines can exceed the length of a football field!



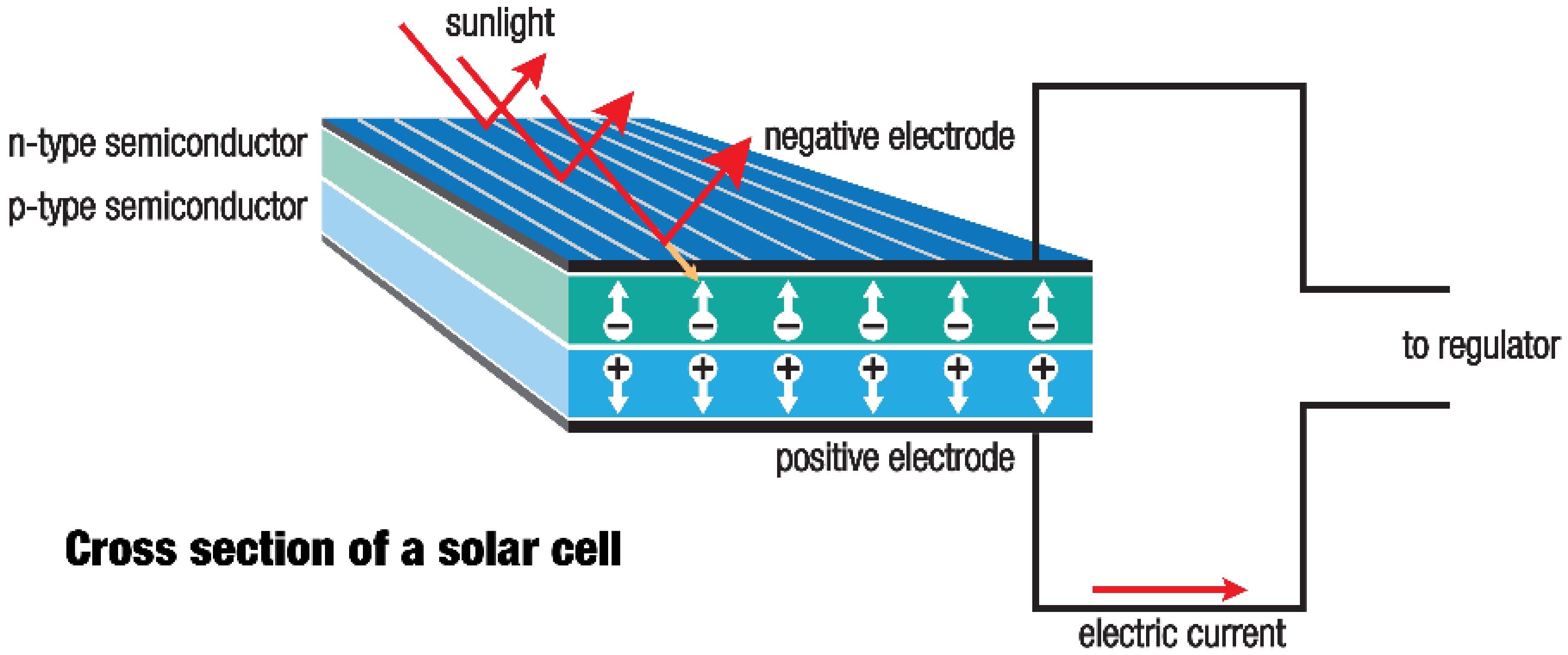
Hydro turbines





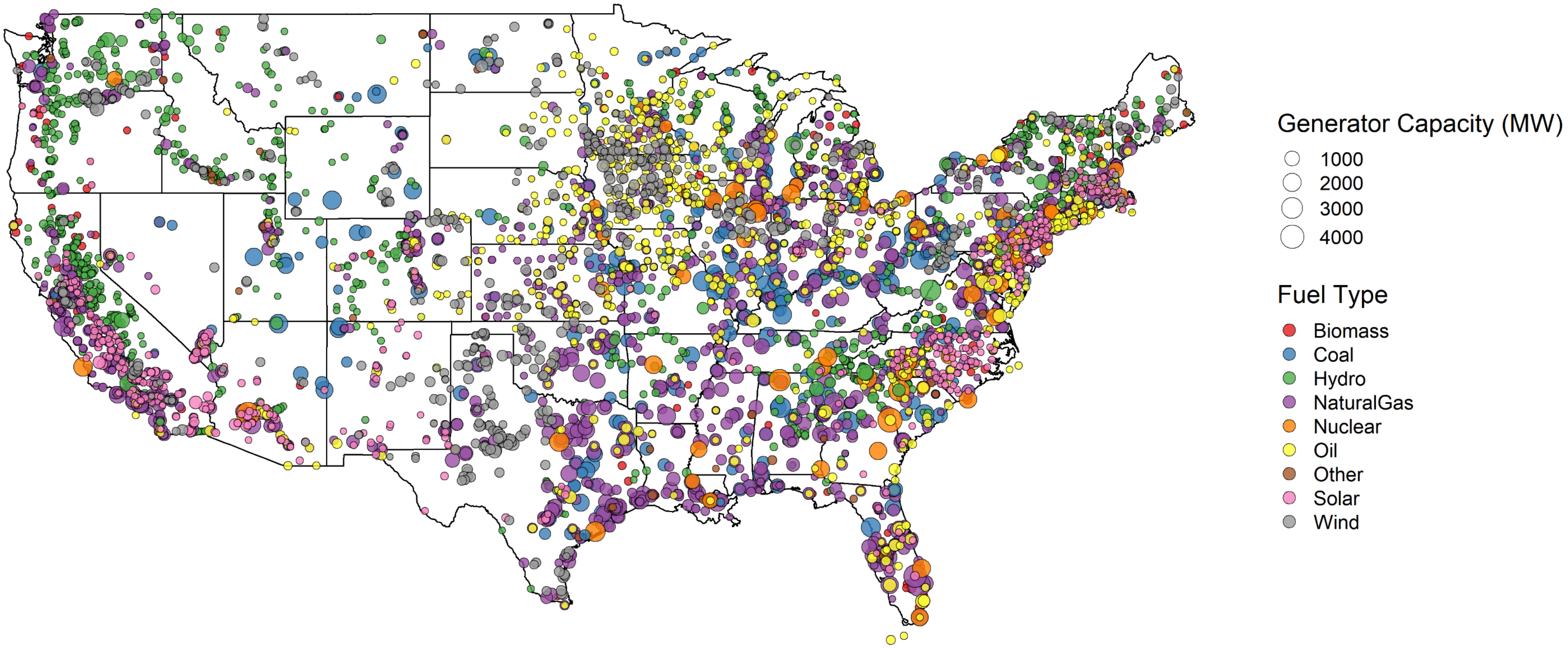
- Hydro turbines exploit the potential energy stored in water due to the height differential between the top and bottom of the dam
- A variety of turbine designs exist depending on the flow rate and height difference of water flowing through the turbine

