

# **The Impact of Shale Gas Development**

## **The Rice World Gas Trade Model: A Discussion of the Reference Case (Unconstrained) Results**

**prepared by:**

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## **The Rice World Gas Trade Model**

## The RWGTM

- The Rice World Gas Trade Model (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 Altos
  - 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.

## The RWGTM: Demand

- Over 290 regions.
  - Regional detail is highly dependent on data availability and existing gas delivery infrastructure.
- Demand is estimated directly for US...
  - United States (residential, commercial, power and industrial sectors)
    - Sub-state detail is substantial (for example, 10 regions in Texas) and is based on data from the Economic Census and the location of power plants.
    - Demand functions estimated using longitudinal state level data.

### Commercial

$$\ln q_{com,i,t} = \alpha_i - 0.154 \ln p_{ng,i,t} + 0.039 \ln p_{ho,i,t} + 0.160 \ln y_t + 0.290 \ln hdd_{i,t} - 0.033 \ln cdd_{i,t} + 0.176 \ln pop_{i,t} + 0.758 \ln q_{com,i,t-1}$$

### Residential

$$\ln q_{res,i,t} = \alpha_i - 0.201 \ln p_{ng,i,t} + 0.049 \ln p_{ho,i,t} + 0.117 \ln y_t + 0.405 \ln hdd_{i,t} - 0.007 \ln cdd_{i,t} + 0.312 \ln pop_{i,t} + 0.683 \ln q_{res,i,t-1}$$

### Industrial

$$\ln q_{ind,i,t} = \alpha_i - 0.071 \ln p_{ng,i,t} + 0.330 \ln manuf_{i,t} + 0.202 \ln hdd_{i,t} + 0.047 \ln cdd_{i,t} + 0.780 \ln q_{ind,i,t-1}$$

### Power Generation

$$\ln q_{pwr,i,t} = \alpha_i - 0.442 \ln p_{ng,i,t} + 0.238 \ln p_{fo,i,t} + 0.102 \ln p_{coal,i,t} + 1.089 \ln elecgen_{i,t} + 0.189 \ln renew_{i,t} - 0.511 \ln hdd_{i,t} + 0.339 \ln cdd_{i,t} + 0.716 \ln q_{pwr,i,t-1}$$

## The RWGTM: Demand (cont.)

- ... but demand is estimated indirectly for RoW.
  - Rest of World (Power Gen, Direct Use, EOR)
    - Energy intensity is estimated as a function of per capita income and energy price using panel data for over 70 countries from 1970-2007.

### Energy Intensity

$$\ln\left(\frac{E}{Y}\right)_{i,t} = \alpha_i - 0.086 \ln y_{i,t} - 0.012 \ln p_{i,t} + 0.834 \ln\left(\frac{E}{Y}\right)_{i,t-1}$$

- Natural gas share is estimated as a function of GDP per capita, own price, oil price, installed thermal capacity, and the extent to which the country imports energy

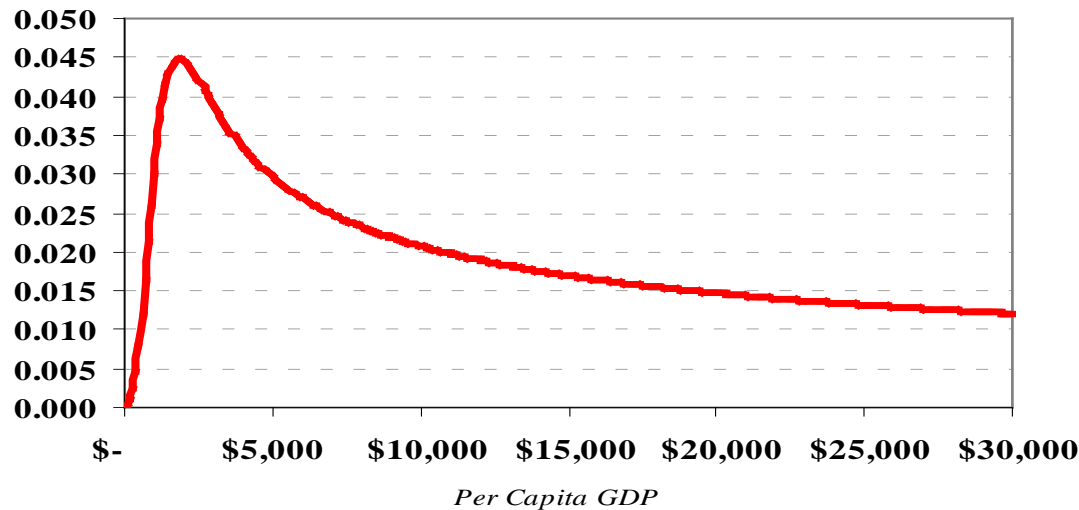
### Natural Gas Share

$$\ln(\ln \theta_{ng,i,t}) = \alpha_i + 0.068 \ln\left(\frac{E}{Y}\right)_{i,t} + 0.043 \ln p_{ng,i,t} - 0.028 \ln p_{oil,i,t} - 0.041 \ln thermcap_i + 0.098 \ln entrade_{i,t} + 0.767 \ln(\ln \theta_{ng,i,t})$$

Note, the natural gas share equation is in double log form, which bounds the share between 0 and 1 (when forecasting). The sign of the estimated coefficients are opposite the sign of the elasticity. In fact, the own price elasticity is given as:  $\varepsilon_{\theta,p} = 0.043 \ln \theta_{ng,i,t}$ . So, the price elasticity is decreasing in natural gas share, ranging between -3.064 and -0.049 across all countries. This feature captures rigidities associated with capital deployment.

## The RWGTM: Demand (cont.)

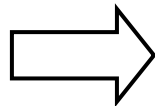
**Energy Intensity**



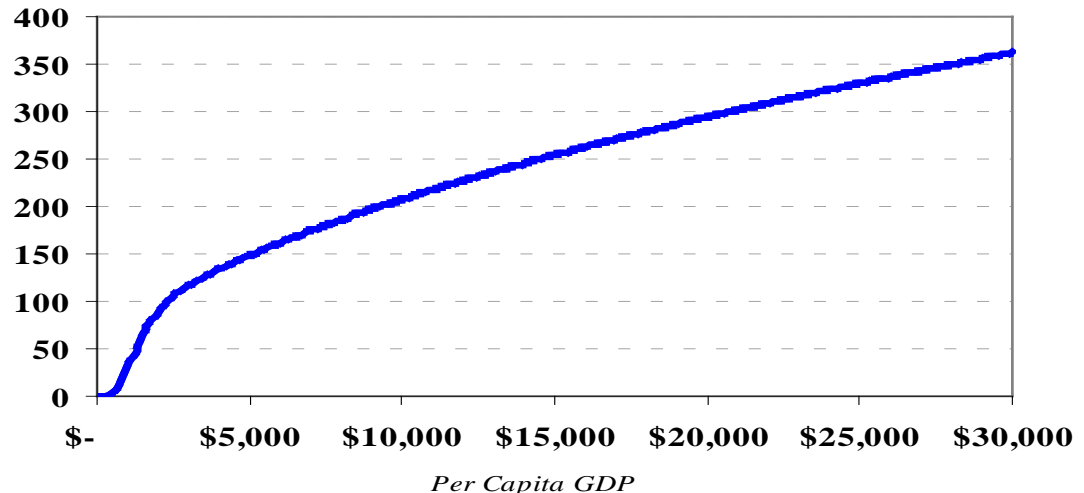
The estimated relationship between energy intensity and per capita GDP reveals that energy intensity generally decreases with rising incomes (see Medlock and Soligo, *Energy Journal* 2001)

The graphic indicates a generic curve. The level of energy intensity for individual countries will vary depending on a number of factors, but each will exhibit a similar pattern.

The forecast path for energy intensity is then multiplied by the projected GDP per capita to reveal a forecast path for per capita energy demand. Population projections are then taken from the UN median case to reveal total energy demand.



