Week Eight: November 8, 2013

1. Wedges
2. Achieving energy efficiency
3. Land use, food, and biocarbon
Your term paper

- Please, no encyclopedia articles. Identify a topic that is narrowly defined, then ask and answer interesting questions.
- It is fine that in your first “interim statement” you identified a broad area where you intend to find your topic. But do enough work before submitting your second interim statement (before midnight next Tuesday) so that Phil and I can understand where you actually wish to head.
- If you are having trouble choosing a specific topic, tell Phil and me how to help you. E.g.: “I’d like to write about one specific country, but it could be A or B. I like A because...; I like B because...”
What makes a good paper? [from L1]

Each short paper should be sharply focused on a single issue. The term paper can be more ambitious.

All papers should be interesting, focused, imaginative, partially quantitative, and coherent. They should be well written, well argued, and well presented.

An unusual requirement is that each paper should display some quantitative reasoning. For example, this can be a sample calculation that verifies a statement that you have read. You should show an interest in numbers.

It is fine to build on some comparative advantage; for example, you could choose a topic related to something you have done before or involving a country or town that you know.

You are encouraged to discuss all papers with Phil and me electronically, but only well ahead of the deadlines. Experience suggests that we will lead you to people in the Princeton community who may be helpful.

No matter what your topic, you will encounter sales pitches, masquerading as impartial analysis. Learning to deal with biased information is one of the aims of this course.
Significant Figures

Source: Peter Gleick, *Significant Figures*, Feb 8 2013: “Thanks to xkcd.org and Randall Munroe, licensed under a Creative Commons Attribution – NonCommercial 2.5 License.”
“Wedges”


I wrote this paper with Prof. Steve Pacala, (Ecology and Evolutionary Biology, Princeton).

The paper helped people conceptualize and understand quantitatively what dealing with climate change looks like. In the last few years, the excitement that the problem is soluble has been dampened by the realization that solutions are disruptive.
Why was “wedges” welcomed?

The stabilization triangle:

Did not concede doubling is inevitable.
Shortened the time frame to within business horizons.

The wedge:

Decomposed a heroic challenge (the stabilization triangle) into a limited set of monumental tasks.

Established a unit of action that permits quantitative discussion of cost, pace, risk, and trade-offs.
Einstein’s advice

“Make everything as simple as possible, but no simpler.”
Historical emissions of CO$_2$ emitted per year.
Today and for the interim goal, global per-capita emissions are $\approx 4$ to $5 \, \text{tCO}_2/\text{yr.}$
Today and for the interim goal, global per-capita emissions are $\approx 4$ to $5$ tCO$_2$/yr.
The Stabilization Triangle

Historical emissions

Current path = "ramp"

Stabilization Triangle

Easier CO₂ target ~850 ppm

Interim goal

Tough CO₂ target ~500 ppm

Flat path

Billions of tons of CO₂ emitted per year

1950 2000 2050 2100
“The target isn’t tough enough”

![Graph showing historical emissions, current path, flat path, and stabilization triangle with interim and tougher interim goals.]

- Historical emissions
- Current path = “ramp”
- Flat path
- Stabilization Triangle
- Interim goal
- Tougher interim goal

Billions of tons of CO₂ emitted per year:

- 1950
- 2000
- 2050
- 2100

***

6
"The target isn’t tough enough"

- Historical emissions
- Billions of tons of $\text{CO}_2$ emitted per year
- Current path = “ramp”
- Stabilization Triangle
- Flat path
- $2^\circ C$
- $3^\circ C$
- Tougher interim goal
- Tough interim goal
The Virtual Triangle: Large Carbon Savings Are Already in the Baseline

Models differ widely in their estimates of contributions to the virtual triangle from structural shifts (toward services), energy efficiency, and carbon-free energy.
A1B, 2000-2050, by fuel

- Gas
- Oil
- Coal
- Deforestation
A1B Virtual Triangle

![Graph showing carbon emissions from 2000 to 2050.](image)
Growth rates:
- GWP: 4.0%/yr
- Primary energy: 2.9%/yr
- Carbon: 1.7%/yr
“Flat” vs. “down 50%” is mostly about the developing world’s emissions

Source of Figure: Socolow and Pacala, “A plan to keep carbon in check,” Scientific American, Sept 2006.
A1B, 2000-2050, by Fuel: Rich vs. Poor

Emissions: Rich vs. Poor Nations

- Coal
- Oil
- Gas

Rich World (OECD90)

Year

Poor World (Rest)
The developing world will decide what kind of planet we live on.