Electricity from solar photovoltaic panels



Cross section of a solar cell

Power generators in the US



Dispatch game

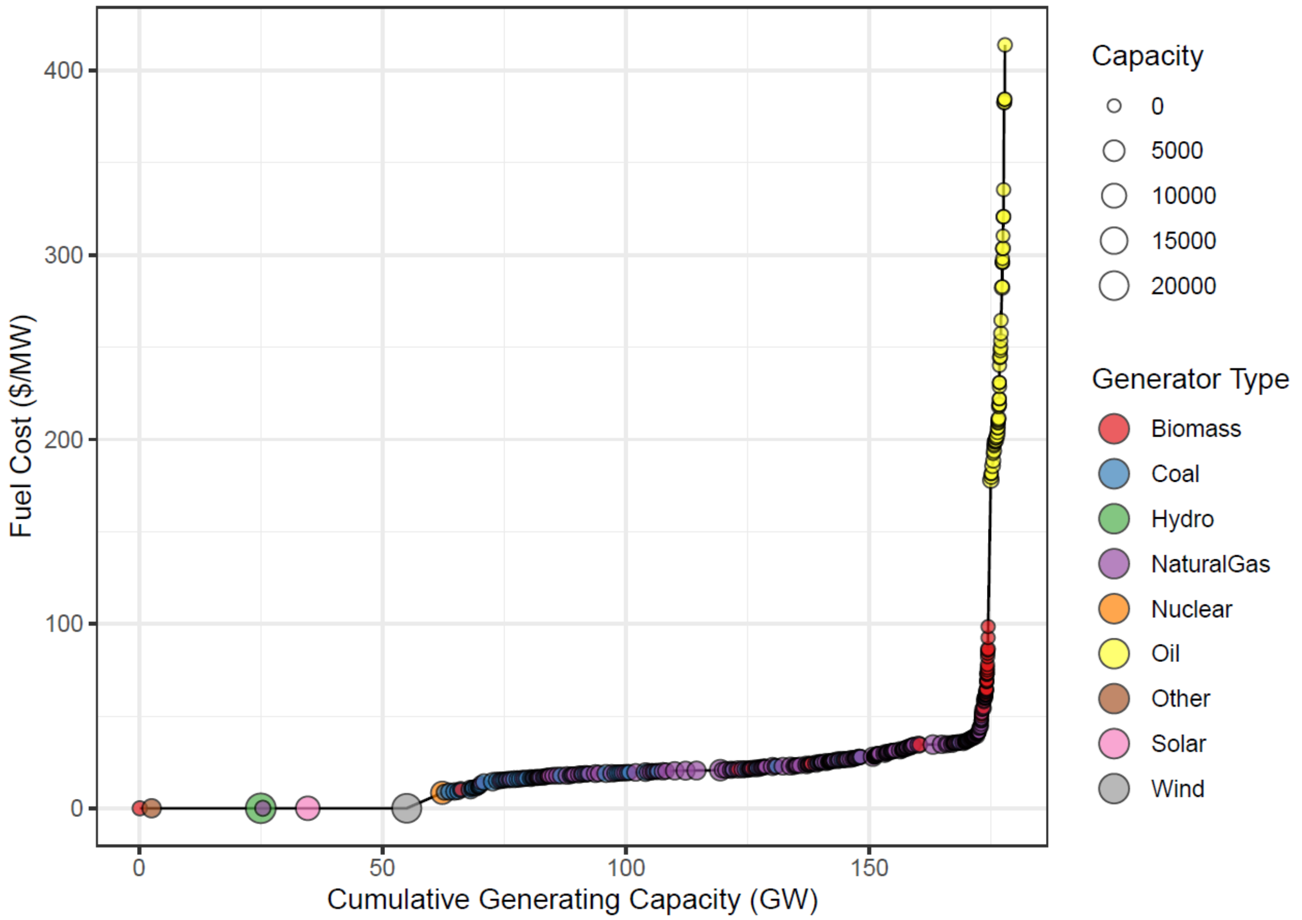
- Everyone gets a power plant that can produce some amount of power (**capacity**) and has a corresponding **fuel price** (each unit of power you sell costs you this much to generate)
- Your goal is to *make as much money as possible*, you do this by selling as much power as you can produce
- You cannot communicate with other people! (anti-monopoly rules!)
- I am the independent system operator (ISO), I choose which power source to buy from

