The Future of Natural Gas

An Interdisciplinary MIT Study

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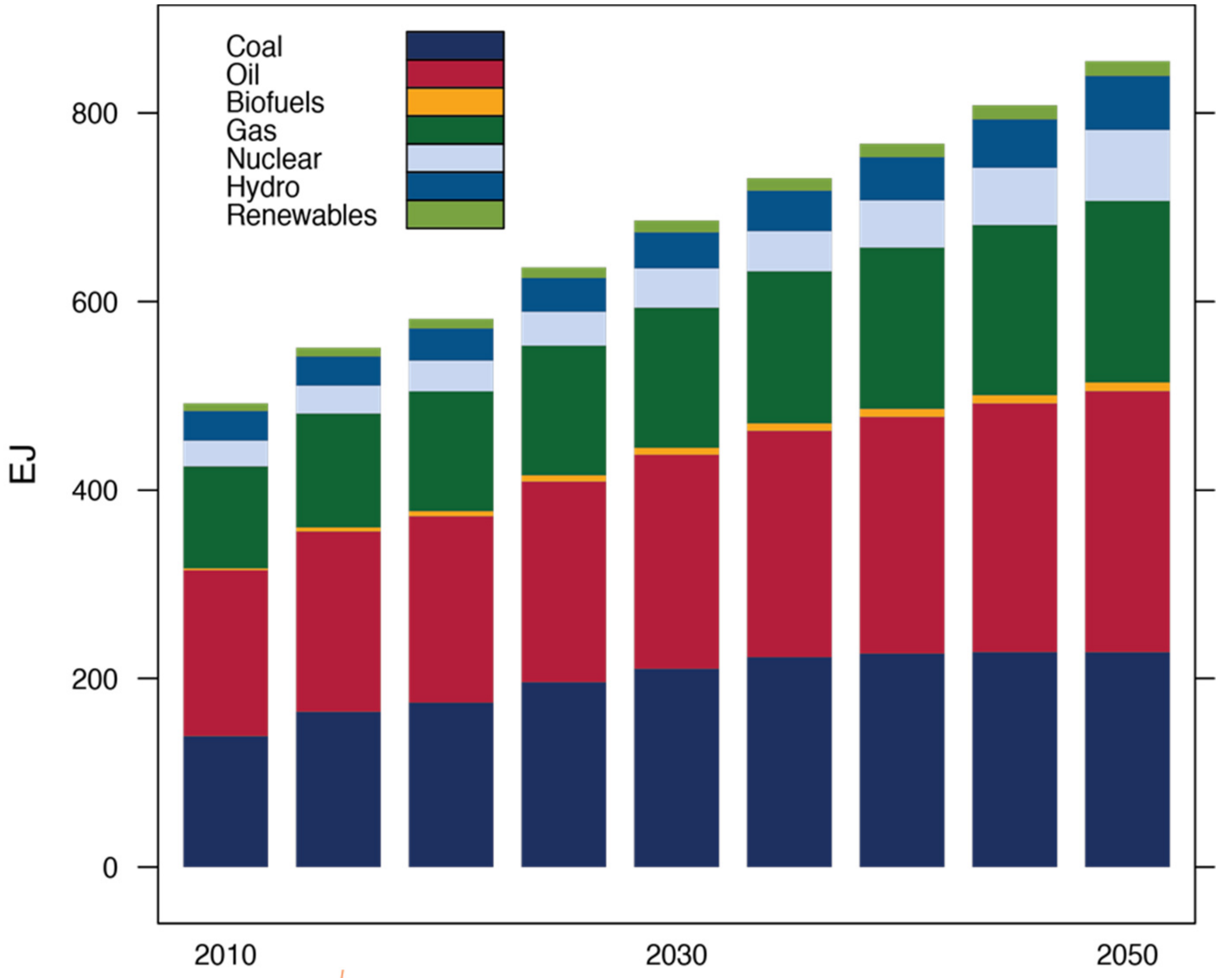
Outline

- Why now?
- Supply
- System impacts
- Demand
- Gas to liquids
- Closing thoughts

Global Energy Use



As population and incomes increase, energy needs and desires will increase – doubling energy use by 2050.

Most energy will come from the same sources currently utilized: coal, oil and natural gas.

http://golbalchange.mit.edu/Outlook2012/

Natural gas central to energy, security, climate debate

- “Bridge” to a low-carbon future?
- Shale/unconventional gas resource assessments
- Expanded use in power, transportation

Third in MIT series examining energy sources under CO_2 emissions constraints

- Nuclear Power (2003) and Coal (2007)
- Integrated analysis with 2050 horizon
- International perspective with US focus

Multiple Uncertainties

- GHG mitigation measures?
- Technology mix over time?
- Evolution of international gas markets?
- Ultimate size/cost of NG resource base?

Overarching Conclusions

- Abundant global resources, expanded use, especially electricity
- Increasing share in US, with key role for unconventional resources
- Larger share with CO_2 emissions constraints; but with very stringent constraints, role of all fossil fuels limited without competitive CCS
- Global gas markets can change dramatically to 2050

Supply – The Approach

- Building on existing assessment data
- Treating resources as an economic concept
- Recognizing and embracing uncertainty

