

Lecture 6: What can be done?

Learners: Climate Redux

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Jonathan F. Ormes

JFOrmes@gmail.com

What can an individual do?

- Vote climate
- Reduce your own carbon footprint
 - Drive and fly less
 - Eat low on the food chain (e.g. minimize cattle and hogs)
 - Buy local
 - Solar energy and home insulation
- Help plant trees (A billion needed globally)
- Support environmental organizations
 - Nature Conservancy
 - Sierra Club
 - Environmental Defense Fund
- Citizen's Climate Lobby
 - Bi-partisan for Carbon "Fee and Dividend"

Deniers, skeptics, believers, etc.

- Strange words these, to a scientist
- Science Denier: One who does not accept as true the consensus opinion of most of the scientific community.
- Skeptics: all good scientists are skeptics
- Scientists don't "believe" in a theory.

Once a theory is well established and verified by experiment or observation, we usually behave as if it is true and assume so in doing our work. But we always keep in the back of our mind that it might not always be true. Most scientists dream of the fame and glory that would come from disproving a commonly accepted paradigm.

THE CLIMATE CHANGE DENIER'S PLAYBOOK

YESTERDAY

IT'S **ALL**
A HOAX.



TODAY

IT'S TOO
COSTLY TO DO
ANYTHING.



TOMORROW

IT'S TOO
LATE TO DO
ANYTHING.



Tragedy of the Commons

The atmosphere is a global commons

- Use of the commons works only if regulated.
- We pay to put solid trash in a landfill
- We pay to put liquid waste in a sewer
- We don't pay for our gaseous wastes

Topics for today

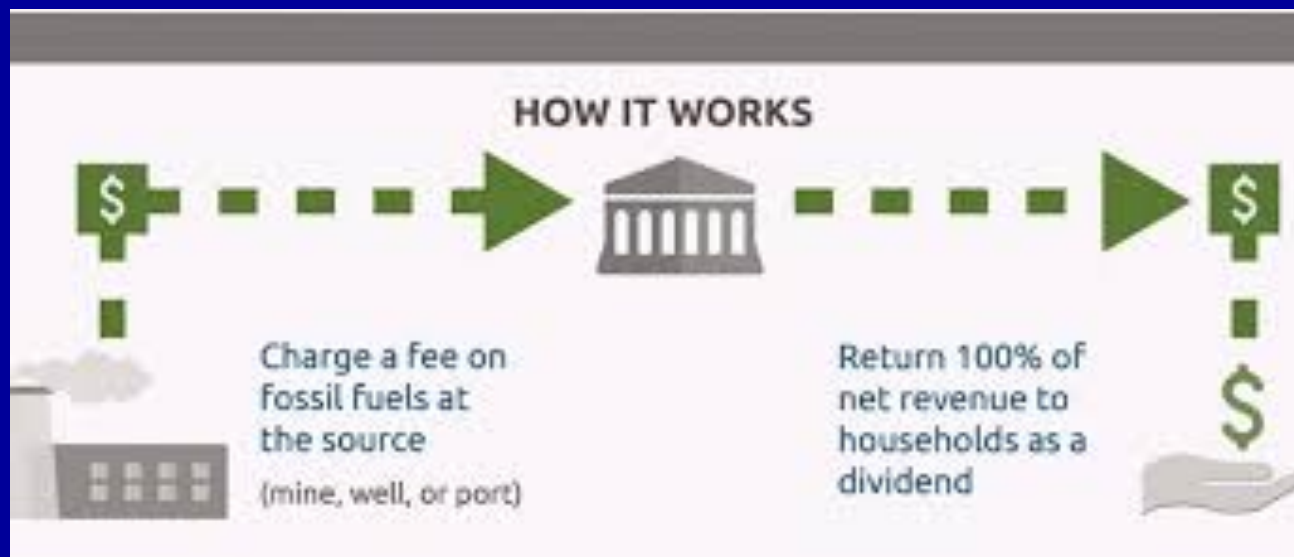
What can be done? Ans: lots

- Carbon Fee and Dividend Act
- Climate Actions
 - Adapt, Modify, Ignore
- Electrify transportation
- A potpourri of solutions

Carbon Fee and Dividend

Citizen's Climate Lobby in US

<https://citizensclimatelobby.org>



Political fights over use of Dividends



Collect fee
\$15 per ton of
CO₂ at wellhead
or port of entry
[fee rises \$10/yr]



\$\$\$

U S Dept. of the Treasury: Trust Fund

All monies returned to households
1 share per adult
0.5 shares per child <18yrs
maximum 3 shares per family





Net + \$



Net - \$



Net +\$

2 of 3 households have net gain of \$.

CO₂ emissions are reduced

Renewable energy is stimulated.
Market will choose the best.



Energy Innovation and Carbon Dividend Act

Nonpartisan: paired sponsors
H. R. 763

Rumors from WSJ that big energy will endorse.

You can see the details here;

<https://www.congress.gov/bill/116th-congress/house-bill/763>

Omnibus bill just passed

- promote technologies to “capture” and store carbon dioxide produced by power and manufacturing plants;
- reduce diesel emissions in buses and other vehicles;
- authorize a 15-year reduction of hydrofluorocarbons

Strategies

Mitigate: Prevent problem by intervening to reduce the *sources* or *enhance the sinks* of greenhouse gases

Climate Intervention

Increase understanding:

- **Research:** measure and model
- **Technology development**

Adapt: Technology fixes everything. Adjust in response to actual or expected climatic stimuli or their effects

Do nothing: There is no problem.

Mitigation

- **Wind energy**
- **Solar cell energy**
- **Solar power plants**
- **Nuclear power**
- **Energy storage**
- **Geothermal**

Adaptation

- **Electric cars**
- **Paint roofs white**
- **Recycle, reuse, repurpose**
- **Dikes, sea walls, artificial reefs, pumps**
- **Buy boat and generator**
- **Put home on stilts**
- **Migrate; move north, buy sweater**

Ethanol

- From corn in the USA
 - Growth and processing cycle emits more CO₂ than gasoline: 5%-10%
- From sugar cane in Brazil
 - Net gain in CO₂; - 30-40%
- Cellulosic ethanol in the USA
 - High expectations: hemp, switchgrass, Carrizo Cane
 - Life cycle CO₂ under study (claims 5 x better)

De Oliveira, 2005, Vaughan and Rykiel, BioScience, 2005, **55**, 593.

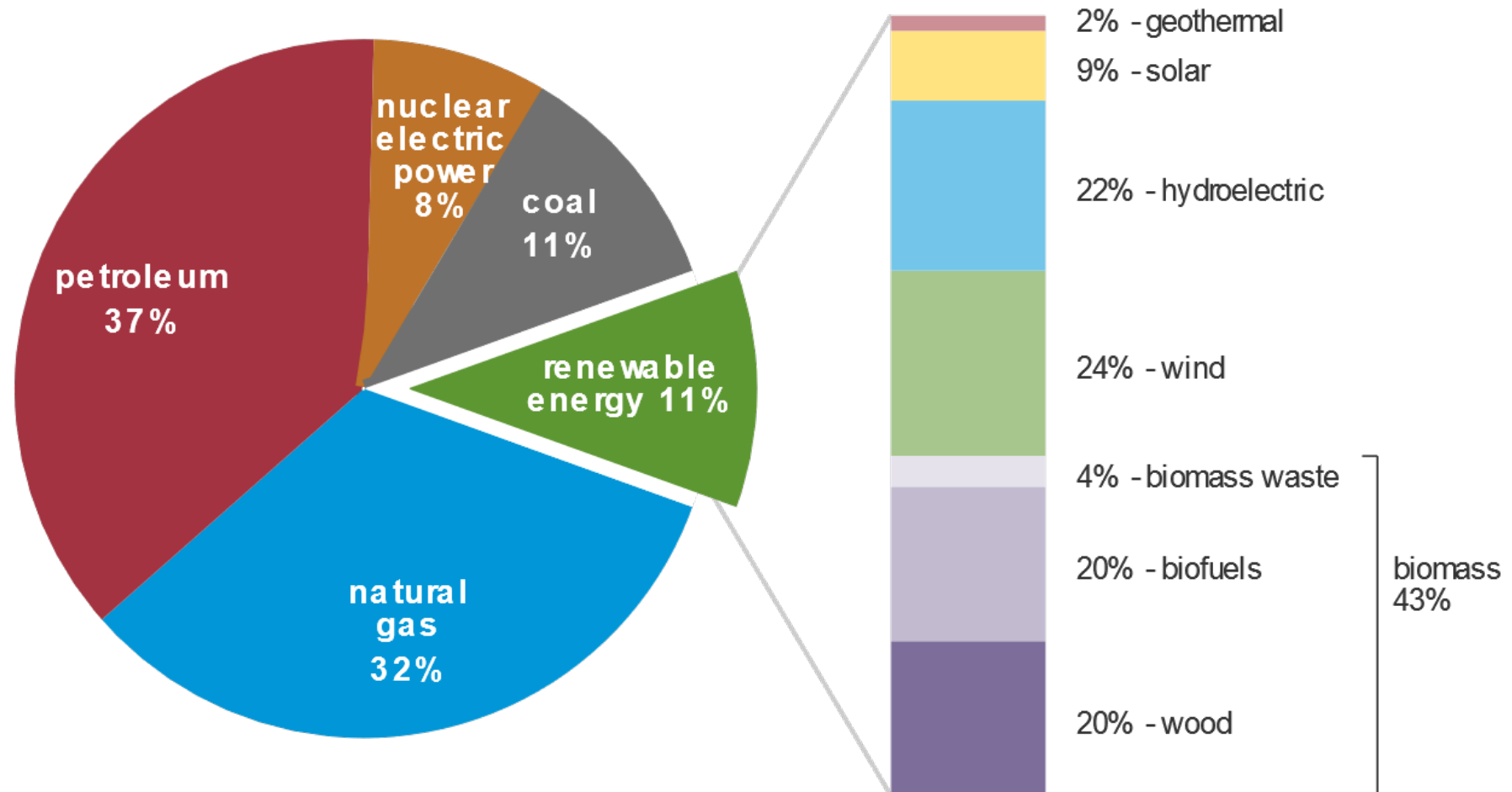
Jones, D.L. 2020, Air & Waste Management Assoc. **60**, 1118.