Dispatch game: Auction rules

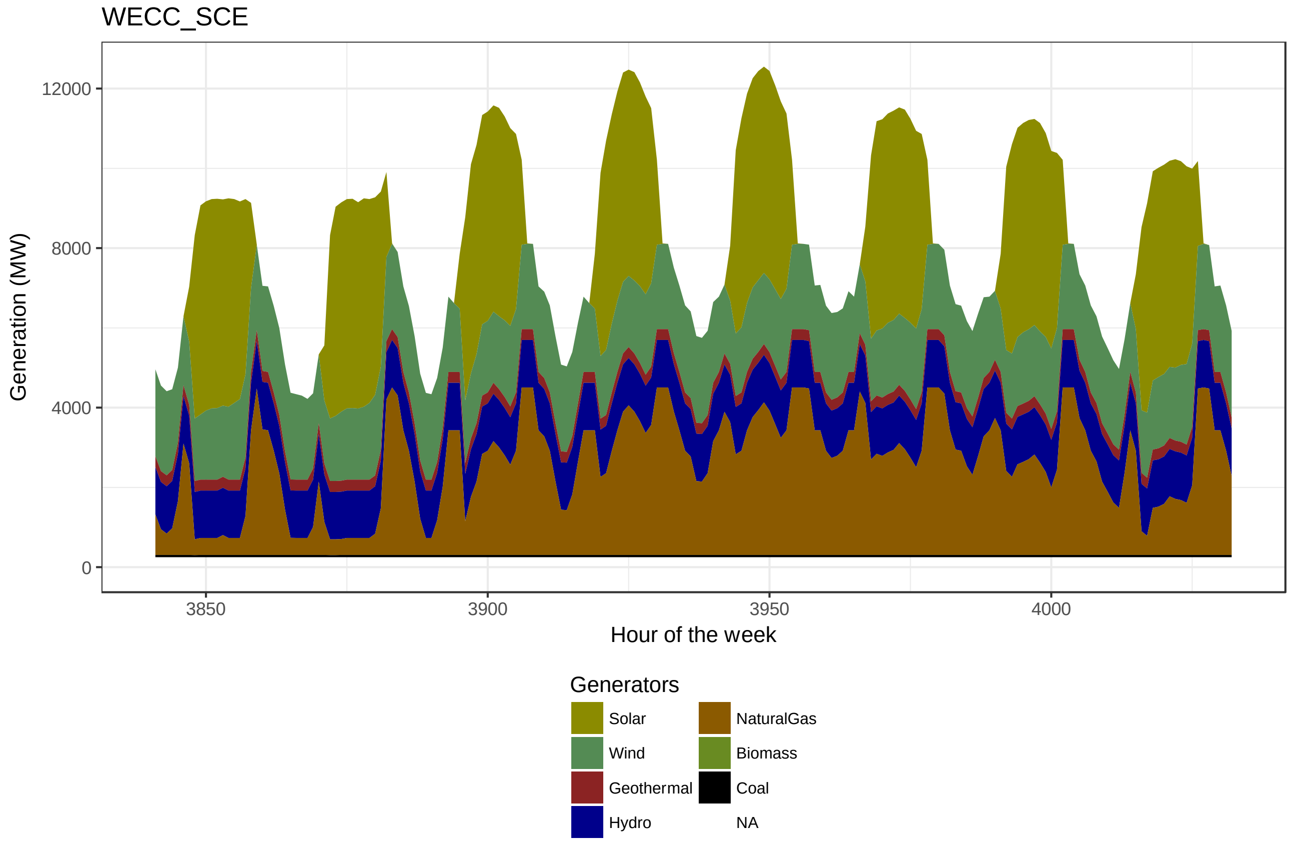
1. Write down a price on a piece of paper, this represents your bid into the market.
2. I need to provide **X** amount of electricity to fulfill demand, I will choose to turn on the power plant that provides me power at the cheapest price.
3. I will continue turning on power plants until I get all the power I need.
4. Once I have fulfilled all the demand, all power plants get paid **the amount of the *highest* bid into the auction**.

Dispatch of electricity

- Turn on generators from left to right until you have enough electricity to meet all demand
- The money paid to any generators that “turn on” is based on what the system pays the “last” generator to be dispatched
- Generators bid into the system based on how much it costs them to produce electricity

