Strategies for Global Energy
"Advanced Technology" (long-term)
or
"Current Technology" (short-term)

Prof. Mike Mauel

Applied Physics Lunch-Time Seminar

Fall 2015

Current Events (9/30/2015)

- (Last Friday, 9/25) U.S. / China Joint Presidential Statement on Climate Change (https://www.whitehouse.gov/the-press-office/2015/09/25/fact-sheet-united-states-and-china-issue-joint-presidential-statement)

- (Last Friday, 9/25) Pope Francis and world leaders adopt 17 "global goals" and urge environmental justice over a "boundless thirst for power and material prosperity," http://www.globalgoals.org and http://www.nytimes.com/2015/09/26/world/europe/pope-francis-united-nations.html)

- (Monday, 9/28) Climate Interactive (a climate "think tank") releases it scorecard: will the proposals reach global goals? (https://www.climateinteractive.org).

- (Last Wed, 9/23) John Lemmon (ARPA-E) publishes his vision for distributed batteries and generation. ("Energy: Reimagine Fuel Cells", Nature, v 525, p 447; http://www.nature.com/news/energy-reimagine-fuel-cells-1.18392)

Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet

Martin I. Hoffert,[1*] Ken Caldeira,[3] Gregory Benford,[4] David R. Criswell,[5] Christopher Green,[6] Howard Herzog,[7] Atul K. Jain,[8] Haroon S. Kheshgi,[9] Klaus S. Lackner,[10] John S. Lewis,[12] H. Douglas Lightfoot,[13] Wallace Manheimer,[14] John C. Mankins,[15] Michael E. Mauel,[11] L. John Perkins,[3] Michael E. Schlesinger,[8] Tyler Volk,[2] Tom M. L. Wigley[16]

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"or" ("and")

Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies

S. Pacala[1*] and R. Socolow[2*]

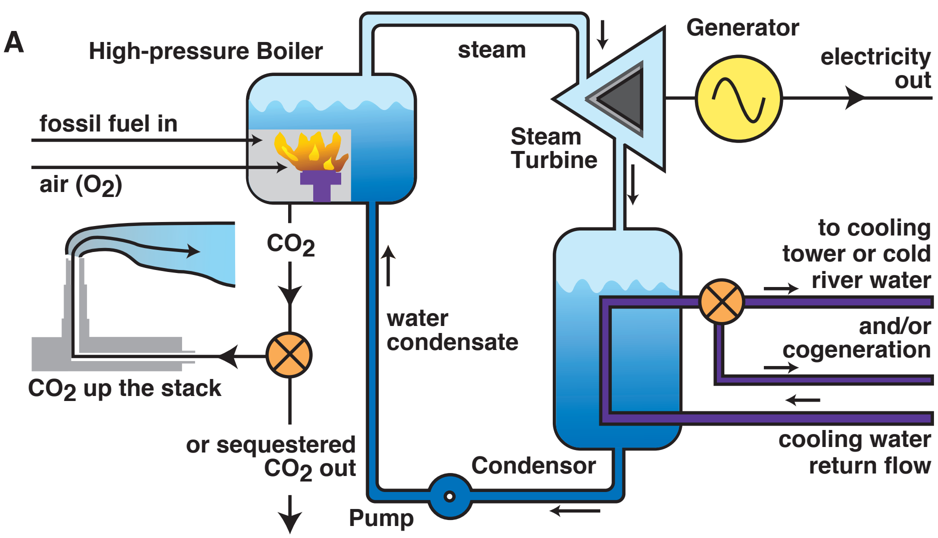
13 AUGUST 2004 VOL 305 SCIENCE www.sciencemag.org

Stabilizing the carbon dioxide–induced component of climate change is an energy problem. Establishment of a course toward such stabilization will require the development within the coming decades of primary energy sources that do not emit carbon dioxide to the atmosphere, in addition to efforts to reduce end-use energy demand. Mid-century primary power requirements that are free of carbon dioxide emissions could be several times what we now derive from fossil fuels ($\sim 10^{13}$ watts), even with improvements in energy efficiency. Here we survey possible future energy sources, evaluated for their capability to supply massive amounts of carbon emission–free energy and for their potential for large-scale commercialization. Possible candidates for primary energy sources include terrestrial solar and wind energy, solar power satellites, biomass, nuclear fission, nuclear fusion, fission-fusion hybrids, and fossil fuels from which carbon has been sequestered. Non–primary power technologies that could contribute to climate stabilization include efficiency improvements, hydrogen production, storage and transport, superconducting global electric grids, and geoengineering. All of these approaches currently have severe deficiencies that limit their ability to stabilize global climate. We conclude that a broad range of intensive research and development is urgently needed to produce technological options that can allow both climate stabilization and economic development.

Primary power consumption today is 12 TW, of which 85% is fossil-fueled. Stabilization at 550, 450, and 350 ppm CO_2 by Wigley *et al*. scenarios require emission-free power by mid-century of 15, 25, and >30 TW, respectively (*8*). **Attaining this goal is not easy.**

