

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?

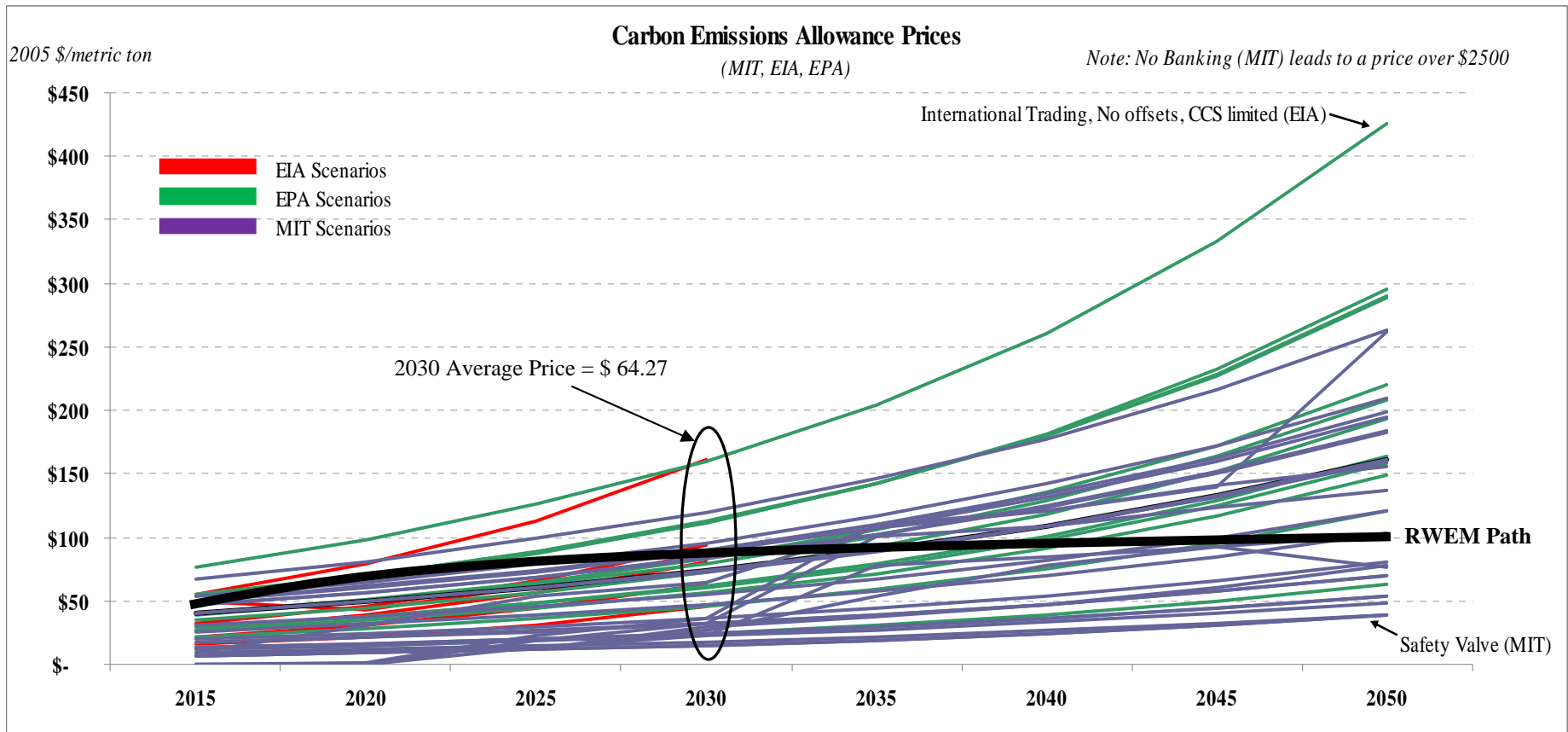
Progress to Date

- 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.

