HONR 229L: Climate Change: Science, Economics, and Governance
Discussion #17: The Economics of Climate Change, Part I

Ross Salawitch & Walt Tribett

rjs@atmos.umd.edu   wtribett@umd.edu

Class Web Site: http://www.atmos.umd.edu/~rjs/class/honr229L

ELMS Page: https://myelms.umd.edu/courses/1229919

1 November 2017
Announcements

- First Paper (35%)
  - 6 Nov deadline to guarantee comments on draft version
    - one received as of 31 Oct 2017!
  - **20 Nov** deadline for paper submission (Mon before Thnks)
  - 6 to 10 pages single spaced; must include references & can include figures, both of which are excluded from the page count
  - expands upon the topic of any class meeting, *other than* class meeting you have led
  - fine to submit via email, if so:
    - please use HONR 229L in the subject
    - send to me as well as Walt <wtribett@umd.edu>
Table 3. Net Energy Ratios for Various Energy Sources

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Net Energy Ratio</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil (global)</td>
<td>35</td>
<td>(Yandle, Bhattarai and Vijayaraghavan 2004)</td>
</tr>
<tr>
<td>Natural gas</td>
<td>10</td>
<td>(Hall 2008)</td>
</tr>
<tr>
<td>Coal</td>
<td>80</td>
<td>(Cleveland 2005)</td>
</tr>
<tr>
<td>Shale oil</td>
<td>5</td>
<td>(Hall 2008)</td>
</tr>
<tr>
<td>Nuclear</td>
<td>5-15</td>
<td>(Lenzen 2008; Murphy and Hall 2010)</td>
</tr>
<tr>
<td>Hydropower</td>
<td>&gt;100</td>
<td>(Hall 2008)</td>
</tr>
<tr>
<td>Wind</td>
<td>18</td>
<td>(Kubiszewski, Cleveland and Endres 2010)</td>
</tr>
<tr>
<td>Photovoltaic cells</td>
<td>6.8</td>
<td>(Battisti and Corrado 2005)</td>
</tr>
<tr>
<td>Ethanol (sugarcane)</td>
<td>0.8 – 10</td>
<td>(Hall, Cleveland and Kaufmann 1986),(Goldemberg 2007)</td>
</tr>
<tr>
<td>Ethanol (corn-based)</td>
<td>0.8 – 1.6</td>
<td>(Farrell, Pelvin and Turner 2006)</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>1.3</td>
<td>(Hall, Cleveland and Kaufmann 1986)</td>
</tr>
<tr>
<td>Farmed willow chips</td>
<td>55</td>
<td>(Keoleian and Volk 2005)</td>
</tr>
</tbody>
</table>

Adapted from Murphy and Hall (2010)
AT 16, Q1. Table 3 provides net energy ratios from various energy sources.

Based on your prior knowledge and/or material covered in this class:

a) what aspect of Table 3 is least surprising?

b) what aspect of Table 3 is most surprising?

not surprised that:

coal and other fossil fuels have a very large net energy ratio

low net energy ratio yielded by biofuels (at 1.3) as a result of the high input costs to extract the useable fuel

wind and solar have a lower net energy ratio than oil and coal? (Sci Am has energy ratio of wind exceeding that of coal)
b) what aspect of Table 3 is most surprising?

net energy ratio was relatively low for nuclear ranging from 5-15. For a energy source that is heavily invested in for many nations (such as France), I would expect the output to far surpass the input ✓

net energy ratio for the hydropower is so high.. It's greater than 100, higher than coal. I'm also surprised that more investments aren't being made in hydro power if it has such a high net energy ratio, since hydroelectric power only accounts for about 2-3% of energy in the US ✓

the efficiency of wind is so low. I figured that there was not much energy to be expended in capturing wind energy, so the ratio would be very high ? (Sci Am has energy ratio of wind exceeding that of coal)

photovoltaic cells only have a net energy ratio of 6.8. I thought that even though they were expensive and difficult to make, the fact that they can harvest energy from the sun and not run out of fuel would make its net energy ratio at least a little higher that 6.8. ✓ Caveat: over what period of time is the net energy ratio found. Because solar is truly the gift that keeps on giving

relatively small net energy ratio of natural gas. For what seems to be the "stepping stone" for renewable energy, a lot of energy is put into obtaining natural gas ? (Table 3 has factor of 7 below that of coal; Sci Am has the difference at a factor of 2.5)

farmed willow chips have actually a high net energy ratio X (looks like an error, as the reference does not support the value in the table)

shale oil at such a considerably low net energy ratio ✓
HONR 229L: Climate Change: Science, Economics, and Governance

https://www.scientificamerican.com/magazine/sa/2013/04-01/
HONR 229L: Climate Change: Science, Economics, and Governance

