Can we ever get to a zero-emission world?

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Climate / Energy is a complex and nuanced subject

Certainties, uncertainties

Science of Natural Systems

Climate science

- How has the climate changed?
- Why does it change? Role of human influences (GHGs, Aerosols)?
- How will it change in the future?

Ecosystem impacts

- Temperature, extreme weather, sea level rise, migration of species, ocean acidification

Societal impacts (negative and positive)

- Agriculture, migration, disease, flood, …

Required output: understanding, confident projections (models) over decades

Challenges: incomplete observations; small changes in a complex chaotic system;

Societal Response

Possible Responses

1. Adapt
2. Reduce GHG emissions
   - Reduce energy demand, emissions-lite supply
   - Technology, economics, behavior, perceptions, politics
3. Geoengineer

Considerations

- Efficacy (time, scale), costs (direct and opportunity), collateral benefits, unintended consequences, public acceptability

Values

- Environment *vs* development, intergenerational/international equity, risk tolerance

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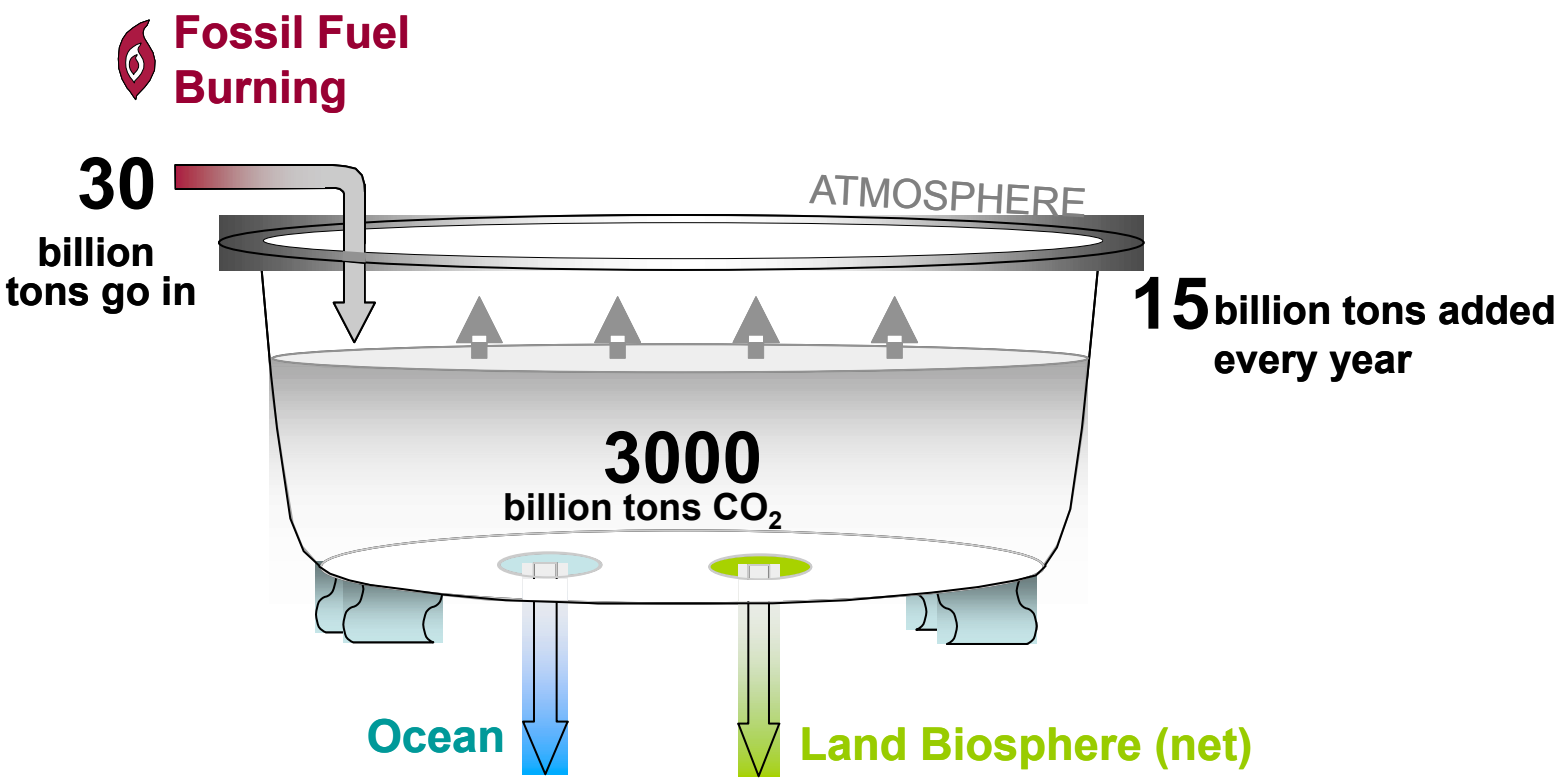
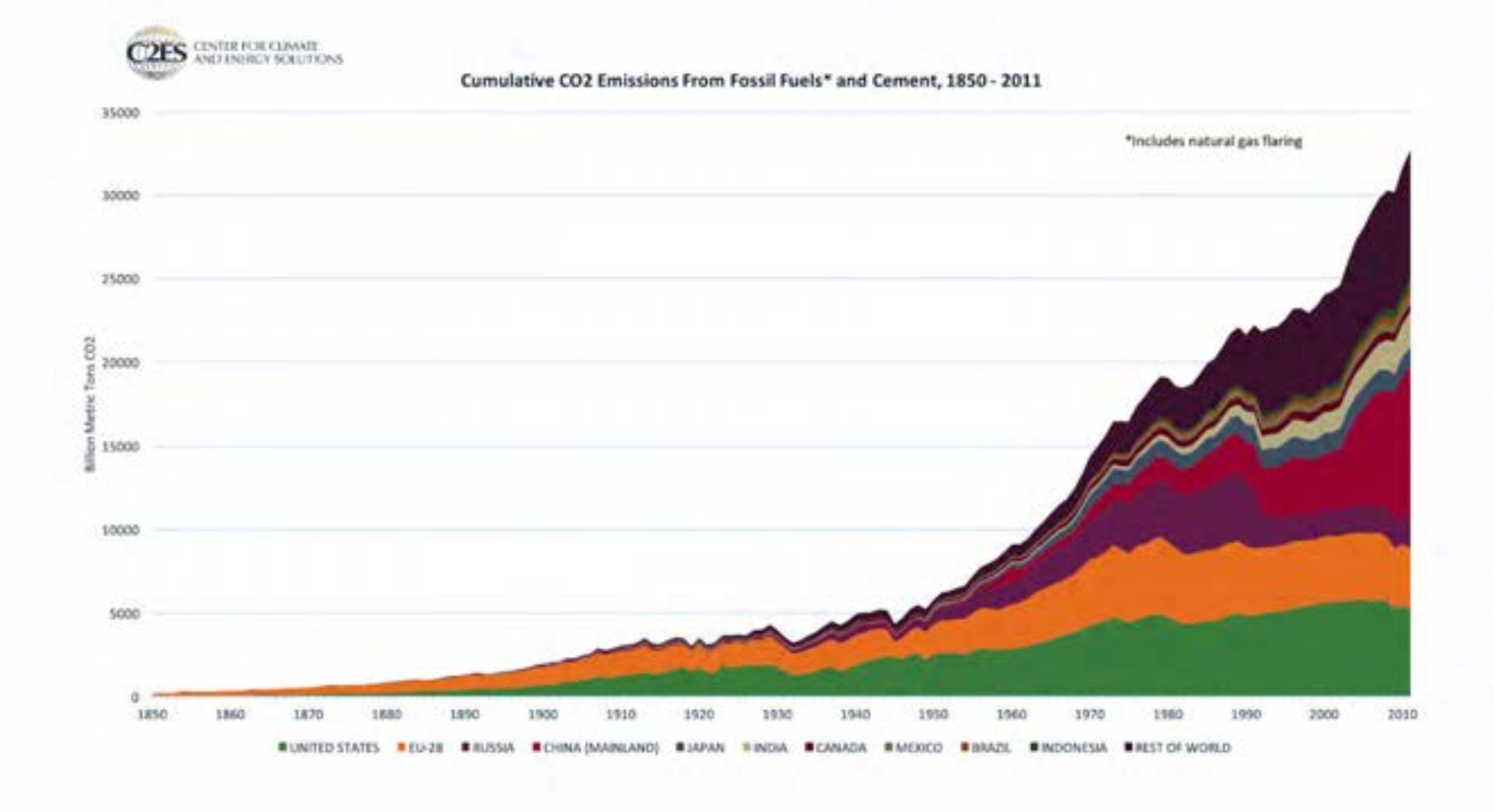
Half of the CO_2 we emit stays in the atmosphere for centuries



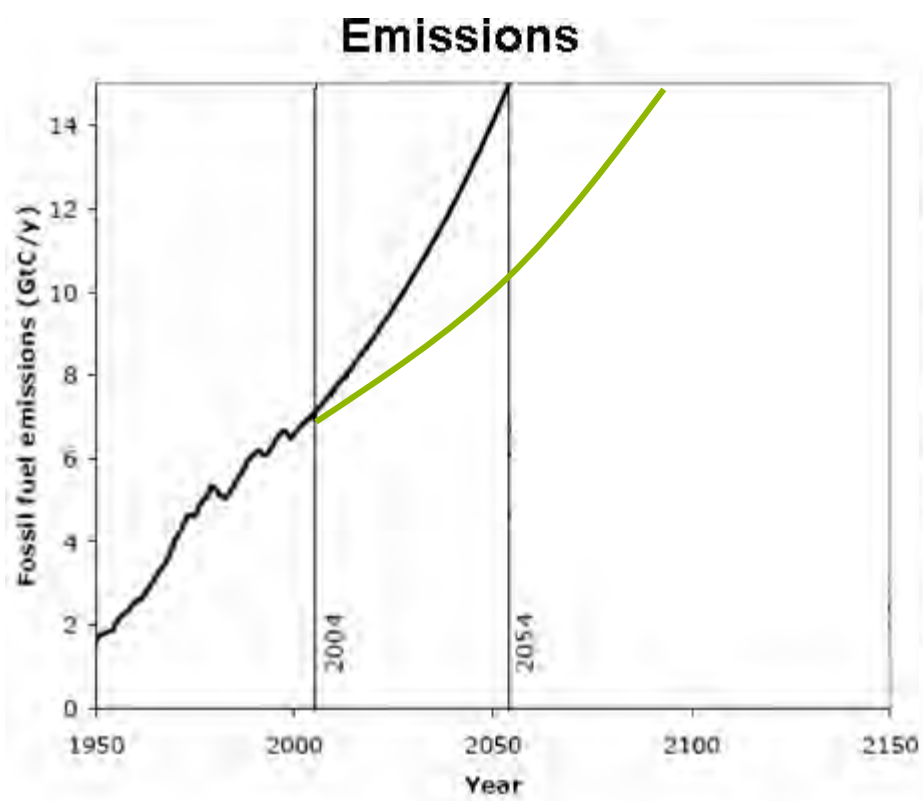
≈8 + ≈7 = 15 billion tons go out

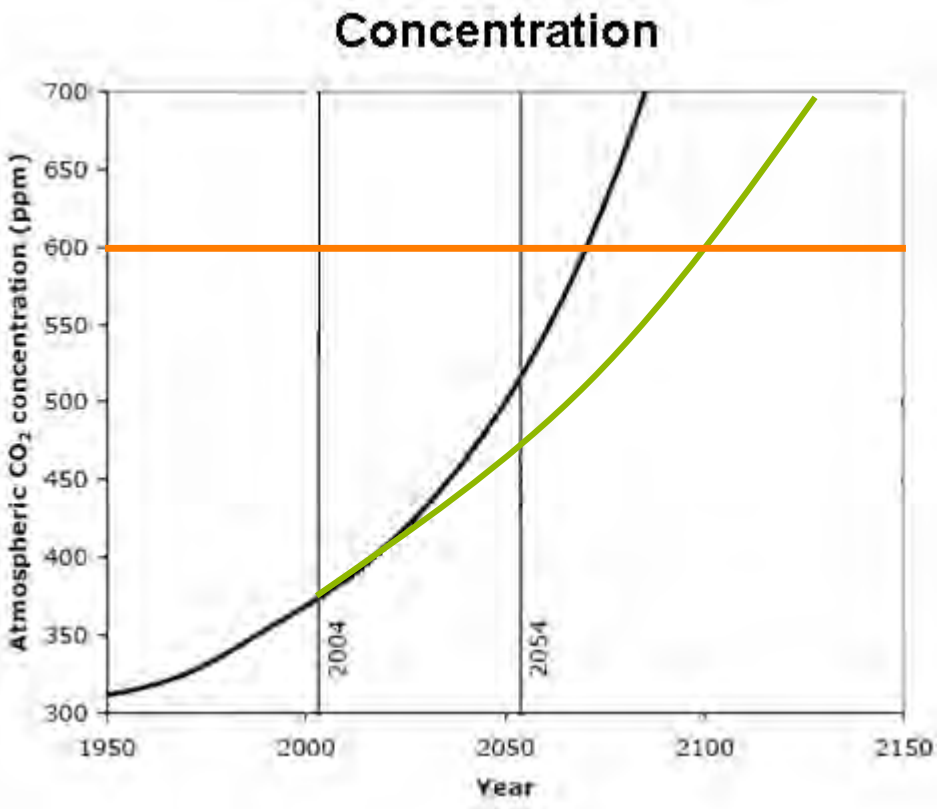
Cumulative global CO_2 emissions



http://www.usgcrp.gov/usgcrp/images/ocp2007/gallery-large/thumbnails/OCP07-Fig-28.jpg

The long CO_2 lifetime is highly problematic

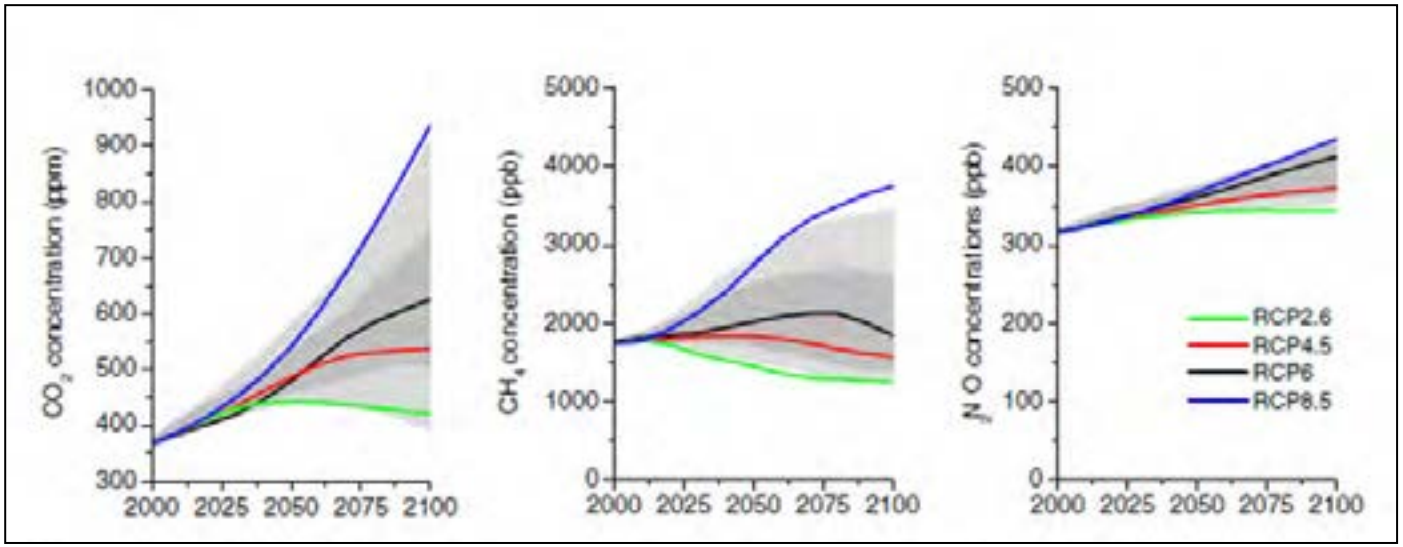




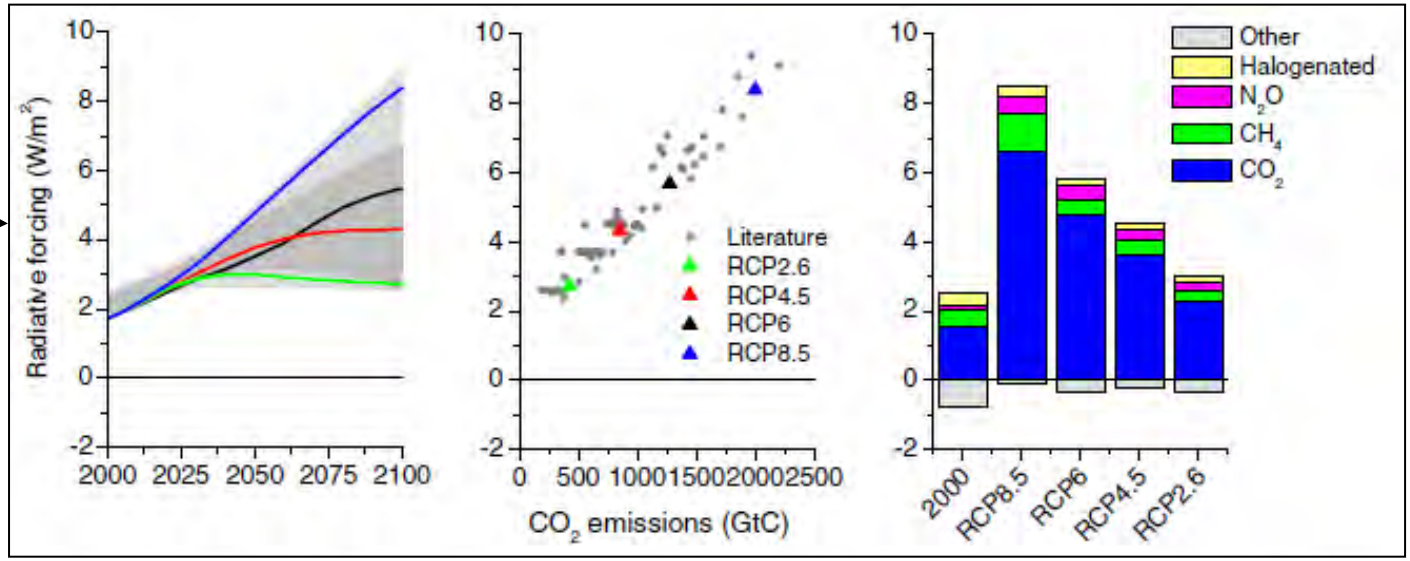
Science dimensions of reducing human influences

