The Rice World Gas Trade Model: Reference Case

prepared by:

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The Rice World Gas Trade Model (RWGTM):
A forecasting tool for policy analysis

The RWGTM

- 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.

The RWGTM: US Demand

- Over 290 regions.
  - Regional detail is dependent on data availability and existing 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

$$\ln q_{com,i,t} = \alpha_i - 0.122 \ln p_{ng,i,t} + 0.027 \ln p_{ho,i,t} + 0.122 \ln y_t + 0.000095 hdd_{i,t} + 0.111 \ln pop_{i,t} + 0.772 \ln q_{com,i,t-1}$$

Residential

$$\ln q_{res,i,t} = \alpha_i - 0.148 \ln p_{ng,i,t} + 0.028 \ln p_{ho,i,t} + 0.053 \ln y_t + 0.000116 hdd_{i,t} + 0.322 \ln pop_{i,t} + 0.722 \ln q_{res,i,t-1}$$

Industrial

$$\ln q_{ind,i,t} = \alpha_i - 0.220 \ln p_{ng,i,t} + 0.105 \ln p_{coal,i,t} + 0.082 \ln ip_{i,t} + 0.000013 hdd_{i,t} + 0.822 \ln q_{ind,i,t-1}$$

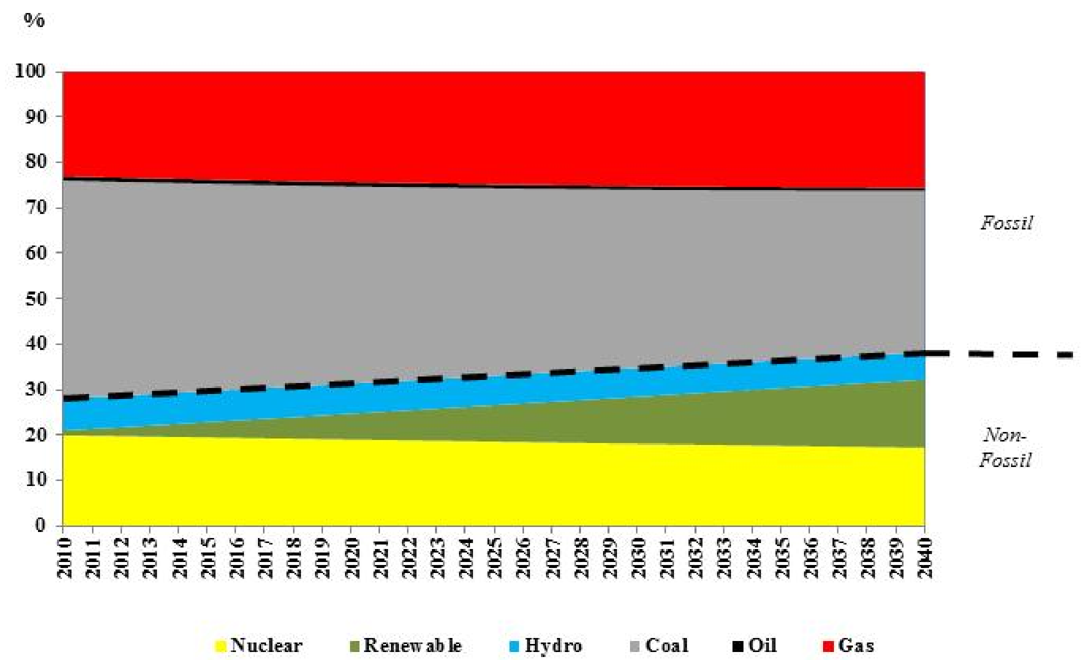
Power Generation

$$\ln \frac{q_{pwr,i,t}}{foss_{pwr,i,t}} = \alpha_i - 0.119 \ln c_{ng,i,t} + 0.105 \ln c_{fo,i,t} + 0.130 \ln c_{coal,i,t} + 0.00055 cdd_{i,t} + 0.851 \ln \frac{q_{pwr,i,t-1}}{foss_{pwr,i,t-1}}$$

The RWGTM: US Demand (cont.)

- A focus on the Power Generation Sector.
  - Gas is modeled as competing against other fossil fuels for market share once nuclear, hydro and other renewables have been modeled.
  - Hydro in every state is assumed to behave according to an assumed "normal" in future years, after accounting for known changes in capacity.
  - Nuclear assumptions are based on a flat to declining outlook for nuclear power generation . New construction is not included in the reference case.
  - Renewables are assumed to grow according to state-specified RPS targets. In every state except CA, the target is met with a 5 year delay. In CA, the target is met as specified.

An example for illustration



The RWGTM: RoW Demand

- 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

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

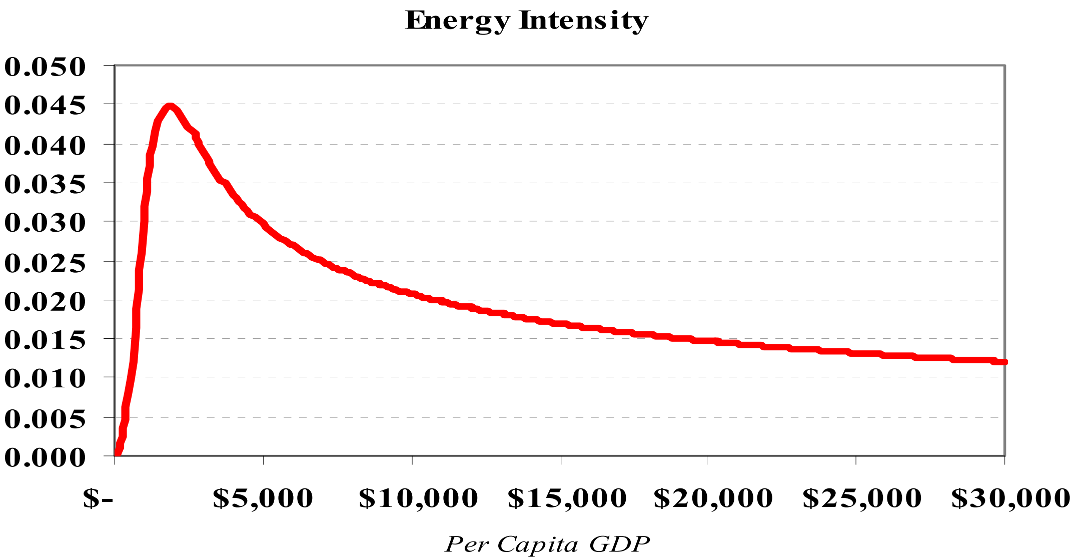
- Natural gas share is estimated as a function of GDP per capita, own price, oil price, installed thermal capacity, and the extent to which the country imports energy

Natural Gas Share

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

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.

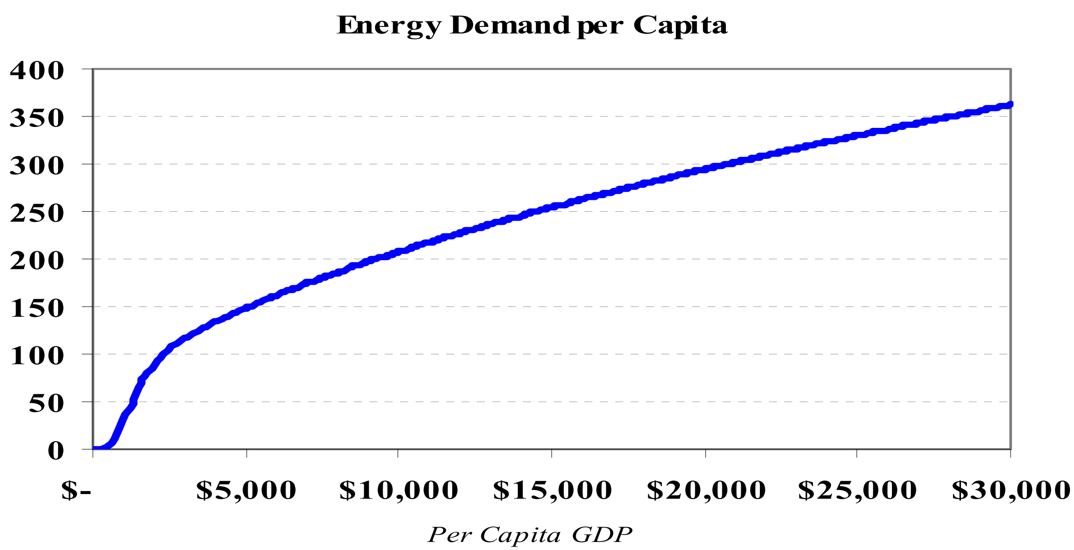
The RWGTM: RoW Demand (cont.)



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)

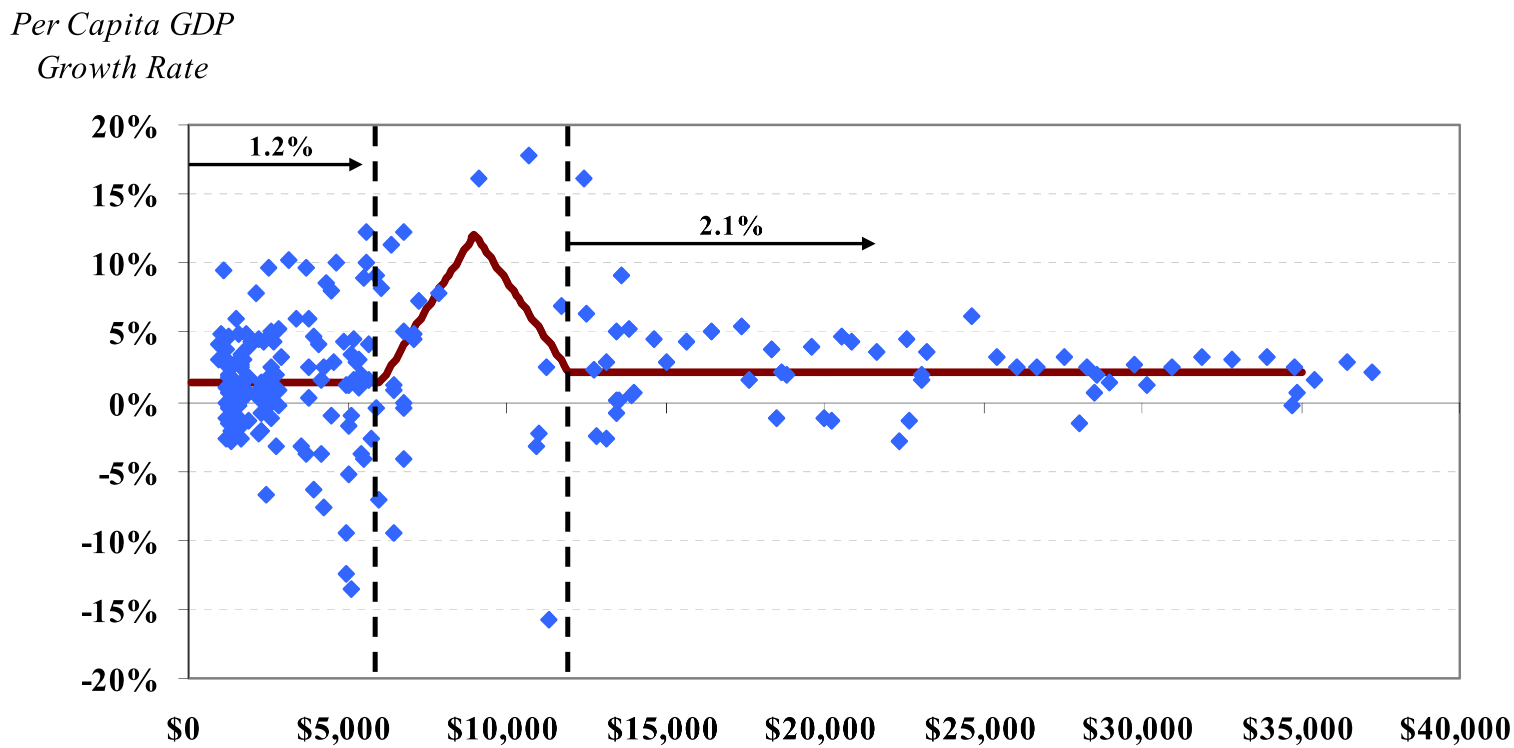
The graphic indicates a path for a generic country. The level of energy intensity for individual countries will vary depending on a number of factors, but each will exhibit a similar pattern.

