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

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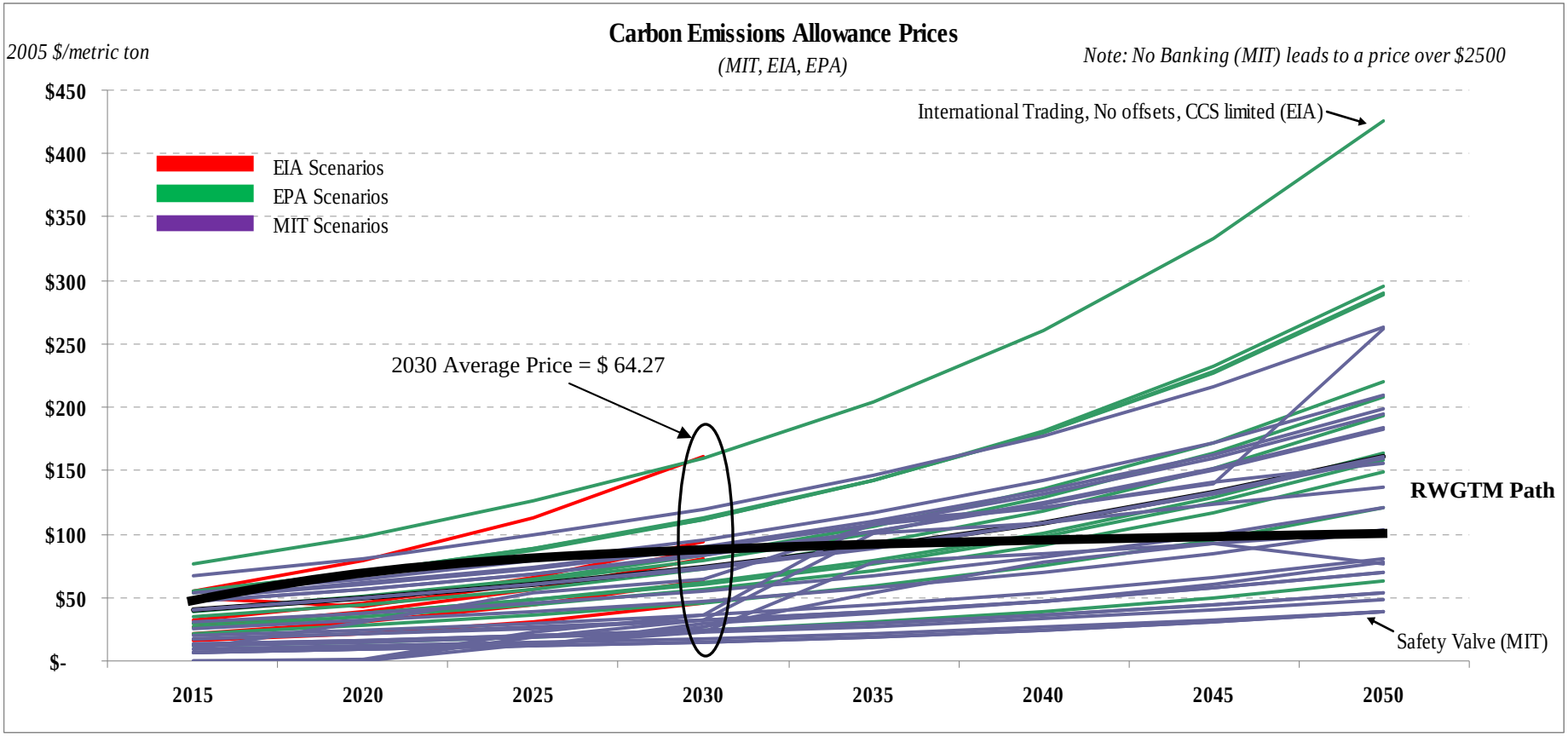
Study Scope

- Currently, we are expanding the RWGTM to explicitly account for:
  - Explicit competition among fuels
  - Trade in industrial output and electricity
  - Substitution possibilities in transportation
- 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.
  - How do various policies influence the issue of carbon leakage?
- Today, we will discuss several model-related issues. We will first recall the basic implications for carbon price and fuel demands from our previous work...

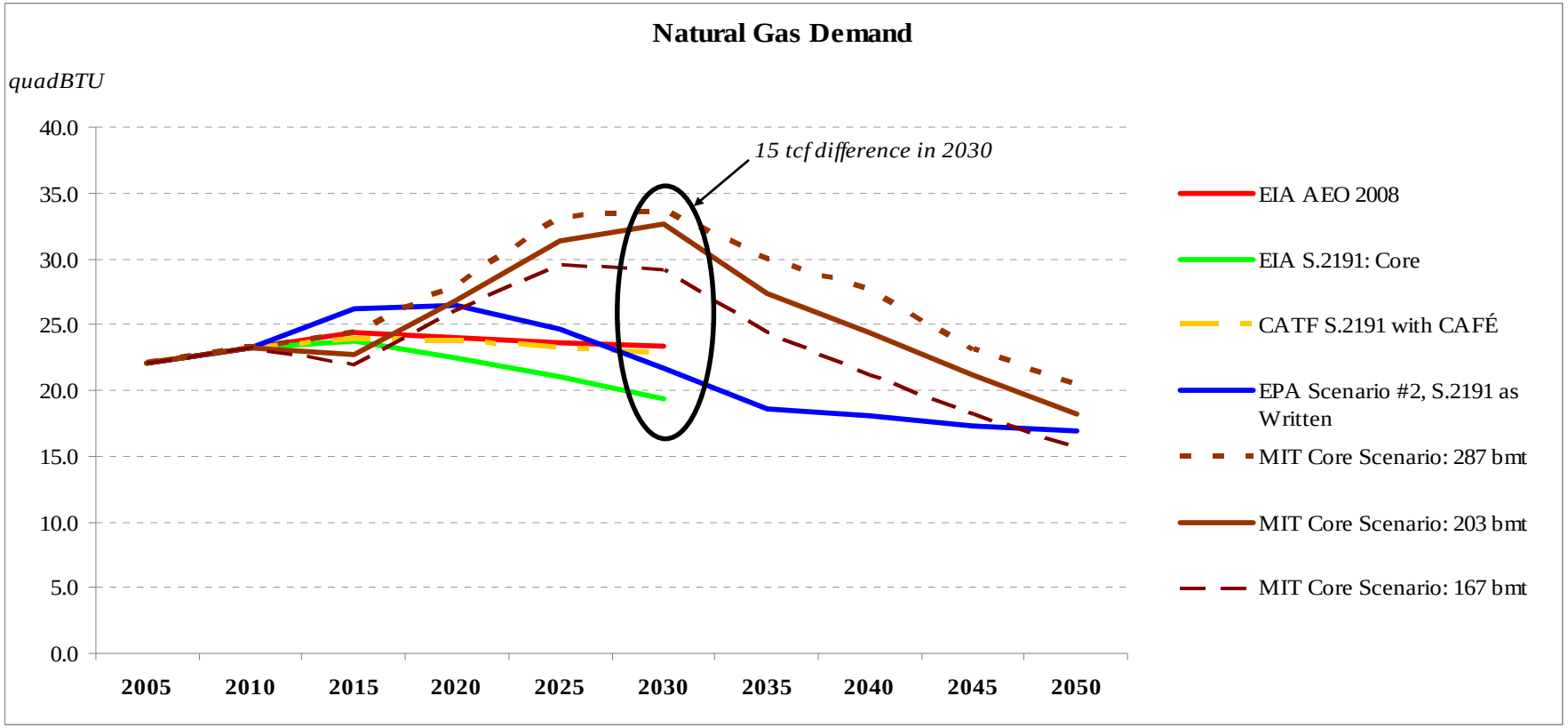
Carbon Prices (Other Model outputs)

