CUMULATIVE EMISSIONS & COSTS FOR ACHIEVING CLIMATE CHANGE TARGETS

ANALYSIS USING EXPLICIT TREATMENT OF CO_2 & NON-CO_2 EMISSIONS BY SECTOR, LIFE CYCLES & RADIATIVE FORCING UNDER UNCERTAINTY

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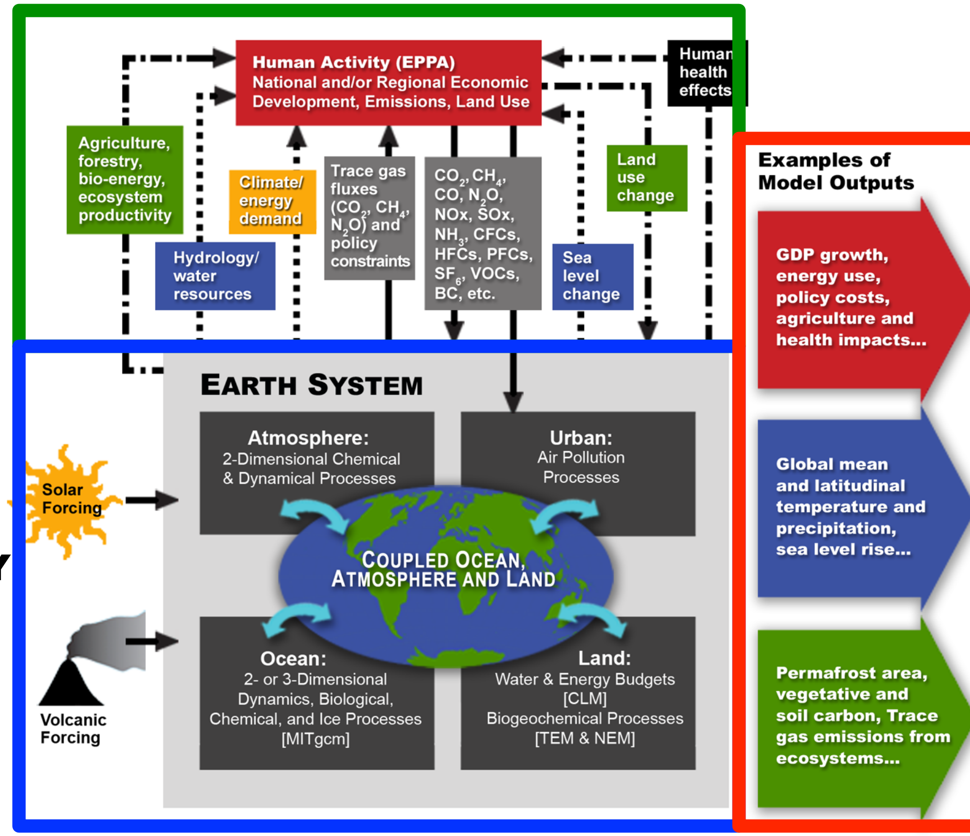
USE MIT INTEGRATED GLOBAL SYSTEM MODEL (IGSM) WITH EMISSION PROJECTION & POLICY ANALYSIS (EPPA) & EARTH SYSTEM MODEL (MESM) COMPONENTS

1. **IGSM RUNS USING IPCC RCP 2.6 EMISSIONS: EFFECTS OF CLIMATE SENSITIVITY & SHORT LIVED CLIMATE FORCERS ON REACHING 2°C TARGET**

2. **IGSM RUNS USING IGSM (EPPA) EMISSIONS: COMBINATIONS OF POLICY (CARBON PRICE) & CLIMATE SENSITIVITY THAT ACHIEVE 2°C TARGET, & POLLUTION CO-BENEFITS**

3. **EVOLUTION OF PRIMARY ENERGY TECHNOLOGIES GLOBALLY & BY NATIONAL GROUPS THAT ACHIEVE 2°C TARGET**



A SIMPLE MODEL FOR THE TRANSIENT RESPONSE OF TEMPERATURE TO CHANGING SOLAR INPUTS AND INFRARED OUTPUTS WITH FEEDBACKS

HEATING = RADIATIVE FORCING = SOLAR INPUT – INFRARED OUTPUT

$$C\frac{dT}{dt} = R = S(1-\omega(T)) - F(M,T)$$

$M(t) =$ mass of greenhouse gas (GHG) in atmosphere $= \int_0^t E(t')\exp(-(t-t')/\tau)\,dt$

$\approx \int_0^t E(t')\,dt$ $\Rightarrow$ equals CUMULATIVE EMISSIONS for long GHG lifetime ($\tau >> t$)

$\approx E(t)\tau$ $\Rightarrow$ proportional to CURRENT EMISSIONS for short GHG lifetime ($\tau << t$)

$T =$ surface air temperature (^{O}C)

$t =$ time (sec)

$C =$ effective heat capacity (atmosphere + ocean + land) (Joule m^{-2} ^{O}C^{-1})

$R =$ "radiative forcing" (Watt m^{-2})

$S =$ average incoming solar flux (Watt m^{-2})

$\omega =$ albedo ($\frac{\partial\omega}{\partial T} < 0$)

$F =$ average outgoing infrared flux (Watt m^{-2}) [$\frac{\partial F}{\partial M} < 0$ and $\frac{\partial F}{\partial T} > 0$]