For a while longer, the industrialized countries will lead.
Billions of tons of CO$_2$ emitted per year

- 16 GtC/y
- Eight “wedges”
- Interim Goal
- Flat path
- Historical emissions
“Wedges reaffirmed,”
a short essay released on Sept 27, 2011

The essay was accompanied by comments from:

Carter Bales
Ralph Cicerone
Freeman Dyson
Christopher Field
Robert Fri
David Hawkins
Rush Holt
Robert May
Phil Sharp
Nicholas Stern

What is a “Wedge”?  

A “wedge” is a strategy to reduce carbon emissions that grows in 50 years from zero to 4 GtCO$_2$/yr. The strategy has the potential to be commercialized at very large scale.

Cumulatively, a wedge redirects the flow of 100 GtCO$_2$ in its first 50 years. This is six trillion dollars at $60/tCO$_2$. A “solution” to the CO$_2$ problem should have the potential to provide at least one wedge.
Global CO₂ Emissions by Sector and Fuel

Allocation of 6.2 GtC/yr (22.7 GtCO₂/yr) emitted in 2000

Electricity: 40%; fuels used directly: 60%.
Global GHG emissions, by source

Figure 1 Greenhouse-gas emissions in 2000, by source

Energy emissions:
- Power (24%)
- Transport (14%)
- Buildings (8%)
- Industry (14%)
- Other energy related (5%)

Non-energy emissions:
- Land use (18%)
- Agriculture (14%)
- Waste (3%)

Total emissions in 2000: 42 GtCO2e.

Energy emissions are mostly CO₂ (some non-CO₂ in industry and other energy related).
Non-energy emissions are CO₂ (land use) and non-CO₂ (agriculture and waste).

Source: Prepared by Stern Review, from data drawn from World Resources Institute Climate Analysis Indicators Tool (CAIT) on-line database version 3.0.
Fill the Stabilization Triangle with Eight Wedges in six broad categories

- Energy Efficiency
- Methane Management
- Extra Carbon in Forests, Soils, Oceans
- Fuel Displacement by Low-Carbon Electricity
- Decarbonized Electricity
- Decarbonized Fuels

Stabilization Triangle:
- 2007: 30 GtCO₂/yr
- 2057: 60 GtCO₂/yr

Additional Carbon in Forests, Soils, Oceans:

Methane Management:
15 Ways to Make a Wedge

15 Ways to Make a Wedge

Industrial energy efficiency
“Upstream” investment
Concentrated solar power
Methane mitigation
Population

Not commercial, so not included:
- Fusion
- Capture of CO₂ from air

Dartboard notes

Notes:
1 World fleet size in 2056 could well be two billion cars. Assume they average 10,000 miles a year.
2 “Large” is one-gigawatt (GW) capacity. Plants run 90 percent of the time.
3 Here and below, assume coal plants run 90 percent of the time at 50 percent efficiency. Present coal power output is equivalent to 800 such plants.
4 Assume 90 percent of CO₂ is captured.
5 Assume a car (10,000 miles a year, 60 miles per gallon equivalent) requires 170 kilograms of hydrogen a year.
6 Assume 30 million barrels of synfuels a day, about a third of today’s total oil production. Assume half of carbon originally in the coal is captured.
7 Assume wind and solar produce, on average, 30 percent of peak power. Thus replace 2,100 GW of 90-percent-time coal power with 2,100 GW (peak) wind or solar plus 1,400 GW of load-following coal power, for net displacement of 700 GW.
8 Assume 60-mpg cars, 10,000 miles a year, biomass yield of 15 tons a hectare, and negligible fossil-fuel inputs. World cropland is 1,500 million hectares.
9 Carbon emissions from deforestation are currently about two billion tons a year. Assume that by 2056 the rate falls by half in the business-as-usual projection and to zero in the flat path.