Smithsonian Magazine: Barth, 2017

U.S. primary energy consumption by energy source, 2019

100 Exa Joules

11 Exa Joules



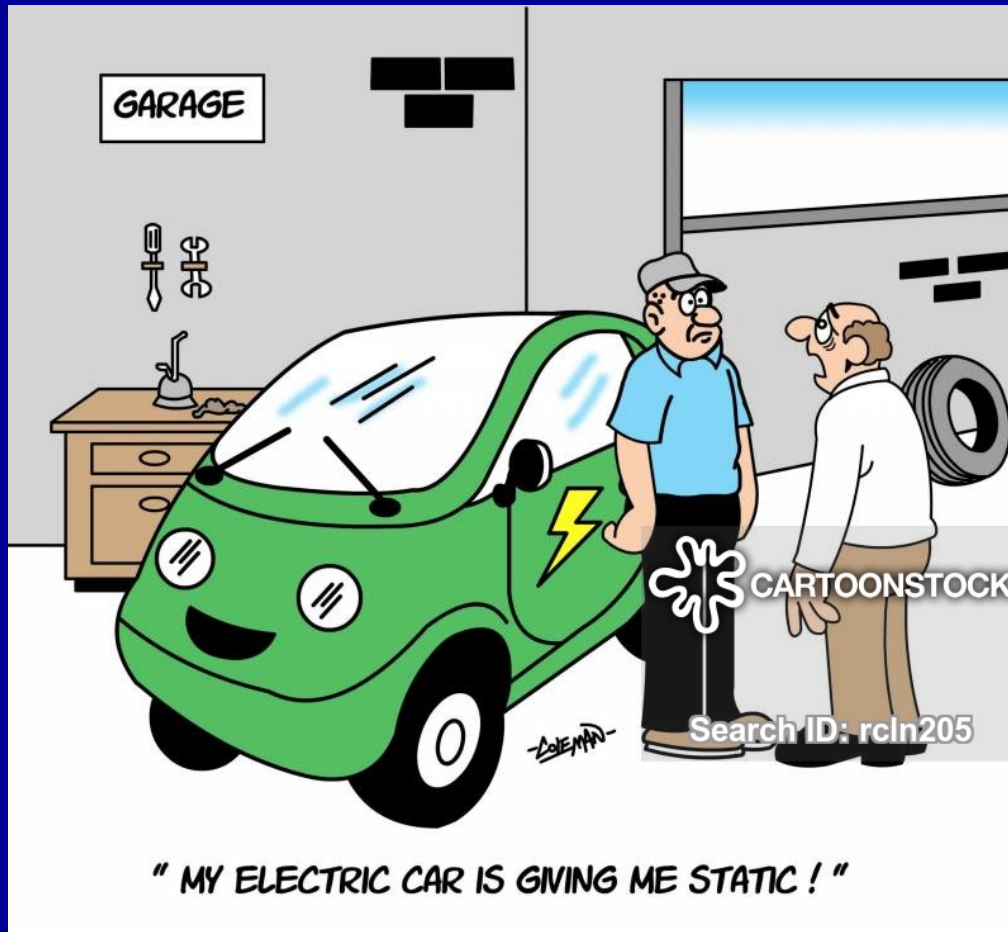
Note: Sum of components may not equal 100% because of independent rounding.

Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2020, preliminary data



WHAT ABOUT ELECTRIC CARS?

They run on electricity.
It depends on what make the electricity.



Advantage
less servicing

The move to EVs

- Federal government fleet
- Colorado initiatives
- Xcel
- Requires abundant CO₂ free fuel

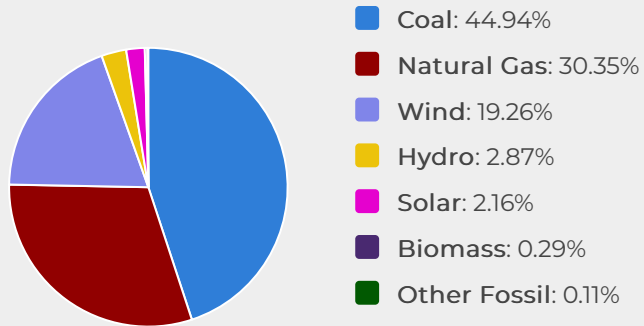


Types of electric vehicles

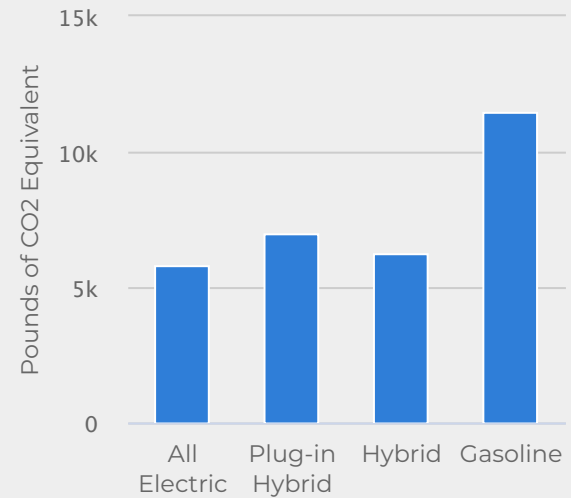
- BEV: battery electric vehicle (no gas)
- PHEV: plug-in hybrid EV
- HEV: some power regenerated by the car itself, mostly powered by gas

State Averages for Colorado

Electricity Sources

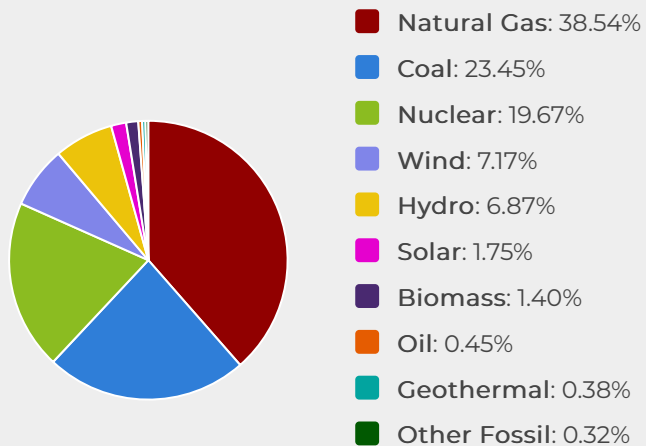


Annual Emissions per Vehicle

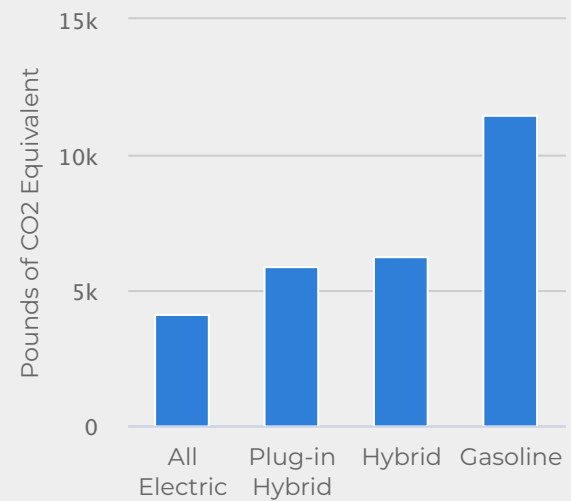


National Averages

Electricity Sources



Annual Emissions per Vehicle



HB19-1261

- Adopts statewide goals for reducing greenhouse gas pollution
 - 26% below 2005 levels by 2025,
 - 50% by 2030 and
 - 90% by 2050,
- and gives broad authority to the Air Quality Control Commission to adopt rules to make progress toward these goals.

SB19-236

- Updates PUC regulation to require the use of the **full social cost of carbon** in evaluating utility plans for electric generation, energy efficiency and beneficial electrification (including transportation electrification).
- Requires the state's largest utility to reduce emissions **80% below 2005 levels by 2030**
 - requires the state's second largest utility to get PUC approval for its electric resource plan.
- This legislation is expected to lead to **rapid decreases in the carbon intensity of electricity** generation in Colorado.

CO 2020 EV plan

- Aug 2017 – June 2019: 11,238 to > 24,000
- Goal 940,000 light duty EVs by 2030
- Developing the EV charging infrastructure
- Reduce GHG emissions from State of Colorado **fleet vehicles** by at least 15% by the end of FY 2022–2023 from a FY 2014–2015 baseline;

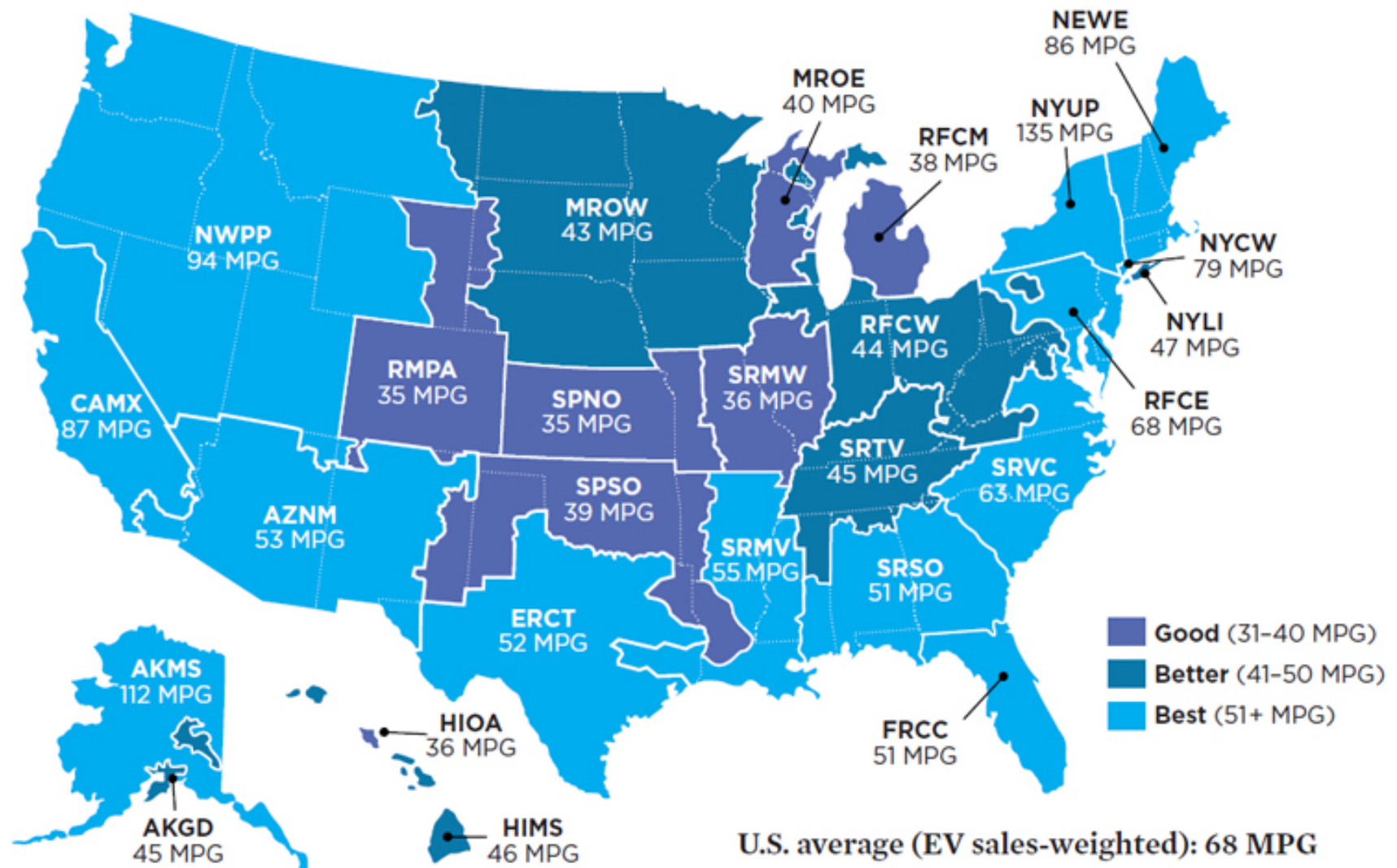
Gas vs electric CO₂ emissions

- Battery operated cars produce more CO₂ than gas cars to manufacture
- EV equivalent mileage 68 MPG fuel economy rating (US average)
- Depends strongly on the fraction of renewable energy from regional power