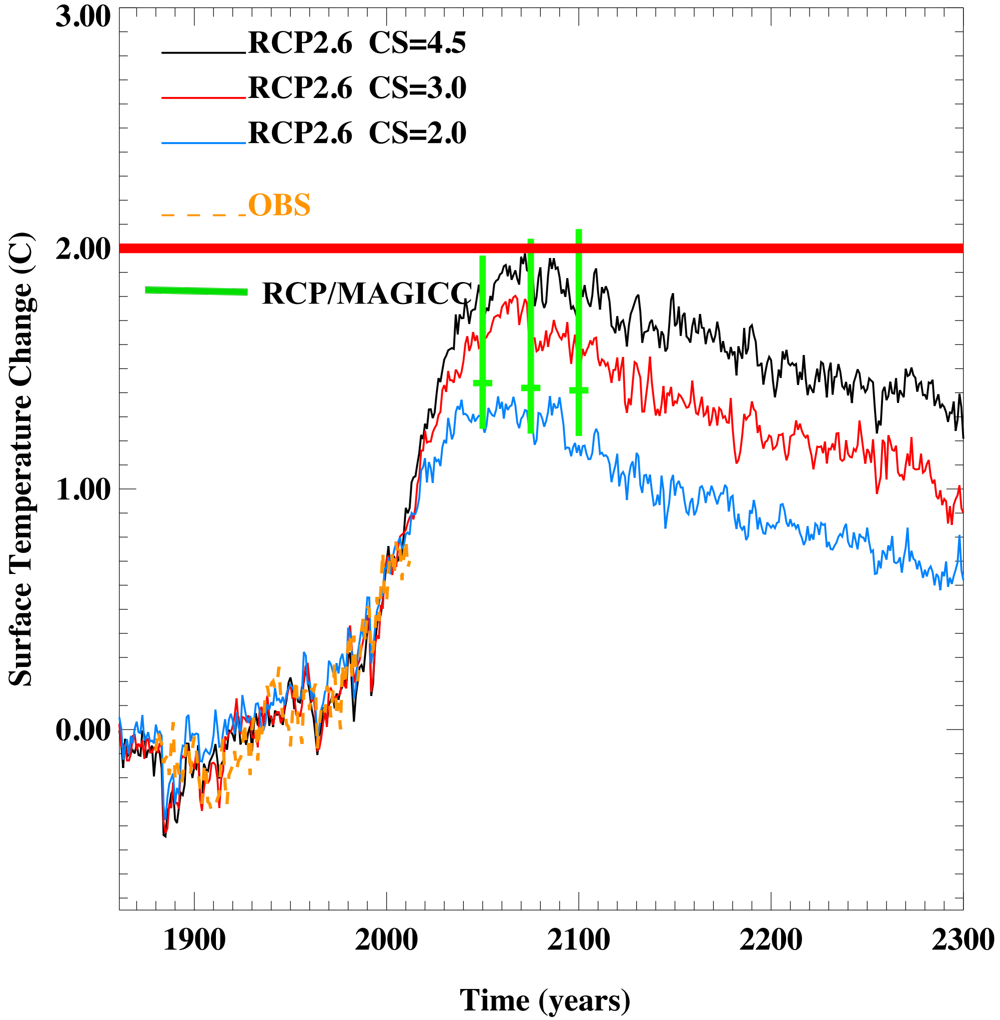
$[\frac{dF}{dT} - \frac{dS}{dT}]^{-1} = -\frac{dT}{dR} =$ "climate sensitivity" (^{O}C Watt^{-1}m^{2} including feedbacks)

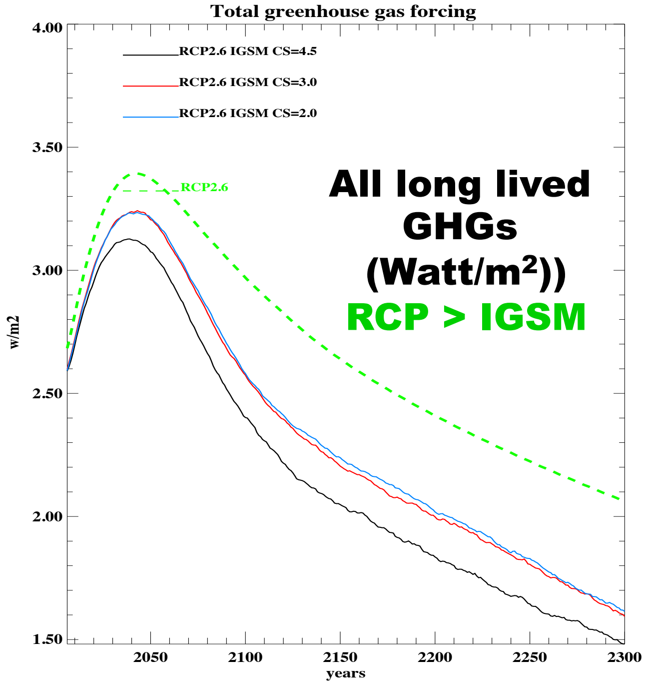
FOR A GIVEN RADIATIVE FORCING, THE AMOUNTS OF SHORT LIVED VERSUS LONG LIVED SPECIES WILL AFFECT THE RESULTS

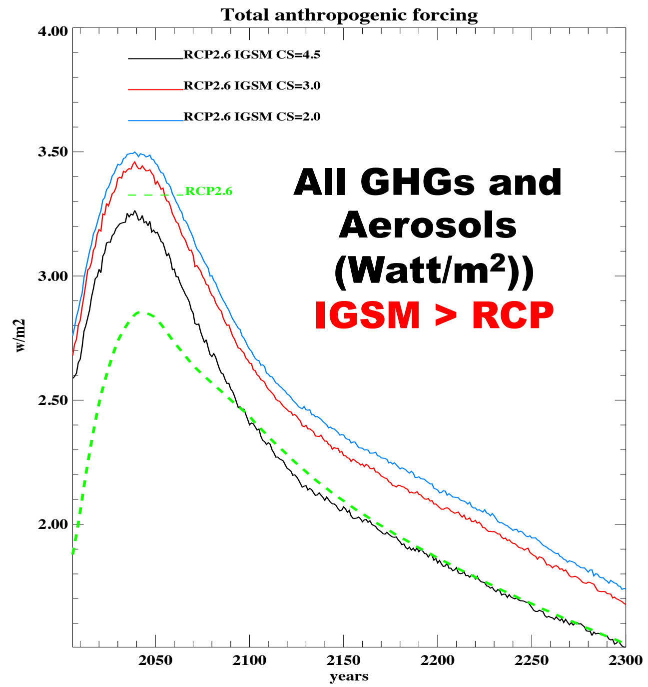
IGSM RUNS USING IPCC RCP 2.6 EMISSIONS

EFFECTS OF CLIMATE SENSITIVITY (2.0, 3.0, 4.5 °C) ON REACHING 2°C TARGET

Temperature & Forcing from 1870 to 2300; IGSM vs RCP2.6/MAGICC (Meinshausen et al, 2011)