Source: Socolow and Pacala, Scientific American, September 2006, p.54
How many wedges of one kind?

Generic questions:

Is the overall cost for the second use of a wedge larger or smaller than the cost of its first use? (Is the second “wind” wedge less costly than the first?)

How many times can the same wedge be used before creating insurmountable problems?

Source; Socolow and Pacala, Scientific American, September 2006, p.54
“The Wedge Model is the iPod of climate change: You fill it with your favorite things.”


Therefore, prepare to negotiate with others, who have different favorite things.
U.S. Wedges


U.S. share of emissions reductions could, in this Natural Resources Defense Council scenario, be achieved by efficiency gains, renewable energy and clean coal.
The Analogous Oil Wedge

1 oil wedge is a strategy or campaign that results in the reduction of pressure on oil markets (by either supply augmentation or demand reduction) by 1 million barrels per day after 10 years.

This is a much smaller wedge than the carbon stabilization wedge:

- Much smaller vertical dimension: \(26 \times (1 \text{ mbd}) = 4 \text{ GtCO}_2/\text{yr}\).
- Smaller slope: \(5.2 \times (1 \text{ mbd}/10 \text{ yr}) = (4 \text{ GtCO}_2/\text{yr})/50 \text{ yr}\).

At $55/bbl, area of oil wedge is $100 billion (30 times smaller).

Inventor of the oil wedge: Robert Hirsch
Mitigation is Not Risk-Free

Therefore, the lowest conceivable greenhouse targets, achievable only by casting caution to the winds, are not optimal.
“Solutions” can bring serious problems of their own.

Every “solution” has a dark side.

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

**Risk management:** In choosing targets, we must take into account both the risks of disruption from climate change and the risks of disruption from mitigation.
Iterative risk management: the basis for a renewed commitment

In another decade we'll know a lot more about the earth, both because of new climate science and because of what the earth tells us about itself.

We’ll also know more about the solutions themselves, thanks to both R&D and field experience.

All this argues for making decisions iteratively.
Iterative risk management

“I will apply, for the benefit of the sick, all measures that are required, avoiding those twin traps of overtreatment and therapeutic nihilism.”

Hippocrates

After the Break we will hunt for wedges of energy efficiency and land-use change.
BREAK
Required readings for Week 9:
Low-carbon fossil-fuel-based energy via CO₂ capture & storage

Required Readings


MIT (2007). The Future of Coal. [Chapter 3: Coal-based electricity generation].

Recommended readings for Week 9:
Low-carbon fossil-fuel-based energy via CO₂ capture & storage

Recommended Readings


Efficiency wedges
Legacy: U.S. Power Plants

Source: Benchmarking Air Emissions, April 2006. The report was co-sponsored by CERES, NRDC and PSEG.
Efficient Use of Electricity

Three images:

- Power electronics for variable-speed-drive motors.
- Integration of electricity and thermal energy ("cogeneration").
- Can also integrate electricity and fuels/chemicals.
- Efficient lighting.
A larger fraction of electricity goes to buildings in rich countries.

“Buildings Electricity” = 100% of “Commercial and Residential” + 15% of “Industrial” + 10% of “Agricultural.”

All data are for 2002 except U.S. 1976 point.
Areas of points: proportional to populations.

Data provided by Paul Waide, graphics by Shoibal Chakravarty
Business as Usual: CO₂ emissions from air conditioners in 2020 are 9x those in 2000.

New Air Conditioner Standard: Down 25% (45 MtCO₂/yr) in 2020.

50 million new, efficient air conditioners per year in 2020
Projections

<table>
<thead>
<tr>
<th>Period</th>
<th>Annual Growth</th>
</tr>
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<tbody>
<tr>
<td>1950s</td>
<td>9.0</td>
</tr>
<tr>
<td>1960s</td>
<td>7.3</td>
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<td>1970s</td>
<td>4.2</td>
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Conceive of the far side of a peak

Red (EIA):

\[ y = 10 \times (2^{-[t/\tau]}) \]

\( \tau = 20 \) years

\( t = 0 \) in 1950

U.S. electricity growth rate (3-year rolling average, percent)
Conceive of the far side of a peak

Physics and economics allow negative values.

