The Role of Technology in Meeting National and Global Mitigation Goals

PART I

GTSP
The Global Energy Technology Strategy Program

Presented by
Leon Clarke and Jae Edmonds
for the GTSP Group
The Cosmos Club
Washington, DC

May 27, 2009
The Questions for this Talk

- What do stabilization goals imply for near-term actions and long-term strategies?
- How low can we go? How fast can we get there?
- Who needs to do what and by when?
- How much technology do we need to limit climate change?
- How are near-term actions affected by long-term technology expectations?
- What is the value of having and developing technology.
What do stabilization goals imply for near-term actions and long-term strategies?
A Quick Cross-walk between units of C and CO$_2$

- **Quantities** expressed in terms of CO$_2$ are larger than those expressed in terms of C.

  1 tonne C = $\frac{44}{12}$ tonnes CO$_2$ ≈ 3.7 tonnes CO$_2$

- **Prices** expressed in terms of CO$_2$ are smaller than those expressed in terms of C.

  $100$/tC = 27 $$/tCO_2$ ≈ 30 $$/tCO_2$
# A Quick Cross-walk between Measures of the Long-Term Goal

<table>
<thead>
<tr>
<th>Targets</th>
<th>Results</th>
<th>Full-Gas** (IPCC Definition)</th>
<th>Equilibrium Temperature</th>
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<tbody>
<tr>
<td>Kyoto Gases Only</td>
<td>CO₂ Only</td>
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<tr>
<td>Radiative Forcing (W/m²)</td>
<td>CO₂-equivalent Concentration (ppmv)</td>
<td>CO₂ Concentration in 2100 (ppmv)</td>
<td>Radiative Forcing (W/m²)</td>
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<td>2.6</td>
<td>450</td>
<td>≈ 385</td>
<td>2.3 - 2.7</td>
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<tr>
<td>3.7</td>
<td>550</td>
<td>≈ 465</td>
<td>3.5 - 3.8</td>
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<tr>
<td>4.5</td>
<td>650</td>
<td>≈ 540</td>
<td>4.2 - 4.6</td>
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1 Full-gas forcing from the MiniCAM, IMAGE, and MESSAGE models participating in EMF 22.

2 Climate sensitivity ranges from IPCC Fourth Assessment Report.
A Quick Cross-walk between Measures of the Long-Term Goal

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1 Full-gas forcing from the MiniCAM, IMAGE, and MESSAGE models participating in EMF 22.
2 Climate sensitivity ranges from IPCC Fourth Assessment Report.
Climate change is a long-term strategic problem with implications for today.

- Stabilization of greenhouse gas concentrations is the goal of the Framework Convention on Climate Change.
- Stabilizing CO₂ concentrations at any level means that global, CO₂ emissions must peak and then decline forever.
Stabilization will require fundamental changes to the global energy system.

From CCSP Product 2.1a: Scenarios of Emissions and Greenhouse Gas Concentrations
Primary Energy from the CCSP Scenarios

(Reference Scenario)

From CCSP Product 2.1a: Scenarios of Emissions and Greenhouse Gas Concentrations
Primary Energy from the CCSP Scenarios
(≈ 750 ppmv CO$_2$)

From CCSP Product 2.1a: Scenarios of Emissions and Greenhouse Gas Concentrations
Primary Energy from the CCSP Scenarios

(≈ 650 ppmv CO₂)

From CCSP Product 2.1a: Scenarios of Emissions and Greenhouse Gas Concentrations
Primary Energy from the CCSP Scenarios

(≈ 550 ppmv CO₂)

From CCSP Product 2.1a: Scenarios of Emissions and Greenhouse Gas Concentrations
Primary Energy from the CCSP Scenarios

(\approx 450\ \text{ppmv\ CO}_2)
How low can we go? How fast can we get there?
In the long-run, it’s physically possible to meet very low goals.

### Cumulative Fossil Fuel Carbon Emissions

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<tr>
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<th>1750 - 2005</th>
<th>2005 - 2100</th>
<th>1750 - 2100</th>
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<tbody>
<tr>
<td>GTSP 450 ppmv</td>
<td>300</td>
<td>480</td>
<td>780</td>
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<tr>
<td>GTSP 550 ppmv</td>
<td>300</td>
<td>862</td>
<td>1162</td>
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<tr>
<td>GTSP 650 ppmv</td>
<td>300</td>
<td>1040</td>
<td>1340</td>
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<tr>
<td>GTSP 750 ppmv</td>
<td>300</td>
<td>1200</td>
<td>1500</td>
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<tr>
<td>GTSP REF</td>
<td>300</td>
<td>1430</td>
<td>1730</td>
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### Long-Term Equilibrium Emissions and Concentrations

