

**APPENDIX B: Development of the Reference Case from the Rice World  
Gas Trade Model**

**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

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

### Residential

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

### Industrial

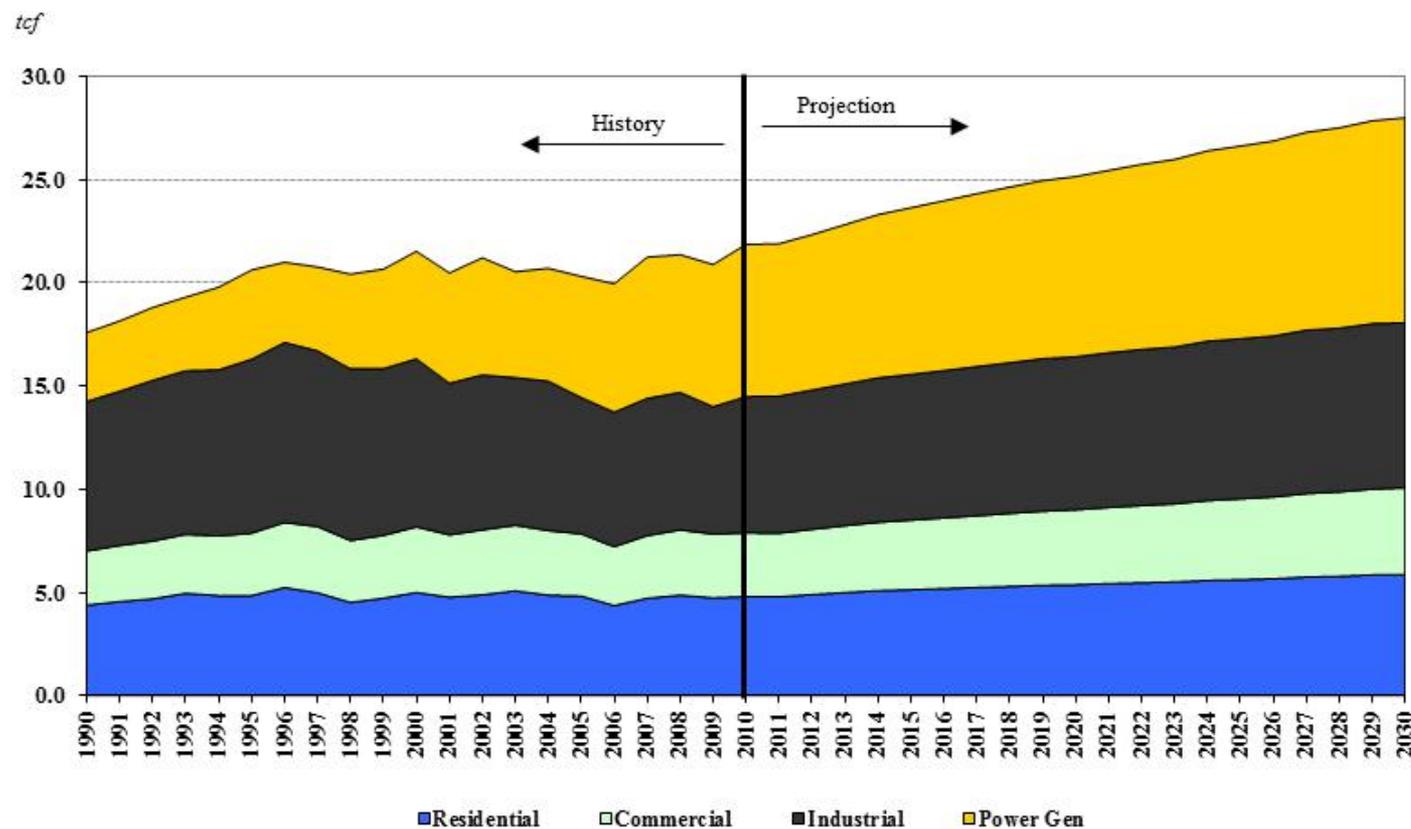
$$\ln q_{ind,i,t} = \alpha_i - 0.220 \ln p_{ng,i,t} + 0.105 \ln p_{coal,i,t} + 0.082 \ln ip_{i,t} + 0.000013hdd_{i,t} + 0.822 \ln q_{ind,i,t-1}$$

### Power Generation

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

## The RWGTM: US Demand (cont.)

- A sample forecast...