LIQUID FUELS: Crude Oil Gives the Best Energy Return—Today

Each raw material has to be extracted—from oil reservoirs or vegetation—and refined into gasoline or other fuels. Each step lowers the EROI. Values are recent industry averages or from typical installations.

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Global Production, 2011 (million barrels a day)</th>
<th>Energy consumed during production steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional oil</td>
<td>69</td>
<td>Drilling → Pumping → Refining</td>
</tr>
<tr>
<td>Ethanol from sugarcane</td>
<td>0.4</td>
<td>Cane production/transportation → Fermentation → Cane cleaning and crushing → Distillation</td>
</tr>
<tr>
<td>Biodiesel from soy</td>
<td>0.1</td>
<td>Farming → Soybean crushing</td>
</tr>
<tr>
<td>Tar sands</td>
<td>1.6</td>
<td>Mining → Steam heating → Refining</td>
</tr>
<tr>
<td>Heavy oil from California</td>
<td>0.3</td>
<td>Steam heating → Pumping → Refining</td>
</tr>
<tr>
<td>Ethanol from corn</td>
<td>1.0</td>
<td>Farming → Fertilizer → Refining</td>
</tr>
</tbody>
</table>

https://www.scientificamerican.com/magazine/sa/2013/04-01/
Mileage Return on Investment: Electricity Wins

Transportation fuels are not created equal. A car will go farthest on energy invested in generating electricity, then on conventional gasoline, followed by ethanol made from sugarcane. The miles traveled are based on the energy required to make each fuel, as well as its energy density (for example, ethanol’s energy density is roughly 67 percent of gasoline’s). For electric cars, this value does include electricity transmission, but not manufacturing batteries.

- **Electric car running on U.S. grid electricity**: 3,600 miles
- **Gasoline from conventional oil**: 2,000 miles
- **Ethanol from sugarcane**: 1,400 miles
- **Biodiesel from soy**: 1,100 miles
- **Gasoline from tar sands**: 900 miles
- **Gasoline from heavy oil**: 300 miles

https://www.scientificamerican.com/magazine/sa/2013/04-01/

Copyright © 2017 University of Maryland.
This material may not be reproduced or redistributed, in whole or in part, without written permission from Ross Salawitch.
Mileage Return on Investment: Electricity Wins

Transportation fuels are not created equal. A car will go farthest on energy invested in generating electricity, then on conventional gasoline, followed by ethanol made from sugarcane. The miles traveled are based on the energy required to make each fuel, as well as its energy density (for example, ethanol’s energy density is roughly 67 percent of gasoline’s). For electric cars, this value does include electricity transmission, but not manufacturing batteries.
Table 4 provides an estimate of the cost of providing electricity from various sources. The authors have decided to use capacity factor in an interesting mathematical manner, for the rank ordering of "capital cost to produce the same amount of electricity as one kW of capacity running continuously" given in Table 4.

Briefly, how has capacity factor been used and state whether you feel the use of capacity factor in this manner is appropriate?

I do not think capacity factor was used appropriately in this manner because actual output of renewable energy sources varies and it is difficult to truly estimate the capacity factor. It would be better if there was a capacity factor range. For example, solar and wind energy sources are very intermittent and their actual output would greatly vary depending on the circumstances (weather, season, etc.). To more accurately represent their capacity factors, the authors should have taken the lowest and highest actual outputs compared to their maximum potentials to make a range.
AT 16, Q3. The reading emphasizes the potential for energy efficiency to play an increasingly important role, in the transition of society towards reducing the emission of greenhouse gases.

In a few sentences, describe what is stated about energy efficiency and also express an opinion as to whether or not you believe the statement:

energy efficiency is the “alternative energy source” with the “greatest potential” (for societal benefit) is correct.