Some Basic Model Results

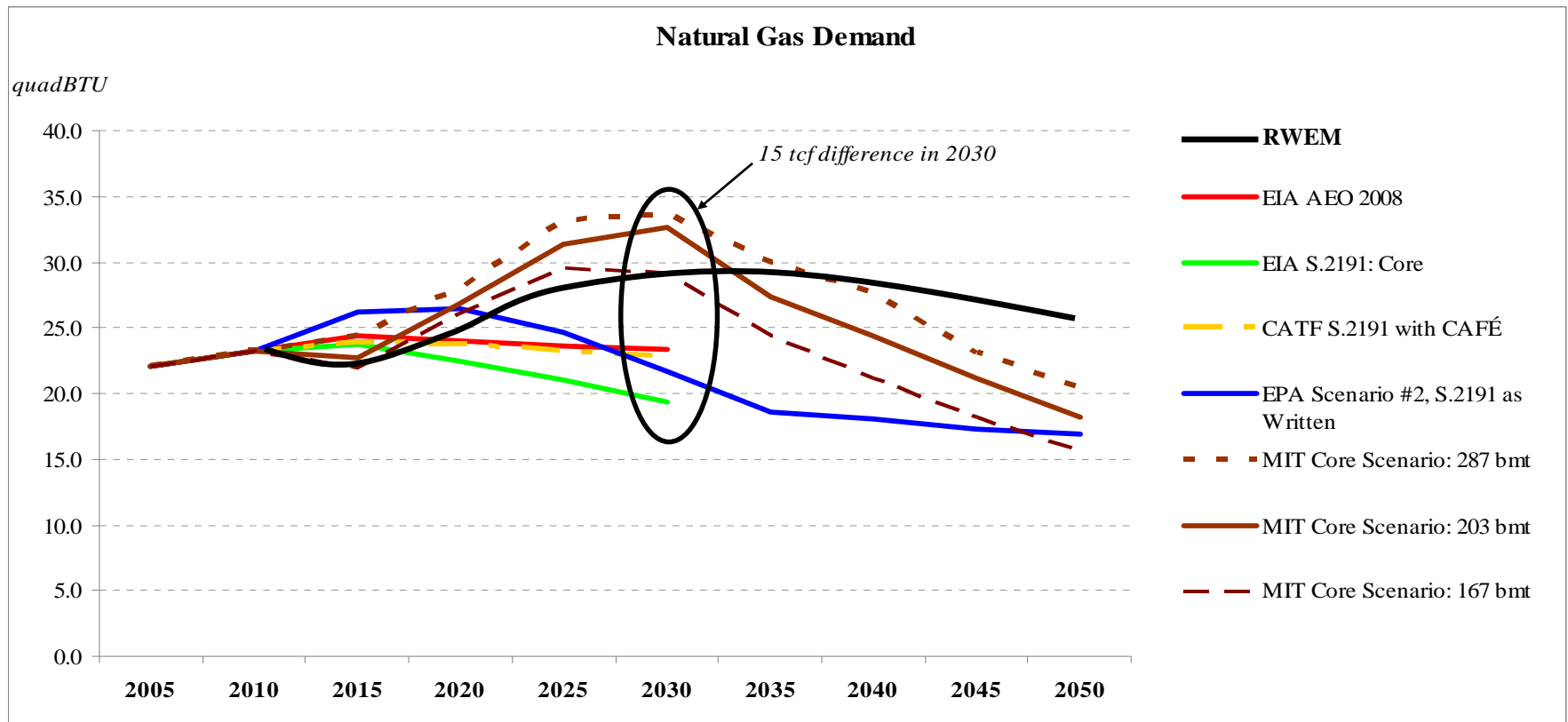
Carbon Prices (Various Model Outputs)

- 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.