- Carbon prices range significantly across scenarios.
  - Generally prices increase with restrictions
  - Rice model indicates prices needed to encourage investments in alternative.



Natural Gas Demand

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

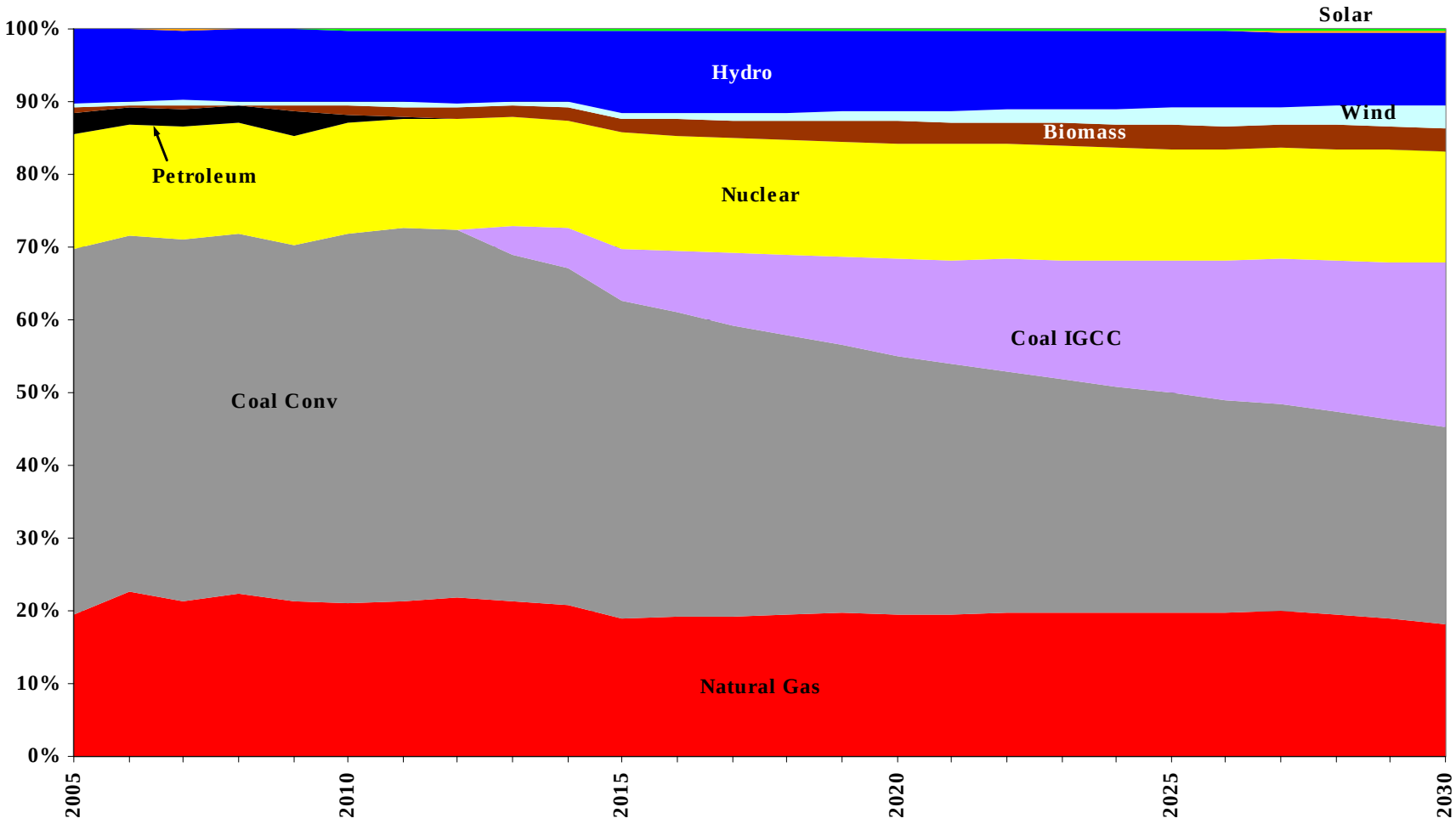


Reference Case

- 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.

