

The Shale Gas Revolution and What It Means for Global Energy Markets

*Presentation at the Baker Institute Roundtable:
Energy Market Consequences of an Emerging U.S. Carbon Management Policy*

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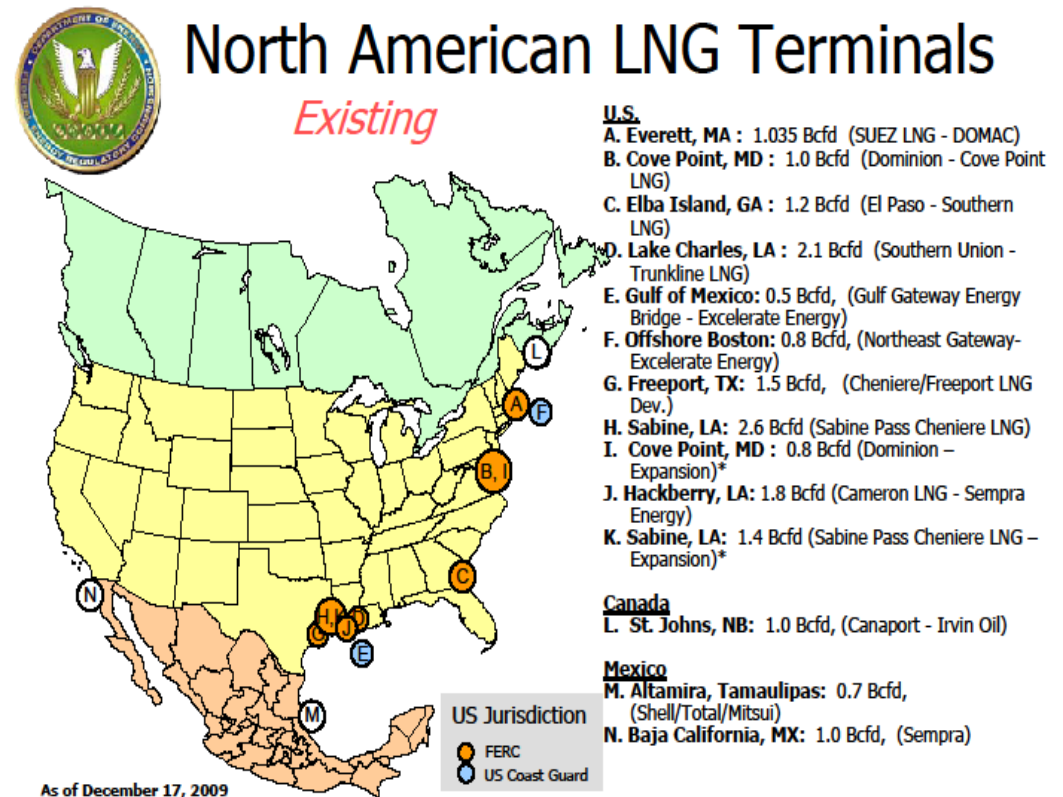
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**James A Baker III Institute for Public Policy
Rice University**

A Paradigm Shift

- The view of natural gas has changed dramatically in only 10 years
 - Most predictions were for a dramatic increase in LNG imports to North America and Europe.
 - Today, growth opportunities for LNG developers are seen in primarily in Asia.
- Many investments were made to expand LNG potential to North America in particular
 - At one point, 47 terminals were in the permitting phase.
 - Since 2000, 2 terminals were re-commissioned and expanded (Cove Point and Elba); 9 others were constructed.
 - In 2000, import capacity was just over 2 bcf/d; It now stands at just over 17.4 bcf/d.
 - By 2012, it could reach 20 bcf/d.
- A similar story in Europe
 - In 2000, capacity was just over 7 bcf/d; It is now over 14.5 bcf/d.
 - By 2012, it could exceed 17 bcf/d.
- Shale gas developments have since turned expectations upside-down



Note: There is an existing import terminal in Pefuelas, PR. It does not appear on this map since it can not serve or affect deliveries in the Lower 48 U.S. states.

The Global Shale Gas Resource

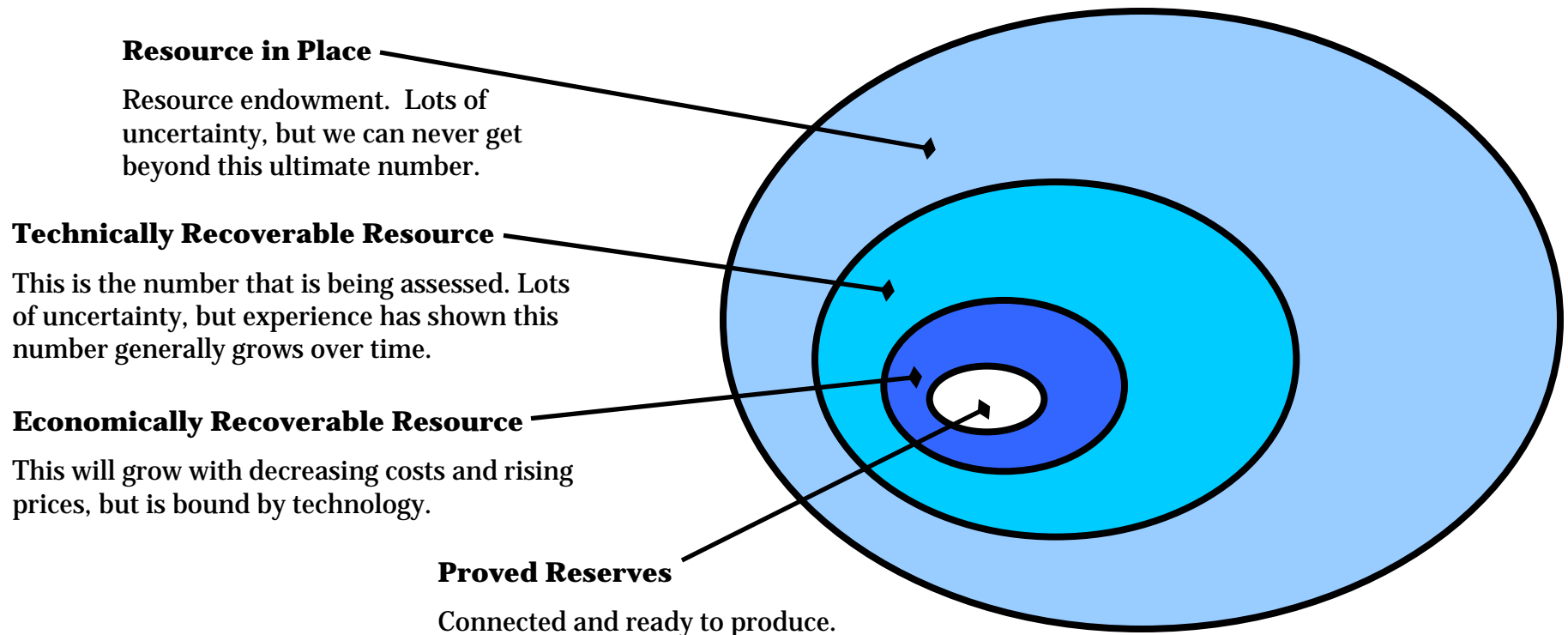
- Knowledge of shale gas resource is not new
 - Rogner (1997) estimated over 16,000 tcf of shale gas resource in-place globally
 - Only a very small fraction (<10%) of this was deemed to be technically recoverable and even less so economically.
- Only recently have innovations made this resource accessible
 - Shale developments have been focused largely in North America where high prices have encouraged cost-reducing innovations.
 - IEA recently estimated about 40% of the estimates resource in-place by Rogner (1997) will ultimately be technically recoverable.
 - Recent assessment by Advanced Resources International (2010) notes a greater resource in-place estimate than Rogner (1997), with most of the addition coming in North America and Europe.
- **We learn as we advance in this play!**