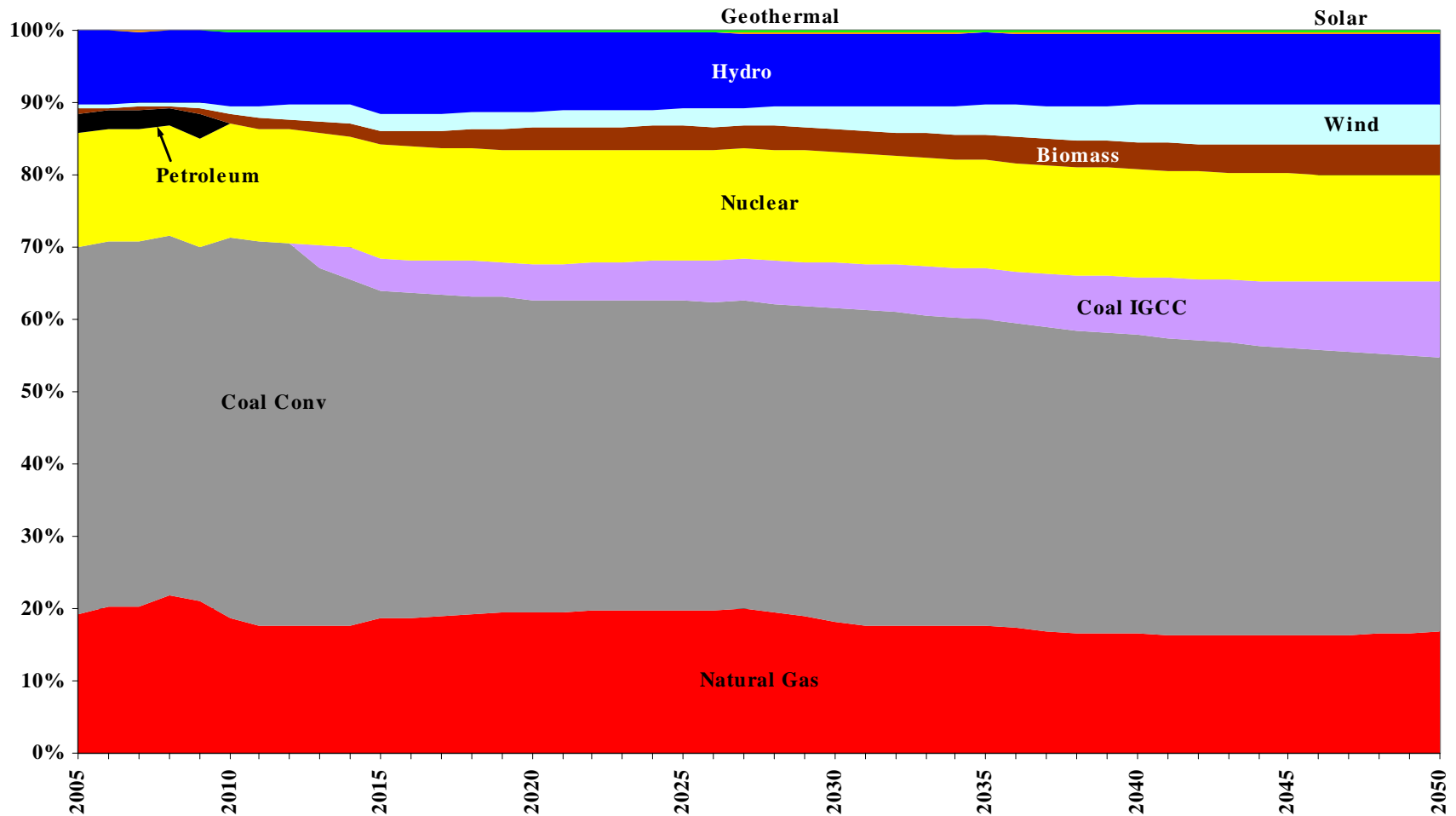


RWEM Reference Case (business as usual)

- 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.

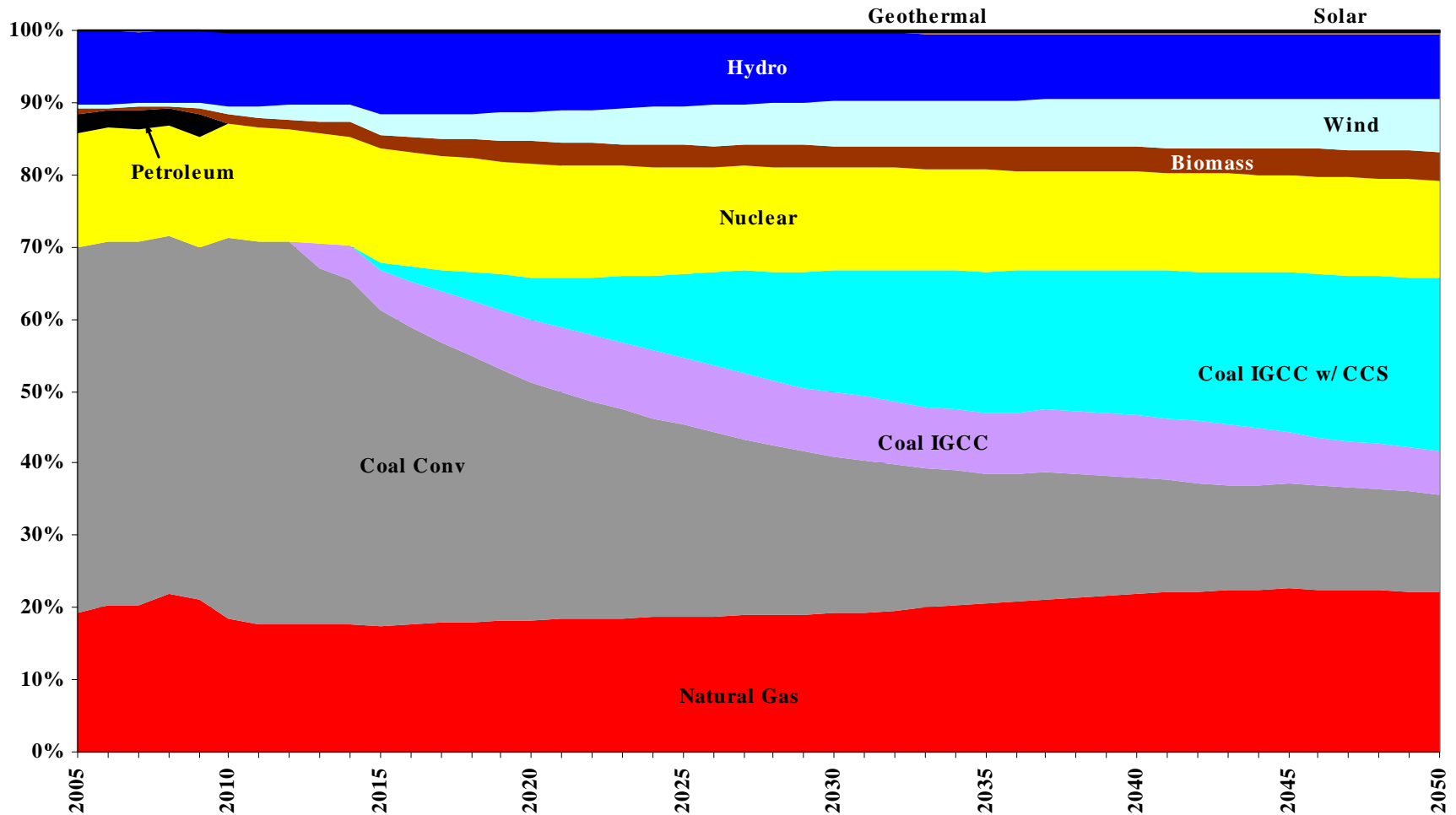
RWEM Reference Case (business as usual)

