The Rice World Gas Trade Model (RWGTM):
Report of Reference Case Results

prepared by:

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The RWGTM:
A Forecasting Tool for Policy Analysis

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

Demand

The RWGTM: Demand

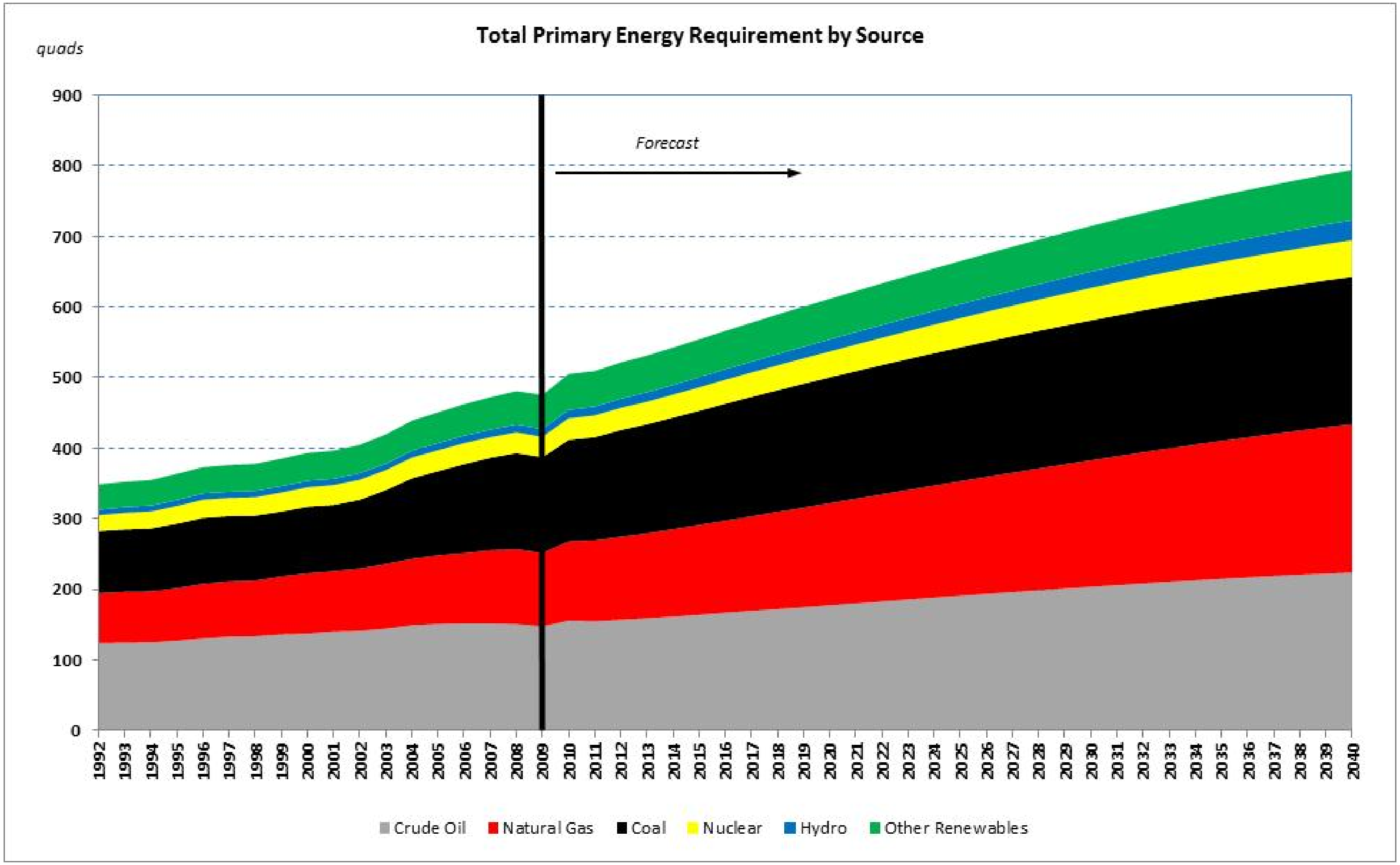
- Recall, there are over 290 regions
  - Regional detail is dependent on data availability and existing infrastructure.
  - In US, sub-state detail is substantial and is based on data from the Economic Census and the location of power plants.
    - For example, 10 regions in Texas, 4 regions in Louisiana, 3 regions in Massachusetts, 4 regions in California, etc.
  - In Rest of World, sub-national detail varies based on infrastructure and data availability.
    - For example, 5 regions in India, 7 regions in China, 6 regions in Germany, 4 regions in the UK, 6 regions in France, 10 regions in Australia, 1 region in Bangladesh, 1 region in Thailand, etc.

Economic Development and Energy Demand

- Time series of per capita energy demand versus per capita GDP for 67 countries. Selected countries are highlighted for illustrative purposes.
- Energy use increases with GDP, but the rate of increase declines as economic development continues. This is driven by both structural and technical change, and it leads to declining energy intensity.

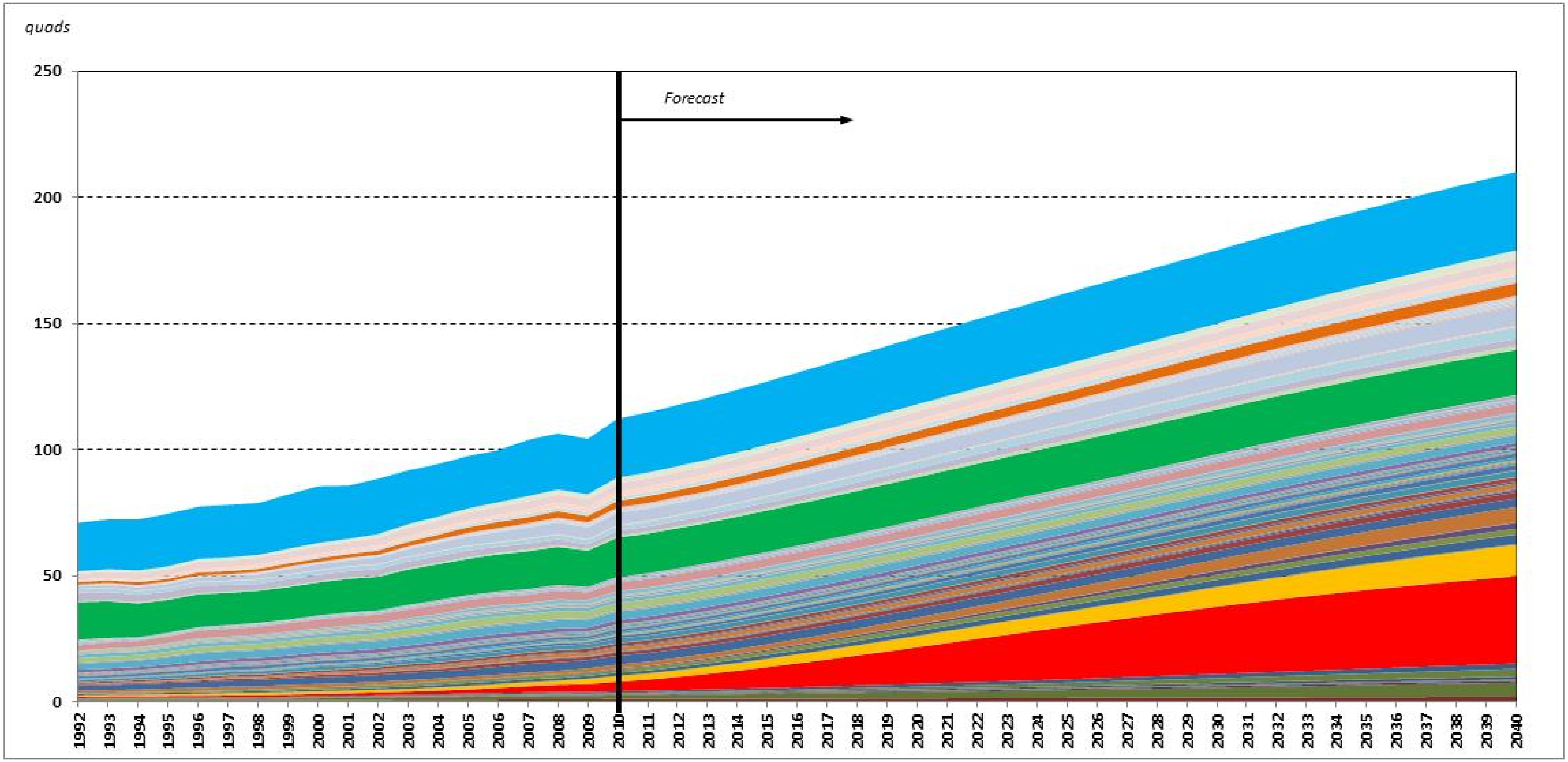
TPER: World

- Summary of global TPER by energy source. Reported as a sum across all sectors, all countries and all fuel sources.



