Implications of Shale Gas Development for Climate Change

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Context

- This presentation is part of workshop on issues related to US and EU energy and environmental policies.
- The presentation focuses on the greenhouse gas impacts of shale gas development.
- Comprehensive analysis should consider the range of impacts relative to other energy sources, as well as the benefits of shale gas development.

What questions are at play?

- Greenhouse gas (GHG) accounting
  - Aggregate level
  - Sectoral technology level
- Decisions by producers, policymakers, equipment manufacturers, and corporate and individual purchasers

Overview

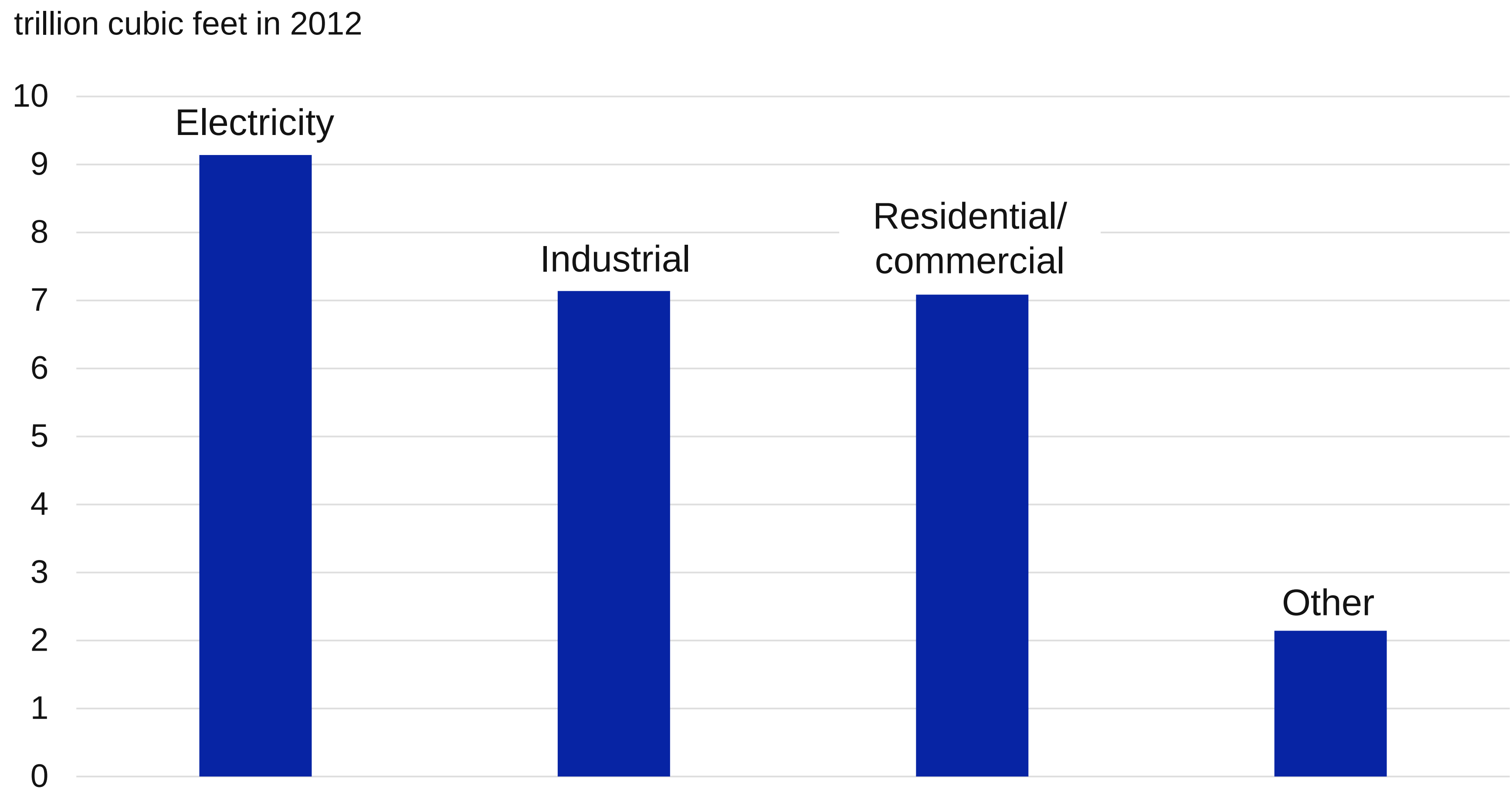
- U.S. natural gas use and shale gas development
- Understanding the potential implications of increased natural gas use on the climate
- Aggregate effects on U.S. energy and economy
- Non-combustion GHG emissions from natural gas
- Sectoral impacts: electricity, residential and commercial buildings, transportation, and industry
- International implications
- Policy interactions and implications

Relevant existing evidence

- Baseline statistics
  - Emissions accounting (EPA, industry, academia, NGOs)
  - Energy data (U.S. Energy Information Administration (EIA), industry)
- Technology lifecycle analysis
  - Various studies (source list at close of presentation)
- Energy modeling projections
  - Results of these projections depend on modeling assumptions
  - EIA *Annual Energy Outlook 2013*
    - Reference case: current policies
    - High oil and gas resource case (note also increases oil)
  - International Energy Agency *World Energy Outlook 2011* and *2012*
    - New Policies case
    - Golden Age of Gas case
  - Other modeling studies

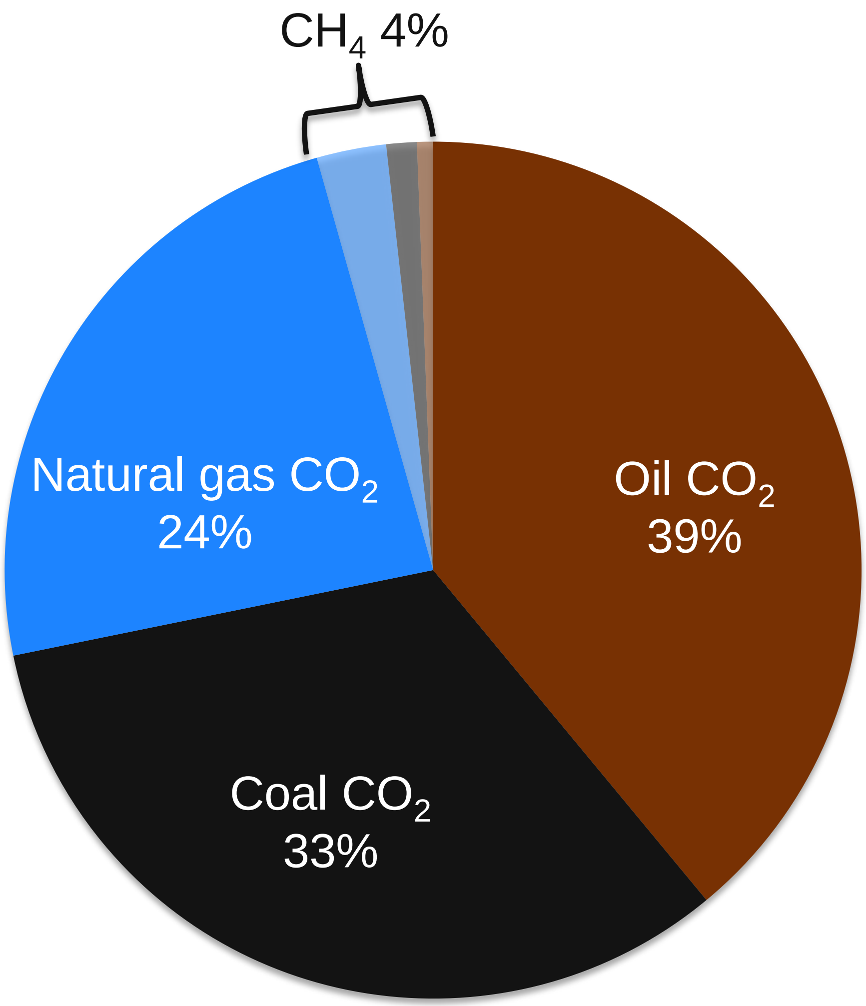
U.S. natural gas use and shale gas development

