Energy Market Consequences of an Emerging U.S. Carbon Management Policy

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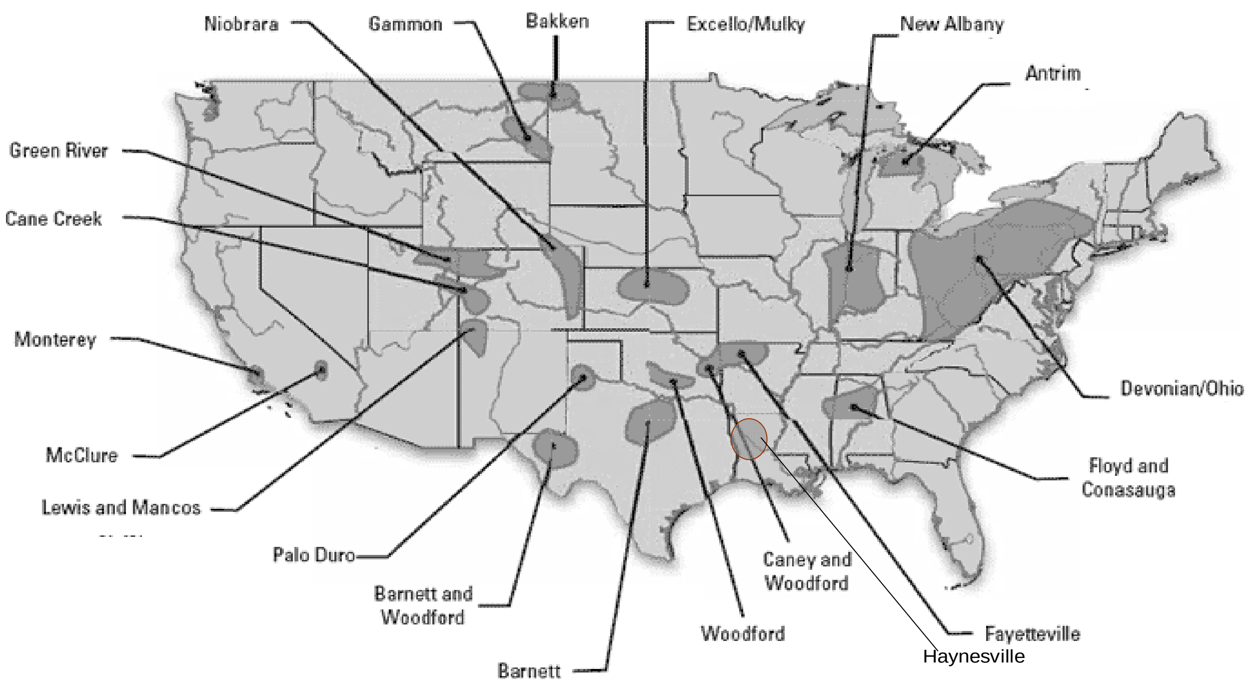
Study Scope

- Last workshop (Aug 2008) we used the Rice World Gas Trade Model to investigate the effects of different CO2 management schemes on the natural gas market
  - We have recently incorporated an updated assessment of shale gas in North America into that work.
- We have now developed the initial structure of what will be the “Rice World Energy Model.” Currently, the model is for the US alone but we will extend it to a multi-region global model in the coming months.
- A scenario approach will be used to examine and compare various outcomes under different sets of assumptions.
  - Various degrees of CO2 constraint and the associated implications for CO2 pricing, energy use and energy prices will be investigated.
  - The effect of changes to operating and capital costs of alternative technologies and other key assumptions will be examined.
  - The rate of technological innovation will be varied.
  - Regional, disconnected policies versus harmonized, international policies.

Shale Gas in the RWGTM

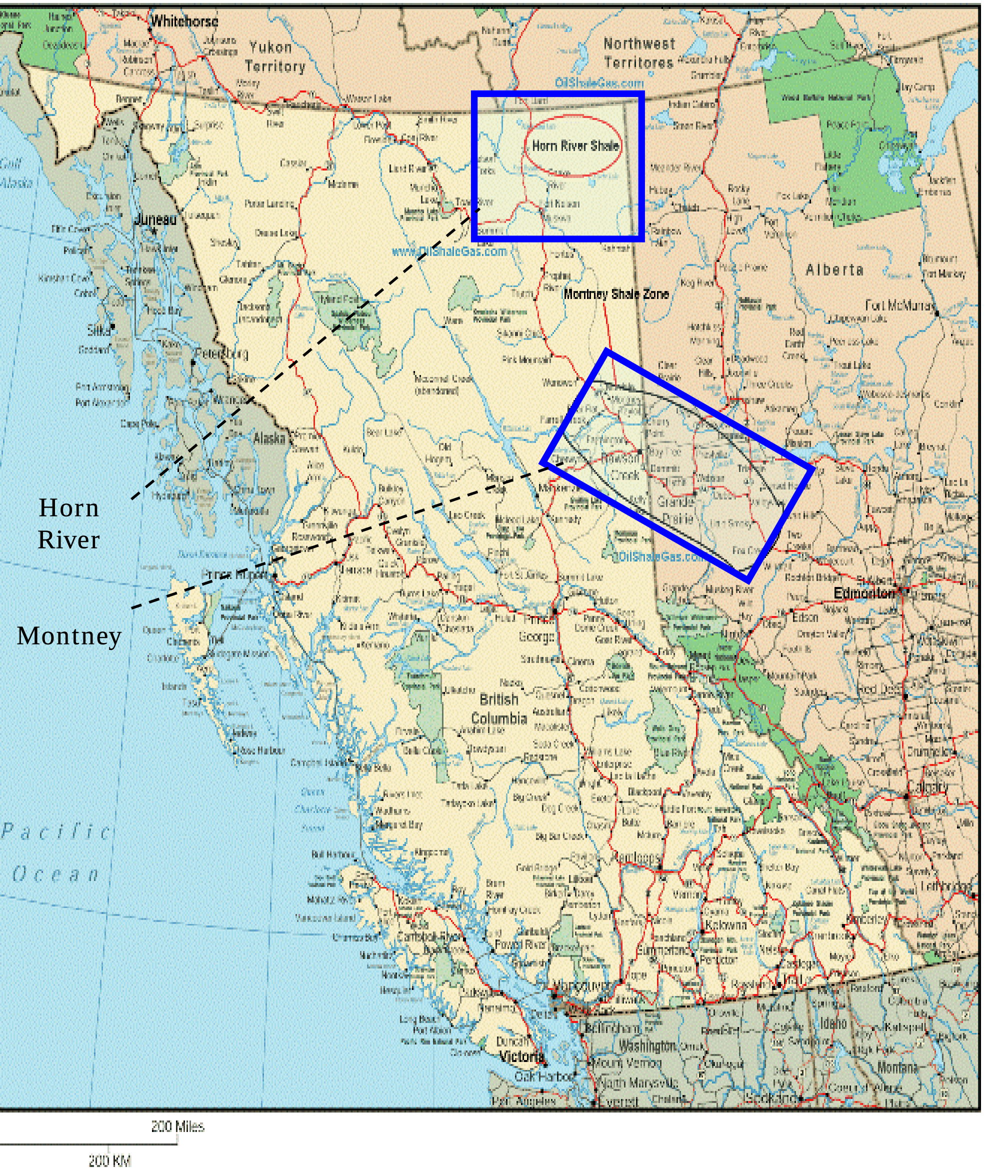
Developments in Shale Gas

- Very active area of exploration and development
  - NCI assessment indicates 275-840 tcf of technically recoverable shale gas
    - Differences driven primarily by producer reports for the Haynesville and Marcellus.
    - Even low end is higher than EIA's 125 tcf (AEO2008) or the 131 tcf cited by PGC (2006)
    - *Do not* include Canada (Montney, Horn River).
    - These are *technically* recoverable estimates. Costs may be an impediment.
      - Breakeven estimated at roughly sub-$7/mcf in most plays, with some in the $4/mcf range.
  - Other studies are ongoing.



Developments in Shale Gas (cont.)

- Shale plays in Canada are also being developed.
- Most active areas are in the Horn River and Montney plays in BC and Alberta.
- Supply potential in BC, in particular, has pushed the idea of LNG exports targeting the Asian market
  - Asia is a premium market.
  - Competing projects include pipelines from Russia and the Caspian States, as well as LNG from other locales.
- BC is a basis disadvantaged market, but selling to Asia could provide much more value to developers.
- Utica Shale in Quebec has been compared to the Barnett in Texas, and price is even more favorable.



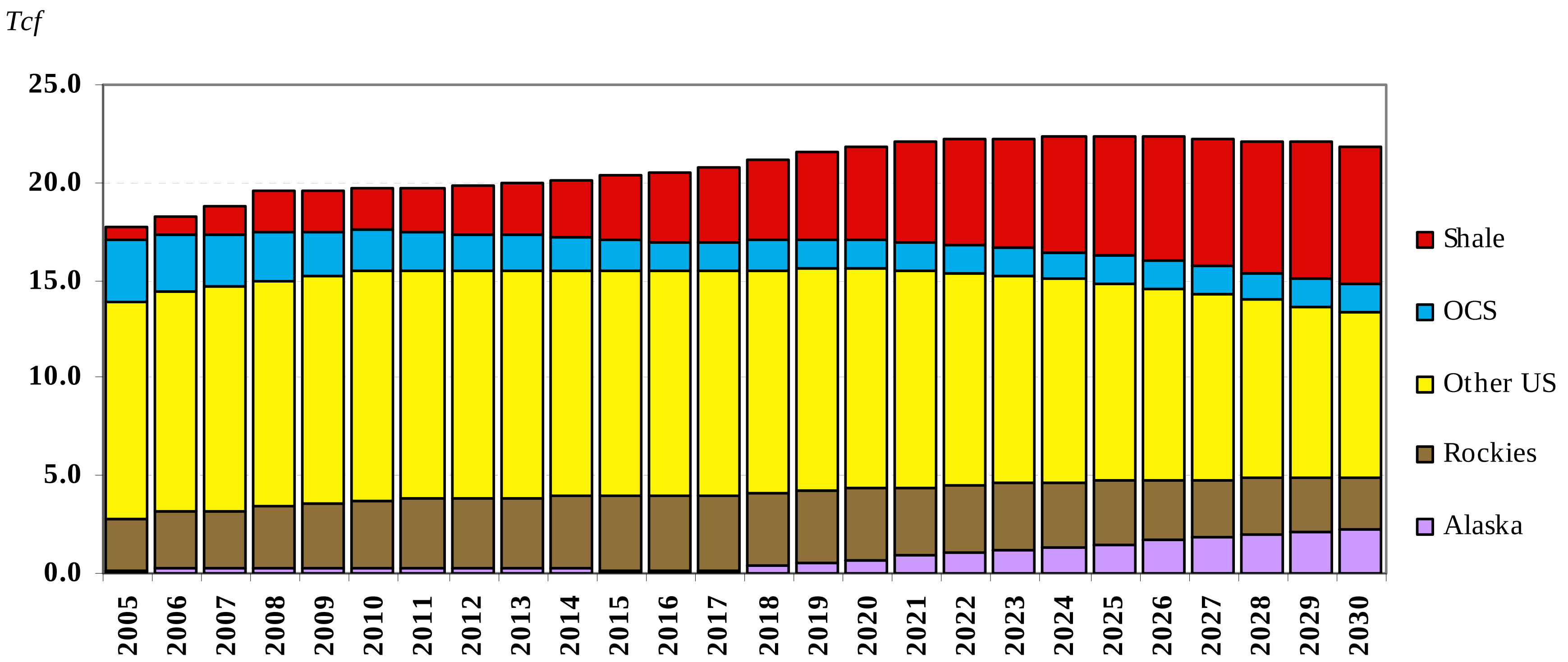
Shale Gas Assessment in the RWGTM

- Technically Recoverable Assessment in RWGTM
- Economically Recoverable Assessment is smaller
  - Development costs based on the breakeven economics from various consultants

