The Energy / Climate-Change Challenge
and the Role of Nuclear Energy in Meeting It

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Prof. David J. Rose
1922-1985

"At least some of our international friction is directly traceable to disputes over possession of the areas favored with abundant energy resources. … The acquisition of land endowed with energy and material resources motivates much of our current strife. It is to be hoped that the nuclear processes of fission and fusion may permanently solve at least the need for energy and thus contribute substantially to the peaceful relations among mankind."

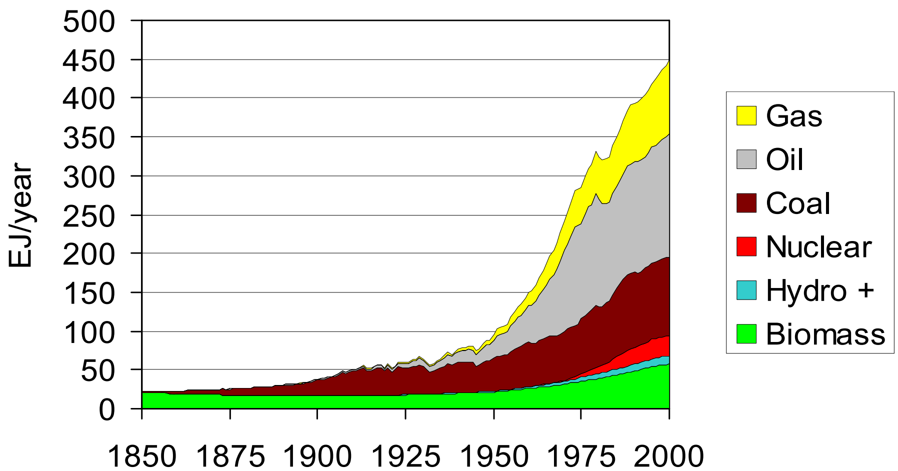
Rose & Clark, *Plasmas and Controlled Fusion*, 1962

Coverage of this talk

- The character of the energy challenge
- The two toughest problems
  - meeting transport needs with less oil
  - meeting economic aspirations with less CO_2
- What needs to be done
- What the Obama Administration is doing
- The role of nuclear energy
  - the future of fission
  - the future of fusion

The character of the challenge

Growth of world population & prosperity over past 150 years brought 20-fold increase in energy use



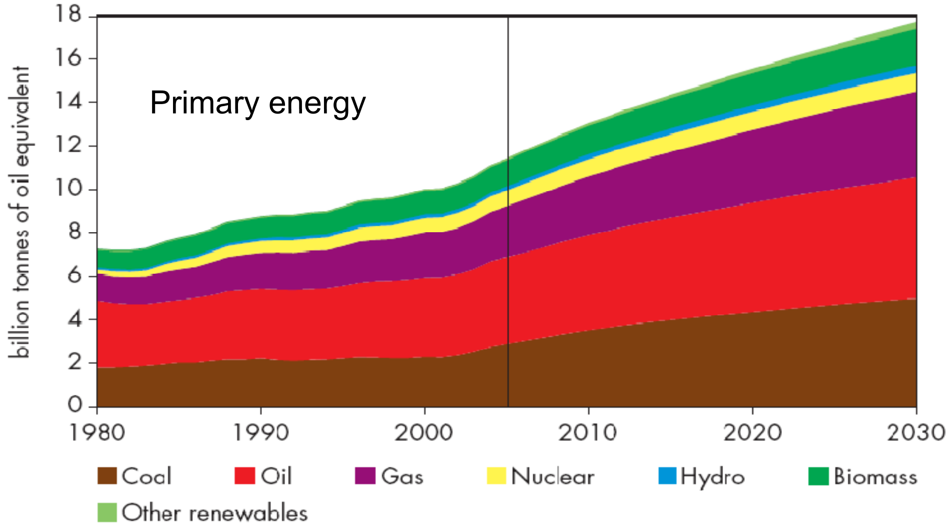
Growth rate 1850-1950 was 1.45%/yr, driven mainly by coal.
From 1950-2000 it was 3.15%/yr, driven mainly by oil & natural gas.

Where we are: energy and fossil CO_2 in 2008

	population (millions)	ppp-GDP (trillion $)	energy (EJ)	fossil E (percent)	fossil CO_2 (MtC)
World	6692	69.7	545	82%	8390
China	1326	7.9	99	85%	1910
USA	304	14.2	105	86%	1670
Russia	142	2.3	30	91%	440
India	1140	3.4	29	64%	390

World Bank 2009, BP 2009

Where we're headed under BAU: by 2030, energy +60%, electricity +75%, continued fossil dominance



WEO 2007

What's problematic about this future?

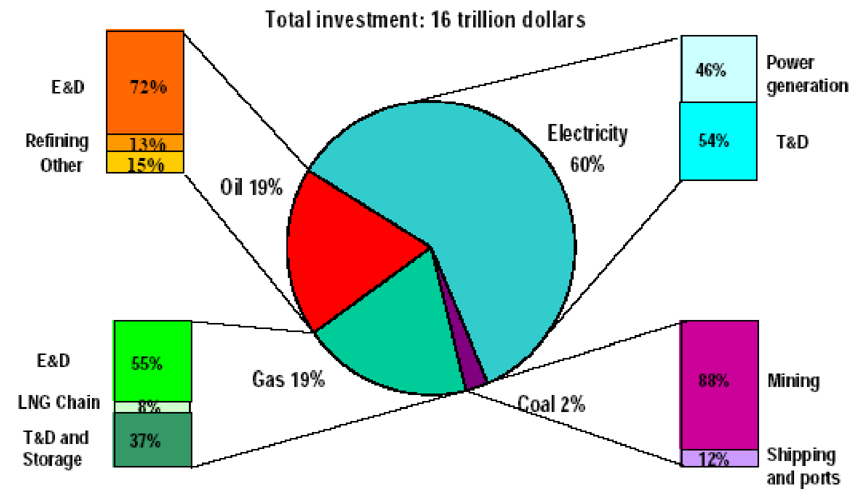
The problem is not "running out" of energy

Some mid-range estimates of world energy resources. Units are terawatt-years (TWy). Current world energy use is ~17 TWy/year.