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.



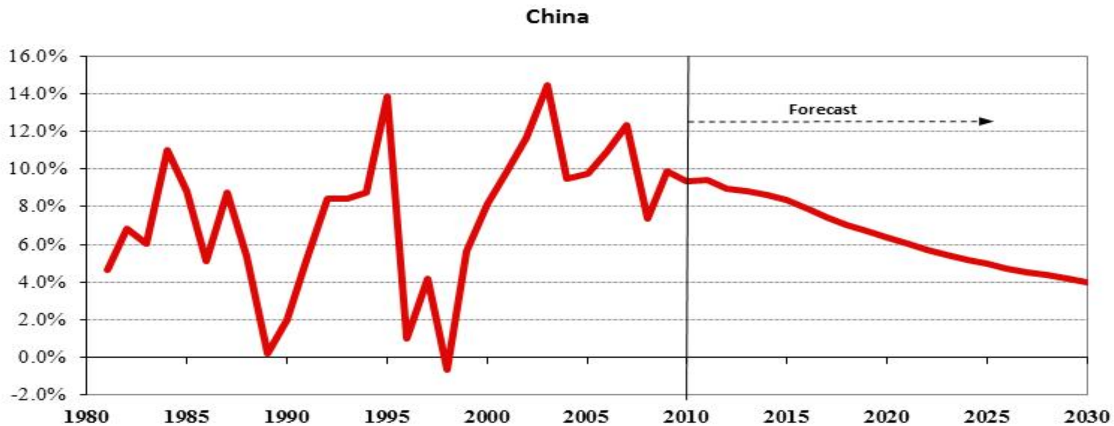
The RWGTM: RoW Demand (cont.)

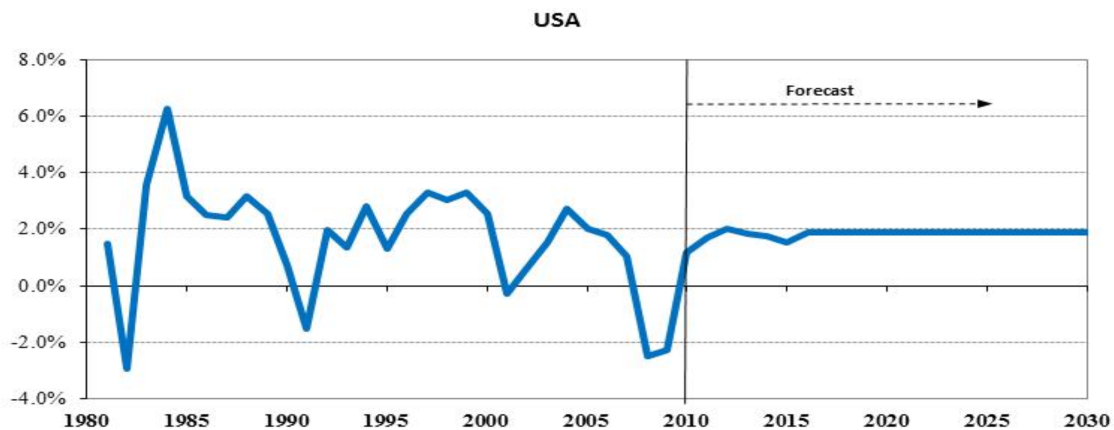
- Economic growth is based on conditional convergence a long run growth path that is based on historical US and UK growth rates (dating back into the 1800s) at various levels of per capita income. The long run growth path is estimated using a piecewise linear spline knot regression.
- Countries converge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



The RWGTM: RoW 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.





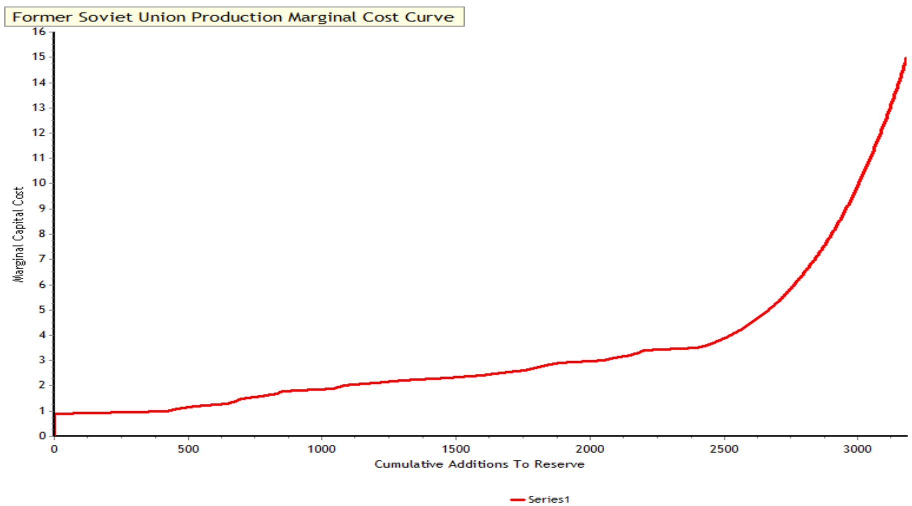
Note, the graphics depict real growth of per capita GDP in PPP terms. These growth estimates will differ from growth estimates of GDP per capita converted using nominal exchange rates to the extent the PPP exchange rate changes. Accordingly, in PPP terms, Chinese per capita income in roughly 60% of US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

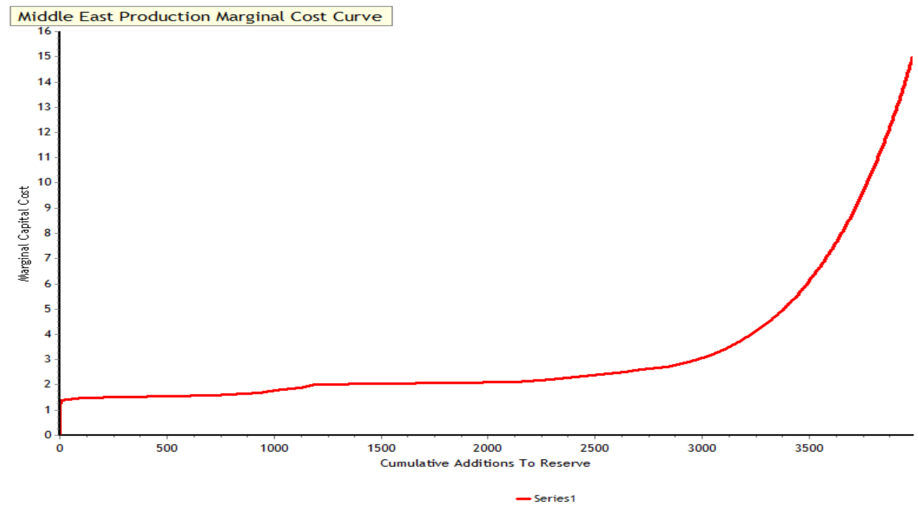
The RWGTM: Supply

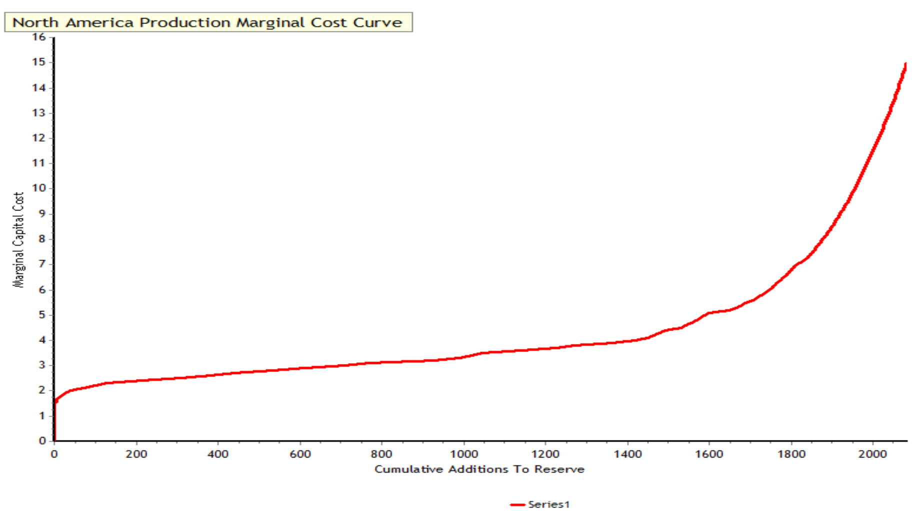
- Over 135 regions
- Natural gas resources are represented as…
  - Conventional, CBM and Shale in North America, China, Europe and Australia, and conventional gas deposits in the rest of the world. Recent ARI assessment of shale around the world is being studied for incorporation.
- … in three categories
  - 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

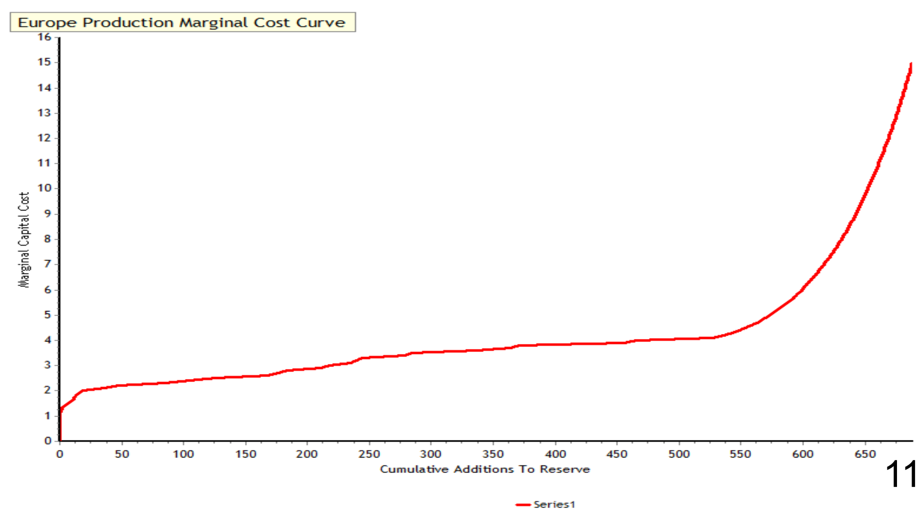
The RWGTM: Supply (cont.)

- Selected examples: Regional marginal cost of supply curves…









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.

More on Shale Resources in the RWGTM

Defining the Resource

- It is an incorrect representation to simply characterize recent estimates of shale gas in North America as "reserves". It is important to understand what these assessments are actually estimating.
- Shale gas GIP numbers are large. *Cost* and *technology* define accessibility.
- **We use estimates of technically recoverable resource and define development cost curves for each assessment.**

Resource in Place

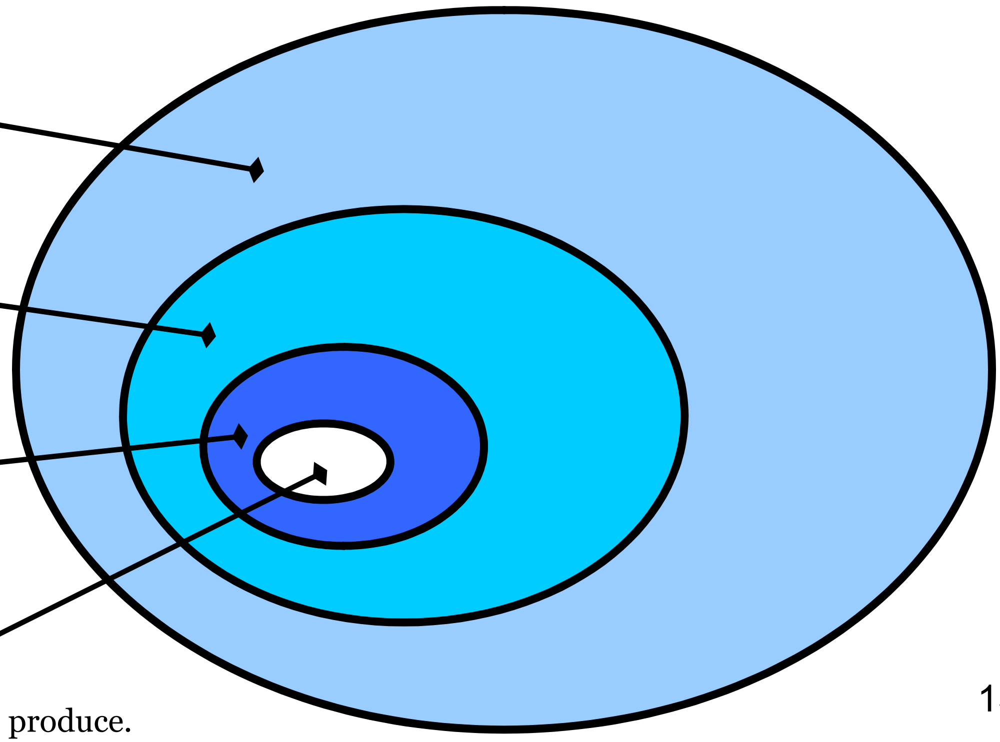
Resource endowment. Lots of uncertainty, but we can never get beyond this ultimate number.