Climatic Change (2011) 109:5–31
DOI 10.1007/s10584-011-0148-z

RCPs = UN IPCC emissions/concentration scenarios

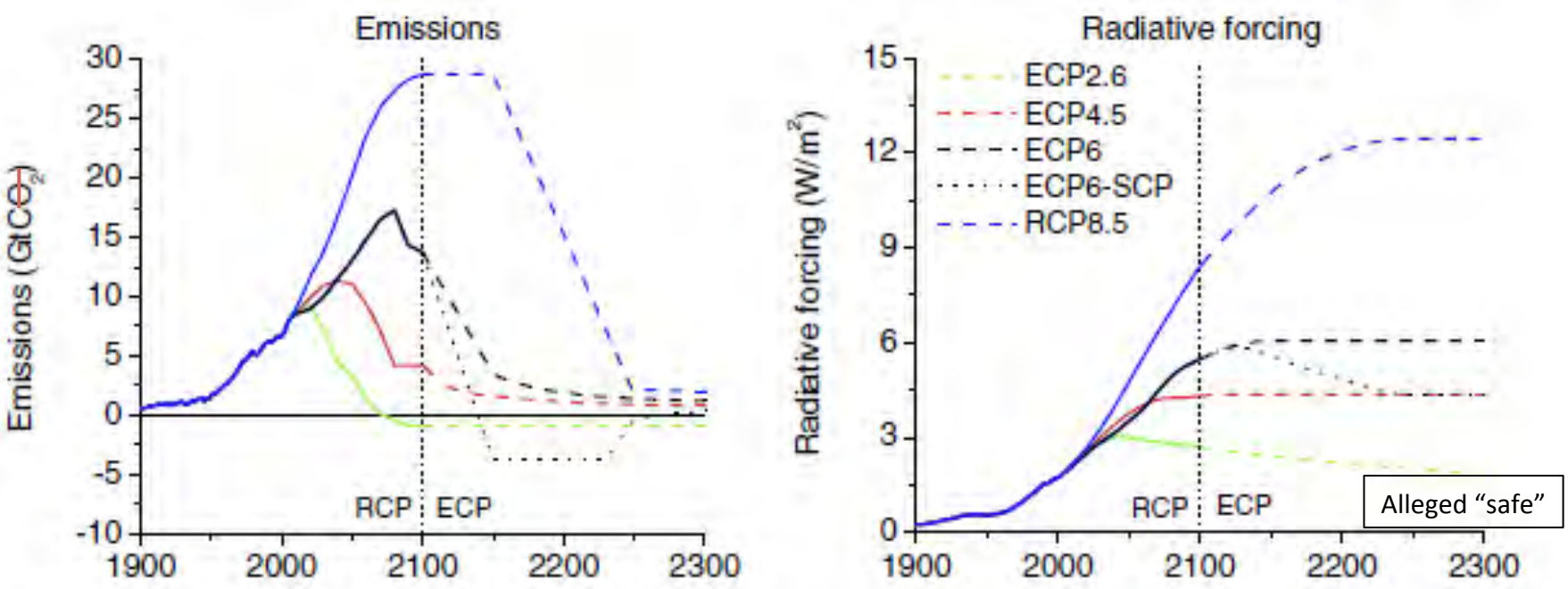


Human influence



Influence at 2100

Severe emission constraints merely to stabilize human influences at “safe” levels

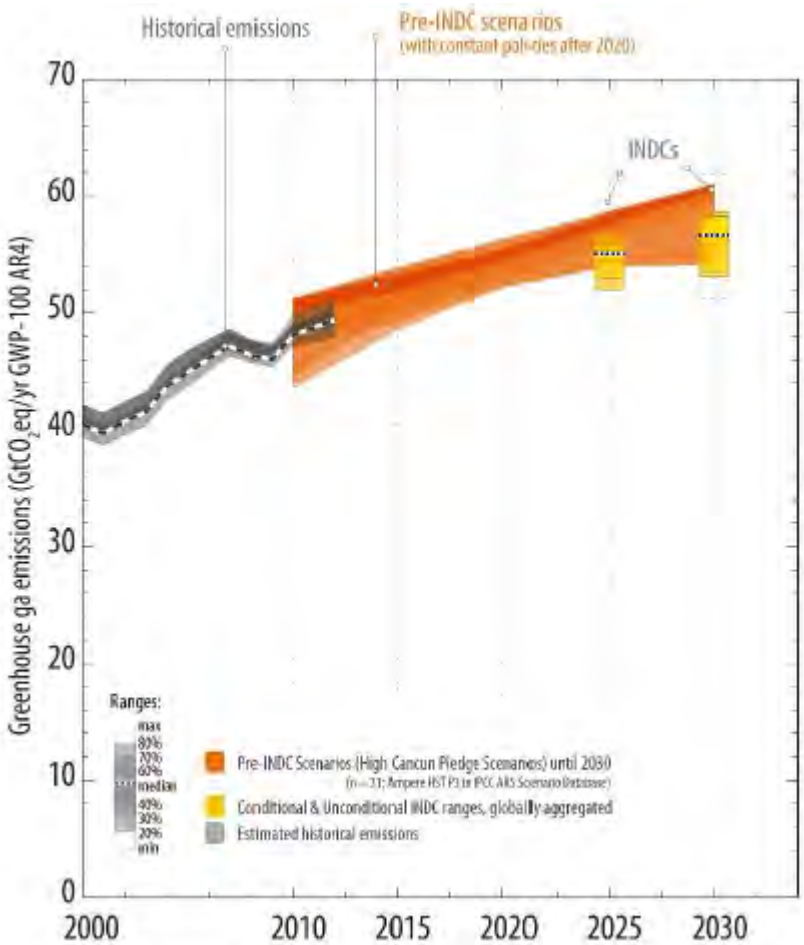


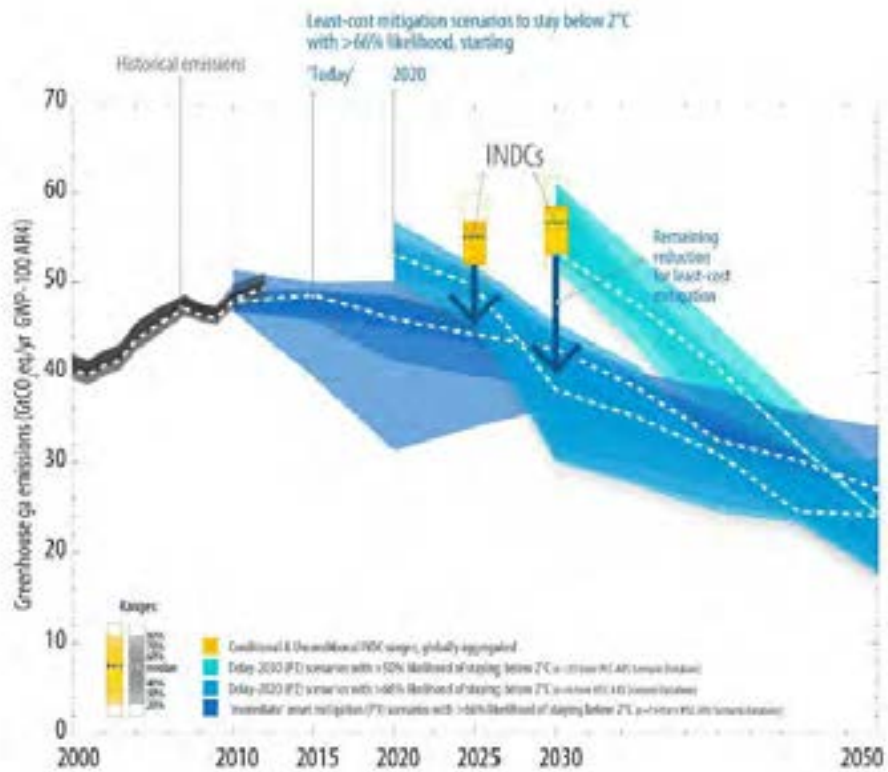
NO oil, NO gas, NO coal post-2075 (absent sequestration or biological offsets)

What are the socio-technical pathways /barriers to that goal?

Effect of the COP21 INDCs*

*Intended Nationally Determined Contributions



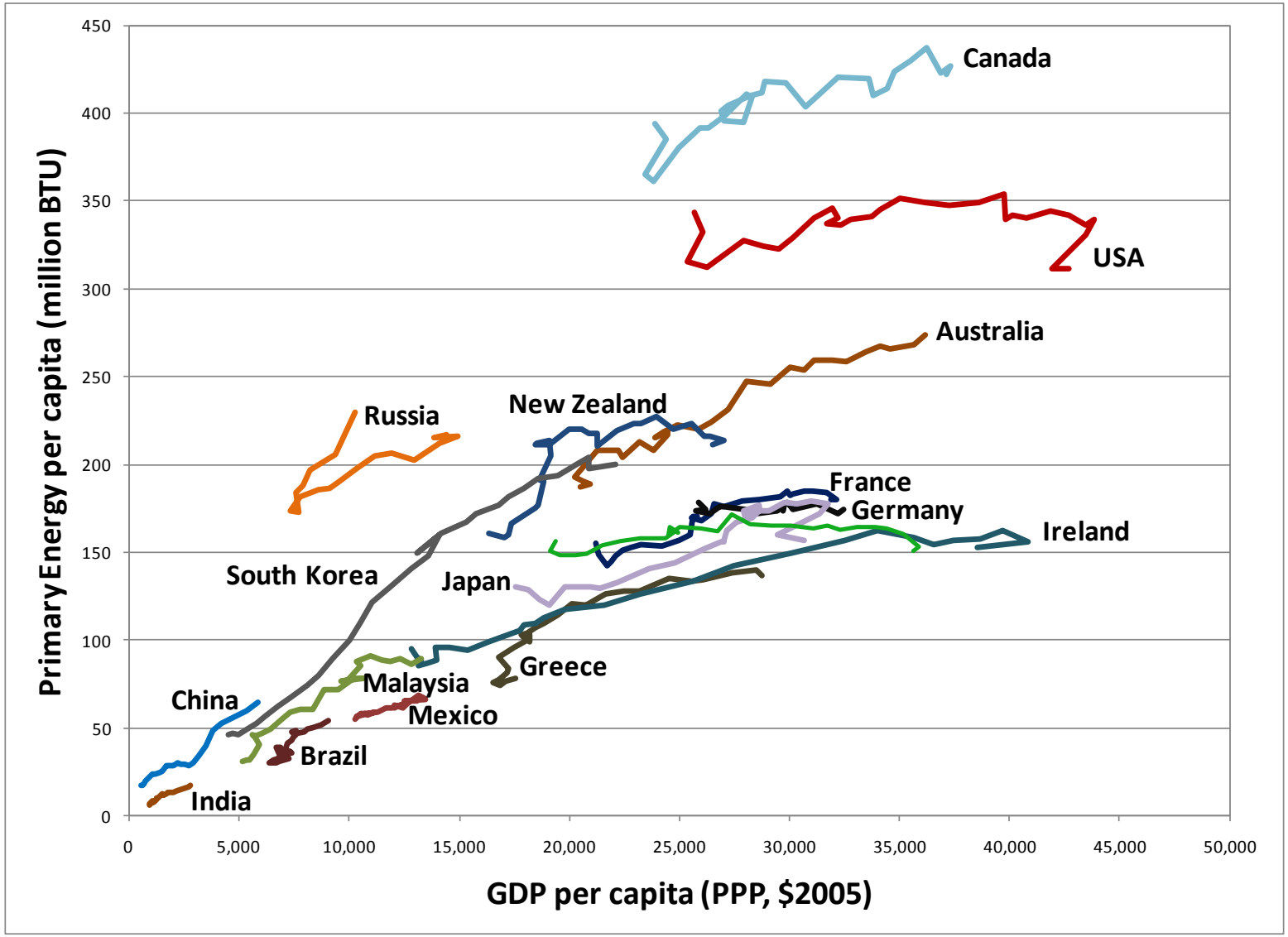


Paris agreement: has 5-year reviews with self-reporting; non=binding, no enforcement

Global contexts to 2050

- Demographic
  - Growing population (7.3B to ~9.7B)
  - “Older” Developed World, “Younger” Developing World
  - Urbanization (50M per year; 50% → 70% urban)
- Economic
  - Development of Most Of the World
  - Growing demand for resources (energy demand + 50-60%)
  - Leveling of the playing field (US out-of-wack by factor of 4)

Energy Use vs. GDP, both per capita (1980-2010)



Source: EIA

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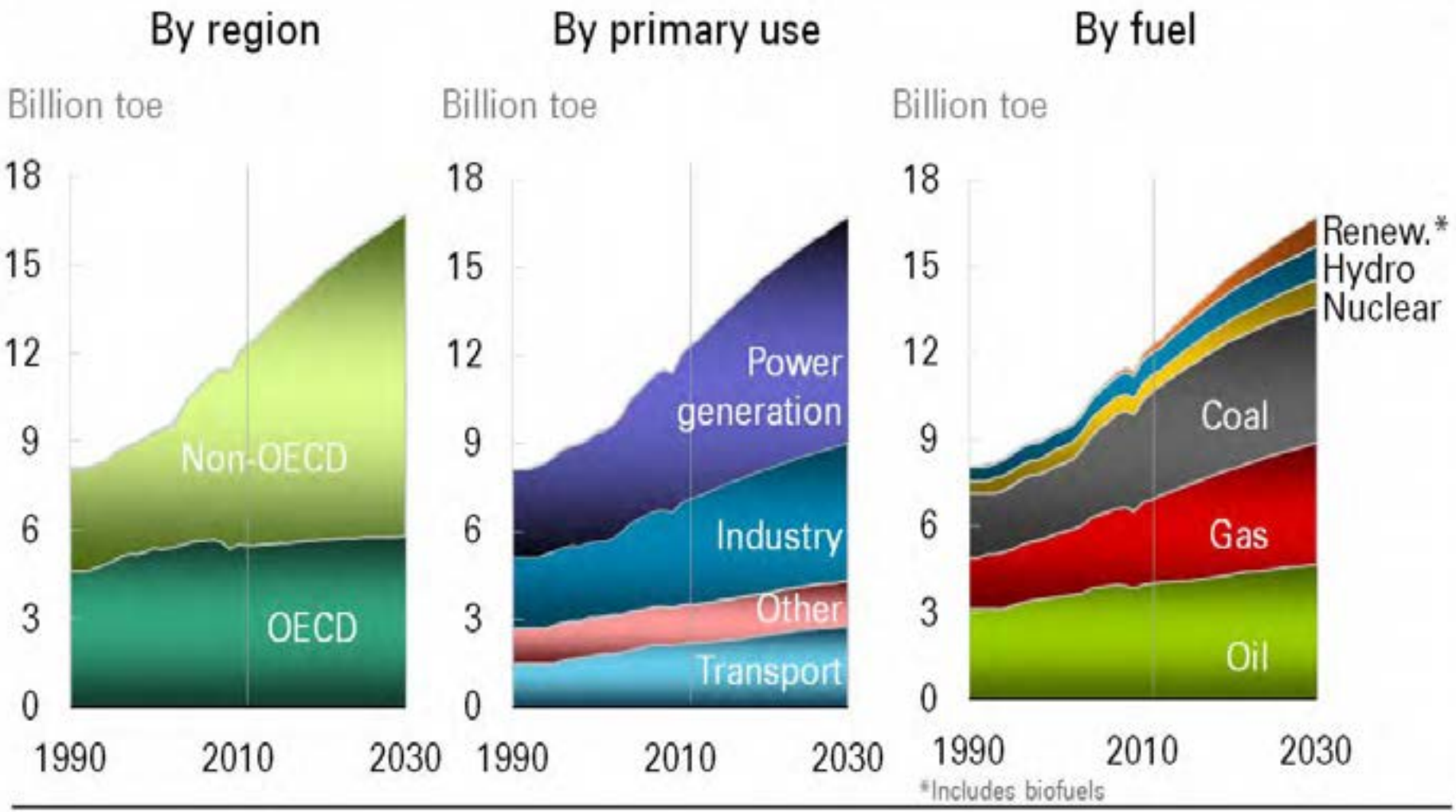
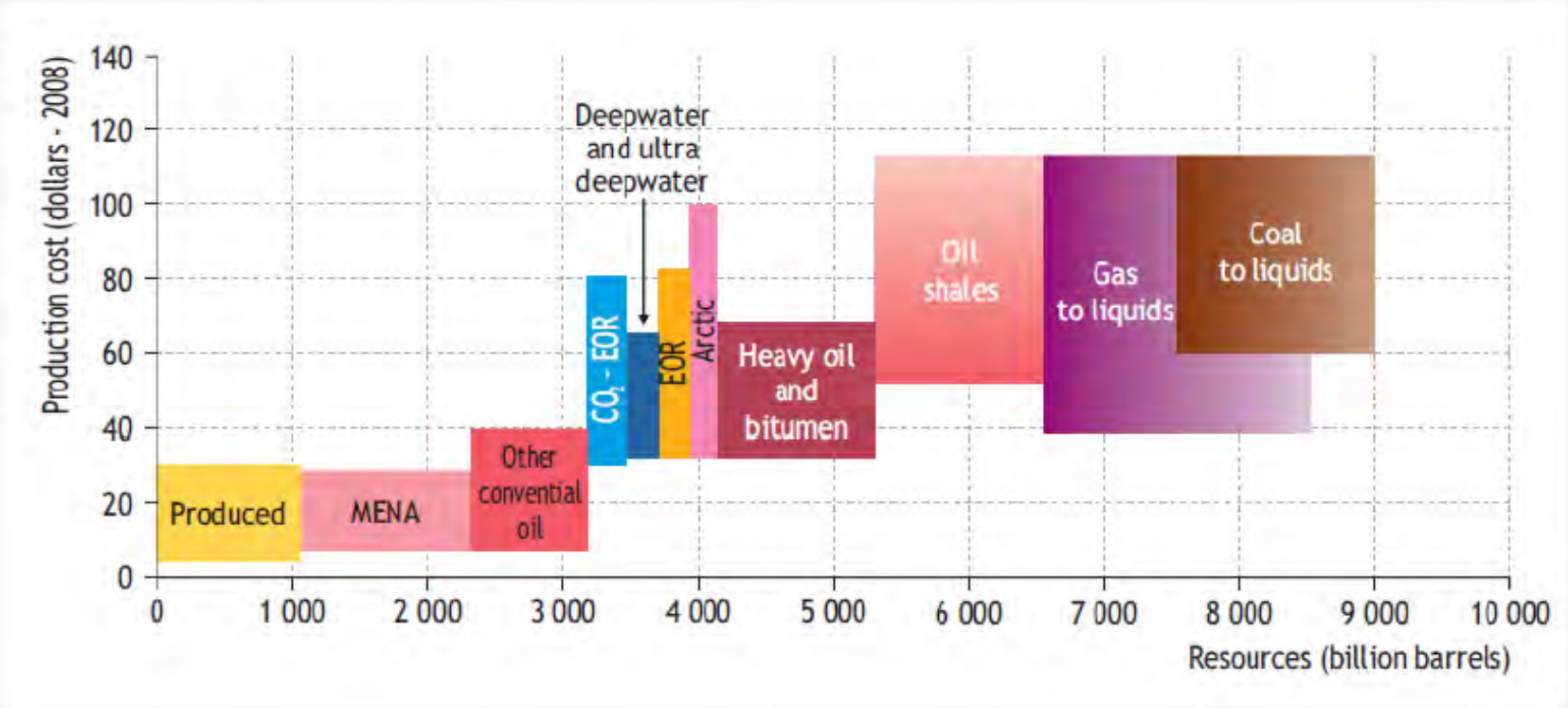
- Energy
  - Fossil fuels are most common (80%), most reliable, cheapest form of energy
  - They won’t be “running out” for a long time