	Shale Play	Basin	Mean technically recoverable gas
US	**Antrim**	Michigan Basin	13.2
	Devonian/Ohio	Appalachian Basin	79.6
	Marcellus	Appalachian Basin	44.2
	New Albany	Illinois Basin	3.8
	Floyd/Chatanooga	Black Warrior Basin	2.1
	Haynesville	Gulf Coast Onshore	34.0
	Fayetteville	Arkoma Basin	26.0
	Woodford Arkoma	Arkoma Basin	8.0
	Caney and Woodford	Arkoma Basin	No Data
	Woodford Ardmore	Ardmore Basin	4.2
	Barnett	Fort Worth Basin	26.2
	Barnett and Woodford	Permian Basin	35.4
	Palo Duro	Palo Duro Basin	4.7
	Lewis	San Juan Basin	10.2
	Cane Creek	Paradox Basin	No Data
	Excello/Mulky	Cherokee Platform	No Data
	Bakken	Williston Basin	1.8
	Gammon	Williston Basin	No Data
	Niobrara (incl. Wattenburg)	Denver Basin	1.3
	Hilliard/Baxter/Mancos	SW Wyoming	11.8
	Lewis	SW Wyoming	13.5
	Mowry	SW Wyoming	8.5
	Monterrey/McClure	San Joaquin Basin	No Data
Canada	**Horn River**	WCSB	49.0
	Montney	WCSB	14.0
	Utica	Quebec	8.0
	Total Shale Gas Assessment		**355.3**

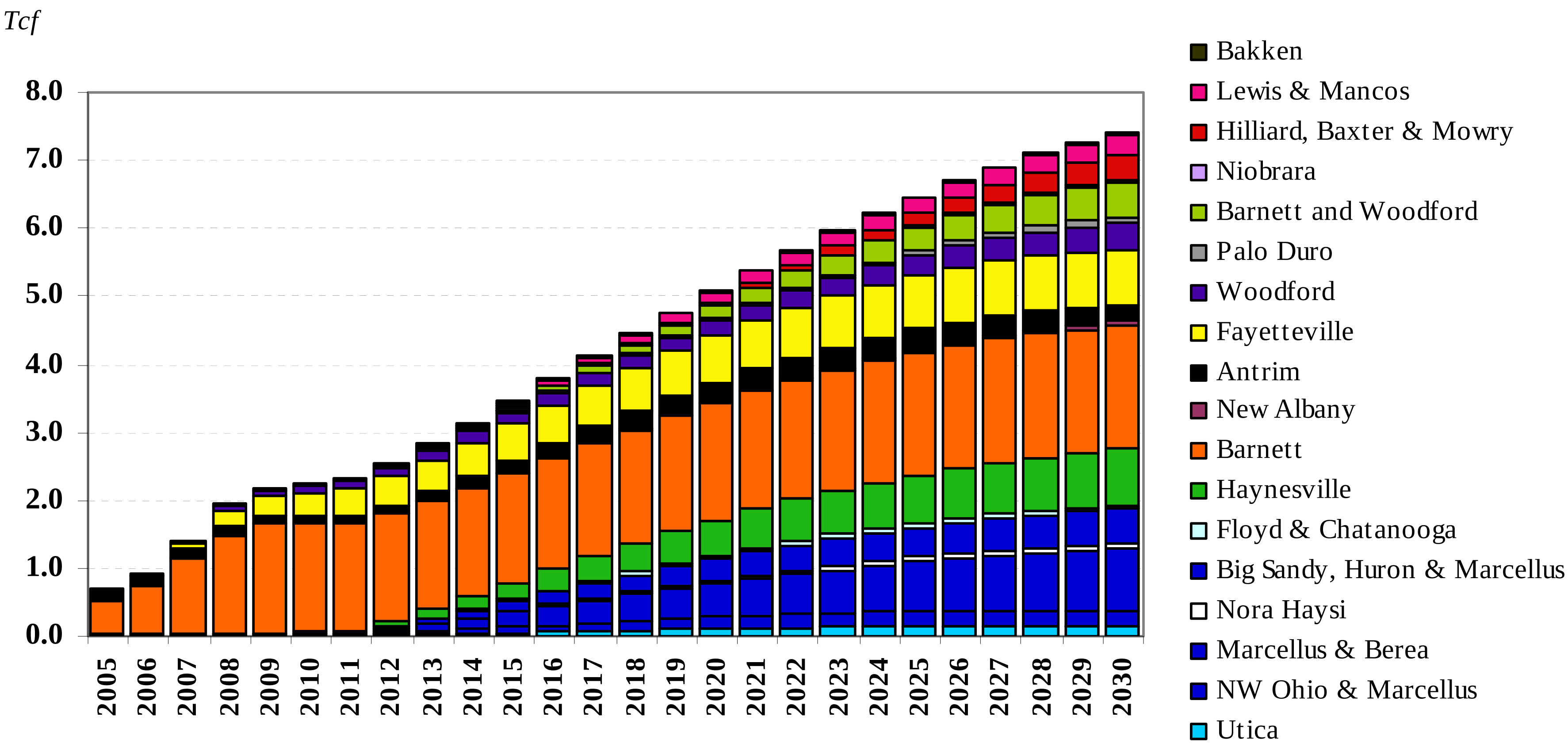
Supply: U.S.

- Growth in U.S. production comes from expansion in shale basins.
- Steady declines in OCS and other regions.
- Medium term growth in Rockies.
- Alaska PL develops early 2020s.



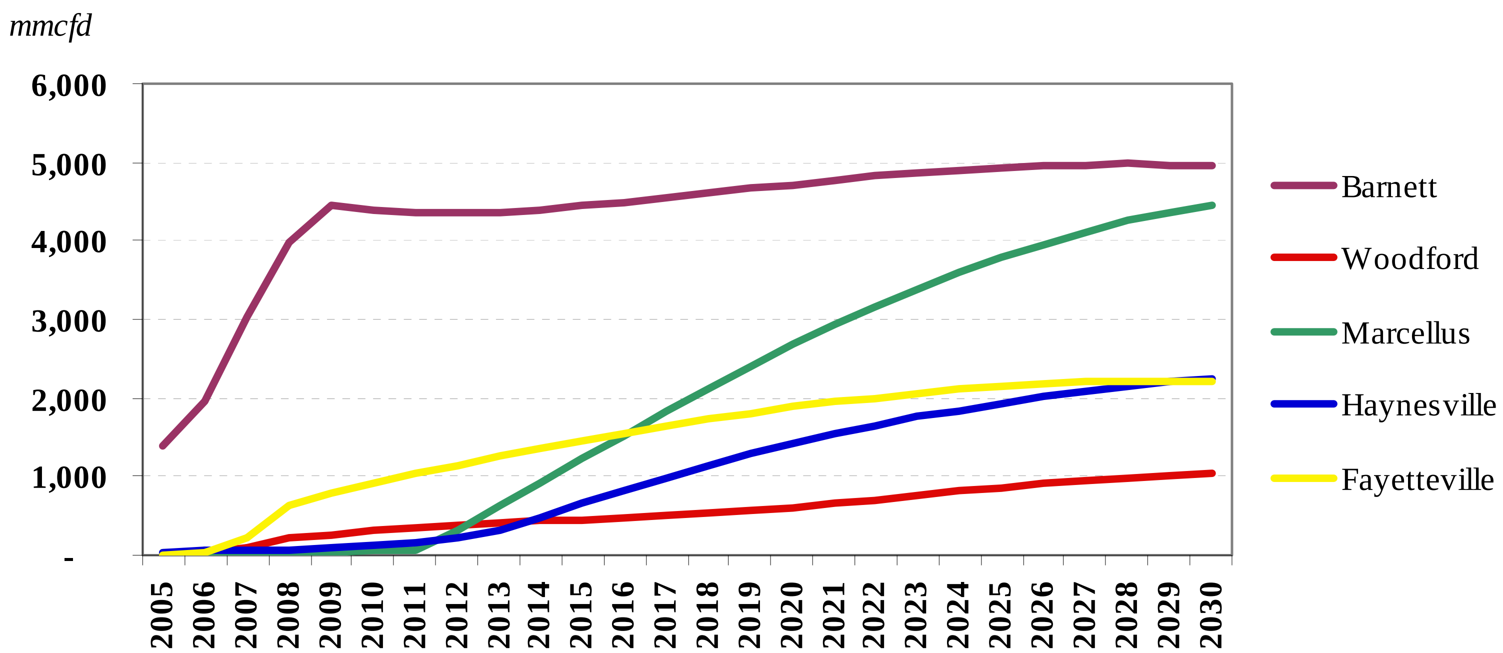
Supply: U.S. Shale

- Strongest shale production is in Barnett.
- There is strong growth in the Marcellus, Fayetteville, and Haynesville shales in particular, with modest growth in several others.



