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The Demand for Energy and the '3Es": From Theory to Practice

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Energy Security, Environment and Efficiency

- The idea of meeting energy needs in an environmentally benign and economically competitive manner is the foundation of most conversations around the concept of 'sustainable' futures.
- Energy security is a desired goal, and its focus can differ across countries.
  - To an import dependent country, energy security generally refers to avoiding the macroeconomic dislocations associated with an unexpected disruption in supply or change in price. As such, energy security policy typically aims to secure <u>*supplies*</u> at a *reasonable* and *stable* price.
  - To an export dependent country, the definition of energy security is similar. But, energy security policy (in a long term setting) typically aims to secure <u>*demands*</u> at a *reasonable* and *stable* price.
  - The definitions of "*reasonable*" across importers and exporters is the point of contract negotiations, but the market will always clear. Price "*stability*" is another matter, but it is in the best interest of both importers and exporters in the long run.
- Environmental goals often advocate the use of less polluting fuels, which tends to turn the discussion to the deployment of renewables. In fact, the focus recently has been on CO2, but that is not the only concern.
  - If renewables are more costly than other energy technologies, there is a risk of compromising one of the tents of energy security. Nevertheless, this may be warranted in a world where price stability is relatively unachievable.
  - Pollution reduction need not equate to more renewables. What about end-use efficiency?
- Efficiency improvements in end-use technologies facilitates the provision of energy services to continue with less energy input. All around, this contributes to both tenets of energy security – *reasonable* and *stable* pricing – by mitigating demand-side pressures.

So, how do we develop a rigorous approach to forecasting energy demand that can be used to inform and evaluate policy while satisfying the 3Es?

By first recognizing the factors that contribute to energy intensity and fuel choice. Then, we can develop policy to achieve a desired outcome while minimizing the costs of doing so.

Energy Intensity vs. Energy Efficiency

- The concept of energy intensity is an accounting measure of energy demand per unit of output. It is most often applied at the macro level when modeling the relationship between energy use and economic development and is used in generating long run demand forecasts. It is measured as

$$\text{Energy Intensity} = \frac{\text{Total Primary Energy Requirement}}{\text{Gross Domestic Product}} = \frac{E}{Y}$$

- Energy efficiency is a technological assessment of energy-using capital service per unit of energy consumed. It is capital-specific, and relates to the technology embodied in the capital stock. It is generally measured as

$$\text{Energy Efficiency} = \frac{\text{Capital Service}}{\text{Energy Consumption}} = \varepsilon$$

- Importantly, energy intensity is NOT the reciprocal of energy efficiency
  - To understand the link between energy intensity and energy efficiency, we must understand the relationship between energy and capital.

Energy Intensity vs. Energy Efficiency (cont.)

- Consider the case of two countries who engage in trade with each other.
- Country A has a comparative advantage in wine production, and Country B has a comparative advantage in steel production.
- Assume each country is using the latest technology in production. Given that steel production is more energy intensive than wine production, Country A's energy intensity will be lower than Country B's.
- Is Country A more energy efficient that Country B? **No.**
- In fact, if Country A tried to make steel and Country B tried to make wine, overall **economic efficiency** would be lower and it could be that energy demand between the two countries would be higher.
- So, when evaluating energy intensity, we can try to account for trade patterns, but we must recognize that, while energy efficiency can lower energy intensity, economic structure also matters and the principle of comparative advantage conveys overall efficiency.

The Energy-Capital Relationship

- Energy is a *derived* demand. It is consumed in order to facilitate a primary service. This generally also requires some capital stock. Thus, we have

$$\text{Energy Use} = \frac{\text{Capital Stock Utilization}}{\text{Efficiency}} * \text{Capital Stock}$$

- As a simple example, let's consider personal transportation services

$$\text{Gallons of Fuel Use} \equiv \frac{\text{Miles per Vehicle}}{\text{Miles per Gallon}} * \#\text{ of Vehicles}$$

- Note this is an identity. So, vehicle fuel use increases (decreases) as
  - Vehicle use rises (falls), Vehicle stock rises (falls), Efficiency declines (increases)
- This generalizes, and is specific to a particular capital stock
  - Refrigerators, air conditioners, industrial boilers, etc.
- Applying it at a macro level requires aggregating technologies and economic sectors.

The Role of Economic Structure

- Total primary energy requirement (TPER) in an economy is the sum of TPER across all sectors of the economy

$$E = E_1 + E_2 + \ldots + E_n$$

- Thus, energy intensity can be written as

$$\frac{E}{Y} = \frac{E_1 + E_2 + \ldots + E_n}{Y} = \frac{E_1}{Y} + \frac{E_2}{Y} + \ldots + \frac{E_n}{Y} = \frac{E_1}{Y_1}\frac{Y_1}{Y} + \frac{E_2}{Y_2}\frac{Y_2}{Y} + \ldots + \frac{E_n}{Y_n}\frac{Y_n}{Y}$$

- So, energy intensity is a share-weighted sum of intensity in each sector

$$\frac{E}{Y} = \frac{E_1}{Y_1}\theta_1 + \frac{E_2}{Y_2}\theta_2 + \ldots + \frac{E_n}{Y_n}\theta_n$$

where θ_i is the share of sector i (for i = 1 n) in the economy.

- It is a simple matter to show that as more energy intensive sectors grow relative to other sectors, energy intensity of the whole economy increases.
- **This highlights a need to understand economic structure as it relates to energy intensity, particularly as policies or economic factors favor growth in certain sectors over others.**

What about Technological Change?

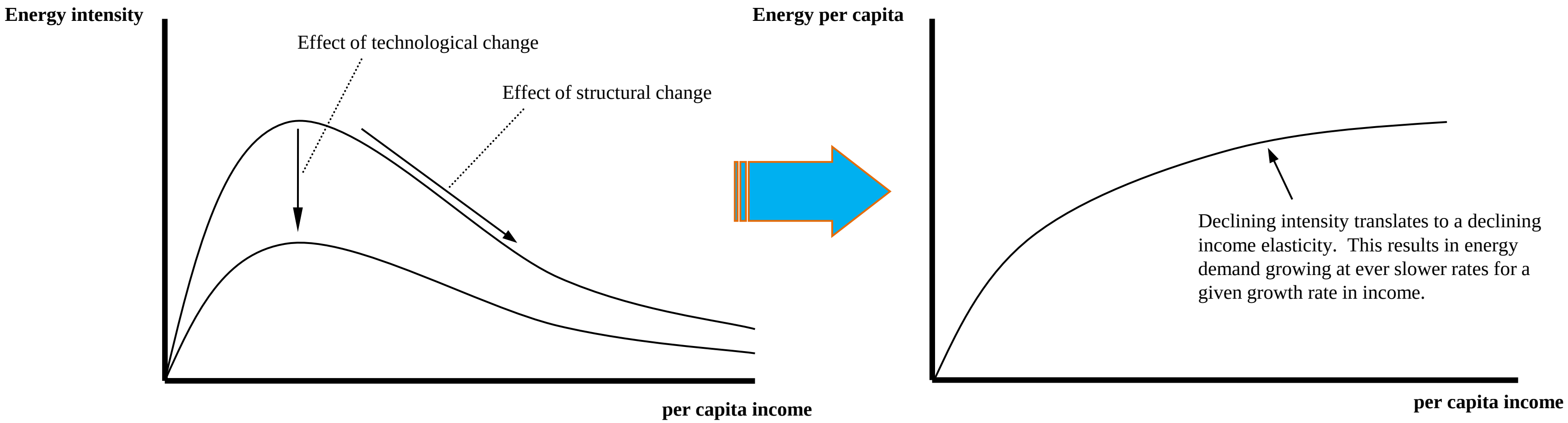
- Again noting that TPER in an economy is the sum of TPER across all sectors of the economy, but now incorporating the energy-capital relationship, we have

$$\frac{E}{Y} = \frac{\left(\frac{u_1}{\varepsilon_1} k_1\right)}{Y_1}\theta_1 + \frac{\left(\frac{u_2}{\varepsilon_2} k_2\right)}{Y_2}\theta_2 + \ldots + \frac{\left(\frac{u_n}{\varepsilon_n} k_n\right)}{Y_n}\theta_n$$

- Thus, as efficiency rise in a particular sector, that sector's contribution to energy intensity declines.
- Note this implies that policies aimed at encouraging efficiency will be more effective if they target sectors that contribute heavily to overall energy intensity, such as
  - if θ_i is large, or if ε_i is currently low.
- If policies target small sectors or those with already high efficiency, they will not be effective.
- **Pricing policies have been shown to be highly effective at influencing energy intensity by promoting efficiency.**

The Concept of Dematerialization

- Energy intensity rises then declines, consistent with shifting economic structure and patterns observed in many other raw materials, through the course of economic development.
- Of course, there are factors that force deviations from the general pattern, particularly in the short run.
- The pattern translates into a declining income elasticity of demand, which yields slower energy demand growth as per capita incomes increase.
- We see this across countries, and understanding its implications are vital to any nation's energy security aspirations – we are all connected!



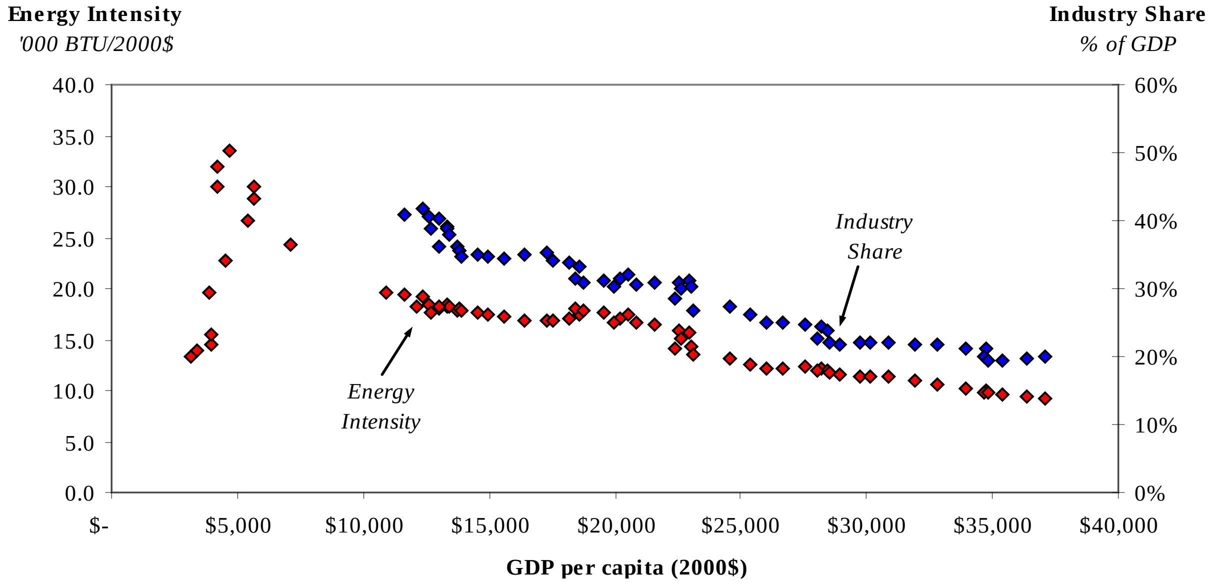
So, what do we see in the data?

