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The Shale Revolution: What it means for North America and the World

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Some Shale Gas Basics

Conventional versus Unconventional

- ***Conventional*** reservoirs produce from sands and carbonates (limestones and dolomites) that contain gas in interconnected pore spaces allowing flow to the wellbore.
- ***Unconventional*** reservoirs are characterized by low permeability, so it is necessary to stimulate the reservoir to create additional permeability and hence flow to the wellbore.
  - Tight Gas: Gas is sourced outside and migrates into the reservoir
  - CBM: Coal seams act as source and reservoir of natural gas
  - Shale: Gas is sourced and trapped in a low permeability shale. This is usually either a source or a saturated cap.
- Hydraulic fracturing is a preferred method of stimulation in shales, as well as tight gas formations and some CBM wells.
  - Shale well water requirements (3-6 million gallons per well)
- Some shales have liquid-rich strata (e.g.-Eagle Ford)

Shale gas

- Production from shale is resembling a manufacturing process.
  - Geologic uncertainty is lower than with conventional wells
  - Fracing and production can be timed to meet better economics for each well. This has been facilitated by a reduction in time-to-drill to 12 days, in some cases fewer.
  - Stimulation and field development can begin to mimic a "just in time" process.
- Well productivity is growing due to innovations in the field.
  - IP rates are improving: Southwestern Energy saw a 350% increase from 2007-2009.
  - Longer laterals: in Woodford, increased from 5 stages covering 2600 feet to 14 stages covering 6500 feet in last 4 years.
  - Multi-well pads have also helped

Some Shale Characteristics

Source: DOE, Office of Fossil Energy, "Modern Shale Gas Development in the US"

EXHIBIT 11: COMPARISON OF DATA FOR THE GAS SHALES IN THE UNITED STATES

Gas Shale Basin	Barnett	Fayetteville	Haynesville	Marcellus	Woodford	Antrim	New Albany
Estimated Basin Area, square miles	5,000	9,000	9,000	95,000	11,000	12,000	43,500
Depth, ft	6, 500 - 8,500[82]	1,000 - 7,000[83]	10,500 - 13,500[84]	4,000 - 8,500[85]	6,000 - 11,000[86]	600 - 2,200[87]	500 - 2,000[88]
Net Thickness, ft	100 - 600[89]	20 - 200[90]	200[91] - 300[92]	50 - 200[93]	120 - 220[94]	70 - 120[95]	50 - 100[96]
Depth to Base of Treatable Water[#], ft	~1200	~500[97]	~400	~850	~400	~300	~400
Rock Column Thickness between Top of Pay and Bottom of Treatable Water, ft	5,300 - 7,300	500 - 6,500	10,100 - 13,100	2,125 - 7650	5,600 - 10,600	300 - 1,900	100 - 1,600
Total Organic Carbon, %	4.5[98]	4.0 - 9.8[99]	0.5 - 4.0[100]	3 - 12[101]	1 - 14[102]	1 - 20[103]	1 - 25[104]
Total Porosity, %	4 - 5[105]	2 - 8[106]	8 - 9[107]	10[108]	3 - 9[109]	9[110]	10 - 14[111]
Gas Content, scf/ton	300 - 350[112]	60 - 220[113]	100 - 330[114]	60 - 100[115]	200 - 300[116]	40 - 100[117]	40 - 80[118]
Water Production, Barrels water/day	N/A	N/A	N/A	N/A	N/A	5 - 500[119]	5 - 500[120]
Well spacing, acres	60 - 160[121]	80 - 160	40 - 560[122]	40 - 160[123]	640[124]	40 - 160[125]	80[126]
Original Gas-In-Place, tcf[127]	327	52	717	1,500	23	76	160
Technically Recoverable Resources, tcf[128]	44	41.6	251	262	11.4	20	19.2

NOTE: Information presented in this table, such as Original Gas-in-Place and Technically Recoverable Resources, is presented for general comparative purposes only. The numbers provided are based on the sources shown and this research did not include a resource evaluation. Rather, publically available data was obtained from a variety of sources and is presented for general characterization and comparison. Resource estimates for any basin may vary greatly depending on individual company experience, data available at the time the estimate was performed, and other factors. Furthermore, these estimates are likely to change as production methods and technologies improve.

Mcf = thousands of cubic feet of gas

scf = standard cubic feet of gas

tcf = trillions of cubic feet of gas

= For the Depth to base of treatable water data, the data was based on depth data from state oil and gas agencies and state geological survey data.

N/A = Data not available

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 though 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 endeavor, 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 in CBM production is distinctly different than when used in shale. 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
- Fracing fluid is primarily water and sand ("slick water"), or ceramics in newer applications in shales. Chemical cocktails are also created to add to the potency of the fracing fluid. Some of these chemicals are toxic.
- While some chemicals in the fracing 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.

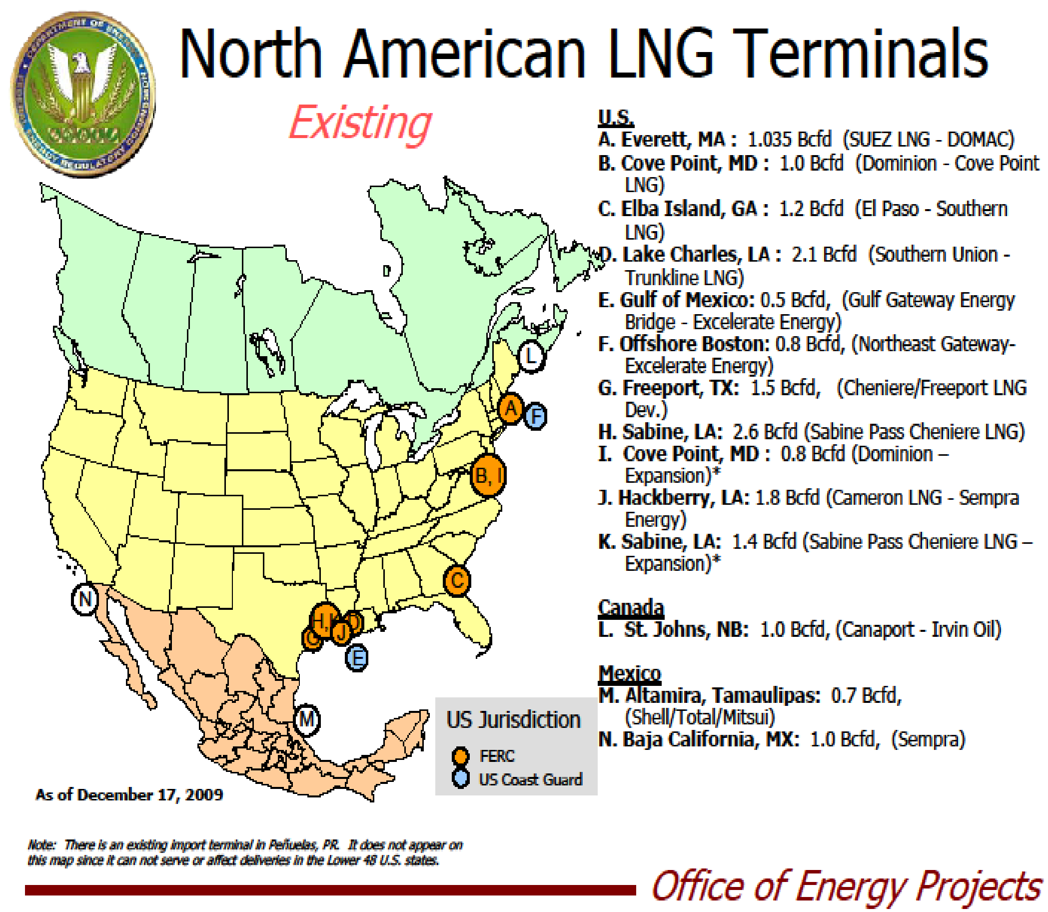
Hydraulic Fracturing (cont.)

