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Rice University World Gas Trade Model

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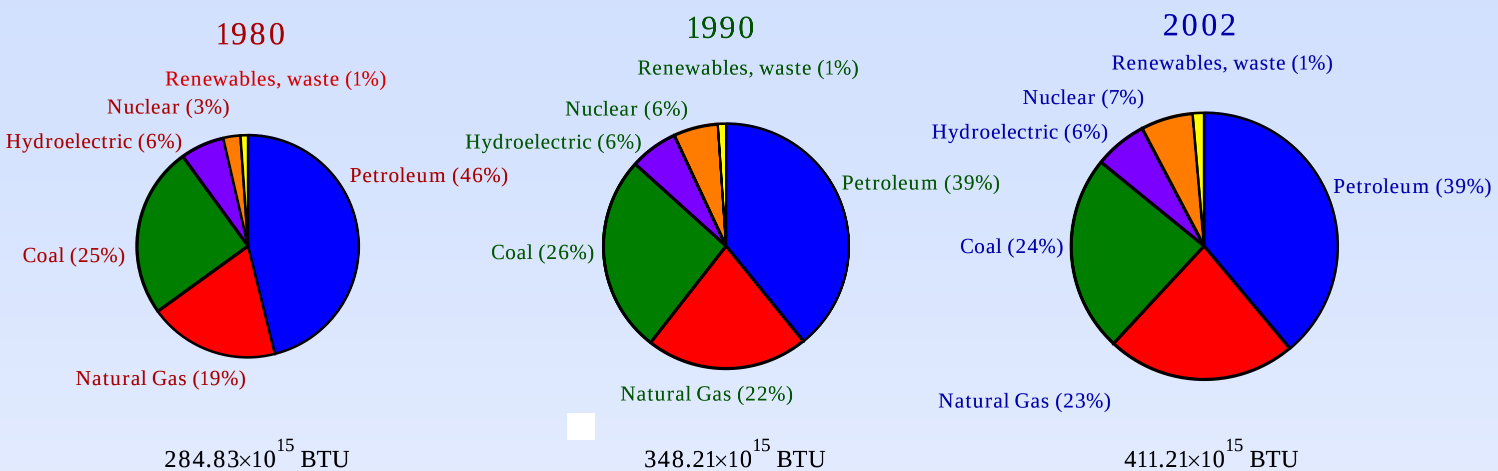
Overview and motivation

- Share of gas in primary energy supply is rising:



Source: EIA

- Environmental pressure for cleaner fuels
- Pro-competitive deregulation of wholesale electricity markets and the development of CCGT
- Gas may supply transport fuel needs (GTL, tar sands, fuel cell)
- Possible contrary influence is that coal gasification, solar, hydro and/or nuclear power could displace gas in electricity generation, perhaps assisted by falling costs of HVDC

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Overview and motivation

- World gas supply potential is large, but:
  - The growth in energy demand in China, India is rapid
  - Gas share of energy demand is rising in developed world
  - North American, North Sea reserves are declining
  - Gas reserves are concentrated in areas remote from markets
  - Production and transport infrastructure is required
  - Unstable political regimes may make investments unattractive
  - Prices need to rise to finance the needed investments
- Russia could be a big supplier of natural gas to both Europe and Asia, making developments there critical
- The Rice World Gas Trade Model (RWGTM) gives a microeconomic framework to examine political and economic influences on the gas market

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Rice World Gas Trade Model

- Model framework: *Market Builder* from *Altos Partners*
  - Calculate *equilibrium* prices and quantities across a fixed number of locations and time periods
    - In each period, allow gas to be produced or transported until there are no opportunities for profitable spatial arbitrage
      - Transport links transmit prices as well as gas – for example, linking to a high priced market raises prices at the supply node
    - Producers schedule resource extraction to eliminate profitable (in *net present value* terms) temporal arbitrage opportunities
      - High current prices accelerate depletion, raising future prices
      - Also, if producers *anticipate* high prices in future period *t*, they may
        - delay some supply from periods before *t*, raising prices before *t*
        - accelerate investment to exploit those prices, affecting prices after *t*
        - The arbitrage actions imply actual prices at *t* would not rise as much
    - Price changes affect future as well as current consumer demand
      - For this reason, too, current prices affect future prices
- Model supply data is based on USGS *World Resource Assessment* updated with latest reserve revisions
- Demand forecasts based on EIA *International Energy Outlook* 2004 and IEA *World Energy Outlook* 2002

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Why a <u>world</u> market model?

- The model examines a *world* market of expanding depth and geographical extent
- Transition to a world market could be rapid
  - An *expectation* of new market dynamics encourages moving away from bilateral trading
    - More *potential* trading partners lowers the risk of investing without complete long-term contract coverage
    - A decrease in average distances between suppliers and/or customers increases arbitrage opportunities
- Bilateral contracts can be fulfilled by *swap agreements* as increased market depth increases the number of profitable alternatives
  - Contracts can be viewed as financial arrangements that do not necessarily constrain physical trades

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Estimating gas demand

- Used 23 years of IEA data from 29 OECD economies to relate per capita natural gas demand to:
  - Level of economic development (GDP/capita)
    - Following Medlock and Soligo (2001), demand increases less with increased GDP/capita as an economy develops
  - Prices (wholesale industrial$/BTU) of natural gas, oil and coal
    - Estimated impact price elasticities are -0.091, 0.076, 0.024
    - There is a lagged response to price changes
      - Effects accumulate over time with long-run elasticities that are around 10 times larger than the impact elasticities
- Demand for gas in country *i* in year *t* is then given by

$$Q_{it} = A_{it}\left(p_{it}^{g}\right)^{-0.091}\left(p_{it}^{o}\right)^{0.076}\left(p_{it}^{c}\right)^{0.024}\left(Q_{it-1}\right)^{0.92}$$

for country and year intercepts A_{it} calibrated, as discussed below, to reflect the effects of economic and population growth and other country-specific factors

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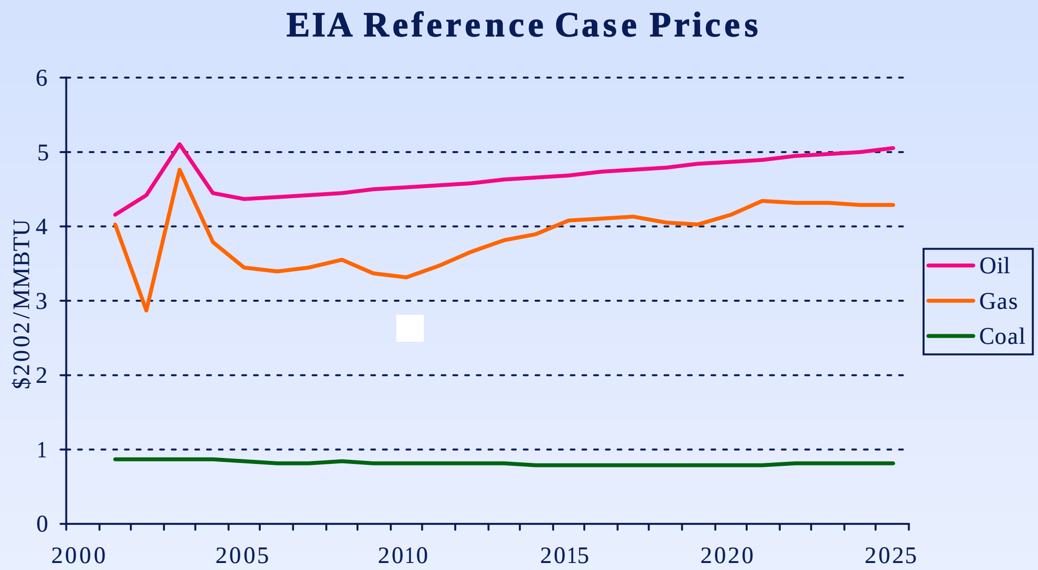
Calibrating demand growth

- Start with EIA "reference case" forecasts of demand growth based on average expected GDP and population growth rates and the following prices of oil, gas and coal in the US



- Carry the price projections forward to 2040, maintaining the oil price growth rate and average inter-fuel price relativities
- Use the RWGTM with 2002 infrastructure to calculate location specific discounts/premiums on the US gas prices and hence projected prices p_{it}
- Choose A_{it} so the calculated demand at projected oil, coal and gas prices p_{it} equals the EIA reference case forecast demand in country i and year t