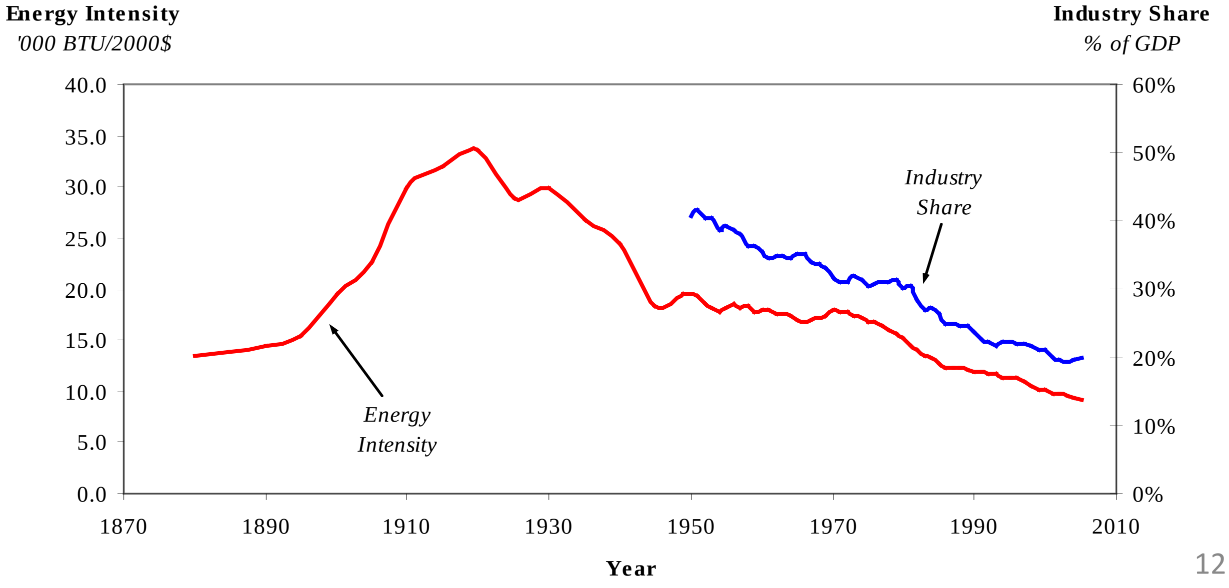
Economic Development and Energy Demand

- 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.

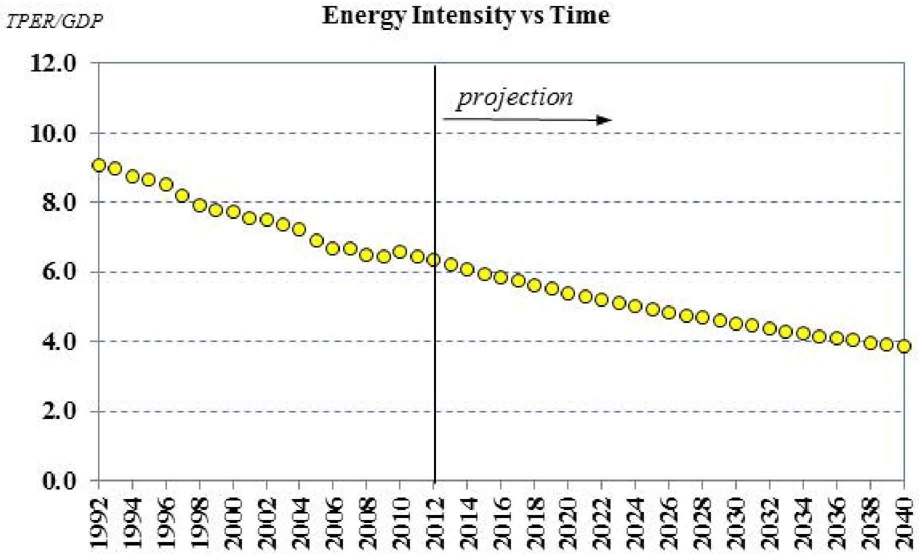
US Energy Intensity and Economic Structure

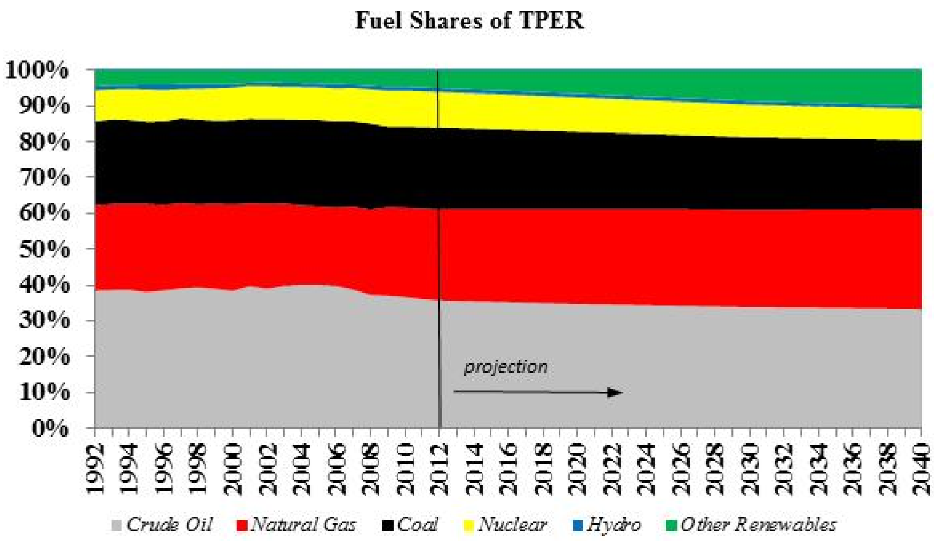
- Top graphic: energy intensity and economic structure versus per capita income.
- Bottom graphic: energy intensity and economic structure versus time.
- Do other countries follow a similar pattern? **YES**.

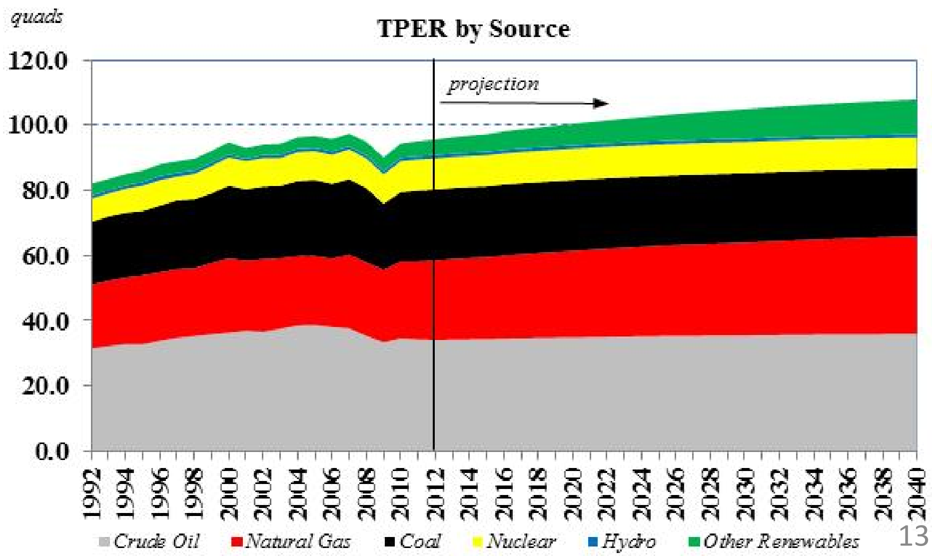




Forecasting TPER: US (baseline)

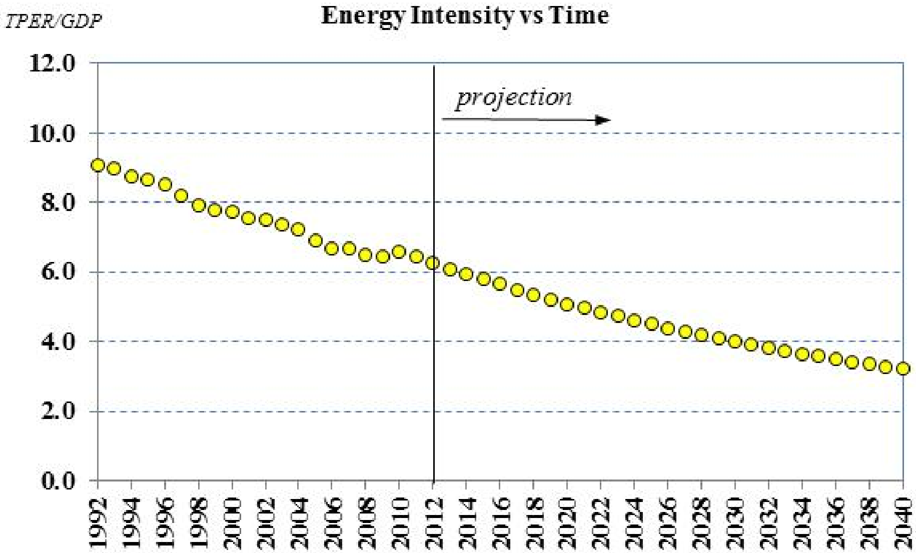


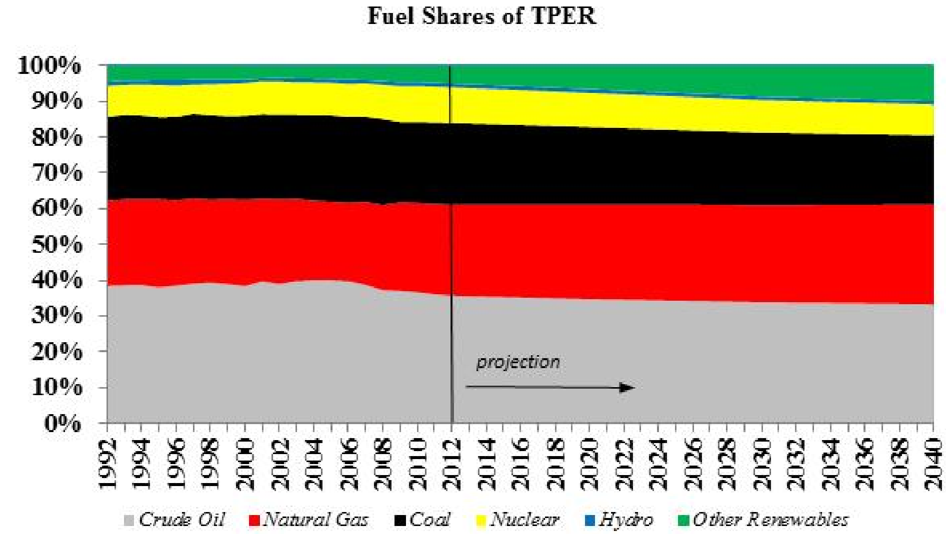


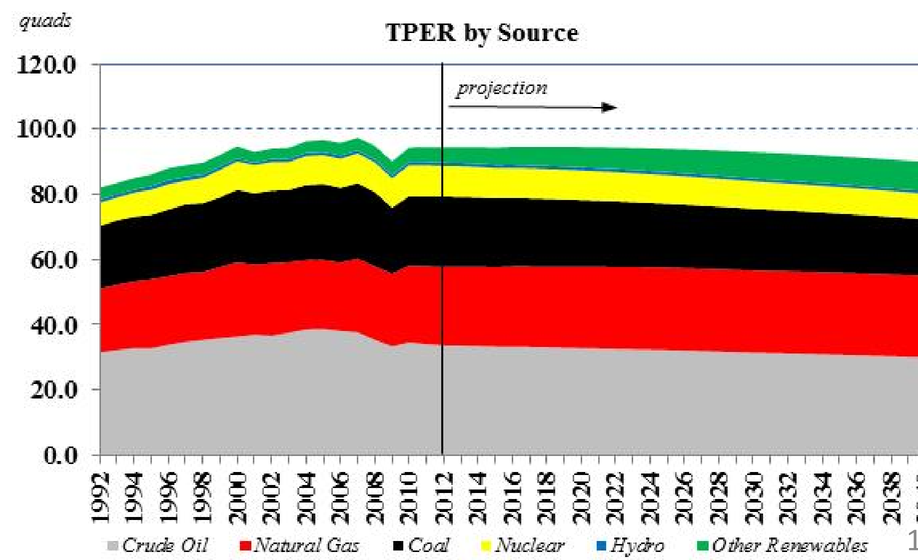


- Energy intensity declines over time with economic growth.
- Coal share declines, largely due to EPA imposed restrictions, and natural gas demand rises as its share increases to 27.5% by 2030.
- Renewables grow as mandated by state RPS regulations.