Global context – energy demand is rising



Energy Outlook 2030

Long-term oil supply curve



The total recoverable oil-resource base is estimated at 9 trillion barrels (including 2.5 trillion barrel of GTL/CTL) of which we have so far produced 1.1 Tb

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  - Fossil fuels are most common (80%), most reliable, cheapest form of energy
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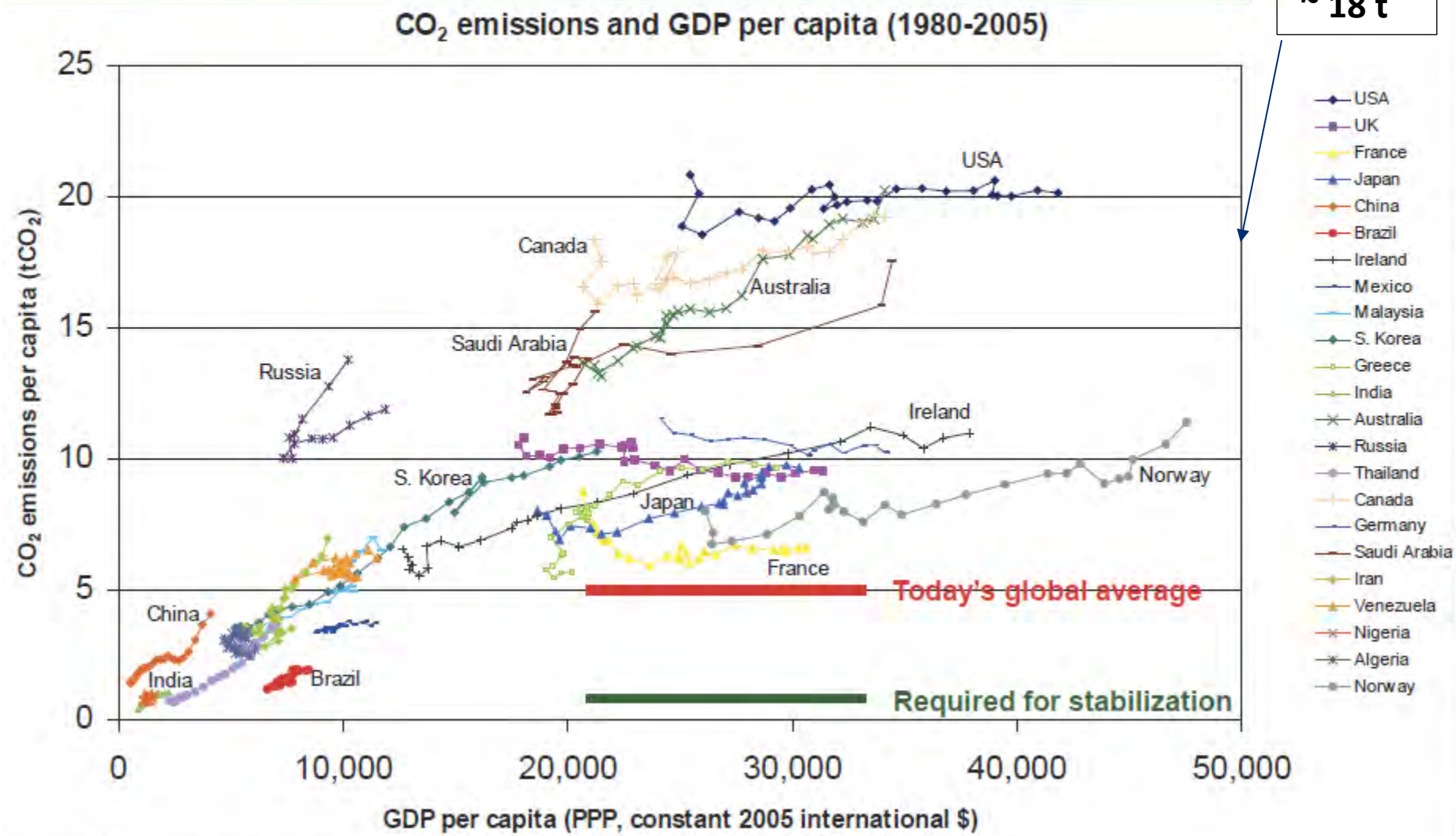
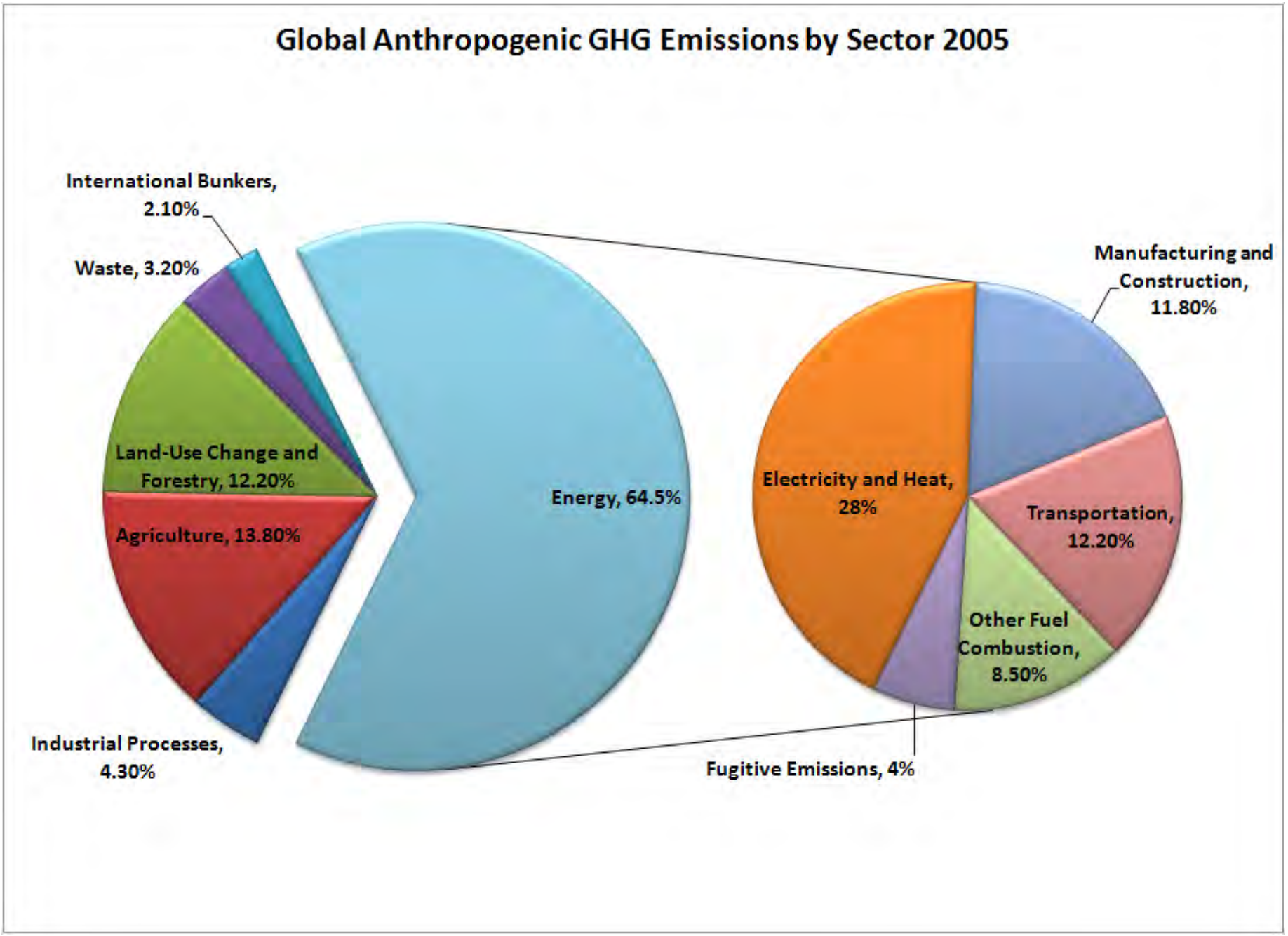
- Environmental
  - Growing environmental impacts ("The only humans who don't pollute …")
  - Push to reduce human influences on climate (GHG emissions)
- Technology progress
  - informatics, robotics, materials/manufacturing, biological
- Greater regulation, globalization of people, goods, ideas, capital

CO_2 emissions and GDP per capita



Source: DOE EIA database (2008)
Russia data 1992-2005, Germany data 1991-2005


Global Anthropogenic GHG Emissions by Sector 2005
International Bunkers, 2.10%
Waste, 3.20%
Land-Use Change and Forestry, 12.20%
Agriculture, 13.80%
Industrial Processes, 4.30%
Energy, 64.5%
Manufacturing and Construction, 11.80%
Electricity and Heat, 28%
Transportation, 12.20%
Other Fuel Combustion, 8.50%
Fugitive Emissions, 4%

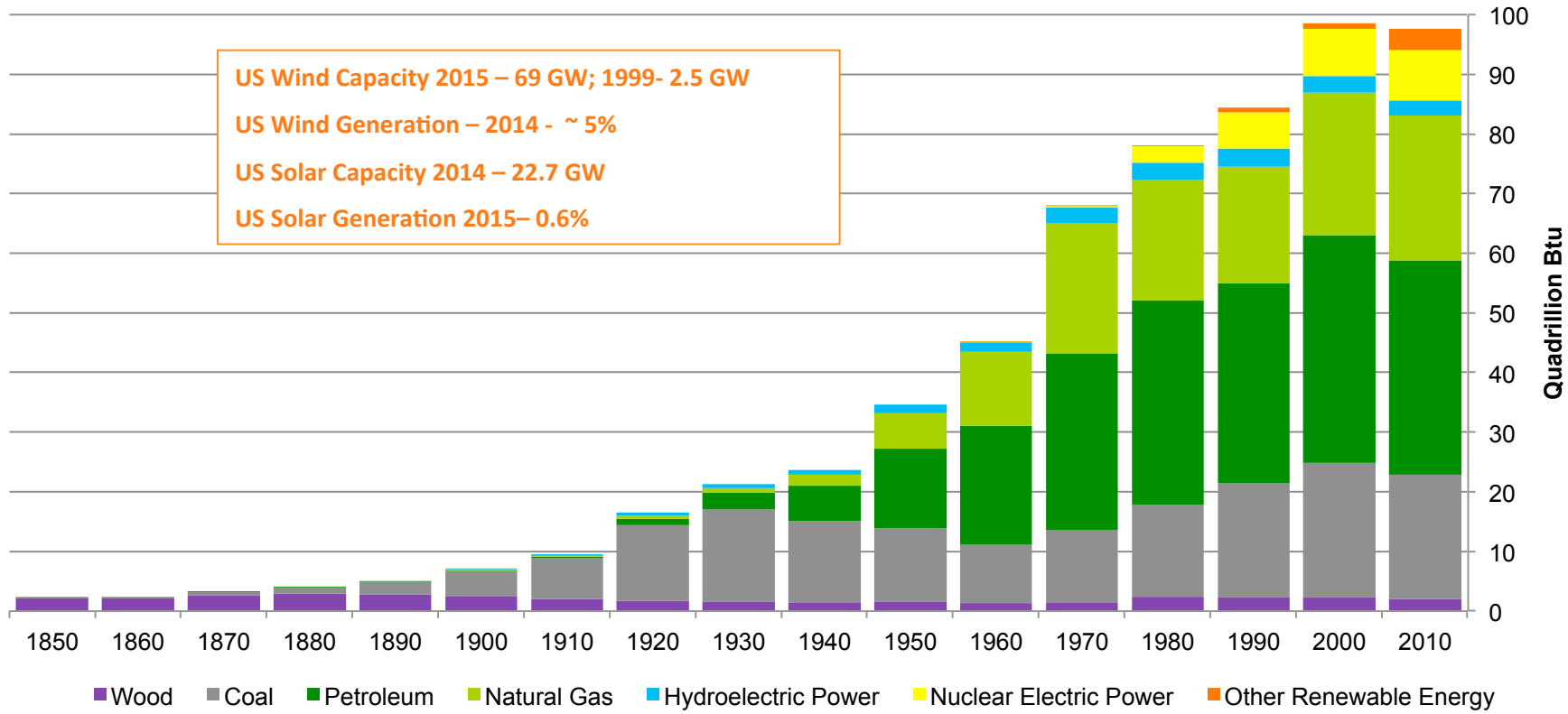
Projecting energy is perilous, but there are some givens

- A zero-emissions world doesn't violate physical laws
  - But it likely violates economic and political laws
- Cost, scale, and carbon constraint are the most important (but not the only) considerations
  - e.g., low tolerance for electricity outages
- Energy system will change slowly
  - Large capital investments, long lifetimes, commodities produced by private sector, interoperability
- It's a local discussion
  - Resource endowment, existing infrastructure, climate, mix of activities

What works in NYC won't work in Niger

Evolution of the US energy supply

U.S. Primary Energy Consumption Estimates by Source, 1850-2010



Source: U.S. Energy Information Administration Annual Energy Review, Tables 1.3, 10.1, and E1

Annual NYC energy consumption

PJ = 10^{15} J (US annual is 100,000 PJ)

- **Transport (total = 158 PJ)**
  - LDVs are 125 PJ (gasoline, ethanol)
  - HDVs are 23 PJ (21.6 diesel, 1.4 CNG in buses/trucks/rail)
    - 30% of buses in 2013 were diesel hybrids
  - Subway + commuter rail = 9.9 PJ electricity
- **Stationary Electricity = 181 PJ**
  - 5.8 GW avg, 13 GW peak
  - Street + traffic lights = 0.8 PJ
- **Heating (oil, gas, steam for water/space) = 304 PJ**