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Growth, %/yr

Year | 3 yrs, centered
--- | ---
2001 | 1.45
2002 | 0.71
2003 | 2.05
2004 | 1.67
2005 | 1.54
2006 | 1.54
2007 | 0.52
2008 | -0.95
2009 | -0.26


2001-2005 data don’t exactly match
Legacy: U.S. Highway System
Transportation Efficiency Wedges

Note: Drive 16,000 km at 8 liters/100km: emit 1 tC (≈ 4 tCO₂)

Efficiency wedge: In 2062, 2 billion cars driven 16,000 km/yr at not 8 but 4 l/100km.

Vehicle-use wedge: IN 2062, 2 billion cars at 8 l/100km, driven not 16,000 but 8,000 km/yr.

2 billion cars at 4 l/100km, driven 8,000 km/yr: 1.5 wedges.
The frontier for motive power

Efficient energy conversion
Combustion, drive train, aerodynamics, rolling resistance

Primary source for traditional fuel (gasoline, diesel, jetfuel)
“Conventional” and “unconventional” crude oil
Synthetic fuel from natural gas, coal, or biomass

Non-traditional “fuel”
Compressed natural gas
Electrochemical energy (battery or fuel cell)
System efficiency

Most cars have only one person in them most of the time.

Many trips can be replaced by information technology.
U.S. vehicle-miles traveled, two views

Has energy demand peaked in industrialized countries?

If any industrialized country makes energy efficiency a priority, at least two of its peaks can be in its past:

- oil consumption
- electric power consumption
Efficiency comes in little packages

“The climate problem was created by millions of bad decisions over decades, but climate stability can be restored by millions of sensible choices—buying a more efficient lamp or car, adding insulation or caulk to your home, repealing subsidies for waste and rewarding desired outcomes (for example, by paying architects and engineers for savings, not expenditures).”

Ways to drive efficiency investments

**Measure, measure, measure: “Trust, but verify”**
Focus attention on performance: construction detail, secondary decisions (interior design), operation and maintenance.

**Set tough performance standards**
Examples: appliance efficiency, interior temperature, light levels

**Use price (spot-market, time-of-day) to flatten loads**
Stimulate load management and storage technology, behavioral change.

**Address poverty via lifeline rates (e.g., for the first 300 kWh/month)**
Subsidize retrofit of highly inefficient older buildings of the urban core.
Explanations for limited success: Consumers

Mistrust of information
Biased information
Inaccurate information
Short time-horizons
Limit to the number of things to worry about
Explanations for limited success: Industry and government

Distraction from key mission
Out of comfort zone
Annual budgets (governments, especially)
Principle-agent problems and split incentives (landlord-tenant)
Limit to the number of things to worry about
Explanations for limited success: Systems

Take-back effects (better insulation yields a warmer house with same energy use)

Rebound effects (higher fuel economy means more driving)

Budget effects (better insulation means money to buy a new appliance)
The technology-behavior axis.

1. Slot-in technology, no changes observable to the consumer (more efficient aircraft engine, extra wall insulation).

2. Technological change, with benefits and costs to consumer (low-flow shower-head, compact fluorescent bulb)

3. Social and technical change (video-conference instead of business trip, on-line shopping)

4. Predominantly societal change (revival of cities reverses suburbanization, higher prices on energy)

5. Change in individual preferences (smaller families, reduced meat consumption, increased use of public transportation, warmer temperatures indoors in summer are acceptable)
Land-use wedges

1. Emissions from land-use change
2. Carbon management via biocarbon
3. Food-energy couplings, present and future
Agriculture and Climate Change
Impacts, contributions and implications for feeding 9 billion people

David Kanter
Guest contribution
WWS 585b – November 28, 2012

A few slides are here.
Kanter’s full set is on Blackboard 2013 in “L8 Supplement.”
Bioenergy as a climate change mitigation technology

Felix Creutzig
Guest contribution
WWS 585b – November 28, 2012

A few slides are here.
Creutzig’s full set is on Blackboard 2013 in “L8 Supplement.”
Land use change emissions have remained relatively constant over time

Le Quéré et al. (2009)
Net CO$_2$ emissions from land use change in tropical countries

Source: Sarmiento (privately), from RA Houghton 2009, unpublished, based on FAO land use change statistics
Biocarbon and fossil carbon

Can’t tell the difference (except $C^{12}$, $C^{13}$, $C^{14}$ ratios).