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.

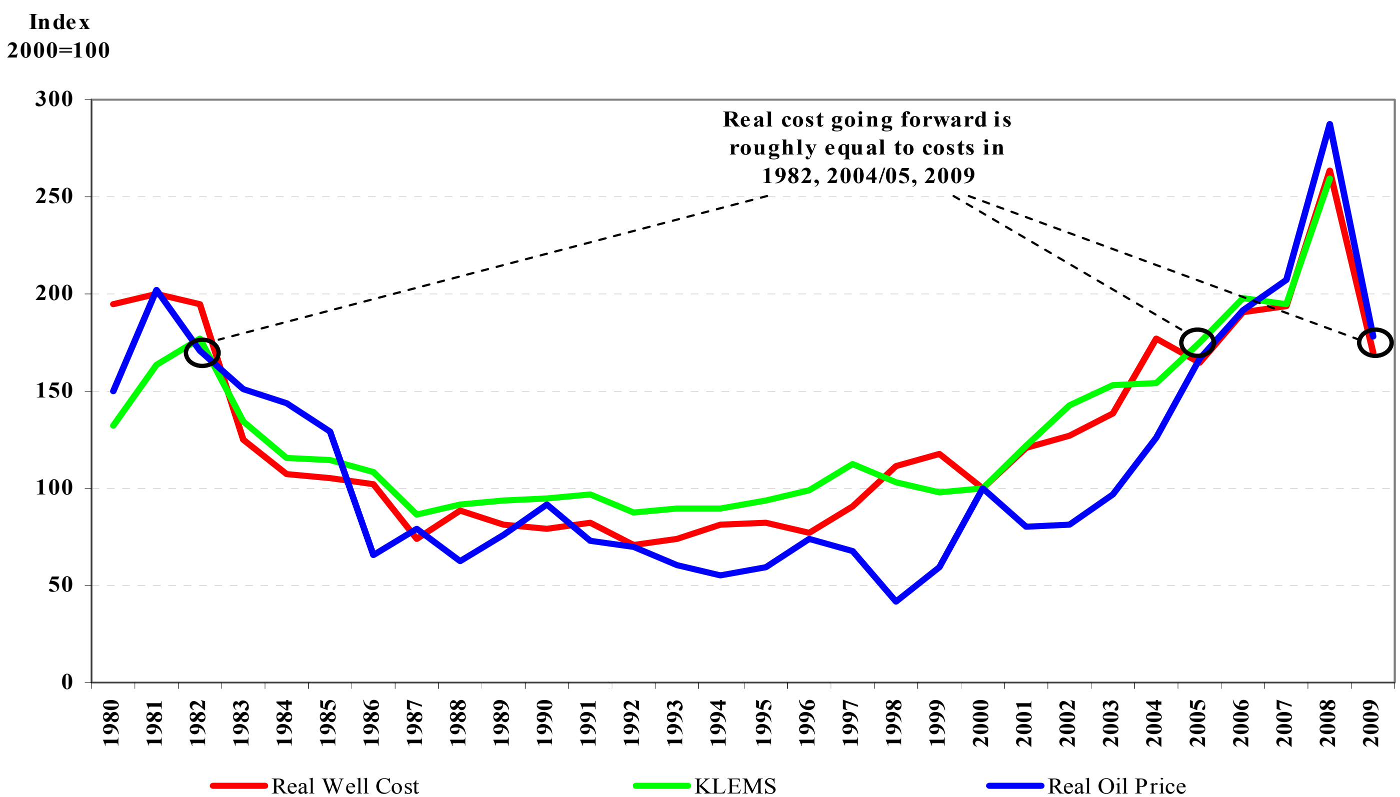


Proved Reserves

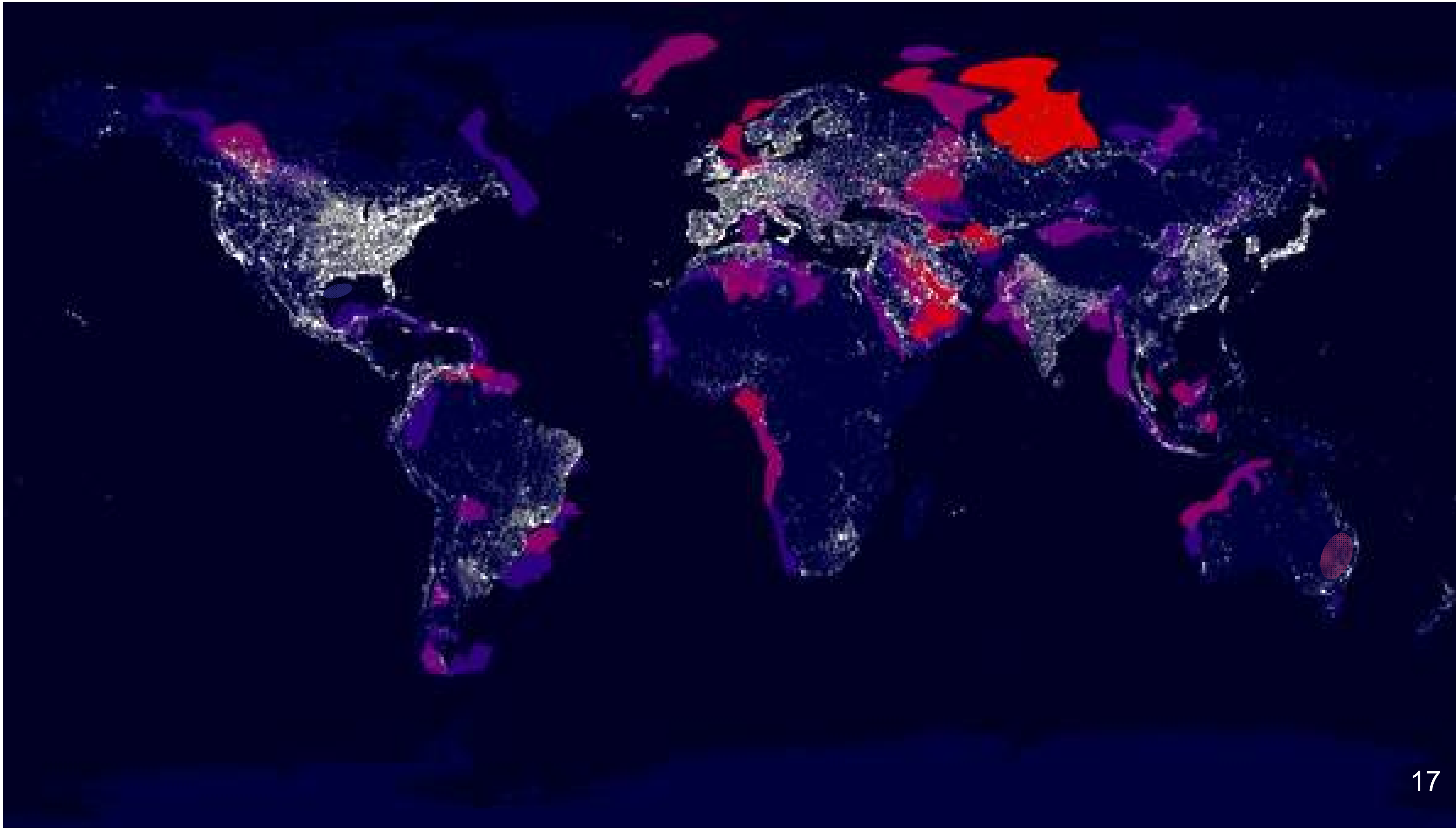
Connected and ready to produce.

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.

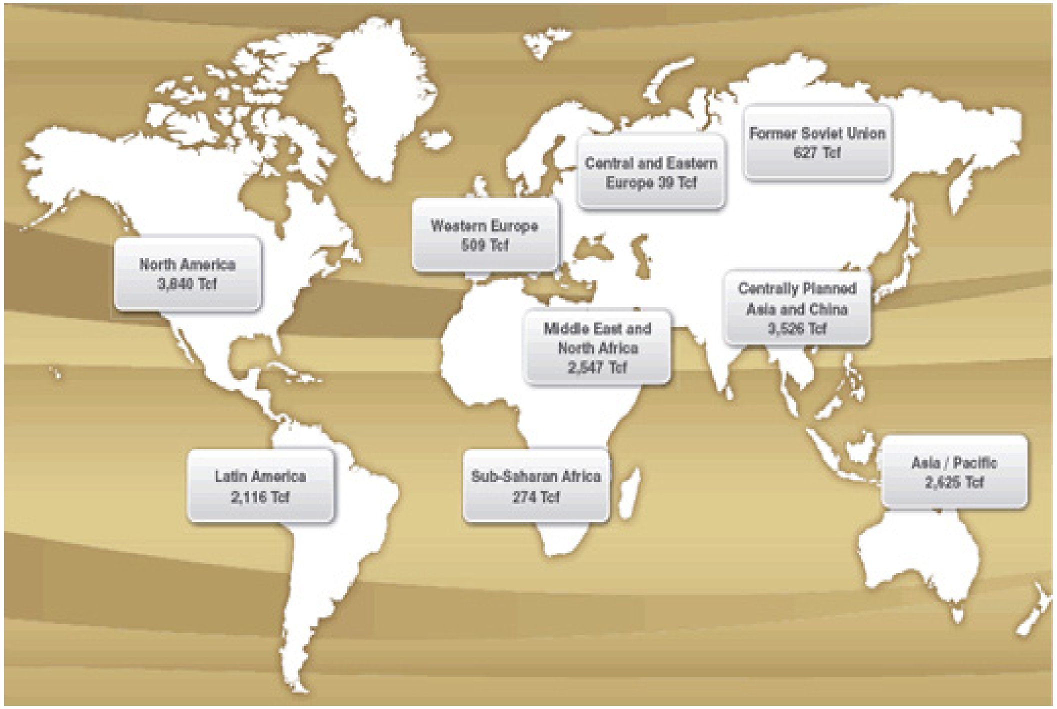


The "50,000 Foot" Natural Gas View in 2000: LNG is coming to North America



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**

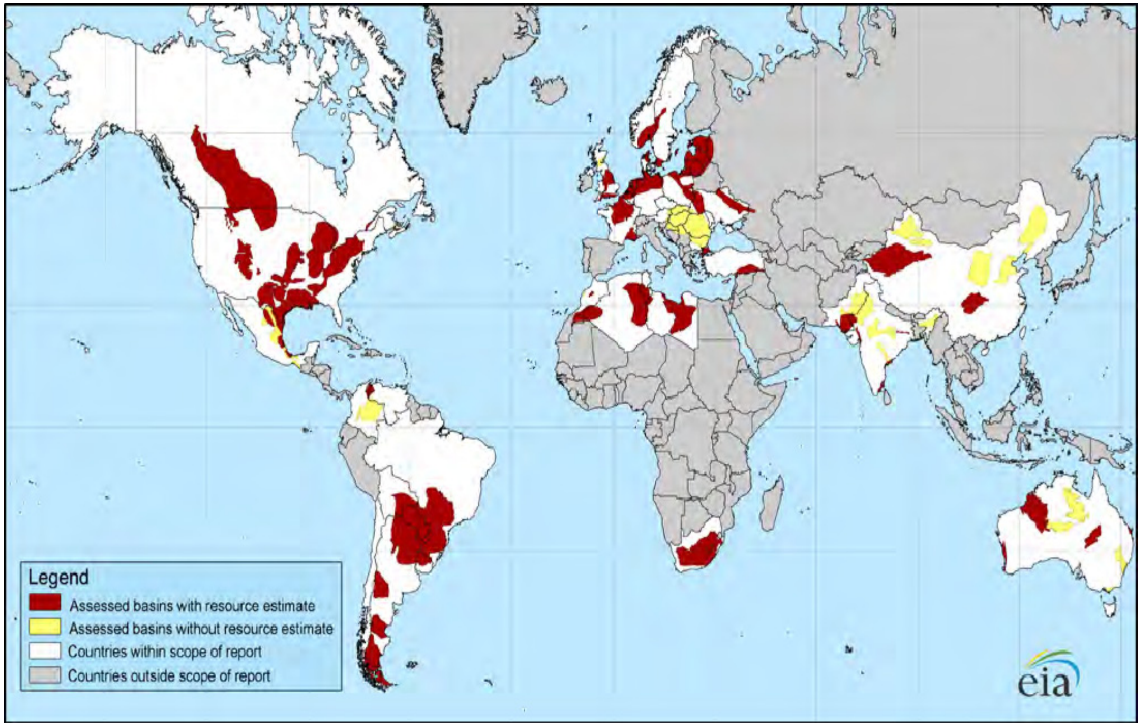
Source: Rogner (1997)

The Global Shale Gas Resource (cont.)

