Modeling Uncertainty Group:
a sensitivity experiment with GCAM

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Agenda

► GCAM: The Global Change Assessment Model

► Model Results

- Population
- GDP
- Primary Energy
- Carbon Dioxide Emissions
- Carbon Dioxide Concentration
- Total Forcing
- Temperature
- Sea Level Rise

► Concluding Thoughts

GCAM:
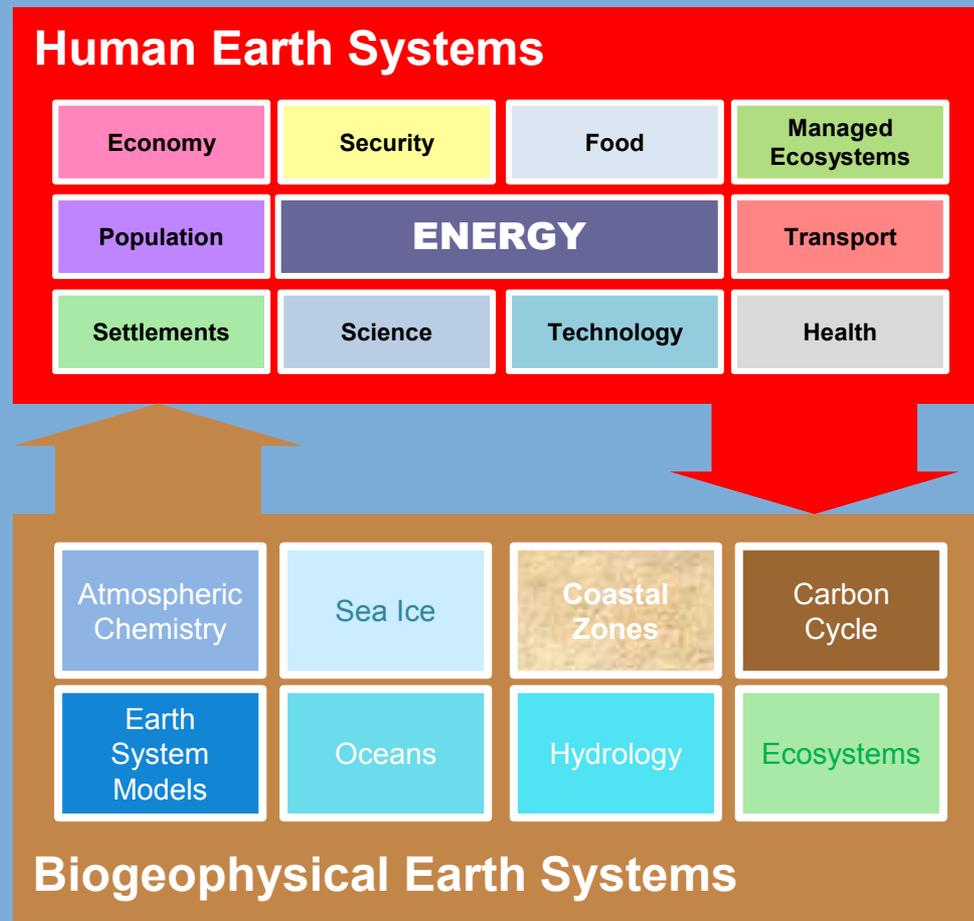# The Global Change Assessment Model

Integrated Assessment Models (IAMs)

IAMs integrate human and Earth system science.

▶ IAMs provide insights that would be otherwise unavailable from disciplinary research.

▶ IAMs capture interactions between complex and highly nonlinear systems.

▶ IAMs provide Earth system science researchers with information about human systems such as GHG emissions, land use and land cover.

IAMs provide important, science-based decision support tools.

▶ IAMs support national, international, regional, and private-sector decisions.

Human Earth Systems

Economy	Security	Food	Managed Ecosystems
Population	ENERGY		Transport
Settlements	Science	Technology	Health

| Atmospheric Chemistry | Sea Ice | Coastal Zones | Carbon Cycle |
| Earth System Models | Oceans | Hydrology | Ecosystems |

