Shale Gas, Emerging Fundamentals, and Geopolitics

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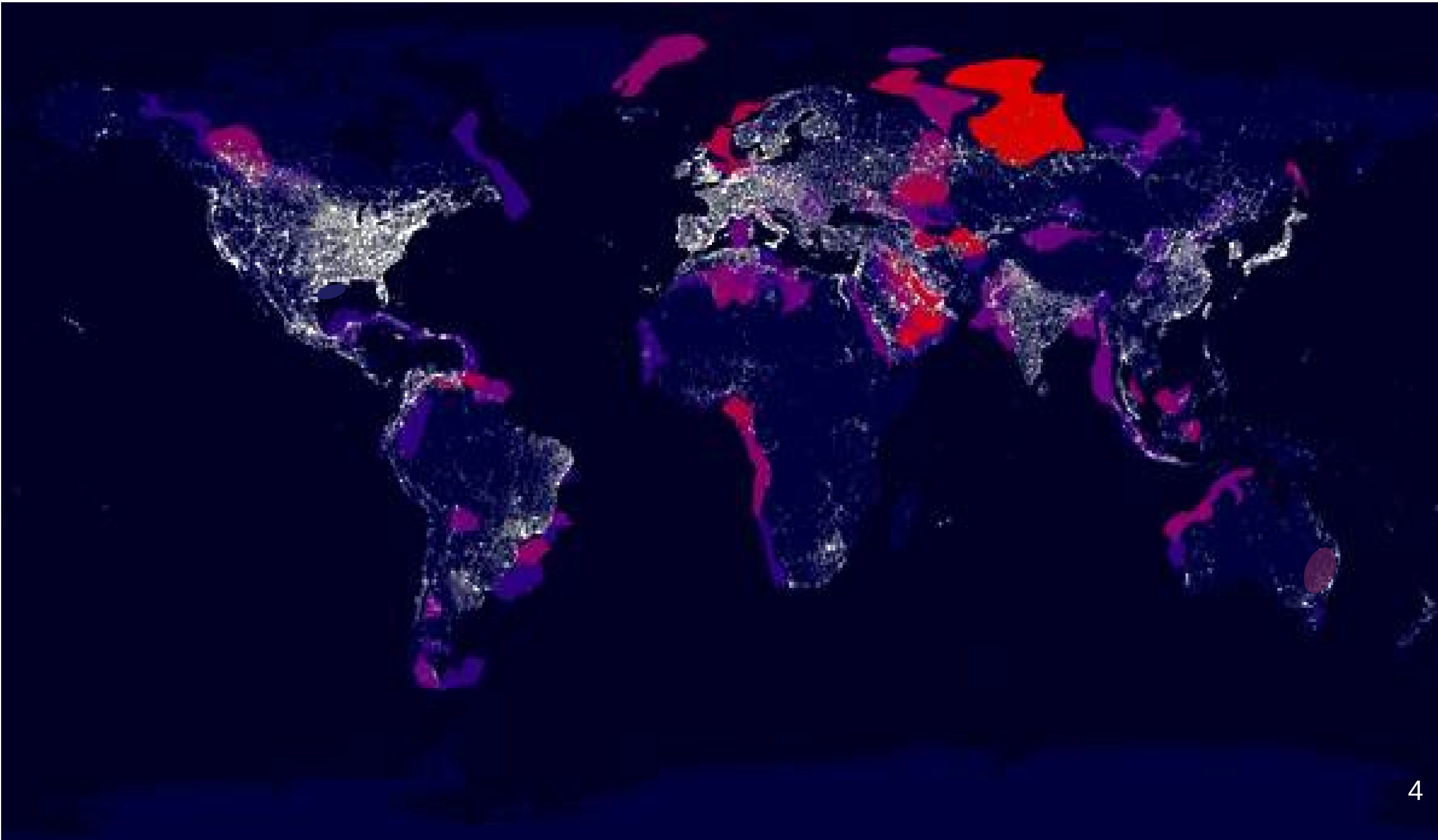
Discussion Points

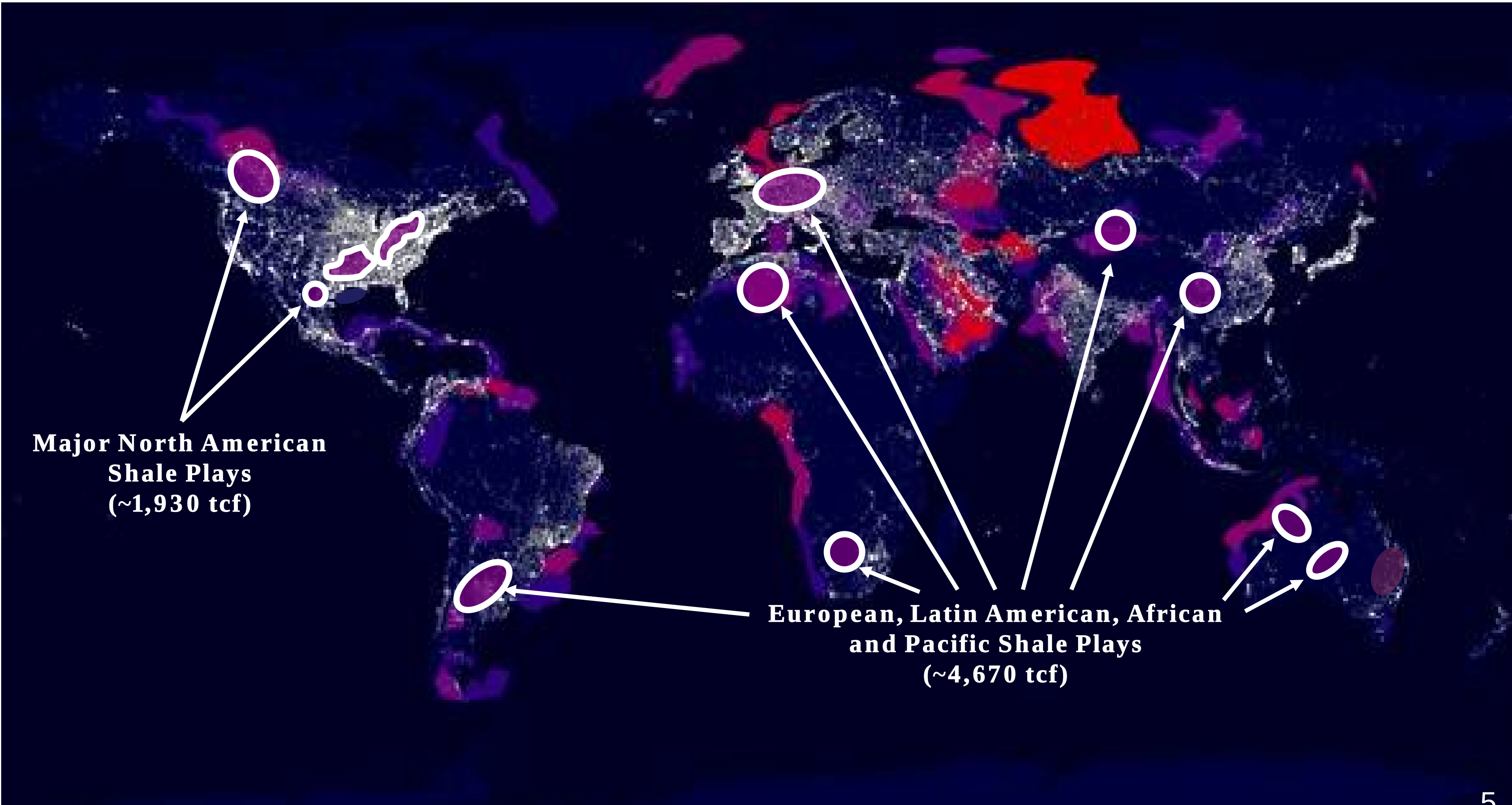
- The impact of shale on global gas market developments
- “Shale Gas and US National Security”
- The prospect and influence of US LNG exports

What has the "shale revolution" meant?

The expectation in the early 2000s: Increasing LNG trade to connect supplies with demands



The expectation in 2012:
Shale resources emerge. This could alter traditional pricing paradigms in major markets, and stress the LNG market.