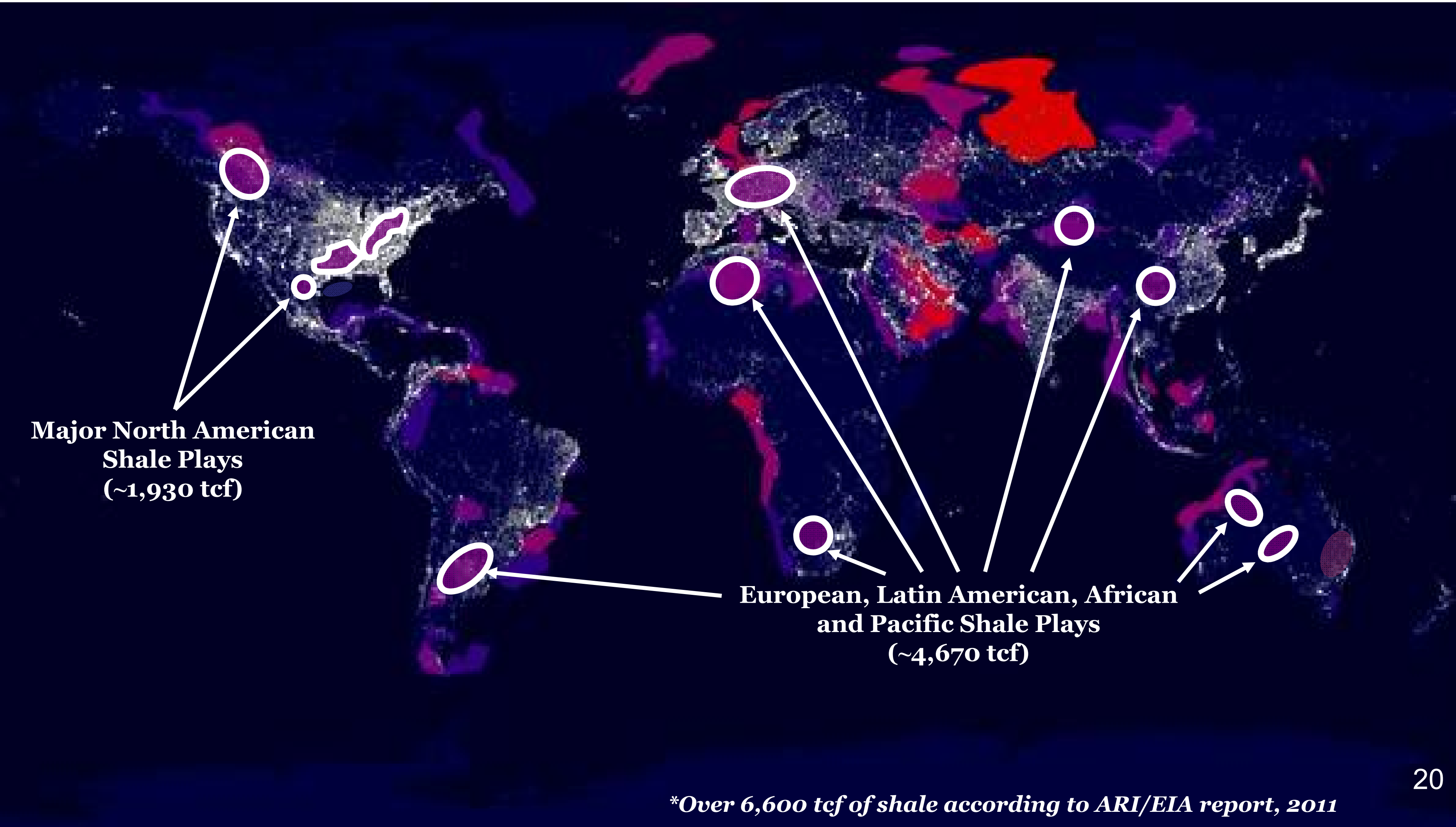
- Recently, however, innovations made the shale resource accessible
  - Shale developments have been focused largely in North America where high prices have encouraged cost-reducing innovations.
  - IEA recently estimated about 40% of the estimates resource in-place by Rogner (1997) will ultimately be technically recoverable.
  - A very recent assessment by Advanced Resources International (2011) assesses a larger resource in-place, and estimates a total technically recoverable resource of 6,600 tcf.

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)



The "50,000 Foot" Natural Gas View in 2011: Over 6,600 tcf of technically recoverable shale*



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

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

US Shale in the RWGTM

- As knowledge continues to advance, more shale plays may become commercial targets and greater proportions of shale resources may become technically feasible.
- Developers also become better at identifying optimal drill sites… Barnett is a good case in point.

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

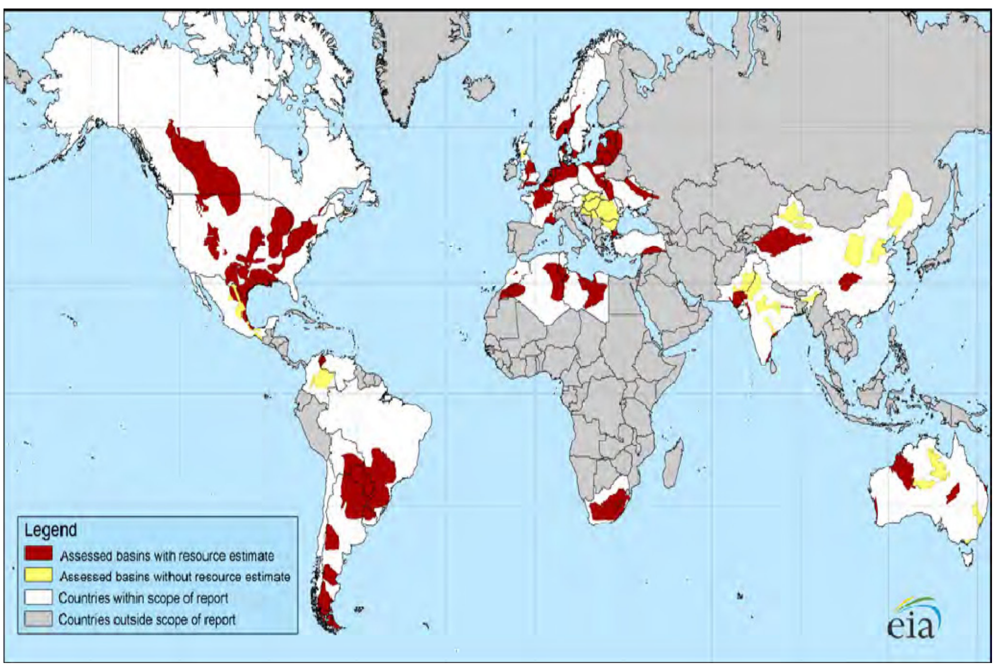
	Mean Technically Recoverable Resource (tcf)	Breakeven Price
Antrim	13.2	$ 5.50
Devonian/Ohio	220.4	
Utica	5.4	$ 6.25
Marcellus	185.0	
Marcellus Tier 1	46.3	$ 4.00
Marcellus Tier 2	64.8	$ 5.25
Marcellus Tier 3	74.0	$ 6.50
NW Ohio	2.7	$ 6.75
Devonian Siltstone and Shale	1.3	$ 6.75
Catskill Sandstones	11.7	$ 6.75
Berea Sandstones	6.8	$ 6.75
Big Sandy	6.3	$ 6.00
Nora/Haysi	1.2	$ 6.25
New Albany	3.8	$ 7.00
Floyd/Chatanooga	4.3	$ 6.00
Haynesville	160.0	
Haynesville Tier 1	32.0	$ 4.00
Haynesville Tier 2	56.0	$ 5.00
Haynesville Tier 3	72.0	$ 6.25
Fayetteville	36.0	$ 4.25
Woodford Arkoma	8.0	$ 4.50
Woodford Ardmore	4.2	$ 5.75
Barnett	58.0	
Barnett Tier 1	30.0	$ 4.00
Barnett Tier 2	28.0	$ 5.50
Barnett and Woodford	35.4	$ 6.50
Eagle Ford	42.0	$ -
Eagle Ford Tier 1	22.0	$ 3.75
Eagle Ford Tier 2	20.0	$ 5.25
Palo Duro	4.7	$ 6.25
Lewis	10.2	$ 6.25
Bakken	1.8	$ 4.50
Niobrara	1.3	$ 6.50
Hilliard/Baxter/Mancos	11.8	$ 6.50
Paradox/Uinta	13.5	$ 6.50
Mowry	8.5	$ 6.50
Total US Shale	637.0	

Rest of World (RoW) 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.

RoW Shale in the RWGTM

- As knowledge continues to advance, more shale plays may become commercial targets.
- The RWGTM *currently* allows 800 tcf of recoverable resource outside the U.S., meaning we allow only a fraction of the recent ARI technical assessment to be commercial.



		Mean Technically Recoverable Resource (tcf)	Breakeven Price
CANADA	Horn River	90.0	
	Horn River Tier 1	50.0	$ 4.50
	Horn River Tier 2	40.0	$ 5.25
	Montney	65.0	
	Montney Tier 1	25.0	$ 4.75
	Montney Tier 2	40.0	$ 5.50
	Utica	10.0	$ 6.50
MEXICO	Burgos Basin	90.0	
	Burgos Tier 1	20.0	$ 5.75
	Burgos Tier 2	30.0	$ 6.75
	Burgos Tier 3	40.0	$ 8.00
	Sabinas Basin	20.0	$ 7.25
	Tampico Basin	25.0	$ 7.00
EUROPE	Austria	40.0	$ 6.25
	Germany	30.0	$ 6.25
	Poland	120.0	
	Silurian Tier 1	45.0	$ 6.00
	Silurian Tier 2	75.0	$ 7.25
	Sweden	30.0	$ 6.50
PACIFIC	China	230.0	
	Sichuan/Jianghan	45.0	$ 6.50
	Ordos	35.0	$ 5.75
	Tarim/Junggar/Tuja	120.0	$ 7.25
	Songliao	30.0	$ 6.00
	Australia	50.0	$ 4.50
	Total non-U.S.	800.0	