Biogeophysical Earth Systems

GCAM:
The Global Change Assessment Model

14 Region Energy/Economy Model Regions

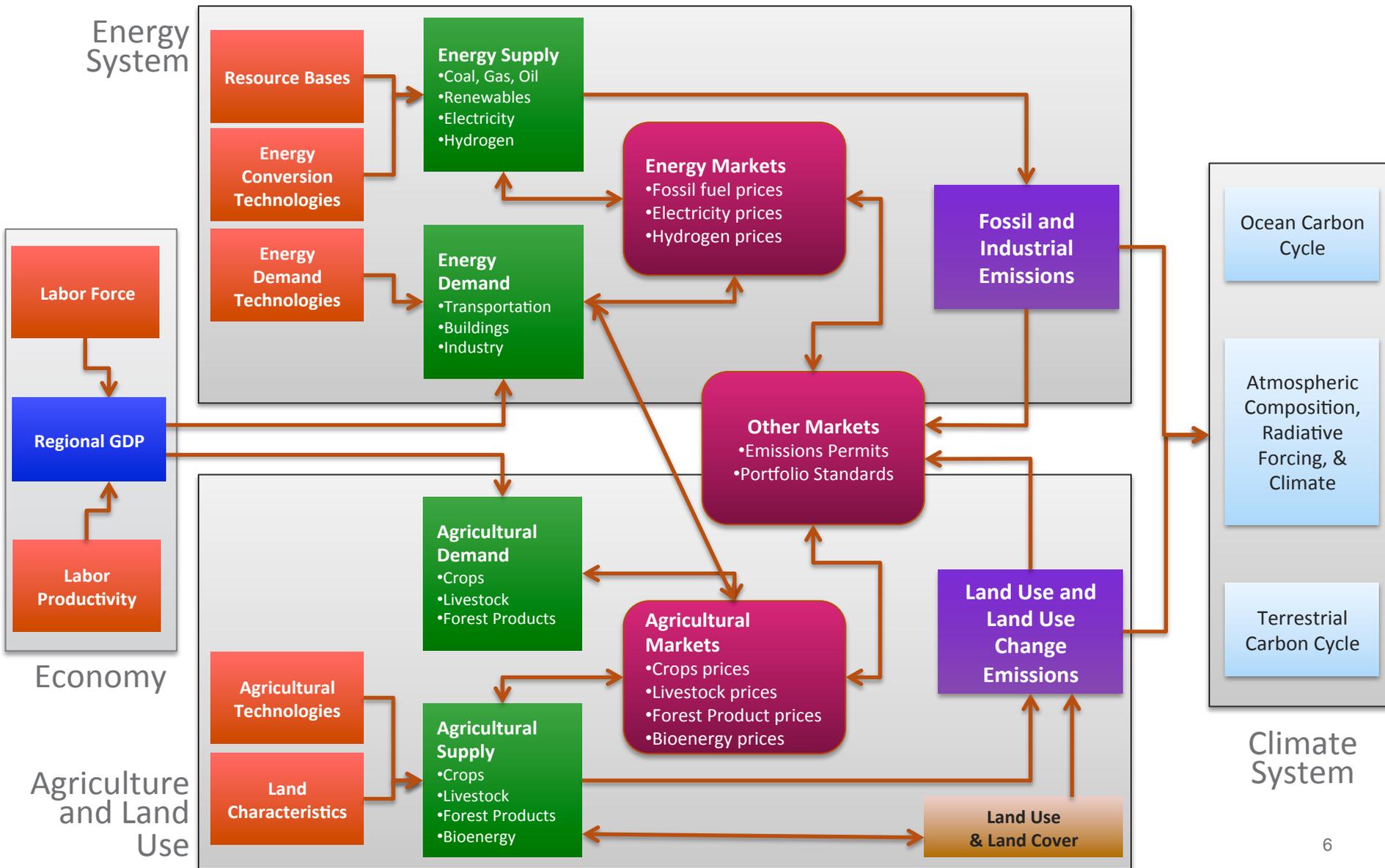**151 Agriculture and Land Use Model Regions**

The GCAM 3.0 Agriculture and Land Use Regions
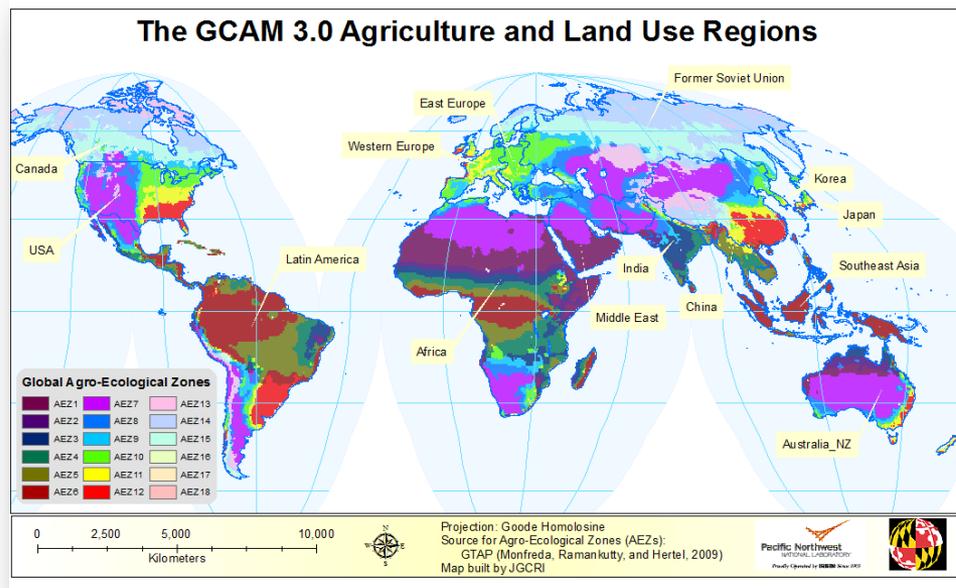
- GCAM is a **global integrated assessment model**

- GCAM links **Economic, Energy, Land-use,** and **Climate** systems

- Emissions of **16 greenhouse gases and short-lived species:** CO_2, CH_4, N_2O, halocarbons, carbonaceous aerosols, reactive gases, sulfur dioxide.