**Over 6,600 tcf of shale according to ARI/EIA report, 2011*

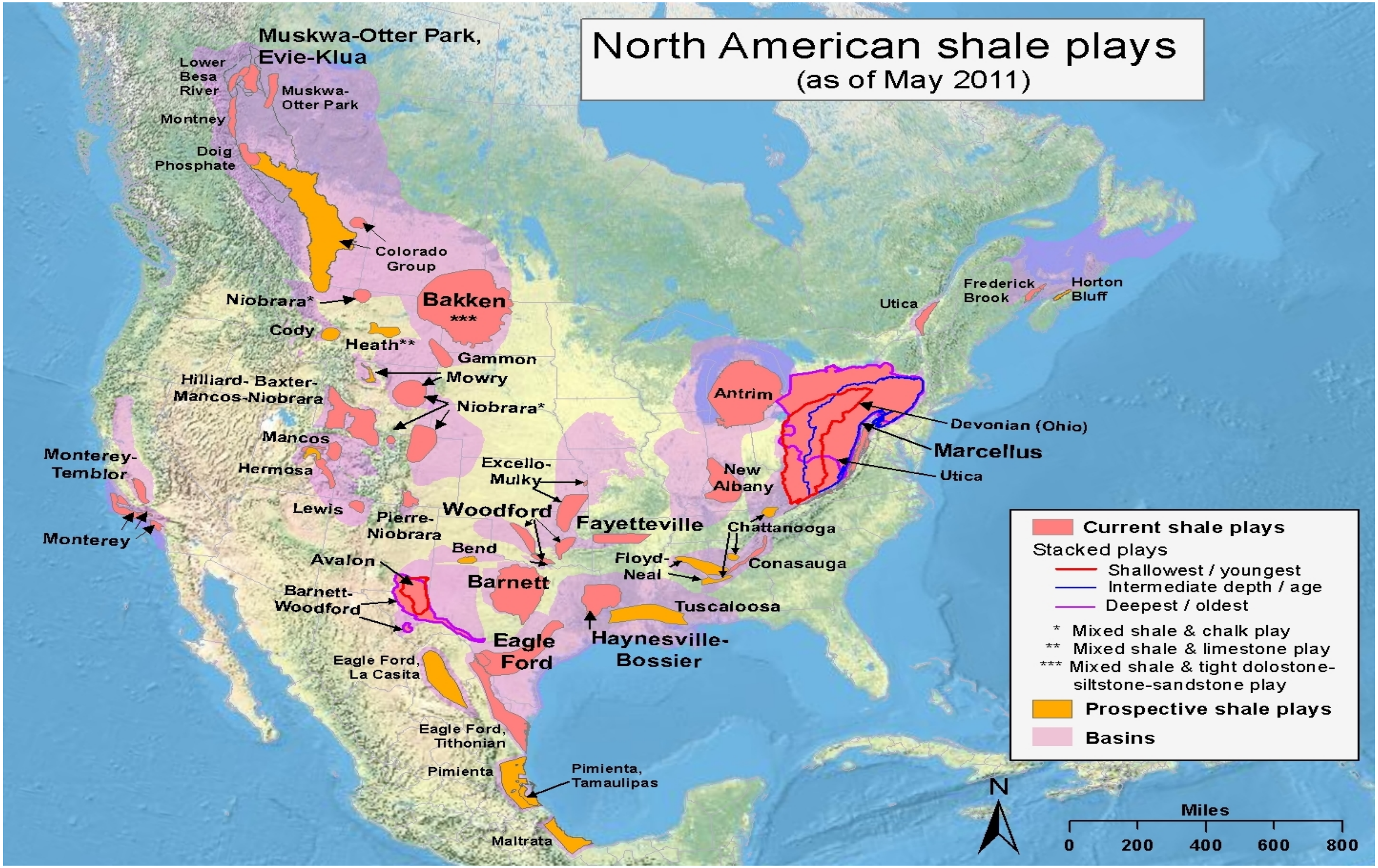
A Paradigm Shift

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, as demand for natural gas appeared to be far from regions with large resource endowments. However, shale gas is proving to be available exactly "where the lights are on" – in the large traditional end-use markets. As such, growth opportunities for LNG developers are now seen as being primarily in Asia.

Shale in The United States: An Evolving State of Knowledge

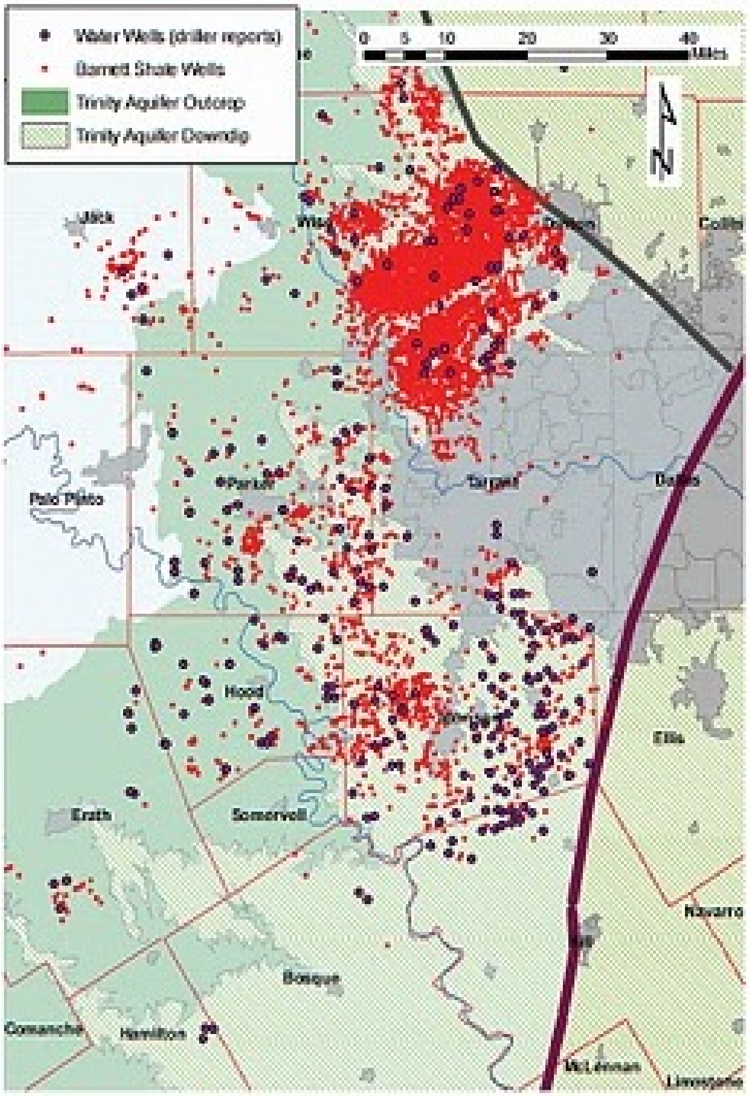
- In 2003, the NPC used an assessment of 38 tcf of technically recoverable shale gas in its study of the North American gas market.
- In 2005, most estimates placed the resource at about 140 tcf.
- Recent estimates are much higher
  - (2008) Navigant Consulting, Inc. estimated a "mean" of about 280 tcf.
    - Survey of producers yielded 840 tcf with the majority of the additional resource in the Marcellus and Haynesville shales.
  - (2009) Estimate from Potential Gas Committee (PGC) over 680 tcf.
  - (2011) ARI estimate of over 900 tcf.
- Resource assessment is large. Our work at BIPP indicates a technically recoverable resource of 687 tcf.
- Point: We learn more as time passes!

Shale in North America – a closer look



Source: US Energy Information Administration

Shale in the US – Learning by doing



- "Learning by doing" appears to be yielding gains in process efficiency.
- The "learning by doing" experience in the Barnett shale is a barometer.
  - Over 16,000 wells drilled, of which over 12,000 are horizontal wells
  - Operator efficiency has dramatically improved in the last 3 years.
    - Rig counts have fallen from 192/wk in Sept. 2008 to 64/wk in Sept. 2011, but...
    - Production was higher in Sept. 2011 than in Sept. 2008.
  - 80 acre spacing being reduced to 40, with some operators now testing 20 acre spacing.
- Currently involved in a study examining the "efficient production frontier" in shale gas to assess the rate of technological change.

Far-reaching implications of shale gas

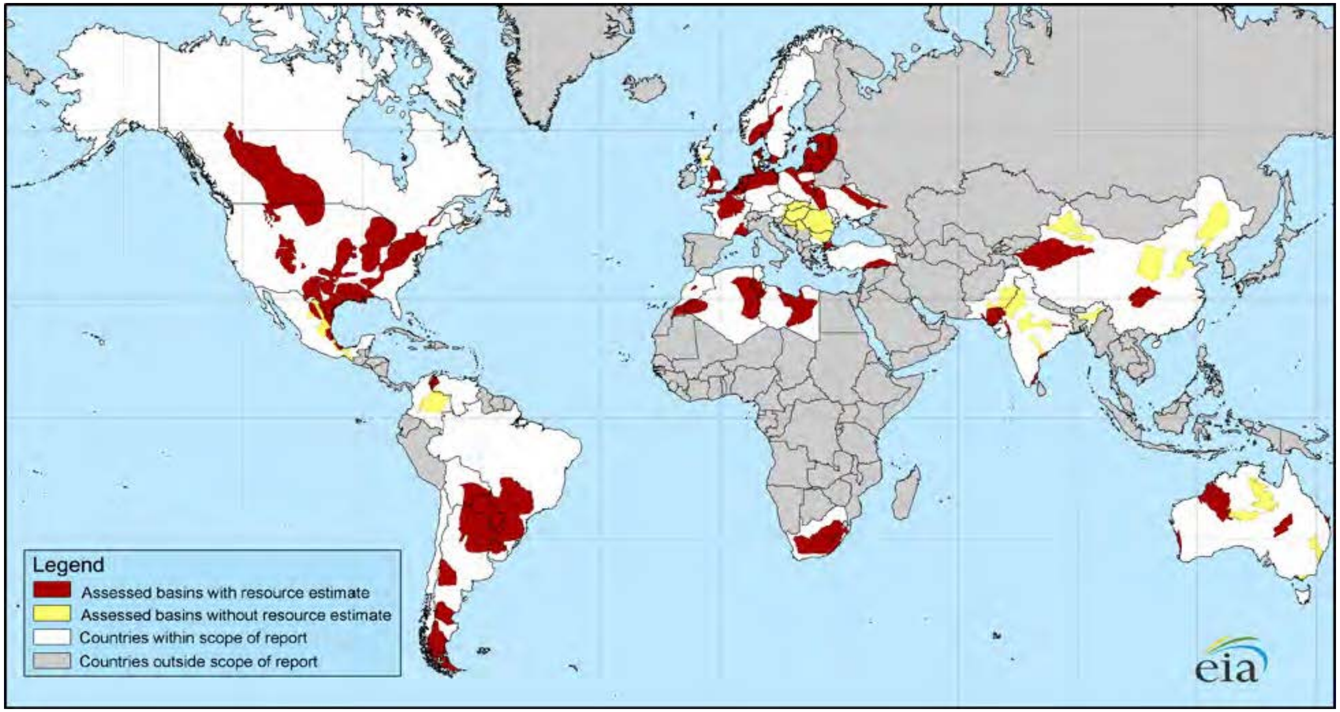
- Expansion of production from shale plays has rendered the utilization of LNG import capacity in the US very low, and aggregate average annual capacity utilization may not approach 15% until after 2040.
- **In fact, it has raised the possibility of US LNG exports.**
  - Domestic price impacts are a central concern, but will not likely be large given domestic elasticity of supply.
  - Recent work by Hartley and Medlock (2011) indicate this apparent opportunity may be highly contingent on the value of the US dollar.
- Current and potential future expansion of shale gas in the US, Europe and Asia effectively makes the *global* natural gas supply curve more elastic.
  - This mitigates the potential for sustained increases in price.
  - To the extent that shale gas production can be more price responsive (through completion delays, for example), "just-in-time" production could simulate the role of storage. Thus, shale gas production may also limit seasonal volatility to some extent.
  - **Greater supply elasticity also puts pressure on traditional pricing paradigms.**