OIL & GAS, CONVENTIONAL	1,000
UNCONVENTIONAL OIL & GAS (excluding clathrates)	2,000
COAL	5,000
METHANE CLATHRATES	20,000
OIL SHALE	30,000
URANIUM in conventional reactors	2,000
...in breeder reactors	2,000,000
FUSION (if the technology succeeds)	250,000,000,000
RENEWABLE ENERGY (available energy per year)	
sunlight on land	30,000
energy in the wind	2,000
energy captured by photosynthesis	120

Nor is the problem running out of money

Projected capital investment for energy supply 2001-2030



This is under 1% of projected Gross World Product for the period, and only about 5% of projected world investment. Could reach 15% of investment in developing countries.

Real problems: the economic, environmental, and security risks of fossil-fuel dependence

- Increasing dependence on imported oil & natural gas means economic vulnerability, as well as international tensions and potential for conflict over access & terms.
- Coal burning for electricity & industry and oil burning in vehicles are main sources of severe urban and regional air pollution – SO_x, NO_x, hydrocarbons, soot – with big impacts on public health, acid precipitation.
- Emissions of CO_2 from *all* fossil-fuel burning are largest driver of global climate disruption, already associated with increasing harm to human well-being and rapidly becoming more severe.

Real problems: Alternatives to conventional fossil fuels all have liabilities & limitations

- traditional biofuels (fuelwood, charcoal, crop wastes, dung) create huge indoor air-pollution hazard
- industrial biofuels (ethanol, biodiesel) can take land from forests & food production, increase food prices
- hydropower and wind are limited by availability of suitable locations, conflicts over siting
- solar energy is costly and intermittent
- nuclear fission has large requirements for capital & highly trained personnel, currently lacks agreed solutions for radioactive waste & links to nuclear weaponry
- nuclear fusion doesn't work yet
- coal-to-gas and coal-to-liquids to reduce oil & gas imports doubles CO_2 emissions per GJ of delivered fuel
- increasing end-use efficiency needs consumer education

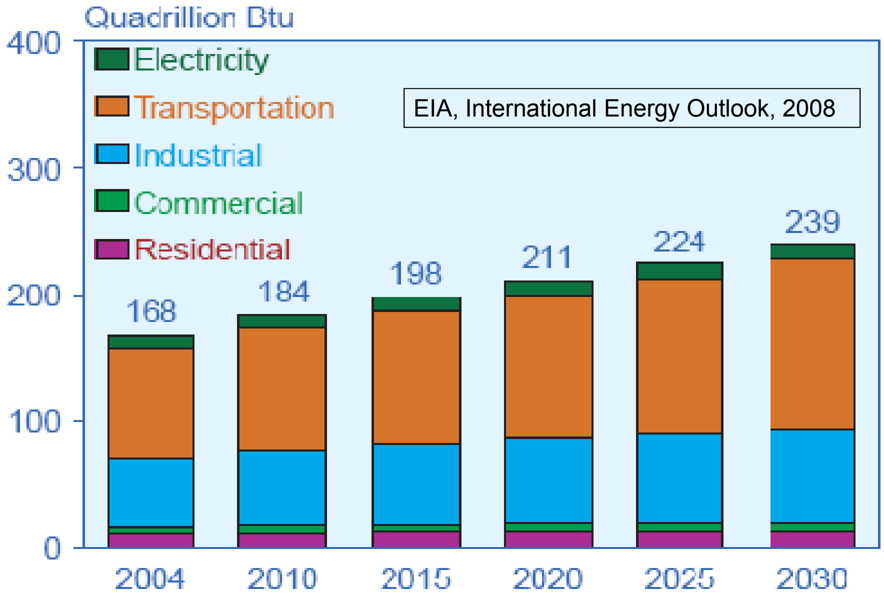
The two toughest problems

- Reducing urban & regional air pollution and the dangers of overdependence on oil despite growing global demand from the transportation system (which accounts for most oil use in USA & elsewhere)
- Providing the affordable energy needed to create & sustain prosperity everywhere without wrecking the global climate with carbon dioxide emitted by fossil-fuel burning

The oil problem: supply & security

- USA in 2008 used 21 million barrels per day of oil, importing 66% of it.
- Forecasts show US oil use rising to 28 Mb/d by 2030, with <u>all</u> of the increase coming from imports.
- World used 82 Mb/d in 2008, 63% of it traded internationally.
- Consumption forecasted to rise from 82 Mb/d in 2008 to 120 Mb/d in 2030.
- China's imports by 2030 expected to pass 12 Mb/d (a level 1^{st} reached by the USA in 2004).
- It remains true that most of the world's known & suspected oil resources are in the Middle East.

Transport accounts for most world oil use

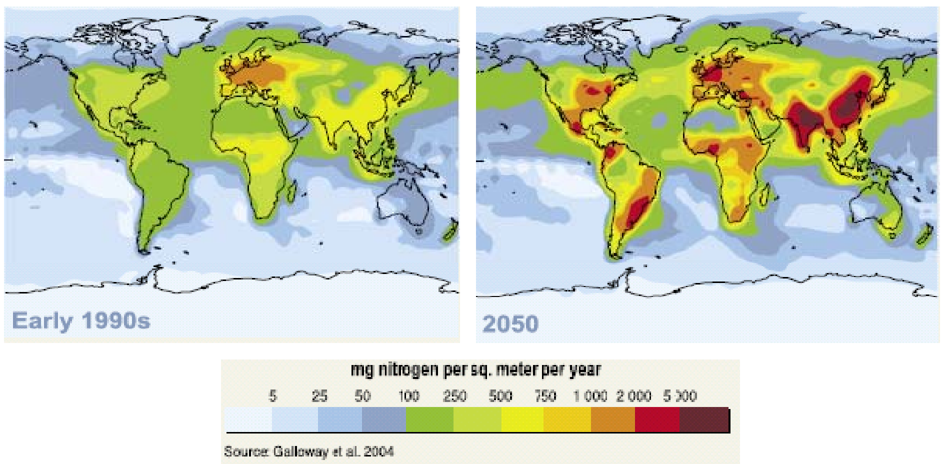


The oil challenge: environment

- Oil used in transport is the largest source of NO_x and hydrocarbon air pollution.
- The number of cars in the world is soaring, producing increased congestion and even more pollution.
- Combustion of petroleum fuels accounts for about 40% of CO_2 emissions from energy – same as coal – and this is expected to continue.