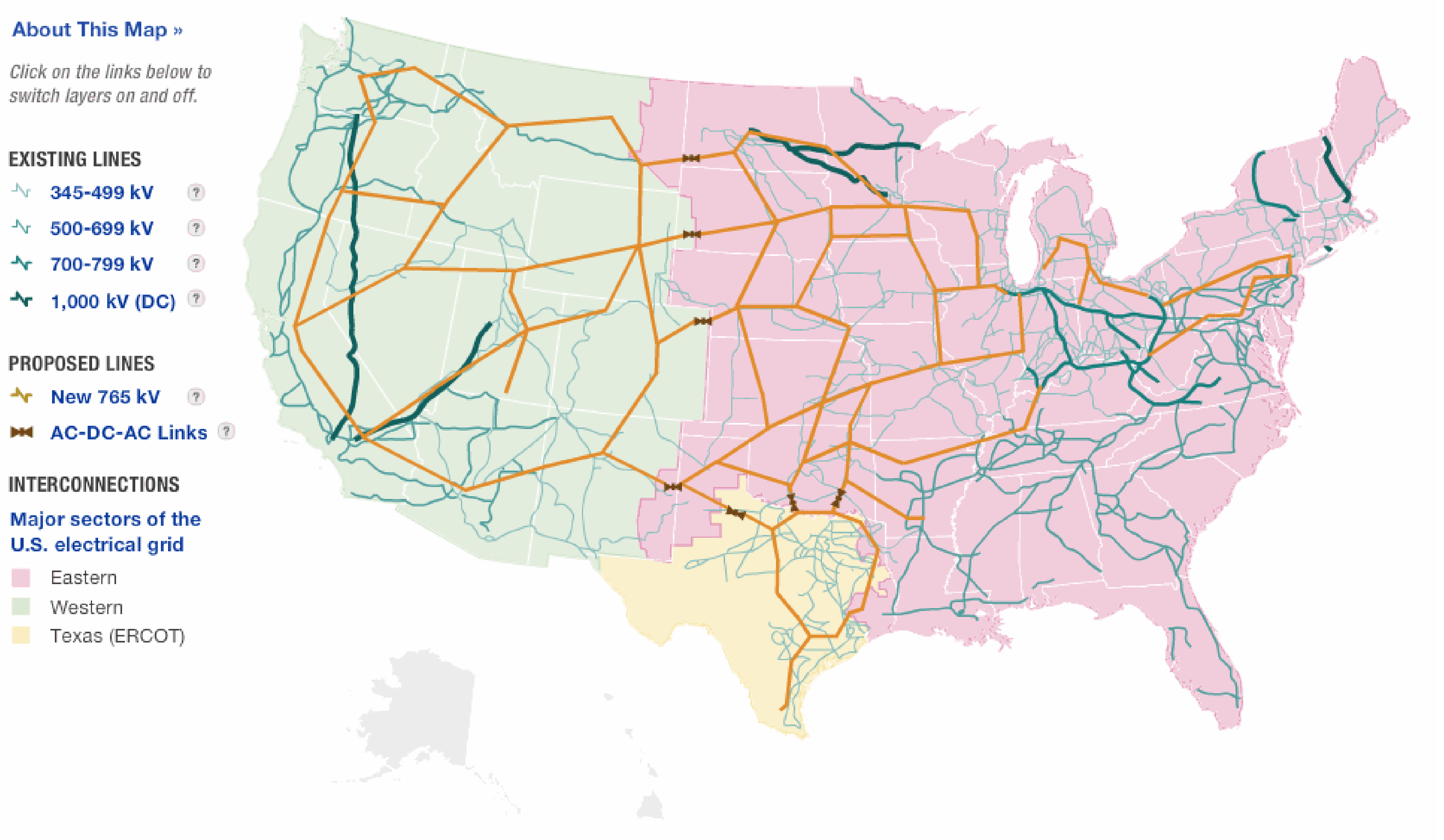


An example 1 week dispatch curve in LA



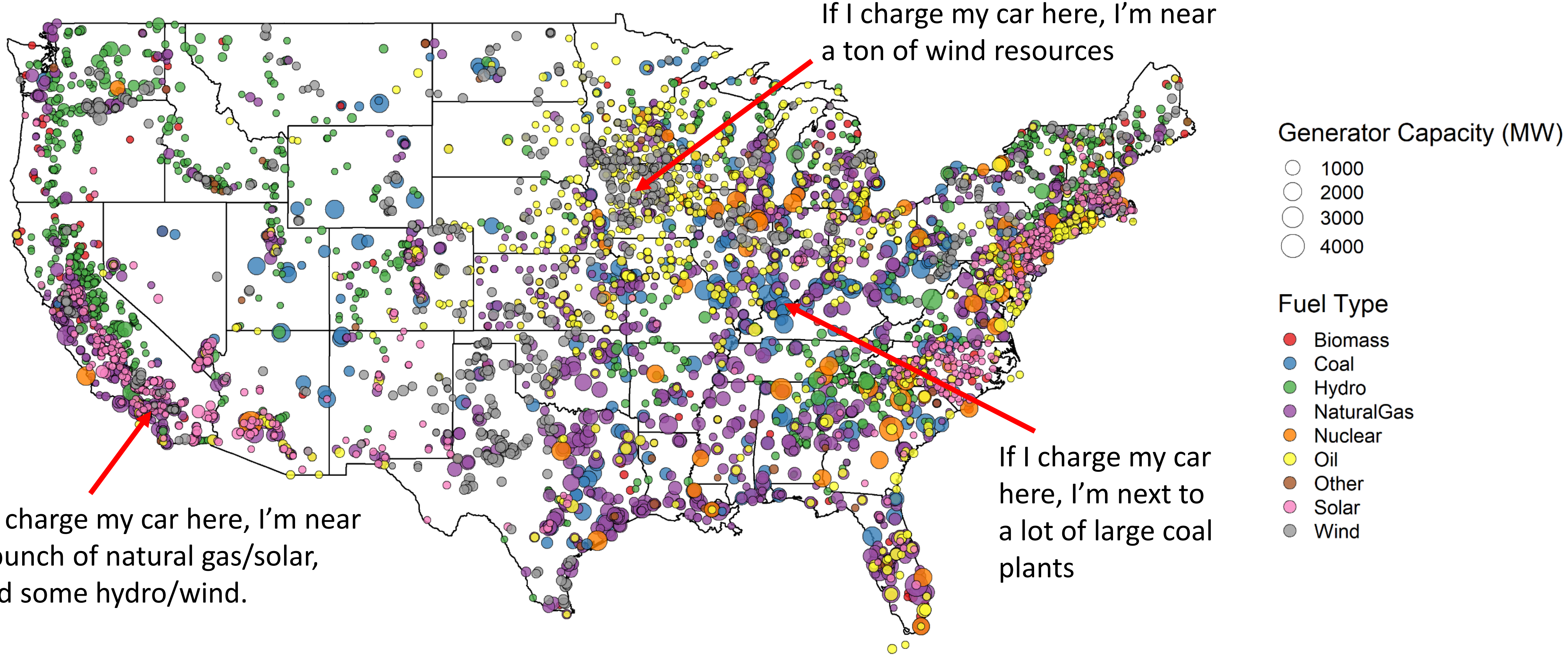
- Fluctuations day to day correspond to changes in demand for electricity over the course of a day
- High usage of solar (day) and wind (night) in the region
- Large fluctuations with natural gas generation to deal with intermittency