Forecasting TPER: US (2x Tech)





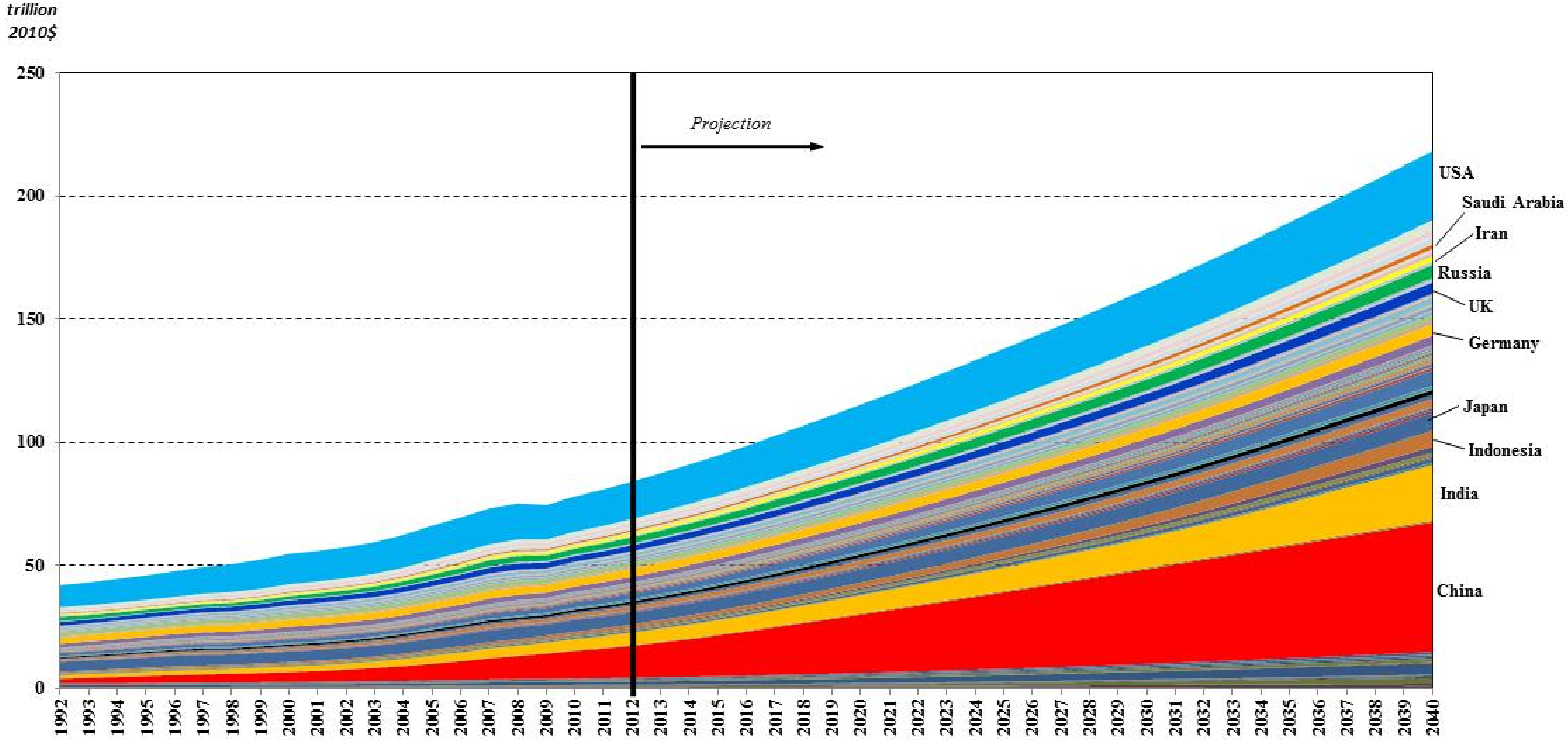


- Energy intensity declines more rapidly due to faster efficiency improvements in all sectors.
- TPER is flat to declining as a result.
- Coal share falls more rapidly.
- Oil demand is steadily declining throughout the projection.

Global Total Primary Energy Requirement (TPER)

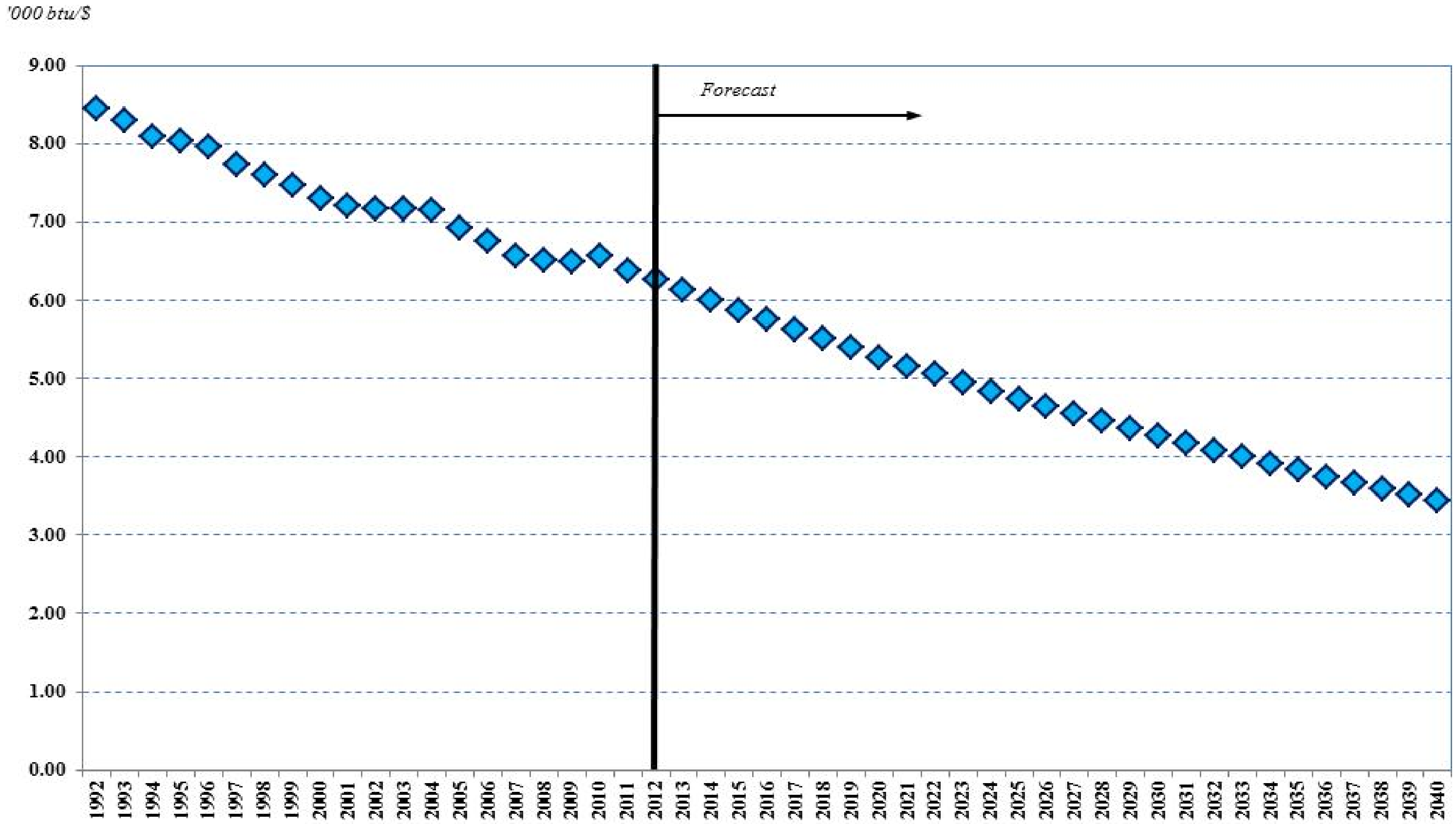
Global GDP by Country

- Baker Institute CES forecast of world GDP by country, 1992-2040 in 2010PPP$.