Acid precipitation under BAU energy growth

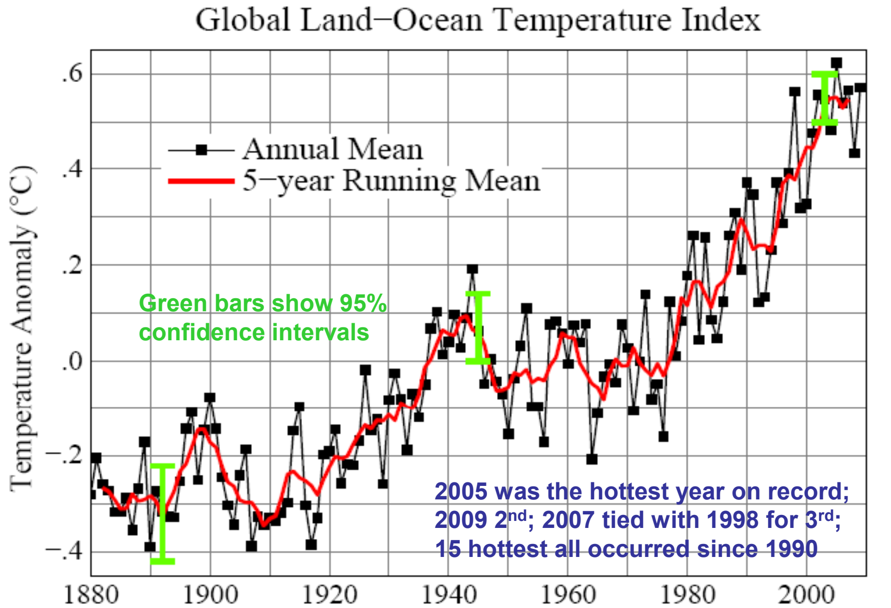
Wet and dry reactive nitrogen deposition from the atmosphere, early 1990s and projected for 2050



The climate-change problem

- Global climate is changing rapidly and humans are responsible for most of the change.
- CO_2 emissions are the largest driver & 75-85% of these come from combustion of fossil fuels (the rest from deforestation).
- Fossil CO_2 emissions are immense (~31 billion tons/yr in 2008) & difficult to capture & store.
- The world's 80%-fossil-fuel-dependent energy system represents a $15 trillion capital invest-ment that takes 30-40 years to turn over.
- Avoiding biggest risks requires sharply reducing CO_2/energy ratio starting immediately.

The Earth <u>is</u> getting hotter

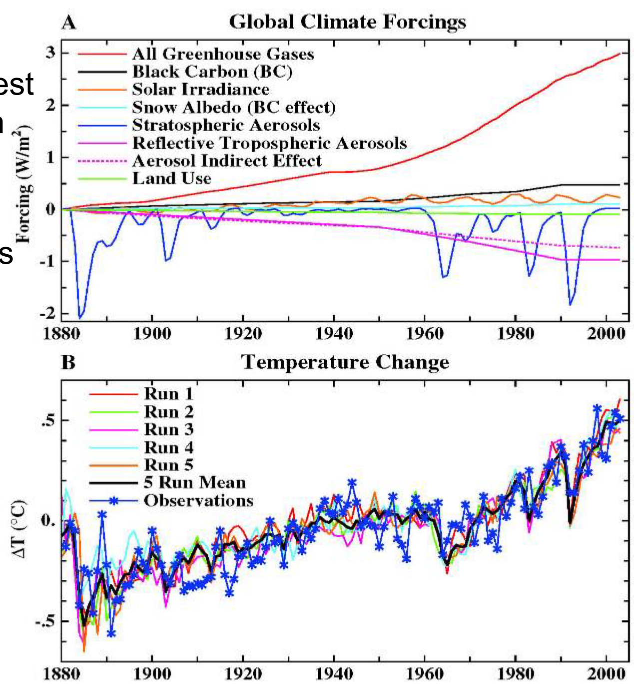


http://data.giss.nasa.gov/gistemp/graphs/

We know why

Top panel shows best estimates of human & natural forcings 1880-2005.

Bottom panel shows that state-of-the-art climate model, fed these forcings, reproduces almost perfectly the last 125 years of observed temperatures.



Source: Hansen et al., *Science 308*, 1431, 2005.

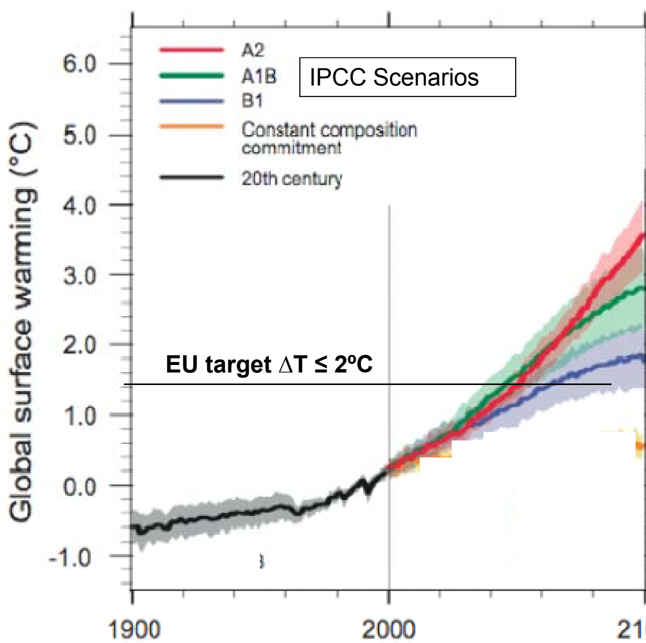
Harm is already occurring

Worldwide we're seeing, variously, increases in

- floods
- wildfires
- droughts
- heat waves
- pest outbreaks
- coral bleaching events
- power of typhoons & hurricanes
- geographic range of tropical pathogens

All plausibly linked to climate change by theory, models, observed "fingerprints"

