Strategies to mitigate climate change

Responses to the Climate Change

- Adaptation

  Adaptation means responding to the negative impacts of climate change. If climate change causes sea- level rise, an adaptive response to this impact would be to build seawalls or relocate communities away from the encroaching sea.

- Mitigation

  Refers to policies that avoid climate change in the first place, thereby preventing impacts such as sea-level rise from occurring it

- Geo-engineering

  Geoengineering refers to active manipulation of the climate system

Strategies to mitigate climate change

1. Adaptation
2. Technology
3. Politics
4. Personal actions
5. Conventional regulations
6. Market-based regulations
7. Information and voluntary methods

Adaptation

- Climate change is happening
- As temperature, precipitation, sea level, and other components of climate change, we can adapt our way of life to adjust to these changes
- Need to think about possible consequences for the region we live in
- If regional projections are available we can consider them in planning
- We can extrapolate past changes according to the principle that we can expect more of what we've observed in the recent past
- Along the coast sea levels will continue to rise and the ocean will continue to acidify
- Regionally changes in sea level or ocean acidification may be different from global mean changes
- Adaptation might also be considered a form of aid, whereby richer societies agree to help poorer ones pay for climate impacts for purely distributional reasons
- In addition to direct aid, governments can also implement regulations to encourage citizens to adapt to a changing climate
- Regulations promoting water conservation

Adaptation

- A third way government policy can facilitate adaptation is by providing reliable information on the climate changes that will occur, as well as possible responses, including technical assistance
- There are several advantages to relying on adaptation as the main response to climate change.
- First, because many of the worst impacts of climate change will occur in the second half of the 21st century, adaptation allows us to wait for decades before we must start adapting
- Another advantage of adaptation is that it does not require national or international intervention
- Decreasing a community's vulnerability to sea-level rise caused by climate change will also decrease the vulnerability to extreme sea-level events caused by hurricanes or other severe storms
- Conserving water to address decreased freshwater availability will also decrease the community's vulnerability to droughts or to increased demand caused by population growth
- An improved public health infrastructure designed to head off disease outbreaks in a warmer world would also help decrease a society's vulnerability to pandemic flu and other nonclimate public health issues
- The world's rich
- economies have built their wealth by consuming massive amounts of energy, which means that these economies are responsible for most of the increase in greenhouse gases over the past two centuries
- Adaptation must be a part of our response. However, relying *entirely* on adaptation as our response is problematic

Mitigation

- Mitigation refers to reductions in emissions of carbon dioxide and other greenhouse gases, thereby preventing the climate from changing in the first place and avoiding the impacts of cli
- Most policy makers view mitigation as playing a vital role in addressing long-term climate change. mate change
- How much do we have to reduce emissions?
- Many experts have made the judgment that warming of more than 2 ◦C above pre-industrial temperatures would be considered dangerous.
- Achieving this target would in turn require a reduction in the global emissions by the middle of the 21st century of greenhouse gases by 50–80% below today's emissions levels
- The factors that control emissions of greenhouse gases: population, affluence, and technology
- Efforts to combat climate change by using policies explicitly targeted at reducing the Earth's population are viewed as politically unachievable
- Reducing consumption is something that most countries simply will not agree to
- The greenhouse-gas intensity, which must be reduced in order to reduce emissions

Technologies

- The technology term is a measure of how much greenhouse gas is emitted per dollar of GDP.
- This in turn can be broken into two constituent terms: the energy intensity, a measure of howmuch energy it takes to generate 1 dollar of GDP (J/$), and
- The carbon intensity, a measure of how much greenhouse gas is emitted to generate a unit of energy (CO2/J).
- Energy intensity is determined to a large extent by the efficiency with which the economy uses energy
- To reduce emissions by 50–80% over the next few decades, which is about what's required to stabiliz the climate with less than 2 ◦C of warming, would require reducing emissions by approximately 3% per year.
- If the world's total GDP (the product of population and affluence) grows by 3% per year, then energy intensity would need to decline by 6% per year or so to achieve the necessary reductions in emissions.
- Reductions in the carbon intensity term, the amount of carbon dioxide emitted per unit of energy generated, that are required to stabilize the climate.