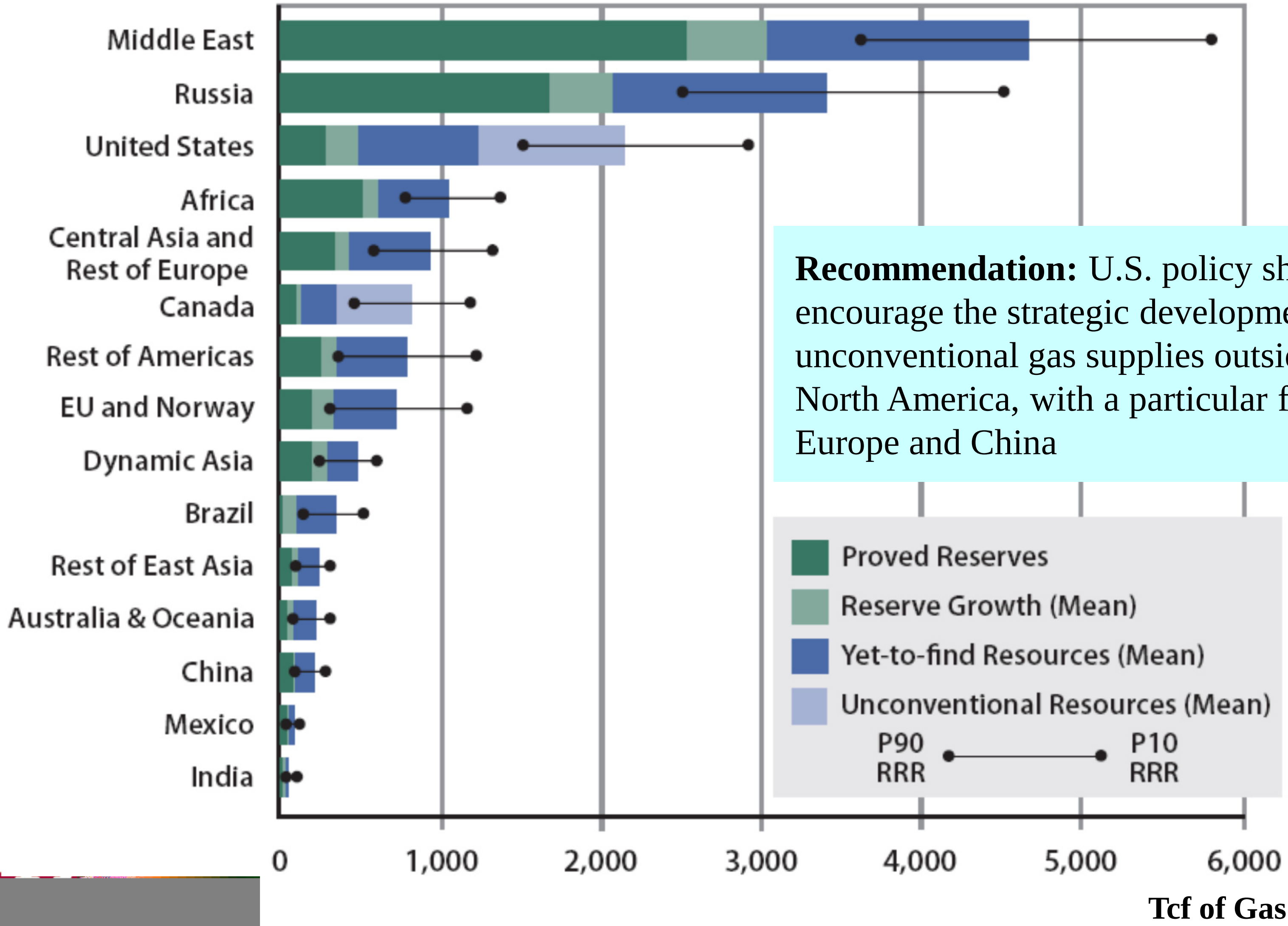
Key Findings

1. **Globally, there are abundant supplies of low cost natural gas resources**
   - 8,000-10,000 Tcf of conventional gas economic at less than $4.00/MMBtu (at export point)
   - Large but poorly defined unconventional resource
   - Policy and politics will play a major role

2. **Unconventional gas will make an important contribution to U.S. energy supply**
   - Unconventional gas is ~50% of the resource base and ~50% of current production
   - Shale gas comprises ~30% of U.S. resource, but there is considerable uncertainty around costs and volumes

3. **Environmental impacts of shale gas development are manageable but challenging**

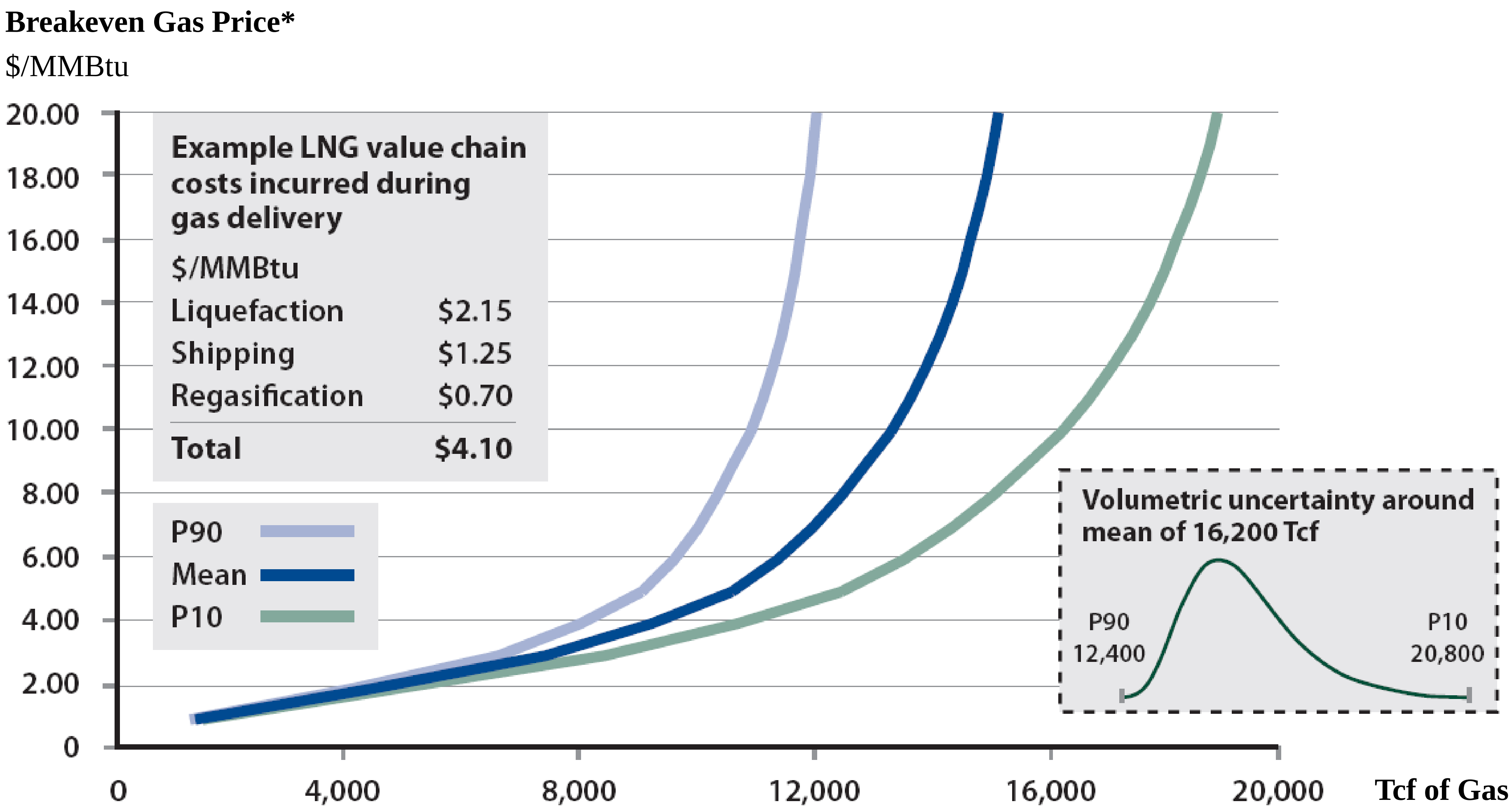
Remaining Recoverable Natural Gas Resources
(Excludes unconventional gas outside North America)



Recommendation: U.S. policy should encourage the strategic development of unconventional gas supplies outside of North America, with a particular focus on Europe and China

Global Gas Supply Cost Curve

(Excludes unconventional gas outside North America)

