Saving the World – and Humanity

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OLLI Fall 2015

Saving the World: Really?!?

Isn't that arrogant in the extreme?

Who – or what – is *the world?*

Save the world from *what?*

Does the world *want* to be saved?

Can the world *be* saved?

Is the world *willing* to do what's *necessary* to be saved?

Life is good as it is; *why bother?*

Climate change

Under a policy of business as usual:

- CC is the greatest existential threat to human welfare going forward
- CC is the greatest threat to the welfare and diversity of life forms going forward
- If we believe we have an obligation, or even an opportunity, to stabilize the planet into the foreseeable future, to give immediate future generations a chance at reasonable quality of life such as we've enjoyed, then we need to get on with serious efforts to mitigate CC

Climate change: the problem

Planet Earth is getting significantly warmer, with melting of glaciers and Arctic ice, rising sea levels, loss of coral reefs, loss of species, acidification of oceans, increasing intensity of precipitation and aridity, &c.

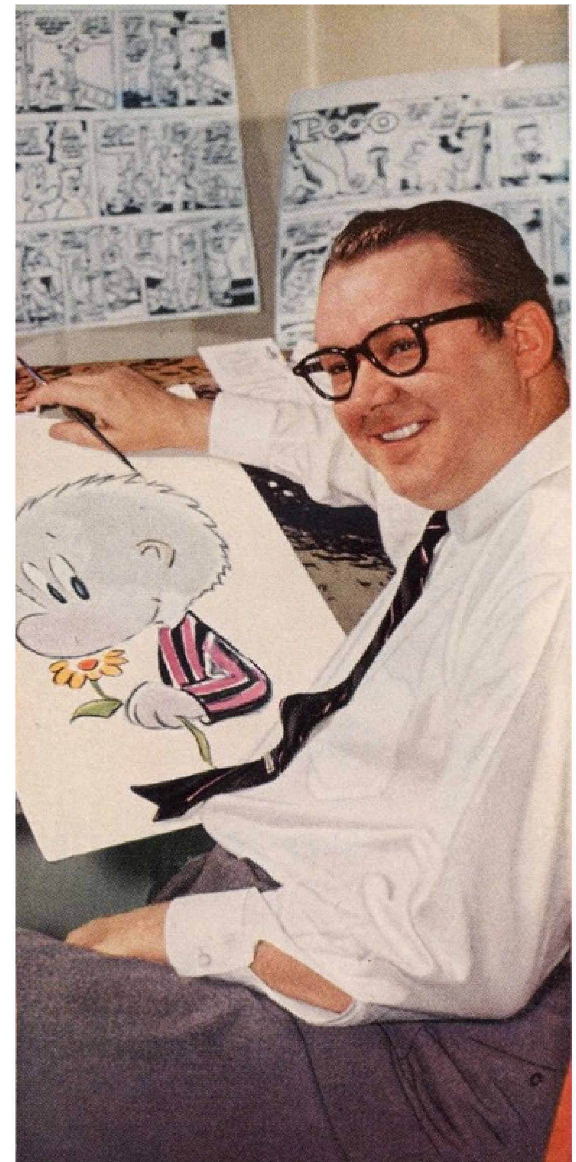
What's going on ???


AH, POGO, THE BEAUTY OF THE FOREST PRIMEVAL GETS ME IN THE HEART.
IT GETS ME IN THE FEET, PORKYPINE.
IT IS HARD WALKIN' ON THIS STUFF.
YEP, SON, WE HAVE MET THE ENEMY AND HE IS US.

Pogo and Walt Kelly

Walt Kelly

- Cartoonist and commenter on human nature
- Initially worked with Walt Disney Studios, on *Fantasia*, *Pinocchio*, and *Dumbo*
- Created *Pogo* in 1948, using critters in the Okefenokee Swamp to communicate his sage observations about the foibles of his fellow man over the next 26 years
- "He is us" was penned for the Earth Day observation in 1971



Climate change: the problem

So, yeah, *we* are the problem

- We need energy to support our way of life
- We've discovered a seemingly unending supply of coal, oil and natural gas to produce energy
- However, burning these "fossil fuels" produces enormous amounts of carbon dioxide
- CO2 accumulates in the atmosphere and the oceans, producing a greenhouse effect that warms the Earth and changes ocean chemistry, with the results previously described

Class Objectives (1)

Anthropogenic climate change (ACC)

- What is ACC?
- How ACC came into being and how it is evolving
- History of the Earth's climate
- How ACC compares to previous climate change
- Potential consequences of ACC
  - Manageable, unmanageable
  - Predictable (incremental), unpredictable (abrupt, discontinuous)
- The future of ACC
  - What humans could be doing: mitigation, adaptation
  - Trajectories of outcomes from various human responses
  - Barriers to human responses

Class Objectives (2)

Novel specific proposals to mitigate (prevent) ACC

- 100% renewable electricity, with hydrogen storage and electrification of transportation
- Policy considerations to drive adoption of solutions
- The power of positive thinking to motivate and support human response sufficient to the challenge

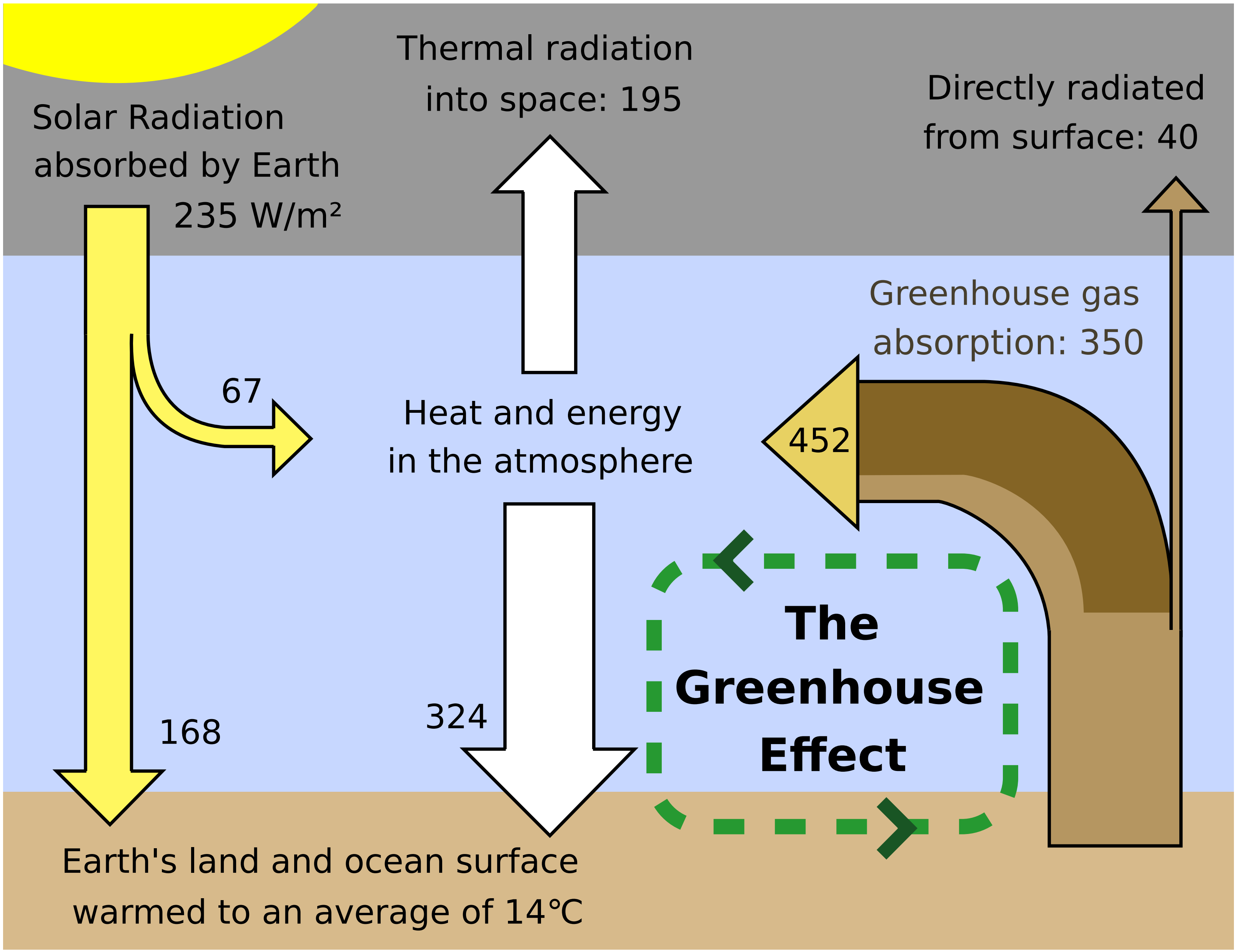
What is ACC?