Natural Gas Demand by Country

- Summary of global natural gas demand by country



Supply: Shale Resources and Costs

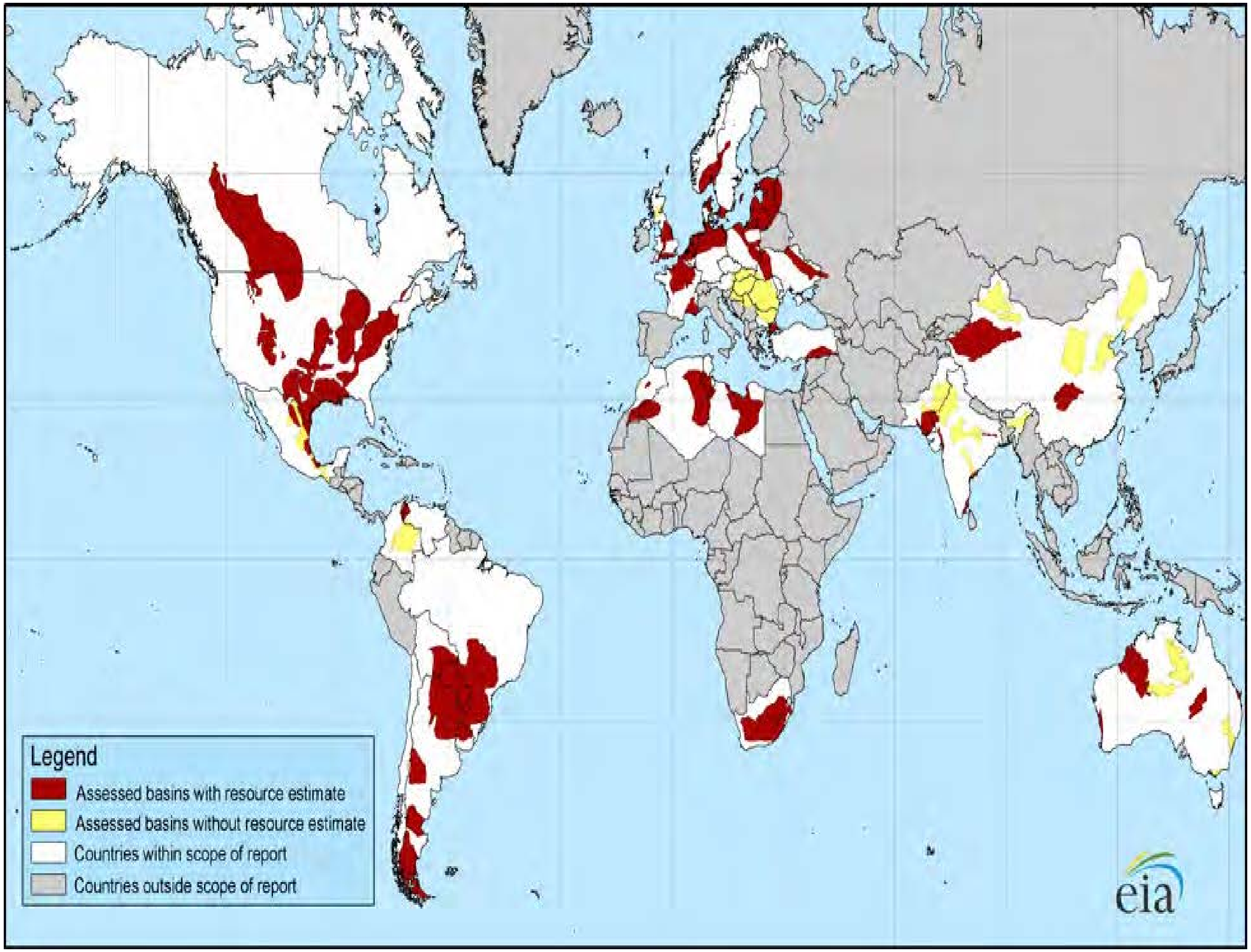
The RWGTM: Supply

- Recall, there are 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. **Changes incorporate the analysis of the recent ARI assessment of shale around 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 Global Shale Gas Resource

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

Source: ARI/EIA (2011)



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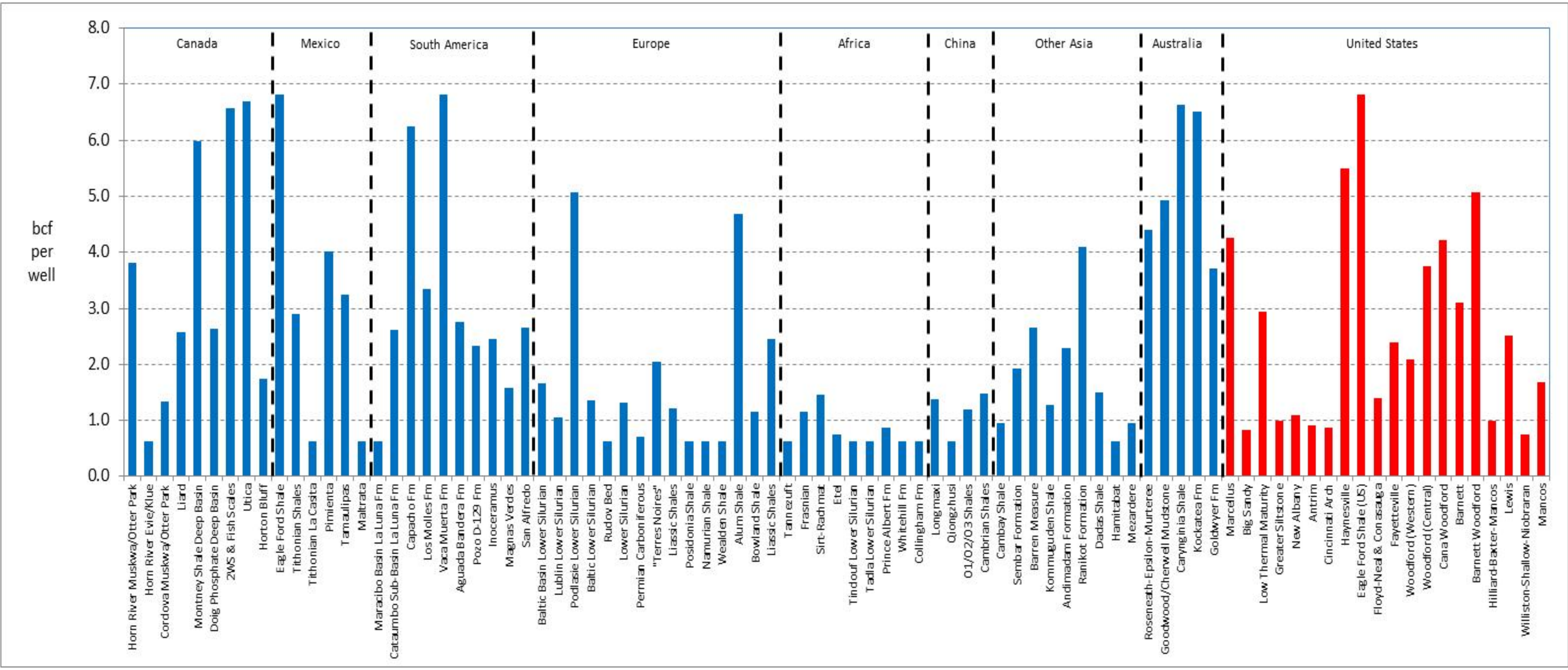
EURs in Shale Plays

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



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

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

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

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

The Global Shale Gas Resource in the RWGTM: A Summary Without Costs

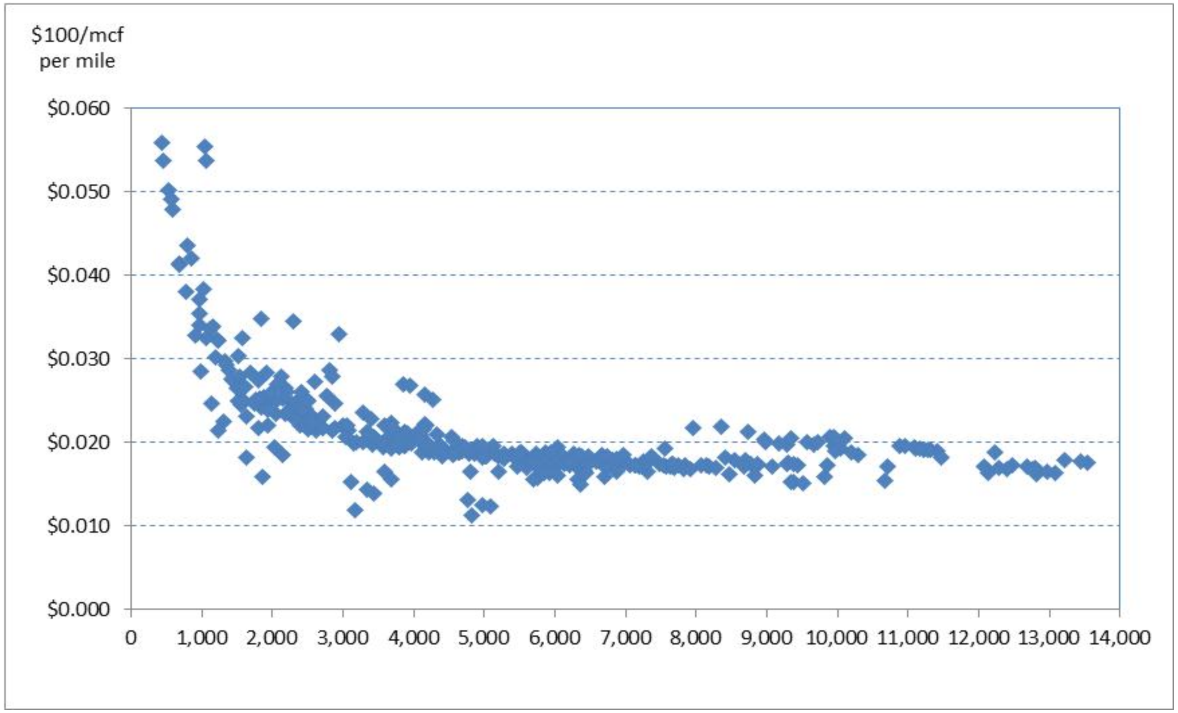
- Through the process of cost development, we have reduced the size of the recoverable resource base presented in the ARI report by 2,600 tcf. Nevertheless, we now include just over 4,024 tcf of recoverable shale gas resource in the RWGTM. This represents an increase of over 2,400 tcf. The majority of the difference is accounted for in shale gas plays outside of the US and Canada.