U.S. natural gas consumption by end-use



Data source: U.S. Energy Information Administration

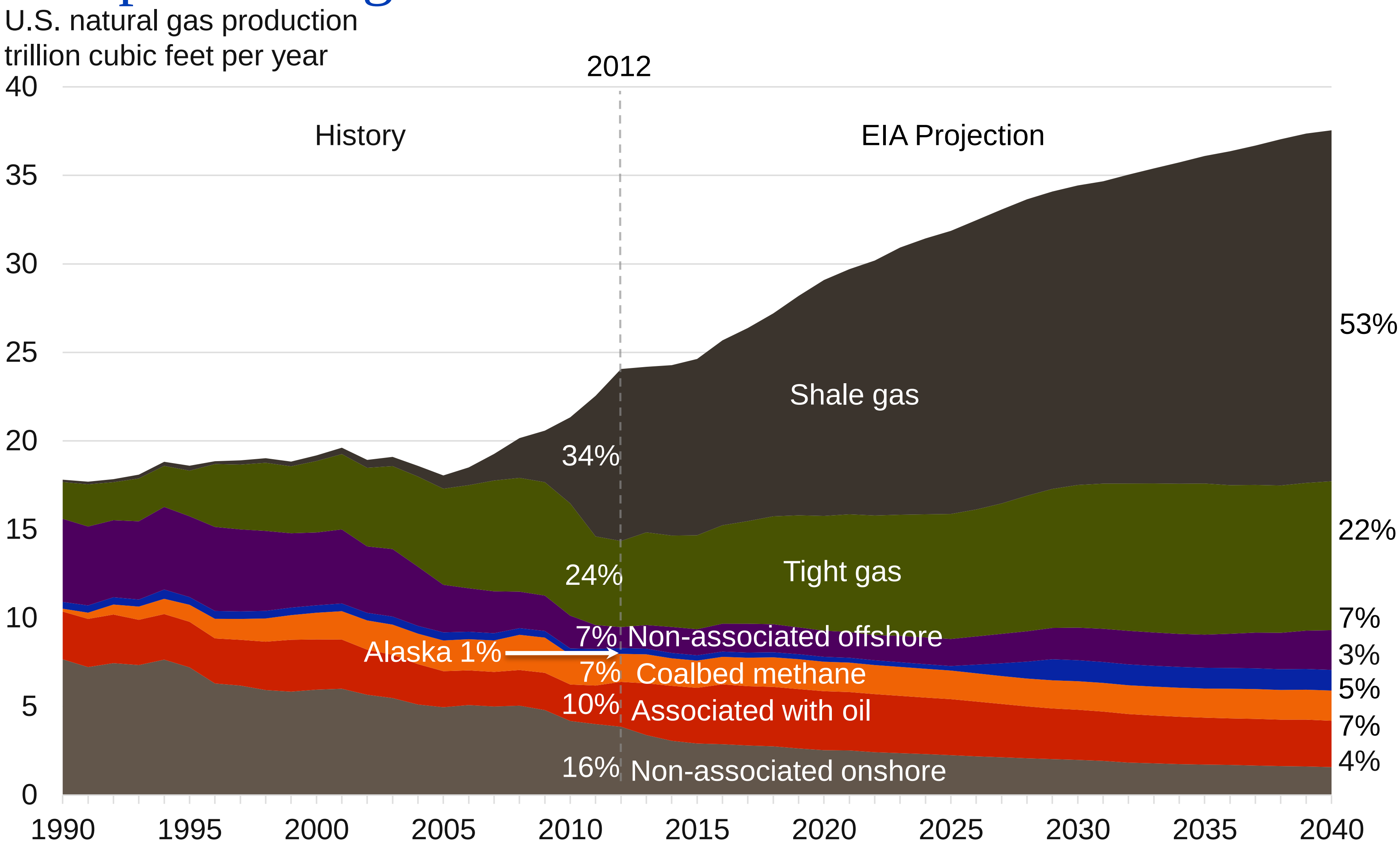
Natural gas was about 26% of total CO_2 and CH_4 emissions from U.S. fossil energy in 2011



2011 fossil energy CO_2 and CH_4 emissions	5,553 Tg CO_2e
Natural gas CO_2 and CH_4	1,469 Tg CO_2e (26%)

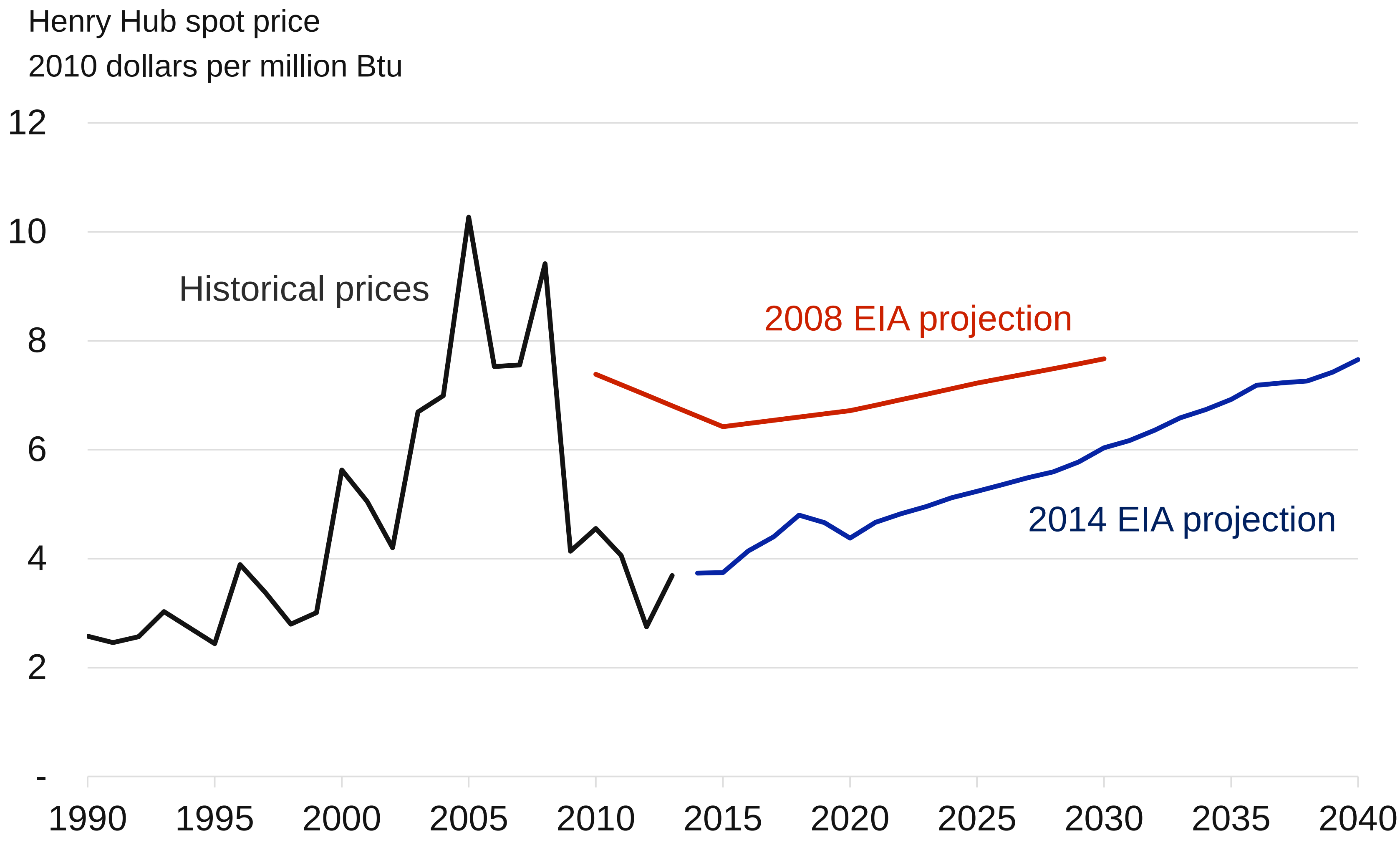
Data source: U.S. EPA Greenhouse Gas Inventory 2013.

U.S. shale gas production has surged and is expected to growth further



Data source: U.S. Energy Information Administration, Annual Energy Outlook 2014, Reference case.

