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Emissions Scenarios Toward the Mid-Century

November 29, 2016

Jae Edmonds

EPRI and IEA Workshop
Renewables and Clean Energy for Industries

The Paris Agreement 2015

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- First, thanks to EPRI for the invitation to speak today

- Thanks also to the *Implications of Paris Project* and its sponsors
- The Dec. 2015 Paris Agreement established a new international architecture substantially different from the Kyoto Protocol.
- Its long-term goal is to limit climate change to no more than 2°C or lower 1.5°C.

Two Degrees (or less) Means Zero Emissions in This Century

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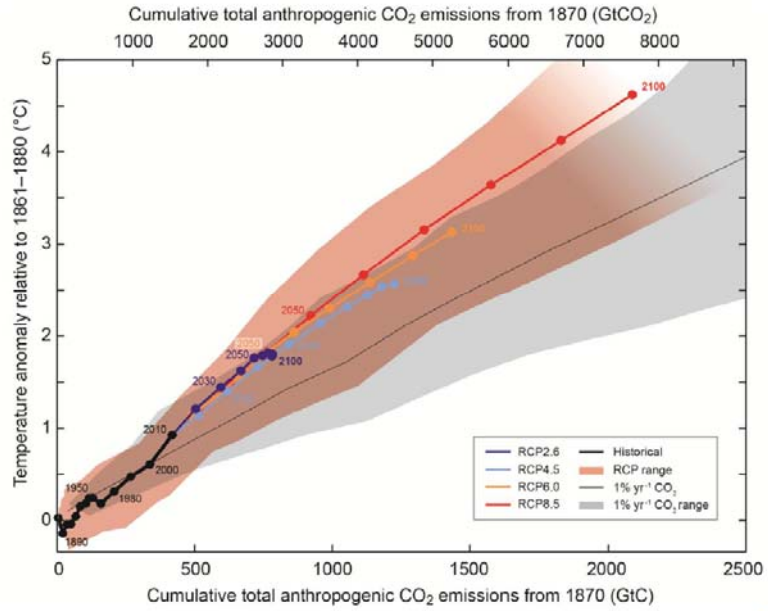
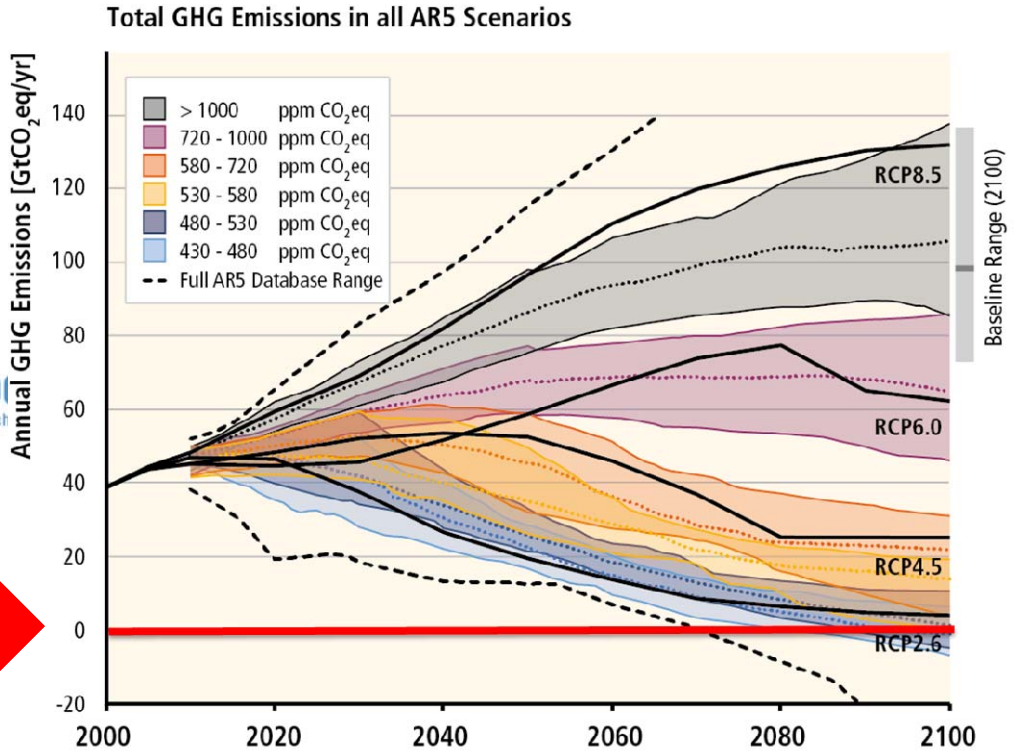
Cumulative carbon determines warming