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Backstop technology

- Expected future prices affect current supply and price
- Estimated demand elasticity reflects historical substitution possibilities, not potential ones
  - Technological change is difficult to predict, but
    - IGCC, nuclear and renewable sources provide alternative sources of electricity supply
    - DOE says IGCC competitive at $4 per Mcf of gas
    - Gasification of coal may also satisfy other uses
- We assume that, starting in 2030, demand is lost to new technologies at prices above $5 with up to 2.5% lost at $5.50 and 5% lost at $10
  - Each year, the proportion of demand vulnerable to the backstop at each price above $5 increases until in 2040 all base case demand could be satisfied at a price of $10

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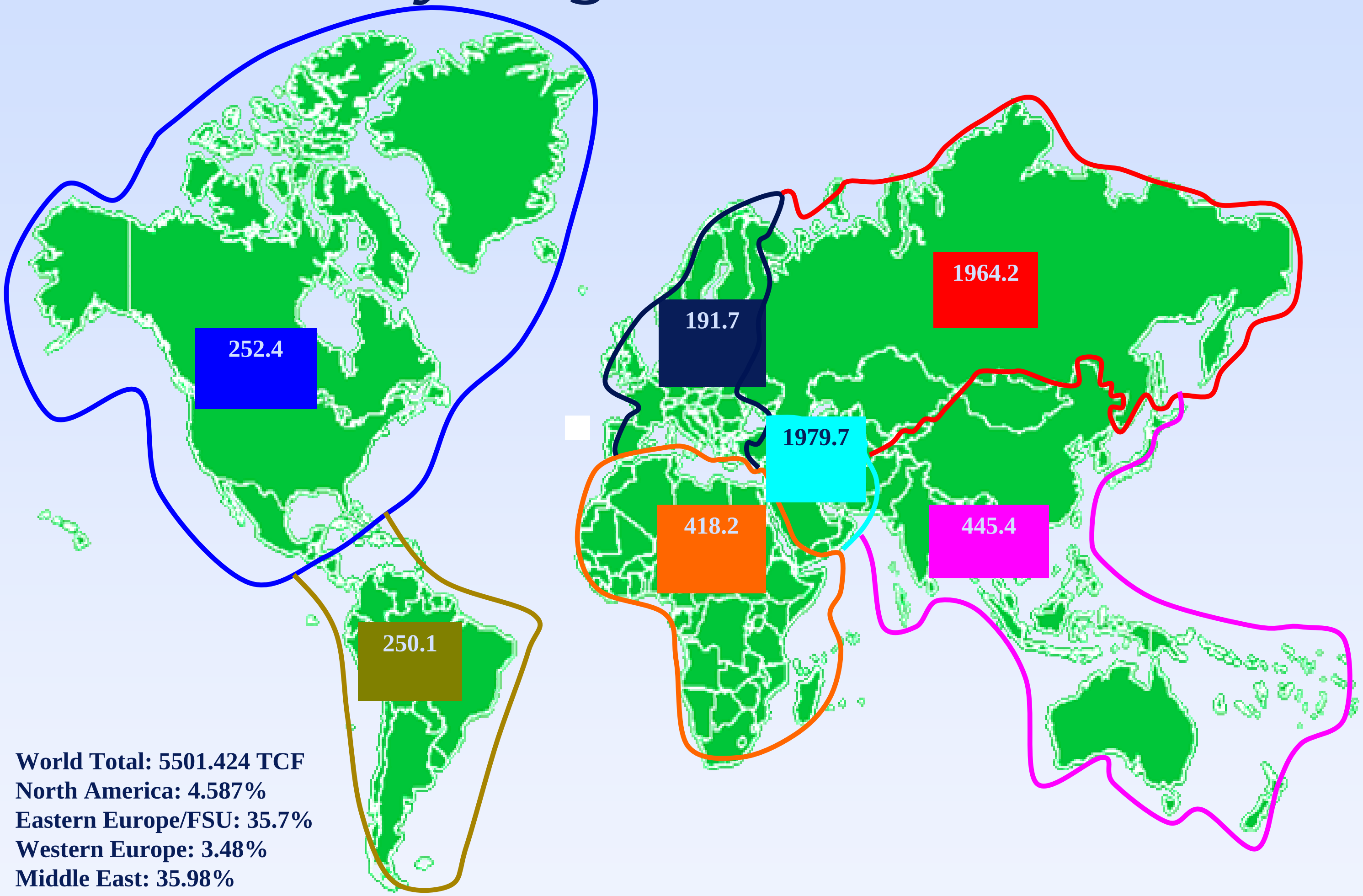
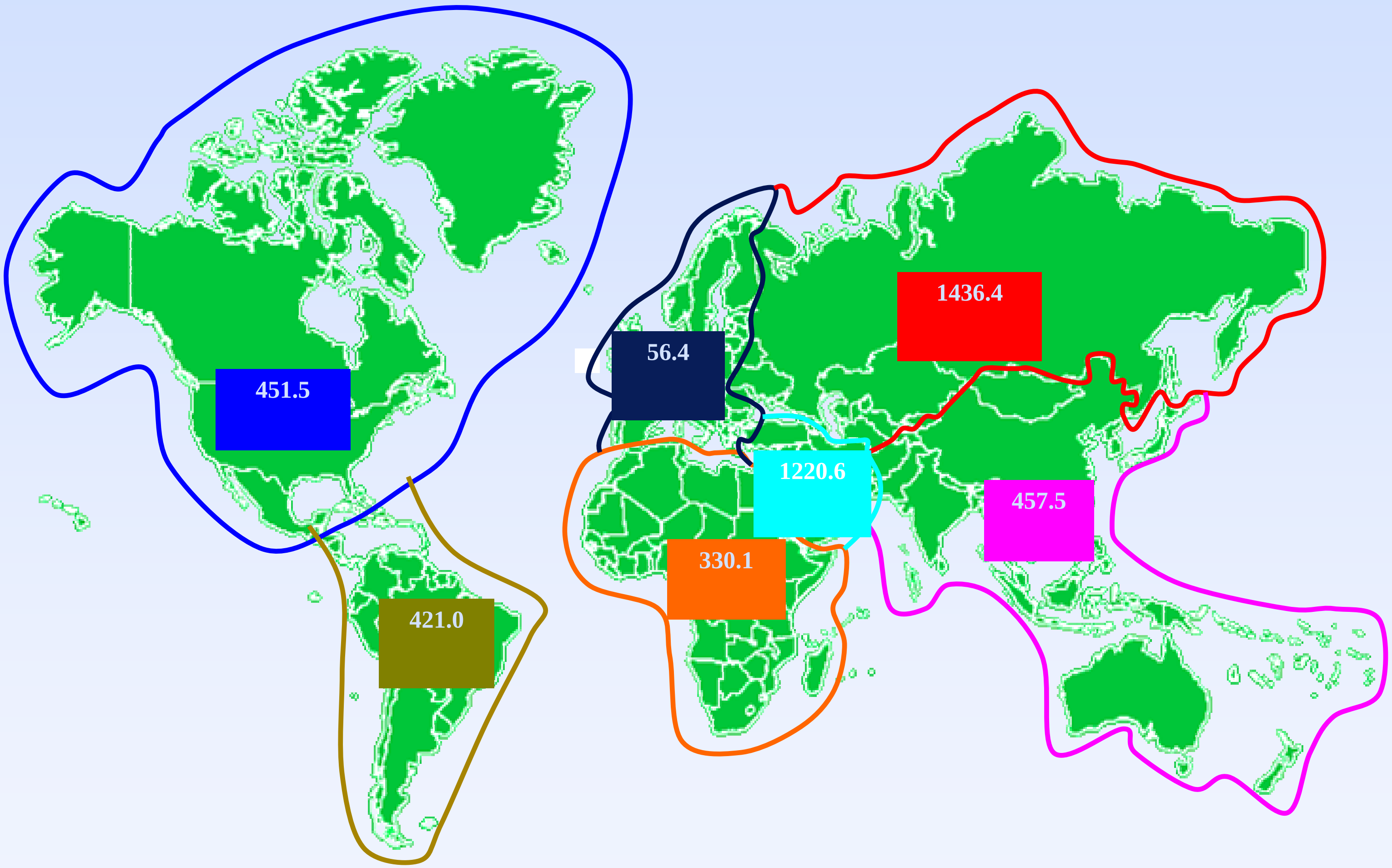
USGS proved natural gas reserves by region, 2003