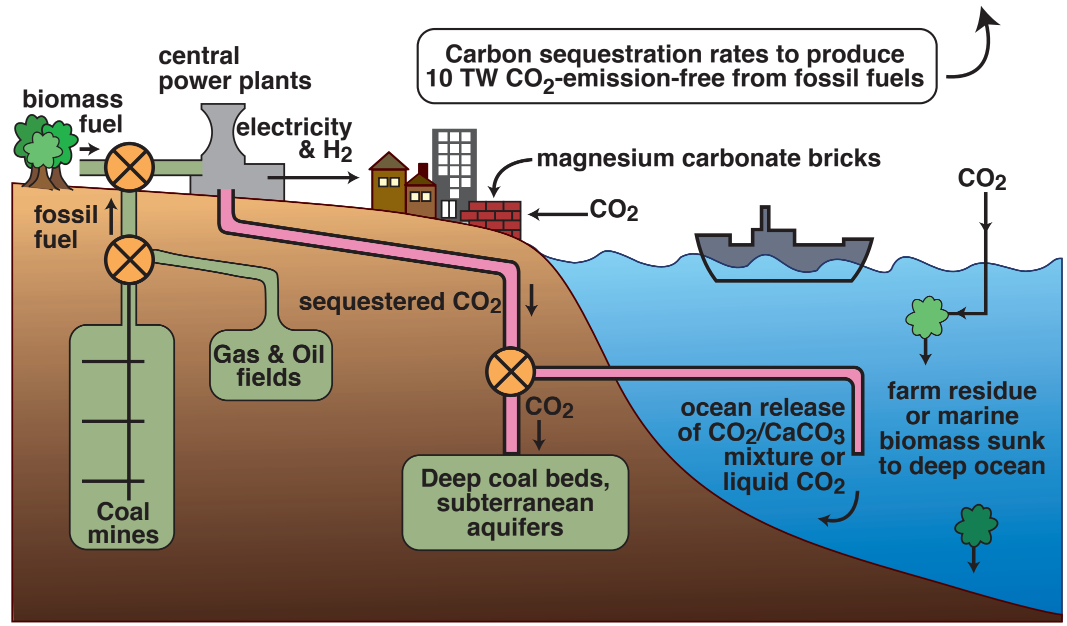
Decarbonization and Sequestration

A



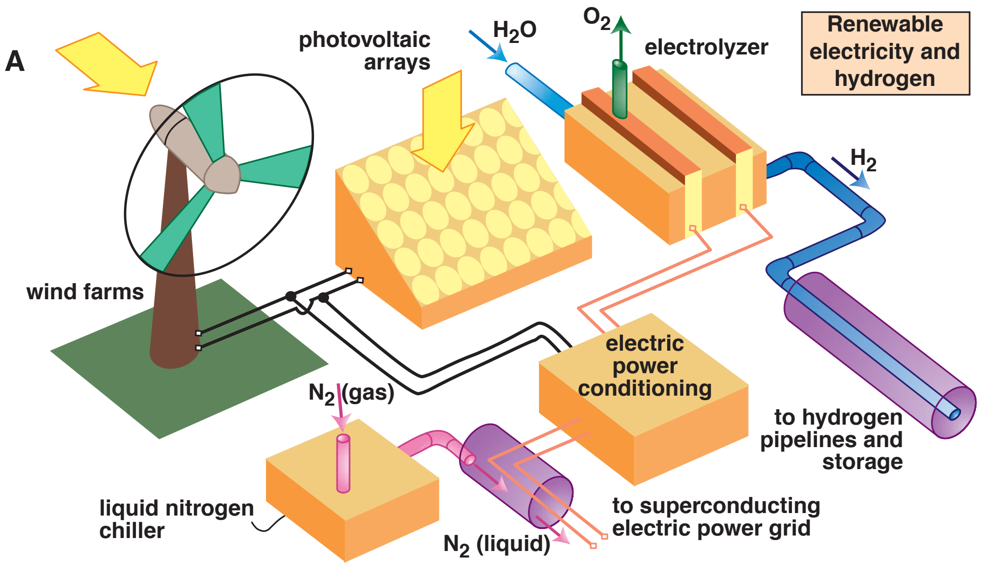
B

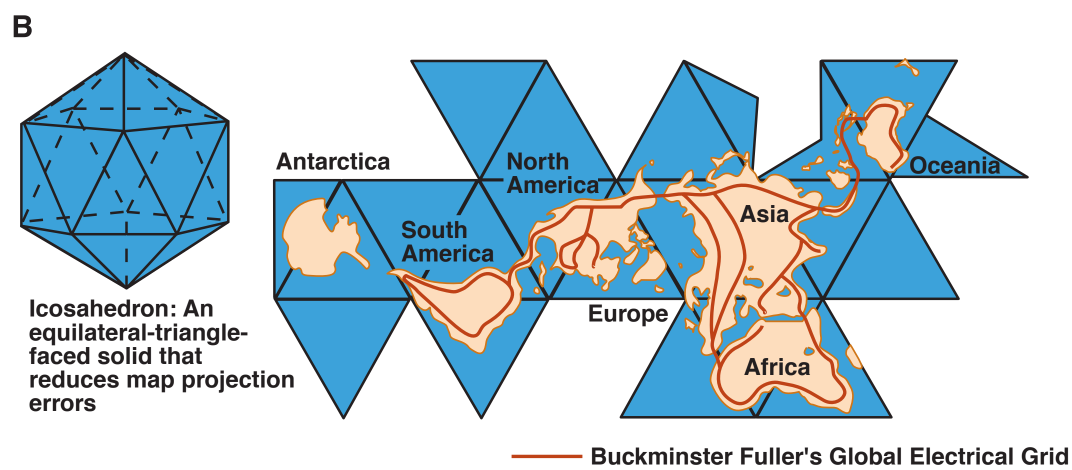
Fossil fuel	Energy content [TW-yr]	Carbon content [GTC]	(E_{fuel}/C) [TW-yr/GtC]	(E/C) [TW-yr/GtC]	Sequestration rate [GtC/yr]
Gas	1200	570	2.1	1.9 - 1.6	5 - 6
Oil	1200	750	1.6	1.4 - 1.2	7 - 8
Coal	4800	3690	1.3	1.2 - 1.0	9 - 10