Of course, there is uncertainty…

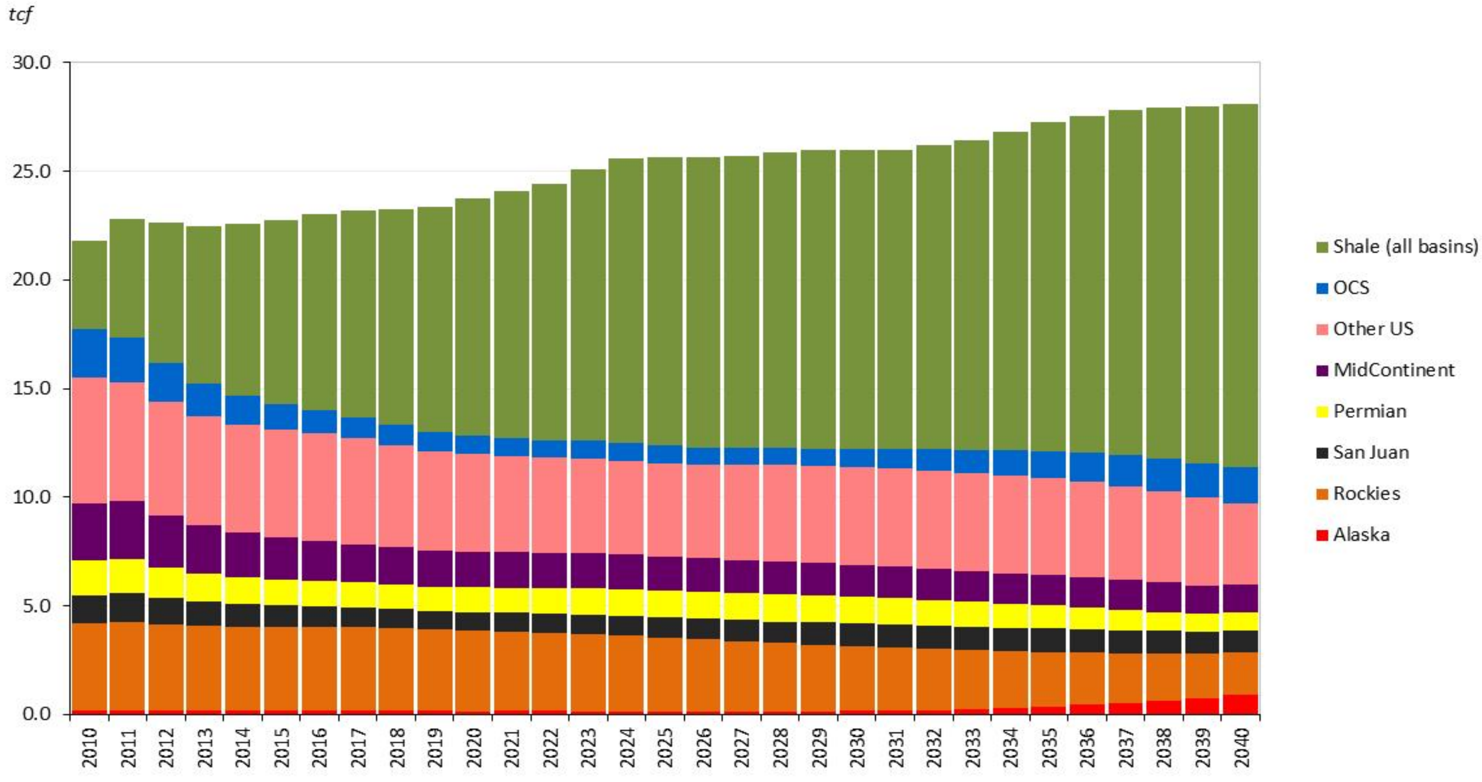
- In general, multiple issues face shale development: some are global, some are not.
  - **Market Structure** – transportation regulatory structure (unbundled access vs. incumbent monopolies); bilateral take-or-pay obligations or marketable rights; existence of gathering and takeaway capacity and hurdles 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.
  - **Resource Access** – mineral rights ownership; acreage acquisition; resource assessments; environmental opposition; etc.
  - **Other issues** – earthquakes related to disposal injection of produced 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.

- A stable regulatory environment that fosters responsible development of domestic resources is critical to achieving the potential benefits presented by shale.

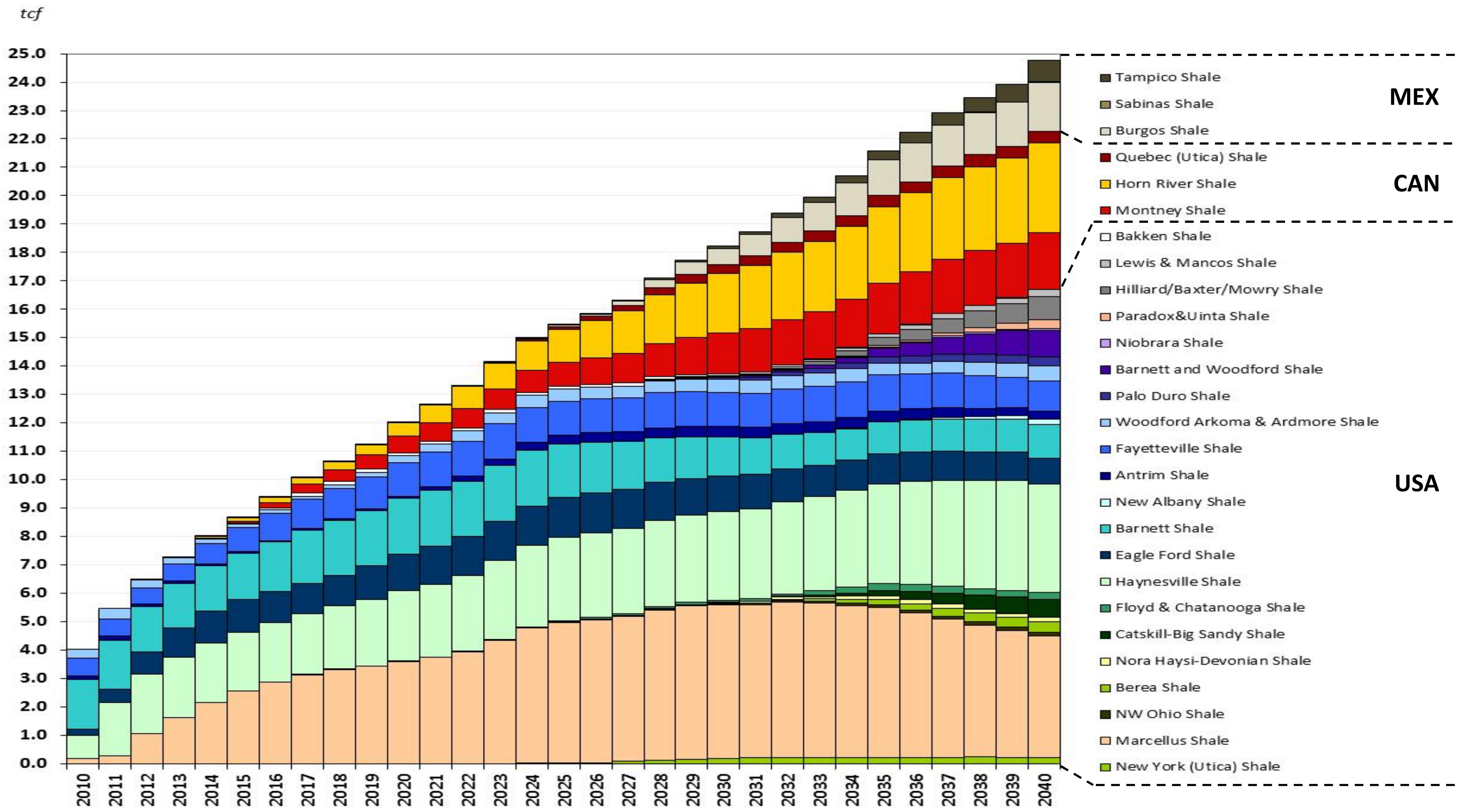
Reference Case Results

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).