World Total: 5501.424 TCF
North America: 4.587%
Eastern Europe/FSU: 35.7%
Western Europe: 3.48%
Middle East: 35.98%
Asia &Oceania: 8.01%
Africa: 7.6%
Central/South America: 4.55%

Units: Trillion Cubic Feet
Source: USGS

Undiscovered natural gas by region, 2001 estimates



Units: Trillion Cubic Feet
Source: USGS

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More detail on supply

- Regional resource potential of
  - associated and unassociated natural gas resources,
  - both conventional and unconventional gas deposits in North America and Australia (CBM), and
  - conventional gas deposits in the rest of the world

  was assessed in three categories:
  - proved reserves (2003 *Oil & Gas Journal* estimates)
  - growth in known reserves (P-50 USGS estimates)
  - undiscovered resource (P-50 USGS estimates)
- Cost estimates, based on information for North America and resource base characteristics, include:
  - capital cost of development as resources deplete, and
  - operating and maintenance costs
- Supplies isolated from markets, or in areas lacking infrastructure, earn lower rents and are extracted last

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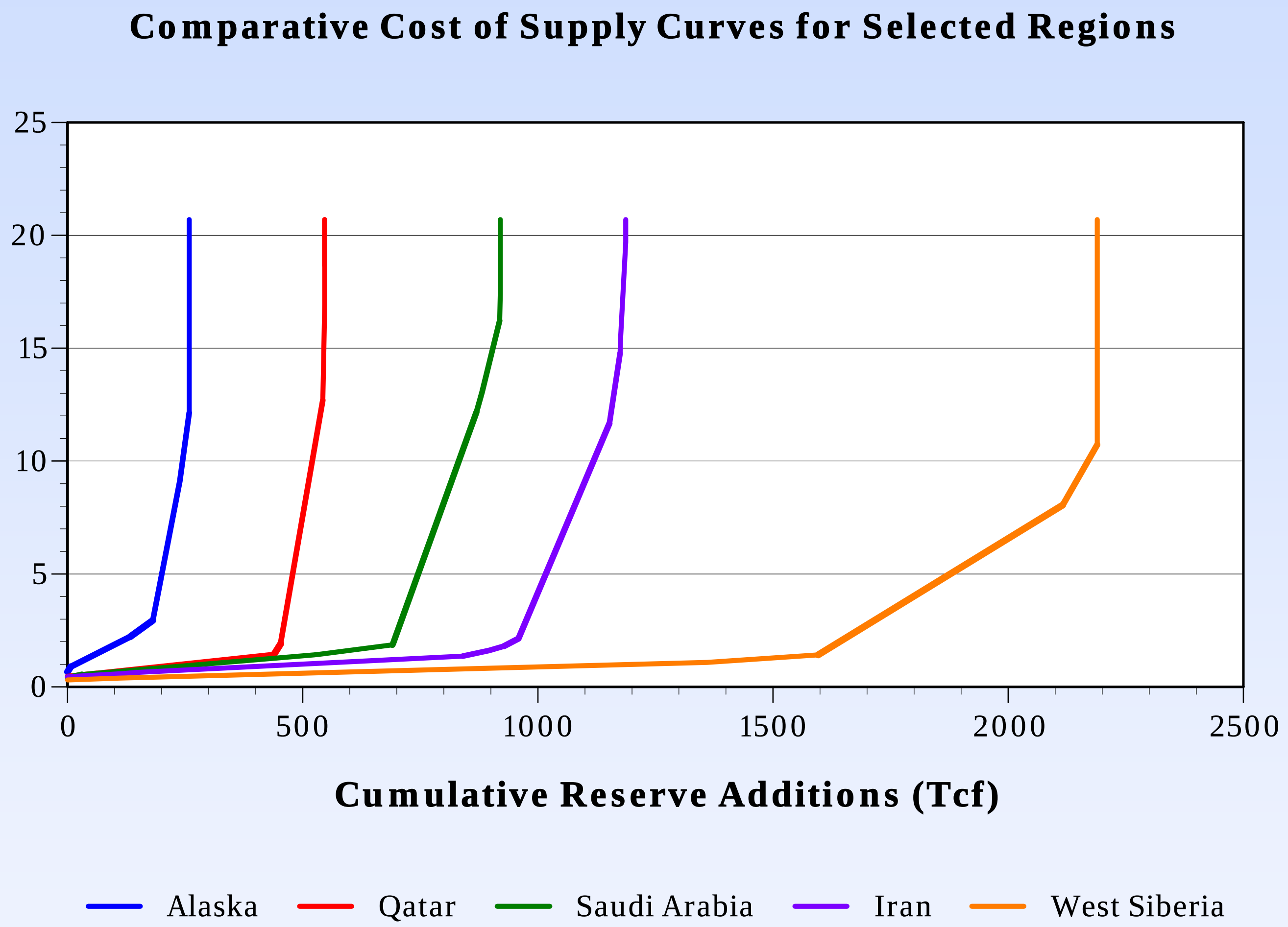
Example cost of supply curves



Sources: USGS, EIA, author calculations

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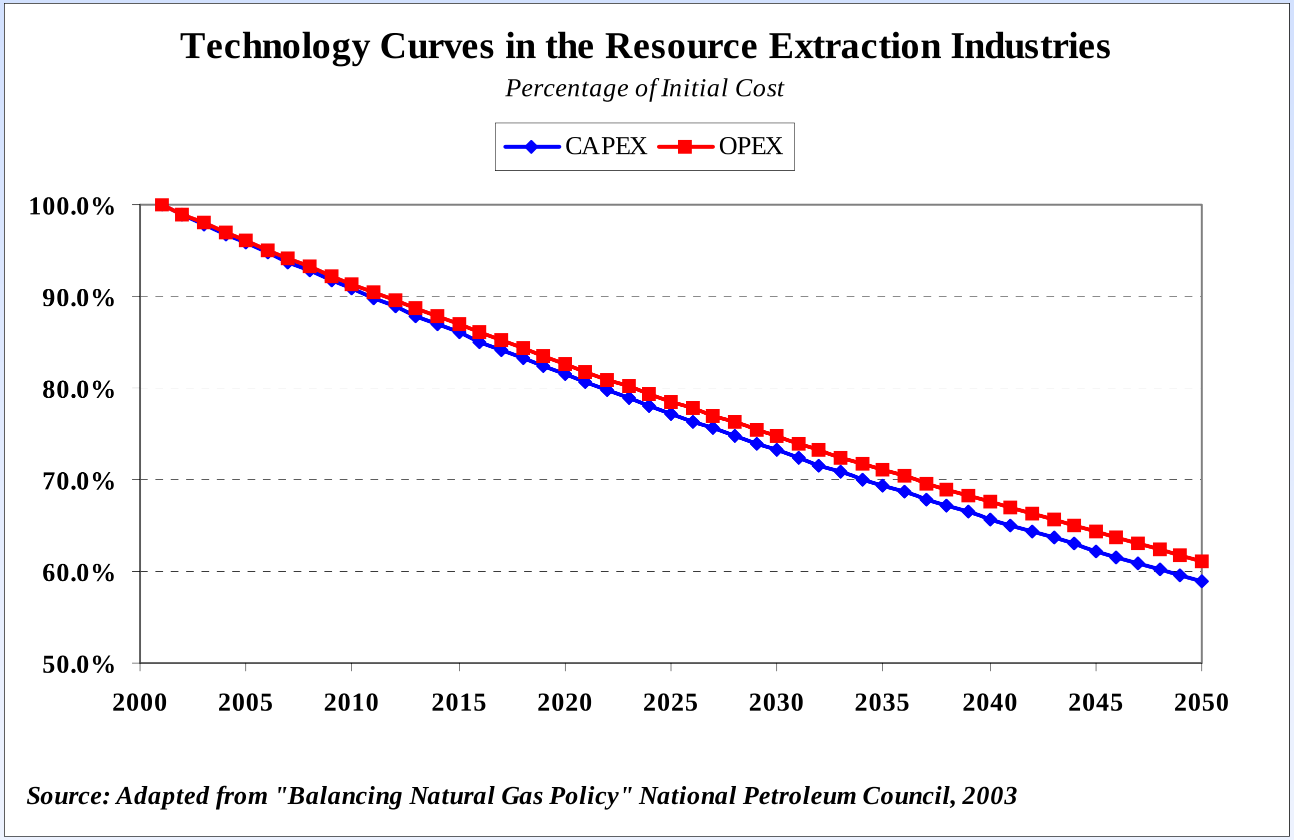
Technological change in mining