- Runs through **2095** in **5-year time-steps.**

- GCAM is implemented using **object-oriented programming**, providing a robust and flexible platform for future work.

- Documentation available at: **wiki.umd.edu/gcam**

- Started in 1978 – a DOE-SC investment to address the need for an explicit research tool to assess the link between human energy systems and carbon emissions (part of the Carbon Cycle Program back then).

- 1984 first integration of GCAM (then called Edmonds-Reilly) with the DOE carbon cycle model.

- Formerly known as MiniCAM

Overview of Human Systems in GCAM

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

Energy System

Resource Bases

Energy Conversion Technologies

Energy Demand Technologies

Energy Supply
- Coal, Gas, Oil
- Renewables
- Electricity
- Hydrogen

Energy Demand
- Transportation
- Buildings
- Industry

Energy Markets
- Fossil fuel prices
- Electricity prices
- Hydrogen prices

Fossil and Industrial Emissions

Other Markets
- Emissions Permits
- Portfolio Standards

Economy

Labor Force

Regional GDP

Labor Productivity

Agriculture and Land Use

Agricultural Demand
- Crops
- Livestock
- Forest Products

Agricultural Technologies

Land Characteristics

Agricultural Supply
- Crops
- Livestock
- Forest Products
- Bioenergy

Agricultural Markets
- Crops prices
- Livestock prices
- Forest Product prices
- Bioenergy prices

Land Use and Land Use Change Emissions

Land Use & Land Cover

Climate System

Ocean Carbon Cycle

Atmospheric Composition, Radiative Forcing, & Climate

Terrestrial Carbon Cycle

6

What is a large number of runs?

Commodity Cluster Solution, Integrated by PNNL and UM

Compute

284 compute nodes
- Dual Quad/Hex-core Intel 2.8 Ghz
- 48GB per node
2512 Cores: ~28 TFLOPS
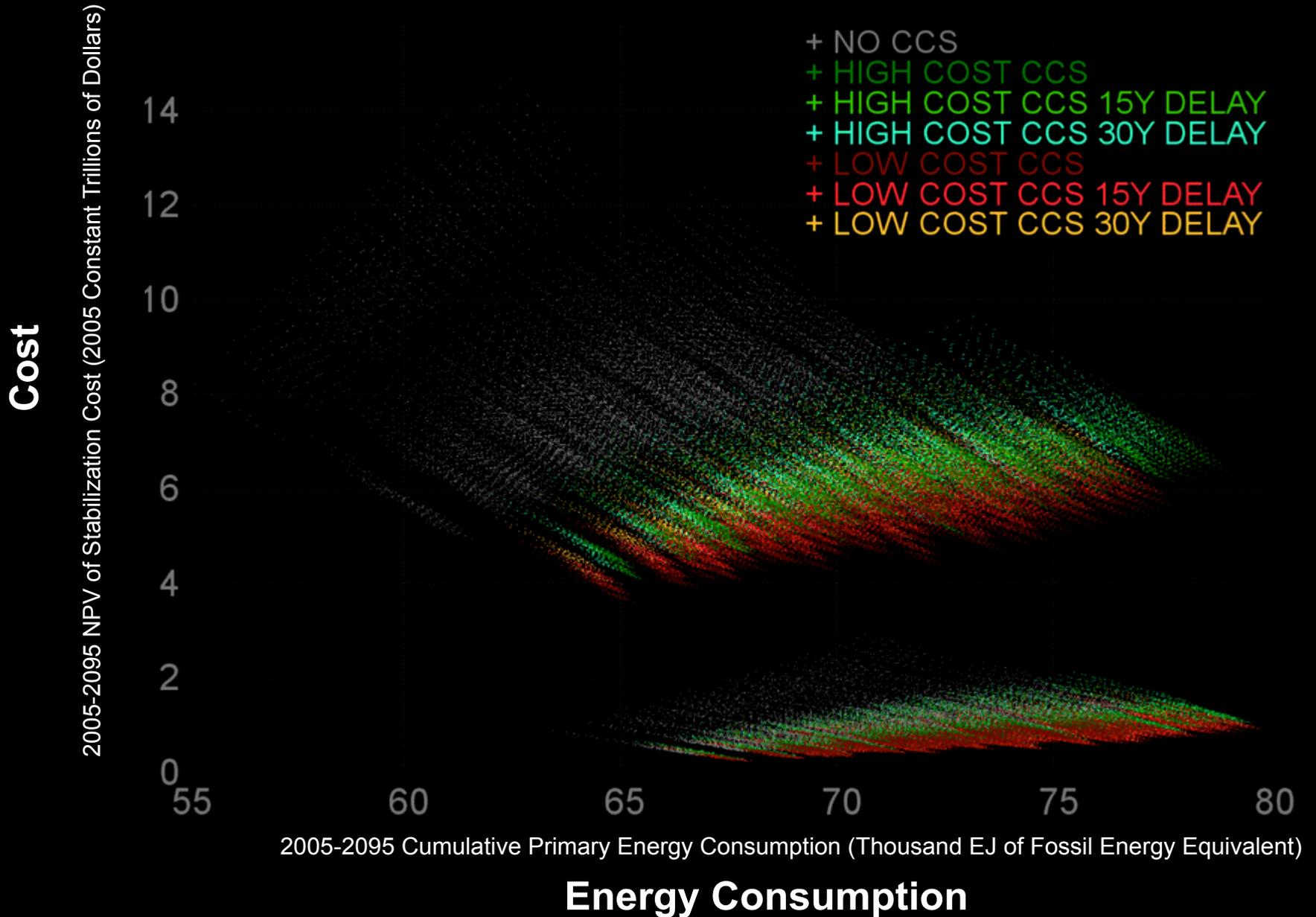
Storage