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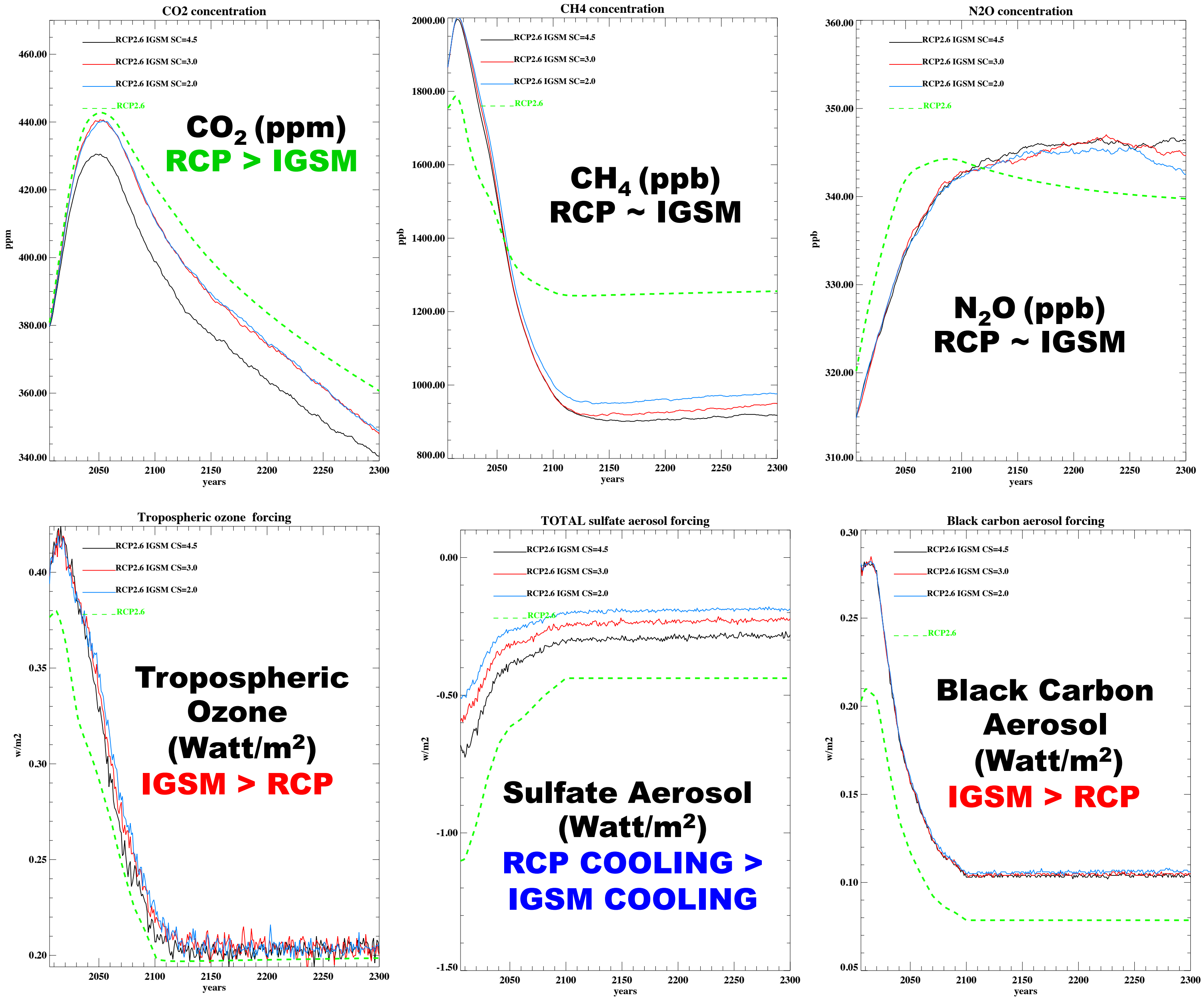
IGSM RUNS USING IPCC RCP 2.6 EMISSIONS: EFFECTS OF CLIMATE SENSITIVITY ON REACHING 2°C TARGET.

Individual GHG and Aerosol Levels: RCP2.6 & IGSM (MESM) Differences



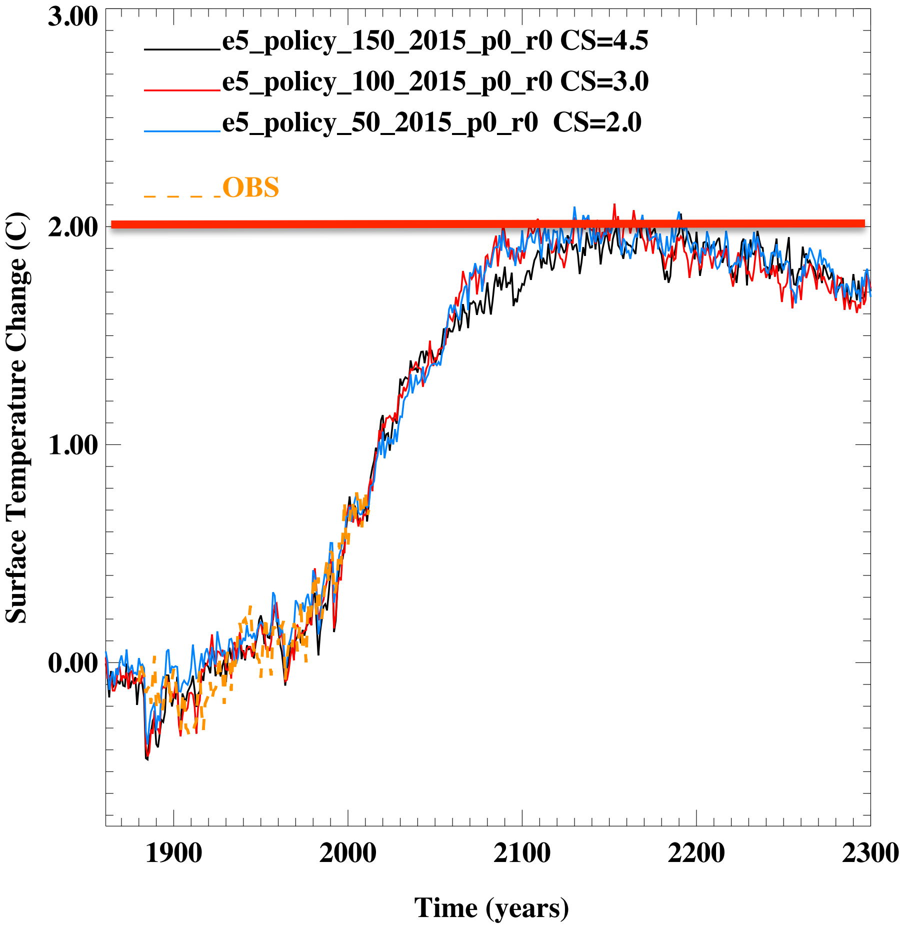
EMISSIONS OF CO_2 & NON-CO_2 SPECIES NEED TO BE CONSISTENT WITH THE TYPE & SCALES OF ENERGY & OTHER TECHNOLOGIES USED TO ACHIEVE A 2° TARGET