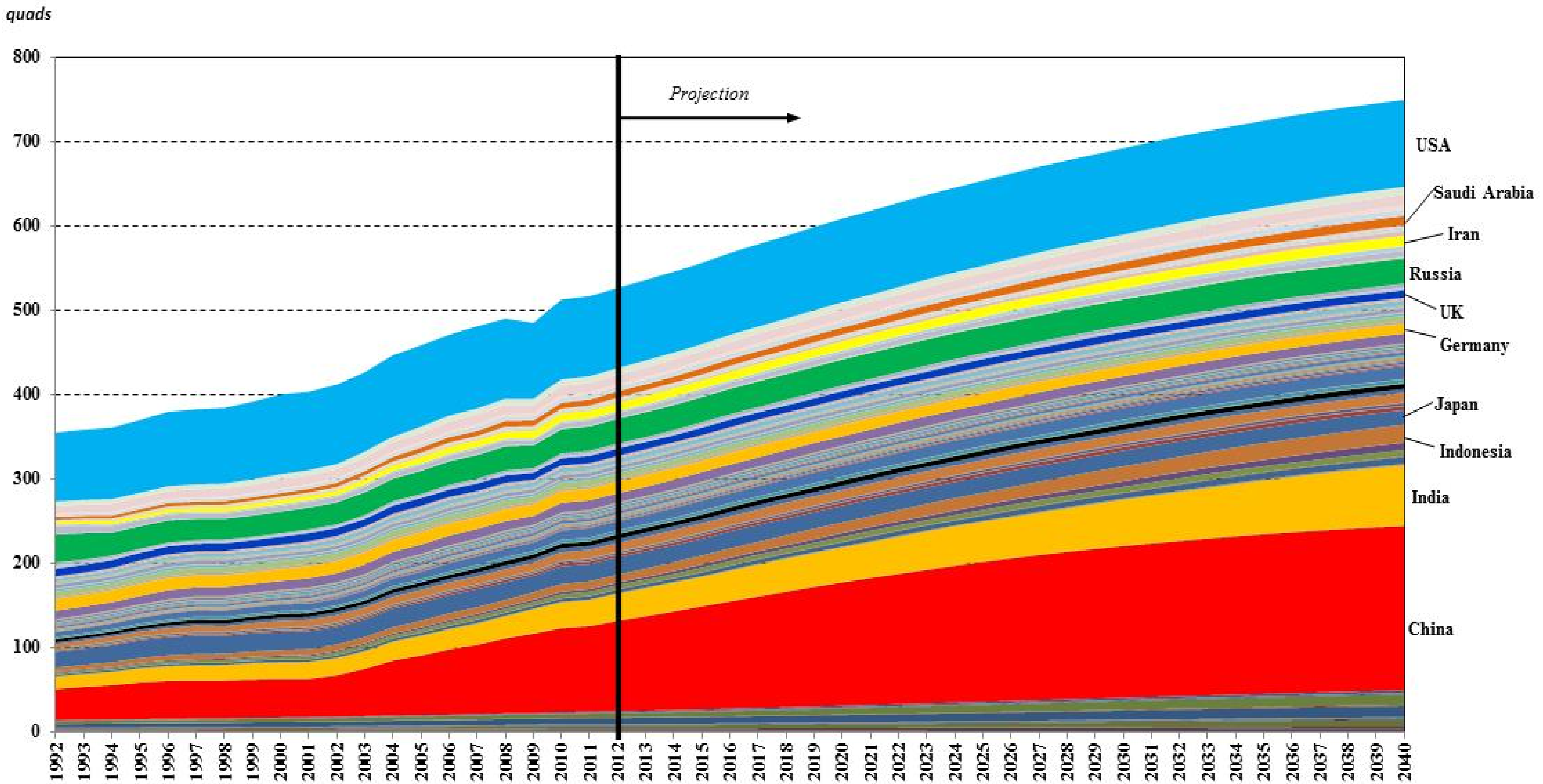
World Energy Intensity

- Baker Institute CES forecast of global energy intensity, 1992-2040



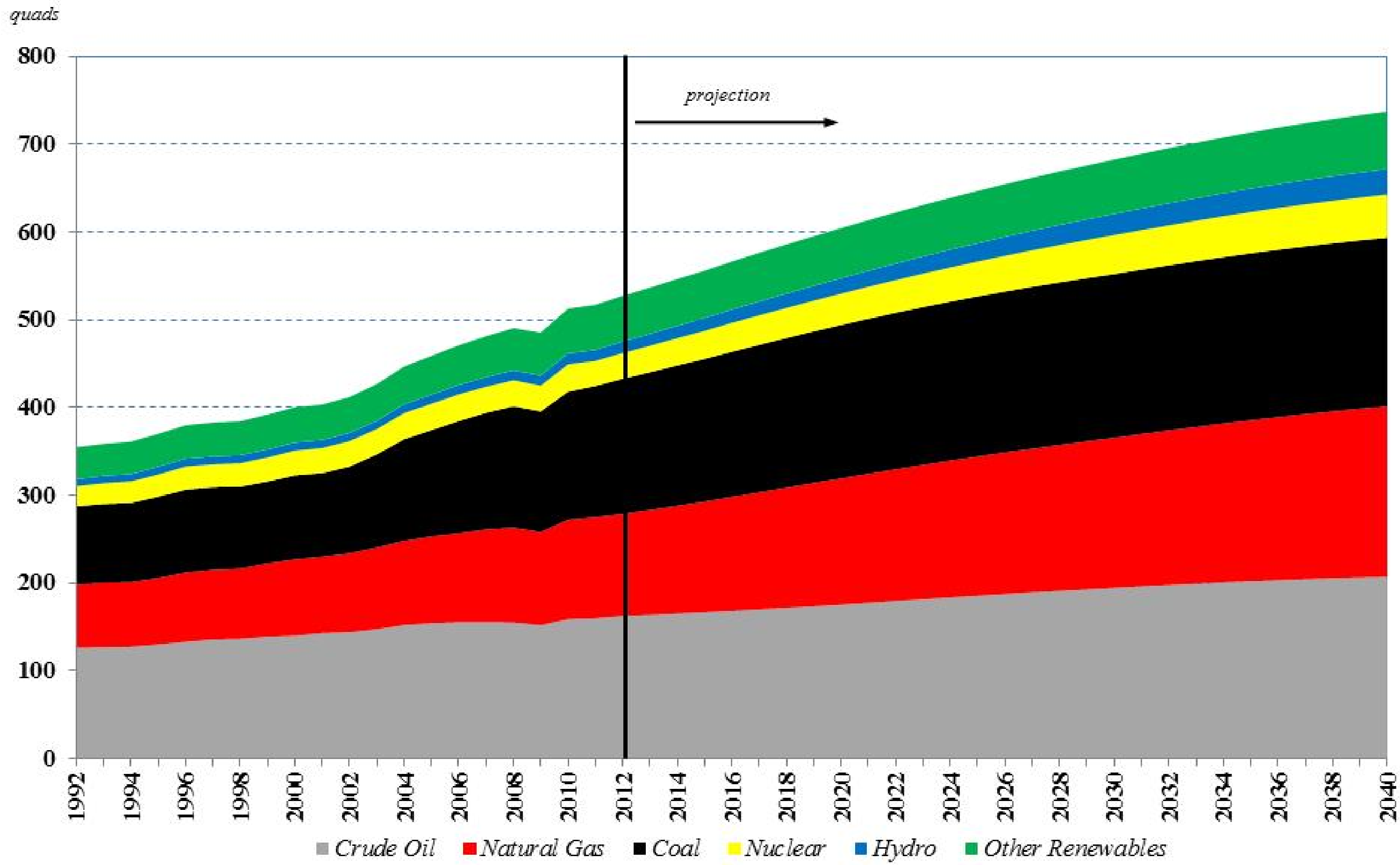
Total Primary Energy Requirement by Country

- Baker Institute CES forecast, 1992-2040



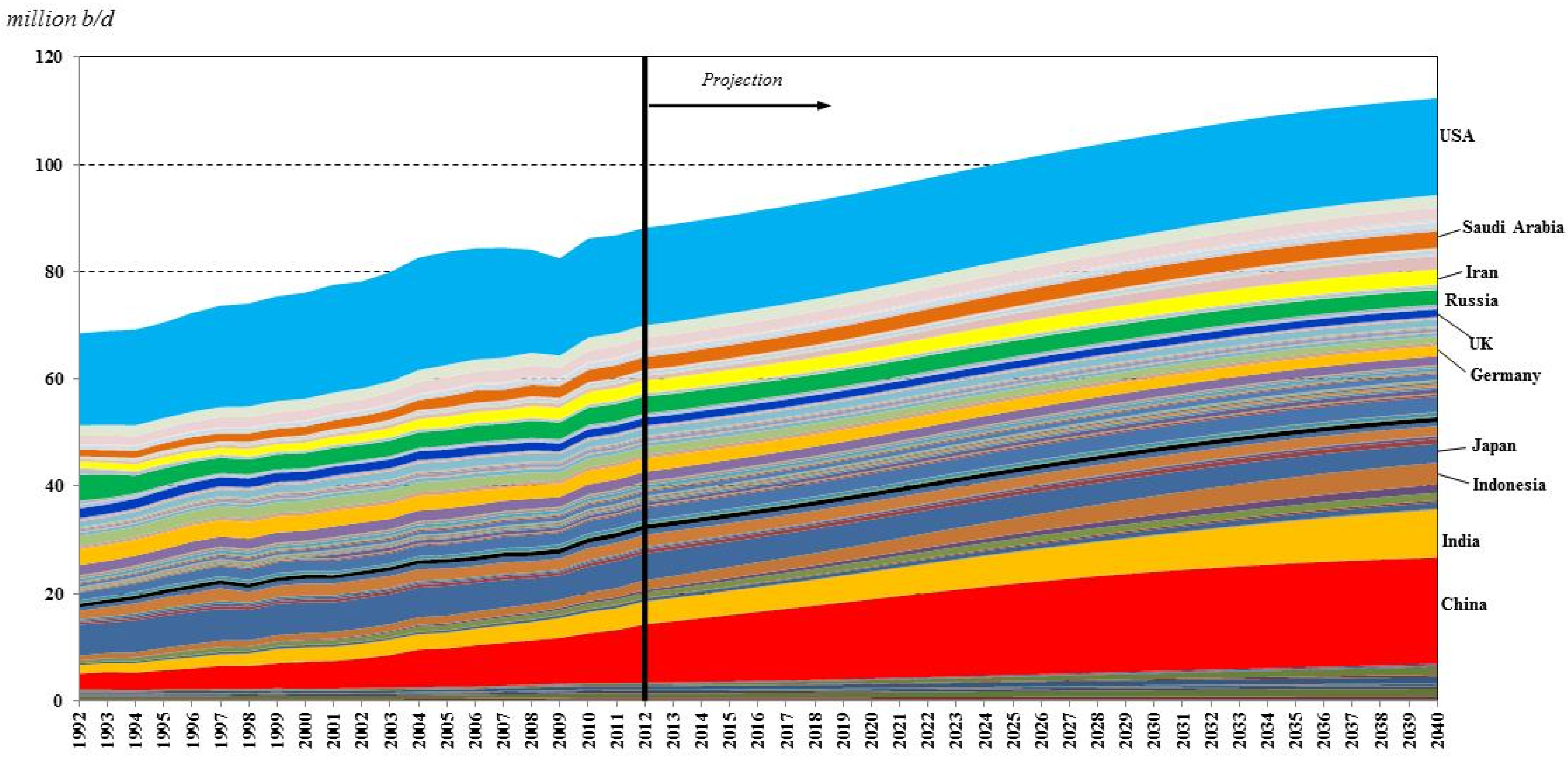
Total Primary Energy Requirement by Fuel

- Baker Institute CES forecast, 1992-2040



Oil Demand by Country

- Baker Institute CES forecast of petroleum demand by country, 1992-2040
  - Demand will continue to grow, driven largely by China and India.
  - In this construct, oil demand peaks in the mid 2050s at just over 120 million b/d.
  - Peak at 100 million b/d? If intensity drops at a rate twice that ever observed, this occurs in the mid-2030s.