Major transmission lines in the US



Locational factors of charging

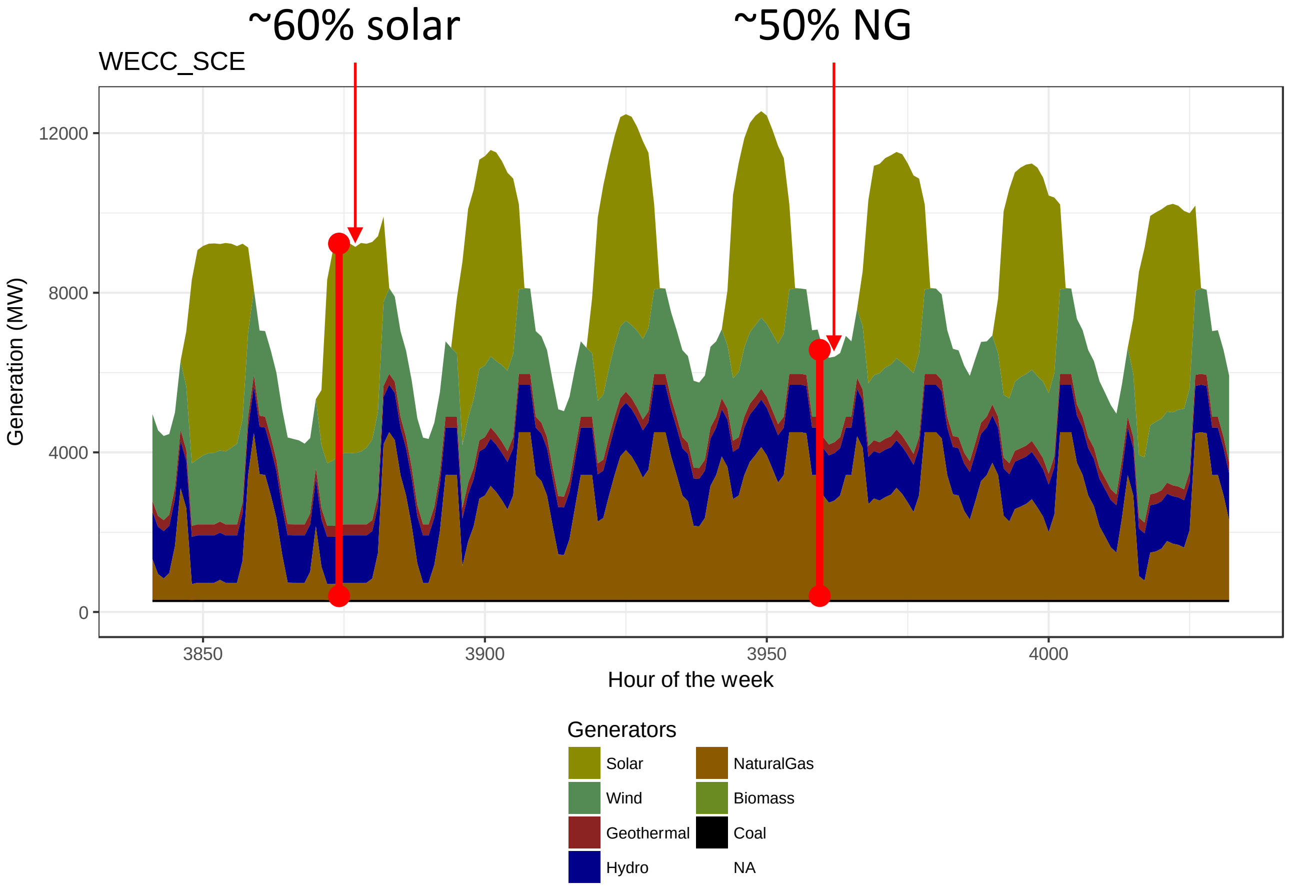
If I charge my car here, I'm near a ton of wind resources



If I charge my car here, I'm near a bunch of natural gas/solar, and some hydro/wind.