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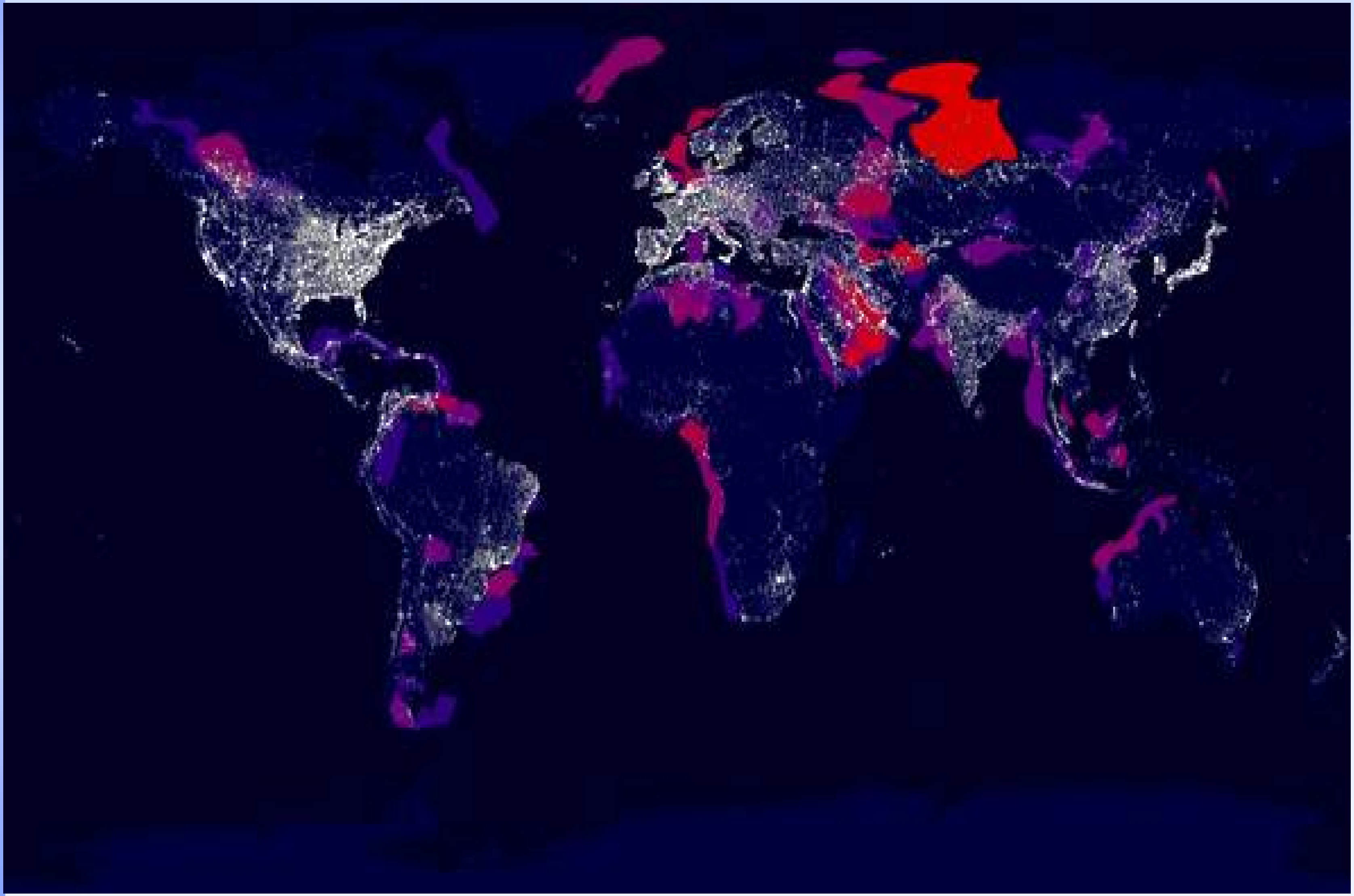
Linking supply with demand



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Representing transport networks

- Pipeline networks in North America and Europe are the main transportation systems
  - LNG is only about 5% of world demand, but is important in Japan & Korea, and increasing in US and Europe
- Aggregate supplies and demands into discrete "nodes"
- Parallel pipes are aggregated into a single link
  - Ignore minor distribution and gathering pipes
- Transport links are inherently discrete
  - Allow many potential links
  - Use a hub and spoke representation for LNG
- Model chooses new or expanded transport capacity from supply sources to demand sinks based on:
  - capital costs of expansion, and
  - operating and maintenance costs of new and existing capacity