		Recoverable Resource (tcf)	
Region	**Country**	**Country Total**	**Region Total**
North America	US	668.7	**1186.8**
	Canada	321.5	
	Mexico	196.6	
South America	Argentina	670.4	**894.5**
	Bolivia	31.3	
	Brazil	137.5	
	Colombia	7.2	
	Paraguay	40.6	
	Venezuela	7.5	
Europe	Austria	32.0	**409.9**
	Denmark	23.5	
	France	62.4	
	Germany	7.5	
	Lithuania	13.8	
	Norway	82.3	
	Poland	104.6	
	Sweden	41.2	
	Ukraine	18.0	
	UK	24.6	
Africa	Algeria	63.1	**296.7**
	Tunisia	6.2	
	Libya	81.9	
	South Africa	145.5	
Asia & Oceania	Australia	396.0	**1236.6**
	China	765.0	
	India	49.8	
	Pakistan	18.6	
	Turkey	7.2	
World		**4024.5**	

LNG Shipping

The RWGTM: LNG Shipping

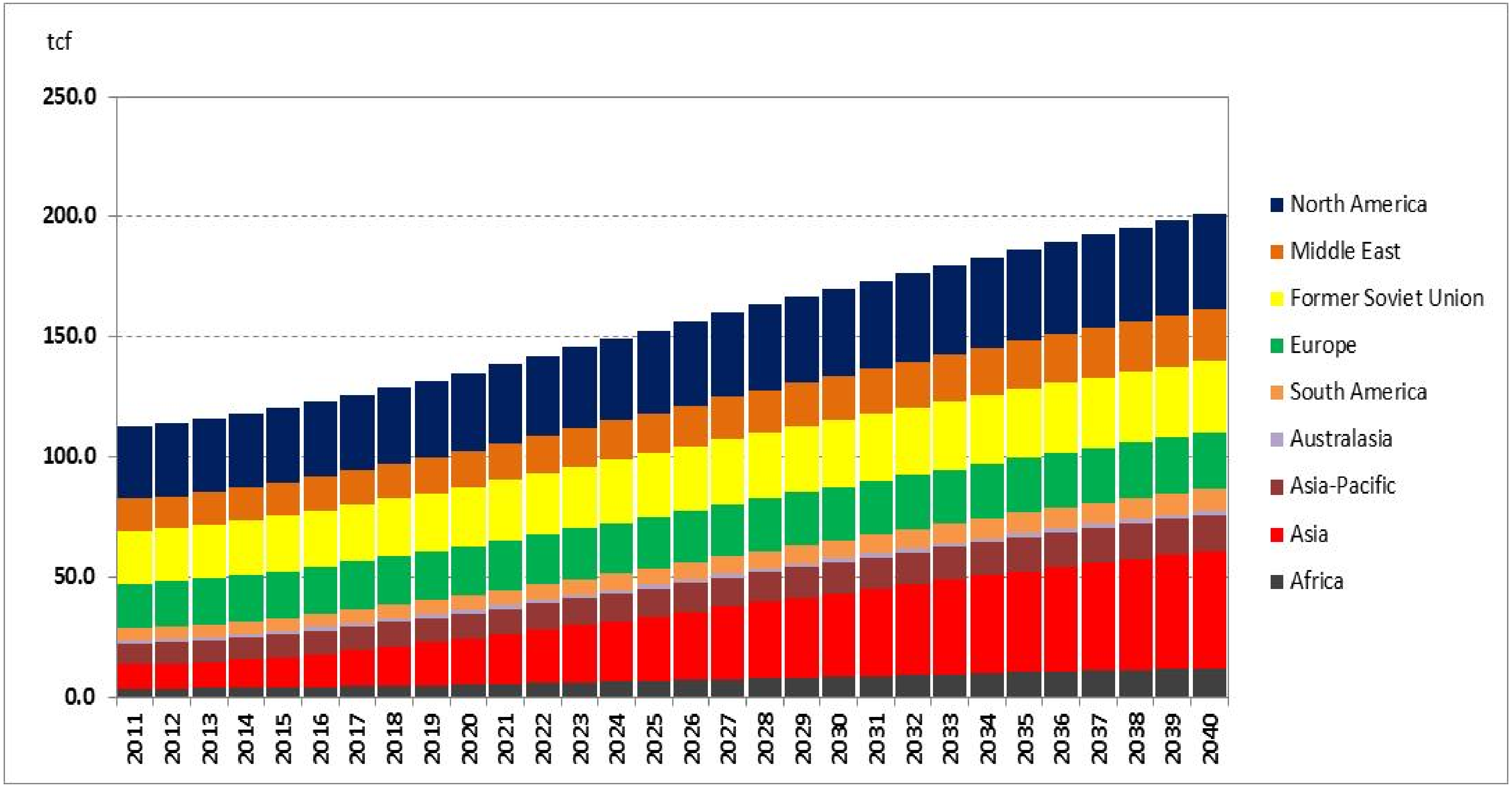
- Changed the manner in which LNG shipping is modeled.
  - Old approach: LNG is represented as a hub-and-spoke network, reflecting the assumption that capacity swaps will occur when profitable.
  - New approach: LNG is modeled as a point-to-point network where initial LNG route capacities are calibrated to 2010 flows. As before, shipping rates are based on lease rates and voyage time.
- Swaps are allowed to occur, but shipping capacity must be added in order to implement.
- All possible shipping routes and costs are implemented. For unknown routes, costs were econometrically fit to known data.



Reference Case Results

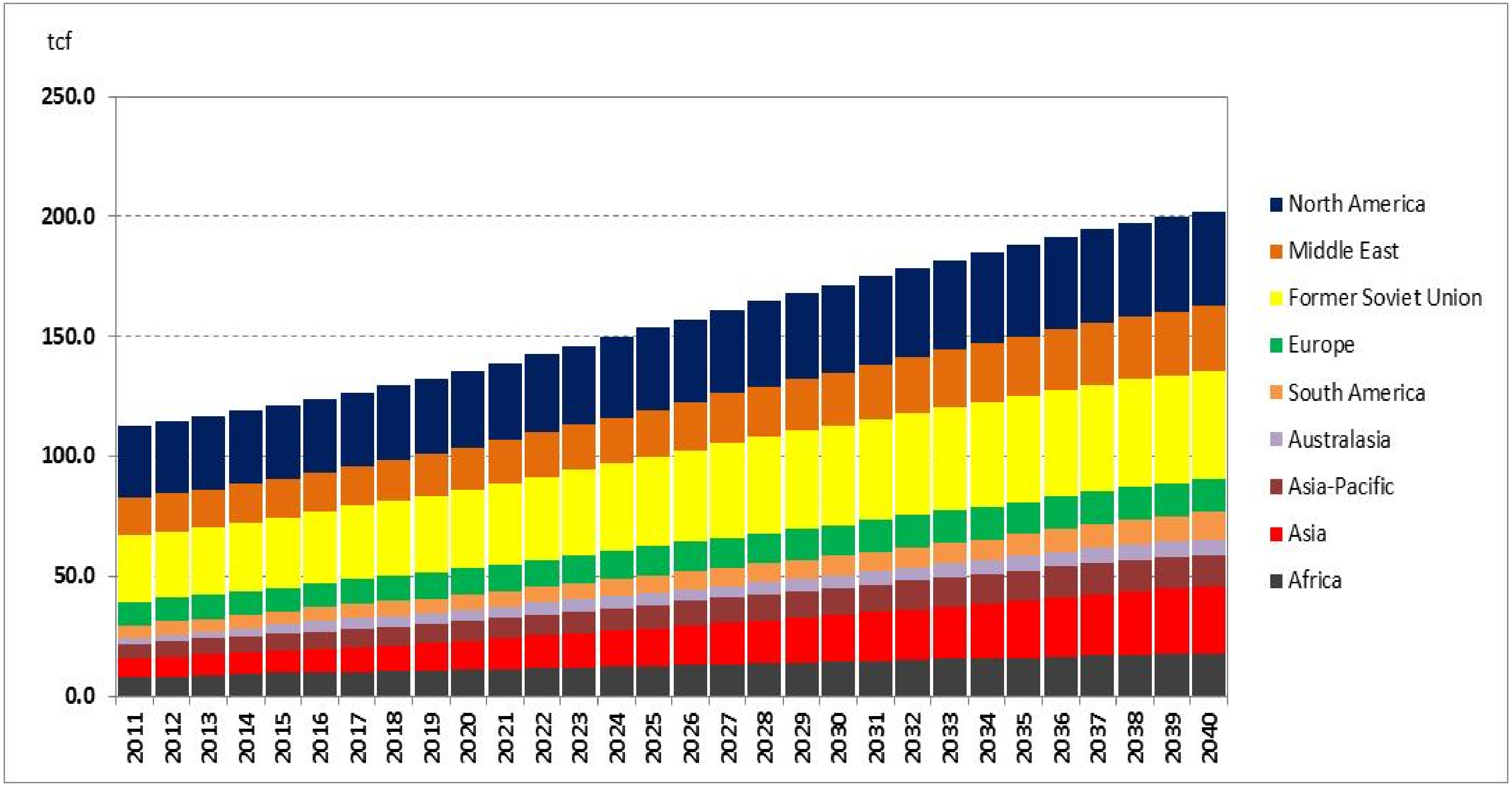
Reference Case:
Demand by Super-Region, 2011-2040

- Asian demands, China and India in particular, set the trend for global natural gas demand growth.



