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

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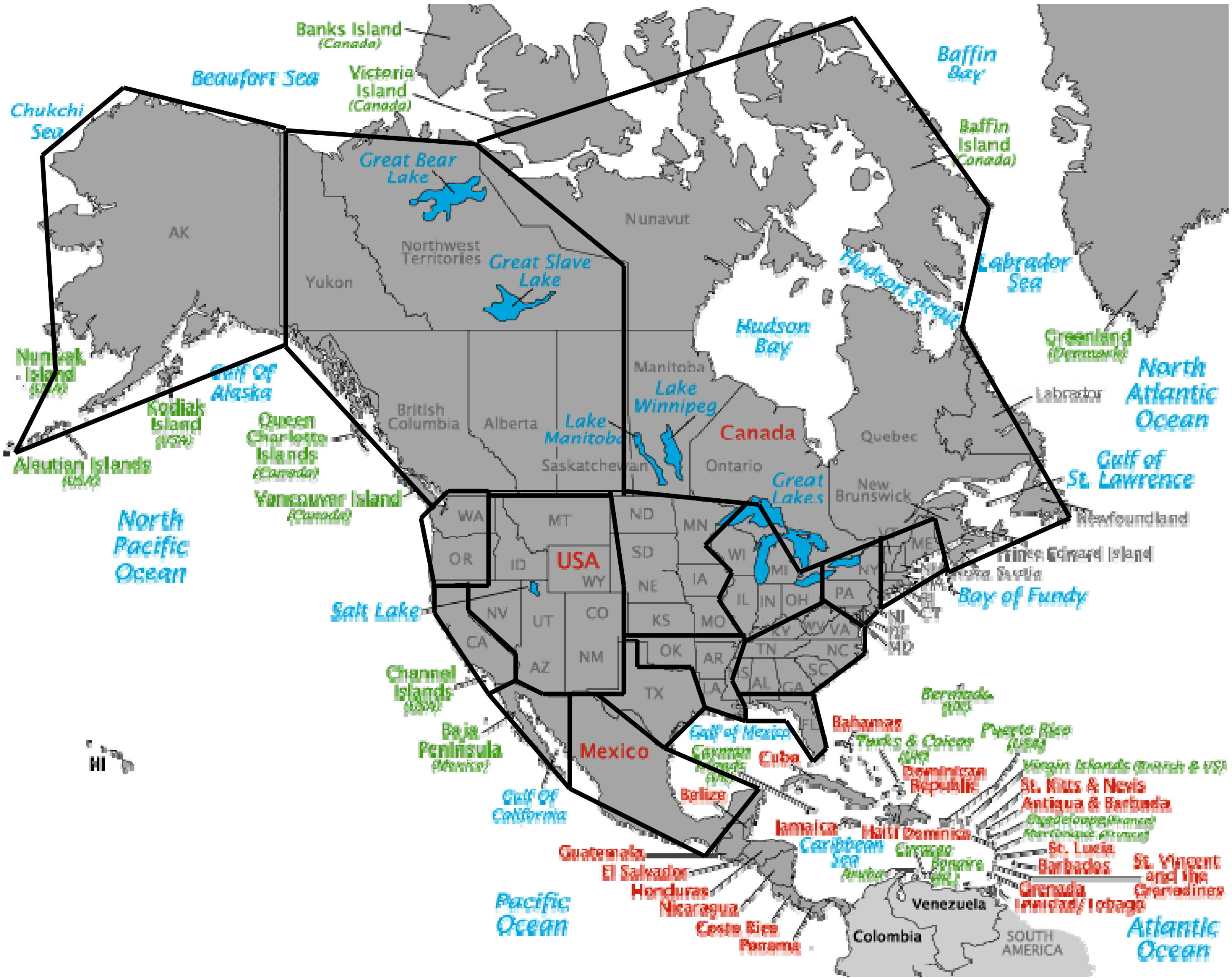
Study Scope

- Currently, we are regionalizing the RWEM 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?

Progress to Date

- North America
  - US split into regions to model likelihood of a regional cap-and-trade system.
    - Examples of Regional Programs: RGGI, WCI, Midwest
  - Industry demand broken into sectors so that “mobile” demand can be modeled. This allows an assessment of carbon leakage issue.
    - Mobile sectors are: Chemicals,
  - Supply and trade opportunities are also highlighted. Can identify movement of fuels and relative production advantages.
  - Not fully calibrated, with a complete set of results.
- Regional North America in an international context
  - Utilized the GTAP database to regionalize and define various industry groupings. Industry separated into “core” and “non-core” so that carbon leakage issue can be identified.
  - Used model of economic growth and the evolution of energy intensity to project future demands. Model solved demands deviate from this projection as a function of price.