- 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 CO₂ 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 CO₂ price, as long as there are not cheaper means of lowering CO₂.
- 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 CO₂ 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 CO₂ 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 CO₂, *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 CO₂ 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 CO₂. 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 CO₂ is directly influenced lower. (Hence relevance of work presented by Ted Temzelides)

Appendix

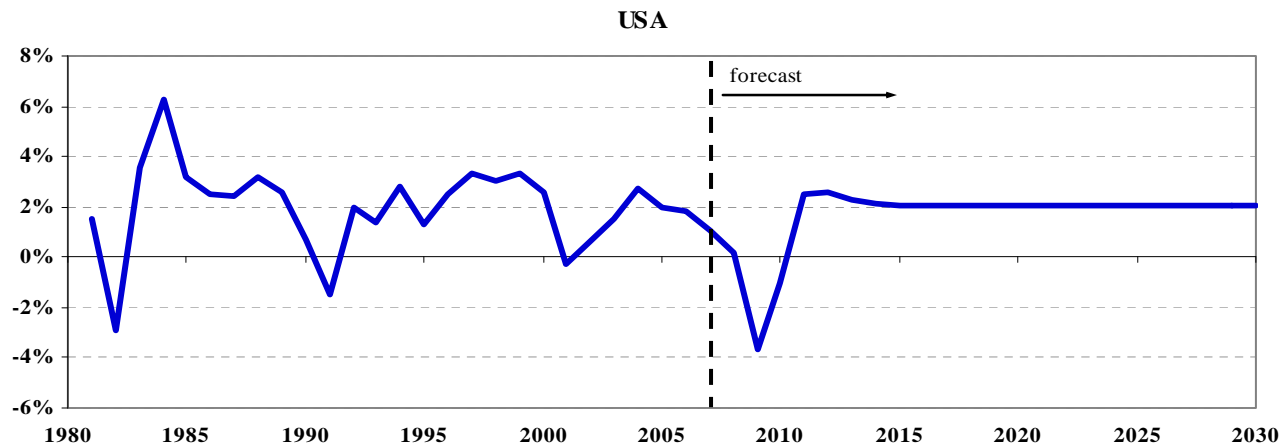
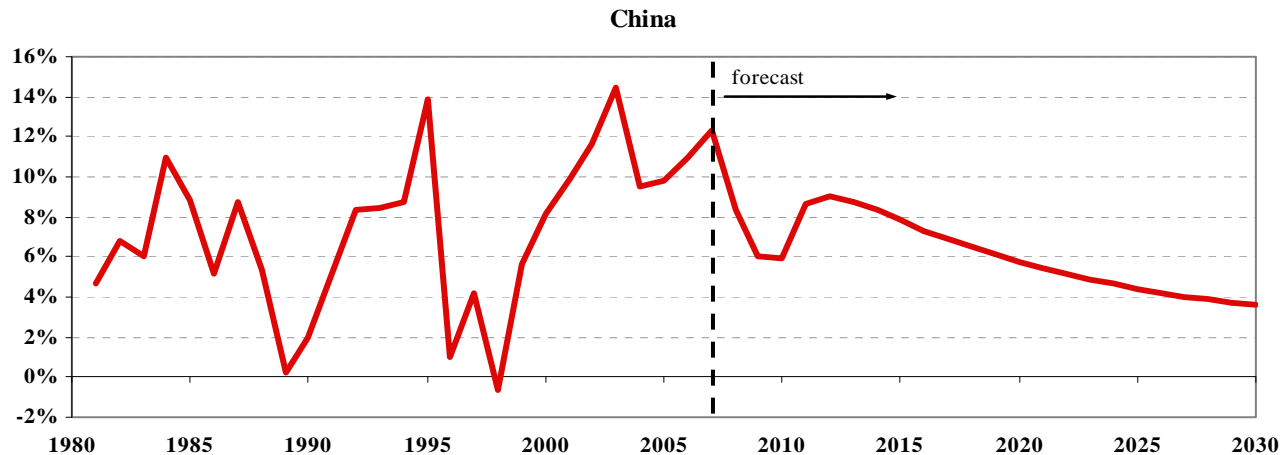
Capital Costs