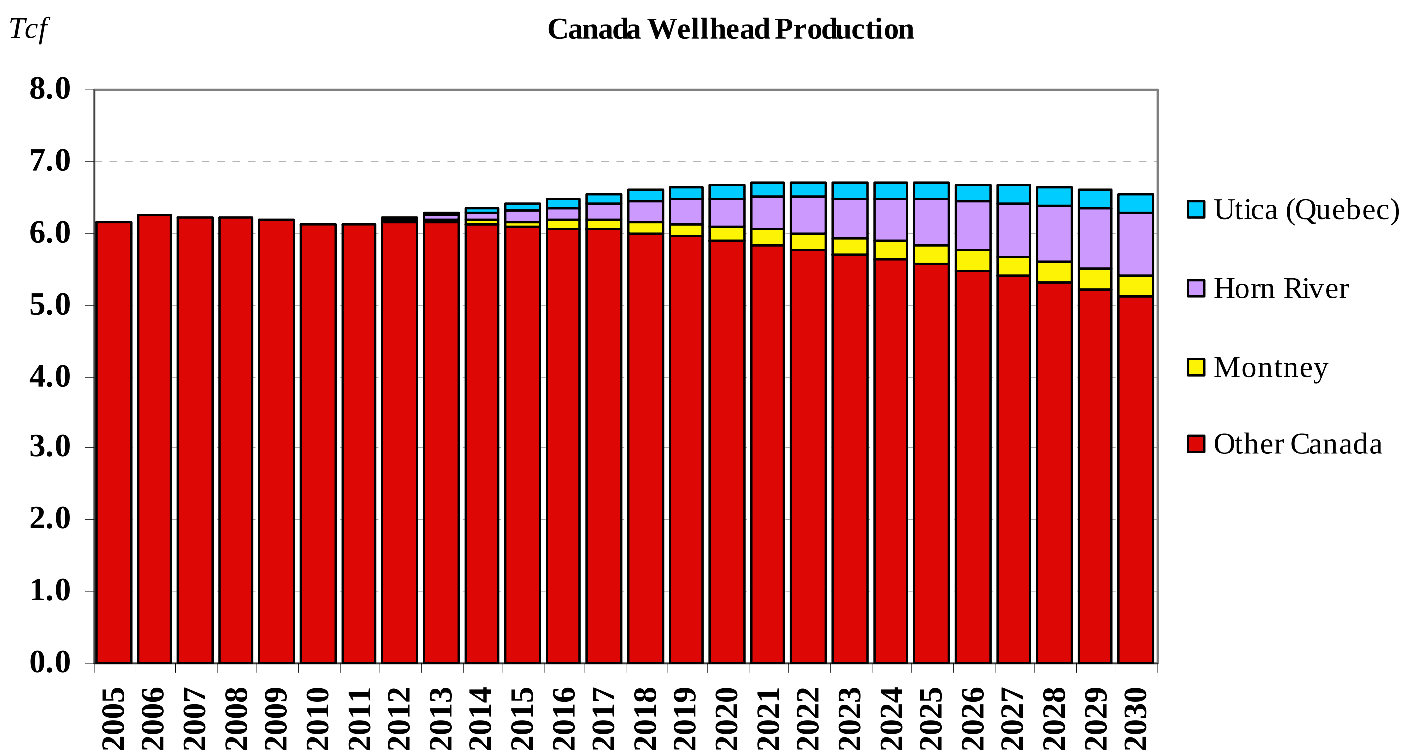
Supply: U.S. (cont.)

- Barnett, Marcellus, Fayetteville, and Haynesville up close.



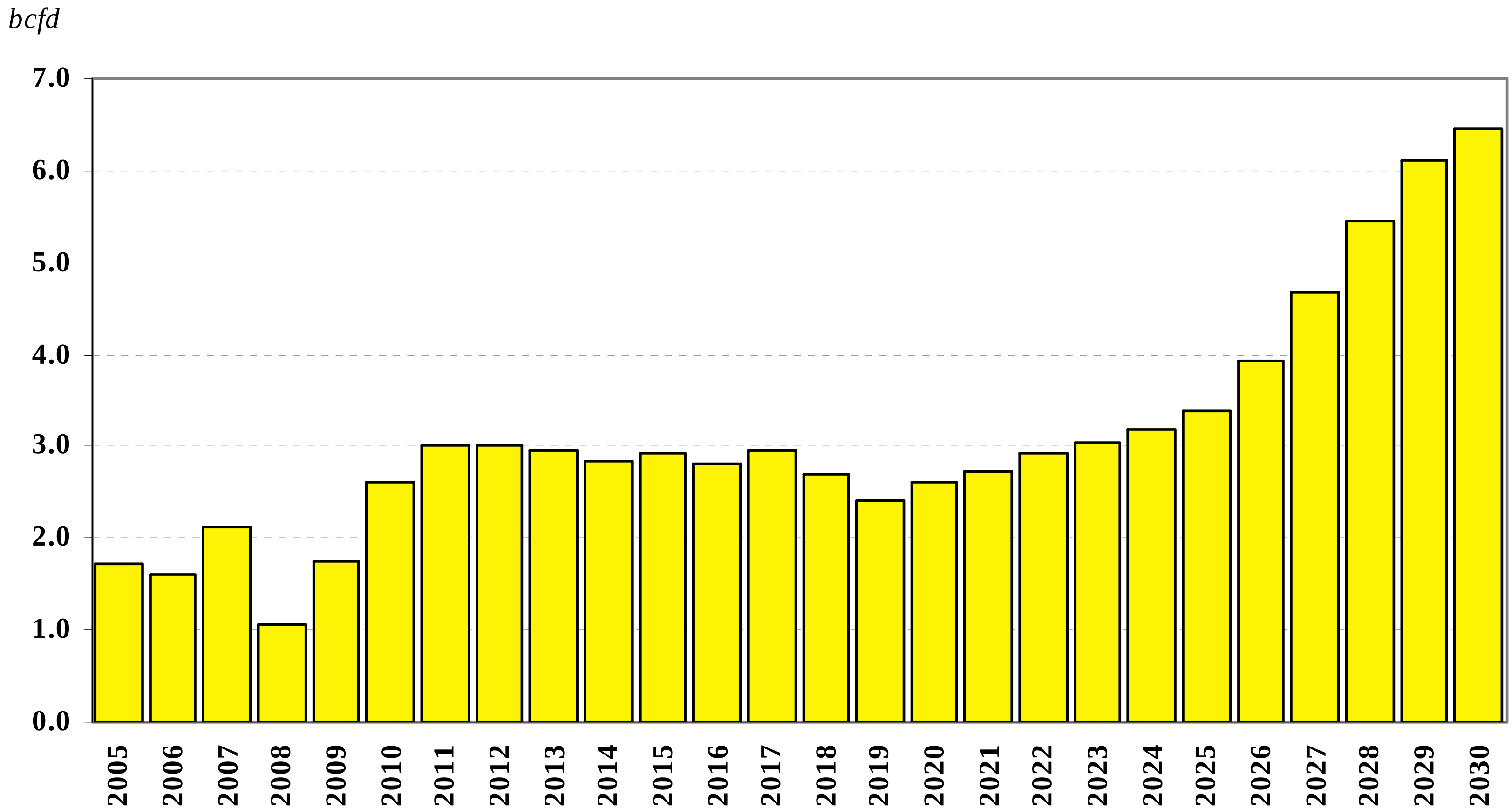
Supply: Canada

- Growth in Canadian production comes largely from British Columbia in the Horn River Shale. However, the growth does not support LNG exports.
- Overall, shale production in Canada offsets decline in other regions and supports expanded tar sands production.



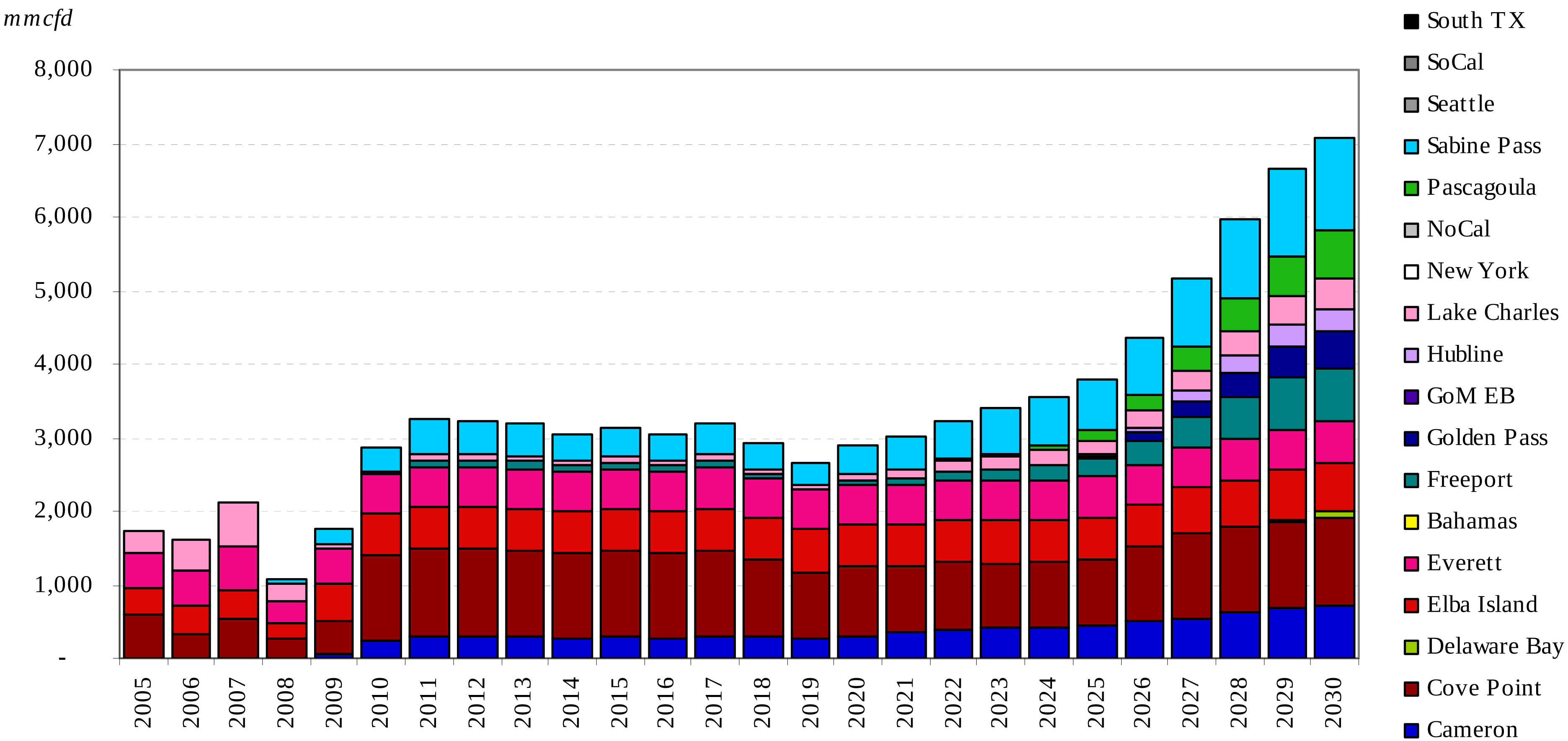
USA: LNG Imports

- Growth out of 2008 as new liquefaction comes online and Japan restarts nukes. However, LNG imports see no growth until 2020s.