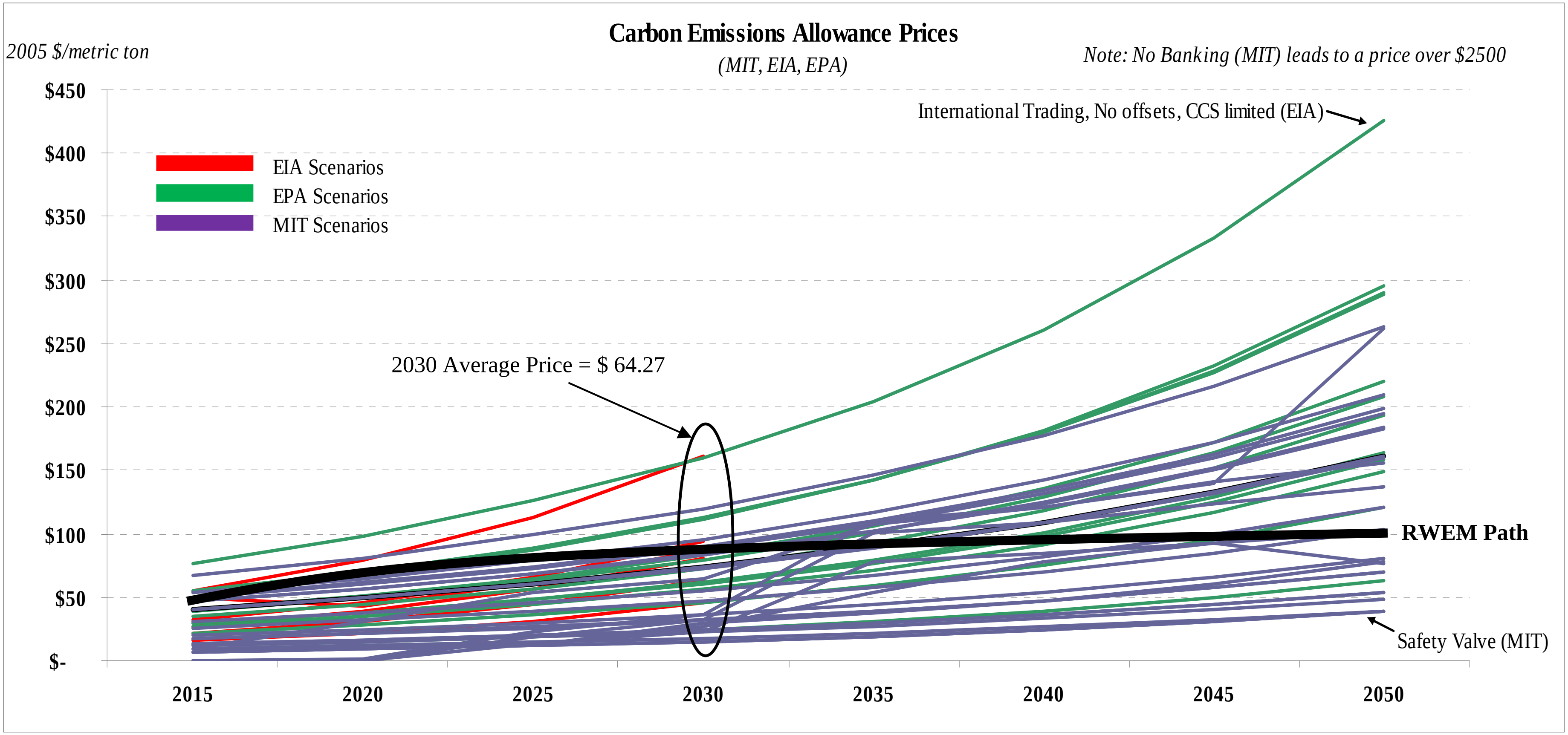
North American Regions



Some Basic Model Results

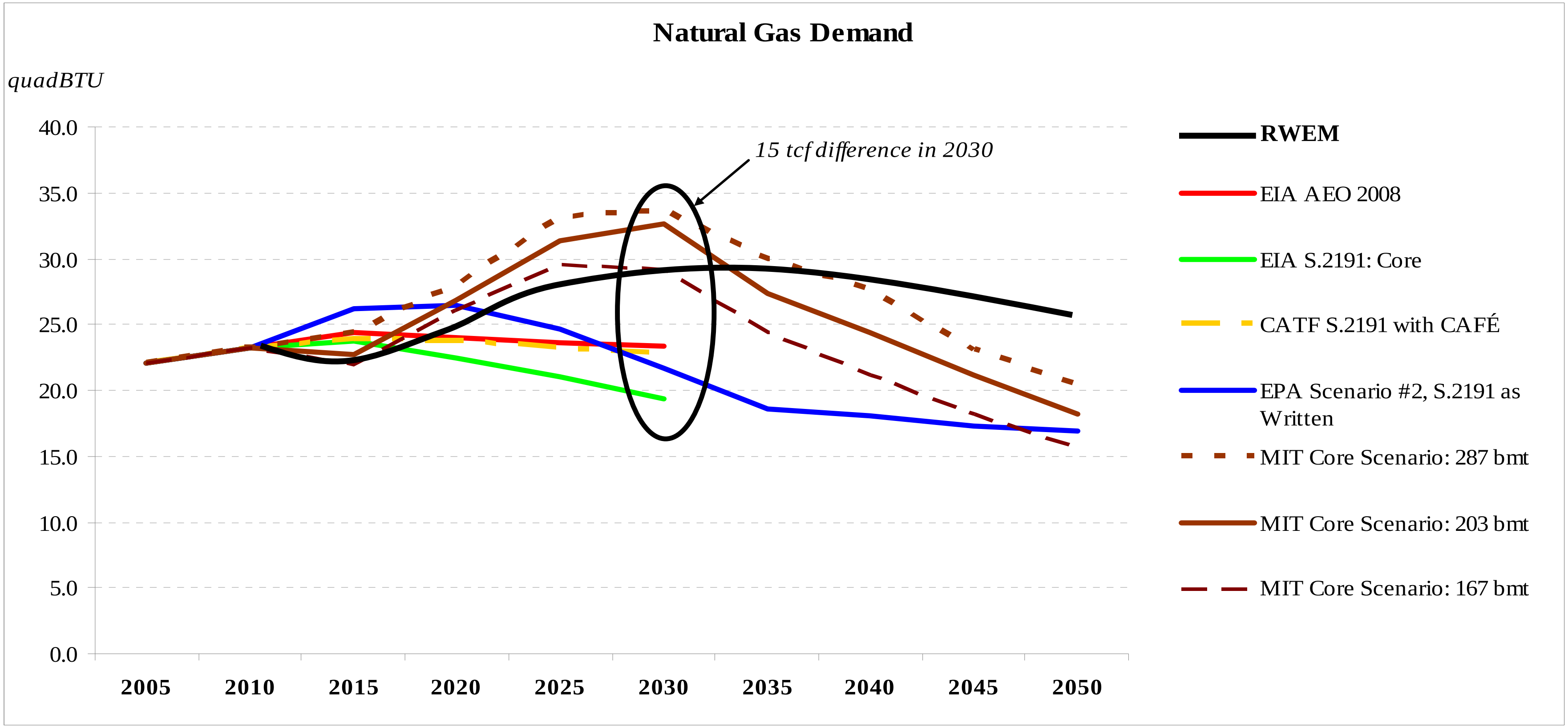
Carbon Prices (Various Model Outputs)

- Carbon prices range significantly across models and scenarios.
  - Generally prices increase with restrictions
  - Rice model reflects price needed to encourage investment in other technologies.