IGSM RUNS USING IGSM (EPPA) EMISSIONS*

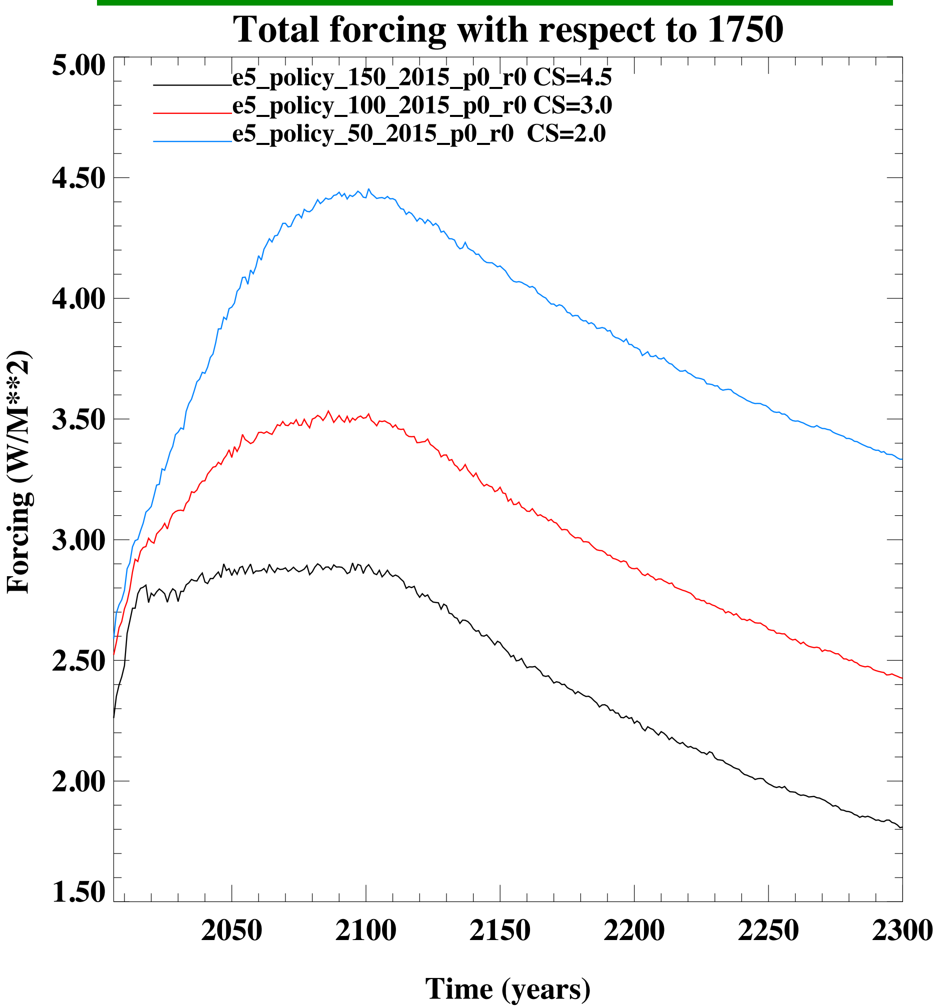
COMBINATIONS OF POLICY (INITIAL CARBON PRICE = 50, 100, 150 US$/ton$CO_2$) & CLIMATE SENSITIVITY (2.0, 3.0, 4.5 ^oC) THAT ACHIEVE 2^{o}C TARGET