Union of Concerned Scientists

<https://blog.ucsusa.org/rachael-nealer/gasoline-vs-electric-global-warming-emissions-953>

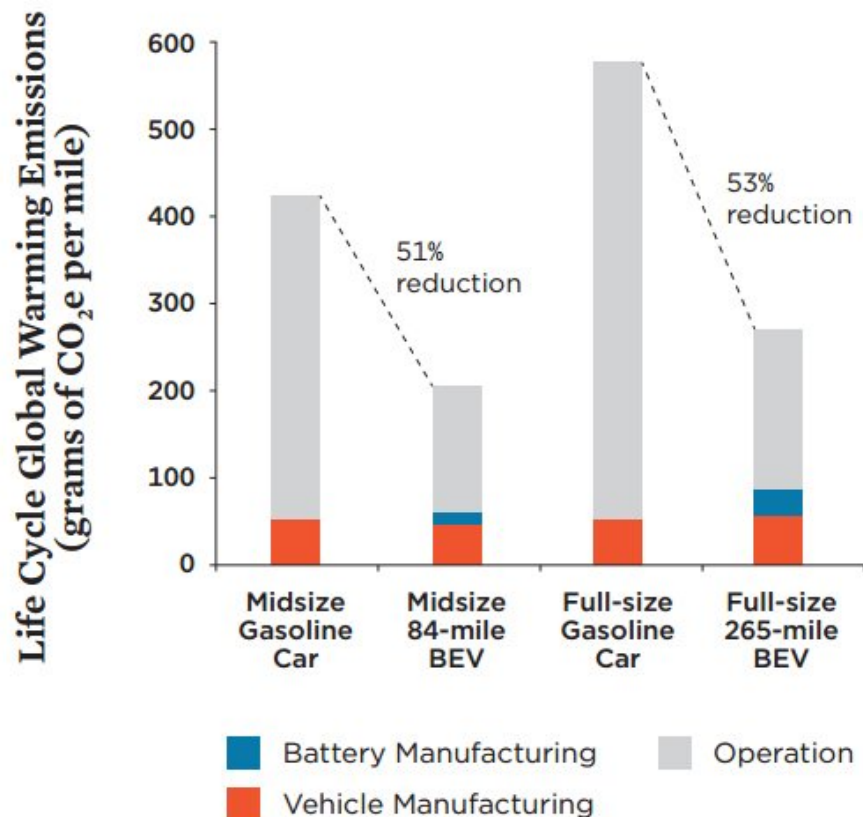
Electric Vehicle Global Warming Pollution Ratings and Gasoline Vehicle Emissions Equivalents by Region



Learn more at: ucsusa.org/EVlifecycle

© Union of Concerned Scientists

Life Cycle Global Warming Emissions from the Manufacturing and Operation of Gasoline and Battery-Electric Vehicles



Note: We assume that the midsize vehicles are driven 135,000 miles over their lifetimes and the full-size vehicles 179,000 miles. The difference in the two mileages derives from the dissimilar uses of 84-mile-range and 265-mile-range battery-electric cars, as described in Chapter 2. We further assume that a consumer buying a BEV would drive it the same total of miles as a corresponding gasoline vehicle. We use U.S. average electricity grid emissions to estimate manufacturing emissions, while the average electricity grid emissions intensity during vehicle operation are based on a sales-weighted average of where EVs are being sold today.

Lifetime comparison of CO₂ emissions

Improves the longer
it is driven. Chart is
for 135,000 miles.

US average grid electric
and sales weighted EV
distribution.

Southern California

Other studies

- A. D. Little
 - Include health hazards of Li-ion batteries
 - Cost of ownership
- National Bureau of Economic Research
 - Should compare with high mileage gas cars as the alternative

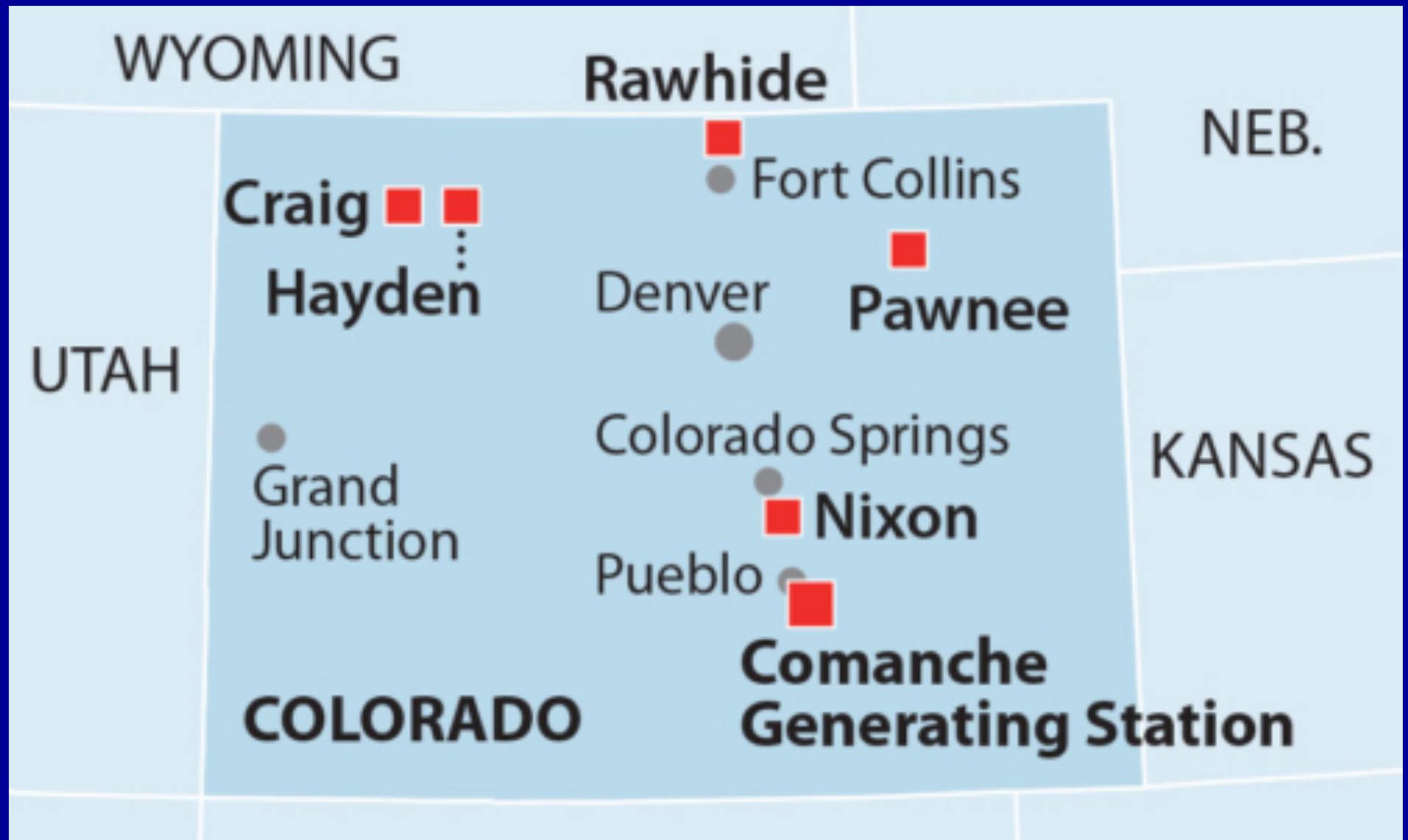
Future of coal in Colorado

- Tri-State Generation and Transmission
 - Coal-fired plant near Craig, CO
 - “We don’t see a future beyond 2030”
 - Jobs lost: 300 direct; 400 indirect; more
- *Office of Just Transition*
- Colorado Springs
 - Martin Drake plant in Colorado Springs
 - Coal part to close by 2023
 - Ray Nixon will convert to non-coal by 2030
- Four Corners due to finish closing 2031

XCEL & other power plants in CO

- Steamboat Springs
 - XCEL: Hayden Station to close in 2028
- Pawnee
 - Scheduled to retire in 2041
- Comanche
 - Built to run until 2070
 - Now seems absurd – (may be shuttered by 2030)
 - Units 1 & 2 to be replaced by nearby wind and solar
- Rawhide
 - Platte River Power
 - To be closed by 2029

Power plants in Colorado



Social cost of carbon: SC-CO₂

- SC-CO₂ is a measure, in dollars, of the long-term damage done by a ton of carbon dioxide (CO₂) emissions in a given year.
- This dollar figure also represents the value of damages avoided for a small emission reduction (i.e., the benefit of a CO₂ reduction).

EPA, [The Social Cost of Carbon, Estimating the Benefits of Reducing Greenhouse Gas Emissions](https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html), January 2017,

https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html

Social cost of carbon

- Biden restored earlier cost of \$51/ton of CO₂.
- Colorado, SB19-236 requires the PUC to use a social carbon cost of \$46 per ton beginning in 2020 when evaluating utility resource plans.

EPA, [The Social Cost of Carbon, Estimating the Benefits of Reducing Greenhouse Gas Emissions](https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html), January 2017,

https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html

‘Geoengineering’ is the deliberate modification of an element of the climate system on a large scale to avoid dangerous impacts of climate change.