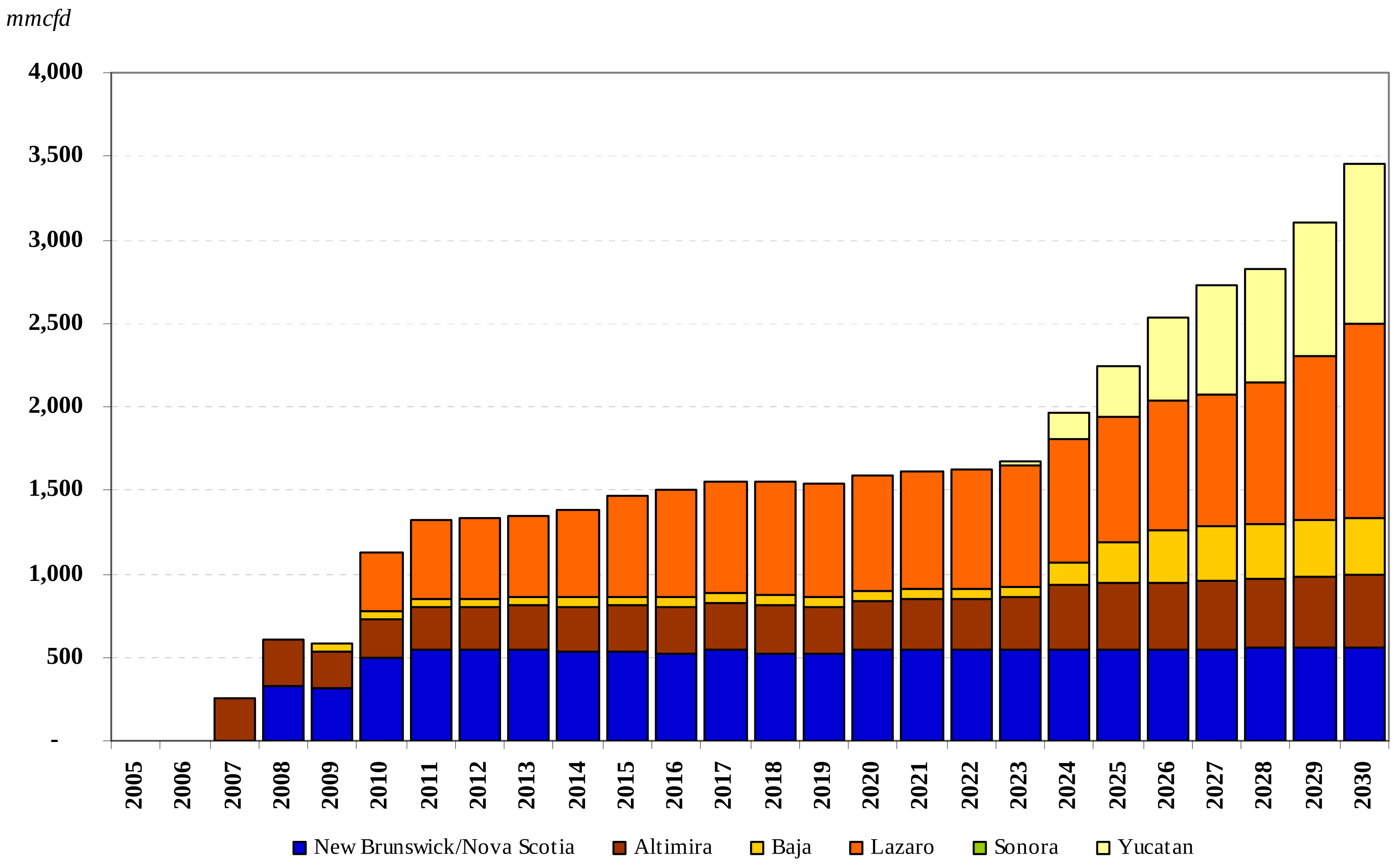
USA: LNG Imports (cont.)

- By facility…



Canada and Mexico: LNG Imports

- By facility…



CO2 constraints in an *Energy* Model: Previous work

MIT (Report 150)

- Apply both forward-looking and recursive versions of the MIT Emissions Prediction and Policy Analysis (EPPA) model to consider the impact of GHG cap-and-trade legislation.
- Effort focuses on the U.S., and aggregates the Rest of the World.
- Model features
  - Constant intertemporal elasticity of substitution utility function dictates household consumption decisions
  - Representative households engage in consumption smoothing
  - Economic growth varies across regions. Convergence is a feature of the model.
  - Macro balance is maintained. Represents international trade and capital flows.
  - "Carbon-free" backstop is assumed at a price of $50/ton. This is chosen via trial and error – anything more is above the 203bmt case so is irrelevant.
    - "Backstop tech" case allows investment in a known abatement technology to occur endogenously. This is different than assuming availability at constant price.
  - Assumes future supply curves in each period for fossil fuels and alternatives

Other Studies

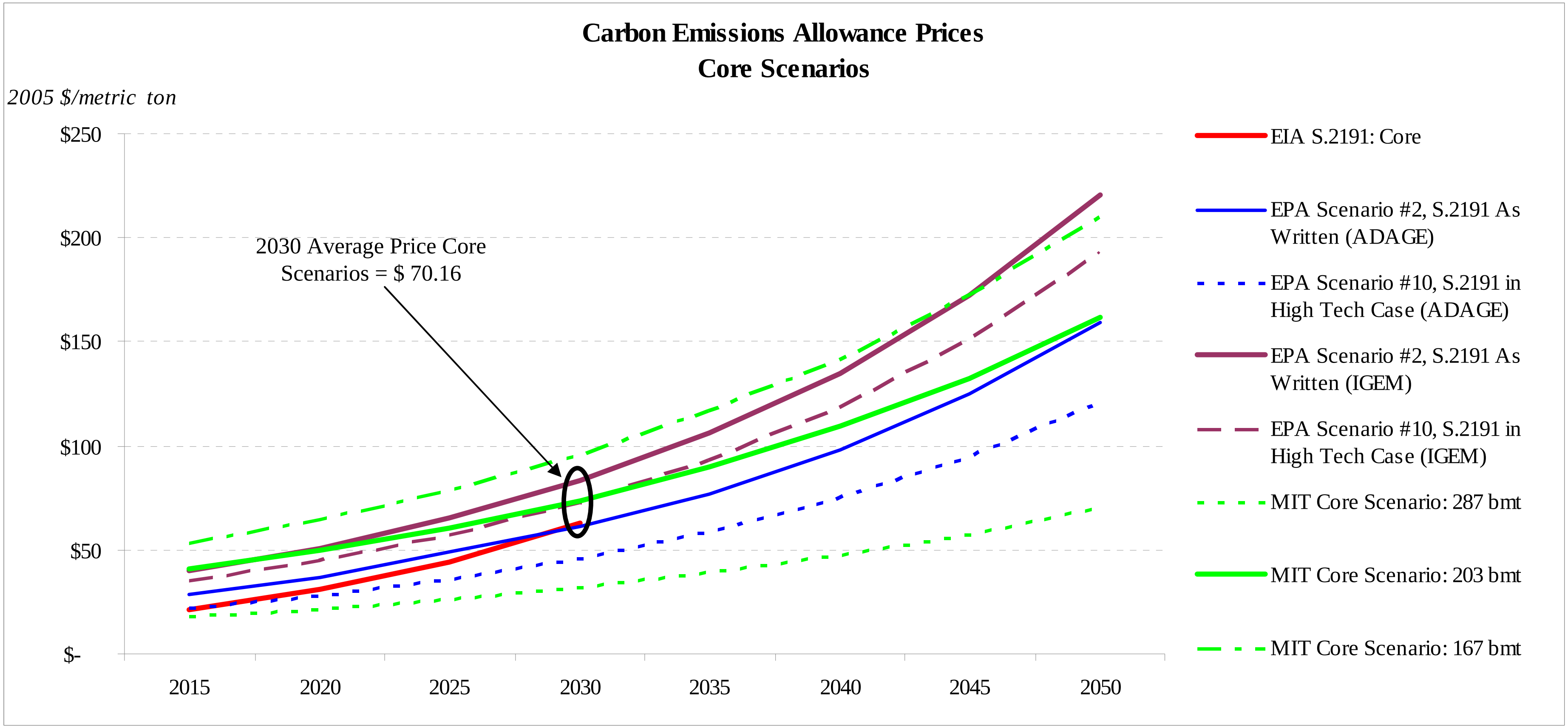
- EIA
  - Source: www.eia.doe.gov/oiaf/service_rpts.htm
  - Specific NEMS runs given S.2191, the Lieberman-Warner Climate Security Act of 2007 legislation. Aggressive adoption of nuclear.
  - Long run carbon price (2030) = $61; P_{NG}(2030) = $5.65 (2006$)
- EPA
  - Source: www.epa.gov/climatechange/economics/economicanalyses.html
  - Two exercises using different models: ADAGE and IGEM
  - Carbon price = ADAGE: $61 ($81 with constraints on nukes), IGEM: $82
  - Natural gas price = $5.76 (2005$)
- NGC
  - Used NEMS to dispute EIA on basis of nuclear power assessment
    - "… the EIA analysis incorrectly assumes 145 new nuclear power plants will be built by 2030. Another study by the Natural Gas Council (NGC) assumes that only 25 nuclear power plants will be built in that same time period. This figure is likely more accurate since only one nuclear power plant has been ordered in the last 30 years…"
  - Natural gas demand up by 14 percent (3.6 trillion cubic feet (TCF)) per year from 2020-2030 on average
  - Natural gas wellhead prices $1/mcf or more higher

Other Studies (cont.)

- Stern Review
  - Received much attention as an authoritative source on the economics of dealing with climate change.
  - Key result: $85/metric ton CO2 equivalent for business as usual case
  - Critics point to various flaws, the most disputed of which centers on a lack of appropriate discounting.
- McKinsey Report
  - Highly cited, especially on Capital Hill.
  - Constructs a marginal cost curve for CO2 abatement measures
  - Identifies a cost of $50/ton.
  - Critics point to low discount rate. McKinsey acknowledges using a "social rate of discount".
- EPRINC
  - Notes cost of cap-and-trade, but argues opportunities will be created as well.