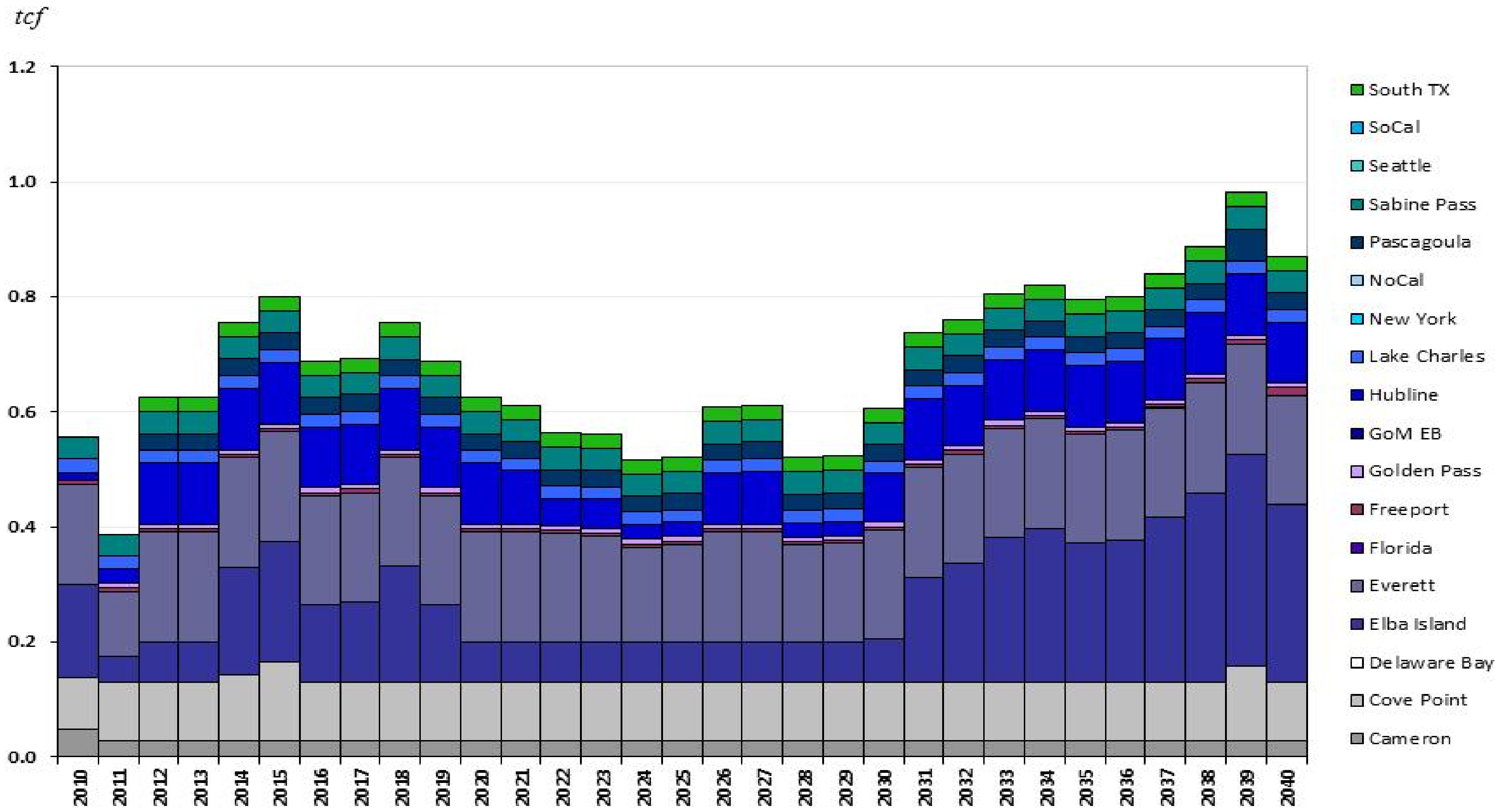


Reference Case:
North American Shale Production, 2010-2040



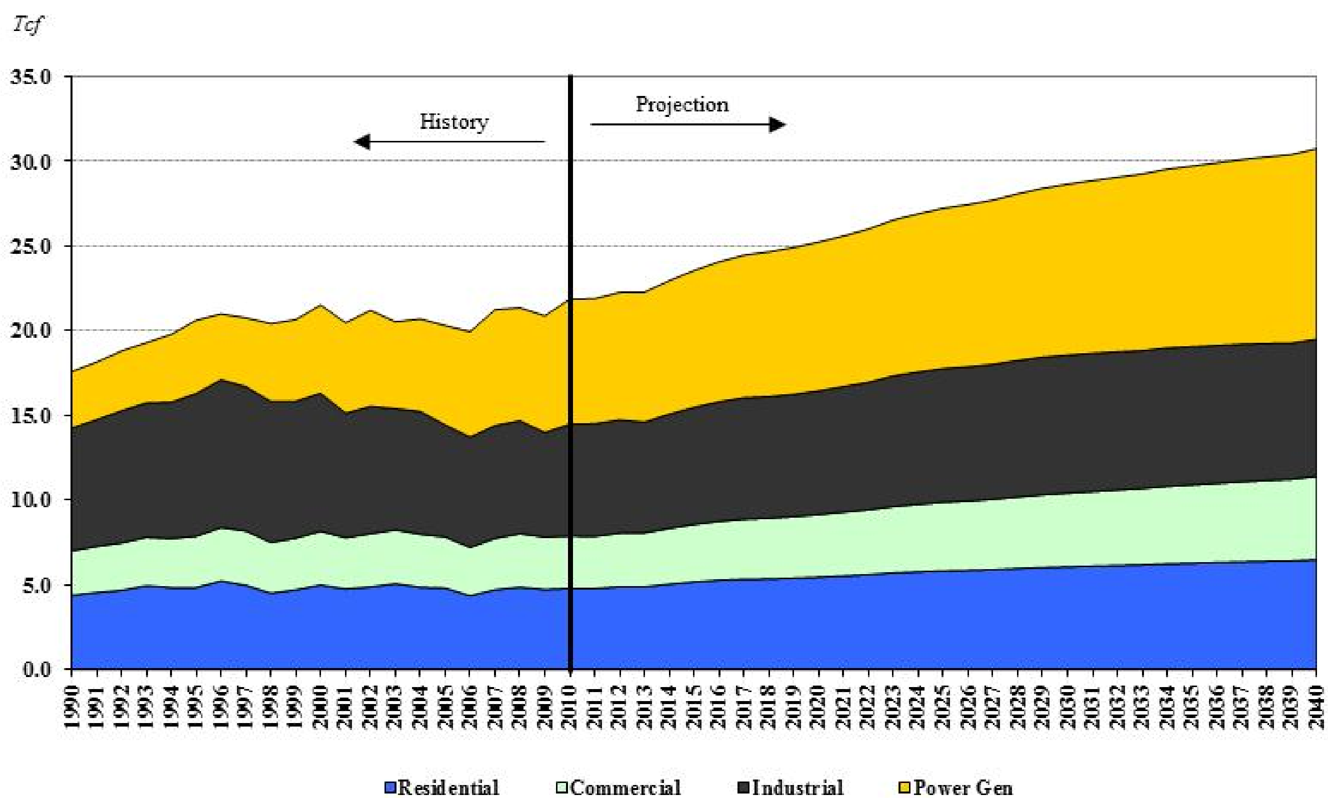
Reference Case:
U.S. LNG Imports, 2010-2040

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



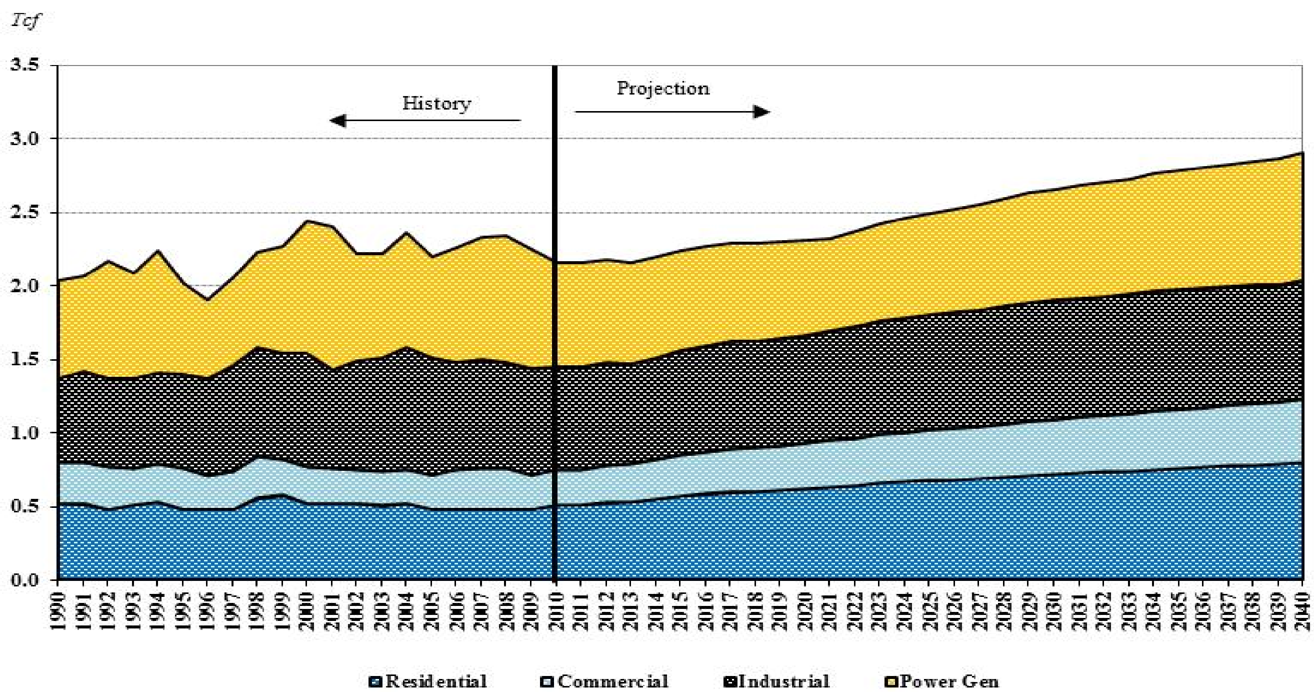
Reference Case:
U.S. Demand, 1990-2040

- Demand is primarily driven by the power generation sector (growth at 1.42% pa).
- Favorable prices also help spur a modest recovery in the industrial sector (growth at 0.68% pa), although it does not reach the magnitude seen in the mid-1990s.



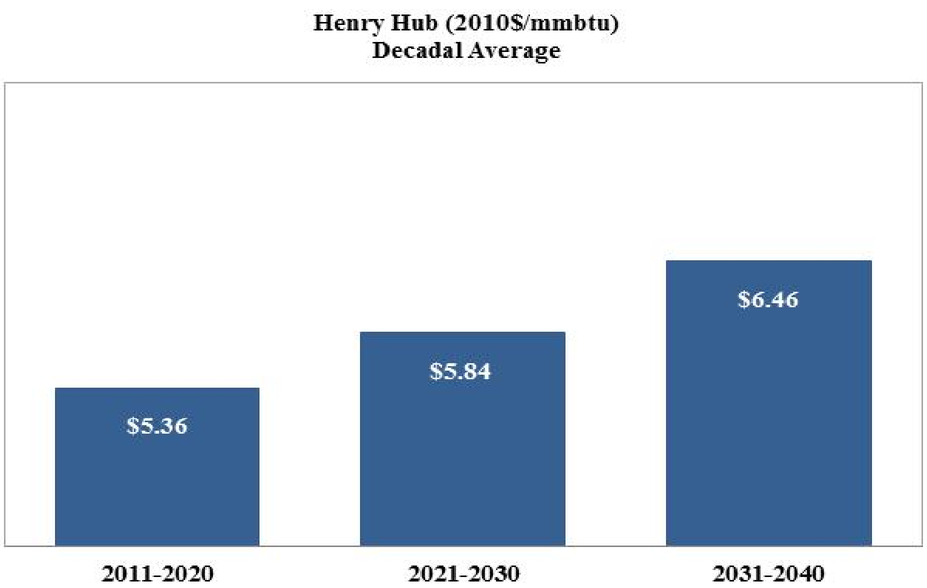
Reference Case:
California Demand, 1990-2040

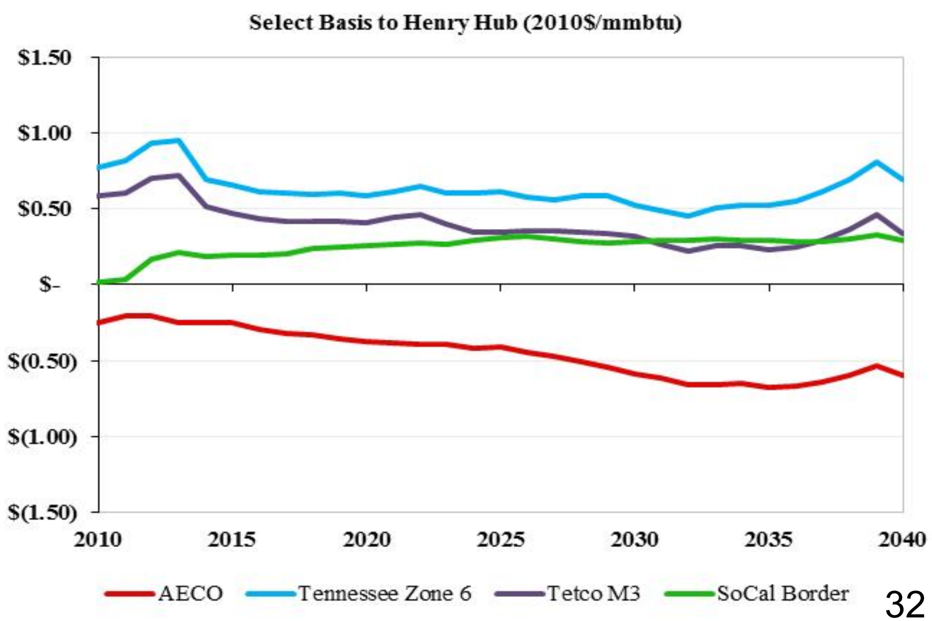
- Strong Renewable Portfolio Standards keep California gas demand from increasing in the same manner as seen in aggregate in the U.S.
  - Power generation demand increases at a more modest 0.69% pa from 2010-40.
  - Industrial demand growth is also lower, increasing at only 0.47% pa.
  - Strong population growth influences growth in the commercial and residential sectors



Reference Case:
Price and Basis in Select Locations, 2010-2040

- The average annual price at Henry Hub tends to rise over time, reflecting both long run growth in demand and a move into higher marginal cost sources of supply.
- Basis in location in the Mid-Atlantic, Northeast, and Canada tends to weaken, reflecting strong supply growth (primarily due to shale gas) in those regions. Basis in Western states tends to strengthen, reflecting a shifting supply-demand balance relative to the Gulf Coast.