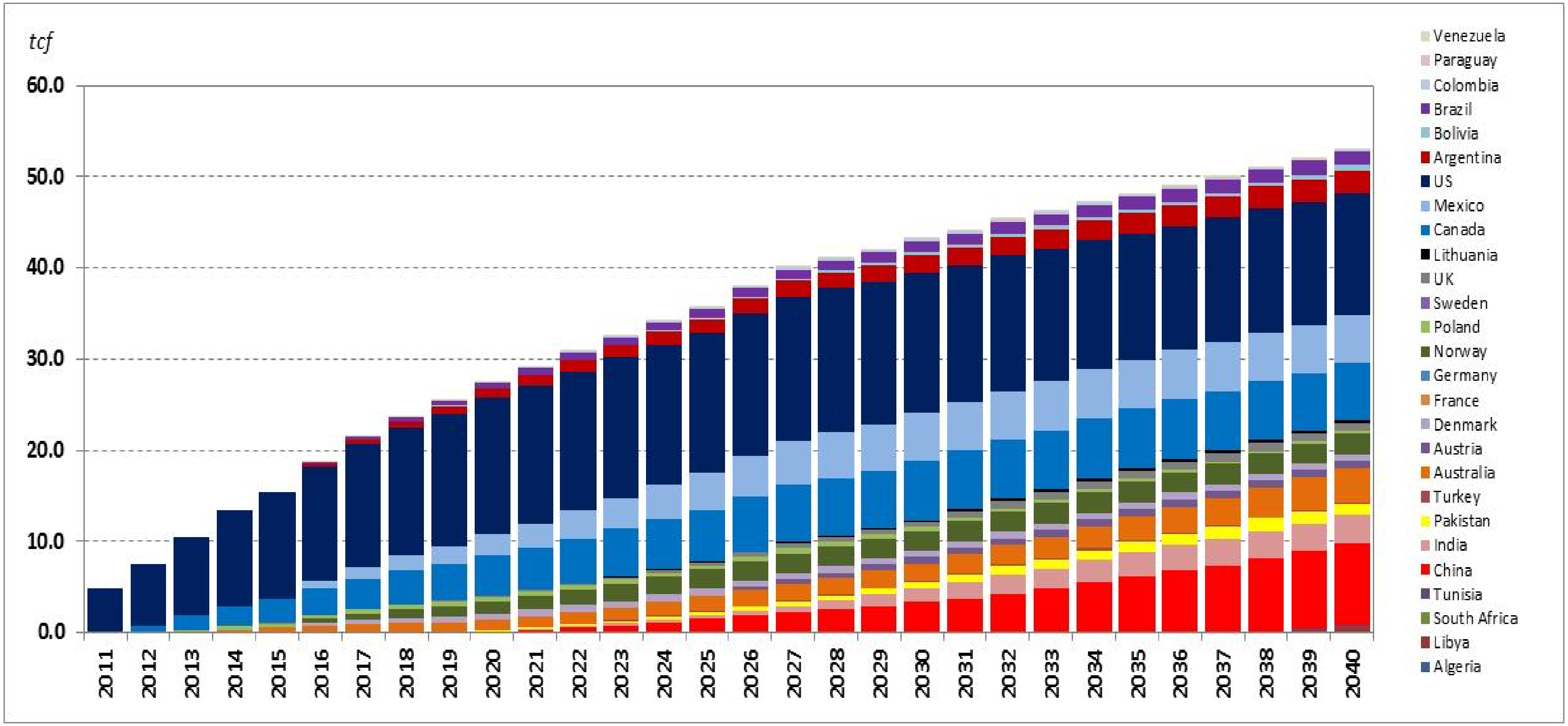
Reference Case: Supply by Super-Region, 2011-2040

- Highest growth rates are seen in Asia where demands grow rapidly, shale gas resources are large, and existing production is relatively low.



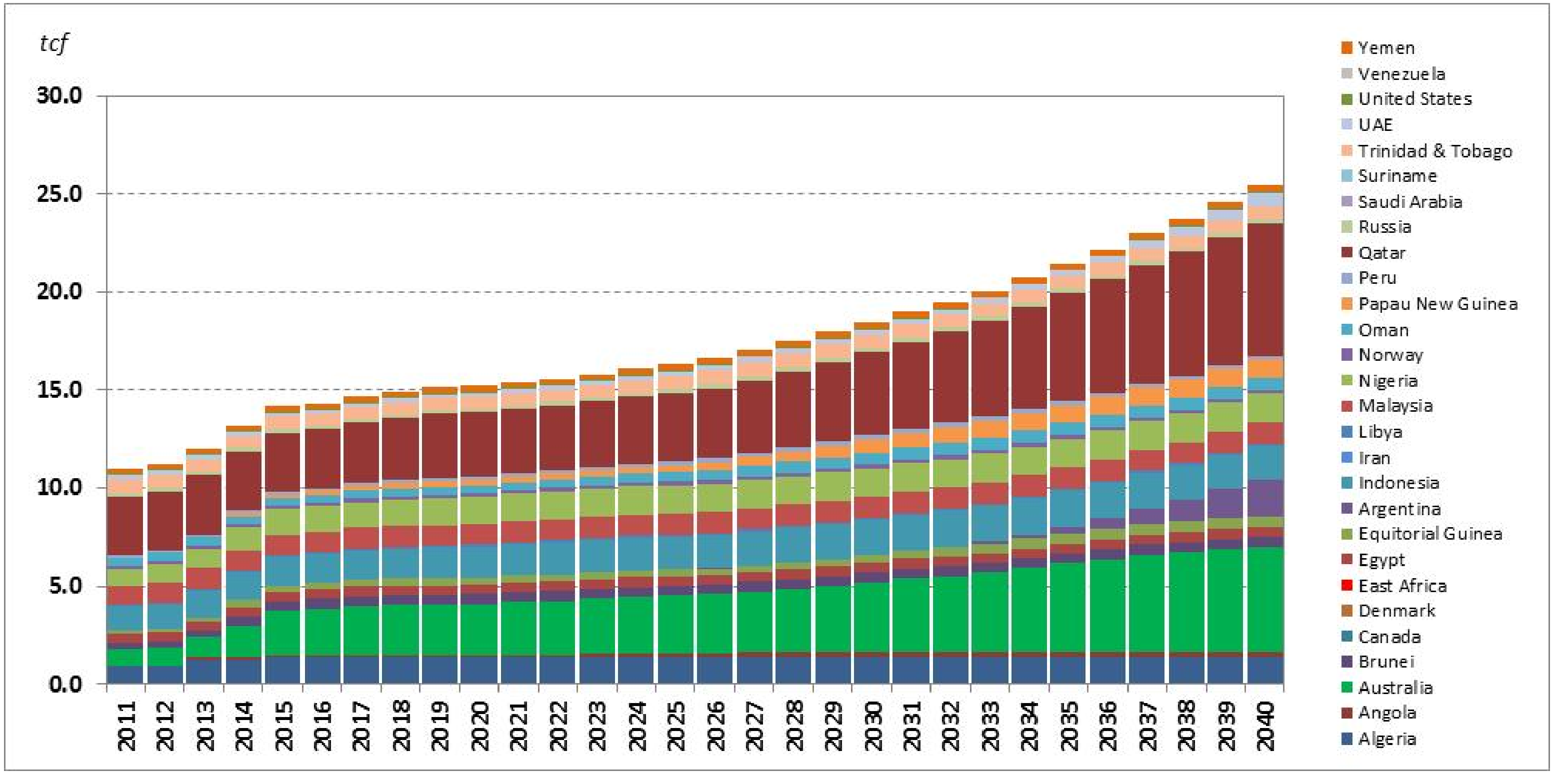
Reference Case: Global Shale Production, 2011-2040