- 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



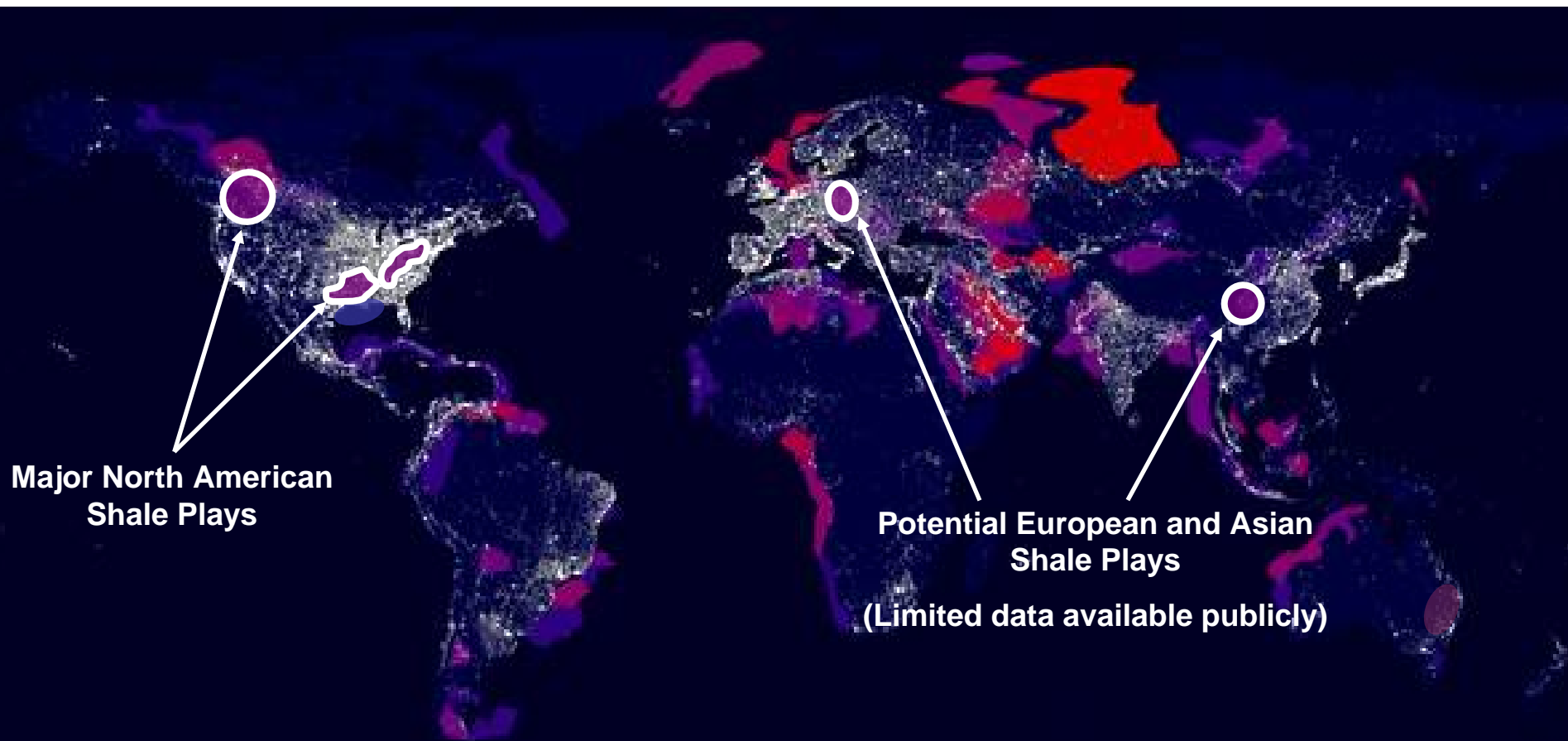
- Antrim**
- Devonian/Ohio**
- Utica**
- Marcellus**
 - Marcellus T1**
 - Marcellus T2**
 - Marcellus T3**
- NW Ohio**
- Devonian Siltstone and Shale**
- Catskill Sandstones**
- Berea Sandstones**
- Big Sandy (Huron)**
- Nora/Haysi (Huron)**
- New Albany**
- Floyd/Chatanooga**
- Haynesville**
 - Haynesville T1**
 - Haynesville T2**
 - Haynesville T3**
- Fayetteville**
- Woodford Arkoma**
- Woodford Ardmore**
- Barnett**
 - Barnett T1**
 - Barnett T2**
- Barnett and Woodford**
- Eagle Ford**
- Palo Duro**
- Lewis**
- Bakken**
- Niobrara (incl. Wattenburg)**
- Hilliard/Baxter/Mancos**
- Lewis**
- Mowry**