Rogner (1997)

Region	Resource In-Place (tcf)	Resource In-Place (tcm)
North America	3,842	109
Latin America	2,117	60
Europe	549	15
Former USSR	627	18
China and India	3,528	100
Australasia	2,313	66
MENA	2,548	72
Other	588	17
Total	16,112	457

“Resource” vs. “Reserve”

- Often, the press and many industry analysts characterize the recent estimates of shale gas in North America as “reserves”.
- This is an incorrect representation! It is important to understand what these assessments are actually estimating.
- With shale gas, the numbers are very large. **The X-factor is cost.**



North American Shale Gas

- Resource assessment is large. Our work at BIPP indicates a technically recoverable resource of 583 tcf.
- Some estimates are much higher
 - (2008) Navigant Consulting, Inc. estimated a high of almost 900 tcf.
 - (2009) Estimate from PGC over 680 tcf.
 - (2010) ARI estimate of over 1000 tcf.
- Note, in 2005, most estimates placed the resource at about 140 tcf.
- 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

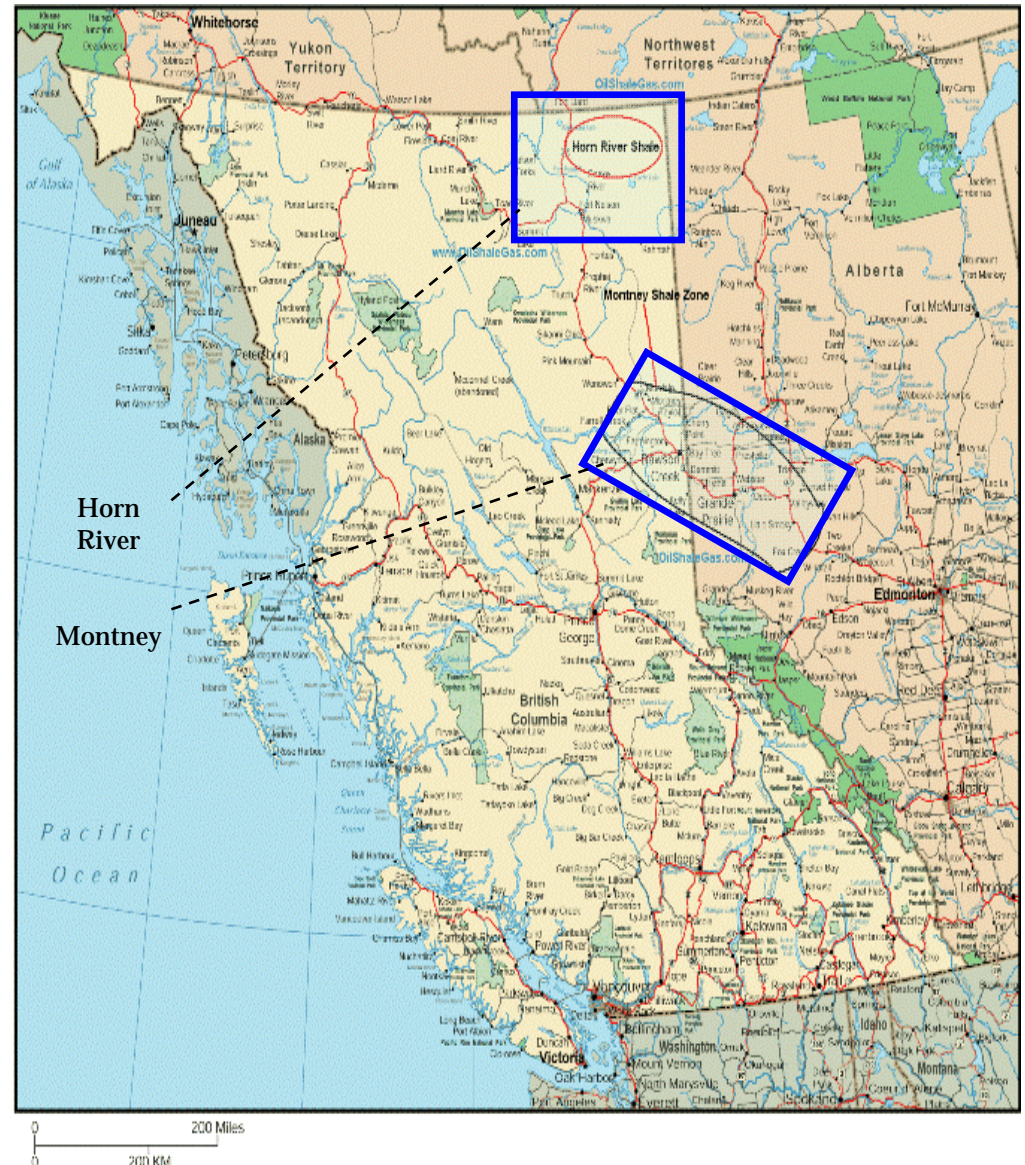
35.0	\$ 4.75
50.0	\$ 5.25
10.0	\$ 7.00

488.0
95.0
583.0

Total US Shale
Total Canadian Shale
Total North America

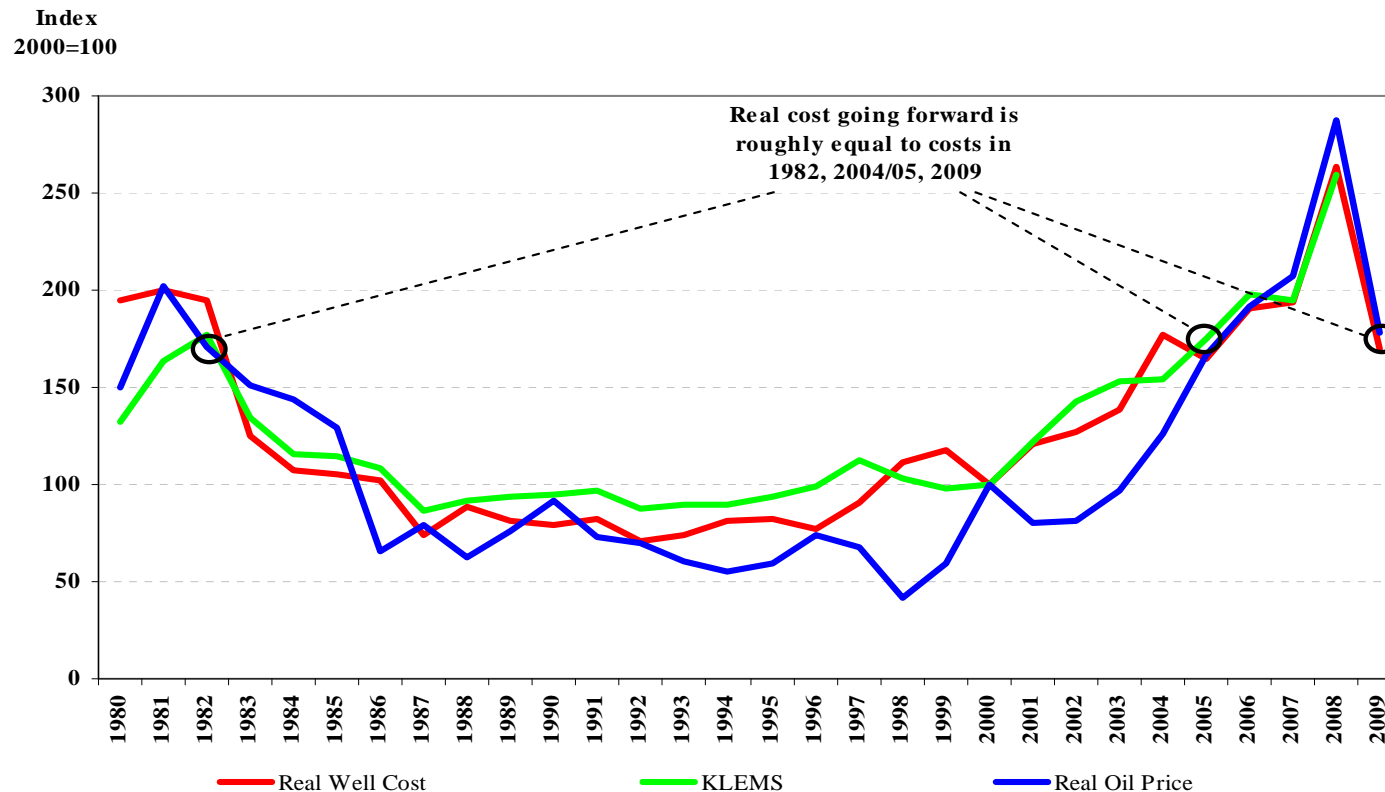
North American Shale Gas (cont.)

- Shale is also in Canada.
- 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 an oil-indexed 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 (not pictured) has been compared to the Barnett, and price is better.