I agree with the above statement because energy efficiency is a cheap and environmentally-friendly option that does not carry many of the associated costs of other renewable sources. For example, energy efficiency programs cost "an average of only about one-half the cost of providing new energy supplies" (26). Additionally, energy efficiency addresses increasing energy demands without undertaking the high initial investment costs of renewable energies. Lastly, individuals (especially in developed countries) are very wasteful and could definitely conserve more energy than they currently do. Energy efficiency programs would emphasize sustainable actions/behaviors and would hopefully instill green habits into individuals who currently do not practice them.
HONR 229L: Climate Change: Science, Economics, and Governance

AT 16, Q3. The reading emphasizes the potential for energy efficiency to play an increasingly important role, in the transition of society towards reducing the emission of greenhouse gases.

In a few sentences, describe what is stated about energy efficiency and also express an opinion as to whether or not you believe the statement:

energy efficiency is the “alternative energy source” with the “greatest potential” (for societal benefit) is correct.

A very bold assertion is made by Timmons et al that "based on the untapped potential for energy efficiency it has been estimated that global demand could be held steady during 26 this time period“ ... I do believe that an emphasis should be placed on energy efficiency, especially because as Timmons et al points out, the EPA names energy efficiency as one of the most "cost effective" methods of cutting fossil fuel consumption and conserving the environment. However, I still think that a greater emphasis should be placed on a complete overhaul of our energy generation systems and integrating renewable energy production into every aspect of our industries and transportation systems ... The world's population will continue to rise and with it the proliferation of the leakage effect. We need to take on the more large-scale and looming energy questions first, and take them on aggressively.

---

If we ever plan to completely move from our fossil fuel dependence, then we will need to focus on renewable energy sources. Increasing energy efficiency is great, but it does not have the greatest potential to save us in the long run.
AT 16, Q3. The reading emphasizes the potential for energy efficiency to play an increasingly important role, in the transition of society towards reducing the emission of greenhouse gases.

In a few sentences, describe what is stated about energy efficiency and also express an opinion as to whether or not you believe the statement:

energy efficiency is the “alternative energy source” with the “greatest potential” (for societal benefit) is correct.

The costs per kilowatt in renewable sources are mostly upfront, and not based on buying fuel, so they are very sensitive to interest rates, unlike non-renewable energy, which is not. There are too many outside variables to simply compare them like this.

---

However, it discounts the fact that while renewables have high start-up costs, their operating costs and the potential to pollute – which ends up costing more long-term — are much lower than non-renewables.

---

Energy efficiency has a lower marginal cost but a higher marginal benefit than finding new energy sources.
The reading emphasizes rather strongly that “directing the bulk of energy subsidies toward fossil fuels tilts the playing field in their favor” and provides numerical estimates for the subsidies directed towards the fossil fuel industry.

a) State the dollar amounts given in the reading, for the subsidies directed towards fossil fuels

b) The reading provides no detail as to what these subsidies entail. Pick a fossil fuel sector (i.e., electricity, transportation, heating fuel, etc) and, based on your own quick research, succinctly provide the missing detail.

c) explain the conundrum that the dollar amount of subsidies directed towards the fossil fuel industry is so large, while at the same time the cent per kilowatt-hour benefit enjoyed by the fossil fuel industry is so much less than the same benefit provided to the renewable energy industry

a) global subsidies to fossil fuels are $100 billion per year in the electricity sector (pg 28), $200 billion in transportation (pg 28), and $550 billion in all sectors (box 5)


c) The problem with fossil fuel vs renewable subsidies is multi-faceted, including the fact that fossil fuels provide an immediate solution to heating and energy problems that a shift towards renewables do not. Additionally, there is politics surrounding the situation, as a shift away from fossil fuels would be construed as getting rid of jobs that are economically beneficial to many areas in the US. Lastly, the large start up costs of renewables – despite the longer-term benefits and the more efficient use of the renewable energy subsidy money – acts as a deterrent, both for the government and the taxpayers whose dollars fund the subsidies.
$1 TRILLION (OR MORE?)
IN GLOBAL FOSSIL FUEL SUBSIDIES
& THE URGENT NEED FOR TRANSPARENCY

In 2009, G20 leaders pledged to phase out fossil fuel subsidies but very little concrete action has followed since. Part of the reason for this failure is that there is not clarity on how much of our money governments provide in fossil fuel subsidies.