IPCC AR5 Working Group I
Climate Change 2013: The Physical Science Basis

INTERGOVERNMENTAL PANEL ON climate ch

Zero Emissions



Source: IPCC, AR5, SPM

Getting to Zero—Five strategy elements

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- Energy efficiency—reduce demand for energy as much as economical
- Decarbonize power generation
  - Renewable power
  - Nuclear power
  - Bioenergy
  - Fossil fuel with CCS
  - Bioenergy with CCS
- Electrify Buildings and Industry
- Decarbonize transport
  - Electrify
  - Biofuels
  - H2
- Halt deforestation/afforestation and continue improving crop yields

Electrification

Environmental Economics and Policy Studies (2006) ■■: ■■–■■
DOI 10.1007/s10018-006-0111-9

Article

Electrification of the economy and CO_2 emissions mitigation*

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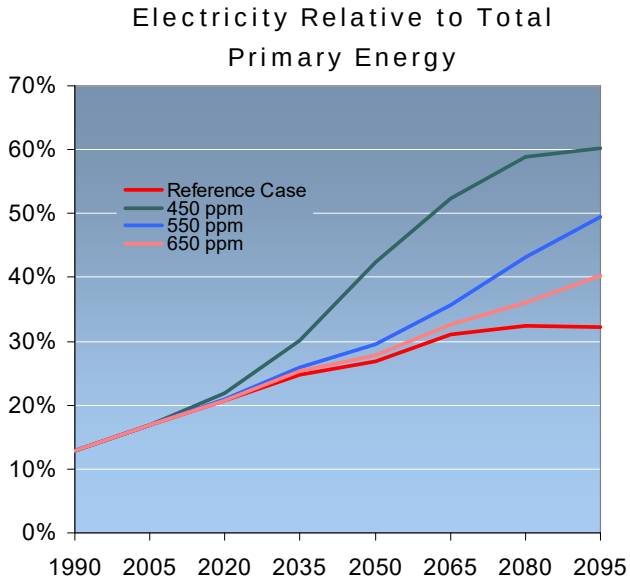
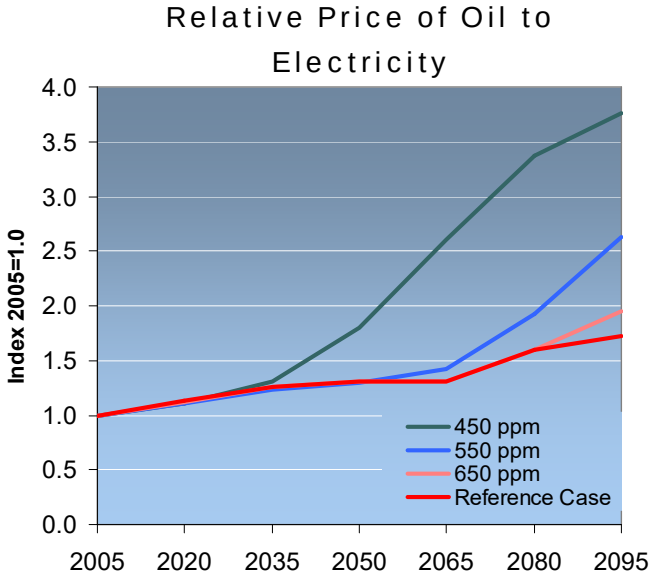