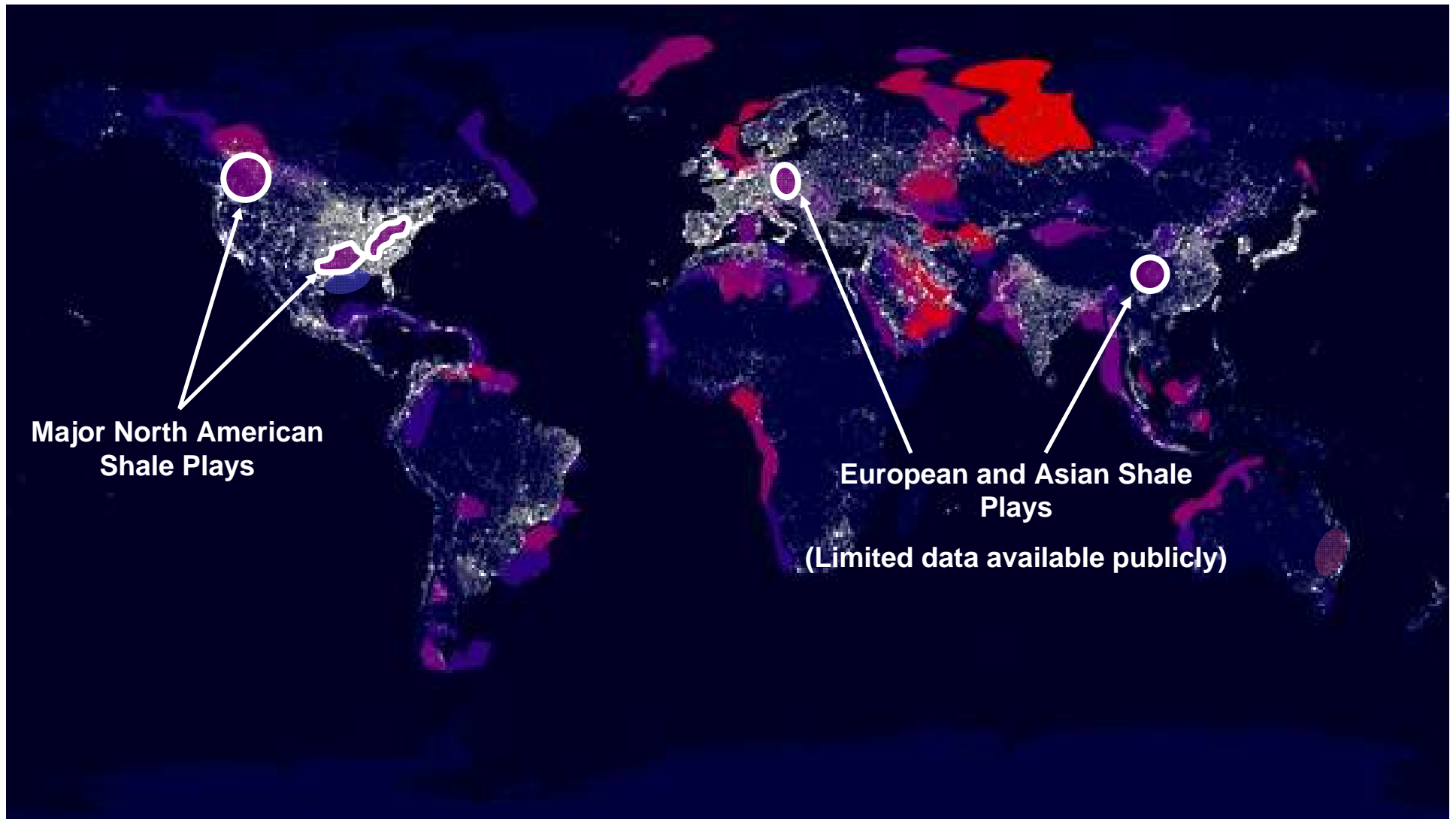


A Comment on Development Costs

- We often discuss “breakeven costs”, but it is important to put this into context...
- The cost environment is critical to understanding what prices will be. For example, F&D costs in the 1990s yield long run prices in the \$3-\$4 range.
- What will the cost of steel and cement be? What about field services? Depends on demand pull and value of the dollar.

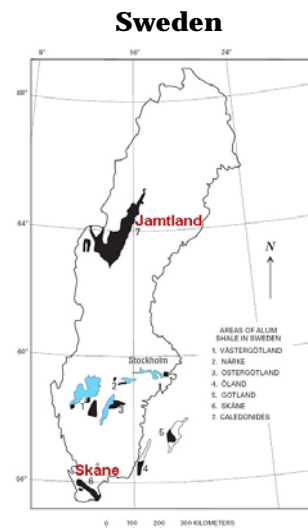
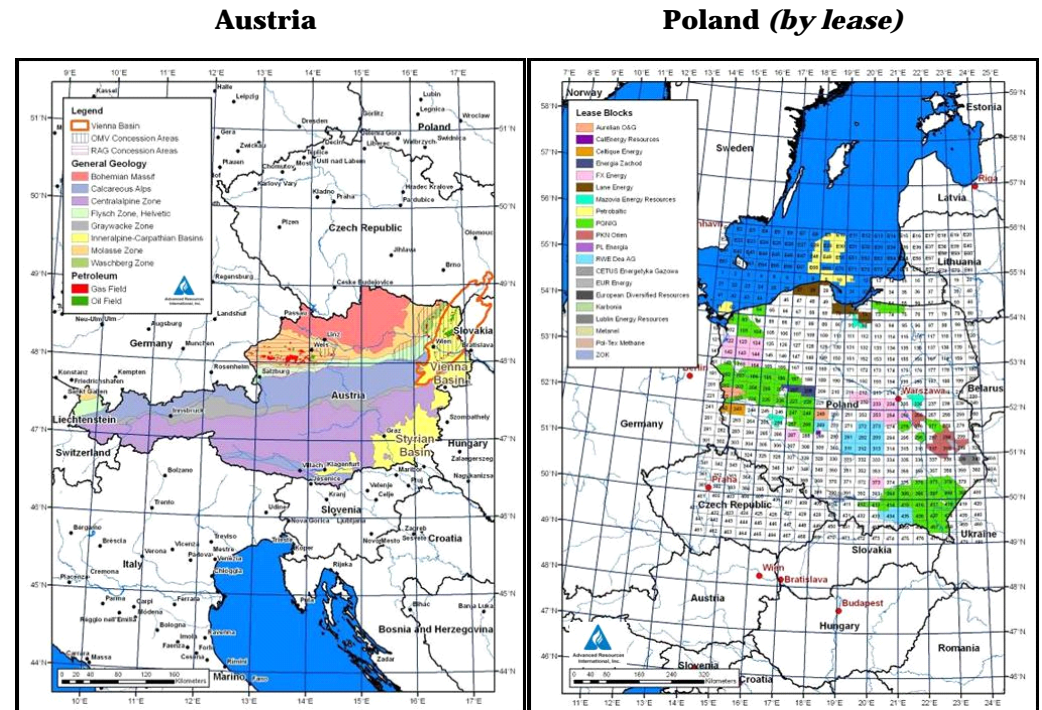


Shale is not confined to North America, and it has significant implications for the global gas market



European Shale Gas

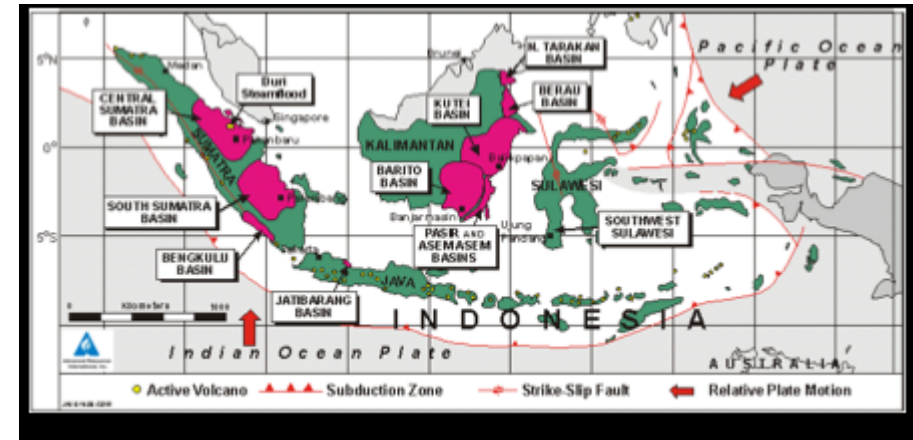
- In depth studies are underway, with on-going independent analysis of shale potential in Austria, Sweden, Poland, Romania, and Germany
- Rogner (1997) estimates
 - In-place: 549 tcf
 - Technically recoverable: No Data
- ARI estimates (2010)
 - In-place: 1000 tcf
 - Technically recoverable: 140 tcf
 - Alum Shale (Sweden), Silurian Shale (Poland), Mikulov Shale (Austria)
 - Europe also has an additional 35 tcf of technically recoverable CBM resource located primarily in Western European countries and Poland.
 - Quote from ARI report: “Our preliminary estimate for the gas resource endowment for Western and Eastern Europe, which we anticipate to grow with time and new data, is already twice Rogner’s estimate of 549 Tcf (15.6 Tcm).”