	Mean Technically Recoverable Resource (tcf)	Breakeven Price
	13.2	\$ 6.00
	169.6	
	5.4	\$ 7.00
	134.2	
	47.0	\$ 4.75
	42.9	\$ 5.75
	44.3	\$ 7.00
	2.7	\$ 7.00
	1.3	\$ 7.00
	11.7	\$ 7.00
	6.8	\$ 7.00
	6.3	\$ 6.00
	1.2	\$ 6.50
	3.8	\$ 7.50
	2.1	\$ 6.25
	90.0	
	36.0	\$ 4.25
	31.5	\$ 5.00
	22.5	\$ 6.50
	36.0	\$ 5.00
	8.0	\$ 5.75
	4.2	\$ 6.00
	54.0	
	32.2	\$ 4.50
	21.8	\$ 5.75
	35.4	\$ 7.00
	20.0	\$ 5.00
	4.7	\$ 7.00
	10.2	\$ 7.25
	1.8	\$ 7.50
	1.3	\$ 7.25
	11.8	\$ 7.25
	13.5	\$ 7.25
	8.5	\$ 7.25
	35.0	\$ 4.75
	50.0	\$ 5.25
	10.0	\$ 7.00

Total US Shale
Total Canadian Shale
Total North America

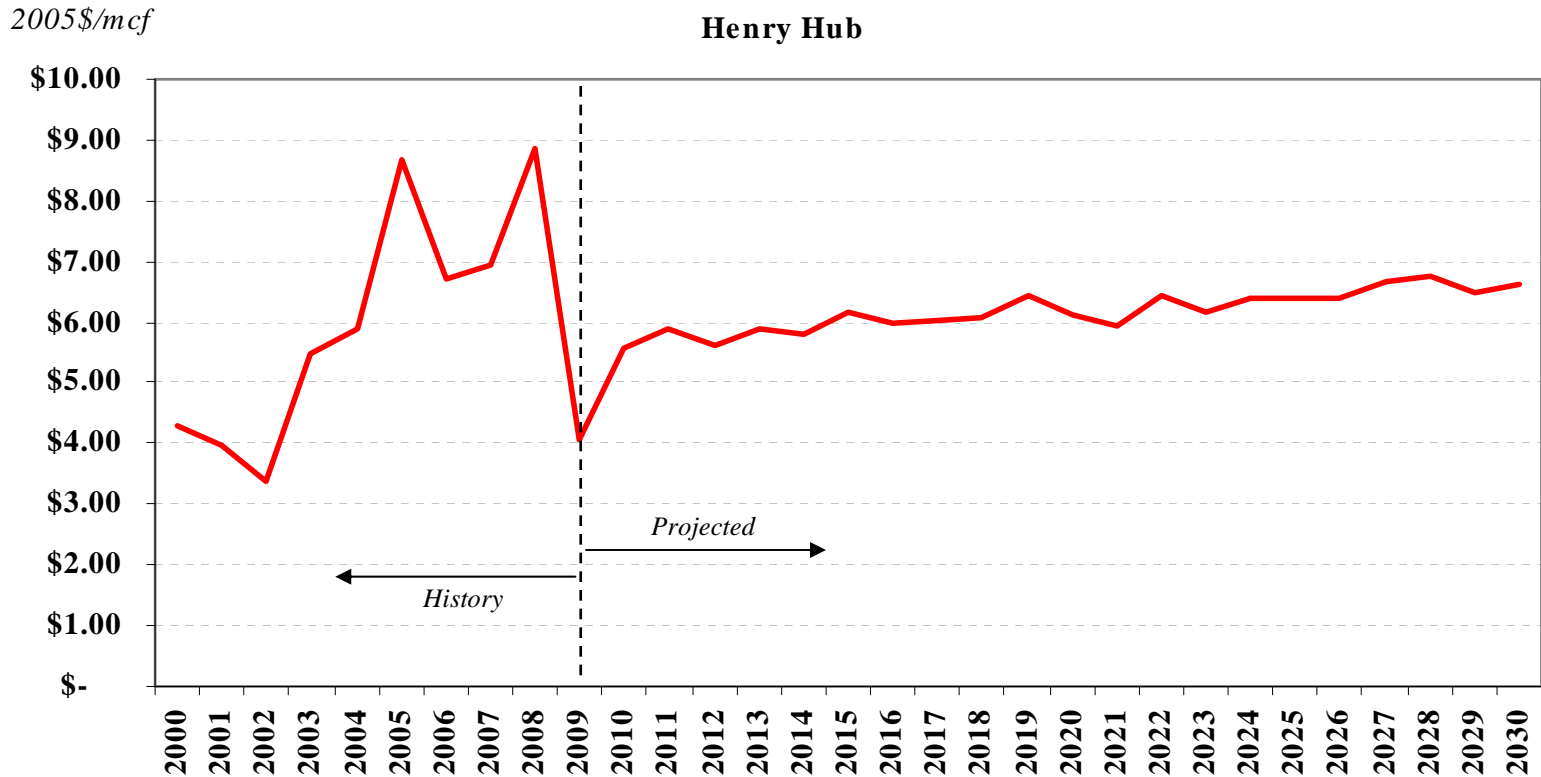
488.0
95.0
583.0

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