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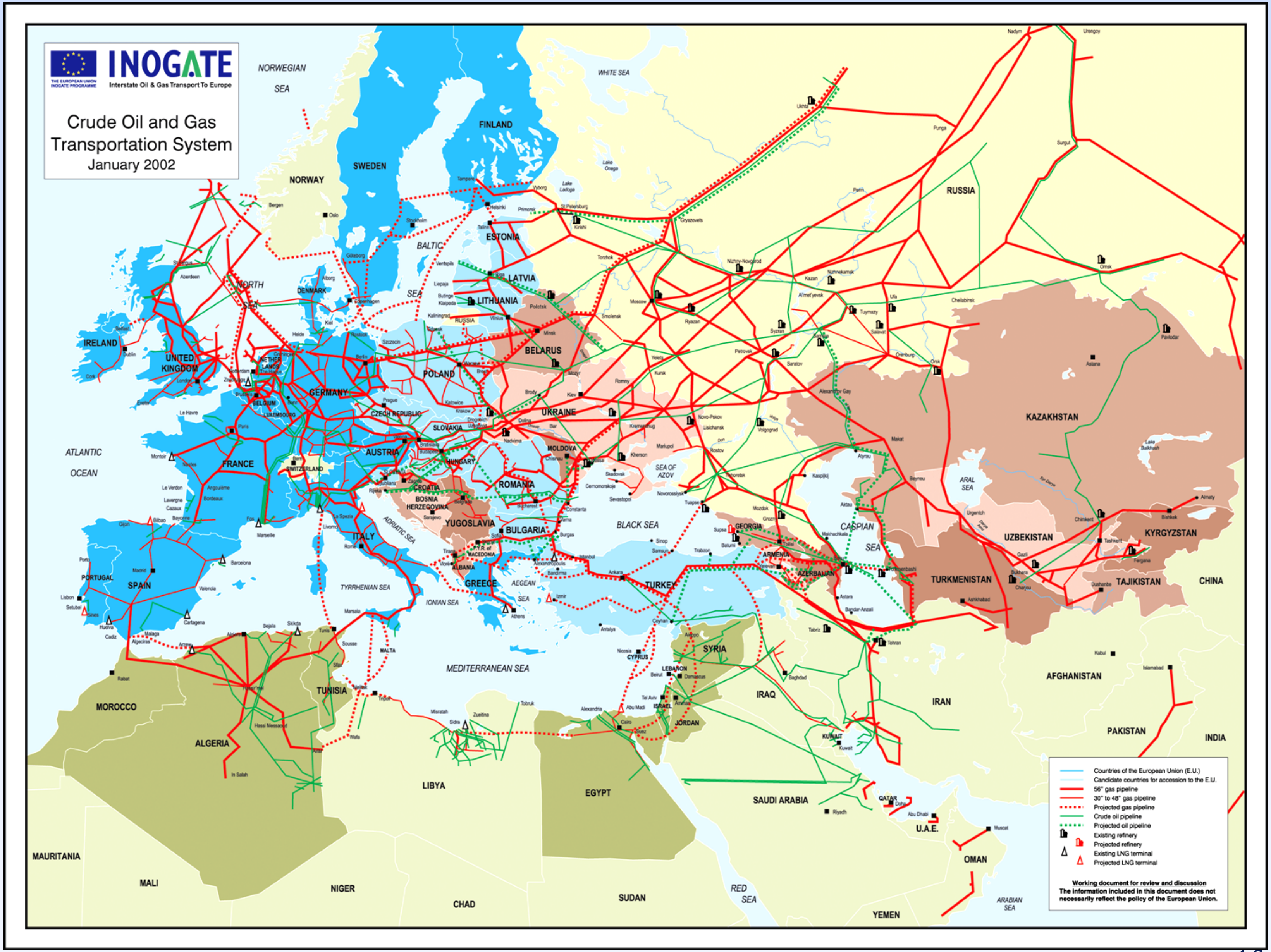
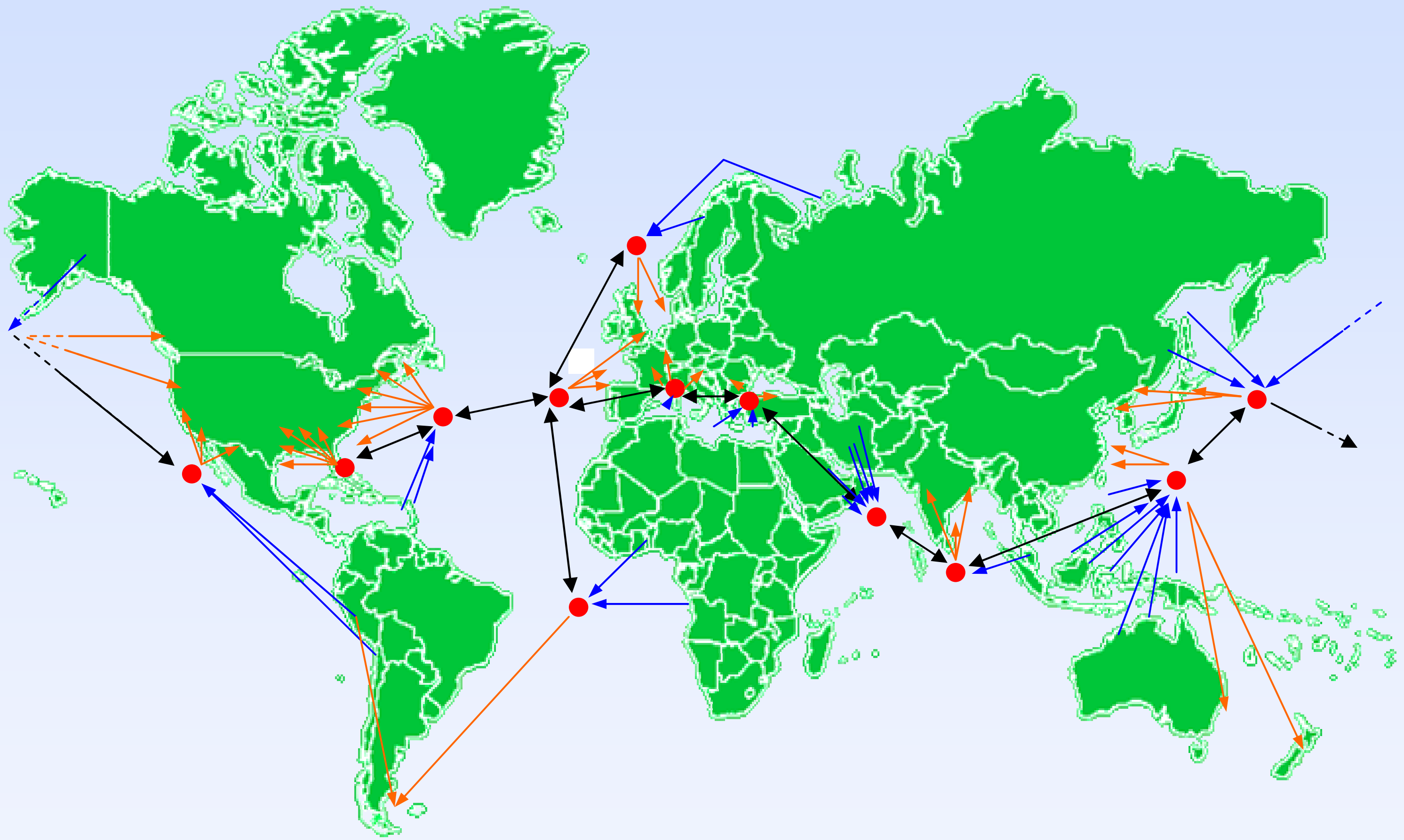
Pipeline link example



LNG transportation network



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Pipeline costs

- EIA published cost data for 52 pipeline projects
- Using this data, we estimated an equation relating specific capital cost (annual cost per unit of capacity) to project characteristics
  - Project cost is raised by:
    - Pipeline length
    - Crossing mountains
    - Moving offshore or crossing a lake or sea
    - Developing in more populous areas
  - Higher capacity reduces *per unit* costs as a result of scale economies

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LNG costs

- Consulted a variety of sources (including a 2003 EIA report) and industry contacts
- Liquefaction costs are a fixed cost ($4.11/mcf/yr) plus a variable feed gas cost (model calculated)
- Shipping costs were based on a data set of estimated lease rates
  - These were converted to implicit costs of using the hub and spoke network via regression analysis
- Regasification costs vary by location (primarily because land costs vary)
  - Based on industry, IEA and EIA reports

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Indicative LNG costs, 2002

Price required for expansion, including capital costs

Route	Feed gas	Liquefaction	Shipping	Regasification	Total
Trinidad to Boston	$0.48	$1.01	$0.32	$0.69	**$2.50**
Algeria to Boston	$0.69	$1.03	$0.45	$0.69	**$2.84**
Algeria to Gulf of Mexico	$0.69	$1.03	$0.63	$0.28	**$2.63**
Qatar to Gulf of Mexico	$0.42	$1.00	$1.30	$0.37	**$3.10**
NW Shelf to Baja	$0.44	$1.01	$0.95	$0.33	**$2.83**
Norway to Cove Point	$0.85	$1.05	$0.54	$0.51	**$2.95**

Sources:

1. "The Global Liquefied Natural Gas Market: Status and Outlook" (December 2003), US Energy Information Administration
2. Various Industry Consultant Reports
3. Author calculations