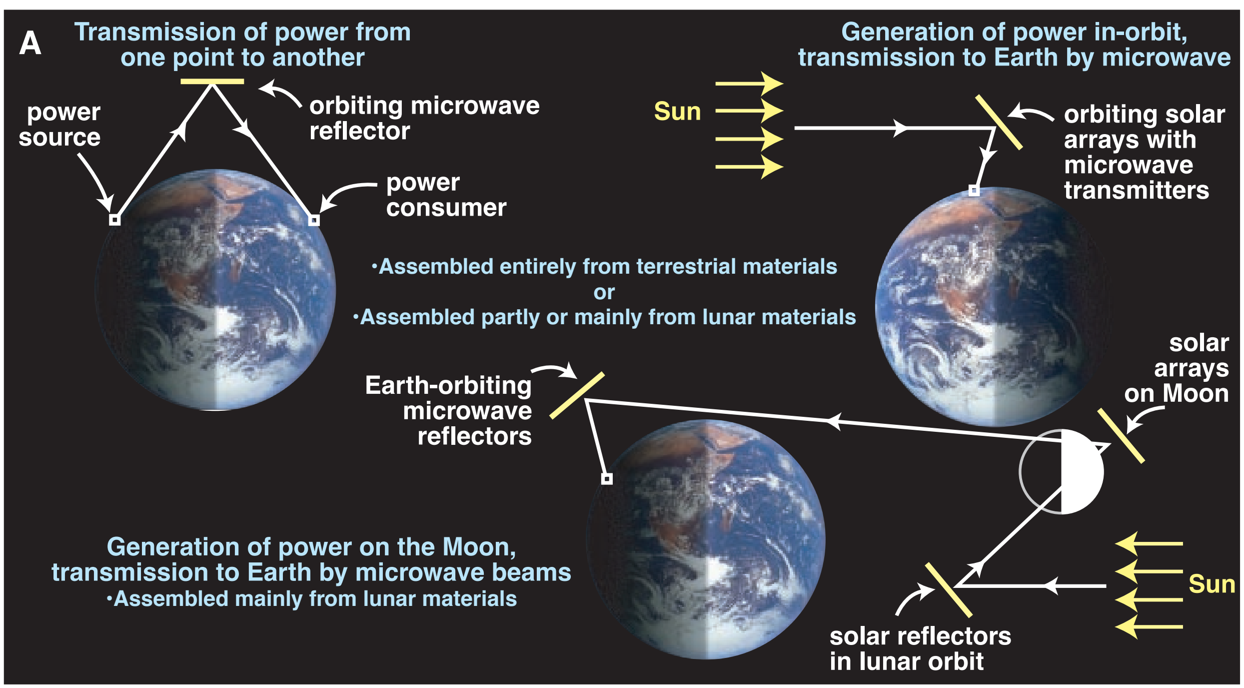


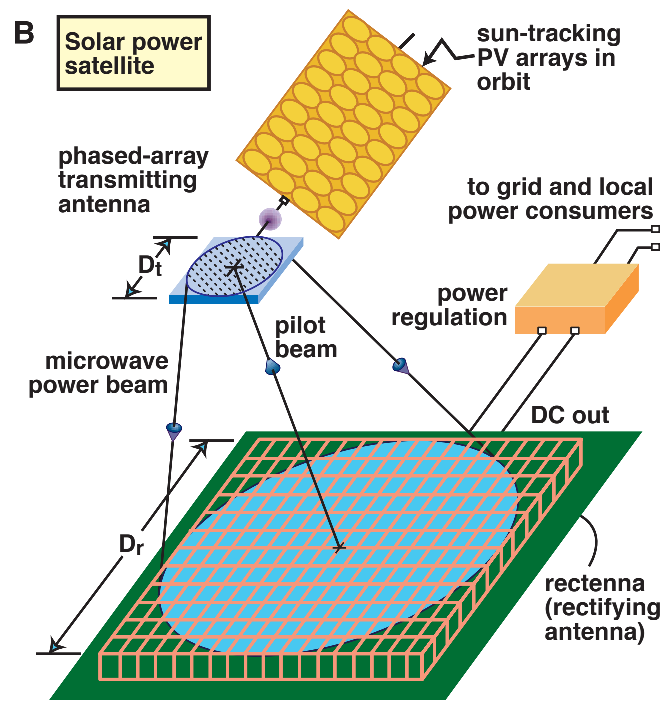
Thus, carbon sequestration could be a valuable bridge to renewable and/or nuclear energy. ***However***, if other emission-free primary power sources of 10 to 30 TW are unavailable by mid-century, then ***enormous sequestration rates*** could be needed to stabilize atmospheric CO_2 .

Renewables

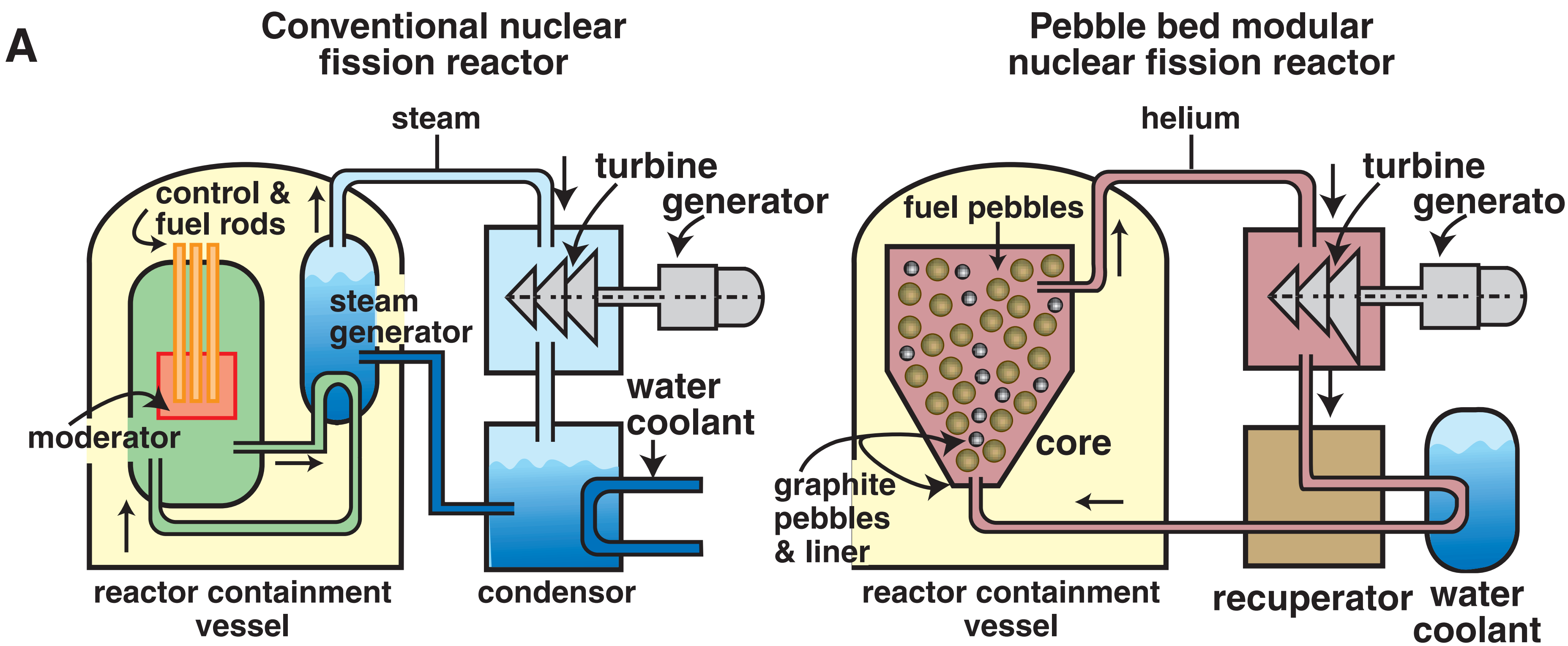

A
photovoltaic arrays
H_2O
O_2
electrolyzer
Renewable electricity and hydrogen
H_2
wind farms
electric power conditioning
N_2 (gas)
to hydrogen pipelines and storage
liquid nitrogen chiller
N_2 (liquid)
to superconducting electric power grid


B
Icosahedron: An equilateral-triangle-faced solid that reduces map projection errors
Antarctica
North America
South America
Europe
Asia
Oceania
Africa
Buckminster Fuller's Global Electrical Grid