## 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

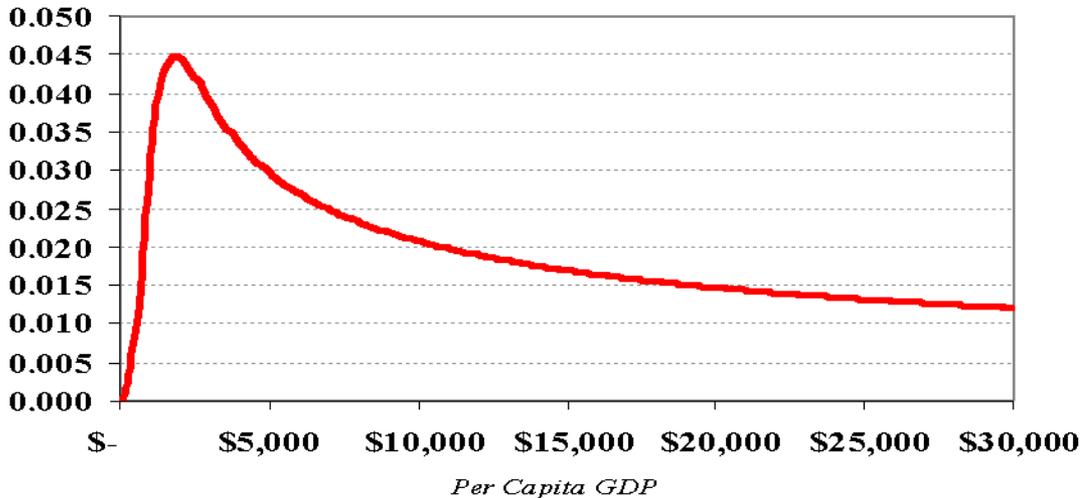
### Natural Gas Share

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

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: RoW Demand (cont.)

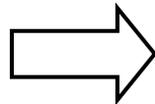
Energy Intensity



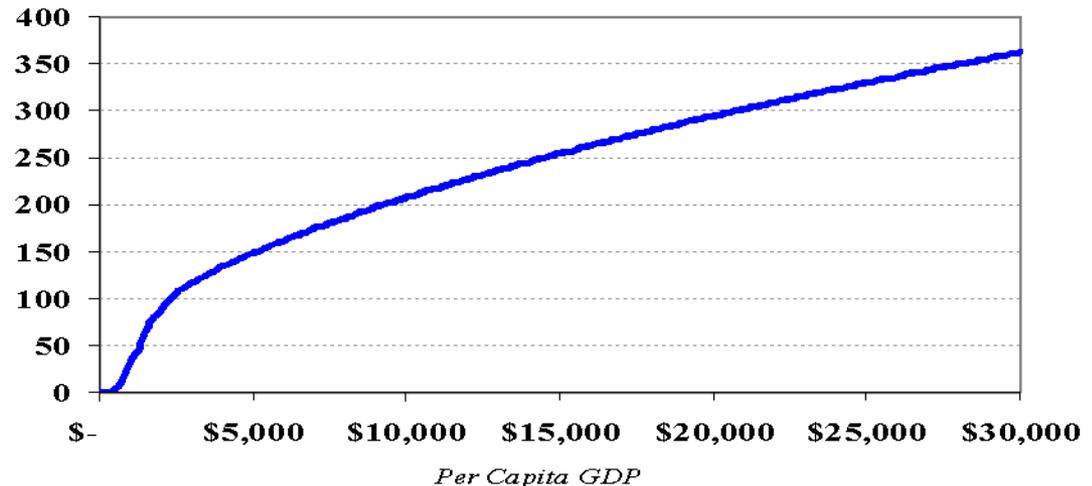
The estimated relationship between energy intensity and per capita GDP reveals that energy intensity generally decreases with rising incomes (see Medlock and Soligo, *Energy Journal* 2001)

The graphic indicates a 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.