Land use concerns and energy concerns are merging.

Biocarbon accounting is sometimes perverse, neglecting “carbon debt.”

The interplay is already in view for world energy, world oil, world hunger, and climate change.
Biocarbon

**Traditional objectives**
- Biofuel to displace oil
- Biopower to displace power from coal and natural gas

**Scrubbing CO\(_2\) from the atmosphere**
- Biopower with CO\(_2\) capture and storage
- Biocarbon stock augmentation (afforestation)

*Back of the envelope:*
- Yield: 10t/ha-yr
- Energy content: 20 GJ/t
- So 200 GJ/ha-yr
- Equivalently: \(200 \text{ EJ/Gha-yr}\)

Global primary energy: 500 EJ/yr
All of U.S. (1 Gha) “makes” 200 EJ/yr.
Net primary production: technical potential from the land

- Benchmark: Current annual global energy consumption: 500 EJ, growing
- Currently: ca. 50 EJ from biomass
- Carbon cycle: 2000 EJ in carbon absorbed by terrestrial plants every year, another 2000 EJ by marine plants (algae)
- This carbon is returned to the atmosphere via respiration, rot, wildfires, etc.
- The question is which part of this carbon cycle can be accessed economically, and without destroying crucial ecosystem services, and food production

Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012
“Significant” primary bioenergy is measured in 100s of EJ/yr

Citation: Creutzig et al., 2012
Inputs to biomass calculations

Areas
World surface area: \( 5 \times 10^{14} \text{ m}^2 = 50,000 \text{ Mha} \)
Land area: \( 1.5 \times 10^{14} \text{ m}^2 = 15,000 \text{ Mha} \)
Cropland (≈ 10% of land area): 1500 Mha
U.S. land area (50 states) 1000 Mha

Yields (tons of dry biomass per hectare per year): hares and tortoises

Plantations for carbon storage: steady, slow growth, 50 years:
2 to 10 t/ha-yr (Steady state of 100 to 500 t/ha)

Plantations for biofuels: fast growth for short periods (1 - 5 years),
frequent harvesting:
10 to 50 t/ha-yr. (Issues: fertilizer, irrigation)

Energy content: 15 GJ/t for grasses, 20 GJ/t for wood (lignin is like oil)

Carbon content: 0.5 tC/t biomass
Biomass as primary energy

Land for primary energy

Land in plantations to produce 100 EJ/yr (≈ U.S. today, ≈ 25% of global primary energy today)

Inputs: 10 to 50 t/ha-yr @ 20 GJ/t: thus 0.2 to 1 TJ/ha-yr.

Result: **100 to 500 Mha**.

Note the inefficiency of photosynthesis. What is the **conversion efficiency** for solar energy to bioenergy for yields of 10 to 50 t/ha-yr?

Assume average flux of incident sunlight is 300 W/m² = 100 TJ/ha-yr.

Result: **0.2% to 1%** conversion efficiency.
Energy density (GJ/ha/y) is much higher for wind and solar than for bioenergy

Table 8: Input and outcomes of case study.