Bigger impacts are in store under BAU



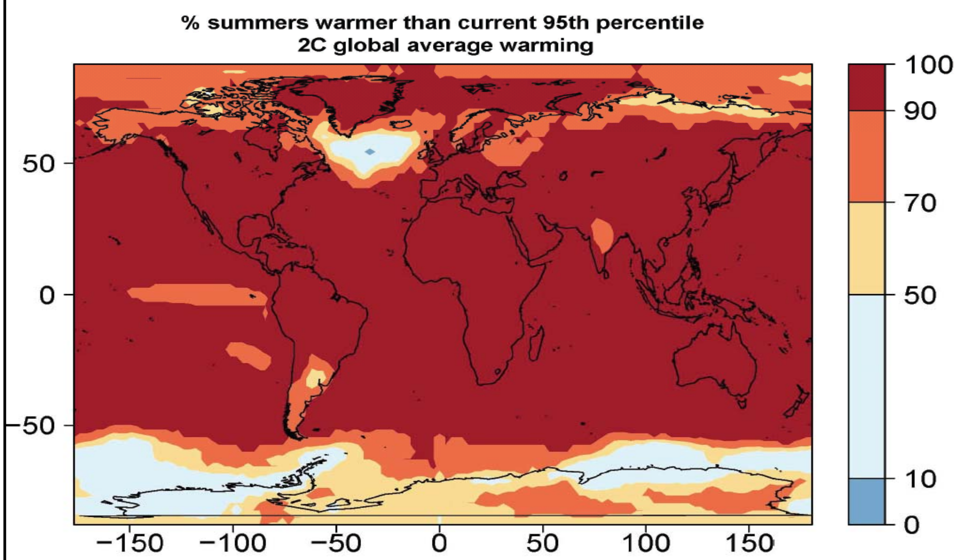
Last time T was 2ºC above 1900 level was 130,000 yr BP, with sea level 4-6 m higher than today.

Last time T was 3ºC above 1900 level was ~30 million yr BP, with sea level 20-30 m higher than today.

Note: Shaded bands denote 1 standard deviation from mean in ensembles of model runs

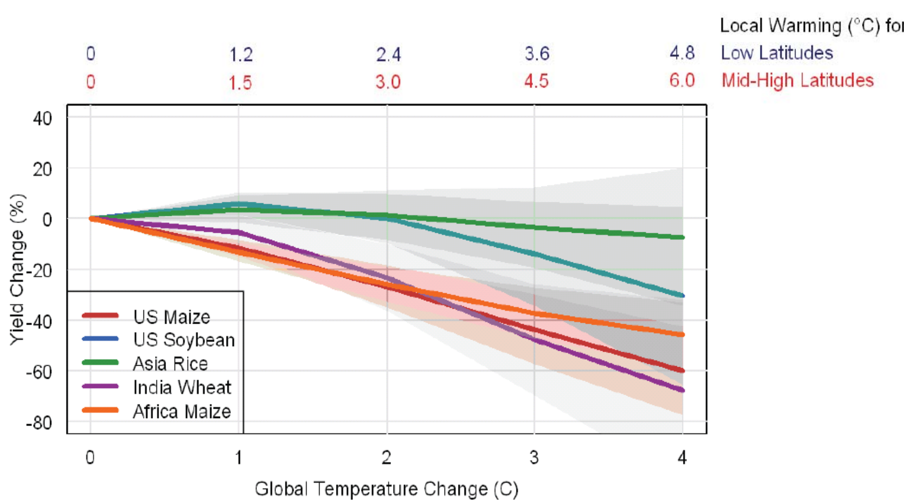
IPCC 2007

What's expected: Hotter summers



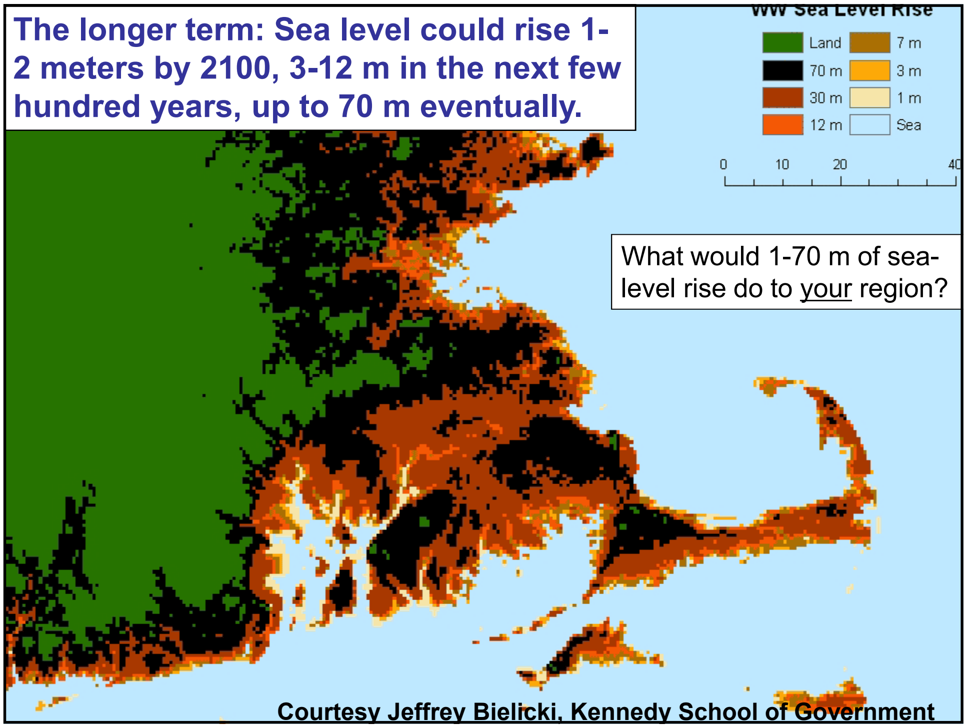
National Academies, Stabilization Targets, 2010

What's expected: declining crop yields



National Academies, Stabilization Targets, 2010

The longer term: Sea level could rise 1-2 meters by 2100, 3-12 m in the next few hundred years, up to 70 m eventually.



What needs to be done?

What needs to be done: Oil

- Improve & promote rail & other public transportation + land-use planning for shorter commutes.
- Strengthen vehicle fuel-economy standards
- Provide manufacturer & consumer incentives to promote domestic production & increased use of advanced diesel & hybrid-electric vehicles.
- Accelerate development & deployment of non-petroleum transportation-fuel alternatives.
- Build international cooperation to promote alternatives to expanded oil use in <u>all</u> countries.