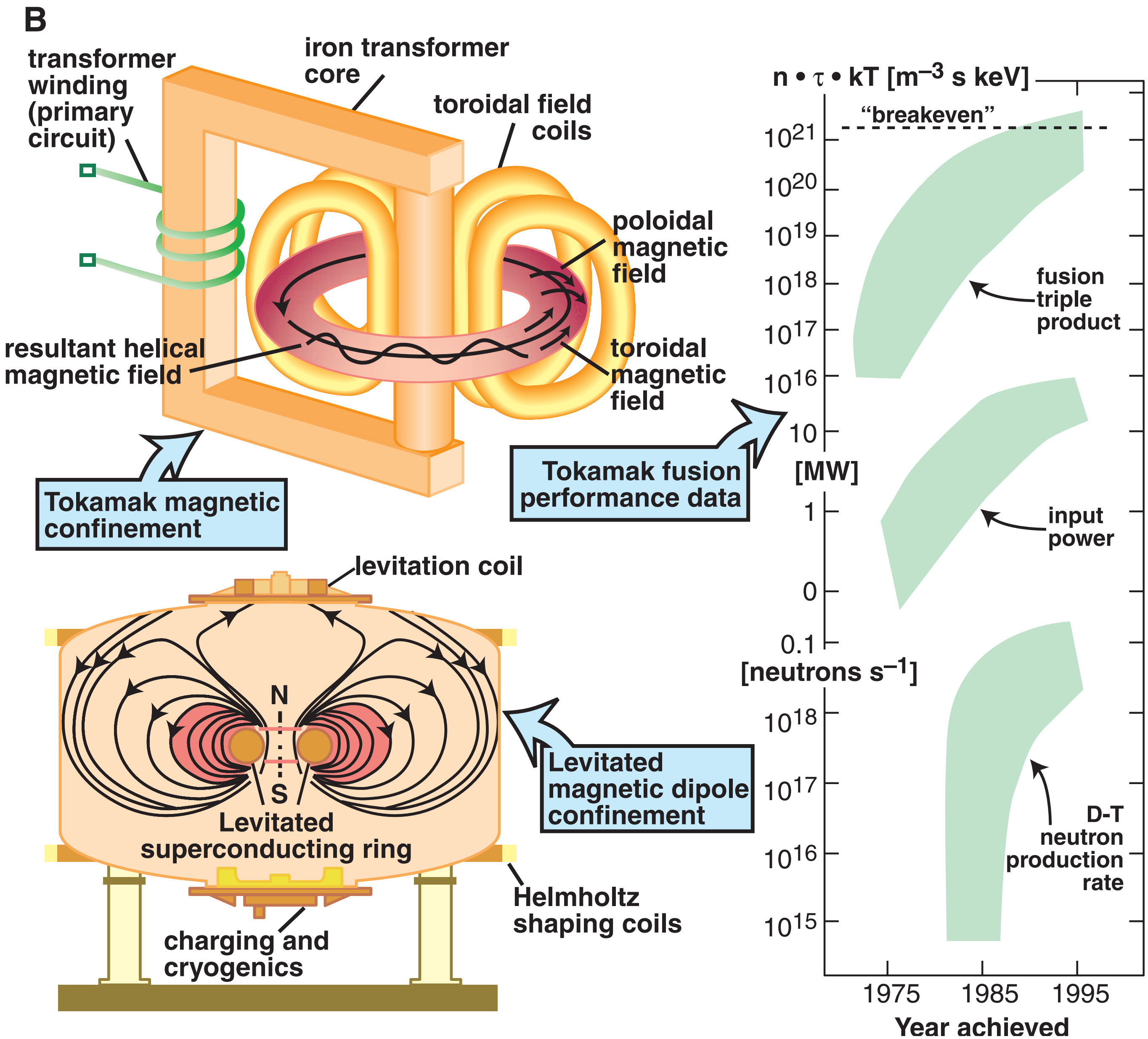

A
Transmission of power from one point to another
power source
orbiting microwave reflector
power consumer
Generation of power in-orbit, transmission to Earth by microwave
Sun
orbiting solar arrays with microwave transmitters
•Assembled entirely from terrestrial materials
or
•Assembled partly or mainly from lunar materials
Earth-orbiting microwave reflectors
solar arrays on Moon
Generation of power on the Moon, transmission to Earth by microwave beams
•Assembled mainly from lunar materials
Sun
solar reflectors in lunar orbit


B
Solar power satellite
sun-tracking PV arrays in orbit
phased-array transmitting antenna
to grid and local power consumers
D_t
power regulation
pilot beam
microwave power beam
DC out
D_r
rectenna (rectifying antenna)