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



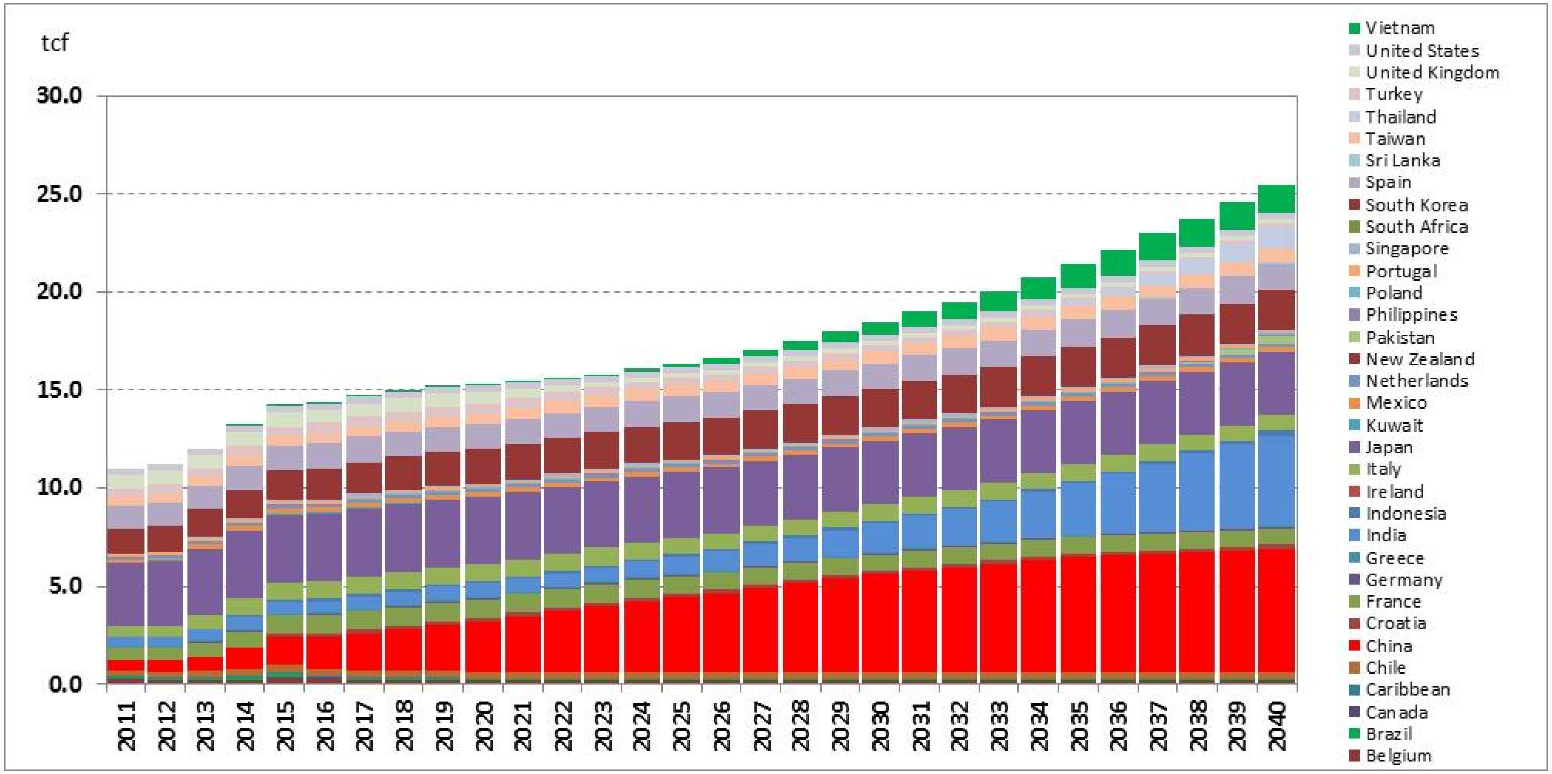
Reference Case:
LNG Exports by Country, 2011-2040

- Qatar and Australia are the largest LNG exporters through 2040, and, collectively, account for about 40% of global *LNG* exports.
- Australia rivals Qatar as the world's largest LNG exporter by 2030.



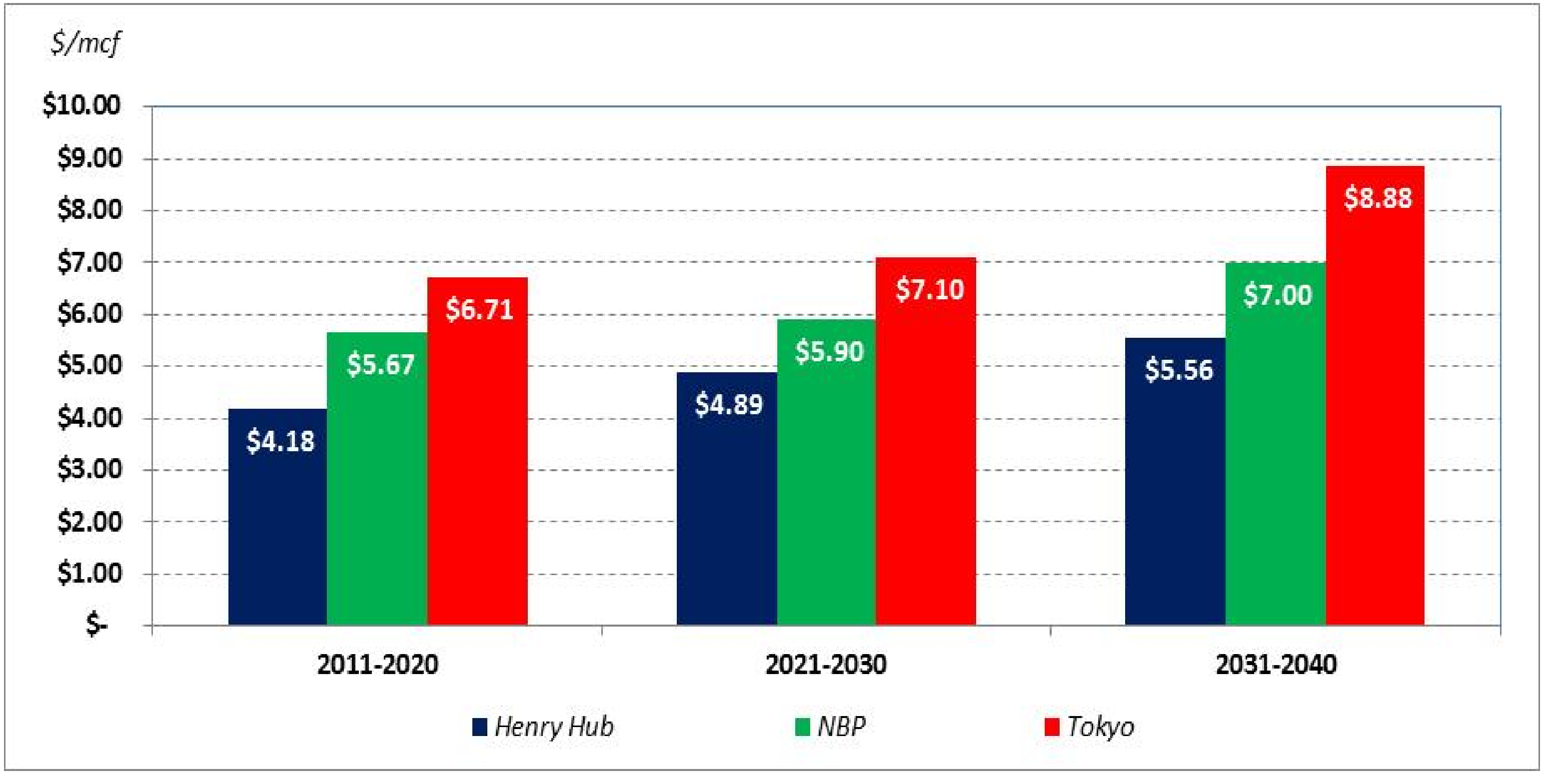
Reference Case: LNG Imports by Country, 2011-2040

- A diverse set of players emerge in the LNG import picture. China, however, is the largest importer, passing Japan in the mid 2020s. India approaches China by 2040.



Reference Case: Global Marker Prices, 2011-2040

- Note, the US price is Henry Hub, the European price is NBP, and the Asian price is the Japanese price paid for spot LNG. Global prices remain above the US price. The prices indicated are *spot* prices not *contract* prices.



Key Drivers

- Iran, Venezuela, Saudi Arabia, Qatar, etc. Energy supply decisions motivated by political considerations both directly and indirectly.
- Policy-driven energy choices, such as long term commitment to renewables.
- Political and regulatory circumstances that do not support investment
  - Nationalization (Argentina and YPF).
  - Regime change
- Substantial changes in costs and/or access to resources

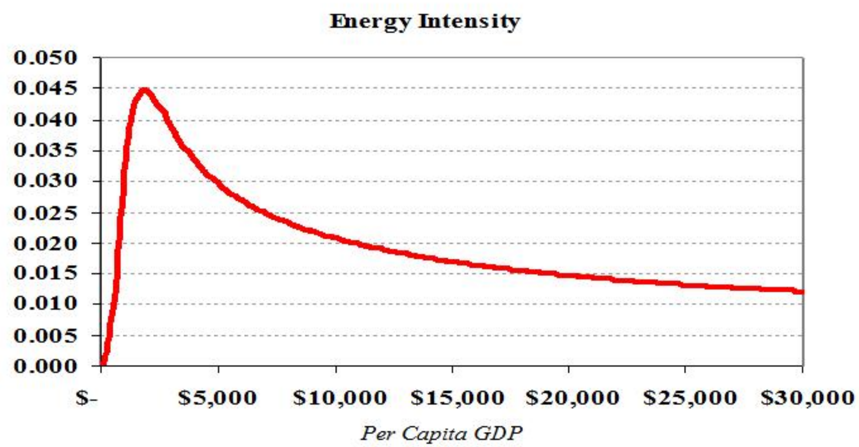
Key Drivers

- The existence of regionally discrete natural gas markets around the globe has persisted due to a lack of capability to directly arbitrage price differences. This is due to several factors, including, but not limited to,
  - the existence of transportation monopolies,
  - high costs of entry and long lead times for LNG and long haul pipeline capacity,
  - lack of storage capacity and basic hub services in Asian and European markets,
  - regulatory frameworks that do not encourage entry and entrepreneurial activity, particularly in the upstream sector (for example regarding property rights for minerals),
  - regulatory frameworks that support the existence of monopolies in transportation and distribution (for example a lack of market oversight that forces unbundling), and
  - lack of physical and financial market liquidity which masks price discovery, which in turn would signal infrastructure opportunities. This is a direct result of the other factors.