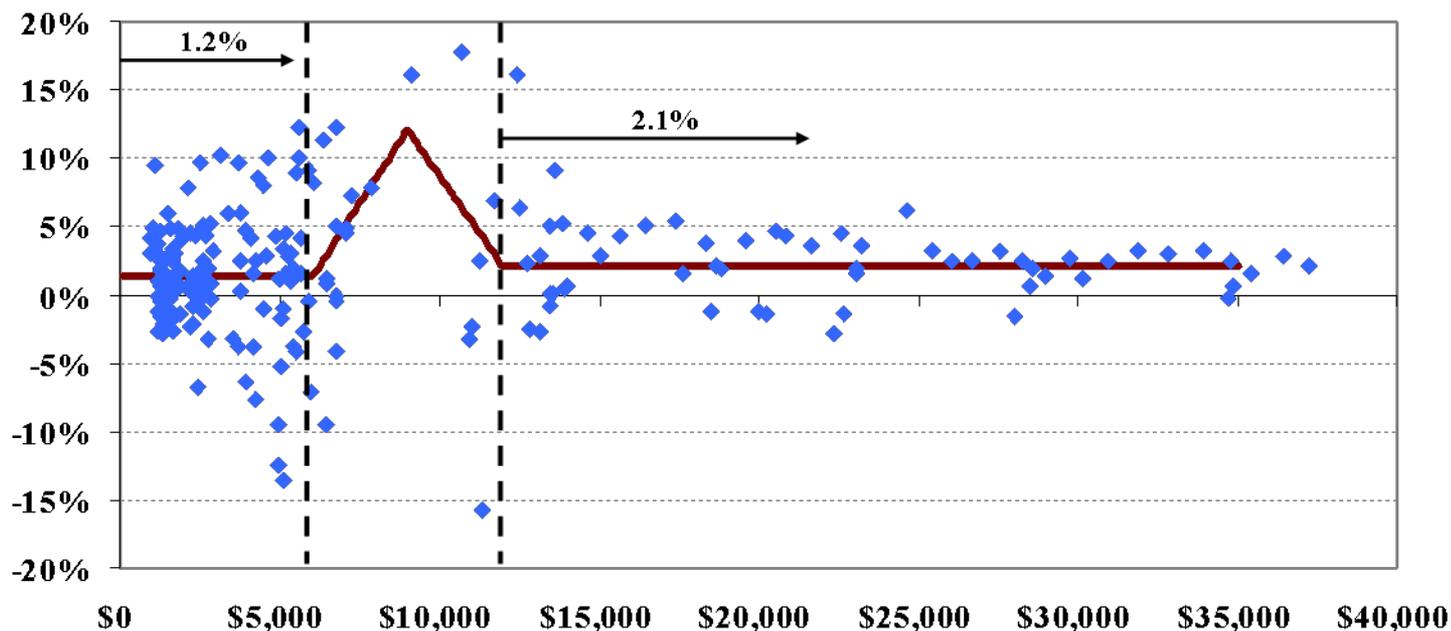
Energy Demand per Capita



## The RWGTM: RoW Demand (cont.)

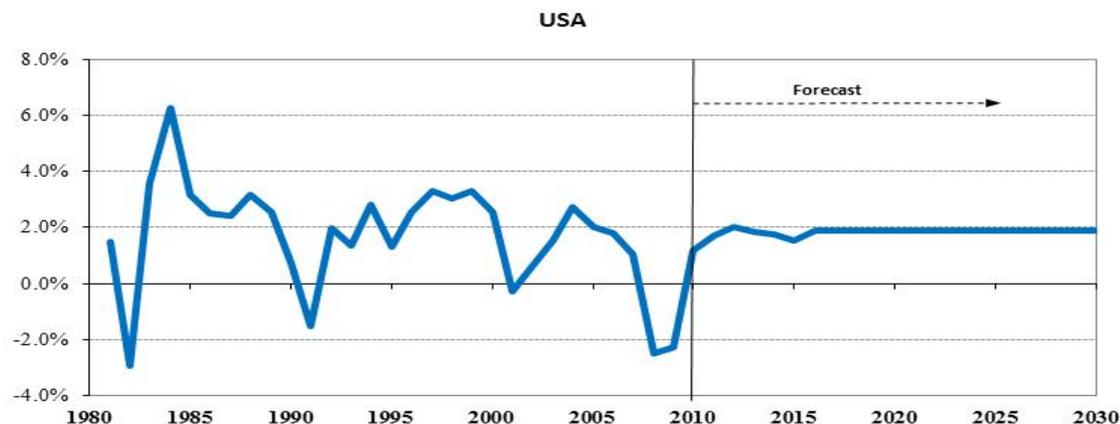
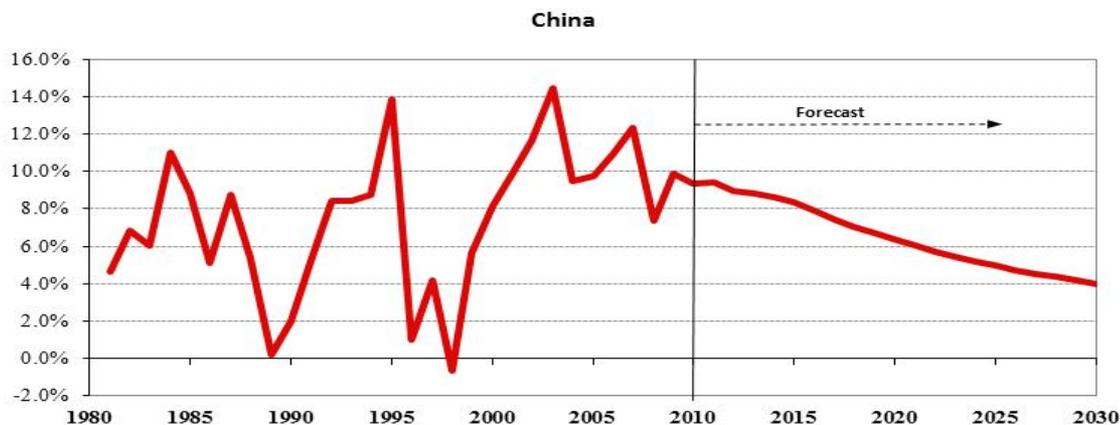
- Economic growth is based on conditional convergence a long run growth path that is based on historical US and UK growth rates (dating back into the 1800s) at various levels of per capita income. The long run growth path is estimated using a piecewise linear spline knot regression.
- Countries converge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