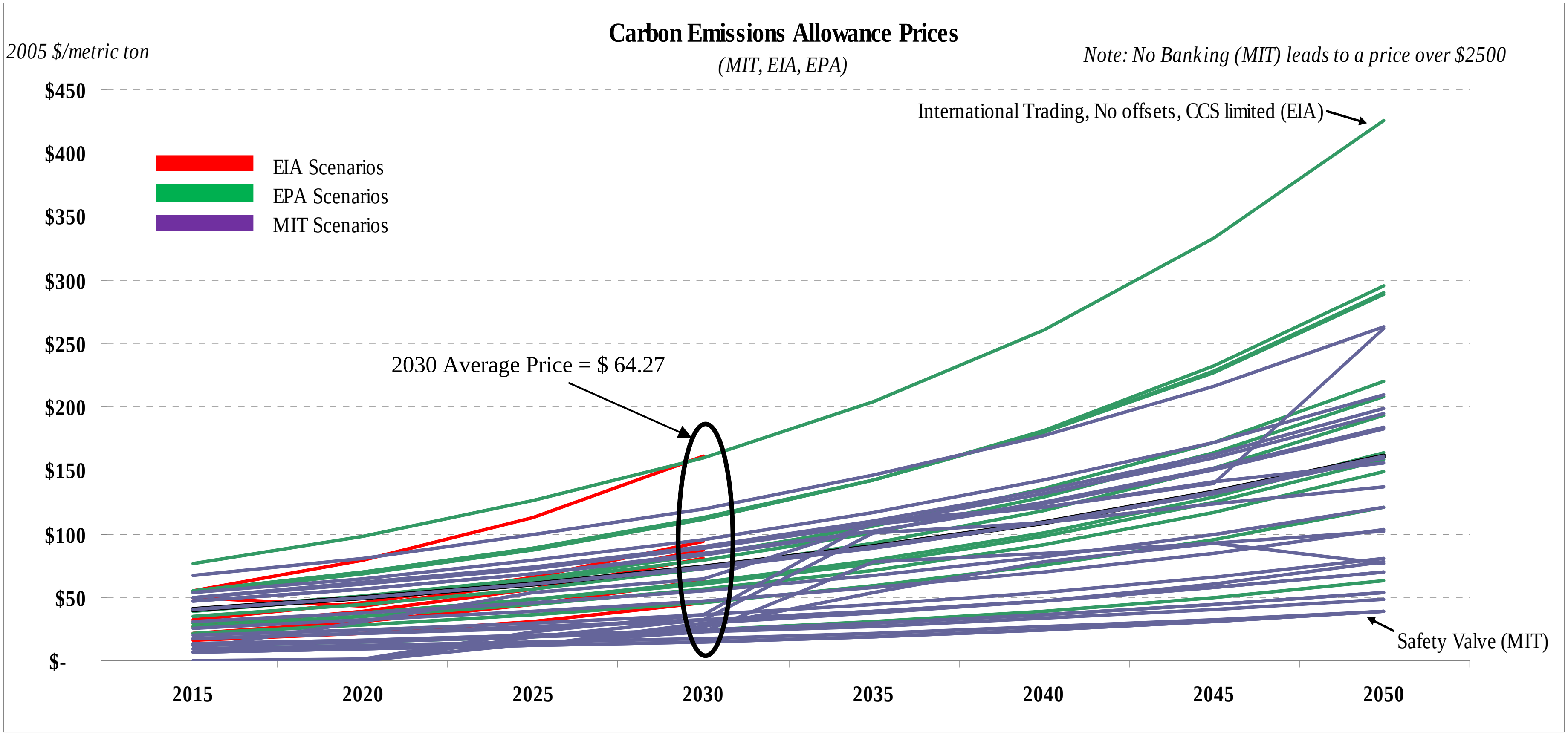
Carbon Prices

- Carbon prices in core scenarios range across models.
  - Generally prices increase with restrictions
  - Technology assumptions are crucial



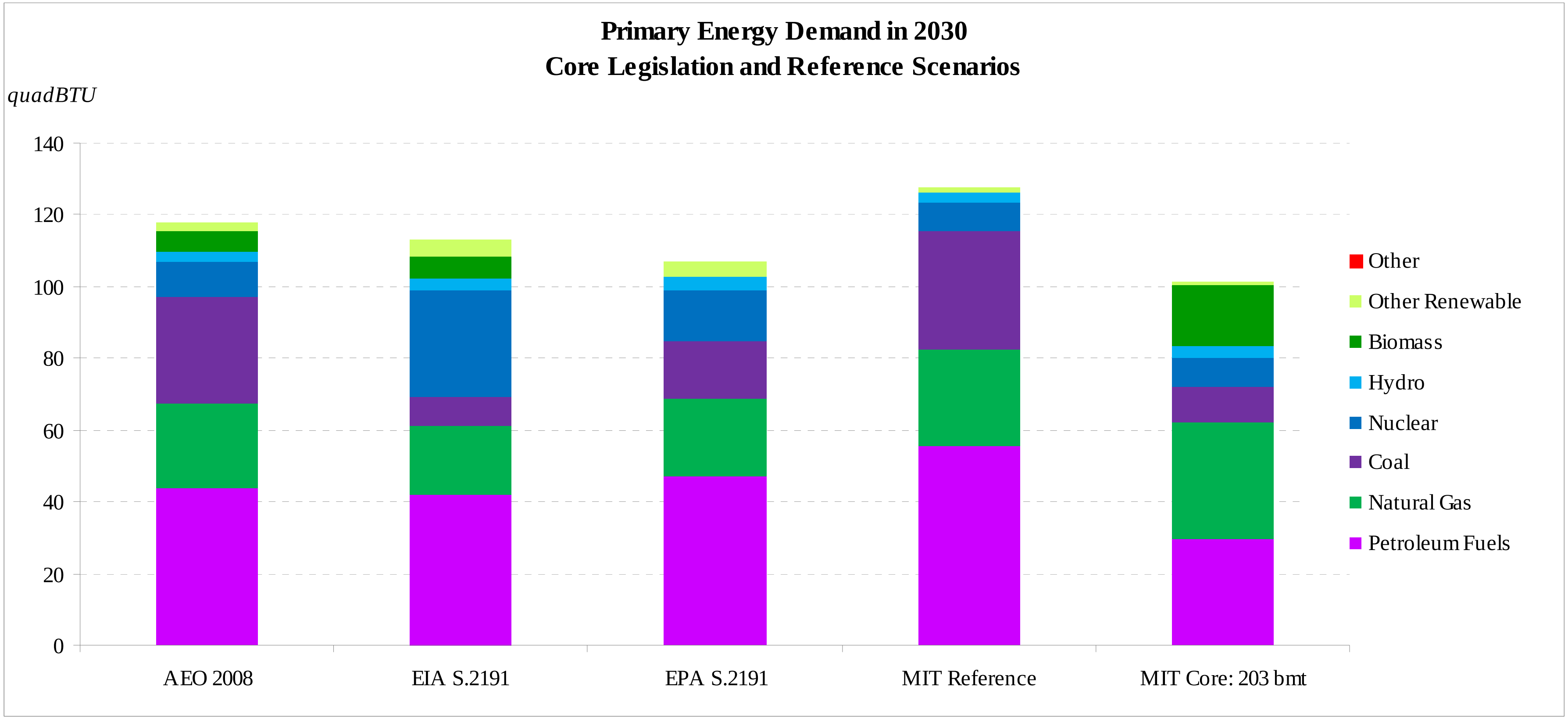
Carbon Prices (all cases)

- Carbon prices range significantly across scenarios.
  - Generally prices increase with restrictions
  - Technology assumptions are crucial



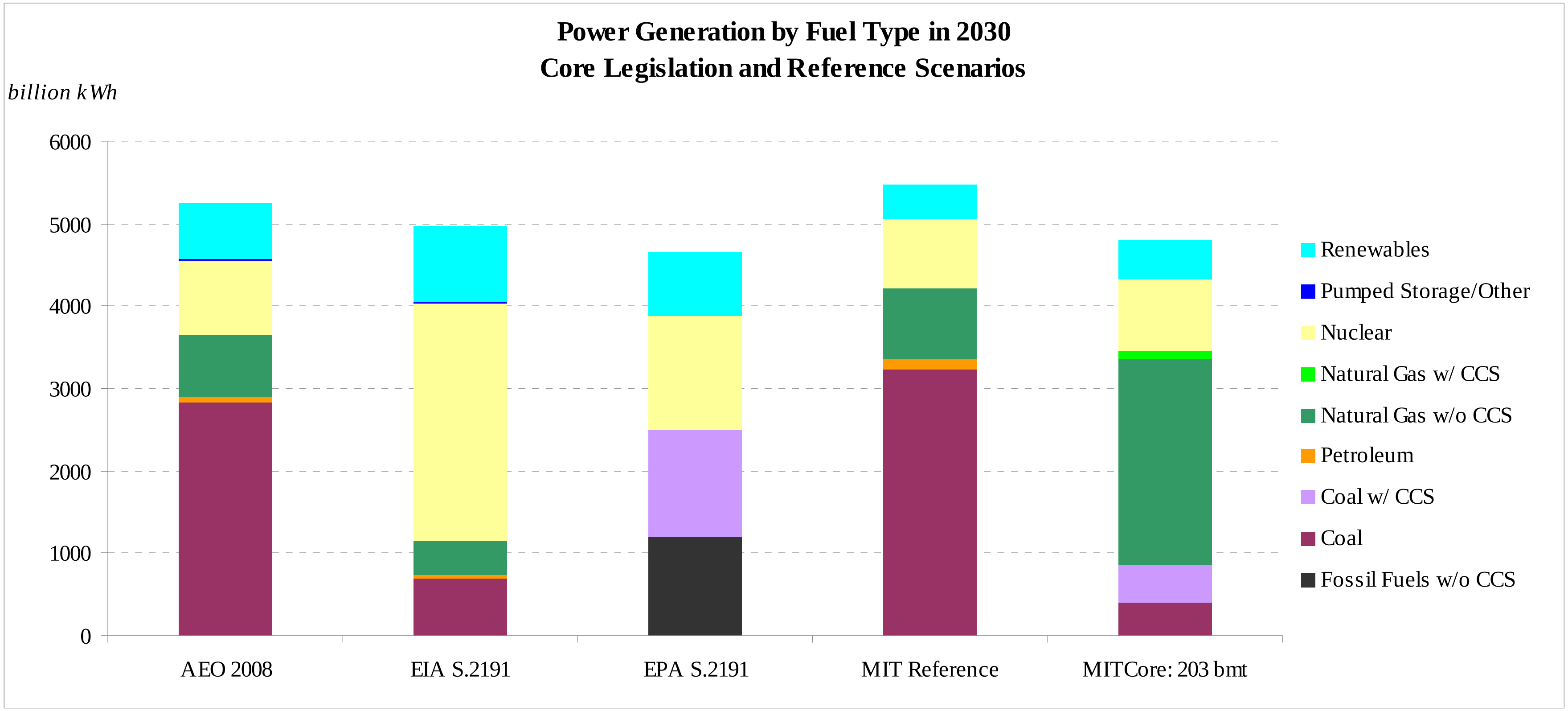
Energy Demand

- Models vary substantially
  - MIT reference growth and effects of legislation are strong; MIT response strong in biofuels and natural gas, with biofuels partially replacing oil in transport
  - EIA responds with strong growth in nuclear
  - EPA gains largely due to altered use of the same fuels