1.4 Petabytes
- Lustre
- 20GB/second

AEON COMPUTING

Network
Voltaire QDR (40 gigabit) InfiniBand

The Evergreen facility provides a platform for large ensemble analyses, including analysis using higher-resolution models like GCAM.

Model Results

How did we implement the sensitivities

Pacific Northwest
NATIONAL LABORATORY

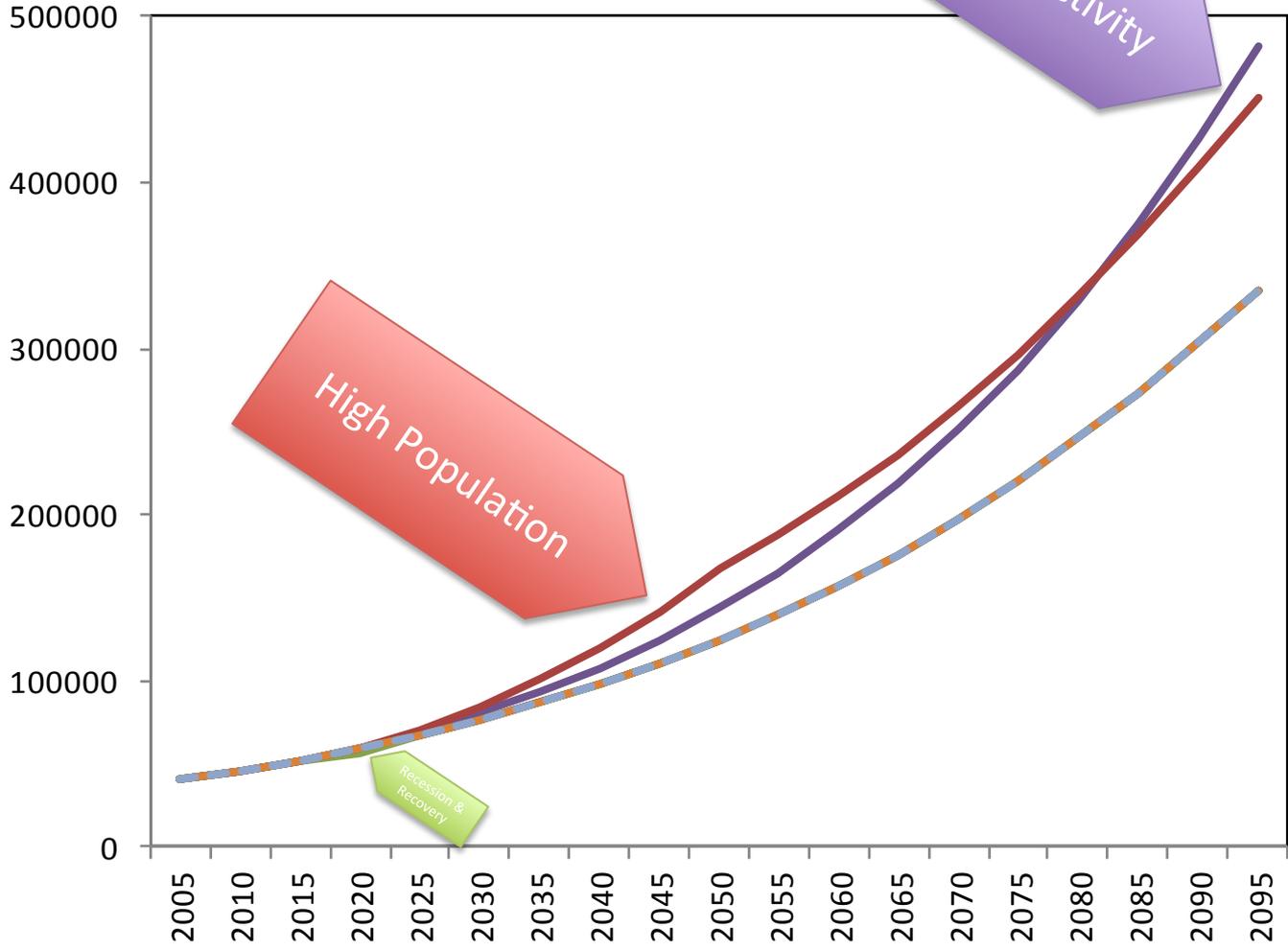*Proudly Operated by* **Battelle** *Since 1965*

► Add an emissions pulse of 10 Gt of CO_2 in 2020 (treat as non-industrial sources) followed by a return to the trend.