*Per Capita GDP*  
*Growth Rate*



## 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.

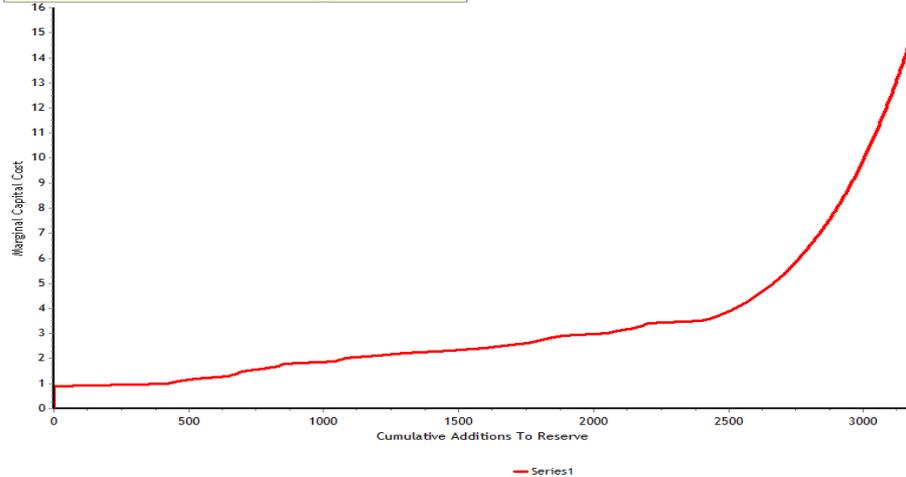
## The RWGTM: Supply

- 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

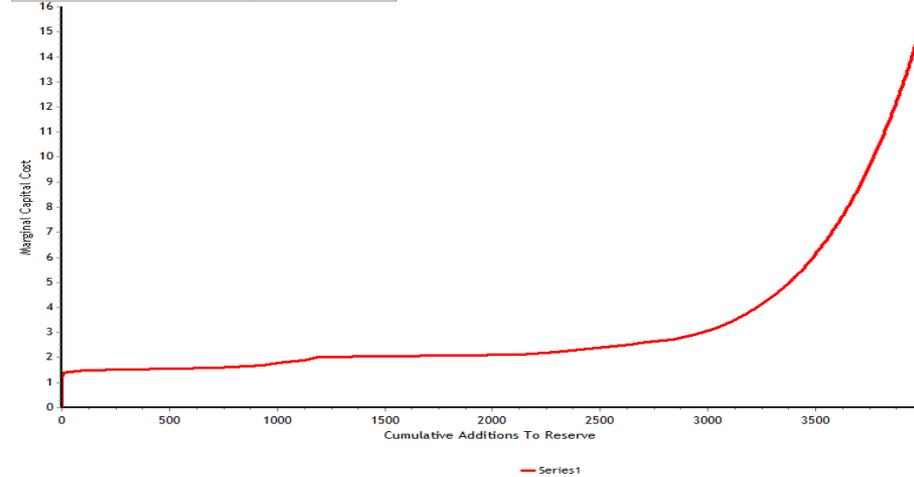
## The RWGTM: Supply (cont.)

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

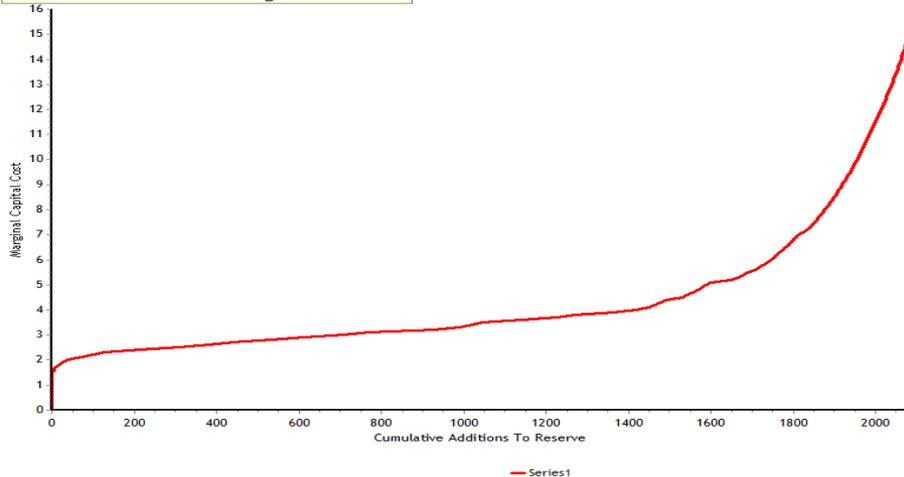
Former Soviet Union Production Marginal Cost Curve



