Technology, Policy, and Values for Living in a Greenhouse

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Rutgers Energy Institute
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How do U.S. actions affect the planet?

1. Directly

2. By reducing the technological uncertainty and lowering the costs of options, so that others can adopt them more easily

3. By setting an example that others will feel compelled to follow.
# Four World Views

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**OUR WORKING ASSUMPTIONS:**

- 2°C: Environmentalists, nuclear advocates are often here.
- 3°C, tough job.
- 5°C: Most people in the fuel industries and most of the public are here.
What happens when an irresistible force meets an immovable object?

Ten-year-olds love this paradox!

*The irresistible force*: Fossil fuels, as vital as ever.

*The immovable object*: Climate change, which looms ominously.

At some unknown pace but conceivably soon, the world will become seriously engaged with climate change.
Fossil fuels continue to dominate

Primary energy world consumption, million tonnes oil equivalent

Our future emissions matter

Thirty year changes for Mass.: 

2010-2039: 
Stamford, CN. Done!

2040-2069: 
Princeton vs. Washington

2070-2099: 
Baltimore vs. South Carolina

This graph probably shows how winters could feel too (to be verified).

Figure from James McCarthy, Harvard

NECIA, 2007 (see: www.climatechoices.org/ne/)
Cumulative-emission targets

The world’s fourth try at framing a global climate target:

1. Emission rate at some future date
2. Concentration never to be exceeded
3. Surface temperature never to be exceeded

Ambiguities: Is land-use change included? Are methane and other greenhouse gases included (CO$_2$ vs. CO$_2$eq)?
“Emissions budgets” mean choices

Fossil fuels are so abundant that, for any carbon budget target, even a weak one, attractive fossil fuel will be left in the ground.

The IPCC connected the carbon-budget idea to a 2°C target. The idea is more general.

The budget concept leads inexorably to choices:

<table>
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<th>Question</th>
<th>Choice</th>
</tr>
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<tr>
<td>When?</td>
<td>Better options someday?</td>
</tr>
<tr>
<td>Whose?</td>
<td>Geopolitical stability</td>
</tr>
<tr>
<td>Used where?</td>
<td>“Fairness”</td>
</tr>
<tr>
<td>For what purpose?</td>
<td>Who judges?</td>
</tr>
<tr>
<td>Which fossil fuels?</td>
<td>Those with the highest H/C ratio?</td>
</tr>
</tbody>
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Carbon dioxide capture and storage (CCS) expands the budget.
Technological and Policy Options
Legacy: National Highway System
Legacy: U.S. Power Plants

Source: Benchmarking Air Emissions, April 2006. The report was co-sponsored by CERES, NRDC and PSEG.
Efficiency and Conservation

- transport
- buildings
- industry
- lifestyle
- power
The UN’s “low” population projection has almost 10 billion fewer people in 2100 than its “high” projection.

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<tr>
<th>Scenario</th>
<th>Population</th>
<th>Average Kids/Mom</th>
</tr>
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<tr>
<td>High</td>
<td>15.8</td>
<td>2.6</td>
</tr>
<tr>
<td>Medium</td>
<td>10.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Low</td>
<td>6.2</td>
<td>1.6</td>
</tr>
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Peak at ≈ 2050

\[ \frac{d\text{Pop}}{dt} \approx -0.8\%/\text{yr} \text{ in 2100.} \] If sustained, 2.8 billion in 2200.

### Four ways to emit 5 ton CO$_2$/yr

**today’s global per capita value**

(U.S. value: 20 tons CO$_2$/yr)

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<th>Activity</th>
<th>Amount producing 5 ton CO$_2$/yr emissions</th>
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<tr>
<td>a) Drive</td>
<td>30,000 km/yr, 5 liters/100km (45 mpg)</td>
</tr>
<tr>
<td>b) Fly</td>
<td>30,000 km/yr</td>
</tr>
<tr>
<td>c) Heat home</td>
<td>Natural gas, average house, average climate</td>
</tr>
<tr>
<td>d) Lights</td>
<td>400 kWh/month if all coal-power (1000 gCO$_2$/kWh)</td>
</tr>
<tr>
<td></td>
<td>800 kWh/month, natural-gas-power (500 gCO$_2$/kWh)</td>
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</table>
Princeton University CO$_2$

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<th>University 2007 emissions*</th>
<th>112,000 tCO$_2$</th>
</tr>
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<td>12,500 participants**</td>
<td></td>
</tr>
<tr>
<td>Per-capita 2007 emissions</td>
<td>9 tCO$_2$</td>
</tr>
<tr>
<td>University 2020 target***</td>
<td>93,000 tCO$_2$</td>
</tr>
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</table>

*On-site cogeneration, purchased electricity, fuel for University fleet.
**7,100 students and 5,400 employees.
*** Equal to 1990 emissions, in spite of adding almost 2 million square feet of building space.

What about Rutgers?
U.S. power plant capacity, by vintage

Issues: Grandfathering, retirement, relicensing, retrofit, repowering

Figure 5-1. Historical U.S. Power Plant Capacity Additions, by Technology, 1940-2011

Source: Form EIA-860 (2011)
Note: Renewables include hydro, geothermal, biomass, solar, and wind energy technologies.
The future coal power plant

Shown here: After 10 years of operation of a 1000 MW coal plant, 60 Mt (90 Mm$^3$) of CO$_2$ have been injected, filling a horizontal area of 40 km$^2$ in each of two formations.