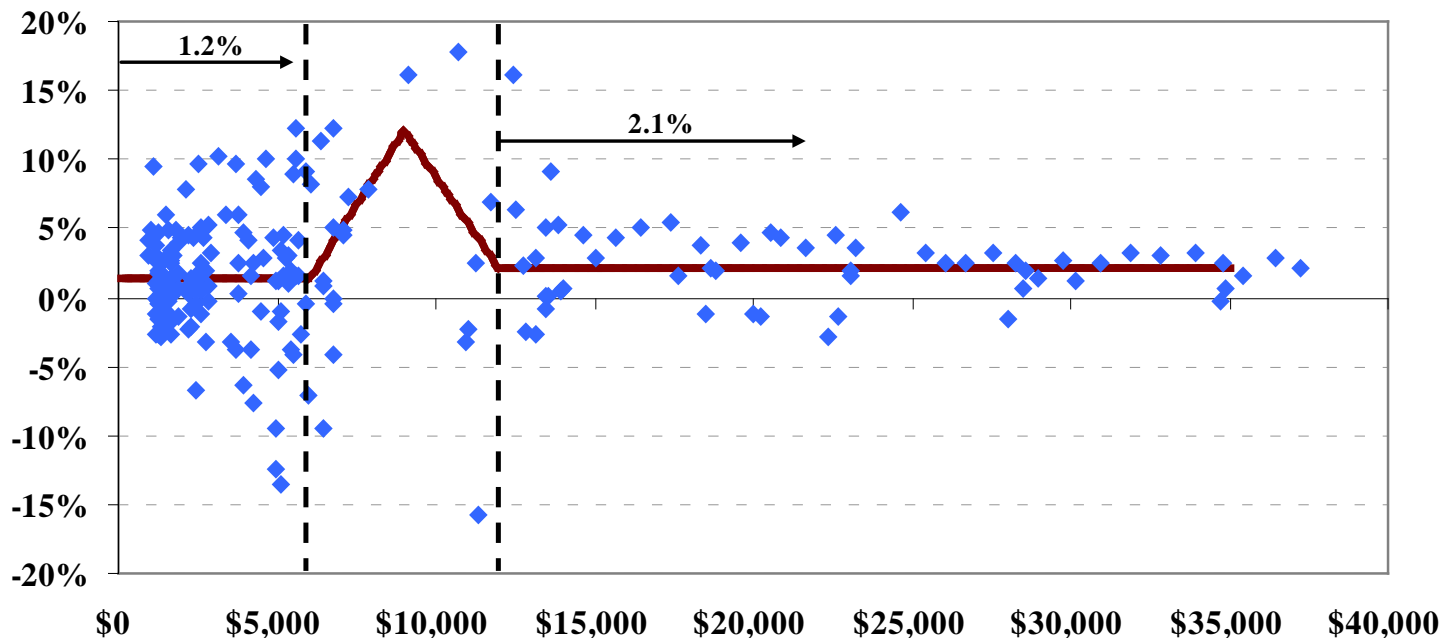
**Energy Demand per Capita**



## The RWGTM: Demand (cont.)

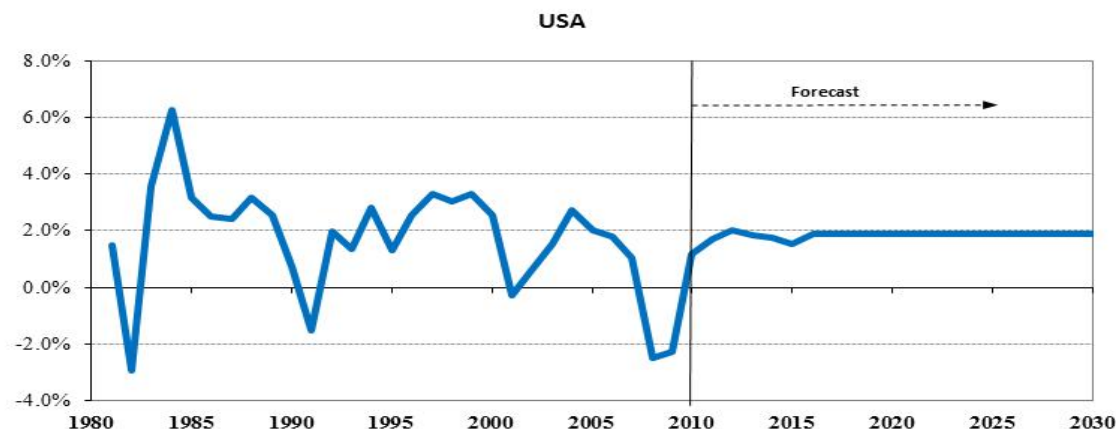
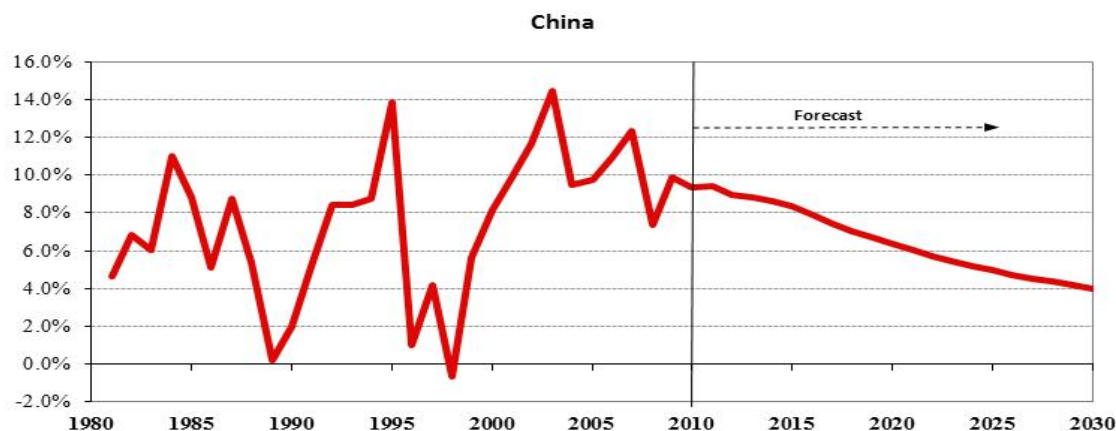
- Economic growth is based on conditional convergence a long run growth path that is based on historical US and UK growth rates (dating back into the 1800s) at various levels of per capita income. The long run growth path is estimated using a piecewise linear spline knot regression.
- Countries converge to the long run growth path at a rate estimated using an unbalanced panel across all countries spanning multiple years.

*Per Capita GDP*  
*Growth Rate*



## The RWGTM: Demand (cont.)

- Recent economic and financial crisis is incorporated. We use the IMF economic outlook for growth through 2015 for all countries. Beyond 2015, growth is governed by the model of conditional convergence. All GDP estimates are in \$2005PPP.



Note, the graphics depict real growth of per capita GDP in PPP terms. These growth estimates will differ from growth estimates of GDP per capita converted using nominal exchange rates to the extent the PPP exchange rate changes. Accordingly, in PPP terms, Chinese per capita income in roughly 60% of US per capita income by 2030, compared to 28% currently. This results due to the conditional convergence feature of the long run growth model.



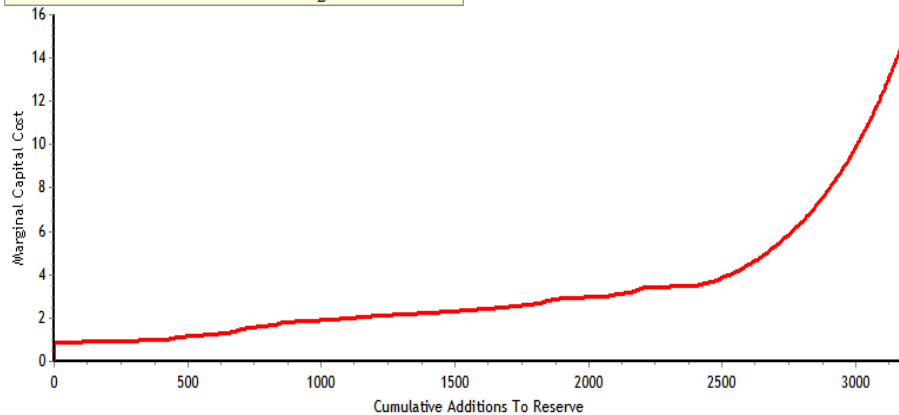
## **The RWGTM: Supply**

- Over 120 regions
- Natural gas resources are represented as...
  - Conventional, CBM and shale in North America, China, Europe and Australia, and conventional gas deposits in the rest of the world
- ... in three categories
  - proved reserves (Oil & Gas Journal estimates)
  - growth in known reserves (P-50 USGS and NPC 2003 estimates)
  - undiscovered resource (P-50 USGS and NPC 2003 estimates)
    - Note: resource assessments are supplemented by regional offices if available.
- North American cost-of-supply estimates are econometrically related to play-level geological characteristics and applied globally to generate costs for all regions of the world.
  - Long run costs increase with depletion.
  - Short run adjustment costs limit the “rush to drill” phenomenon.
  - We allow technological change to reduce mining costs longer term

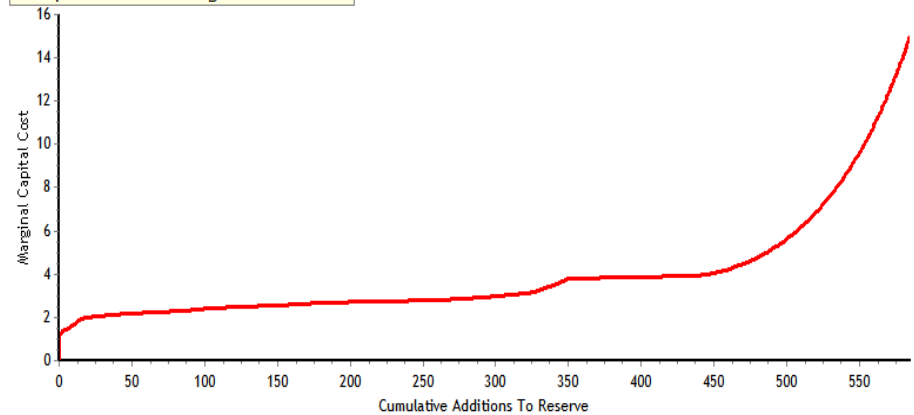
## The RWGTM: Supply (cont.)

- Selected examples: Regional marginal cost of supply curves...

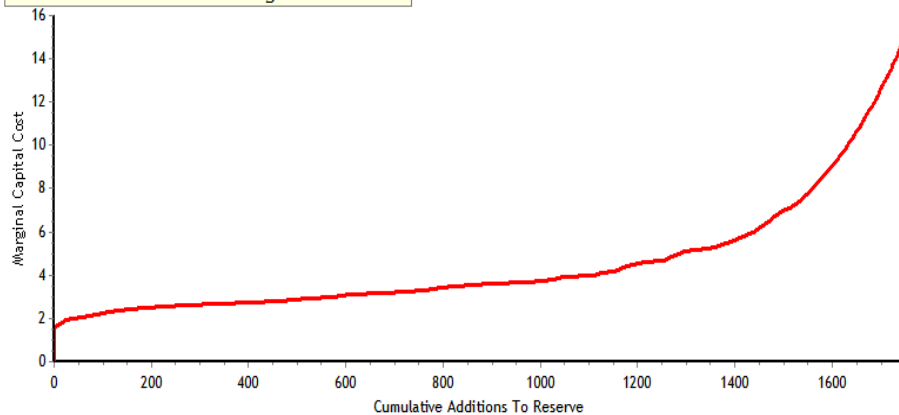
Former Soviet Union Production Marginal Cost Curve



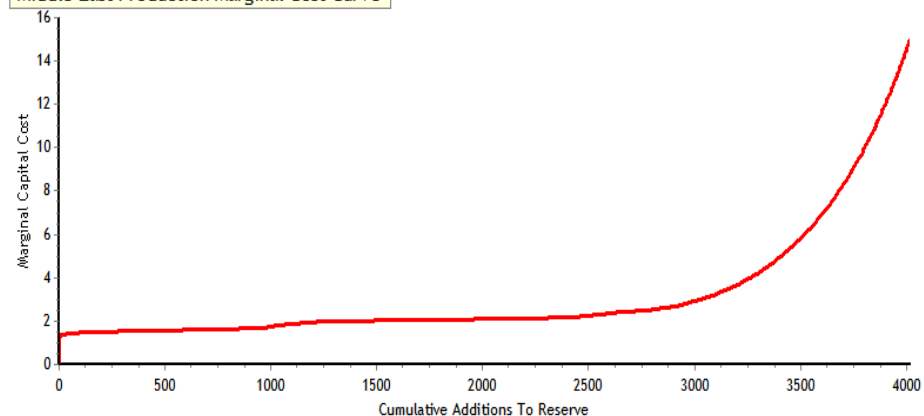
Europe Production Marginal Cost Curve



North America Production Marginal Cost Curve



Middle East Production Marginal Cost Curve



## **The RWGTM: Infrastructure**

- Required return on investment varies by region and type of project (using ICRG and World Bank data)
- Detailed transportation network
  - Pipelines aggregated into corridors where appropriate.
  - Capital costs based on analysis of over 100 pipeline projects relating project cost to various factors.
  - Tariffs based on posted data, where available, and rate-of-return recovery.
  - LNG is represented as a hub-and-spoke network, reflecting the assumption that capacity swaps will occur when profitable.
  - LNG shipping rates based on lease rates and voyage time.
- For all capital investments in both the upstream and midstream, we allow for existing and potential pipeline links, then “let the model decide” optimal current and future capacity utilization.
- For detailed information please see Peter Hartley and Kenneth B Medlock III, “The Baker Institute World Gas Trade Model” in *The Geopolitics of Natural Gas*, ed. Jaffe, Amy, David Victor and Mark Hayes, Cambridge University Press (2006).