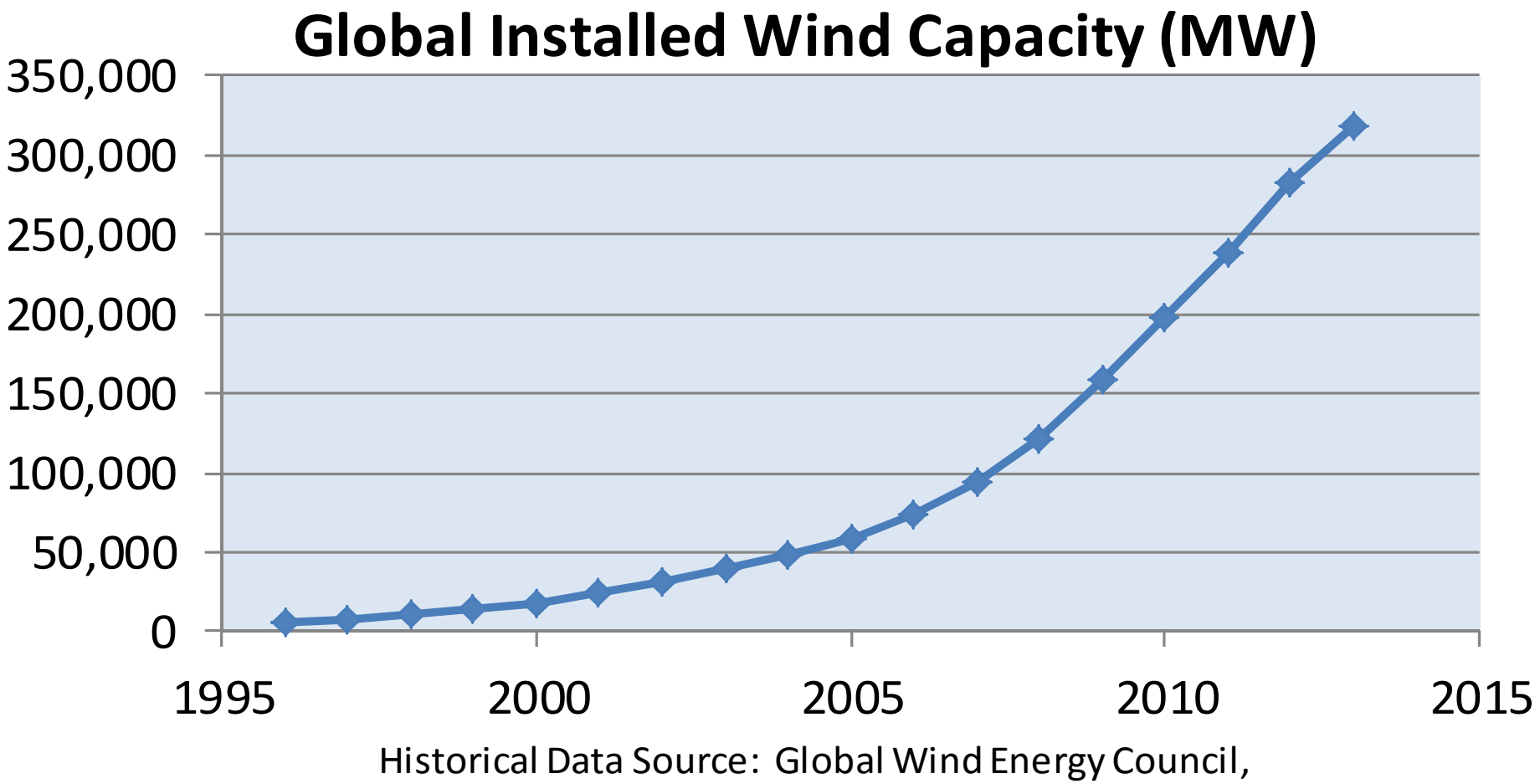
- Electrification is a core component of a mitigation strategy.
- This result goes back to a question that Tom Wilson asked, “what do the models say about electricity?”
- This result was in the EMF data but had gone unrecognized.

Energy Efficiency

- The opportunities for electrification in buildings and industry are relatively obvious
- The transport sector could be part of the electrification story but transport could go either
  - Electricity
  - Bioenergy
  - Combination

Scaling Up Renewable Power Will Require Major Deployment Efforts

- Historical Growth in Wind Installed Capacity: 1996-2013



Historical Data Source: Global Wind Energy Council,

Installed Wind Capacity: 450 ppm CO_2-e Limit (No Nuclear and No CCS)