Natural Gas Demand (Various Model Outputs)

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

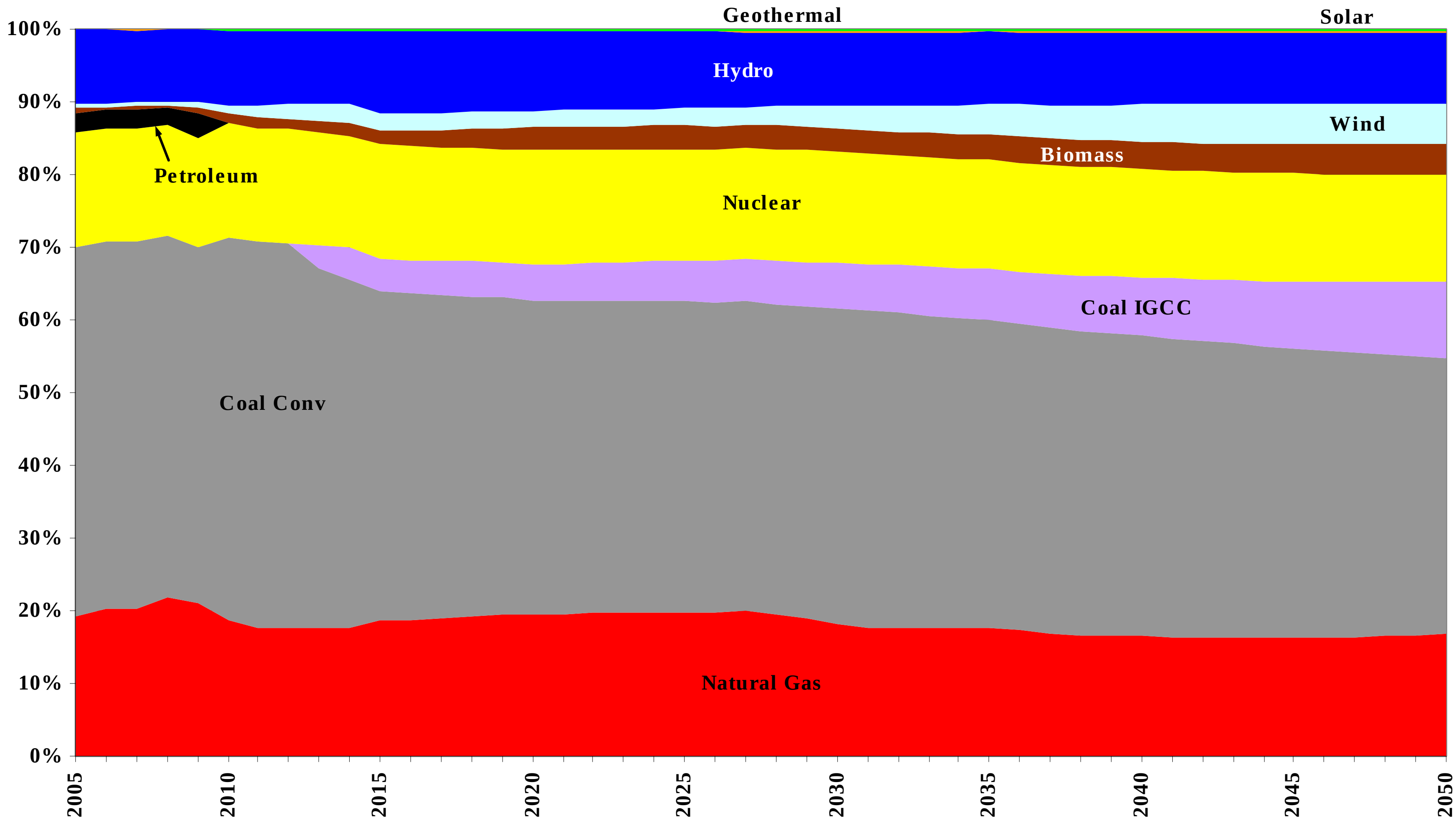


RWEM Reference Case (business as usual)

- CO_2 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.