## The RWGTM: Infrastructure (cont.)

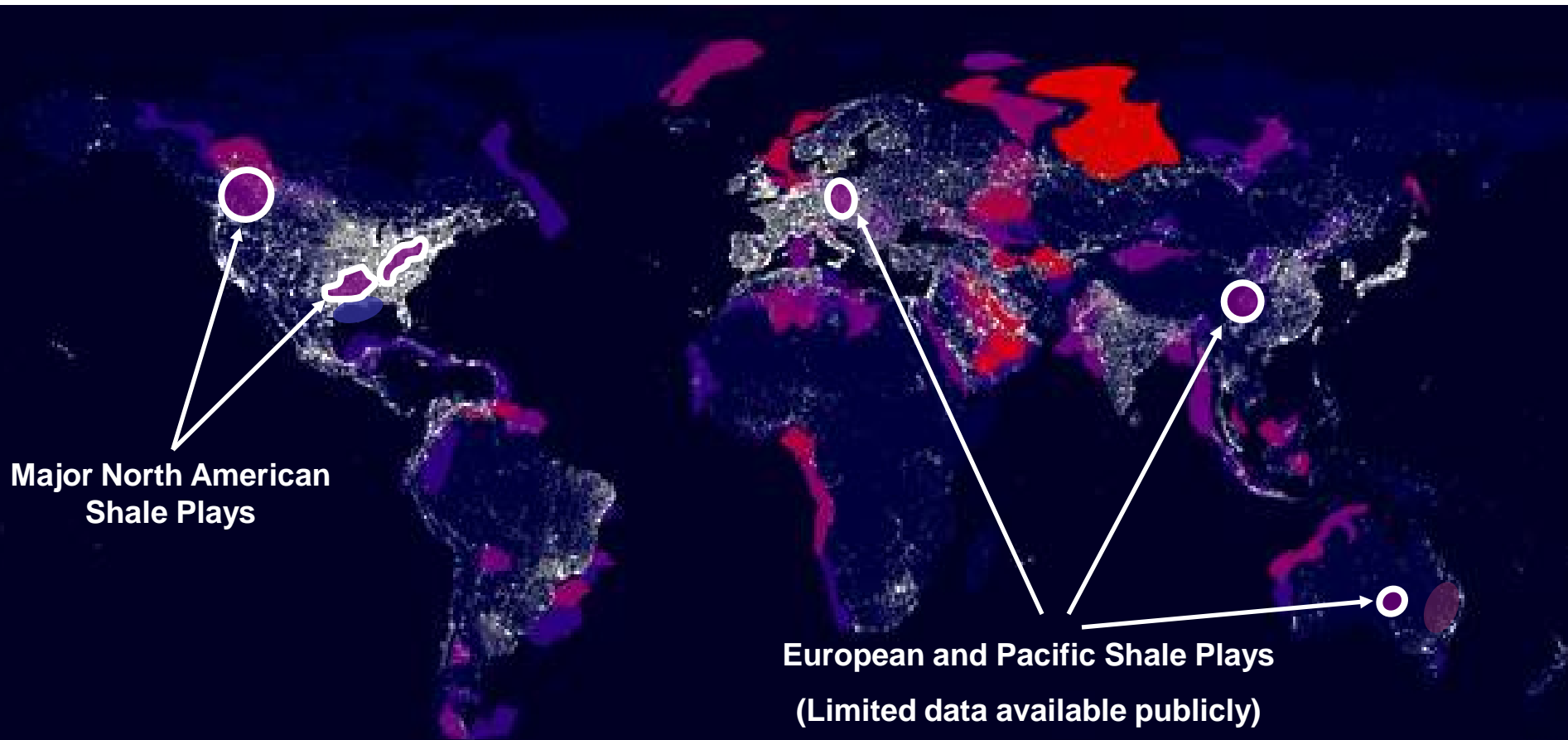
- A brief focus on LNG costs
  - These are generally generic with regard to region.

Sample Capital Cost for Liquefaction		
	Capex (\$/mcf)	Capex (\$/ton)
Australia	12.8934	\$ 620.2
Australia (Queensland)	9.0988	\$ 437.7
Atlantic	7.7854	\$ 374.5
Pacific	9.0988	\$ 437.7
Middle East	8.4784	\$ 407.8
Arctic	18.2287	\$ 876.8

- A facility must earn a minimum return to capital prior to the model choosing to build it. Hence, construction is based on current *and* future prices, as well as construction costs and financial parameters defining things such as tax rates and the required rates of return to debt and equity.

## **Shale Gas in the RWGTM**

## **Shale is everywhere, and it has significant implications for global energy markets**



## 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.
- 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!**

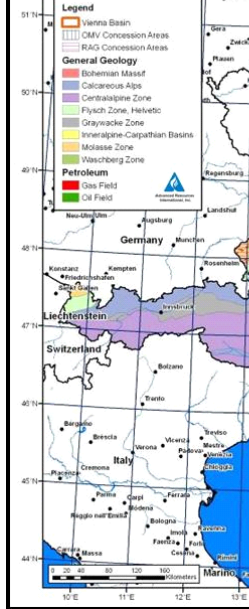
**Rogner (1997)**

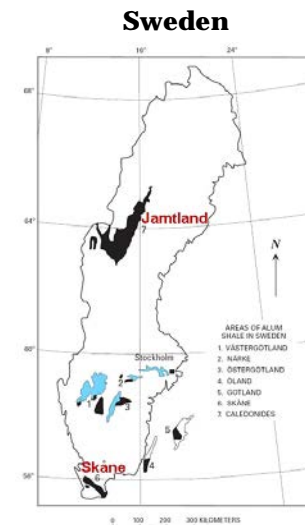
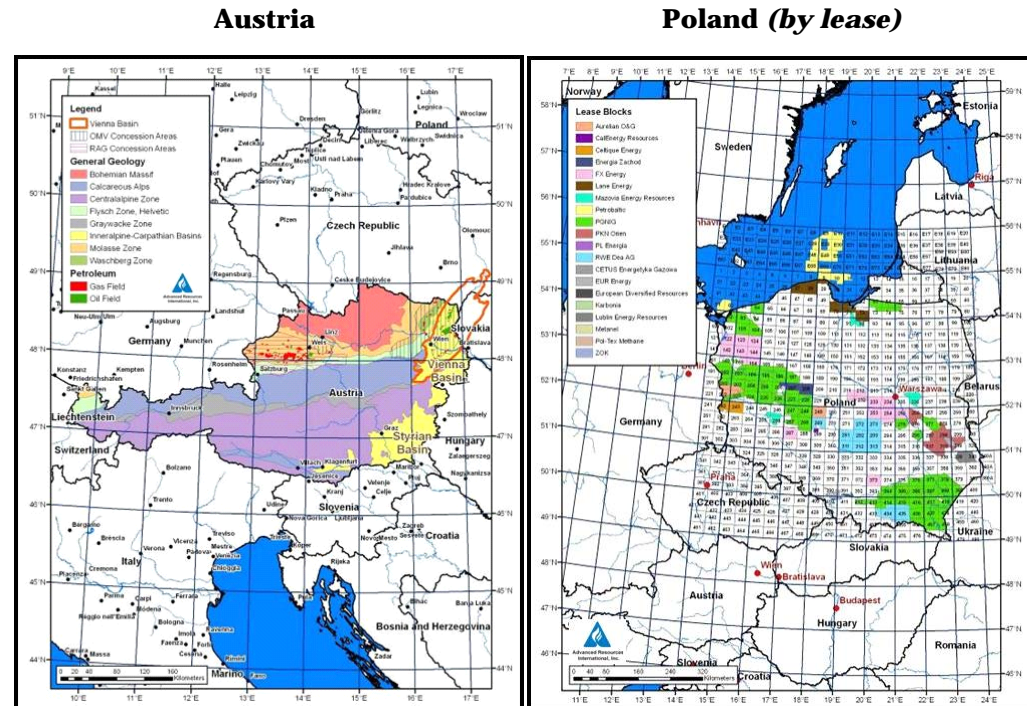
Region	Resource In-Place (tcf)	Resource In-Place (tcm)
North America	3,842	109
Latin America	2,117	60
Europe	549	15
Former USSR	627	18
China and India	3,528	100
Australasia	2,313	66
MENA	2,548	72
Other	588	17
<b>Total</b>	<b>16,112</b>	<b>457</b>





# 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).”
- 
- The map displays the geographical distribution of shale gas resources across Europe. Key features include:
  - Legend:**
    - Basins:** Vienna Basin (orange), OMV Concession Areas (yellow), RAK Concession Areas (light blue).
    - General Geology:**
      - Bohemian Massif (red), Calcareous Alps (purple), Central Alpine Zone (light blue), Flysch Zone, Helvetic (grey), Grayswacke Zone (dark grey), Inneralpine-Carpathian Basins (yellow), Molasse Zone (light green), Vaischberg Zone (dark green).
    - Petroleum:** Gas Field (red), Oil Field (green).
  - Geographical Labels:** Countries shown include Germany, Switzerland, Austria, Italy, and parts of France, Poland, and the UK. Major cities like London, Paris, Rome, Berlin, and Vienna are marked.
  - Shaded Regions:** Various areas are shaded in different colors corresponding to the geological zones, indicating regions of interest for shale gas exploration.
  - Scale and Coordinates:** The map includes a scale bar (0 to 1000 km) and latitude/longitude markings.