If I charge my car here, I'm next to a lot of large coal plants

Timing factors of charging



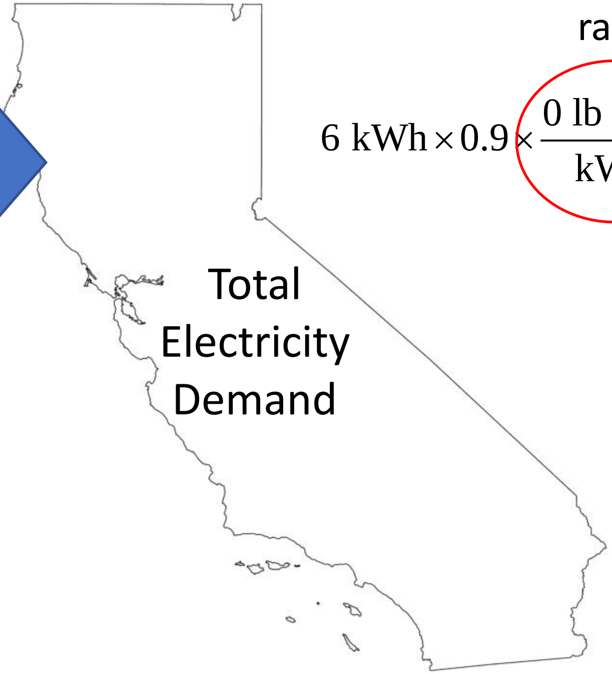
- In Los Angeles:
  - If a vehicle charges in the middle of the day, the proportion of power from solar is substantially higher
  - If a vehicle charges at nighttime, the proportion of power from natural gas is substantially higher
- This effect will differ depending where in the country you are charging

Calculating emissions from EVs

- It’s 3 PM in Davis, I charge my car @ L2 for 1 hour.

90% from solar

10% from NG



Solar emissions rate

NG emissions rate

$$6\text{ kWh} \times 0.9 \times \frac{0\text{ lb CO}_2}{\text{kWh}} + 6\text{ kWh} \times 0.1 \times \frac{1\text{ lb CO}_2}{\text{kWh}}$$

$$= .6\text{ lb CO}_2$$

Average Emissions Rate (attributional)

Calculating emissions from EVs

- It's 3 PM in Davis, I charge my car @ L2 for 1 hour.

On average:

90% solar

10% NG

Still room to ramp up

Fully "on", nothing left to increase

But when I plug in my car:

Natural gas plant is what ramps up to meet the load

New emissions calculation:

NG emissions rate

$$6 \text{ kWh} \times \frac{1 \text{ lb } CO_2}{\text{kWh}} = 6 \text{ lb } CO_2$$

Exact same situation, *TEN* times higher emissions depending on how we decide to count it!

Marginal Emissions Rate (consequential)

What is smart charging?

For a single car:

I receive some signal that tells me to charge earlier in the day

In aggregate:

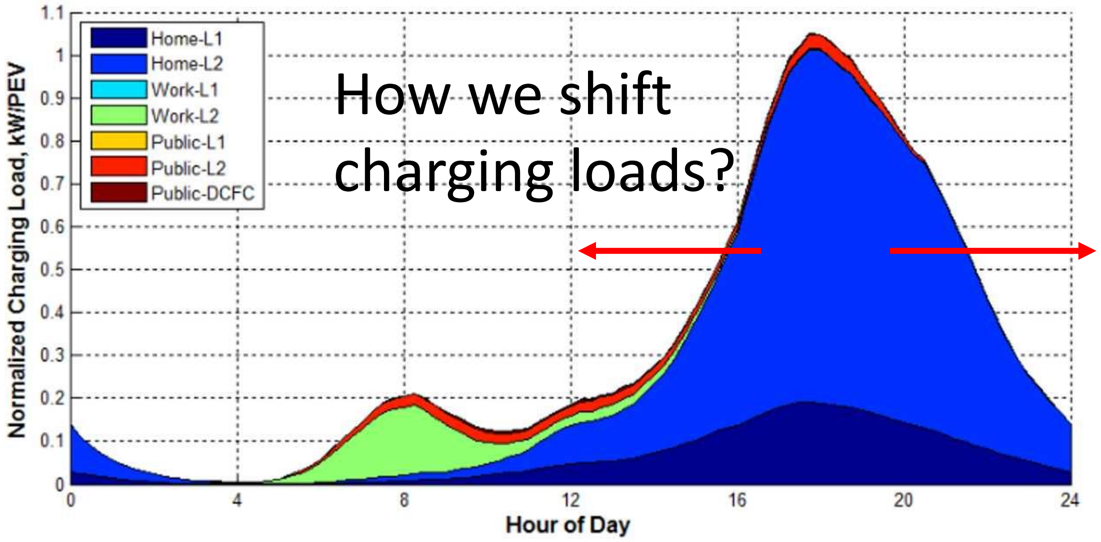
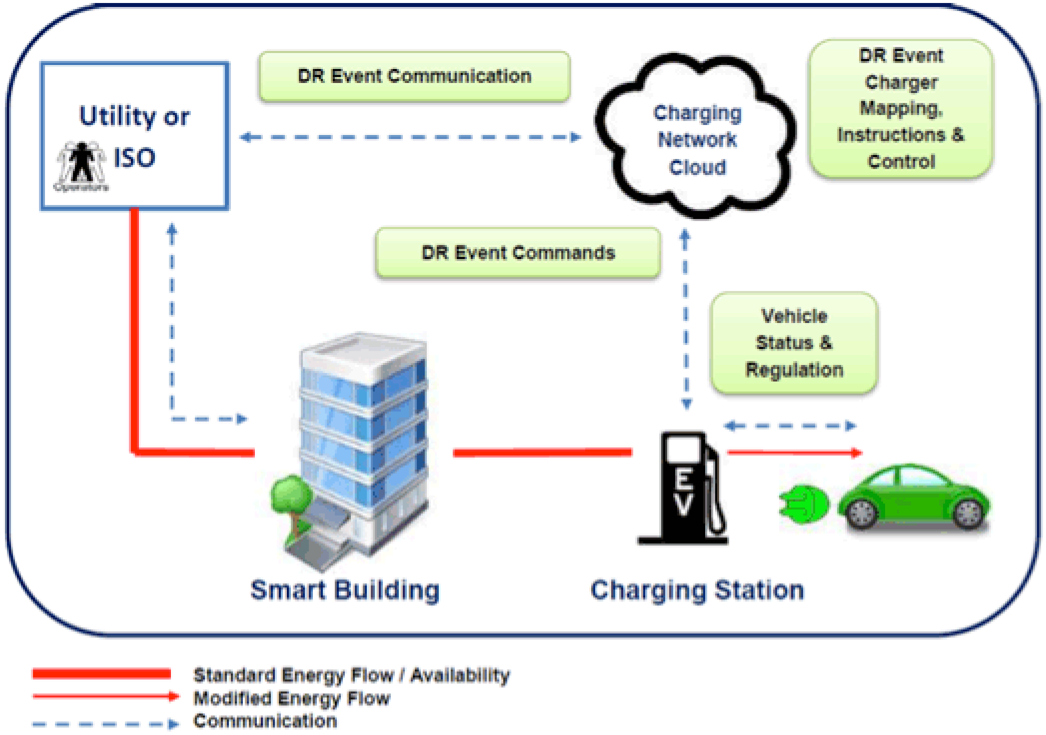