Technologies

- Reducing carbon intensity is code for switching from conventional combustion of fossil fuels to energy sources that do not release greenhouse gases
- Nuclear energy, carbon capture and sequestration, and energy sources known as *renewable energy*
  - *Solar photovoltaic or solar thermal methods*
  - *Wind Energy*
  - *Biomass energy*
  - *Nuclear energy*
  - *Carbon capture and storage*

Solar photovoltaic or solar thermal methods

- Photovoltaic energy is the most common form of solar energy
- It takes advantage of the fact that, when exposed to light, certain materials such as silicon produce electricity.
- Solar thermal energy, in contrast, uses mirrors to concentrate sunlight on a working fluid (such as an oil, molten salt, or pressurized steam), heating it to several hundred degrees Celsius. This hot fluid is then used to boil water and drive a turbine, which in turn drives a generator that produces electricity.
- the amount of solar energy falling on the planet is staggering –more than 100,000 TW.
- This is an enormous amount of energy compared to the amount humans consume, which is about 15 TW of primary power.
- Solar energy can supply power at a level of approximately 10–20 W/m2. To satisfy all human energy needs would therefore require roughly 1 million km2 to be covered with solar energy collectors, corresponding to 0.2% of the Earth's surface

Wind Energy

- This is a mature technology – the Dutch have been using wind energy for hundreds of years to do useful work, such as pumping water
- The largest ones are 130 m tall, the same as a 40-story building, with 125-m blades.
- A single one of these wind turbines can generate as much as 6 MW of power, which is approximately 1% of the power produced by a standard-size fossil fuel power plant
- Wind also has the problem of intermittency
- Wind farm generates power at a level of approximately 2 W/m2
- To satisfy human energy requirements would require covering approximately 1.5% of the Earth's surface area with wind farms containing a total of a few million windmills
- It should be noted that putting up windmills does not preclude using the land simultaneously for other activities, such as agriculture.
- Wind and solar energy sources remain more expensive than electricity from fossil fuels, and the intermittency problem has yet to be solved.
- Thus, we are not yet on the verge of a wholesale transition of our energy supply to these renewable sources

Biomass energy

- It refers to the process of growing crops and then burning them to yield energy.
- Because the carbon dioxide released from burning biomass was absorbed from the atmosphere during the growth of the plant, there is no net increase in carbon dioxide in the atmosphere
- It is an intuitively attractive energy source, but there are several issues that must be considered.
- First, the rate of photosynthesis limits the power generated by biomass to roughly 0.6 W/m2 of farmed land.
- Thus, to generate 15 TW would require that 15% or so of the land surface be devoted to growing biomass for energy – comparable to the area presently under cultivation today
- Considerations – Deforestation and method of farming
- Food, such as corn, as feedstock for biomass energy severely stresses the food supply.
- A Technological breakthrough will allow us to produce energy from waste biomass that does not have other uses, such as the waste from corn processing (e.g., corn stalk, corn cobs) or cellulosic biomass such as switch grass
- Corn-based ethanol: Automobiles that run on gasoline can be modified to use ethanol with a few inexpensive and minor modifications to the engine

Hydroelectric energy

- Hydroelectric energy is the most widespread renewable energy source in the world today, providing 16% of the world's electricity.
- Despite the many advantages of this energy source, it seems unlikely that this power source can be greatly increased.
- Many of the world's big rivers are already dammed, and new dams often cause local environmental problems and therefore generate significant opposition from those individuals living in the area

Nuclear energy

- Currently, nuclear reactors generate nearly 16% of the world's electricity.
- Although nuclear is not actually a renewable energy source, with the technology to recycle and reprocess spent nuclear fuel, there are centuries worth of uranium in the ground, even assuming a massive expansion of the world's nuclear generation capacity.
- Nuclear is a mature technology, so there are no questions about its technical feasibility
- Difficulties:

  Reactor safety –

  Nuclear waste –
- Waste is extraordinarily radioactive, and it must be safely isolated for many thousands of years. If it were released accidentally or intentionally released in a so-called dirty bomb, the resulting harm in both human cost and ecological damage could be severe.
- One way to reduce the quantity of waste is to reprocess the fuel, in which usable isotopes of plutonium and uranium are removed and converted back into fuel for another trip through the reactor.