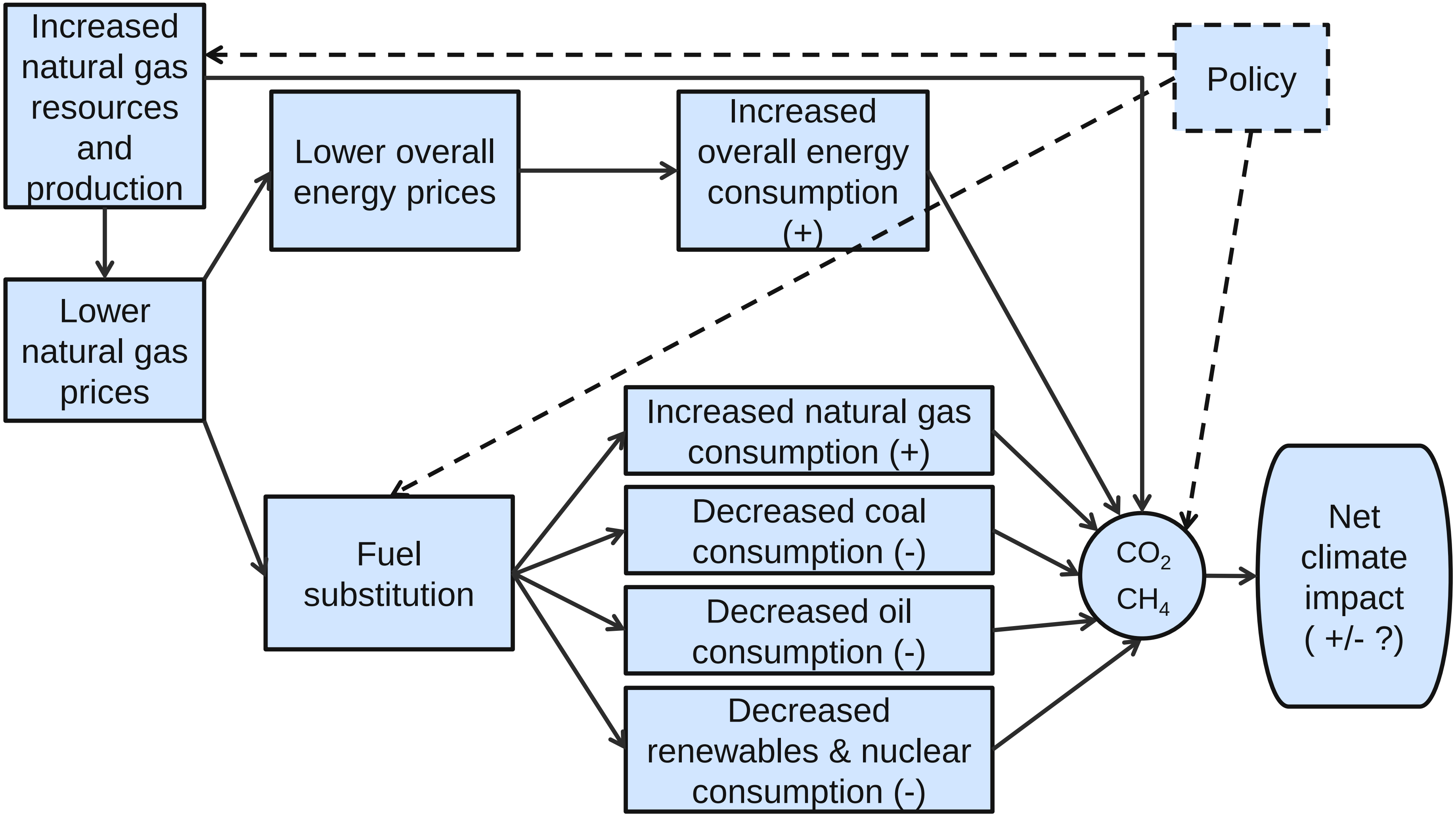
Current and projected U.S. natural gas prices have declined



Data source: U.S. Energy Information Administration, Annual Energy Outlook 2008 and 2014, Reference case.

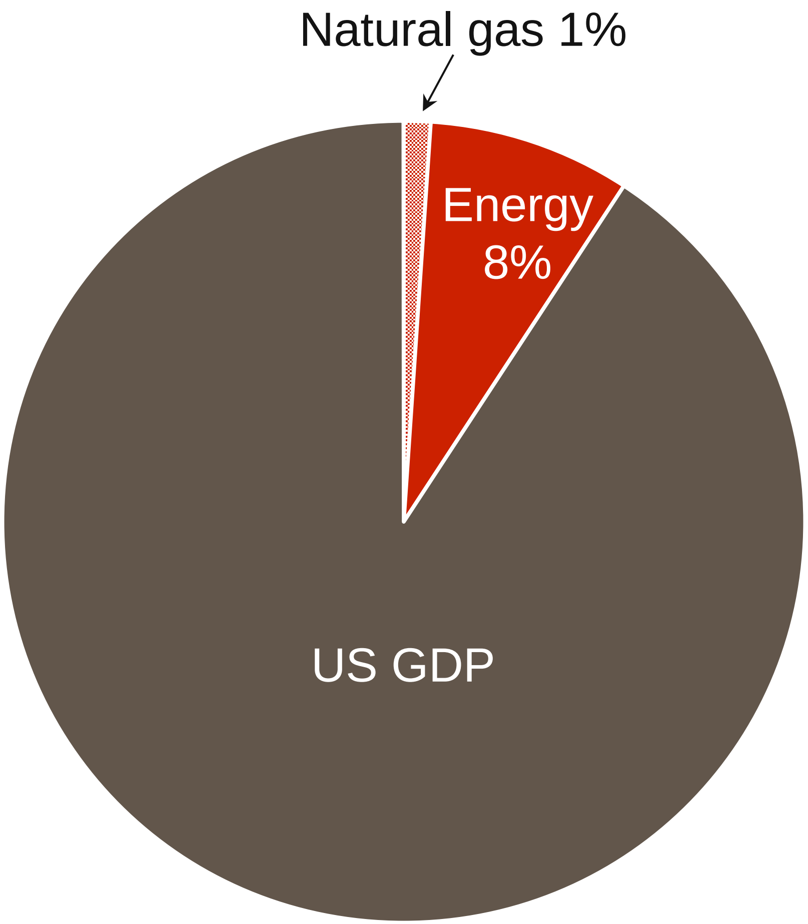
Understanding the potential implications of increased natural gas use on the climate

Natural gas abundance has both direct and indirect effects on GHG emissions and climate



Aggregate effects on U.S. energy economy

Natural gas is an important energy source, but is only 13% of all U.S. energy expenditures and 1% of GDP



2010 US GDP	$15 Trillion
Energy expenditures	$1.2 Trillion
Natural gas expenditures	$159 Billion

Data source: U.S. Energy Information Administration Annual Energy Review 2012.

Effects related to fuel substitution are likely to dominate effects on aggregate energy demand

- Aggregate energy demand is driven primarily by
  - Population growth
  - Overall economic growth and stage of economic development
  - Composition of GDP (e.g., share of services, manufacturing)

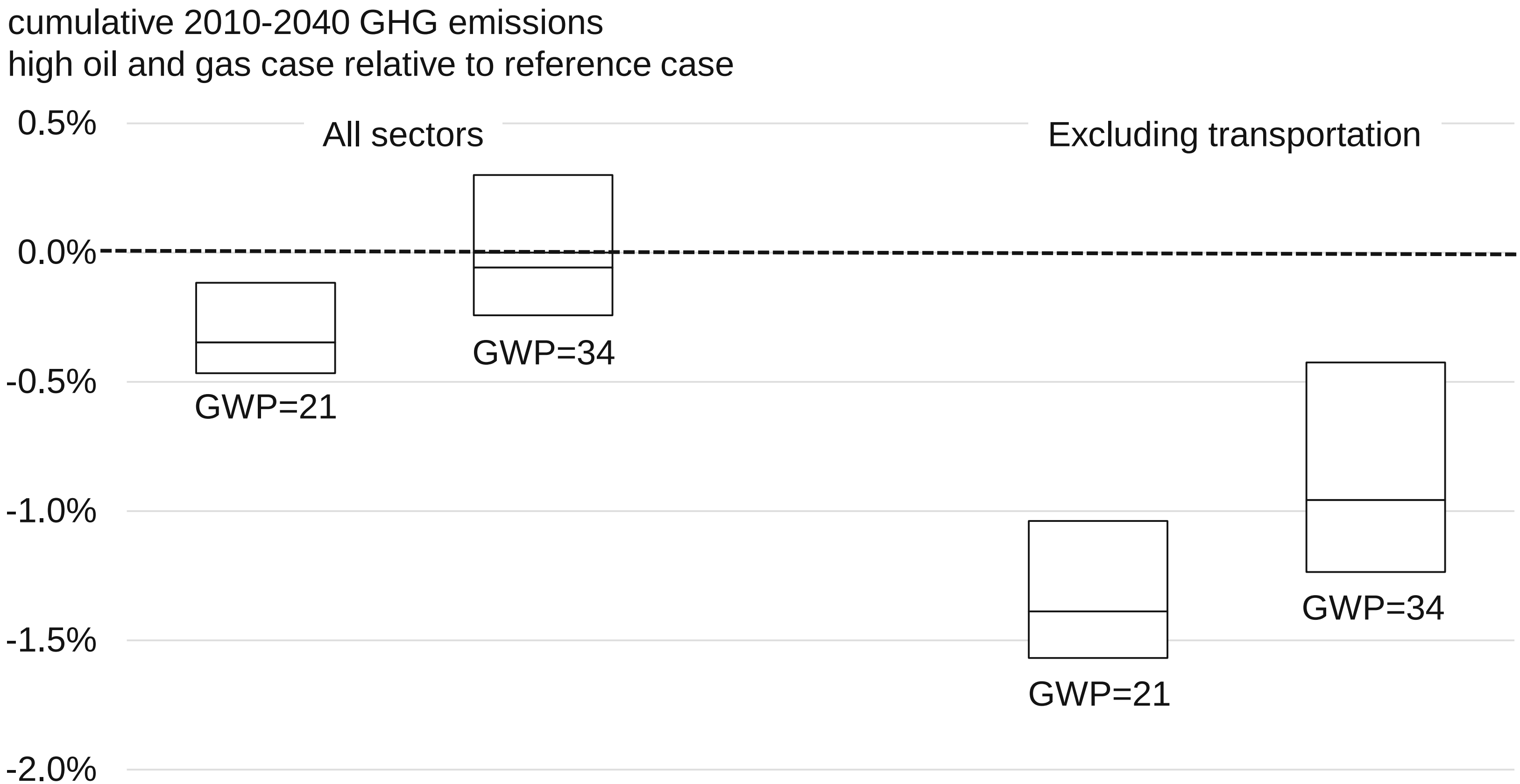
- Price changes have much bigger effects on fuel substitution than overall energy demand
  - Economists summarize this responsiveness through *demand elasticities* measuring the % increase in consumption with respect to a % decrease in price
  - EIA modeling, e.g., which embodies numerous such relationships has:
    - very low elasticity of aggregate energy demand with respect to natural gas price changes (<0.1)
    - low-moderate elasticity of natural gas demand with respect to natural gas prices in the residential/commercial (<0.3) and industrial sectors (<0.5)
    - quite elastic demand for natural gas for electricity generation (1.5 - 2.5)