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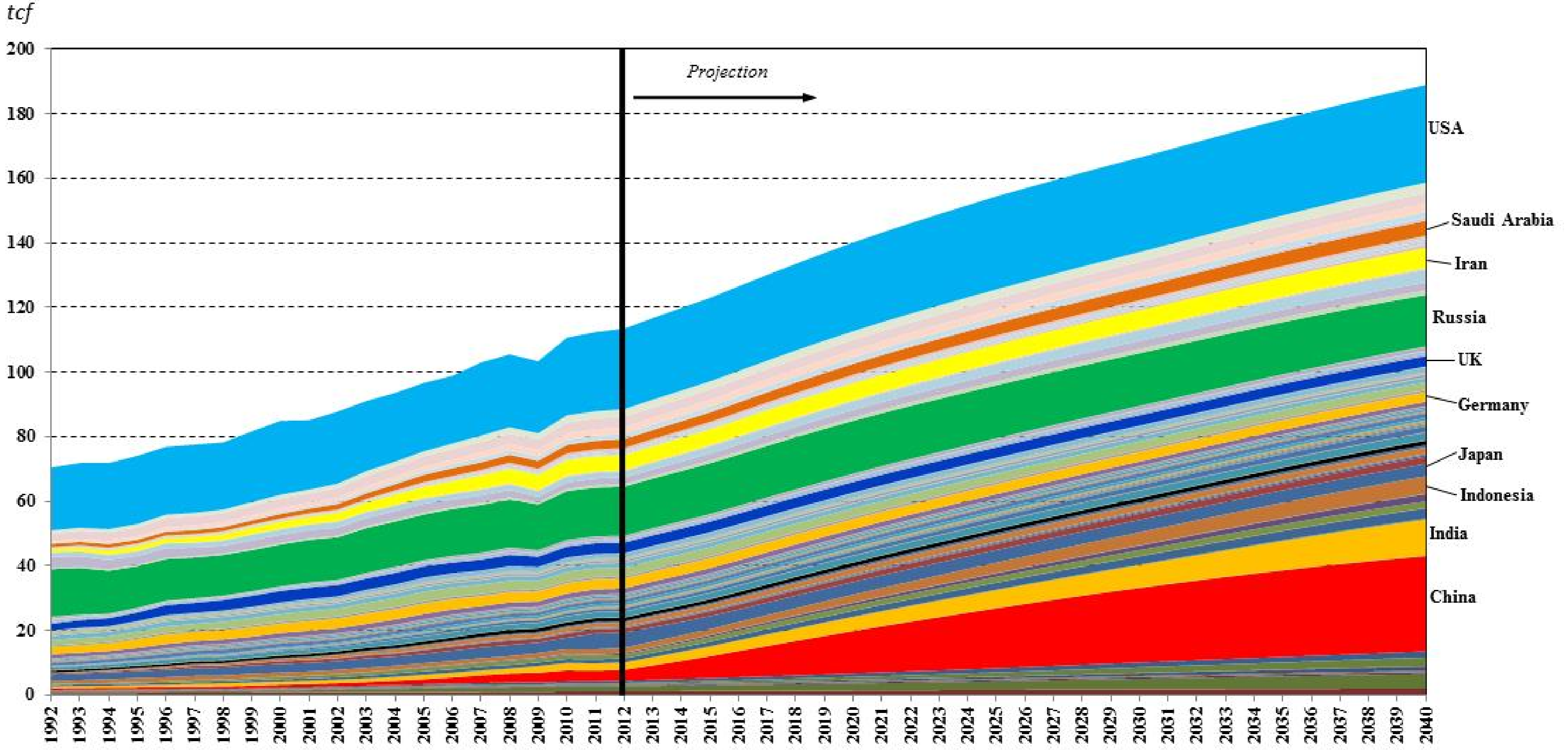
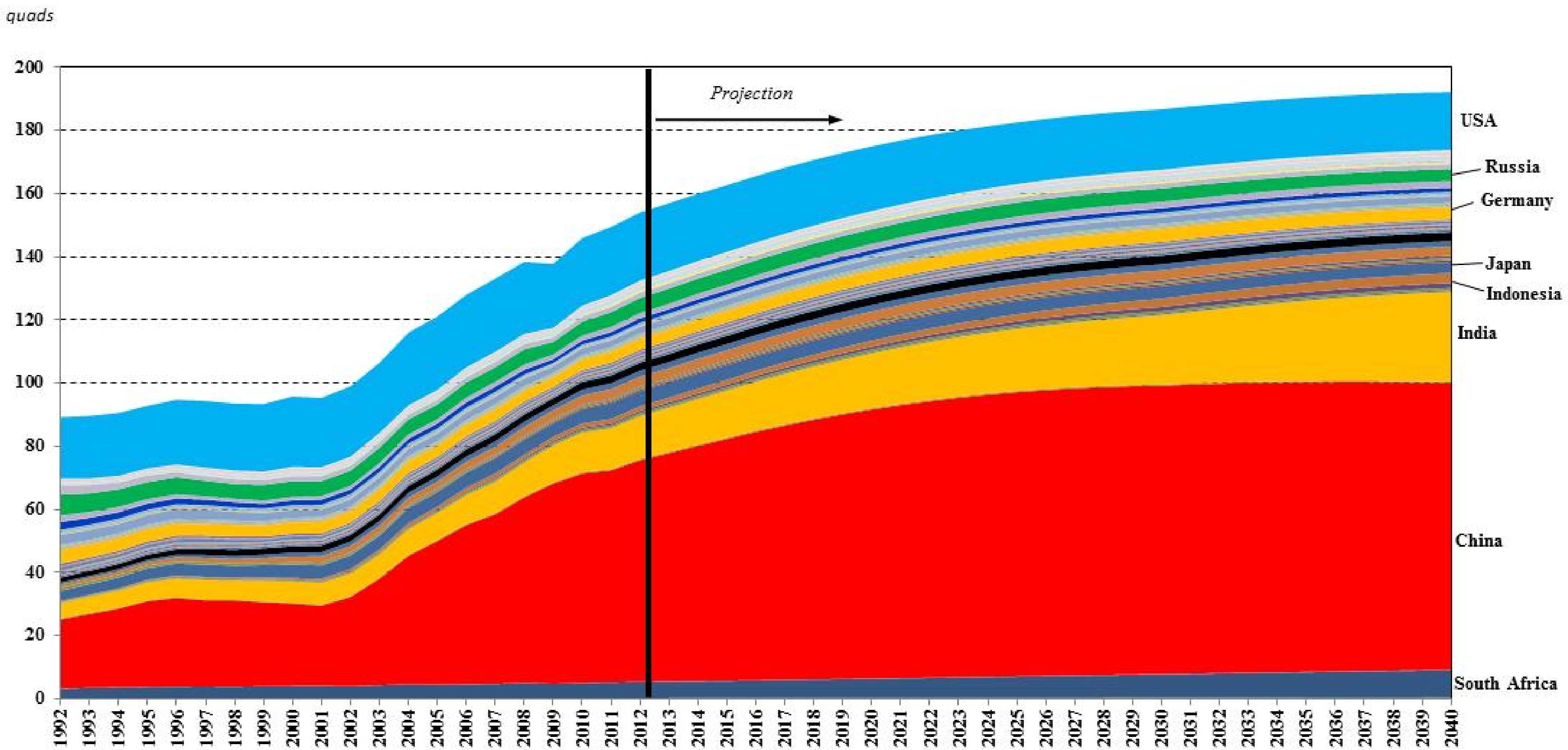
Natural Gas Demand by Country

- Baker Institute CES forecast of natural gas demand by country, 1992-2040
  - Similar patterns as with oil… demand driven by Asia
  - Unlike oil, natural gas demand continues to grow beyond 2070.



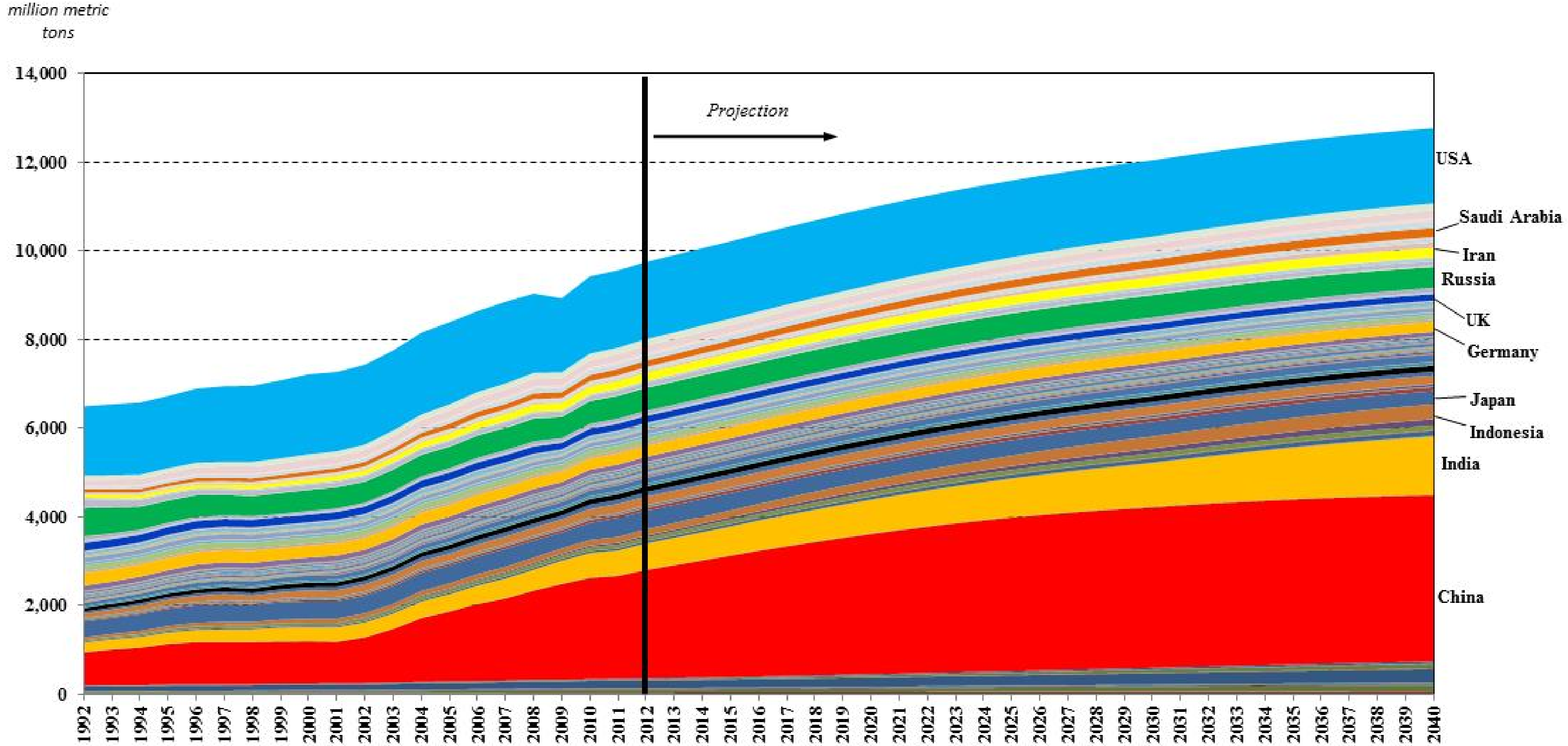
Coal Demand by Country

- Baker Institute CES forecast of coal demand by country, 1992-2040
  - Infrastructure in China has been developed around coal... will China switch away, or upgrade environmental controls? The answer will shape coal's future.



CO_2 Emissions by Country

- Baker Institute CES forecast of CO_2 emissions by country, 1992-2040. Of course, this is all contingent on the previous slides…



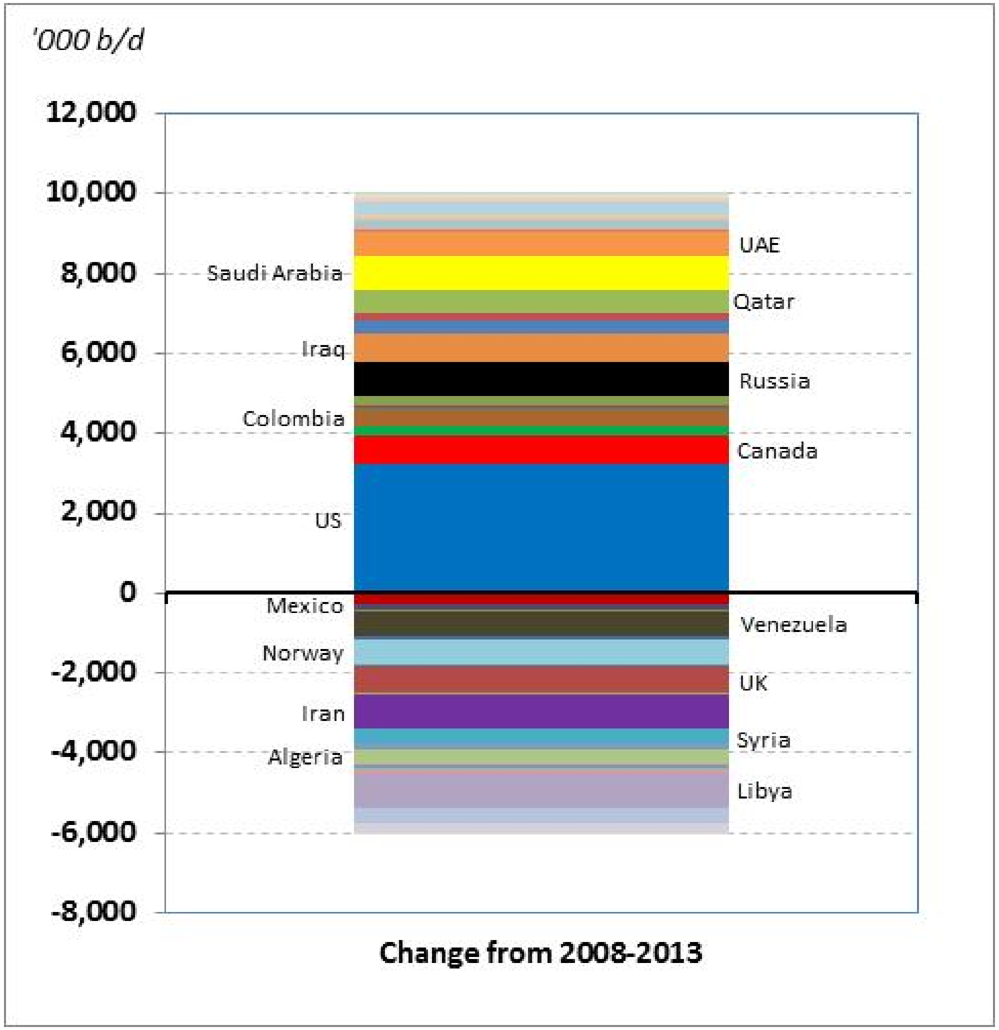
Achieving the 3Es…

Global Oil Supply – The Source Matters

- Natural declines in some provinces are being realized, in some case due to under investment.