Global Shale

The Global Shale Gas Resource

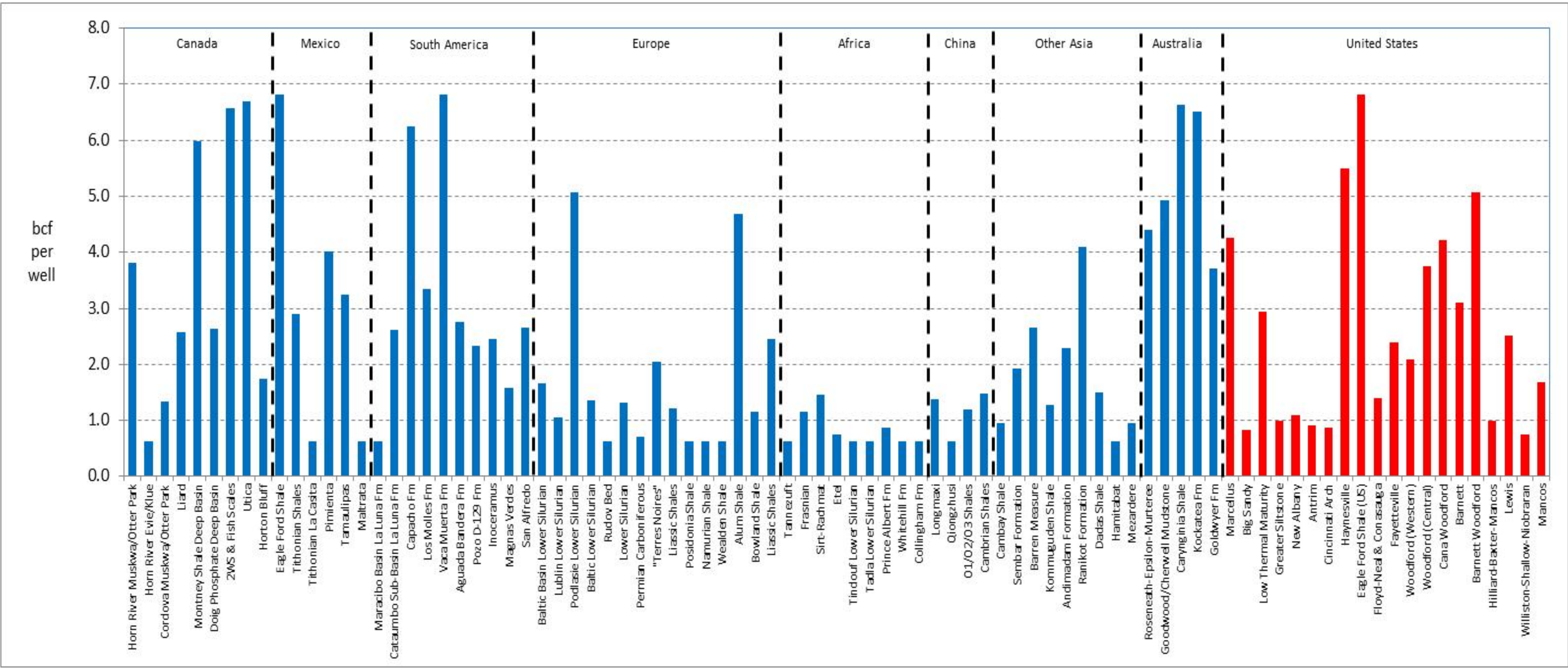
Region	Technically Recoverable Resource (tcf)
North America	1,931
Latin America	1,225
Europe	639
Former USSR	---
China and India	1,338
Australasia	396
Africa	1,043
Middle East	---
Other	51
Total	**6,622**

Source: ARI/EIA (2011)



EURs in Shale Plays

- EURs estimated using geologic data for known shale plays in North America and econometrically fit for RoW shales.
  - EUR a function of porosity, TM, TOC, Clay Content, GIP Concentration, Thickness, Depth
  - Tiers constructed with pdfs of EURs informed by average EUR and US well performance.



- Drilling and Completion costs estimated using known North American plays and econometrically fit to drilling depth and reservoir pressure.

	Total Included Recoverable Resource (tcf)	Tier 1 Recoverable Resource (tcf)	Tier 1 Wellhead Breakeven Price ($/mcf)	Tier 2 Recoverable Resource (tcf)	Tier 2 Wellhead Breakeven Price ($/mcf)	Tier 3 Recoverable Resource (tcf)	Tier 3 Wellhead Breakeven Price ($/mcf)
Antrim	**7.9**	4.0	$ 4.91	4.0	$ 7.09	5.3	$ 13.87
Devonian/Ohio	**299.9**						
Utica	**6.8**	3.4	$ 3.74	3.4	$ 5.40	4.5	$ 10.56
Marcellus	**278.0**	83.4	$ 2.93	83.4	$ 4.24	111.2	$ 8.28
Cincinnatti Arch	**0.7**	0.4	$ 6.03	0.4	$ 8.71	0.5	$ 17.03
Devonian Siltstone and Shale	**7.0**	3.5	$ 5.34	3.5	$ 7.71	4.7	$ 15.07
Big Sandy	**5.0**	2.5	$ 6.31	2.5	$ 9.11	3.3	$ 17.81
Nora Haysi	**2.4**	1.2	$ 6.47	1.2	$ 9.34	1.6	$ 18.27
New Albany	**8.3**	4.1	$ 5.05	4.1	$ 7.29	5.5	$ 14.25
Floyd-Neal & Conasauga	**2.6**	1.3	$ 6.25	1.3	$ 9.02	1.7	$ 17.65
Haynesville	**106.0**	31.8	$ 2.92	31.8	$ 4.22	42.4	$ 8.25
Fayetteville	**36.2**	10.9	$ 2.79	10.9	$ 4.03	14.5	$ 7.88
Woodford Arkoma	**22.3**	6.7	$ 3.13	6.7	$ 4.51	8.9	$ 8.83
Woodford Ardmore	**4.2**	1.3	$ 4.54	1.3	$ 6.56	1.7	$ 12.83
Cana Woodford	**8.0**	2.4	$ 3.31	2.4	$ 4.78	3.2	$ 9.35
Barnett	**58.0**	17.4	$ 2.66	17.4	$ 3.83	23.2	$ 7.50
Barnett and Woodford	**35.4**	10.6	$ 2.88	10.6	$ 4.16	14.2	$ 8.13
Eagle Ford	**42.0**	12.6	$ 2.36	12.6	$ 3.40	16.8	$ 6.66
Lewis	**20.2**	6.1	$ 3.12	6.1	$ 4.50	8.1	$ 8.79
Bakken	**3.8**	1.1	$ 2.31	1.1	$ 3.34	1.5	$ 6.53
Niobrara	**0.8**	0.8	$ 7.28	0.8	$ 10.50	1.1	$ 20.54
Hilliard/Baxter/Mancos	**3.5**	3.5	$ 9.65	3.5	$ 13.94	4.7	$ 27.25
Paradox/Uinta	**9.5**	4.7	$ 6.80	4.7	$ 9.82	6.3	$ 19.21
Total US Shale	**668.7**						

		Tier 1		Tier 2		Tier 3	
	Total Included Recoverable Resource (tcf)	Recoverable Resource (tcf)	Wellhead Breakeven Price ($/mcf)	Recoverable Resource (tcf)	Wellhead Breakeven Price ($/mcf)	Recoverable Resource (tcf)	Wellhead Breakeven Price ($/mcf)
Horn River/Cordova/Liard	**158.5**	56.7	$ 3.69	48.6	$ 5.33	53.2	$ 10.42
Montney/Deep Colorado	**136.0**	40.8	$ 2.58	40.8	$ 3.73	54.4	$ 7.30
Utica	**27.0**	8.1	$ 2.89	8.1	$ 4.17	10.8	$ 8.16
Horton Bluff	**1.2**	0.6	$ 4.85	0.6	$ 7.00	0.8	$ 13.69
Total Canadian Shale	321.5						
Burgos/Sabinas (incl. Eagle Ford)	**163.3**	51.3	$ 2.96	48.0	$ 4.27	64.0	$ 8.36
Tampico/Tuxpan/Veracruz	**33.3**	18.0	$ 3.64	15.3	$ 5.26	20.4	$ 10.29
Total Mexican Shale	196.6						
Maracaibo/Catatumbo (Venezuela)	**7.5**	5.4	$ 4.62	2.1	$ 6.67	2.8	$ 13.04
Catatumbo (Colombia)	**7.2**	3.6	$ 2.98	3.6	$ 4.30	4.8	$ 8.41
San Alfredo (Bolivia)	**31.3**	15.6	$ 4.86	15.6	$ 7.01	20.8	$ 13.71
San Alfredo (Brazil)	**137.5**	68.8	$ 4.27	68.8	$ 6.16	91.7	$ 12.04
San Alfredo (Paraguay)	**40.6**	20.3	$ 4.54	20.3	$ 6.56	27.1	$ 12.82
San Alfredo (Argentina)	**103.2**	51.6	$ 4.27	51.6	$ 6.16	68.8	$ 12.04
Neuquen (Argentina)	**407.0**	122.1	$ 2.76	122.1	$ 3.98	162.8	$ 7.79
San Jorge/Magallanes (Argentina)	**160.2**	80.1	$ 4.38	80.1	$ 6.32	106.8	$ 12.35
Total South American Shale	894.5						
Australia (Cooper)	**85.0**	25.5	$ 3.10	25.5	$ 4.47	34.0	$ 8.75
Australia (Maryborough)	**23.0**	6.9	$ 3.32	6.9	$ 4.79	9.2	$ 9.37
Australia (Perth)	**59.0**	17.7	$ 2.96	17.7	$ 4.27	23.6	$ 8.35
Australia (Canning)	**229.0**	68.7	$ 3.57	68.7	$ 5.16	91.6	$ 10.09
Total Australian Shale	396.0						