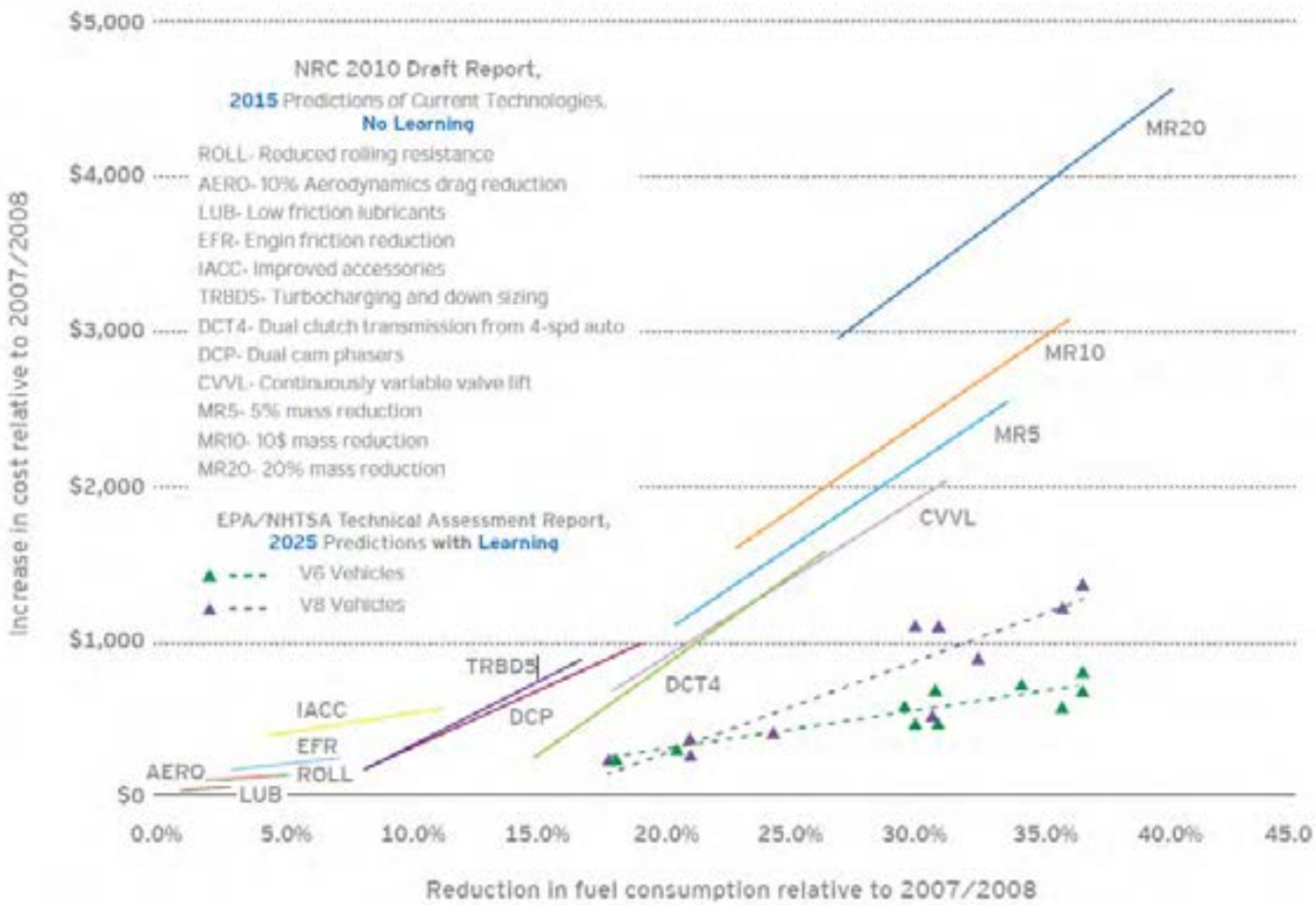
Decarbonization strategy

- Cost effective efficiency is good for all seasons, and becomes increasingly feasible with technology improvements, but …
  - Lack of capital funds; principal-agent disconnects; rebound
- Decarbonize transport
  - Light-duty vehicles (LDVs)
  - Heavy-duty vehicles (HDVs)
- Decarbonize electricity (baseload, peak)
- Decarbonize heat (space, water, industry)

Decarbonizing transport

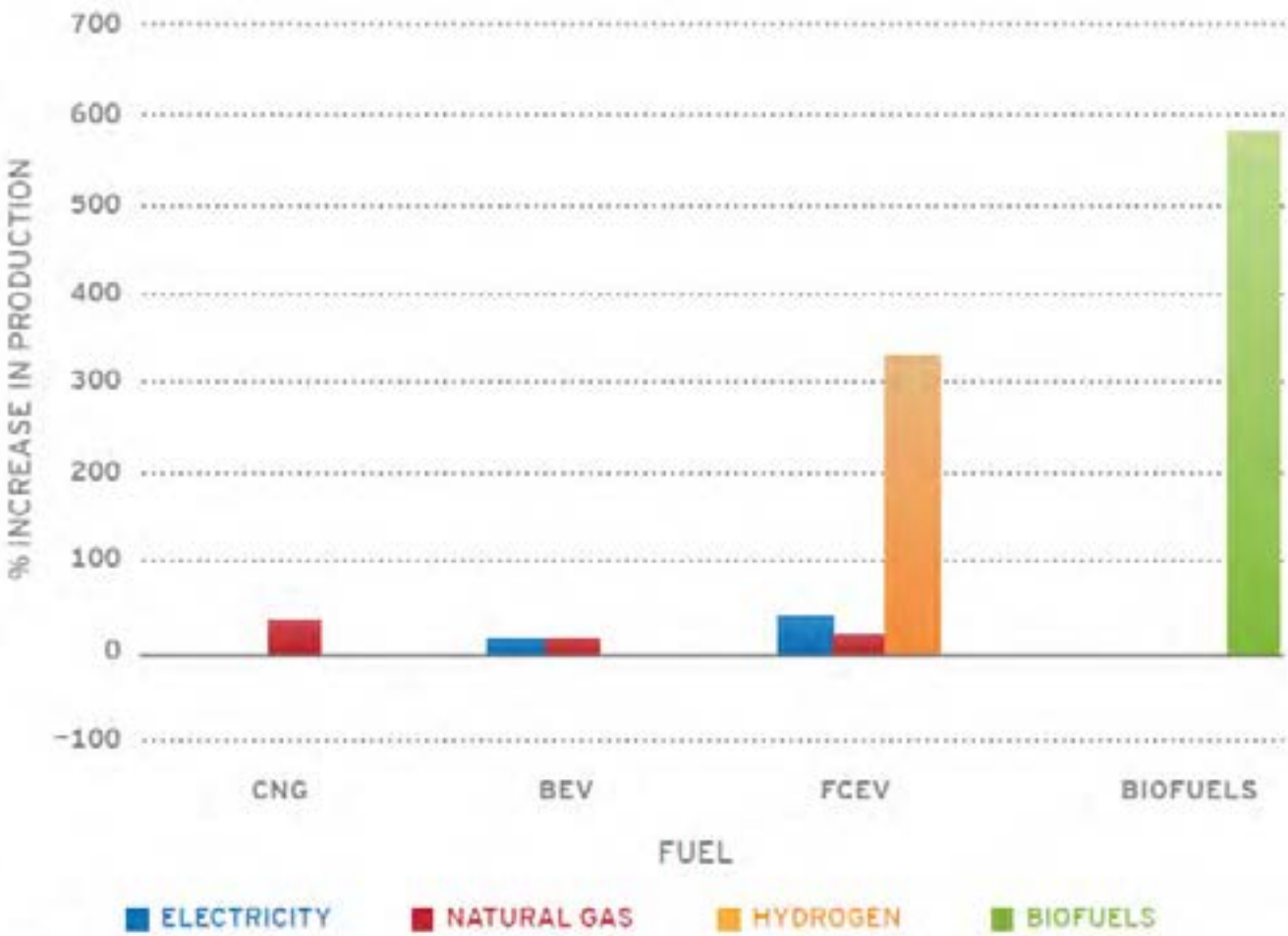
- Vehicle efficiency through mass reduction, autonomy, connectivity
- Fuel choices are electricity, cellulosic biofuels, hydrogen
- LDVs will likely go electric
  - Gradual transition from ICE to HEV to PHEV to BEV
    - stock of 240 M; 14M sold /yr; 120k PHEV + BEV sold in 2014
  - Batteries are (marginally) good enough now; Charging infrastructure partially in place
  - Small increase in generation required, mostly at night
    - ICE: 30 mpg = ¼ mile/MJ; BEV: 4 miles/kWh; all NYC LDVs require 31 PJ of electricity, or +16%

Projected Reductions in the Fuel Consumption of Large Cars and Small Trucks through Technology

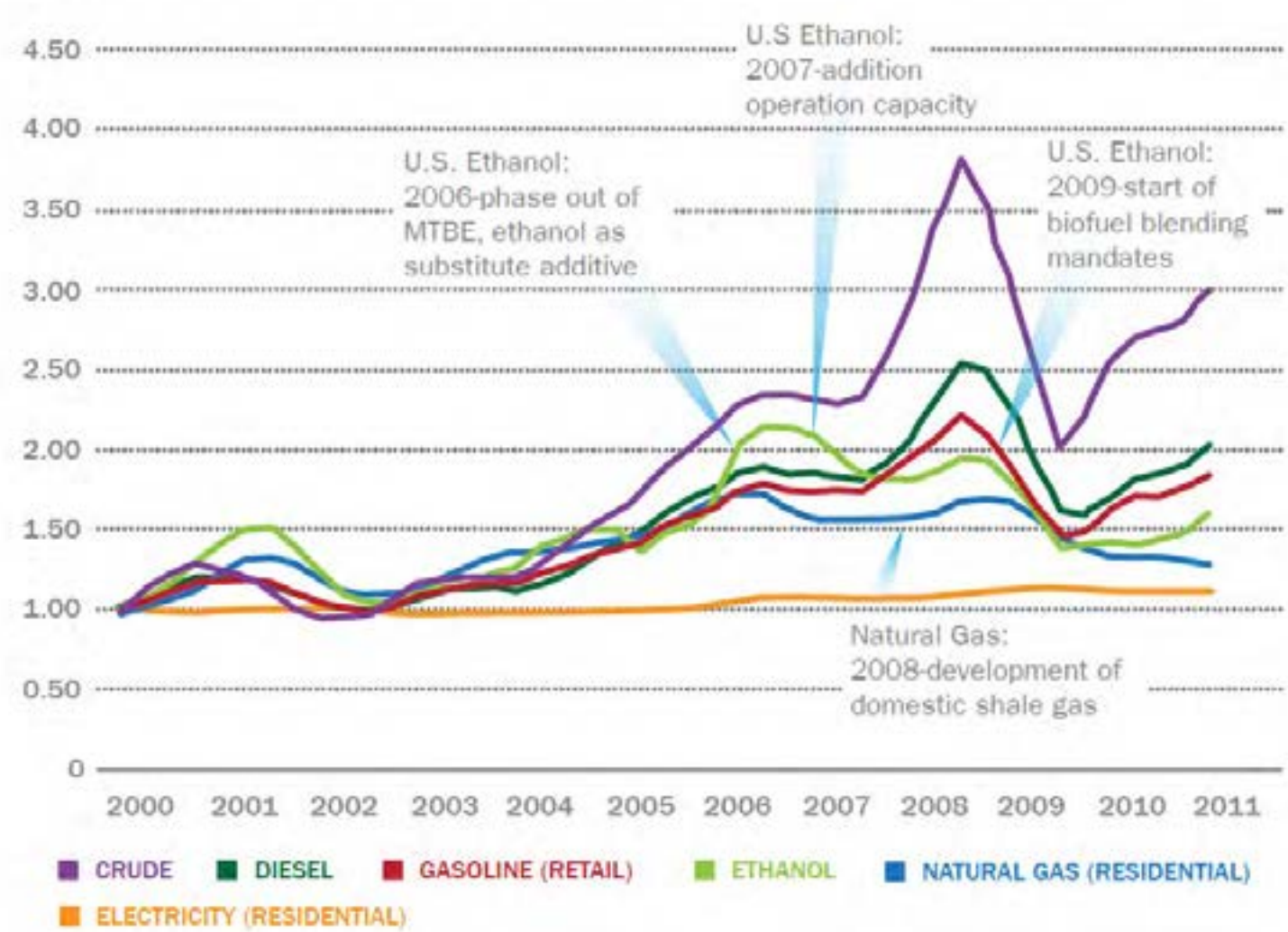


Source: National Research Council with data adapted by a National Petroleum Council study committee; joint study by the Environmental Protection Agency and National Highway Traffic Safety Administration (EPA/NHTSA).

Estimated Supply Impacts of Meeting 50% of Today's LDV Demand by Various Alternative Fuels



Relation of Fuel Prices to Crude Oil Price, 2000–2011



Data from EIA and Nebraska Energy Office

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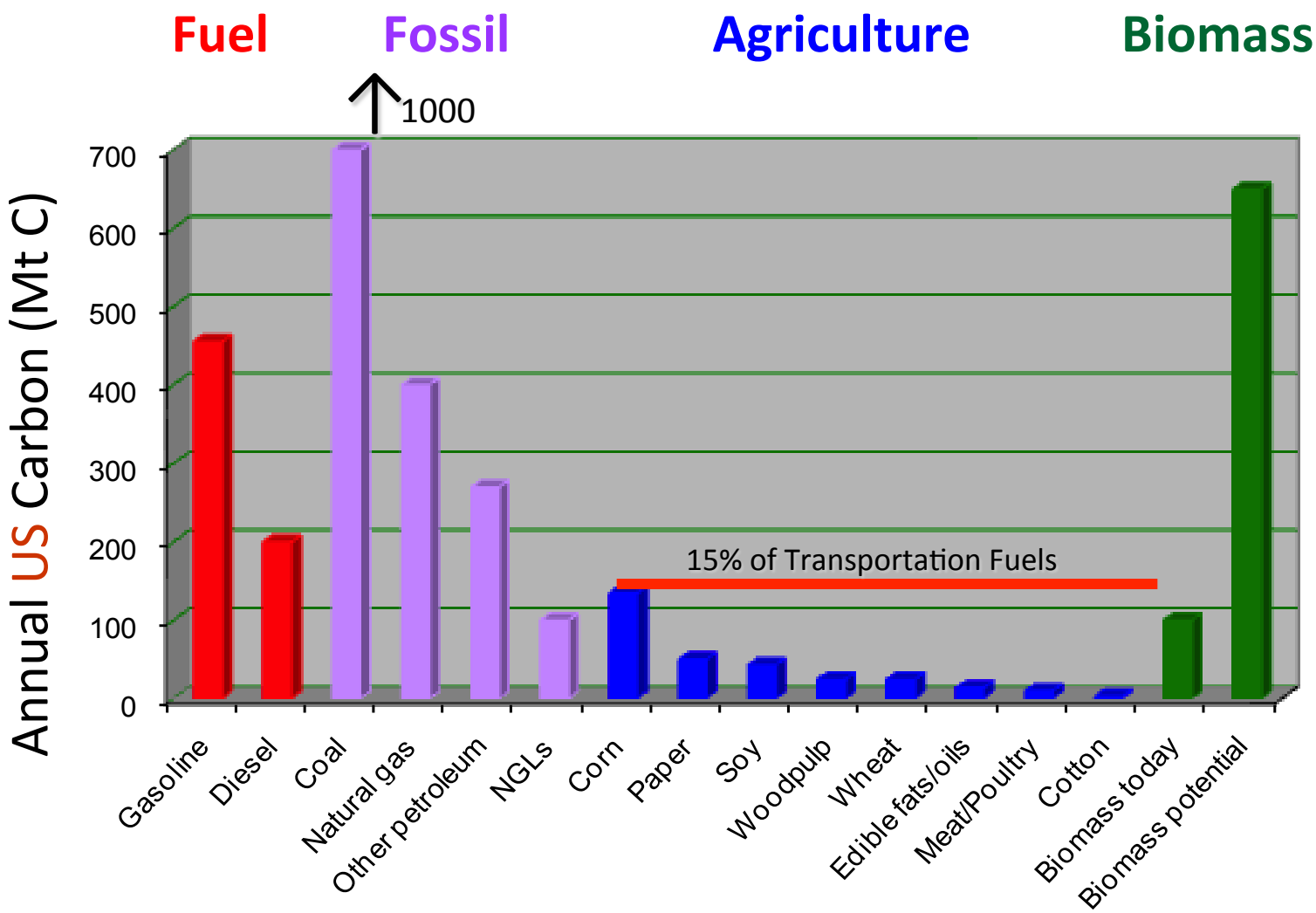
  - Fleet nature makes fueling infrastructure less of an issue

Biomass can provide significant carbon



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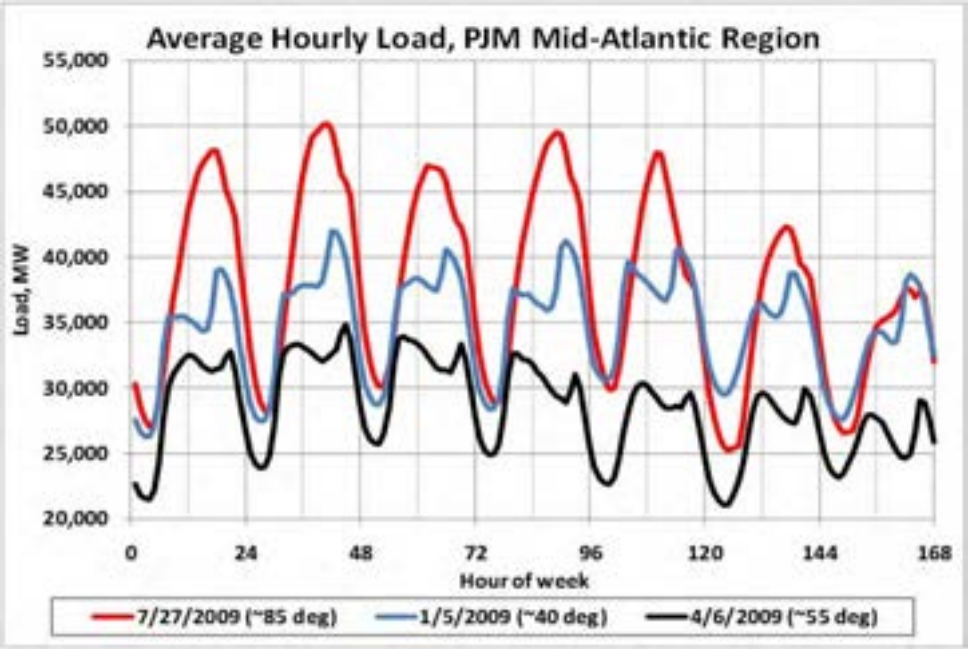
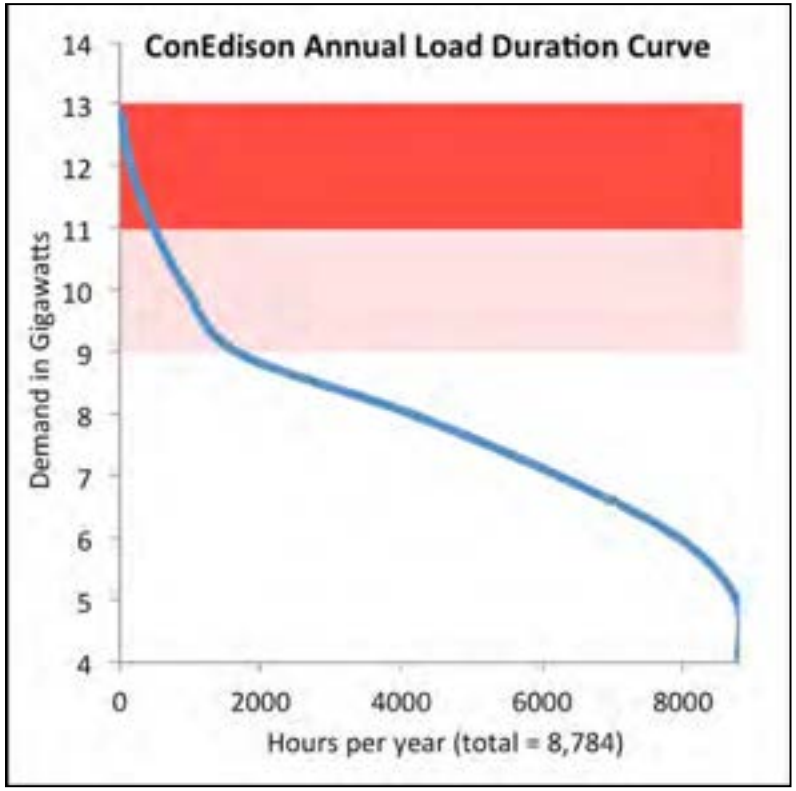
- Some consequences of doing this nationally or globally
  - Low oil demand creates lower prices, extending decarbonization transition
  - Higher vehicle costs, lower fuel costs
  - Stability of transport fuel costs
  - Is there enough biomass for biodiesel with growing global transport?
  - Oil reserve assets become essentially worthless