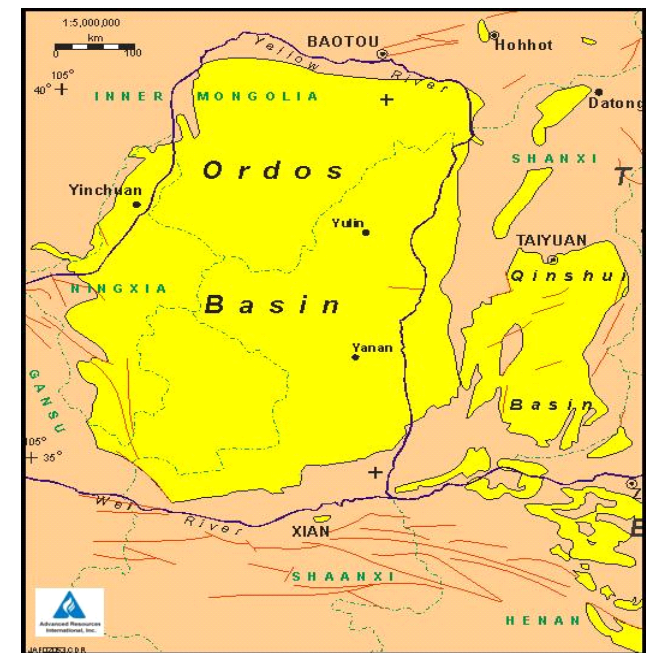
Asia/Pacific Shale and CBM

- Limited data availability
- Rogner (1997) estimates
 - China/India In-place: 3,530 tcf
 - Technically recoverable: No Data
- China and the U.S. Department of Energy have recently entered into a “U.S.-China Shale Gas Resource Initiative” to support gas shale development in China.
- CBM potential in the Asia-Pacific Region is large and generally better known (ARI, 2010).
 - Indonesia: 450 tcf (in-place)
50 tcf (technically recoverable)
 - China: 1,270 tcf (in-place)
100 tcf (technically recoverable)
 - India: 90 tcf (in-place)
20 tcf (technically recoverable)
 - Australia: 1,000 tcf (in-place)
120 tcf (technically recoverable)

Indonesia (CBM)



China (CBM)

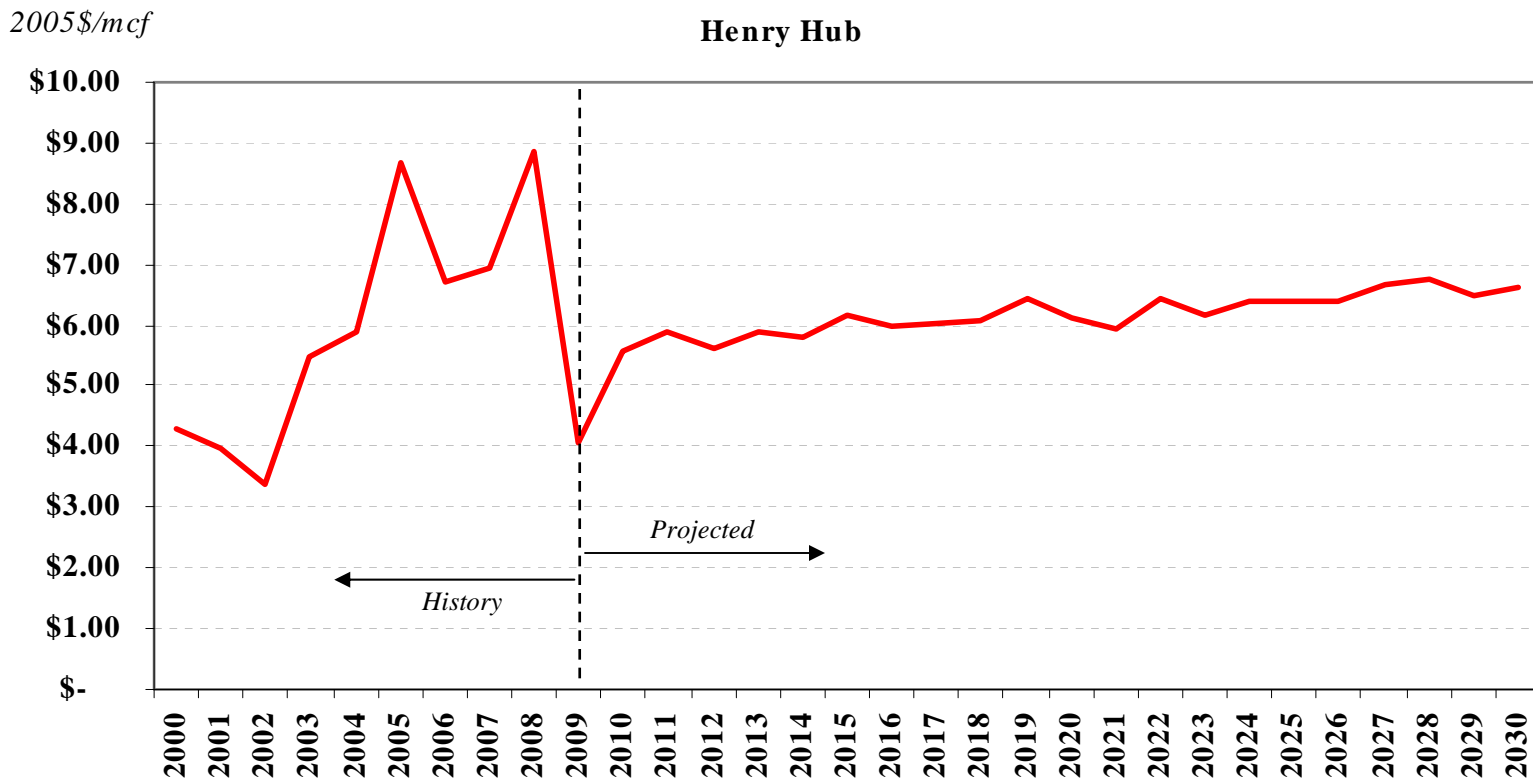


Source: Graphics from ARI (2010)