What needs to be done: Climate change

There are only three options:

- <u>Mitigation</u>, meaning measures to reduce the pace & magnitude of the changes in global climate being caused by human activities.
- <u>Adaptation</u>, meaning measures to reduce the adverse impacts on human well-being resulting from the changes in climate that do occur.
- <u>Suffering</u> the adverse impacts that are not avoided by either mitigation or adaptation.

Mitigation & adaptation are both essential

- No feasible amount of mitigation can stop climate change in its tracks.
- Adaptation efforts are already taking place and must be expanded.
- But adaptation becomes costlier & less effective as the magnitude of climate changes grows.
- We need enough mitigation to avoid unmanage-able climate change, enough adaptation to manage the degree of change that's unavoidable.

Adaptation possibilities include…

- Changing cropping patterns
- Developing heat-, drought-, and salt-resistant crop varieties
- Strengthening public-health & environmental-engineering defenses against tropical diseases
- Building new water projects for flood control & drought management
- Building dikes and storm-surge barriers against sea-level rise
- Avoiding further development on flood plains & near sea level

Some are "win-win": They'd make sense in any case.

Mitigation possibilities

CERTAINLY

- Reduce emissions of greenhouse gases & soot from the energy sector
- Reduce deforestation; increase reforestation & afforestation
- Modify agricultural practices to reduce emissions of greenhouse gases & build up soil carbon

CONCEIVABLY

- "Geo-engineering" to create cooling effects offsetting greenhouse heating (white roofs...)
- "Scrub" greenhouse gases from the atmosphere technologically

How much mitigation is enough?

- 550 ppmv CO_2-e (50% chance of $\Delta T_{avg} < 3^0C$) looks unlikely to avoid unmanageable change
- 450 ppmv CO_2-e (50% chance of $\Delta T_{avg} < 2^0C$) would be more prudent
- Achieving 450 ppmv requires that...
  - global emissions level off by ~2020 and decline thereafter to ~50% below 2000 emissions by 2050.
  - emissions in USA & other industrial countries level off by 2015 and decline thereafter to ~80% below 2000 emissions by 2050.

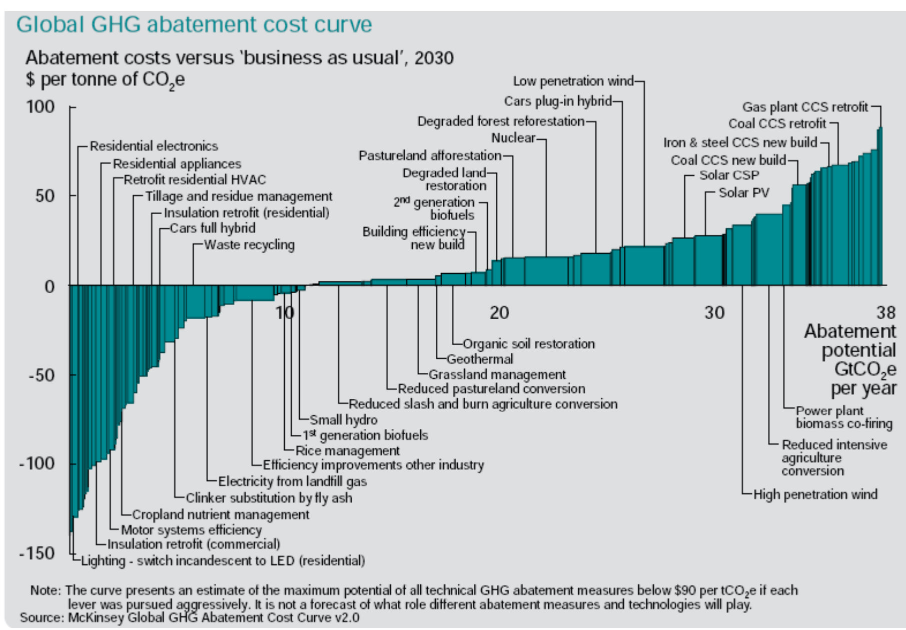
Some realities about mitigation

- Stabilizing at 450 ppmv CO_2-e means 2050 global CO_2 emissions must be at least ~7-9 GtC/yr below BAU (i.e., a cut of 50% or more from BAU).
- Ways to avoid 1 GtC/yr in 2050 include…

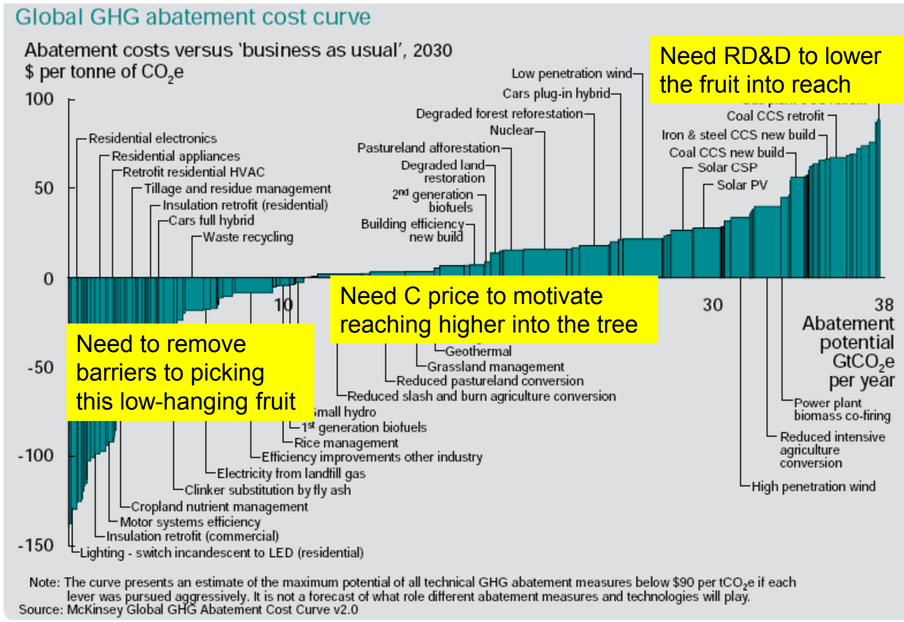
  - energy use in buildings cut 20-25% below BAU in 2050,
  - fuel economy of 2 billion cars ~60 mpg instead of 30,
  - carbon capture & storage for 800 1-GWe coal-burning power plants,
  -700 1-GWe nuclear plants replacing coal plants,
  -1 million 2-Mwe-peak wind turbines (or 2,000 1-Gwe-peak photovoltaic power plants) replacing coal power plants

Socolow & Pacala, 2004

Mitigation supply curve for 2030: aiming for 450 ppm CO_2e



Policy needs for the 450 ppm CO_2e supply curve



What's the Obama Administration Doing?