Decarbonizing electricity

- It’s much more than cost of electricity and emissions
  - Intermittency, dispatchability, land, water, local environment, …

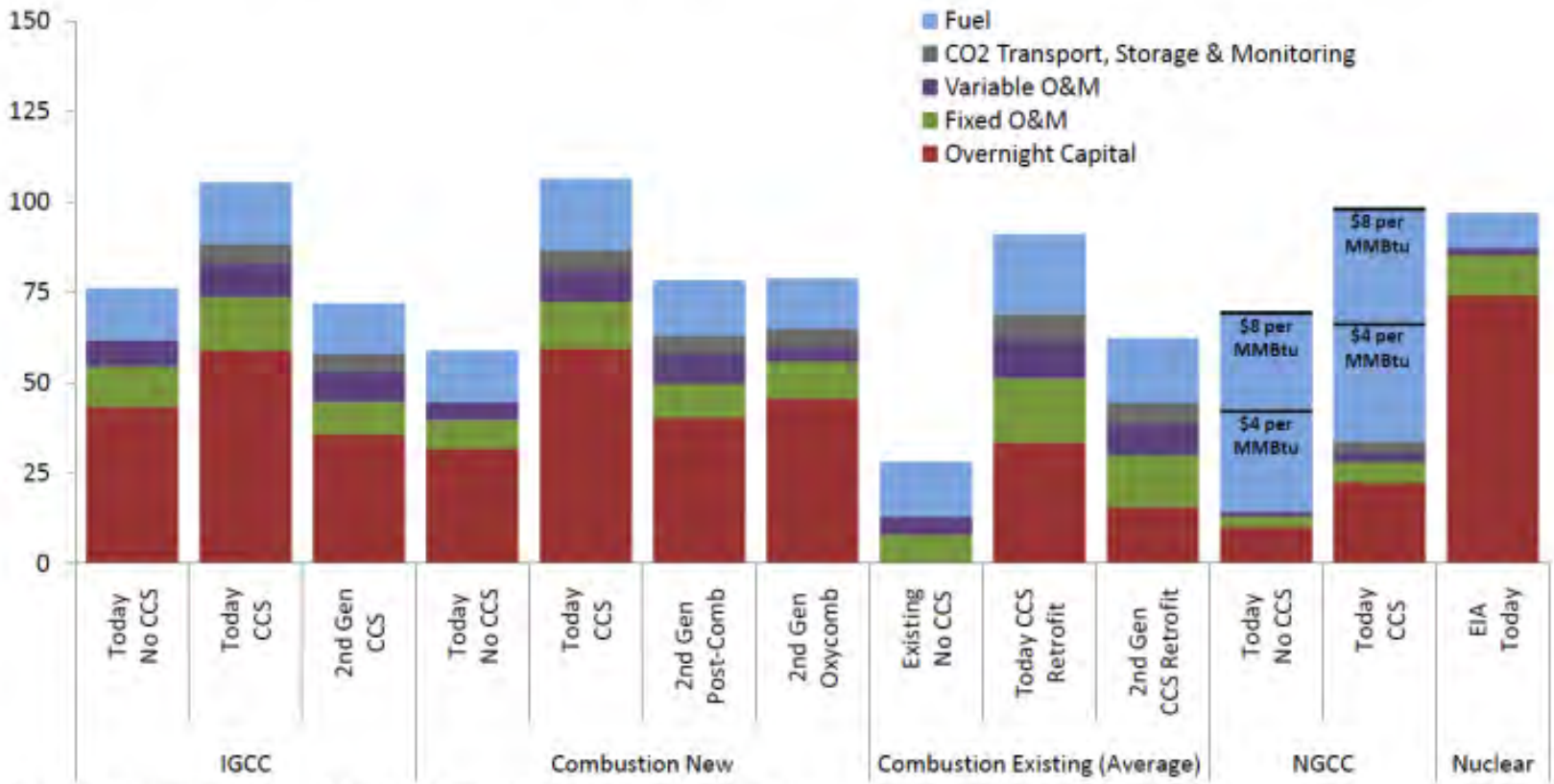
Power demand is highly variable and there's no practical storage





Baseload Power Systems Cost Comparison

Cost of Electricity (2010$/MWh)

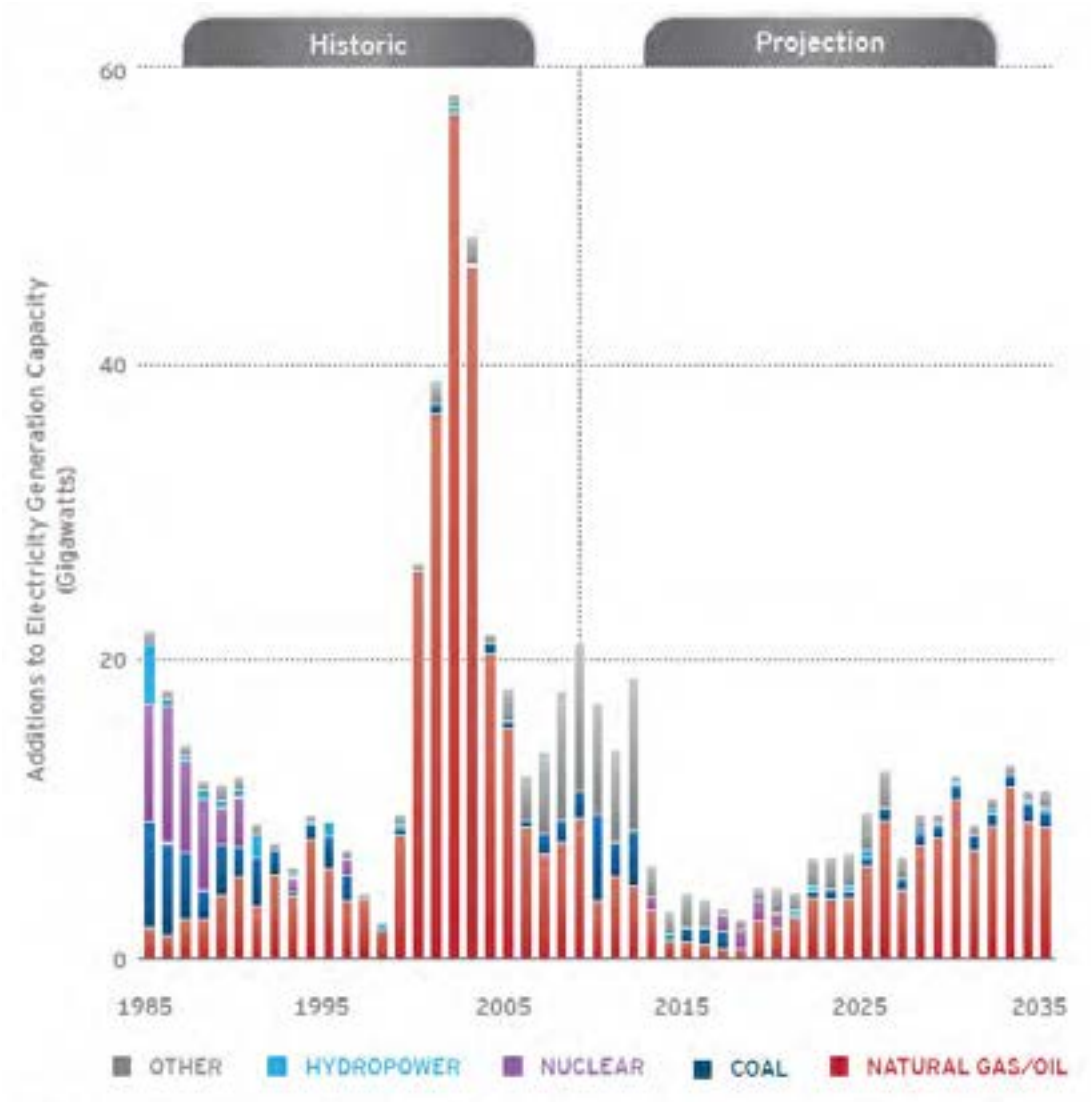


Fuel Cost Assumptions:
Coal - $1.64/MMBtu
Nuclear – $9.7/MWh*
NG - $4-8/MMBtu

Capacity Factor Assumptions:
PC Today – 85%
IGCC Today – 80%
NGCC – 85%
Nuclear – 90%

Sources:
NETL Today – Cost and Performance Baseline for Fossil Energy Plants (NETL/2010)
NETL 2nd Gen – Multiple NETL technology pathway study reports
EIA – EIA/R. W. Beck (2010) using NETL study finance structure

Additions to U.S. Electricity Generation Capacity, 1985–2035 (total US capacity ~ 1.1 TW, so 100-year turnover time)

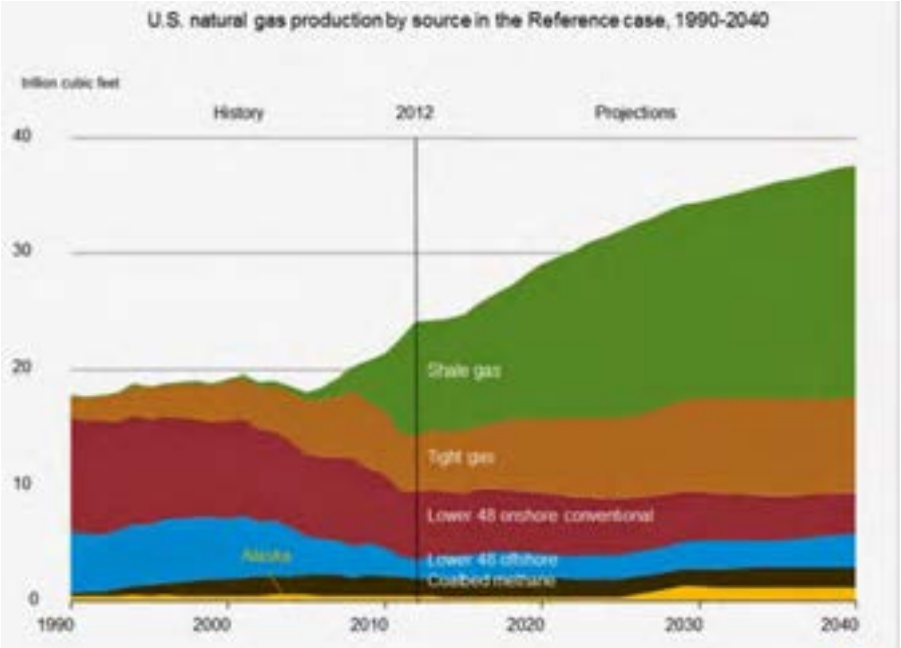


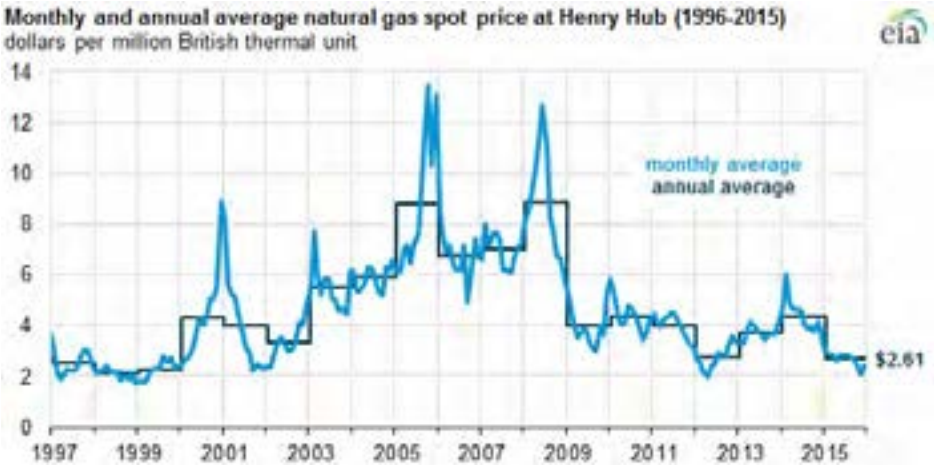
Source: EIA

Decarbonizing electricity

- It's much more than cost of electricity and emissions
  - Intermittency, dispatchability, land, water, local environment, …
- Methane halves CO_2 relative to coal, but likely climate neutral

Cheap gas is changing the US energy system





- On 9/6/16, gas was $2.88
- Gas <$8 beats fission
- Gas <~$3 beats renewables (without backup costs)
- Cheap gas in the US has brought back manufacturing, converted gas imports to exports
- Bankruptcies in coal (Peabody, Arch, …), renewables (Abengoa, SunEdison, …)

A "gas world" has lower CO_2, but CH_4 leaks and loss of aerosol cooling result in essentially no reduction in radiative forcing

Decarbonizing electricity

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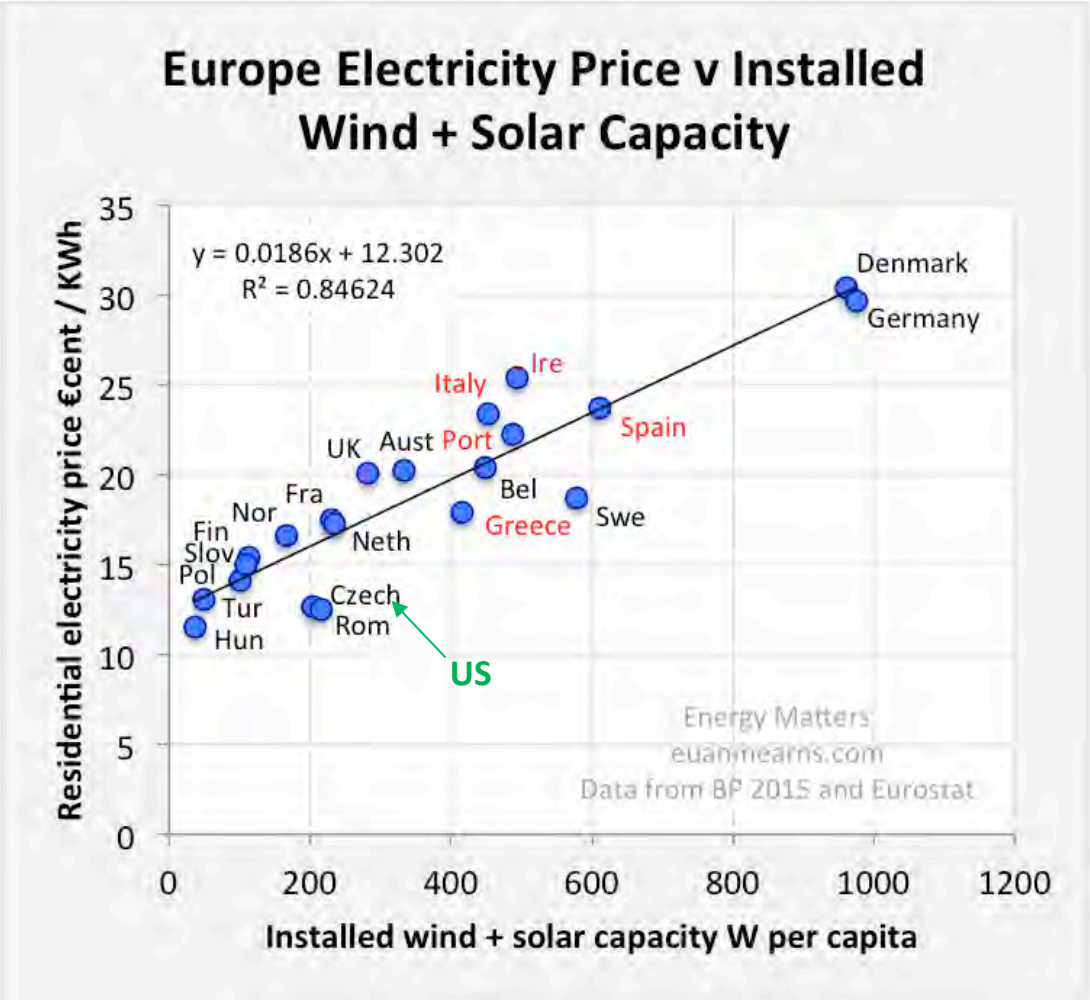
  - Intermittency, dispatchability, land, water, local environment, …
- Methane halves CO_2 relative to coal, but likely climate neutral
- Baseload
  - Nuclear
    - U resource; Repository integrity; Seismic hazard; Water availability? Acceptance? SMRs?
  - Carbon Capture and Storage fueled by coal/gas
    - Costs? Reservoir integrity (<0.3% /yr leak rate for hundreds of years)
  - Biomass
    - If we use it for power, can't use if for fuel; BioCCS net carbon negative
- Renewables
  - Hydro essentially tapped out nationally
  - Solar/wind have limited potential (20%-30% of generation)
    - Weather stats (variability, covariability)
    - Land use; local environmental impacts
    - Need massive storage and extra generation in the absence of fossil backup
    - Transmission infrastructure; frequency regulation
  - Geothermal
    - Deep resource characterization / access; cost?
  - Storage a key enabling technology