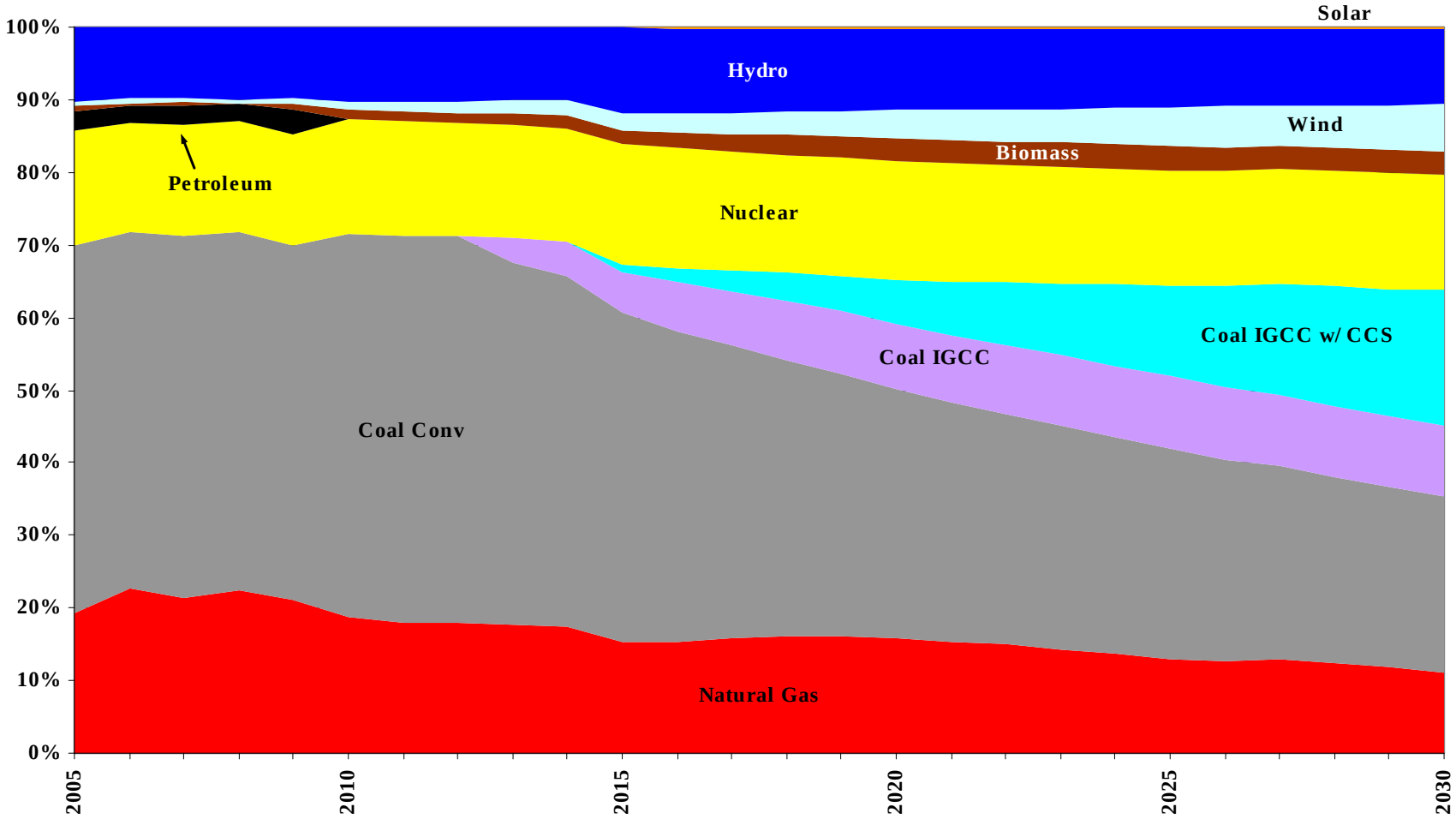
Reference Case (cont.)

- Fuel use in power generation, 2005-2030



CO2 Constrained (Downstream)