		Tier 1		Tier 2		Tier 3	
	Total Included Recoverable Resource (tcf)	Recoverable Resource (tcf)	Wellhead Breakeven Price ($/mcf)	Recoverable Resource (tcf)	Wellhead Breakeven Price ($/mcf)	Recoverable Resource (tcf)	Wellhead Breakeven Price ($/mcf)
Austria (Mikulov)	32.0	16.0	$ 6.50	16.0	$ 9.38	21.3	$ 18.35
Poland (Baltic)	77.4	38.7	$ 6.68	38.7	$ 9.64	51.6	$ 18.86
Poland (Lublin)	13.2	13.2	$ 9.64	13.2	$ 13.92	17.6	$ 27.22
Poland (Podlasie)	14.0	4.2	$ 3.48	4.2	$ 5.02	5.6	$ 9.82
Lithuania (Baltic)	13.8	6.9	$ 6.68	6.9	$ 9.64	9.2	$ 18.86
Ukraine (Dneiper-Donets)	---	3.6	$ 18.21	3.6	$ 26.29	4.8	$ 51.41
Ukraine (Lublin)	18.0	9.0	$ 7.40	9.0	$ 10.68	12.0	$ 20.88
France (Permian Carb)	---	22.8	$ 17.68	22.8	$ 25.52	30.4	$ 49.91
France (Terres Noires/Liassic)	62.4	31.2	$ 4.58	31.2	$ 6.60	41.6	$ 12.92
Germany (Posidonia/Wealden)	7.5	7.5	$ 10.02	7.5	$ 14.46	10.0	$ 28.28
Norway (Alum)	82.3	24.7	$ 3.15	24.7	$ 4.54	32.9	$ 8.88
Sweden (Alum)	41.2	12.3	$ 3.22	12.3	$ 4.65	16.5	$ 9.09
Denmark (Alum)	23.5	7.1	$ 3.18	7.1	$ 4.59	9.4	$ 8.97
UK (Bowland)	11.4	5.7	$ 5.89	5.7	$ 8.50	7.6	$ 16.62
UK (Liassic)	13.2	6.6	$ 4.55	6.6	$ 6.57	8.8	$ 12.85
Total European Shale	409.9						
Algeria (Ghadames)	63.1	63.1	$ 8.87	63.1	$ 12.80	84.1	$ 25.04
Algeria (Tindouf)	---	15.0	$ 15.31	15.0	$ 22.10	20.0	$ 43.23
Tunisia (Ghadames)	6.2	6.2	$ 8.51	6.2	$ 12.29	8.3	$ 24.03
Libya (Sirt/Etel)	81.9	81.9	$ 7.83	81.9	$ 11.30	109.2	$ 22.10
Morocco (Tadla)	---	0.9	$ 14.65	0.9	$ 21.15	1.2	$ 41.37
South Africa (Prince Albert/Whitehill/Collingham)	145.5	145.5	$ 10.34	145.5	$ 14.93	194.0	$ 29.19
Total African Shale	296.7						
China (Sichuan-Longmaxi/Qiongzhusi)	415.2	207.6	$ 7.15	207.6	$ 10.33	276.8	$ 20.20
China (Tarim-O1,O2,O3 Shales/Cambrian)	349.8	174.9	$ 6.87	174.9	$ 9.92	233.2	$ 19.40
India (Cambay/Indus)	24.0	12.0	$ 6.25	12.0	$ 9.03	16.0	$ 17.65
India (Damodar/Krishna)	20.4	10.2	$ 4.11	10.2	$ 5.93	13.6	$ 11.60
India (Cauvery)	5.4	2.7	$ 5.47	2.7	$ 7.90	3.6	$ 15.45
Pakistan (Indus)	18.6	9.3	$ 4.19	9.3	$ 6.05	12.4	$ 11.83
Turkey (Anatolia)	5.4	2.7	$ 6.73	2.7	$ 9.71	3.6	$ 18.99
Turkey (Thrace)	1.8	1.8	$ 10.31	1.8	$ 14.89	2.4	$ 29.11
Total Asian Shale	840.6						

A view of the future

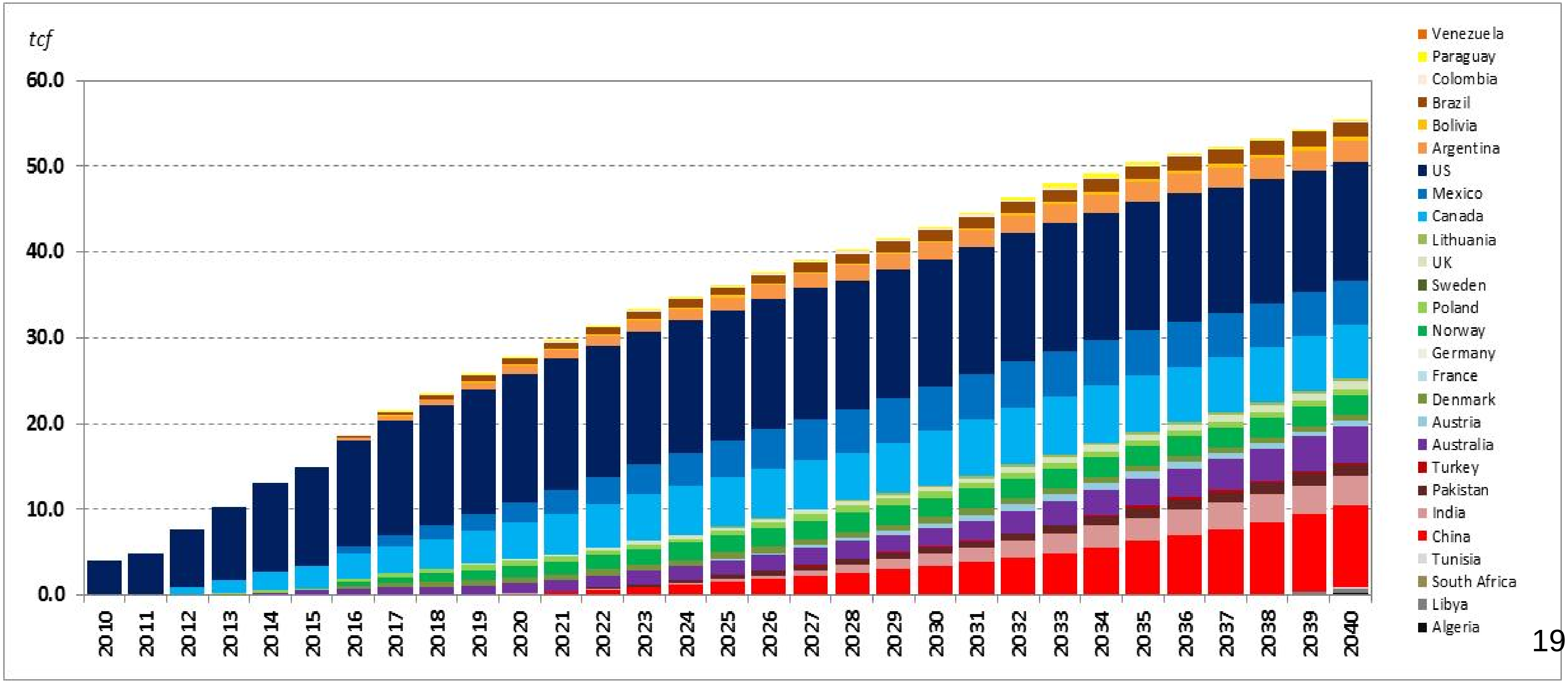
Simulations based on the recent DOE funded
Baker Institute Study,
"Shale Gas and US National Security"
an exercise in the counterfactual to demonstrate what all this shale could really mean

The Rice World Gas Trade Model (RWGTM):
A Tool for Policy Analysis

- The RWGTM has been developed to examine potential futures for global natural gas, and to quantify the impacts of geopolitical influences on the development of a global natural gas market.
- The model predicts regional prices, regional supplies and demands and inter-regional flows.
- Regions are defined at the country and sub-country level, with extensive representation of transportation infrastructure
- The model is non-stochastic, but it allows analysis of many different scenarios. Geopolitical influences can alter otherwise economic outcomes
- The model is constructed using the *MarketBuilder* software from Deloitte MarketPoint, Inc.
  - Dynamic spatial general equilibrium linked through time by Hotelling-type optimization of resource extraction
  - Capacity expansions are determined by current *and* future prices along with capital costs of expansion, operating and maintenance costs of new and existing capacity, and revenues resulting from future outputs and prices.