Wind/solar electricity is currently more costly



Solar costs dropping rapidly, but deployment still driven by

- Financial incentives
  - Tax credits
  - Feed-in tariffs
  - Loan guarantees
- Portfolio standards

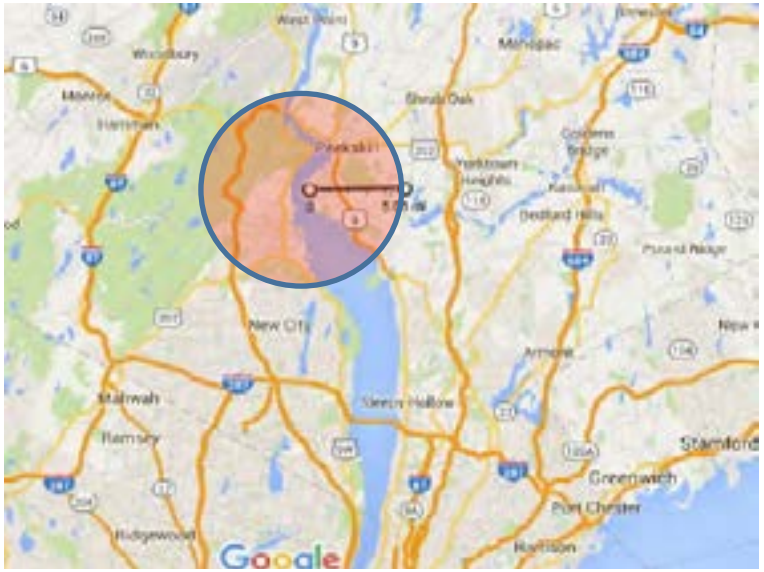
Fossil backup requirement has unintended GHG consequences

Additional transmission to make wind viable

Source: http://www.npr.org/series/103281114/power-hungry-reinventing-the-u-s-electric-grid?ps=rs

Solar takes land

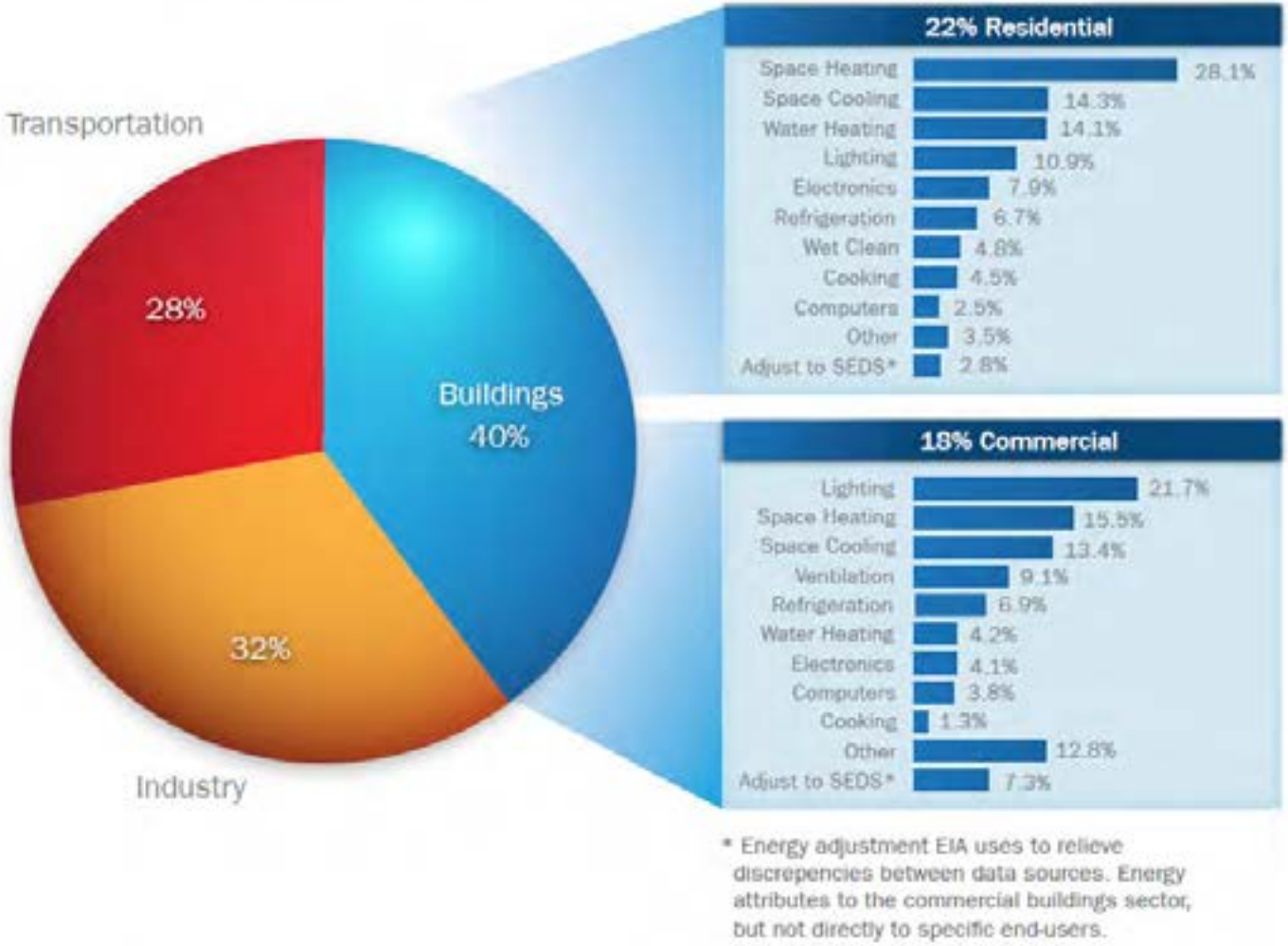
- Long Island Solar Farm
  - 200 acres (81 ha) for 5 MW average (37 MW peak)
- Indian Point 2 GW average power
  - Equivalent to 32000 ha, or a 5.5 mile circle
  - Ecological, logistical impacts?
  - Need 3 of these for NYC baseload



Decarbonizing heat

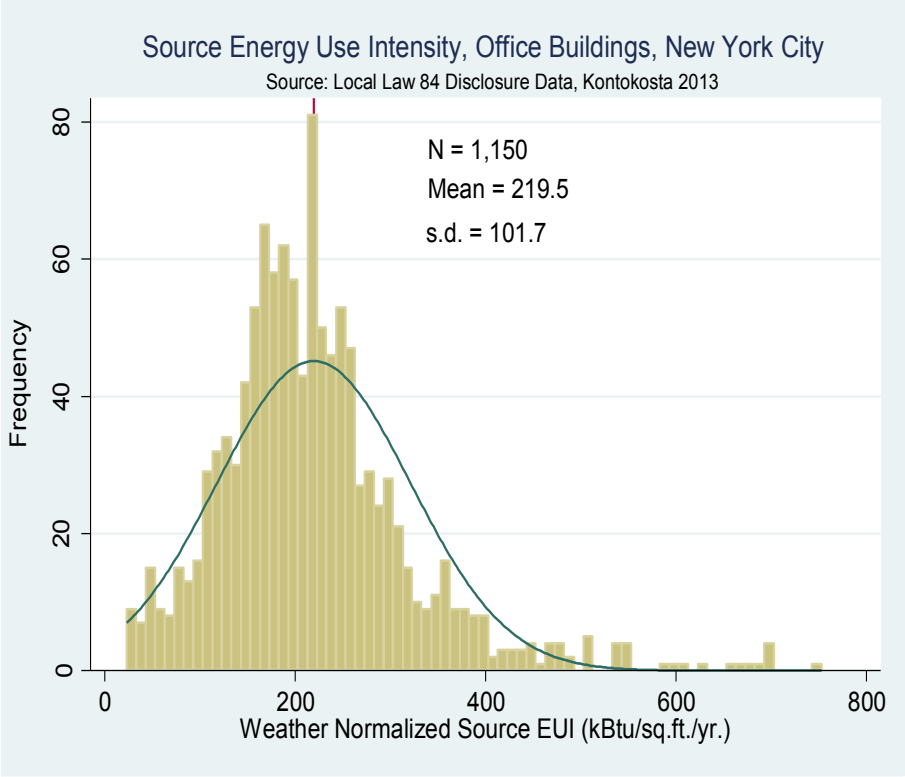
- Residential
  - Solar for hot water, space heating by building design
  - Carbon-free electricity to heat is inefficient
    - NYC electricity goes to + 1.5X to 15 GW average!
  - Heat pumps are inappropriate in cold climate, urban areas
  - Carbon-free district heating in urban areas
    - SMRs, biomass
- Industrial
  - Biomass?
  - ????

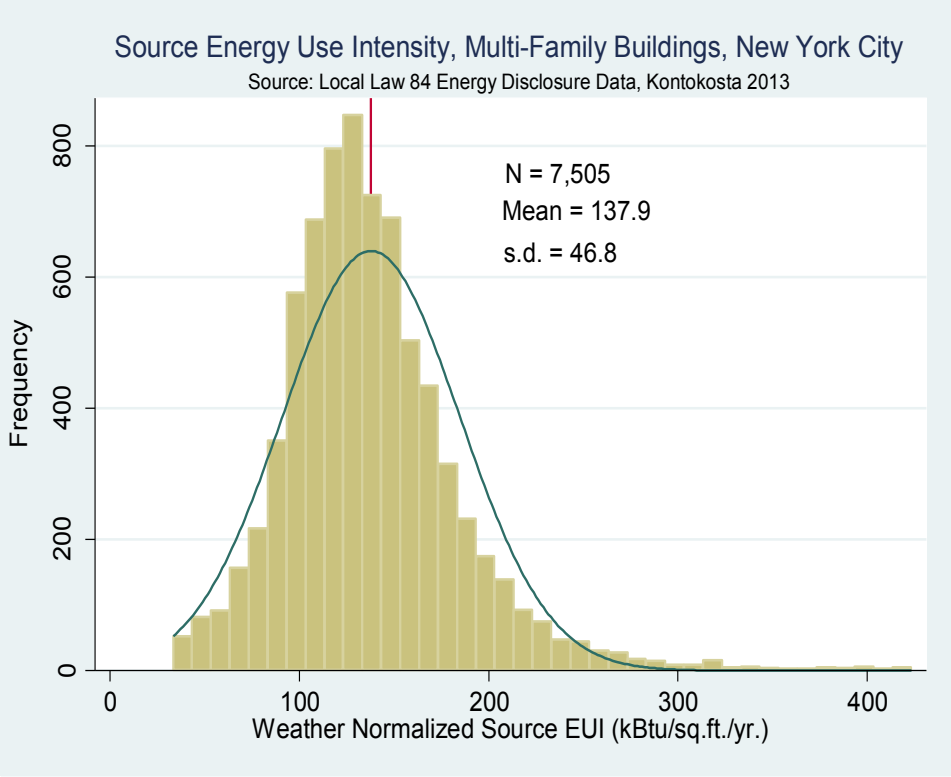
U.S. Energy Use in Residential and Commercial Buildings in 2008



Source: DOE Buildings Energy Data Book

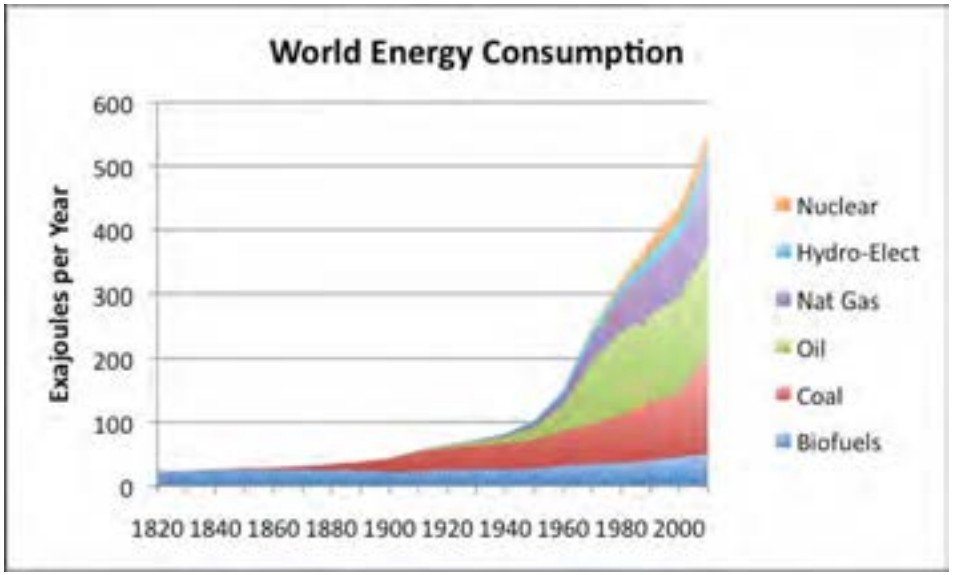
Building Energy Efficiency

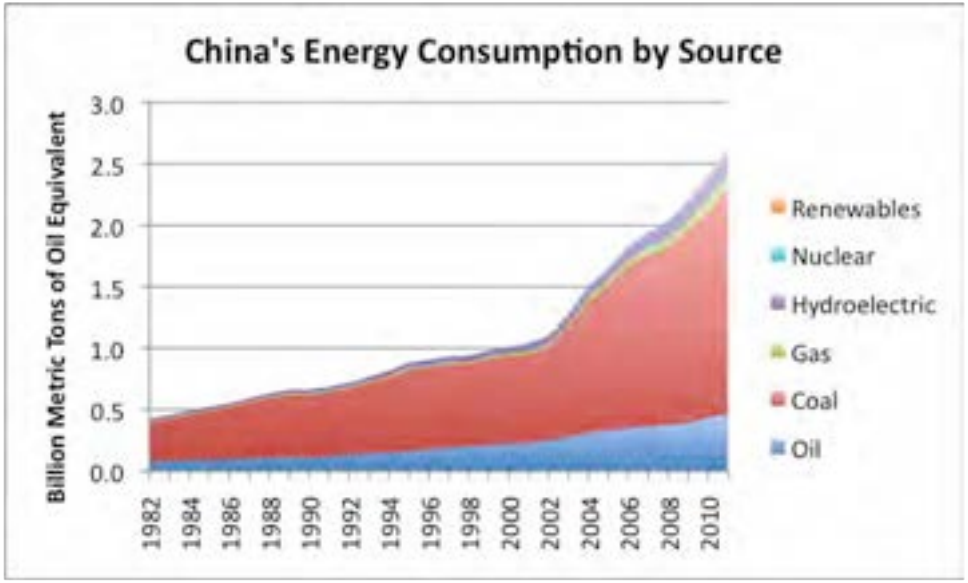




Kontokosta 2013

And in the rest of the world …

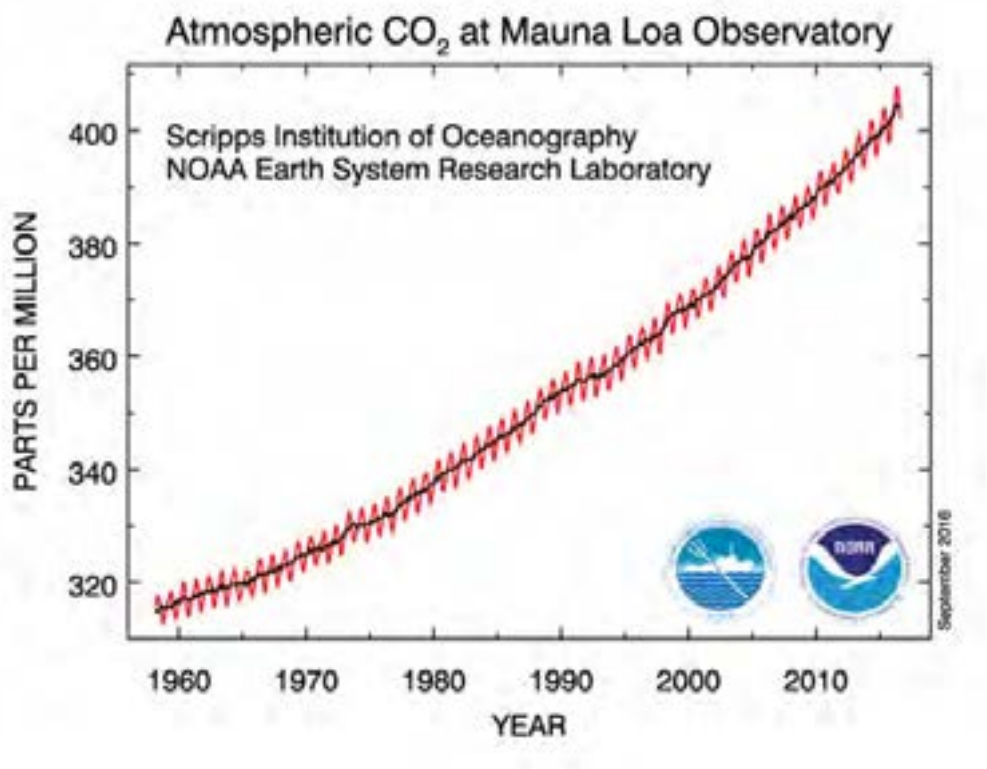




Energy is central to nearly every major challenge, and opportunity the world faces today. Be it jobs, security, climate change, food production or increasing incomes, access to sustainable energy for all is essential for strengthening economies, protecting ecosystems and achieving equity.