<table>
<thead>
<tr>
<th>Region</th>
<th>Input</th>
<th>NED GJ/ha/y</th>
<th>Distance driven* 10^4 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beets from sugar beet</td>
<td>&amp;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>47^b</td>
<td>t/ha/y</td>
<td>10.9</td>
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<tr>
<td>NL</td>
<td>62^c</td>
<td>t/ha/y</td>
<td>15.5</td>
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<tr>
<td>ES</td>
<td>27^d</td>
<td>t/ha/y</td>
<td>4.8</td>
</tr>
<tr>
<td>Biodiesel from rapeseed</td>
<td>&amp;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>2.9^e</td>
<td>t/ha/y</td>
<td>18.8</td>
</tr>
<tr>
<td>NL</td>
<td>3.7^f</td>
<td>t/ha/y</td>
<td>24.6</td>
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<tr>
<td>ES</td>
<td>1.3^g</td>
<td>t/ha/y</td>
<td>7.2</td>
</tr>
<tr>
<td>Electricity from wood</td>
<td>&amp;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>2.4^h</td>
<td>t/ha/y</td>
<td>12.3</td>
</tr>
<tr>
<td>NL</td>
<td>2.8^i</td>
<td>t/ha/y</td>
<td>14.5</td>
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<tr>
<td>ES</td>
<td>0.5^j</td>
<td>t/ha/y</td>
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<td>Electricity from wind</td>
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<tr>
<td>SE</td>
<td>7.0^l</td>
<td>m/s</td>
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<td>m/s</td>
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<td>Electricity from solar PV</td>
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<td>SE</td>
<td>824^o</td>
<td>kWh/kWp</td>
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<td>NL</td>
<td>873^p</td>
<td>kWh/kWp</td>
<td>421</td>
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<tr>
<td>ES</td>
<td>1473^q</td>
<td>kWh/kWp</td>
<td>1213</td>
</tr>
</tbody>
</table>

Table notes: NED=net energy density; SE, NL and ES refer to rural areas of Sweden, Netherlands and Spain, respectively.

<table>
<thead>
<tr>
<th>Bioenergy from forestry residues</th>
<th>Biomass from silvicultural thinning and logging, and wood processing residues such as sawdust, bark and black liquor. Dead wood from natural disturbances, such as storms and insect outbreaks, represents a second category. Environmental effects of primary residue removal depend on land management practice and local conditions, and removal rates need to be controlled considering local ecosystem, climate, topography, and soil factors.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioenergy from forest unutilized forest growth</td>
<td>Biomass from growth occurring in forests judged as being available for wood extraction, which is above the projected biomass demand in the forest industry. Includes both biomass suitable for, e.g., pulp and paper production and biomass that is not traditionally used by the forest industry.</td>
</tr>
<tr>
<td>Bioenergy from forest plantations and agroforestry</td>
<td>Includes biomass from woody plants grown in short-rotation coppice or single stem plantations (e.g., willow, poplar, eucalyptus, pine). Both monoculture plantations and mixed production systems including agroforestry are included.</td>
</tr>
</tbody>
</table>

*Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012*
<table>
<thead>
<tr>
<th>Bioenergy from crop residues</th>
<th>Use of crop residues for Bioenergy; Use of by-products associated with crop production and processing, both primary (e.g., cereal straw from harvesting) and secondary residues (e.g., rice husks from rice milling) to produce bioenergy.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioenergy from dedicated crops</td>
<td>Cultivation of high yielding crops specifically designed for energy end use. Includes cultivation of both conventional agriculture crops and bioenergy feedstock plants such as oil crops (e.g., Jatropha), grasses (e.g., switchgrass, Miscanthus).</td>
</tr>
<tr>
<td>Bioenergy from manure mgt (Biogas)</td>
<td>Animal dung from confined livestock production. Currently dung is often burned directly as a cooking fuel in many developing countries. Dung can be converted to biogas in biodigesters.</td>
</tr>
<tr>
<td>Bioenergy from Organic Wastes</td>
<td>A heterogeneous category that can include, e.g., organic waste from households and restaurants, discarded wood products such as paper and demolition wood, and wastewaters suitable for anaerobic biogas production.</td>
</tr>
</tbody>
</table>

*Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012*
Biomass for CO$_2$ removal (CDR)

Two bio strategies for CDR
   Biopower with CCS (BECCS)
   Afforestation

Land for afforestation, removing 1 ppm/yr from the atmosphere

Inputs:
   10 t biomass/ha-yr (for 50 years)
   0.5 tC/t biomass.
   1 ppm = 2 GtC

Result: **400 Mha**. (Recall: U.S. area is 1000 Mha.)
BECCS

- BECCS: Bioenergy Carbon Capture and Storage
- Produce energy from biomass and store the CO2 emissions underground
- High uncertainty on costs and storage availability
- Same post-capture issues as fossil fuel CCS (transition to L9)

Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012
Biomass supply complexities

“Dry” biomass
Drying can require significant energy inputs.