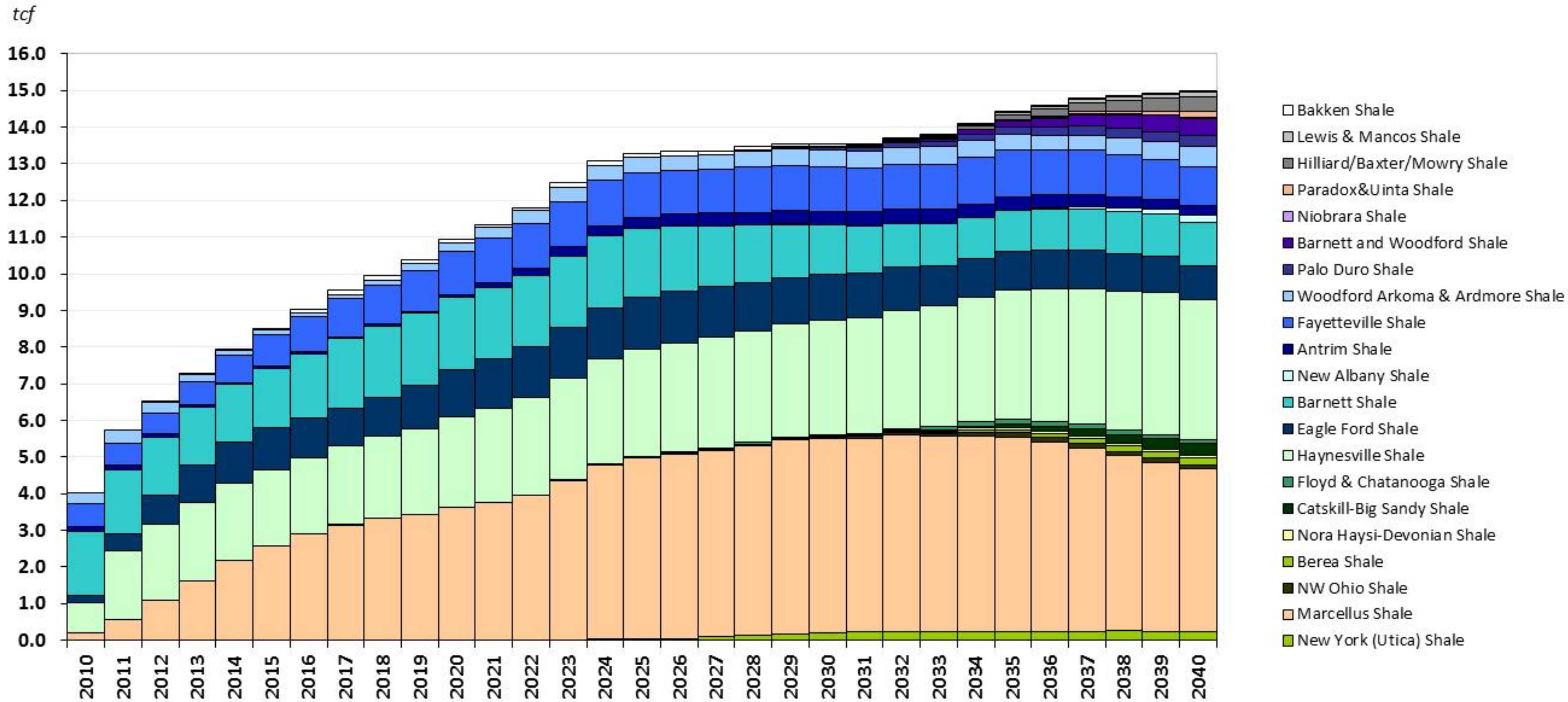
Reference Case:
Global Shale Production, 2010-2040

- Shale production grows commensurate with local market conditions. Strongest supply in North America, accounting for over 50% of all shale gas volumes in 2040.
- Shale accounts for about 25% of all global production by 2040.



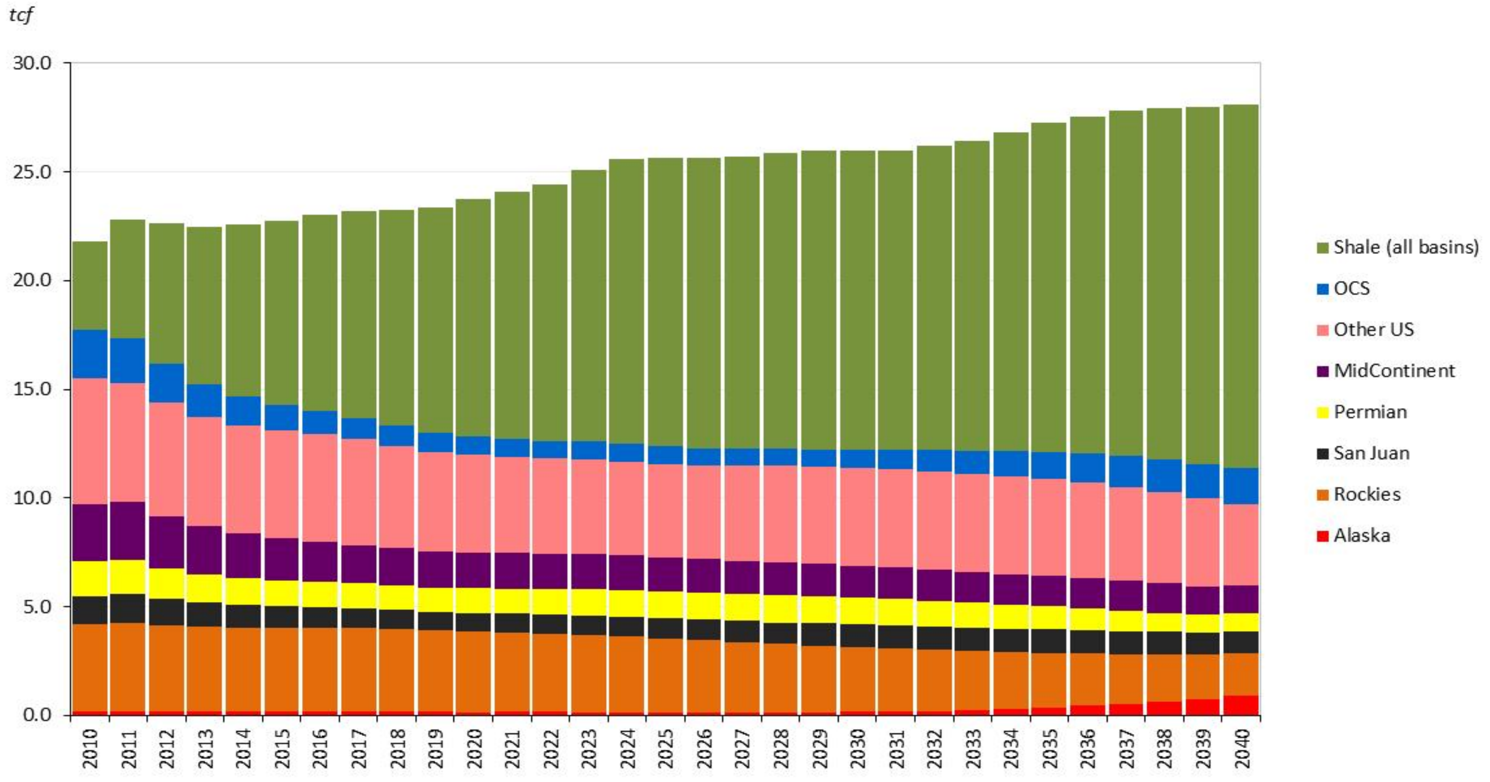
Reference Case:
U.S. Shale Production, 2010-2040

- US shale production accounts for over 50% of domestic production by the 2030s.
- Strongest long term production in the Marcellus and Haynesville shales, followed by Barnett, Eagle Ford, and Fayetteville shales.
- Regional production growth has implications for regional pricing and infrastructure.



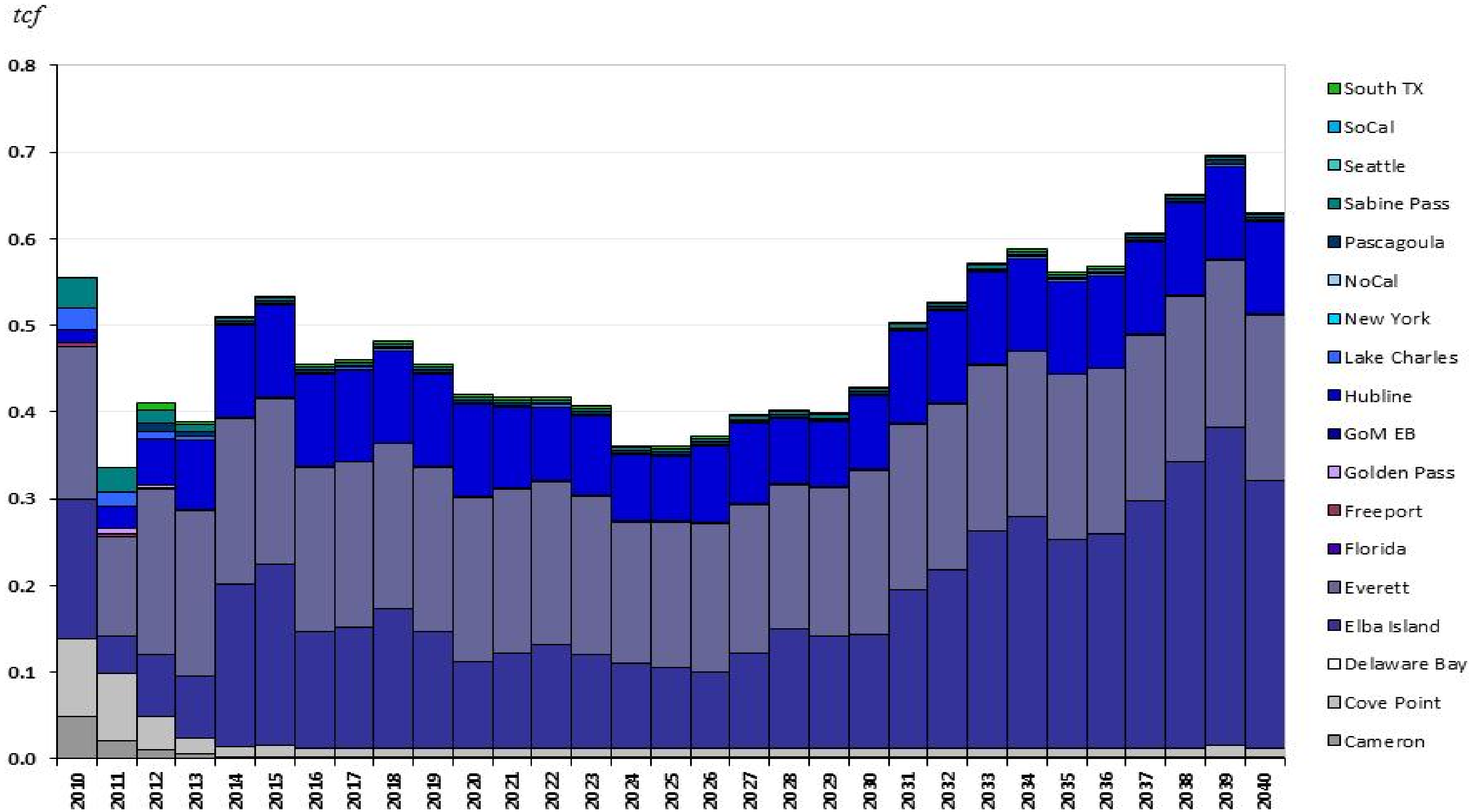
Reference Case: Composition of U.S. Production, 2010-2040

- U.S. shale gas production exceeds 50% of total production by 2030.
- Canadian shale gas production grows to 1/3 of total output by the mid-2030's (not pictured).



