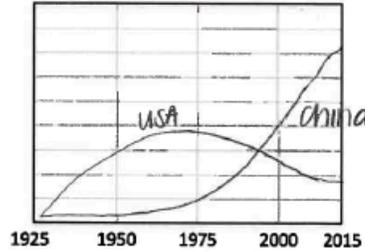


- 1a) What are the *total annual global* CO₂ emissions? 30.6T
- b) On the graph, show (total) annual national emissions of CO₂ for both USA and China. Label the two curves, so I can distinguish them. You don't have to put the scale on the y-axis, we can just focus on understanding the general behavior.
- c) Please comment on why the two graphs look different and what this means about each country's development.
- d) What do you see as the role of USA as an international leader in energy development?



c) china developed later than the US so its CO₂ emission rate didn't increase until later. The US is now abating their CO₂ emission rate due to implementation of laws & tech. BUT overall, US has emitted more CO₂ (area under curve)

d) As a major power in the world, the US should be working to set an example for the world as a developer of renewables. At the very least it should be working to be comparable to European countries. US should also be working to aid developing countries establish cleaner energy.

- 2) We learned how to calculate the cost of electricity, the cost of conserved energy, and the cost of abated carbon.

a) I discovered a way to generate electricity at \$0.10/kWh and I want YOU to give me your money to build this technology. What things would determine if my invention is going to be a market place success? Possible choices include: duty cycle, dispatchability, and deployment location and size or anything else.

b) I invent an automatic switch that turns the lights off in our building when no one moves. The Cost of Conserved Electricity is \$0.10/kWh. Would this be a good investment? Explain why.

c) I calculate that the Cost of Abated Carbon is about \$50 / CO₂ Ton for a company. Under what circumstances (if any) would this efficiency investment be cost effective? Explain.

a) ~~If the duty cycle is high, then it could become a cheap base load electricity source.~~ Dispatchable elec is also useful. If this could be a small scale elec source w/ low emissions, then it could be placed locally and reduce the need for long transmission. It also depends on the cost of existing elec. In CA, elec. is \$0.15/kWh so \$0.10/kWh is cheaper but in some areas \$0.10/kWh may be more expensive & thus less favorable. *cost of generation = 5¢/kWh*

b) In CA, this would be a good investment b/c \$0.10 < \$0.15. But in another area where elec is < \$0.10 then this wouldn't be a good investment.

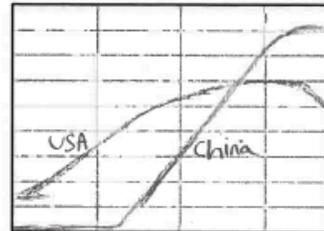
c) If a carbon tax existed that was equivalent or greater than \$50/ton then this investment would be effective.

For this question, many people listed good concerns about the cost of a technology such as capital cost, cost of fuel, size, etc., but these are wrong answers because these costs are what is used to calculate the \$0.10 / kWh. California electricity costs about \$0.15 / kWh, although there is some time dependence. However less than half of this cost is the cost of generation. The rest is distribution costs. Also, we will (soon) no longer be worried about generation on sunny days, and so there are a few things that would make your \$0.10 / kWh electricity a very good value if:

- 1) It is easily dispatchable – we can turn it on with short notice to fill in when variable renewable energy isn't available.

- 2) It can achieve this cost with low duty cycle. If this \$0.10 / kWh was calculated assuming 100% duty cycle, then this electricity is way more expensive than NGCC to generate.
- 3) It is a small technology that isn't dangerous. If we can put on in the house or local neighborhood, then this *distributed generation* would by-pass some of the transmission and distribution costs making the \$0.10 / kWh compete with the delivered cost of electricity rather than the generation cost of electricity.
- 4) If this electricity produces no GHG, then it can be part of California's renewable portfolio (50% by 2030), and the cost won't go up with a carbon tax.

- 1a) What are the total annual global CO₂ emissions? 36 GT ✓
- b) On the graph, show total annual national emissions of CO₂ for both USA and China. Label the two curves, so I can distinguish them. You don't have to put the scale on the y-axis, we can just focus on understanding the general behavior.
- c) Please comment on why the two graphs look different and what this means about each country's development.
- d) What do you see as the role of USA as an international leader in energy development?