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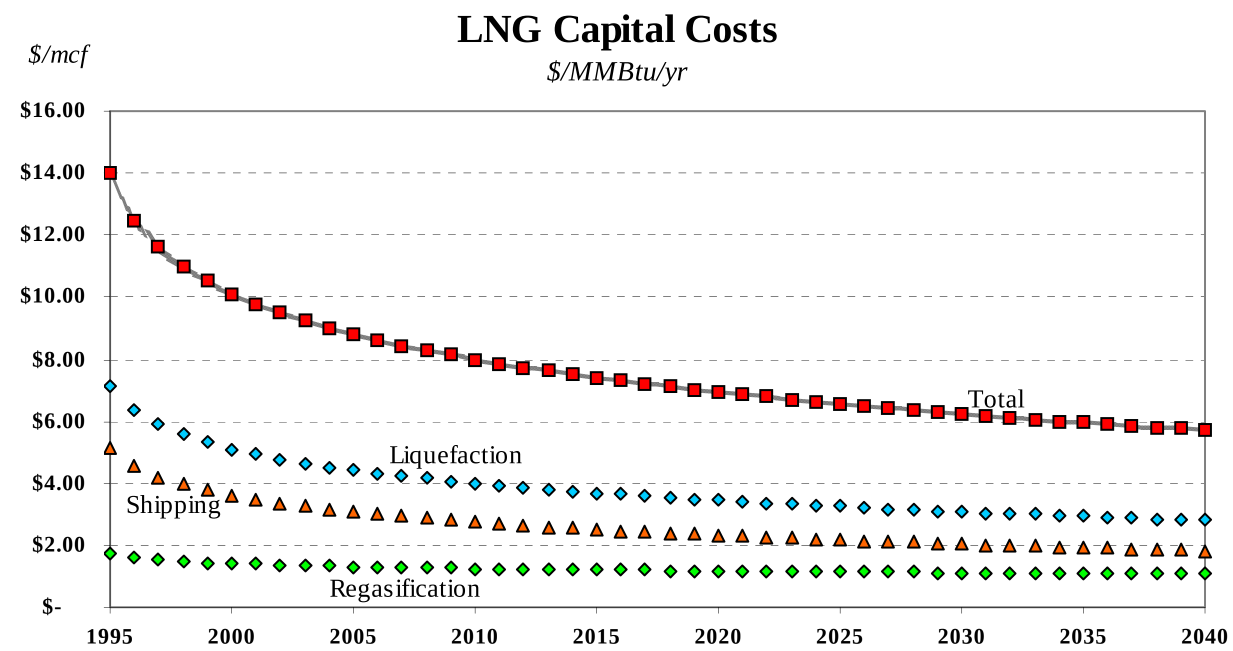
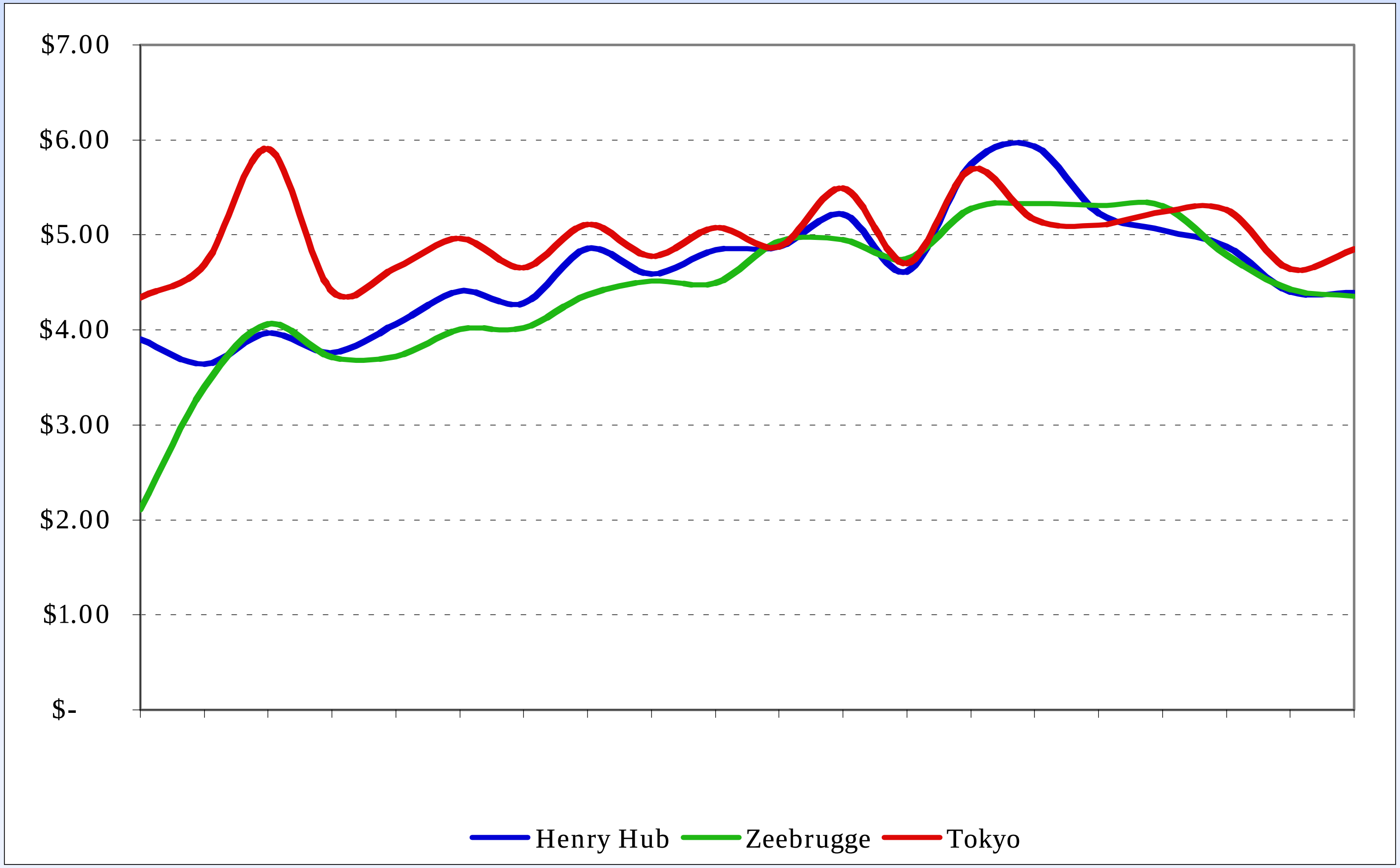
Technological change in LNG

- LNG transport, liquefaction, and regasification capital and O&M costs are expected to decline
  - Rates of change in the model are based on a statistical fit to WEIO rates