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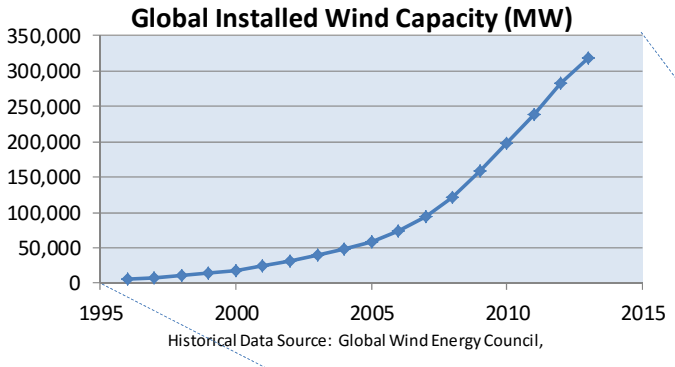
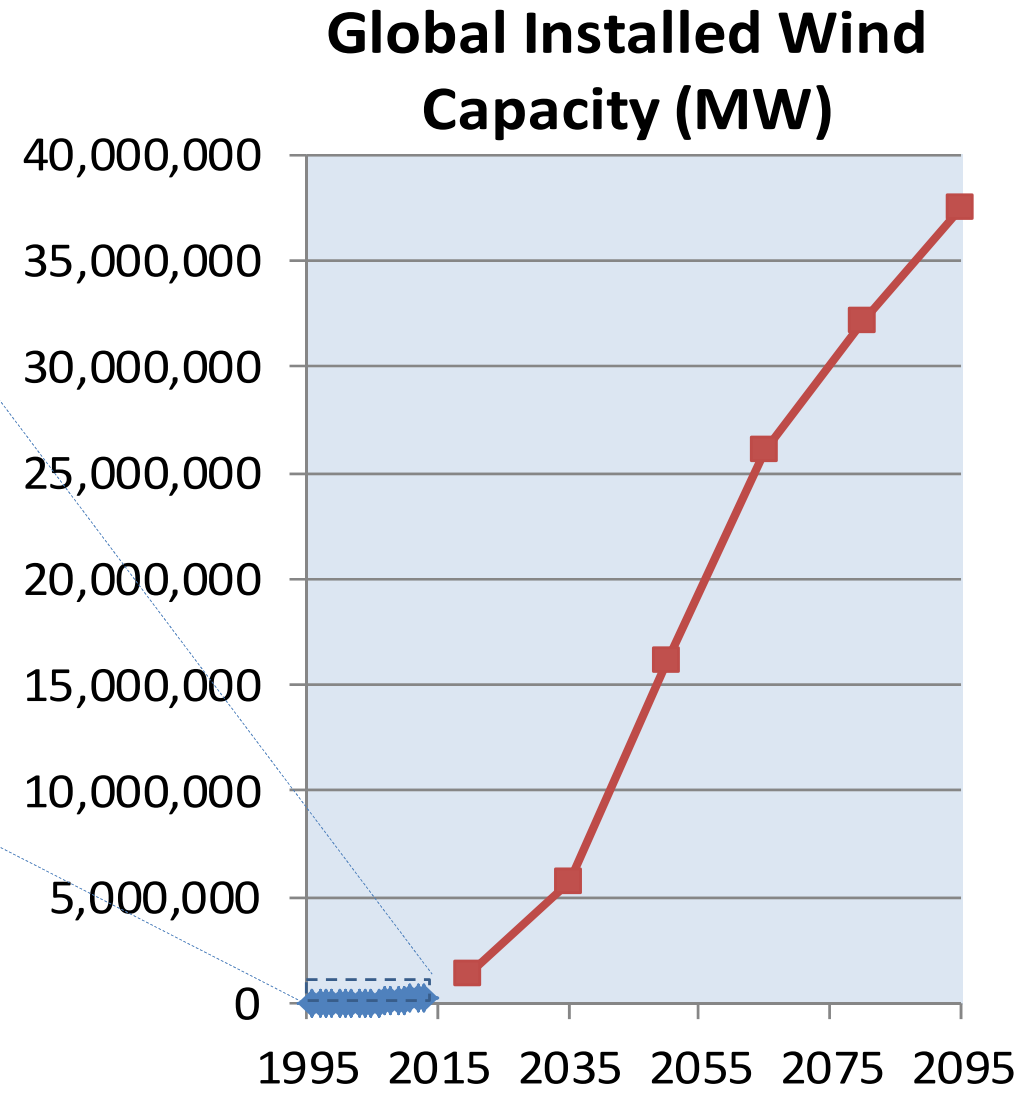