The Obama administration's strategy

- Promote recognition that the energy-climate challenge is real and warrants early action
  - The longer we wait, the more money we send abroad, the more pollution we suffer, the bigger the damage from climate change, and the faster we'll need to move later to avoid unmanageable consequences
  - Prudent action will be cheaper than inaction or delay.
  - We can reduce costly and risky oil imports and dangerous air pollution with the same measures we employ to reduce climate-disrupting emissions.
  - The needed surge of innovation in clean-energy technologies and energy efficiency will create new businesses & new jobs and help drive economic recovery& growth, maintain global competitiveness.

Obama administration strategy (continued)

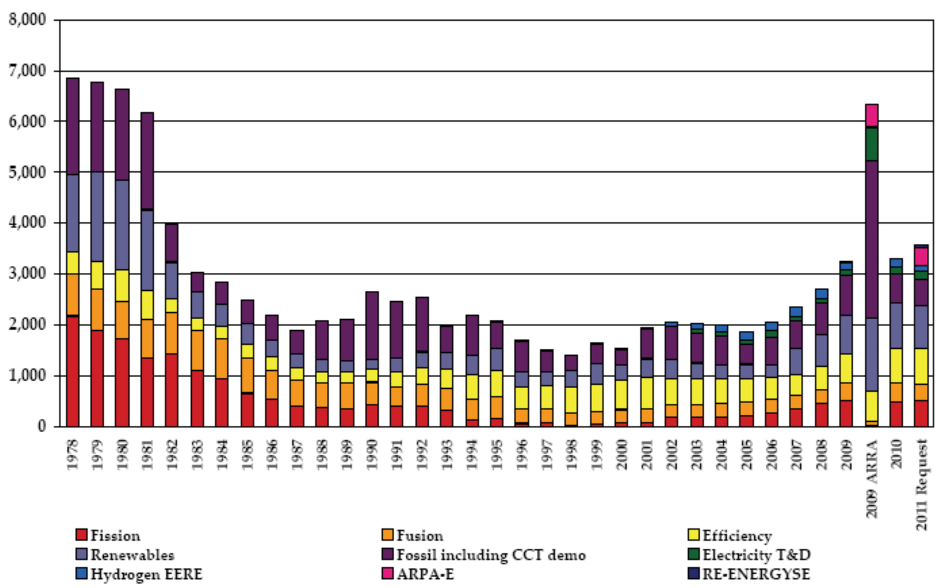
- Provide new funding & initiatives for energy RD^3, climate-change research, adaptation.
- Revitalize USGCRP & other interagency efforts
- Work with Congress to get comprehensive energy-climate legislation that puts a price on GHG emissions.
- Work with other major emitting countries – industrialized & developing – to build technology cooperation and individual & joint climate policies to "avoid the unmanageable" and "manage the unavoidable".

Agency initiatives

- Recovery Act has ~$80B for clean & efficient energy (incl efficient transportation) in 2009-10
- New ARPA-E in DOE gets $400M in Recovery Act, $300M proposed for FY2011
- Other DOE increases in FY2011 budget proposal:
  - All applied energy RD&D = $3.9B, up 7%
    - Energy Frontier Research Centers = $140M
    - Energy Innovation Hubs[a] = $107M
  - Basic Energy Sciences = $1.8B, up 12%

[a] Energy Efficient Building System Design, Fuels from Sunlight, Modeling & Simulation, Batteries & Energy Storage

DOE Applied Energy Technology RD&D 1978-2011



Harvard Kennedy School Energy Technology Innovation Project, April 2010

Agency initiatives (continued)

- EPA/DOT: fuel-economy/CO_2 tailpipe standards for light-duty vehicles (coming soon for trucks)
- EPA: "endangerment finding" that CO_2 imperils health & welfare, allowing regulation as a pollutant
- NOAA: restructuring to consolidate "climate services" germane to climate-change adaptation.
- DOI: restructuring to develop Climate Change Response Centers and Landscape Conservation Cooperatives, Carbon Storage Project
- DOT-HUD-EPA: Partnership for Sustainable Communities

Revitalizing broad interagency efforts

- The "Green Cabinet" (OECC Director chairs)
  - Secretaries of Energy, Interior, Agriculture, Transportation, HUD, Labor; EPA Administrator; SBA Administrator; CEQ Chair; OSTP Director
- National Science & Technology Council (NSTC)
  - Committee on Environment and Natural Resources (CENR) – chaired by Abbott, Lubchenco, Anastas
- The US Global Change Research Program
  - New science, integrated assessment, adaptation focuses, budget to $2.6B (up ~20%)
- Climate-Change Adaptation Task Force
  - Co-chaired by OSTP, CEQ, NOAA, with senior representation from all relevant agencies

National climate-change legislation

- President Obama was emphatic that new US energy legislation should include climate, above all a price on carbon emissions.
- The climate component was reluctantly & temporarily abandoned because of insufficient support in the US Senate.
- We will try anew in the next Congress; in the meantime, EPA is moving ahead to limit greenhouse-gas emissions by regulation.

International engagement

- Personal engagement of President Obama to salvage a tolerable outcome in Copenhagen
- Energy & climate cooperation elevated to priorities in:
  - Multilateral Economic Forum, G-8, G-20
  - revitalized ministerial-level Commissions on Science & Technology Cooperation (with Brazil, China, India, Japan, Korea, Russia)
  - US-China Strategic & Economic Dialogue
  - US-Russia Bilateral Presidential Commission
- New bilateral clean-energy projects with China, India

The Roles of Fission & Fusion

Current contribution of nuclear energy

WORLD

- About 440 nuclear-fission power reactors* totaling 375 GWe of capacity in some 30 countries generated ~13% of world electricity in 2009. (Share has been falling.)
- Completion of reactors currently under construction will make the total around 500 reactors and 430+ GWe.

UNITED STATES

- The 104 operating US power reactors have a total capacity of 100.8 GWe and generated 20% of US electricity in 2009.
- As of 1 October 2010, 1 more is under construction and 9 additional are planned, totaling 13 Gwe.