Fission and Fusion

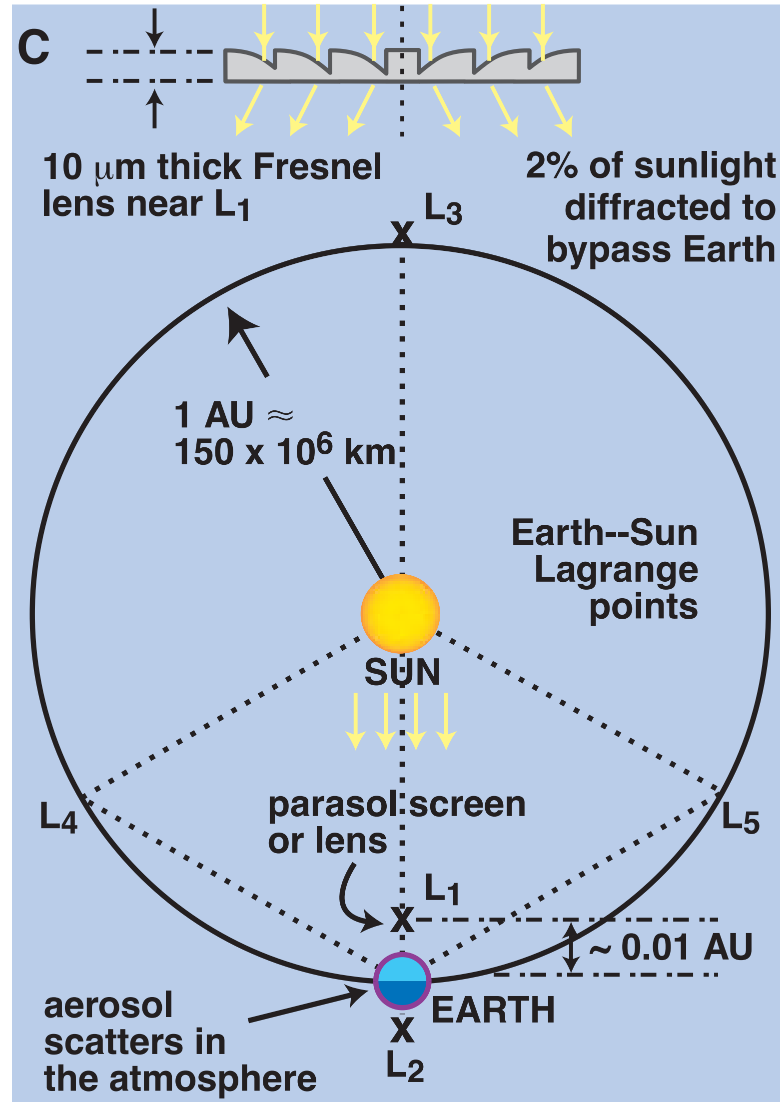


Fission and Fusion



Geoengineering

Our assessment reveals major challenges to stabilizing the fossil fuel greenhouse with energy technology transformations. *It is only prudent to pursue geoengineering research as an insurance policy should global warming impacts prove worse than anticipated and other measures fail or prove too costly*. Of course, large-scale geophysical interventions are inherently risky and need to be approached with caution.



Summary

We have identified a portfolio of promising technologies here—some radical departures from our present fossil fuel system.

Many concepts will fail, and staying the course will require leadership.

Stabilizing climate is not easy. At the very least, it requires political will, targeted research and development, and international cooperation.

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Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies

S. Pacala[1]* and R. Socolow[2]*

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Humanity already possesses the fundamental scientific, technical, and industrial know-how to solve the carbon and climate problem for the next half-century. A portfolio of technologies now exists to meet the world's energy needs over the next 50 years and limit atmospheric CO_2 to a trajectory that avoids a doubling of the preindustrial concentration. Every element in this portfolio has passed beyond the laboratory bench and demonstration project; many are already implemented somewhere at full industrial scale. Although no element is a credible candidate for doing the entire job (or even half the job) by itself, the portfolio as a whole is large enough that not every element has to be used.

The debate in the current literature about stabilizing atmospheric CO_2 at less than a doubling of the preindustrial concentration has led to needless confusion about current options for mitigation. ***On one side,*** the Intergovernmental Panel on Climate Change (IPCC) has claimed that "technologies that exist in operation or pilot stage today" are sufficient to follow a less-than-doubling trajectory "over the next hundred years or more". ***On the other side,*** a recent review in *Science* asserts that the IPCC claim demonstrates "misperceptions of technological readiness" and calls for "revolutionary changes" in mitigation technology, such as fusion, space-based solar electricity, and artificial photosynthesis.

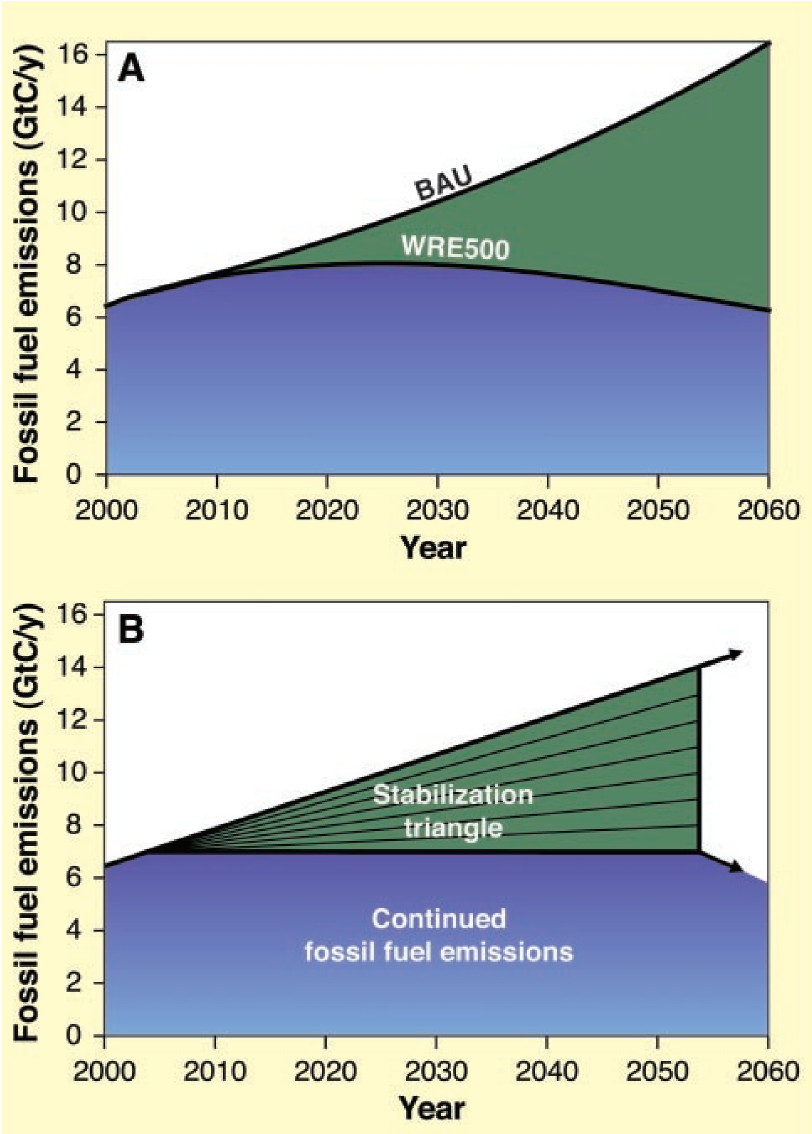
What Do We Mean by "Solving the Carbon and Climate Problem for the Next Half-Century"?

- Proposals to limit atmospheric CO_2 to a concentration that would prevent most damaging climate change have focused on a goal of 500 ±50 parts per million (ppm), or less than double the preindustrial concentration of 280 ppm.
- Very roughly, stabilization at 500 ppm requires that emissions be held near the present level of 7 billion tons of carbon per year (GtC/year) for the next 50 years, even though they are currently on course to more than double.

Stabilization Wedges

To keep the focus on technologies that have the potential to produce a material difference by 2054, we divide the stabilization triangle into seven equal "wedges." A wedge represents an activity that reduces emissions to the atmosphere that starts at zero today and increases linearly until it accounts for 1 GtC/year of reduced carbon emissions in 50 years.

It is important to understand that each of the seven wedges represents an effort beyond what would occur under BAU.



What Current Options Could Be Scaled Up to Produce at Least One Wedge?

- Category I: Efficiency and Conservation
- Category II: Decarbonization of Electricity and Fuels
- Category III: Natural Sinks

Category I: Efficiency and Conservation

Table 1. Potential wedges: Strategies available to reduce the carbon emission rate in 2054 by 1 GtC/year or to reduce carbon emissions from 2004 to 2054 by 25 GtC.