Greater U.S. shale gas leads to lower gas prices, more energy use, slightly higher GDP, and slightly lower GHG emissions in EIA projections

Scenario (for 2040)	Natural gas price $2011 at Henry Hub	Total energy use Quadrillion Btu	GDP Trillion $2005	Cumulative emissions 2010-2040* billion tonnes CO_2e
Reference	7.83 $/mmBtu	108	$27.3	179
Percent difference relative to Reference case				
High oil/gas resource	-45%	+3%	+1%	-0.3% (-0.5 to +0.3%)

Data source: U.S. Energy Information Administration, 2013 Annual Energy Outlook.
*Notes: *CO_2e emissions computed by augmenting EIA CO_2 emission estimates for coal, oil, and natural gas to account for non-combustion CO_2 and CH_4 emissions, based on EPA Greenhouse Gas Inventory 2013. Sensitivity cases for cumulative GHG emissions based on a methane global warming potential of 34 instead of 21 and a range of CH4 emissions from 25% below to 50% above EPA's estimates of CH4 emissions from natural gas systems.*

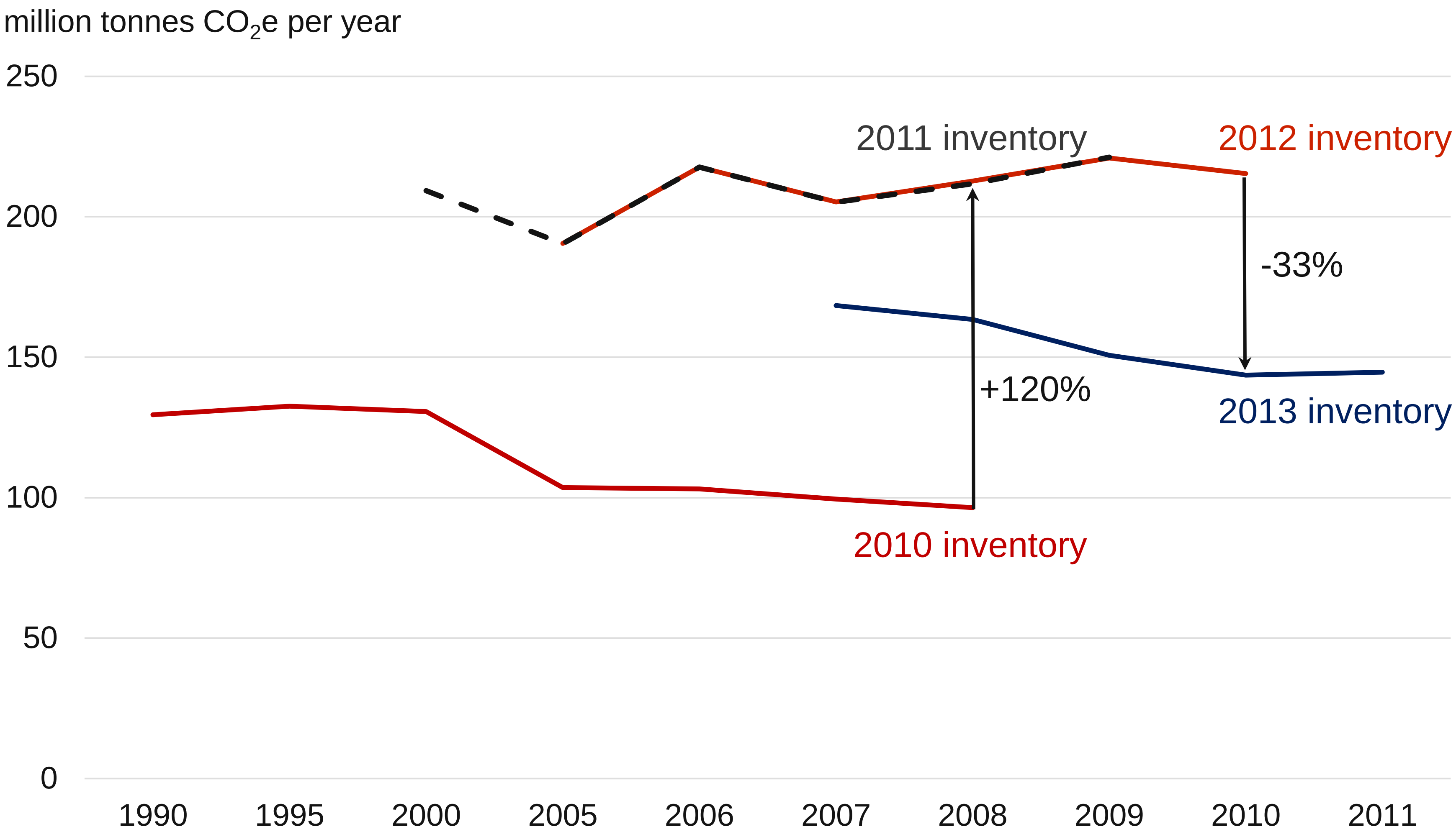
Emissions reduction estimates are affected by methane emissions and its GWP



Data sources: U.S. Energy Information Administration, 2013 Annual Energy Outlook.
*Notes: *CO_2e emissions computed by augmenting EIA CO_2 emission estimates for coal, oil, and natural gas to account for non-combustion CO_2 and CH_4 emissions, based on EPA Greenhouse Gas Inventory 2013. Sensitivity cases based on a range of CH4 emissions from 25% below to 50% above EPA's estimates of CH4 emissions from natural gas systems.*

Non-combustion GHG emissions from natural gas

EPA estimates of methane emissions from natural gas systems have changed over time



Data source: EPA Greenhouse Gas Inventories 2010, 2011, 2012, and 2013.