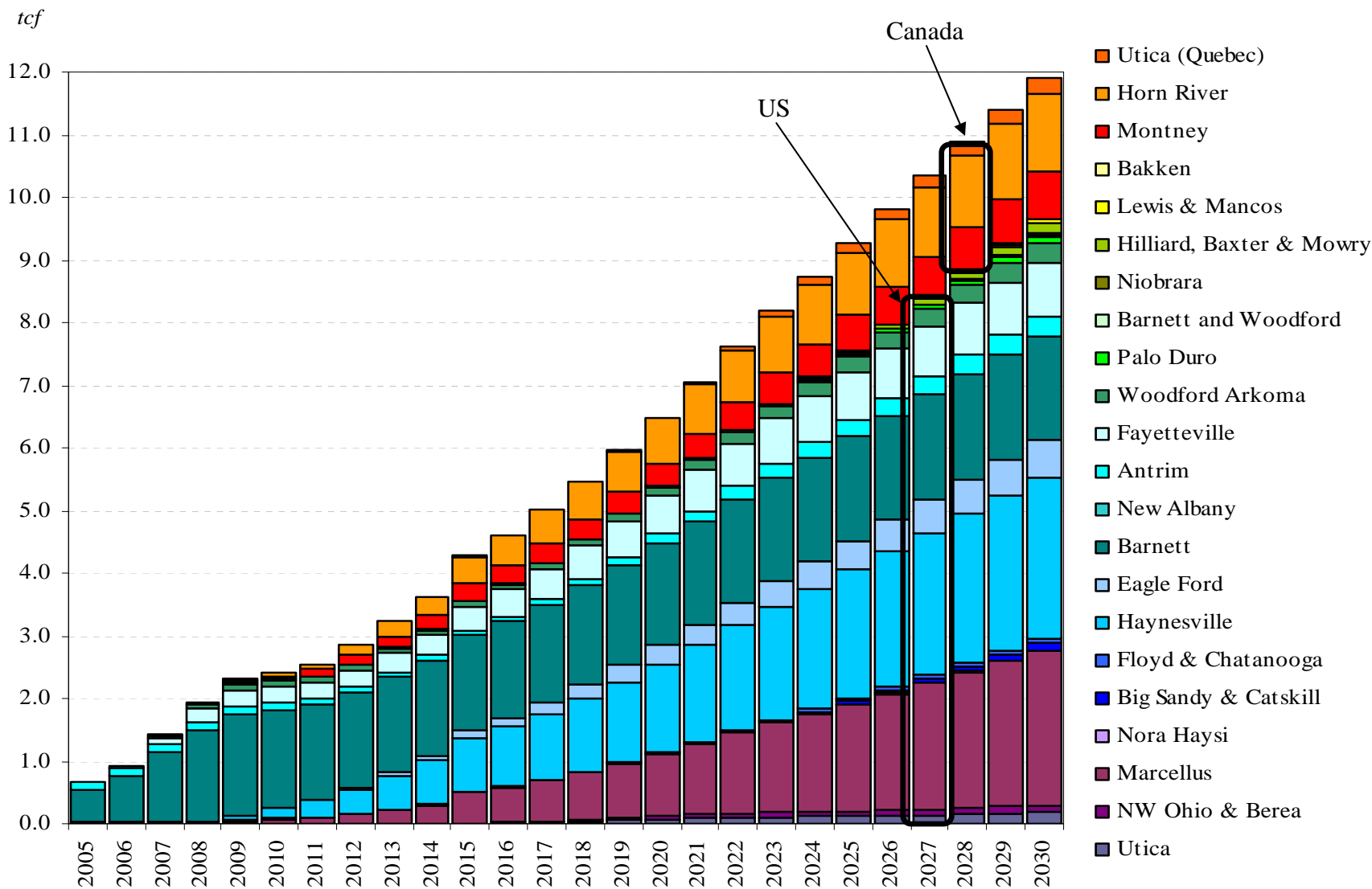


Henry Hub Natural Gas Price

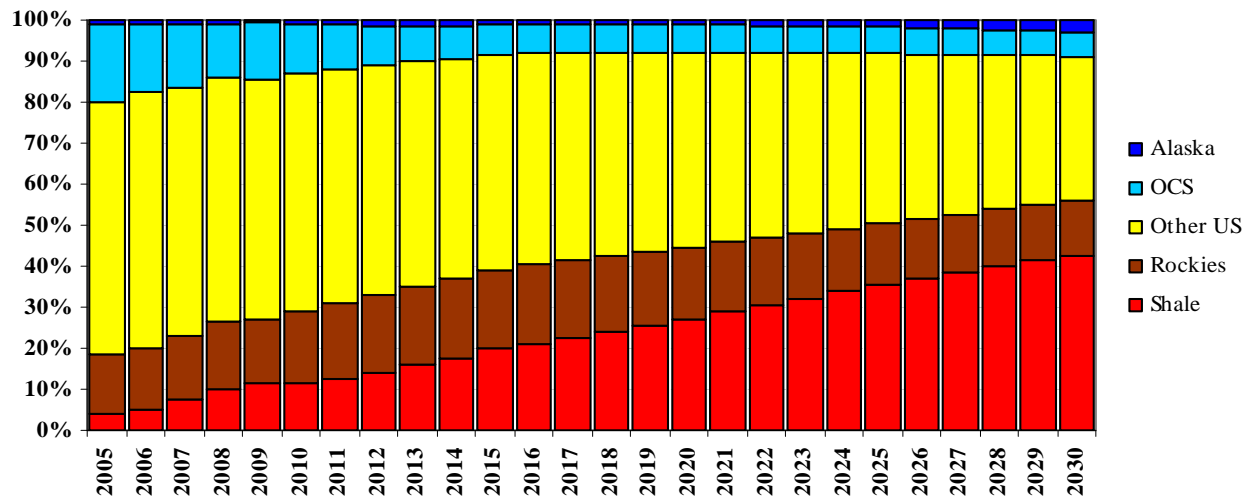
- Long term prices at Henry Hub (averages, inflation adjusted)
 - 2010-2020: \$ 5.98
 - 2021-2030: \$ 6.42



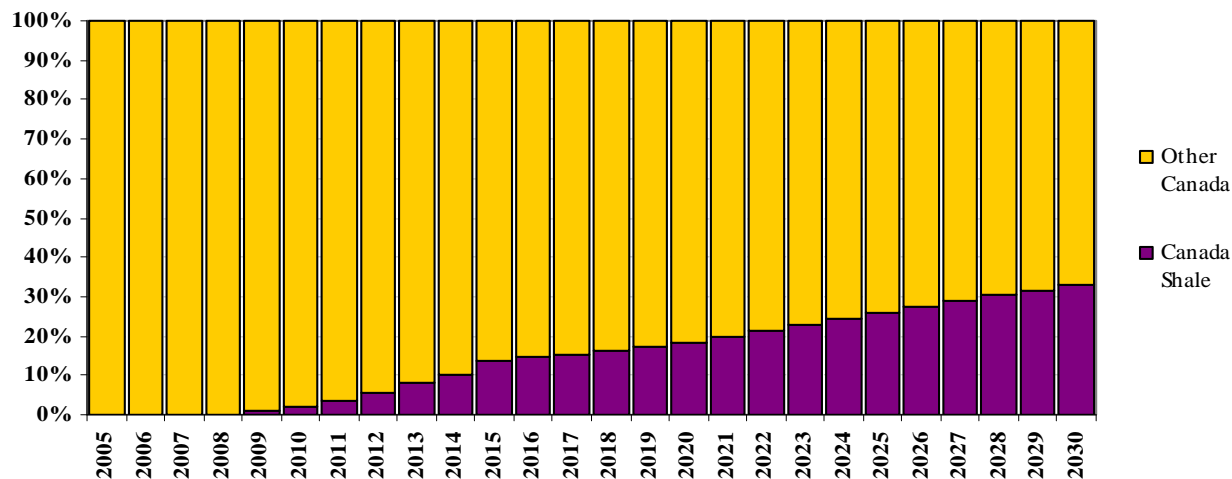
North American Shale Production



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%.