Residues
Residues of commercial forestry (slash) and agriculture (rice husks, corn stover), in principle, can become biomass feedstocks. The need to sustain soil nutrients (N, P, …) will limit residue use.

Unavailable land
Steep slopes
Stream banks
Urban areas
Wilderness (deliberately left unmanaged)

Net energy, net carbon
In the back-of-the-envelope calculations of land requirements biomass “overheads” are often neglected.
In energy conversion, energy inputs are neglected.
In carbon conversion, carbon inputs are neglected.
Land use/climate change complexities

*If climate change is what matters:*
- Direct emissions of CO$_2$ in biomass system
  - Fertilizer, tractors, distillation
- Indirect land use change (ILUC) -- requires planetary analysis
  - Conversion of forest managed for pulp and paper to forest for carbon storage may lead to forest conversion to pulp and paper elsewhere.
  - Conversion of land for fodder (for corn, soybeans) to land for bioenergy may lead to forest clearing elsewhere to produce equivalent fodder.
  - Conversion of pasture to bioenergy may elicit feedlot cattle-raising and land clearing for fodder.
- Evapotranspiration change
- Emissions of CH$_4$, N$_2$O
- Albedo change
## Time required to repay carbon debt

<table>
<thead>
<tr>
<th>Location</th>
<th>Land Use</th>
<th>Biodiesel Type</th>
<th>Years to Repay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indonesia/Malaysia</td>
<td>Tropical rainforest</td>
<td>Palm biodiesel (&gt; 85% of global palm production)</td>
<td>86</td>
</tr>
<tr>
<td>Brazil</td>
<td>Cerrado wooded</td>
<td>Sugarcane ethanol</td>
<td>423</td>
</tr>
<tr>
<td>Brazil</td>
<td>Cerrado grassland</td>
<td>Soybean biodiesel</td>
<td>319</td>
</tr>
<tr>
<td>US</td>
<td>Central grassland</td>
<td>Corn ethanol</td>
<td>7</td>
</tr>
<tr>
<td>US</td>
<td>Abandoned cropland</td>
<td>Corn ethanol</td>
<td>93</td>
</tr>
</tbody>
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Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012

Citation: “Land Clearing and the Biofuel Debt,” Fargione et al., 2008.
Slide courtesy of Heiner von Bothmer.
Biomass as fuel

Land for oil

If oil is what matters, everything that grows is a potential liquid-fuel feedstock.

Land in plantations to produce the feedstock for biomass synthetic fuels plants for **1 million barrels per day** (mbd) of fuels:

Examples: sugar cane to ethanol, palm oil to diesel

Assume 10,000 liters/ha-yr (above what can be done today)

(100 liters/t biomass * 100 t biomass/ha-yr)

1 mbd = 365*10^6*150 liters/yr = 50 *10^9 liters/yr.

So, **5 million hectares for 1 mbd**. A very different ballpark.

If liquid fuel is the objective, inputs of coal and natural gas do not need to be charged against the liquid-fuels balance. But these inputs could have become fuels by direct conversion (CTL, GTL).
AR5 WG2 leak: food impacts of climate change

On the food supply, the new report finds that benefits from global warming may be seen in some areas, like northern lands that are now marginal for food production. But it adds that over all, global warming could reduce agricultural production by as much as 2 percent each decade for the rest of this century.

During that period, demand is expected to rise as much as 14 percent each decade, the report found, as the world population is projected to grow to 9.6 billion in 2050, from 7.2 billion today, according to the United Nations, and as many of those people in developing countries acquire the money to eat richer diets.