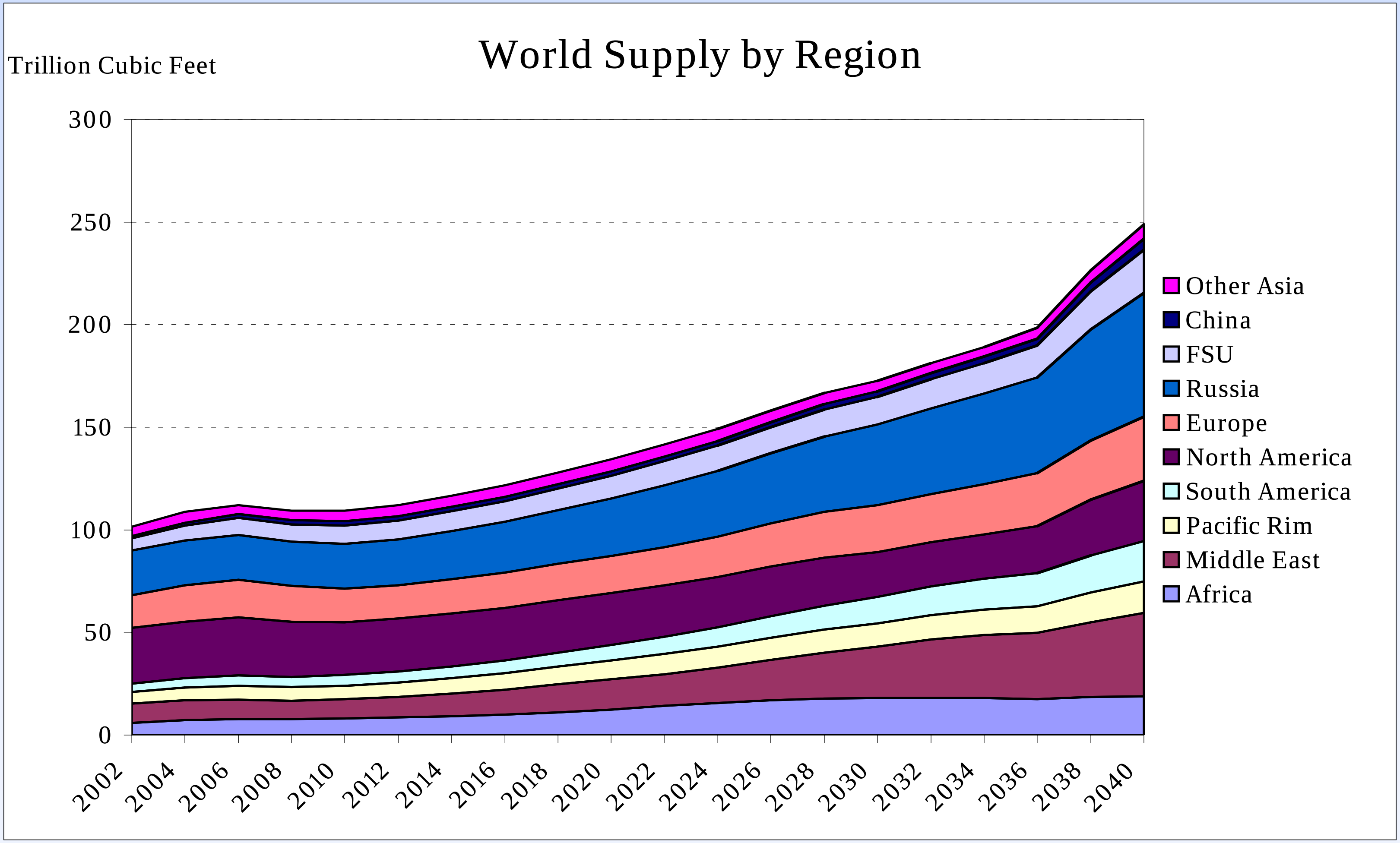


Source: *World Energy Investment Outlook, 2003* , International Energy Agency

Selected price projections



Supply projections



Demand projections

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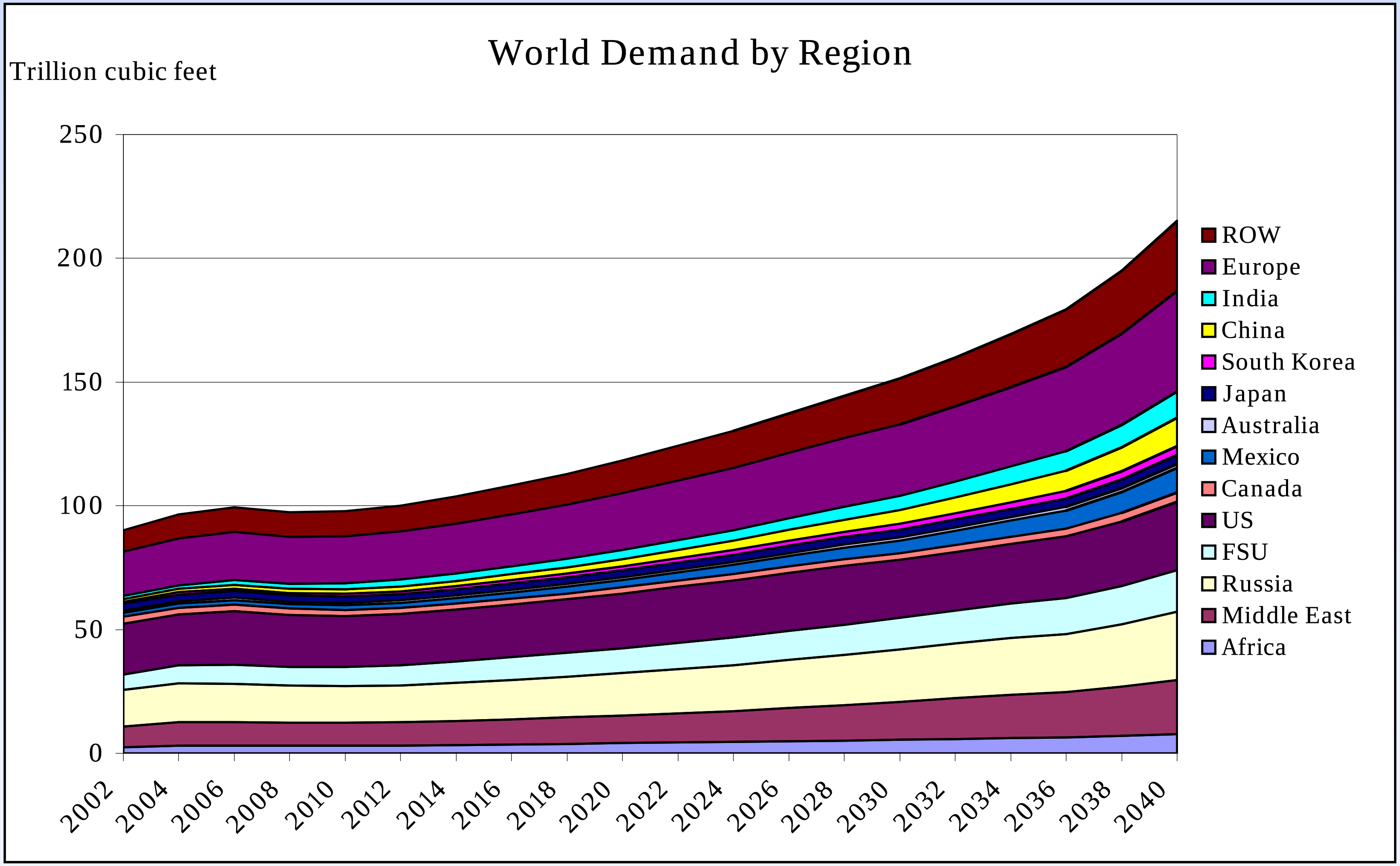
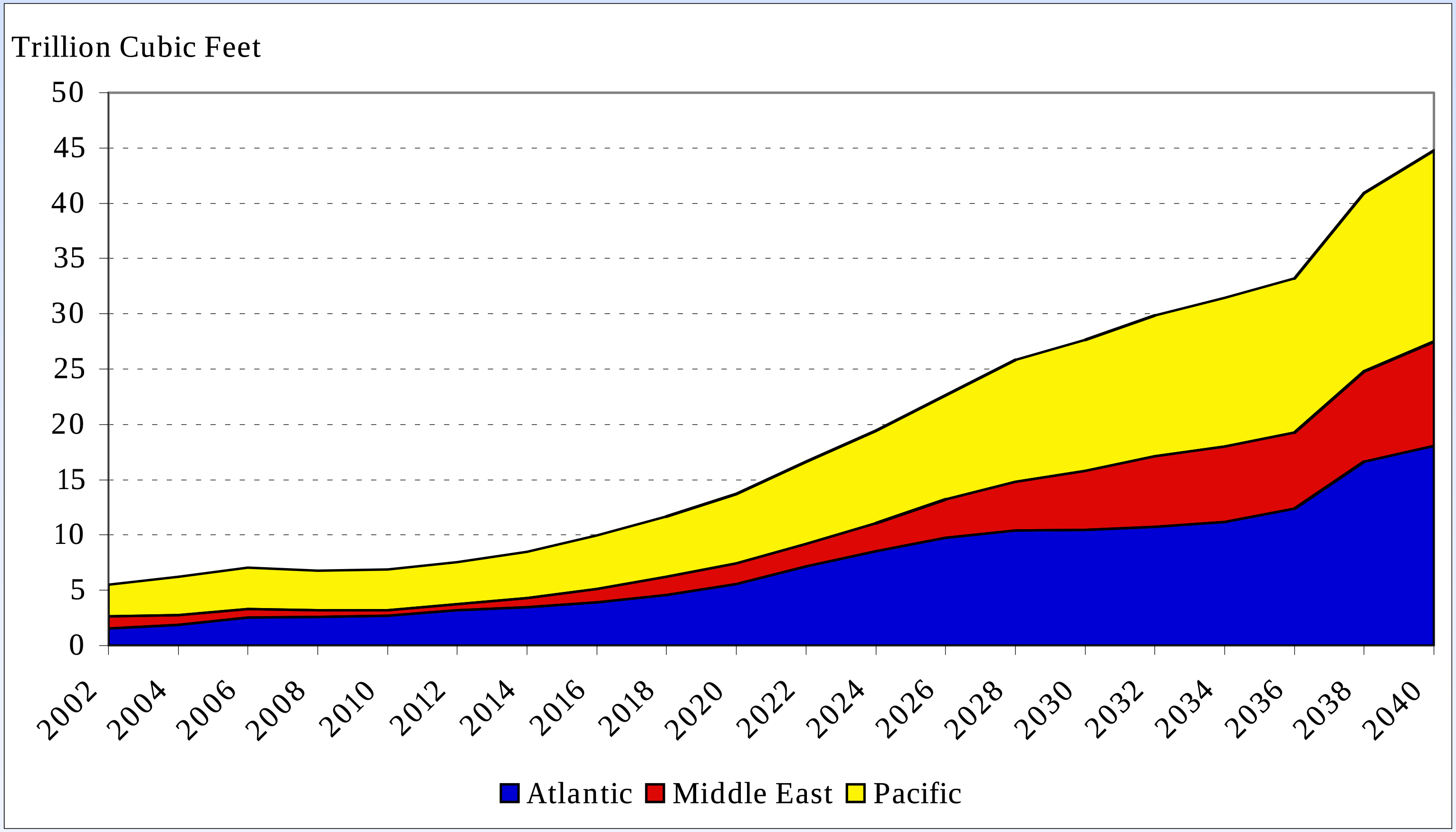
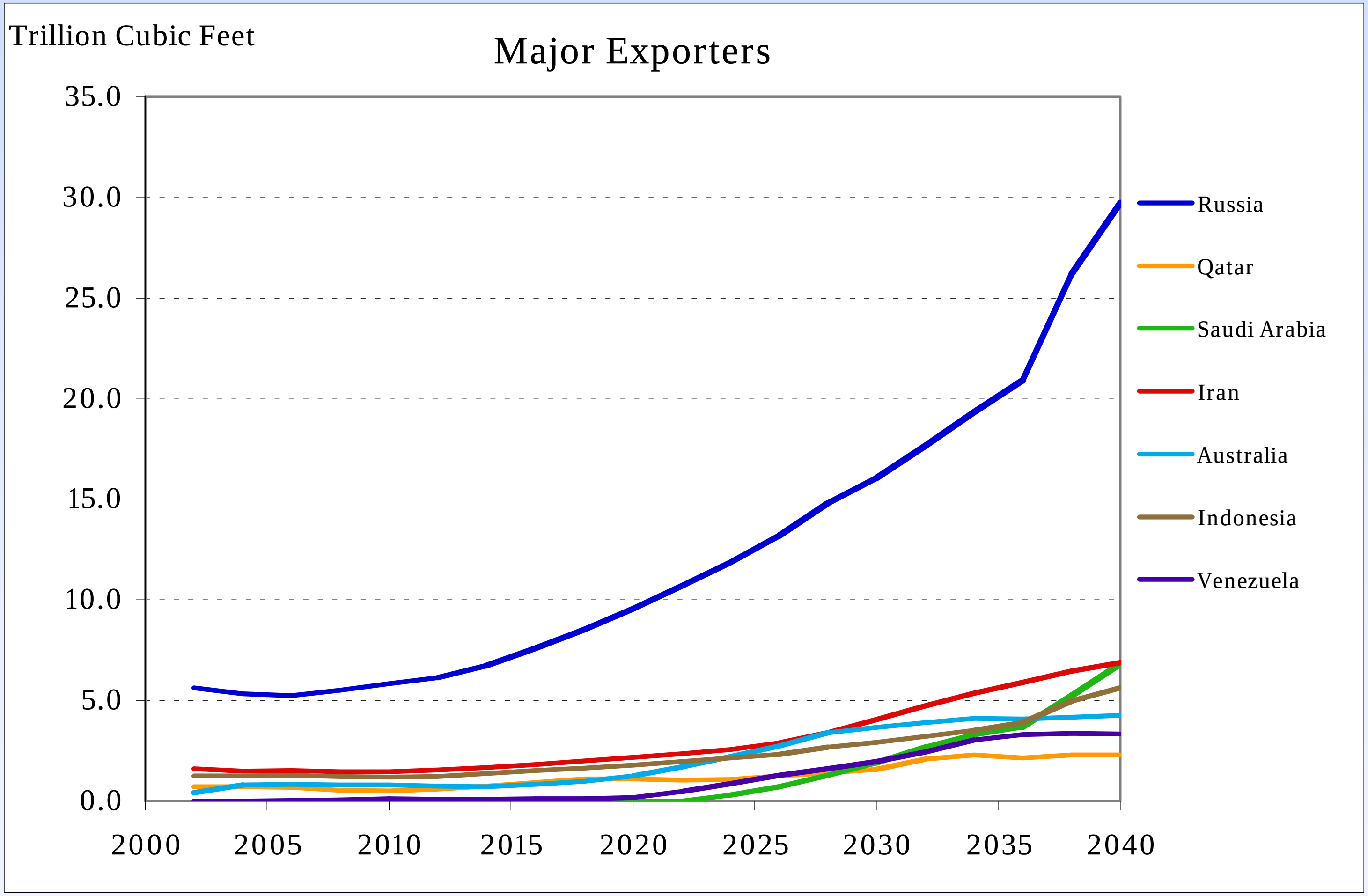