- In 2004 the EPA found no evidence of contamination of drinking water from fracing activities. It did, nevertheless, enter into a MoA with CBM developers that precludes the use of diesel fuel in the fracking fluids.
- The US EPAs 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.
- Is fracing 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.
- EPA study on hydraulic fracturing has been initiated
  - NY announced hydraulic fracturing moratorium until EPA study completed
- Full disclosure will likely be a critical piece of any regulation that may be forthcoming.

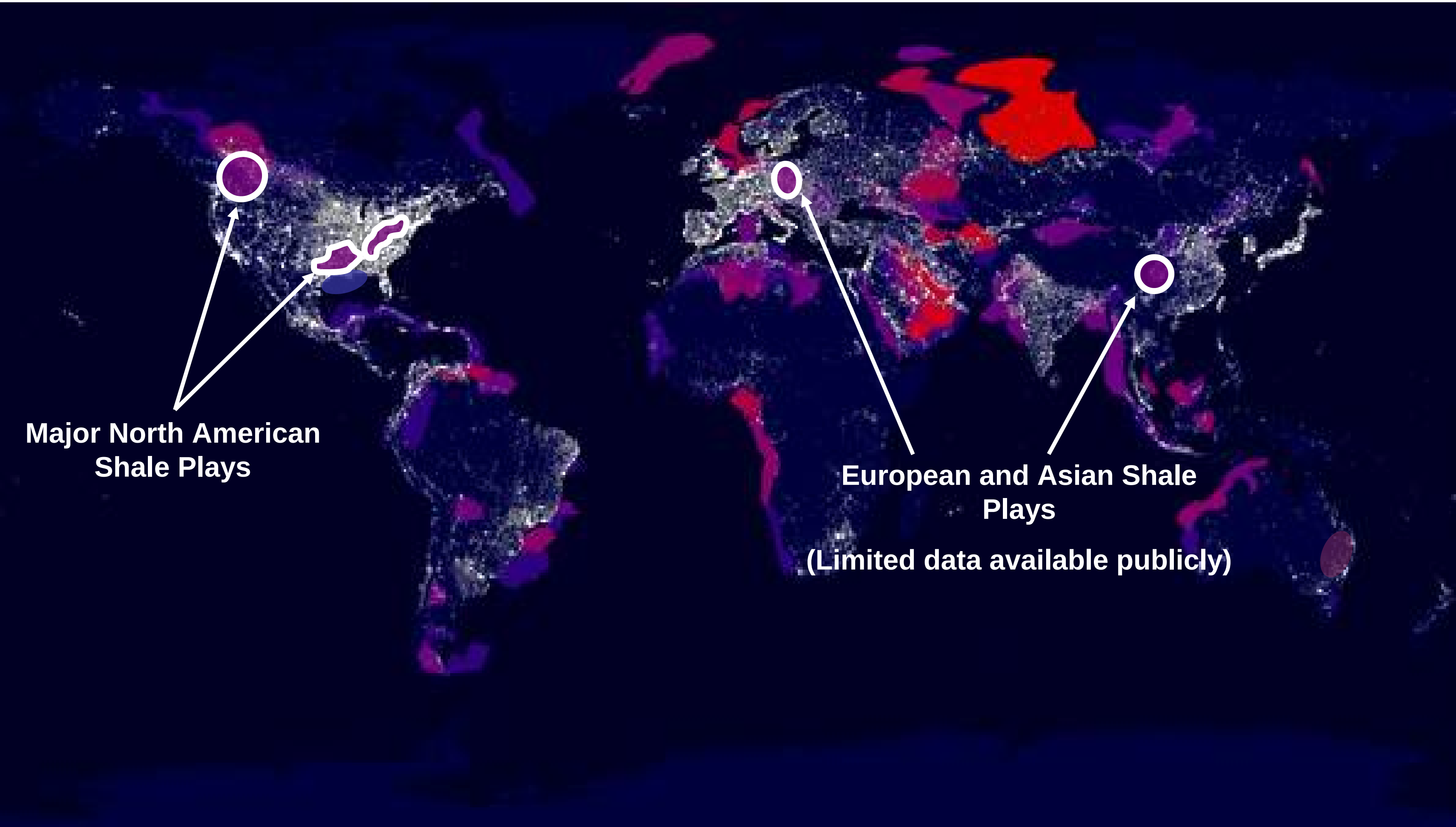
What does the “shale revolution” mean?

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 bcfd; It now stands at just over 17.4 bcfd.
  - By 2012, it could reach 20 bcfd.
- A similar story in Europe
  - In 2000, capacity was just over 7 bcfd; It is now over 14.5 bcfd.
  - By 2012, it could exceed 17 bcfd.
- Shale gas developments have since turned expectations upside-down



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

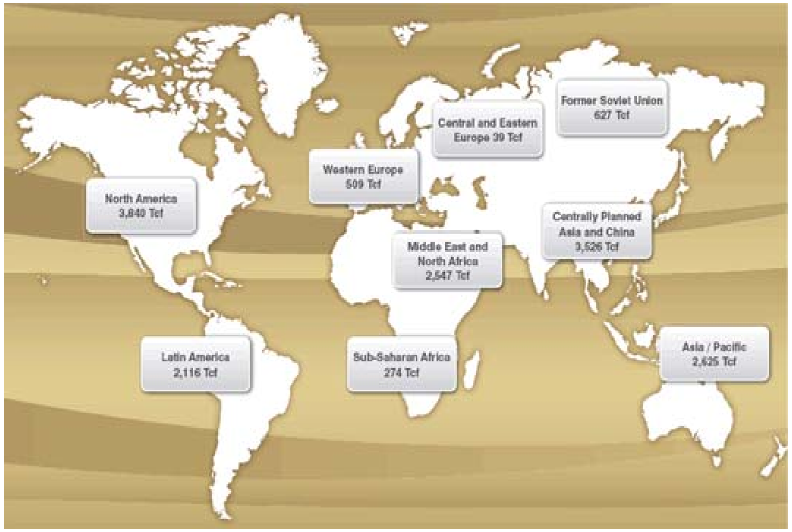


The Global Shale Gas Resource

- 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, GIP numbers are very large. **The X-factor is cost.**

Resource in Place

Resource endowment. Lots of uncertainty, but we can never get beyond this ultimate number.