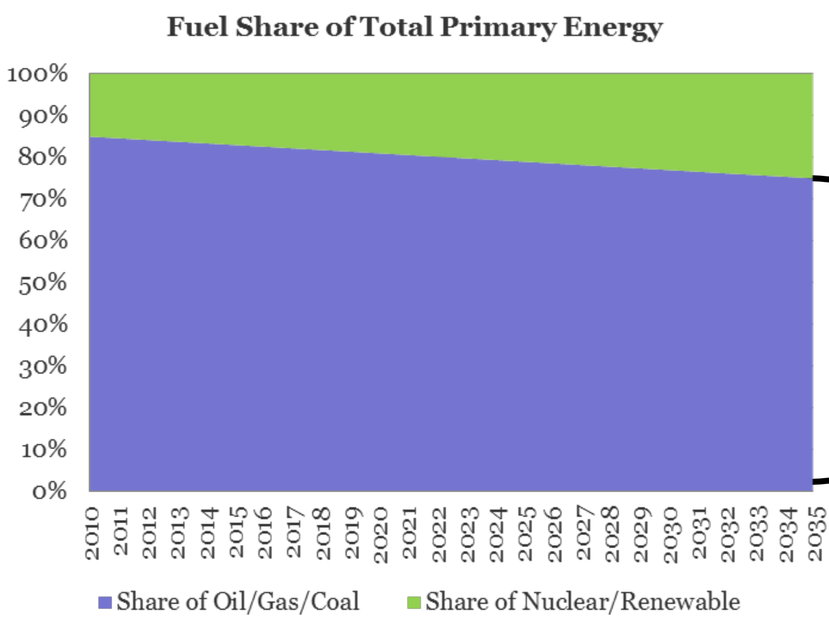
Anything altering these points will have a profound impact on the global gas market.

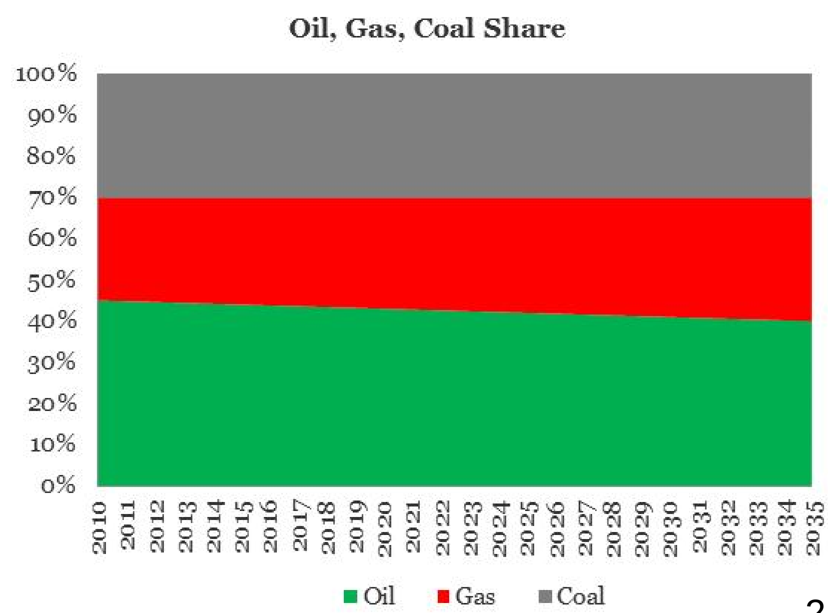
Appendix

The Rice Model of Total Primary Energy Requirement

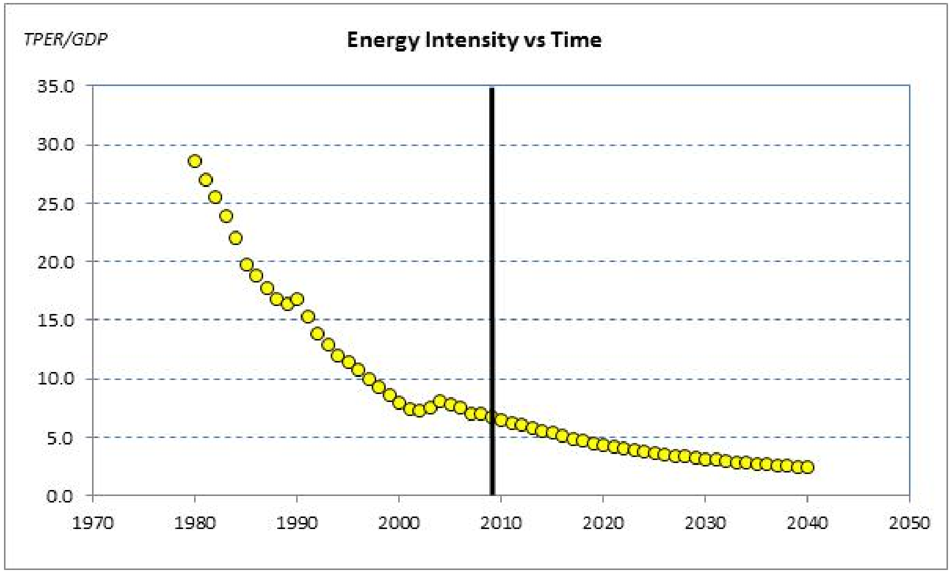


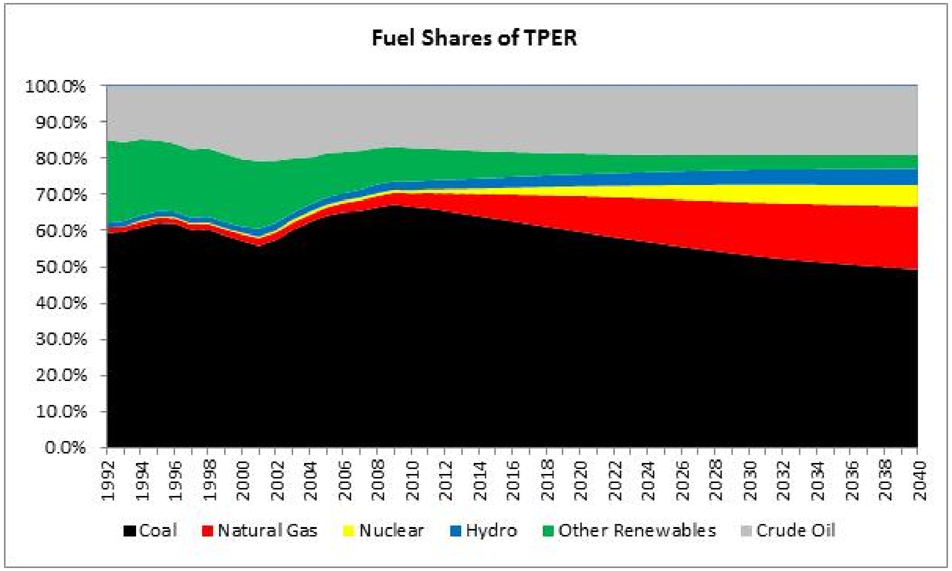
- Estimate country level energy intensity, then TPER.
- TPER is divided into fuel shares as follows: coal, gas, oil, nuclear, and renewable.
- Use views on policy-driven energy shares, then allow econometrics to drive other results.