LNG share of world supply by source



Major exporter projections



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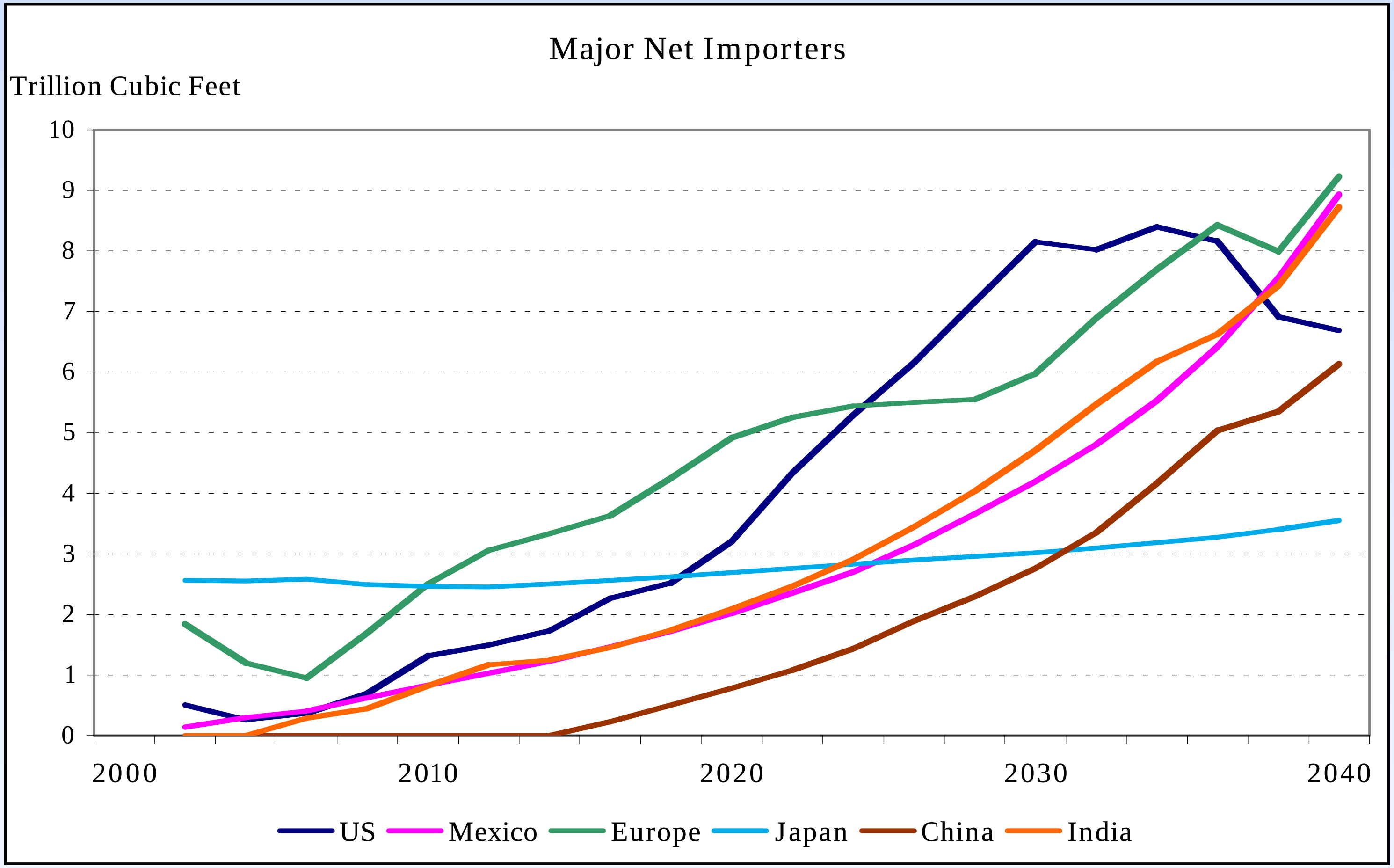
Major importer projections



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Some implications

- Russia becomes a major force in the global gas market
  - Russian pipeline gas continues to be important for Europe
  - Russia also becomes a major supplier of natural gas to China, Korea and Japan
    - But Japan continues to rely substantially on LNG as the high cost prevents a national gas grid from being built
    - Ultimately, gas is also piped east from West Siberia
  - Russia also enters the LNG market possibly supplying the US
    - "Net back" prices in Russia have to be equilibrated
- North America becomes a major importer of LNG
  - Gas prices in the US then exceed prices in Japan
  - Russia, Middle East, Australia retain low gas prices
- The backstop technology is built in Japan, some parts of the US and Europe, Chile but not India or China