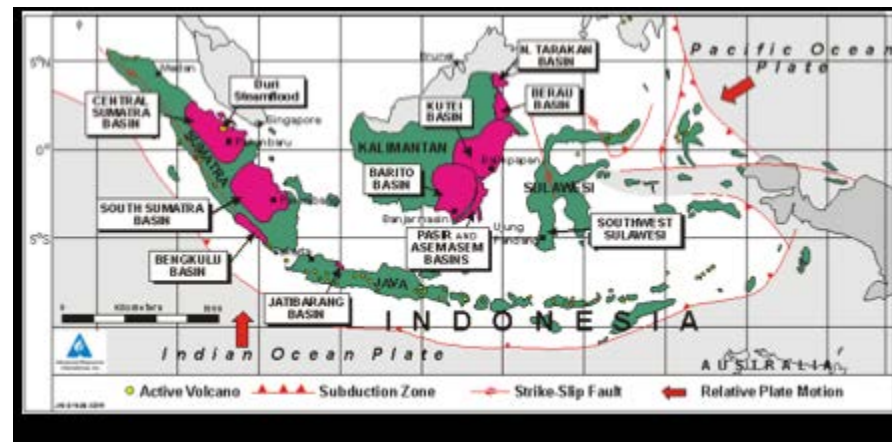
*Source:*  
*Graphics from*  
*ARI (2010)*



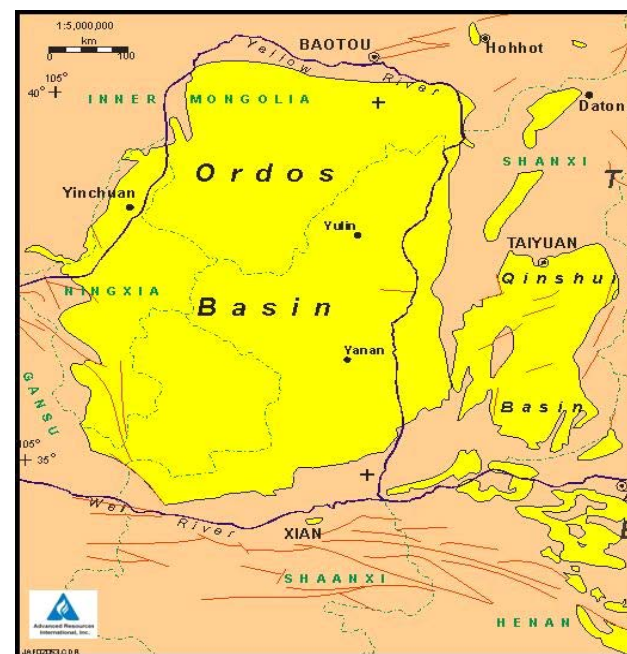
## Asia/Pacific Shale and CBM

- 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)



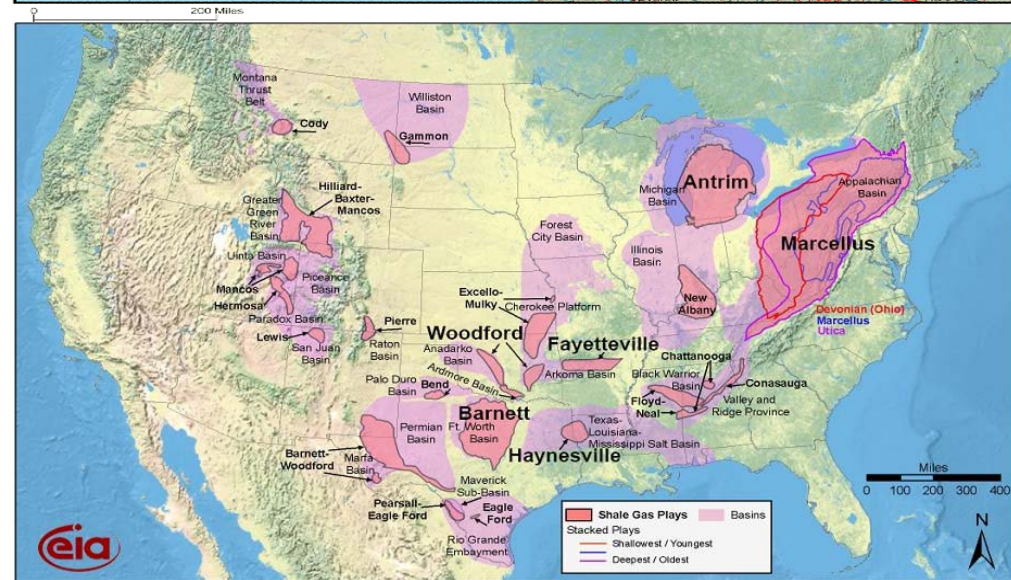
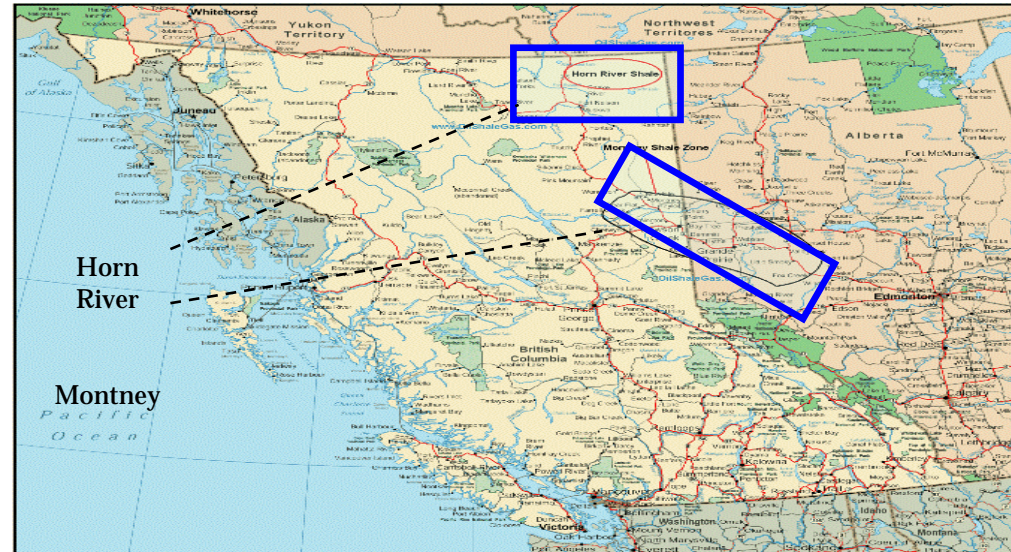
China (CBM)



Source: Graphics from ARI (2010)

## North American Shale Gas

- Shale is distributed in many locations, some traditional producing areas but others are in the heart of market areas.
- Supply potential in BC, in particular, has pushed the idea of LNG exports targeting the Asian market
  - Asia is an oil-indexed 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.
- For those regions not accustomed to seeing robust natural gas development, regulatory conflicts are being realized.





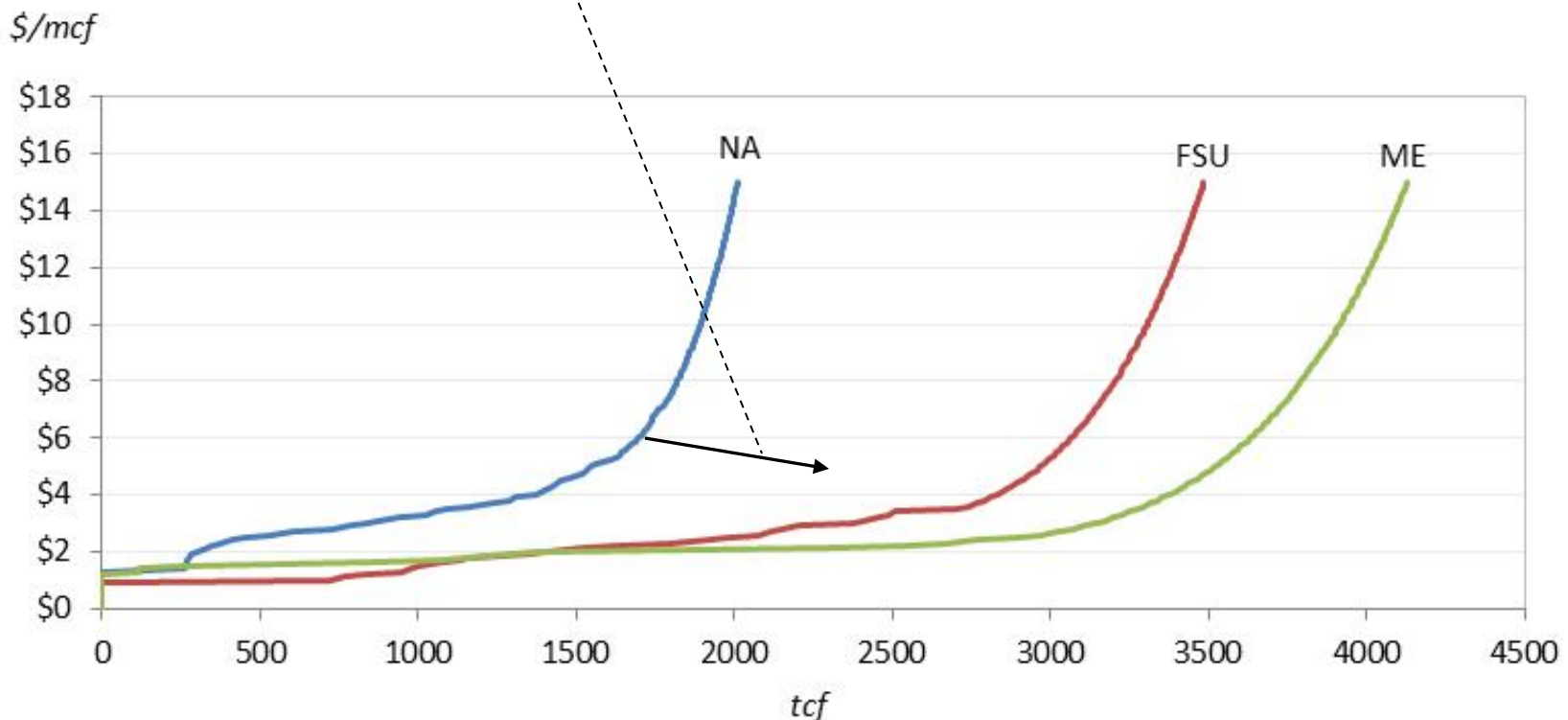
## North American Shale (cont.)

- 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 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 686 tcf.
- Point: We learn more as time passes!

	Mean Technically Recoverable Resource (tcf)	Breakeven Price
Antrim	13.2	\$ 5.50
Devonian/Ohio	170.8	
Utica	5.4	\$ 6.25
Marcellus	135.4	
Marcellus T1	47.4	\$ 4.00
Marcellus T2	43.3	\$ 5.25
Marcellus T3	44.7	\$ 6.50
NW Ohio	2.7	\$ 6.75
Devonian Siltstone and Shale	1.3	\$ 6.75
Catskill Sandstones	11.7	\$ 6.75
Berea Sandstones	6.8	\$ 6.75
Big Sandy (Huron)	6.3	\$ 6.00
Nora/Haysi (Huron)	1.2	\$ 6.25
New Albany	3.8	\$ 7.00
Floyd/Chatanooga	4.3	\$ 6.00
Haynesville	105.0	
Haynesville T1	42.0	\$ 4.00
Haynesville T2	36.8	\$ 5.00
Haynesville T3	26.3	\$ 6.25
Fayetteville	36.0	\$ 4.25
Woodford Arkoma	8.0	\$ 4.50
Woodford Ardmore	4.2	\$ 5.75
Barnett	54.0	
Barnett T1	32.2	\$ 4.25
Barnett T2	21.8	\$ 5.75
Barnett and Woodford	35.4	\$ 6.50
Eagle Ford	35.0	\$ 4.00
Palo Duro	4.7	\$ 6.25
Lewis	10.2	\$ 6.25
Bakken	1.8	\$ 6.50
Niobrara (incl. Wattenburg)	1.3	\$ 6.50
Hilliard/Baxter/Mancos	11.8	\$ 6.50
Lewis	13.5	\$ 6.50
Mowry	8.5	\$ 6.50
Horn River	90.0	
Horn River T1	50.0	\$ 4.50
Horn River T2	40.0	\$ 5.25
Montney	65.0	
Montney T1	25.0	\$ 4.75
Montney T2	40.0	\$ 5.50
Utica	10.0	\$ 6.25
Total US Shale	521.4	
Total Canadian Shale	165.0	
Total North America	686.4	

## North American Resources in a Global Context

- North American resources are large, but must be placed in a global context.
  - FSU and Middle East (pictured for comparison) are larger and generally less costly. However, access and transportation costs make North American resources preferential in the short-to-medium term.
  - Cost reductions and higher recoverable resource estimates benefit the US supply picture.