Carbon capture and storage

- *.Also known as Carbon sequestration*
- This refers to a process by which fossil fuel is burned in such a way that the carbon dioxide generated is not vented to the atmosphere. Rather, the carbon dioxide is captured and placed in long-term storage
- An example of a CCS method is to expose the coal to steam and carefully controlled amounts of air or oxygen under high temperatures and pressures.
- Under these conditions, atoms in coal break apart and react with the water vapor, producing a mixture of hydrogen, carbon dioxide, and several other gases. The carbon dioxide is captured, while the other gases are burned in order to generate electricity.
- Once captured, the carbon dioxide must be stored. The most likely place to put the carbon dioxide is to inject it deep underground into porous sedimentary rocks, which are distributed widely around the world.
- The capacity of these rocks is large enough that they could conceivably hold all of the carbon emitted by human activities.
- Using available technology, approximately 85–95% of the carbon dioxide produced can be captured
- However, although CCS is a promising technology, it remains unproven because no large-scale CCS power plant has ever been built.

Policies to reduce carbon emissions

- *Free Market* : In economics, a free market is an economic system in which the prices of goods and services are determined by supply and demand expressed by sellers and buyers. Such markets, as modeled, operate without the intervention of government or any other external authority.
- Switching to carbon-free energy is something we want to do, wouldn't the free market take care of this all by itself?
- Efficiency of the equipment that you buy today is more efficient than the comparable piece of equipment that was available a few decades ago - primary factors behind the world economy's long-term decrease in energy intensity
- Increases in energy efficiency are, by themselves, insufficient to solve the climate change problem.
- Solving the climate problem requires a large-scale shift toward carbon-free energy that is not currently occurring. May never occur without government intervention.
- Economists call the costs of climate change imposed on the rest of the world by the widget manufacturer an ***externality*.**
- Because of the externality, the economically preferred outcome does not occur, resulting in what is frequently referred to as a ***market failure*.**
- When people can exploit and degrade some common assets for free, then the result is that these assets tend to be overutilized – resulting in a situation known as the ***tragedy of the commons***.

Policies to reduce carbon emissions

- To encourage the adoption of new technologies, most proposed mitigation policies put a price on emissions. Right now, emitting carbon dioxide to the atmosphere is free, and the costs of climate change are imposed on everyone in the world.
- In this situation, there is no incentive for the emitter to reduce emissions of greenhouse gases. Putting a price on emissions solves this by making emitters pay the full cost of their emissions, thereby giving them the appropriate incentive to adopt climate-safe energy technology.

Geoengineering

- Refers to actively manipulating the climate system in order to prevent the climate from changing – or even to reverse climate changes that have already occurred.
- Geoengineering efforts can be roughly divided into two categories: *solar radiation management* and *carbon-cycle engineering*.
- *Solar radiation management* refers to efforts to engineer a reduction in the amount of solar energy absorbed by the Earth, $E\text{in} = S\,(1 - \alpha)/4$
- Sun shade and increasing the albedo
- The most frequently discussed way to do this is to inject sulfur dioxide (SO2) into the stratosphere. Once in the stratosphere, this gas reacts with water vapor to form what are known as aerosols – liquid droplets that are so small that they have negligible fall speed.
- These aerosols reflect sunlight back to space, thereby increasing the albedo of the Earth and leading to cooling. Injection of sulfur into the stratosphere is the same mechanism by which volcanoes cool the planet
- Another option is to increase the reflectivity of clouds.
- If the particles in clouds are made smaller, clouds would become more reflective and raise the albedo of the Earth.

Geoengineering

Disadvantages

- Solar radiation management schemes focus on temperature, but temperature increases are only one of many impacts associated with climate change
- Reducing the amount of solar radiation reaching the Earth, in addition to cooling the planet, would also lead to changes in the amount and distribution of global precipitation.
- Geoengineering by a group of countries might be considered an act of war by another group of countries that suffer some type of weather-related injury at the same time
- As long as our society is increasing the amount of greenhouse gas in the atmosphere, geoengineering efforts must continually be strengthened in order to provide an ever-increasing cooling influence to keep the climate stable.