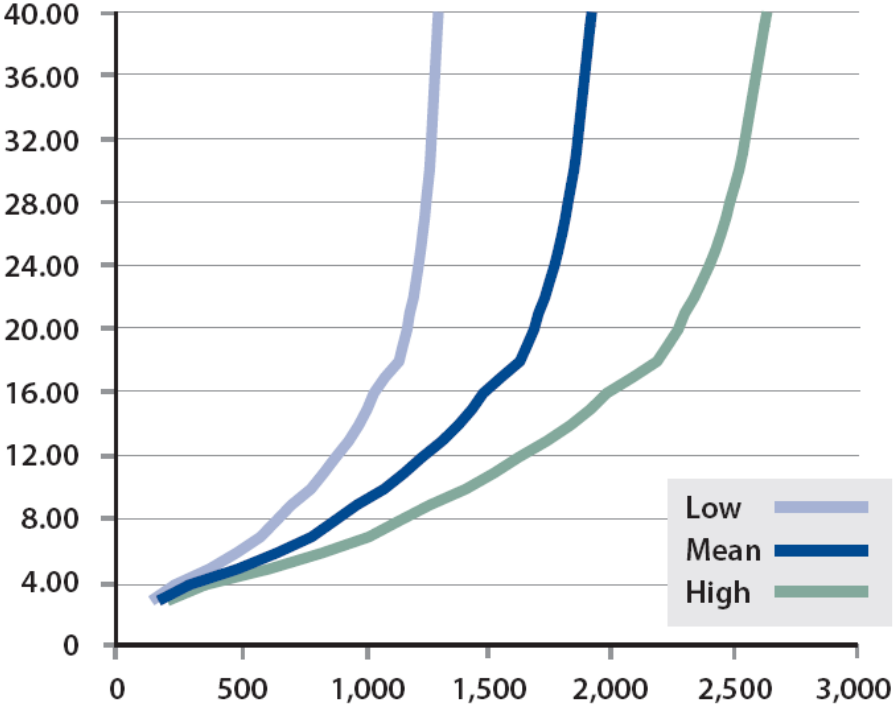


* Cost curves based on 2007 cost bases. North America cost represent wellhead breakeven costs. All curves for regions outside North America represent breakeven costs at export point.
Cost curves calculated using 10% real discount rate, ICF Hydrocarbon Supply Model
** Assumes two 4MMT LNG trains with ~6,000 mile one-way delivery ru, Jensen and Associates

U.S. Gas Supply Cost Curve

Breakeven Gas Price*

$/MMBtu

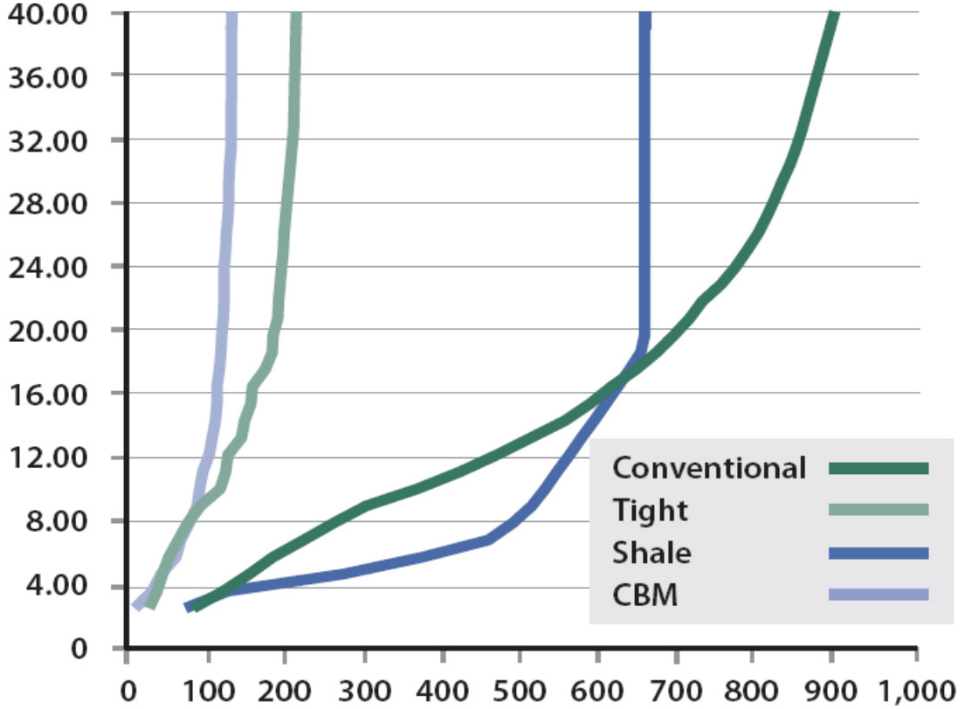


Tcf of Gas

Breakdown of Mean U.S. Supply Curve by Gas Type

Breakeven Gas Price*

$/MMBtu



Tcf of Gas

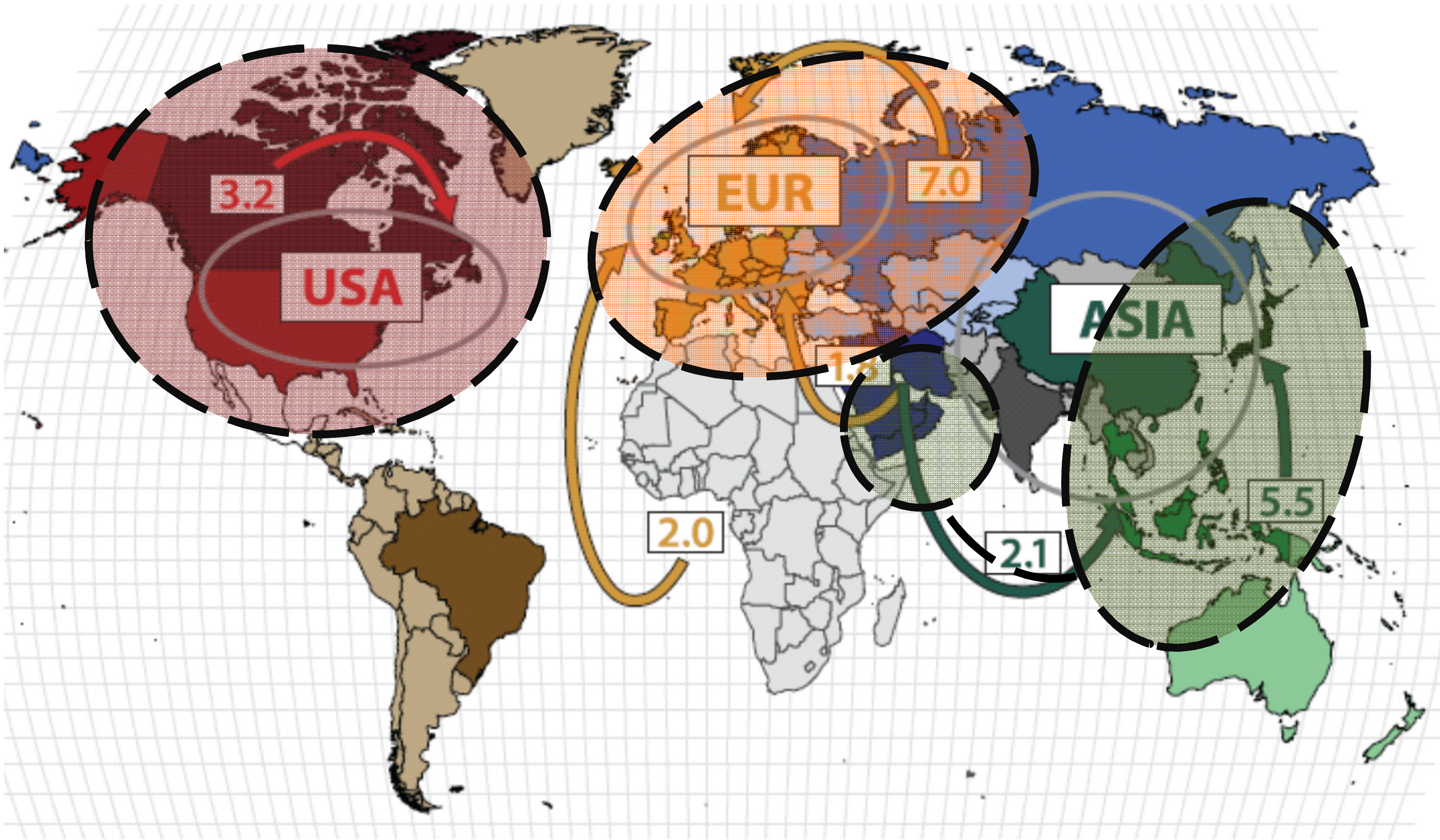
* Cost curves calculated using 2007 cost bases. U.S. costs represent wellhead breakeven costs. Cost curves calculated assuming 10% real discount rate, ICF Hydrocarbon Supply Model