Technically Recoverable Resource

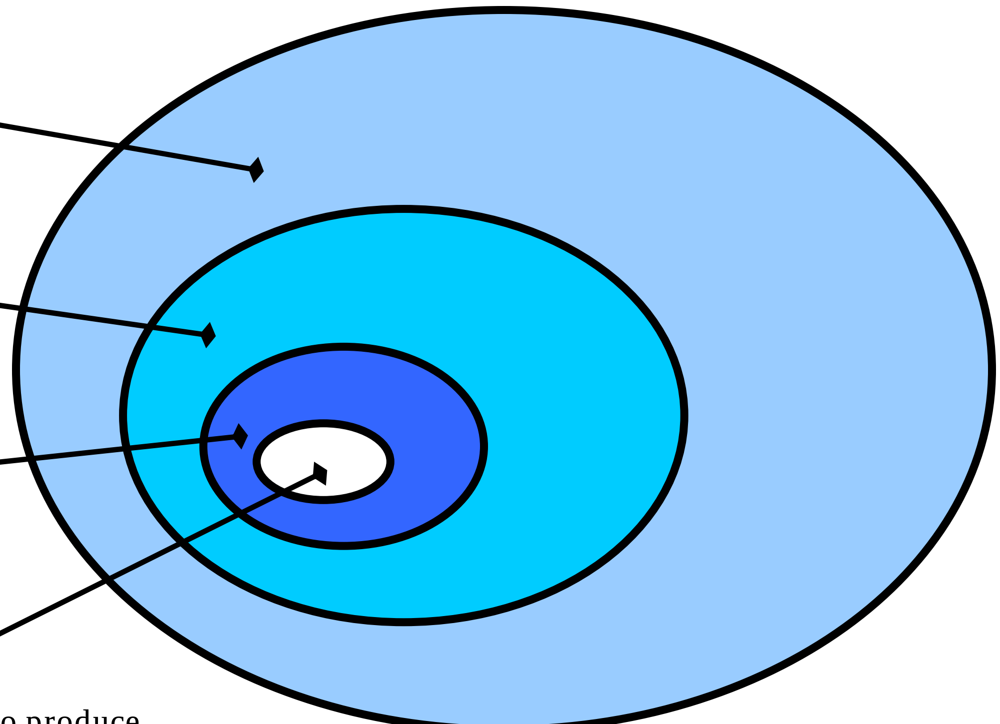
This is the number that is being assessed. Lots of uncertainty, but experience has shown this number generally grows over time.

Economically Recoverable Resource

This will grow with decreasing costs and rising prices, but is bound by technology.

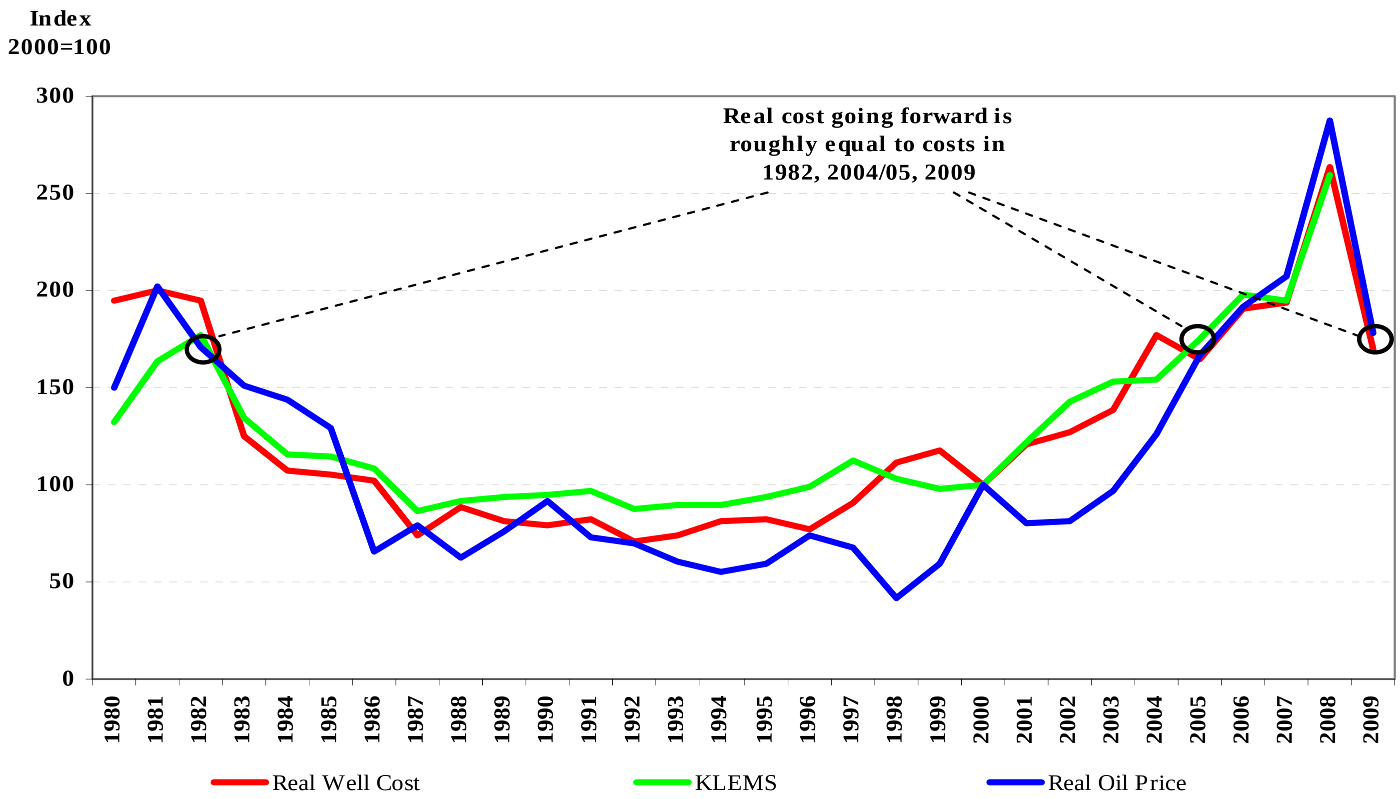
Proved Reserves

Connected and ready to produce.



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?