► Reduce world output by a one-time pulse of 5% of world GDP in 2020 uniform across regions followed by a return to the trend. Consider this a one-time productivity shock.

► Increase world GDP growth rate by 0.5 % per year 2020-2100 (from productivity growth, not population growth) uniform across regions. Return to the previous trend afterwards.

► Change climate sensitivity by +1 °C (equilibrium °C per CO_2 doubling)

► Increase population growth by 1 % per year from 2020 to 2050 uniform across regions. Return to previous trend afterwards.

► Place a carbon tax on all CO_2 emissions (only CO_2 , do not tax non-CO_2 sources) following the AM3ND1 scenario used for AMPERE (listed at bottom). This is included for comparison purposes.

Primary Energy

Legend:
- **Reference** (black solid line)
- **GDP_Shock_Sc** (green line)
- **GDP_increase_Sc** (purple line)
- **Population_Increase_Sc** (dark red line)
- **Climate_Sensitivity_Increase_Sc** (teal line)
- **Carbon_Tax_Sc** (orange line)
- **Emission Pulse** (dashed light blue line)

Y-axis: PE in EJ (0 to 2000)
X-axis: 2005 to 2095

Annotations: High Population, High Productivity, Carbon Tax, Recession & Recovery

Final Energy

FE in EJ

Legend:
- Reference
- GDP_Shock_Sc
- GDP_increase_Sc
- Population_Increase_Sc
- Climate_Sensitivity_Increase_Sc
- Carbon_Tax_Sc
- Emission Pulse

Carbon Dioxide Emissions

Emissions in MTC

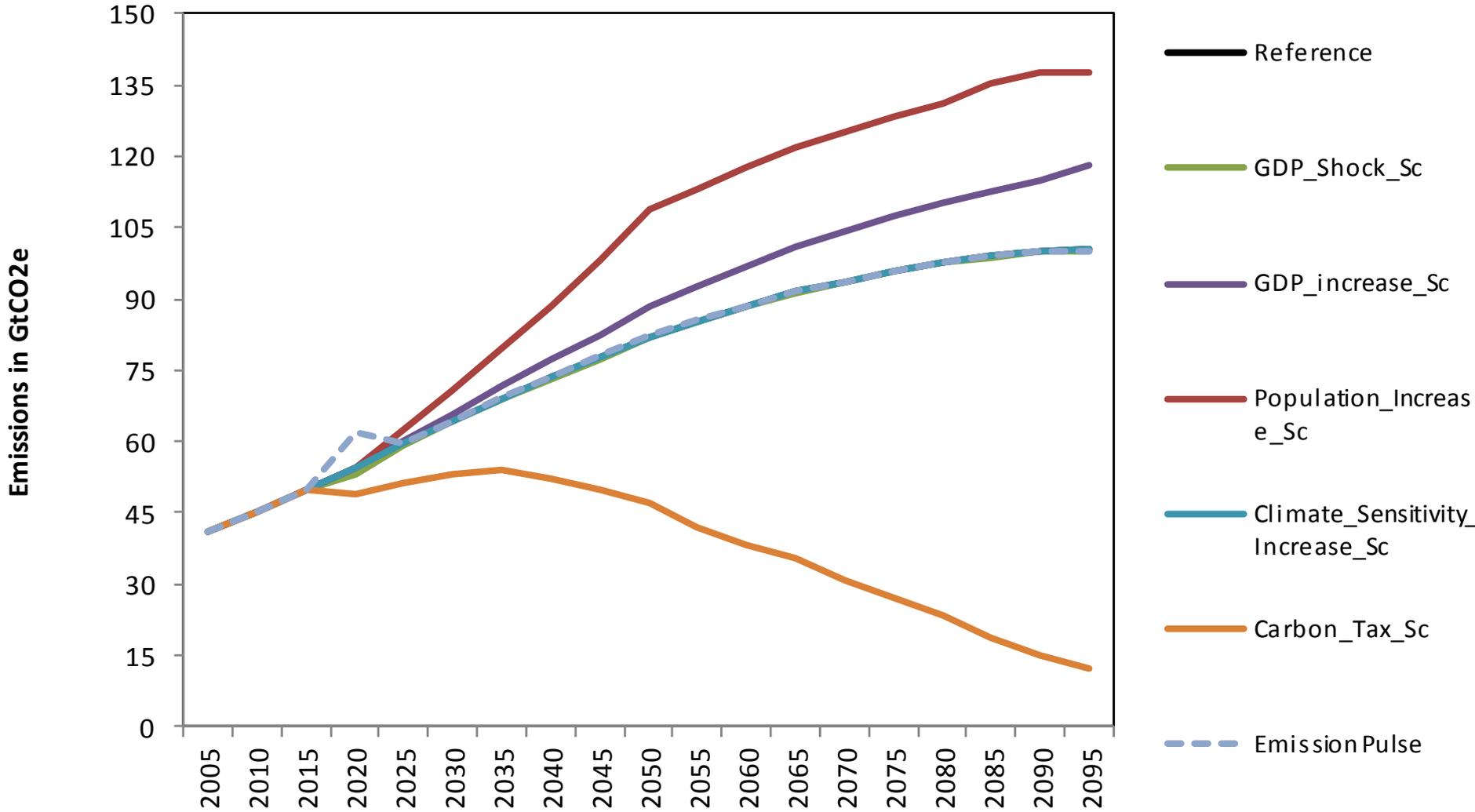Legend:
- Reference
- GDP_Shock_Sc
- GDP_increase_Sc
- Population_Increase_Sc
- Climate_Sensitivity_Increase_Sc
- Carbon_Tax_Sc
- Emission Pulse

