SAND2015-1583PE

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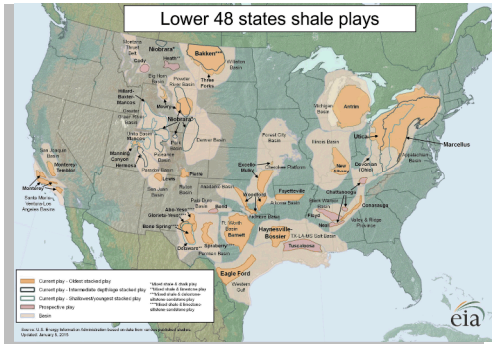

Shale Gas: Modeling the Economic Factors and Quantifying Uncertainty

Dr. Peter H. Kobos

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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Today is A Unique Time In Energy History

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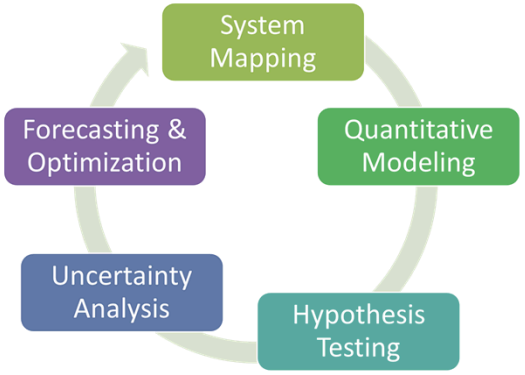
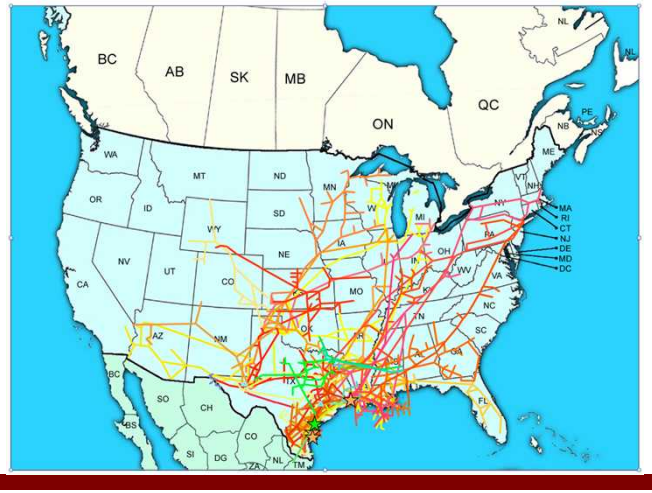
- **Shale gas boom**
  - Extraction in the United States has led to a drop in domestic prices and interest in using more natural gas throughout the economy
- **Many sources of uncertainty**
  - Geoscience, Technology, Markets
- **Research Project Developing Several Efforts**

Systems Dynamic (SD) Model – Address Interaction of Geoscience, Technology and Markets



Agent-Based Modeling - Address Supply, Demand and Infrastructure Shocks



Source: GPCM, RBAC, NGSM

Natural Gas in the U.S. Economy

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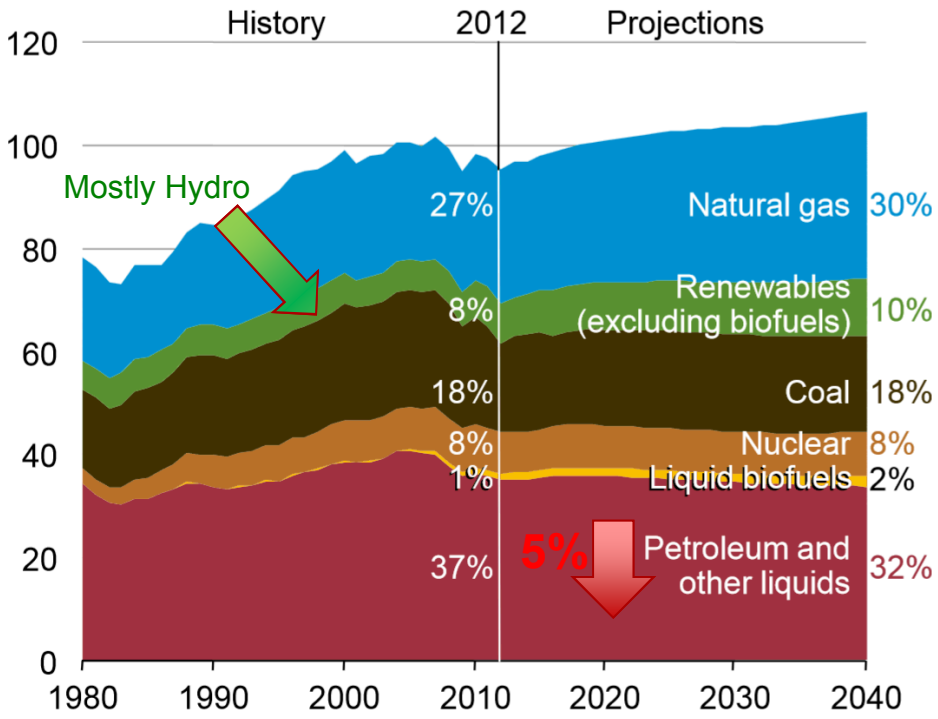
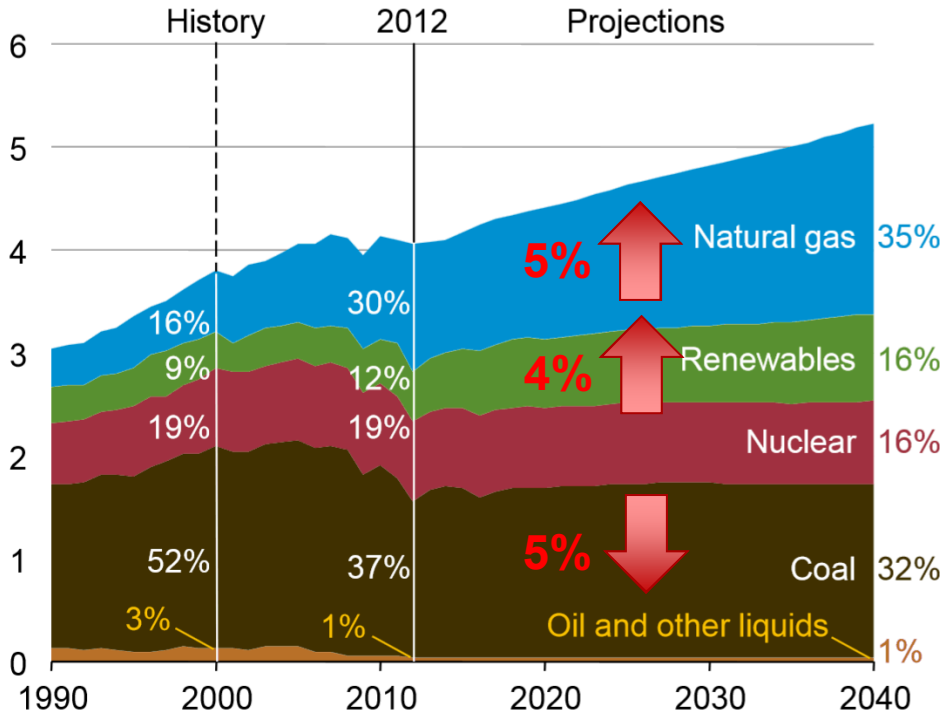
The U.S. Economy



Primary energy use by Fuel
1980-2035 (quadrillion Btu)

The U.S. Electricity Sector



Electricity Generation by fuel
1990-2035 (trillion kilowatthours per year)

Source: Energy Information Administration's Annual Energy Outlook, Early Release, 2014.

Stanford University Energy Modeling Forum

Slow increase in U.S. Natural Gas prices & Total Consumption.