Non-combustion GHG emission estimates for shale gas are not consistently lower or higher than conventional gas

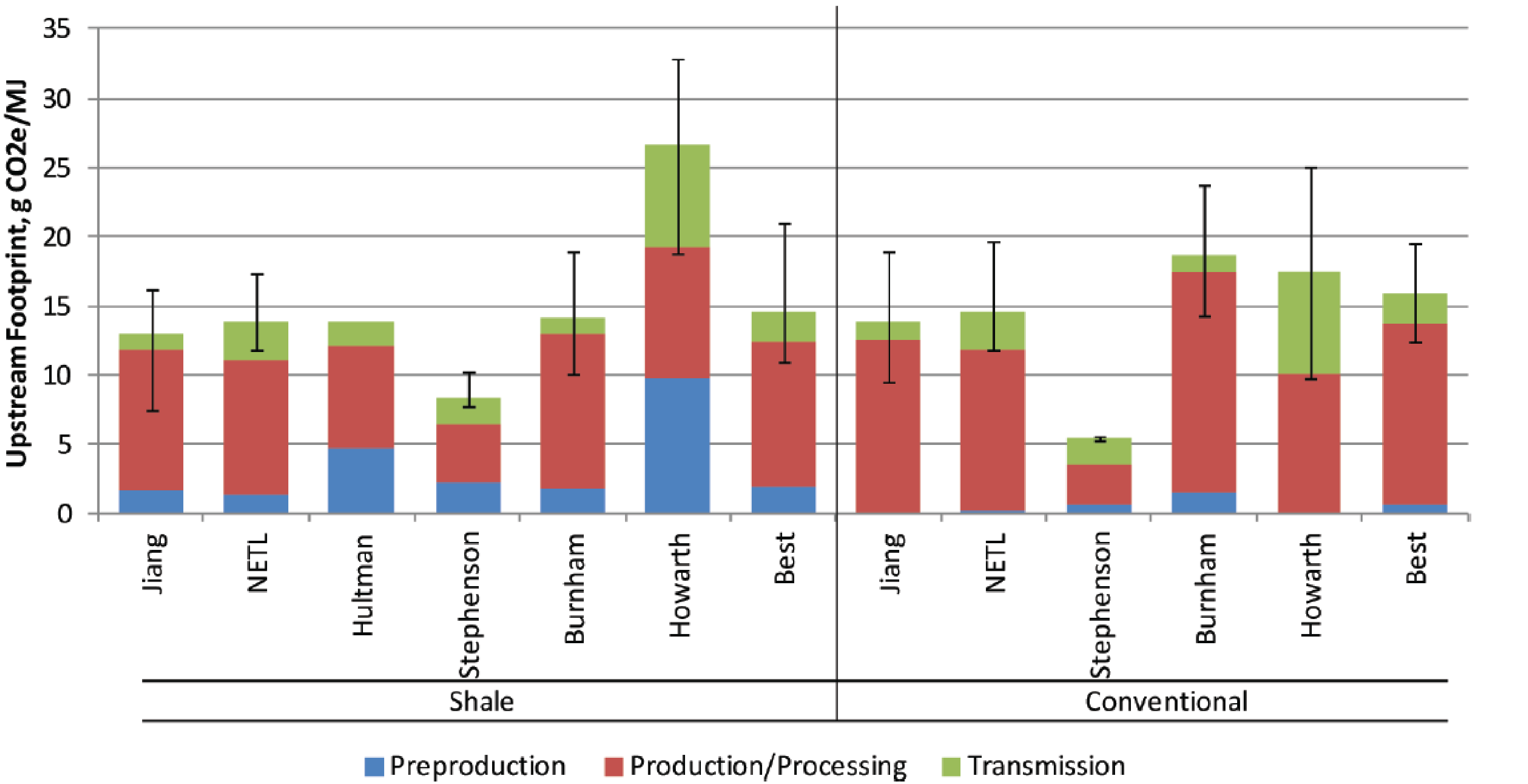
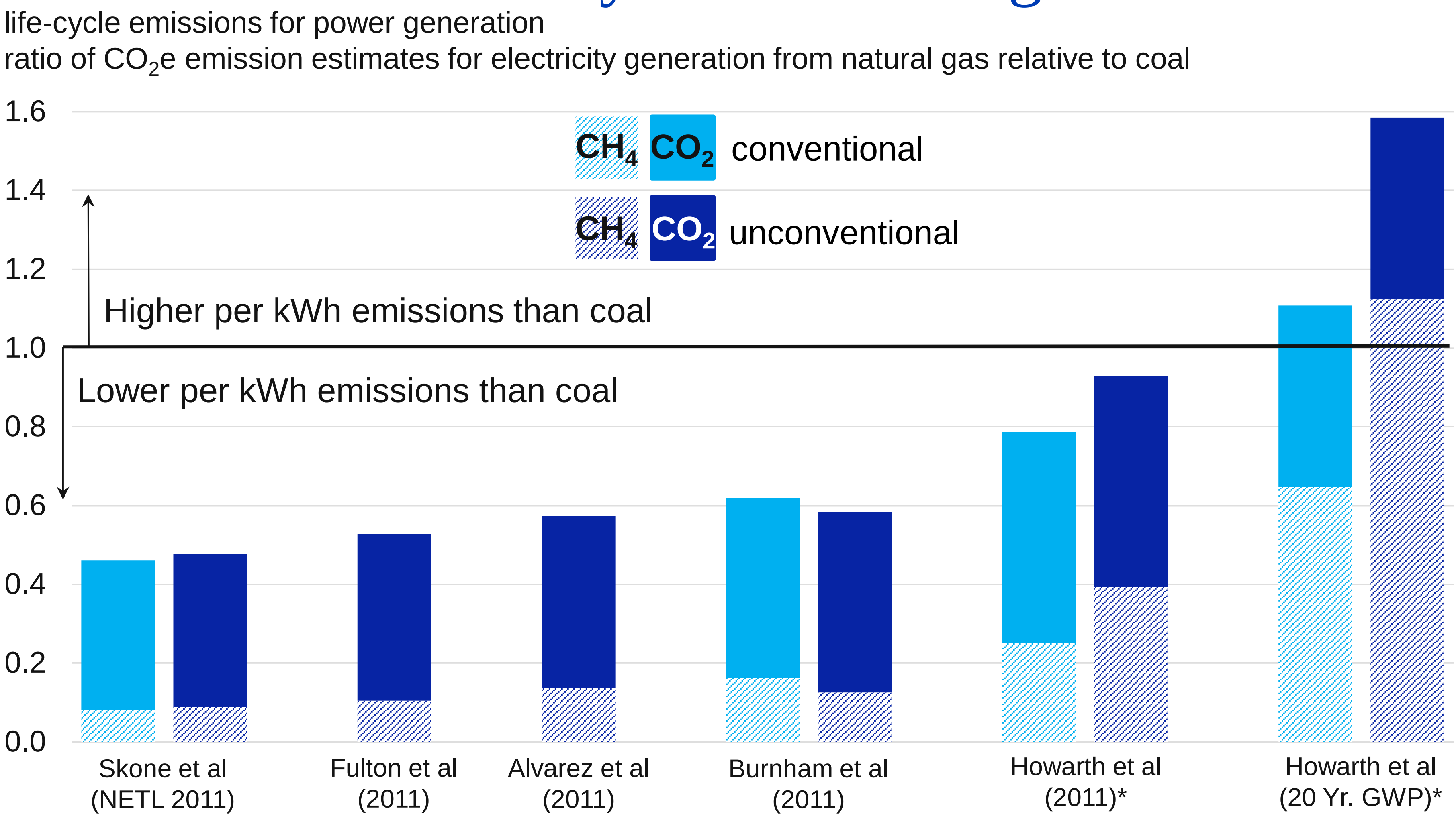


Image source: Weber and Clavin 2012.