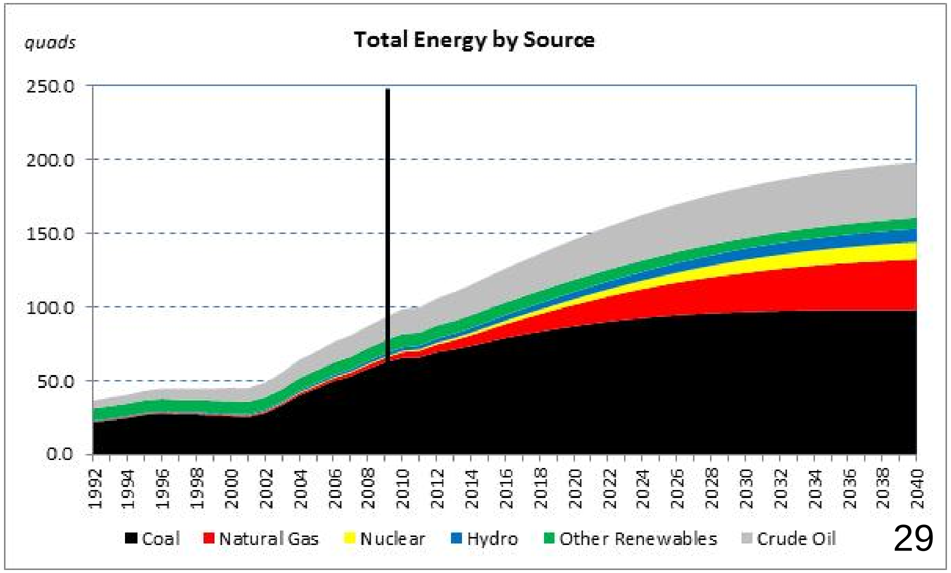




TPER: China

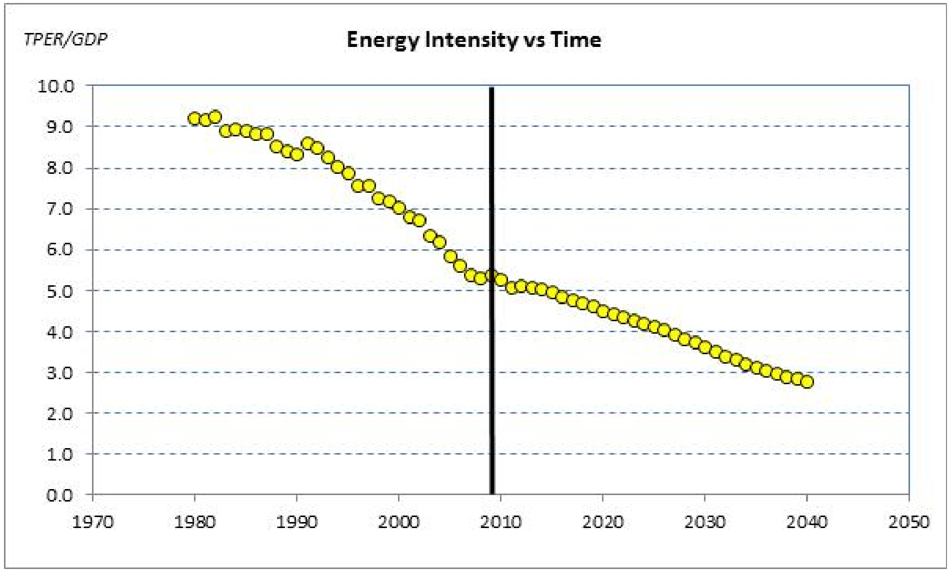


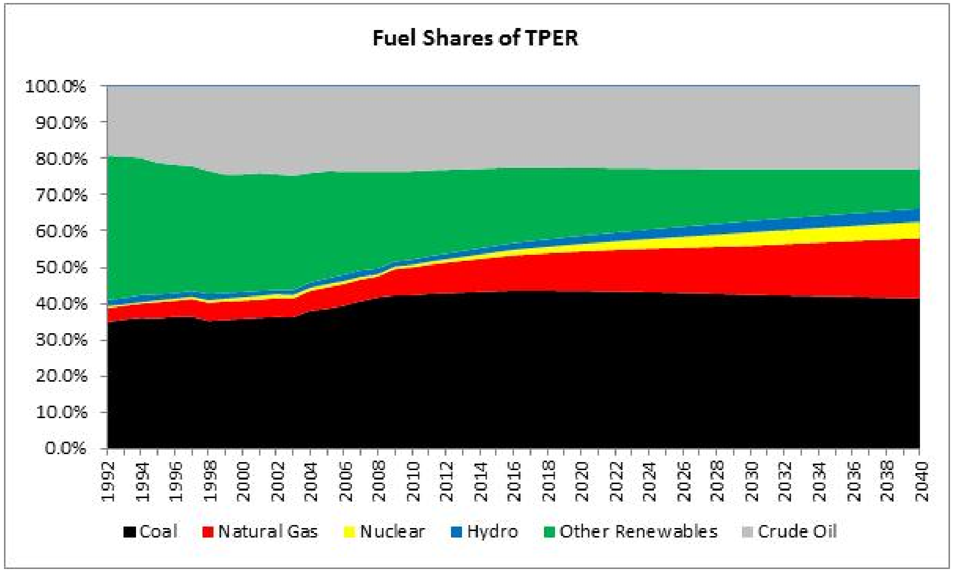


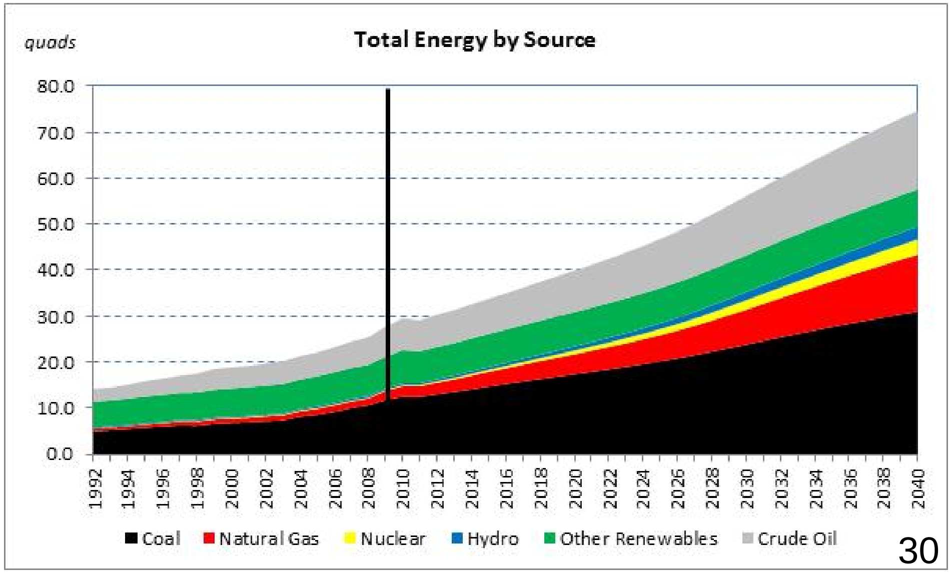


- Energy intensity declines over time with economic growth.
- Total energy use grows, with natural gas taking an increasing share of demand, rising to 15.1% by 2030.

TPER: India

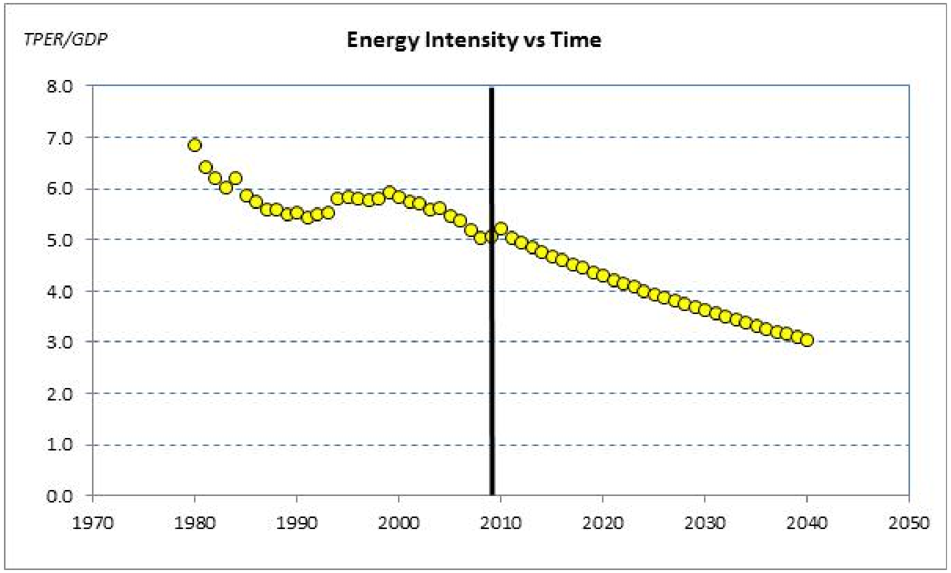


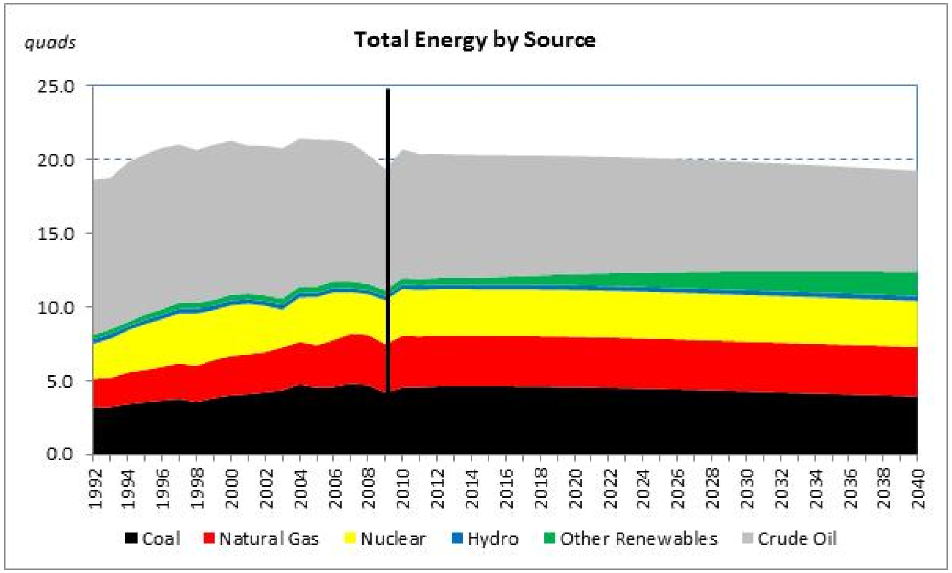


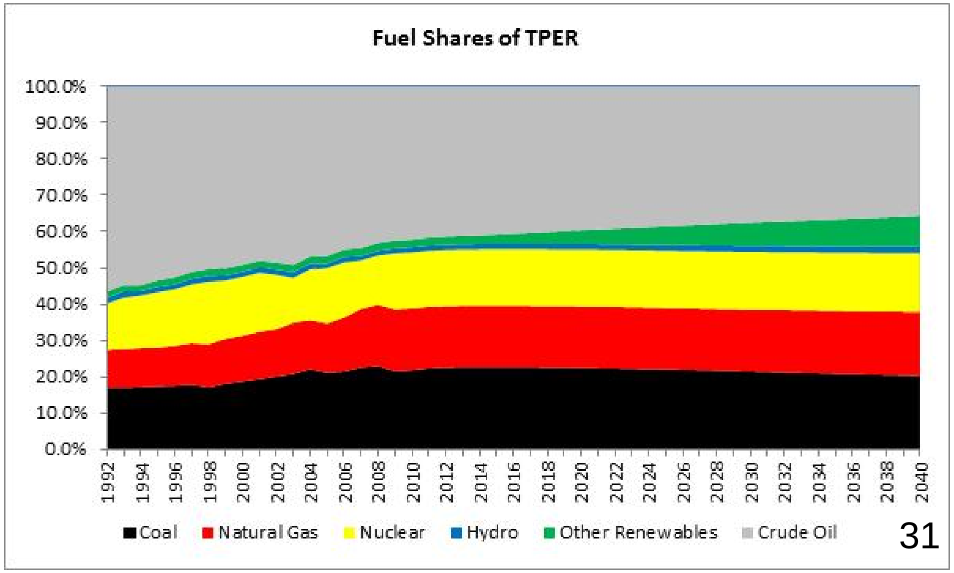


- Energy intensity declines over time with economic growth.
- Total energy use grows, with natural gas taking an increasing share of demand, rising to 13.5% by 2030.