*After 2100 all anthropogenic GHG emissions decrease 1%/year

Surface Temperature Change



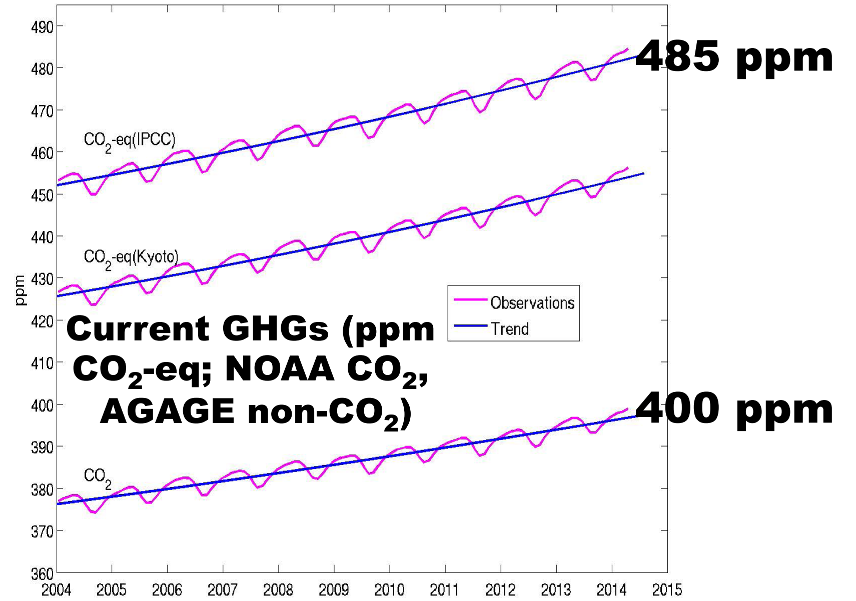
Total Radiative Forcing

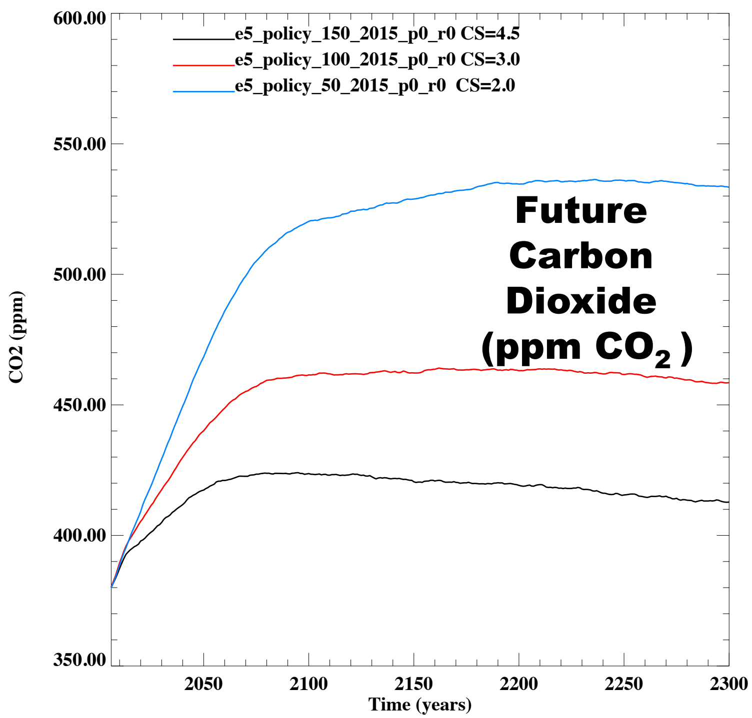


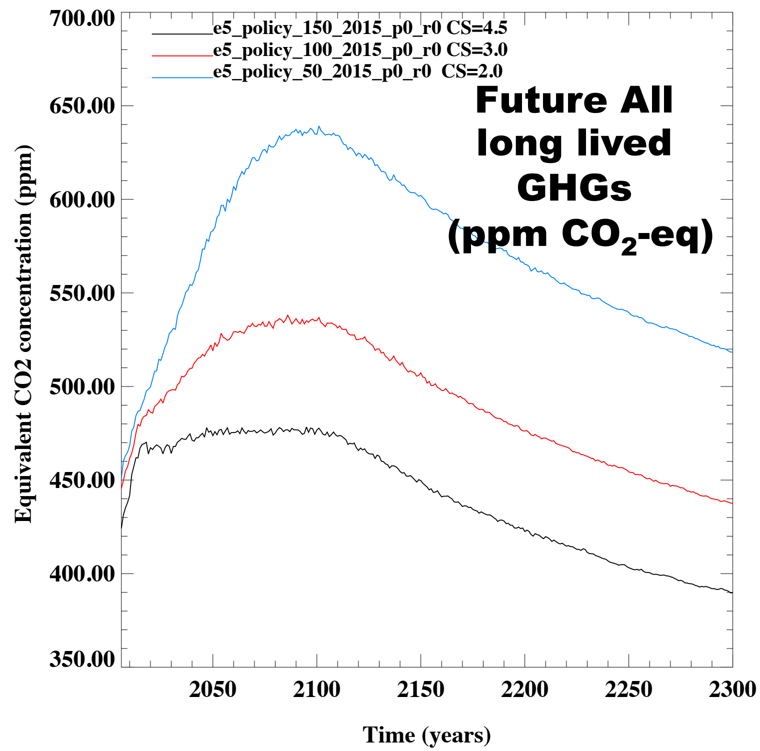
IGSM RUNS USING IGSM (EPPA) EMISSIONS*

COMBINATIONS OF POLICY (CARBON PRICE) & CLIMATE SENSITIVITY THAT ACHIEVE 2°C TARGET

CO_2 and CO_2-equivalent mole fractions

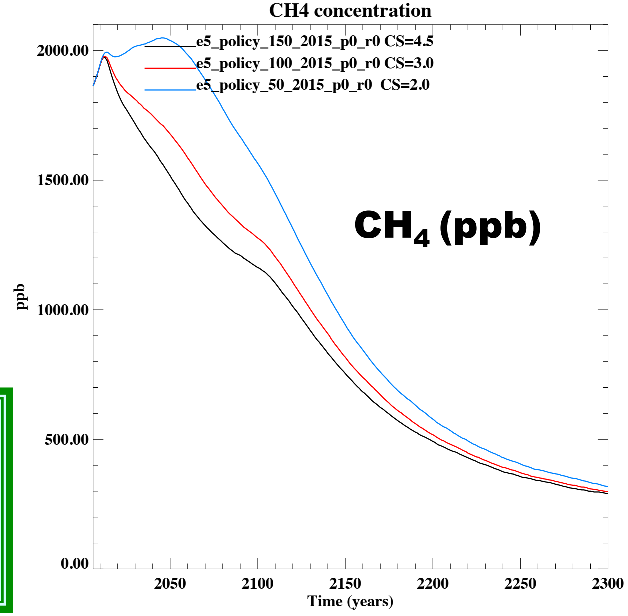


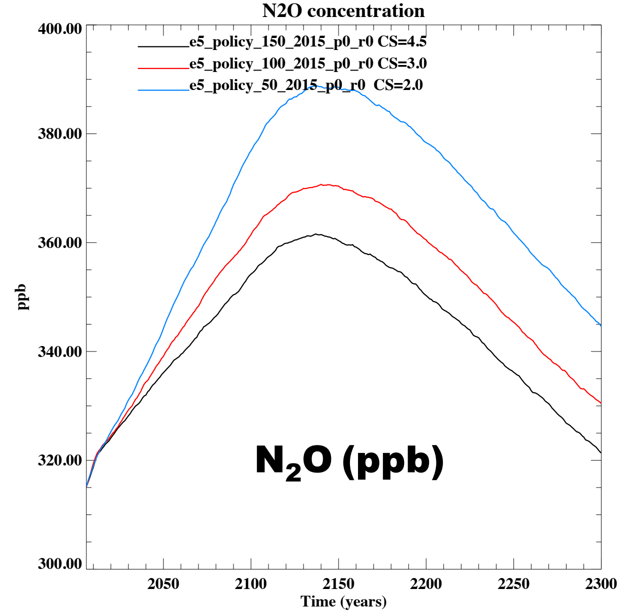


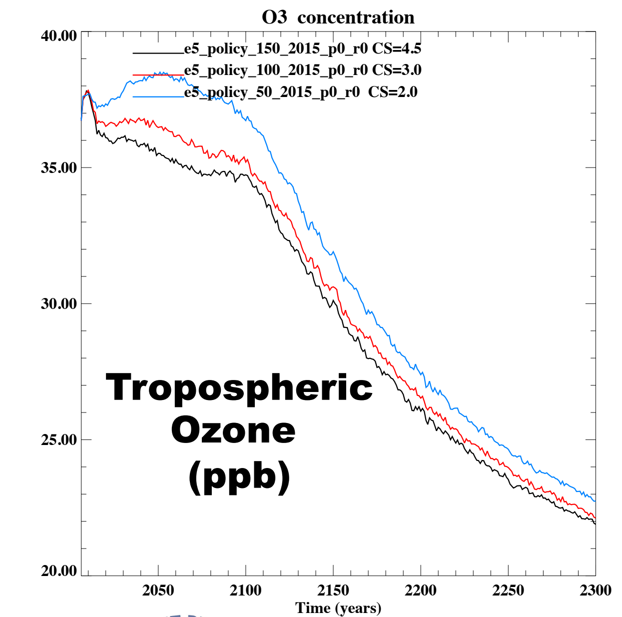


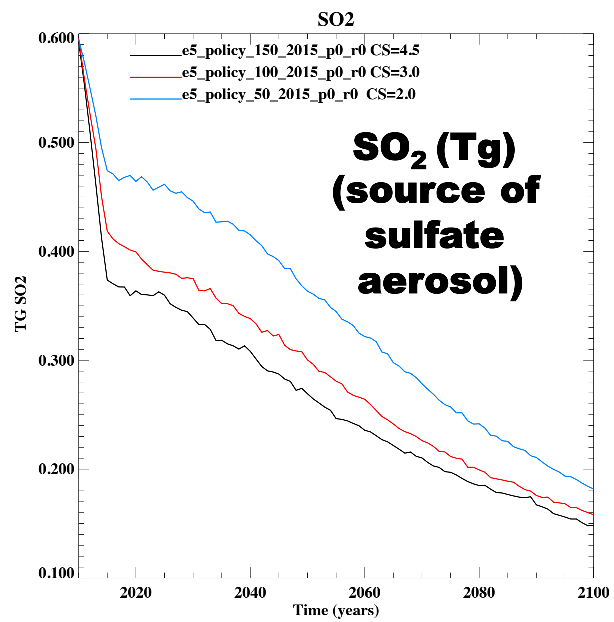
IGSM RUNS USING IGSM (EPPA) EMISSIONS*
COMBINATIONS OF POLICY (CARBON PRICE) & CLIMATE SENSITIVITY THAT ACHIEVE 2°C TARGET