- Fuel use in power generation, 2005-2030

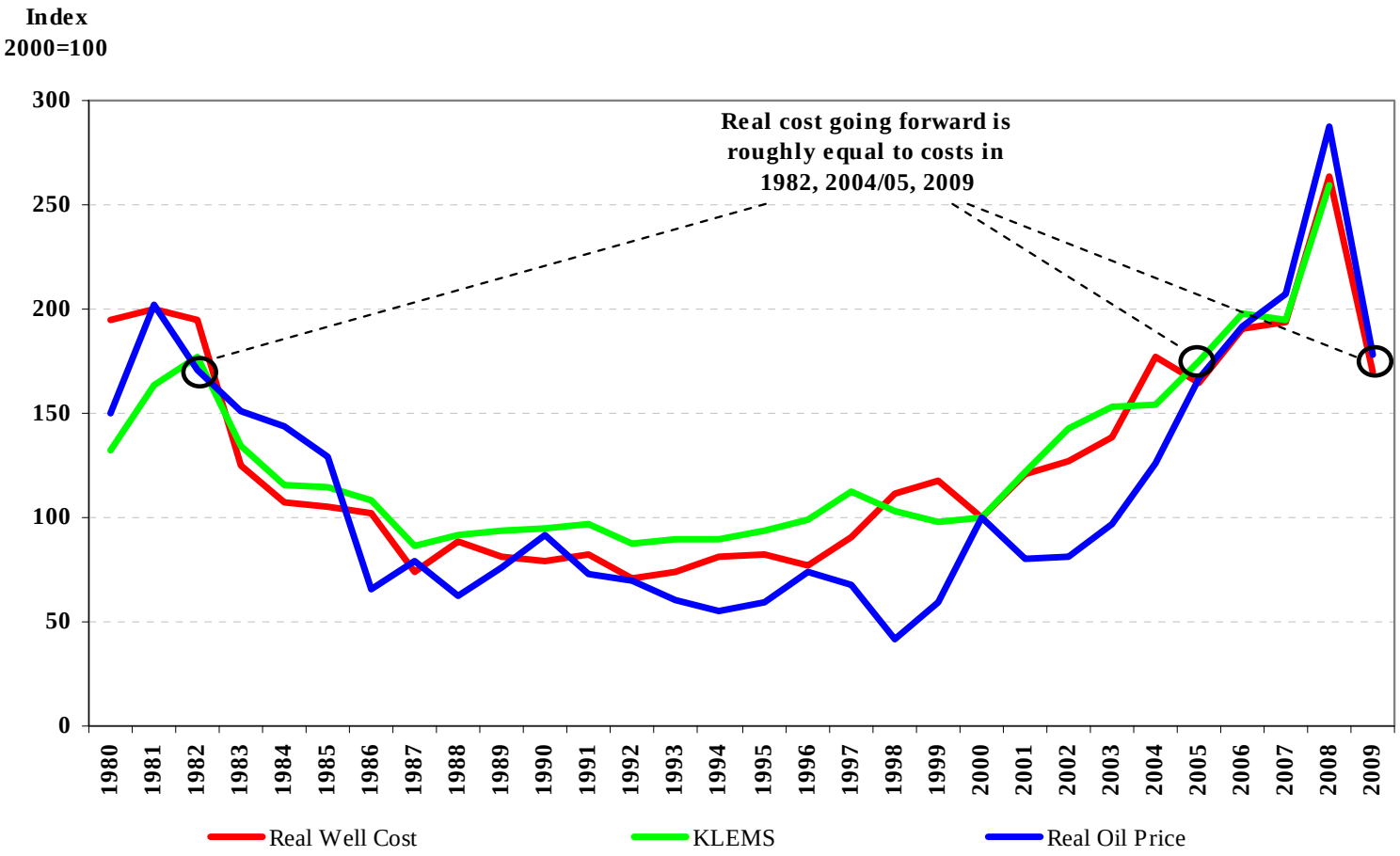


Discussion Items

- Long Run F&D Costs… what is the appropriate reference point?
- Capex for Generation types, CTL, CCS and Alternative Energy
- Views on shale, flow/decline rates, costs, etc.
  - Current inputs
- Economic outlook
- Industrial demand relocation… “carbon leakage” issue.
  - Composition of load… what is exportable?
- Discussion of wind and other renewables for gas and electricity
- Approach to liberalization in European PL market/Russian domestic market. Model or not?
- When will investments begin to grow substantially in Iraq? Current view is 2015.
- When do backstops become relevant? Discuss the impact of R&D and the expected rate of innovation. Modeling to inform.
- What form of CO2 constraint should be modeled? Should we model scenarios or do we want to predict policy. What sort of issues do you see looming?

Long Run F&D Cost

- Index to oil price… we currently assume a long run price of $60 to establish costs



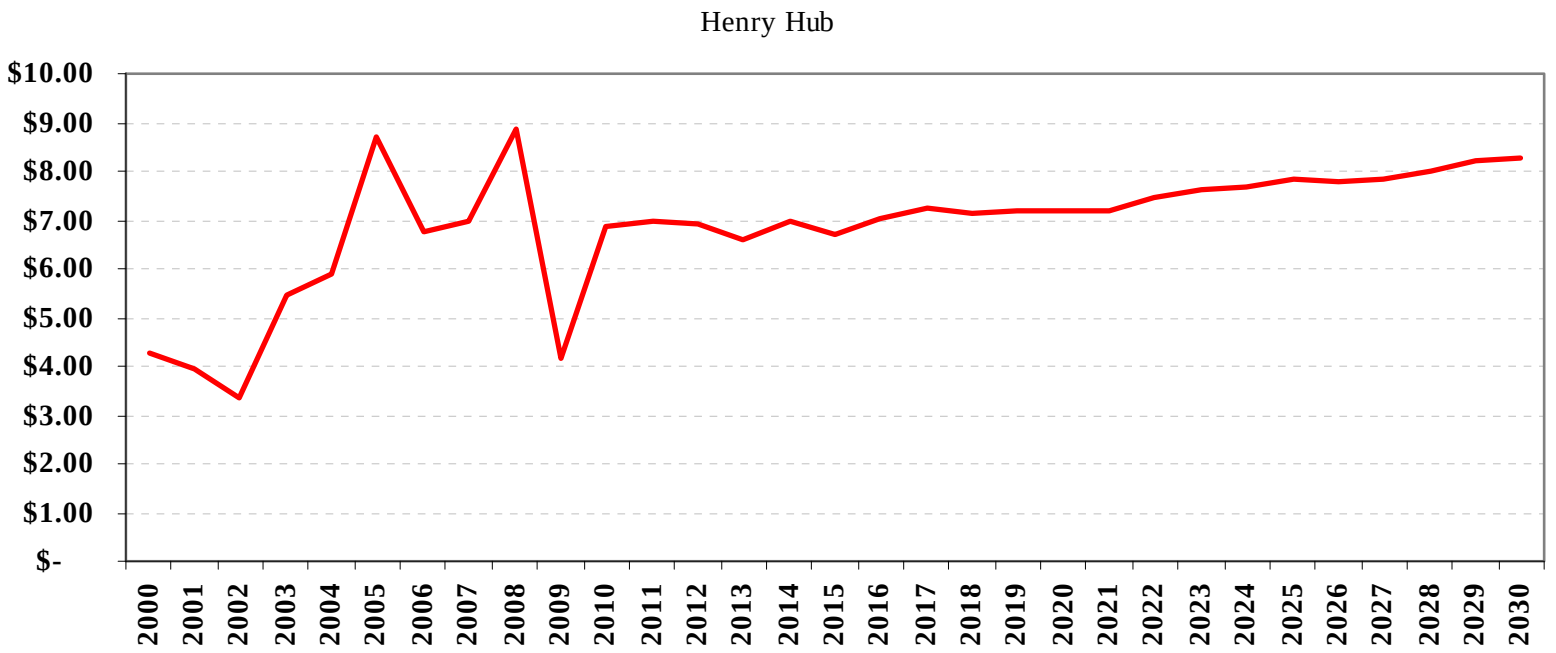
Capital Costs

- Capital costs for Generation Sources
  - Two scenario tracks defined by DOE costs in one and industry-vetted costs in the other
  - In general, industry-vetted = 1.8 x DOE... is this a myopic view?