ACC is a code name for a set of alterations in Earth systems primarily due to rising CO_2 emissions

- Rising atmospheric CO_2 concentration
- Rising average global temperature (global warming)
- Offshoots of global warming
- Offshoots of excess CO_2

Sub-optimal term: fails to capture the scope, immediacy and urgency of the issue

- "ICA: Impending Carbon Apocalypse"?



Solar Radiation
absorbed by Earth
235 W/m²
Thermal radiation
into space: 195
Directly radiated
from surface: 40
Greenhouse gas
absorption: 350
67
Heat and energy
in the atmosphere
452
The
Greenhouse
Effect
168
324
Earth's land and ocean surface
warmed to an average of 14℃

Rising atmospheric CO_2 level

Svante Arrhenius (1859-1927)

- Swedish physicist / chemist
- Father of physical chemistry
- "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground" - 1896
- Attributed rising atm. [CO_2] to human combustion of fossil fuels; considered it likely beneficial

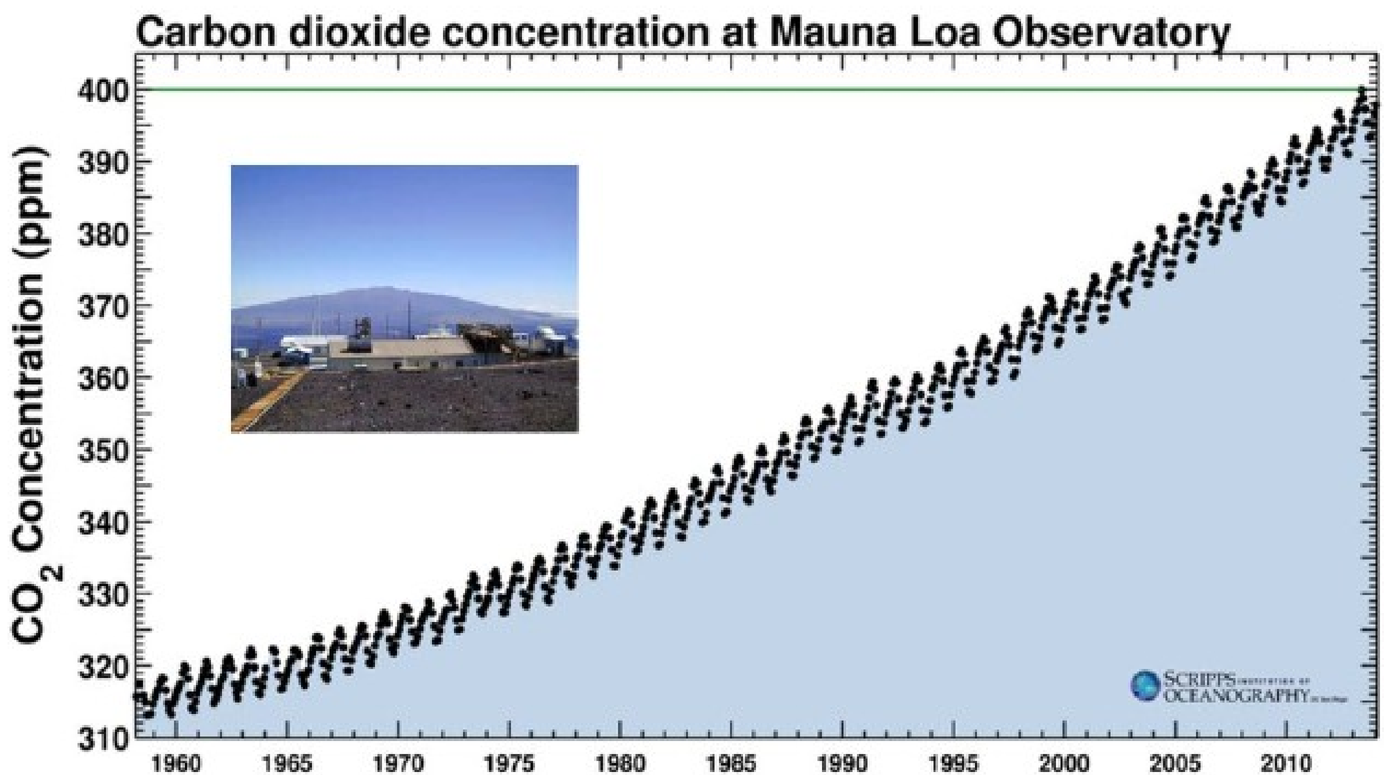
Rising atmospheric CO_2 level

Charles David Keeling (1928-2005)

- Geochemist / oceanographer
- Scripps Institute of Oceanography
- Developed instrument to measure atm [CO_2]
- Instrument deployed at Mauna Loa observatory (Hawaii) in 1958
- By 1963, warned of rate of [CO_2] rise and its potential consequences
- Continuous monitoring for over 40 years established the "Keeling curve" central to climate change understanding

Rising CO2 levels

Keeling Curve: Measured CO_2 Concentration (Mauna Loa, Hawaii)



http://keelingcurve.ucsd.edu/

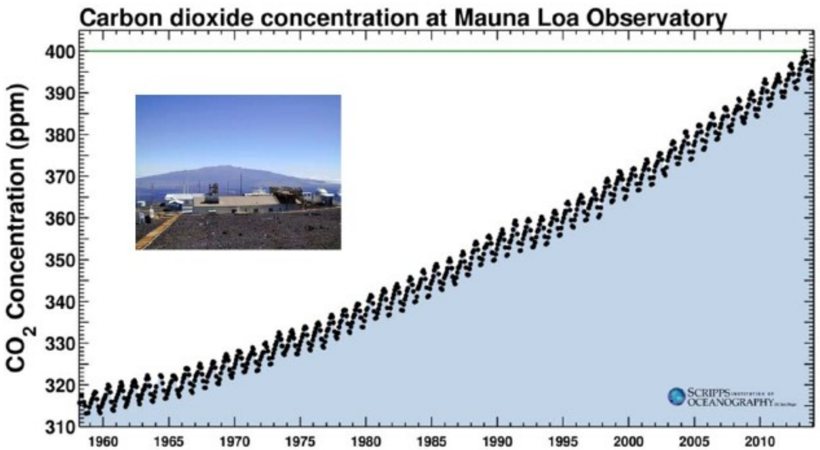
Keeling curve: [CO2] vs time

Annual seasonal variation in [CO2] due to uptake and release by Northern Hemisphere vegetation

