RICE UNIVERSITY

The Rice World Gas Trade Model

with some recent results on China Shale and discussion of ongoing modifications

Presentation by:

Kenneth B Medlock III

James A Baker III and Susan G Baker Fellow in Energy and Resource Economics, and

Deputy Director, Energy Forum

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James A Baker III Institute for Public Policy
Rice University

Today's talk

- Highlight recent results of the Rice World Gas Trade Model
  - DOE sponsored study "Shale Gas and US National Security" by Medlock, Jaffe and Hartley (2011). Used as motivation to consider the potential impacts of shale development in China...
  - Discussion of results from "Quantitative Analysis of Scenarios for Chinese Unconventional Natural Gas Resources and Their Role in Global LNG Markets" by Hartley and Medlock (2011)

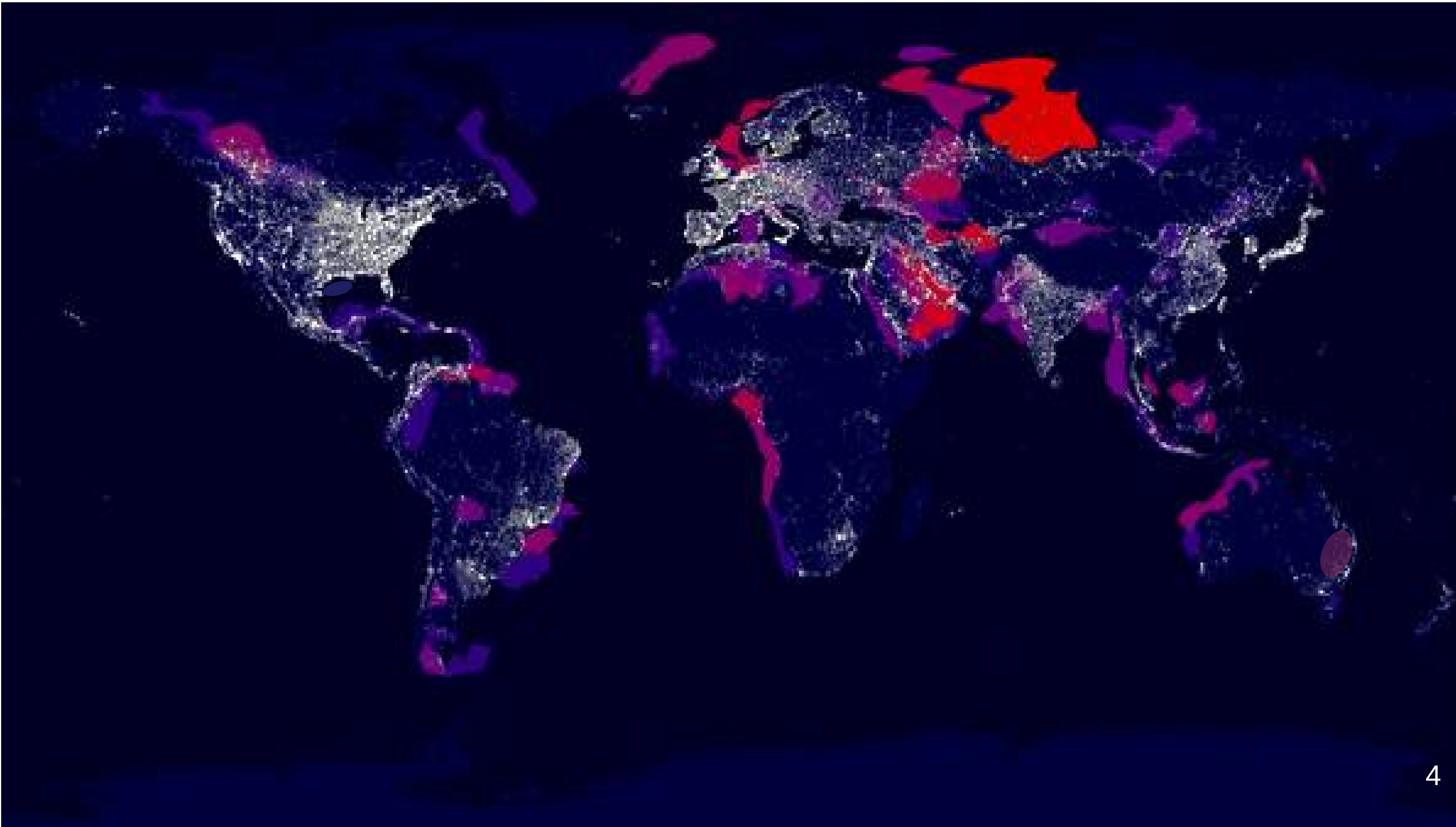
- Discuss recent changes to the RWGTM that are currently being implemented.
  - LNG trade modeled "point-to-point" vs "hub-and-spoke"
  - Incorporation of data from the recent ARI study on global shale resources through the development of cost-of-supply curves by analysis of reported geophysical data.

Some Recent Baker Institute Analysis

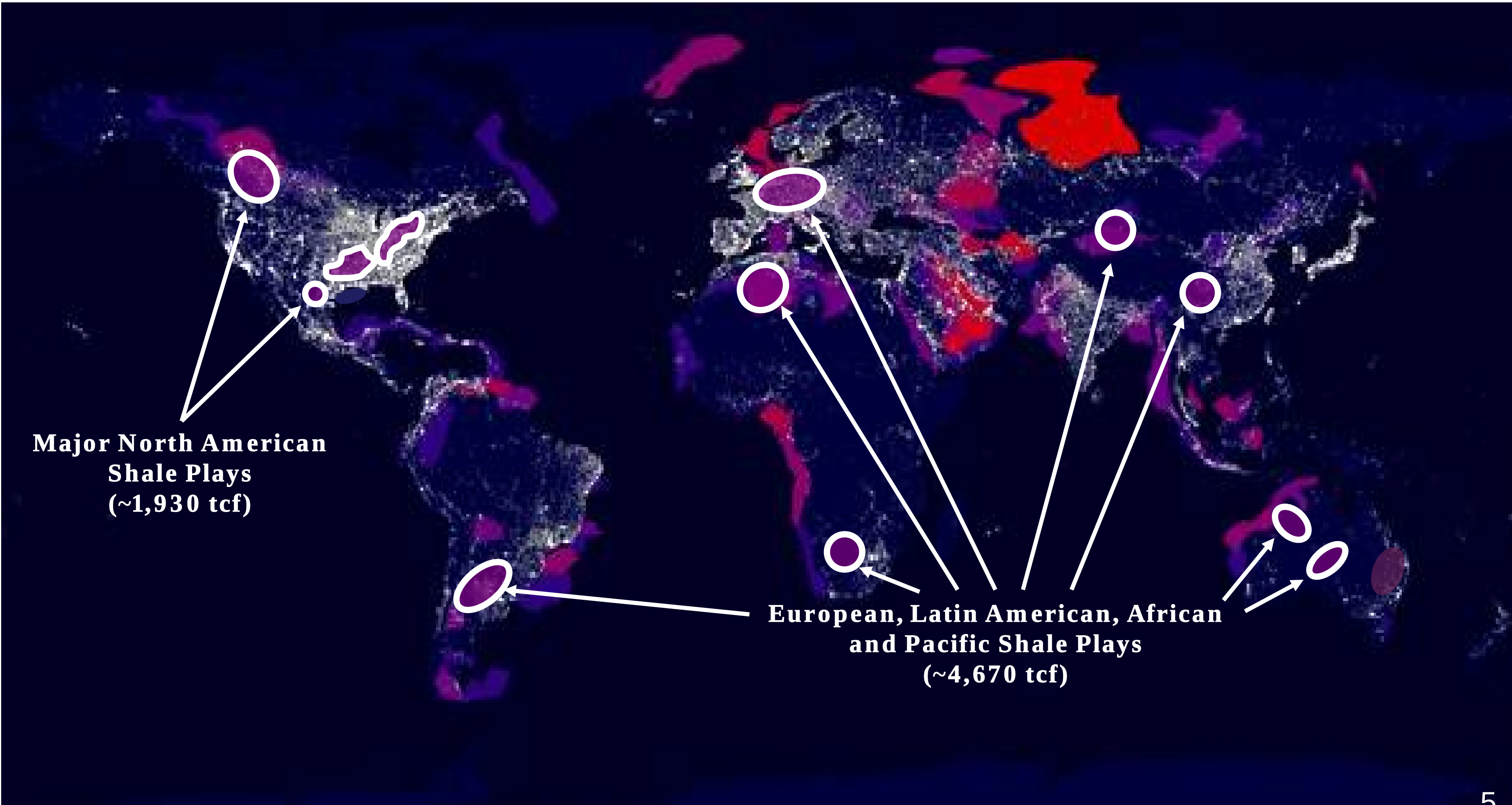
- Shale gas developments of the past decade in the North American gas market have been nothing short of transformative. In fact, expectations have been significantly altered and the way we view our energy future is now dramatically different. Moreover, the effects extend beyond the North American market.
  - "Shale Gas and US National Security" by Medlock, Jaffe and Hartley (2011)

- Recent assessments of recoverable shale resource have been very high. ARI published an assessment of up to 1275 tcf of technically recoverable shale gas. So, we ask the basic questions:
  - What if the Chinese shale resource base is both large and commercially attractive? Will it too be transformative?
  - "Quantitative Analysis of Scenarios for Chinese Unconventional Natural Gas Resources and Their Role in Global LNG Markets" by Hartley and Medlock (2011)

Some context:
Consensus was that LNG is coming to North America…



… shale changed that. LNG to Asia is the new consensus. Might shale also change this?