## Rest of World Shale Gas

- There is tremendous uncertainty about shale resources outside of North America.
- To be certain, the estimates of resource in place are very large, and location is a premium with regard to prevailing market prices and energy security benefit.
- 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.

	Mean Technically Recoverable Resource (tcf)	Breakeven Price
Austria	40.0	\$ 5.75
Germany	30.0	\$ 5.50
Poland	120.0	\$ 5.25
Sweden	30.0	\$ 6.00
China	45.0	\$ 5.00
Australia	50.0	\$ 4.00
Total non-North America	315.0	

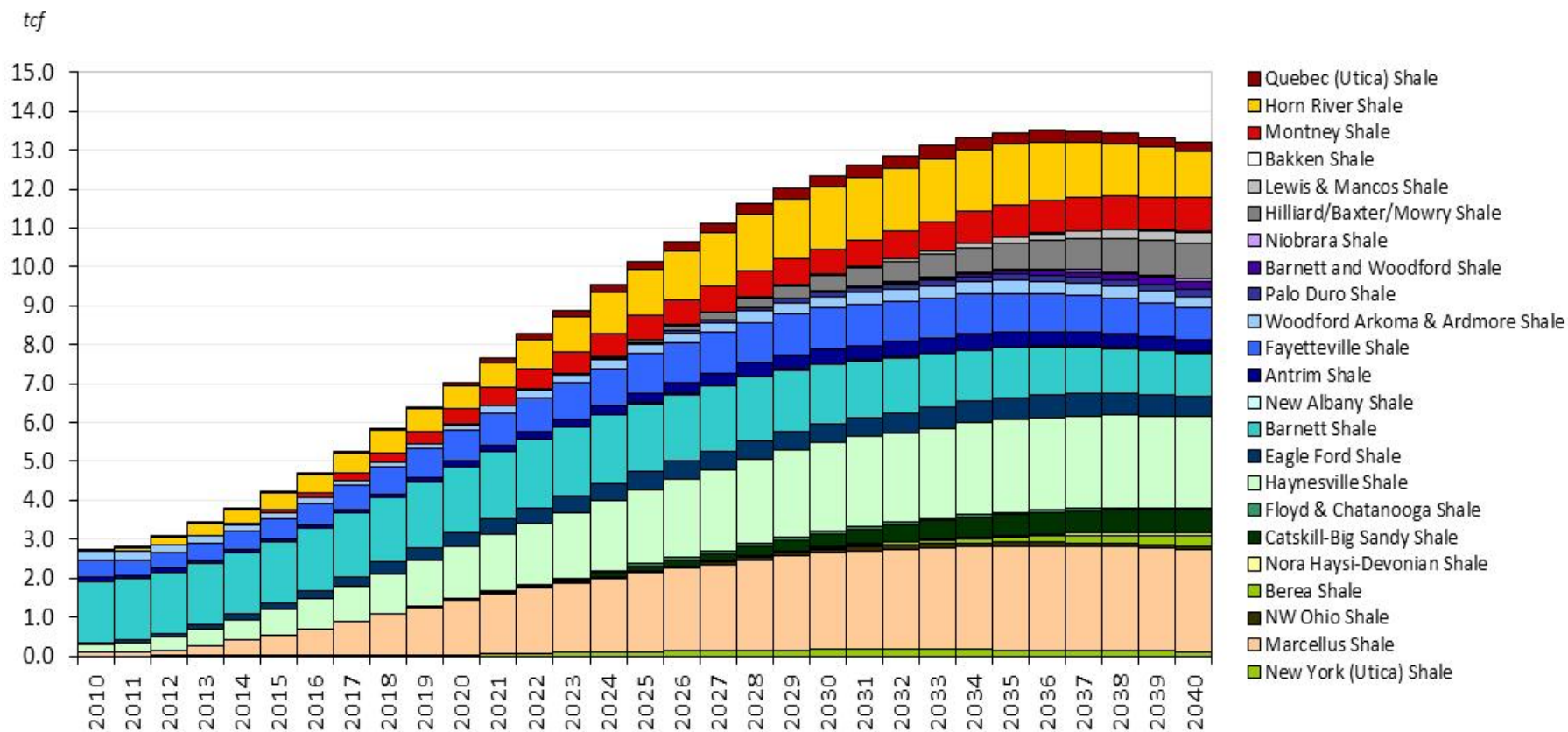
Note, ongoing work will likely add assessments for technically recoverable resource in Croatia, Denmark, France, Hungary, Netherlands, Ukraine, and the United Kingdom. Estimates are currently too preliminary to be presented in this case.

## **Reference Case**

**Allows economics to drive outcomes. No political constraints are modeled, and no bilateral relationships are superimposed.**

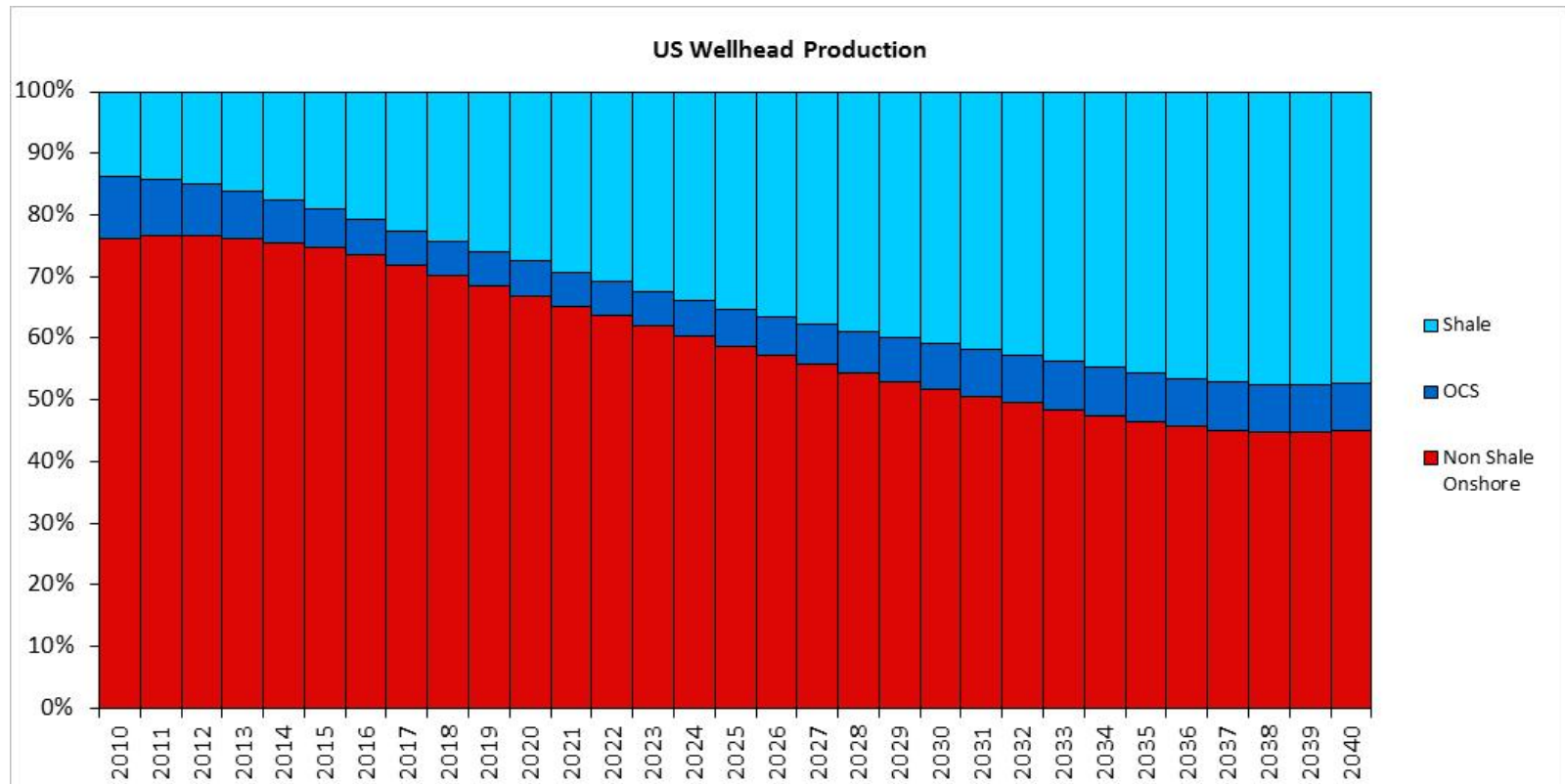
**This is what we will be departing from after today...**