North American Shale Gas

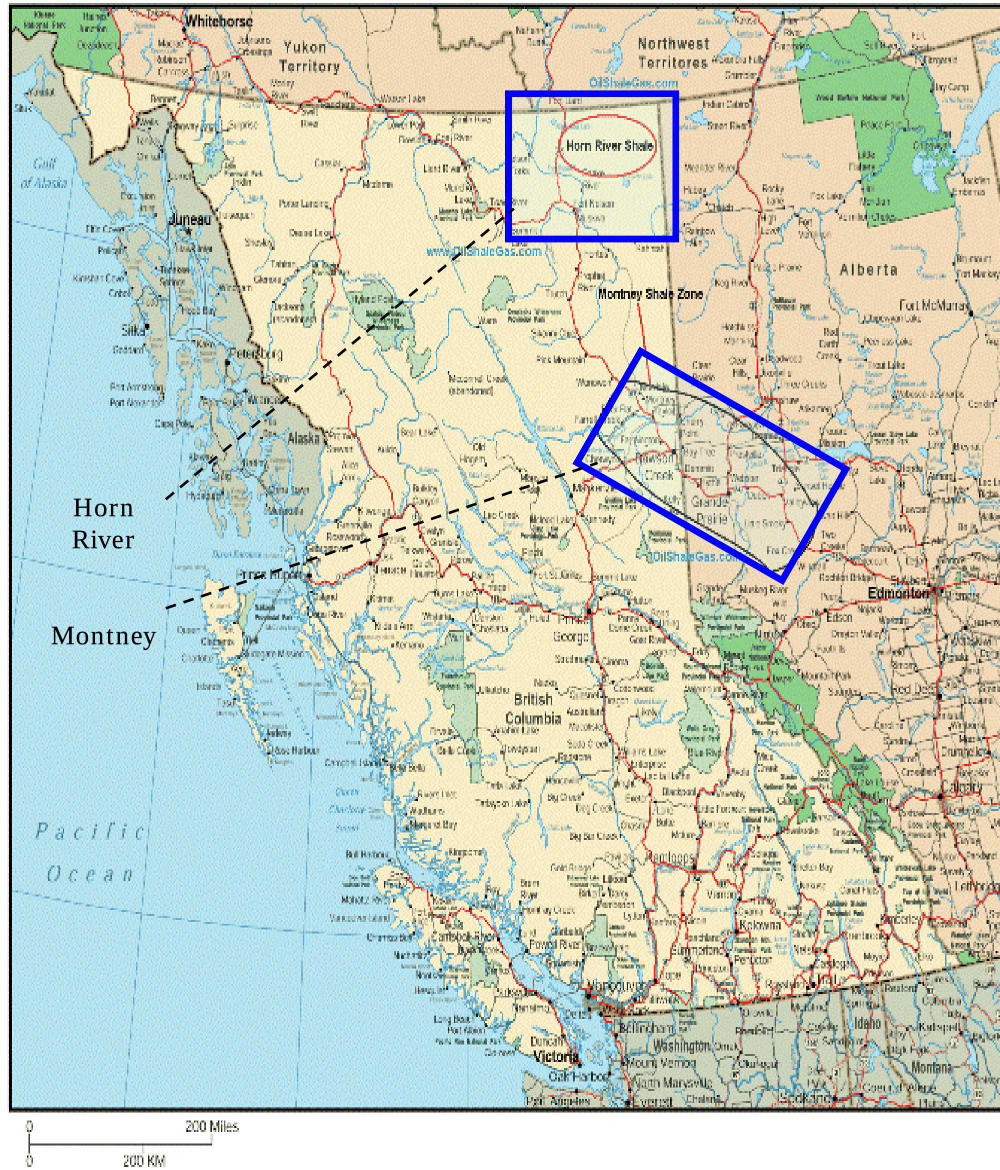
- Note, in 2005, most estimates placed the resource at about 140 tcf.
- Some estimates are much higher
  - (2008) Navigant Consulting, Inc. estimated a mean of about 520 tcf.
  - (2009) Estimate from PGC over 680 tcf.
  - (2010) ARI estimate of over 1000 tcf.
- Resource assessment is large. Our work at BIPP indicates a technically recoverable resource of 583 tcf.
- We learn more as time passes!

Source: Energy Information Administration based on data from various published studies
Updated: May 28, 2009

	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	

North American Shale Gas (cont.)

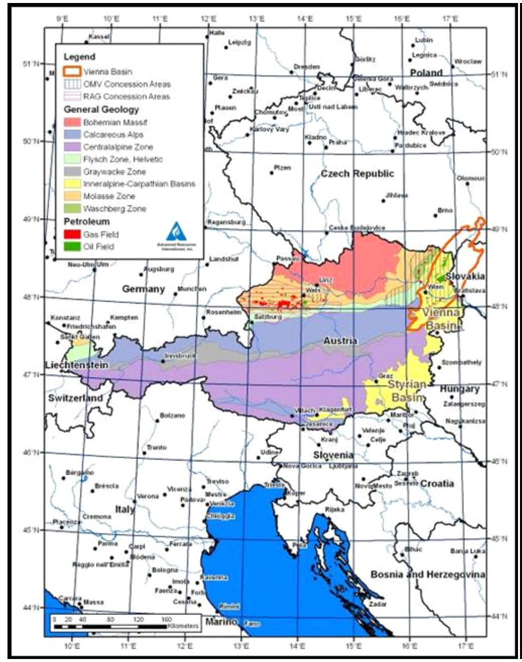
- Shale is also in Canada.
- Most active areas are in the Horn River and Montney plays in BC and Alberta.
- Supply potential in BC, in particular, has pushed the idea of LNG exports targeting the Asian market
  - Asia is an oil-indexed premium market.
  - Competing projects include pipelines from Russia and the Caspian States, as well as LNG from other locations.
  - 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 by some to the Barnett.



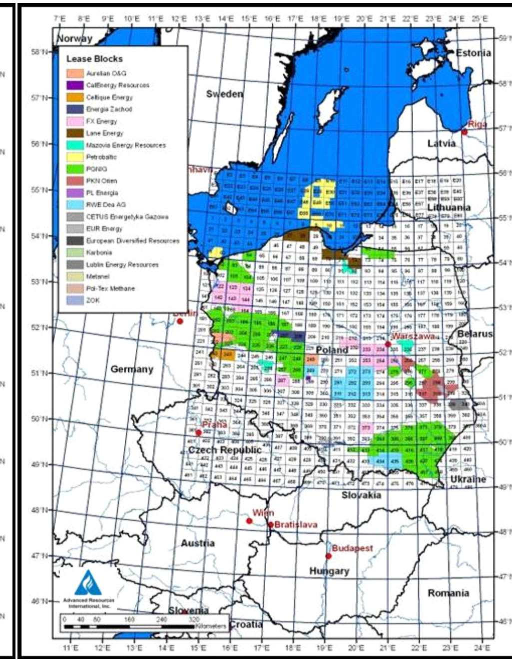
European Shale Gas

- 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).”

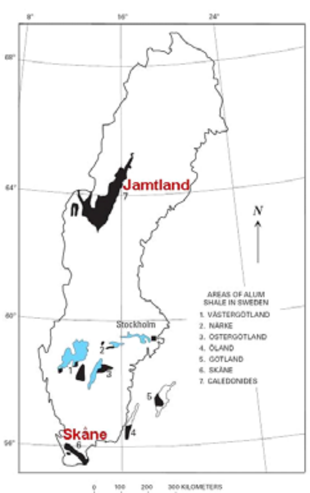
Austria



Poland *(by lease)*



Sweden



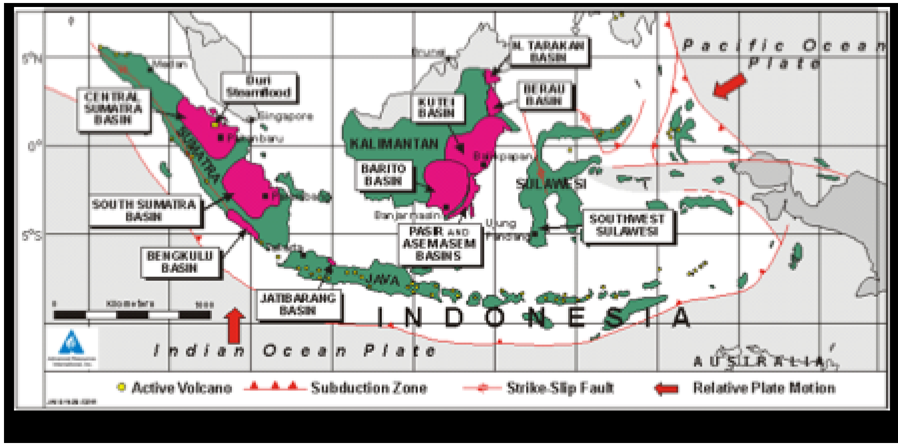
Source:

Graphics from ARI (2010)