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

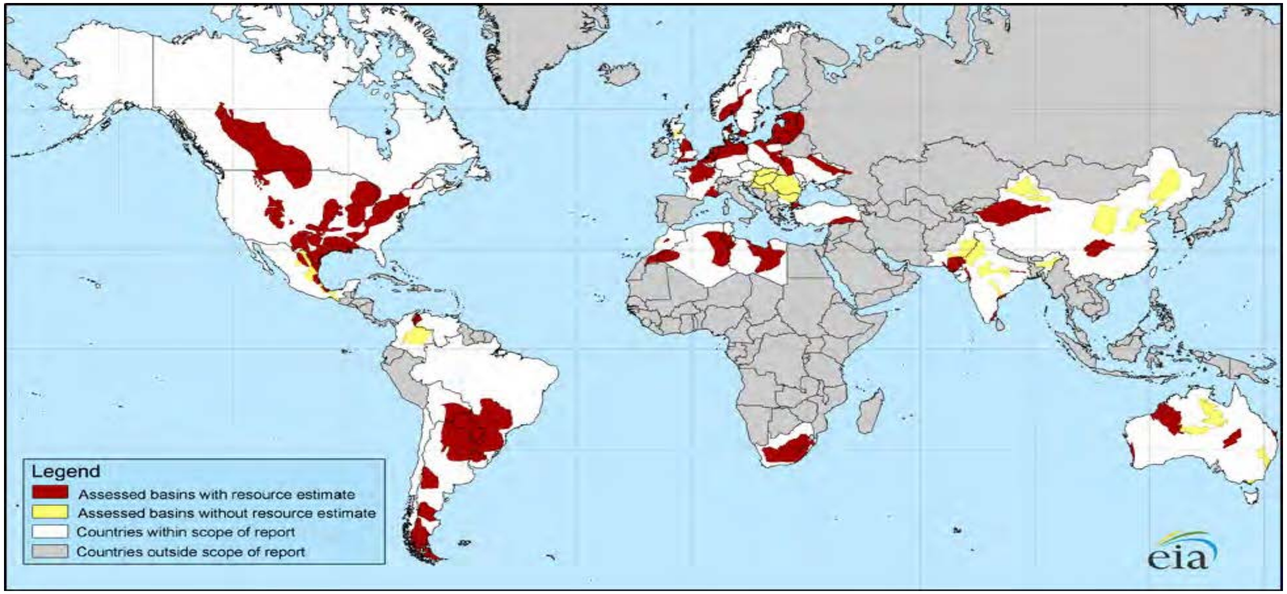
Paradigm Shifts: The New Norm?

Fewer than 10 years ago, most predictions were for a dramatic increase in LNG imports to North America, as demand for natural gas was set to outstrip domestic production. However, shale gas development in North America has completely altered this view. As a result, growth opportunities for LNG developers are now seen as being primarily in Asia.

However, if shale gas developments they prove to be significant in China – could dramatically diminish the long term prospect for LNG markets, and be every bit as “game-changing” as developments in North America have proven to be.

The Global Shale Gas Resource

- Shale developments have been focused largely in North America, but producers are starting to move abroad
  - IEA recently estimated up to 40% of the estimated resource in-place by Rogner (1997) will ultimately be technically recoverable.
  - Advanced Resources International (2011) assessed a larger resource in-place, and estimates a total technically recoverable resource of 6,600 tcf.
  - In this study, the Baker Institute uses an estimate of economically recoverable resource of 1,030 tcf (at prices below $9.00/mcf). But our very recent work has expanded this to over1,700 tcf and we are continuing to develop cost curves for identified technically recoverable resource.



The Global Shale Gas Resource (cont.)

- A comparison of estimates of recoverable shale.
  - RWGTM estimates are not directly comparable. See table footnote.

	Rogner (1997)*	ARI (2011)	RWGTM
North America	1537	1931	686
Latin America	847	1225	---
Europe	220	639	220
FSU	251	---	---
China	1411	1275	75
India		63	---
Australasia	925	396	50
Middle East	1019	---	---
North Africa		558	---
Other	235	538	---
Total	6445	6625	1031

*- applies a 40% recovery factor to the estimated gas in place.

**- The assessments in the RWGTM incorporate an assessment of economic viability as well as a discount factor applied to reflect other constraints.

Global Shale: Little Data and Lots of Uncertainty

- There is uncertainty about shale resources outside of North America.
- The estimates of resource in-place are very large, and location is a premium in many instances.
- However, accessibility is critical. Not only do cost and technology matter, but market structure and government policy is equally as important.
  - Arguably, if the current market structure in the United States did not exist, the shale gas boom would not have occurred. This is due to the fact that the small producers who initiated the proof of concept had little to no risk of accessing markets from very small production projects. A market in which capacity rights are not unbundled from facility ownership does not foster entry by small producers.

Recoverable Shale Resource in China for this Exercise

- The Reference Case in this paper contains only 75 tcf of *recoverable* shale resource. We stress this assessment considerably in the High Shale Case.

Units: trillion cubic feet

<table>
<tr><th></th><th></th><th>Reference</th><th>High China Shale</th></tr>
<tr><td rowspan="3">West</td><td>Tarim Basin</td><td rowspan="3">---</td><td rowspan="3">250</td></tr>
<tr><td>Junggar Basin</td></tr>
<tr><td>Tuja Basin</td></tr>
<tr><td rowspan="2">Central</td><td>Sichuan Basin</td><td rowspan="2">45</td><td rowspan="2">120</td></tr>
<tr><td>Jianghan Basin</td></tr>
<tr><td>North Central</td><td>Ordos Basin</td><td>30</td><td>150</td></tr>
<tr><td rowspan="2">Northeast</td><td>Songliao Basin</td><td rowspan="2">---</td><td rowspan="2">80</td></tr>
<tr><td>Bohai Bay Basin</td></tr>
<tr><td></td><td>Total</td><td>75</td><td>600</td></tr>
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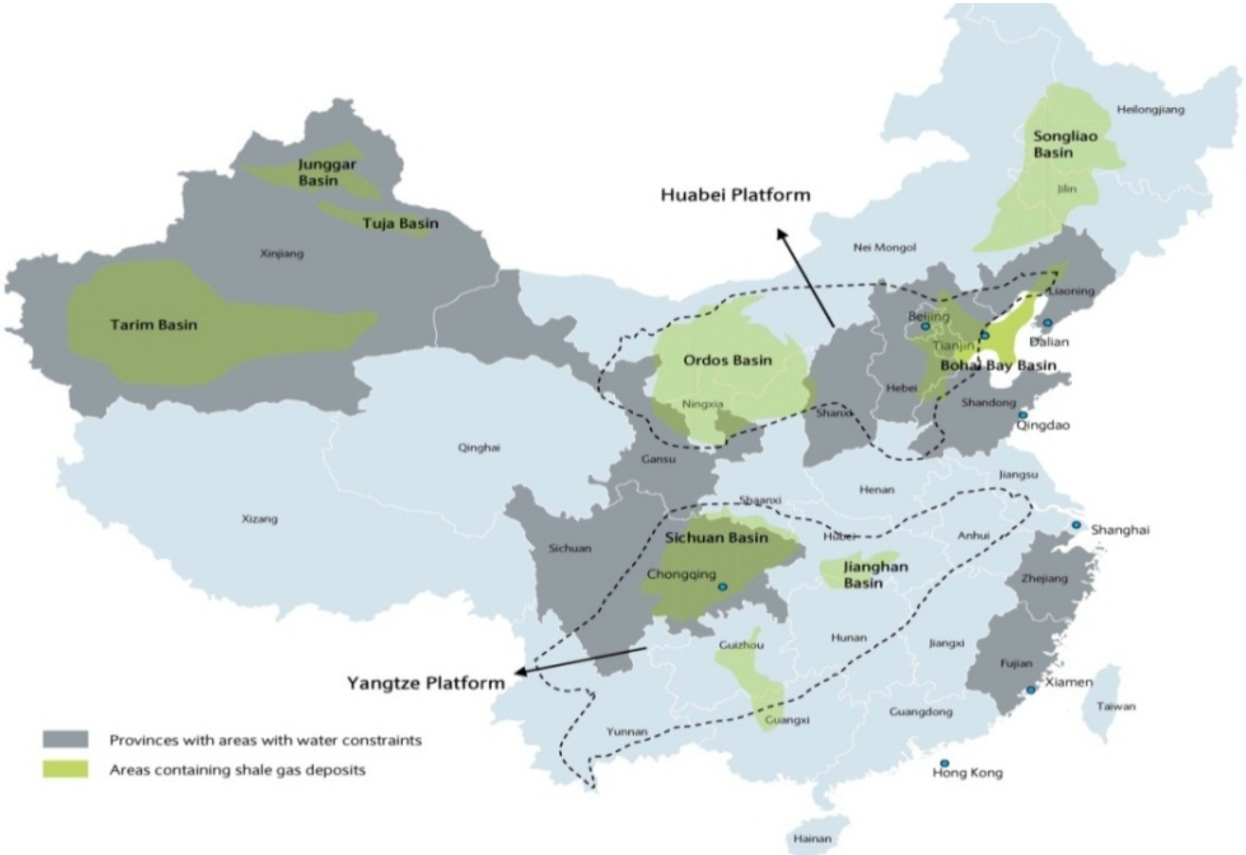
A Potential Problem?
Water Availability in China

- Water could play a major role in Chinese shale gas production endeavors, as indicated by the fact that known shale plays are highly coincident with regions where water stress is already high.