Labels on chart: Emission Pulse, High Population, High Productivity, Recession & Recovery, Carbon Tax

X-axis years: 2005, 2010, 2015, 2020, 2025, 2030, 2035, 2040, 2045, 2050, 2055, 2060, 2065, 2070, 2075, 2080, 2085, 2090, 2095

Y-axis: 35000, 31500, 28000, 17500, 14000, 10500, 7000, 3500, 0, -3500
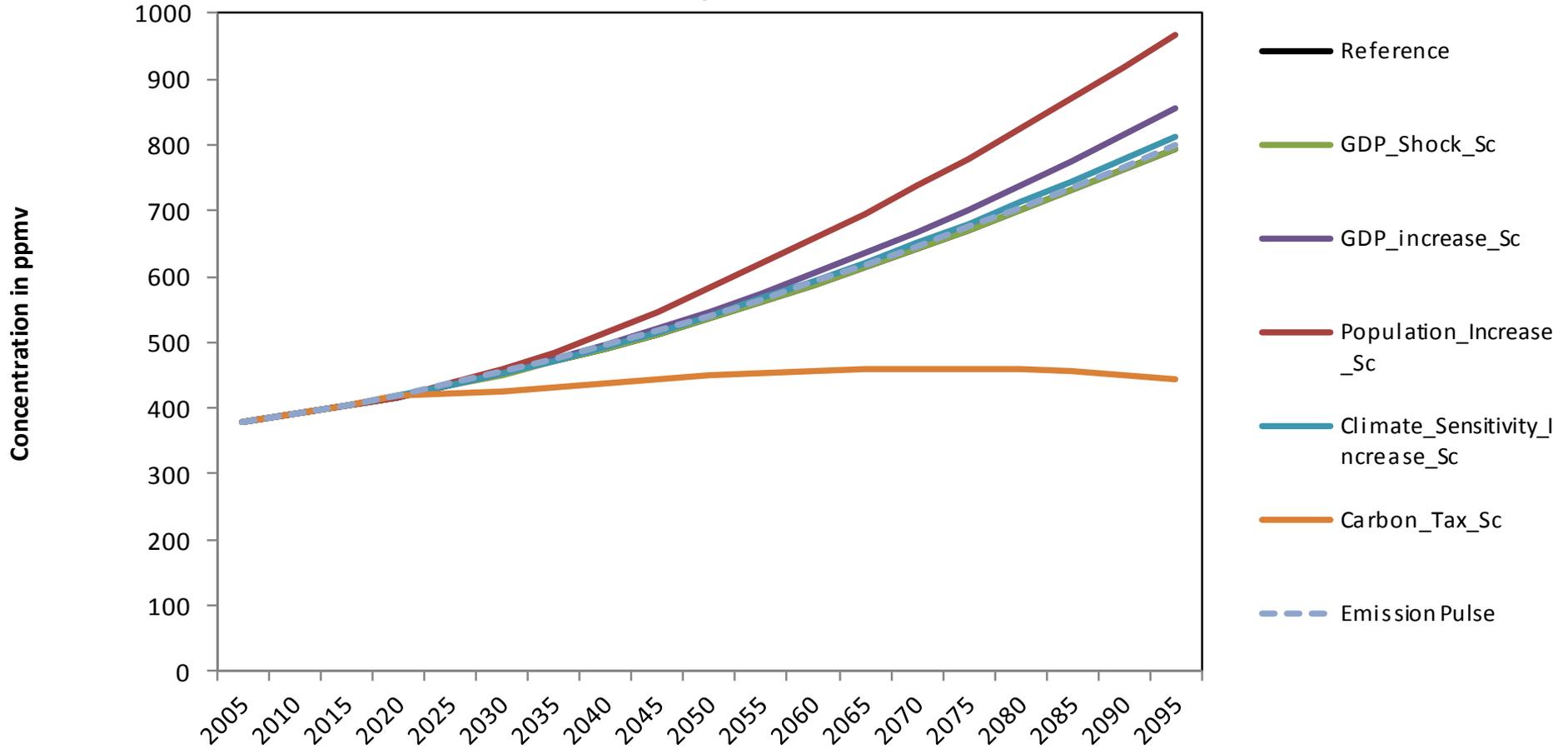
CO2 Equivalent Emissions

