Solving the Climate and Energy Problem: Available Technologies and Policy Frameworks

Stephen W. Pacala
Petrie Professor of Biology

Princeton University

Energy and Nanotechnology: Storage and the Grid
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Three interdependent problems lead to the conclusion that it is time to replace our energy system...

- The Oil Problem (OP)
- The Air Pollution Problem (APP)
- The Climate Problem (CP)

What kind of an energy system could we have?
What kind of an energy system do we want?
What policies will give us what we want?
Rate of growth of U.S. real GDP

1947-48 Postwar dislocations
1952-53 Iranian nationalization, strikes
1956-57 Suez Crisis
1969 strikes
1973-74 OAPEC embargo
1978-79 Iranian revolution
1980-81 Iran-Iraq War
1990 Persian Gulf War
2000 East Asian Economic Growth

Source: James D. Hamilton
Economic Benefits of Reduced Volatility

- ~ 1% of GDP or ~ 100 Billion Dollars/Y

\[ U_{vol} = \int_{0}^{\infty} \ln(C(t)) e^{-0.03t} dt \]

\[ U_{ave} = \int_{0}^{\infty} \ln(C(t)) e^{-0.03t} dt \]

Value = \( U^{-1}(U_{ave} - U_{vol}) \)

Source: Richard Tol
<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iraq</td>
<td>214.6</td>
</tr>
<tr>
<td>Afganistan</td>
<td>73.0</td>
</tr>
<tr>
<td>Enhanced Security</td>
<td>24.2</td>
</tr>
<tr>
<td>Other</td>
<td>45.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>356.7</strong></td>
</tr>
<tr>
<td><strong>Time Frame</strong></td>
<td>FY 2002-2005</td>
</tr>
<tr>
<td><strong>Source</strong></td>
<td>Congressional Research Service Report Oct 7, 2005</td>
</tr>
</tbody>
</table>
Estimated Deaths Per Year from Air Pollution

US – 130,000

World – >3,000,000

Source: The Skeptical Environmentalist pp. 168, 182

@ $2.5 million per life, US cost is $330 billion/y
Surface Air Warming (°F)

2xCO₂ Climate

4xCO₂ Climate

Source: GFDL R15 Climate Model; CO₂ transient experiments, years 401–500.
$100/tC

Carbon emission charges in the neighborhood of $100/tC can enable most available alternatives. (PV is an exception.)

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<td>Today’s US energy system</td>
<td>~ $150 billion/year (~1% of GDP)</td>
</tr>
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$100/tC is approximately the October 2005 EU trading price.

Source: Robert Socolow
Evidence of Global Warming

* Climate change in the past
* Theory and models
* Current records
Monsters Behind the Door

- Ocean Circulation
- Hurricanes
- Sahel Drought
- Ice Sheets
Instability of Ocean Circulation
Increasing Hurricane Intensity

Aggregate results: 9 GCMs, 3 basins, 4 parameterizations, 6-member ensembles

Source: Knutson and Tuleya 2004, Journal of Climate 17, 3477-3495
Drought in the Sahel
Ice Sheet Instability

Sea Ice Thickness (10-year average)

1950's

2050's

100% of 1955 volume
Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies

Stephen W. Pacala and Robert Socolow
Science Vol. 305 968-972 August 13, 2004
Past Emissions

Billion of Tons of Carbon Emitted per Year

Historical emissions

1.9 → 0
1955  2005  2055  2105
The Stabilization Triangle

- Billion of Tons of Carbon Emitted per Year
- Currently projected path = "ramp"
- Historical emissions
- Flat path
- Interim Goal
- 1.9 →

1955 | 2005 | 2055 | 2105
The Stabilization Triangle: Beat doubling or accept tripling (details)

Values in parentheses are ppm. Note the identity (a fact about the size of the Earth’s atmosphere): 1 ppm = 2.1 GtC.
The Demography of Capital

2003-2030 power-plant lifetime CO₂ commitments
WEO-2004 Reference Scenario.
Lifetime in years: coal 60, gas 40, oil 20.