Recent reports put fossil fuel subsidies at a combined 3/4s of a trillion (and perhaps as much as a trillion or more) dollars globally per year.

HOW MUCH IS A TRILLION?

- $10,000,000,000,000 (10 billion USD)

Cost per year of eradicating global hunger (FAO estimates)

$100 BILLION
Production Subsidies

$45 BILLION
Consumption Subsidies
in Developed Countries

$630 BILLION
Consumption Subsidies
in Developing Countries

But there are somewhere on the order of between $105 billion and over a trillion dollars in even more subsidies lurking beneath the surface, yet still being tapped by the fossil fuel industry.

Governments need to admit these exist, and eliminate them as soon as possible.

http://priceofoil.org/fossil-fuel-subsidies/
Fossil fuel subsidies are a staggering $5 tn per year

A new study finds 6.5% of global GDP goes to subsidizing dirty fossil fuels

In this photo taken on November 19, 2015, smoke belches from a coal-fired power station near Datong, in China's northern Shanxi province. Photograph: Greg Baker/AFP/Getty Images

However, economic efficiency requires that energy prices reflect not only supply costs but also (i) environmental costs like global warming and deaths from air pollution and (ii) taxes applied to consumer goods in general. The broader notion of energy subsidies—what we term “post-tax subsidies”—arises when consumer prices are below supply costs, plus a Pigouvian tax* to reflect environmental damages and general consumer taxes.

Post-tax subsidies, which are the main focus here, are the relevant concept from an economic perspective, as they reflect the gap between consumer prices and economically efficient prices—the portion of this gap due to undercharging for supply costs, environmental costs, and general consumer taxes, is irrelevant from an efficiency perspective. Moreover, environmental damages from energy consumption are just as real as are supply costs (even if harder to measure), and any failure to fully internalize them means that some of the damages from fossil fuel use are not borne by fuel consumers and this constitutes a form of subsidy.

* named after British economist Arthur C. Pigou
Key findings include:

- Fossil fuel subsidies have been defended by a Congress influenced by $350 million in campaign contributions and lobbying expenditures by the fossil fuel industry – which equates to an 8,200% return on investment.

- The cost of annual federal fossil fuel production subsidies is equivalent to the projected 2018 budget cuts from Trump’s proposals to slash 10 public programs and services that benefit some of the nation’s most vulnerable children and families.

- Government giveaways in the form of permanent tax breaks to the fossil fuel industry – one of which is over a century old – are seven times larger than those to the renewable energy sector.

http://priceofoil.org/2017/10/03/dirty-energy-dominance-us-subsidies/
TABLE 1:
Direct Spending on Section 1603 Grants, R&D, and other Programs in 2010 and 2013 ($ million, nominal).

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Section 1603</th>
<th></th>
<th>R&amp;D</th>
<th></th>
<th>Other</th>
<th></th>
<th>Total</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>-</td>
<td>-</td>
<td>307</td>
<td>202</td>
<td>46</td>
<td>74</td>
<td>353</td>
<td>276</td>
</tr>
<tr>
<td>HC</td>
<td>-</td>
<td>-</td>
<td>9</td>
<td>34</td>
<td>45</td>
<td>50</td>
<td>54</td>
<td>84</td>
</tr>
<tr>
<td>Nuclear</td>
<td>-</td>
<td>-</td>
<td>446</td>
<td>406</td>
<td>46</td>
<td>9</td>
<td>492</td>
<td>415</td>
</tr>
<tr>
<td>Renewables</td>
<td>4,481</td>
<td>8,169</td>
<td>1,060</td>
<td>976</td>
<td>26</td>
<td>11</td>
<td>5,567</td>
<td>9,156</td>
</tr>
<tr>
<td>Wind</td>
<td>4,002</td>
<td>4,273</td>
<td>58</td>
<td>49</td>
<td>1</td>
<td>1</td>
<td>4,061</td>
<td>4,323</td>
</tr>
<tr>
<td>Solar</td>
<td>359</td>
<td>2,941</td>
<td>320</td>
<td>284</td>
<td>22</td>
<td>6</td>
<td>701</td>
<td>3,231</td>
</tr>
<tr>
<td>Other-RE</td>
<td>120</td>
<td>955</td>
<td>682</td>
<td>643</td>
<td>3</td>
<td>4</td>
<td>805</td>
<td>1,602</td>
</tr>
<tr>
<td>Biomass</td>
<td>112</td>
<td>310</td>
<td>301</td>
<td>251</td>
<td>1</td>
<td>1</td>
<td>414</td>
<td>562</td>
</tr>
<tr>
<td>Geothermal</td>
<td>4</td>
<td>310</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td>314</td>
</tr>
<tr>
<td>Hydropower</td>
<td>-</td>
<td>196</td>
<td>11</td>
<td>10</td>
<td>-</td>
<td>1</td>
<td>11</td>
<td>207</td>
</tr>
<tr>
<td>Other</td>
<td>4</td>
<td>139</td>
<td>368</td>
<td>380</td>
<td>1</td>
<td>-</td>
<td>373</td>
<td>519</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4,481</strong></td>
<td><strong>8,169</strong></td>
<td><strong>1,822</strong></td>
<td><strong>1,618</strong></td>
<td><strong>163</strong></td>
<td><strong>144</strong></td>
<td><strong>6,466</strong></td>
<td><strong>9,931</strong></td>
</tr>
</tbody>
</table>