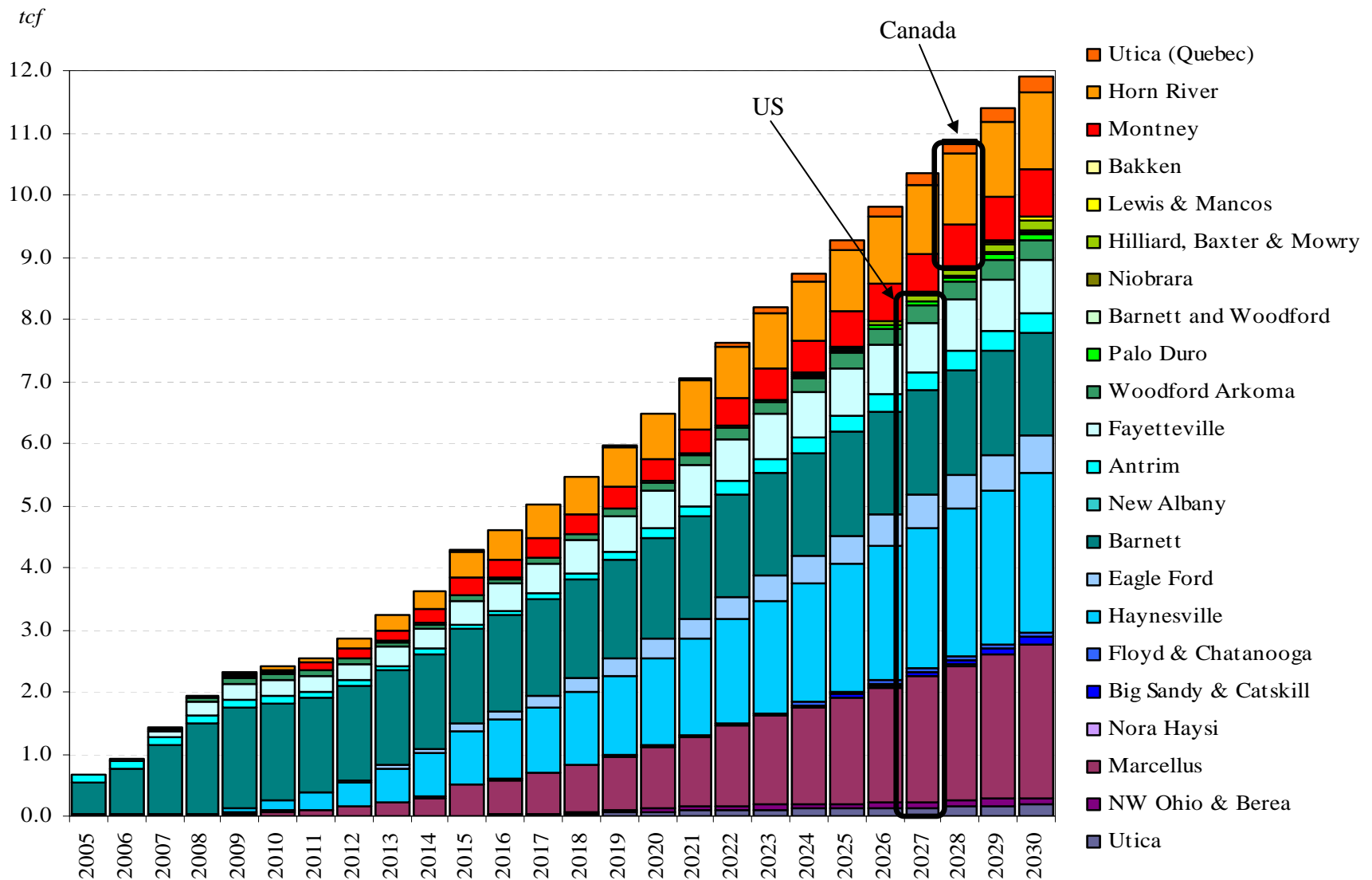
Some BIPP Modeling Results

Henry Hub Natural Gas Price

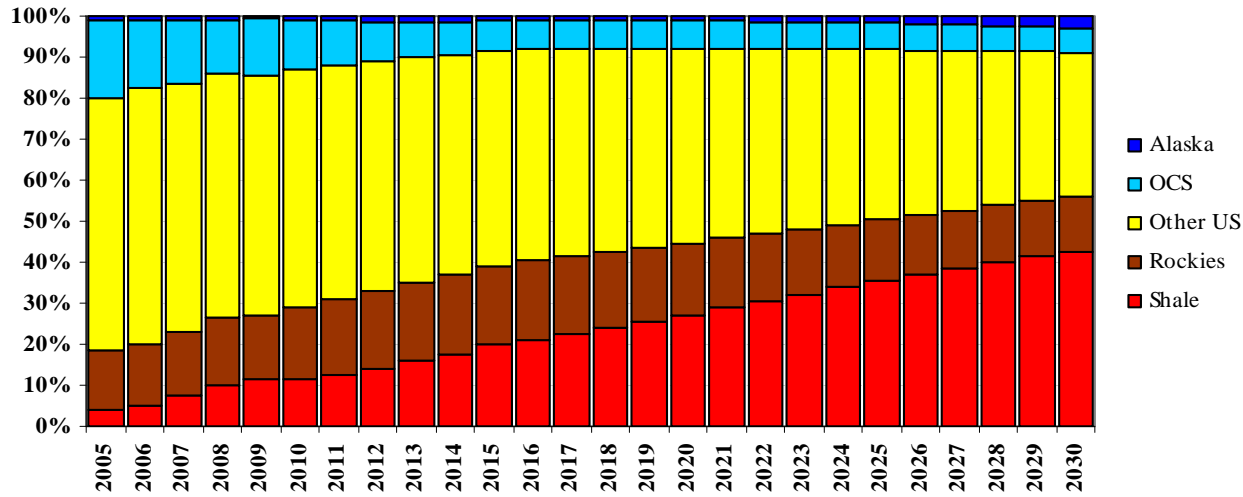
- Long term prices at Henry Hub (averages, inflation adjusted)
 - 2010-2020: \$ 5.98
 - 2021-2030: \$ 6.42