Steady rise due to emissions from human combustion of fossil fuel

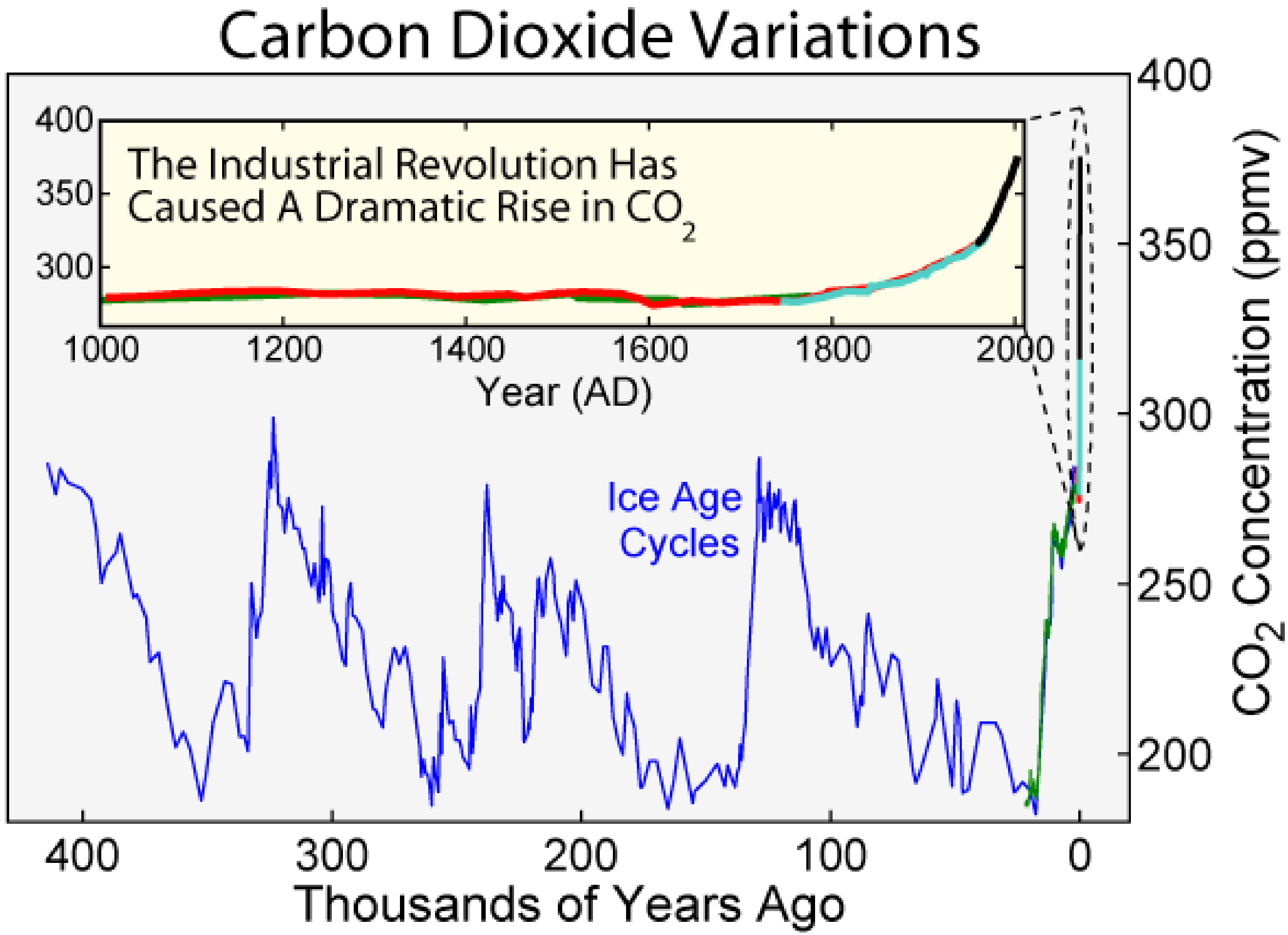
Rise from 315 ppm in 1960 to 400 by 2015

Keeling Curve: Measured CO_2 Concentration (Mauna Loa, Hawaii)