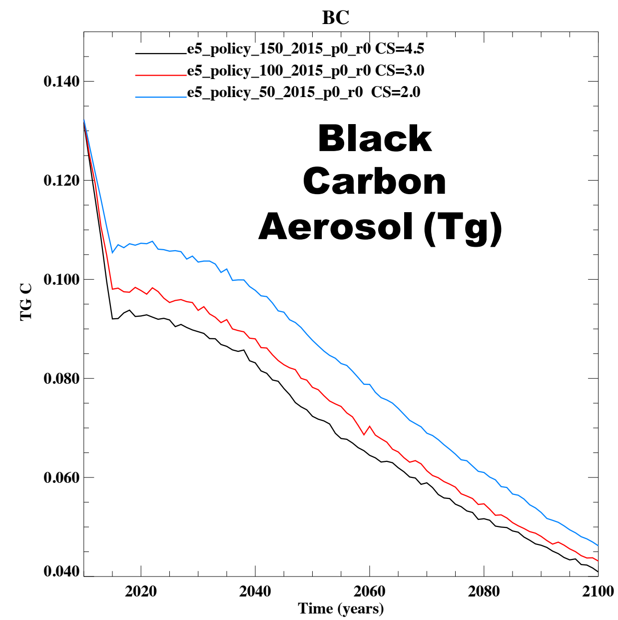
NON-CO_2 GHGs (POLICY REGULATED), O_3 & AEROSOLS: POLLUTION CO-BENEFITS











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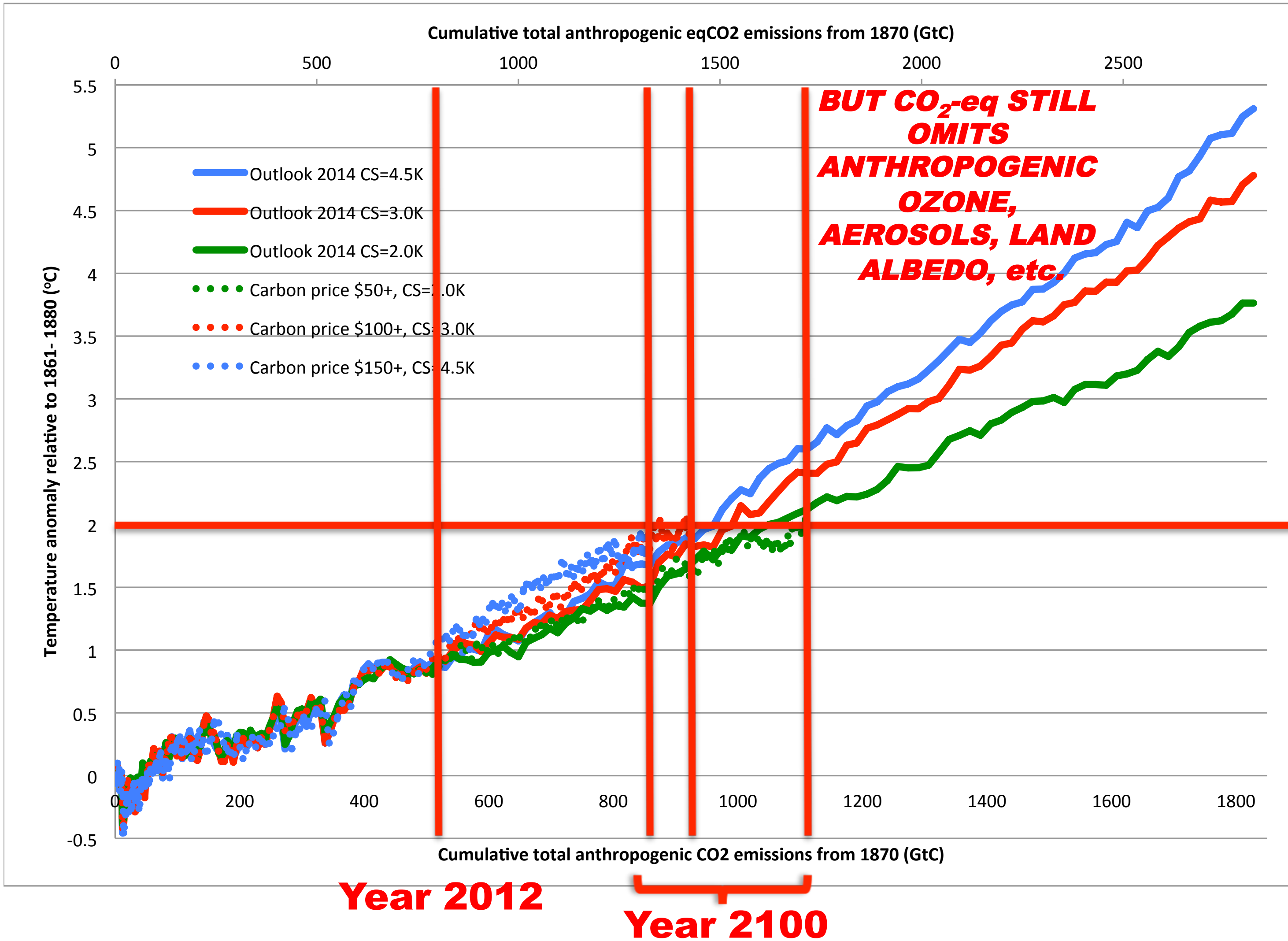
Higher the carbon price, the greater the air pollution reduction, but the lesser the sulfate aerosol cooling.

IGSM RUNS USING IGSM (EPPA) EMISSIONS*

3 COMBINATIONS OF POLICY (CARBON PRICE) & CLIMATE SENSITIVITY (CS) THAT ACHIEVE 2°C TARGET (also Outlook 2014 Copenhagen-Cancun emission & temperature results for same 3 CS values)