Worldwide, about 1.2 billion people have no access to electricity and the development benefits it brings, and 1 billion more have access only to unreliable electricity networks. Nearly 3 billion people rely on traditional biomass (such as wood and charcoal) for cooking and heating.
- UN Foundation

Informal poll



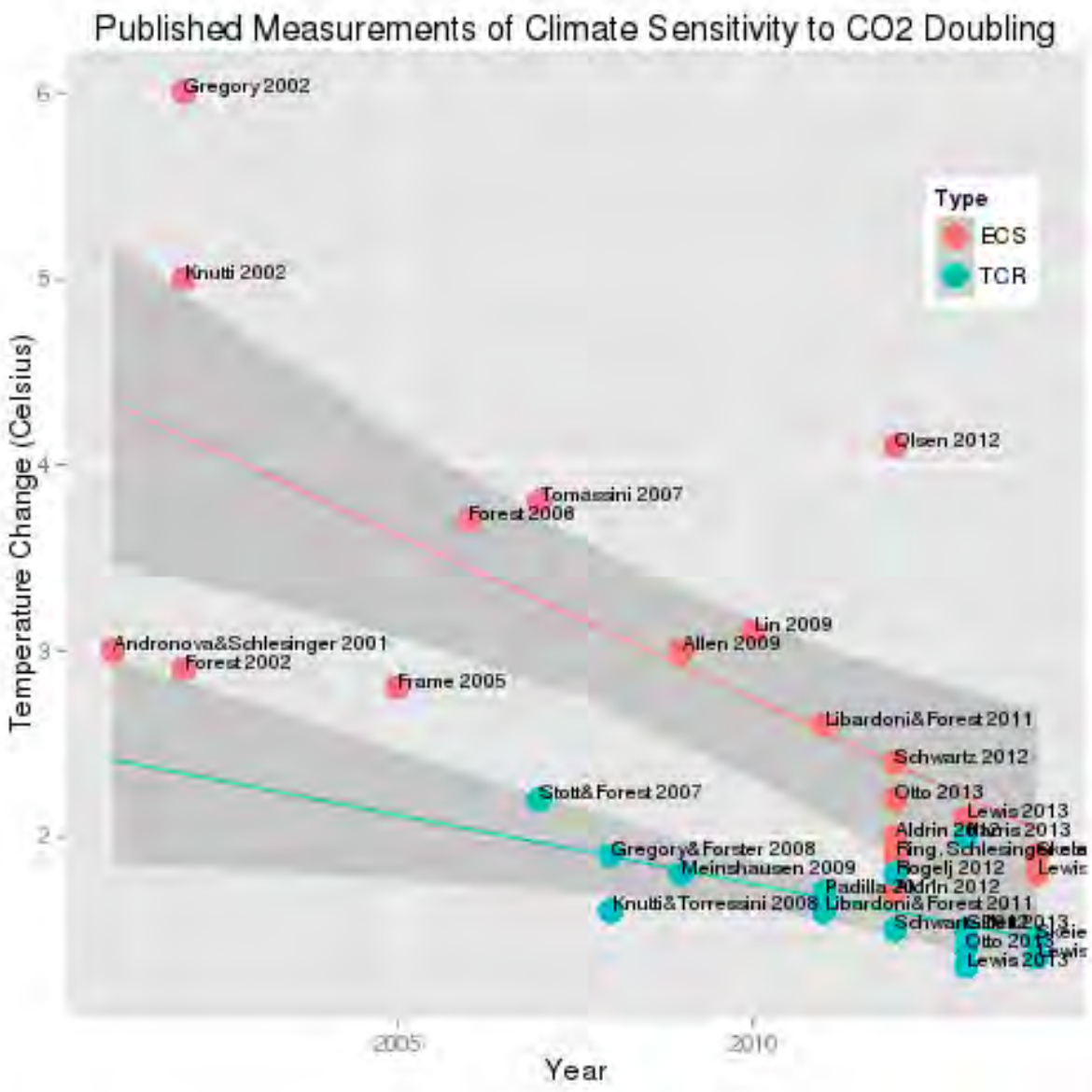
Mauna Loa CO_2 in August 2016 = 402.25 ppm

With which of the following do you agree?

- CO_2 levels will exceed **450** ppm during the 21st century
- CO_2 levels will exceed **550** ppm during the 21st century
- CO_2 levels will exceed **650** ppm during the 21st century
- CO_2 levels will exceed **750** ppm during the 21st century

Koonin's "not so fast" strategy

- **Clarify the policy discussion and the science that underpins it**
  - Sustain and bolster climate observations
  - A scientific "red team" exercise to accurately portray uncertainties
  - Reframe the discussion to "values"; don't use alleged certainty as a club


Published Measurements of Climate Sensitivity to CO2 Doubling
Temperature Change (Celsius)
Year
Type
ECS
TCR
Gregory 2002
Knutti 2002
Olsen 2012
Tomassini 2007
Forest 2006
Lin 2009
Allen 2009
Andronova&Schlesinger 2001
Forest 2002
Frame 2005
Libardoni&Forest 2011
Schwartz 2012
Stott&Forest 2007
Otto 2013
Lewis 2013
Gregory&Forster 2008
Meinshausen 2009
Rogelj 2012
Knutti&Torressini 2008
Libardoni&Forest 2011
Lewis 2013
2005
2010

Koonin's "not so fast" strategy

- **Clarify the policy discussion and the science that underpins it**
  - Sustain and bolster climate observations
  - Reframe the discussion to "values"; don't use alleged certainty as a club
  - A scientific "red team" exercise to accurately portray uncertainties
- **Pursue "easy" emissions reductions**
  - Cost-effective efficiencies; Leverage credible side benefits (local environment, energy security)
  - RD&D for low-cost, emissions-free technologies
    - Fission, solar, storage/grid management, biofuels, CCS, fusion, …
- **Reduce emissions further if/when**
  - the science becomes more certain *or*
  - a values consensus emerges *or*
  - zero-emissions technologies become more feasible

Americans' Level of Worry About National Problems -- 2014 Rank Order

Next, I'm going to read a list of problems facing the country. For each one, please tell me if you personally worry about this problem a great deal, a fair amount, only a little, or not at all? First, how much do you personally worry about ... [RANDOM ORDER]?

	Great deal	Fair amount	A little/ not at all
	%	%	%
The economy	59	29	11
Federal spending and the budget deficit	58	22	20
The availability and affordability of healthcare	57	20	23
Unemployment	49	28	23
The size and power of the federal government	48	20	31
The Social Security system	46	29	24
Hunger and homelessness	43	33	23
Crime and violence	39	31	29
The possibility of future terrorist attacks in the U.S.	39	24	37
The availability and affordability of energy	37	30	33
Drug use	34	29	37
Illegal immigration	33	24	42
The quality of the environment	31	35	34
Climate change	24	25	51
Race relations	17	26	56

Question asked of a half sample
March 6-9, 2014

GALLUP

Koonin's "not so fast" strategy

- **Clarify the policy discussion and the science that underpins it**
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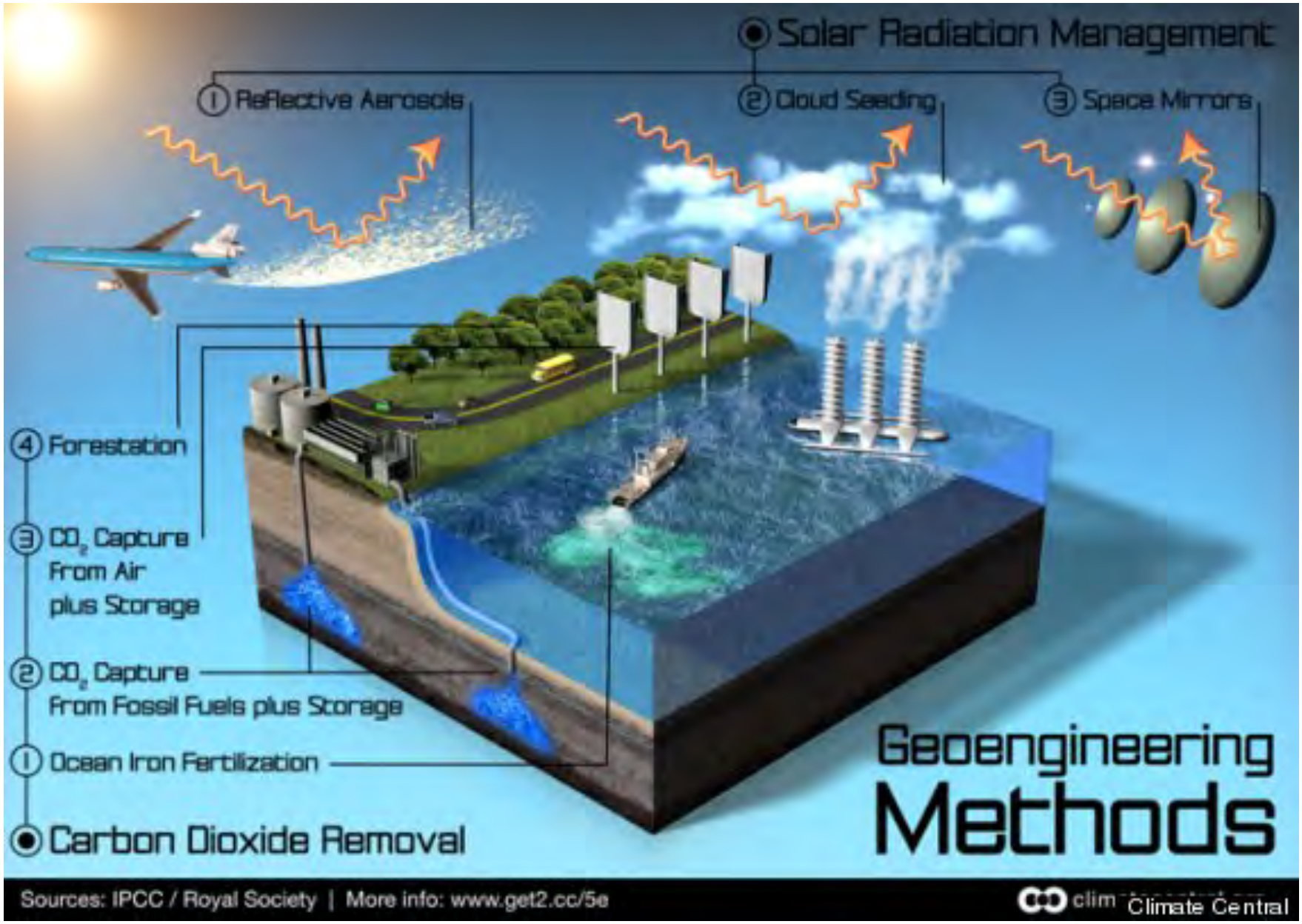
    - Fission, solar, storage/grid management, biofuels, CCS, fusion, …
- **Reduce emissions further if/when**
  - the science become more certain *or*
  - a values consensus emerges *or*
  - zero-emissions technologies become more feasible
- **Pursue adaptation vigorously**
  - It is effective (we manage to muddle through)
  - It is agnostic (indifferent to natural *vs* human-caused)
  - It is proportional (adapt more if the change is greater)
  - It is local (politically palatable; does not require global consensus)
  - It is autonomous (it will happen/ is happening on its own)
  - Modes of adaptation ("wedges")? What are we adapting to?
- **Develop geoengineering as a last-resort option**
  - Research program? Feasibility tests? Governance?


Solar Radiation Management
1 Reflective Aerosols
2 Cloud Seeding
3 Space Mirrors
4 Forestation
3 CO_2 Capture From Air plus Storage
2 CO_2 Capture From Fossil Fuels plus Storage
1 Ocean Iron Fertilization
Carbon Dioxide Removal
Geoengineering Methods
Sources: IPCC / Royal Society | More info: www.get2.cc/5e
clim Climate Central

Bottom line thoughts

- It is unlikely that we can get to a zero-emission world (by 2100)
  - Human influences on the climate will continue to grow through this century
  - *If* human influences are already deteriorating the climate, we're in for at least another century
- R&D essential to prepare for a contingent future
- Society will adapt to a climate changing under human and natural influences
- It would be good to know if we can have geoengineering options "on the shelf"

COMMENTS/QUESTIONS??

Political climate-speak

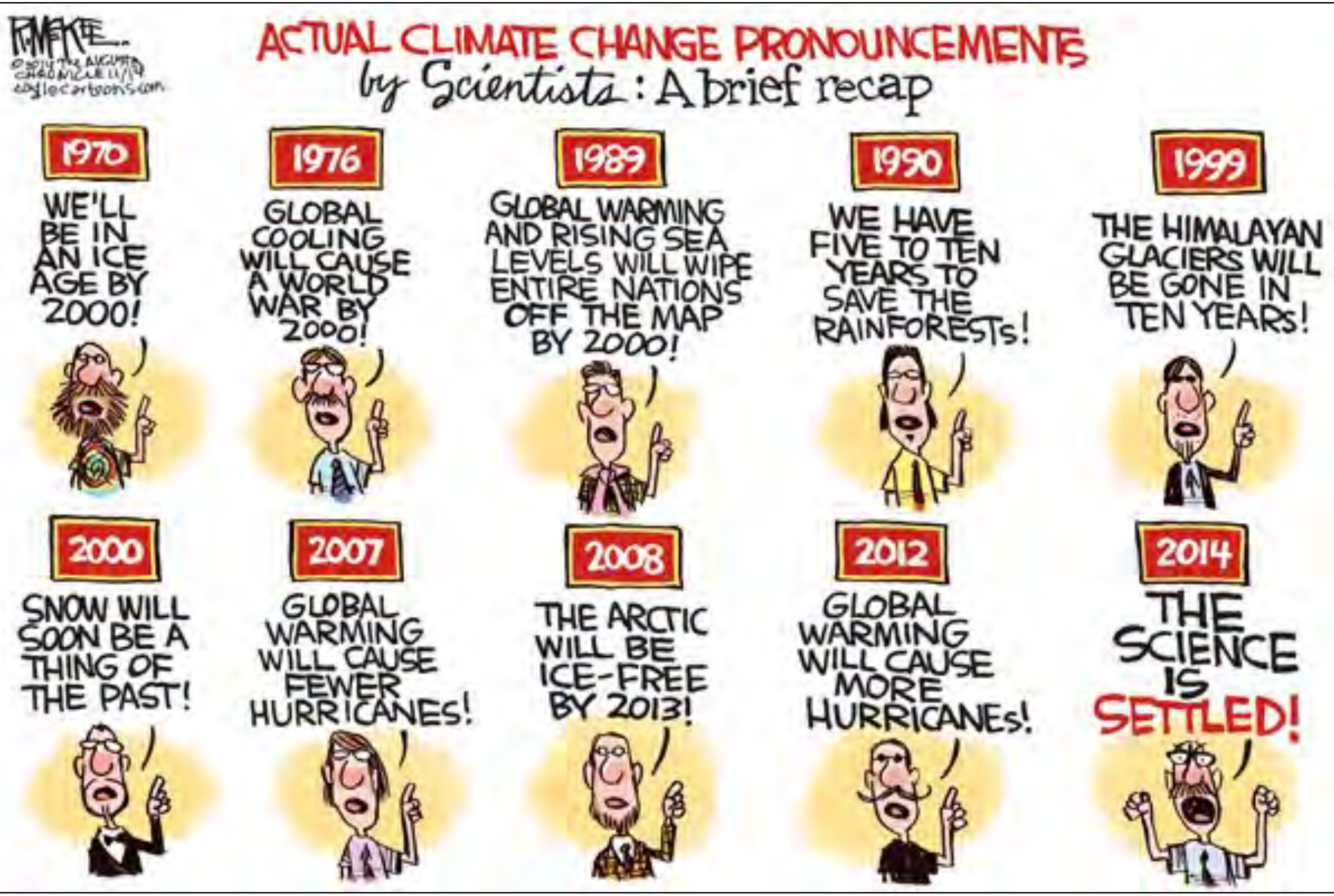
The Agreement sets a goal of keeping warming well below 2 degrees Celsius and for the first time agrees to pursue efforts to limit the increase in temperatures to 1.5 degrees Celsius. It also acknowledges that in order to meet that target, countries should aim to peak greenhouse gas emissions as soon as possible. – *White House Fact Sheet on Paris Agreement*

Implicit assumptions

1. There is an agreed-upon baseline [± <0.5C] against which to judge warming
2. GHG emissions are the sole control knob for warming
3. We know how the climate will respond to GHGs to within 25%
4. Warming of 2C (1.5C) will be net detrimental

As a result, we see

- "Certainty" statements by political figures and science administrators
  - *Kerry:* The science of climate change is leaping out at us like a scene from a 3D movie. It's warning us; it's compelling us to act. **And let there be no doubt in anybody's mind that the science is absolutely certain.** It's something that we understand with absolute assurance of the veracity of that science.
  - *McNutt*: **The time for debate has ended.**
- Most extreme IPCC scenario morphed by media into "business as usual" to exaggerate impacts
- Alarmist predictions that never materialize and are soon forgotten
- Minimization of uncertainties
  - The IPCC AR5 Summary for Policy Makers is discordant with the scientific report


FUNKE
ACTUAL CLIMATE CHANGE PRONOUNCEMENTS
by Scientists: A brief recap
1970
WE'LL BE IN AN ICE AGE BY 2000!
1976
GLOBAL COOLING WILL CAUSE A WORLD WAR BY 2000!
1989
GLOBAL WARMING AND RISING SEA LEVELS WILL WIPE ENTIRE NATIONS OFF THE MAP BY 2000!
1990
WE HAVE FIVE TO TEN YEARS TO SAVE THE RAINFORESTS!
1999
THE HIMALAYAN GLACIERS WILL BE GONE IN TEN YEARS!
2000
SNOW WILL SOON BE A THING OF THE PAST!
2007
GLOBAL WARMING WILL CAUSE FEWER HURRICANES!
2008
THE ARCTIC WILL BE ICE-FREE BY 2013!
2012
GLOBAL WARMING WILL CAUSE MORE HURRICANES!
2014
THE SCIENCE IS SETTLED!