* ~350 of the 440 reactors worldwide are light-water reactors (LWRs). The rest are mainly heavy-water reactors, gas-cooled reactors, and graphite-moderated light-water reactors.

Factors governing expandability of nuclear energy in the USA & worldwide

- Demand
  - economic growth, degree of electrification (esp transport), success of end-use efficiency improvements
  - ability of nuclear energy to deliver non-electric energy products (high-T process heat, hydrogen)
- Economics
  - cost of electricity, construction cost, risk premium, unit size (affects market size and investment "lumpiness")
  - economics of competing sources
- Resource availability
  - uranium supply vs cost
  - effect on fuel-cycle choice and cost

Factors governing expandability in the USA & worldwide (continued)

- Safety & environment
  - comparison with alternatives in fact & perception
  - radioactive wastes, reactor safety *vs* air pollution, climate change, land use
- International security
  - energy dependence/independence
  - nuclear-weapon proliferation

Economics: Costs of nuclear vs fossil-fueled generation

Table 1.1 Costs of Electric Generation Alternatives

			LEVELIZED COST OF ELECTRICITY		
	OVERNIGHT COST	FUEL COST	BASE CASE	W/ CARBON CHARGE $25/TCO$_2$	W/ SAME COST OF CAPITAL
$2007	$/KW	$/MBTU	¢/KWH	¢/KWH	¢/KWH
Nuclear	4,000	0.67	8.4		6.6
Coal	2,300	2.60	6.2	8.3	
Gas	850	4/7/10	4.2/6.5/8.7	5.1/7.4/9.6	

MIT, Future of the Nuclear Fuel Cycle, 2010

- Carbon charges >>$25/t$CO_2$ highly likely by 2025
- Small modular reactors could drop unit cost, maybe COE

World uranium reserves & resources

kgU = kilogram of uranium; t = metric ton = 1,000 kg
RURR = remaining ultimately recoverable resources

Australian U Info Ctr (2002): RURR (<$80/kgU) ~30 million t

Red Book (2009): RURR (<$130/kgU) ~13 million t

MIT (2010): RURR (<$260/kgU) ~100 million t

Extrapolation from US: RURR (<$260/kgU) 60-180 million t

In a conventional light-water reactor (LWR) w once-through fuel cycle, 1 million t U yields 400 EJ = 13 TWy thermal energy = 4 TWy electricity = 36 trillion kWh electricity.

100 million t = 400 TWye; year 2100 with 3500 GWe is ~3.2 TWye/yr, so 100 Mt is 100+ years at this level.

Table 3.1 Alternative Reference Points for Nuclear Deployment in 2050 in GWe for Different Assumptions about Electricity Growth Rates and Nuclear Market Share[a]

	ALTERNATIVE AVERAGE ELECTRICITY GROWTH RATES 2000–2050 %		
NUCLEAR GENERATION MARKET SHARE %	1.5	2.0	2.5
17	650	838	1,060
20	770	970	1,235
25	880	1,235	1,545

a. We assume the global average capacity factor increases from 75% to 85%.

MIT, The Future of Nuclear Power, 2003

How much nuclear to get significant leverage in reducing CO_2 emissions?

- As another reference point in this vein, I calculated how much nuclear would be needed to double nuclear's share of world electricity from the 2000 figure of 17% to 33% by 2050, given business as usual electricity growth.
- The answer is ~1700 GWe of nuclear capacity in 2050, or roughly 1400 GWe more than existed in 2000.
- If these 1400 GWe of additional nuclear capacity all replaced what would otherwise have been coal-fired power plants lacking CO_2 capture, the avoided emissions would be 2 GtC/yr (C content of avoided CO_2).
- So this aggressive nuclear expansion goal yields 2 GtC/yr out of the 7-9 GtC/yr reduction from BAU that we need – an important contribution, but we'll also need renewables, CO_2 capture from fossil, and bigger efficiency increases.

Implications of nuclear at this scale

- Consider 1700 GWe of world nuclear capacity by 2050 (to make 1/3 of projected electricity and save 2 GtC/yr)
- If these were light-water reactors on the once-through fuel cycle, enrichment of their fuel would require ~250 million Separative Work Units (SWU).
  - Diversion of 0.1% of this enrichment to production of HEU from natural uranium would make ~20 gun-type or ~80 implosion-type bombs.
- If half the reactors were recycling their plutonium, the associated flow of separated, directly weapon-usable plutonium would be 170,000 kg per year.
  - Diversion of 0.1% of this quantity would make ~30 implosion-type bombs.
- Spent-fuel production in the once-through case would be 34,000 tonnes/yr. (Total production to date ~300,000 t.)

Safety and environment

- REACTOR SAFETY, in a world of 1,700 or more reactors, will probably be considered adequate if the probability of a major core-melt accident can be kept to the range of 10^{-6} per reactor per year. This is probably already achieved by the best current designs, at least absent deliberate attack/sabotage. Bolstering defenses against the latter may entail further effort.
- RADIOACTIVE WASTES must be shown to be manage-able without significant worker or public radiation exposure in the short to medium term, with the expectation of a problem-free permanent solution in the long term. This is surely achievable technically – relying on centralized engineered interim storage in the short to medium term – but public acceptance could remain challenging.

Proliferation

- PROLIFERATION RESISTANCE should be increased by a combination of technical and institutional means. In the short term, this will involve
  - avoiding use of highly enriched uranium,
  - minimizing horizontal proliferation of enrichment facilities by offering fuel on attractive terms (with take-back) & establishing fuel banks
  - minimizing inventories of separated plutonium (by minimizing reprocessing and maximizing disposition), and
  - improving protection and safeguards for all stocks of these materials.

  In the longer term, it might well require
  - foregoing plutonium recycle indefinitely (using, e.g., uranium from sea water and other very low-grade ores), or
  - developing recycle technologies that do not separate plutonium completely from fission products, and/or
  - placing all enrichment and reprocessing facilities in internationally operated and guarded complexes.

2010 MIT Nuclear Fuel Cycle Study: Recommendations

Implementation of the first mover program of incentives should be accelerated for the purposes of demonstrating the costs of building new nuclear power plants in the U.S. under current conditions and, with good performance, eliminating the financial risk premium. This incentive program should not be extended beyond the first movers (first 7–10 plants) since we believe that nuclear energy should be able to compete on the open market as should other energy options.