Assumptions:
- 10% porosity
- 1/3 of pore space accessed
- 60 m total vertical height for the two formations.

• Note: Plant is still young.

Injection rate is 150,000 bbl(CO$_2$)/day, or 300 million standard cubic feet/day (scfd). Lifetime injection: 3 billion barrels, or 6 trillion standard cubic feet, over 60 years.
CO$_2$ sorption and desorption

At In Salah, Algeria, natural gas purification by CO$_2$ removal plus CO$_2$ pressurization for nearby injection.

Separation at amine contactor towers.
Fukushima #1 in better times

Source: “After the Deluge: Short and Medium-term Impacts of the Reactor Damage Caused by the Japan Earthquake and Tsunami.” Nautilus Institute for Security and Sustainability, March 17, 2011. *Figure 4*: Fukushima Number 1 Nuclear Power Plant.
After-heat: A fire you can’t put out.

Percent of pre-shutdown power

Figure 4-1. THERMAL POWER AFTER REACTOR SHUTDOWN. After the nuclear chain reaction ceases, radioactivity remaining in the fuel will generate heat as a result of radioactive decay. Assuming that the reactor had been operating for a substantial period, the power generated immediately after shutdown will be approximately 7% of the level before shutdown. For a 3000 MWth reactor, with 1000 MWe capacity, this implies an initial decay power level of about 200 MWth. Due to the rapid decay of short-lived species, this decay heat level decreases rapidly, but is this heat that imposes the requirement that, in a light-water reactor, cooling water remain available to prevent damage to the fuel.

Source: A. Nero. Jr., The Guidebook to Nuclear Reactors, p. 54
Global nuclear power expansion, today, would lead to nuclear weapons proliferation.

Widespread deployment of nuclear power lowers global CO$_2$ emissions but increases the risks of nuclear war.

International management of uranium enrichment and plutonium disposition (the “nuclear fuel cycle”) can reduce these risks.

Until effective international management is in place, substantial global expansion of nuclear power is too dangerous.

Calls for global low-carbon targets must include calls for effective management of nuclear power and nuclear weapons.
Photovoltaic Power

Graphics courtesy of DOE Photovoltaics Program
Florida Power and Light’s “Next Generation Solar Energy Center,” Martin County: 75 MW, 500 acres, 190,000 mirrors.
Wind electricity

2.5 MW Nordex wind turbine (80-m tall)
Grevenbroich, Germany

Source: Danish Wind Industry Association

Source: Hal Harvey, TPG talk, Aspen, CO, July 2007
Renewables penetration

The intermittency of sunlight and wind presents formidable problems for any all-renewables energy system.

Together, the partnering of natural gas with renewables and the shifting of demand via a “smart grid” can provide the necessary “load-following.”

Compared to coal power, a system with half natural gas and half renewables is four times less carbon intensive.

Multi-hour electricity storage may be able to increase renewables penetration, but, hey, a factor of 4 is a good start.
“Solutions” can bring serious problems of their own.

Every “solution” has a dark side.

Conservation  Reglementation
Renewables  Competing uses of land
“Clean coal”  Mining: worker and land impacts
Nuclear power  Nuclear war
Geoengineering  Technological hegemony

*Risk management:* We must take into account both the risks of disruption from climate change and the risks of disruption from mitigation. We must not privilege the atmosphere. Climate change is just one aspect of “fitting on the earth.”
“I will apply, for the benefit of the sick, all measures that are required, avoiding those twin traps of overtreatment and therapeutic nihilism.”

Hippocrates

A big new idea

Science has introduced a big, counterintuitive idea: *Human beings are able to change the planet at global scale.*

Forests have been cleared and fisheries have been depleted on a global scale. Most of the low-cost oil has been found. The surface oceans are already more acidic.

That we are changing the climate is just another example.
An unwelcome idea.

We would much rather live on a larger planet, where all our actions mattered less.

Our new assignment: “Fitting on Earth.”
Don’t shoot the messenger

The messenger has been shot before.

Galileo argued that the earth wasn’t at the center of the universe and was excommunicated.

Darwin argued that human beings were part of the animal kingdom and was cruelly mocked.

The idea that humans can’t change our planet is as out-of-date and wrong as the earth-centered universe.
In the past 50 years we have become aware of the history of our Universe, our Earth, and life.

Can we achieve a comparable understanding of human civilization at various future times: 50 years ahead – vs. 500 years and vs. 5000 years? Destiny Studies will address planning horizons, infrastructure, waste management....

We have scarcely begun to ask: What are we on Earth to do?
Grounds for optimism

1. The world today has a terribly inefficient energy system.

2. Carbon emissions have just begun to be priced.

3. Most of the 2064 physical plant is not yet built.

4. Very smart scientists and engineers now find energy problems exciting.
Fitting on the Earth

Fortunately:

Our science has discovered threats fairly early;

We can identify a myriad of helpful technologies;

We have a moral compass that tells us to care not only about those alive today but also about the collective future of our species.

What has seemed too hard becomes what simply must be done.