Why a red team?

"On the one hand, as scientists we are ethically bound to the scientific method, in effect promising to tell the truth, the whole truth, and nothing but - which means that we must include all the doubts, the caveats, the ifs, ands, and buts. On the other hand, we are not just scientists but human beings as well. And like most people we'd like to see the world a better place, which in this context translates into **our working to reduce the risk of potentially disastrous climatic change. To do that we need to get some broad-based support, to capture the public's imagination. That, of course, entails getting loads of media coverage. So we have to offer up scary scenarios, make simplified, dramatic statements, and make little mention of any doubts we might have.** This 'double ethical bind' we frequently find ourselves in cannot be solved by any formula. Each of us has to decide what the right balance is between being effective and being honest. I hope that means being both."
– S. Schneider, Stanford, 1996

Why a red team? (II)

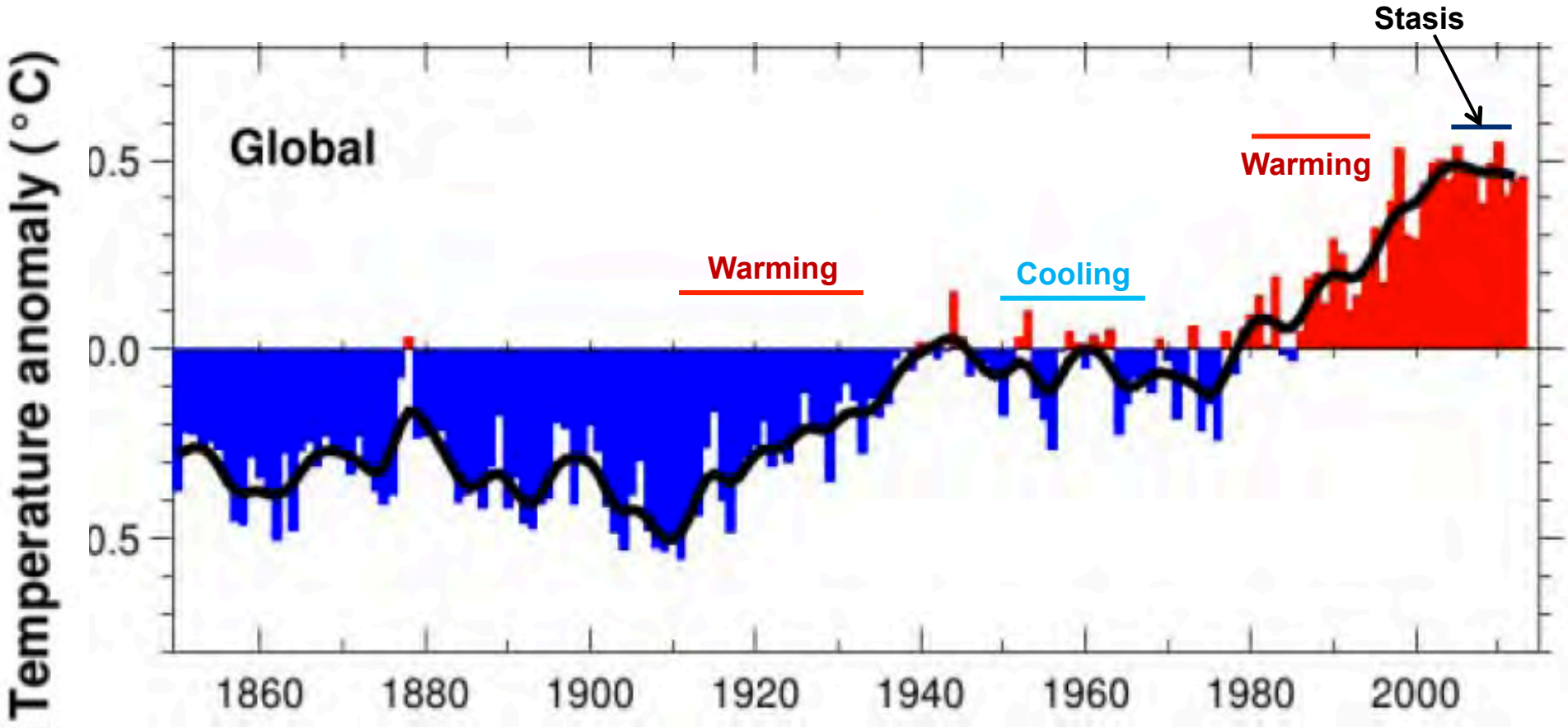
The central problem of climate science is to ask what you do and say when your data are, by almost any standard, inadequate? If I spend three years analyzing my data, and the only defensible inference is that "the data are inadequate to answer the question," how do you publish? **How do you get your grant renewed? A common answer is to distort the calculation of the uncertainty, or ignore it all together, and proclaim an exciting story that the New York Times will pick up**…How many such stories have been withdrawn years later when enough adequate data became available?"

- *C. Wunsch, MIT*

Lack of transparency is a huge political advantage. It was really, really critical to getting the [ACA] passed. [At least one key provision was a] very clever basic **exploitation of the lack of economic understanding** of the American voter.

- *J. Gruber. MIT*

Global surface temperature anomaly



IPCC AR5: *It is **extremely likely** that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by [humans]**. The best estimate of the human induced contribution is similar to the observed warming over this period.***

Models fail to produce historical variation

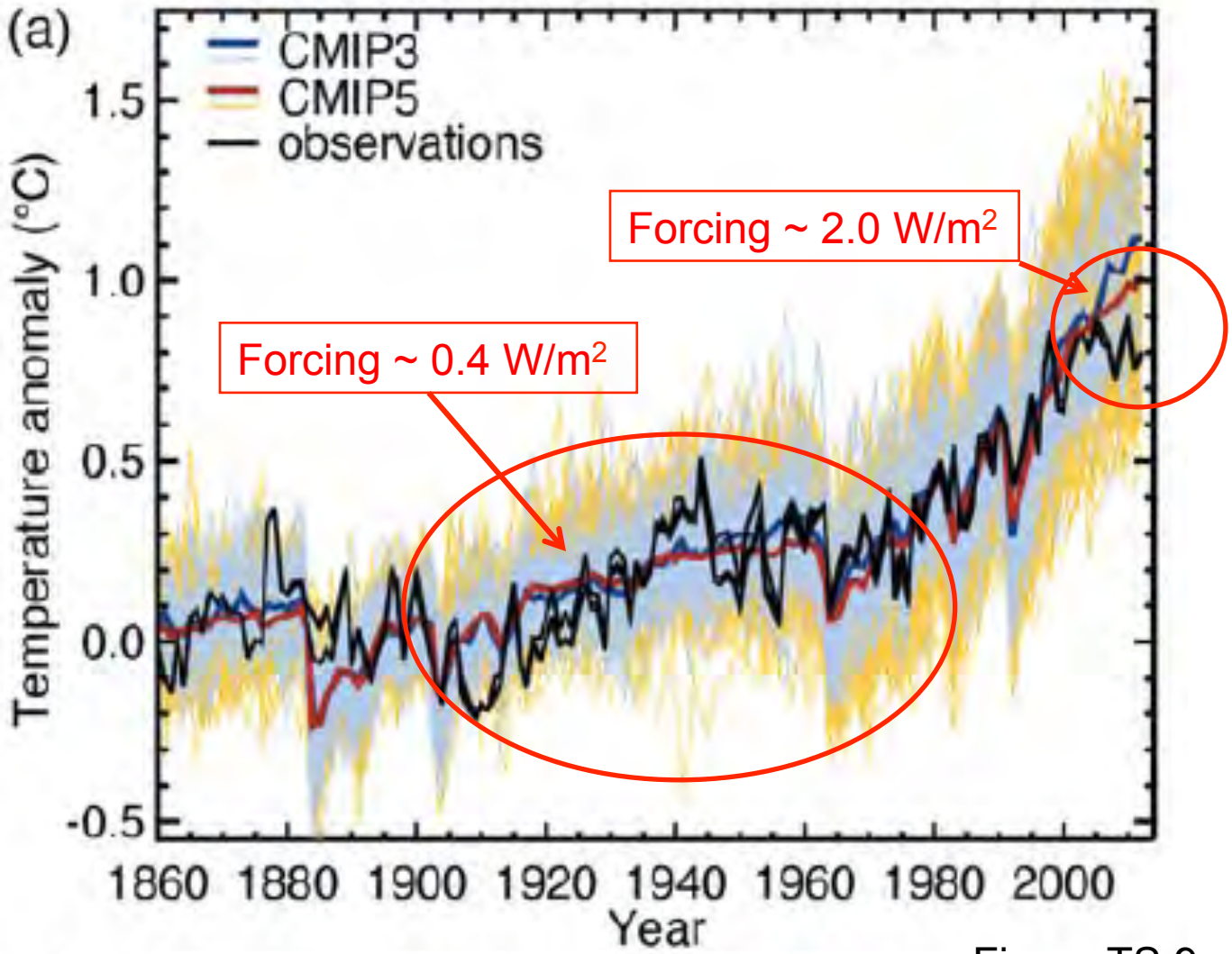
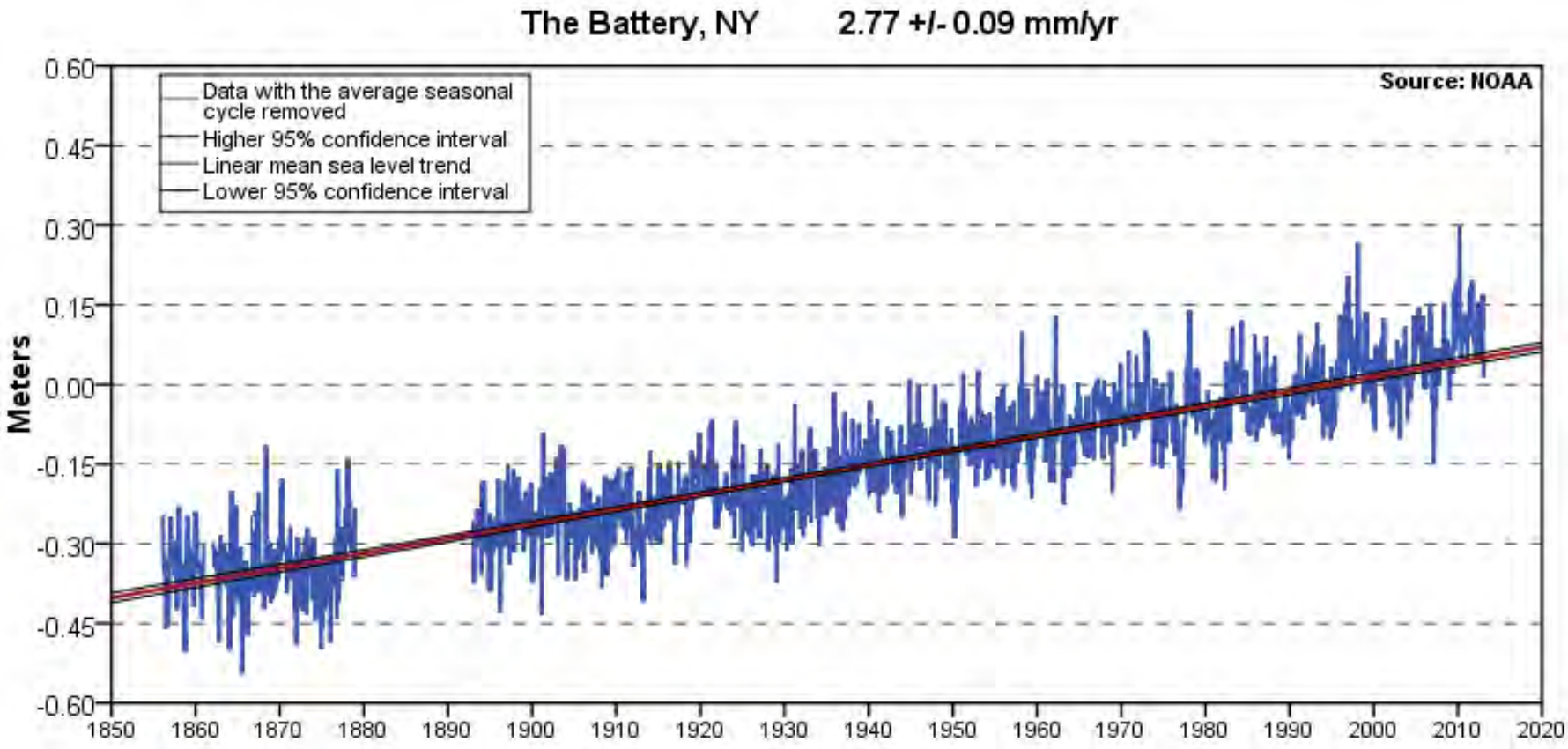
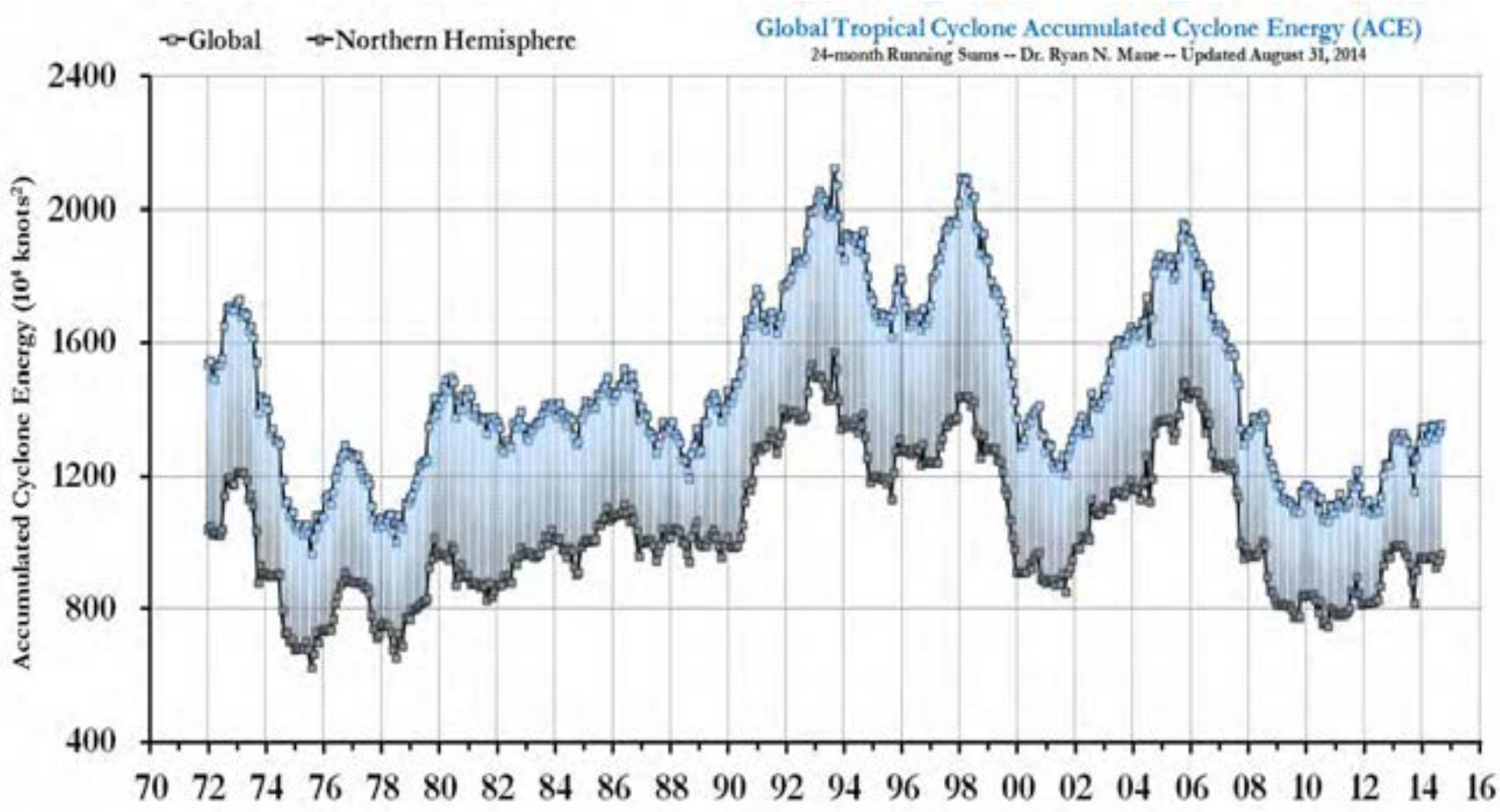


Figure TS.9, pg TS-93

Manhattan Battery sea-level record



No increase in tropical cyclone activity



Comments?/Questions?

Small satellites for earth observations:
http://fas.org/irp/agency/dod/jason/smallsats-full.pdf
High Performance Computing for climate models:
http://fas.org/irp/agency/dod/jason/chammp.pdf
Atmospheric Radiation Measurements:
http://fas.org/irp/agency/dod/jason/arm.pdf
Earthshine observations of the global albedo:
http://www.iac.es/proyecto/earthshine/media/publications/Palle_etal_GRL_2005.pdf
Science biofuels editorial:
http://science.sciencemag.org/content/311/5760/435
GHG Treaty Monitoring study:
http://www.osti.gov/scitech/biblio/1033495/
Energy Innovation:
Accelerating the Pace of Energy Change, with A.M. Gopstein, Issues in Science and Technology, Winter 2011
DOE Quadrennial Technology Review:
http://cms.doe.gov/sites/prod/files/ReportOnTheFirstQTR.pdf
American Physical Society Climate Statement Review:
http://www.aps.org/policy/statements/climate/index.cfm
WSJ OpEd on climate science uncertainties:
http://www.wsj.com/articles/climate-science-is-not-settled-1411143565
NYT OpEd on achieving a zero-emissions world:
http://www.nytimes.com/2015/11/04/opinion/the-tough-realities-of-the-paris-climate-talks.html?ref=opinion