Map replicated from "Natural Gas Weekly Kaleidoscope," Barclay's Capital Commodities Research (November 16, 2010).

Scenario Results

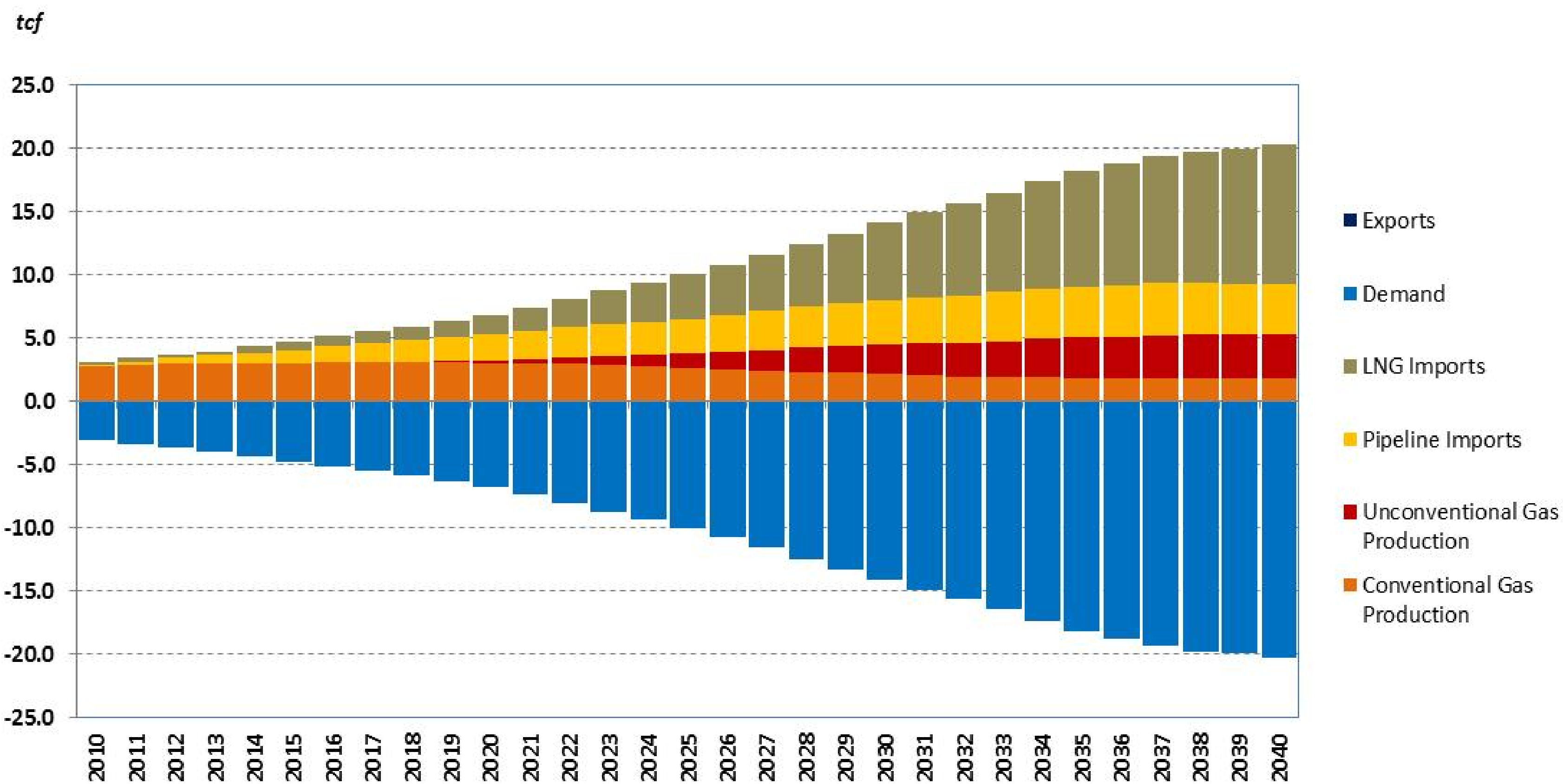
Key findings

- Robust development of shale gas in China, which would occur if a significant proportion of its domestic resource can be done profitably, is just as game-changing as shale gas developments in North America have been.
  - Significant reduction in LNG imports… fall from just over a 42% market share to just under a 25% market share in 2030.
  - Significant reduction in pipeline imports… fall from just under a 25% market share to just under a 13% market share in 2030.
  - Development of pipeline exports from Northeast China to the Korean peninsula… rise to just under 1.0 bcfd by 2040.
  - Price impacts are contingent on development costs of shale. As modeled, Asian LNG price is lowered by almost $0.50 on an average annual basis by the 2030s. But, some regional impacts in China are larger.

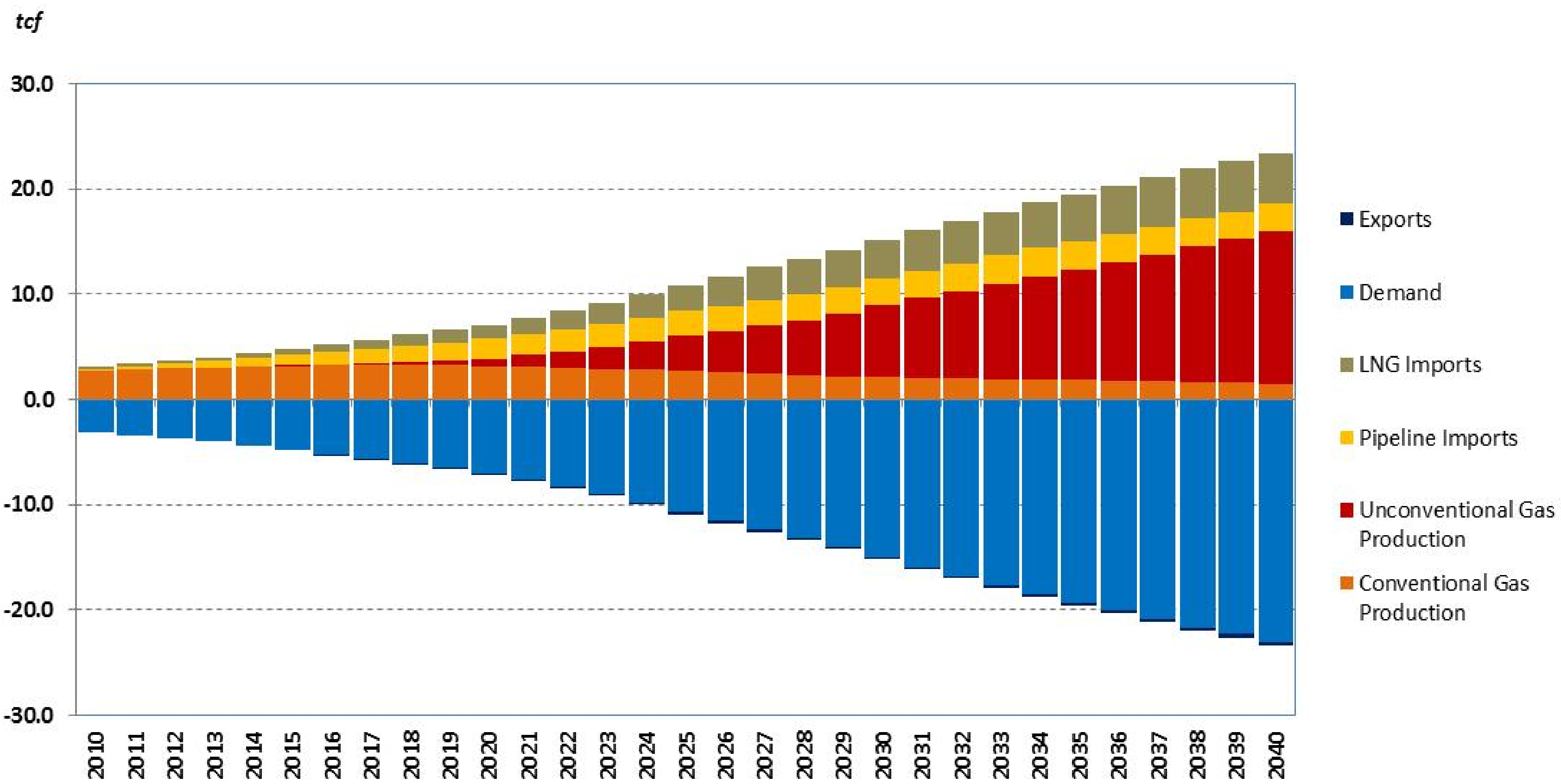
A Key Point: Shale gas development will impact LNG more than other sources of supply. Thus, developments in China will have a lasting commercial and geopolitical impact on global gas market developments.