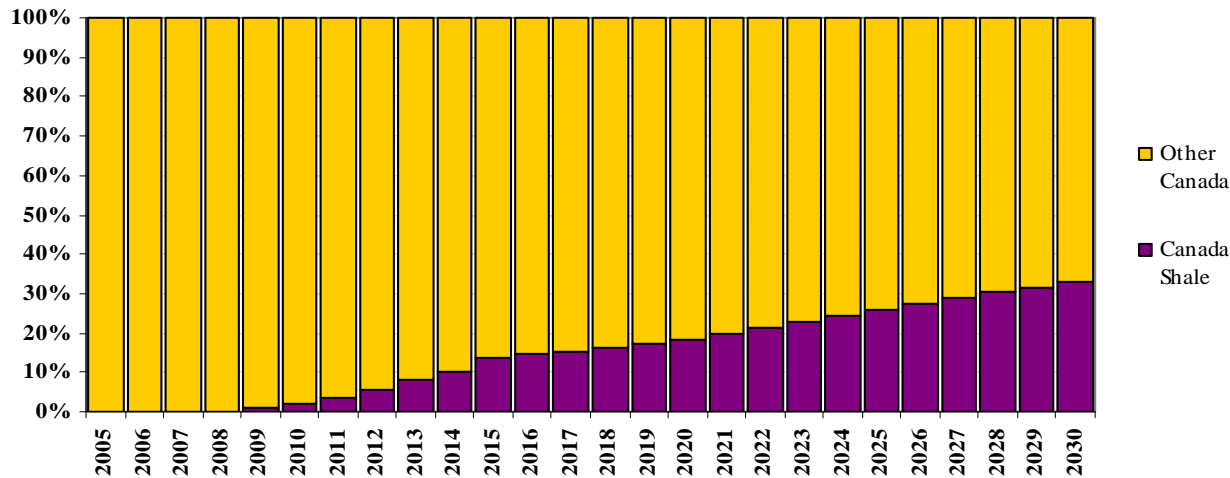
North American Shale Production



Composition of North American Production



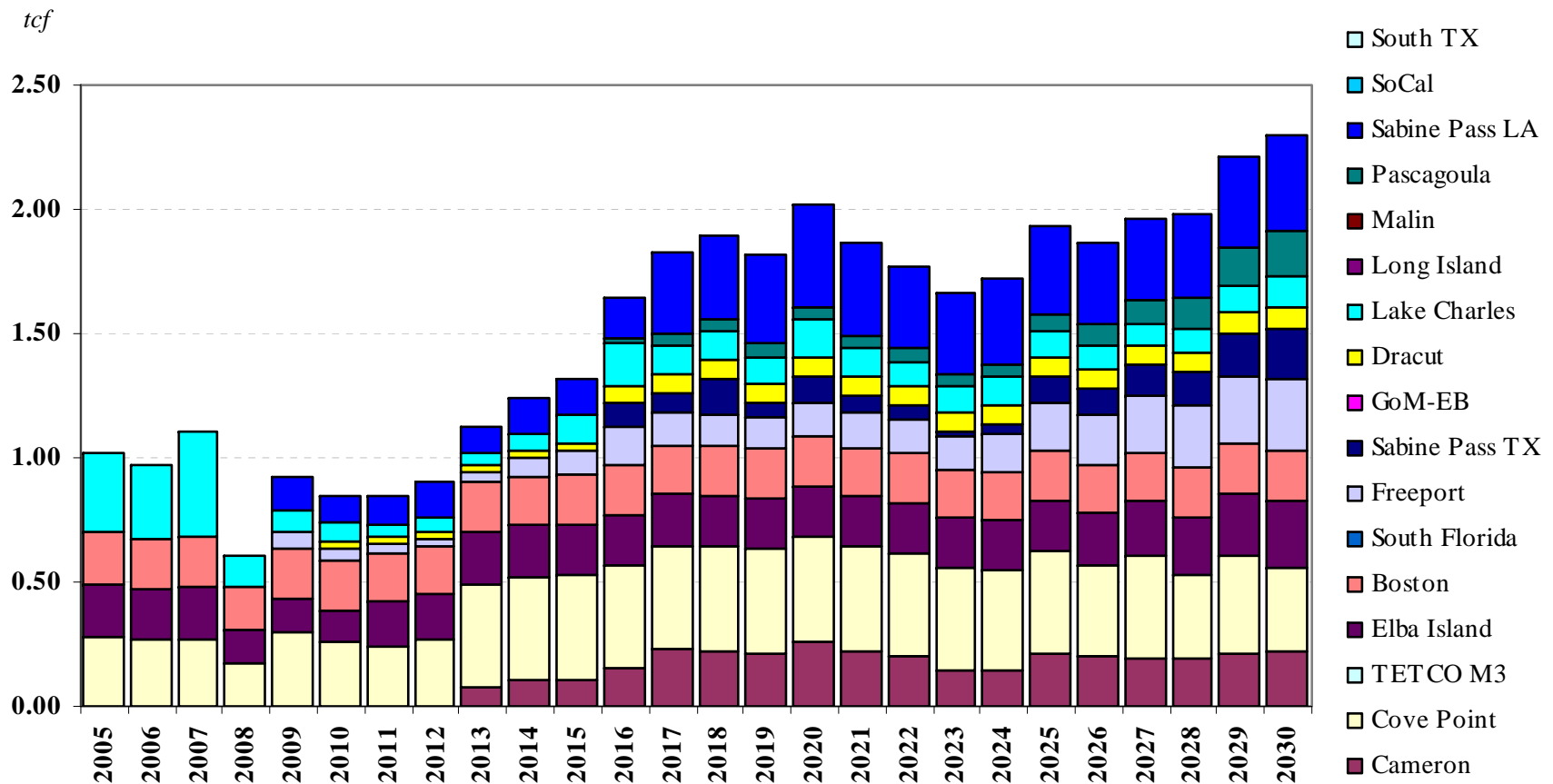
- US shale production grows to about 45% of total production by 2030.