Option	Effort by 2054 for one wedge, relative to 14 GtC/year BAU	Comments, issues
	Energy efficiency and conservation	
Economy-wide carbon-intensity reduction (emissions/$GDP)	Increase reduction by additional 0.15% per year (e.g., increase U.S. goal of 1.96% reduction per year to 2.11% per year)	Can be tuned by carbon policy
1. Efficient vehicles	Increase fuel economy for 2 billion cars from 30 to 60 mpg	Car size, power
2. Reduced use of vehicles	Decrease car travel for 2 billion 30-mpg cars from 10,000 to 5000 miles per year	Urban design, mass transit, telecommuting
3. Efficient buildings	Cut carbon emissions by one-fourth in buildings and appliances projected for 2054	Weak incentives
4. Efficient baseload coal plants	Produce twice today's coal power output at 60% instead of 40% efficiency (compared with 32% today)	Advanced high-temperature materials

Category II: Decarbonization of Electricity and Fuels

Table 1. Potential wedges: Strategies available to reduce the carbon emission rate in 2054 by 1 GtC/year or to reduce carbon emissions from 2004 to 2054 by 25 GtC.

Option	Effort by 2054 for one wedge, relative to 14 GtC/year BAU	Comments, issues
	Fuel shift	
5. Gas baseload power for coal baseload power	Replace 1400 GW 50%-efficient coal plants with gas plants (four times the current production of gas-based power)	Competing demands for natural gas
	CO_2 Capture and Storage (CCS)	
6. Capture CO_2 at baseload power plant	Introduce CCS at 800 GW coal or 1600 GW natural gas (compared with 1060 GW coal in 1999)	Technology already in use for H_2 production
7. Capture CO_2 at H_2 plant	Introduce CCS at plants producing 250 MtH_2/year from coal or 500 MtH_2/year from natural gas (compared with 40 MtH_2/year today from all sources)	H_2 safety, infrastructure
8. Capture CO_2 at coal-to-synfuels plant	Introduce CCS at synfuels plants producing 30 million barrels a day from coal (200 times Sasol), if half of feedstock carbon is available for capture	Increased CO_2 emissions, if synfuels are produced without CCS
Geological storage	Create 3500 Sleipners	Durable storage, successful permitting
	Nuclear fission	
9. Nuclear power for coal power	Add 700 GW (twice the current capacity)	Nuclear proliferation, terrorism, waste
	Renewable electricity and fuels	
10. Wind power for coal power	Add 2 million 1-MW-peak windmills (50 times the current capacity) "occupying" 30×10^6 ha, on land or offshore	Multiple uses of land because windmills are widely spaced
11. PV power for coal power	Add 2000 GW-peak PV (700 times the current capacity) on 2×10^6 ha	PV production cost
12. Wind H_2 in fuel-cell car for gasoline in hybrid car	Add 4 million 1-MW-peak windmills (100 times the current capacity)	H_2 safety, infrastructure
13. Biomass fuel for fossil fuel	Add 100 times the current Brazil or U.S. ethanol production, with the use of 250×10^6 ha (one-sixth of world cropland)	Biodiversity, competing land use

Category III: Natural Sinks

Table 1. Potential wedges: Strategies available to reduce the carbon emission rate in 2054 by 1 GtC/year or to reduce carbon emissions from 2004 to 2054 by 25 GtC.

Option	Effort by 2054 for one wedge, relative to 14 GtC/year BAU	Comments, issues
	Forests and agricultural soils	
14. Reduced deforestation, plus reforestation, afforestation, and new plantations.	Decrease tropical deforestation to zero instead of 0.5 GtC/year, and establish 300 Mha of new tree plantations (twice the current rate)	Land demands of agriculture, benefits to biodiversity from reduced deforestation
15. Conservation tillage	Apply to all cropland (10 times the current usage)	Reversibility, verification

Summary

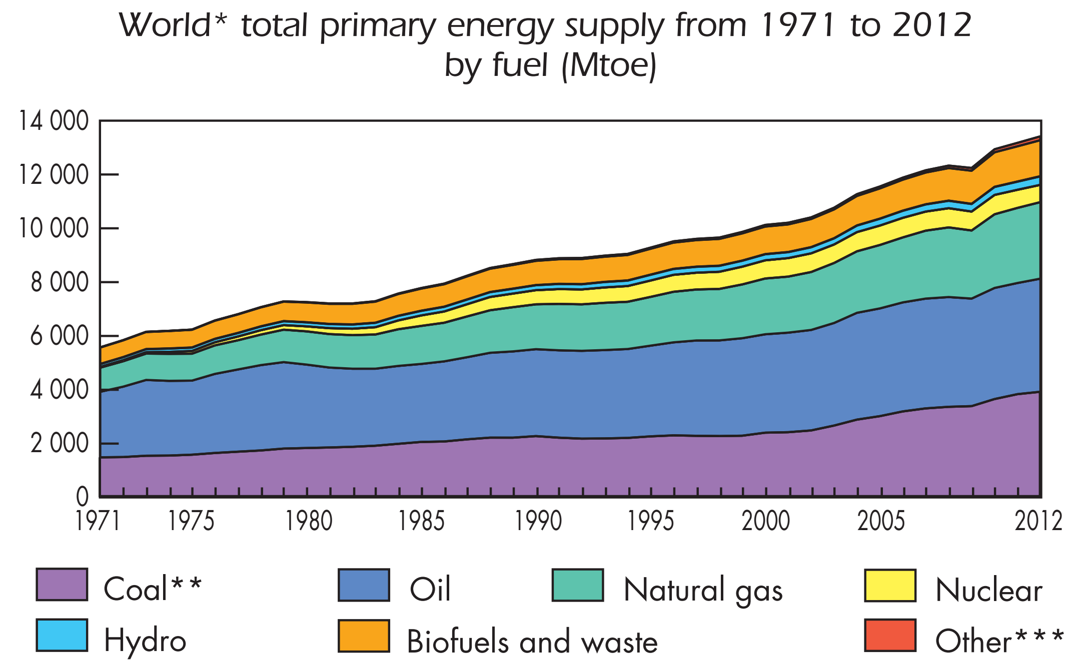
In confronting the problem of greenhouse warming, the choice today is between action and delay. Here, we presented a part of the case for action by identifying a set of options that have the capacity to provide the seven stabilization wedges and solve the climate problem for the next half-century.