System Studies of Gas Futures

- The economic models (EPPA and USREP)
  - Strengths
  - Limitations
- Interactions and uncertainties

• Gas Resources	(High, Mean, Low)
• Greenhouse gas mitigation	(3 scenarios)
• Technology cost	(Sensitivity tests)
• International gas markets	(Regional vs. global)

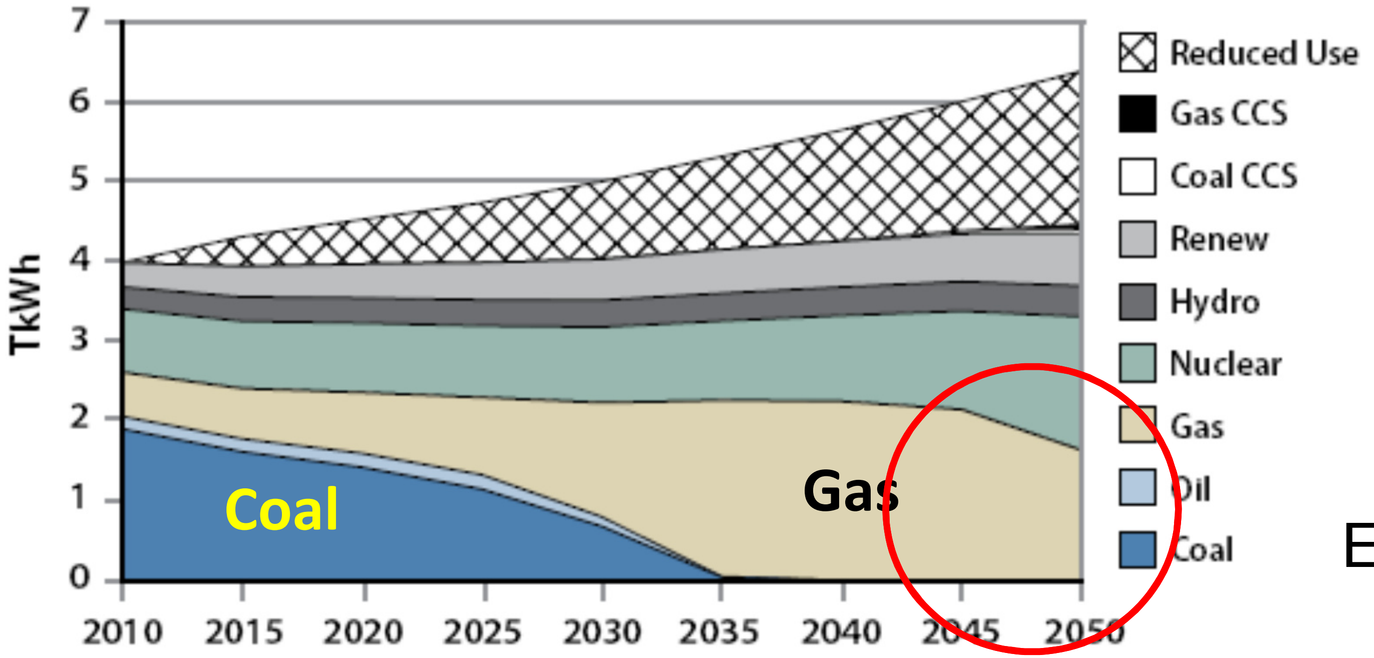
Regional Gas Markets in 2030 (Tcf)