- c) China developed later than us and thus began increasing their emissions later than we did. Since they have so many more people, their graph rose higher than ours.
- d) The US should set an example by continuing to lower our emissions. Our choices are very influential, as we can see by how the Kyoto Protocol lost its teeth and power when the US rejected it.

2) We learned how to calculate the cost of electricity, the cost of conserved energy, and the cost of abated carbon.

- a) I discovered a way to generate electricity at \$0.10/kWh and I want YOU to give me your money to build this technology. What things would determine if my invention is going to be a market place success? Possible choices include: duty cycle, dispatchability, and deployment location and size or anything else.
- b) I invent an automatic switch that turns the lights off in our building when no one moves. The Cost of Conserved Electricity is \$0.10/kWh. Would this be a good investment? Explain why.
- c) I calculate that the Cost of Abated Carbon is about \$50 / CO₂ Ton for a company. Under what circumstances (if any) would this efficiency investment be cost effective? Explain.

a) If I have a high duty cycle, you'll be able to generate more electricity and profit more. If it can be distributed rather than centrally located, that's great because then you don't have to pay for transformers or power losses.

b) This would be a good investment in CA bc the cost of regular electricity is 15¢/kWh, which is more expensive than 10¢. In another state where electricity is less than 10¢/kWh, it would be financially unwise.

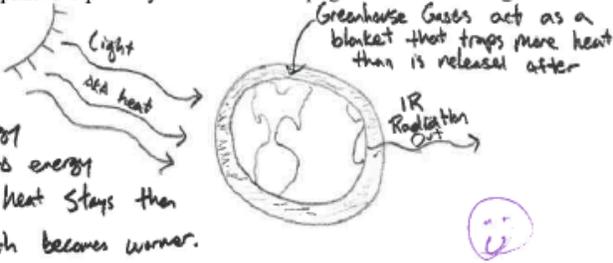
c) This is cost effective only if there's a carbon tax of \$50/ton CO₂ or more because then you'd be paying less than or equal to the amount you would be taxed had you not made this investment.

I received all kinds of answers for next question, 3a) because it was poorly written... I should have written, "describe the mechanism/process of climate change and how it heats the earth."

3) Climate change

a) With a good drawing, please explain the primary cause of anthropogenic climate change:

With the increased emissions of CO_2 , CH_4 , NO_2 , H_2O , and CFCs, these greenhouse gases throw off the balance of energy entering Earth's atmosphere to energy leaving the atmosphere. More heat stays than leaves and thus, the Earth becomes warmer.



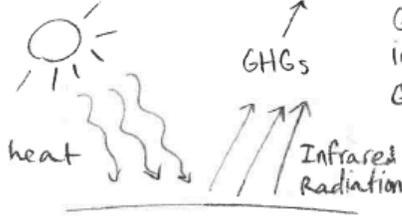
b) Please describe secondary causes (feedback loops) that amplify climate change.

One feedback loop is the land becoming warmer which leads to more H_2O vapor in the air which adds to the blanketing effect and so the land gets hotter.

Another feedback loop is the snow melting that leads to less solar reflectivity and so more snow melts.

3) Climate change

a) With a good drawing, please explain the primary cause of anthropogenic climate change:



Greenhouse gases in the atmosphere increasingly (due to ↑ human emission of GHGs) trap IR heat leaving Earth and since that heat is prevented from leaving Earth gets hotter.

A earth

b) Please describe secondary causes (feedback loops) that amplify climate change.

As permafrost melts w/ inc. temperatures, it releases stored methane that inc CC

As snow white snow melts and darker surfaces are revealed, areas that used to reflect heat now absorb it and cause warmer temps

As glaciers on land begin to melt, the water lubricates them and cause them to slide into the ocean even easier ^{↑ melted ice} but not a CC cause....

c) Why should we care about mitigating climate change?

Climate change has many consequences: sea level rise causing flooding of coastal land, more drought, more severe storms. These all will have disastrous impacts and cause destruction and loss of lives, loss of wealth, and loss of well being. Other species will see mass extinctions, coral bleaching, and ocean acidification. Mitigating it ahead of time will cost much less (~1% world GDP) than dealing with the repercussions as it occurs (5-20% world GDP) *really good answer*

d) What are the Environmental Justice (EJ) issues related to climate change? That is, who benefits and who suffers?

many people will suffer from CC who didn't make the choices that led to CC, which is unjust. An example is Bangladesh, whose ~~poor~~ mostly poor inhabitants do not emit much CO₂, but whose ~~low~~ low-elevation land is at high risk for flooding and displacing or killing many people

4) Petroleum

- a) As we use up the petroleum, the total global reserve has increased... *really?* Does this mean that more petroleum has formed in the earth since the 1970s? Please explain the societal mechanisms that have led to an increase in estimated global reserves of petroleum over the past half century.