## North American Shale Production



## Composition of U.S. Production

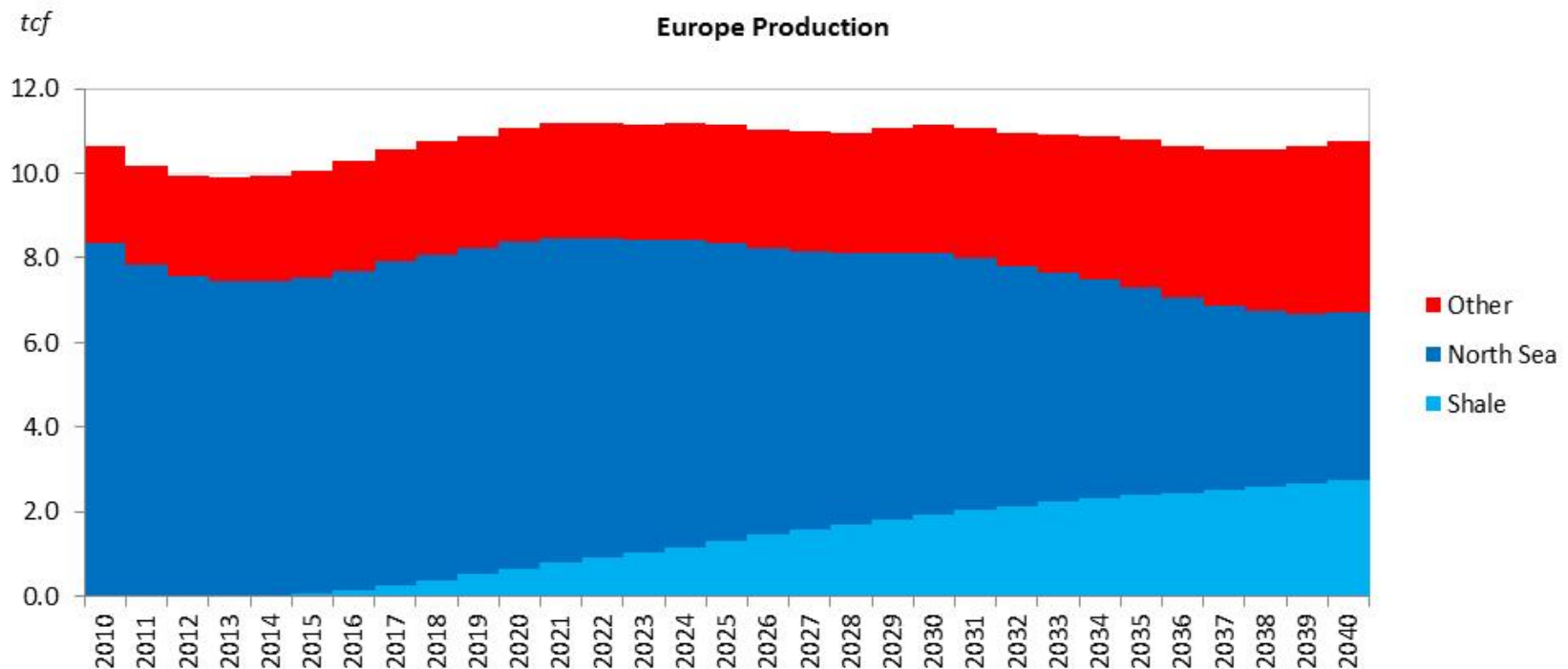
- US shale production grows to about 50% of total production by 2040.
- Canadian shale production grows to about 1/3 of total output by 2040 (not pictured). This offsets declines in other resources as total production remains fairly flat.





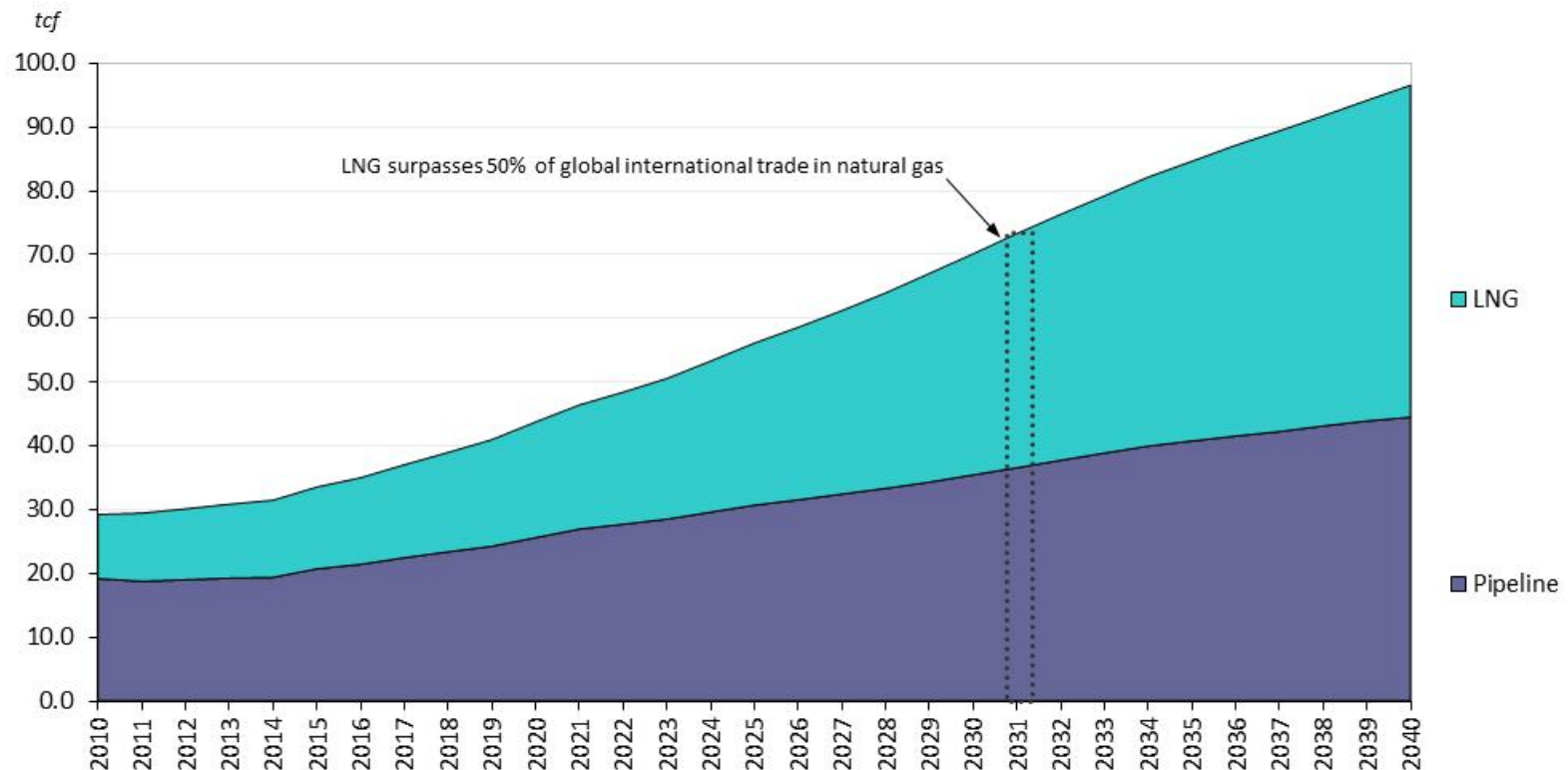
## Impact of Shale Production outside North America

- European shale production grows to about 25% of total production by 2040. China shale production is a smaller portion, accounting for about 8% of total production by 2040 (not pictured). While this is not as strong as North America, it does offset the need for increased imports from Russia, North Africa, and 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.



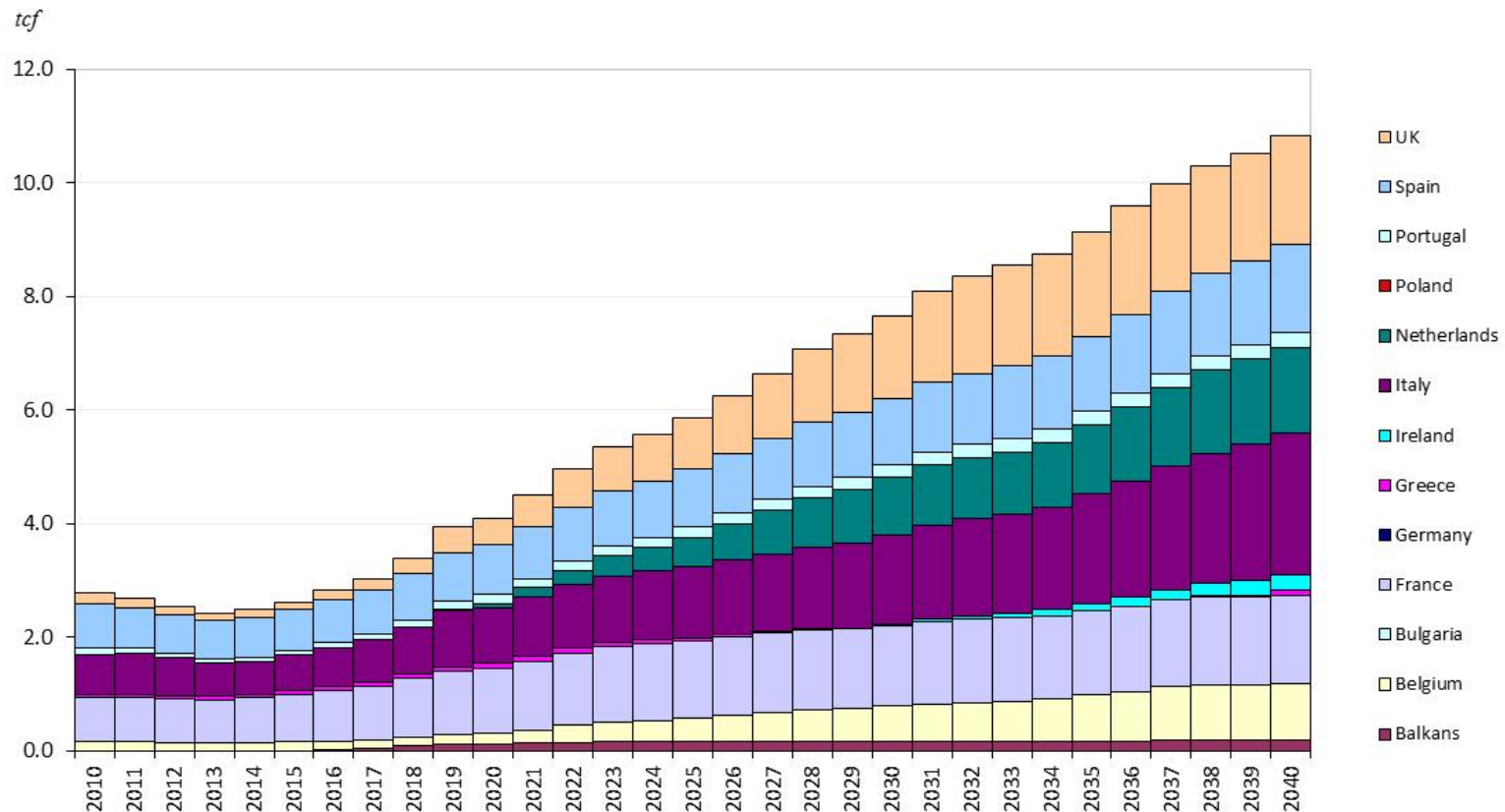
## Global Gas Trade: LNG vs. Pipeline and Market Connectedness

- Globally, LNG growth is strong, reaching about 50% of total international natural gas trade by the early 2030s. This is driven largely by demand in Asia, which makes Asian demand growth a critical feature of this study.
- Previously disconnected regional markets become linked.