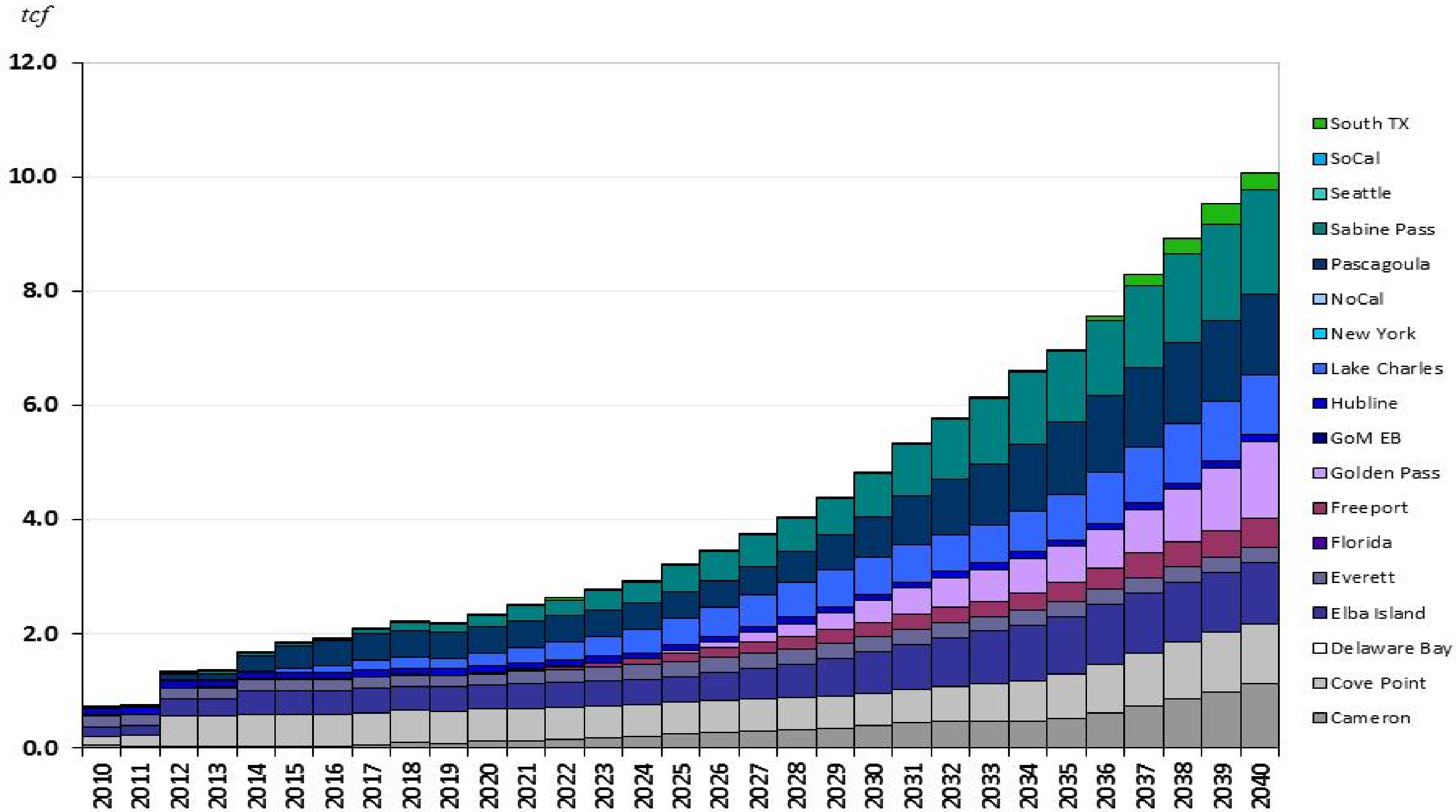
Reference Case:
U.S. LNG Imports, 2010-2040

- Very low re-gas terminal capacity utilization through 2040.



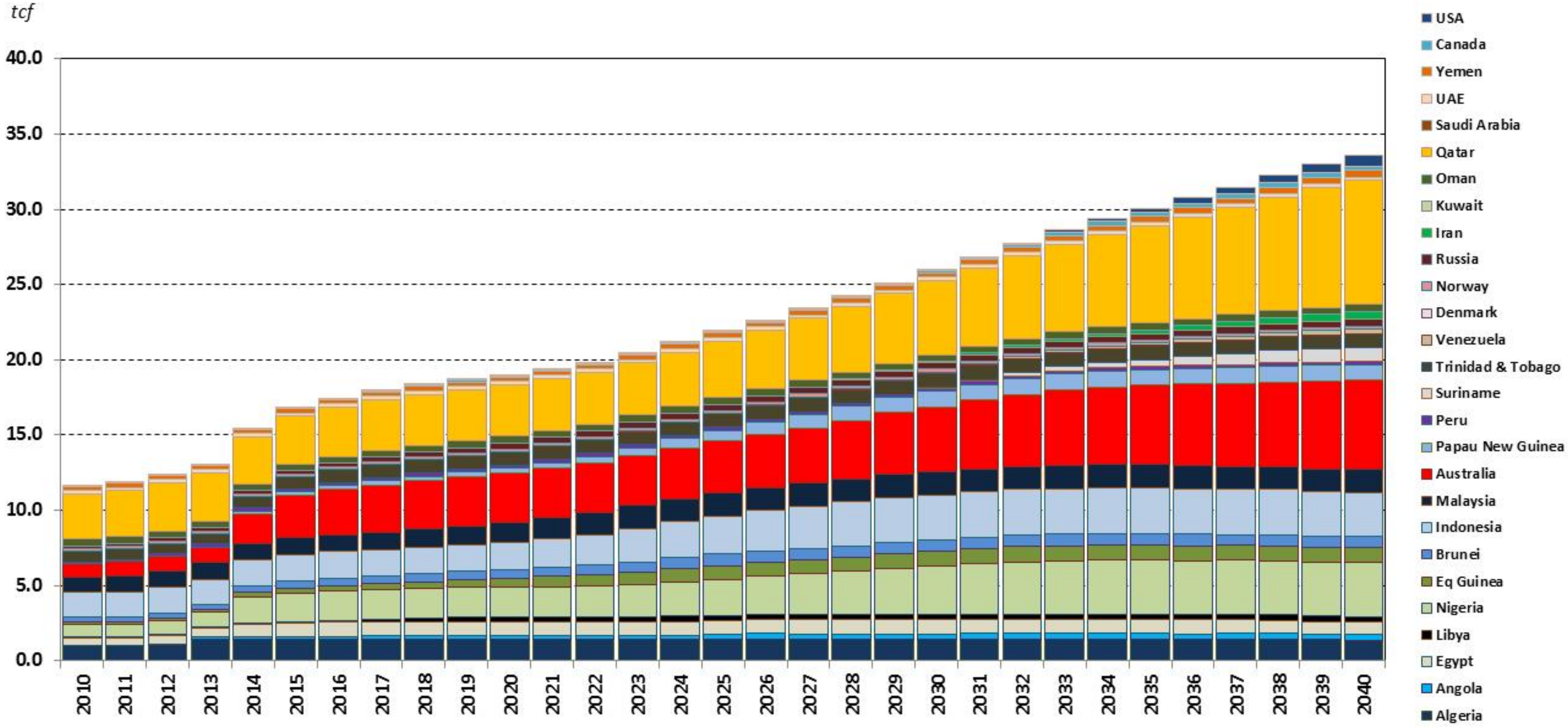
U.S. LNG Imports, 2010-2040 – had shale not occurred

- Absent shale resources, U.S. LNG imports would be substantially higher.