Reference Case: Shale Gas and Market Balance in China

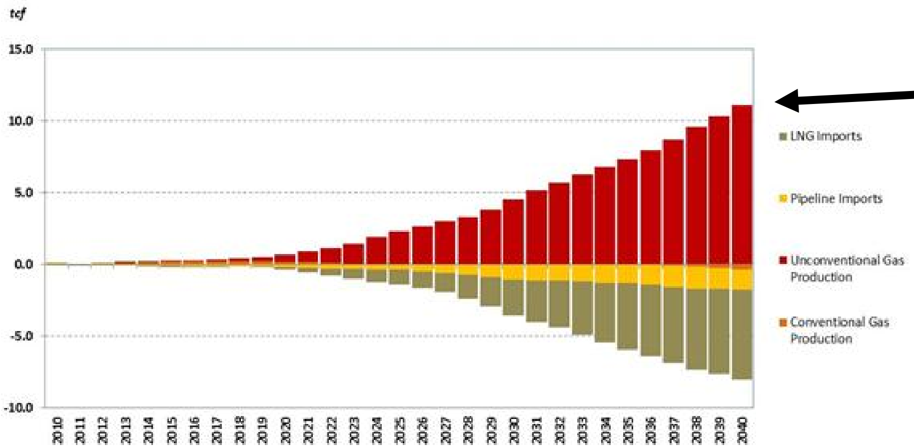
- Shale gas production increases, but LNG imports are by far the largest source of supply in China, reaching over 50% of the market by 2035.



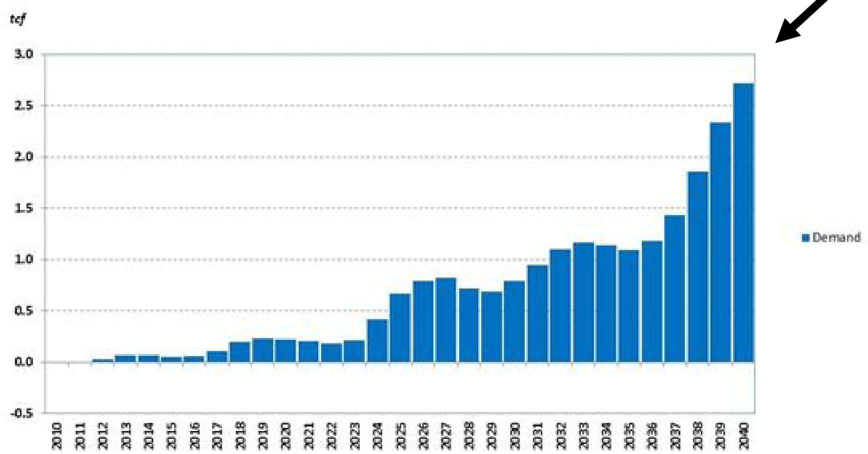
High China Shale Case: Shale Gas and Market Balance in China

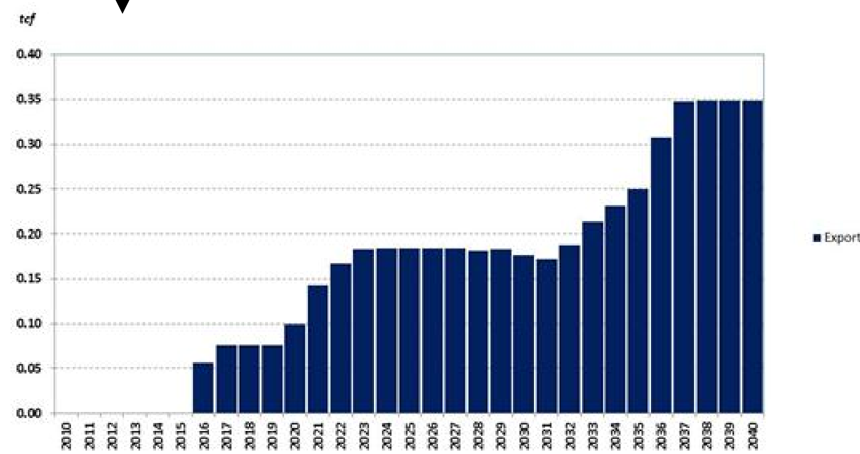


High China Shale Case:
Sources of Change in the Supply-Demand Balance



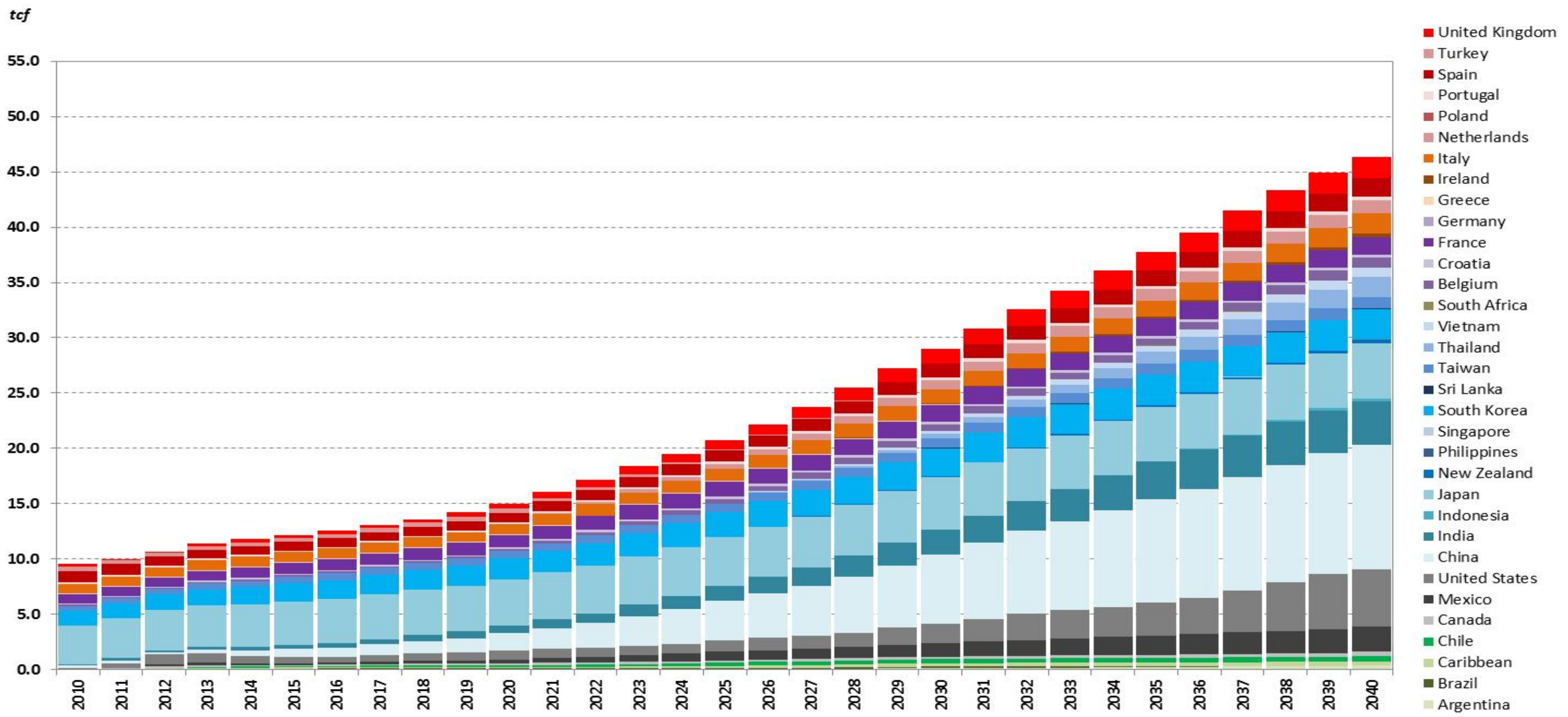
- Higher shale gas production displaces both LNG imports and pipeline imports. LNG is affected the most.
- Demand is higher
- Exports develop to the Korean peninsula