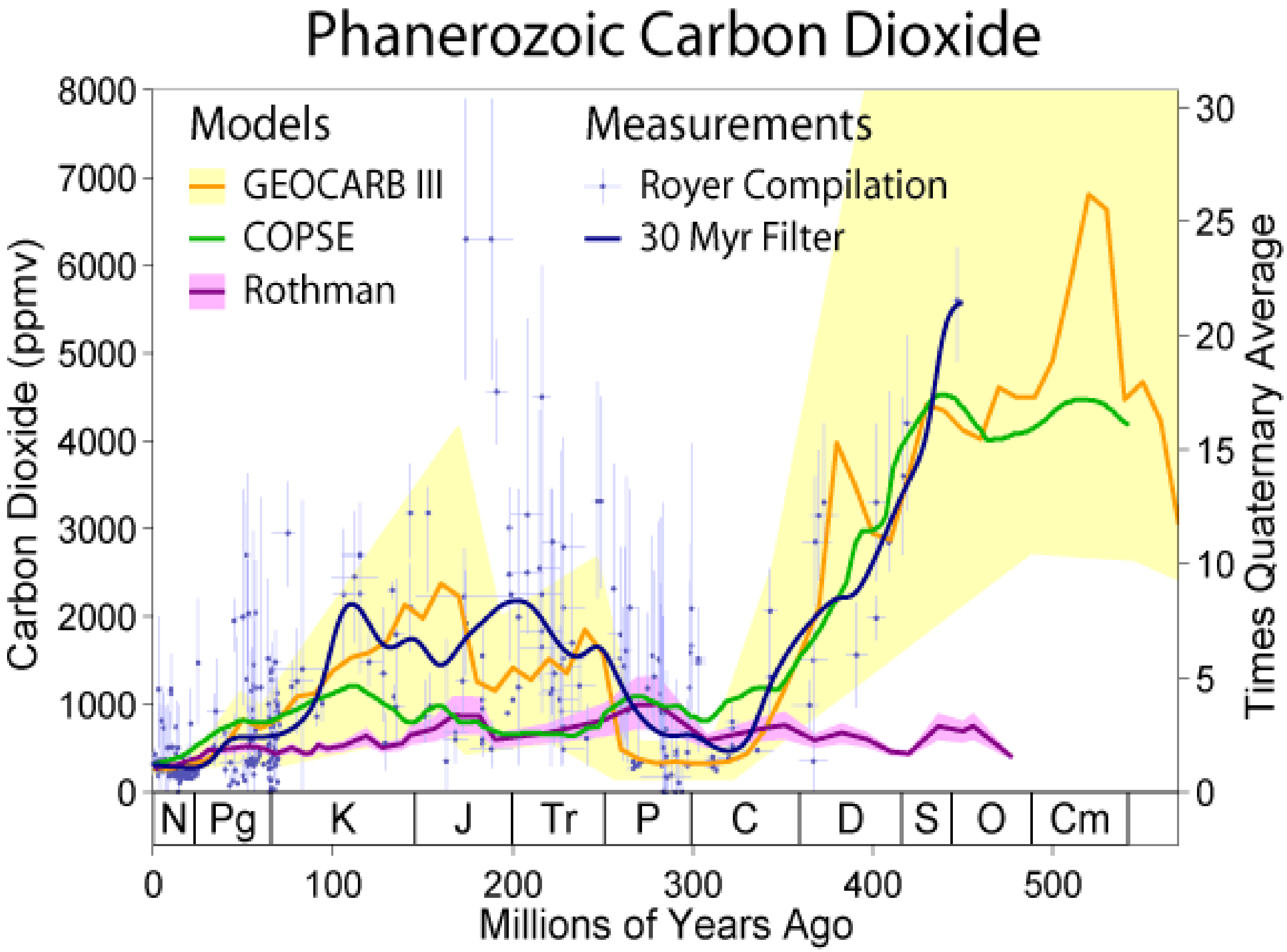


http://keelingcurve.ucsd.edu/

Global [CO2] over millenia



Global [CO2] over eras

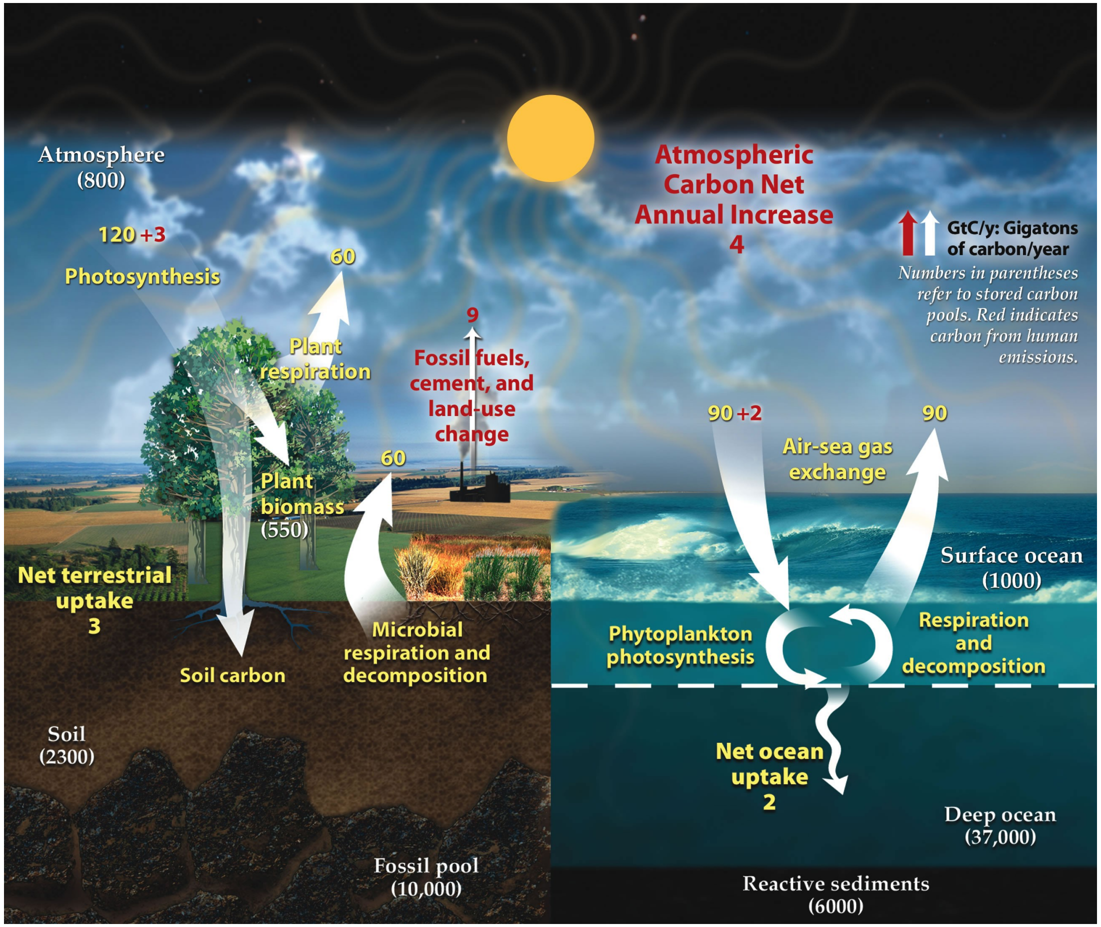


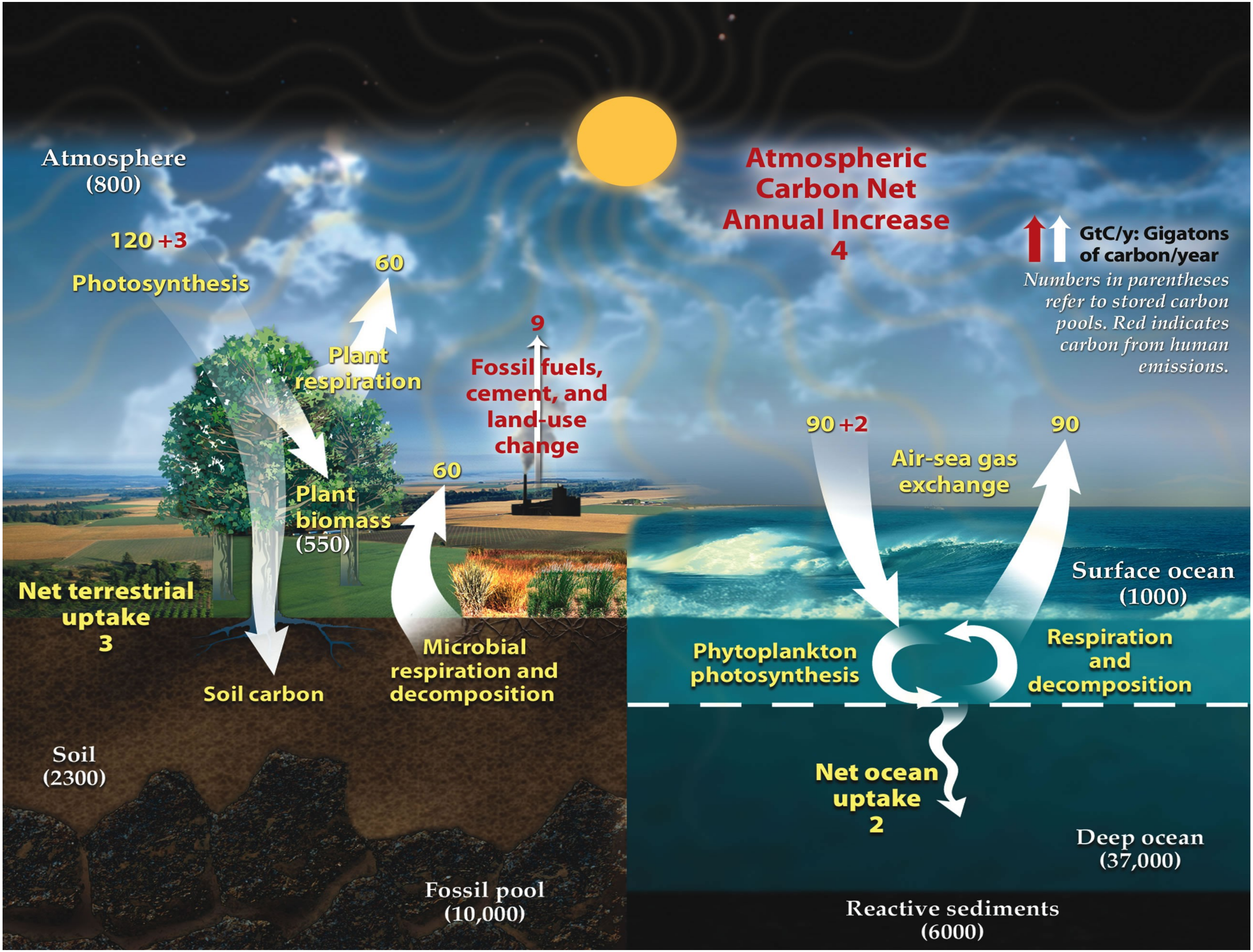
International efforts via UN

Initiatives of the United Nations to address CC

- IPCC 1988
- UNFCCC 1992
- Kyoto Protocol 1997
- Copenhagen 2009
- Many others

Earth's carbon cycle




Atmosphere
(800)
120 +3
Photosynthesis
60
Plant
respiration
9
Fossil fuels,
cement, and
land-use
change
Atmospheric
Carbon Net
Annual Increase
4
GtC/y: Gigatons
of carbon/year
Numbers in parentheses
refer to stored carbon
pools. Red indicates
carbon from human
emissions.
90 +2
90
Air-sea gas
exchange
60
Plant
biomass
(550)
Net terrestrial
uptake
3
Surface ocean
(1000)
Microbial
respiration and
decomposition
Soil carbon
Phytoplankton
photosynthesis
Respiration
and
decomposition
Soil
(2300)
Net ocean
uptake
2
Deep ocean
(37,000)
Fossil pool
(10,000)
Reactive sediments
(6000)

CC effects all bad - not?

Most often, attention gets focused on negative, especially dire, effects of CC

- Risks “bad news fatigue”, denial as coping mechanism

In actuality, some effects could be beneficial

- Reduced mortality from cold-related diseases in cold-dominant climates
- Increased crop yields

Credibility will be compromised by dwelling solely on negative effects without giving positive effects their due

On the other hand, enough concern is needed to motivate action and avoid procrastination

CC effects manageable – or not

Manageable vs. unmanageable

- Manageable effects are those which may be successfully controlled by a combination of improving technology and wealth: health effects, agriculture
- Unmanageable effects are largely or completely outside our control: sea level rise, increasing hurricanes, acidification of oceans, loss of species

CC effects predictable – or not?

Predictable and continuous

- Sea level rise vs. temperature without feedback
- Crop yields vs. temperature
- Adaptation reasonably likely

Unpredictable and discontinuous

- Sea level rise with feedback (ice sheet melt)
- Ocean acidification effects cascading through the food chain
- Adaptation possibly difficult and unreliable

CC effects uniform – or variable?

Winners and losers

- Consequences are local
- Small sea level rise obliterates certain islands and widely effects low-lying countries (Bangladesh)
- Hurricanes more strongly affects certain regions (Central America)
- Wealthier nations able to adapt more readily, less impact on economy

Possible responses to CC

Mitigation (prevention)

- Undertaking measures to slow or prevent CC
- Specifically, reducing CO2 emissions

Geoengineering

- For example, putting tiny particles in atmosphere to reflect sunshine

Adaptation

- Living with CC by responding to its effects: e.g., migration from areas inundated by sea level rise

Decisions, decisions

Do nothing

- Easiest, cheapest (short-term)

Do everything possible to stop CC

- Precautionary principle, especially in view of unpredictable hazards
- "We broke it, we should fix it"
- Moral arguments for preventing extinction, intergenerational equity