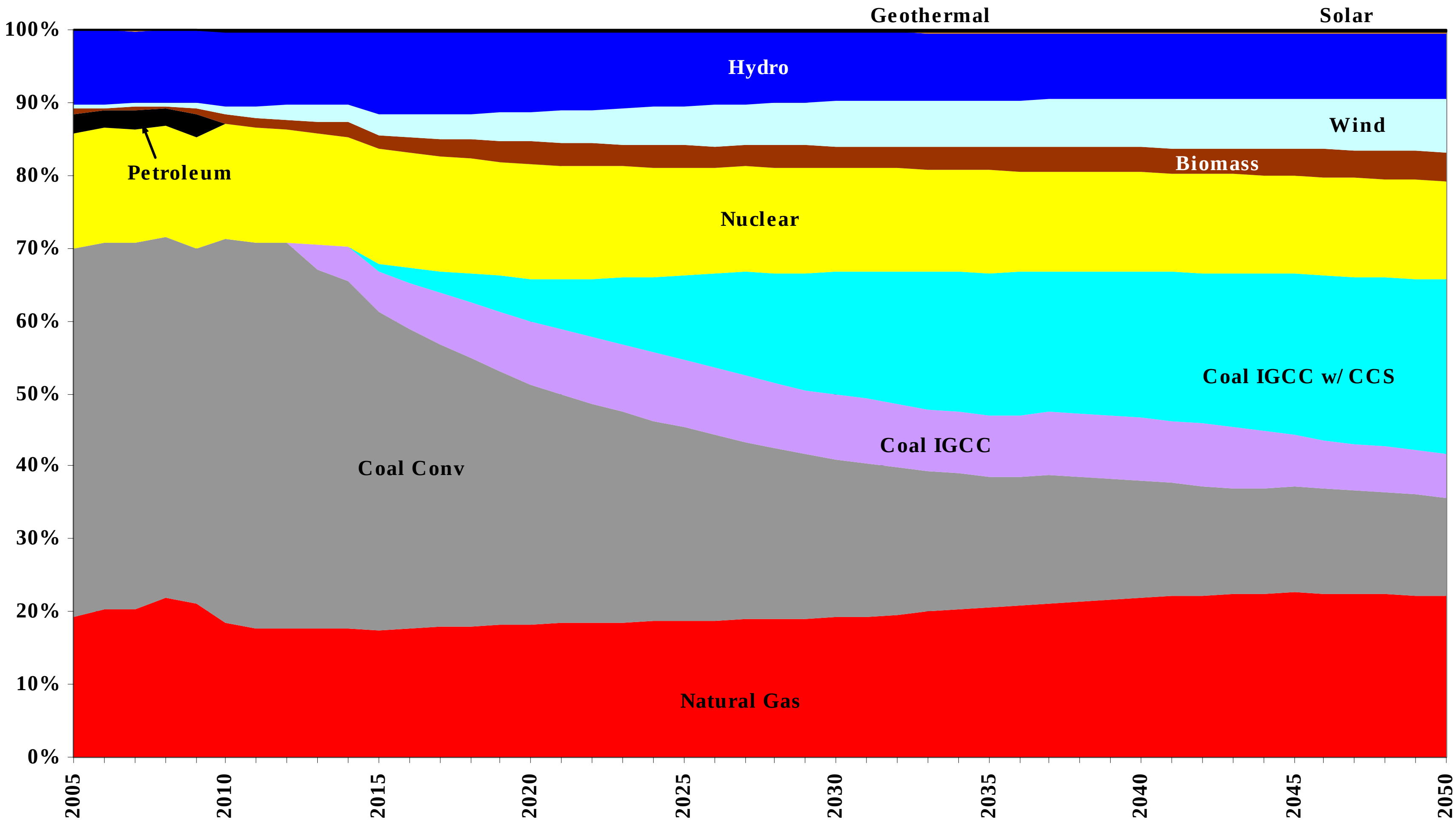
RWEM Reference Case (business as usual)

- Fuel share in power generation, 2005-2050 (US only)



RWEM: CO2 Constrained to 2005 levels

- Fuel share in power generation, 2005-2050 (US only)



Major Sensitivities

- The price of CO_2 is ultimately determined by the cost of deploying lower carbon alternatives. So, if we need $100/ton to deploy CCS, then that will be the CO_2 price, as long as there are not cheaper means of lowering CO_2.
- Preliminary runs indicate the following factors are very important to determining the outcome:
  - Elasticity of supply of low carbon fuels.
    - For example, if the supply curve for natural gas is very flat, then the price of CO_2 need only rise to the point at which natural gas substitutes for coal. (Note, this assumes natural gas is less expensive to deploy and use than other energy sources.)
    - Shale gas could prove very important in determining the CO_2 price.
  - Elasticity of demand for energy
    - If energy demand is very inelastic, so that consumers do not reduce demand very much when price increases, then the price of CO_2, *ceteris paribus*, will be higher to achieve a given reduction.

Major Sensitivities (cont.)

- Preliminary runs indicate the following factors are very important to determining the outcome (cont.):
  - Assumptions regarding capital costs
    - In model runs using DOE cost estimates, the cost of deploying IGCC is sufficiently low to ensure that coal maintains market share. Increasing this cost raises the price of CO_2 and pushes coal out of use more quickly.
  - Assumptions regarding long term load factors
    - If the capacity factors on wind increase, then wind becomes a more favorable option. This tends to lower the price of CO_2. Thus, any technological innovation that raises the capacity factor of wind is favorable. (Hence relevance of work presented by Peter Hartley)
  - Assumptions regarding availability of new technologies
    - If new technologies are made available sooner and more cheaply, then the price of CO_2 is directly influenced lower. (Hence relevance of work presented by Ted Temzelides)