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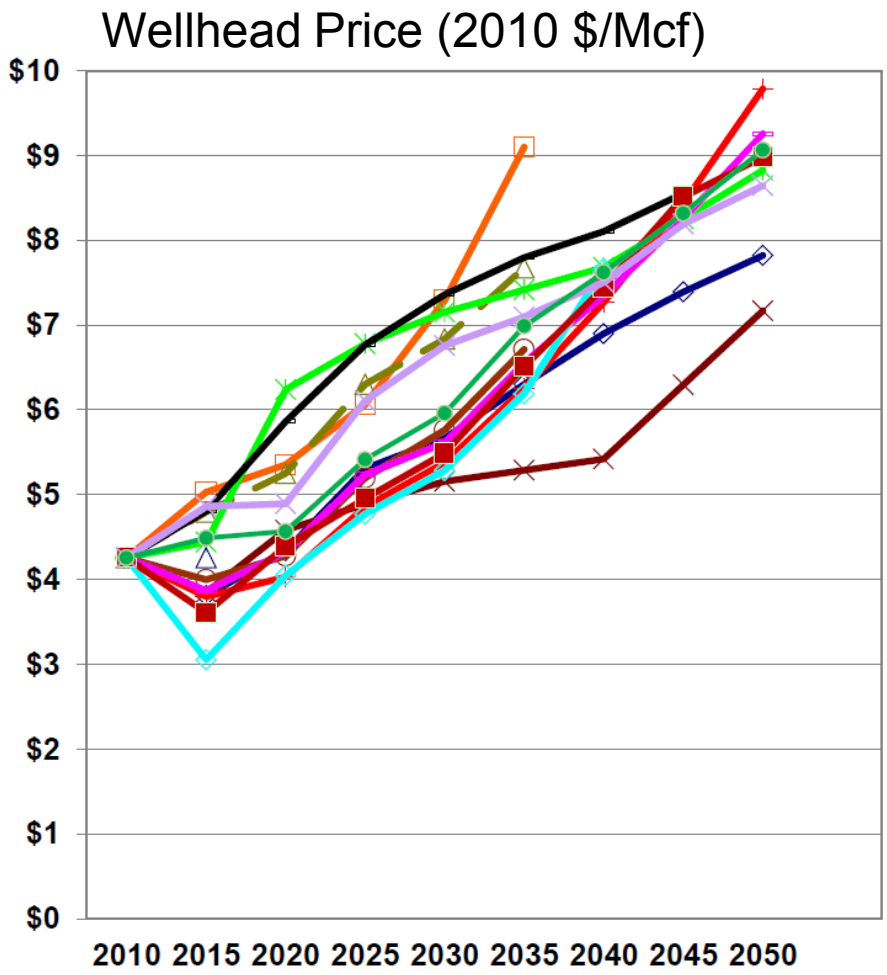
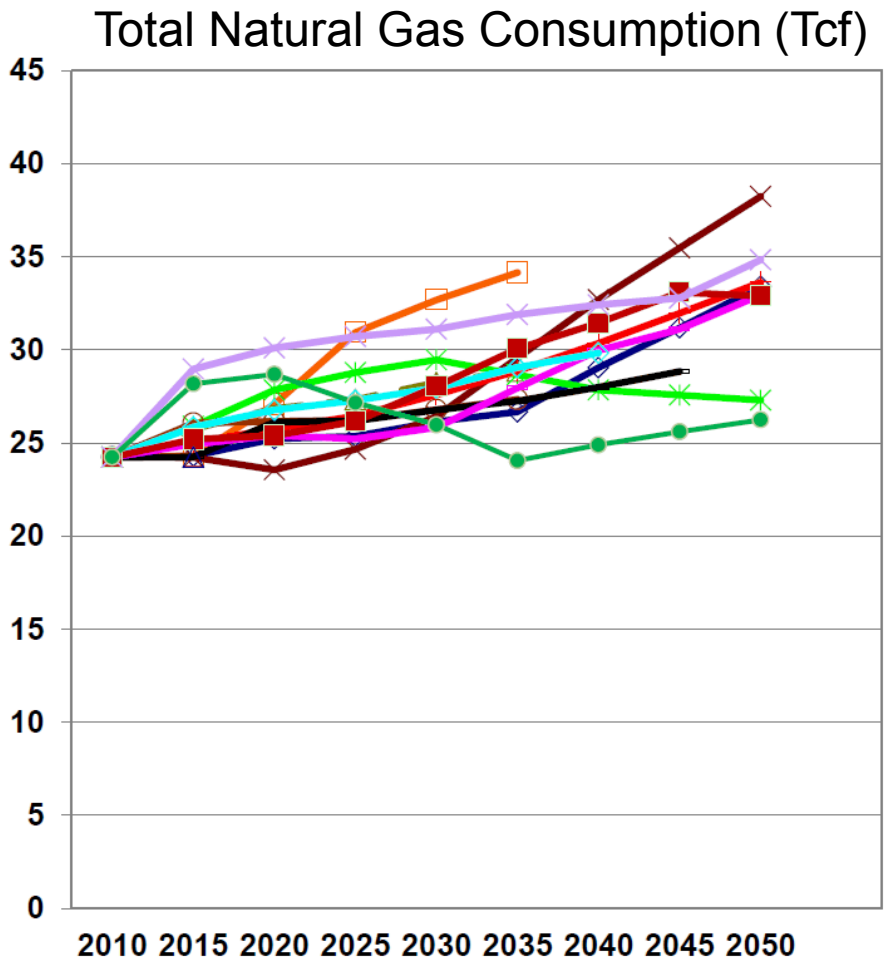
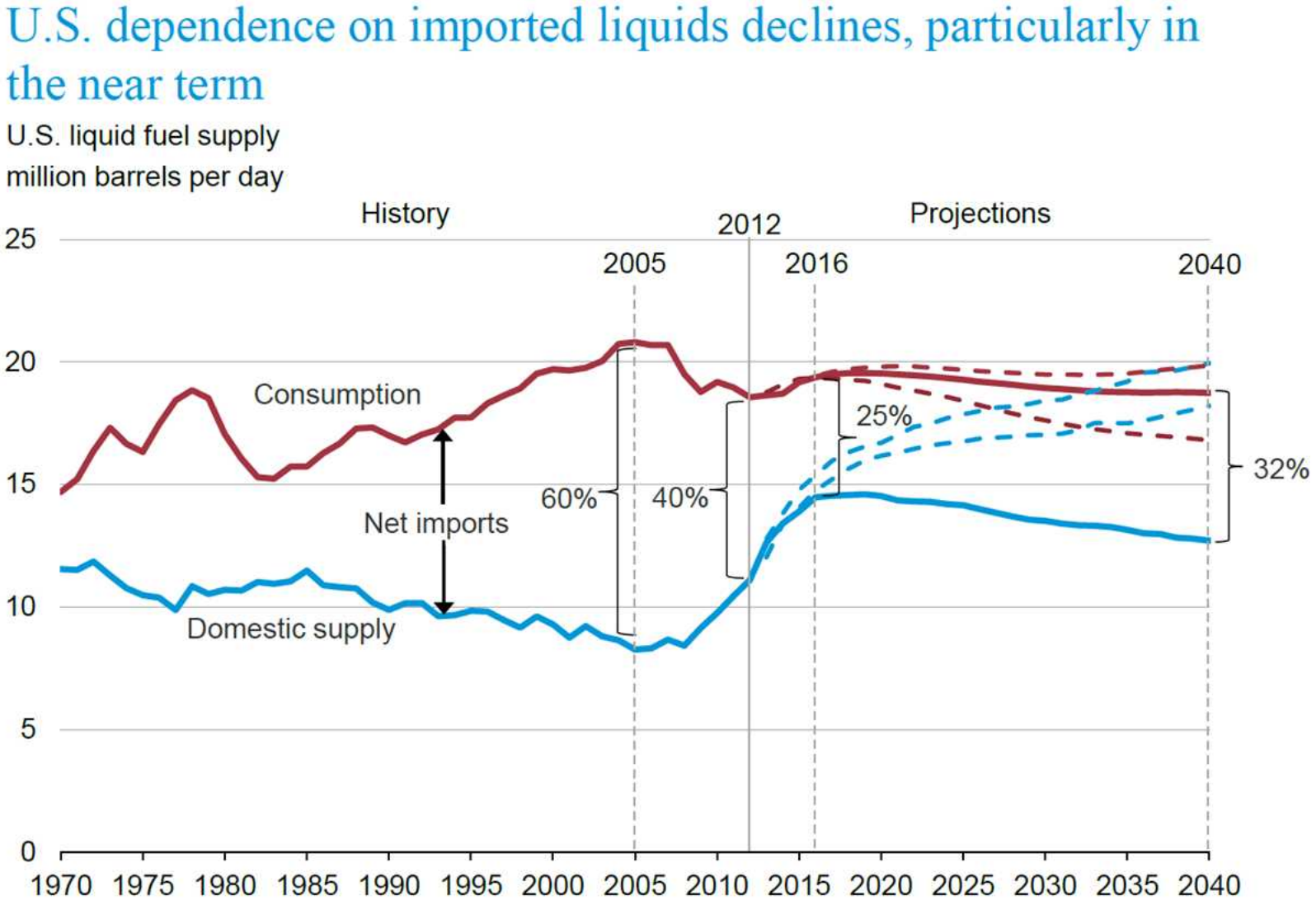