AMS, AGU, UK RS

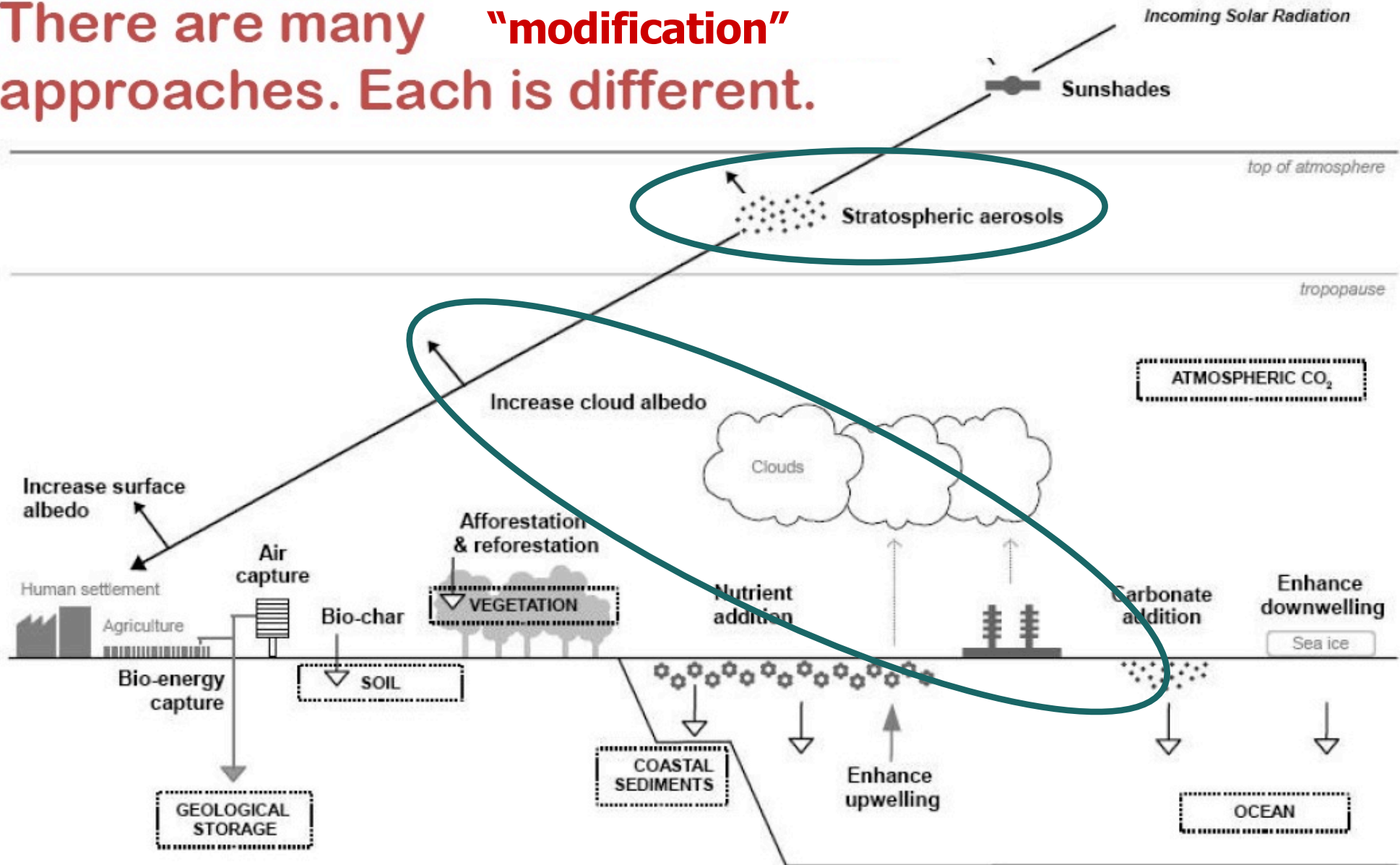
~~Geo-engineering~~ Climate Modification

<http://earthobservatory.nasa.gov/Features/Aerosols/>

Two main methods of climate modification

- Carbon cycle management
- Solar radiation management
 - (using clouds & aerosols)

There are many **“modification”** approaches. Each is different.

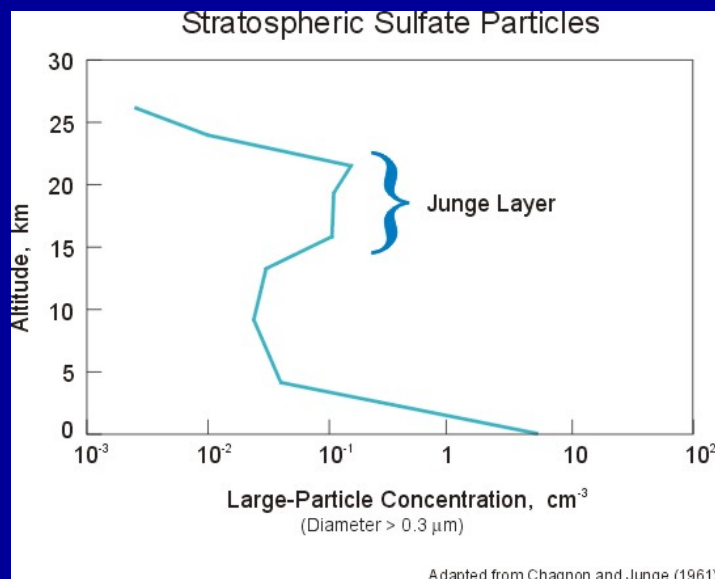


Junge Layer

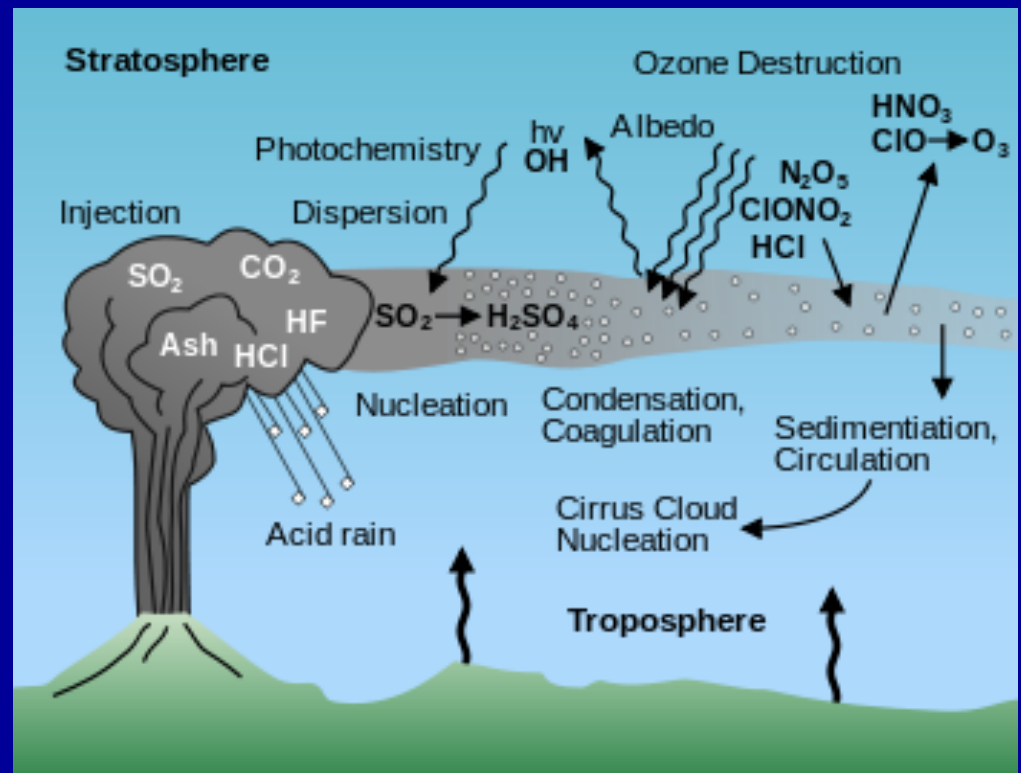
Volcanic sulfates end up here as sulfuric acid droplets and have a strong cooling effect (aka global dimming) on the planet until they fall out over a few years.



Mt. Pinatubo, June 1991



Modification:
Imitate the natural volcanic action by shooting H_2S and SO_2 into the stratosphere: artillery shells, aircraft or stratospheric balloons.



Pinatubo eruption June 1991



Some of the pros and cons

PRO

- Potent: Could offset warming from CO₂
- Affordable and feasible
- We know it works – big volcanic eruptions cool Earth this way
- Beautiful sunsets

CON

- Reduces rainfall
- Alters regional climates
 - local famines?
- Cools tropics, not poles
- Won't stop ocean acidification
- Can't stop, else sudden pulse of warming CO₂ takes over
- Will make sky whiter

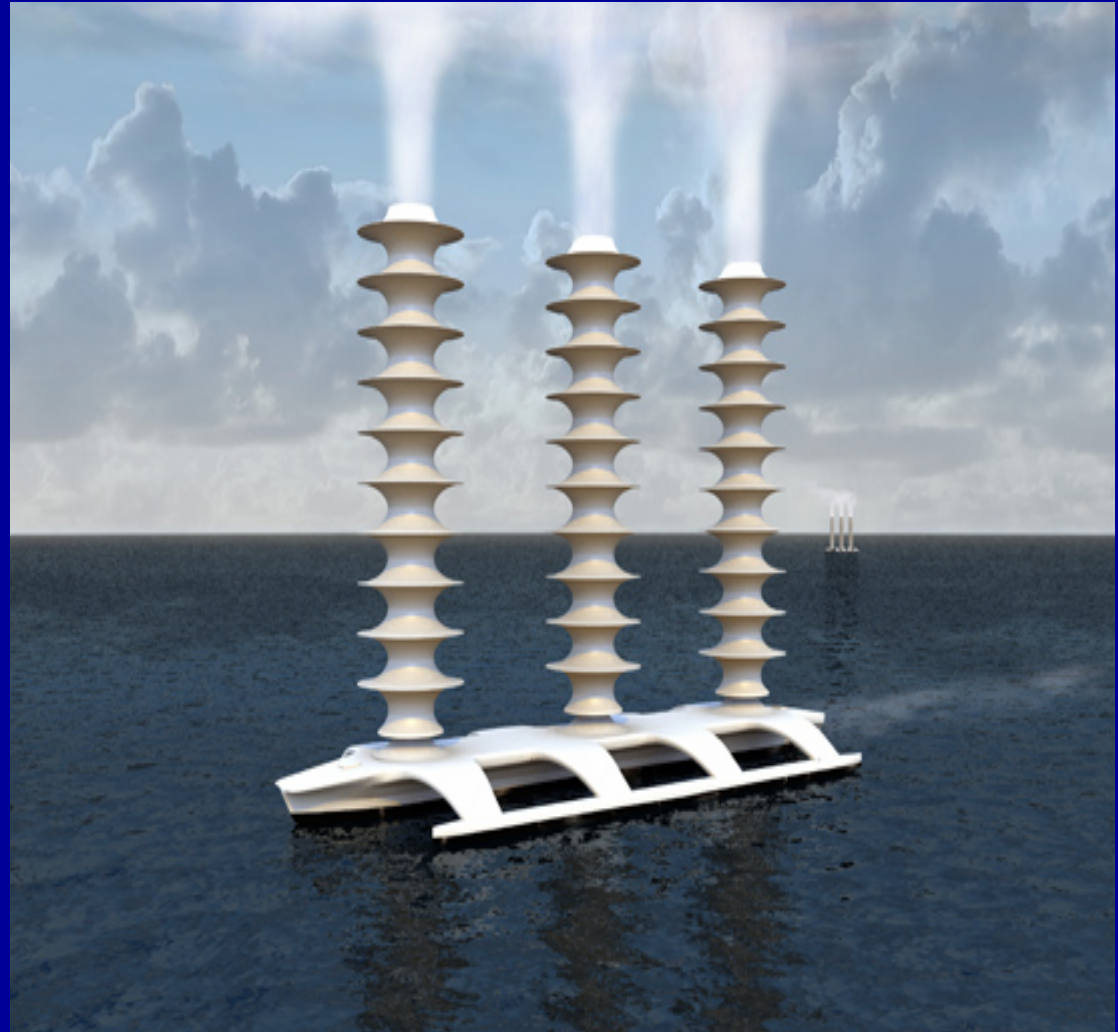
Unintended consequences??