Appendix

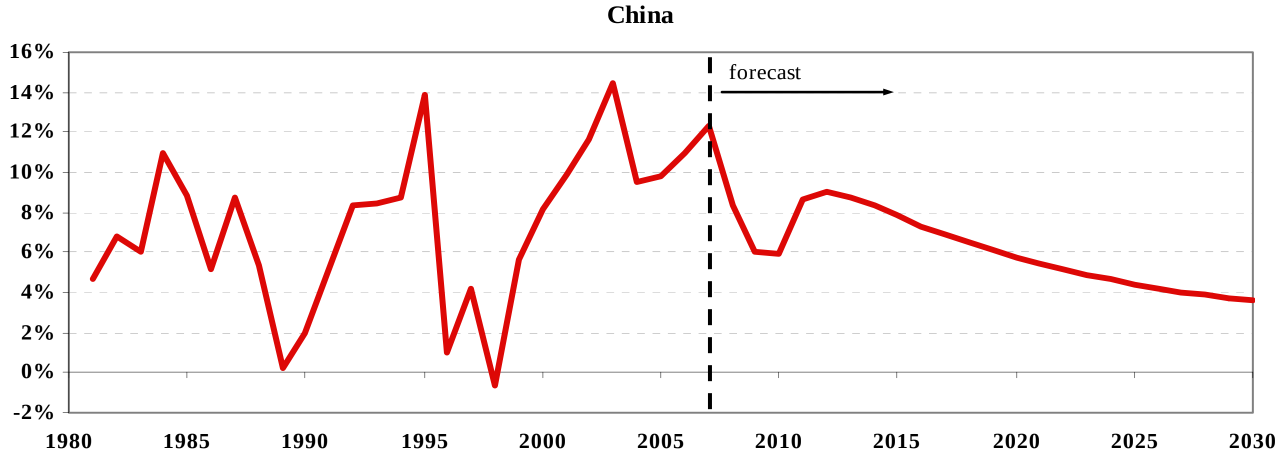
Capital Costs

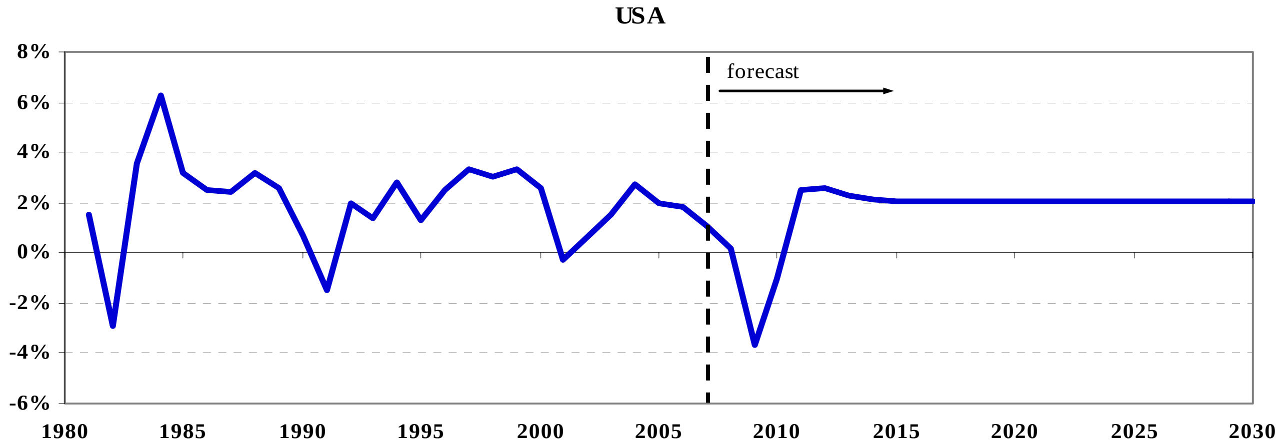
- Capital costs for Generation Sources
  - Two scenario tracks defined by DOE costs in one and industry-vetted costs in the other
  - In general, industry-vetted = 1.8 x DOE… is this a myopic view?

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

Economic Growth

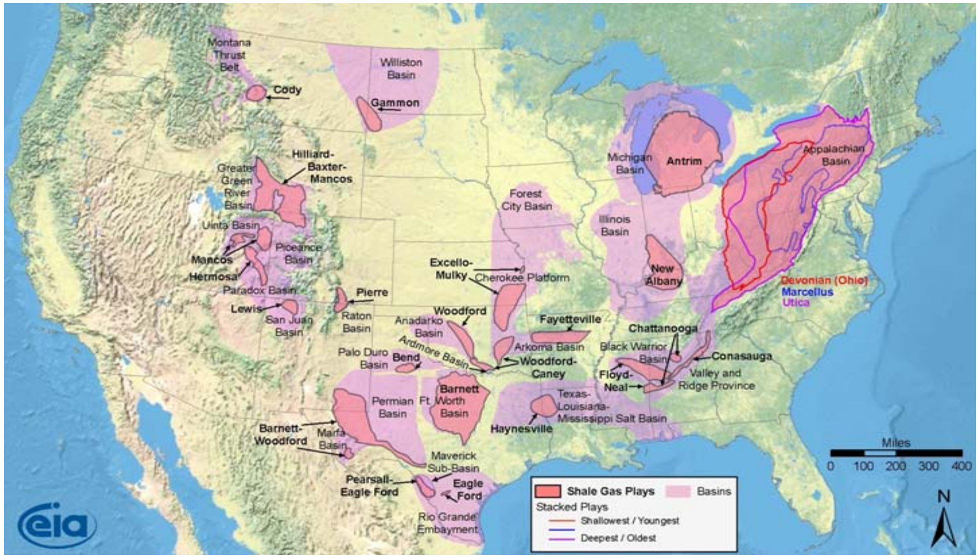
- Current economic and financial crisis is incorporated. We use the IMF June ‘09 outlook for growth through 2014 for all countries. Beyond 2014, growth is governed by a model of conditional convergence.





North American Shale Gas

- Resource assessment is large
  - Our work at Rice indicates a technically recoverable resource of 583 tcf
  - Input to the modeling efforts
- Some estimates are much higher
  - Recent estimates from the PGC exceed our estimates by about 100 tcf.
  - Navigant Consulting, Inc. estimated almost 900 tcf of recoverable resource.
- We learn more as time passes