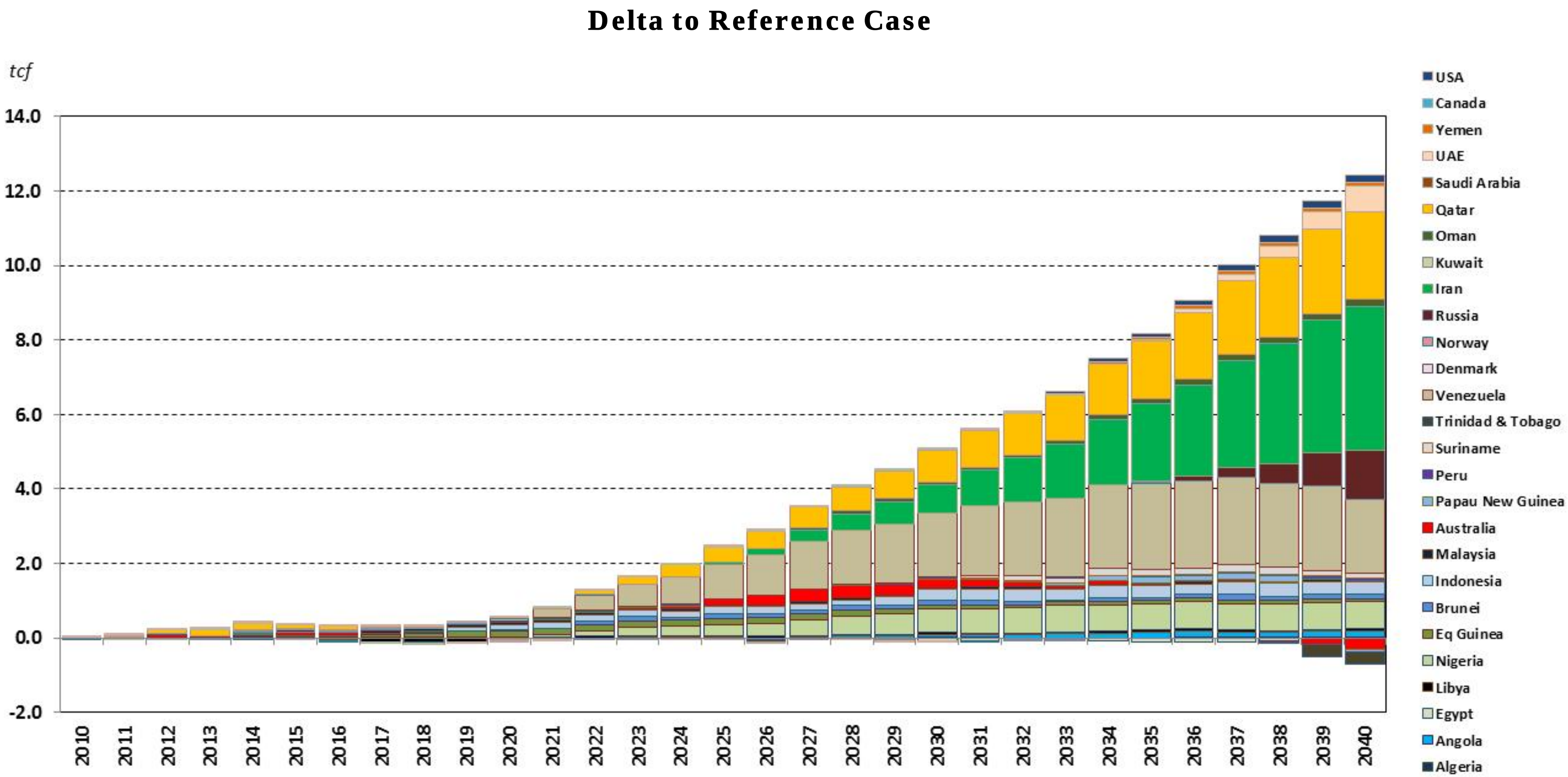
Reference Case: LNG Exports by Country, 2010-2040

- Qatar and Australia are the largest LNG exporters through 2040, and, collectively, account for over 40% of global *LNG* exports.
- Exports are primarily destined for Asian markets, accounting for over 60% of global LNG trade (not pictured).



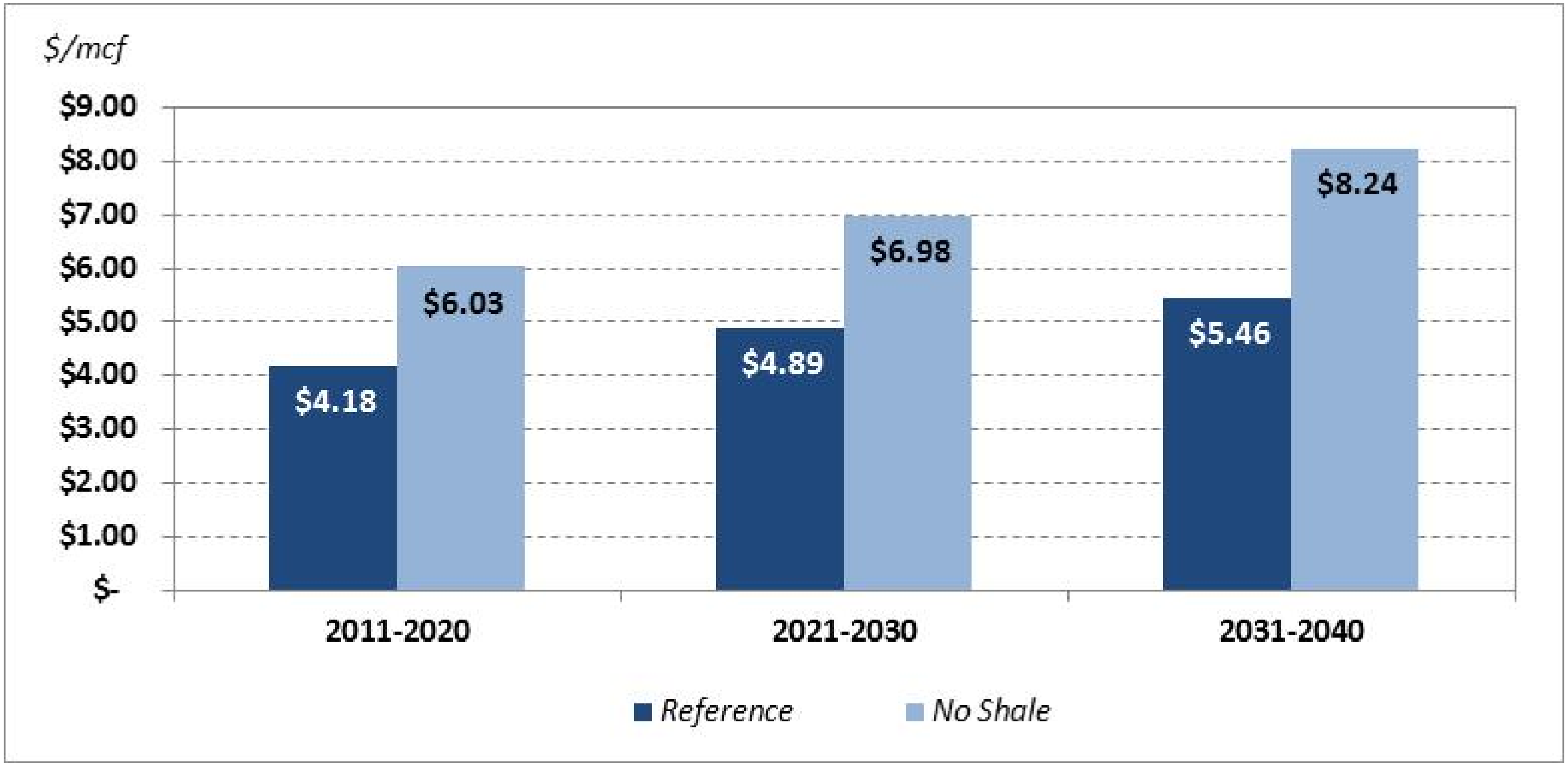
LNG Exports by Country, 2010-2040 – had shale not occurred

- Growth in Qatar, Nigeria, Venezuela and Iran are all much higher. The lack of shale in the U.S. favors LNG suppliers in or near the Atlantic basin.



Impact of Shale on Henry Hub, 2011-2040

- The domestic supply curve is much more elastic as a result of shale gas developments. In fact, production is lower and price is higher without shale.
- Domestic long run elasticity
  - with shale = 1.52; without = 0.29.



Can shale, and unconventional resources more generally, be long term game changing?

- Uncertainty about the commercial scope of shale resources.
  - Current stresses are transitory, but may have lasting effects, particularly if financial stress leads to consolidation.
- Accessibility, not just cost and technology, is critical.
  - Environmental costs, market structure, public sentiment and government policy are all important.
    - For example, *market structure* in which capacity rights are *unbundled* from facility ownership has been critical in the United States.
    - For example, *public perception* of possible watershed contamination associated with hydraulic fracturing has led to the implementation of *local government policy* in the State of New York banning all such activities. Similar policies have been implemented at the national level in countries such as France and Bulgaria.
- Firms must now consider the "social engineering" of project development to ensure local support.

Could this happen in oil?

Tight Oil and What It Means for the US

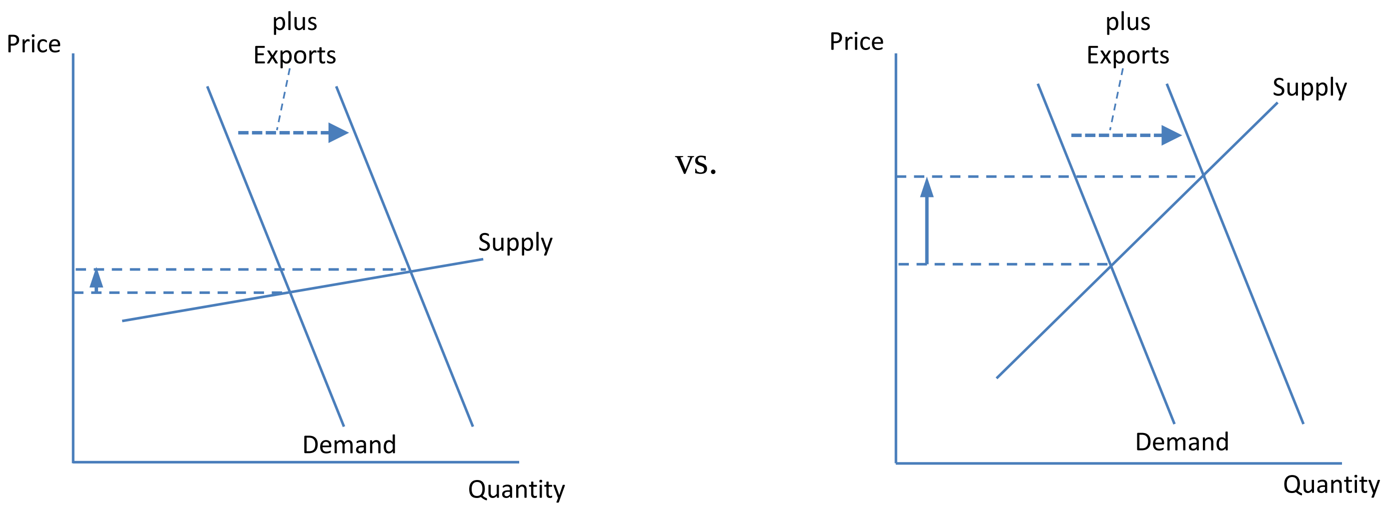
- Tight oil resources are still being understood.
- Resource potential in North America is distributed widely.
  - For example, North Dakota (Bakken), Texas/New Mexico (Permian – Avalon, Bone Springs, Wolfcamp, South Texas – Eagleford), Ohio (Utica), Pennsylvania (Marcellus), Colorado/Wyoming (Niobrara), Florida (Sunniland), Louisiana (Tuscaloosa), Oklahoma (Mississippian), California (Monterrey).
    - Just as in gas, not all shales are created equal, but the total technically recoverable resource endowment may exceed 60 billion barrels.
    - ***If*** 50% of this crude oil is commercial, the endowment could support 2.0 million barrels per day of production for 40 years.
    - To date, activity in the Bakken and Eagleford accounts for most domestic tight oil production (about 640 thous b/d).
- Technical and cost hurdles still exist, but high oil prices provide lots of incentive. Room for lots of "learning by doing."