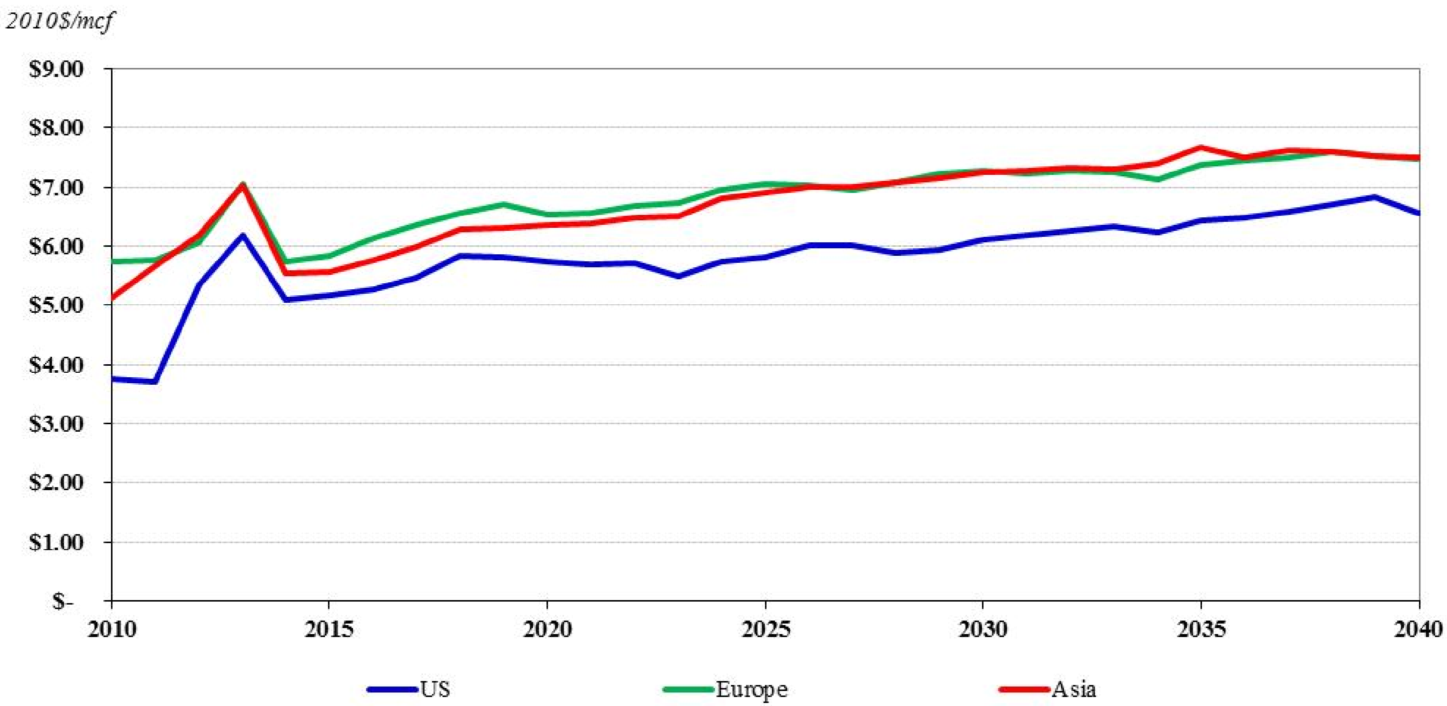




Selected Results outside of North America

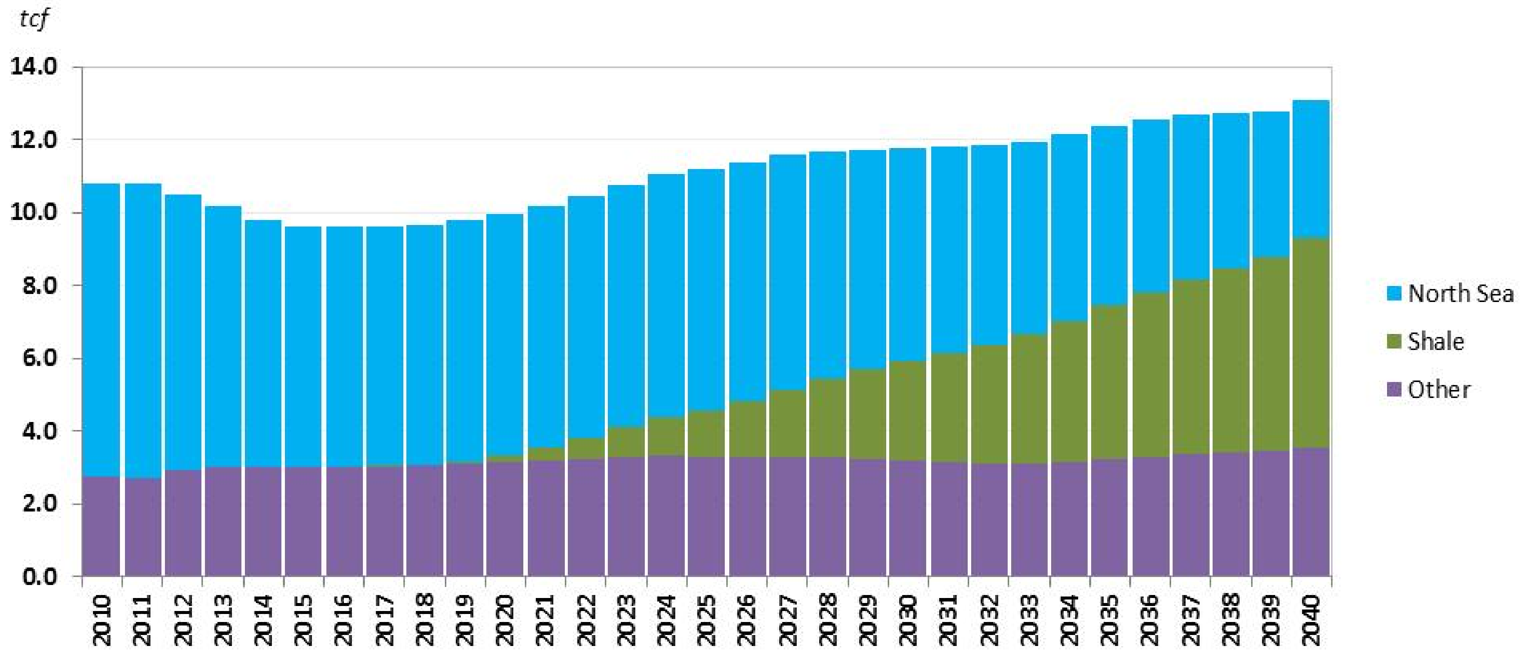
Reference Case: Global Marker Prices, 2010-2040

- Note, the US price is Henry Hub, the European price is NBP, and the Asian price is the Japanese price paid for LNG. Global prices remain above the US price.
- Price pressures abroad do get reflected back to the US, however, as witnessed in the stronger demand pull from 2012-2014 due to global economic recovery, stronger Japanese demand due to the Fukushima disaster, and strong demand growth in China. New supplies from Australia beginning in 2014 and 2015 soften this impact.



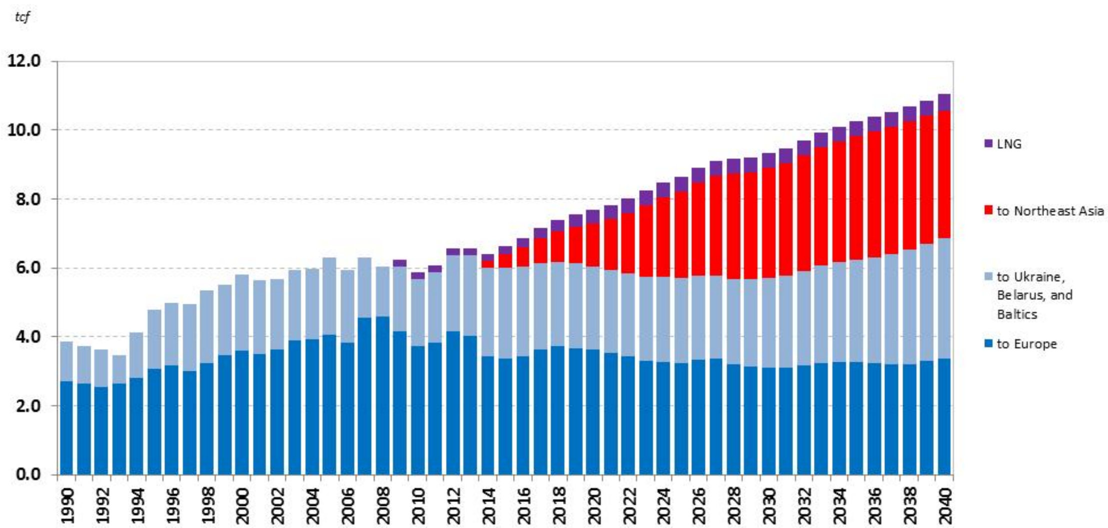
Reference Case: Composition of Production in Europe, 2010-2040

- European shale production grows to about 35% of total production by 2040. While this is not as strong as North America, it does offset the need for increased imports from Russia, North Africa, and as 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.

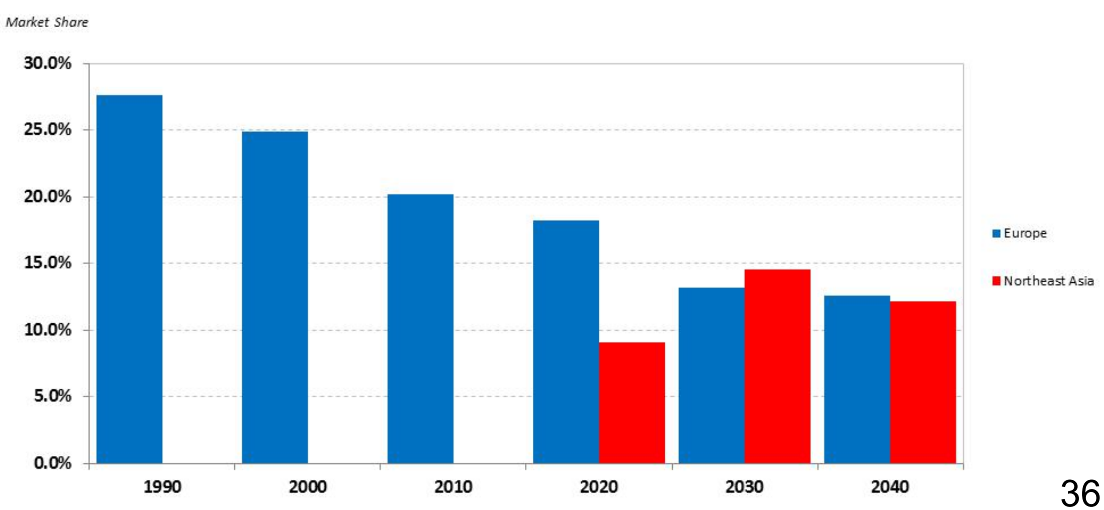


Reference Case:
Russian Exports, 1990-2040

- Russian opportunities to Europe are diminishing as a result of shale production growth and Europe's increased pull on LNG.

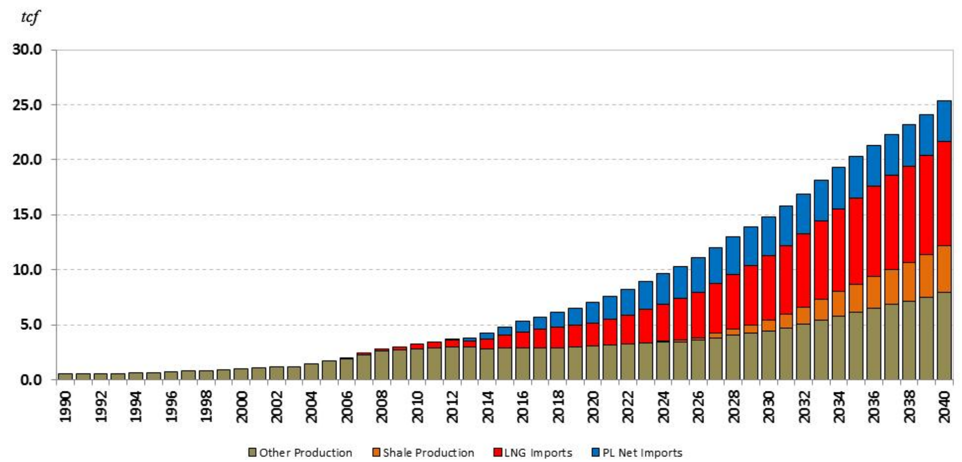


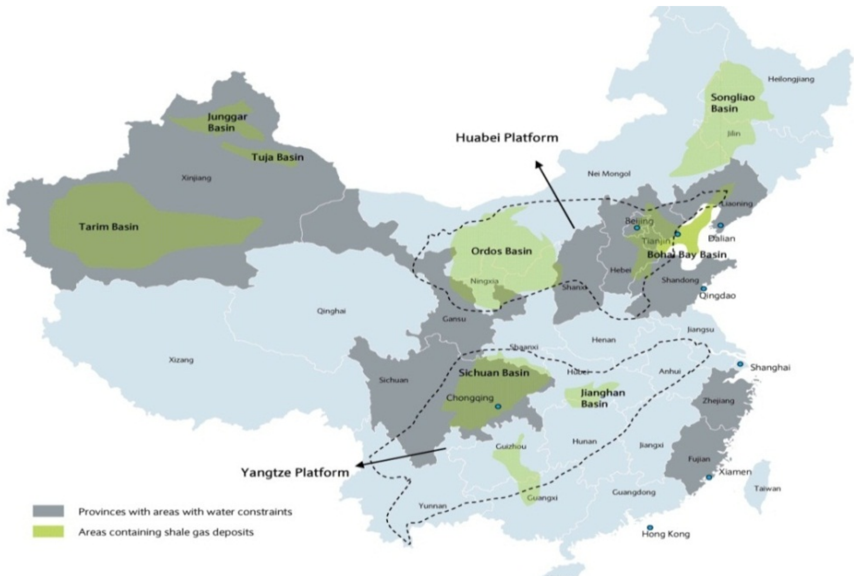
- The market share of Russia in non-FSU Europe falls to just over 13% by 2040, while it rises then stabilizes at just over 12% in Northeast Asia.



Reference Case:
Disposition of Supply in China, 1990-2040

- Shale gas production in China grows to about 15% of the domestic market, but LNG is by far the largest single source of natural gas supply to China out to 2040.