**Need to reduce CO₂ emissions anyway.
Should be, and is being, debated.**

Modifying low marine clouds (Latham, 1990)

- Flettner rotor ship sprays seawater up
- Resulting salt particles nucleate clouds
- More clouds, less sunlight at surface

Twomey effect:
small aerosols condense rainless clouds
(e.g. contrails)

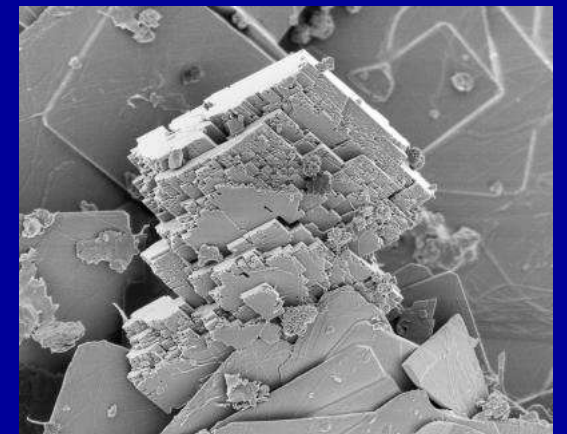
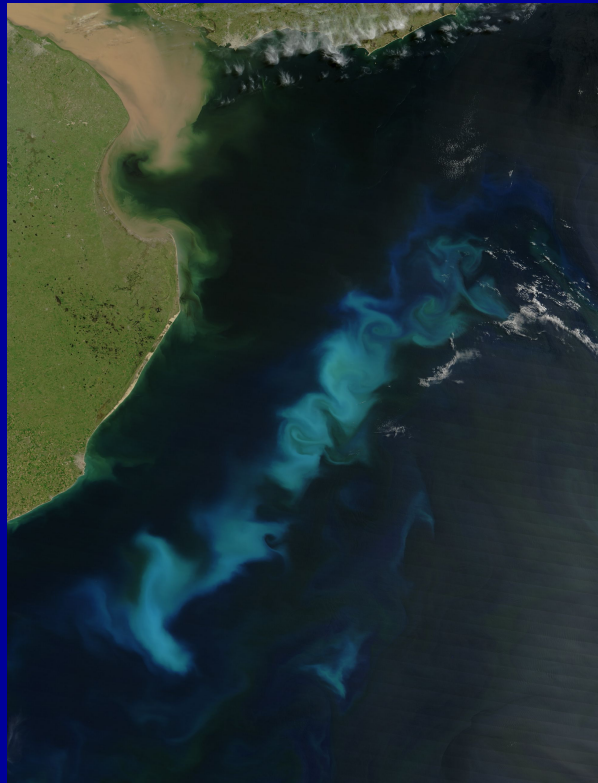


You don't need to create clouds to reflect more sunlight,
just modify them to have smaller drops

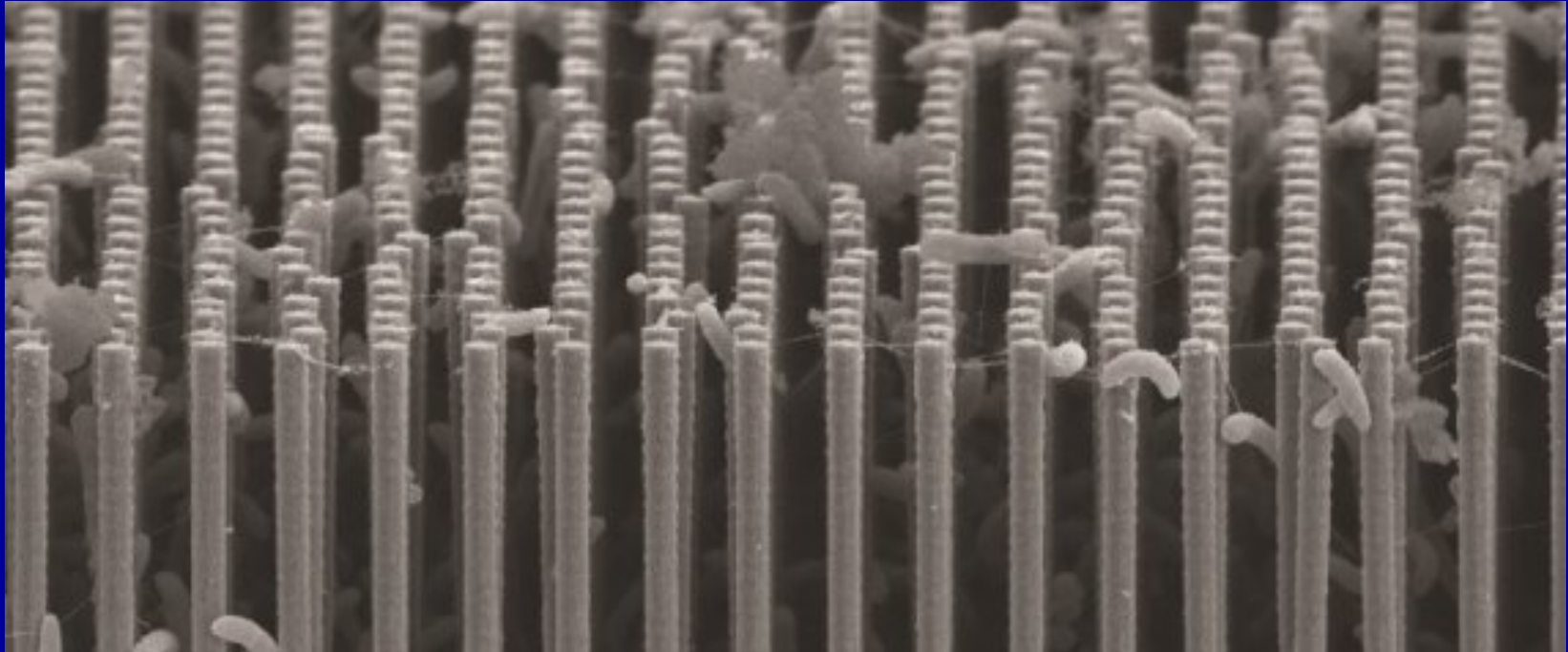


Credit Warren Wiscombe: NASA, GSFC 2013

Stimulated algal production (middle).
Artificial weathering (right).
Artificial trees (left).



Artificial photosynthesis



A system that can capture carbon dioxide emissions before they're released into the atmosphere and convert them into fuels, pharmaceuticals, plastics, and other valuable products.

Basalt dust on farmer's fields

CO₂ mineralization sequestration is the same as the natural “slow process” for Natural removal of CO₂ from the atmosphere.



Good for soil
Can be spread by
existing equipment



Agricultural practices

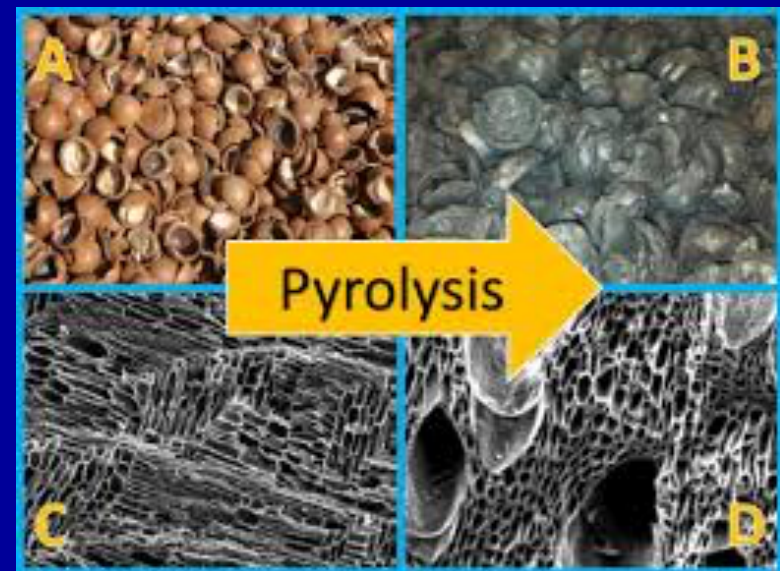
- No-till farming
- Drip watering
- Improve land productivity
- Protect soil from erosion loss
- Permaculture, polycultures & crop rotation
- Cover crops
- Integrating forestry & livestock with crops

Biochar

Natives in Amazon
have enriched their
soils for millennia.



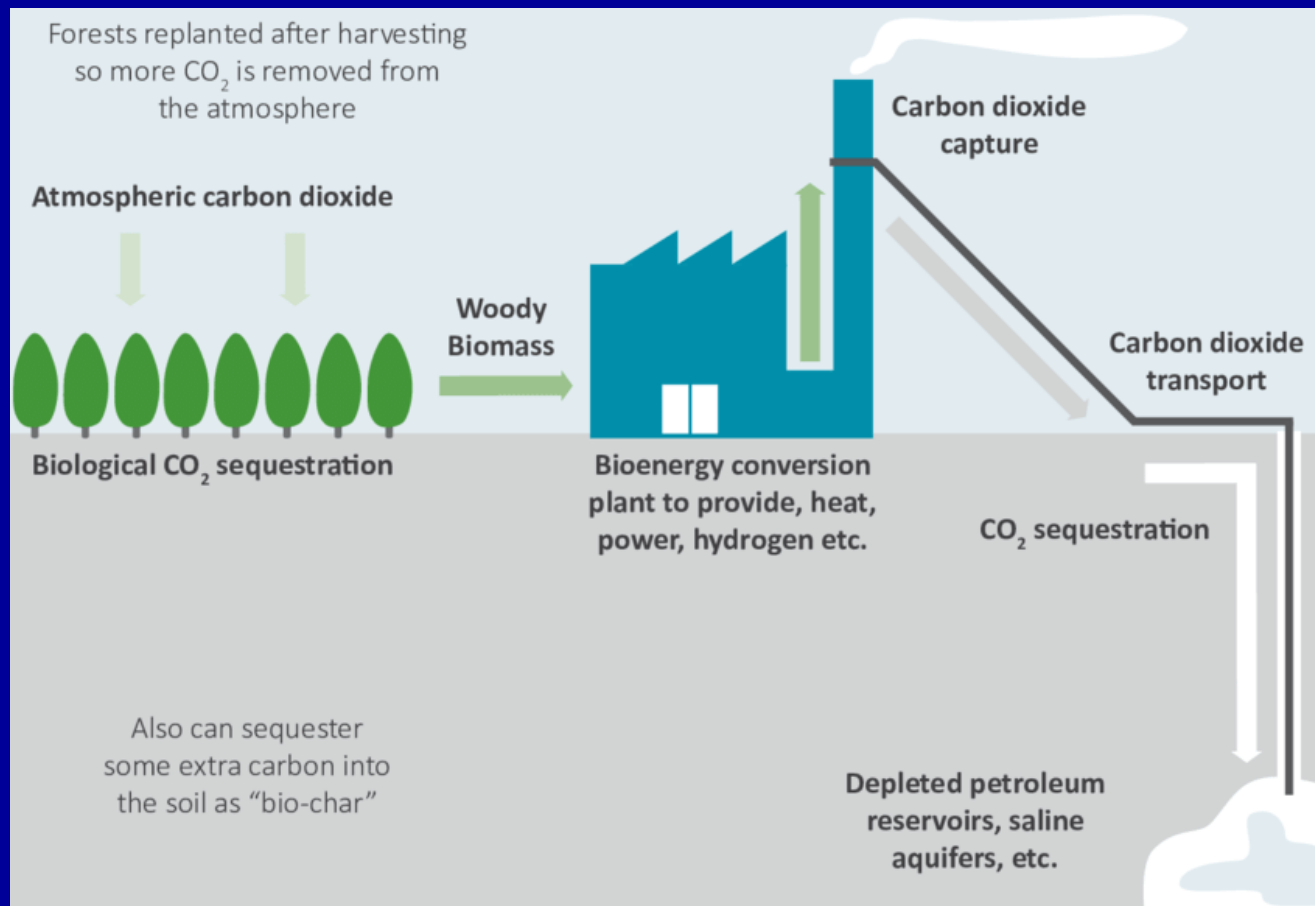
Pyrolysis
Burn organic
materials
without O_2