Figure 7. Nominal charging load profile from EVI-Pro simulations (home dominant charging behavior).

- Why would we do this? Shifting charging behavior in order to:
  - Charge when its cheaper
  - Charge when its cleaner
  - Reduce stress on grid infrastructure (capacity, ramping, etc)

Example schematic of managed charging for demand response



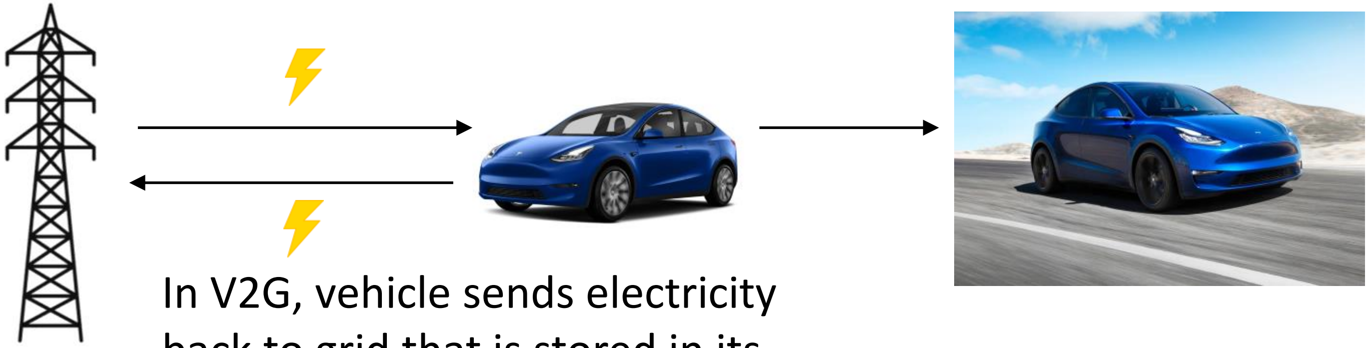
Challenges with smart charging

- Technical challenges:
  - What sort of external “signals” would be used and how would this be communicated to the vehicle?
  - Which factors should smart charging try to address? All of the above?
  - Cooperation among different automakers to standardize procedures
  - Hardware to support managed charging
- Behavioral challenges:
  - How will customers be convinced to participate?
  - Taking control of charging out of the customers hands!

What is V2G?