- 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

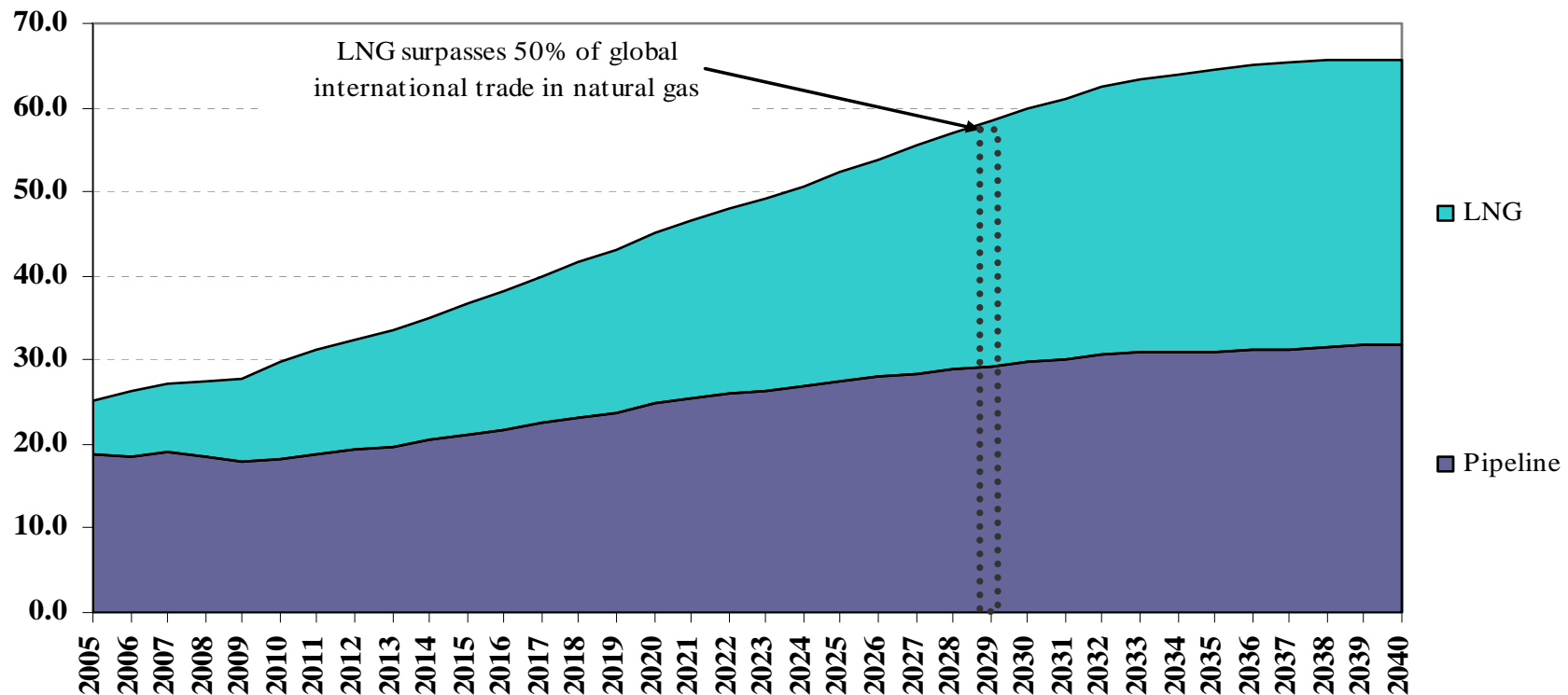
- Growth in domestic shale resources renders load factors on LNG import facilities very low... an overall average of less than 20%.



Global Gas Trade: LNG vs. Pipeline and Market Connectedness

- Globally, LNG growth is strong, reaching about 50% of total international natural gas trade by the late 2020s.
- Once regional disconnected markets become linked.

Tcf per year



A Role for Gas in a CO₂ Constrained World

- Already identified today was the fact that the elasticity of supply of low carbon fuels is important to determining the CO₂ price and the composition of primary energy.
 - This is where shale fits in. As a low-carbon, abundant fuel source it has potentially dramatic capabilities to meet increased demand in a carbon-constrained world. This follows because 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. So, shale gas could prove very important in determining the CO₂ price.

**Hydraulic Fracturing:
Policy and Public Concern**

Some Production Basics

- Shale gas is different from conventional gas formations in that no reservoir or trap is required. Production occurs from rock that spans large areas. The aim is to reduce pressure through fracturing and production so that gas is released from rock (shale) and flows to the wellbore.
- Shale formations are drilled horizontally and fracs are staged to increase the productivity of each well drilled.
- In any production venture, the water table is passed. Oil and gas wells usually require (1) conductor casing (pre-drilling), (2) surface casing (through the aquifer), (3) intermediate casing (deep to prevent well contamination), and (4) production casing (conduit for production). The production casing is the final casing for most wells, and it completely seals off the producing formation from water aquifers.

Hydraulic Fracturing

- The first commercial “frac” was performed by Halliburton in 1949. Despite what is indicated in the press, the technology is not new. The innovation is in the application of the process.
- Fracturing has been used in CBM production. This is distinctly different than shale in that CBM deposits can coincide with water aquifers. In fact, the documented cases of changes in water quality (as documented by Earthworks) almost all have to do with CBM developments.
- Fracturing has been used to increase flow to water wells
- Fracking fluid is primarily water and sand (known as “slick water”), or ceramics in newer applications in shales. Chemical cocktails (some of which are toxic) are also created to add to the potency of the fracking fluid.
- While some chemicals in the fracking fluid can become bound in the shale, the majority of the fluid returns through the wellbore.
 - Problems can arise in the disposal process. This is a preventable issue.
 - Problems can also arise when casings fail. This raises concerns in particularly sensitive areas.

Hydraulic Fracturing (cont.)

- In 2004 the EPA found no evidence of contamination of drinking water from fracking activities. It did, nevertheless, enter into a MoA with CBM developers that precludes the use of diesel fuel in the fracking fluids.
- The US EPA's Underground Injection Control Program regulates
 - Injection of fluids (Class II wells) to enhance oil and gas production
 - Fracturing used in connection with Class II and Class V injection wells to “stimulate” (open pore space in a formation).
 - Hydraulic fracturing to produce CBM in Alabama.

Note, fracking in shale and CBM is not done via an “injection well” – fluid is injected via the producing well.

- Fracking fluids are currently exempt from the Safe Drinking Water Act. This is perhaps the biggest problem as it includes disposal.
- Is fracking appropriate everywhere? Perhaps technically but maybe not socially... Need to understand risks and weigh them against reward. Thus, any externalities must be considered and appropriately internalized. This will likely require a case-by-case review. Regardless, full disclosure will likely be a critical piece of any regulation that may be forthcoming.