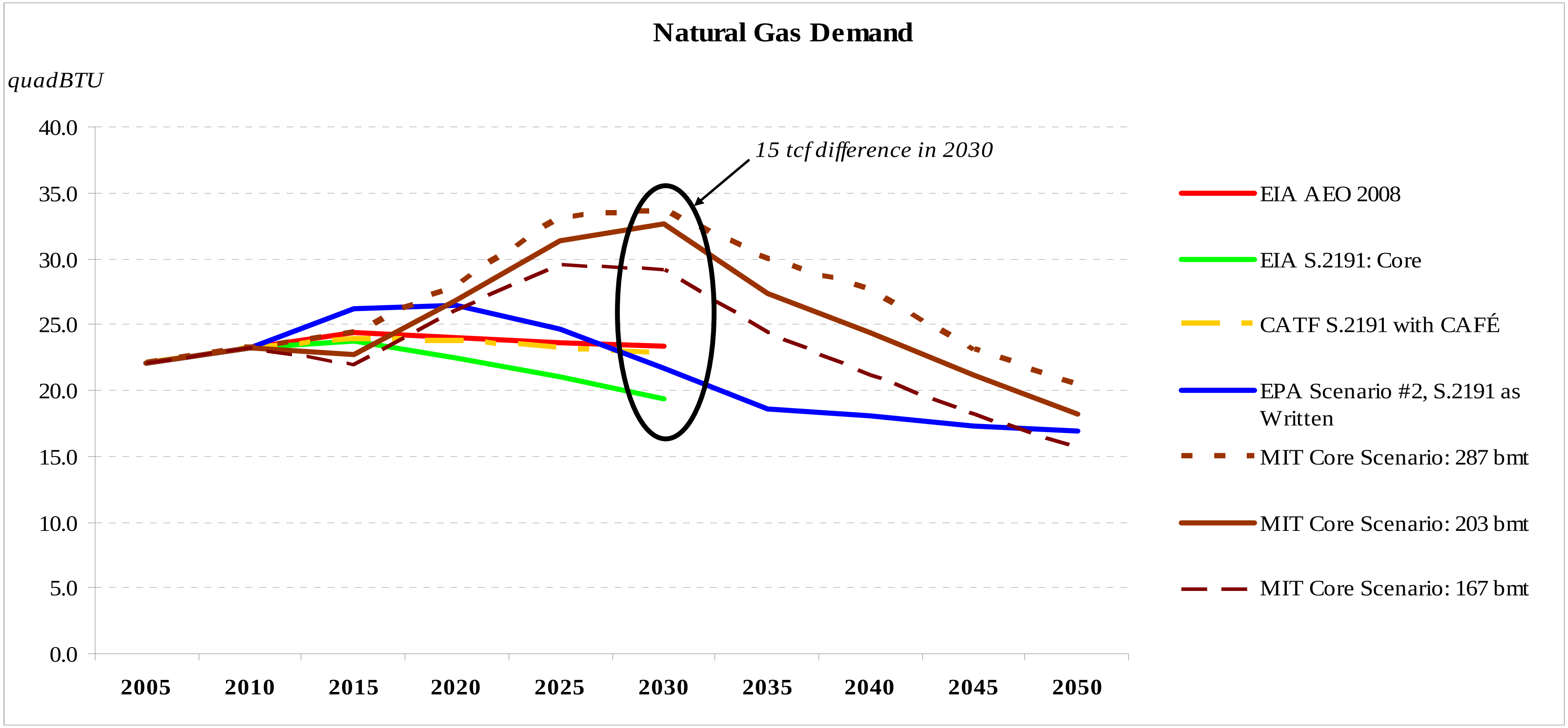
Power Generation by Source

- Significant differences across models.
  - All models see strong growth in renewables in all cases
  - MIT sees strong growth in natural gas to displace coal
  - EIA strong in nuclear
  - EPA only distinguishes “Coal w/ CCS” from “Fossil Fuels w/o CCS”



Natural Gas Demand

- Trends vary significantly, as does timing.
  - Strong relationship between natural gas demand, CCS technology availability and assumptions regarding nuclear power.



Work at BIPP (to date):
The Rice World *Energy* Model

Today's presentation

- Already completed some simple work focusing only on the global natural gas market
  - Scenarios regarding cost of alternatives can be analyzed
- Today we are going to discuss a simple model of the US energy market, which will later be extended as discussed above
  - The first step has been to construct a simple version of what will be regionalized and connected via trade. The US itself will be split into multiple regions to analyze the potential impact of regional CO_2 policies, should they emerge.
- We will also present some preliminary scenario analyses
  - Reference Case
  - CO_2 cap on upstream sectors
  - CO_2 cap on downstream sectors

Primary energy supplies

- Natural gas
  - Domestic (associated and unassociated), imported
  - Production and imports based on Reference case runs from the RWGTM
- Crude Oil
  - Domestic and imported
  - Also allow for imports of refined products
- Coal
  - Domestic and imported
- Electricity
  - Fossil Fuel
    - Coal, FO2, FO6, NGCC, NGCT; Each with CCS
  - Non-fossil fuel
    - Nuclear, Hydro, Wind, Biofuels/biomass, Solar, Geothermal
  - Imported electricity
- For now, the fossil fuel supplies are exogenous, but we will allow for intertemporally optimal production in the future (as in the RWGTM)

Fuel Conversion

- Refineries included in the model
  - Assumed a "smoothed LP" production function. Fit parameters using data on crude inputs, product outputs, oil prices and product prices
- Gas processing separates dry gas and NGLs
- Investment in coal-to-liquids technology is allowed.
- Electricity generators included using current thermal efficiencies
  - CTL plants also produce electricity in small amounts along with diesel & naptha
  - Distributed generation and co-generation are included
- For the moment, we assume new electricity generating plants have the heat rates given by the EIA for new plants built in 2007
  - In the future, we will allow for efficiency improvements
- We allow CO2 production to be limited in different ways
  - Permits that need to be purchased by primary energy producers
  - Permits that need to be purchased by downstream users
  - Investments in offset activities allowed
  - Later we will also allow for CO2 taxation as an alternative to permits

EIA future generation costs

- First analysis – New Power Plant Capital Costs (DOE Office of Fossil Energy)
- Next steps – Use industry sourced costs for these technologies (and others)

Technology	Total Overnight Cost in 2007 (2006 $/kW)	Variable O&M[5] (million 2006 $/kW)	Fixed O&M[5] (2006 $/kW)	Heat Rate in 2007[6] (BTU/kWh)	Heat Rate nth-of-a-kind (BTU/kWh)
Scrubbed Coal New[7]	1,534	4.46	26.79	9,200	8,740
Integrated Gasification Combined Cycle (IGCC)[7]	1,773	2.84	37.62	8,765	7,450
IGCC with CCS	2,537	4.32	44.27	10,781	8,307
Conventional Gas/Oil Combined Cycle	717	2.01	12.14	7,196	6,800
Advanced Gas/Oil Combined Cycle (CC)	706	1.95	11.38	6,752	6,333
Advanced CC with CCS	1,409	2.86	19.36	8,613	7,493
Conventional Combustion Turbine[8]	500	3.47	11.78	10,833	10,450
Advanced Combustion Turbine	473	3.08	10.24	9,289	8,550
Fuel Cells	5,374	46.62	5.50	7,930	6,960
Advanced Nuclear	2,475	0.48	66.05	10,400	10,400
Distributed Generation - Base	1,021	6.93	15.59	9,200	8,900
Distributed Generation - Peak	1,227	6.93	15.59	10,257	9,880
Biomass	2,798	6.53	62.70	8,911	8,911
MSW - Landfill Gas	1,897	0.01	111.15	13,648	13,648
Geothermal[7, 9]	1,110	0.00	160.18	35,376	33,729
Conventional Hydropower[9]	1,551	3.41	13.59	10,022	10,022
Wind	1,434	0.00	29.48	10,022	10,022
Wind Offshore	2,886	0.00	87.05	10,022	10,022
Solar Thermal[7]	3,744	0.00	55.24	10,022	10,022
Solar Photovoltaic[7]	5,649	0.00	11.37	10,022	10,022