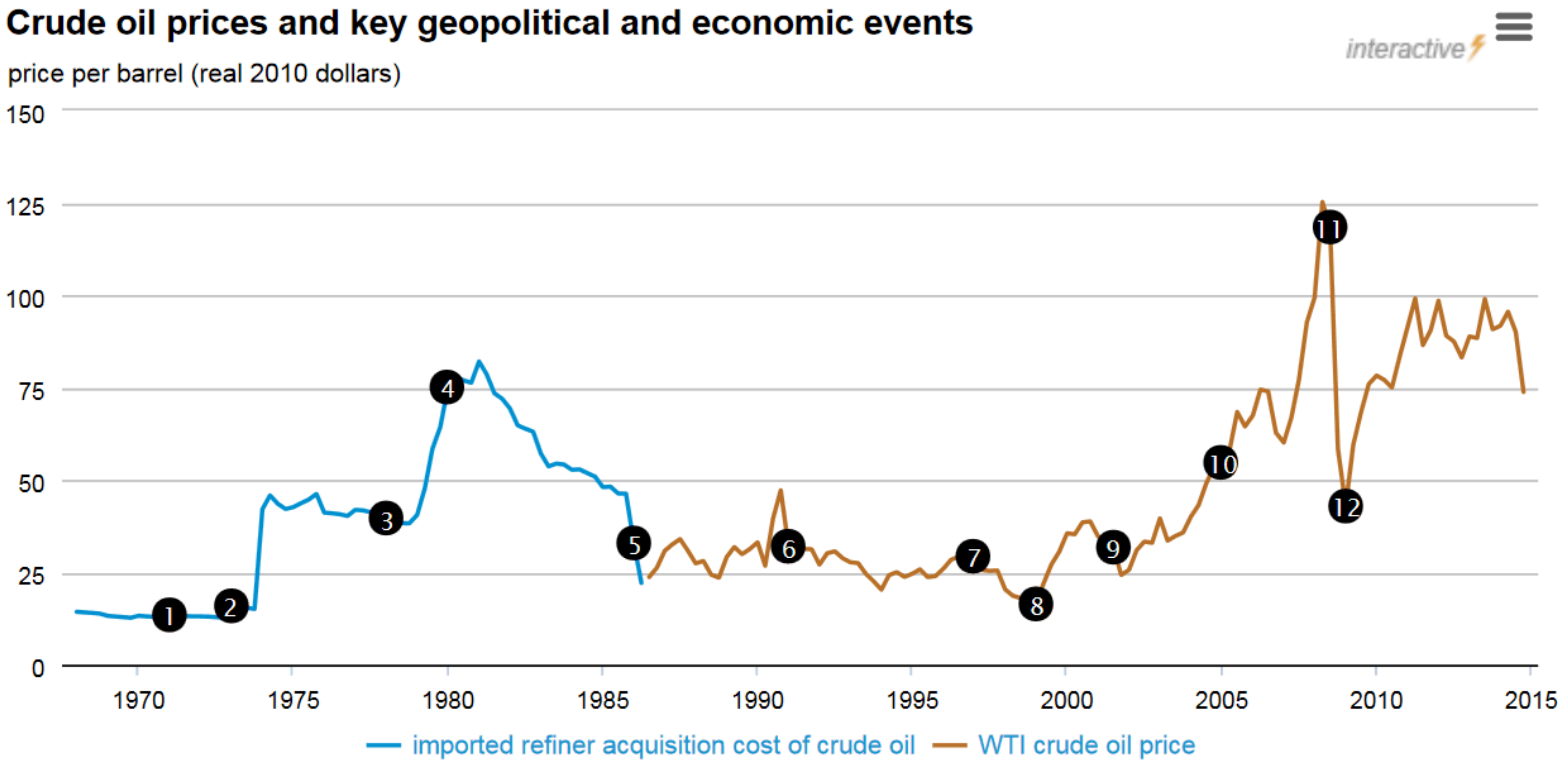
Source: Energy Modeling Forum (EMF) Report 26, Volume I, 2013. Reference Case.

U.S. Net Imports decreased



Source: EIA, Annual Energy Outlook 2014 Reference case and draft analysis.

U.S. Historical Crude Oil Prices



Source: U.S. Energy Information Administration, Thomson Reuters.
Updated: quarterly | Last Updated: 12/31/2014

1: US spare capacity exhausted
2: Arab Oil Embargo
3: Iranian Revolution
4: Iran-Iraq War
5: Saudis abandon swing producer role
6: Iraq invades Kuwait
7: Asian financial crisis
8: OPEC cuts production targets 1.7 mmbpd
9: 9-11 attacks
10: Low spare capacity
11: Global financial collapse
12: OPEC cuts production targets 4.2 mmbpd

Source: http://www.eia.gov/finance/markets/spot_prices.cfm as of 2/5/2015

U.S. Historical Natural Gas Data

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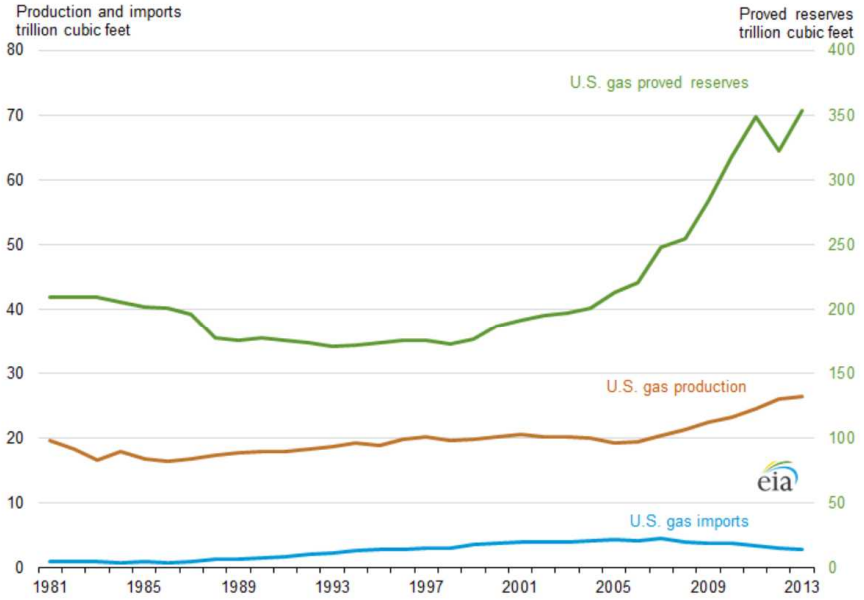
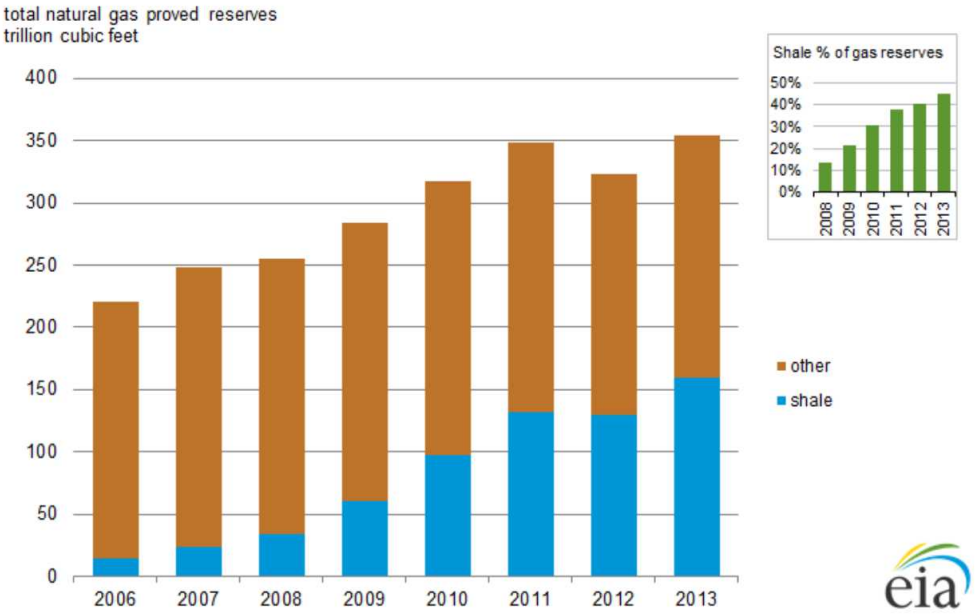
Total Natural Gas proved reserves, production & imports