<table>
<thead>
<tr>
<th>CO₂ Concentration (ppmv)</th>
<th>Cumulative Emissions (GtC)</th>
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<tr>
<td>275</td>
<td>0</td>
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<tr>
<td>300</td>
<td>292</td>
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<td>325</td>
<td>560</td>
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<tr>
<td>350</td>
<td>808</td>
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<tr>
<td>375</td>
<td>1,039</td>
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<tr>
<td>400</td>
<td>1,255</td>
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<tr>
<td>425</td>
<td>1,459</td>
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<td>450</td>
<td>1,653</td>
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<td>550</td>
<td>2,338</td>
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<td>600</td>
<td>2,641</td>
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<tr>
<td>650</td>
<td>2,924</td>
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Negative emissions mean that very low steady-state concentrations are thinkable:

- How long above the very long-term value?
- How high above the long-term value?
- How much irreversible change?
MiniCAM can solve for a 2.6 W/m² (Kyoto gases only)

- The EMF 22 study asked modeling teams to examine scenarios that limited radiative forcing to 2.6 W/m² (450 ppm CO₂e).
- Radiative forcing from Kyoto gases was 2.36 in 2005.

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<tr>
<th></th>
<th>Immediate participation by all countries</th>
<th>Delayed participation by ANNEX I (ex. Russian Federation)</th>
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<tbody>
<tr>
<td>Overshoot</td>
<td>Solved</td>
<td>Solved</td>
</tr>
<tr>
<td>Not to exceed</td>
<td>Solved</td>
<td>X</td>
</tr>
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</table>

From our *EMF 22 International* paper on meeting low stabilization levels
## The Challenges of 450 CO\textsubscript{2}-e

*(From the MiniCAM Paper: Calvin et al.)*

<table>
<thead>
<tr>
<th>Immediate Accession</th>
<th>Not-to-Exceed</th>
<th>Overshoot</th>
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<tbody>
<tr>
<td>1) Includes immediate participation by all regions</td>
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<tr>
<td>2) Includes 70% dramatic emissions reductions by 2020</td>
<td>2) Includes the construction of 126 new nuclear reactors and the capture of nearly a billion tons of CO\textsubscript{2} in 2020</td>
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<tr>
<td>3) Includes substantial transformation of the energy system by 2020, including the construction of 500 new nuclear reactors, and the capture of 20 billion tons of CO\textsubscript{2}</td>
<td>3) Includes negative global emissions by the end of the century, and thus requires broad deployment of bioCCS technologies</td>
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<tr>
<td>4) Includes negative global emissions by the end of the century, and thus requires broad deployment of bioCCS technologies</td>
<td>4) Carbon prices escalate to $775/tCO\textsubscript{2} in 2095</td>
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<tr>
<td>5) Includes a carbon price of $100/tCO\textsubscript{2} globally in 2020</td>
<td>5) Possible without a tax on land-use emissions, but would result in a tripling of carbon taxes and a substantial increase in the cost of meeting the target.</td>
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<td>6) Includes advanced technologies</td>
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<td>6) Includes advanced technologies</td>
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<table>
<thead>
<tr>
<th>Delayed Accession</th>
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<tbody>
<tr>
<td>1) Includes dramatic emissions reductions for Groups 2 and 3 at the time of their accession,</td>
<td>2) Includes negative emissions in Group 1 by 2050 and negative global emissions by the end of the century, and thus requires broad deployment of bioCCS technologies</td>
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<td>3) Includes negative emissions in Group 1 by 2050 and negative global emissions by the end of the century, and thus requires broad deployment of bioCCS technologies</td>
<td>3) Carbon prices begin at $50/tCO\textsubscript{2}, and rise to $2000/tCO\textsubscript{2}</td>
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<td>4) Results in significant land-use leakage, where crop production is outsourced to non-participating regions resulting in a substantial increase in land-use change emissions in these regions</td>
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Who is doing the heavy lifting in these low scenarios?

- **Group 3** = Rest of World.
- **Group 2** = Brazil, Russian Fed., China, India.
- **Group 1** = Annex I ex. Russian Fed.