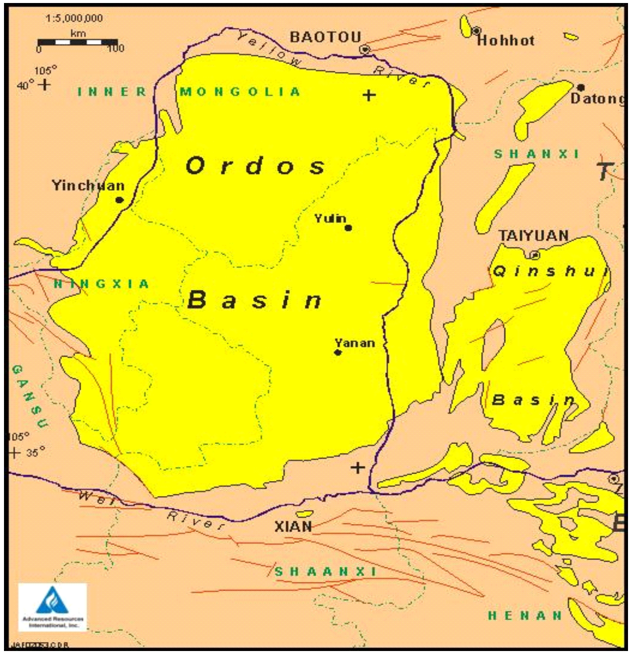
Asia/Pacific Shale and CBM

- 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)

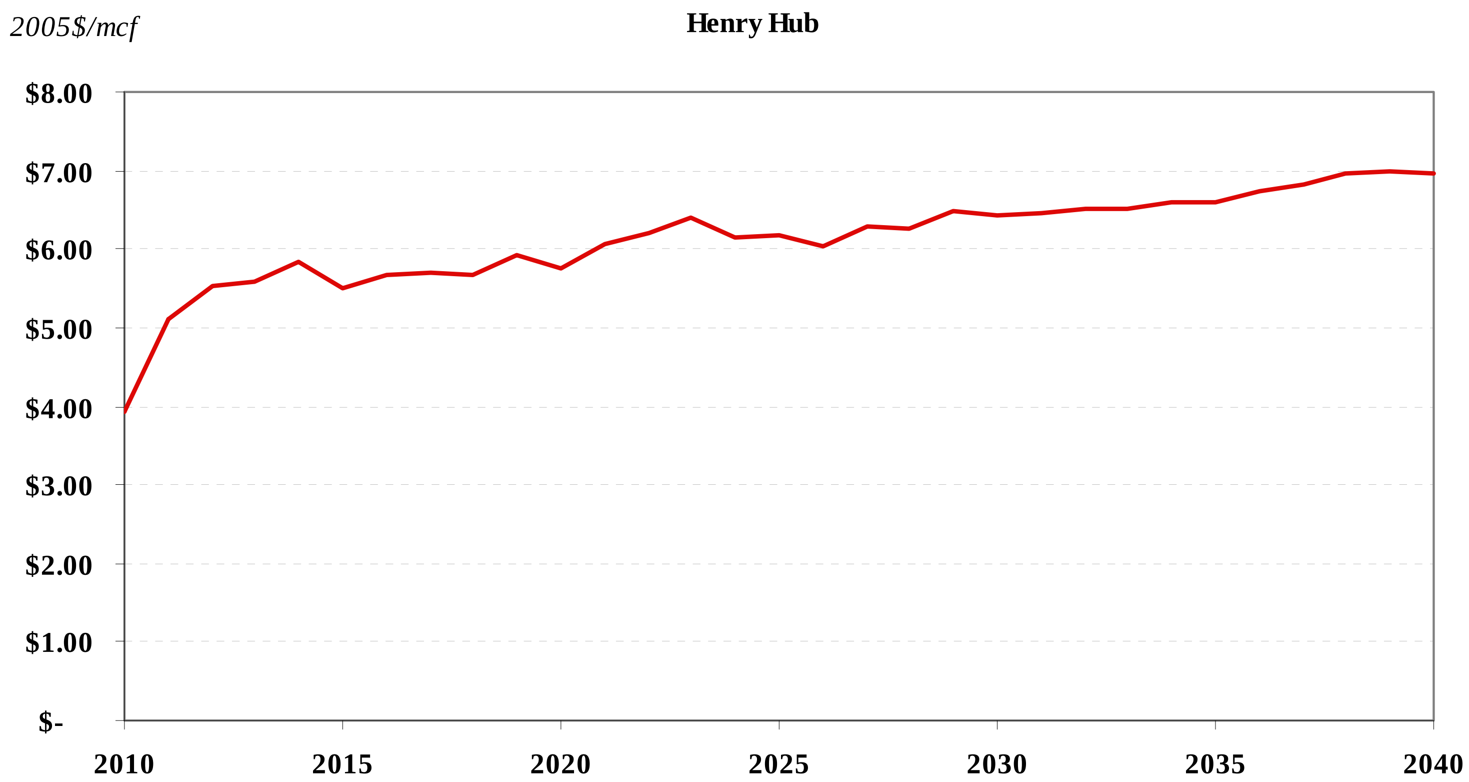


Source: Graphics from ARI (2010)