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

Selected Regional Natural Gas Prices

- Increased trade leads to price differentials that reflect transport differentials
- NBP over HH by about 30 cents... (this is the result of shale)
- Longer term prices at Henry Hub (averages)
  - 2010-2020: $ 6.98 2021-2030: $ 7.79



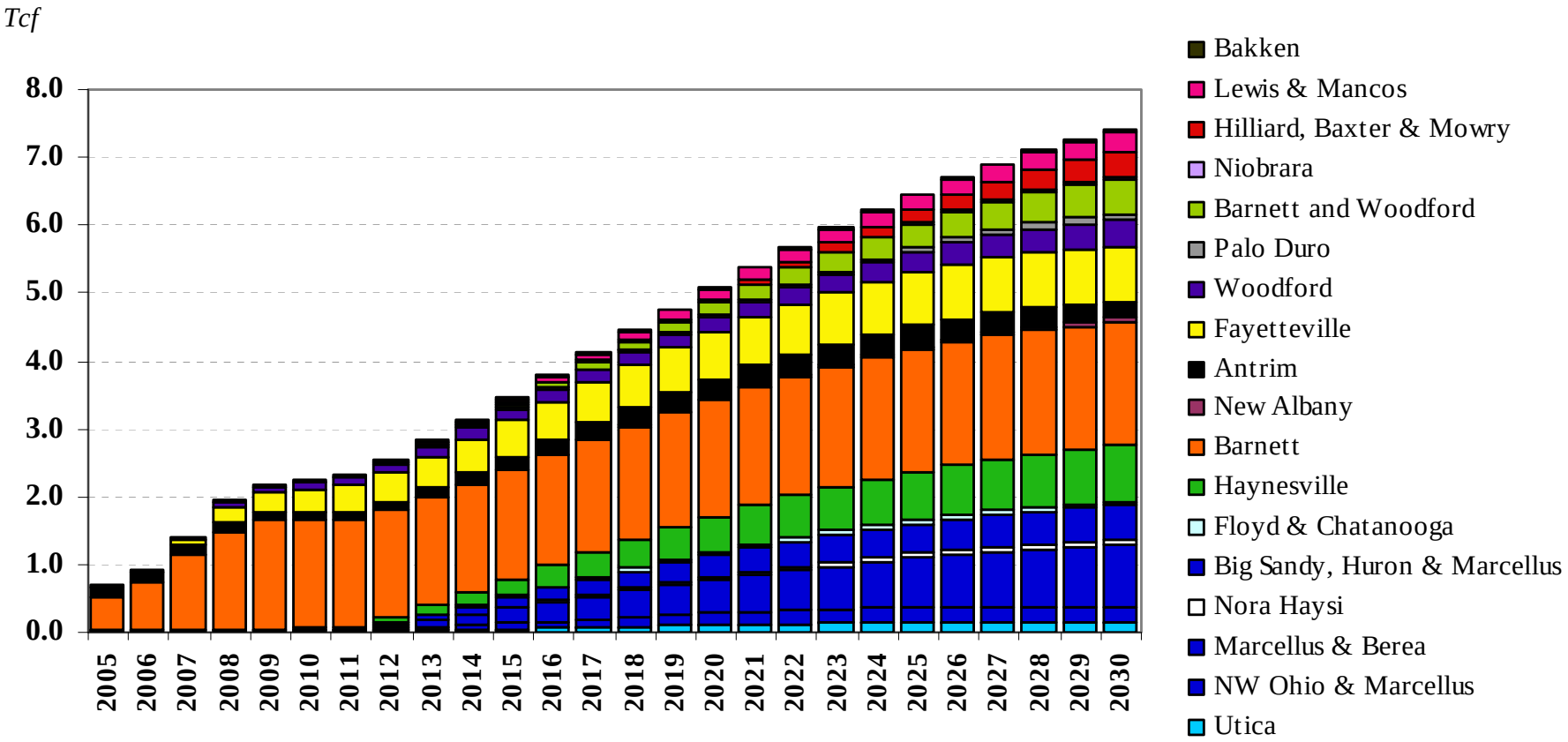
Shale gas

- Resource assessment is large. Cost curves assume about 80% of the resource is available at the associated "break-even" price.
- However, short run pressures can push cost in any given period higher.
- Costs have been falling, and may yet continue. Recent estimates from the PGC exceed current estimates in the model.

	Mean Technically Recoverable Resource	Breakeven Price
Antrim	13.2	$ 6.50
Devonian/Ohio	169.6	
Utica	5.4	$ 7.00
Marcellus	134.2	
Marcellus T1	47.0	$ 5.75
Marcellus T2	42.9	$ 6.50
Marcellus T3	44.3	$ 7.00
NW Ohio	2.7	$ 7.25
Devonian Siltstone and Shale	1.3	$ 7.25
Catskill Sandstones	11.7	$ 7.25
Berea Sandstones	6.8	$ 7.25
Big Sandy (Huron)	6.3	$ 6.50
Nora/Haysi (Huron)	1.2	$ 7.25
New Albany	3.8	$ 7.25
Floyd/Chatanooga	2.1	$ 6.50
Haynesville	90.0	
Haynesville T1	36.0	$ 4.75
Haynesville T2	31.5	$ 5.75
Haynesville T3	22.5	$ 6.75
Fayetteville	36.0	$ 5.25
Woodford Arkoma	8.0	$ 6.00
Woodford Ardmore	4.2	$ 6.00
Barnett	54.0	
Barnett T1	32.2	$ 4.50
Barnett T2	21.8	$ 6.00
Barnett and Woodford	35.4	$ 7.00
Palo Duro	4.7	$ 7.00
Lewis	10.2	$ 7.25
Bakken	1.8	$ 7.50
Niobrara (incl. Wattenburg)	1.3	$ 7.25
Hilliard/Baxter/Mancos	11.8	$ 7.25
Lewis	13.5	$ 7.25
Mowry	8.5	$ 7.25
Montney	30.0	$ 6.00
Horn River	50.0	$ 5.25
Utica	10.0	$ 7.00
Total US Shale	468.0	
Total Canadian Shale	90.0	
Total North America	558.0	