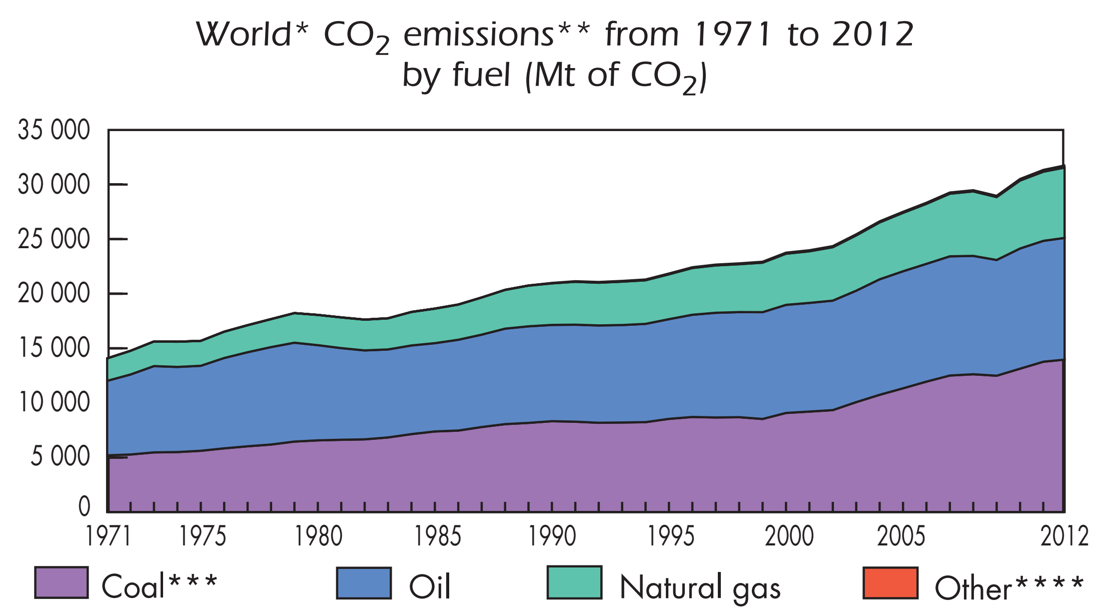
None of the options is a pipe dream or an unproven idea.

How are we doing?

- World-wide attention is growing (as evidenced by last week at the UN and the US-China Joint Presidential Declaration)

- But, energy consumption and GHG emissions continue as BAU...





Carbon Disclosure Project

In 2010, CDP was called "The most powerful green NGO you've never heard of" by the Harvard Business Review.

CDP DRIVING SUSTAINABLE ECONOMIES

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Commit to adopt a science-based emissions reduction target

Companies globally are raising their ambitions around target-setting to ensure their long-term sustainability and profitability, driving bolder business action. To meet the challenges that climate change presents, the world's leading climate scientists and governments agree that it is essential to limit the increase in global average temperature to below 2°C. Science-based targets allow companies to work toward this goal by aligning corporate GHG reductions with global emissions budgets generated by climate models.

More than 60 companies worldwide have now committed to do just that as part of an initiative led by WWF, CDP, the World Resources Institute and the UN Global Compact.

They hope to have 100 companies signed on by year's end, when nations meet in Paris to hammer out a potentially groundbreaking agreement on climate change that is likewise centered around the 2-degree target.

http://www.bna.com/companies-put-positive-n57982058787/?elq=caed47a573f34ba7b21acea9bf252b66&elqCampaignId=1638&elqaid=2803&elqat=1&elqTrackId=c7a38e89f56a4b1686ff463563b8544b

THE WHITE HOUSE
PRESIDENT
GEORGE W. BUSH

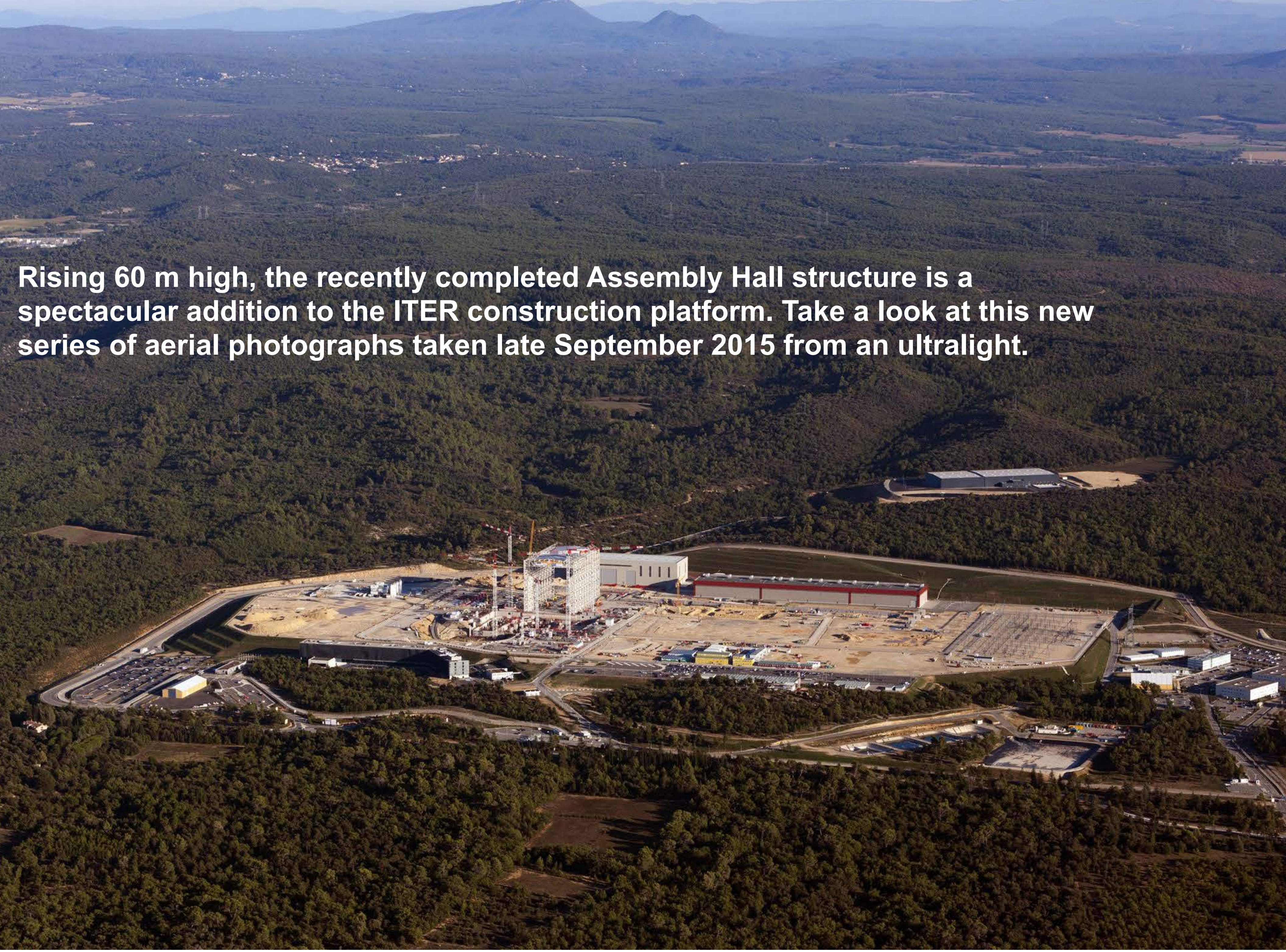
For Immediate Release
Office of the Press Secretary
January 30, 2003