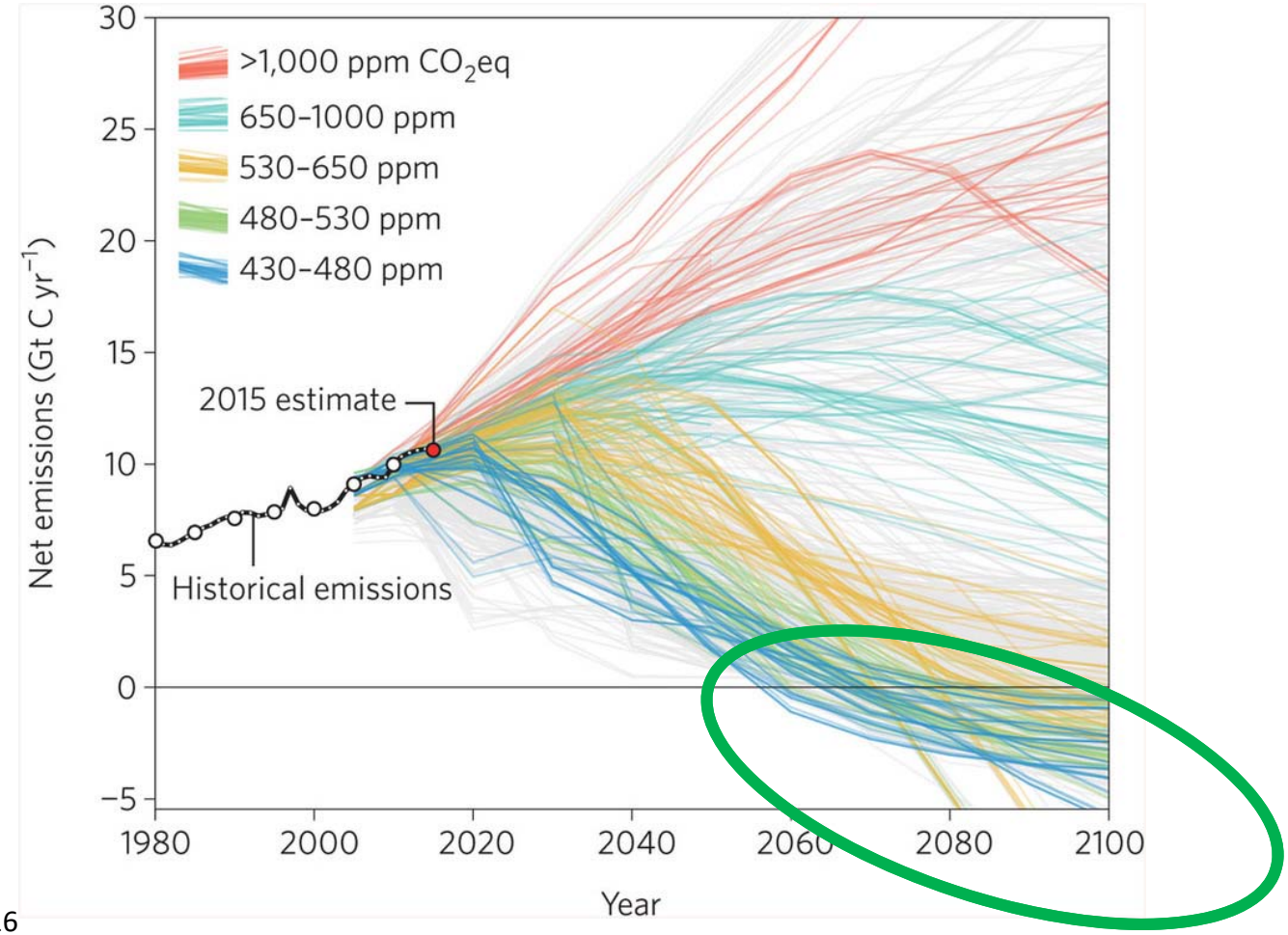


Future Scenario Source: Calvin, Katherine, James Edmonds, Ben Bond-Lamberty, Leon Clarke, Page Kyle, Steve Smith, Allison Thomson, Marshall Wise. 2009. 2.6: Limiting Climate Change to 450 ppm CO2 Equivalent in the 21st Century, Energy Economics, Volume 31, Supplement 2, December 2009, Pages S107-S120 .

Historical Data Source: Global Wind Energy Council, http://www.gwec.net/global-figures/graphs/

Bioenergy with CCS Enables Net Negative Emissions

- BECCS facilitates net negative emissions found in low climate stabilization scenarios



Source: Smith, et al., 2016

A 2-Degree World Is Different with and Without CO_2 Capture and Storage (CCS)

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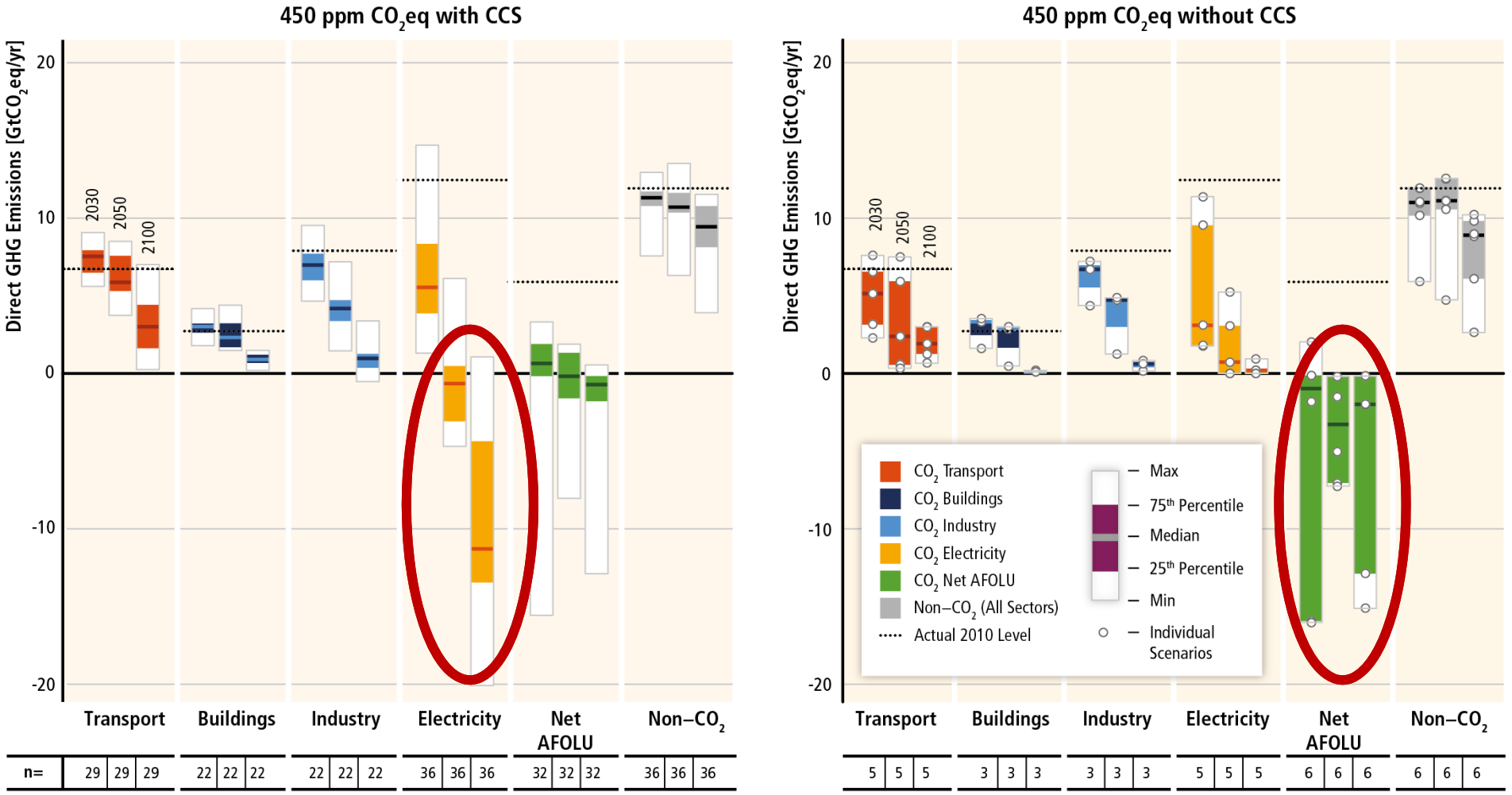