Find a rational middle ground guided by economics

- Resources limited; they must be judiciously allocated to maximize human welfare
- Market approach - favored by economists
- Use hard data where possible – monetary valuation of market activities such as production, mitigation and adaptation costs, and damages
- Tools such as contingent valuation methodology for non-market activities and resources
- Formulate policy to give proper signals to markets

Intergenerational considerations

Expenses to reduce carbon emissions must be incurred today

Benefits of reducing carbon emissions now (mitigation of CC) will be experienced in the (distant) future

Advancing wealth and technology will reduce cost of future mitigation and adaptation relative to current costs

Is it fair to ask that *we*, who will not be alive in the future to enjoy the benefits, incur the costs?

Is it fair to allow *us,* who will not bear the damages of CC, to emit carbon freely in the present without cost?

International considerations

Susceptibility to consequences of CC is not uniformly distributed

- Island nations and coastal populations are at higher risk than highlanders

CC cannot be stopped by the actions of one nation or even one regional consortium

- A harmonized convention among nations emitting 90% of annual CO2 is essential to effective mitigation

Decisions, decisions

What should we do to stop CC? Nothing, "everything possible", or something in between?

Right now, we are doing nothing!

Doing everything possible would require a global "going to war against CC" mentality; is that conceivable?

International conventions have attempted to find a middle ground: no success thus far, but efforts continue

Meanwhile, IPCC has done an excellent job of compiling information, defining gaps in knowledge and projecting outcomes as a basis for the international negotiations

Cost-benefit analysis

Faced with limited resources and a suite of alternative uses of capital, CBA is an objective tool for determining investment(s) that providing the greatest welfare

CBA as applied to CC:

- Use temperature targets as the outcome variable
- Calculate abatement cost vs. temperature – falls with T
- Calculate damages vs. temperature – rises with T
- Plot both relationships on single chart
- Plot sum – U-shaped curve
- Find minimum sum → optimal solution at trough of U

Cost-benefit analysis

CBA is one aspect of integrated analysis model (IAM)

IAM combines the economic and scientific components into a single integrated analysis

DICE (Dynamic Integrated Climate - Economy) model is one of several

- Developed by William Nordhaus, Yale economist
- Following results and graphics taken from DICE model as shown in Nordhaus' book, **The Climate Casino**

Cost-benefit analysis of mitigation cost vs. damages

Y-axis: Cost as % of GDP

X-axis: Global temp limit

Cost of damages increases with rising temp limit

Cost of mitigation decreases as limit rises

Total cost falls to a minimum, then rises, as limit increases

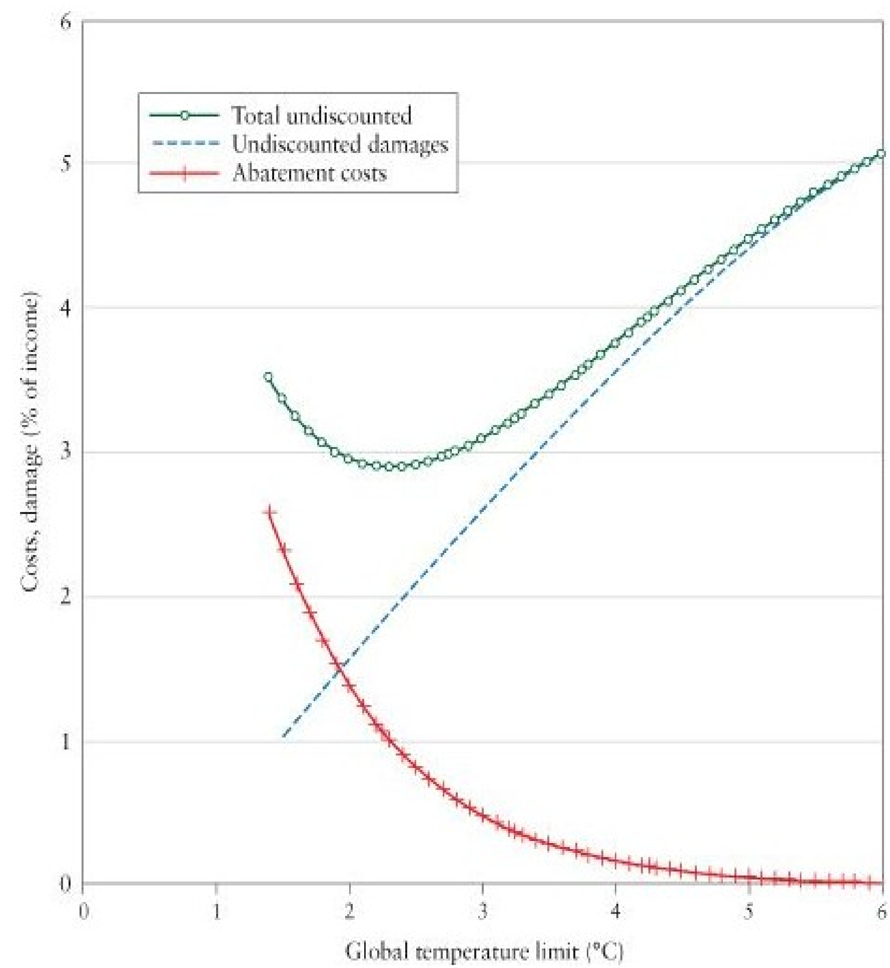


Figure 29. Total costs of different temperature targets assuming 100 percent efficiency and no discounting. This figure shows the