Reference Case:
LNG Imports by Country, 2010-2040

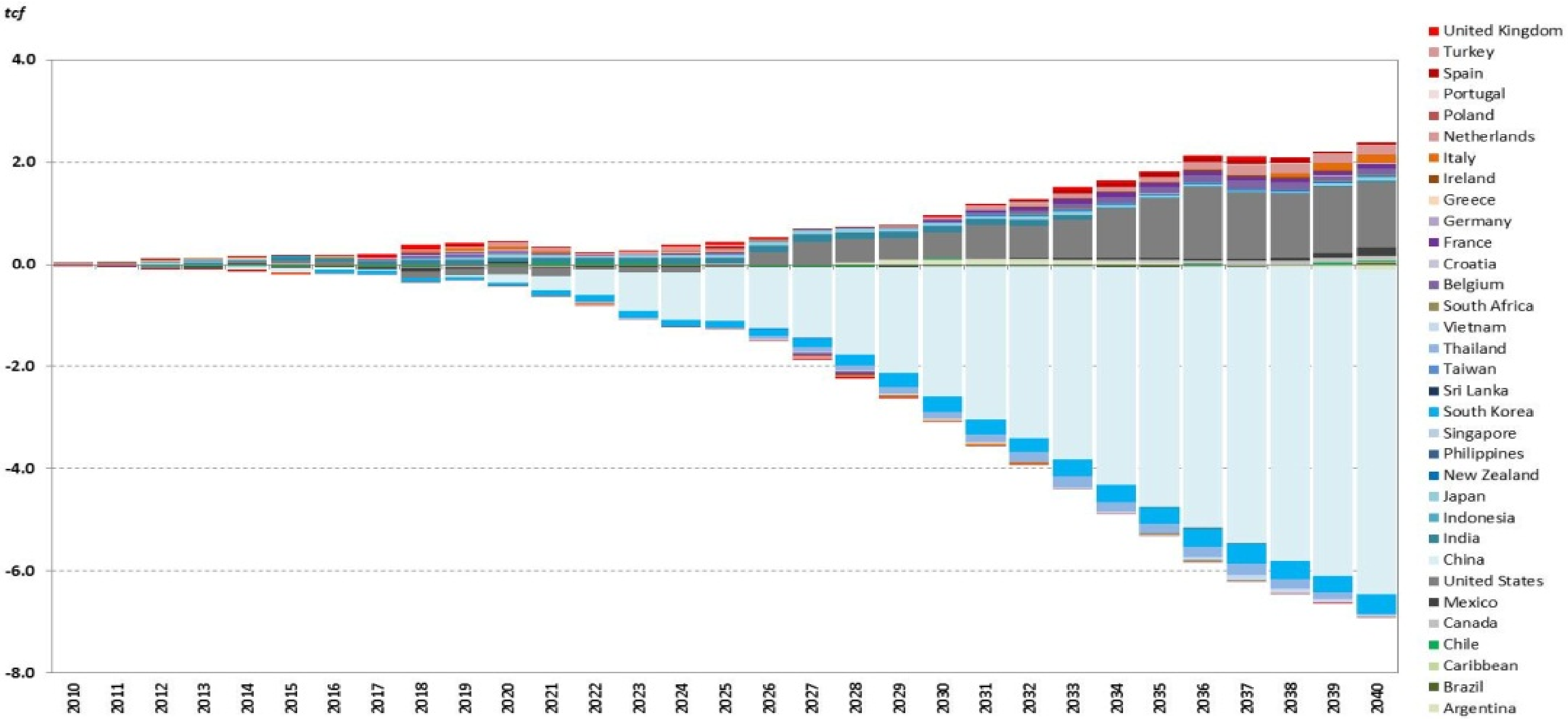
- Developments in China drive LNG market growth



High China Shale Case:
LNG Imports by Country, 2010-2040

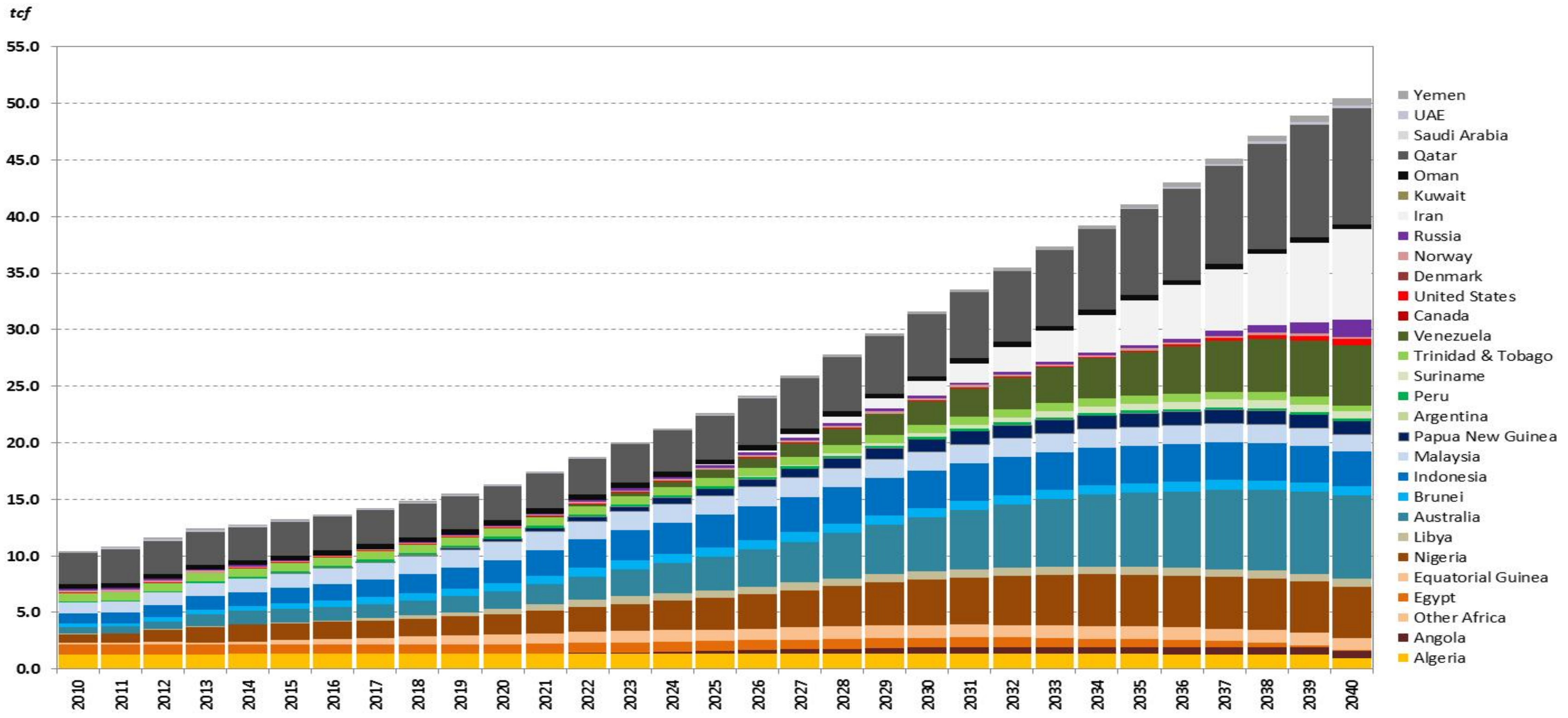
- The reduction in LNG imports to China is partially offset by a rise in imports in other countries.

Delta to Reference Case



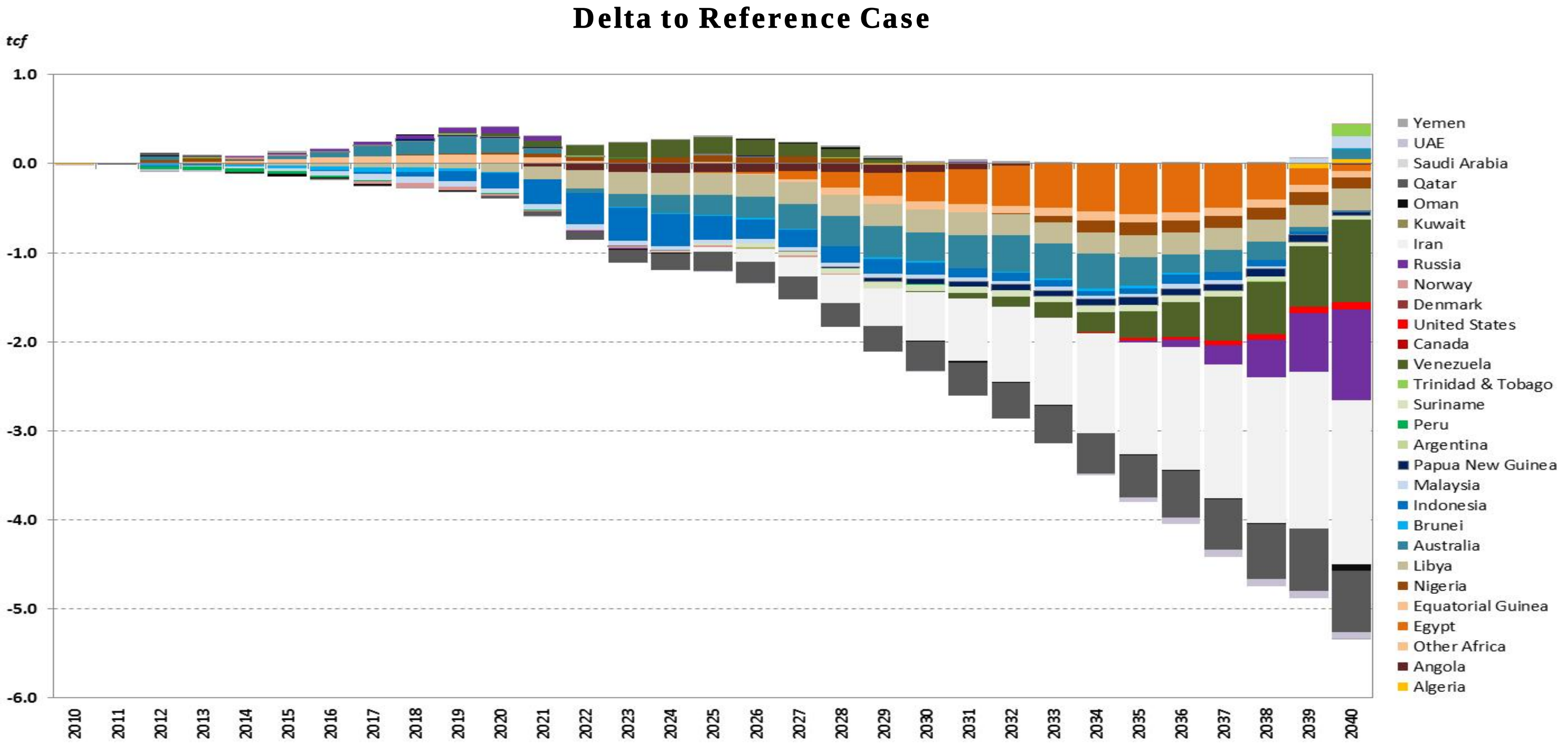
Reference Case:
LNG Exports by Country, 2010-2040

- Developments in China drive LNG market growth. Market balance ultimately results in market entry by Iran and Venezuela.