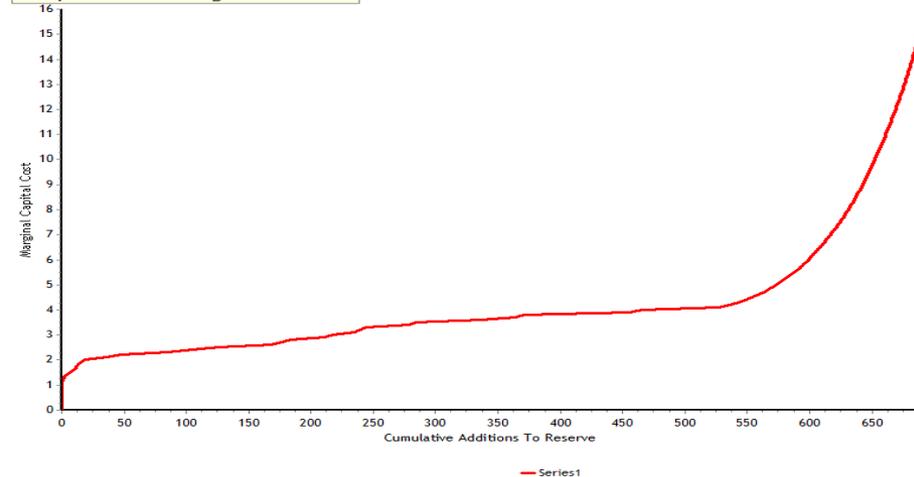
Middle East Production Marginal Cost Curve



North America Production Marginal Cost Curve



Europe 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.

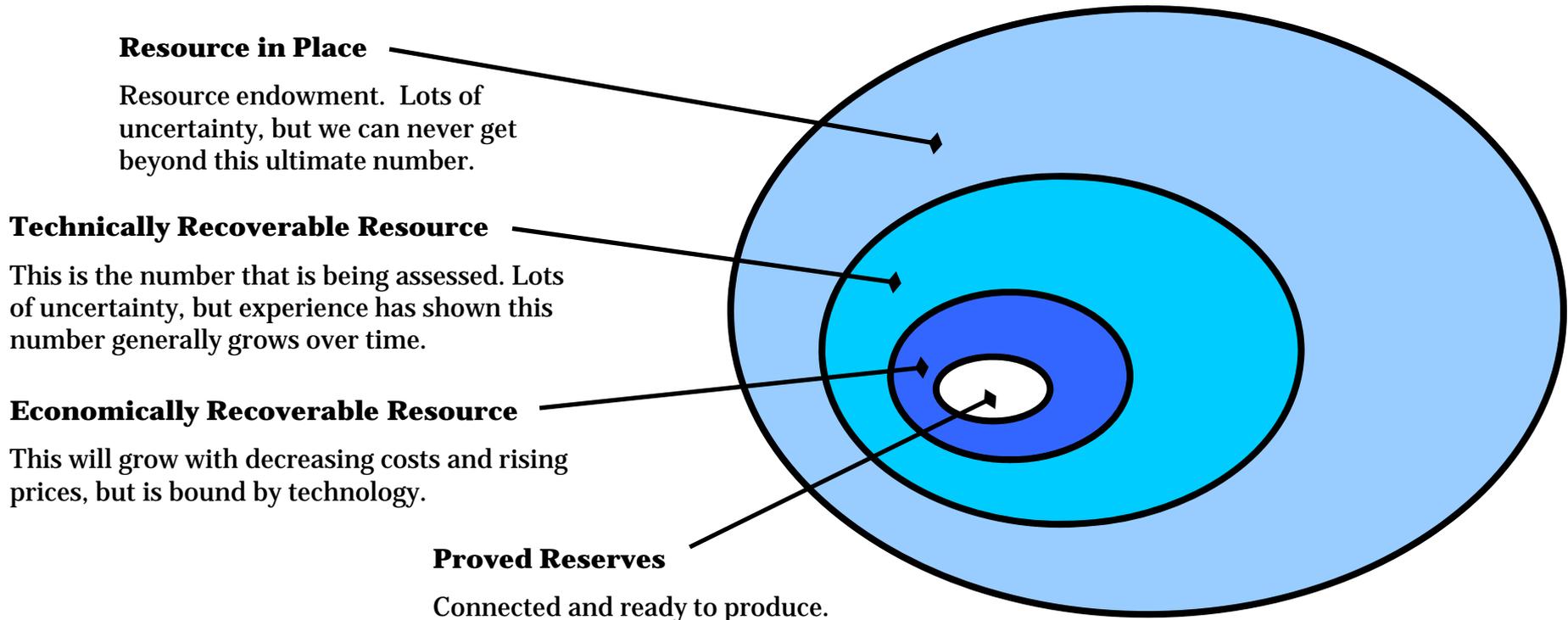
Sample Capital Cost for Liquefaction		
	Capex (\$/mcf)	Capex (\$/ton)
<b>Australia</b>	<b>12.8934</b>	<b>\$ 620.2</b>
<b>Australia (Queensland)</b>	<b>9.0988</b>	<b>\$ 437.7</b>
<b>Atlantic</b>	<b>7.7854</b>	<b>\$ 374.5</b>
<b>Pacific</b>	<b>9.0988</b>	<b>\$ 437.7</b>
<b>Middle East</b>	<b>8.4784</b>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