2.3 million b/d
  - Norway: 650 thous b/d
  - UK: 700 thous b/d
  - Mexico: 300 thous b/d
  - Venezuela: 600 thous b/d
- But, strife is an ongoing threat.

2.7 million b/d
  - Syria: 350 thous b/d
  - Libya: 840 thous b/d
  - Algeria: 400 thous b/d
  - Sudan: 340 thous b/d
  - Iran: 900 thous b/d
- What about Iraq, continued growth or disruption?
  - Iraq: 3.1 million b/d



Source: BP

Technology and Frontier Resources

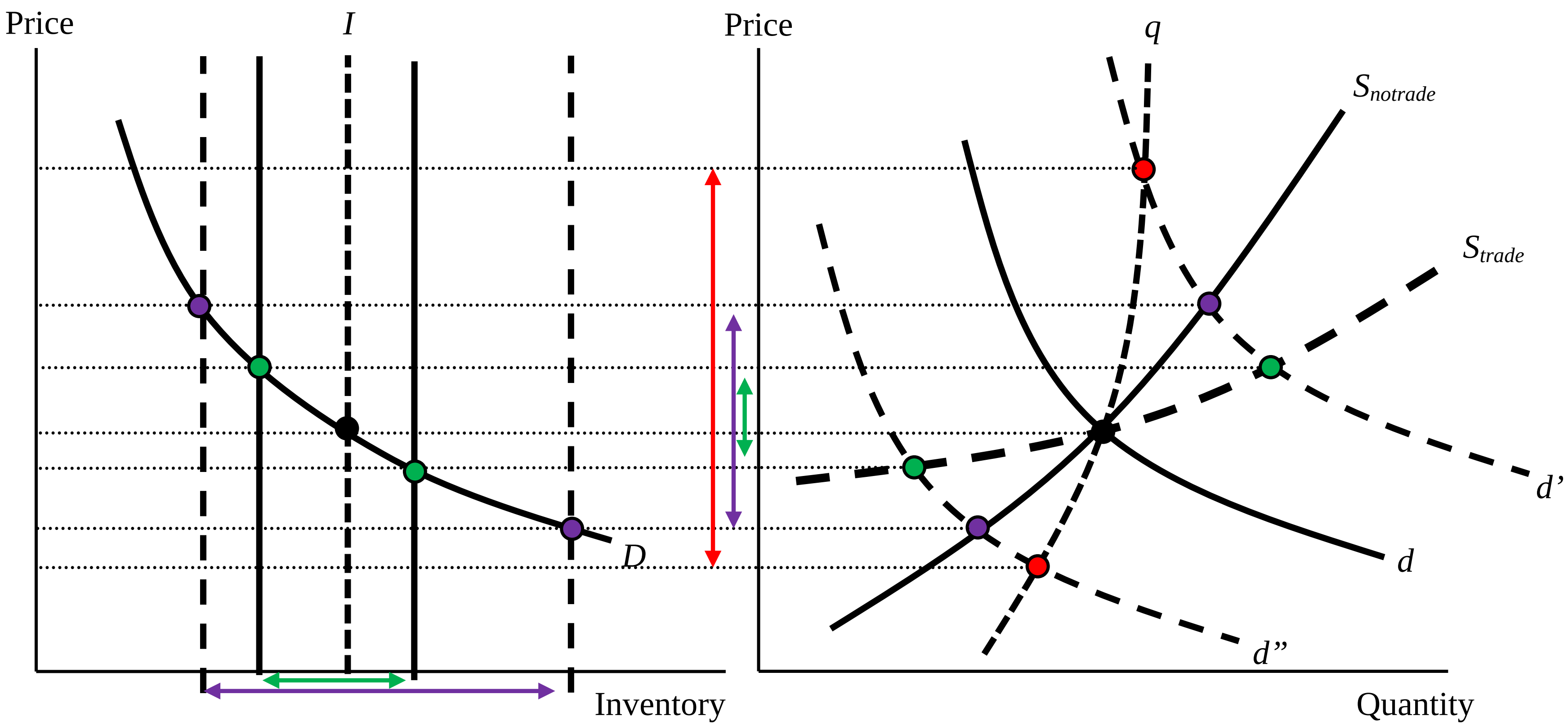
- Production growth has occurred in multiple locations, with unconventional oil resource development leading the way.
- Natural declines in some provinces, under investment in others, and civil strife is an ongoing threat. This indicates a strong need for new and *stable* supplies of oil.
- But, questions abound.
  - What does the re-entry of Iran mean for market balance?
  - What will transpire in Iraq?
  - How will sanctions directed at Russia play out?
  - What will reform in Mexico yield?
  - What about frontier resources such as pre-salt in Brazil, shale in Argentina, heavy oil in Venezuela, and oil sands in Canada?
  - What will happen with US export policy ?

Western Hemisphere

- Altogether, these trends could indicate a major shift in global oil markets. We could see a push to the Western Hemisphere for new supplies.
- Productivity gains in shale-directed activity are likely, and there is a lot of room for improvement. The current price environment will emphasize such gains.

A Note on Trade, Storage and Energy Security

- The ability to trade – through the use of inventory (intertemporal) and/or interregional movement (spatial) – lowers price volatility and provides distinct energy security benefits. So, open trade pathways contribute to energy security. This argues for a lifting of the US crude oil export ban.



Some Key Drivers of Uncertainty

- Technological change in end-use
  - CNGVs, EVs, LNG Fleets
  - What does it take to see oil demand peak at 100 million b/d? Global efficiency must grow just over 50% faster than it *ever* has. In fact, if it does, global demand will peak at that level in the mid-2030s.
  - Or, alternative fueled vehicle adoption must accelerate substantially. Could this happen in emerging economies like China and India? Unit sales in China already exceed 18 million per year, so it needs to happen now before the vehicle stock gets too large.
- Environmental Policy
  - Trade policy used as an environmental tool. Restrictions impact price and will affect both demand response and upstream investment. But, is this the appropriate path forward?
  - CO_2 targets that encourage adoption of alternatives. Notably, the CPP could result in retirement of 113 GWs of coal capacity in the US, according to CES projections. Can this be successful, or will it exert pressure on price that drives a reversal?
- Economic Growth
- Supply-side drivers
  - For example, will unconventional and frontier resource (shale, heavy oil, deep water) development see improvements in productivity that lend to price stability?

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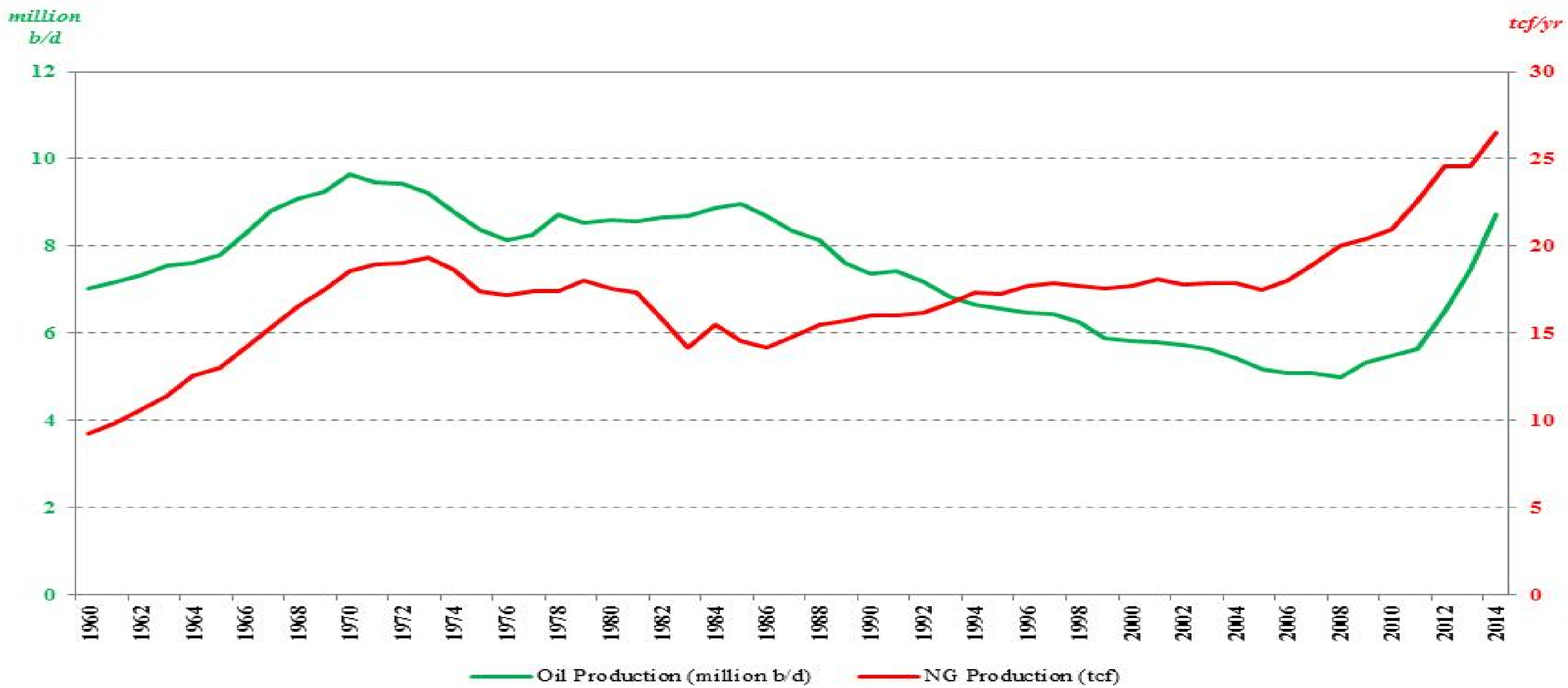
Appendix