Scarcity has driven up the price, which has caused new technologies to be invented (the high prices created an opportunity for inventors & investors to profit), which has led to more petroleum being accessible than we once thought

- b) The economist says, "In order for the petroleum market to work, the decision maker must bear the full cost." Market distortions prevent the market from working. Please list a few market distortions with regard to petroleum and state how these distortions prevent the market from optimally serving society.

Oil is subsidized by the government, causing the price to be ~~at~~ lower than it should. *how?*

~~The~~ External costs to society, are not a part of the cost consumers pay either. *why is this a problem?*
like climate change costs, environmental damage to ecosystems (fracking) and earthquake damage (fracking)

- c) Identify a command and control mechanism to mitigate one of the distortions above.

Axx
Ban vehicles with very poor mileage so that less gasoline is purchased.

CAFE!

- d) Identify a market mechanism to mitigate one of the distortions above.

Put a carbon tax on gasoline so that less gasoline is purchased and purchasers are bearing the full cost to society

- e) Let's say the USA is concerned that Iran is going to build nuclear weapons and decides to boycott Iran's petroleum. Will this boycott effectively apply pressure on Iran's economy? Why or why not?

No - the petroleum is global, so if we don't buy it from Iran, another ^{industry} country will.

I received a large number of very good answers for the following, but most of them were incorrect, so I marked them wrong, but still gave some credit.

5) Nuclear Power.

a) Why is PG&E choosing to close Diablo?

Their most recent contract expired & California wants PG&E to increase their renewable energy portfolio (of which they don't count nuclear). PG&E doesn't think it's worth keeping it open at this point.

b) I have a friend who thinks we should keep Diablo and other nuclear plants open, but not build new nuclear power plants. You don't have to agree with her, but why would she have differing opinions about old and new plants?

There is a very high cost to building nuclear plants that requires a lifetime of capital ^{decades to make up} 😊. Since the energy landscape is shifting towards renewables so fast, it seems smart not to make the huge capital investment. On the other hand, nuclear is really cheap and low CO₂ to run day-to-day, so since existing ones can do that without an additional large capital cost, it makes sense to continue with the good benefits.

c) What are "delay neutrons"?

a. Why are they important to nuclear energy?

b. What challenge do they present for nuclear energy?

They are a product of fission that can then ^{controlled} fission themselves. They allow nuclear reactions to be self-limiting but can be problematic because the heat from their reactions continues even if the reactor is "turned off." If the cooling system were to go down, this heat could cause accidents like Fukushima.

d) Proliferation concerns: Please describe what we mean by proliferation concerns and the particular role of Plutonium and the reprocessing of spent nuclear fuel.

Proliferation concerns are concerns that spent nuclear fuel could be used for nuclear weapons. While U_{235} (fissile) and U_{238} (non-fissile) are very hard to separate since they are the same element and thus hard to enrich to the 95% required for weaponization.

Plutonium (not found in nature, same fission effects as U_{235} , found as nuclear ~~the~~ fission byproduct) is a separate element and thus much easier to enrich into a weapon should it be in the wrong hands.

c) What are "delay neutrons"?

- a. Why are they important to nuclear energy?
- b. What challenge do they present for nuclear energy?

- a. Delay neutrons are the "danger neutrons" that continue to be active as a nuclear power plant cools down past "sub critical".
- b. They present the challenge of preventing operators from having instantaneous control over the power/process as well as making cooling an important step even during and after the "sub critical" stage.

d) Proliferation concerns: Please describe what we mean by proliferation concerns and the particular role of Plutonium and the reprocessing of spent nuclear fuel.

Proliferation refers to the advance of nuclear weapons around the world in different countries, especially the US & Russia in the Cold war. Plutonium is an unnatural element that is useful specifically for nuclear weapons and is extracted during reprocessing spent nuclear fuel when Plutonium²³⁹ and Uranium²³⁵ are extracted from U²³⁸.