- 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 in the RWGTM**

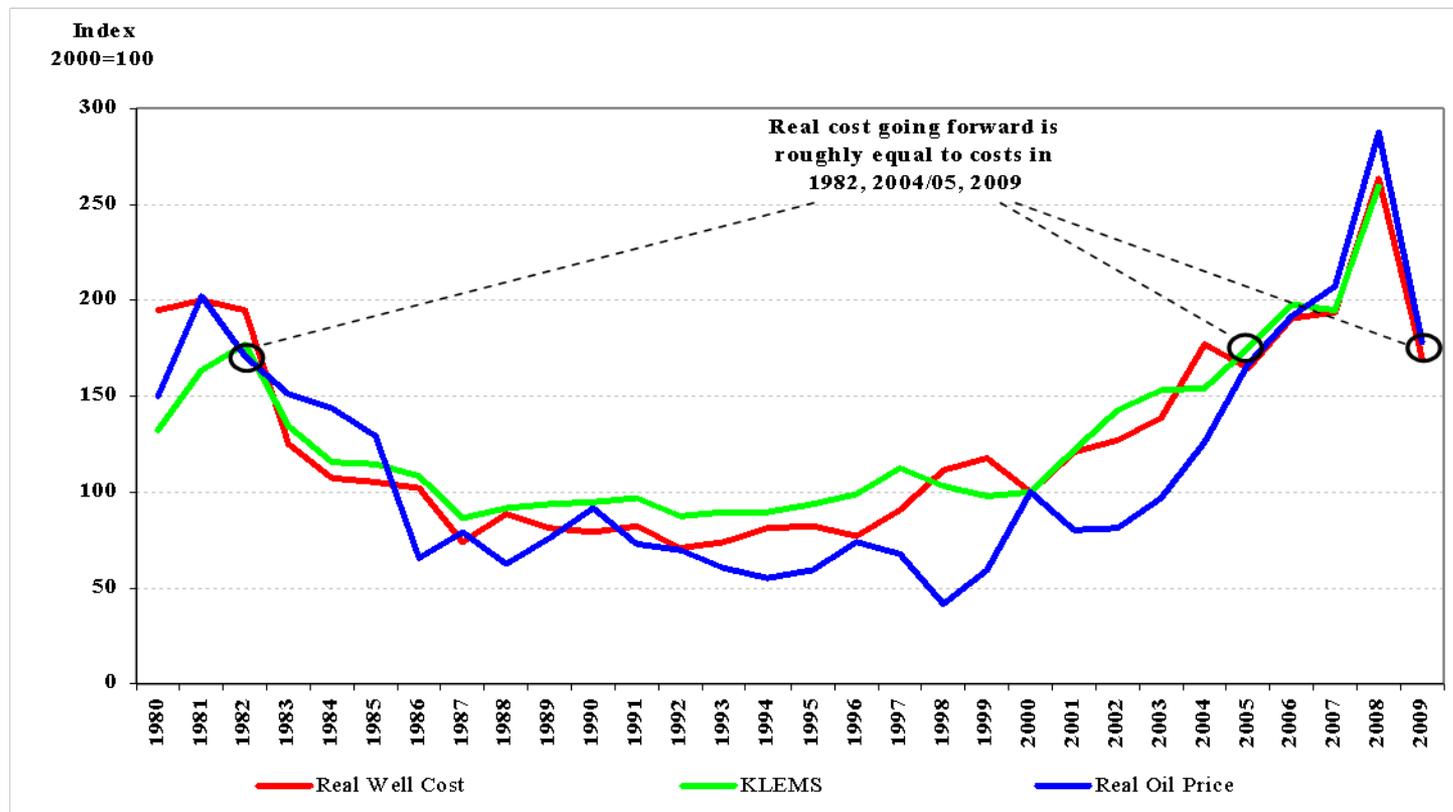
## Defining the Resource

- 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.**



## 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.



## US Shale

- 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 800 tcf.
- Resource assessment is large. Our work at BIPP indicates a technically recoverable resource of 637 tcf.
- Point: We learn more as time passes!

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

## Rest of World Shale

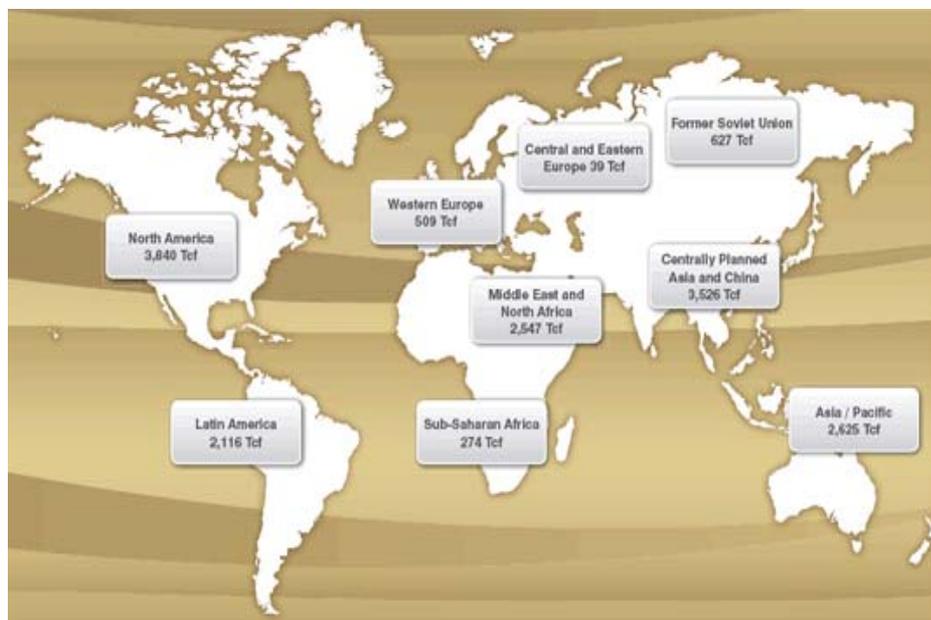
- There is uncertainty about shale resources outside of North America.
- The estimates of resource in-place are very large, and location is a premium.
- However, accessibility is critical. Not only do cost and technology matter, but market structure and government policy is equally as important.
  - 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
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/Jiangnan	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
	<b>Total non-U.S.</b>	<b>800.0</b>	

Note: New ARI assessment is under review for incorporation into the Reference Case. This will likely add technically recoverable resource in Croatia, Denmark, France, Hungary, Netherlands, Ukraine, the United Kingdom, Argentina and South Africa.

## 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
<b>Total</b>	<b>16,112</b>	<b>457</b>

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.
- **We continue to learn as we advance in this play!**

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
<b>Total</b>	<b>6,622</b>

Source: ARI/EIA (2011)