AT 16, Q4a. The reading emphasizes rather strongly that “directing the bulk of energy subsidies toward fossil fuels tilts the playing field in their favor” and provides numerical estimates for the subsidies directed towards the fossil fuel industry.

a) State the dollar amounts given in the reading, for the subsidies directed towards fossil fuels.

b) The reading provides no detail as to what these subsidies entail. Pick a fossil fuel sector (i.e., electricity, transportation, heating fuel, etc) and, based on your own quick research, succinctly provide the missing detail.

c) explain the conundrum that the dollar amount of subsidies directed towards the fossil fuel industry is so large, while at the same time the cent per kilowatt-hour benefit enjoyed by the fossil fuel industry is so much less than the same benefit provided to the renewable energy industry.

c) Looking at subsidies in a price per kilowatt-hour, the subsidies are lowering the price of per kilowatt-hour of wind energy, concentrated solar energy, and solar photovoltaics more than they are lowering the price per kilowatt-hour of fossil fuels. In this way, the subsidies are actually helping countries switch to renewable energy sources ... However, this is not enough to successfully "force" companies to switch to renewable sources of energy – more needs to be done on a larger scale in order to achieve this.
AT 16, Q4b. The phrase internalizing externalities seems like an oxymoron. Yet this might be the best hope for avoiding catastrophic climate change due to societal dependence on fossil fuels.

Provide a brief essay explaining this phrase and either support, or refute, the view that internalizing externalities is indeed is our best hope for avoiding catastrophic climate change.

If externality costs were included in energy prices, renewable energies would not only be more competitive but the transition to renewables would also occur faster. For example, if externalities were included in the cost of conventional electricity, onshore wind, wave energy, concentrated solar, and potentially offshore wind would be more competitive energy sources (Figure 7). Additionally, the "social marginal cost" path in Figure 8 accounts for the higher costs of externalities and demonstrates that the transition to renewables would occur much sooner (t2 instead of t1).

---

Altering the prices of fossil fuels to be less appealing is one of the biggest things that can be done to avoid a climate change disaster. One way certain regions of the world are internalizing externalities is through Pigovian taxes. These taxes increase the prices of fossil fuels, either causing consumers to limit their fossil fuel energy use or resort to different sources of energy. This is why it is no surprise that countries in Europe are taking the lead in renewable energy development, as those same countries have the highest Pigovian taxes on fossil fuels. The language that almost everyone can understand is that of the dollar Euro, and it will be the biggest tool in combating our fossil fuel dependency.
AT 16, Q4b. The phrase internalizing externalities seems like an oxymoron. Yet this might be the best hope for avoiding catastrophic climate change due to societal dependence on fossil fuels.

Provide a brief essay explaining this phrase and either support, or refute, the view that internalizing externalities is indeed is our best hope for avoiding catastrophic climate change.

On a planet filled with business-driven individuals blind to the intrinsic values of nature, the only way to curb their detrimental actions is to speak their language, economics. Though the sounds of trees falling and mountaintops being blown from their bodies may not reach the ears of the environmentally-blind business people, less pennies in their pocket will seize their immediate attention.
The Economics of Climate Change, Part I

Ross Salawitch
Figure 12: Energy-Related Carbon Dioxide Emissions, Projected to 2040

Source: EIA, 2016.