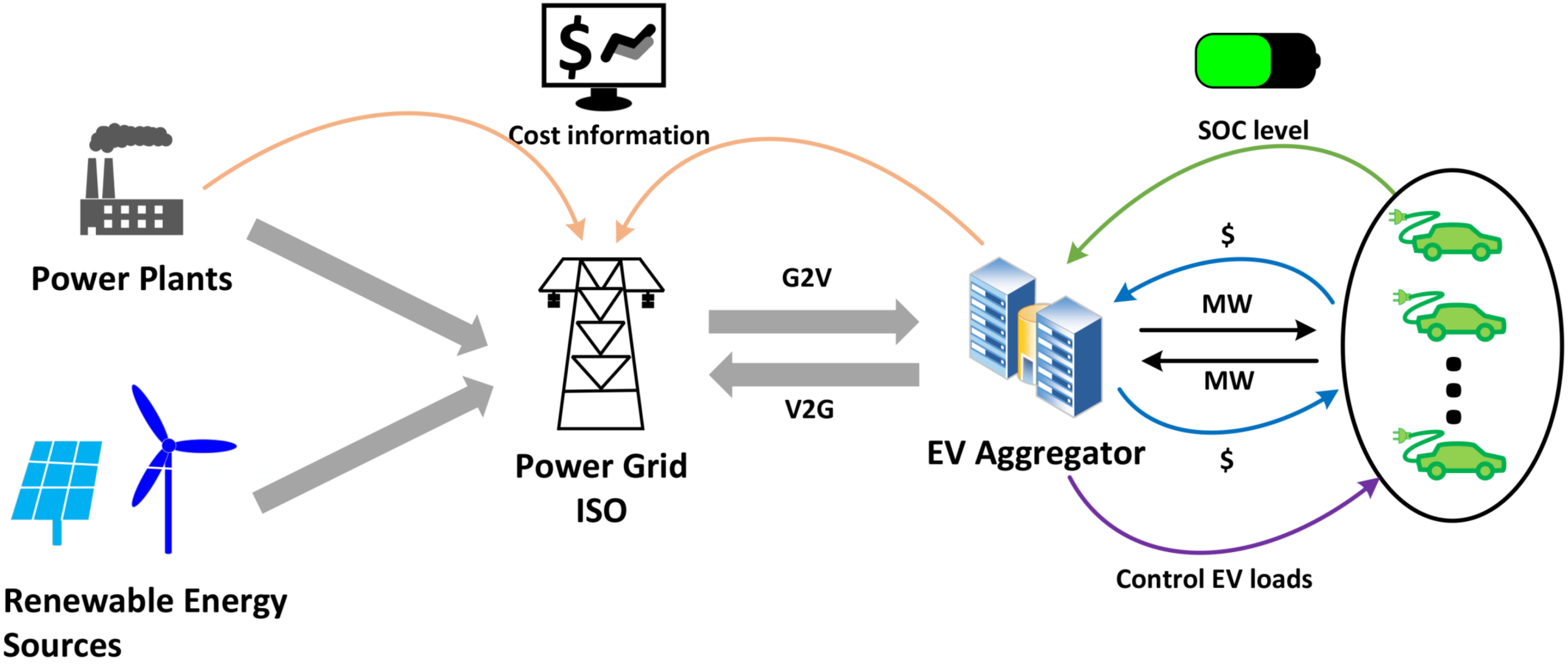
- V2G stands for “vehicle-to-grid”: this involves any scheme where electric vehicles *discharge* electricity back to the grid

The electric vehicle can be thought of as a large storage asset

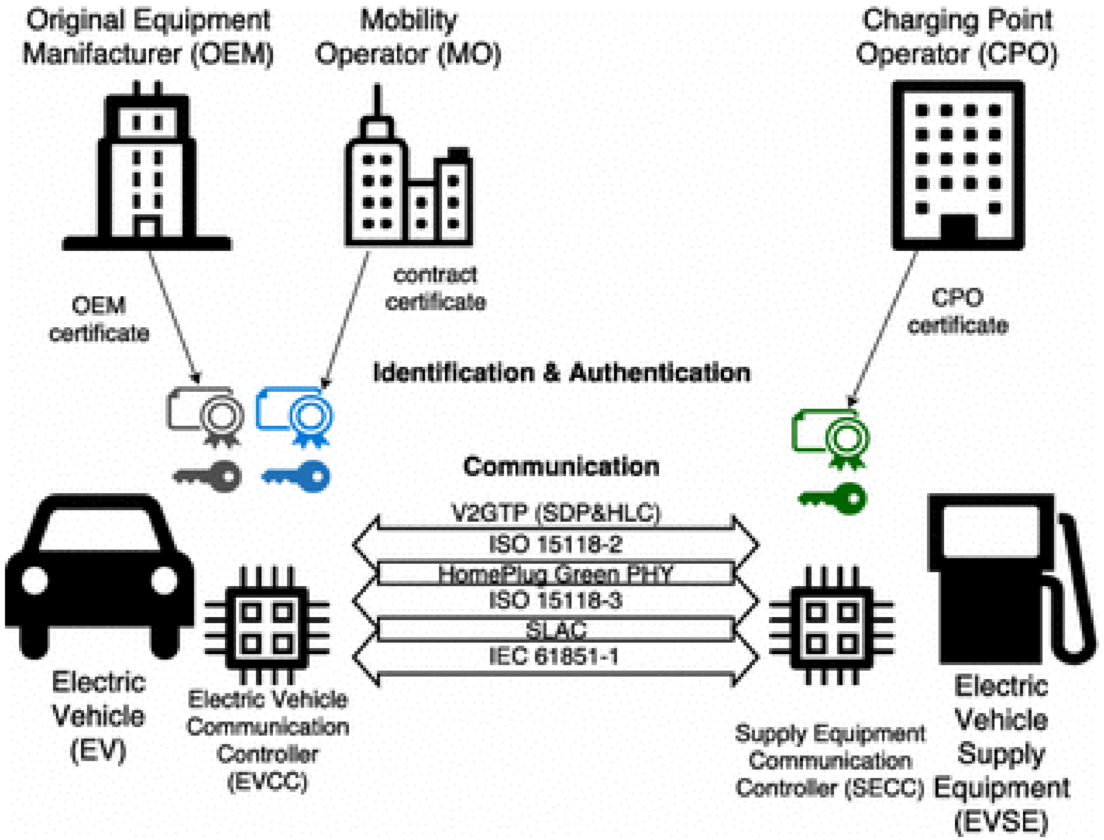


In V2G, vehicle sends electricity back to grid that is stored in its battery

Example of energy arbitrage with V2G



ISO 15118 Protocol



Tremendous potential for storage

- California plans to have 5 million EVs on the road by 2030. Let's roughly assume 50 kWh batteries per vehicle on average.
  - 1% of all EVs plugged into DC fast chargers discharging = 2.5 GW instantaneous capacity
  - 50% of all EVs plugged into L2 discharging = 16.5 GW instantaneous capacity
  - Total battery capacity: 250 GWh
- For reference:
  - CA currently has ~1.4 GW storage capacity
  - Peak load in California: ~50 GW
  - Daily electricity usage in California: ~700 GWh