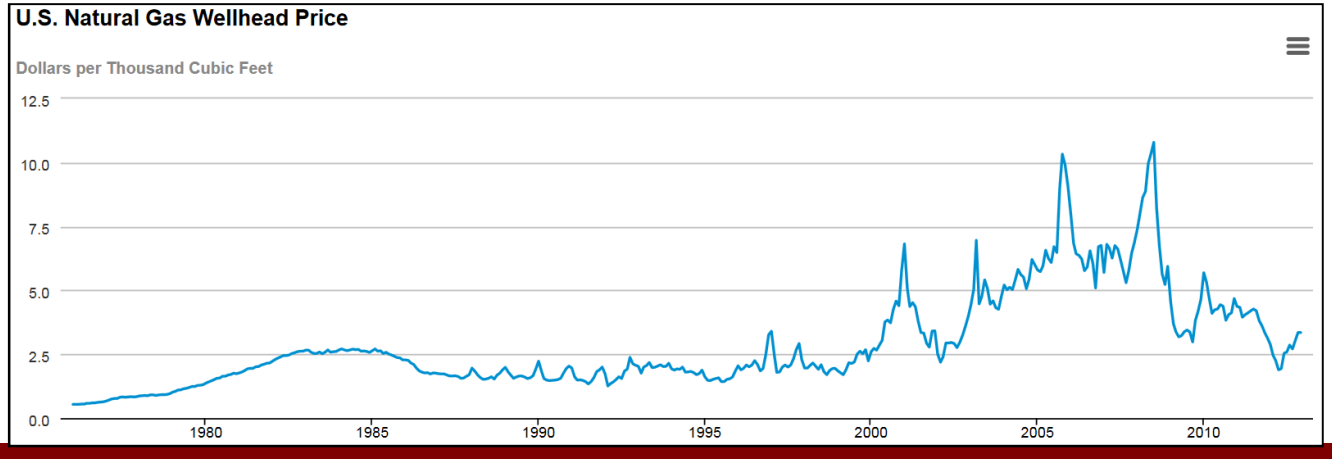


Sources : U.S. Energy Information Administration, Form EIA-23L, Annual Survey of Domestic Oil and Gas Reserves; Form EIA-814, Monthly Imports Report; and U.S. Department of Energy, Office of Fossil Energy, Natural Gas Imports and Exports.

Shale and Other sources of Natural Gas



Source: U.S. Energy Information Administration, Form EIA-23L, Annual Survey of Domestic Oil and Gas Reserves, 2006-13.



Source: EIA website as of 3/4/2015, http://www.eia.gov/dnav/ng/hist/n9190us3m.htm, http://www.eia.gov/naturalgas/crudeoilreserves/

SD Natural Gas Simulation Modeling

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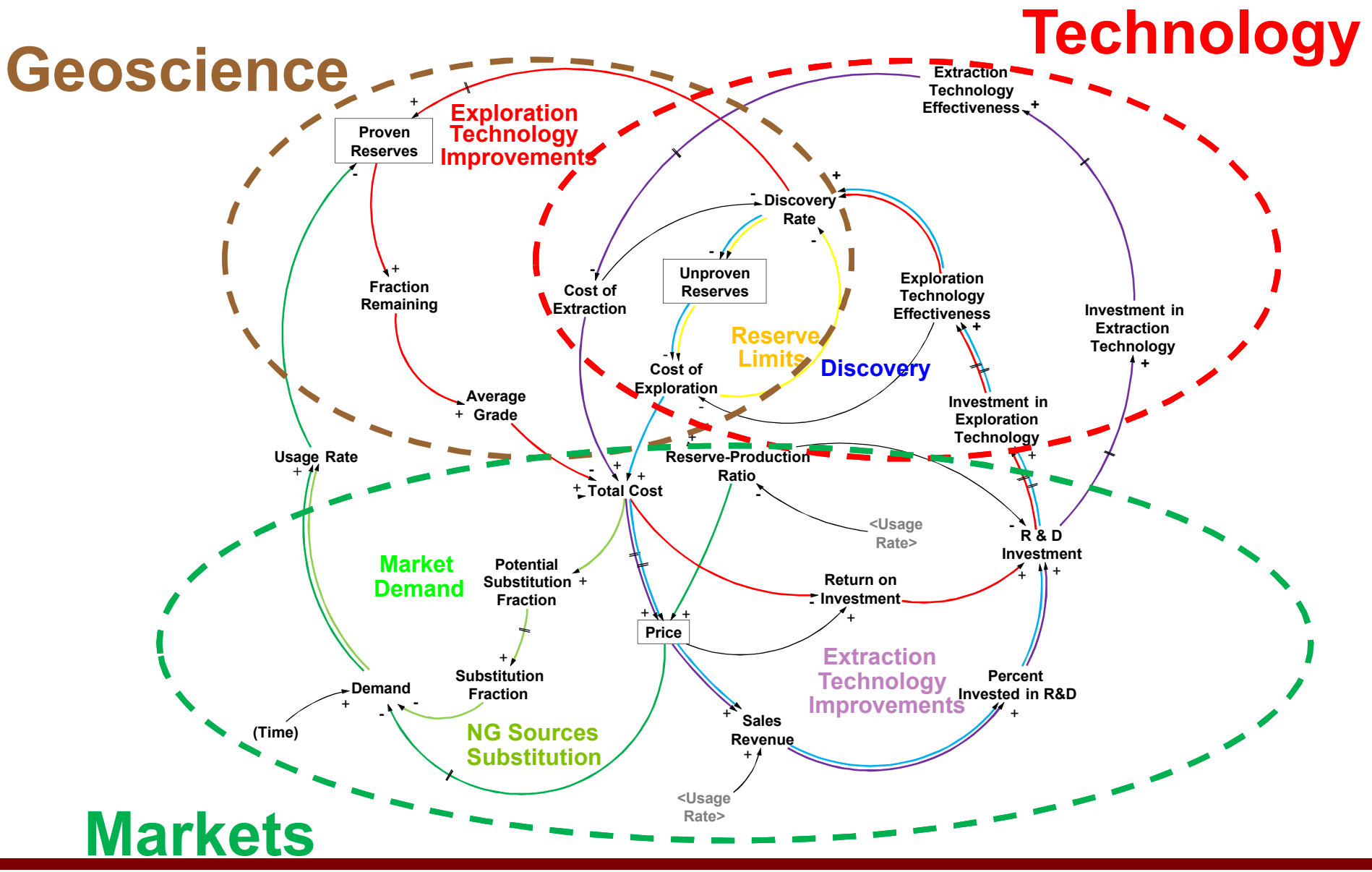
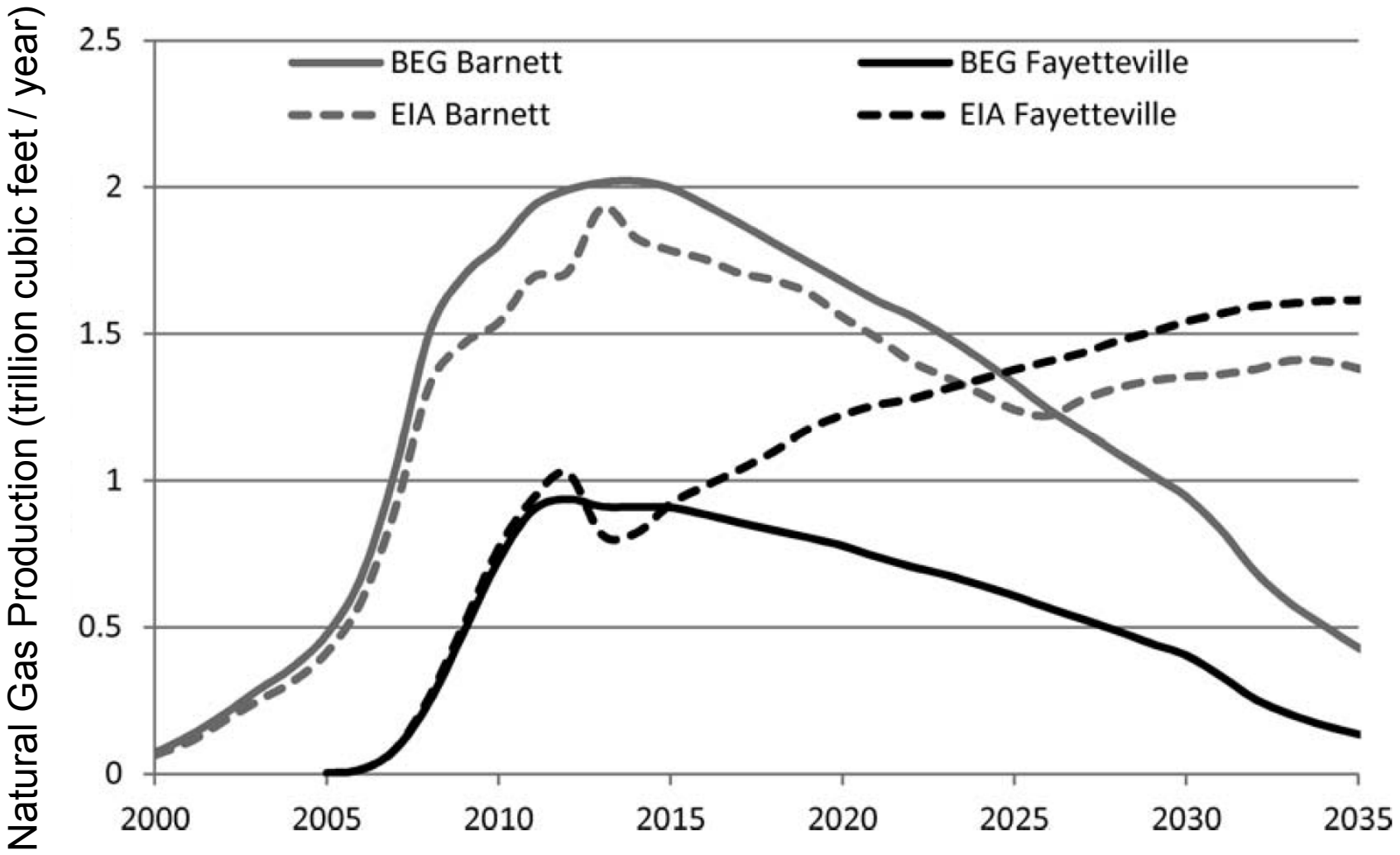