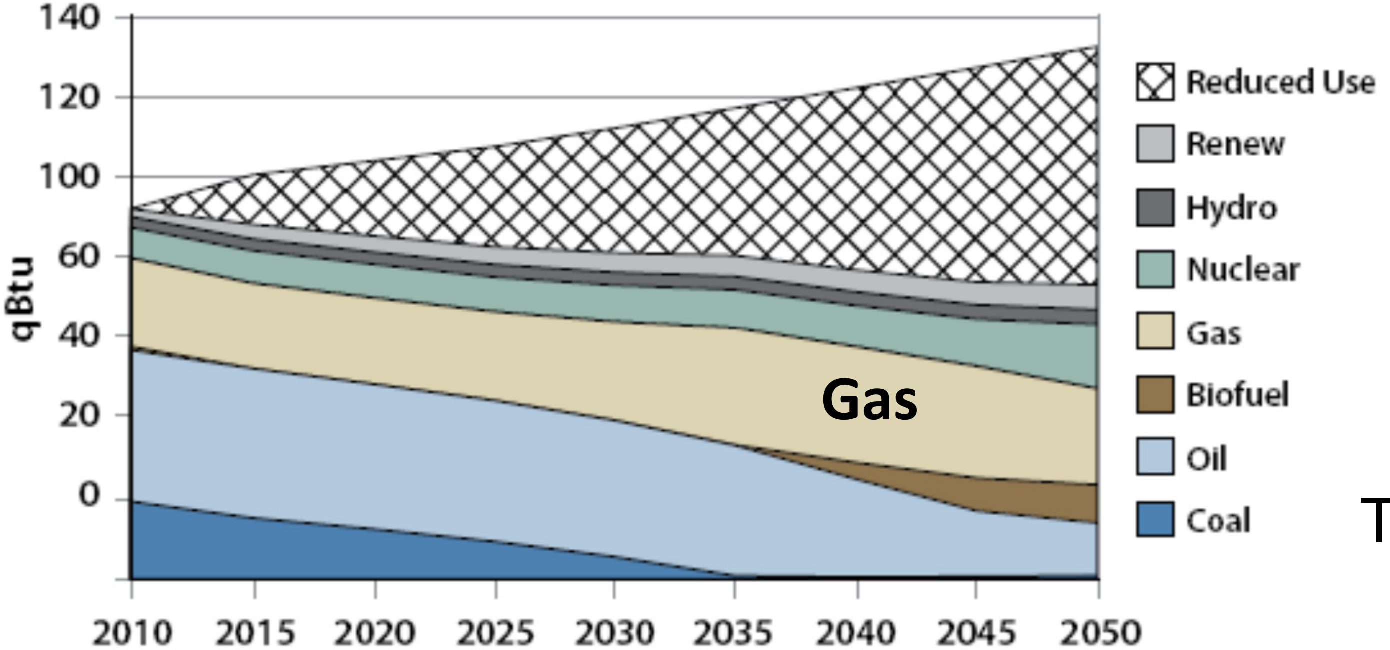
Price-based mitigation

50% by 2050

No offsets



Electric sector

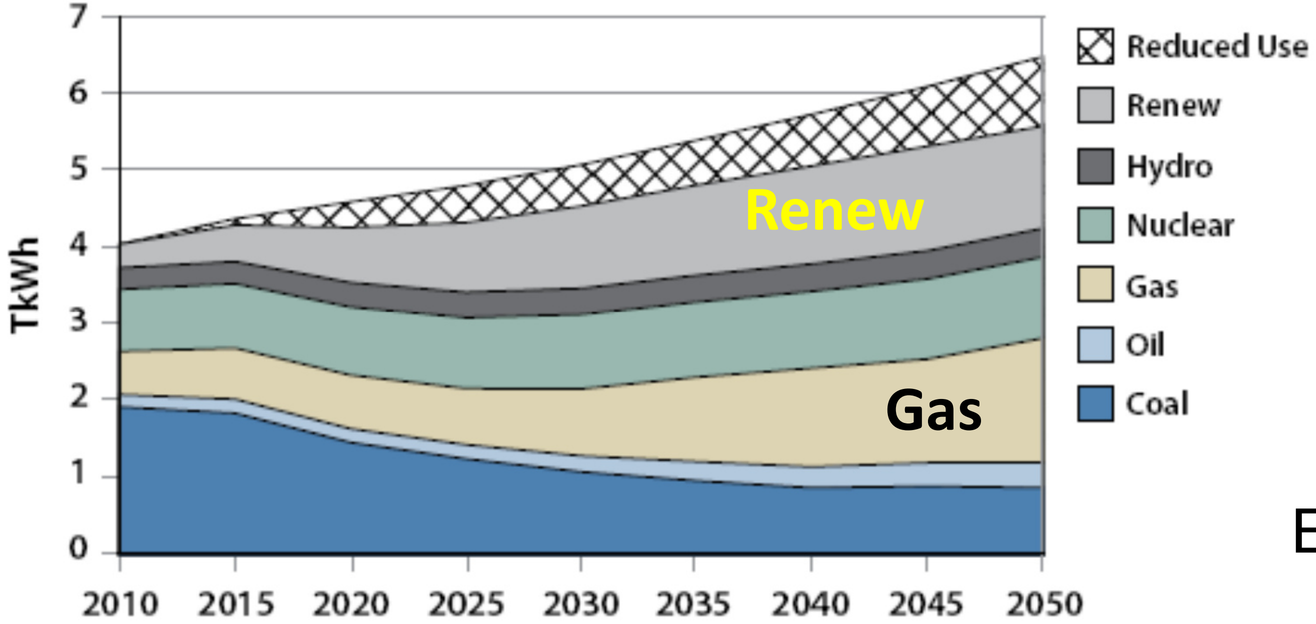


Total energy

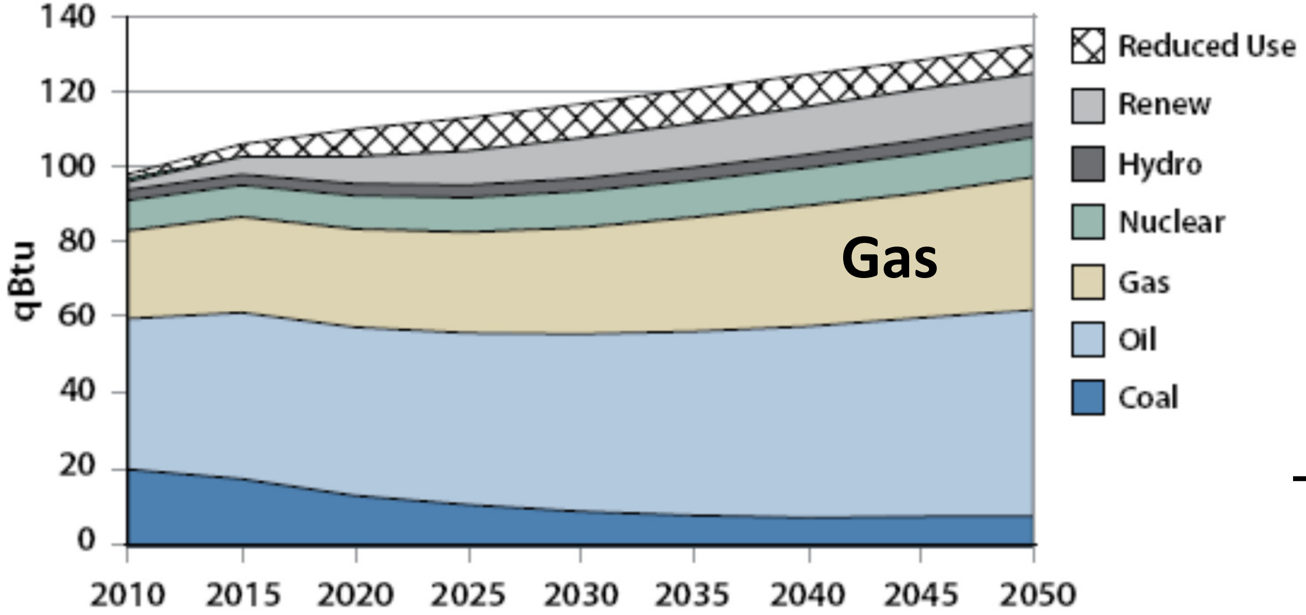
Regulatory mitigation

25% RES 2030

55% coal retire