Geoengineering

Carbon-cycle engineering

- Planting trees is an example of carbon-cycle engineering.
- Another scheme is to add iron to the ocean. Iron is thought to be a limiting nutrient there, so the addition of iron will stimulate the growth of phytoplankton.
- As the phytoplankton grow, carbon dioxide will be drawn out of the atmosphere and into the ocean. The phytoplankton is then consumed by larger organisms, and subsequent biological activity creates a flux of dead organisms and fecal matter from surface waters into the deep ocean.
- This net transport of carbon from the upper layers into the deep ocean is known as the *biological carbon pump*. Thus, adding iron to the ocean has the net effect of drawing carbon dioxide out of the atmosphere and transporting it to the deep ocean.
- Another option is to remove carbon dioxide from the air chemically, which is often referred to as *air capture*. This is like CCS, but CCS removes carbon dioxide from the hot exhaust gas of a power plant whereas air capture removes carbon from the free atmosphere.
- This is an attractive option, but the amount of energy required with the use of today's technology is staggering

Geoengineering

- Real engineering of the carbon cycle, such as adding iron to the ocean, is risky. Because of significant uncertainties in our knowledge of how carbon cycles in the ocean, there is a possibility that that these schemes will not work
- Adding iron to the ocean might have unforeseen and serious impacts on ocean ecosystems
- Geoengineering is an appealing but risky approach to dealing with climate change. Although it may work, the risk exists that geoengineering may lead to unintended consequences that leave the world worse off.
- In addition, it may not address all impacts of climate change and may only be viable for a relatively short period of time (less than a century). Thus, in a world where climate change is handled responsibly through mitigation and adaptation, it is unlikely that geoengineering would be needed.
- Nevertheless, it is easy to imagine a future where the world makes no progress in reducing emissions. If, by the middle of the 21st century, emissions are large and climate change is out of control, geoengineering may represent the last hope for avoiding truly disastrous climate change.
- It is in this type of scenario that the deployment of geoengineering is a reasonable strategy. But even here, geoengineering is unlikely to be the final solution. Rather, it would be a way to buy time to let emergency mitigation efforts catch up and begin significantly reducing emissions

Mitigation policies

Politics

- United Nations Framework Convention on Climate Change (UNFCCC) -1992
  - *Stabilization of greenhouse gas concentrations in the atmosphere at a level that would* ***prevent dangerous anthropogenic interference with the climate system***. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally *to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner*

- The Paris Agreement has the goal to limit global warming to well below 2ºC and it was ratified by 174 countries

- The Kyoto Protocol, an international agreement linked to the UNFCCC, commits its Parties, which are developed countries, to binding carbon emission reduction targets

Personal actions

- Individual actions
  - Switching to energy efficient appliances such as LED lights
  - Recycling also helps.
  - Driving less or choosing an energy efficient car like a hybrid or an electrical car or a smaller vehicle will reduce your carbon footprint
  - Even better is riding your bicycle
- It is important that everybody does her/his part in making the world a better place
- Governmental actions such as a carbon tax or a cap-and-trade system will be able to accelerate the transition to renewable energy sources that we need to avoid potentially dangerous climate change
- Thus, perhaps the most important individual actions we can take is to vote and to engage in the political process to make change happen
- Part of that is talking to family, friends, neighbors and politicians

Mitigation policies

- The reduction of greenhouse gases emissions so as to avoid climate change
- Mitigation schemes will have little effect on the climate of the next few decades, but a successful mitigation effort would allow us to avoid large climate changes occurring in the second half of this century and beyond
- Reducing greenhouse-gas emissions requires improvements in the energy efficiency of our economy
- Converting our energy system to one that primarily utilizes carbon-free energy sources, such as solar, wind, nuclear, and CCS

Conventional regulations

- *Commandand- control* regulation, requires all emitters in a particular economic sector to meet a single standard
- Alternatively, regulations may limit total emissions of a pollutant, or enforce a standard of greenhouse gases emitted per kilowatt-hour generated (for power plants) or greenhouse gases emitted per mile driven (for cars)
- Weaknesses with this approach have been identified and it has been falling out of favor with regulators.
  - First, technologies specified (e.g., wind, CCS) may not actually turn out to be the best ones.
  - Second, the regulations force all emitters to meet the same emissions standards. This ignores the fact that some emitters can reduce emissions more cheaply than others.
  - Third, conventional regulations provide no incentive for the development of new technologies for emissions reductions beyond the specified target
- Little scope in policy circles of attempting to solve the climate change problem with conventional regulations

Market-based regulations

- Free market is unlikely to solve climate change without intervention from the government:
- The basic reason is that it is free to emit greenhouse gases into the atmosphere
- These emissions impose a cost, but it is on the rest of the world, not the emitter
- Because the costs of the emissions are not imposed on the emitter, there is no incentive for the emitter to make any effort to reduce emissions
- Make emitters pay for emitting greenhouse gases
- Making emitters pay for their emissions is a market-based solution. It does not tell anyone how much they can emit, or what technology to use – it only requires them to pay for whatever emissions they do make