Bioenergy with Carbon Capture and Storage (aka BECCS)



Carbon capture and sequestration.



Home Solar Panels

- Bangladesh



© 2009 Majority World/UIG via Getty Images

Credit: Climate Reality

Solar-Powered Laptops

- Sierra Leone, Africa



Fort Carson Army Base, Colorado



Source: U.S. Army

Credit: Climate Reality

As of Jan, 2020 Tesla batteries

- Plant is 30% complete
- Mass production of batteries underway
- Powerwall-2 for homes
- Powerpack for commercial
- Batteries for \$35,000 car
 - Production still the limit

Tesla Gigafactory, near Reno, NV



Powerwall 1 100 kWhr \$3000
2 200 kWhr \$5500

Powerpacks for Utility and Business Energy Storage

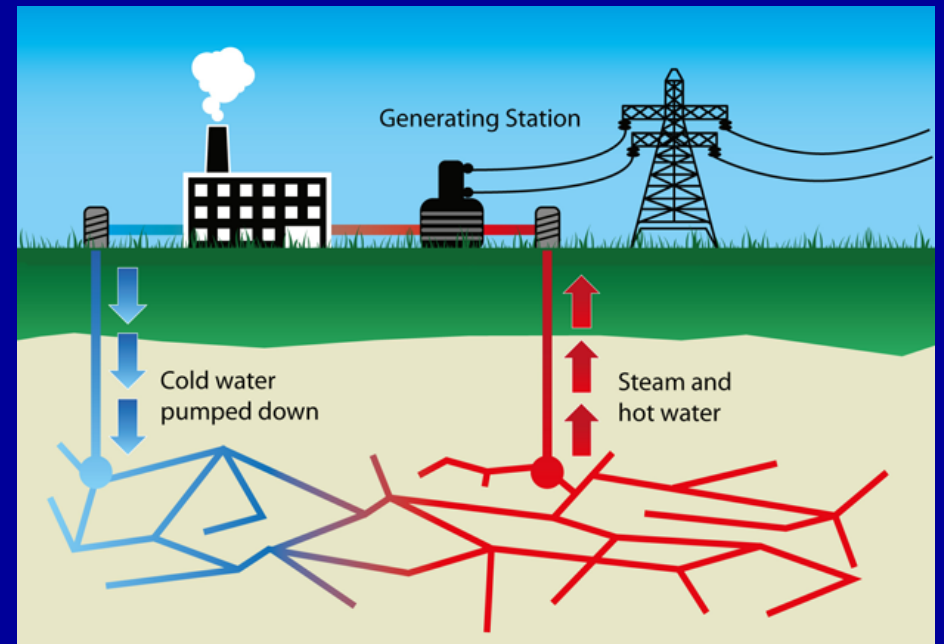


Kauai is fully solar powered

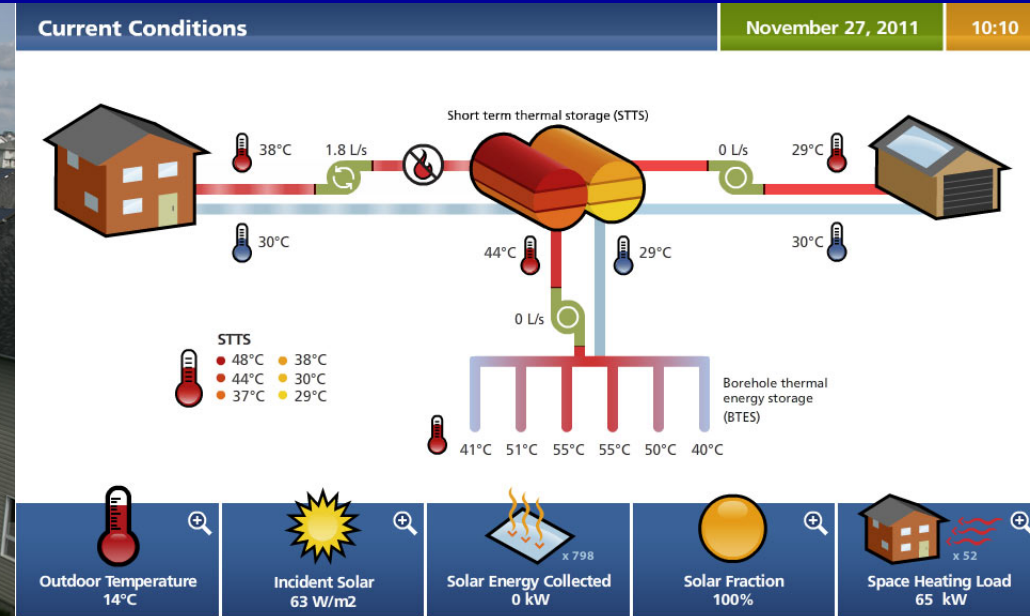


Energy efficiency

Geothermal



Drake Landing Solar Community, Alberta, Canada



52 homes
heat capture in summer on garage roofs
seasonal storage in the rock under a community park
provides 97% of the community's heating energy requirements

Heat sink Earth

Solutions for a Sustainable World

Renewable Energy: Geothermal Heating and Cooling



The earth has a constant temperature of about 55 degrees.

In the summer, the geothermal system transfers this relatively cooler temperature from the earth to the building.

In the winter, when it's cold outside, the relatively warmer temperature of the earth is harnessed to assist with the building's heating needs.

600 ft.



The geothermal system at Argonne's Visitor Center **saves \$4,000** in heating costs per year and **53 tons** of greenhouse gas emissions.

As a U.S. Department of Energy facility, Argonne uses clean renewable energy, consistent with our commitment to sustainable practices and our role as a responsible member of the community.

Geothermal heating and cooling uses the temperature of the earth to heat and cool buildings. We harness this energy by boring deep into the earth.

blogs.anl.gov/greenlab

Scan with any barcode scanner on your smartphone.



Energy storage: molten salt

Solar 2: 10 MW – 7,500 homes – grid connected
runs for 3 hrs after sunset

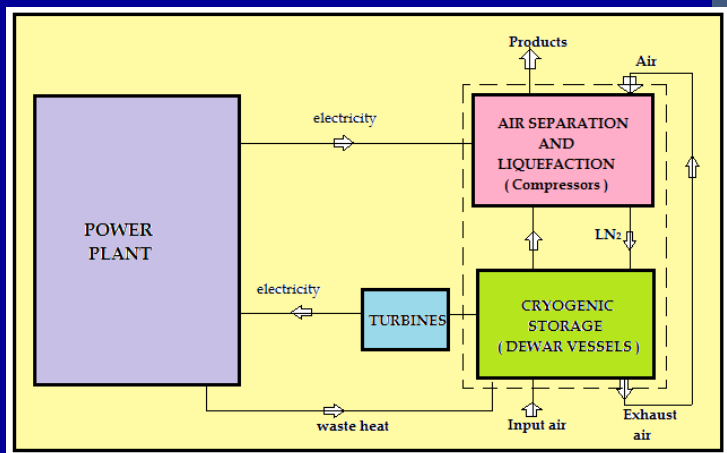


Experimental, now decommissioned
Southern California Edison
Next generation is 19.9 MW station
by Gemasolar Thermosolar Plant in Spain
Storage 600 MWhr for 24/7 ops during the summer
Operational since May 2011



Energy storage: liquid air

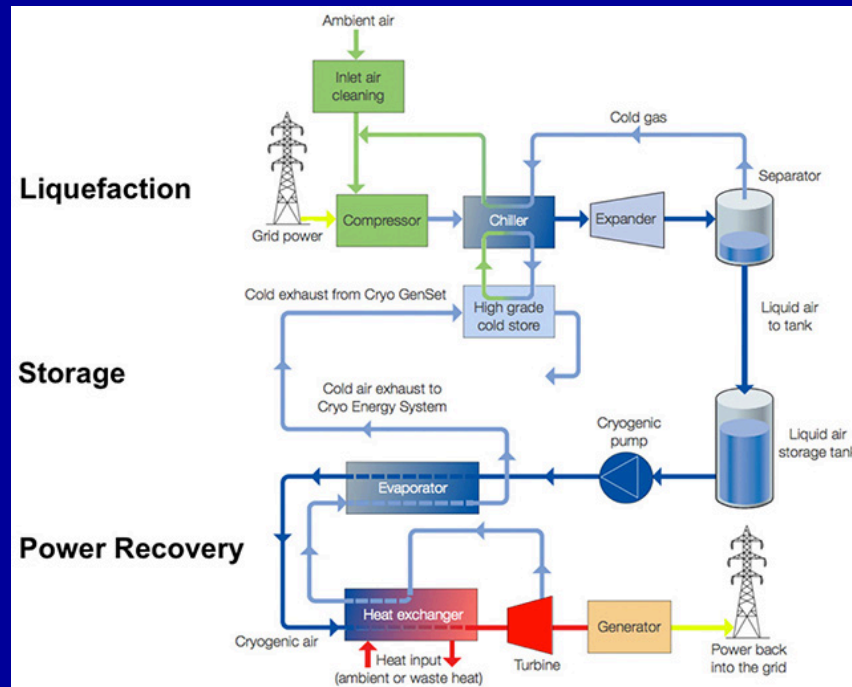
Off peak power or unused energy is used to cool air (nitrogen gas) to liquid form (-196°C). Expansion into the gaseous phase is used to drive turbines and generate electricity. The cold air is recycled to help the cooling process, increasing the efficiency to about 50%. The potential is higher (up to 70%) if waste heat is used to boil the liquid nitrogen.