The Prospect of US LNG Exports

Price Impacts of US LNG Exports

- Common claim: US price will rise to the international price
  - Only true if US domestic supply is highly inelastic (pictured below) and foreign supply is highly elastic (not pictured)… this claim seems highly unlikely.

Elasticity of Domestic Supply and the Impact of Exports on Price

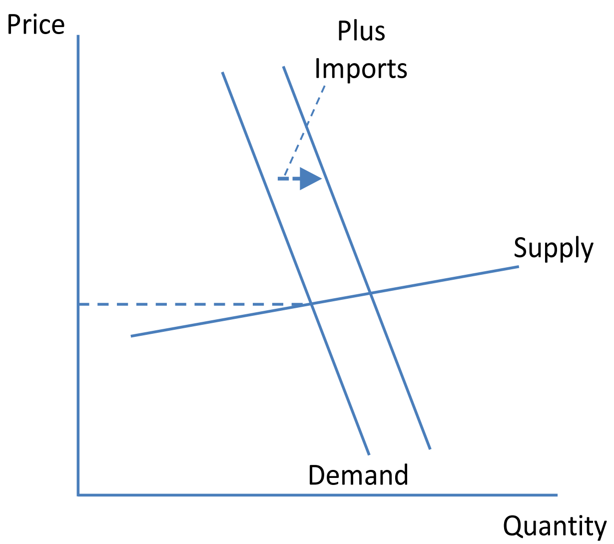


Price Impacts of US LNG Exports (cont.)

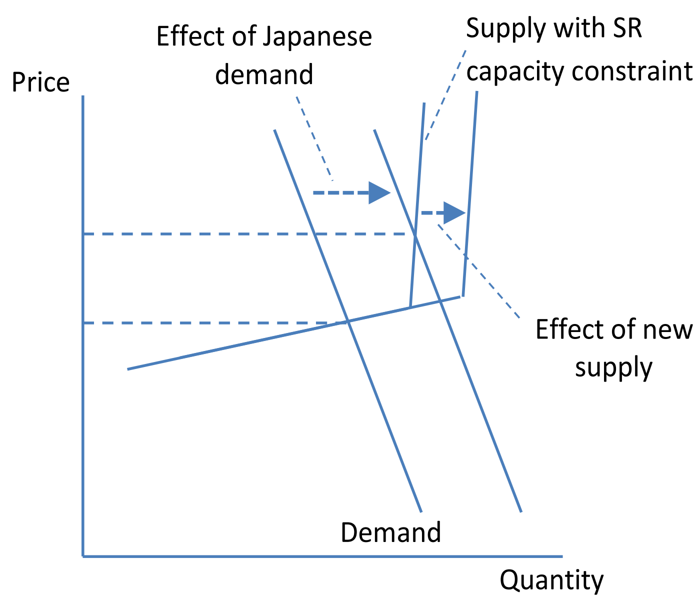
- Lots of attention given to current international spot price, but several factors are often ignored, such as
  - short term capacity constraints,
  - increased Japanese demand, and
  - a weak US dollar.
- In fact, US LNG exports could put significant downward pressure on international price. (In 2010, LNG trade totaled just over 28 bcfd. Current US filings total 6.6 bcfd.)
- Key point… Issues related to international trade are contingent on both domestic and foreign elasticities of supply and demand.

Price Impacts of US LNG Exports (cont.)

- What can the current situation tell us about the future?
- Alleviating the capacity constraint will effect international prices more greatly than US prices.



domestic



foreign

Viability of US LNG Exports

- Current arbitrage value is high, but there is risk
  - Price impact in foreign market could be significant
    - Depends on relative elasticities of supply and demand. Price impact abroad increases as the domestic supply becomes more elastic and/or the foreign supply becomes less elastic.
  - Risk of foreign supply development (e.g.- China shale)
  - Exchange rate risk is present.
    - Recent paper by Hartley and Medlock (2012) indicates exchange rates are important in determining the crude oil-natural gas price differential when (i) there is limited capability for direct arbitrage and (ii) fuel-switching capabilities are limited. This means even oil-indexed flows are potentially exposed.
    - Gas-indexed trades are also exposed. Foreign gas is traded in own currencies, meaning an exchange rate is required to evaluate the arbitrage opportunity.

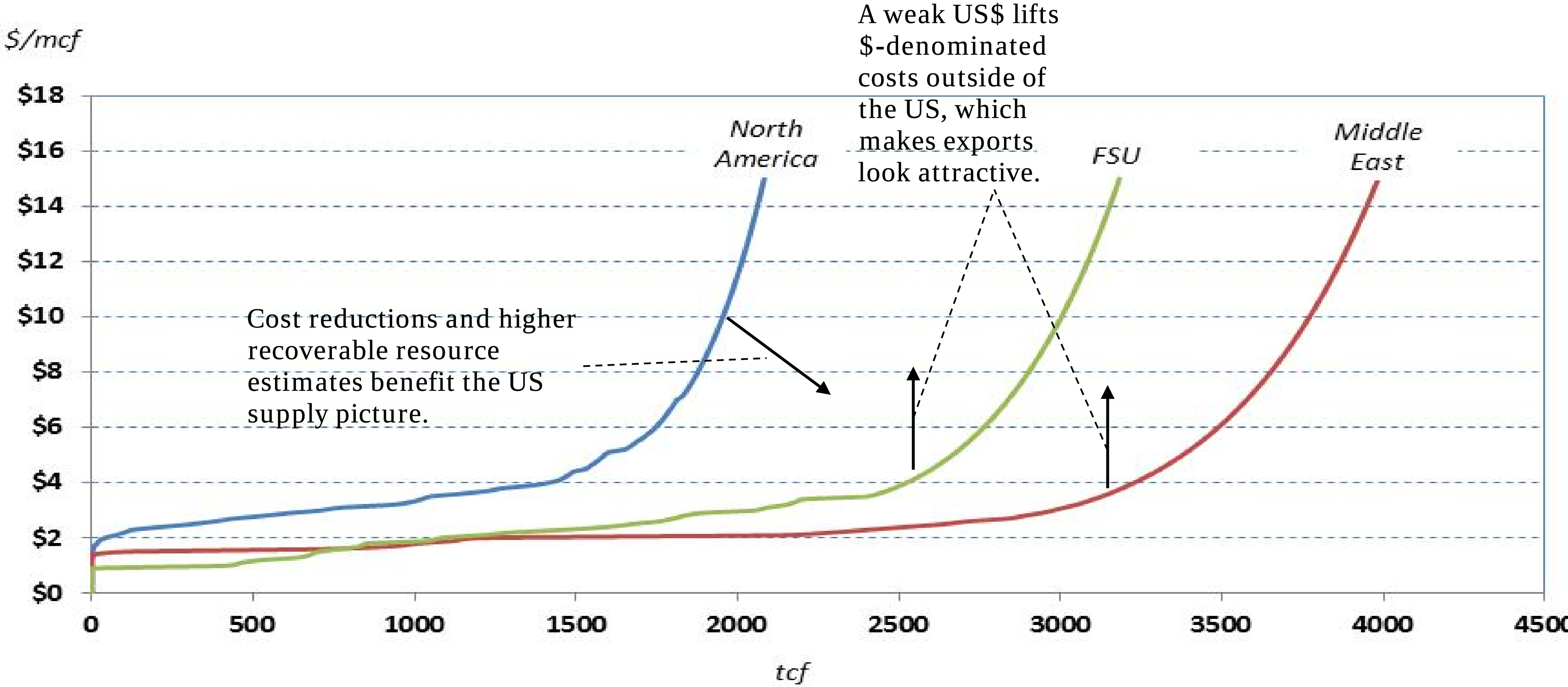
Exchange Rate Influence

- US dollar is weaker than it has been in recent memory.
- Why does this matter? Because the exchange rate helps determine the value of any given trade.

$$P_{US} - P_{UK} \cdot XR \cdot HR = arb\ value$$

North America in a Global Context

- North American resources are large, but must be placed in a global context.
  - Multiple forces are at work: cost reduction and exchange rate movements.
  - Former Soviet Union (FSU) and Middle East (pictured for comparison) are larger and generally less costly. Access, transportation costs, and the value of the dollar all make North American resources preferential in the short-to-medium term.



RWGTM Reference Case: US Gulf Coast LNG Arbitrage Value, 2011-2040

- Modeling indicates the current arbitrage value may be transitory. In fact, the positive export margin tends to disappear after 2015.
- Moreover, even substantial changes to the table values indicate the result is robust.

	2011	2011-2020	2021-2030	2031-2040
Feed gas cost ($/mcf)	$ 3.80	$ 3.98	$ 4.69	$ 5.26
Liquefaction ($/mcf)	$ 2.51	$ 2.51	$ 2.51	$ 2.51
Transport cost ($/mcf)				
UK	$ 1.07	$ 1.07	$ 1.07	$ 1.07
Japan	$ 2.15	$ 2.15	$ 2.15	$ 2.15
Landed cost ($/mcf)				
UK	$ 7.38	$ 7.56	$ 8.27	$ 8.85
Japan	$ 8.46	$ 8.64	$ 9.35	$ 9.93
Market price ($/mcf)				
NBP	$ 8.84	$ 6.08	$ 6.20	$ 7.48
Tokyo	$ 11.73	$ 6.92	$ 7.03	$ 8.29
Export Margin ($/mcf)				
UK	$ 1.46	$ (1.48)	$ (2.07)	$ (1.37)
Japan	$ 3.26	$ (1.72)	$ (2.31)	$ (1.63)

Questions/Comments