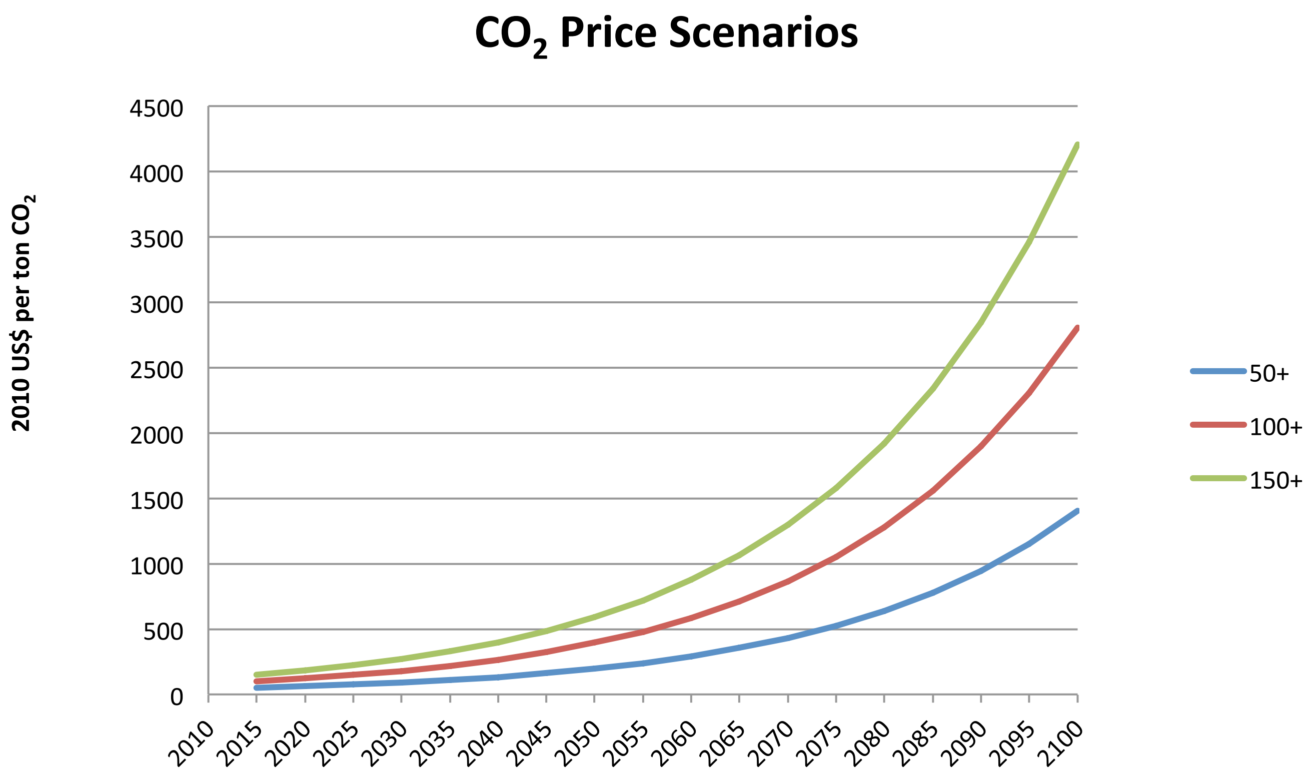
Temperature change since 1870 (1861-1880) versus Cumulative Total CO_2 Emissions (lower axis) and Cumulative Total CO_2 - Equivalent Emissions) (sum of cumulative emissions of each GHG multiplied by its GWP; upper axis).



IGSM RUNS USING IGSM (EPPA) EMISSIONS*

COMBINATIONS OF POLICY (INITIAL CARBON PRICE = 50, 100, 150 US$/ton$CO_2$-eq) & CLIMATE SENSITIVITY (2, 3, 4.5 °C) THAT ACHIEVE 2°C TARGET

Carbon-equivalent price (2010 US$ per ton CO_2-eq) from 2015 to 2100



These policy scenarios require a very unlikely global agreement starting in 2015 involving all nations & an efficient market mechanism (cap & trade or carbon taxes). Actual costs are expected to be greater.

NOTE: EPPA model resolves all major national economies and trade between them, and has detailed energy and non-energy sectoral treatments that makes it more realistic than other models that in general yield lower costs. We can lower costs if we remove some realism from our model (like inter-industry structure, vintaging, international trade specification, etc) or reduce the costs of low-carbon technologies.

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IGSM RUNS USING IGSM (EPPA) EMISSIONS*

COMBINATIONS OF POLICY (INITIAL CARBON PRICE = 50, 100, 150 USA $/ton$CO_2$-eq) & CLIMATE SENSITIVITY (2, 3, 4.5 ^oC) THAT ACHIEVE 2^oC TARGET

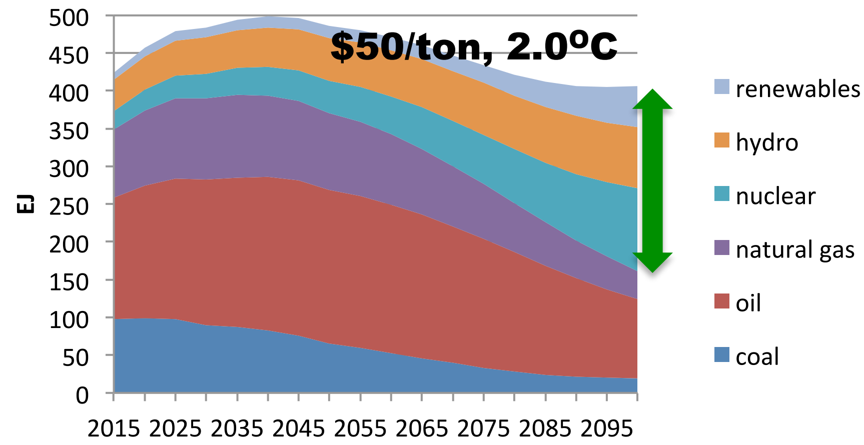
SOME RECENT TRENDS IN THE VIABILITY OF LOW & ZERO EMISSIONS TECHNOLOGIES THAT INFLUENCE OUR RESULTS

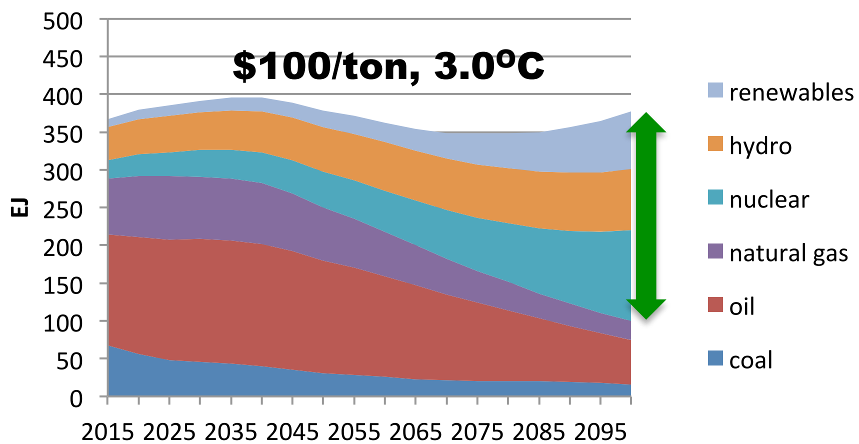
- **After several years of research, estimates of the cost of Carbon Capture & Sequestration (CCS) have risen substantially.**
- **Entry of China and other countries into the Nuclear Power Sector has lowered costs and increased the future viability of Nuclear at least in Developing Countries (see Paltsev, Session 3).**
- **Current & projected costs of solar power (manufacture and installation) have steadily decreased, and to a lesser extent of wind power, but intermittency remains a challenge for both.**
- **Expectations for affordable biofuels (cellulosic in particular) and to a lesser extent biomass electricity have grown.**

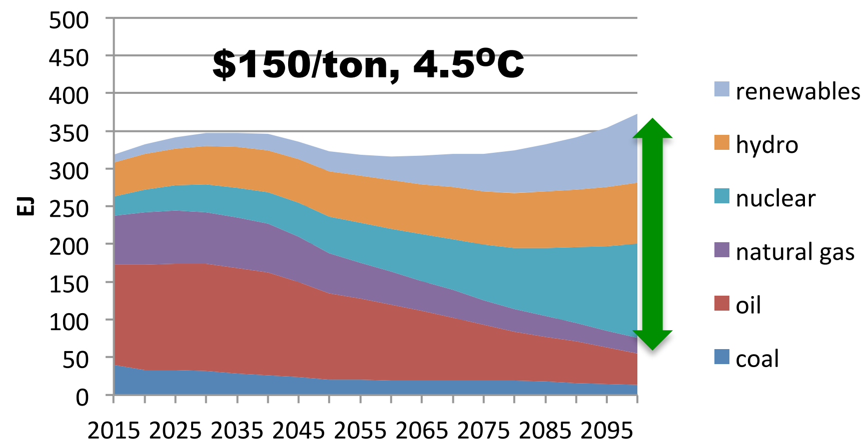
IGSM RUNS USING IGSM (EPPA) EMISSIONS*

COMBINATIONS OF POLICY (INITIAL CARBON PRICE = 50, 100, 150 USA \$/tonCO_2-eq) & CLIMATE SENSITIVITY (2, 3, 4.5 °C) THAT ACHIEVE 2°C TARGET

Global Total Energy Use (Exa-Joules per year) by Production Technology.