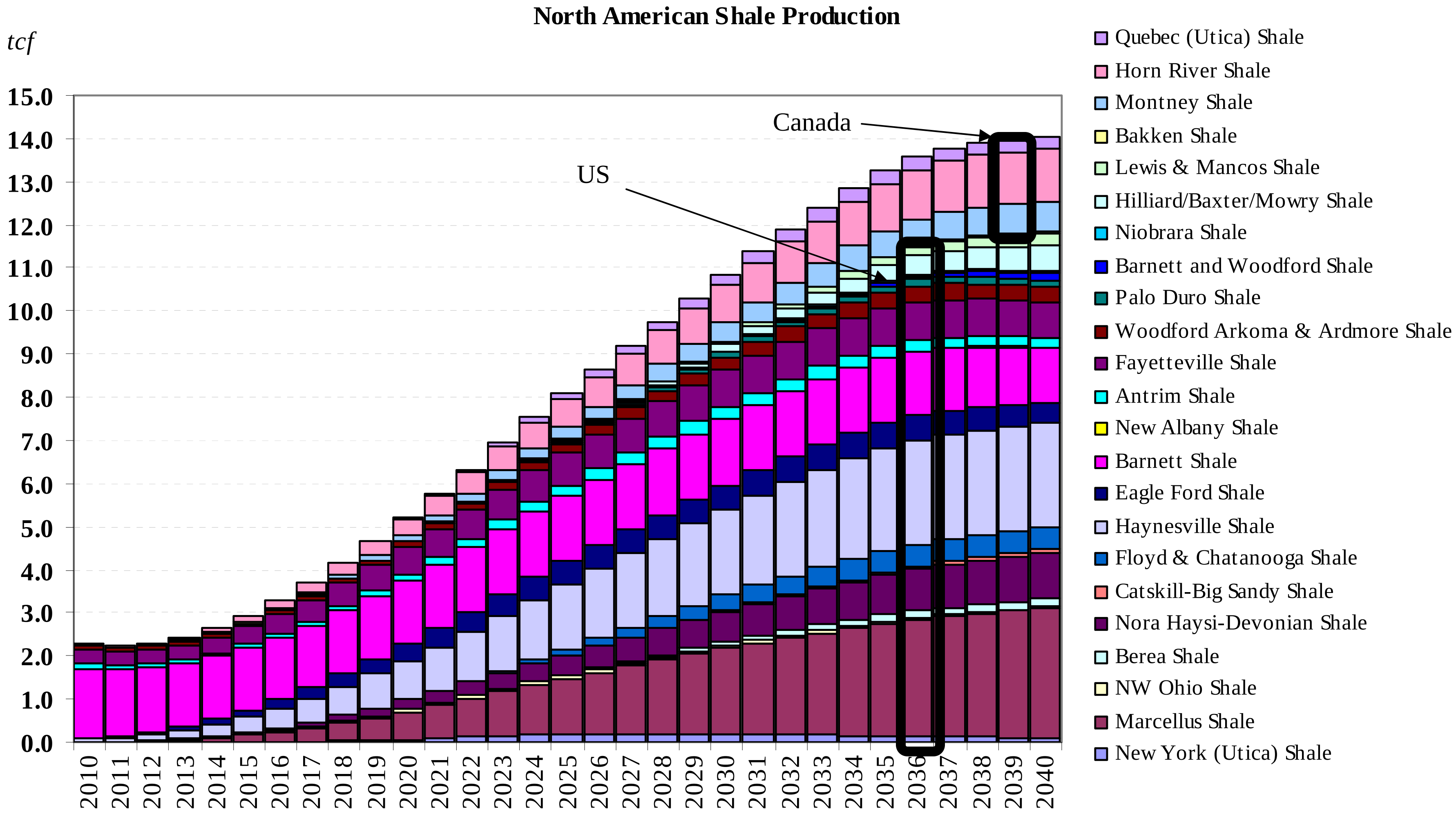
Some BIPP Modeling Results

Henry Hub Natural Gas Price

- Long term prices at Henry Hub (averages, inflation adjusted)
  - 2010-2020: $ 5.47 2021-2030: $ 6.25 2031-2040: $ 6.71

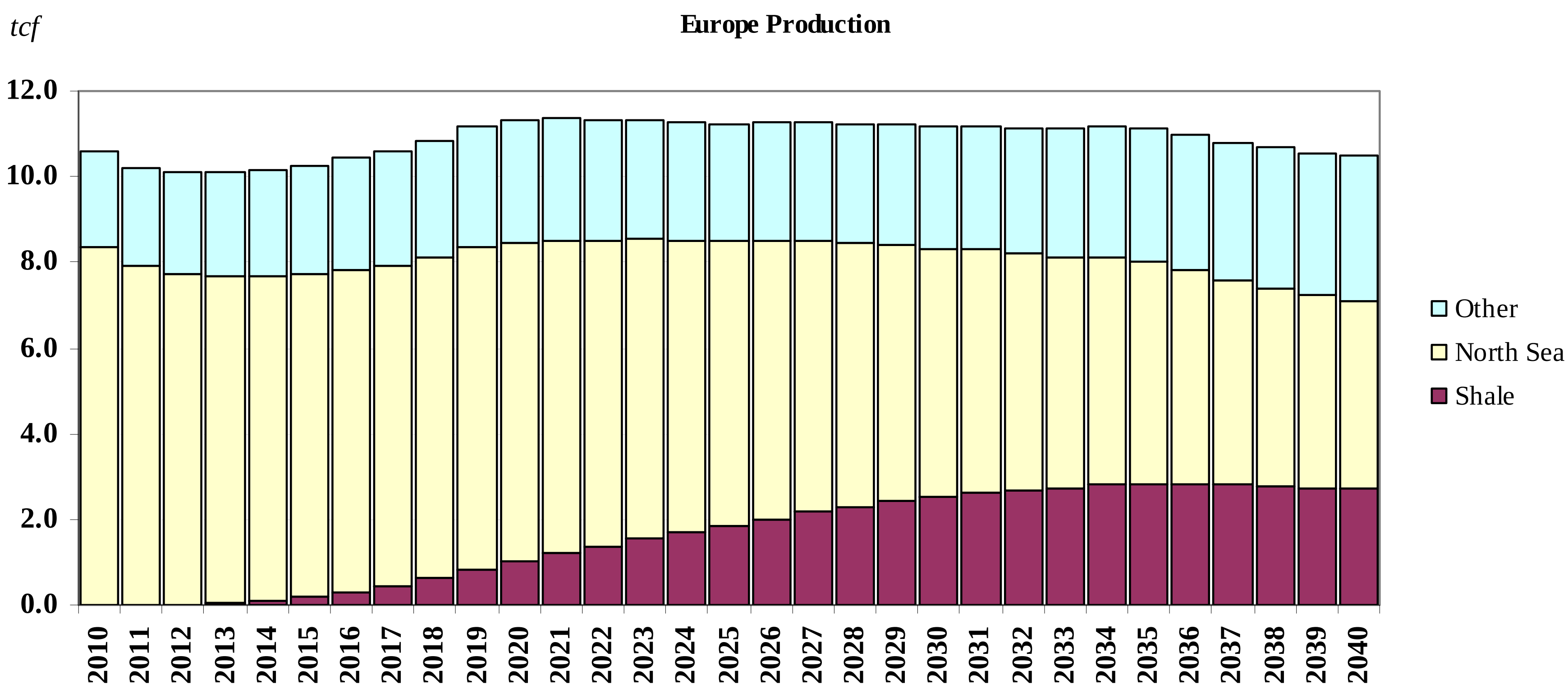


North American Shale Production



The Impact of European Shale Production

- European shale production grows to about 18% of total production by the mid-2030s. While this is not as strong as North America, it does offset the need for increased imports from Russia, North Africa, and via LNG. In fact, the impact of shale growth in Europe is tilted toward offsetting Russian imports, but it also lowers North Sea production at the margin, as well as other sources of imports.