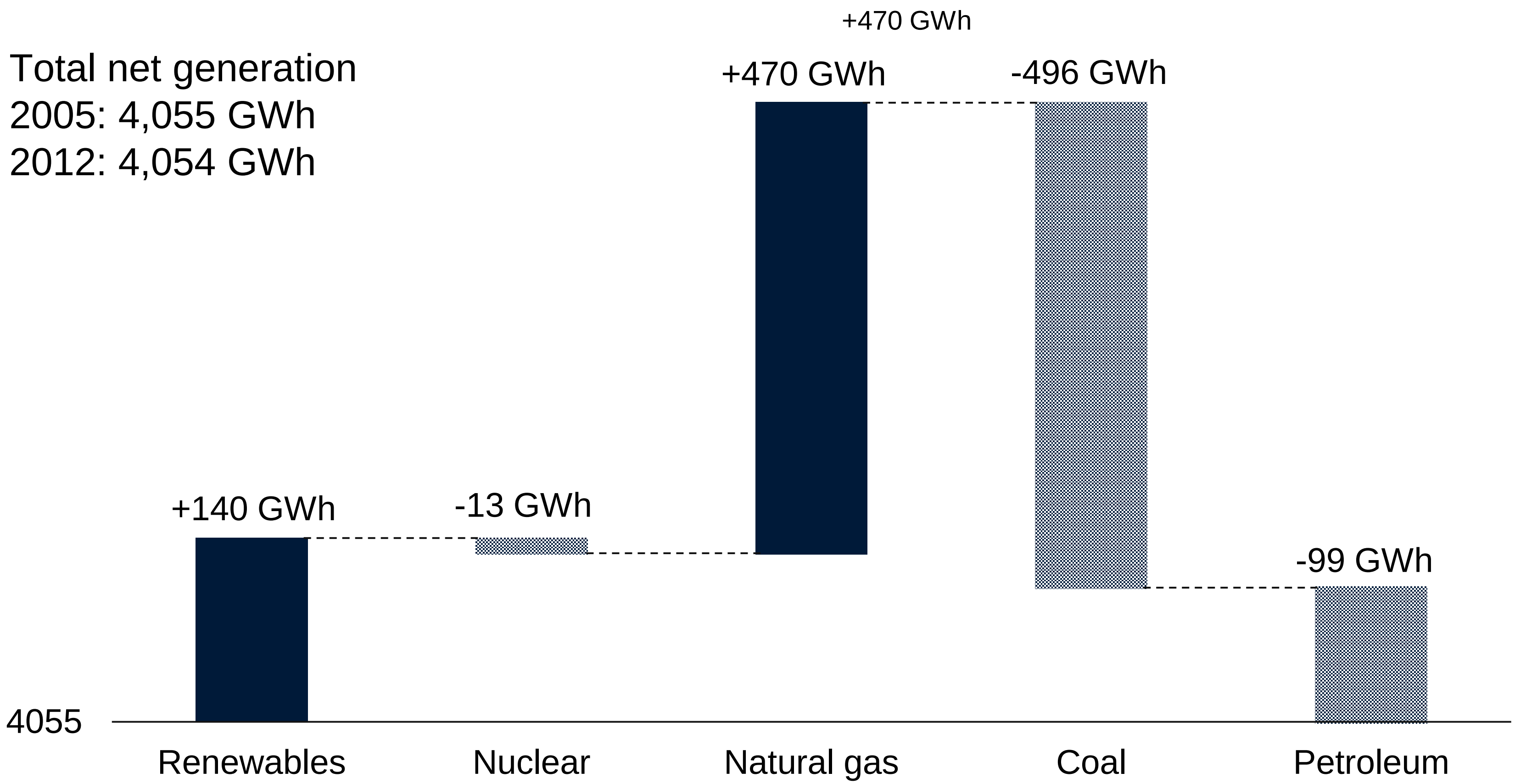
Electricity sector

Most estimates have 40%-50% lower lifecycle GHG emissions for electricity from natural gas than coal



*Data source: Listed authors. Notes: 100-year global warming potential (GWP) used unless otherwise indicated. *Howarth does not account for differences in combustion efficiency of coal versus gas.*

U.S. electric-sector CO_2 emissions declined 16% from 2005 to 2012 due to fuel switching



Data source: U.S. Energy Information Administration.
Note: An additional change of ~2GWh of net generation is attributable to other small generation sources

Greater shale gas leads to lower prices, fuel switching to gas, and lower electricity GHG emissions in EIA projections

Scenario (for 2040)	Natural gas prices (delivered for elec.)	Average electricity prices	Electricity consumption	Natural gas consumption for electricity	Coal consumption for electricity	Nuclear and renewables consumption	Cumulative electricity CO_2e emissions* 2010-2040
Reference	8.55 $/mmBtu	10.8 ¢/kWh	5,200 GWh	1,600 GWh	1,800 GWh	1,800 GWh	71 billion tonnes
Percent and absolute difference relative to Reference case							
High oil and gas	-39%	-14%	+4.2% (+200 GWh)	+49% (+800 GWh)	-21% (-400 GWh)	-9% (-200 GWh)	-5% (-5.4% to -3.8%)

*Data source: U.S. Energy Information Administration, 2013 Annual Energy Outlook. Notes: *CO_2e emissions computed by augmenting EIA CO_2 emission estimates for coal, oil, and natural gas to account for non-combustion CO_2 and CH_4 emissions, based on EPA Greenhouse Gas Inventory 2013. **Sensitivity cases for cumulative GHG emissions based on a methane global warming potential of 34 instead of 21 and a range of CH4 emissions from 25% below to 50% above EPA's estimates of CH4 emissions from natural gas systems.*

Residential and commercial buildings sector

Natural gas space and water heating tends to have significantly lower GHG emissions than electricity

- Space heating*
  - Natural gas boilers are about 50% less GHG-intensive (CO_2 and CH_4) than electric furnace heat from natural gas electricity
  - Heat pumps could further reduce emissions
  - Lower-GHG electricity would improve the electric heat footprint
- Water heating**
  - In most states, natural gas water heating systems are ~60% less CO_2 intensive than electric heating systems
  - Variation occurs between states due to electricity fuel mix
  - Lower-GHG electricity would improve the electric water heating footprint

*Sources: *Delucchi 2003 and Brenn et al 2010. **Czachorski and Leslie 2009, Gas Technology Institute.*

Greater shale gas leads to lower prices, more energy use, and lower GHG emissions in EIA residential and commercial projections

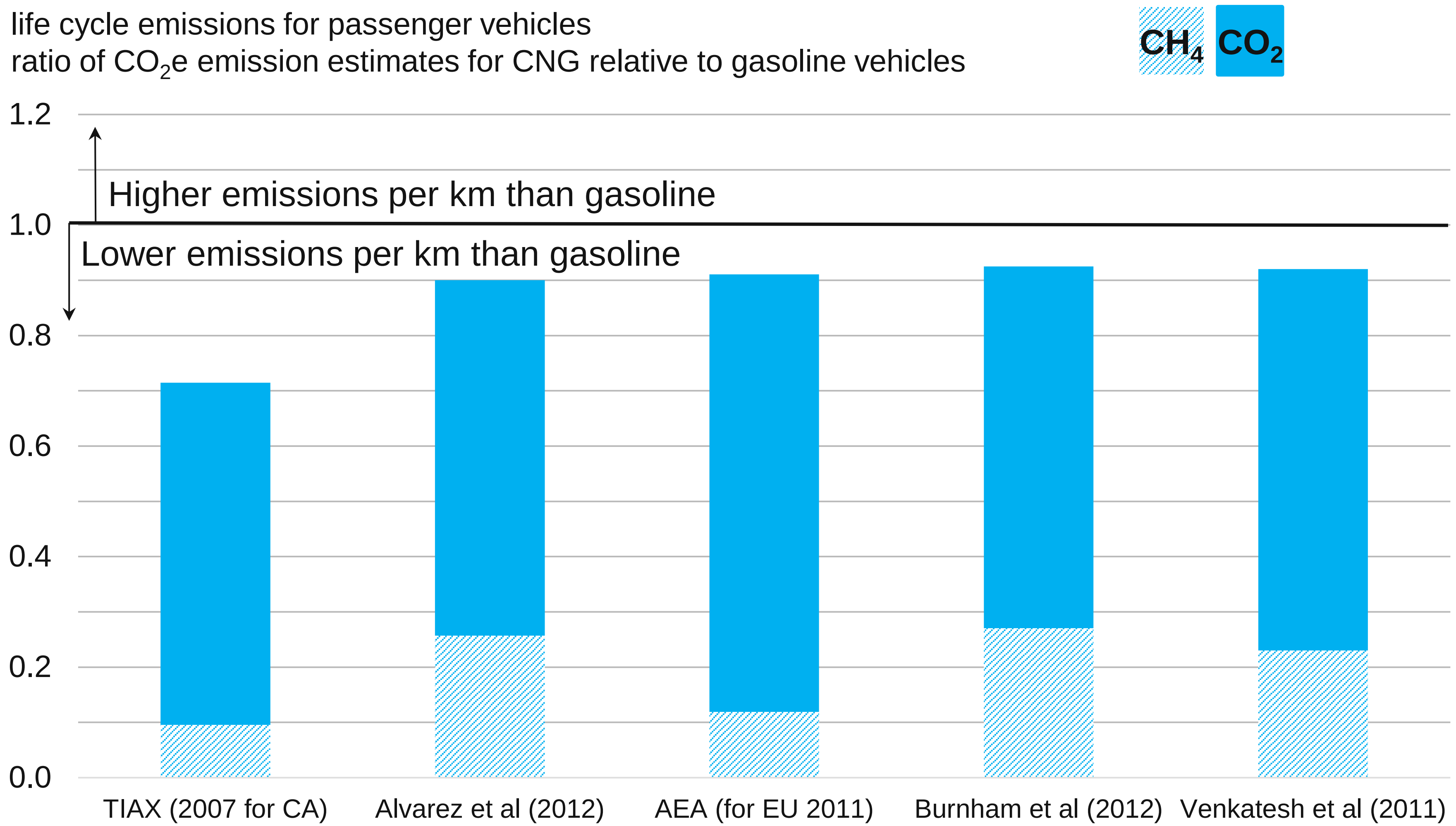
Scenario (for 2040)	Natural gas prices (avg. res/ comm price)	Electricity prices (avg. res/ comm price)	Aggregate res/comm energy* consumption	Natural gas consumption for res/comm	Electricity* consumption for res/comm	Cumulative res/comm CO_2e emissions** 2010-2040
Reference	15.13 $/mmBtu	11.7 ¢/kWh	21.8 QBtu	7.9 QBtu	11.8 QBtu	67 billion tonnes
Percent and absolute difference relative to Reference case						
High oil and gas	-22%	-13%	+5% (+1.1 QBtu)	+7% (+0.6 QBtu)	+4% (+0.5 QBtu)	-3.3% (-3.3% to -3.0%)