Legend:
- Reference
- GDP_Shock_Sc
- GDP_increase_Sc
- Population_Increase_Sc
- Climate_Sensitivity_Increase_Sc
- Carbon_Tax_Sc
- Emission Pulse

Y-axis: Emissions in GtCO2e (0, 15, 30, 45, 60, 75, 90, 105, 120, 135, 150)

X-axis: 2005, 2010, 2015, 2020, 2025, 2030, 2035, 2040, 2045, 2050, 2055, 2060, 2065, 2070, 2075, 2080, 2085, 2090, 2095

Carbon Dioxide Concentration

Carbon Dioxide Equiv Concentration

Concentration in ppmv

Legend:
- Reference
- GDP_Shock_Sc
- GDP_increase_Sc
- Population_Increase_Sc
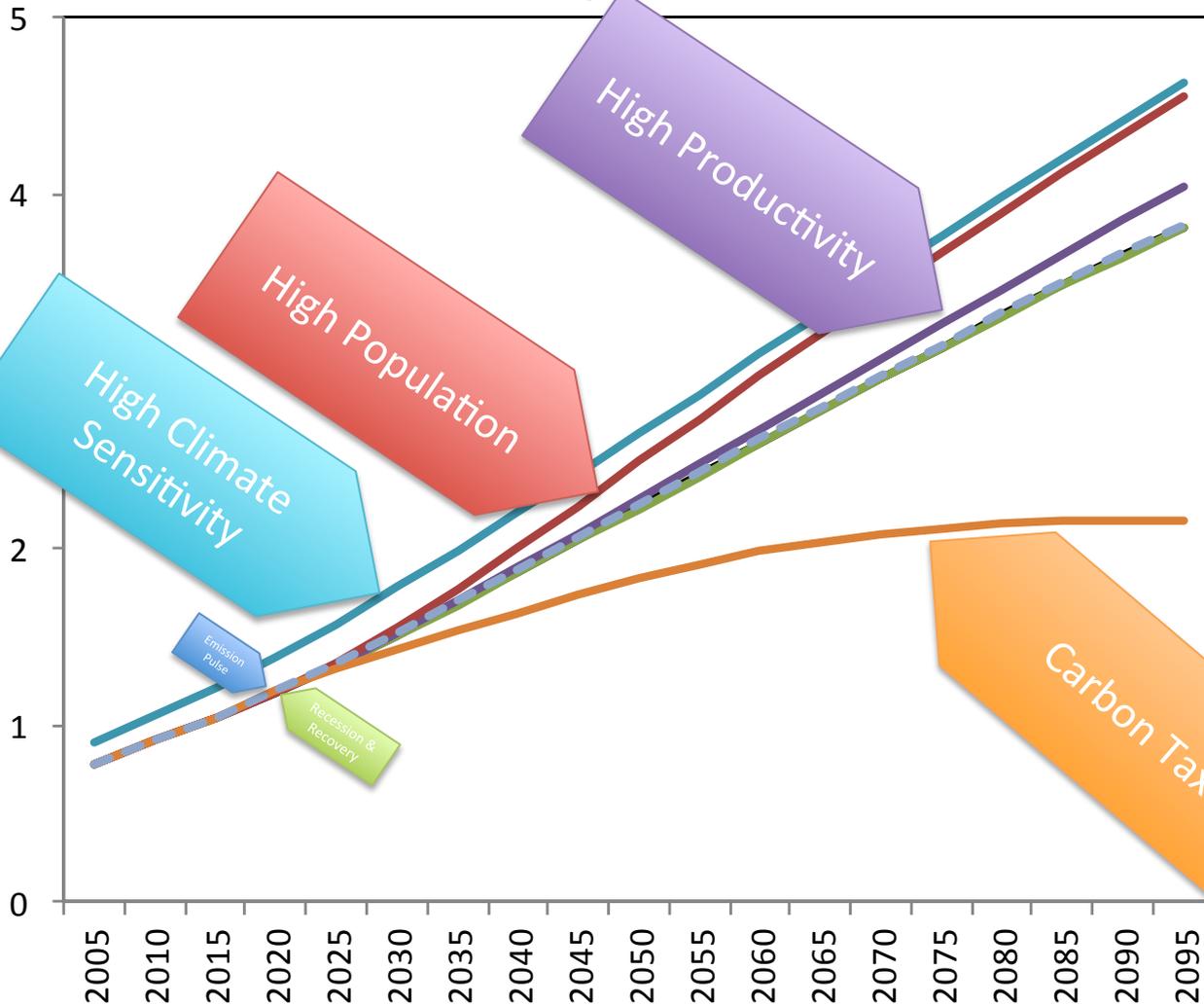- Climate_Sensitivity_Increase_Sc
- Carbon_Tax_Sc
- Emission Pulse