Historic emissions, all uses

Policy priority: Deter investments in new long-lived high-carbon stock: not only new power plants, but also new buildings.

Credit for comparison: David Hawkins, NRDC
The Virtual Triangle: Large Carbon Savings Are Already in the Baseline

- Historical emissions
- Currently projected path
- Flattened path
- Reduced carbon intensity of the baseline economy
- Virtual Triangle
- Stabilization Triangle

GtC/yr
emission growth = GDP growth

1.5% emission growth
3% GDP growth

2% emission growth
3% GDP growth

Western Europe
Mexico
India
Canada
Japan
China
USA
Billion of Tons of Carbon Emitted per Year

Historical emissions

Currently projected path

Flat path

1.9 → 14 GtC/y

Seven “wedges”

2055
What is a “Wedge”? 

A “wedge” is a strategy to reduce carbon emissions that grows in 50 years from zero to 1.0 GtC/yr. The strategy has already been commercialized at scale somewhere.

Cumulatively, a wedge redirects the flow of 25 GtC in its first 50 years. This is 2.5 trillion dollars at $100/tC.

A “solution” to the CO₂ problem should provide at least one wedge.
Revolutionary Technology: Artificial Photosynthesis
Filling the Triangle With Technologies Already in the Marketplace at Industrial Scale

- Coal to Gas
- CCS
- Nuclear
- Renewables
- Efficiency
- Natural Sinks
Wedges

EFFICIENCY
• Buildings, ground transport, *industrial processing, lighting*, electric power plants.

DECARBONIZED ELECTRICITY
• Natural gas for coal
• Power from coal or gas with CCS
• Nuclear power
• Power from renewables: wind, photovoltaics, *hydropower, geothermal*.

DECARBONIZED FUELS
• Synthetic fuel from coal or natural gas, with carbon capture and storage
• Biofuels
• Hydrogen
  – from coal and natural gas, with carbon capture and storage
  – from nuclear energy
  – from renewable energy (hydro, wind, PV, etc.)

FUEL DISPLACEMENT BY LOW-CARBON ELECTRICITY
• Grid-charged batteries for transport
• *Heat pumps for furnaces and boilers*

NATURAL SINKS
• Forestry (reduced deforestation, afforestation, new plantations)
• Agricultural soils
Efficiency and Conservation

Effort needed by 2055 for 1 wedge:
2 billion cars at 60 mpg instead of 30 mpg.
Electricity

Effort needed by 2055 for 1 wedge:
700 GW (twice current capacity) displacing coal power.

Nuclear Electricity

Phase out of nuclear power creates the need for another half wedge.

Graphic courtesy of NRC
Figure 52. World Recoverable Coal Reserves

Note: Data for the United States represent recoverable coal estimates as of January 1, 2004. Data for other countries are as of January 1, 2003.

King Coal

Partial Combustion

Shift Reaction
Best CO/H Ratio
For Liquid Fuels

Complete the
Shift Reaction

CO + H₂O

CO₂

IGCC
Liquid Fuels
Hydrogen Cars
Hydrogen Electricity
Geologic Storage

APP
OP
OP,APP
OP,APP
CP
Soon, BP’s DF-1: natural gas power with CCS

- Peterhead: 350 MW via H₂ turbines
- Miller field: 1.3 MtCO₂/yr
- Sleipner
- UK-Norway border
- Aberdeen, 30 miles south
In the middle of the Sahara

At In Salah, Algeria, natural gas purification by CO₂ removal plus CO₂ pressurization for nearby injection

Separation at amine contactor towers
Power with Carbon Capture and Storage

Effort needed by 2055 for 1 wedge:

Carbon capture and storage at 800 GW coal power plants.