Carbon tax

- Emitters have complete freedom to emit as many tons of greenhouse gas to the atmosphere as they choose, as long as they pay a specified fee to the government for each ton released to the atmosphere
- The carbon tax is cheaper because of its *flexibility* – it shifts reductions to the lowest marginal cost emitters, in this case.
- In this way, emissions reductions under a carbon tax are made where they are cheapest, which lowers overall cost to society.
- A carbon tax would be reasonably easy to implement. Most greenhouse gases come from fossil fuels, and these are produced at a relatively small number of sites.
- A carbon tax could be applied to the fossil fuel when it is extracted from the ground, using the administrative infrastructure for existing taxes, such as excise taxes on coal and petroleum.
- The price of the tax would then follow the fuel through the market, where the end user would finally pay it.
- A tax credit would be generated if the carbon is used in such a way that it was not released into the atmosphere (such as production of plastic or capture of carbon in coal combustion followed by sequestion)

Carbon tax

- As part of a long-term policy, the carbon tax would start out relatively small and, over several decades, gradually increase until emissions reached the target level.
- Gases other than carbon dioxide, such as methane or nitrous oxide, would also be taxed, but at a rate that takes into account how effective each one is at warming the planet.
- For example, 1 ton of methane contributes approximately 20 times more warming than a ton of carbon dioxide, so the tax on methane should be proportionately higher than the tax on carbon dioxide
- The net effect of a carbon tax is to raise the prices of goods and services by an amount determined by the amount of the greenhouse gases released.
- Goods and services that are produced with little or no emission of greenhouse gases will not experience price increases, whereas the costs of goods and services that require the emission of significant amounts of greenhouse gases may see large prices increases.

Carbon tax

- For activities that generate negative externalities (costs imposed on society, such as emitting greenhouse gases or smoking cigarettes), a free market prices these activities too low, leading to overconsumption of the associated good or service.
- Taxes on these activities will provide correction for this and reduce consumption, which produces a more socially beneficial outcome.

Cost of reducing emissions for Plants A and B

Emissions reduced by (tons)	Units emitted (tons)	Plant A's cost ($)		Plant B's cost ($)	
		Marginal	Total	Marginal	Total
0	10	–	–	–	–
1	9	1	1	2	2
2	8	2	3	4	6
3	7	3	6	6	12
4	6	4	10	8	20
5	5	5	15	10	30
6	4	6	21	12	42
7	3	7	28	14	56

Cap and trade

- Under cap and trade, the government issues a fixed number of permits each year, with each permit allowing the holder to emit a fixed amount (often 1 ton) of greenhouse gas to the atmosphere
- Emitters must hold permits for the amount of greenhouse gas they emit to the atmosphere
- The total number of permits issued sets a cap on total emissions. Emitters with extra permits can sell them to those needing additional permits (hence the *trade* part).
- The price of the permits is set by the market, not by the government
- If the marginal cost of reducing 1 ton of greenhouse gas emissions is less than the cost of the permit, then the emitters will pay to not emit that ton
- when a unit of greenhouse gas is emitted, a permit is retired. Therefore, the government must continually issue new permits to replace those that have been used
- One approach is for the government to auction the permits off. In that case, companies would buy the permits from the governments and then pass the cost of the permits on to their customers through higher prices for their products.

Offsets

- Actions taken to remove carbon dioxide from the atmosphere are known as *offsets*, which can be thought of as "negative emissions."
- Whether credit is given for offsets in a carbon tax or cap-and-trade regime, and how much credit, is one of the most contentious issues in the debate over climate policy
- Offsets are processes that remove carbon from the atmosphere – they can be thought of as negative emissions.
- Whether these are allowed to offset real emissions is one of the most contentious parts of emissions-reduction policy debates.
- Offsets should satisfy additionality for them to count. This means that the offsetting activity would not have occurred without the additional value of the activity from its impact on emissions.

Information and voluntary methods

- A final way to reduce emissions is simply to give people information.
- If people can be convinced that climate change is a serious problem, and then provided ways to address the problem, they may take some action to address it without any furtherprompting by the government.
- Although informational and voluntary approaches are quite useful and can be effective at encouraging people to make some changes to their behavior, these approaches generally do not compel people to make large or difficult changes
- Thus, informational and voluntary approaches will likely form part of our response to climate change. They will not, however, form the fundamental basis for our approach to reduce emissions.