*Data source: U.S. Energy Information Administration, 2013 Annual Energy Outlook. Notes: *CO_2e emissions computed by augmenting EIA CO_2 emission estimates for coal, oil, and natural gas to account for non-combustion CO_2 and CH_4 emissions, based on EPA Greenhouse Gas Inventory 2013. **Sensitivity cases for cumulative GHG emissions based on a methane global warming potential of 34 instead of 21 and a range of CH4 emissions from 25% below to 50% above EPA's estimates of CH4 emissions from natural gas systems.***Does not include electricity-related losses*

Transportation sector

Natural gas passenger vehicles reduce emissions by 10%-30% relative to gasoline

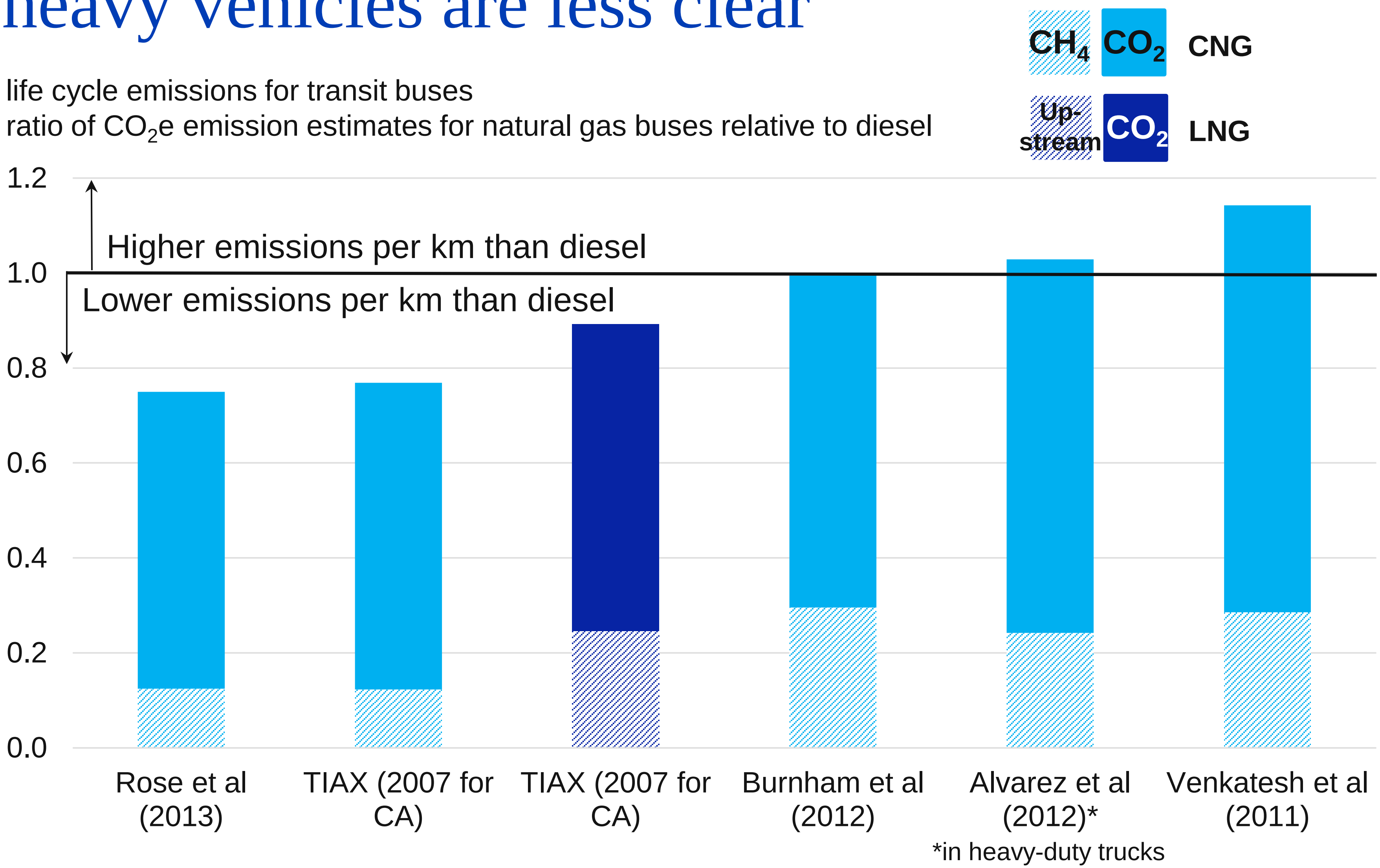
life cycle emissions for passenger vehicles
ratio of CO_2e emission estimates for CNG relative to gasoline vehicles



Data source: Listed authors.

Climate benefits from natural-gas powered heavy vehicles are less clear

life cycle emissions for transit buses
ratio of CO_2e emission estimates for natural gas buses relative to diesel



Data source: Listed authors.

Industrial sector

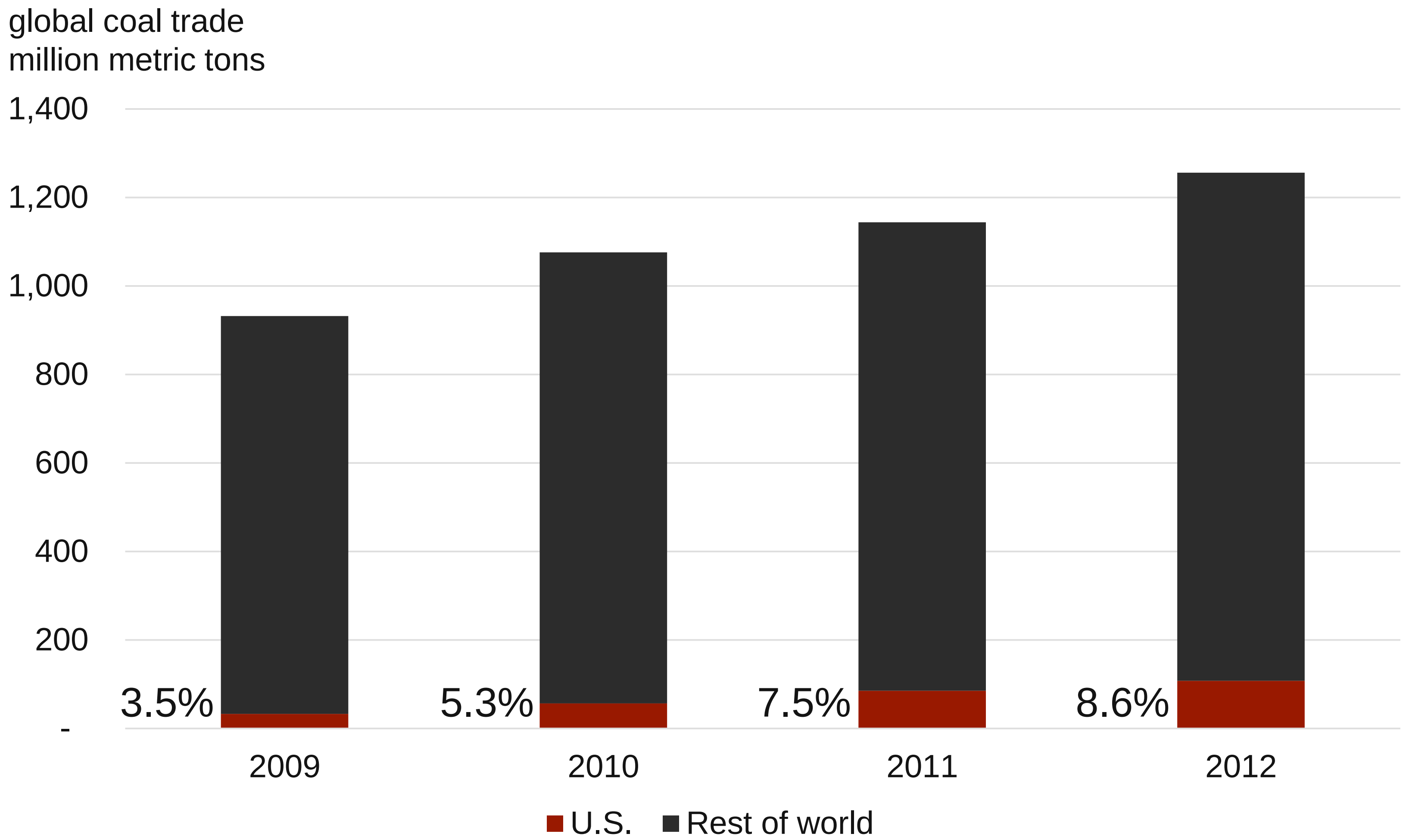
Greater shale gas leads to more industrial energy use and slightly higher GHG emissions in EIA projections