TPER: Japan

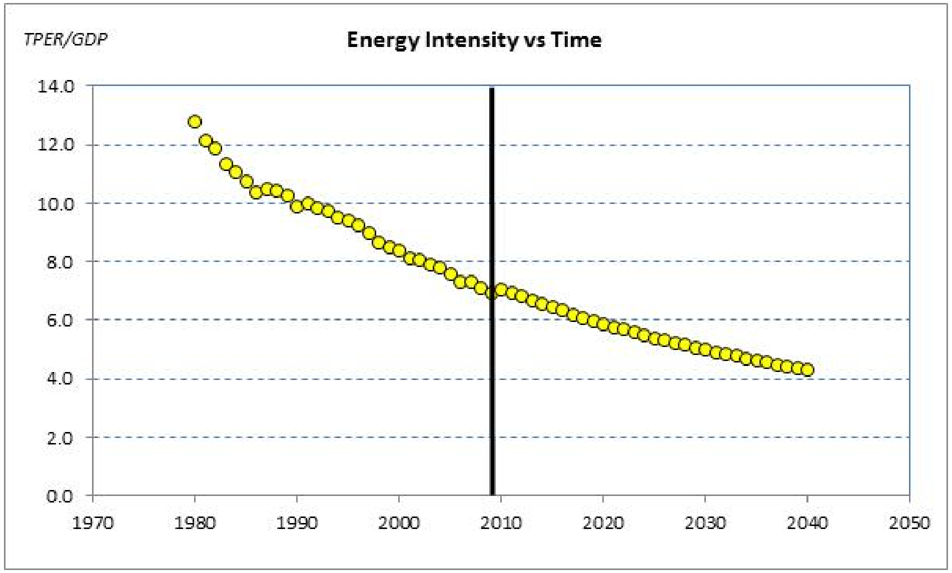


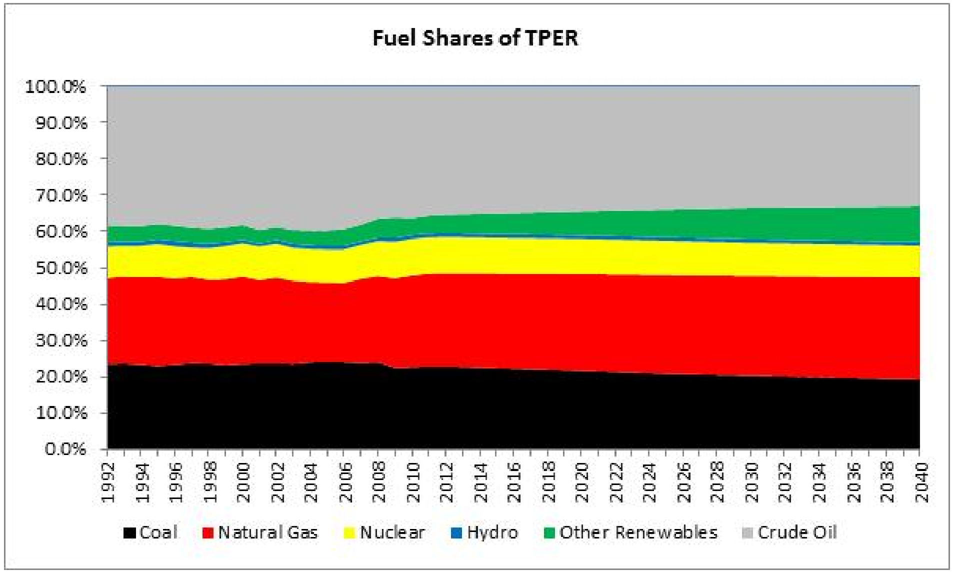




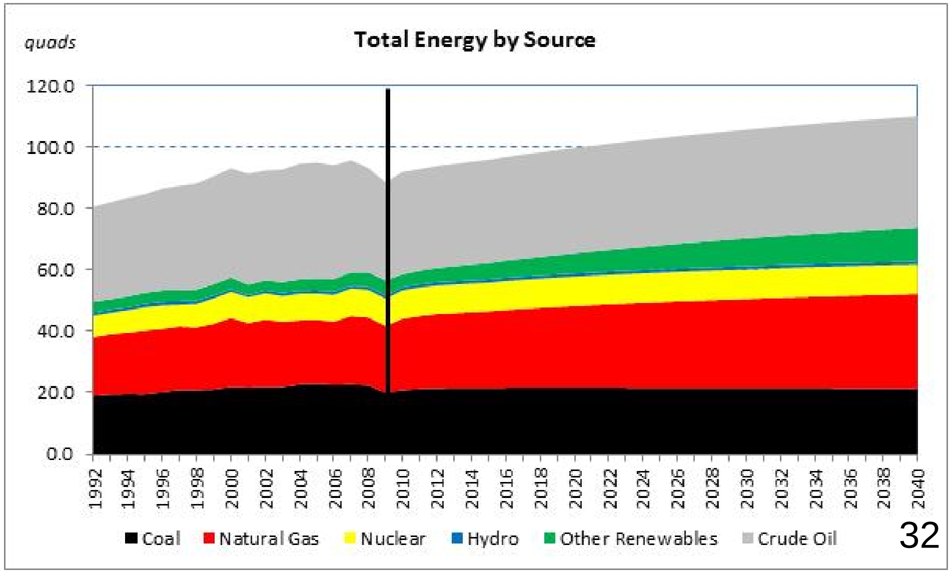
- Energy intensity declines over time with economic growth, and declining population (not pictured) leads to lower TPER.
- Nuclear declines slightly, and natural gas demand rises slightly as its share increases slightly to 18.1%.

TPER: US

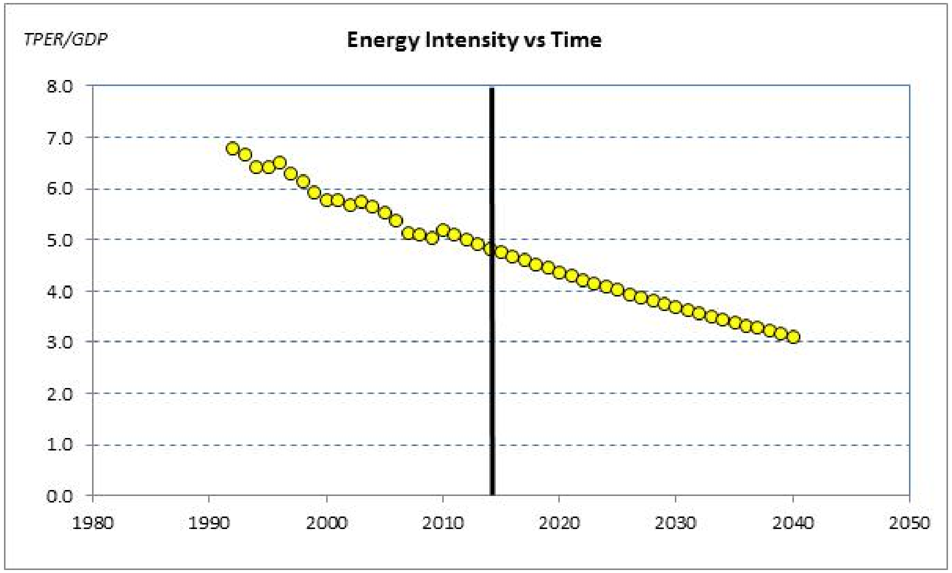


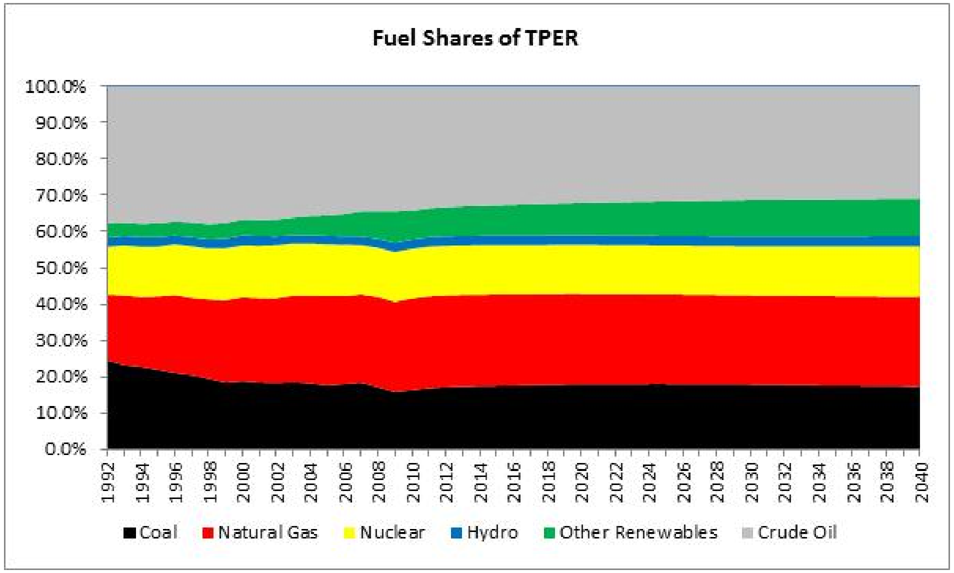


- Energy intensity declines over time with economic growth.
- Coal share declines, largely due to EPA imposed restrictions, and natural gas demand rises as its share increases to 27.5% by 2030. Renewables also grow as mandated by current state-level RPS regulations.



TPER: Europe





- Data presented as an aggregate of all European countries.
- Energy intensity declines over time with economic growth.
- Nuclear declines slightly. Natural gas demand rises despite its share remaining flat through 2030. Renewables increase to a 13.8% market share by 2030.