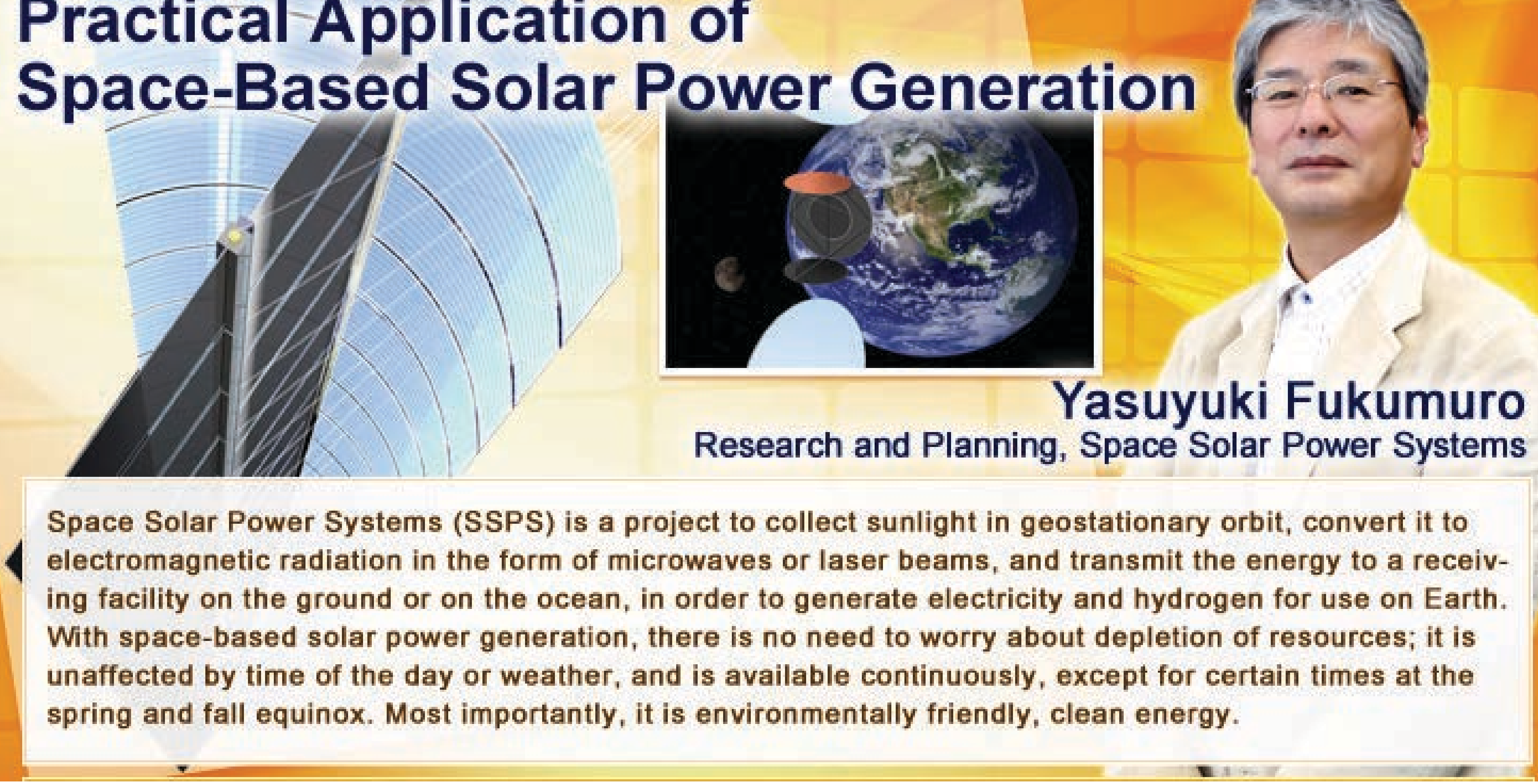
ITER: International Research Project Statement

Statement by the President

I am pleased to announce that the United States will join ITER, an ambitious international research project to harness the promise of fusion energy. The results of ITER will advance the effort to produce clean, safe, renewable, and commercially-available fusion energy by the middle of this century. Commercialization of fusion has the potential to dramatically improve America's energy security while significantly reducing air pollution and emissions of greenhouse gases.

The United States will be working with the United Kingdom, other European Union nations, Russia, China, Japan and Canada on the creation of ITER. Today, I am directing the Secretary of Energy to represent the United States at the upcoming ITER meetings in St. Petersburg, Russia. We welcome the opportunity to work with our partners to make fusion energy a reality.


Rising 60 m high, the recently completed Assembly Hall structure is a spectacular addition to the ITER construction platform. Take a look at this new series of aerial photographs taken late September 2015 from an ultralight.



Japan space scientists make wireless energy breakthrough

March 12, 2015 Researchers used microwaves to deliver 1.8 kilowatts of power—enough to run an electric kettle—through the air with pinpoint accuracy to a receiver 55 m (170 feet) away.

While the distance was not huge, the technology could pave the way for mankind to eventually tap the vast amount of solar energy available in space and use it here on Earth, a spokesman for The Japan Aerospace Exploration Agency (JAXA) said.

"This was the first time anyone has managed to send a high output of nearly two kilowatts of electric power via microwaves to a small target, using a delicate directivity control device," he said.

Read more at: http://phys.org/news/2015-03-japan-space-scientists-wireless-energy.html#jCp

Task for Next Week

- I will present and summarize each Team's Ideas
- Before hand:
  - Discuss your ideas with your Team members. Be prepared to comment/disagree/amplify my presentation
  - **Everyone**: Send any revisions or additions before end of weekend…
    - Why you think this is an energy/climate opportunity worthy of further consideration
    - Your reasoning why this is should be considered a "short-term" or a "long-term" effort

Send by email to mauel@columbia.edu before C.O.B. next Tuesday