High China Shale Case:
LNG Exports by Country, 2010-2040

- The brunt of the impact falls to Iran, Russia, Venezuela, and Qatar. Australian volumes also are lower.



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.
- China could follow suit!
- **A lot hinges on outcomes in China. Greater domestic production dramatically alters the outlook for LNG markets.**
  - Note that lower demand has a similar impact.
- 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.
  - **Greater supply elasticity also puts pressure on traditional pricing paradigms.**

But, nothing is certain…

- A stable regulatory environment that fosters responsible development of domestic resources is critical to achieving the benefits presented by shale.
- Multiple issues face shale development: some are global, some are not.
  - **Resource Access** – mineral rights ownership; acreage acquisition; resource assessments; environmental opposition; etc.
  - **Market Structure** – transportation regulatory structure (unbundled access vs. incumbent monopolies); bilateral take-or-pay obligations or marketable rights; existence of gathering and takeaway capacity and hurdles to development; competing resources (RPS, coal, nuclear, etc.); pricing paradigms; etc.
  - **Water** – volume and availability for production; water rights and resource management regulation; flowback options (recycle and/or treatment and disposal) and native infrastructure; concerns about watershed protection during drilling operations (casing failures and fracture migration); etc.
  - **Other issues** – earthquakes related to injection of produced and treated water; long term environmental effects of methane (and other gases) escape; concerns about potential chemical and/or radiation contamination from produced water; ecological concerns related to land use and reclamation; etc.

Some Modeling Results

New Approaches

LNG Trade

Modeling LNG Trade

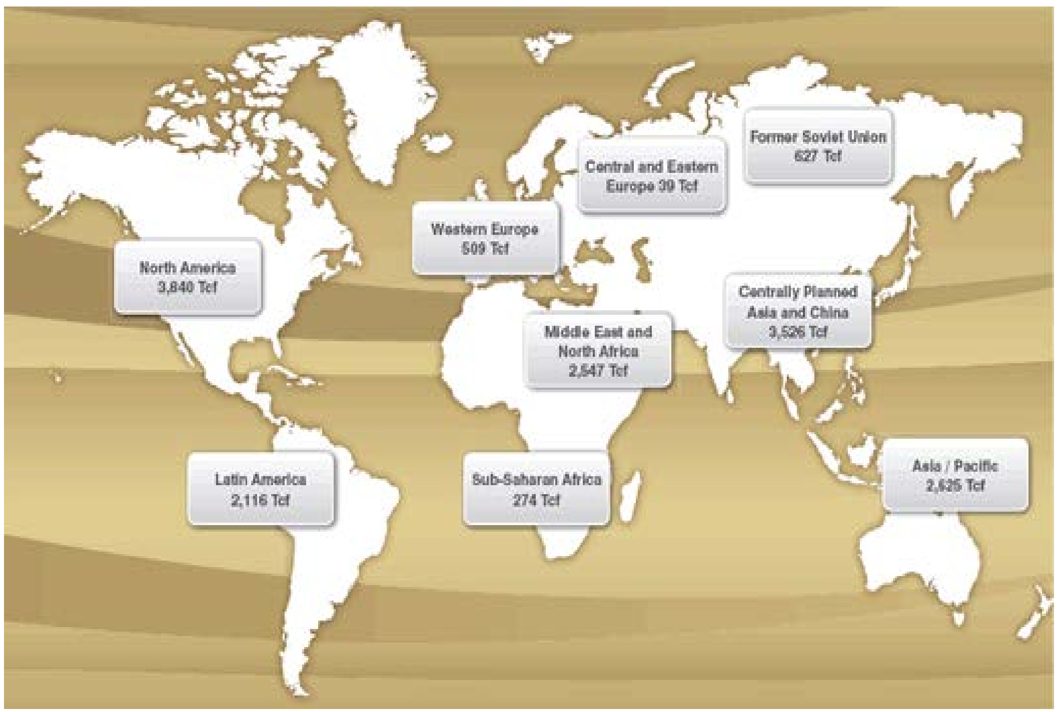
- In the past, we have modeled LNG trade using a “hub-and-spoke” network. This simplifies the model architecture and implicitly assumes all profitable arbitrage opportunities will be eliminated.
- However, the “hub-and-spoke” approach does not accommodate an analysis of where individual trades occur.
- Thus, we are adopting a “point-to-point” network for LNG trade. This will still allow the elimination of profitable arbitrage opportunities, but we also have the flexibility to model specific trade strategies and flows.

New Approaches

Global Shale Resource

The Global Shale Gas Resource

- Knowledge of the shale 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.

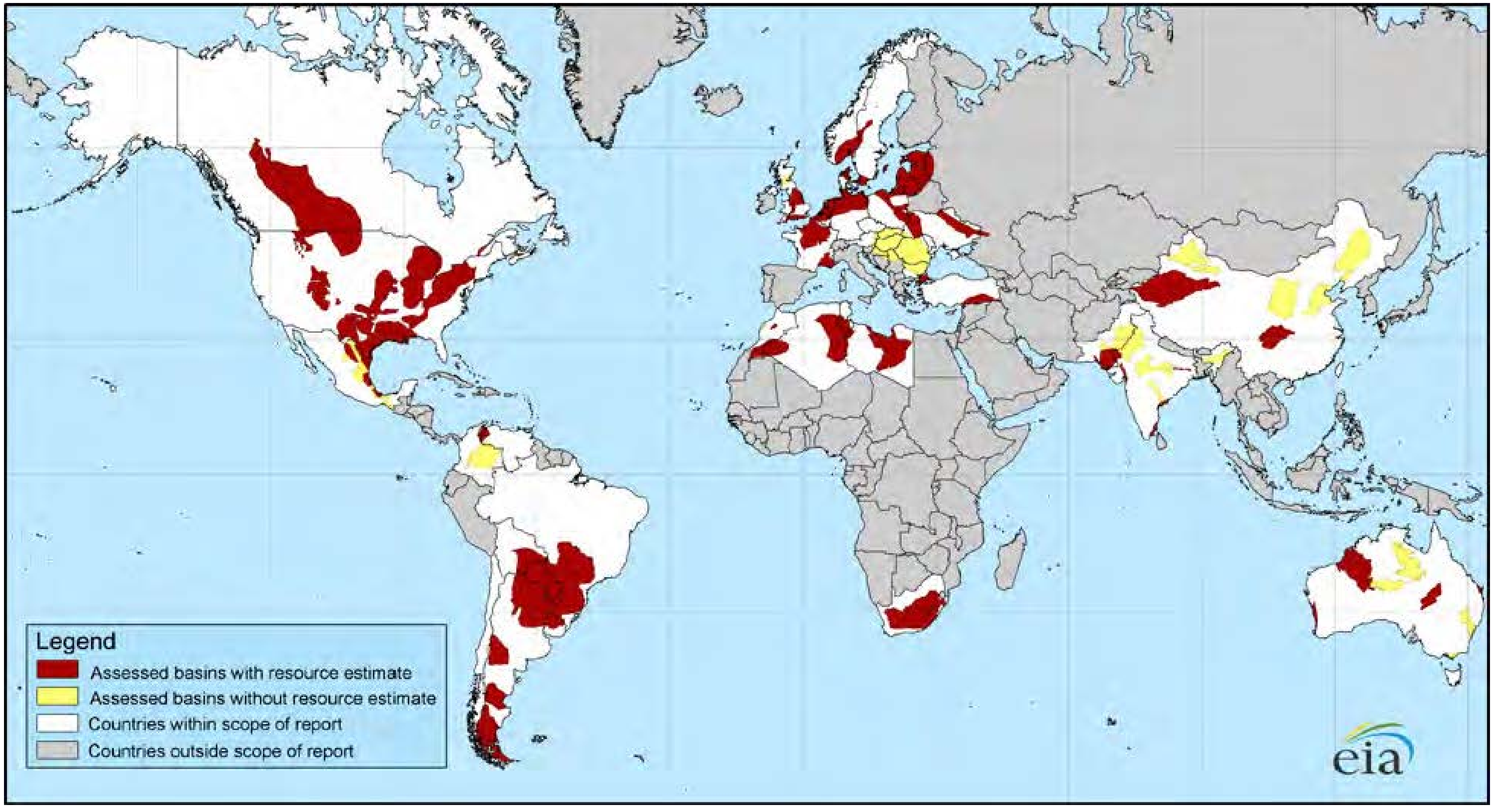


Region	Resource In-Place (tcf)	Resource In-Place (tcm)
North America	3,842	109
Latin America	2,117	60
Europe	549	15
Former USSR	627	18
China and India	3,528	100
Australasia	2,313	66
MENA	2,548	72
Other	588	17
Total	**16,112**	**457**

Source: Rogner (1997)

The Global Shale Gas Resource (cont.)