Cost-benefit analysis of mitigation cost vs. damages

100% participation, 0% discount

No catastrophic damages or tipping points

Optimal point occurs at 2°

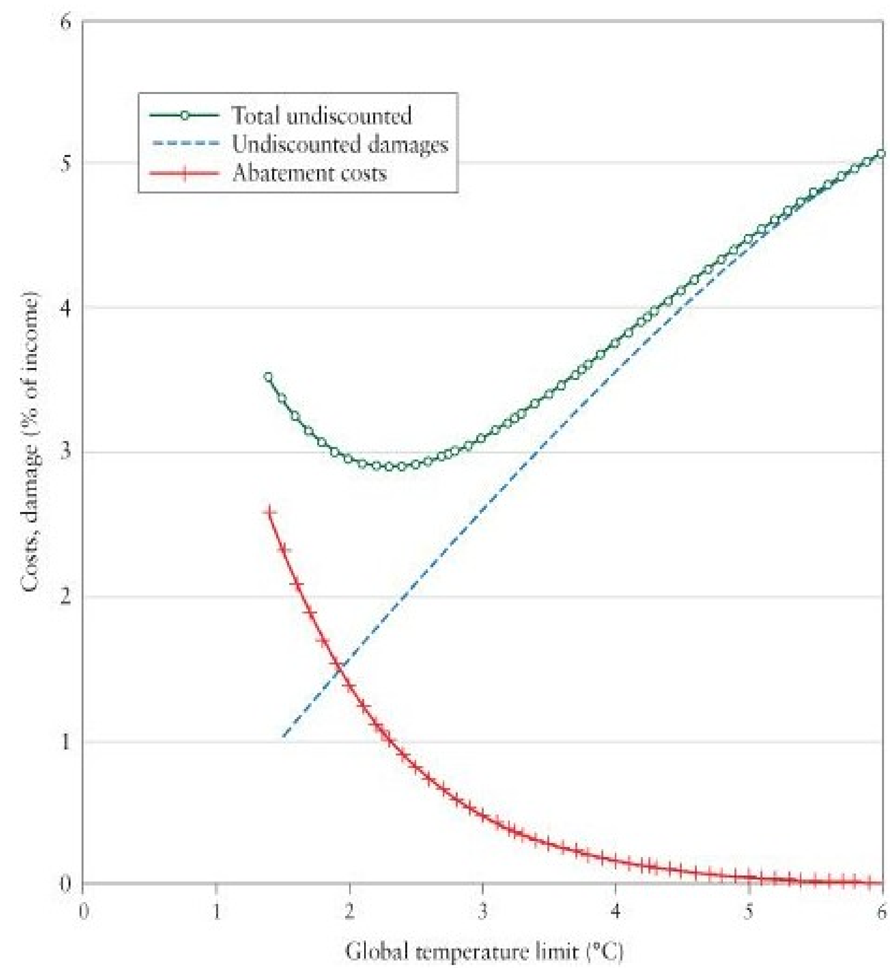


Figure 29. Total costs of different temperature targets assuming 100 percent efficiency and no discounting. This figure shows the

Cost-benefit analysis of mitigation cost vs. damages

50% participation, 0% discount

No catastrophic damages or tipping points

Optimal point occurs at 3.8°

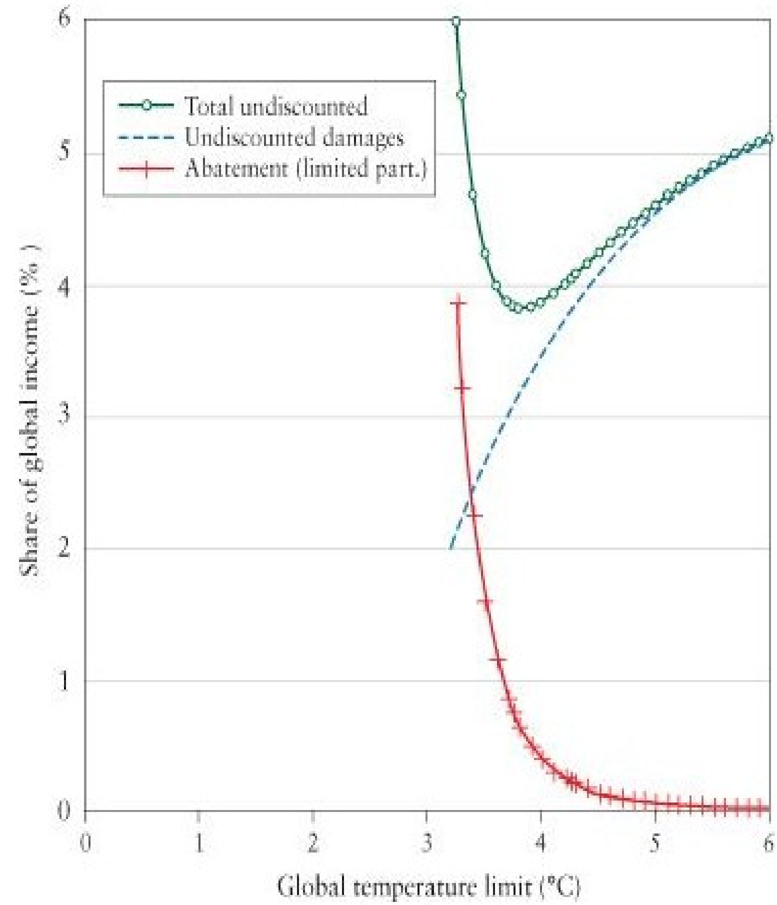


Figure 30. The temperature target rises with inefficient abatement without discounting. The second case assumes inefficient abatement