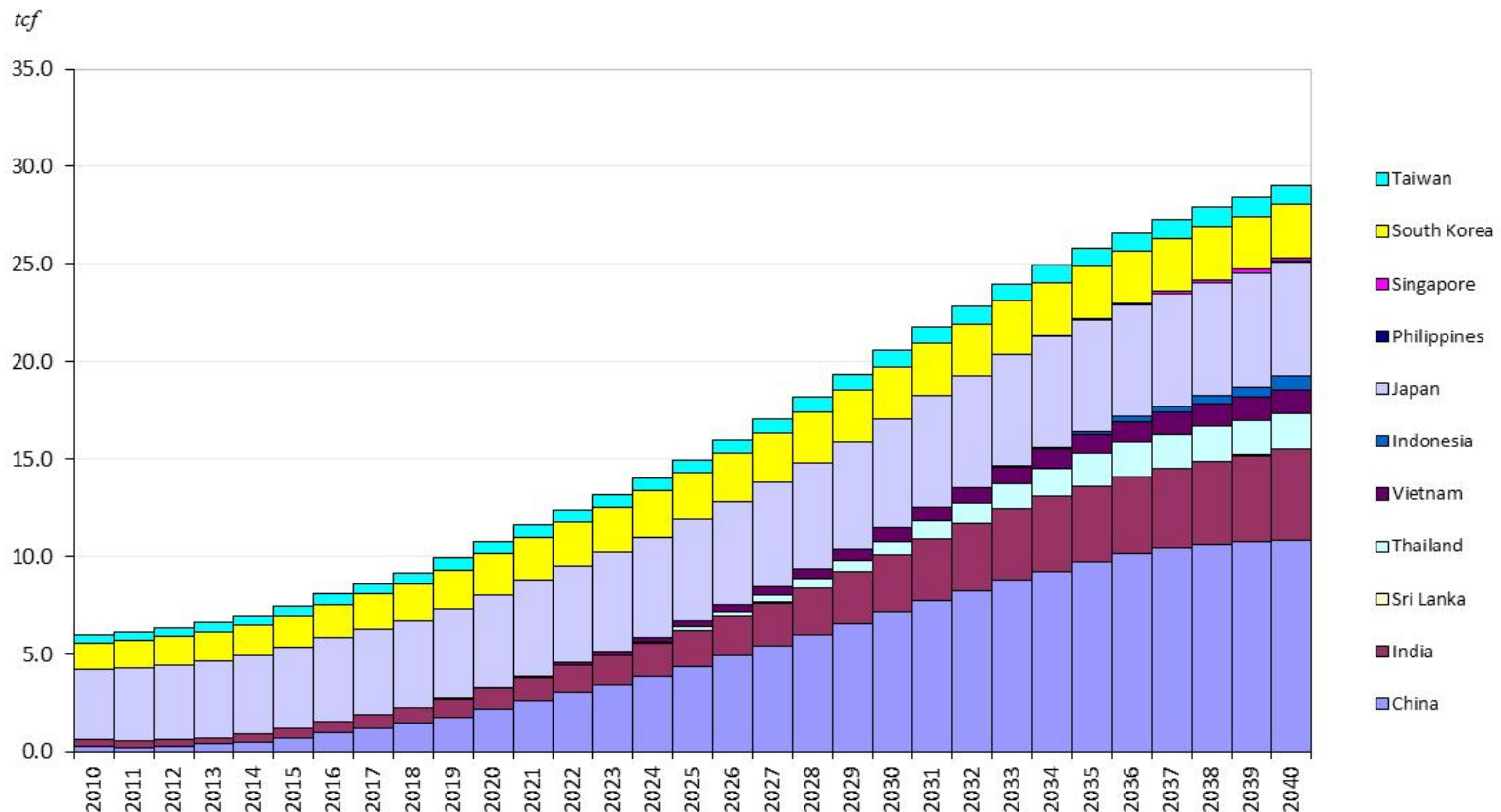
## LNG Imports to Europe

- Growth in LNG is an important source of diversification to Europe. Indigenous shale gas opportunities abate this to some extent. However, shale production does not grow as strongly as in North America, so LNG imports in Europe rise.



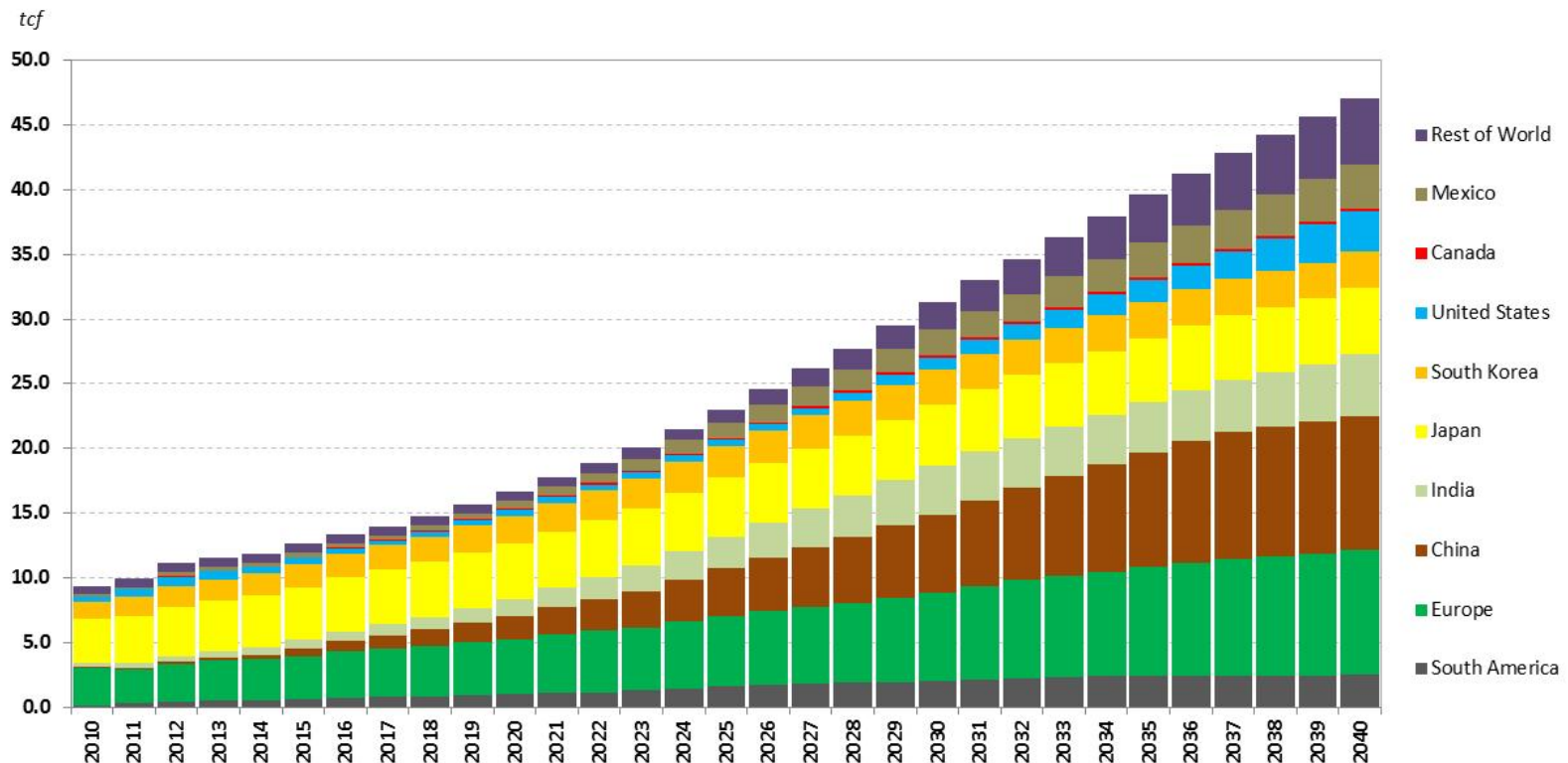
## LNG Imports to Asia

- 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.

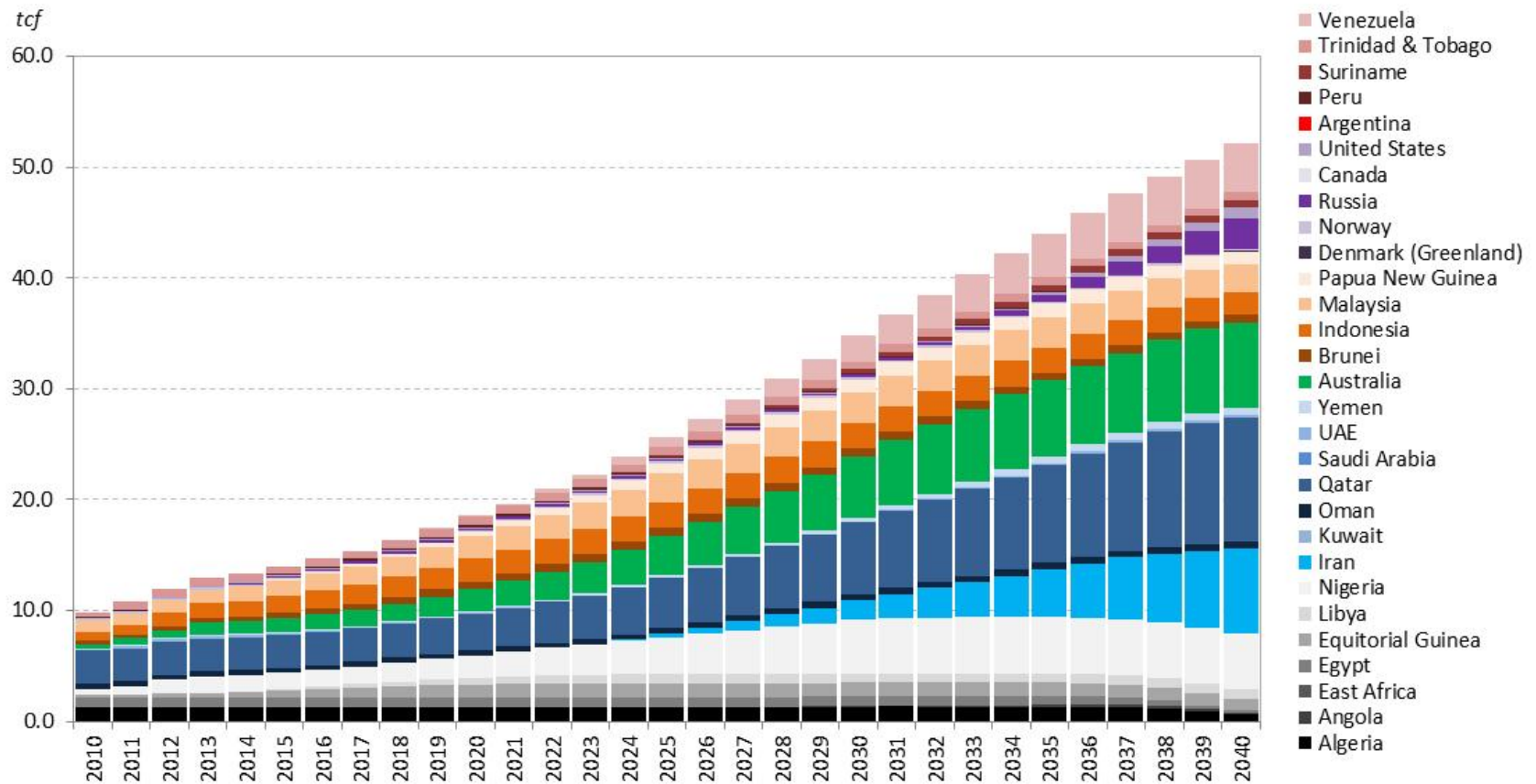
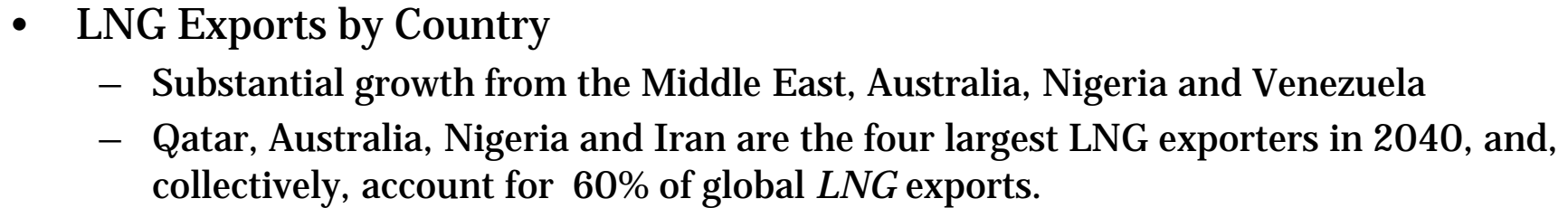