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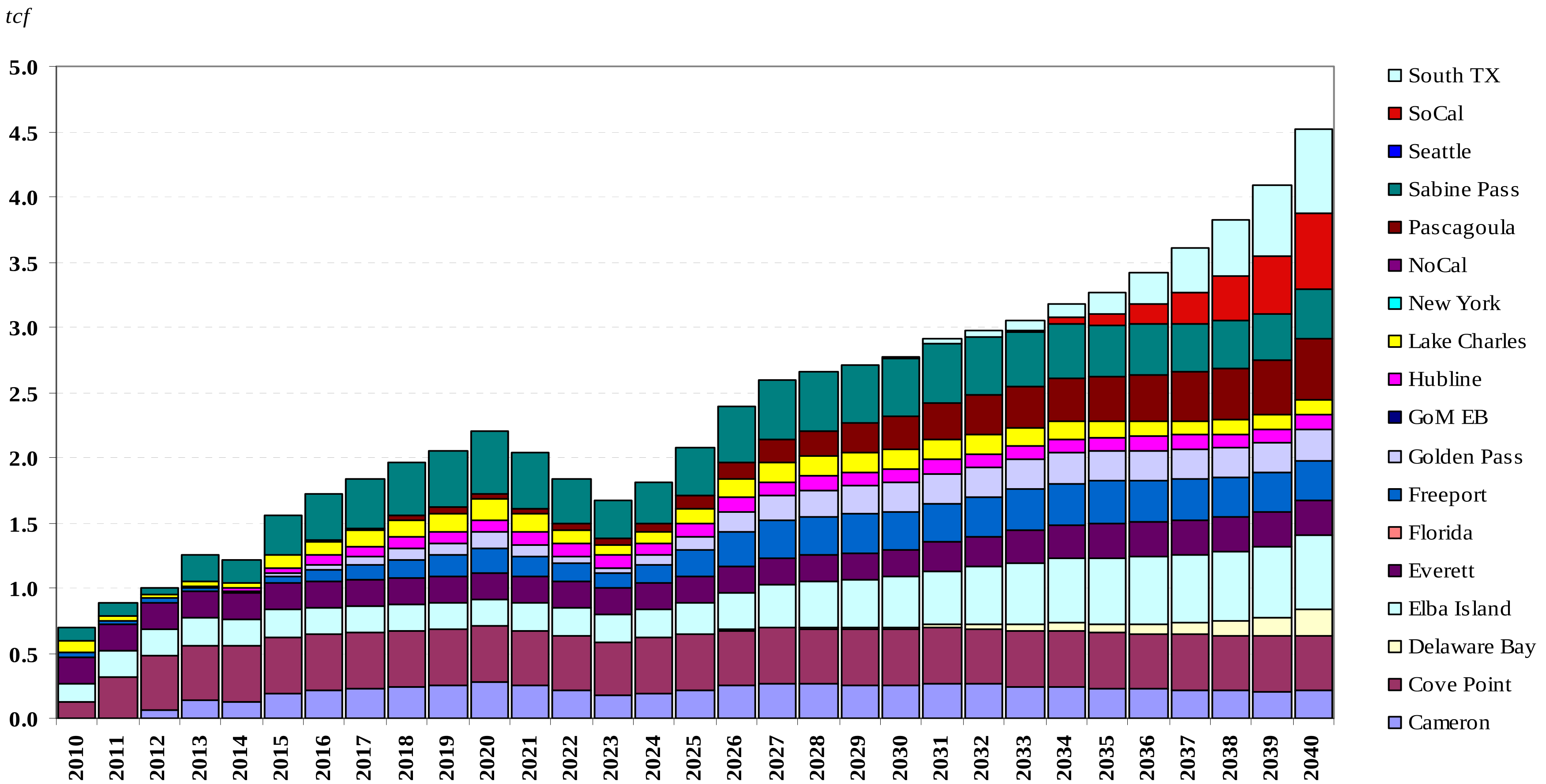
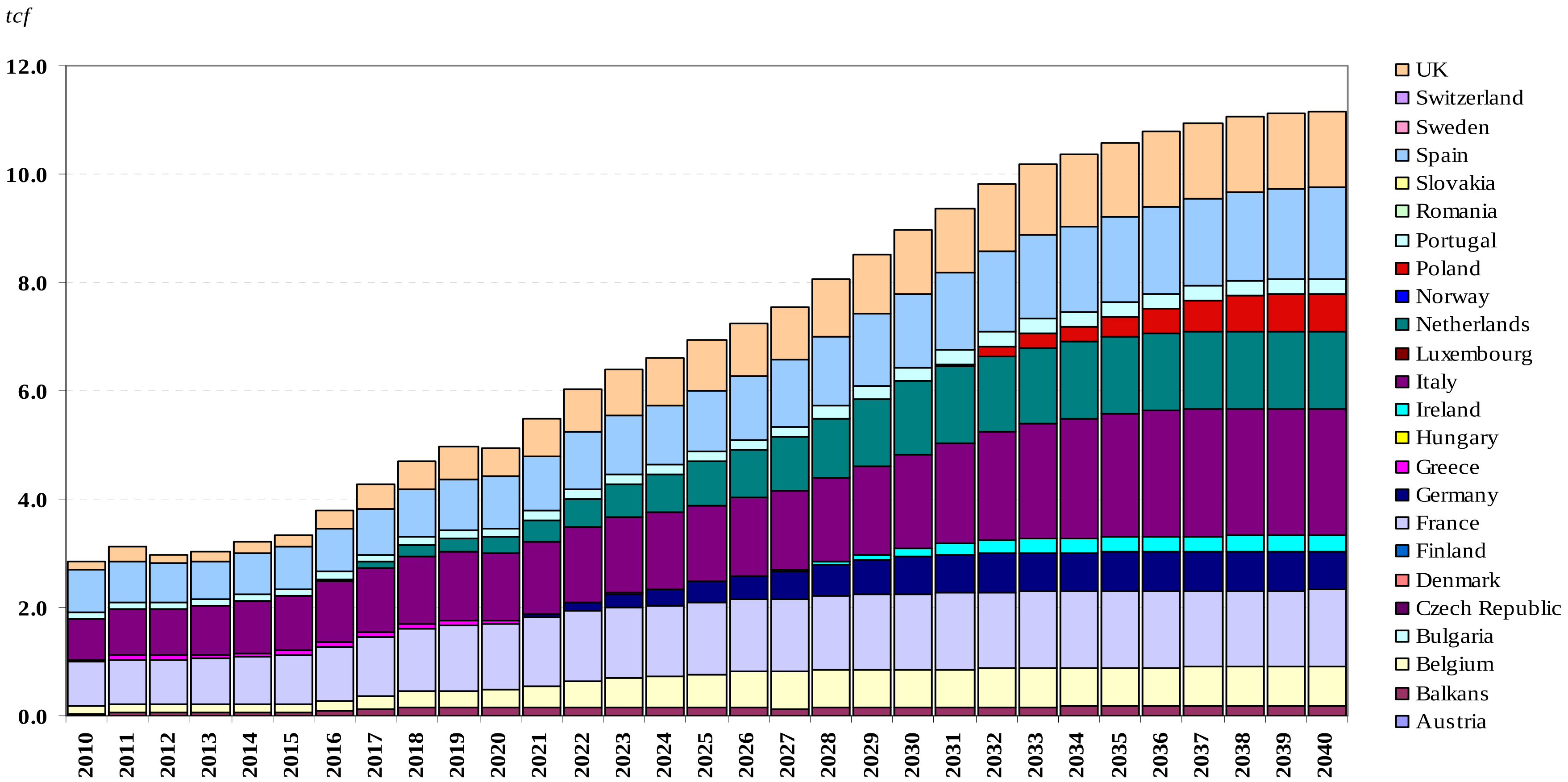
LNG Imports to the US

- Growth in domestic shale resources renders load factors on LNG import facilities very low.
  - Load factors approach an average of 25% by the late 2030s.