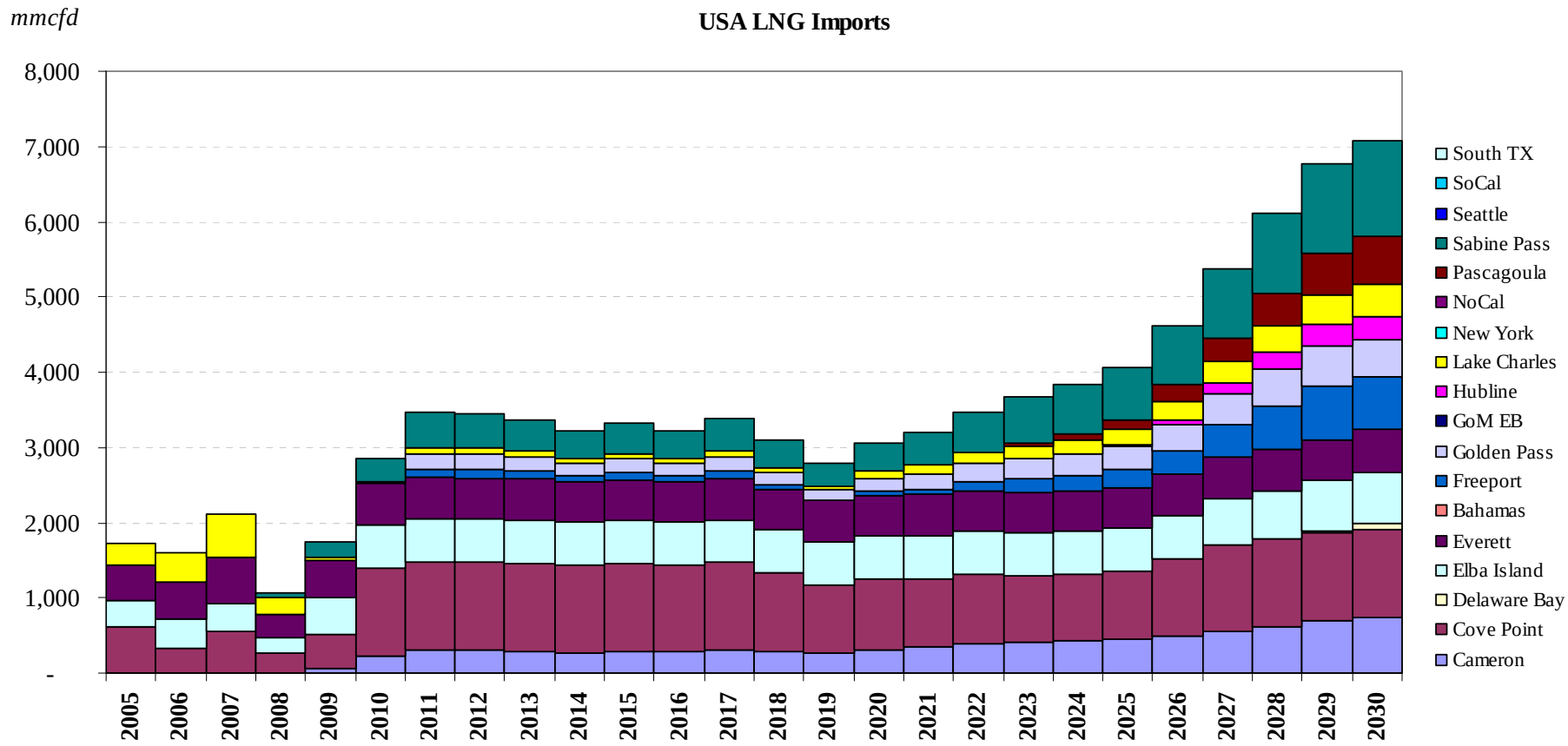
Shale Production

- 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.



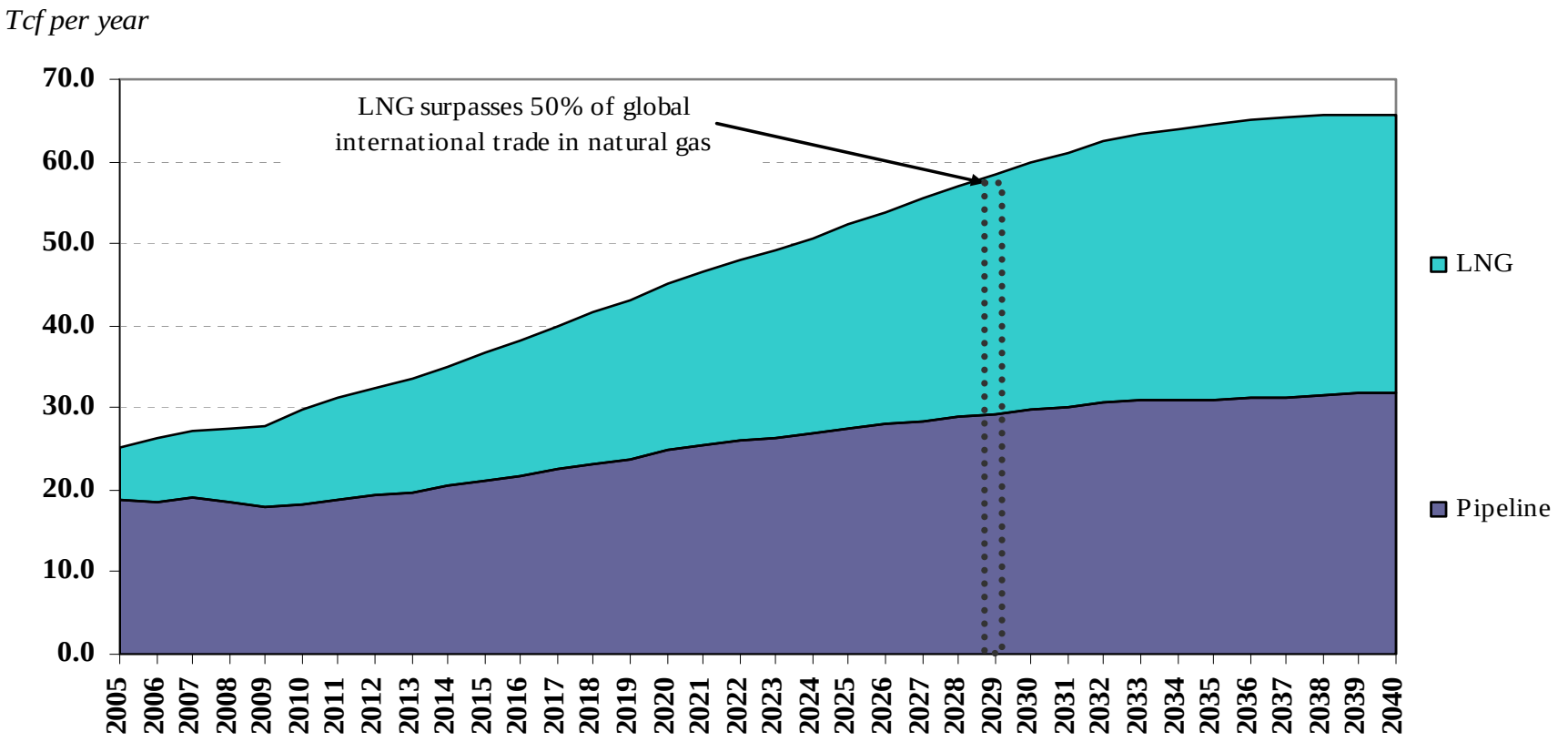
LNG Imports to the US

- Growth out of 2008 but stagnant from 2011-early 2020s. Low annual load factors on LNG regas facilities.