Source: U.S. Illustrative Working Natural Gas Systems Model as of March 2015, Causal Loop Diagram illustrating the conceptual intersections of Naill's NG Discovery Model and Behrens's Natural Resource Utilization Model. In Toward Global Equilibrium: Collected Papers, Edited by: Dennis L Meadows and Donella H Meadows,1973.

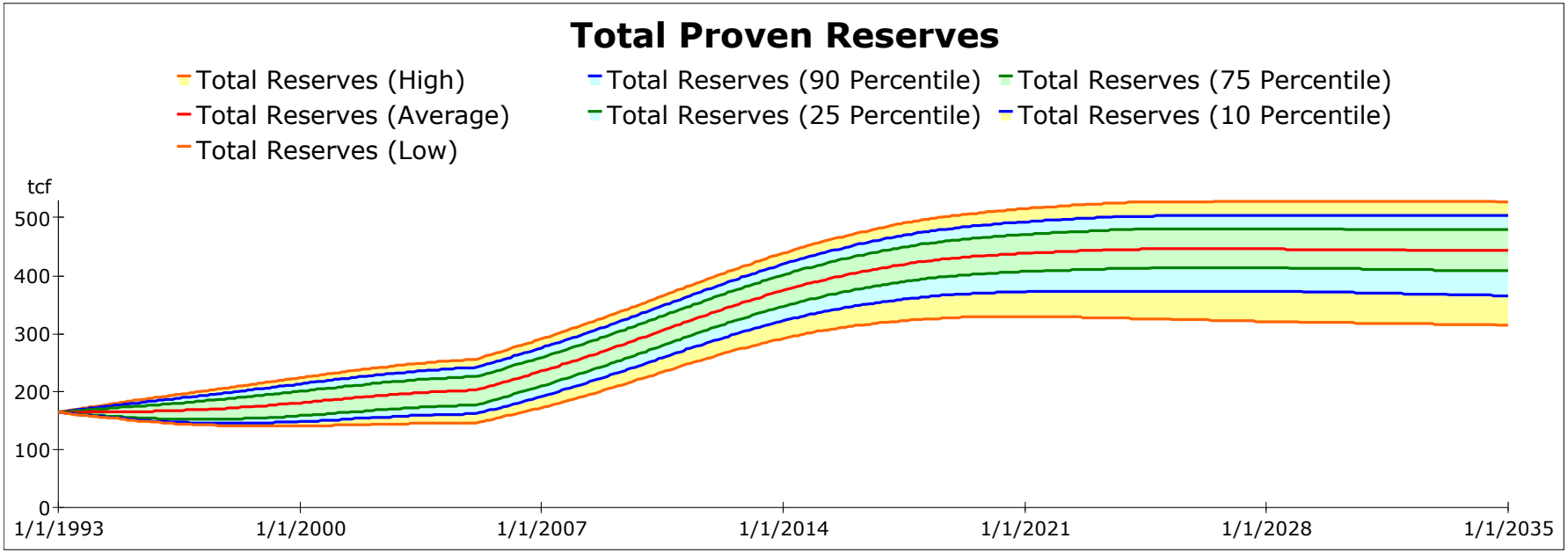
Production Uncertainty In the Research Community Drive Modeling Results



Source: Figure adapted from Ikonnikova S., Browning, J., Gulen, G. Smye, K. and S.W. Tinker, 2014, Factors influencing shale gas production forecasting: Empirical studies of Barnett, Fayetteville, Haynesville, and Marcellus Shale plays, Economics of Energy & Environmental Policy, Vol. 4, No. 1.

SD Total Proven Reserves:

An Uncertainty Analysis, Desired Reserve to Production Ratio



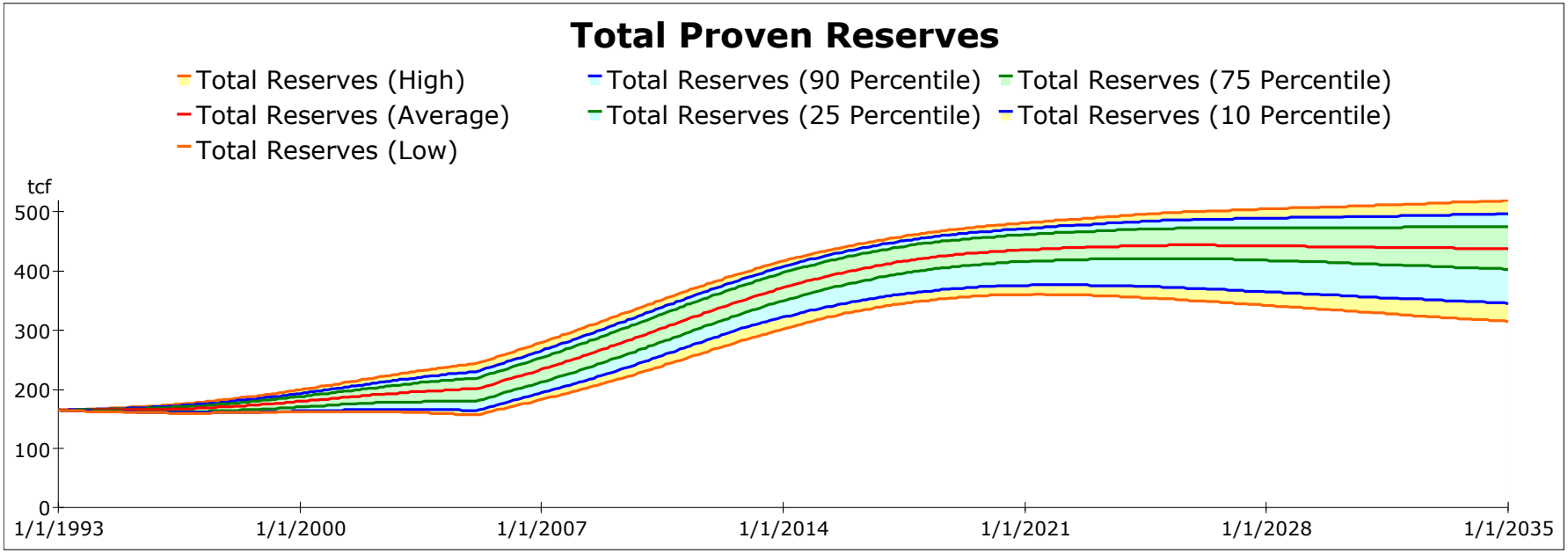
SD Modeling to address:

- The model's sensitivity to changing the Desired Reserve to Production Ratio
- Natural Gas Demand in the United States
- Natural Gas Supplies (existing and ongoing discoveries)
- Total Proven Reserves = Economically Recoverable Reserves + New Economically Recoverable Discoveries – Natural Gas Utilized

Based off of a Desired Reserve to Production Ratio, working results

SD Total Proven Reserves:

An Uncertainty Analysis, Initial Unproven Reserves

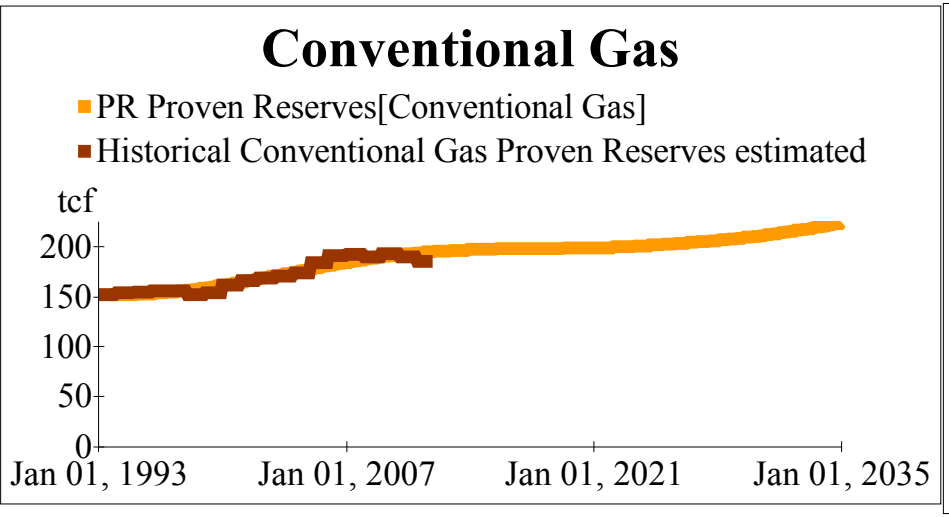


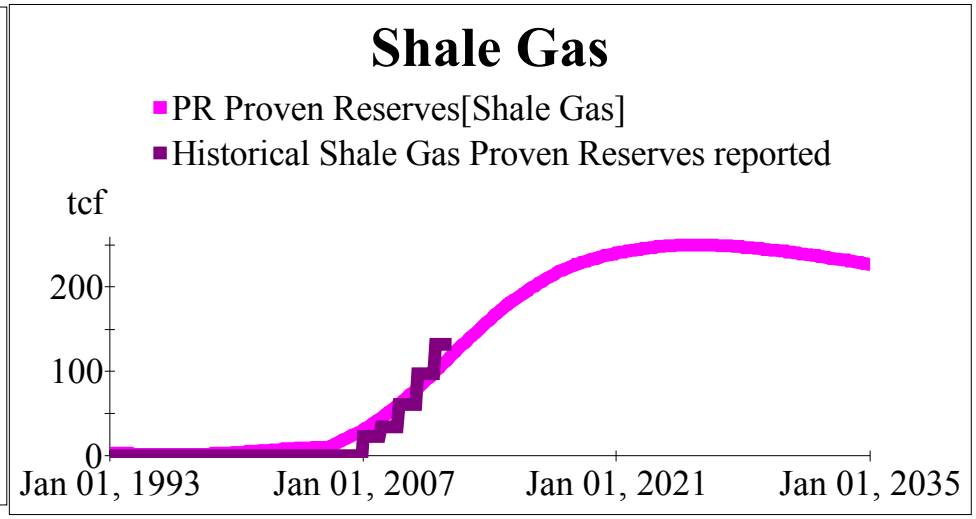
SD Modeling to address:

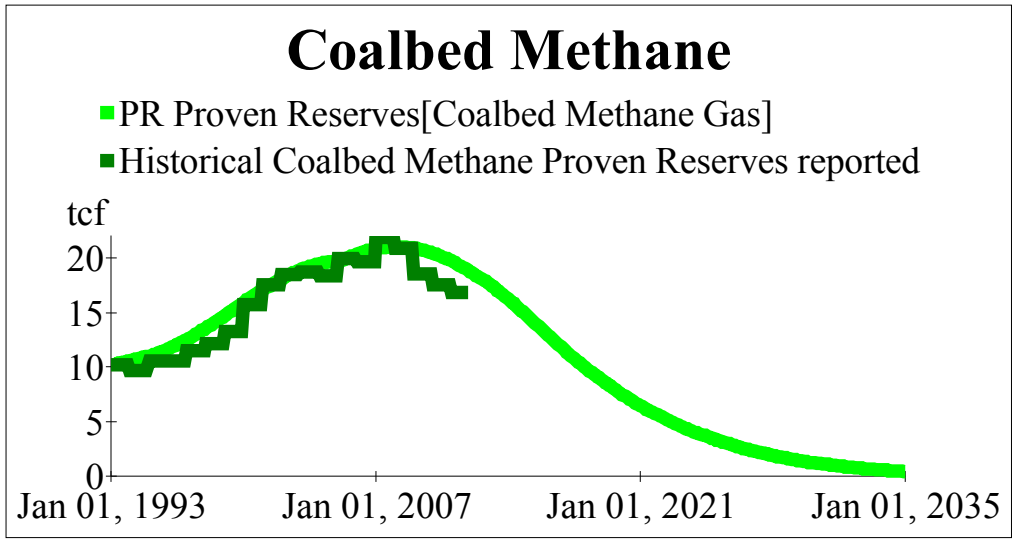
- The model's sensitivity to uncertainty in the Initial Unproven Reserves
- Based on Low, Medium and High initial reserve estimates to drive the model

SD Simulated Reserves:

Capturing U.S. Market Dynamics by Matching History



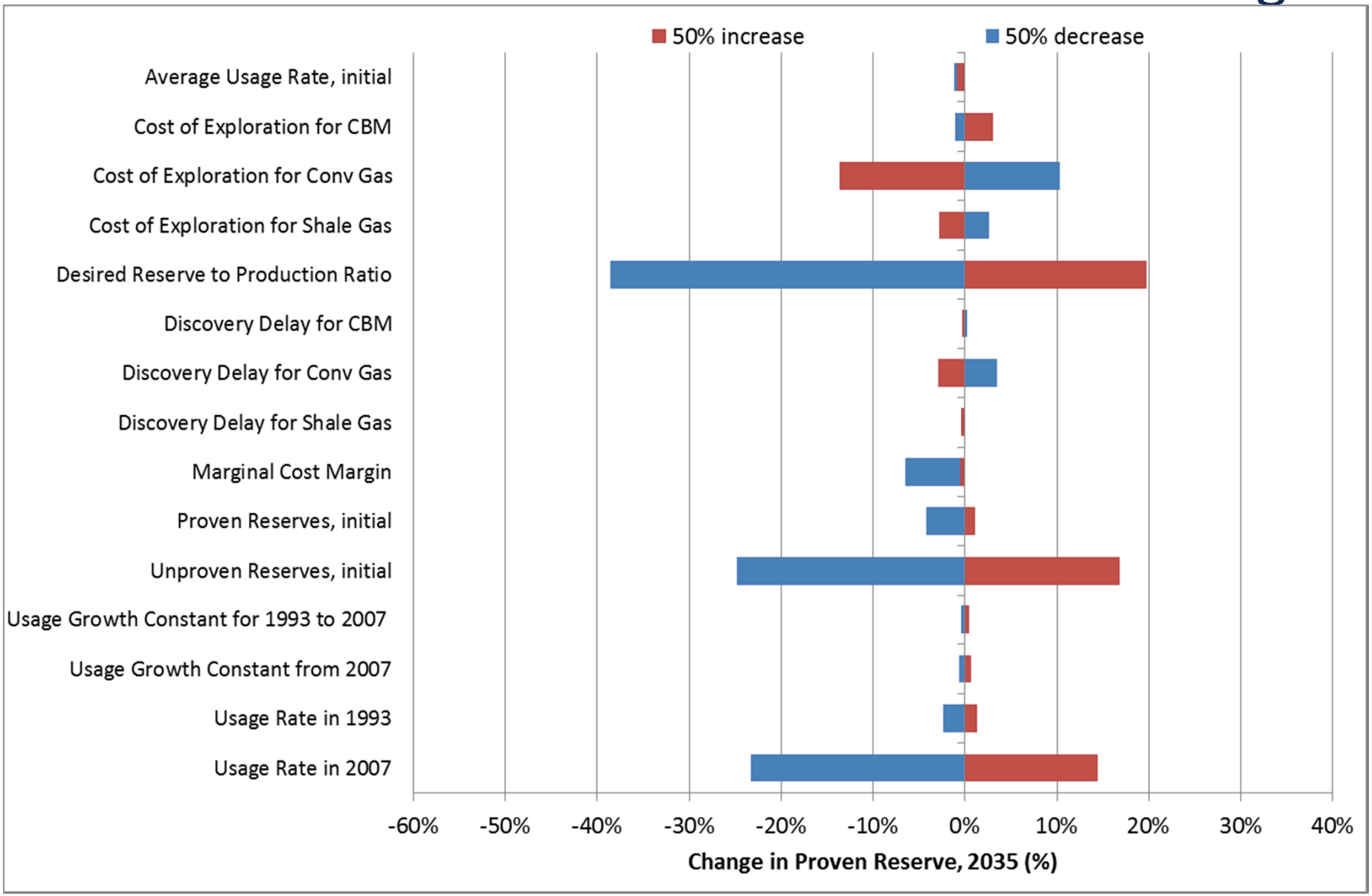




Working results as of 2014.