Any shortfall would lead to rising food prices that would hit the world’s poor hardest, as has already occurred from price increases of recent years. Research has found that climate change, particularly severe heat waves, was a factor in those price spikes.

The agricultural risks “are greatest for tropical countries, given projected impacts that exceed adaptive capacity and higher poverty rates compared with temperate regions,” the draft report finds.

If the report proves to be correct about the effect on crops from climate change, global food demand might have to be met — if it can be met — by putting new land into production. That could entail chopping down large areas of forest, an action that would only accelerate climate change by sending substantial amounts of carbon dioxide into the air from the destruction of trees.

Population and per capita consumption projected to increase

By 2050, people will be eating 60 percent more food, increasing the demand for, and prices of, agricultural products. Source: FAO, 2006

Source: David Kanter, Guest contribution
WWS 585b – Nov. 28, 2012

Meridian Institute, 2011; Tilman et al. 2011
Climate impacts on agricultural productivity without and with CO$_2$ fertilization

Source: David Kanter, Guest contribution
WW5 585b – Nov. 28, 2012
Poorest most vulnerable

Source: David Kanter, Guest contribution
WWS 585b – Nov. 28, 2012

Center for Global Development
Mapping the Impacts of Climate Change
Coupling of energy and land markets

Market value of bioenergy is coupled to oil price....

Oil price shock:

Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012
## Summary: bioenergy impacts

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<td>biodiversity loss, land use change (deforestation, drainage of wetlands etc.), soil degradation, influence of pesticides</td>
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<td>resource “land” more or less available in all parts of the world (in contrast to fossil fuel)</td>
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*Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012*
### Key conditionalities

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<th>Failure of condition</th>
</tr>
</thead>
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<td><strong>Land-intensity</strong></td>
<td>• Land carbon loss&lt;br&gt;• Biodiversity loss&lt;br&gt;• Competition with food</td>
</tr>
<tr>
<td>Produce bioenergy by land-intensive biomass, not by land expansion</td>
<td></td>
</tr>
<tr>
<td><strong>Food demand</strong></td>
<td>• Less land available for bioenergy crops&lt;br&gt;• see above</td>
</tr>
<tr>
<td>Reduce consumption of red meat</td>
<td></td>
</tr>
<tr>
<td><strong>Costs</strong></td>
<td>• Not economically viable OR&lt;br&gt;• False options chosen&lt;br&gt;• see above</td>
</tr>
<tr>
<td>Reduce costs of cellulosic biofuels</td>
<td></td>
</tr>
<tr>
<td><strong>Regulation</strong></td>
<td>• Very high risks of “leakage”&lt;br&gt;• see above</td>
</tr>
<tr>
<td>Global forest/peatland protection</td>
<td></td>
</tr>
<tr>
<td><strong>Labor and value chain</strong></td>
<td>• Disempowerment&lt;br&gt;• Inequality&lt;br&gt;• Exclusion</td>
</tr>
<tr>
<td>Rural communities take part in value chain, get labor, ownership &amp; keep land rights</td>
<td></td>
</tr>
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*Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012*
Conditionality for biocarbon

What will go wrong if we move headlong to maximize either global biostocks or global biofuels without conditionalities?

Suppose you were a forester or an agronomist in a world where the carbon price was very high. You were told that storing carbon was your only objective. What would you do? Establish a monocrop? Pour on fertilizer? Be inventive…. 
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Now, change roles. You are the policy maker in the same world. What conditionalities would you place on the carbon market for biostocks in the interest of eliciting actions you would welcome and deterring out comes you would decry?
EXTRA SLIDES
Billions of tons of CO₂ emitted per year

Two alternative mid-century emissions targets

- Historical emissions
- Flat path
- Current path = “ramp”
- Stabilization Wedges, ca. 2008
- Eight “wedges”
- 16 GtC/y

Tough interim goal

Tougher interim goal
Figure 4: Global energy-related CO₂ emissions by major world region in Gt C/yr (see the Energy Primer in the Working Group II SAR volume).
Carbon in fossil fuels by region, 1961-95
McKinsey abatement curve

U.S. MID-RANGE ABATEMENT CURVE – 2030

Source: McKinsey analysis