The US Oil and Gas Production Surge

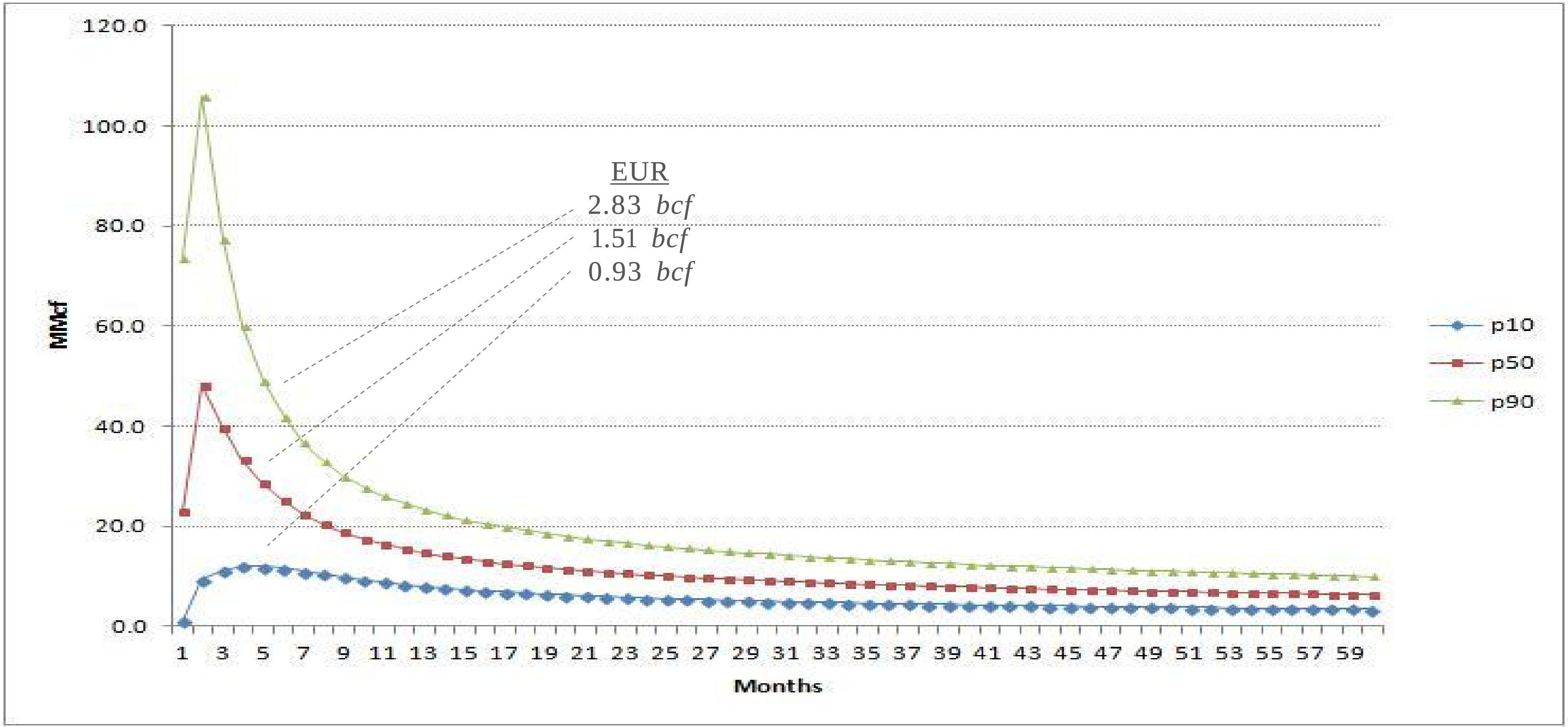
- Over the last 5 years, high price has aided growth in US oil production from unconventional reservoirs *and* old fields. In fact, the last 4 years have seen 3 of the 4 largest annual increases ever in a single country.
- Shale is at the center of the US experience.



Source: EIA

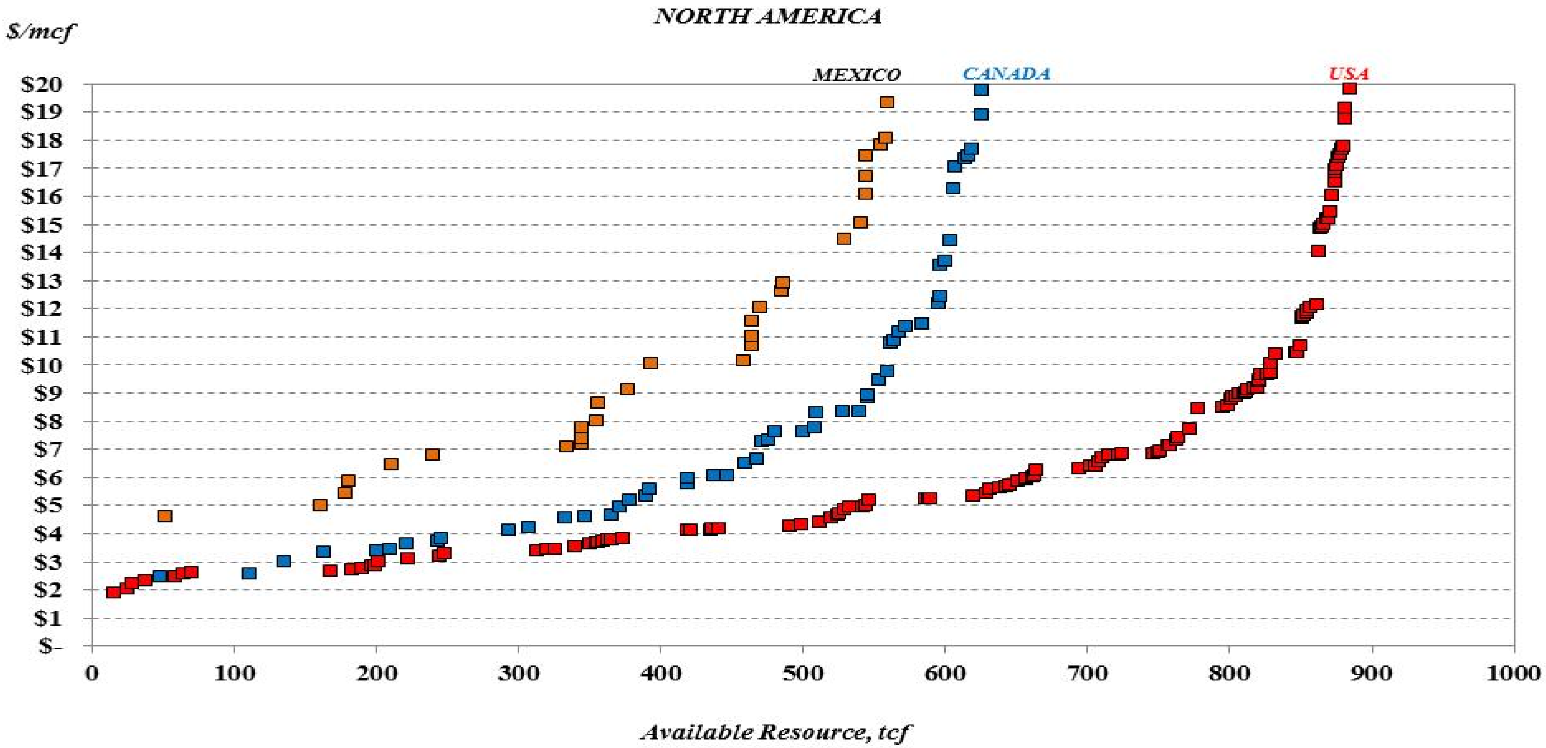
Will it Last? Shale Well Performance

- Well-specific EURs can vary within a shale play substantially
  - Ultimately, profitability matters, as there is little debate about resource scale
  - Some wells are profitable at $2.65/mcf, others need $8.10… median is $4.85.



A *Long Term* Opportunity in North America

- About 1,400 tcf of shale gas at prices below $6, making North America a driver of supply-side global gas developments for years to come.
- Importantly, sustained development will require lots of activity.



A Quick Look at the Future of the Global Natural Gas Market…

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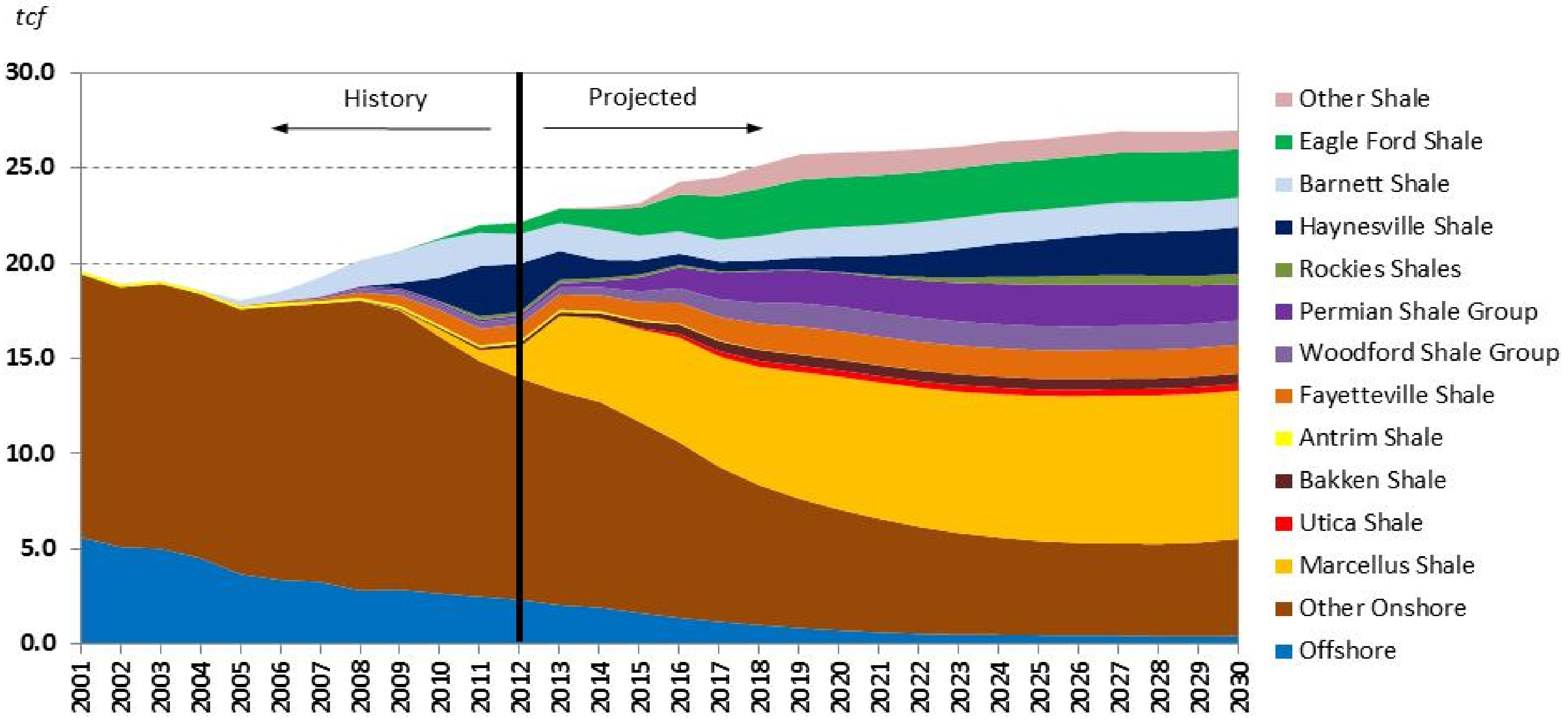
US Production – Status Quo Case (RWGTM*)

- A shale dominated picture emerges, but this only one view…



Source: BIPP CES RWGTM

*Results are from the Rice World Gas Trade Model (RWGTM) developed by Peter R Hartley and Kenneth B Medlock III. Detail on RWGTM available upon request. The RWGTM is built in the Marketbuilder platform licensed to CES by Deloitte MarketPoint Inc.