From our *EMF 22 International* paper on meeting low stabilization levels.
Who needs to do what and by when?
Implications of Delayed Participation in Global Emissions – A Zero Sum Game

Global Carbon Emissions
450 ppmv (Not-to-Exceed)

Global Carbon Emissions
550 ppmv (Not-to-Exceed)

From our Climate Policy paper on delayed participation.
Near-term Implications for U.S. Emissions Mitigation of 450 ppm Stabilization

U.S. Carbon Emissions
450 ppmv (Not-to-Exceed)

U.S. Carbon Emissions
550 ppmv (Not-to-Exceed)

From our Climate Policy paper on delayed participation
Near-term Implications for CHINA Emissions Mitigation of 450 ppm Stabilization

Chinese mitigation to achieve 450 ppm CO₂ stabilization ("not-to-exceed") depends on what other countries do.

Our Climate Policy paper keyed non-Annex I emissions mitigation to China.

- Immediate accession of all regions means emissions mitigation of 40% in 2050.
- If China enters the mitigation coalition in 2020, then it needs to roughly get on a track for 80% reductions from 2020 emissions by 2065.
- If China enters the mitigation coalition in 2035, then mitigation needs to be dramatic.

From our Climate Policy paper on delayed participation.
Indian mitigation to achieve 450 ppm CO₂ stabilization (“not-to-exceed”) depends on what other countries do.

Our *Climate Policy* paper keyed non-Annex I emissions mitigation to China.

- Immediate accession of all regions means that 50% emissions mitigation in 2050 is more than adequate.
- China enters the mitigation coalition in 2020, then India enters in 2035 (by assumption).
- India entering in 2035 means that it needs to get on track toward an 80% reduction from 2035 emissions by 2080.

From our *Climate Policy* paper on delayed participation.
The Implications of Participation for Discounted Costs over the Century

Overshoot to 500 ppmv by 2100 with and without delayed participation by developing regions

From our *Harvard Project* paper on delayed participation and technology
Technology implications can be larger than those from the international architecture.

Overshoot to 500 ppmv by 2100 with and without delayed participation by developing regions

More aggressive assumptions about the evolution of technology can substantially reduce costs.

From our *Harvard Project* paper on delayed participation and technology
How much technology do we need to limit climate change?
How much technology we need depends on what is available.

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<td>Transportation: Electric Vehicles</td>
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<td>Agricultural Productivity</td>
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<td>Hydrogen Production</td>
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<td>Wind Power</td>
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<td>Nuclear Fission</td>
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</table>

A wide range of technology combinations were explored for the U.S. Climate Change Technology Program.

From our technical report on technology scenarios for the Climate Change Technology Program.
How much technology we need depends on what is available.

You use what you’ve got.

From our technical report on technology scenarios for the *Climate Change Technology Program*
How much technology we need depends on what is available.

The character of the energy system could vary dramatically depending on how technology evolves. How different will it be in the nearer-term?

From our technical report on technology scenarios for the Climate Change Technology Program.
How much technology we need depends on what is available.

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From our technical report on technology scenarios for the Climate Change Technology Program.
How linked is near-term technology deployment to the long-term future?

From our technical report on technology scenarios for the *Climate Change Technology Program*.
How linked is near-term technology deployment to the long-term future?

A Technology Strategy:
1. Use what you’ve got.
2. Improve what you’ve got.
3. Lay the foundations for new and different options.

Near-term investments will take place on the investment margin* and are not necessarily indicative of where the energy system will end up in the long-term.

From our technical report on technology scenarios for the *Climate Change Technology Program*.
Getting to better technology does not mean waiting until the technology is delivered.

CO₂ Storage—550 ppm Stabilization Case

Millions of Tons of Carbon per Year

Monitored CO₂ Storage Today

2020 (550 ppm)
In the mid- and long-term the challenge grows

CO₂ Storage—550 ppm Stabilization Case

- Monitored CO₂ Storage Today
- 2020 (550 ppm)
- 2050 (550 ppm)
- 2095 (550 ppm)
How different are deployment actions for regions that delay action?

China Primary Energy 2020: 500 ppmv Overshoot

From our *Harvard Project* paper on delayed participation and technology.

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<table>
<thead>
<tr>
<th>Region</th>
<th>Energy Reduction</th>
<th>Geothermal</th>
<th>Wind &amp; Solar</th>
<th>Hydro</th>
<th>Biomass w/CCS</th>
<th>Biomass w/o CCS</th>
<th>Coal w/CCS</th>
<th>Coal w/o CCS</th>
<th>Gas w/CCS</th>
<th>Gas w/o CCS</th>
<th>Oil w/CCS</th>
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<td>BioCCS: Full</td>
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<td>BioCCS: Delay</td>
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RNE: Full

Reference

Harvard Project

BioCCS: Delay

BioCCS: Full

Adv: Delay

Adv: Full

From our *Harvard Project* paper on delayed participation and technology.
How different are deployment actions for regions that delay action?