Highview Power
Storage Ltd.'s pilot
plant in Slough, UK

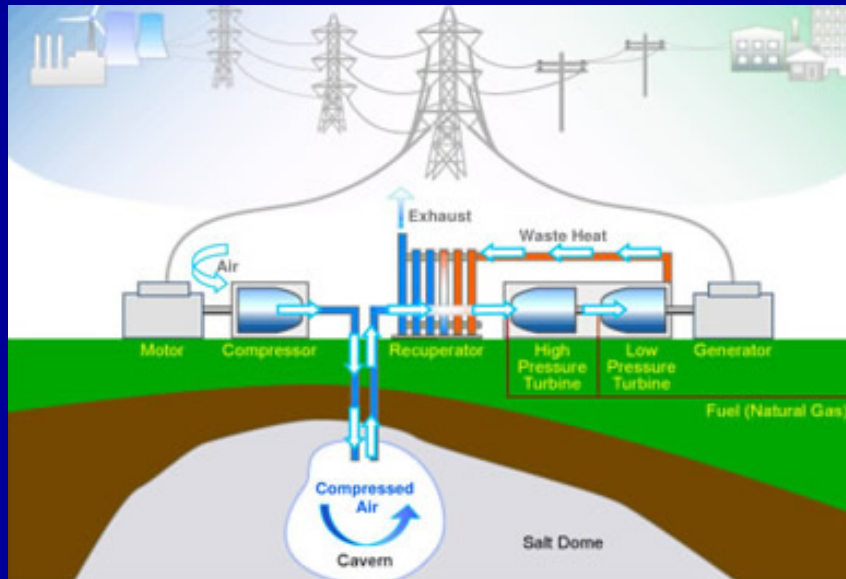


Liquid Air Energy Storage (LAES)



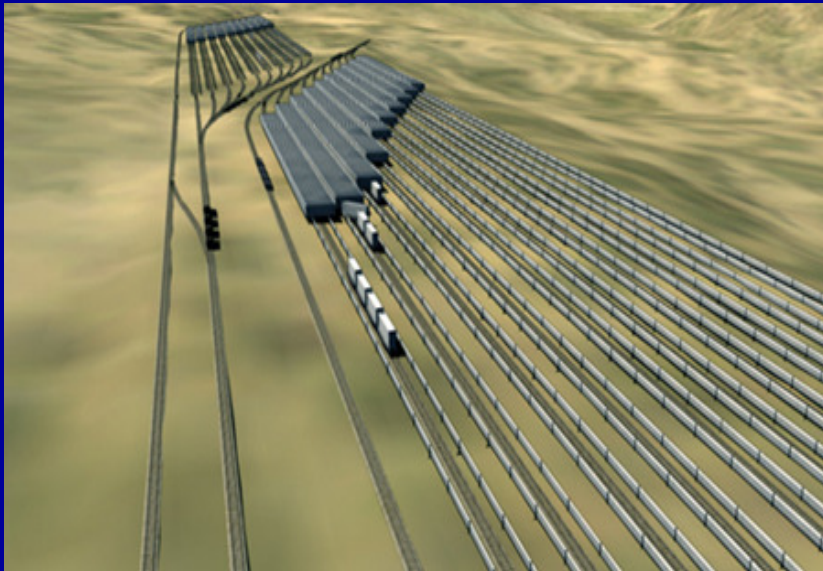
- Compress → Purify → Liquefy (Cool to -196 C)
- Currently being demonstrated by Highview-Power
 - Built 2.5 MWh demonstration facility
 - Currently being funded by GE
- Employs already well-developed technologies for cryogenic storage of liquid nitrogen
- Not Geographically limited
- Efficiency = 50 – 70 %
 - Cold Recycle → recaptures cold air exhaust in power recovery process to aid in initial cooling process
 - Thermal Store → When air is initially liquefied waste heat is produced → this heat is captured and used in the power recovery process to increase efficiency (note: waste heat from other sources can be used as well).

Compressed Air Energy Storage (CAES)



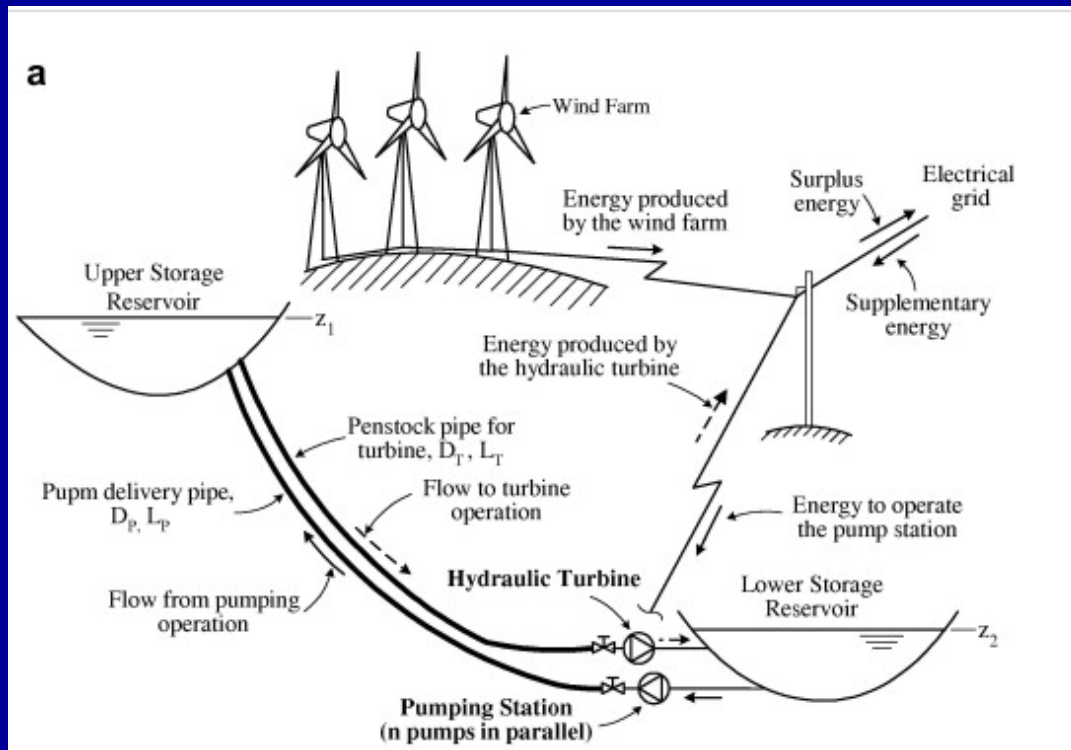
- Capture → Compress → Cool
- Compressed air = increase temperature → refrigeration cells cool to approximately 110 C
- Add heat and release into electric turbine for use
- Storage → Chemically inert cavern
 - salt caverns ideal, Natural aquifers are also used
 - Pro: Little energy input needed after stored
 - Con: Geographically limited
- Efficiency = 60 – 90 %
- A precursor to LAES
 - Only makes sense to use if a natural cavern exists (otherwise LAES makes more sense)

Rail Energy Storage



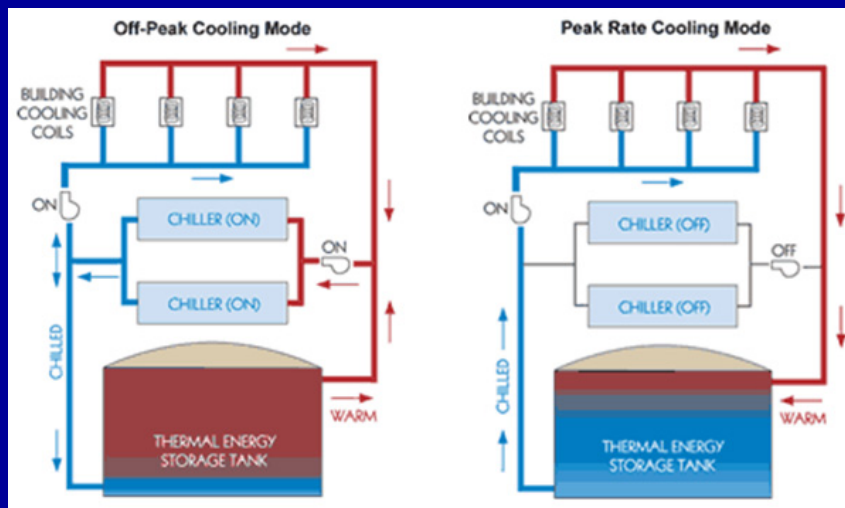
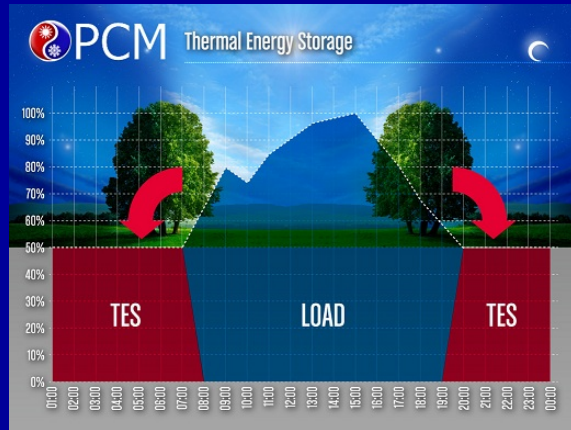
- Essentially hydroelectric storage on rails
- Advanced Rail Energy Storage (ARES North America)
 - Founded 2010 (Bill Peitzke, Matt Brown)
 - Advanced method of utility stale storage
- Uses induction motors to go uphill
→ motors become generators when going downhill
 - Employs regenerative braking (same as a prius)
- Smaller environmental impact than hydroelectric storage
- Makes sense in areas that lack water resources
- Efficiency = 85%