Note: The Organization for Economic Cooperation and Development (OECD) includes primarily industrialized countries, and non-OECD comprises the rest of the world, including developing countries and including China.
Figure 12: Energy-Related Carbon Dioxide Emissions, Projected to 2040

OECD Population, 2013: 1.257 billion
OECD Emissions, 2013: 12 billion metric tons of CO₂
OECD per capita emissions, 2013: 9.5 tons of CO₂ per person
World Population: 1950-2050

Source: U.S. Census Bureau, International Data Base, August 2017 Update.

World Population, 2013: 7.162 billion

https://www.census.gov/population/international/data/worldpop/graph_population.php
Non-OECD Population, 2013: 7.162 billion − 1.257 billion = 5.9 billion
Non-OECD Emissions, 2013: 20 billion metric tons of CO₂
Non-OECD per capita emissions, 2013: 3.4 tons of CO₂ per person
If the 5.9 billion people in Non-OECD nations were to emit at 9.5 tons per person, then the global emissions of CO2 would be:

13 billion tons (OECD)
+ 56 billions tons (non-OECD)

69 billions tons (i.e., more than double today’s level!)
What is the **moral obligation** of the Developed World to assist the Developing World to attempt to have the global emissions of CO₂ fall at least below the RCP 4.5 curve shown in Figure 14.

If the 5.9 billion people in Non-OECD nations were to emit at 9.5 tons per person, then the global emissions of CO₂ would be:

- 13 billion tons (OECD)
- + 56 billions tons (non-OECD)

**69 billions tons** (i.e., more than double today’s level!)

*Source: IPCC, 2014d, p. 11.

*Note: Upper line represents IPCC RCP 4.5 scenario (moderate stabilization in the range of 530 – 580 ppm CO₂ accumulation) and lower line represents IPCC RCP 2.6 scenario (stronger stabilization at 430 – 480 ppm CO₂ accumulation).*
AT 17, Q2

The Stern Review on the Economics of Climate Change, published in 2007, was extraordinarily influential. I have posted links to both the 4-page and 27-page executive summaries of this document in the auxiliary material column for Wednesday’s class. I hope everyone will be able to at least have a look at the 4-page PDF file prior to class: it’s only 4 pages and this was a watershed report!

This week’s assigned reading lists three differences between the Stern Review and prior work of Nordhaus.

a) What are these three differences?
The Stern Review on the Economics of Climate Change, published in 2007, was extraordinarily influential. I have posted links to both the 4-page and 27-page executive summaries of this document in the auxiliary material column for Wednesday’s class. I hope everyone will be able to at least have a look at the 4-page PDF file prior to class: it’s only 4 pages and this was a watershed report!

This week’s assigned reading lists three differences between the Stern Review and prior work of Nordhaus.

a) What are these three differences?

1. Choice of discount rate
2. Treatment of uncertainty
3. Assessments of economic costs of action to mitigate climate change
Figure 14: Present Value of a Future $100 Cost or Benefit: The Effects of Different Discount Rates
Figure 13: Increasing Damages from Rising Global Mean Surface Temperature

Note: The three different models (ENVISAGE, DICE, and CRED) shown in this figure give damage estimates that are similar at low to moderate levels of temperature change, but diverge at higher levels, reflecting different assumptions used in modeling.
Stern Review

Nicholas Stern:

https://en.wikipedia.org/wiki/Nicholas_Stern,_Baron_Stern_of_Brentford
There is still time to avoid the worst impacts of climate change, if we take strong action now.

The cost of stabilising climate are significant but manageable; delay would be dangerous and much more costly.

- Stabilisation will require ~80% drop in F.F. emissions.
- Could cost ~1% of GDP if we begin to take strong action now ← 2007 😞

International action needed and it need not cap aspirations for growth of poor countries.

- Carbon markets in rich countries should deliver financial support for low-carbon development through the Clean Development Mechanism.