Total Forcing

Forcing in Watt/m2 (vertical axis, 0 to 10)

Horizontal axis: 2005, 2010, 2015, 2020, 2025, 2030, 2035, 2040, 2045, 2050, 2055, 2060, 2065, 2070, 2075, 2080, 2085, 2090, 2095

Annotations on chart: High Population, High Productivity, High Climate Sensitivity, Emission Pulse, Recession & Recovery, Carbon Tax

Legend:
- Reference
- GDP_Shock_Sc
- GDP_increase_Sc
- Population_Increase_Sc
- Climate_Sensitivity_Increase_Sc
- Carbon_Tax_Sc
- Emission Pulse

Temperature

Sea Level Rise
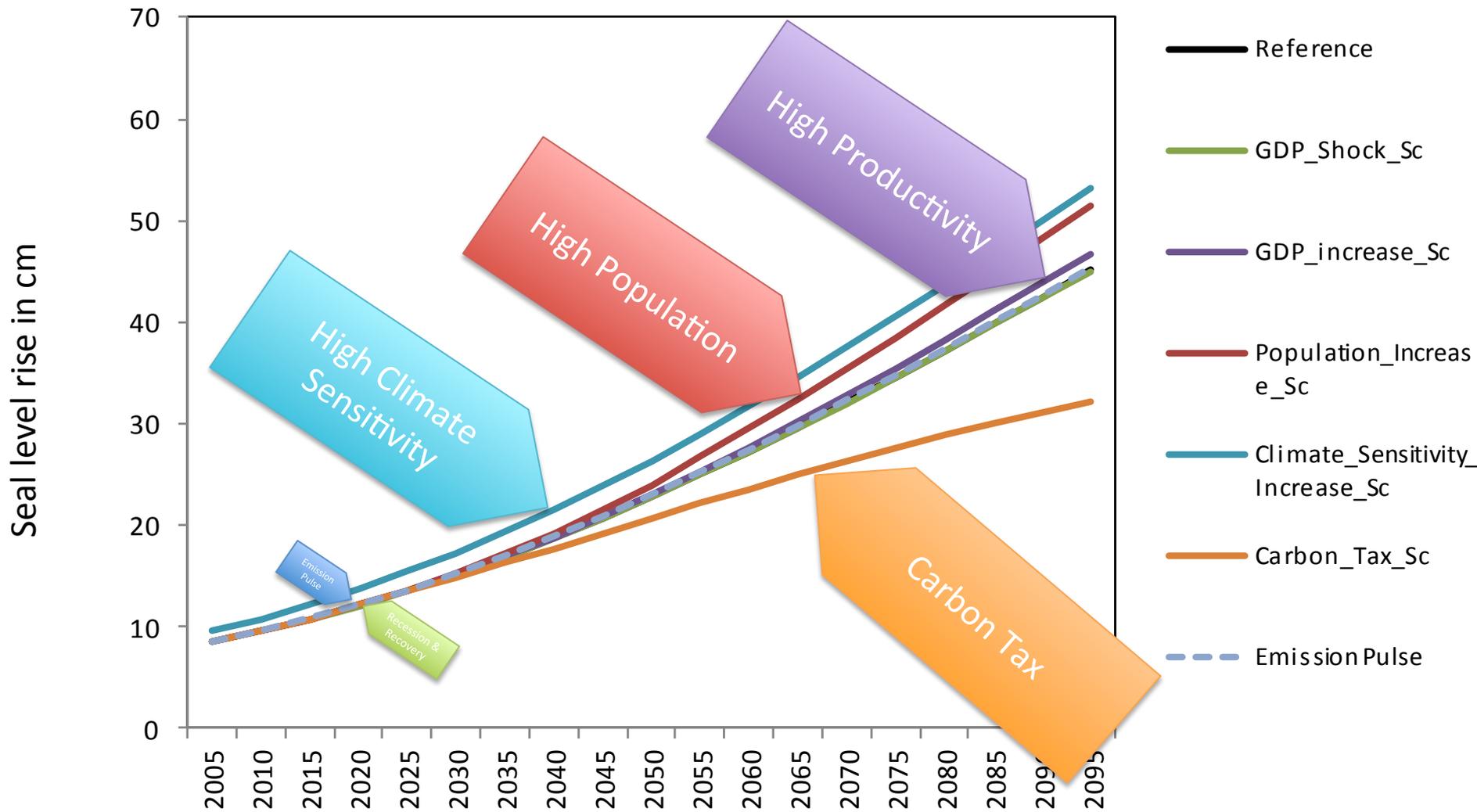
Concluding Thoughts

► First trial of MUG model sensitivity analysis.

► Some shocks have lasting impact.
- Population growth rate
- Productivity growth rate
- Carbon Tax

► Others have temporary impact.
- Recession and recovery
- Emission pulse

► Relative magnitudes are a function the type of parameter and the value

► Where is technology?

► What's the next step?

► What questions are we trying to answer?

The End