Demand

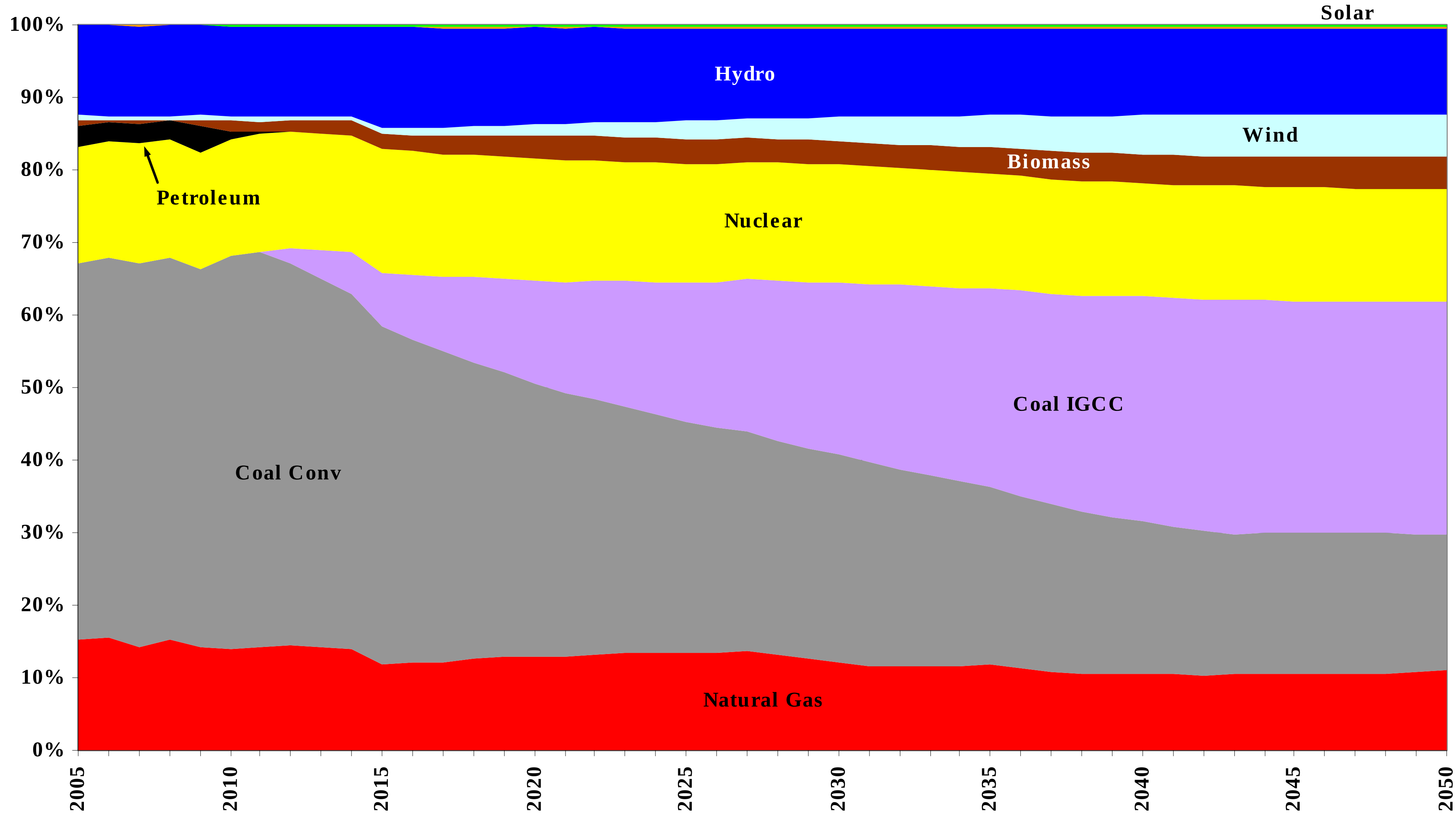
- Residential
  - Direct use
  - Electricity – grid and distributed generation
  - Electricity converted to direct use energy to allow for substitution of electric power for direct consumption
  - Direct use converted to electricity through distributed generation
- Commercial
  - Same options as residential sector
- Air transportation
  - Jet fuel & aviation kerosene
- Ground transportation
  - Gasoline, Diesel, natural gas, LPG, electricity
- Industry
  - Distillate, fuel oil, natural gas, LPG, coal, asphalt, electricity
  - Also allow conversions through co-generation, and electricity converted to direct use as in residential and commercial sectors

Reference Case

- $CO2$ unconstrained
- Key observations:
  - Fuel shares in electricity generation more or less remain unchanged, although IGCC replaces conventional coal over time
  - Wind and biomass also gain share in electricity generation over time.
  - In transportation, natural gas share grows at the expense of gasoline in the near term but shares then stabilize.
  - In residential and commercial, natural gas displaces heating oil.
  - Fuel prices generally rise over time to almost double their 2005 levels by 2040. Prices stabilize thereafter.

Reference Case (cont.)

- Fuel use in power generation, 2005-2050



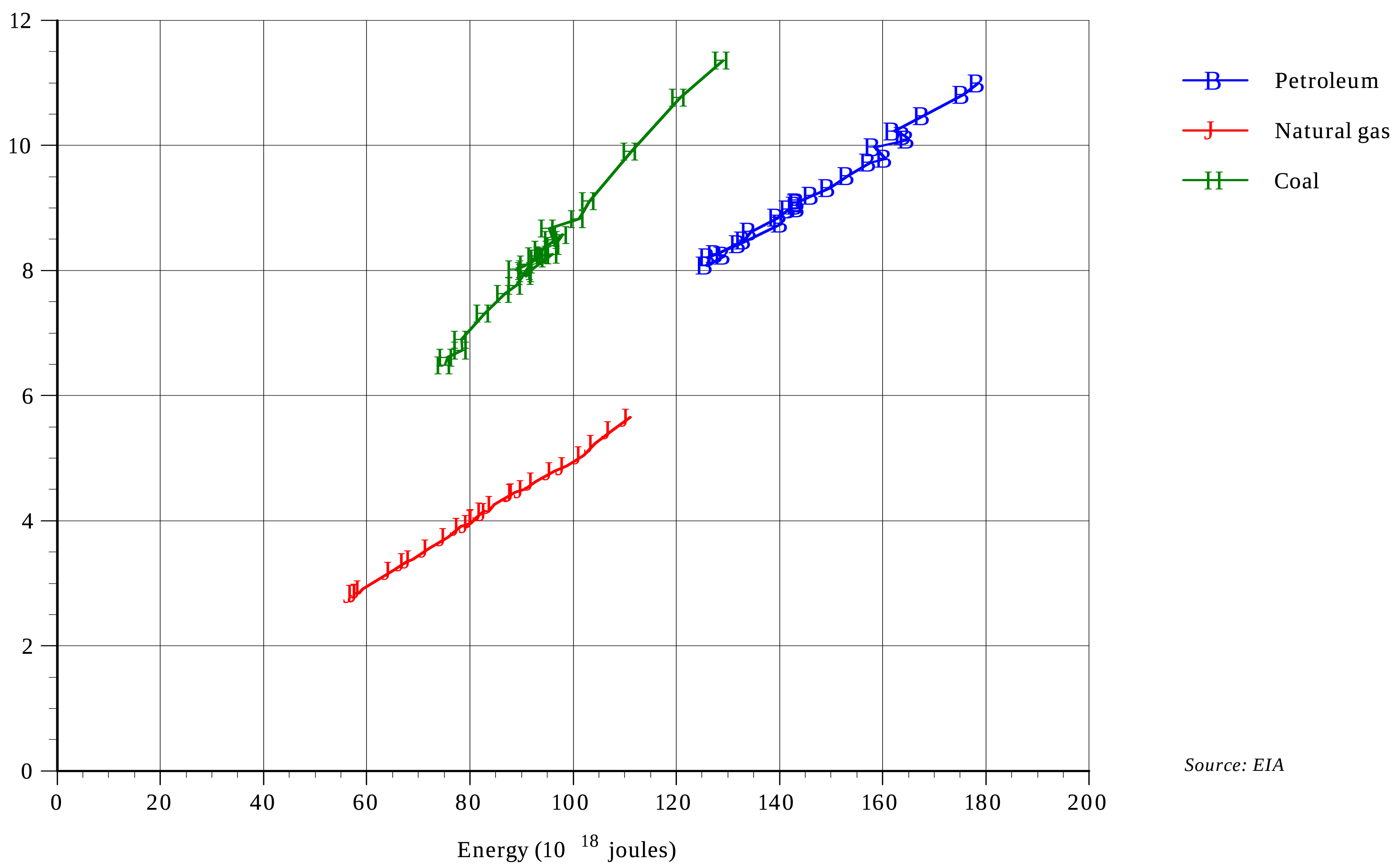
CO2 constrained with offsets

- Restrict total CO_2 allowances to the 2005 level from 2010-2100. Permit trading begins in 2010.
- However, we allow for investment in offsets
- Key observation:
  - Offset investments dominate other changes and the outcome does not look very different from the reference case

CO_2 permits *upstream*, no offsets

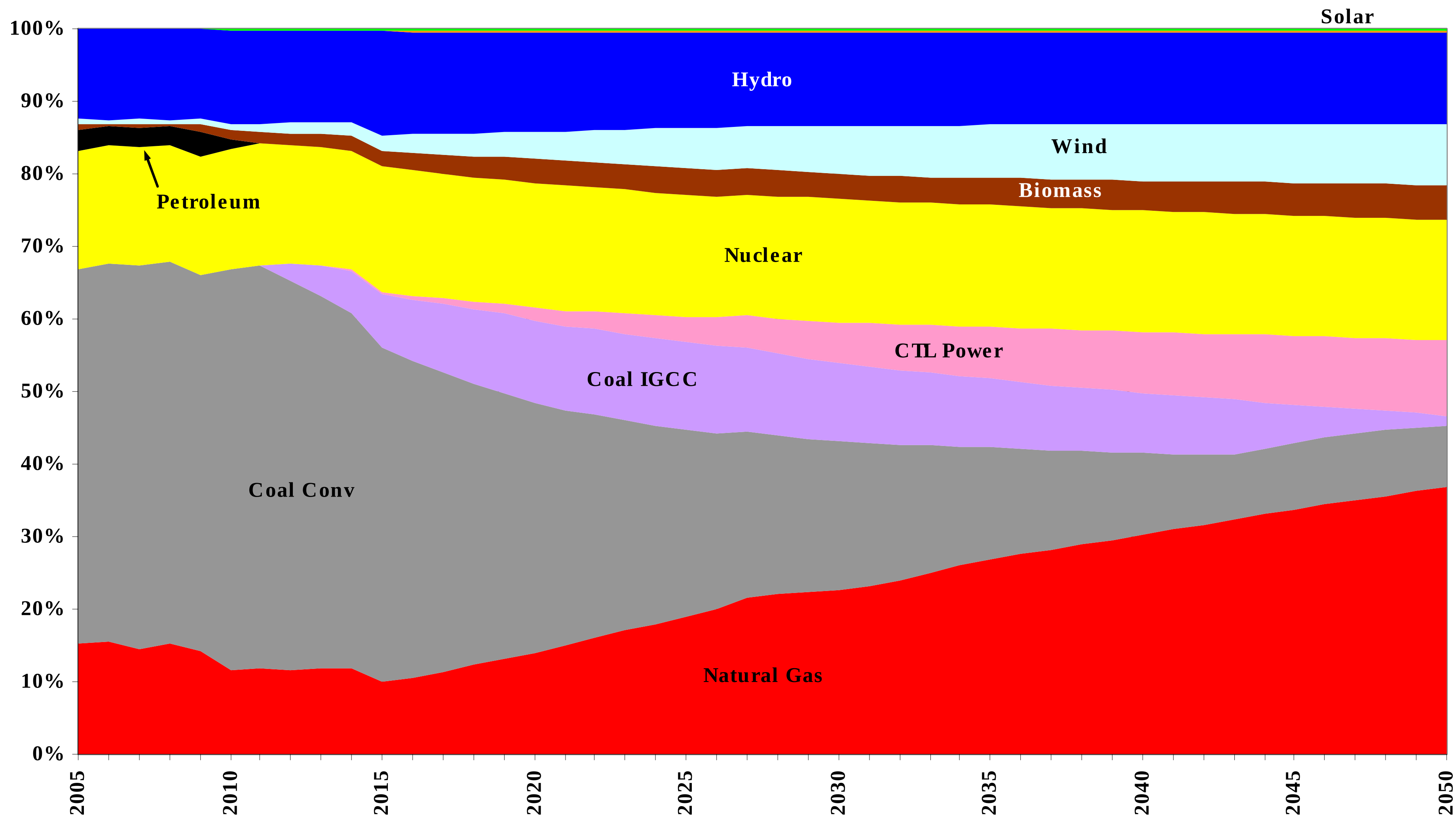
- Again, restrict CO_2 emissions to the 2005 level in the reference case from 2010-2100. Disallow investment in offsets.
- The basic idea is that the C/H ratio in the fossil fuel determines the ultimate amount of CO_2 emitted, not how the fuel is ultimately used.
  - See figure next slide
- Key observations:
  - Natural gas displaces coal in electricity generation
  - Less IGCC is built, conventional coal gradually falls, as in the base case
  - Coal use in transportation via CTL increases, with increased electricity production as a by-product
  - Diesel displaces gasoline in transportation, while natural gas increases much less and LPG grows somewhat more
  - Heating oil share initially falls in the commercial and residential sectors but regains market share as natural gas is used more for electricity generation

CO2 intensity of fossil fuels



CO2 Permits Upstream (cont.)