SD Model Parameter Sensitivity:

Effect on Proven Reserves due to Variable Changes



Working results as of 2014.

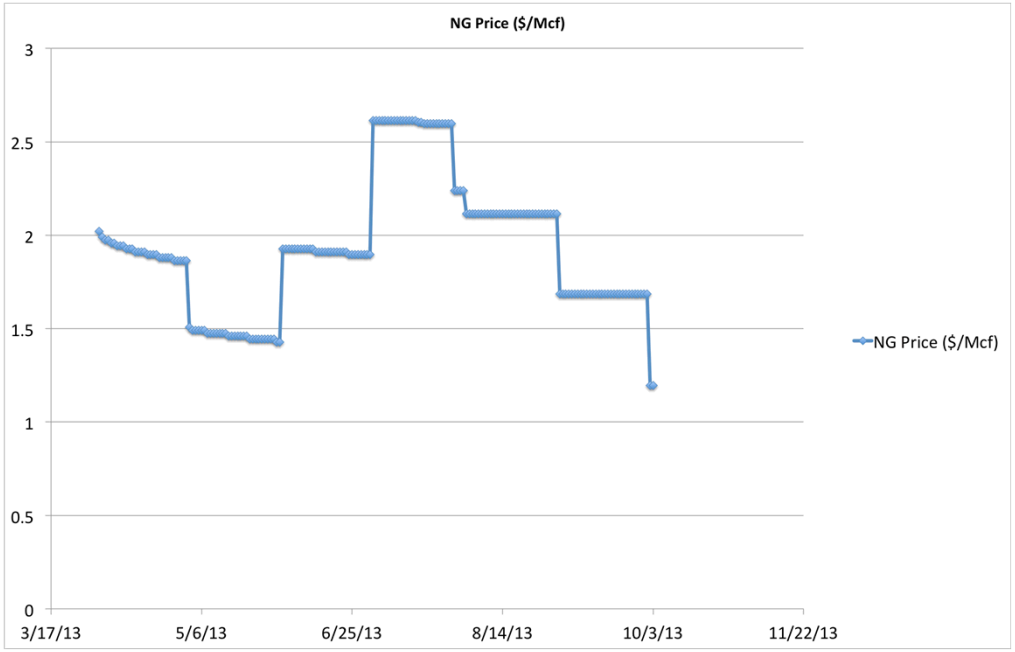
Agent Based Modeling (ABM) Efforts:

Addressing Supply, Demand and Infrastructure Shocks

- ABMs structure represents the U.S. Natural Gas Market
- Agents (Supply, Demand, Storage, etc.) are autonomous decision-making entities
- The dynamics of systems emerge from large numbers of interactions among heterogeneous agents

Initial working prices results:

- Reflecting seasonal storage behaviors and monthly demand fluctuations
- Endogenous Agent Behaviors developing
- Goal is to be able to address infrastructure shocks in both the short and long term timescale



Summary Slide

- Shale Gas (and Oil)
  - Changing the net Import Energy Balance of the United States
- Technical and Market Uncertainties
  - Will continue to alter the future supply and demand growth paths for Shale Gas in the United States
- Ongoing Research Efforts
  - Will continue to model the supply, demand and infrastructure balance in the U.S. and beyond
  - Notable Researchers (Stanford University, University of Texas Bureau of Economic Geology) finding broad uncertainties in forecasts of production assessments, and potential market price effects
- Additional References

  - Walker, L.N., Malczynski, L.A., Kobos, P.H., Barter, Garrett, 2014, The Shale Gas Phenomenon: Utilizing the Power of System Dynamics to Quantify Uncertainty, 32nd International Conference of the System Dynamics Society, SAND2014-16613C, Delft, Netherlands, July 20 – 24, 2014.
  - Outkin, A.V., Vargas, V.N., Kobos, P.H., Myerly, M.M., and G. Barter, 2014, "An Agent-Based Modeling Approach to Non-Equilibrium Dynamics of Natural Gas Supply Shock Propagation," 37th IAEE International Conference, SAND2014-3033C, New York, NY, June 15 – 18, 2014.

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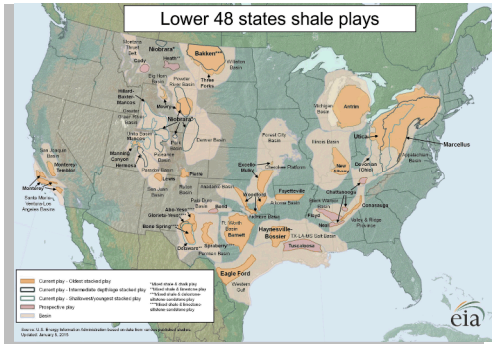

Thank You

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Energy and Economic Security Interdependencies

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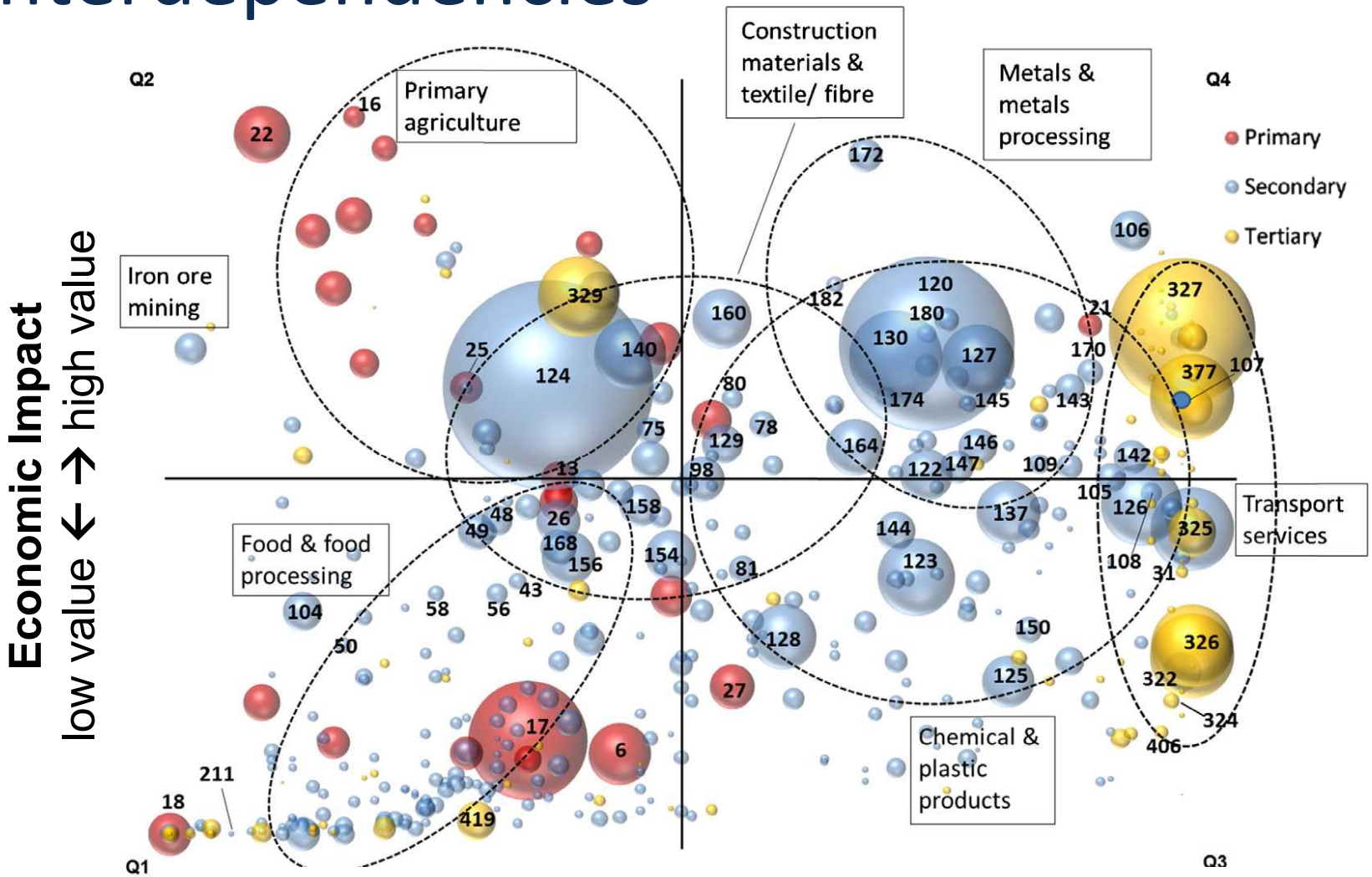
Backup Slide