	Mean Technically Recoverable Resource (tcf)	Breakeven Price
Antrim	13.2	$ 6.00
Devonian/Ohio	169.6	
Utica	5.4	$ 7.00
Marcellus	134.2	
Marcellus T1	47.0	$ 4.75
Marcellus T2	42.9	$ 5.75
Marcellus T3	44.3	$ 7.00
NW Ohio	2.7	$ 7.00
Devonian Siltstone and Shale	1.3	$ 7.00
Catskill Sandstones	11.7	$ 7.00
Berea Sandstones	6.8	$ 7.00
Big Sandy (Huron)	6.3	$ 6.00
Nora/Haysi (Huron)	1.2	$ 6.50
New Albany	3.8	$ 7.50
Floyd/Chatanooga	2.1	$ 6.25
Haynesville	90.0	
Haynesville T1	36.0	$ 4.25
Haynesville T2	31.5	$ 5.00
Haynesville T3	22.5	$ 6.50
Fayetteville	36.0	$ 5.00
Woodford Arkoma	8.0	$ 5.75
Woodford Ardmore	4.2	$ 6.00
Barnett	54.0	
Barnett T1	32.2	$ 4.50
Barnett T2	21.8	$ 5.75
Barnett and Woodford	35.4	$ 7.00
Eagle Ford	20.0	$ 5.00
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	35.0	$ 4.75
Horn River	50.0	$ 5.25
Utica	10.0	$ 7.00
Total US Shale	488.0	
Total Canadian Shale	95.0	
Total North America	583.0	

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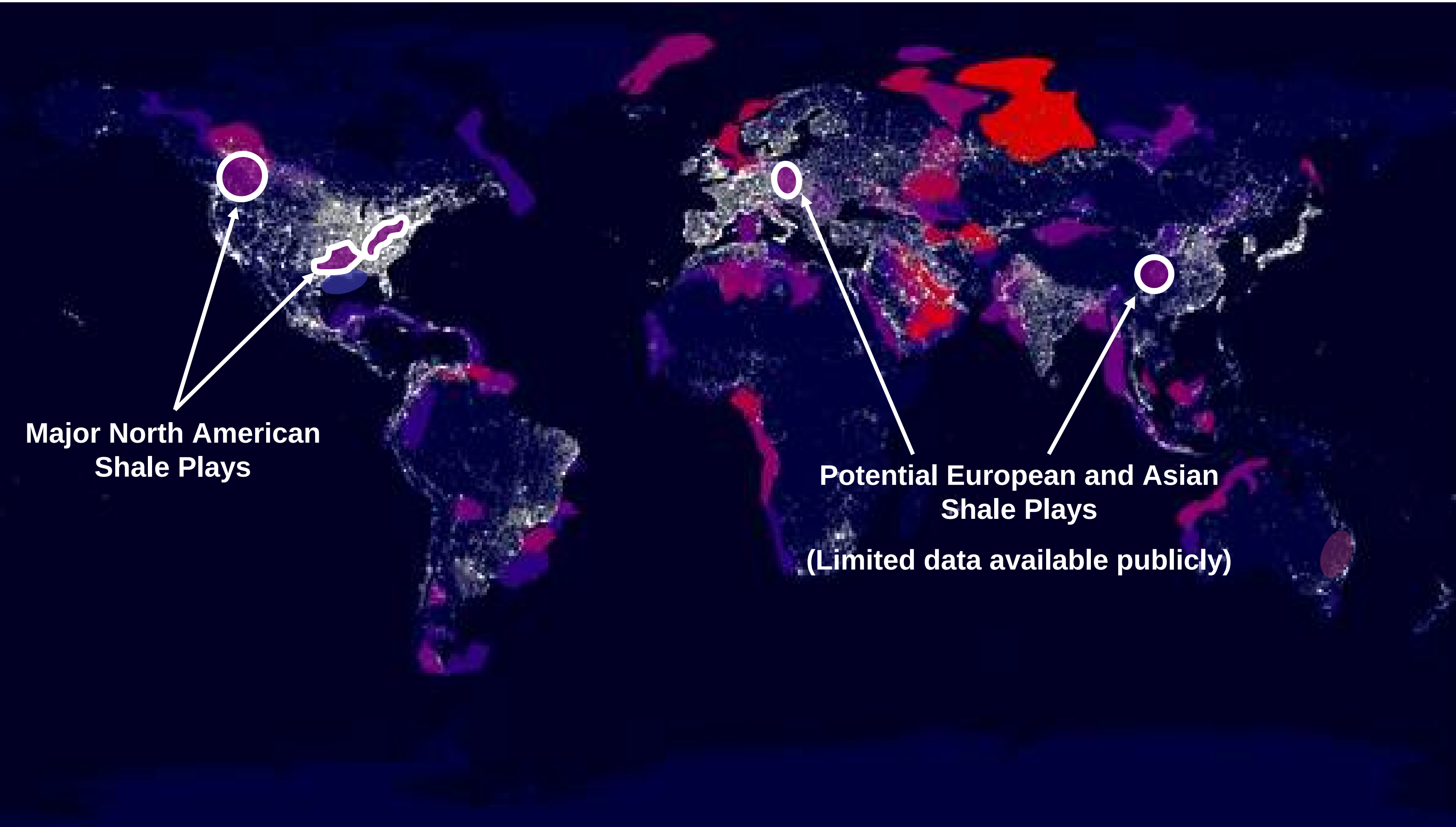
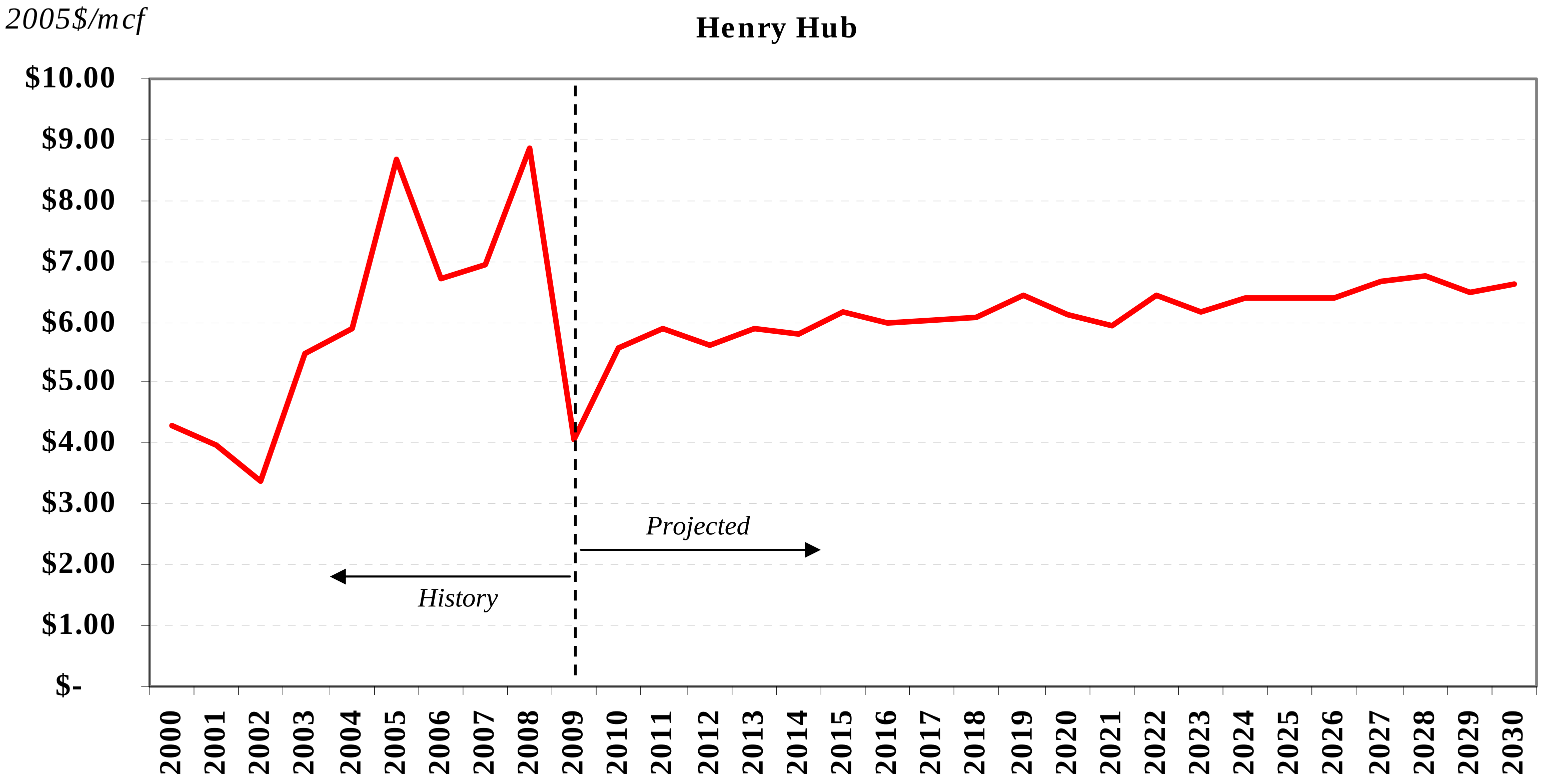
Shale is not unique to the US, and it has significant implications for the global gas market