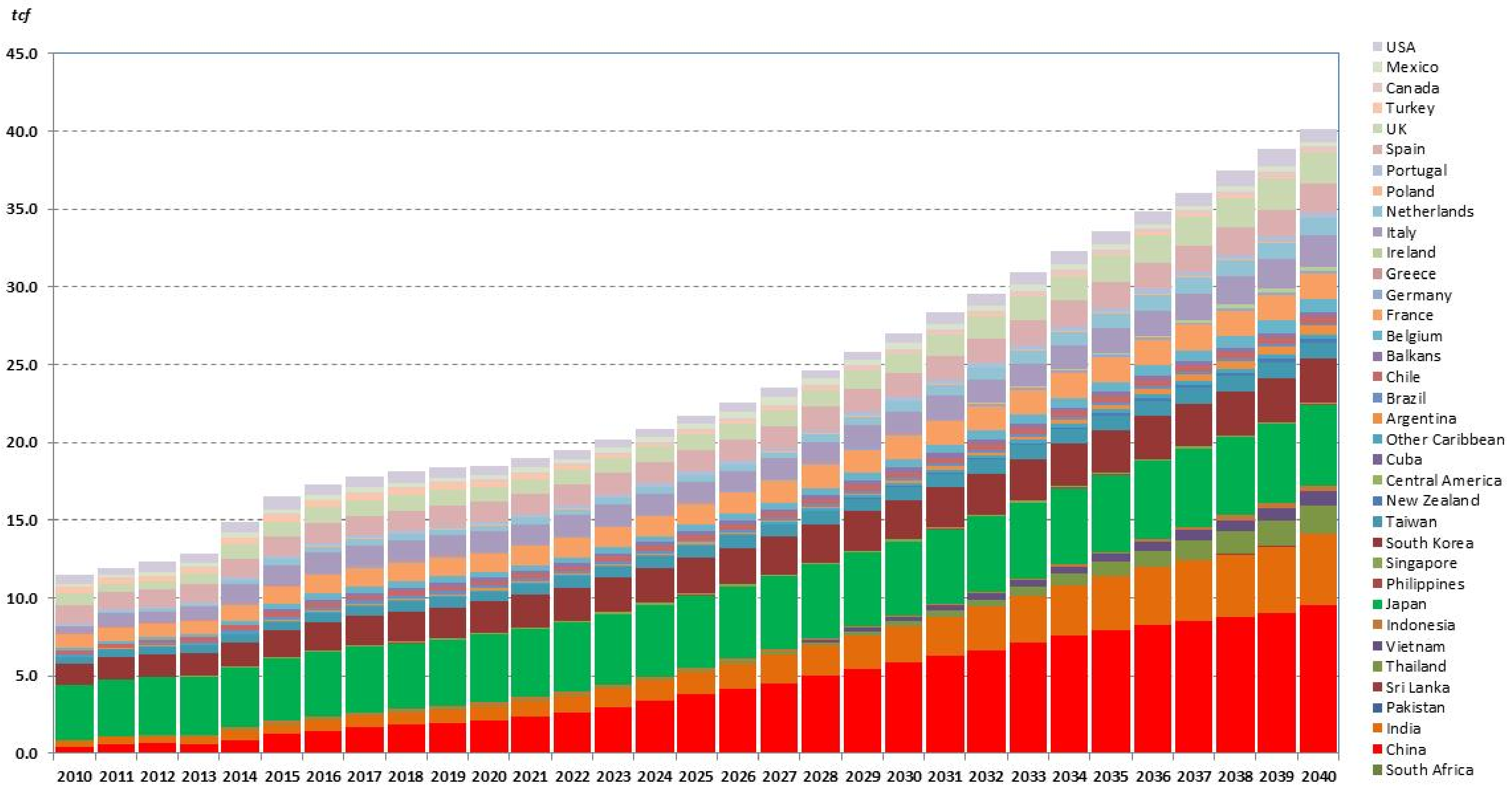


- Water will likely play a major role in Chinese shale production endeavors, as indicated by the fact that known shale plays are coincident with regions where water stress is already high.

Map replicated from “Natural Gas Weekly Kaleidoscope,” Barclay’s Capital Commodities Research (November 16, 2010).

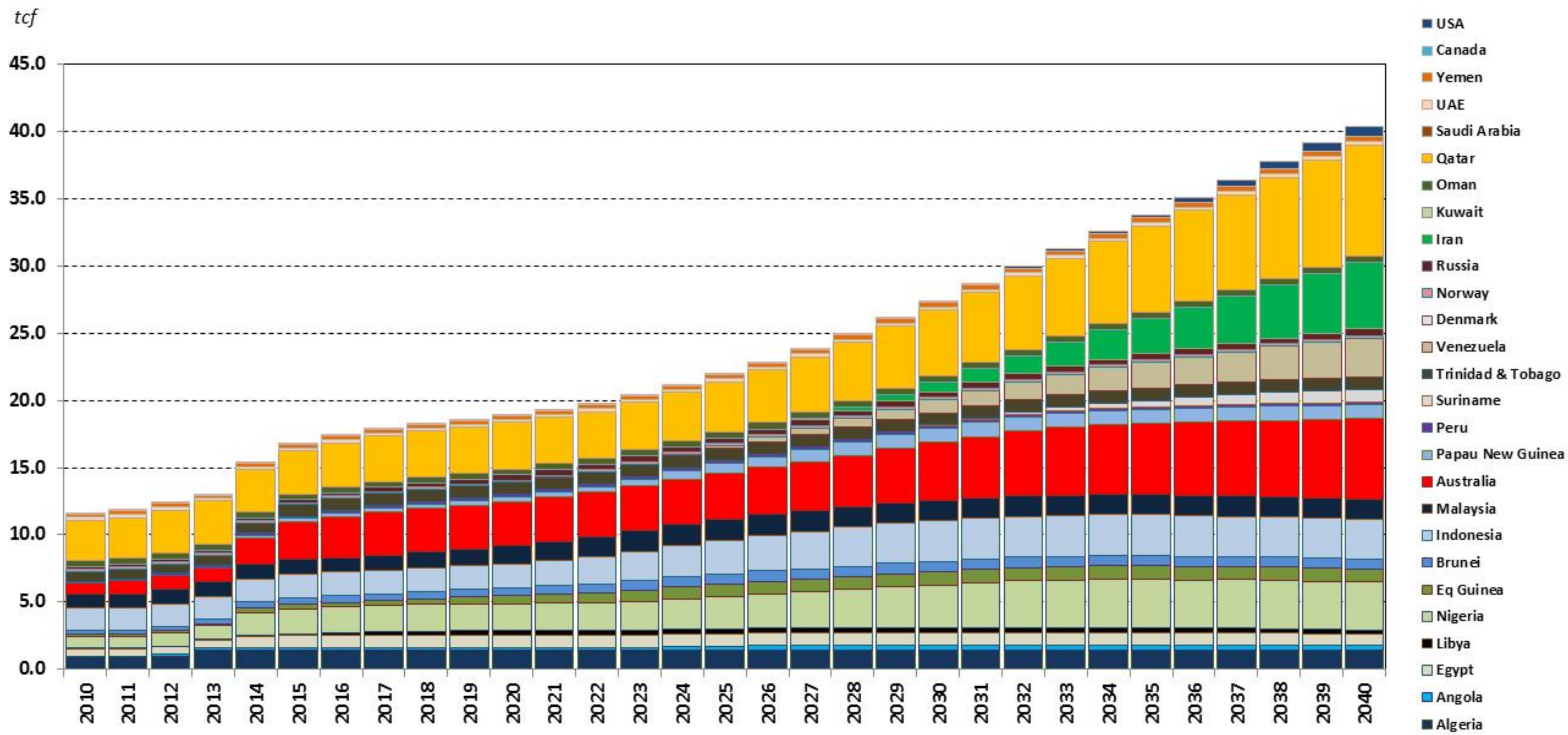
Reference Case:
LNG Imports by Country, 2010-2040

- A diverse set of players emerge in the LNG import picture. China, however, is the largest importer, passing Japan in the late 2020s.



Reference Case:
LNG Exports by Country, 2010-2040

- Substantial long term growth from the Middle East, Australia, and Venezuela. Qatar and Australia are the largest LNG exporters through 2040, and, collectively, account for over 35% of global *LNG* exports.

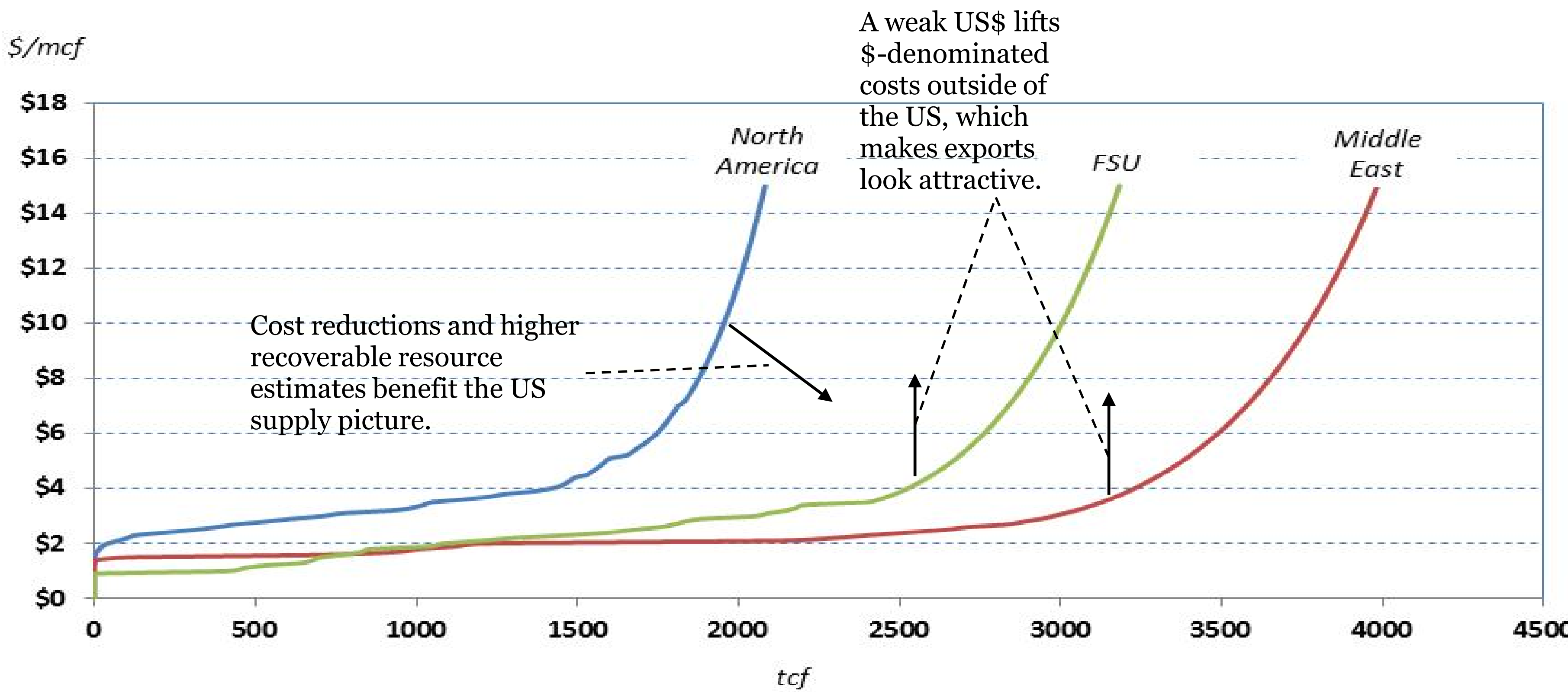


Appendix

U.S. LNG Exports

LNG Exports: 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 make North American resources preferential in the short-to-medium term *in North America*.



The Exchange Rate Effect

- Two recent working papers indicates the exchange rate plays an important role in the determination of:
  - The spread between oil and US gas prices (Medlock and Hartley (2011))
- Key Points:
  - Exchange Rate (XR) is vital to the stability of the relationship.
  - Dynamic adjustment is sensitive to seasonal factors.
- Example: The cointegrating (or long run equilibrium) relationship between crude oil and natural gas prices for different US$ values.

	XR (US$ vs Major Cur)		HH ($/mmbtu)	Oil Price ($/bbl)
Average	88.715	⇨	$ 7.94	$ 96.15
High	102.941	⇨	$ 10.79	
Low	74.490	⇨	$ 5.54	
current	69.764	⇨	$ 4.84	
		Actual HH	*$ 4.55*	

- Implication: LNG exports are at least partly an exchange rate arb. This begs the question, "What happens to the oil-gas price ratio if the US$ strengthens?"

Oil Indexation, Liquidity, and the Role of Shale Gas

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