Source: Figure adapted from Kerschner et al., 2013

The Shale Revolution in North America

Backup Slide

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

Global Shale Resources:

Large Potential and Uncertainty in Production Volumes

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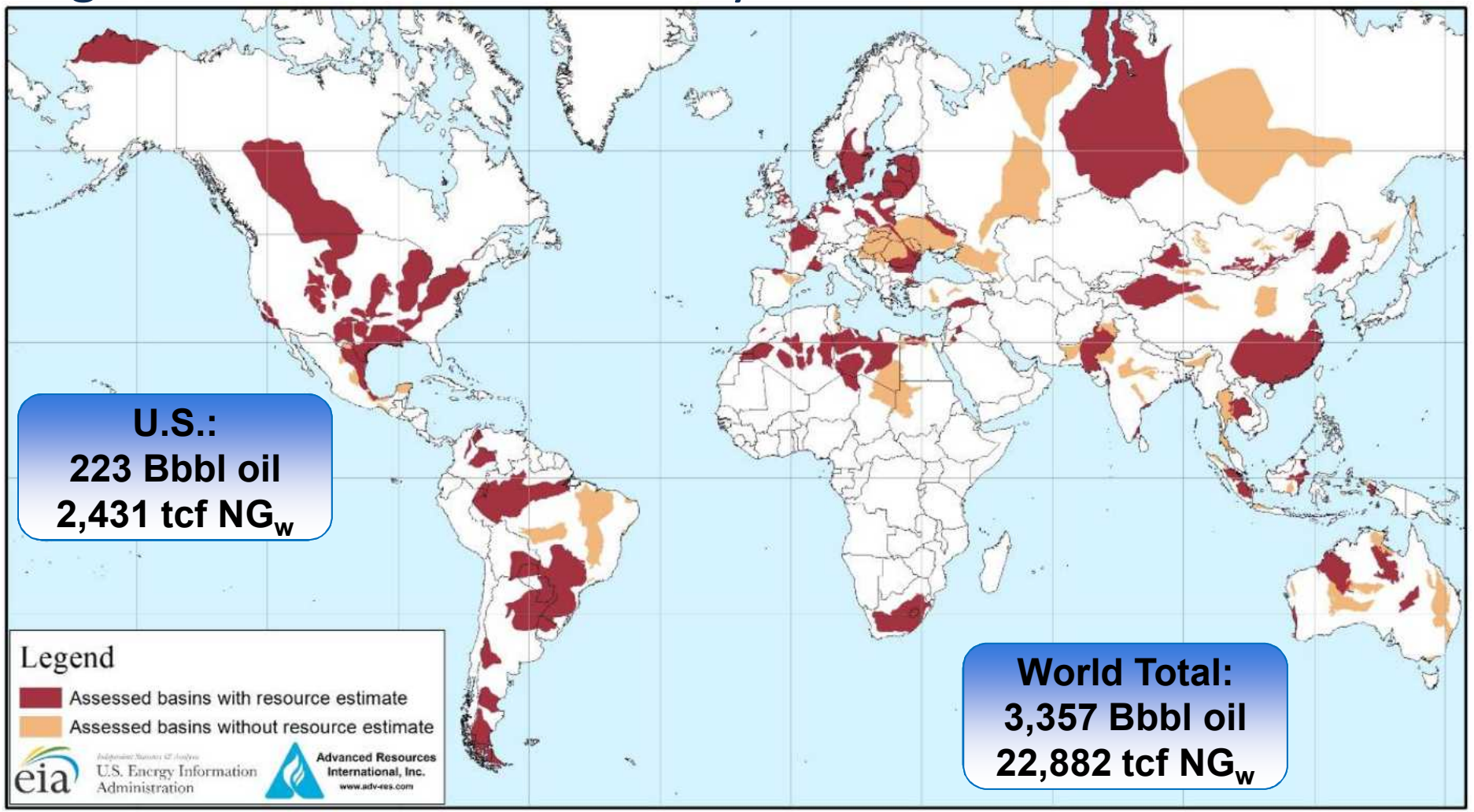
Backup Slide



U.S. Basins from U.S. EIA and the USGS; other basins from ARI based on data from various published studies. Billion barrels (Bbbl), trillion cubic feet, wet natural gas (NG_w)

EIA website, 2/2015, http://www.eia.gov/analysis/studies/worldshalegas/ , based on AEO 2013 and other sources, illustrative U.S. and World data from 2013.

U.S. Residential, Monthly Natural Gas Prices: Nominal and Real Prices

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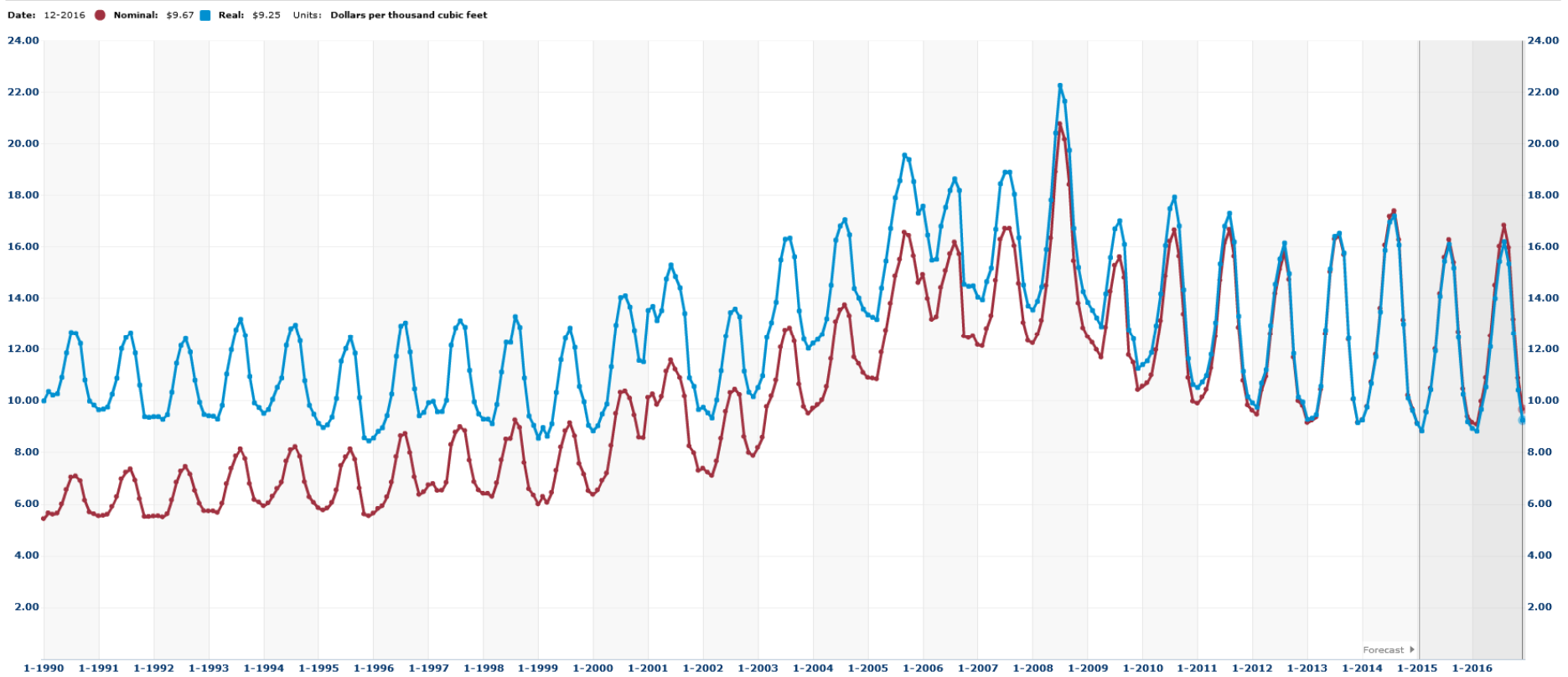
Backup Slide

($US 2014 / thousand ft^3)



Source: EIA website as of 3/4/2015. http://www.eia.gov/forecasts/steo/realprices/