## LNG Imports by Region

- LNG Imports by Region – putting the US in a global context
  - Most LNG import growth is in Asia, particularly in China and India.
  - There are strong increases in Mexico, Europe and South America as well.
  - The United States and Canada remain very minor LNG importers, with US LNG imports growing to the size of South Korea's by the late 2030s.



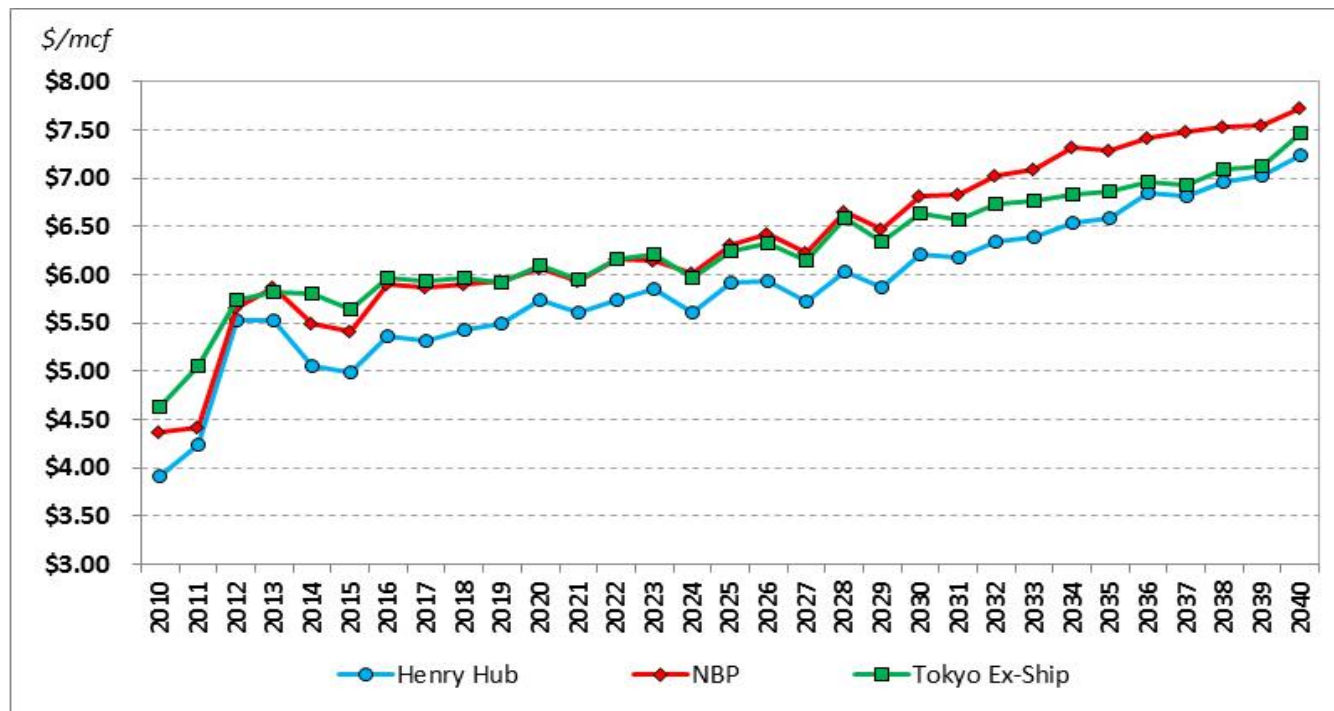
# LNG Exports by Country





## Select Regional Prices

- Prices tend to rise over time as lower cost supplies are depleted.
- Prices tend to move together as LNG growth increasingly connects markets, meaning gas markets are increasingly connected. Note this occurs despite lack of LNG trade into the US because arbitrage *opportunity* forces equilibrium.
- Europe emerges as the highest priced market, averaging about \$0.50 over Henry Hub through the 2030s.



## **Comments on Gas Market Globalization**



## Globalization

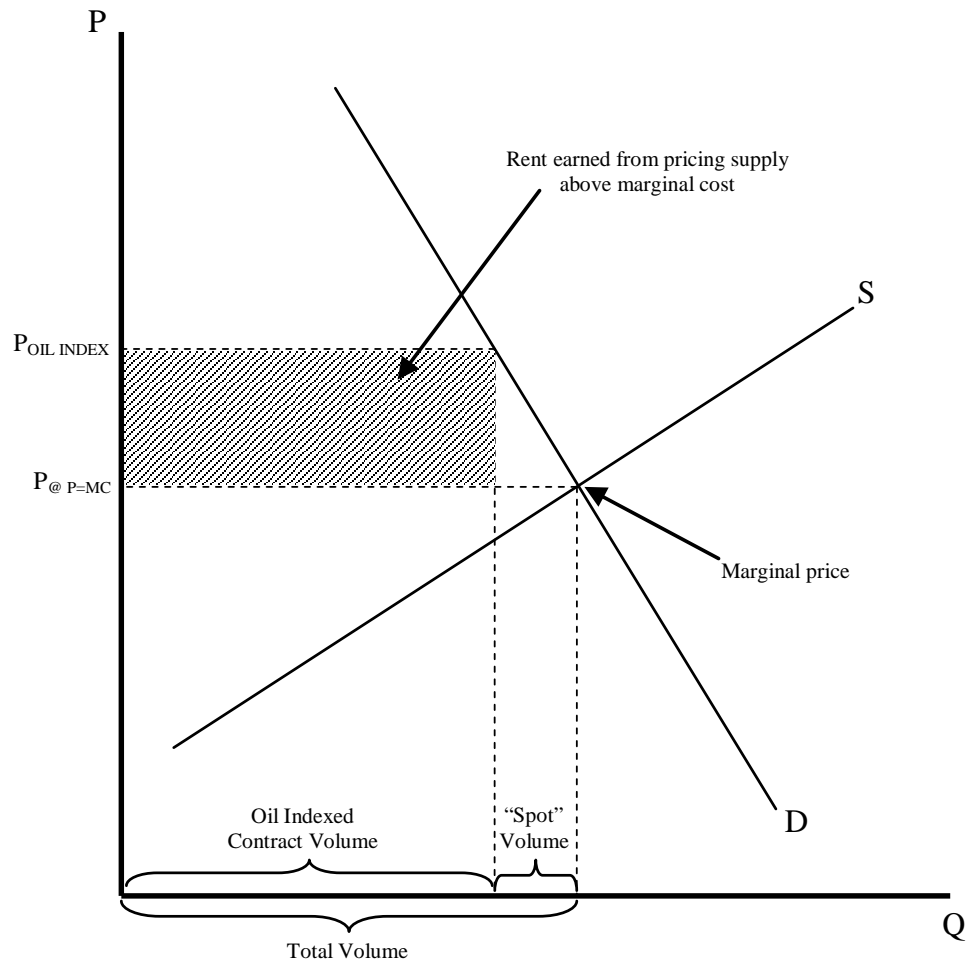
- Hartley and Medlock (2006) demonstrate that *local* shocks will be transmitted across previously disconnected *regional* markets more easily as LNG trade expands.
- This begs the question, “Will increased LNG trade leave the US increasingly exposed to international market fluctuations?”
  - If so, we can also ask, “Is globalization welfare improving?”
- Hartley and Medlock (2006, 2008, 2009) demonstrates that growth in LNG trade implies growth in *physical liquidity*, i.e. - supply options are expanded. This provides a means of dealing with unexpected shocks.
  - Example 1: Europe dealing with a Russian cut-off of supplies
  - Example 2: Market flexibility in the event of a US hurricane disruption

## Globalization (cont.)

- Brito and Hartley (2007) also show that growth in physical liquidity also limits the ability of a single supplier to price above marginal cost.
- Of course, other important questions are motivated in the context of globalization of gas markets, such as
  - What is the likelihood of a cartel emerging?
  - What is the effect of environmental policy aimed at reducing CO<sub>2</sub> emissions?
    - or even New Source Performance Standards in the US?
  - What is the effect of policy that limits access to resources?
  - What is the effect of the expansion of shale gas production?

## The Role of Oil Indexation

- Absent storage and physical liquidity, oil indexation provides an element of price certainty.
- Oil indexation is a form of price discrimination
  - (1) Firm must be able to distinguish consumers and prevent resale.
  - (2) Different consumers have different elasticity of demand.
  - Both conditions are met in Europe and Asia, but not in North America.
    - Lack of transport differentials in Europe is evidence of discrimination.
- Increased ability to trade between suppliers and consumers (physical liquidity) violates condition (1).
  - This will happen in a liberalized market or as LNG trade grows.
- Evidence of a weaker ability to price discriminate is emerging in Europe.
  - Recent changes in contractual terms



## The Role of Shale Gas

- Expansion of production from shale plays has rendered the utilization of LNG import capacity in the US very low.
- Moreover, Hartley and Medlock (2010) indicate that, in the aggregate, average annual capacity utilization of US LNG regasification terminals may not exceed 20% until the 2030s.
- 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 is more of a manufacturing process than production from other natural gas plays, the idea of “just-in-time” production could also simulate the traditional role of storage. Thus, shale gas production may also limit seasonal volatility to some extent.