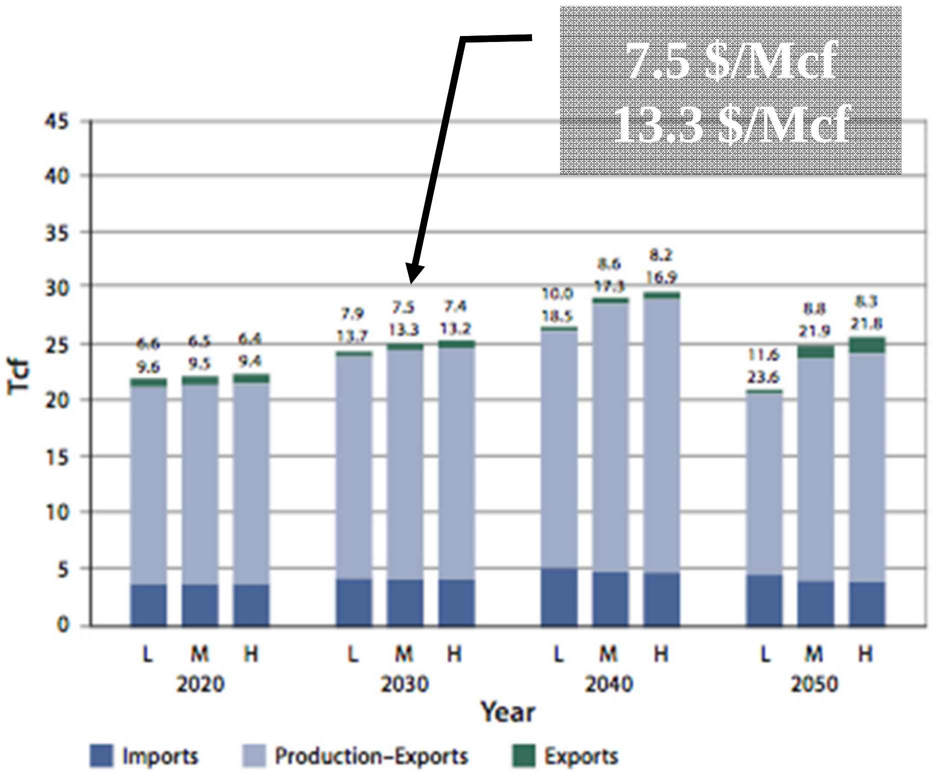


Electric sector

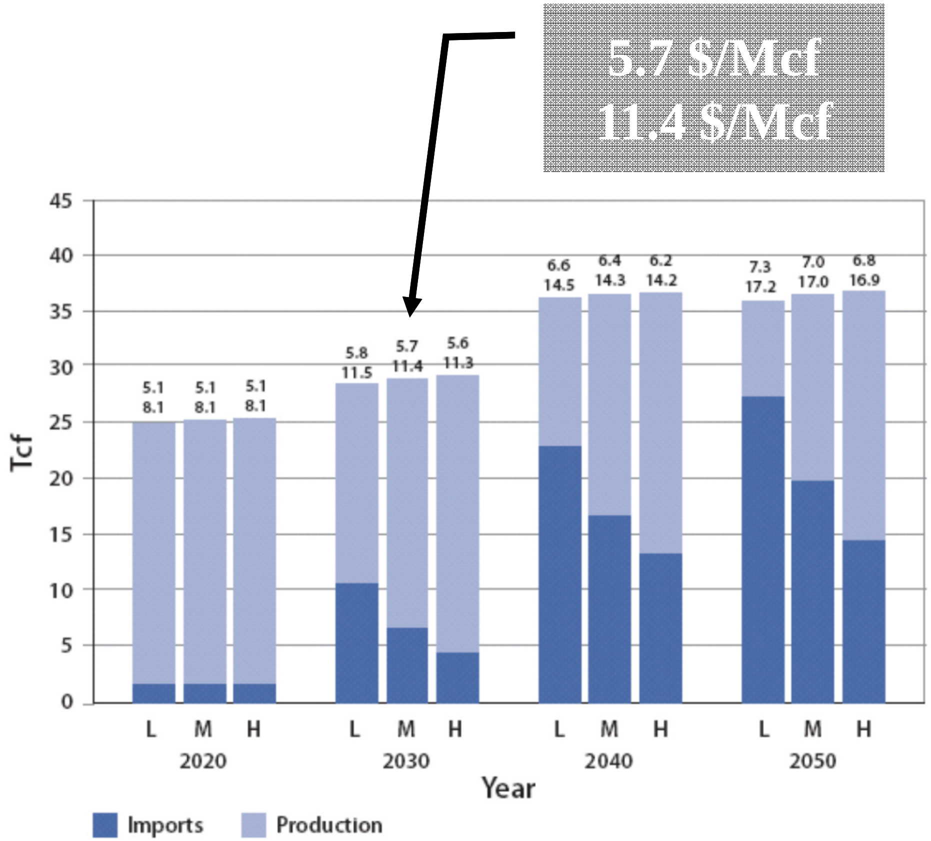


Total energy

International Market Evolution

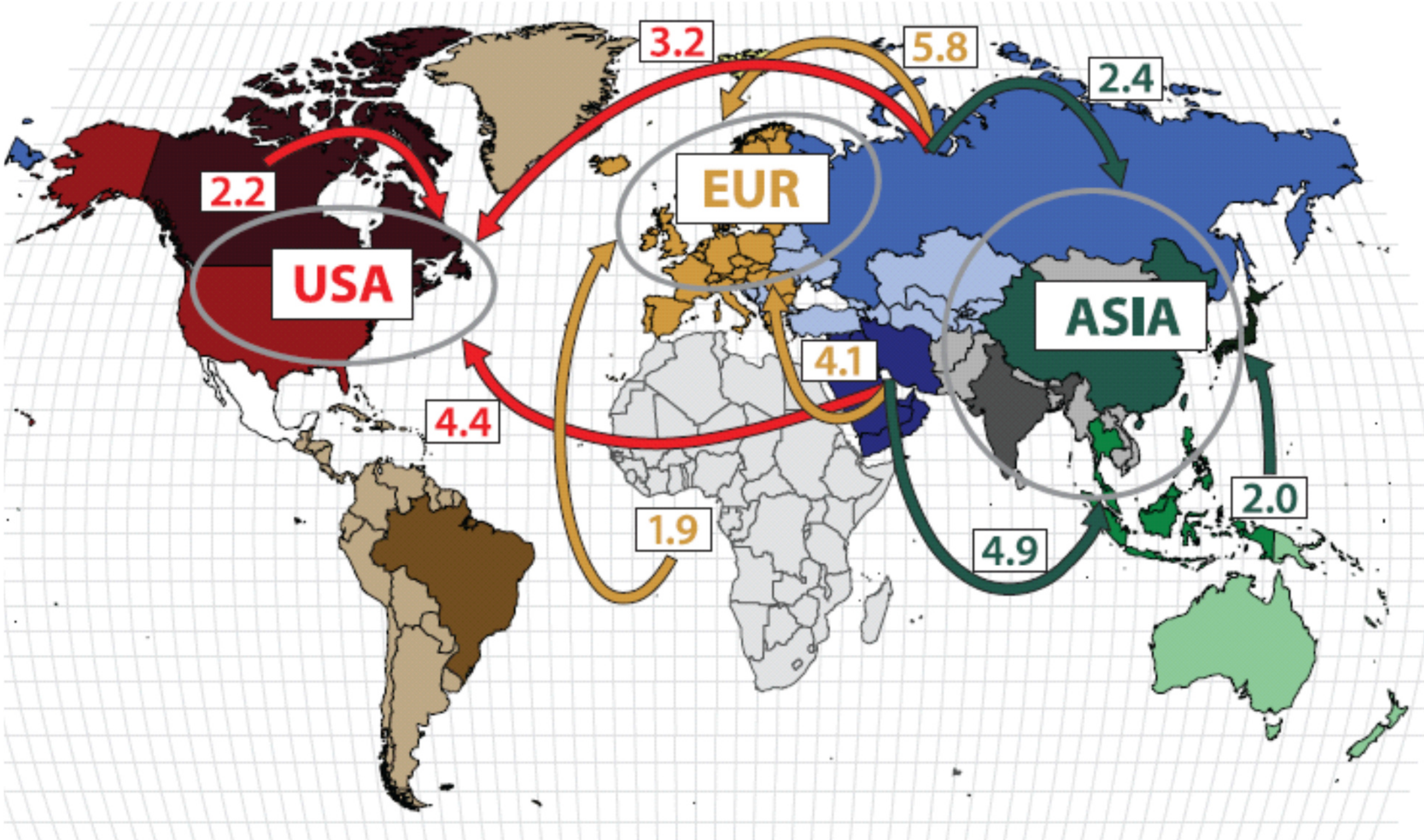


Regional Markets



Global Market

Global Gas Markets in 2030 (Tcf)