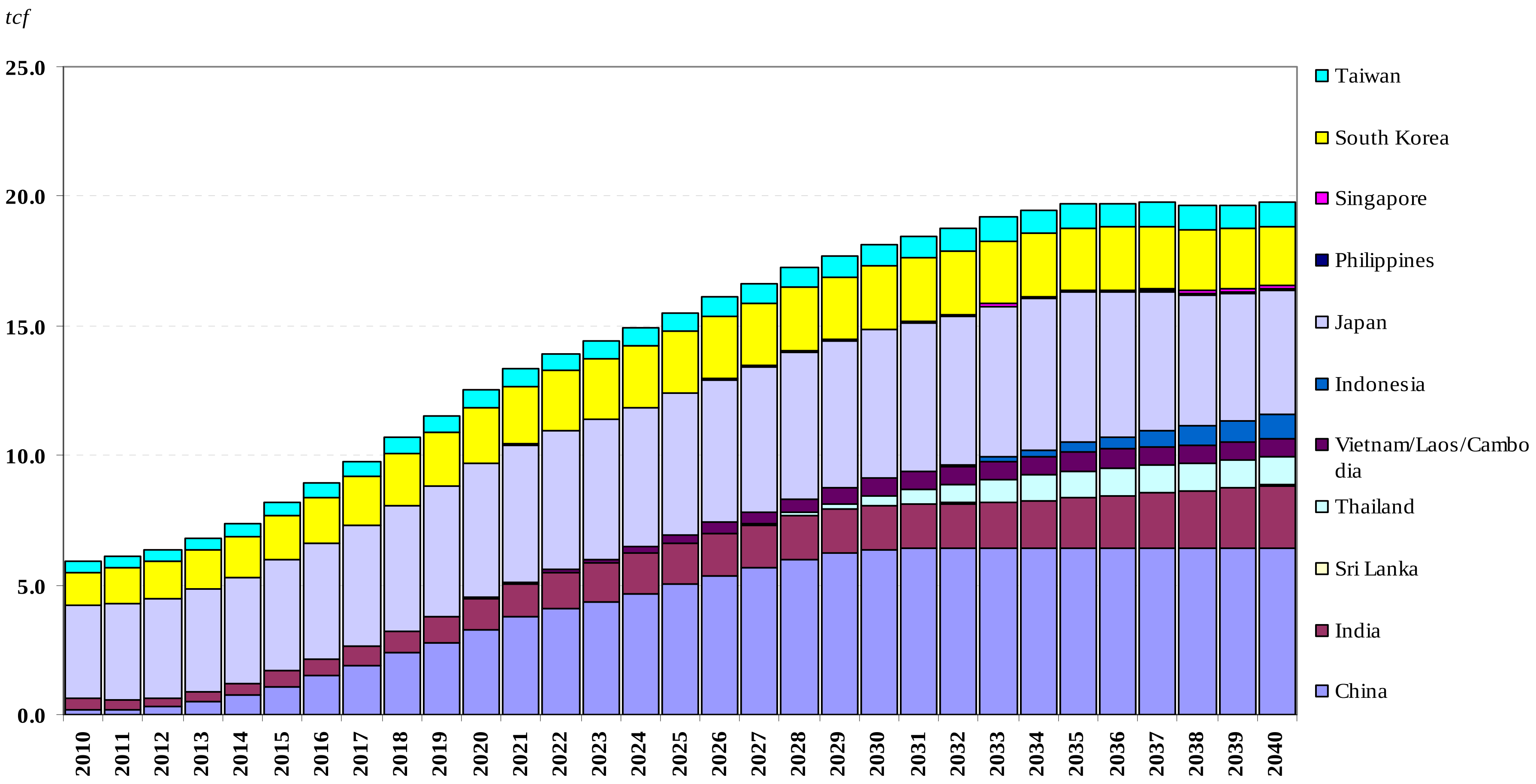
LNG Imports to Europe

- Growth in LNG is an important source of diversification to Europe. Indigenous shale gas opportunities abate this to some extent, but the shale revolution is not as strong as in North America.



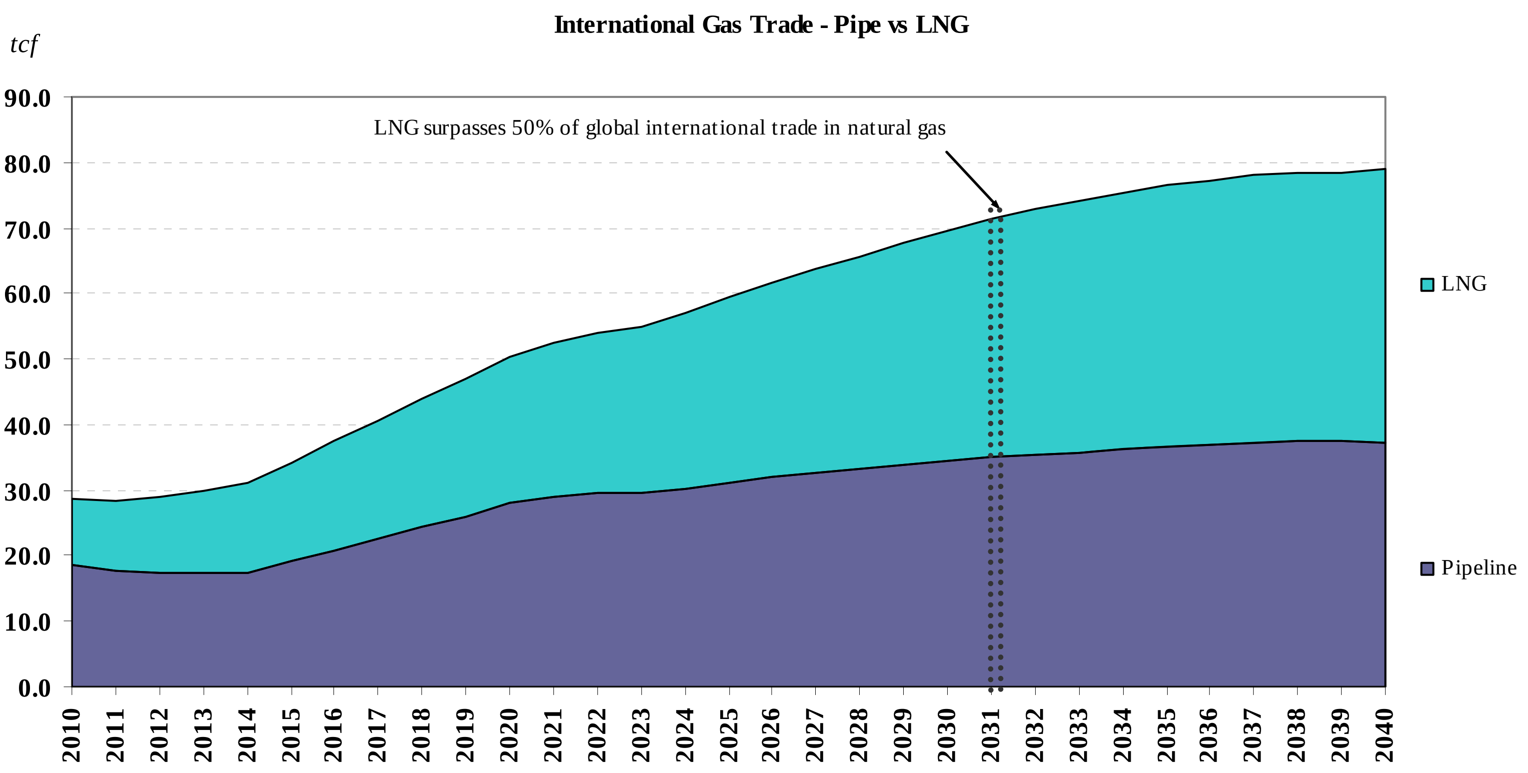
LNG Imports to Asia

- Strong demand growth creates a much needed sink for LNG supplies.
  - China leads in LNG import growth despite growth in pipeline imports and supplies from domestic unconventional sources.



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 early 2030s.
- Previously, regional disconnected markets become linked.



A Role for Gas in a CO_2 Constrained World

- Already identified today was the fact that the elasticity of supply of low carbon fuels is important to determining the CO_2 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 CO_2 need only rise to the point at which natural gas substitutes for coal. So, shale gas could prove very important in determining the CO_2 price.