Cost-benefit analysis of mitigation cost vs. damages

50% participation, 4% discount

No catastrophic damages or tipping points

Optimal point occurs at 4°

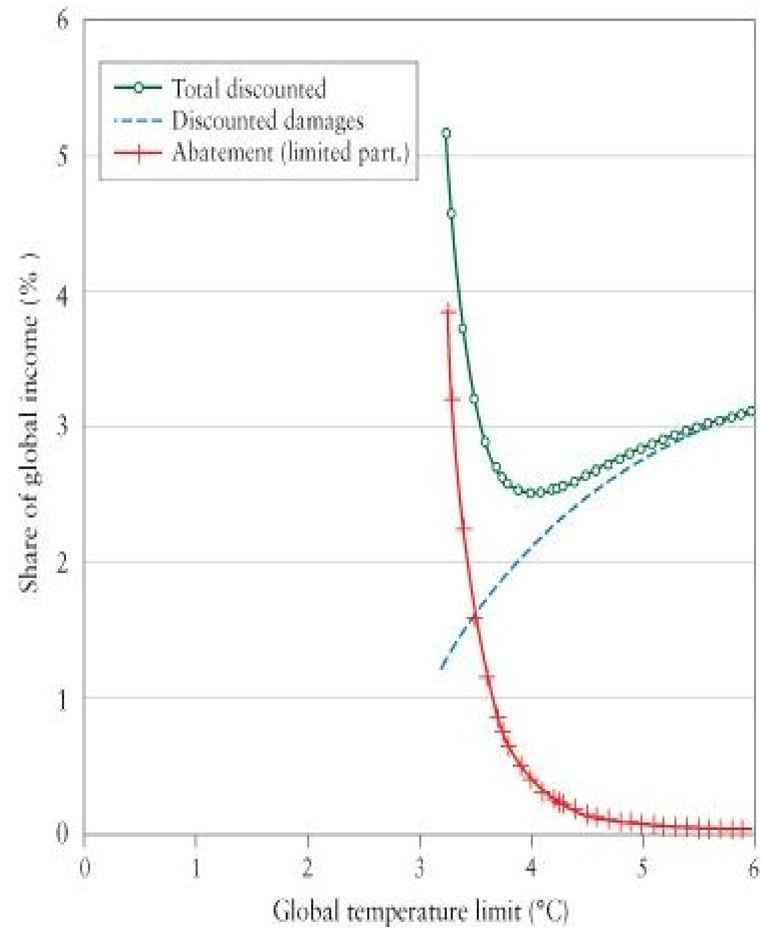


Figure 31. Total costs of different targets assuming limited participation and discounting of future incomes. This calculation shows the

Cost-benefit analysis of mitigation cost vs. damaaes

50% participation, 4% discount

Tipping point at 3.5°

Optimal point occurs at 3.5°, the tipping point

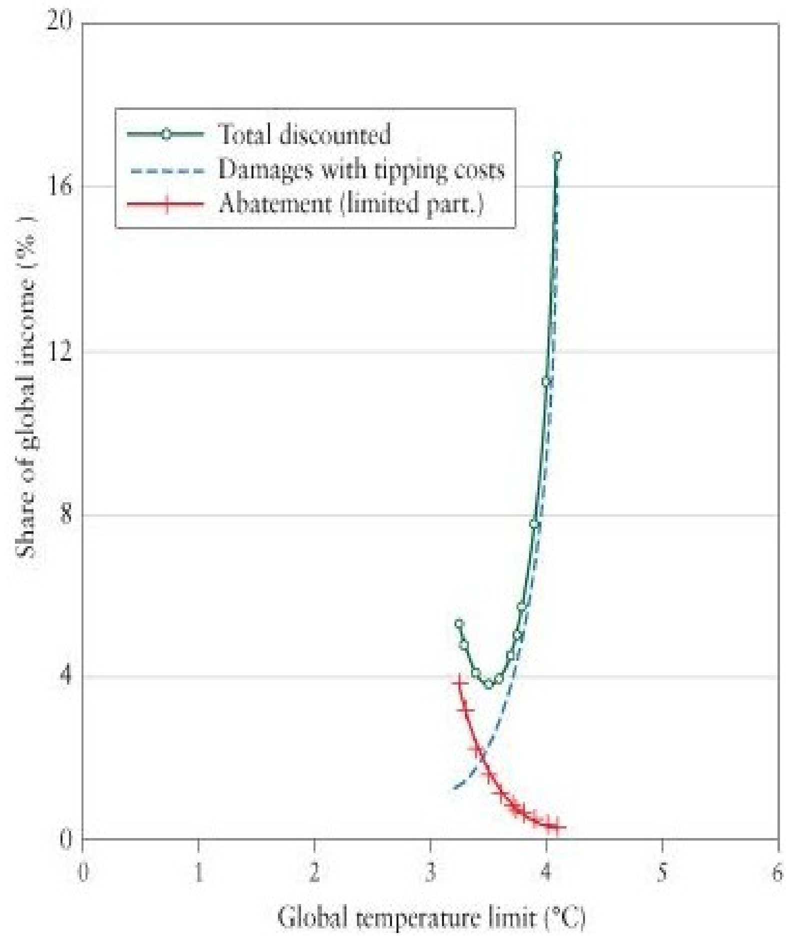


Figure 32. Climate policy with a sharp tipping point at 3½°C. The final example has a threshold or tipping point at a temperature increase of 3½°C in a situation with discounting and limited participation. This

Cost-benefit analysis of mitigation cost vs. damages

Problems of CBA as applied to CC

- Estimates of damage function - wide ranges
- Estimates of cost function - sensitive to participation rates
- Tipping points and associated damages – almost no information known
- Appropriate discount rate – depends on perspective

Helpful in a heuristic sense, but too imprecise as basis for policy formulation

Looking ahead, we will find...

Limiting factor in mitigating climate change at any predefined goal is not technical

- The technology may not be cheap or optimal, but it does exist

Limiting factors are economic and behavioral

Even if economic barrier were inconsequential (which it is), there are daunting behavioral barriers

- Pushback from powerful potential losers
- Inertia / procrastination
- Future benefits vs. immediate costs; discounting

Policies to guide desired behavior

Regulations

- Limit amount of CO_2 emissions allowed

Incentives

- Rebates / subsidies for purchase of equipment that reduces CO_2 emissions

Carbon tax

Carbon emission cap-and-trade

Carbon tax

Favored solution by Nordhaus and many economists

- Efficient, easy to implement, and utililizes normal market function to achieve goal

Revenues from carbon tax reduce other tax rates, so overall tax burden is unchanged

Ultimate cost is (appropriately) borne by those benefiting from goods and services produced by carbon-emitting energy sources

- As it is now, emitting carbon is "free goods"; those doing so are, in effect, receiving a subsidy paid from future damages – how fair is that?

Carbon tax

Amount of carbon tax based on target of maximum temperature

DICE model suggests $25/ton to limit to 2.5°

Range of rates from other models from ½ to 2x that amount

Tax would rise gradually to damp down CO2 emissions due to increasing population and wealth

But won't that cause household expenses to rise dramatically?

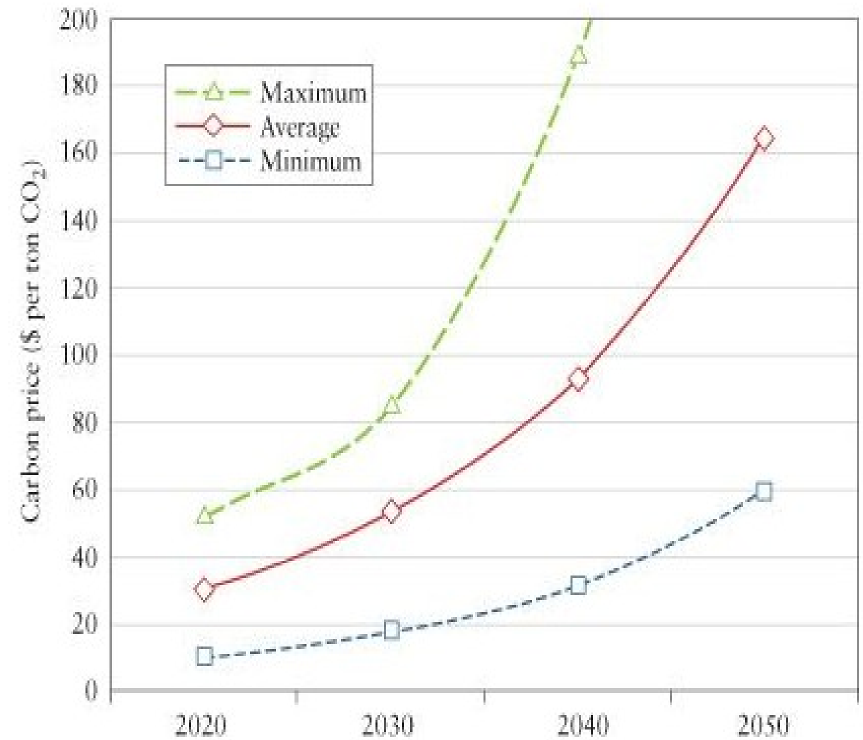


Figure 33. Illustrative carbon prices needed for a 2½°C temperature limit. This figure shows target price paths for CO_2 that would lead to a maximum temperature rise of around 2½°C. These results are from a group of thirteen models and show the central tendency as well as