Hydroelectric Energy Storage



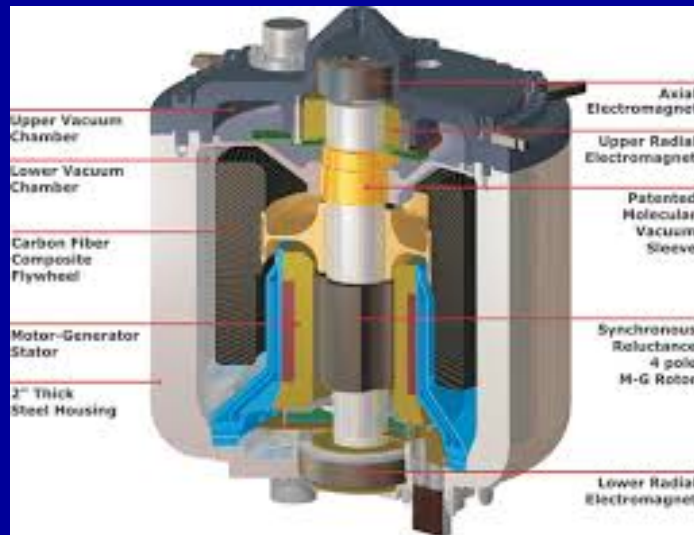
- More cost effective than battery banks or air storage facilities
 - However, depending on storage capacity needed, dam investments can be costly
- Provides rapid-response to energy demand → already used to balance electric grid in some area
- Hydroelectric power generation plants are common → infrastructure already exists many places
- Norway for example could make a large dent in Europe's' energy demands with a combined renewable power generation to hydro storage system
- Downside = negative environmental impact
 - Change in water temp
 - Displaces people
 - Methane is sometimes formed
 - Spreads invasive species
- Efficiency = 70 – 85 %

Thermal Energy Storage

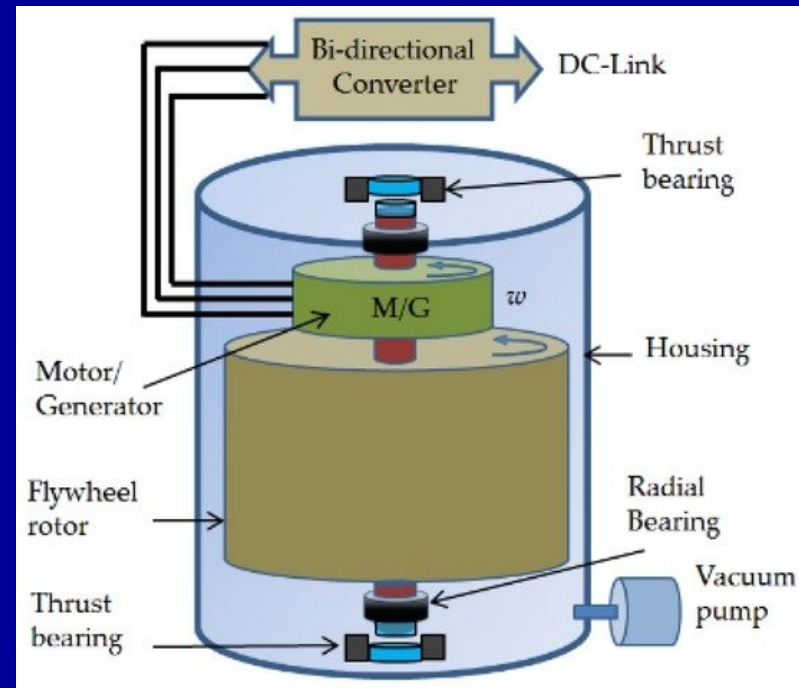


- Not for grid scale applications
- Used to balance heating/cooling demands of large facilities and institutions
- When used properly
 - Decreases cooling costs for customers
 - Reduces strain on producers to meet demands
- Stratified tank method (shown)
 - Use off-peak energy to chill water and replace heated water from building
 - Use built up cold water to cool building at peak energy usage

Flywheel storage



Carbon fiber flywheel



Cement flywheel



There's plenty of energy:

use $18.5 \text{ TWy/y} = 0.5 \text{ Zetta}(10^{21})\text{-Joules}$

WORLD ENERGY

2015 Use ²⁶ 18.5 TWy/y

RENEWABLES

Solar ¹² 23,000 TWy/y

Wind ³ 75-130 TWy/y

Waves ⁴ 0.2-2 TWy/y

OTEC ⁵ 3-11 TWy/y

Biomass ⁶ 2-6 TWy/y

Hydro ⁷ 3-4 TWy/y

Geotherm. ^{8,22,23} 0.2-3++ TWy/y

Tidal ² 0.3 TWy/y

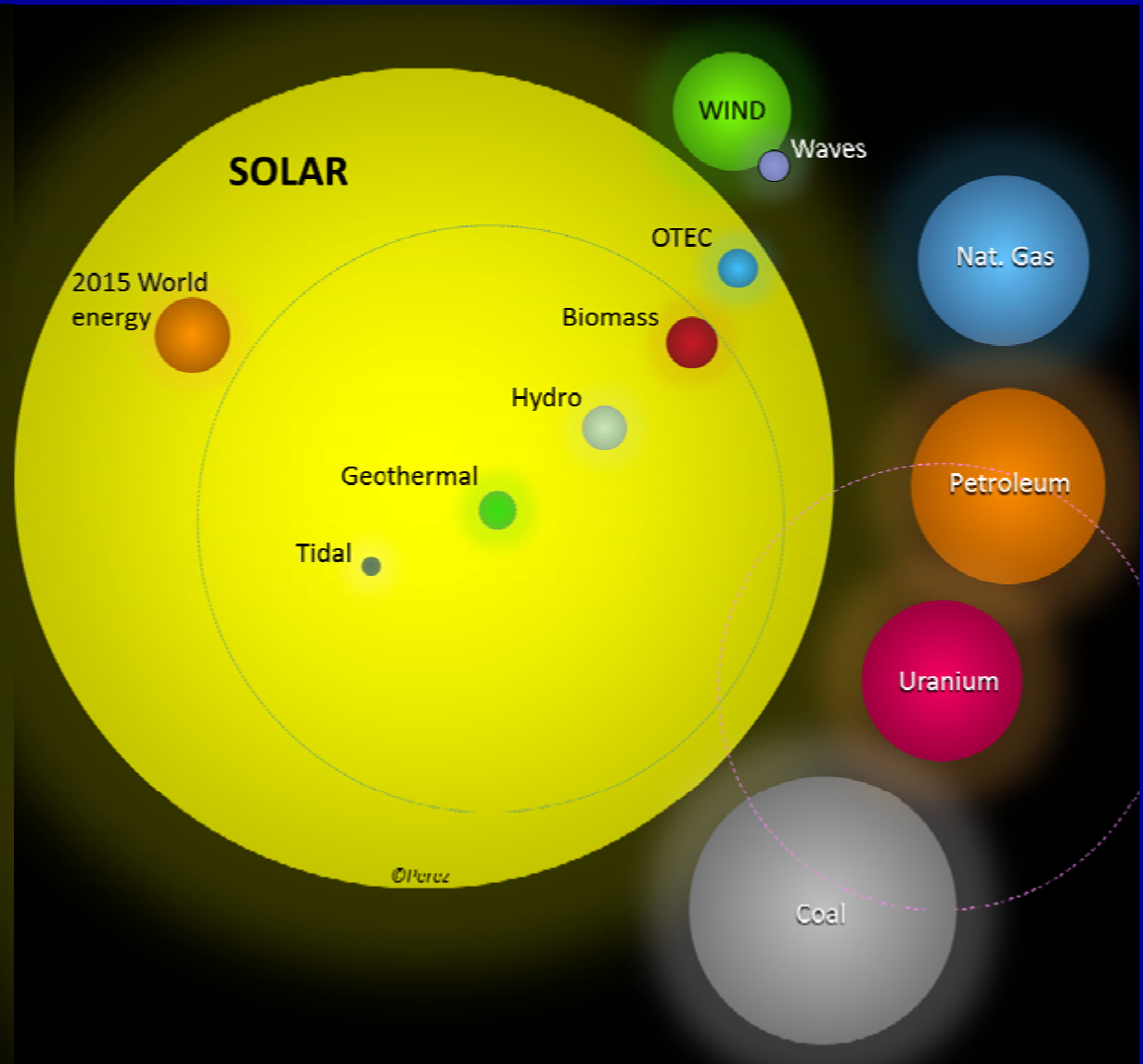
FINITE

Nat. Gas ^{9,21} 220 TWy

Petroleum ^{9,21} 335 TWy

Uranium ^{13 to 20} 185++ TWy

Coal ^{9,21} 830 TWy



Paris accord: COP21 aka 2015 Paris Climate Conference

Dec 7,8, 2015

- First international agreement on GHG
- Limit ΔT to $<2^{\circ}\text{C}$ (already have 0.8°C)
 - Try to hold ΔT to $<1.5^{\circ}\text{C}$
- Statements of intention with tracking
- Arguments about enforcement

Rio Earth Summit in 1992
established the Conference of Parties (hence COP)

<http://www.cop21paris.org>

Climate Organizations

- Citizens Climate Lobby (CCL)
- 350.org (Bill McKibben)
- Sierra Club
- Union of Concerned Scientists
- Colorado Renewable Energy Society (CRES)
- Alliance for Sustainable Colorado
- Greenpeace
- Idle No More (mostly Canadian)

**"Never doubt that a small group of thoughtful
committed citizens can change the world;
indeed, it's the only thing that ever has."**

....Margaret Meade

Topics discussed

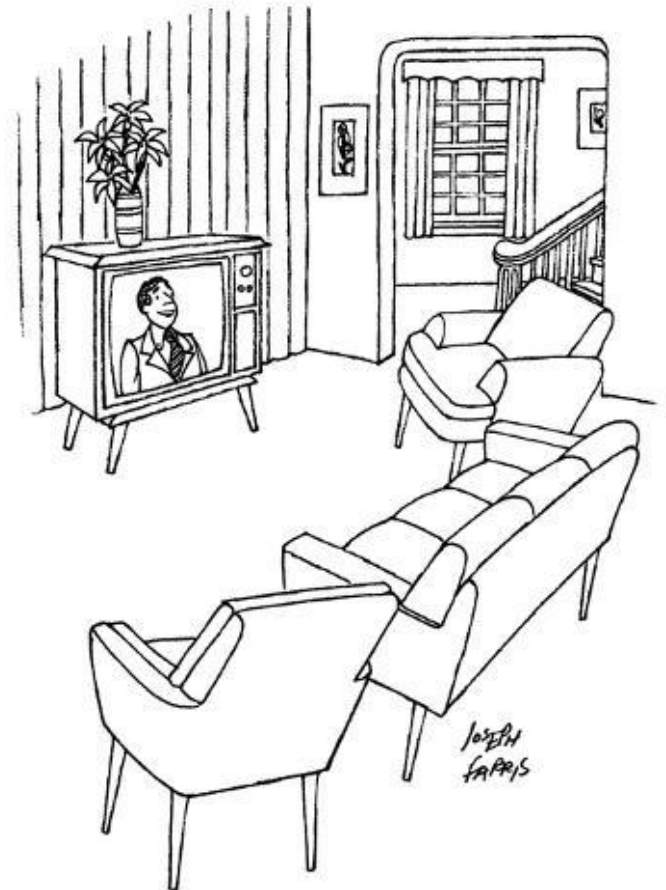
- Carbon Fee and Dividend Act
- Climate Actions
 - Adapt, Modify, Ignore
- Electrify transportation
- A potpourri of solutions

Economics will choose which work best.

Thank you for your participation.



"Handwrite and mail grandma's thank you note instead of texting? I don't have this kind of time!"



Thank you for attending Climate Redux this morning."

The end