The Wabash River Coal Gasification Repowering Project

Graphics courtesy of DOE Office of Fossil Energy
Coal-based Synfuels with CCS*

*Carbon capture and storage

Effort needed for 1 wedge by 2055

Capture and storage of the $\text{CO}_2$ byproduct at plants producing 34 million barrels per day of coal-based synfuels

Assumption: half of C originally in the coal is captured, half goes into synfuels.

Result: Coal-based synfuels have no worse $\text{CO}_2$ emissions than petroleum fuels, instead of doubled emissions.
Fossil-fuel-based H₂ with CCS

*Carbon capture and storage*

Effort needed by 2055 for 1 wedge:

**Use**: H₂ instead of gasoline or diesel in 2 billion 60 mpg vehicles

**Production**: Capture and store, instead of venting, the CO₂ byproduct of 250 MtH₂/year produced from coal

Today: 40 MtH₂/year is produced from all sources.

Graphics courtesy of DOE
Office of Fossil Energy
Carbon Storage

Effort needed by 2055 for 1 wedge:

3500 In Salahs or Sleipners @1 MtCO₂/yr
100 x U.S. CO₂ injection rate for EOR
A flow of CO₂ into the Earth equal to the flow of oil out of the Earth today

Sleipner project, offshore Norway

Graphic courtesy of Statoil ASA
Wind Electricity

Effort needed by 2055 for 1 wedge:

Two million 1-MW windmills displacing coal power.

Today: 40,000 MW (2%)

Prototype of 80 m tall Nordex 2.5 MW wind turbine located in Grevenbroich, Germany
(Danish Wind Industry Association)
Wind Hydrogen

Effort needed by 2055 for 1 wedge:

- H₂ instead of gasoline or diesel in 2 billion 60 mpg vehicles
- Four million 1 MW windmills
  - Twice as many windmills as for a wedge of wind electricity
- Today: 40,000 MW (1%)
- Assumes the H₂ fuels 100-mpg cars

Prototype of 80 m tall Nordex 2,5 MW wind turbine located in Grevenbroich, Germany (Danish Wind Industry Association)
Solar Electricity

Effort needed for 1 wedge:

Install $40 \text{ GW}_{\text{peak}}$ each year

2 GWpeak in place today, rate of production growing at 20%/yr (wedge requires 50 years at 15%).

2 million hectares dedicated use by 2055 = 2 m² per person.

Graphics courtesy of DOE Photovoltaics Program
Biofuels

Effort needed by 2055 for 1 wedge:

Two billion 60 mpg cars running on biofuels

250 million hectares of high-yield crops (one sixth of world cropland)

Usina Santa Elisa mill in Sertaozinho, Brazil

(http://www.nrel.gov/data/pix/searchpix.cgi?getrec=5691971&display_type=verbose&search_reverse=1)
Effort needed by 2055 for 1 wedge:

Elimination of tropical deforestation

and

Rehabilitation of 400 million hectares (Mha) temperate or 300 Mha tropical forest

Photo: SUNY Stonybrook

Effort needed by 2055 for 1 wedge:

Conservation tillage on all cropland

Photo: Brazil: Planting with a jab planter. FAO
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Three Interdependent Problems

- The Oil Problem (OP)
  ~ $100 billion/y for Iraq and ~$100 billion/y for oil price shocks

- The Air Pollution Problem (APP)
  ~ $100 billion/y for air pollution

- The Climate Problem (CP)
  ~ $100 billion/y to solve the problem
Policy Options

- Cap and Trade
- Revenue-generating tax
- Zero-revenue tax
  (i.e. Tierny NY Times, 10/3/2005)
- Guaranteed Floor Price for Oil
- Technology Subsidy
- Portfolio Standard
Conclusions

What is needed is a national policy designed to solve the oil problem, the air pollution problem, and the climate problem.

We already possess cost-effective technologies for the next fifty years, if costs are seen in the context of what we are already paying.

The solution will only get cheaper, as investment elicits industrial R&D, and especially when you people invent revolutionary alternatives.
$100/tC (≈EU trading price)

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Atmospheric CO$_2$ with 5600 GtC emissions
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What kind of an energy system do we want?