Effect of carbon tax on consumers

Carbon tax set at \$25/ton CO2, for example

Greatest impact is on electricity prices, due to their reliance on coal (20% increase)

Driving (8%) and flying (6%) next most affected

Some behaviors will be modified – e.g., taking vacations near home rather than foreign travel

However, overall household consumption cost only affected 1%

Table 9. Impacts of a \$25 per ton CO_2 price.

Example	Tons of CO_2	Increase in spending due to \$25 CO_2 price	Increase in spending (%)
Year's electricity use	9.34	\$233.40	19.45
Year's driving	4.68	\$116.90	7.79
Economy class transcontinental flight	0.67	\$16.80	5.61
One year's household communication services	0.01	\$0.36	0.04
One year's household financial services	0.02	\$0.41	0.04
One year's household consumption	29.48	\$737.00	0.92

Effect of carbon tax on prices

Carbon tax set at $25/ton CO2 initially and rising gradually over decades

Temperature limited to 2.5°

Cost as % of GDP never more than 1.25%

Table 10. Economic impacts of proposed carbon tax, United States, 2010–2030.

Year	Tax rate (2005 \$/ton CO_2)	Emissions (billion tons CO_2)	Revenues (2005 billion \$)	Revenues (% of GDP)
2010	0	6.3	0	0.00
2015	25	5.9	147	0.96
2020	30	5.5	168	0.97
2025	42	5.4	225	1.14
2030	53	5.2	277	1.25

Comparing methods of reducing emissions

Carbon tax or cap-and-trade achieve substantial reductions are low cost

Other taxes, regulations, standards, rebates and subsidies are partial solutions at higher cost per ton of CO2 avoided

Policy	Effect (as % of 2010–2030 emissions)	Cost ($ per ton of CO_2)
Gasoline tax	1.8	40
Building codes	0.1	51
Tighter auto standards	0.6	85
Liquid natural gas trucks	1.5	85
Weatherization tax credits	0.3	255
Federal interest subsidy	0.0	71,075
Cap and trade/Carbon tax	10.2	12

How do we get to zero-carbon?

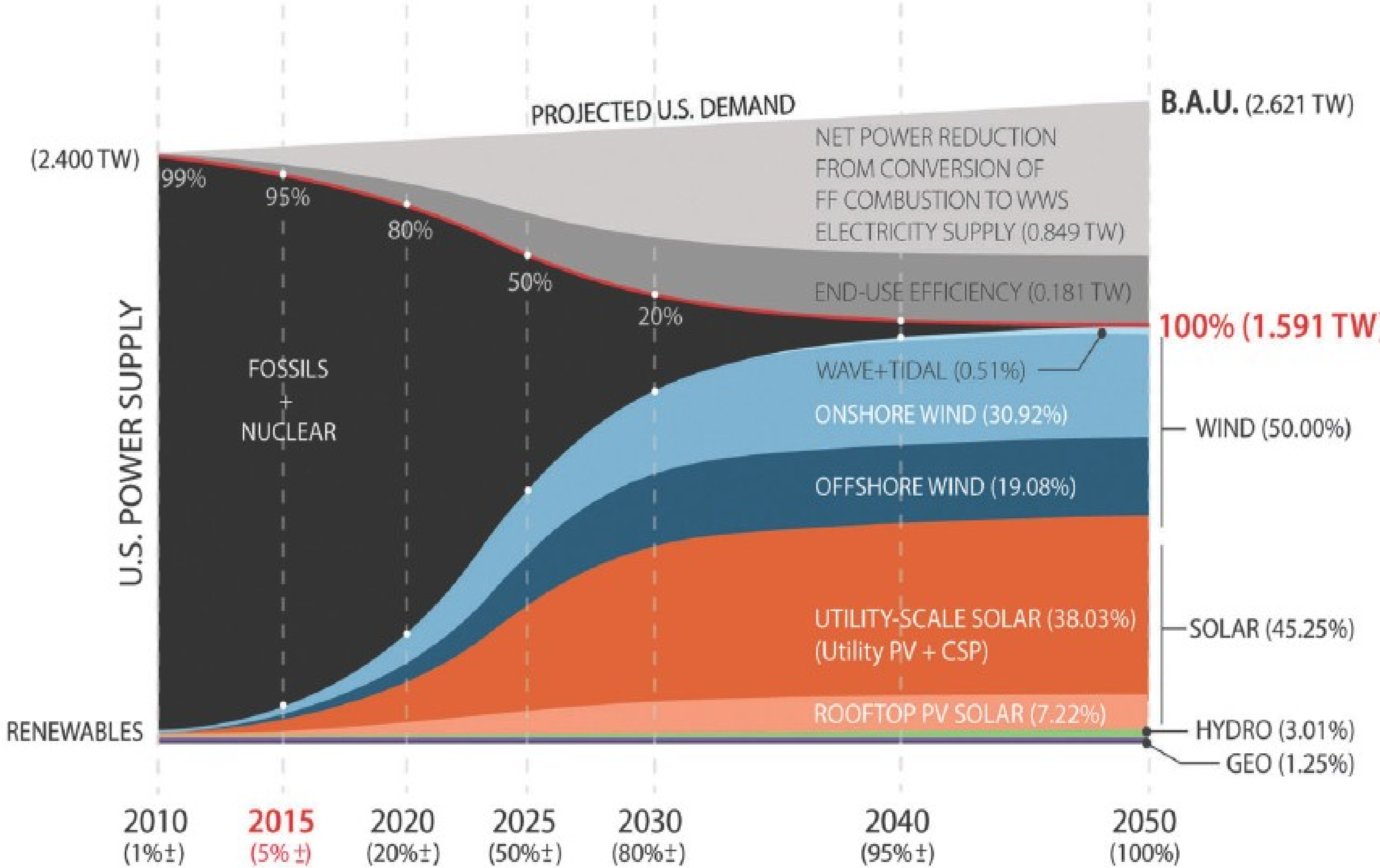
ROYAL SOCIETY OF CHEMISTRY

Energy & Environmental Science

100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States†

Mark Z. Jacobson,*[a] Mark A. Delucchi,[b] Guillaume Bazouin,[a] Zack A. F. Bauer,[a] Christa C. Heavey,[a] Emma Fisher,[a] Sean B. Morris,[a] Diniana J. Y. Piekutowski,[a] Taylor A. Vencill[a] and Tim W. Yeskoo[a]

100% WWS solution - Jacobson



Carbon tax → Jacobson WWS?

Would imposing a carbon tax lead to the Jacobson schema?

- Not necessarily, and probably not
- Research and innovation will produce unanticipated developments
- Jacobson's solution could reasonably be viewed as a "worst case"

There will be solutions, but will we adopt them?