For the next several decades, a once through fuel cycle using light water reactors (LWRs) is the preferred economic option for the U.S. and is likely to be the dominant feature of the nuclear energy system in the U.S. and elsewhere for much of this century. Improvements in light-water reactor designs to increase the efficiency of fuel resource utilization and reduce the cost of future reactor plants should be a principal research and development focus.

2010 MIT Nuclear Fuel Cycle Study: Recommendations (continued)

Planning for long term managed storage of spent nuclear fuel—for about a century—should be an integral part of nuclear fuel cycle design. While managed storage is believed to be safe for these periods, an R&D program should be devoted to confirm and extend the safe storage and transport period.

The possibility of storage for a century, which is longer than the anticipated operating lifetimes of nuclear reactors, suggests that the U.S. should move toward centralized SNF storage sites—starting with SNF from decommissioned reactor sites and in support of a long-term SNF management strategy.

We recommend an R&D program to improve existing repository options and develop alternative options with different technical, economic, geological isolation, and institutional characteristics.

2010 MIT Nuclear Fuel Cycle Study: Recommendations (continued)

The US and other nuclear supplier group countries should actively pursue fuel leasing options for countries with small nuclear programs, providing financial incentives for forgoing enrichment, technology cooperation for advanced reactors, spent fuel take back within the supplier's domestic framework for managing spent fuel, and the option for a fixed term renewable commitment to fuel leasing (perhaps ten years).

Integrated system studies and experiments on innovative reactor and fuel cycle options should be undertaken in the next several years to determine the viable technical options, define timelines of when decisions need to be made, and select a limited set of options as the basis for the path forward.

These are sound recommendations and track what the Administration is doing.

Fusion: Is it worth the trouble?

- Fuel supply

  Much larger than for fission, but fission fuel supply is so huge (with breeder reactors) that there is little practical advantage here.

- Cost

  Fusion fuel costs are negligible, but engineering complexity, exotic materials requirements, and likely high replacement rate of neutron-damaged components mean that construction costs & nonfuel O&M costs may more than offset this advantage.

- Accidents / sabotage

  Significant radioactivity releases are still possible with fusion, because of tritium & neutron activation of structural material. But very large releases are less likely by accident (and harder to cause by sabotage) because volatile radioactivity inventory is smaller than fission, radioactive "afterheat" is smaller, and a runaway reaction is highly improbable.

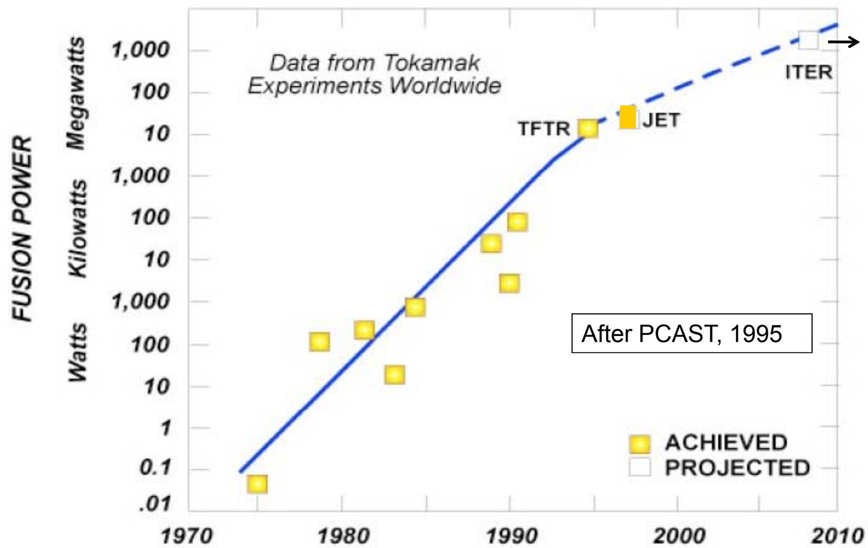
Fusion: Is it worth the trouble? (cont)

- Radioactive-waste management

  By the most meaningful measures (integrated dose potential, not volume), fusion burden should be 10 to 1,000 times smaller than for fission (ratio depending on fusion material choices and design).

- Nuclear-weapon proliferation
  - The essential material ingredient for any nuclear explosive is plutonium or highly enriched uranium (HEU). Fusion reactors would not contain or make either one in normal operation. (They could be modified to make plutonium, but this would require prolonged control of the reactor and would be easy to detect.)
  - Tritium would be present in 1st-generation nuclear reactors and is used in some kinds of nuclear weapons, but such cannot be made at all without plutonium or HEU.
  - One of the approaches to harnessing fusion energy – the "inertial confinement" approach – exploits insights & computational techniques germane to some aspects of nuclear weaponry; but, again, making actual weapons requires plutonium or HEU.

Progress in fusion power



Progress 1970-95 was faster than Moore's Law, but best performance (JET) still short of energy "break-even". ITER not expected to operate until 2018.

Fusion: Worth the trouble? If so, how soon?

- Fusion has been pursued for 50+ years with much funding, enthusiasm, and international cooperation because of
  - the above listed potential advantages over fission
  - (like fission) a lack of CO_2 emissions, lower land use than many renewables, and possible cost advantages over solar.
  - potential exotic applications beyond electricity generation
  - fascinating science with valuable non-energy spin-offs
- But after ~$30 billion worldwide it still doesn't work as an energy source, and finding out whether it will could cost another $30-50 billion and take another 30 to 50 years.

  My personal judgment is that we should invest this money. We have too few inexhaustible energy options not to try. But it's hard to justify spending $0.4-0.8 billion/yr of taxpayer money (in the USA) on fusion if we're only spending $4 billion per year on energy research, development, and demonstration of all energy-supply and energy-end-use-efficiency technologies combined.

The answer…

…is not to forego investing in fusion RD&D but to increase the total US federal investment in energy-technology R&D from ~$4B/yr to ~$15B/yr, as President Obama advocated in his campaign, as well as incentivizing increased private-sector investments in energy RD&D.

This is the sort of level of effort required to develop the potential of <u>all</u> the energy options we'll need to meet the energy / climate-change challenge – nuclear, advanced fossil, renewable, increased end-use efficiency.

Where to get the money in the current difficult economic situation is a challenge, but not necessarily an insurmountable one. (See, most recently, the Brookings / American Enterprise Institute report.)

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