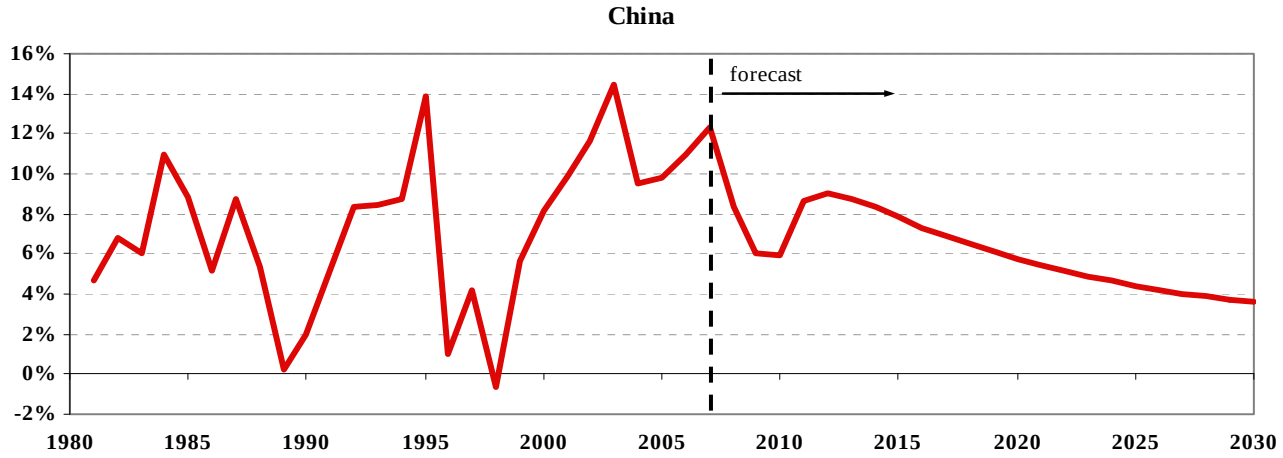
Global Gas Trade: LNG vs. Pipeline

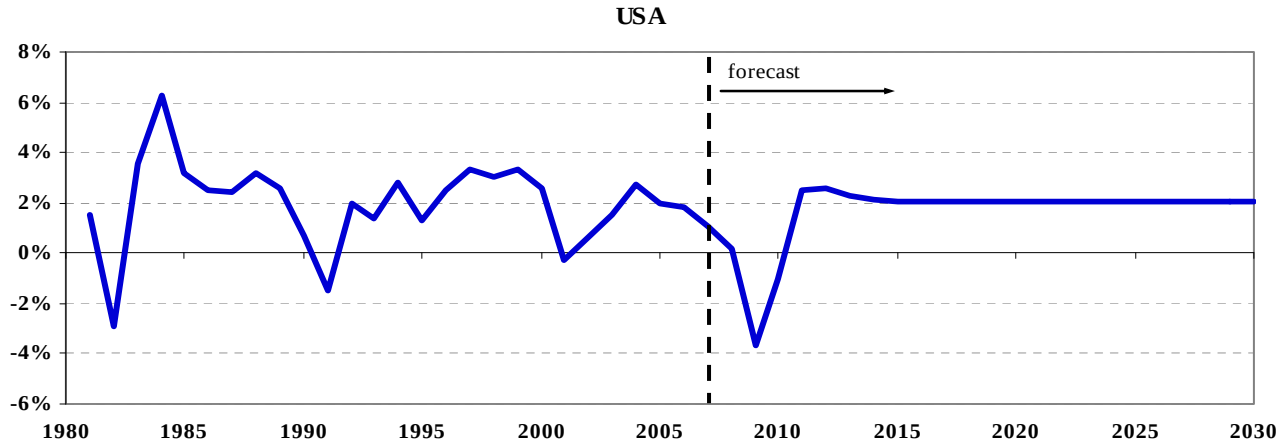
- LNG growth is strong, reaching about 50% of total international natural gas trade by the late 2020s.
  - This date moves under different scenarios, but the pace of growth in LNG is generally stronger than pipeline trade.