- Recently, however, innovations made the shale resource accessible
  - Shale developments have been focused largely in North America where high prices have encouraged cost-reducing innovations.
  - We have been analyzing the recent ARI (2011) assessment to incorporate newer data on global shale resources. The task: construct cost curves for shales for which there is a technically recoverable assessment.



The Global Shale Gas Resource (cont.)

- IEA recently estimated about 40% of the estimates resource in-place by Rogner (1997) will ultimately be technically recoverable, which yields 6,445 tcf.
- A very recent assessment by Advanced Resources International (2011) assesses a larger resource in-place, and estimates a total technically recoverable resource of 6,623 tcf.
- We use internal assessments for the United States and Canada, paired with ARI data for the rest of the world. This yields a technically recoverable global shale of 6,023 tcf.

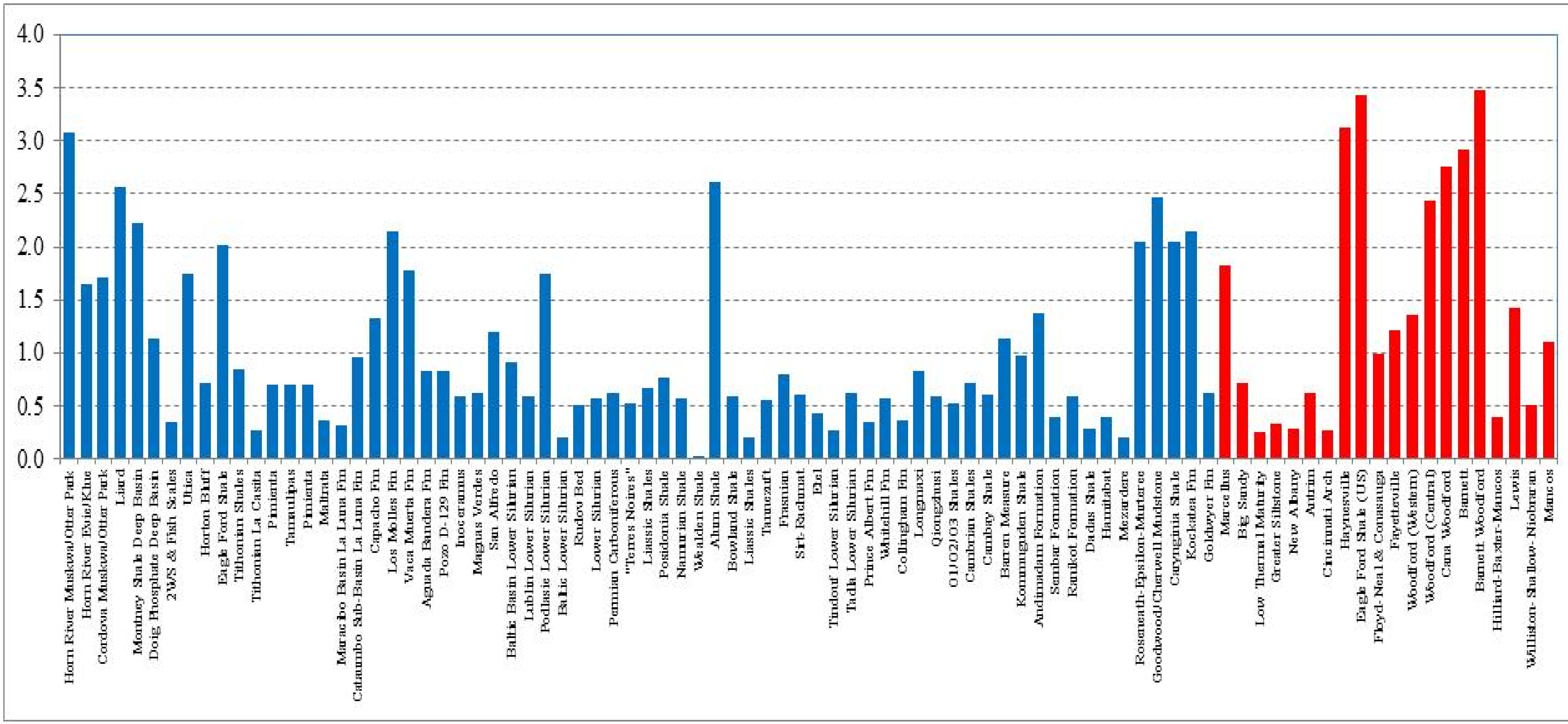
	Technically Recoverable Resource (tcf)		
Region	**Rogner/IEA**	**ARI/EIA**	**BIPP**
North America	1,537	1,931	1,331
Latin America	847	1,225	1,225
Europe	220	639	639
Former USSR	251	---	---
China and India	1,411	1,338	1,338
Australasia	925	396	396
Africa	1,019	1,043	1,043
Middle East		---	---
Other	235	51	51
Total	**6,445**	**6,623**	**6,023**

Global Shale Cost Assessment

- **Step 1**: compile cost and geophysical data for US shales under active development.
- **Step 2**: econometrically estimate the relationship between geophysical data and drilling and completion cost data for an "average" type well in the United States.
- **Step 3**: compile geophysical data for shales in other regions of the world. The primary source of information for this is the recent ARI assessment.
- **Step 4**: Use fitted relationship from step 2 to estimate drilling and completion costs for wells drilled in other parts of the world.
- **Step 5**: Econometrically estimate well spacing as a function of basin-specific characteristics
- **Step 6**: Given total recoverable resource, well spacing and prospective area, calculate EUR for the average type well.
- **Step 7**: Given EURs and drilling and completion costs we can calculate the per unit costs associated with the average type well for each shale.
- **Step 8**: Use EIA data on actual EURs for high and low performing wells to estimate the standard deviation of EUR as a function of the average.
- **Step 9**: Fit the distribution of EUR for each shale play so "tiers" can be accommodated.
- **Step 10**: Use distribution of EURs to calculate per unit costs for resource tiers.

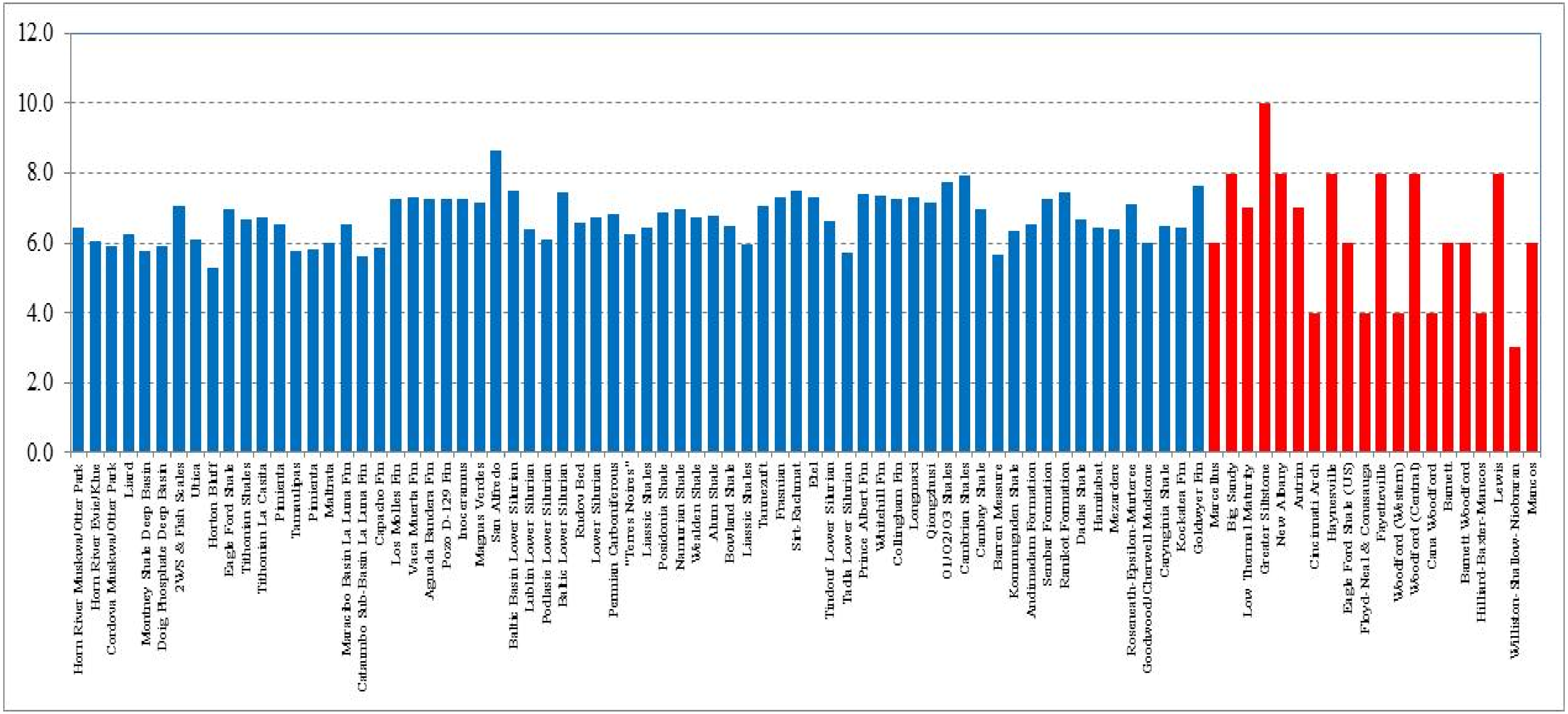
Global Shale Cost Assessment (cont.)