Key elements of future international frameworks should include:

- Emissions trading (Mon)
- Technology cooperation (this occurred in the effort to save the ozone layer)
- Action to reduce deforestation (critically important, but not easy to accomplish)
- Adaptation (some change is coming; poorest countries most vulnerable)

http://www.atmos.umd.edu/~rjs/class/honr229L/readings/stern_short_executive_summary.pdf
The impacts of weather events influenced by human-induced climate change and direct human health consequences of pollution from fossil fuel use are currently causing, on average, $240 billion a year in economic losses, damages and health costs—or about 40 percent of the current growth of the United States economy (Table 1). This amount equals 1.2 percent of the GDP. This is a conservative estimate because the sum does not include economic losses due to additional consequences of extreme weather events, such as decreased agricultural yields or health costs for premature deaths due to heat waves. This total is more than three times the amount spent for the Department of Education ($67 billion) or five times the amount for the Department of Homeland Security ($48 billion) for this year.39

These massive costs are being borne mainly by individuals, not the Government or the private sector.

https://feu-us.org/case-for-climate-action-us2
Stabilizing greenhouse gas emissions is insufficient; at the current rate of emissions carbon dioxide and other greenhouse gases will continue to accumulate in the atmosphere.

Stabilizing accumulations of greenhouse gases will require a significant cut below present emission levels.
Carbon Dioxide Stabilization

CO₂ is long lived:
society must reduce emissions soon
or we will be committed to dramatic
future increases!

curve that levels off at ~550 ppm
has emissions peaking in 2027
(less than 20 years from now!)

Created by Robert Rohde, for a defunct website called Global Warming Art
Pacala and Socolow: CO₂ Stabilization Wedges

Fig. 1. (A) The top curve is a representative BAU emissions path for global carbon emissions as CO₂ from fossil fuel combustion and cement manufacture: 1.5% per year growth starting from 7.0 GtC/year in 2004. The bottom curve is a CO₂ emissions path consistent with atmospheric CO₂ stabilization at 500 ppm by 2125 akin to the Wigley, Richels, and Edmonds (WRE) family of stabilization curves described in (11), modified as described in Section 1 of the SOM text. The bottom curve assumes an ocean uptake calculated with the High-Latitude Exchange Interior Diffusion Advection (HILDA) ocean model (12) and a constant net land uptake of 0.5 GtC/year (Section 1 of the SOM text). The area between the two curves represents the avoided carbon emissions required for stabilization. (B) Idealization of (A): A stabilization triangle of avoided emissions (green) and allowed emissions (blue). The allowed emissions are fixed at 7 GtC/year beginning in 2004. The stabilization triangle is divided into seven wedges, each of which reaches 1 GtC/year in 2054. With linear growth, the total avoided emissions per wedge is 25 GtC, and the total area of the stabilization triangle is 175 GtC. The arrow at the bottom right of the stabilization triangle points downward to emphasize that fossil fuel emissions must decline substantially below 7 GtC/year after 2054 to achieve stabilization at 500 ppm.

Pacala and Socolow, Science, 2004


Copyright © 2017 University of Maryland.
This material may not be reproduced or redistributed, in whole or in part, without written permission from Ross Salawitch.
### Pacala and Socolow: CO₂ Stabilization Wedges