Source: IPCC, AR5, SPM

Carbon Storage and Sequestration

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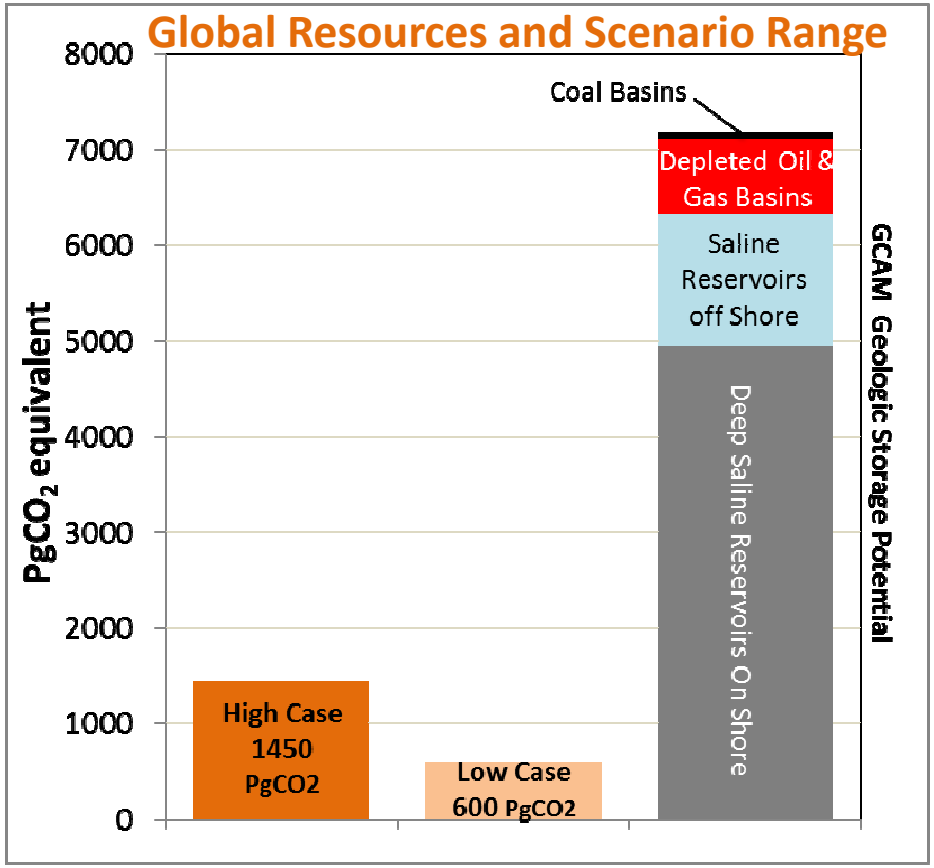
- Plays a major role in scenarios when available
- There is no reason to believe that storage capacity will limit CCS deployment in an important way.
- Some regions will be constrained by storage availability