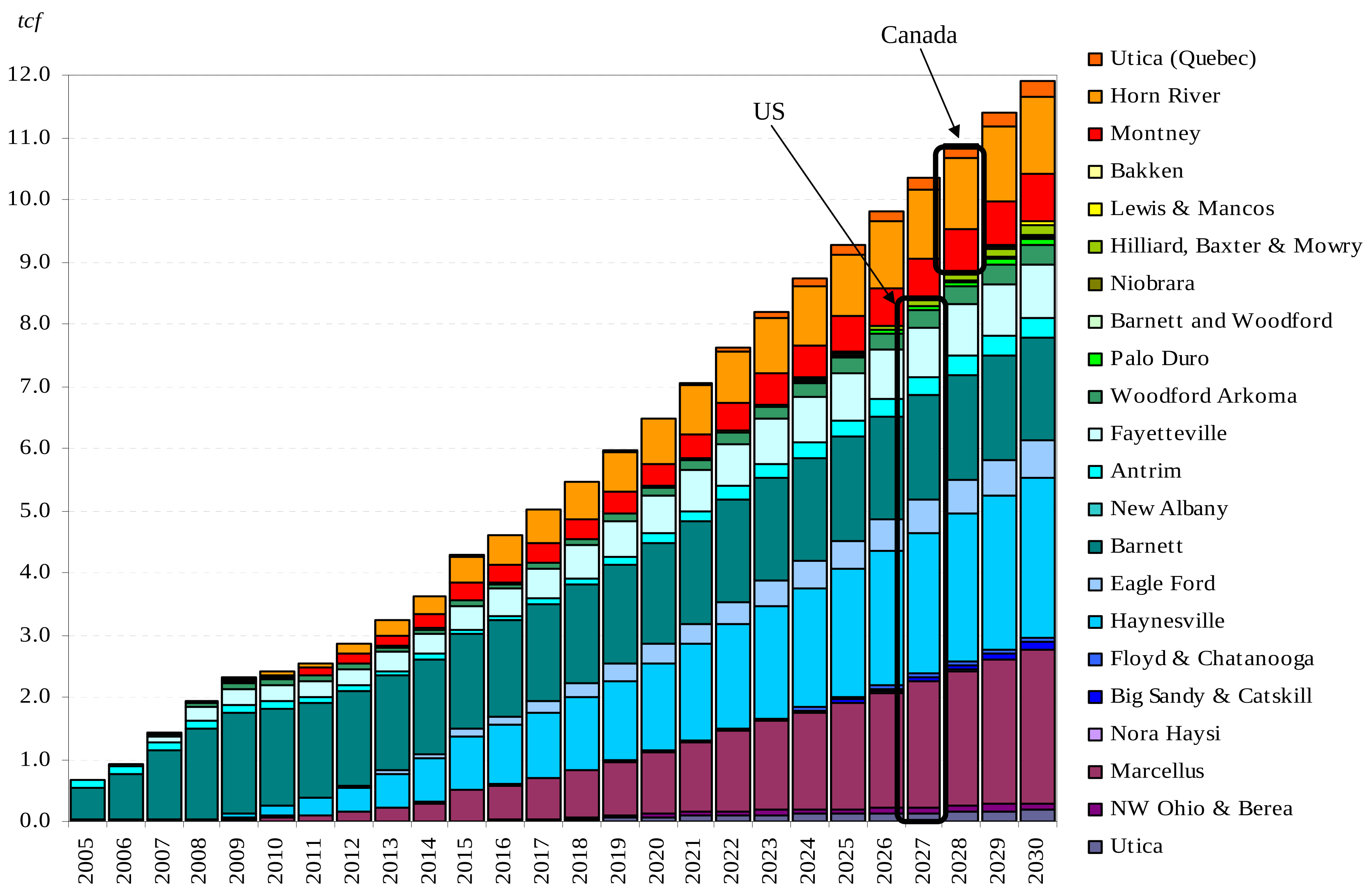


Henry Hub Natural Gas Price

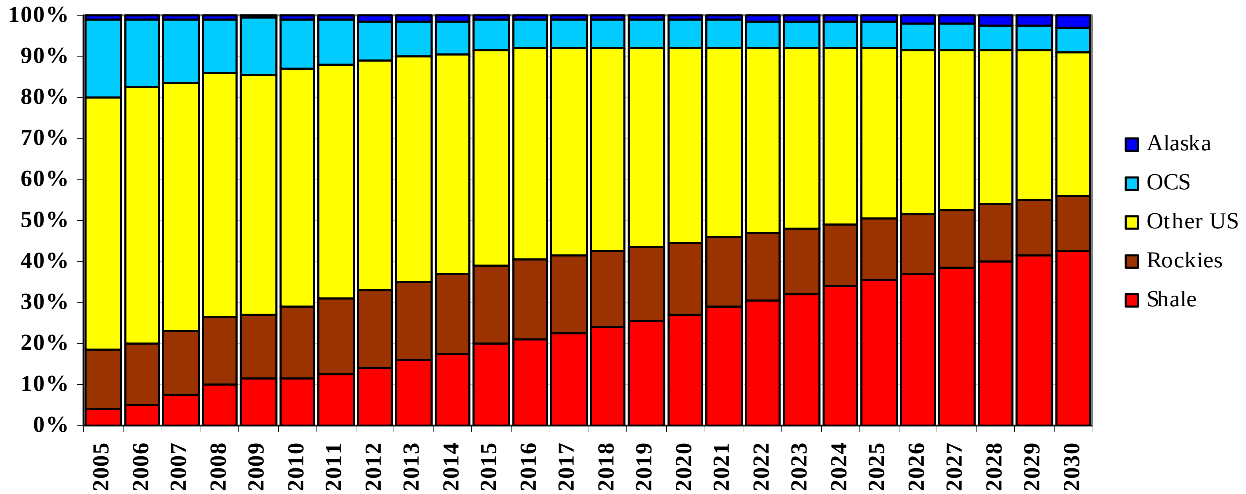
- Long term prices at Henry Hub (averages, inflation adjusted)
  - 2010-2020: $ 5.98 2021-2030: $ 6.42



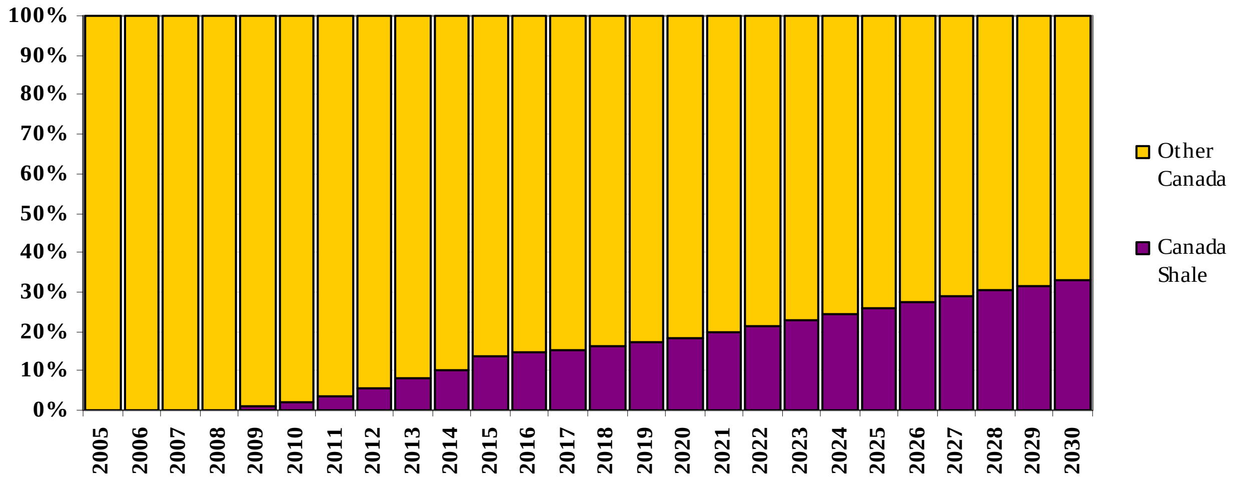
North American Shale Production



Composition of North American Production



- US shale production grows to about 45% of total production by 2030.



- Canadian shale production grows to about 1/3 of total output by 2030. This offsets declines in other resources as total production remains fairly flat.

LNG Imports to the US

- Growth in domestic shale resources renders load factors on LNG import facilities very low… an overall average of less than 15%.