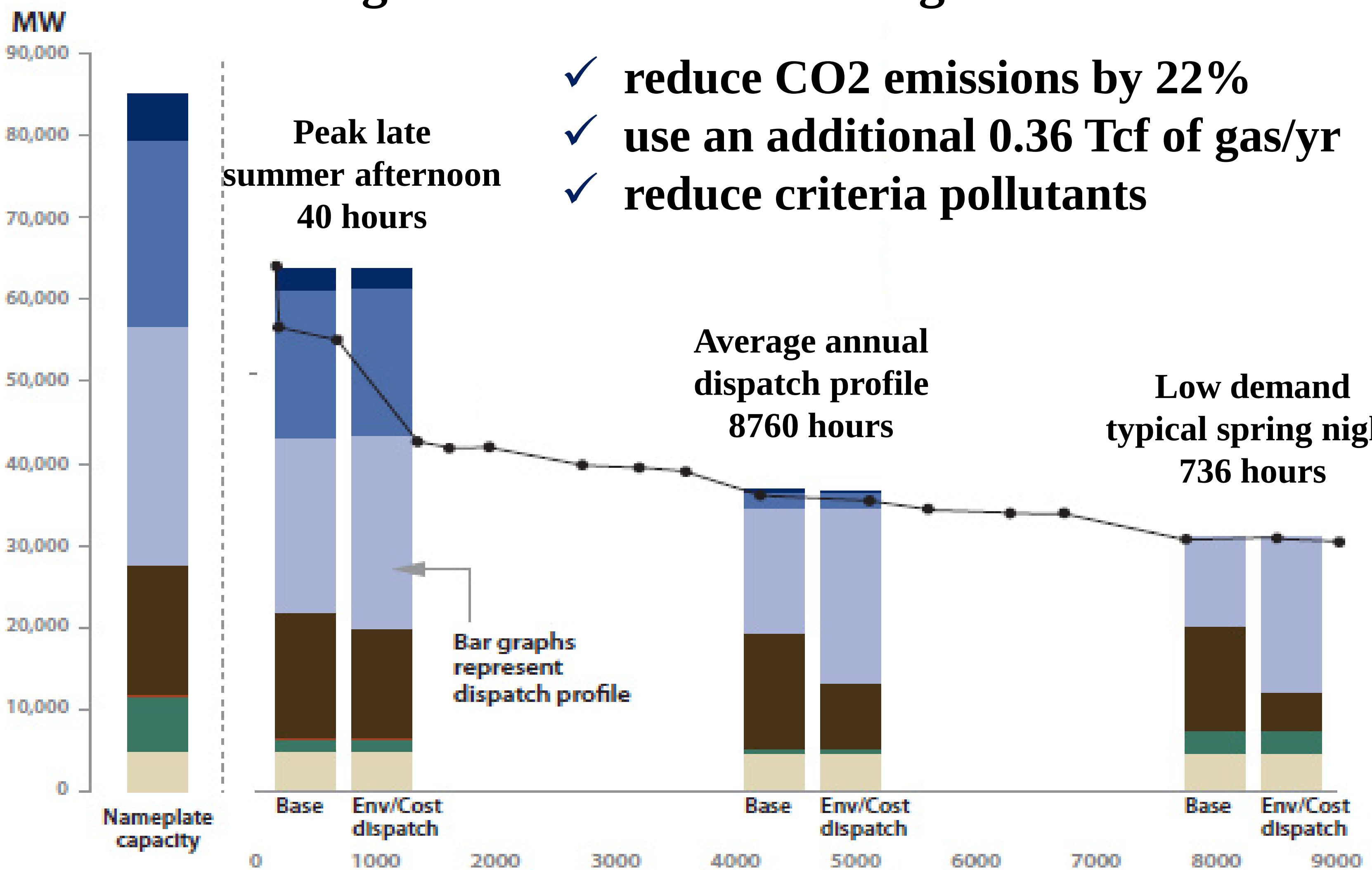


Demand

- Resilience in gas use across sectors
- Potential major growth areas:
  - Electricity
    - Natural gas substitution for coal
    - Intermittent sources/variability & uncertainty
  - Transportation
    - Long term potential for CNG
    - LNG not currently attractive
    - Natural gas to liquid fuels/oil dependence

Coal generation displacement with NGCC generation in ERCOT region would:

- ✓ reduce CO_2 emissions by 22%
- ✓ use an additional 0.36 Tcf of gas/yr
- ✓ reduce criteria pollutants

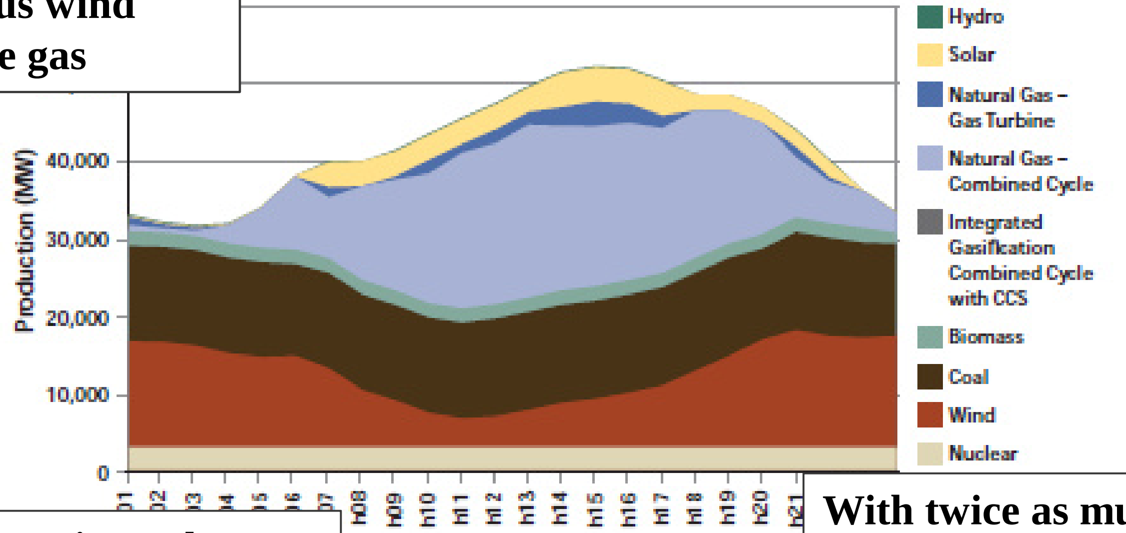


Nationwide, coal generation displacement with surplus NGCC would:

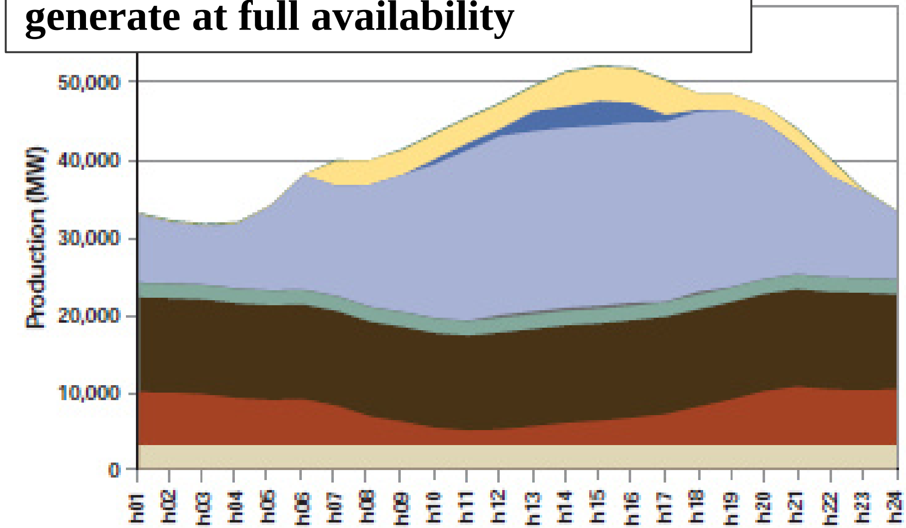
- reduce CO_2 emissions from power generation by 20%
- reduce CO_2 emissions nationwide by 8%
- reduce mercury emissions by 33%
- reduce NO_x emissions by 32%
- cost roughly $16 per ton/$CO_2$

The displacement of coal generation with NGCC generation should be pursued as the only practical option for near term, large scale CO2 emissions reductions

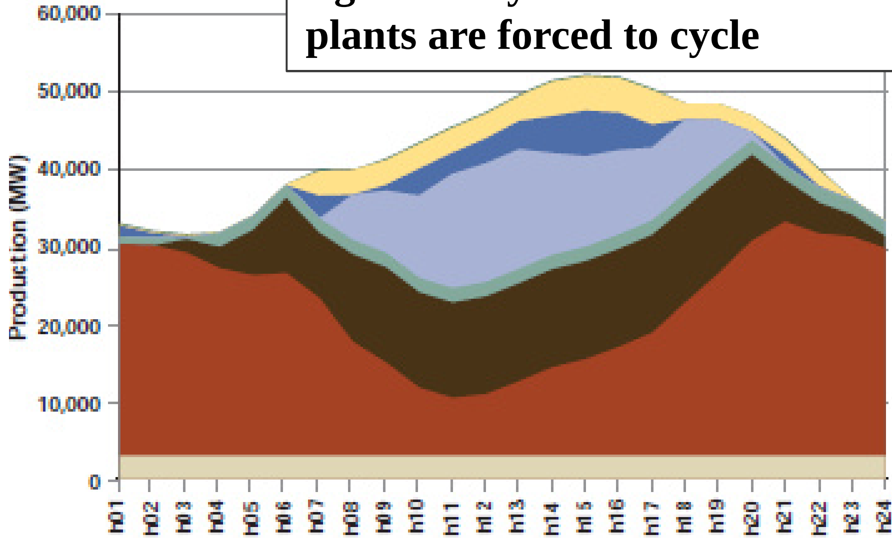
Base case: night time load is met by baseload plus wind without appreciable gas



With ½ the wind, NGCC is used to meet demand and baseload plants generate at full availability



With twice as much wind, gas generation is reduced significantly & baseload coal plants are forced to cycle



Opportunity – Gas to Liquid Options

- Basic Driver
  - Energy basis: 1 bbl oil = 6 MCF gas
  - Cost basis: $100/bbl vs. $3 / MCF
- Challenges
  - Capital costs very high and uncertain
    - e.g., Pearl plant was completed in 2011 and uses Shell technology. FT liquids capacity is 140,000 Barrels per day. Cost was $19+ billion. >$135,000/BPD.
    - Oryx was completed in 2006 and uses Sasol technology. FT liquids capacity is 34,000 Barrels per day. Cost was $1.5 billion. $46,000/BPD

Bookends for Methane Conversion

- Complete Pyrolysis
  - $CH_4 \rightarrow C + 2\ H_2$
  - Theoretical efficiency ~60%
  - H_2 is not a liquid fuel. Solid carbon is not valuable.
  - Not helpful for stranded gas or associated gas
- Combustion
  - $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$
  - CO_2 and H_2O are not valuable energy carrying products
- Between the bookends there are many potential routes

Methane Conversion Routes

- Direct (one reactor; usually need to separate & recycle CH_4)
  - Pyrolysis
    - To acetylene
  - Oxidative coupling
    - To ethane and ethylene
  - Partial oxidation
    - To methanol and formaldehyde
- Indirect (several reactors, often separations in between)
  - Via methyl-X (e.g. X= -Br, $-SO_3H$, $-CF_3CO_2^-$)
  - Via syngas to methanol or FT
  - Syngas options:
    - Steam reforming
    - Partial oxidation
    - CO_2 reforming
    - Combinations of the above including autothermal

Why is "Direct" so Hard?

- CH_4 is much less reactive than most products
- So initial products converted to something else (e.g., CO_x or coke)… classic $A \rightarrow B \rightarrow C$

Highly reactive catalysts, high T are best: Attack CH_4 about as fast as they attack the desired product. Free radicals: OH is best. High T followed by fast quench also works. But usually cannot achieve even 50% yield.

- At low conversions, make desired product, but then reacts on to undesired product.
- Figure of merit: single-pass yield of desired product

“Indirect” Routes: Synthesis Gas

- The popular indirect route: $CH_4 + H_2O = CO + 3\ H_2$
  - Favorable equilibrium only at high T~1100 K
  - Endothermic, must supply heat
  - External heat (furnace): “Steam Methane Reforming”
  - Internal heat generation (by adding O_2): “autothermal reforming”
  - Heat generated by burning CH_4. Heat recuperation can recover some free energy, but much is wasted.
  - Wrong H_2:CO ratio. Can adjust using CO_2 if available.
  - Reagents H_2O and O_2 are readily available everywhere

Natural Gas – Bio-GTL

- Advantage: can operate at significantly smaller (10x) plant sizes than current chemical GTL plants.
  - Allows distributed liquid fuel production based on smaller gas wells throughout the world.
- New technology based on anaerobic CO_2-fixing bacteria
  - Requires conversion of natural gas to synthesis gas.
  - The product is then used as feedstock for production of various liquid fuels, such as isobutanol, oils and linear hydrocarbons.
  - Preliminary cost estimates are encouraging.

Looming Issues

- Export vs. feedstock
- Fracking
- Water impacts
- Methane emissions
- Flaring
- CNG vs. LNG
- Gas to liquids

Closing Observations

- Natural gas supplies are globally abundant and low cost for at least several decades to come
- Create level playing field/CO_2 price for all fuels
- Support integrated global gas market
- Favorable economics of gas relative to oil suggest re-examination of methane as a feedstock for liquid fuels and chemicals
- Coupled gas-electricity infrastructure presents interesting challenges going forward

Thank You!

Scale and Location of Fully-Dispatched NGCC Potential and Coal Generation (MWh, 2008)