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As carbon price rises,* the fraction of energy from low/ zero emission technologies *rises (renewables [wind, solar, biofuel], hydro, nuclear) relative to fossil.

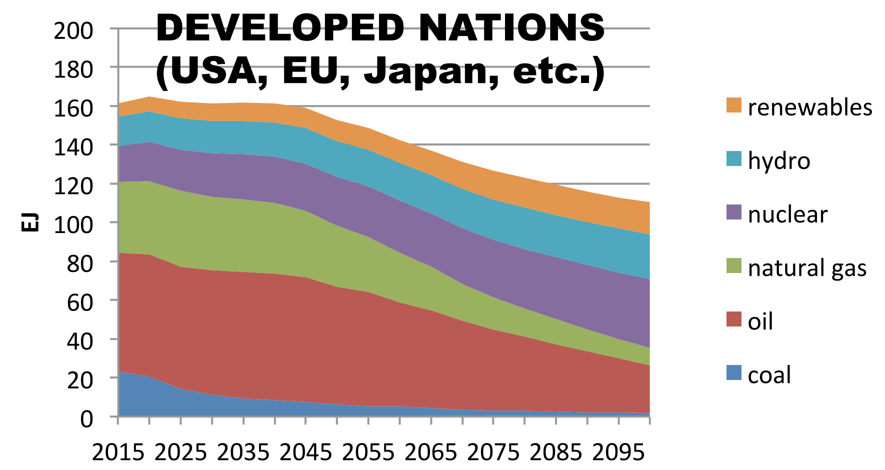
As carbon price increases,* the energy use *decreases due to higher energy efficiency.

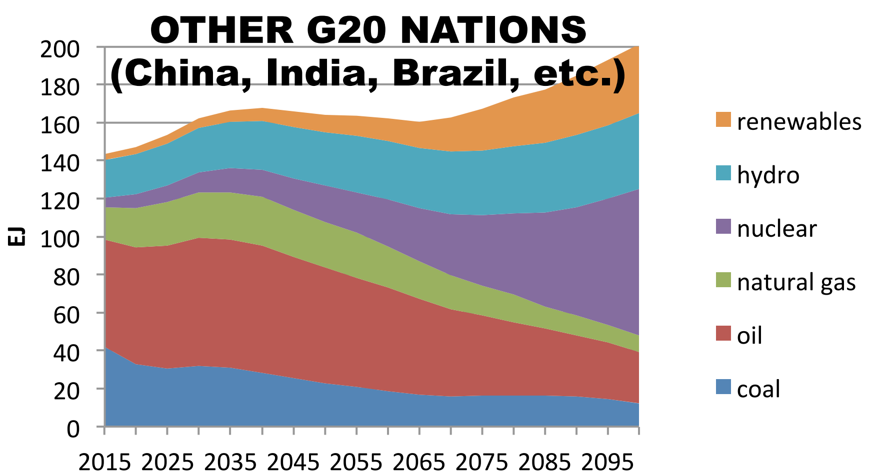
***CCS use on coal and natural gas electricity* is limited due to high cost.**

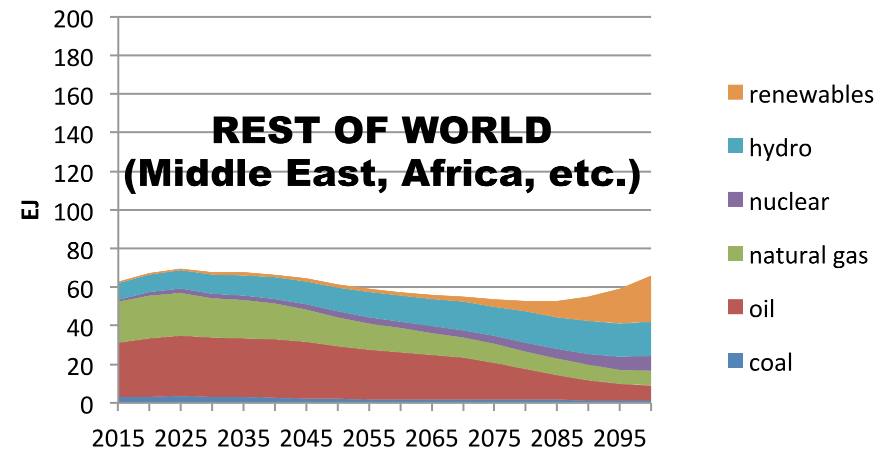
IGSM RUNS USING IGSM (EPPA) EMISSIONS*

COMBINATIONS OF POLICY (INITIAL CARBON PRICE = 50, 100, 150 USA \$/tonCO_2-eq) & CLIMATE SENSITIVITY (2, 3, 4.5 °C) THAT ACHIEVE 2°C TARGET

Total Energy Use (EJ/year) by Production Technology & National Grouping for \$100/ton/3°C case.







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As carbon price rises, the fraction of energy from low/zero emission technologies rises in all National Groups.

As carbon price increases, the energy use decreases in Developed Nations but increases in other G20. Rest of World mixed.

Industrialization & population growth drive increases in non-developed nation energy.

CONCLUDING REMARKS

- Restricting cumulative emissions to levels that allow 50% chance of keeping future global average surface temperatures less than 2°C above 1870 values is feasible, but the technological, economic and political challenges are potentially insurmountable.
- Developing affordable technologies for carbon capture and sequestration (CCS) would help meet these challenges, and also provide a "safety valve" allowing large scale biomass electric power generation with CCS to create a gigatons-level carbon sink.
- Economic and political barriers motivate adoption of national & global policies that use market mechanisms to minimize costs and revenue neutrality to gain acceptance .
- Achieving the 2°C target has significant air pollution reduction co-benefits.
- The many difficulties in achieving the 2°C target argue for substantial efforts in adaptation in concert with mitigation.

THANK YOU.

FOR MORE INFORMATION ON THE GLOBAL CHANGE JOINT PROGRAM SEE: http://globalchange.mit.edu/