- Fuel use in power generation, 2005-2050

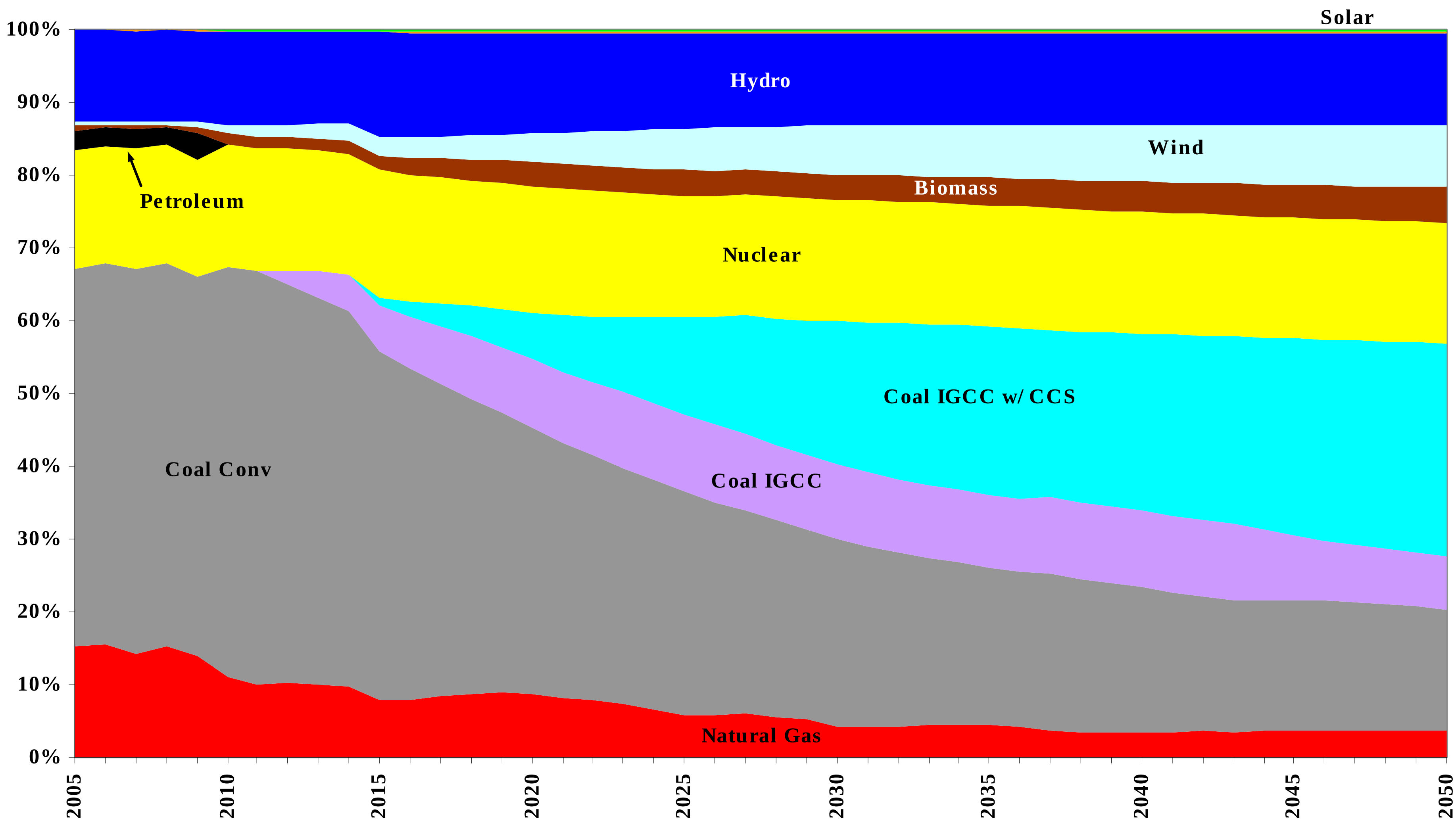


CO_2 permits *downstream*, no offsets

- Again, restrict CO_2 emissions to the 2005 level in the reference case from 2010-2100. Disallow investment in offsets.
- Now we require electricity generators, industry and refiners (on behalf of customers) to buy permits
- Key distinctions with previous case:
  - CO_2 emissions based on fuel type, not energy type
  - Plants with CCS do not need to buy permits
- Key observations:
  - Coal share in electricity generation looks more like the base case, but replacement of depreciating conventional coal is mostly by IGCC with CCS rather than IGCC
  - Coal is displaced by natural gas and residual fuel oil in industrial sector
  - CTL is never developed.
  - Natural gas again is used more in transportation, displacing gasoline
  - Natural gas again almost completely displaces heating oil in residential and commercial direct use

CO2 Permits Downstream (cont.)

- Fuel use in power generation, 2005-2050



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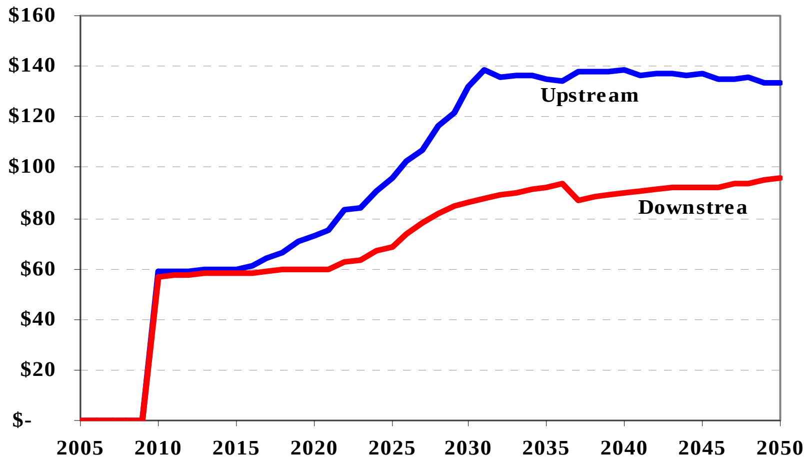
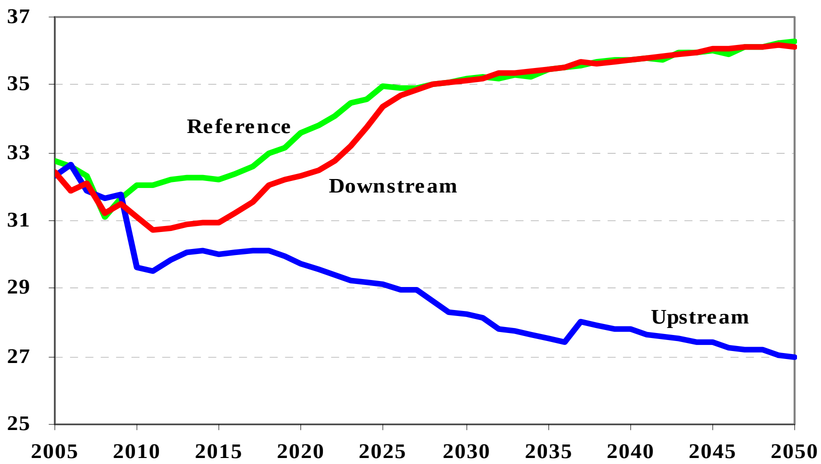
Some Data for Case Comparisons

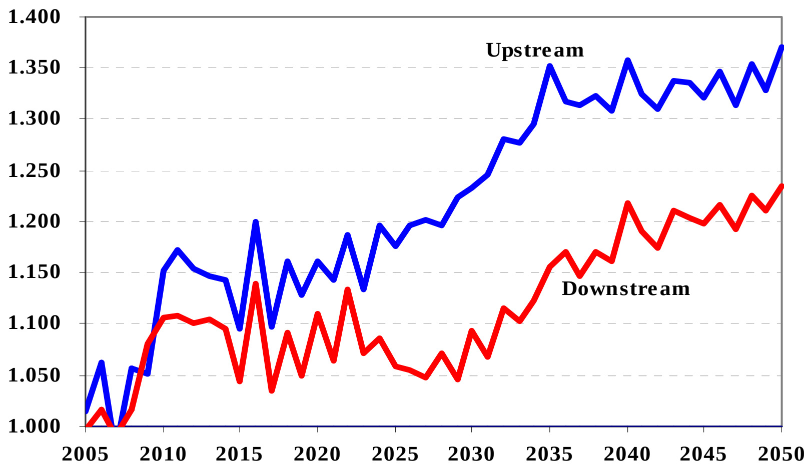
CO2 Price, 2005-2050



Refinery Throughput, 2005-2050



NG Relative Price, 2005-2050



Data sources

- At the moment, EIA and RWGTM for natural gas
- We will use USGS resource assessments for oil, gas, and coal
- IEA data for countries outside of the US.
- Disaggregate industry into sub-sectors to allow for more explicit accounting of fuel use and hence CO2 permits allocations.
- Big hole:
  - We would like better data on industry costs…
- Study done at Southern States Energy Board (Gray, 2008) on coal-to-liquids technology

Future steps in modeling

- Expand to a *global* model, with regional interaction
- Fossil fuel supply based in geology
  - Development of supply is based on capital recovery. Thus, anything that alters the profitability of supply within any period will alter the intertemporal investment decision of the project developer.
- Risk-adjusted discount rates that may be capital specific, technology specific, etc. We will consider different discount rates as a sensitivity.
- We will also consider least cost approaches to dealing with climate change
  - Abatement is not the only option. Mitigation of consequences is also part of the conceptual framework.

Comments/Discussion