Geology *AND* market structure yields the recipe for success… and competitive advantage

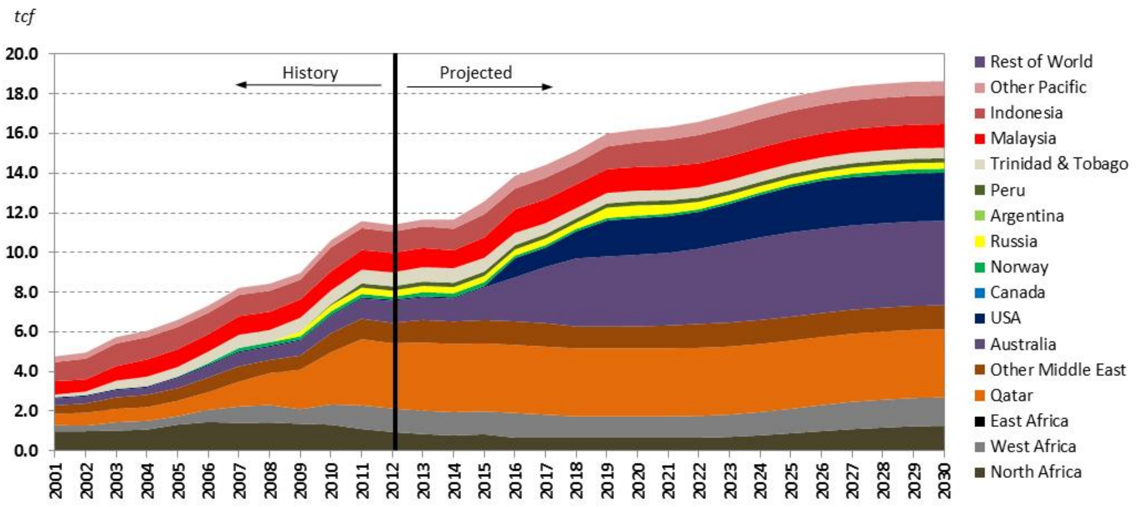
- Geology is a *necessary* condition for vibrant and successful upstream activity…
- … but it is NOT *sufficient*!
- A host of above ground factors must be aligned for commercial success to be realized.
- Once in play, commercial success builds on itself because it encourages entrepreneurial activity, and creates an environment that is attractive to capital inflows.
- Thus, a variety of regulatory and market institutions must be in place if North America is to reach its full potential in terms of energy security and economic well-being.

The *sufficient* conditions…

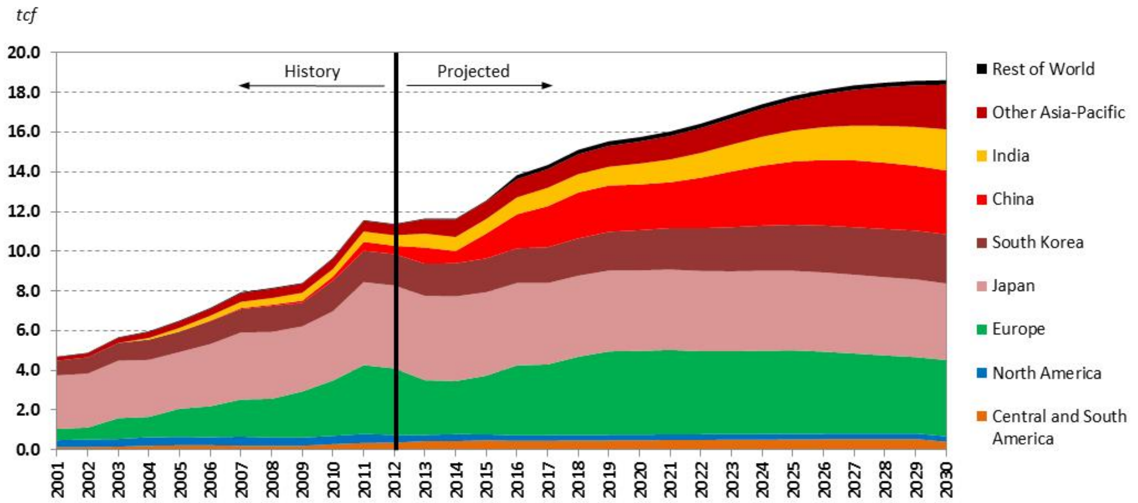
- Upstream firms negotiate directly with landowners for access to mineral rights.
- A market in which liquid pricing locations, or hubs, exist and are easily accessed due to liberalized transportation services being unbundled from pipeline ownership.
- A well-developed pipeline network that can accommodate new production volumes.
- A market in which interstate pipeline development is relatively seamless due to a well-established governing body – the Federal Energy Regulatory Commission (FERC) – and a comparatively straightforward regulatory approval process.
- A market in which demand pull is sufficient, and can materialize with minimal regulatory impediment thus allowing new supplies to compete for market share.
- A market where a well-developed service sector exists that can facilitate fast-paced drilling activity and provide rapid response to demands in the field.
- A competitive service sector that strives to lower costs and advance technologies in order to gain a commercial advantage.
- A rig fleet that is capable of responding to upstream demands without constraint.
- A deep set of upstream actors – the independent producer – that can behave as the "entrepreneur" thereby facilitating a flow of capital into the field toward smaller scale, riskier ventures than those typically engaged by vertically integrated majors.

Global LNG trade will grow, …

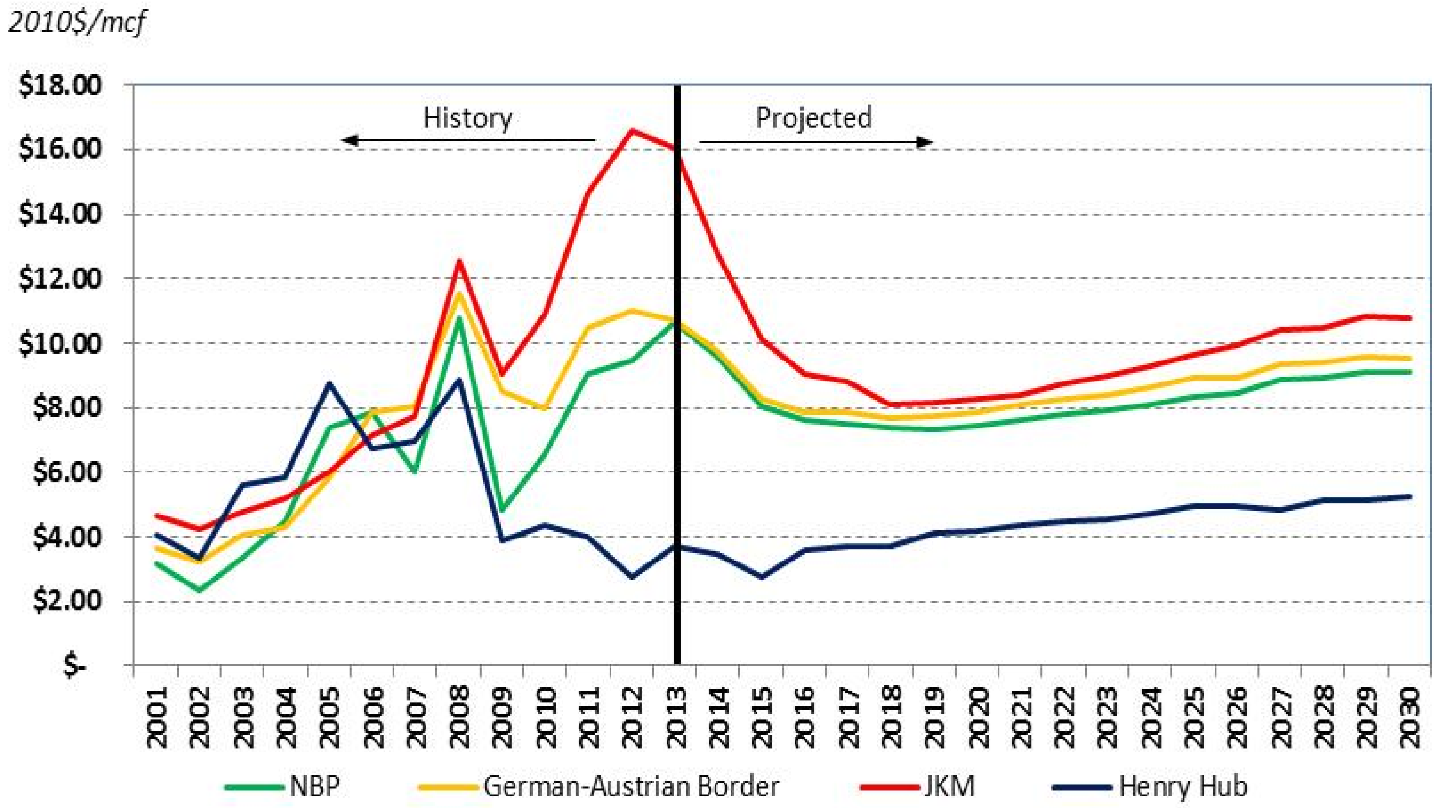
- LNG exports increase in multiple locations and…



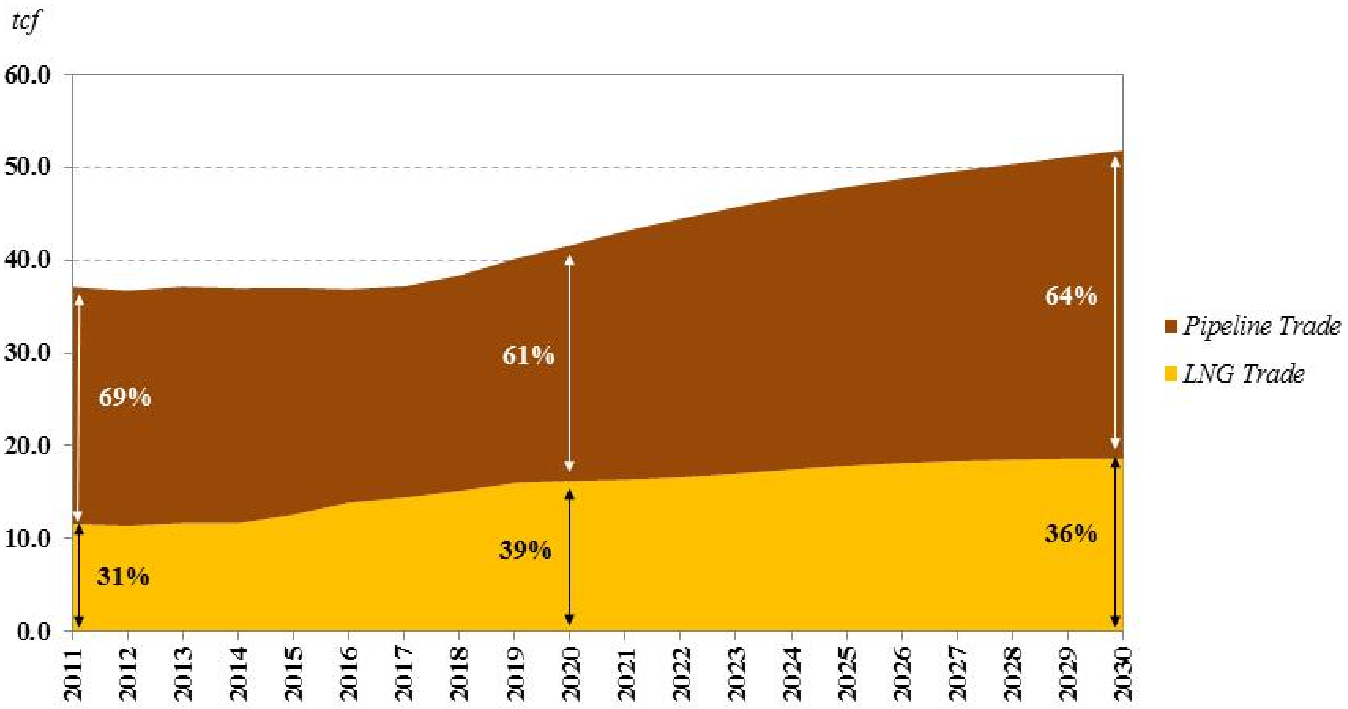
- … new consumers enter the market as global demands increase.



… constraints are relieved and prices will moderate to reflect transportation costs…



… and LNG is an important "balancing" mechanism in the global market.*



* The results herein are taken from the Rice World Gas Trade Model (RWGTM). The RWGTM was developed by Kenneth B Medlock III and Peter Hartley at Rice University using the MarketBuilder software platform provided through a research license with Deloitte MarketPoint, Inc. The architecture of the RWGTM, the data inputs, and modeled political dimensions are distinct to Rice and its researchers.