- Projected EURs for “average” type wells (units: bcf/well)



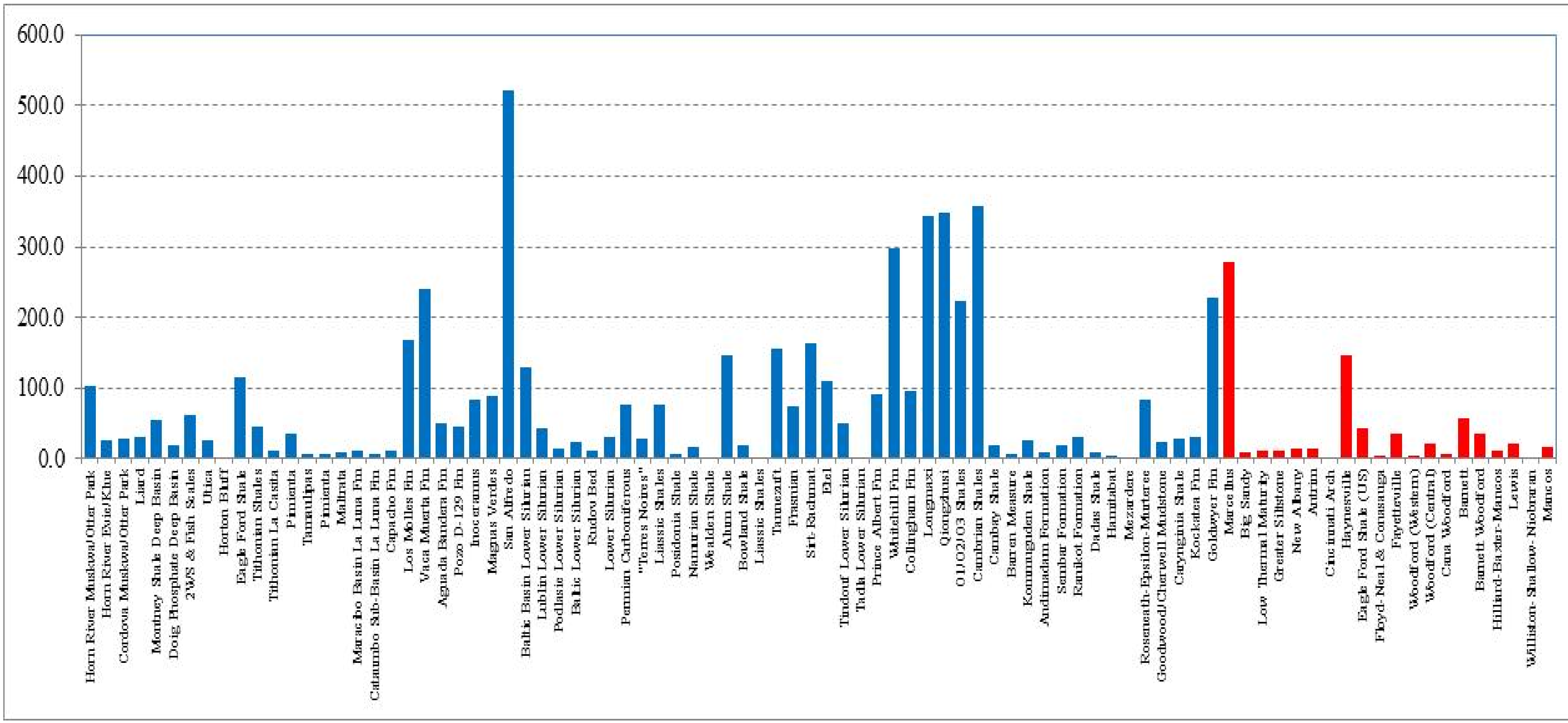
Global Shale Cost Assessment (cont.)

- Projected well spacing (units: wells/mi^2)



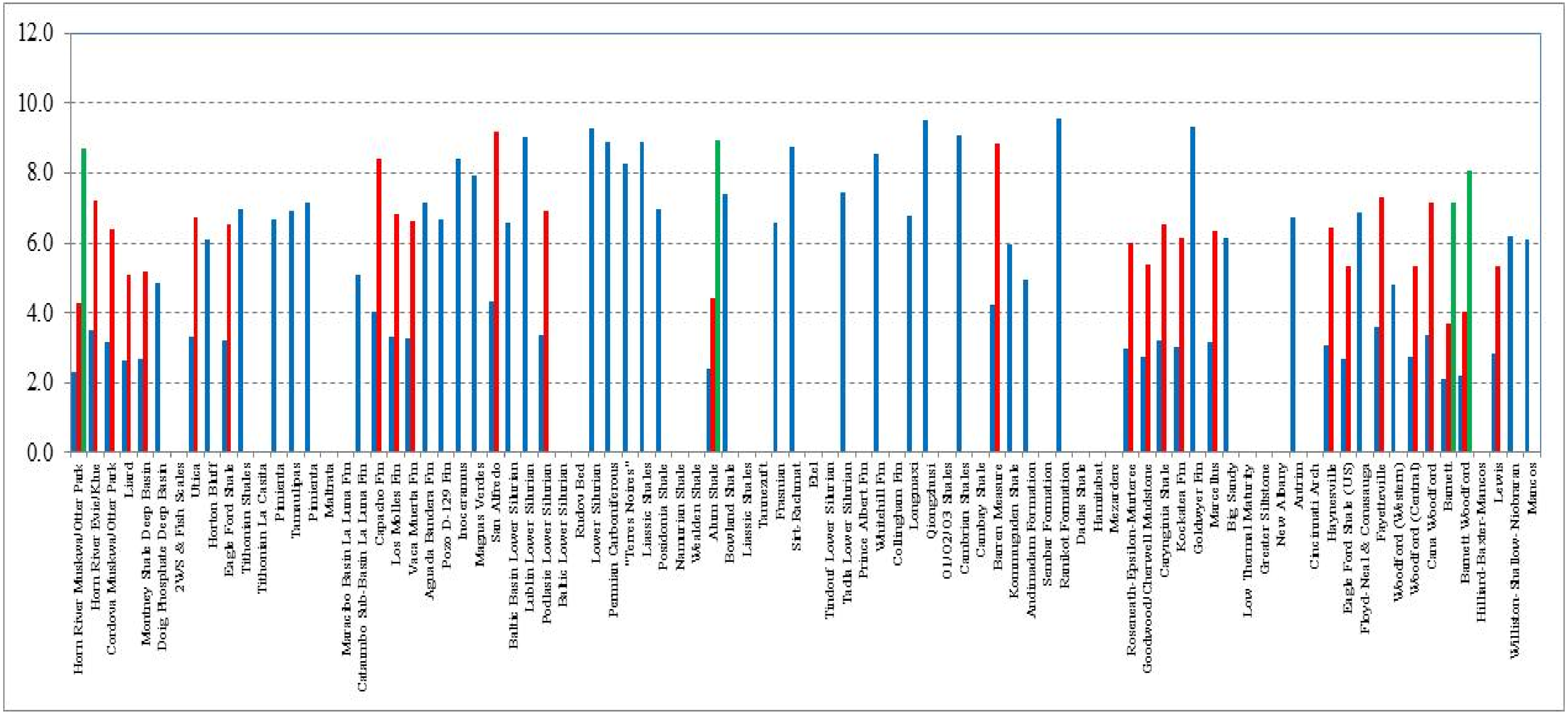
Global Shale Cost Assessment (cont.)

- Projected total *technically* recoverable resource (units: tcf)



Global Shale Cost Assessment (cont.)

- Projected breakeven prices by tier (units: $/mcf)
  - Note: Breakeven prices above $10/mcf are excluded for presentation purpose.



Global Shale Cost Assessment (cont.)

- Global technically and commercially recoverable resource (units: tcf)
- Commercial recovery is lower than technical, but this will likely change as time passes. Thus, we will continue to run scenarios to stress the analysis.
- Indeed, it is likely that both technically recoverable resource as well as costs will continue to evolve.

	Technical Resource	***Commercial Resource***
Region	*tcf*	*tcf*
North America	1,331	798
Latin America	1,225	707
Europe	639	299
Former USSR	---	---
China and India	1,338	396
Australasia	396	189
Africa	1,043	188
Middle East	---	---
Other	51	0
Total	**6,023**	**2,577**