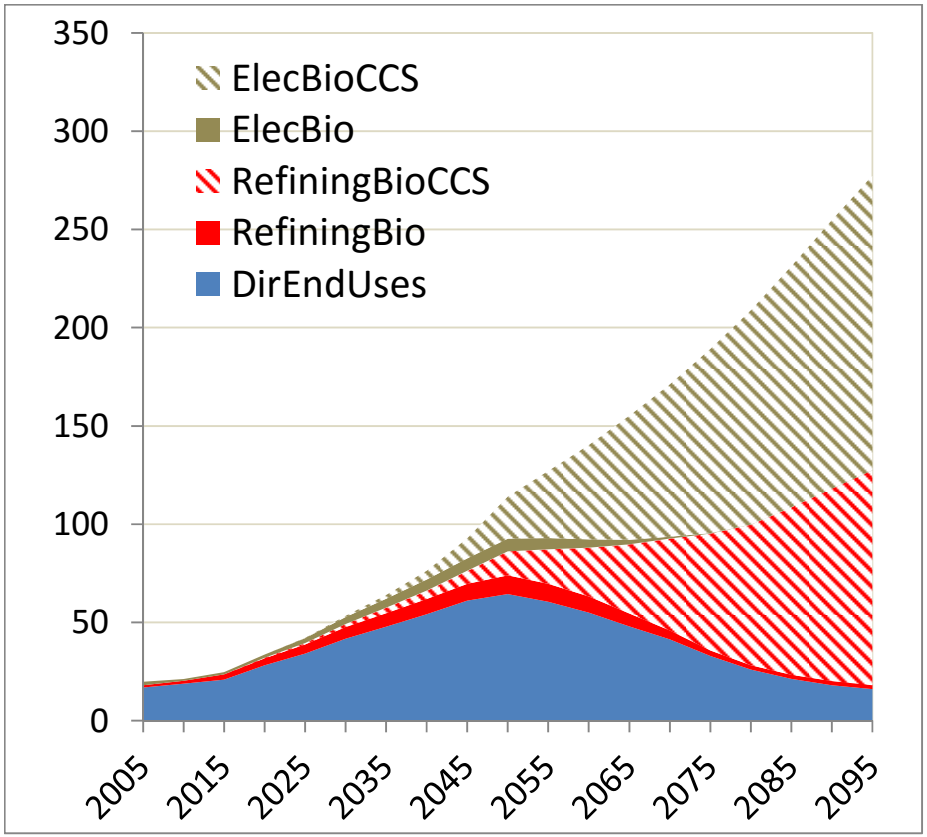
Source: Edmonds, et al., 2013.

U.S. Experiments

Source: U.S. DOE

Bioenergy Is a Versatile Energy Form

- Bioenergy can be used as either a **solid**, **liquid**, or **gas**
- Bioenergy with CCS can be used in either **power** or **transport**.
- **Both produce negative emissions.**



Source: Edmonds, et al., 2013.