<table>
<thead>
<tr>
<th>Action</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economy-wide carbon-intensity reduction (emissions/$GDP)</td>
<td><strong>Energy efficiency and conservation</strong> Increase reduction by additional 0.15% per year (e.g., increase U.S. goal of 1.96% reduction per year to 2.11% per year)</td>
</tr>
<tr>
<td>1. Efficient vehicles</td>
<td><strong>Fuel shift</strong> Increase fuel economy for 2 billion cars from 30 to 60 mpg</td>
</tr>
<tr>
<td>2. Reduced use of vehicles</td>
<td>Decrease car travel for 2 billion 30-mpg cars from 10,000 to 5000 miles per year</td>
</tr>
<tr>
<td>3. Efficient buildings</td>
<td>Cut carbon emissions by one-fourth in buildings and appliances projected for 2054</td>
</tr>
<tr>
<td>4. Efficient baseload coal plants</td>
<td>Produce twice today’s coal power output at 60% instead of 40% efficiency (compared with 32% today)</td>
</tr>
<tr>
<td>5. Gas baseload power for coal baseload power</td>
<td>Replace 1400 GW 50%-efficient coal plants with gas plants (four times the current production of gas-based power)</td>
</tr>
<tr>
<td>6. Capture CO₂ at baseload power plant</td>
<td><strong>CO₂ Capture and Storage (CCS)</strong> Introduce CCS at 800 GW coal or 1600 GW natural gas (compared with 1060 GW coal in 1999)</td>
</tr>
<tr>
<td>7. Capture CO₂ at H₂ plant</td>
<td>Introduce CCS at plants producing 250 MtH₂/year from coal or 500 MtH₂/year from natural gas (compared with 40 MtH₂/year today from all sources)</td>
</tr>
<tr>
<td>8. Capture CO₂ at coal-to-synfuels plant</td>
<td>Introduce CCS at synfuels plants producing 30 million barrels a day from coal (200 times Sasol), if half of feedstock carbon is available for capture</td>
</tr>
<tr>
<td>Geological storage</td>
<td>Create 3500 Sleipners</td>
</tr>
<tr>
<td>Action</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td></td>
</tr>
<tr>
<td>9. Nuclear power for coal power</td>
<td></td>
</tr>
<tr>
<td>10. Wind power for coal power</td>
<td></td>
</tr>
<tr>
<td>11. PV power for coal power</td>
<td></td>
</tr>
<tr>
<td>12. Wind H₂ in fuel-cell car for gasoline in hybrid car</td>
<td></td>
</tr>
<tr>
<td>13. Biomass fuel for fossil fuel</td>
<td></td>
</tr>
<tr>
<td>14. Reduced deforestation, plus reforestation, afforestation, and new plantations.</td>
<td></td>
</tr>
<tr>
<td>15. Conservation tillage</td>
<td></td>
</tr>
<tr>
<td>Details</td>
<td></td>
</tr>
<tr>
<td>Add 700 GW (twice the current capacity)</td>
<td></td>
</tr>
<tr>
<td>Add 2 million 1-MW-peak windmills (50 times the current capacity) &quot;occupying” $30 \times 10^6$ ha, on land or offshore</td>
<td></td>
</tr>
<tr>
<td>Add 2000 GW-peak PV (700 times the current capacity) on $2 \times 10^6$ ha</td>
<td></td>
</tr>
<tr>
<td>Add 4 million 1-MW-peak windmills (100 times the current capacity)</td>
<td></td>
</tr>
<tr>
<td>Add 100 times the current Brazil or U.S. ethanol production, with the use of $250 \times 10^6$ ha (one-sixth of world cropland)</td>
<td></td>
</tr>
<tr>
<td>Decrease tropical deforestation to zero instead of 0.5 GtC/year, and establish 300 Mha of new tree plantations (twice the current rate)</td>
<td></td>
</tr>
<tr>
<td>Apply to all cropland (10 times the current usage)</td>
<td></td>
</tr>
</tbody>
</table>

*Nuclear fission

*Renewable electricity and fuels

*Forests and agricultural soils

Copyright © 2017 University of Maryland.
This material may not be reproduced or redistributed, in whole or in part, without written permission from Ross Salawitch.
Carbon Emission, 1902 to 2015

Data Source: Carbon Dioxide Information Analysis Center (CDIAC)
Carbon Emission, 1902 to 2015

Data Source: Carbon Dioxide Information Analysis Center (CDIAC)
When did China pass the U.S.?

Data Source: Carbon Dioxide Information Analysis Center (CDIAC)
Carbon Emission, 1902 to 2015

Data Source: Carbon Dioxide Information Analysis Center (CDIAC)

Copyright © 2017 University of Maryland
This material may not be reproduced or redistributed, in whole or in part, without written permission from Ross Salawitch.
Cumulative Carbon Emission, U.S., 1902 to 2015

Data Source: Carbon Dioxide Information Analysis Center (CDIAC)

Data Source: Carbon Dioxide Information Analysis Center (CDIAC)

Copyright © 2017 University of Maryland
This material may not be reproduced or redistributed, in whole or in part, without written permission from Ross Salawitch.
Cumulative Carbon Emission, Big Four, 1902 to present

Data Source: Carbon Dioxide Information Analysis Center (CDIAC)
Per Capita Carbon Emission, Big Four, 1902 to present

Data Source: Carbon Dioxide Information Analysis Center (CDIAC)
WHAT CAN WE LEARN from each other?

- Environment: You can’t tackle one without the other
- Poverty

Make our HAND PRINTS

- Decrease our FOOT PRINTS!
- Developed
- CO2
- UNSUSTAINABLE

We want to be like THEM!

- Developing
- Coz

Data is skewed but so are the DREAMS

#EDD15