Economic Growth

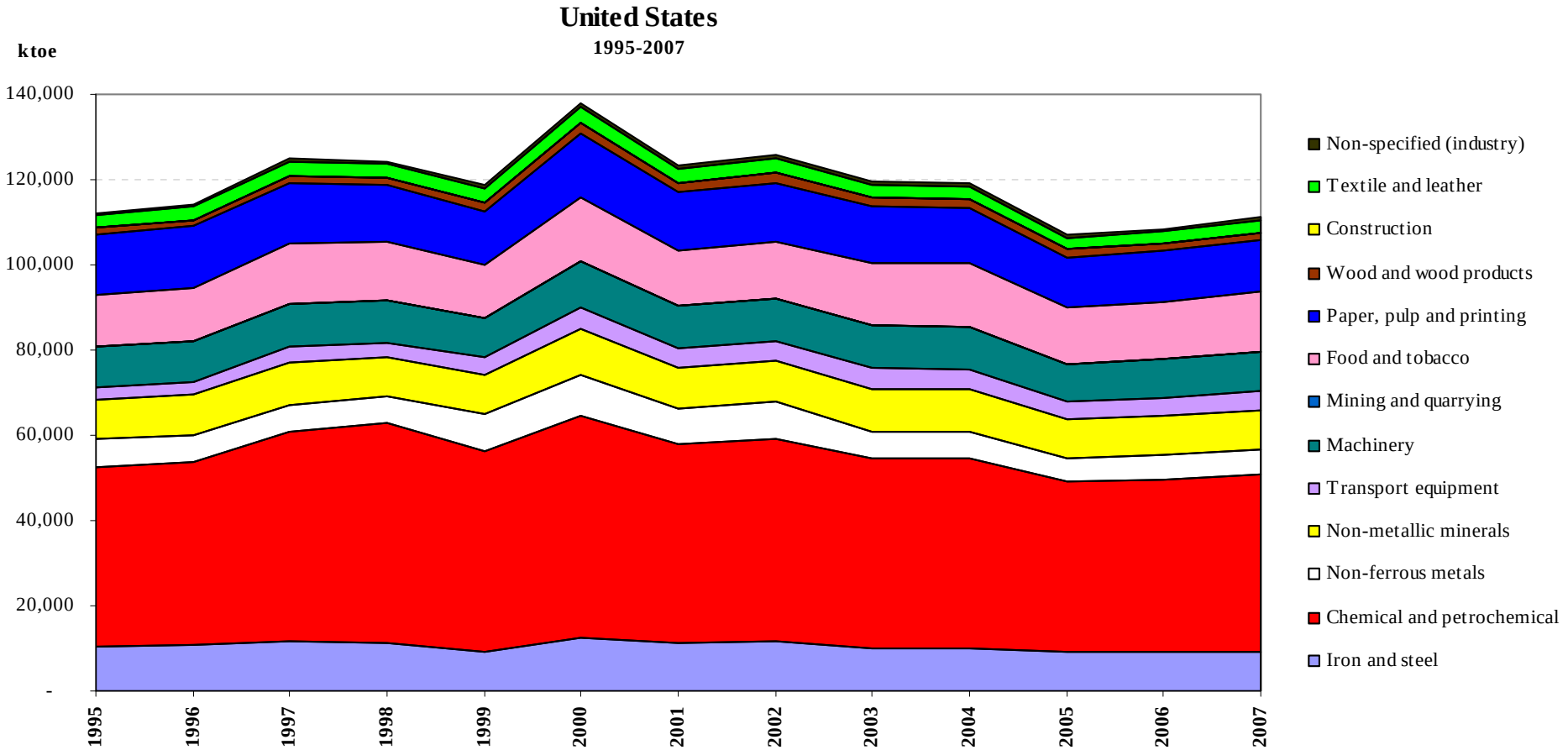
- Current economic and financial crisis is incorporated. We use the IMF June '09 outlook for growth through 2014 for all countries. Beyond 2014, growth is governed by a model of conditional convergence.





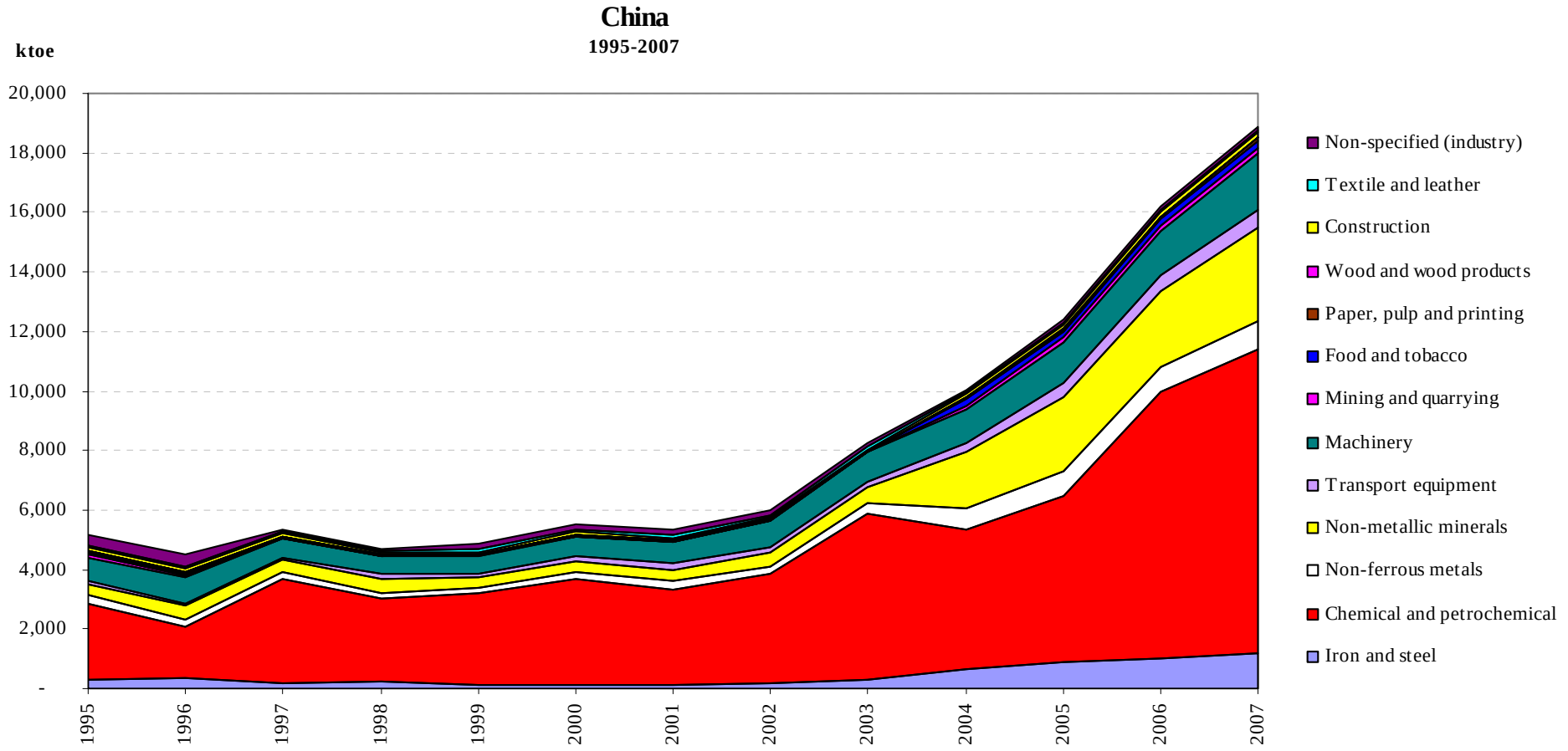
Industrial gas demand

- Will incorporate model of industrial output to capture extent of relocation… the "carbon leakage" issue. Key question, what load is "exportable"?
  - Data Sources: UN trade data (Comtrade Database) and IEA Energy Balances



Industrial gas demand (cont.)

- Where will load go?
  - We are analyzing the trade databases to discern any changes in the flow of trade in gas-intensive industries.



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