Bioenergy Use Produces Upward Pressure On Food Prices

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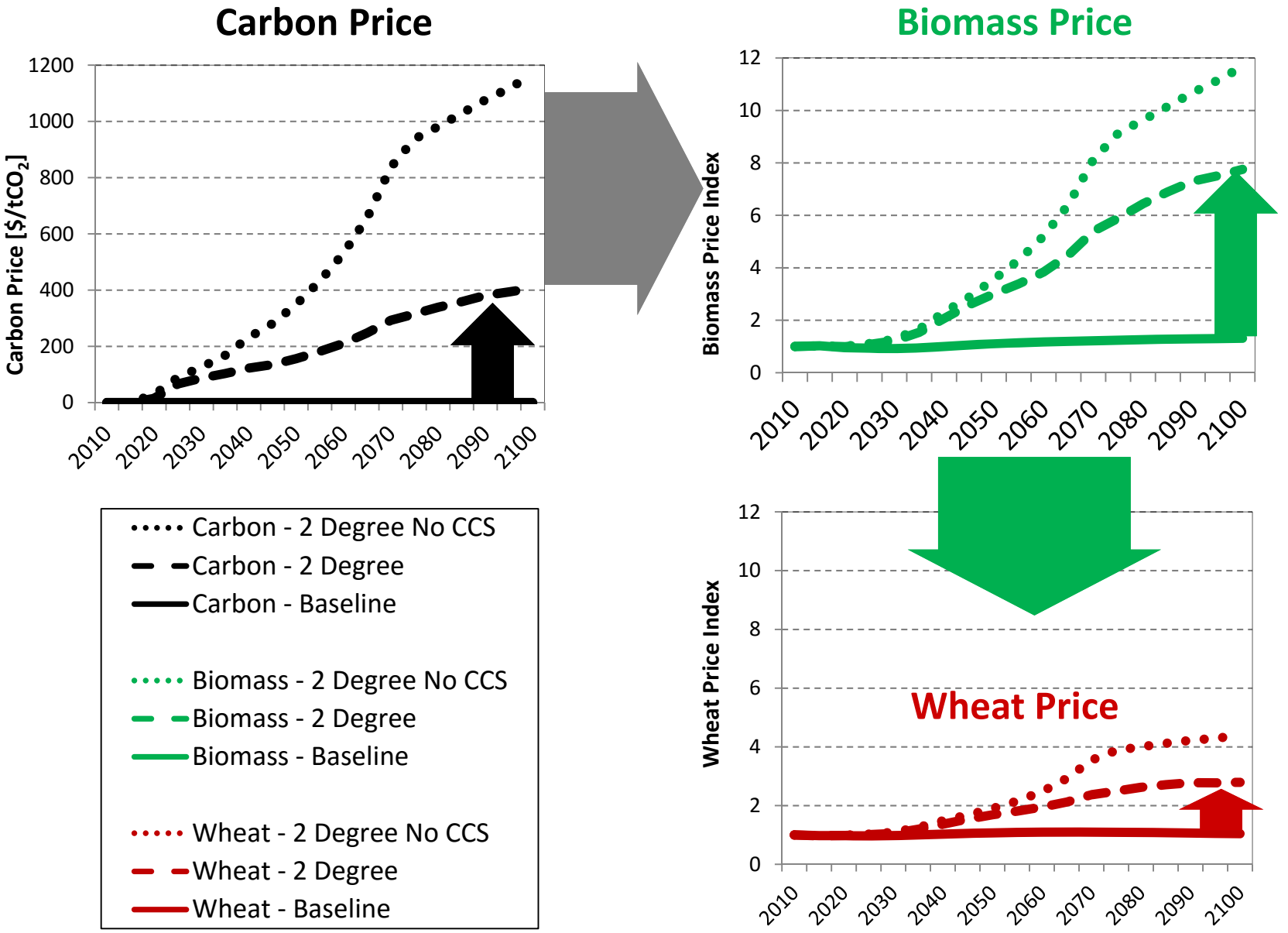
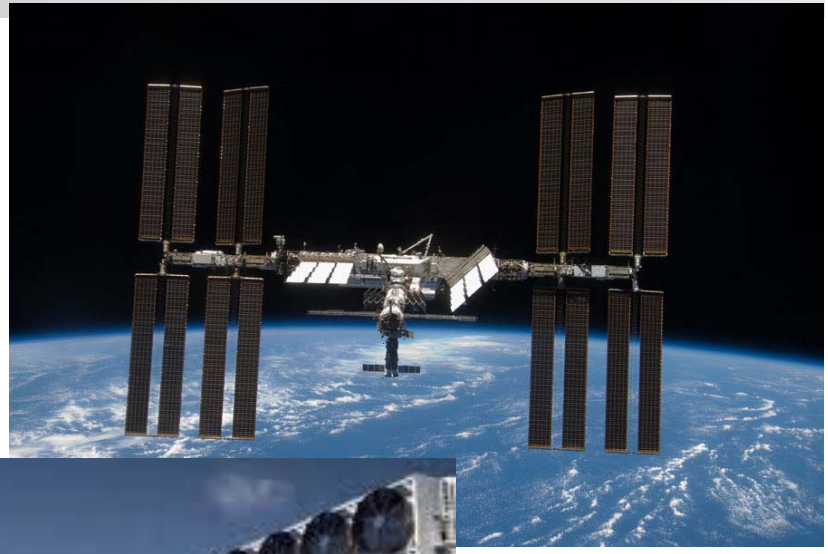
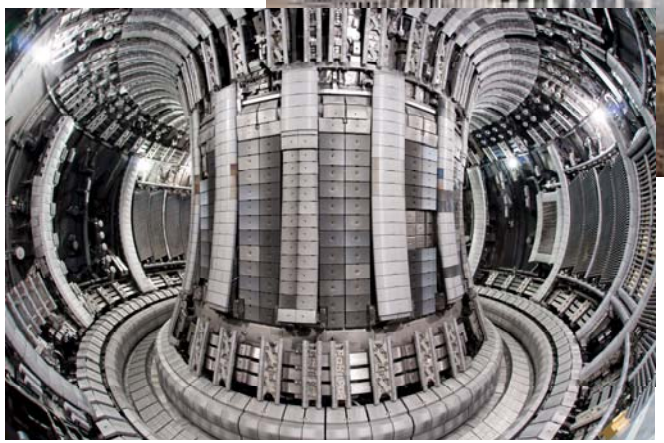


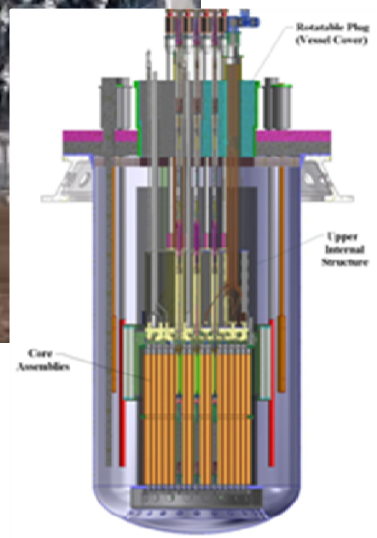
Source: Muratori, et al., 2016

Technology Wild Cards

- Some technologies that scenarios may or may not include, but which could make a large contribution include:
  - Advanced Nuclear Reactor (HTGR, SFR, FHRs, aSMR)
  - Hydrogen
  - Nuclear Fusion
  - Space Solar Power
  - Free air capture







Advanced Sodium-cooled Fast Reactor (AFR-100)