Even without explicit climate policy, there may be technology opportunities.
How different are deployment actions for regions that delay action?

With fewer technology options, China reduces energy more in 2050 under delay.

By 30 years after entering the coalition, the effects of delay are largely gone.

From our *Harvard Project* paper on delayed participation and technology.
How are near-term actions affected by long-term technology expectations?
Economic consequences of stabilization were very different among the CCSP scenarios.

From CCSP Product 2.1a: Scenarios of Emissions and Greenhouse Gas Concentrations
While the technology stories for the three modeling teams are similar through 2050, they are different in the far future.

From *CCSP Product 2.1a: Scenarios of Emissions and Greenhouse Gas Concentrations*
While the mitigation supply schedule for MIT and MiniCAM were similar up to the year 2050 in the CCSP SAP 2.1a, near-term carbon prices were much higher in the MIT scenarios. This is in part due to differences in technology availability in the post-2050 period.

Investments in basic scientific research in the first half of the 21st century can be transformed into energy technologies that can become a major part of the global energy system in the second half of the century.
In these scenarios, limitations on the ability reduce non-CO2 GHGs, particularly in agriculture, imply higher carbon prices and influence the degree of banking.

From our *EMF 22 U.S.* paper on technology and U.S. emissions goals.
The Influence of our Ability to Make Deep Cuts by Mid-Century and Beyond

In these scenarios limitations on the ability reduce non-CO2 GHGs, if we expect limited future technology options, it could drive premature retirement of existing capital.

But then how likely is it that society will be ready to take the deep cuts required mid-century and beyond?

From our EMF 22 U.S. paper on technology options...
Long-Term Emissions Pathways: The Influence of Technology and Delay

U.S. CO₂ Emissions: 500 ppmv Overshoot

From our Harvard Project paper on delayed participation and technology
Long-Term Emissions Pathways: The Influence of Technology and Delay

India CO₂ Emissions: 500 ppmv Overshoot

From our Harvard Project paper on delayed participation and technology.
What is the value of having and developing technology?
Technology can dramatically reduce the costs of mitigation.

U.S. CO₂ prices to meet a 80% reduction cumulative goal by 2050

In EMF 22, the MiniCAM U.S. scenarios span the range of carbon prices among models based exclusively on variations in technology.

From our EMF 22 U.S. paper on technology and U.S. emissions goals.
Less efficient climate regimes increase the value of technology.

From our *Harvard Project* paper on delayed participation and technology
International diffusion is critical for in-country R&D

From our Harvard Project paper on delayed participation and technology
The value of international diffusion of technology swamps the value to a single country.

From our Harvard Project paper on delayed participation and technology
The value of any single technology depends on what else is available.

- Stabilization Level: 450ppm and 550ppm
- Full combination of inputs – 768 MiniCAM runs:
  - Supply:
    - Solar: (1) REF (2) ADV
    - Wind: (1) REF (2) ADV
    - Nuclear: (0) FIX (1) REF (2) ADV
    - CCS: (0) FIX (1) REF
  - End-Use:
    - Buildings: (1) REF (2) ADV
    - Industry: (1) REF (2) ADV
    - Transportation: (1) REF (2) ADV
  - Others: agLU efficiency, geothermal, hydrogen, cement
A wide range of mitigation costs are possible.

Distribution of mitigation costs for 450 ppmv stabilization
Every technological advance reduces the chance of high costs.
What technology do you need on-hand, if you absolutely don’t want to go above $7tril?

Effects of delaying the availability of CCS by 15-year increments
Summing Up
Summing Up

What do stabilization goals imply for near-term actions and long-term strategies? How low can we go? How fast can we get there?

*In the long-term almost anything is possible, but the faster we want to get there, the harder it is and the more important technology becomes.*

Who needs to do what and by when?

*Emissions mitigation may start in the developed world, but in the long term China, India and other developing nations will need to lead. Getting to 450 ppm with gradually expanding participation means rapid reductions by everyone as soon as they begin.*
Summing Up

► How much technology do we need to limit climate change?

*You always begin with what you’ve got. But, the better the technology (both end-use and energy supply) the less “doing without” is needed. And, getting to low scenarios means a rapidly accelerating deployment of emissions mitigation technologies.*

► How are near-term actions affected by long-term technology expectations?

*The poorer you expect future technology to be, the more you need to do today. You “bank” emissions mitigation today to avoid really deep reductions in the future.*

► What is the value of having and developing technology?

*Technology is more important to controlling mitigation costs the less perfect the world. Most of the value of developing technology is in other countries getting and deploying it.*
END PART 1