Scenario (for 2040)	Industrial natural gas prices	Aggregate industrial energy* consumption	Natural gas consumption by industry	Coal consumption by industry	Electricity* consumption by industry	Cumulative industrial CO_2e emissions** 2010-2040
Reference	9.09 $/mmBtu	28.7 QBtu	10.4 QBtu	1.6 QBtu	3.9 QBtu	52 billion tonnes
Percent and absolute difference relative to reference scenario						
High oil and gas	-39%	+7% (+2.1 QBtu)	+18% (+1.8 QBtu)	-3% (-0.05 QBtu)	+2% (+0.1 QBtu)	+0.3% (+0.2% to +1.1%)

*Data source: U.S. Energy Information Administration, 2013 Annual Energy Outlook. Notes: *CO_2e emissions computed by augmenting EIA CO_2 emission estimates for coal, oil, and natural gas to account for non-combustion CO_2 and CH_4 emissions, based on EPA Greenhouse Gas Inventory 2013. **Sensitivity cases for cumulative GHG emissions based on a methane global warming potential of 34 instead of 21 and a range of CH4 emissions from 25% below to 50% above EPA's estimates of CH4 emissions from natural gas systems.*

International implications

U.S. coal exports have increased, but represent a fairly small share of global trade



Data source: U.S. Energy Information Administration and the World Coal Association. Calculated as U.S. net exports as a share of global coal trade.

Policy interactions and implications

How does abundant natural gas interact with and affect climate/energy policy?

- Lower natural gas prices make the cost of some policies lower and other policies higher
  - lowering the cost of options with relatively low GHG intensity will tend to make achievement of climate goals less costly
    - e.g., in current *baseline* scenarios no new US coal power is built in part due to low natural gas prices; as a result, regulations that would regulate new coal plant GHG emissions have no apparent impact
    - e.g., under an emissions constraint, lower natural prices lower the cost of meeting emission targets and (by design) do not affect emissions (e.g., EIA AEO 2013, Jacoby et al. 2011, Brown and Krupnick 2010)
  - in the context of renewable energy standards, however, lower gas prices will tend to increase the incremental cost of maintaining those standards

- With substantial long-term GHG reductions, natural gas would need to incorporate carbon capture and storage at reasonable cost to continue as a competitive option

Concluding thoughts

- Natural gas abundance alone will probably not have a substantial effect on future GHG concentrations; policy is the key factor
  - projections could show small positive or negative depending on modeling assumptions
  - but could influence relevant policy in ways that have a substantial effect
- The GHG emissions intensity of natural gas has fallen; further reductions in non-combustion emissions and improved combustion efficiency could further this trend
  - upstream emission estimates have fluctuated, and high methane emissions would reduce the climate benefits of substituting natural gas for other fuels
- Thus far, shale gas has led to decreased GHG emissions by lowering prices and displacing more coal than renewables/nuclear
- Using current lifecycle GHG estimates, natural gas tends to lower GHG emissions relative to coal electric power, gasoline personal vehicles, and electricity for space/water heating

Sources

Advanced Resources International and ICF International. Greenhouse gas life-cycle emissions study: Fuel life-cycle of U.S. natural gas supplies and international LNG. Prepared for Sempra Energy, Nov. 2008.

AEA, 2012. Climate impact of potential shale gas production in the EU. Report for the European Commission DG CLIMA AEA/R/ED57412.

Allen, D. T., Vincent M. Torres, James Thomas, David W. Sullivan, Matthew Harrison, Al Hendler, Scott C. Herndon, Charles E. Kolb, Matthew P. Fraser, A. Daniel Hill, Brian K. Lamb, Jennifer Miskimins, Robert F. Sawyer, and John H. Seinfeld, Measurements of merthane emissions at natural gas production sites in the United States. Proceedings of the National Academy of Sciences 2013, Early Edition.

Alvarez, R.A., Pacala, S.W., Winebrake, J.J., Chameides, W.L., Hamburg, S.P., 2012. Greater focus needed on methane leakage from natural gas infrastructure. Proceedings of the National Academy of Sciences 109, 6435-6440.

Brandt et al., 2014. Methane leaks from North American natural gas systems. Science vol. 343 no. 6172 pp. 733-735.

Brenn, J., Soltic, P., Bach, Ch., 2010. Comparison of natural gas driven heat pumps and electrically driven heat pumps with conventional systems for building heating purposes. Energy and Buildings 42, 904-908.

Brown, S.P.A., Krupnick, A.J., 2010. Abundant shale gas resources: long-term implications for U.S. natural gas markets. Resources for the Future Discussion Paper 10-41.

Burnham, A., Han, J., Clark, C.E., Wang, M., Dunn, J.B., Palou-Rivera, I., 2011. Life-Cycle Greenhouse Gas Emissions of Shale Gas, Natural Gas, Coal, and Petroleum. Environmental Science & Technology 46, 619-627.

Czachorski, M., and Leslie, N., 2009. Source energy and emission factors for building energy consumption. Prepared for American Gas Association.

Delucchi, M., 2003. A lifecycle emissions model (LEM): lifecycle emissions from transportation fuels, motor vehicles, transportation modes, electricity use, heating and cooking fuels, and materials. UC Davis Institute of Transportation Studies.

Fulton, M., Mellquist, N., Kitasei, S., Bluestein, J., 2011. Comparing life-cycle greenhouse gas emissions from natural gas and coal. Deutsche Bank Group, Worldwatch Institute, and ICF International. August, 2011.

Hekkert, M.P., Hendriks, F.H.J.F., Faaij, A.P.C., Neelis, M.L., 2005. Natural gas as an alternative to crude oil in automotive fuel chains well-to-wheel analysis and transition strategy development. Energy Policy 33, 579-594.

Howarth, R.W., Santoro, R., Ingraffea, A., 2011. Methane and the greenhouse-gas footprint of natural gas from shale formations. Climatic Change 106, 679-690.

Hultman, N., Rebois, D., Scholten, M., Ramig, C., 2011. The greenhouse impact of unconventional gas for electricity generation. Environmental Research Letters 6.

Sources

International Energy Agency, 2011. Are we entering a golden age of gas? . Organization for Economic Cooperation and Development.

Jacoby, H.D., O'Sullivan, F., Paltsev, S., 2011. The influence of shale gas on U.S. energy and environmental policy. MIT Joint Program on the Science and Policy of Global Change, Report No. 207.

Jaramillo, P., Griffin, Michael W., Matthews, Scott H., 2007. Comparative life-cycle air emissions of coal, domestic natural gas, LNG, and SNG for electricity generation. Environmental Science and Technology 41, 6290-6296.

Lu, X., Salovaara, J., McElroy, M.B., 2012. Implications of the Recent Reductions in Natural Gas Prices for Emissions of CO2 from the US Power Sector. Environmental Science & Technology 46, 3014-3021.

Miller et al. 2013. Anthropogenic emissions of methane in the United States. Proceedings of the National Academy of Sciences. Early Edition, approved Oct. 18, 2013.

National Energy Technology Laboratory, 2011. Life cycle greenhouse gas inventory of natural gas extraction, delivery, and electricity production. DOE/NETL-2011/1522.

Paltsev, S., Jacoby, H.D., Reilly, J.M., Ejaz, Q.J., Morris, J., O'Sullivan, F., Rausch, S., Winchester, N., Kragha, O., 2011. The future of U.S. natural gas production, use, and trade. Energy Policy 39, 5309-5321.

Rose, L., Hussain, M., Ahmed, S., Malek, K., Costanzo, R., Kjeang, E., 2013. A comparative life cycle assessment of diesel and compressed natural gas powered refuse collection vehicles in a Canadian city. Energy Policy 52, 453-461.

TIAX LLC, 2007. Full fuel cycle assessment: well-to-wheels energy inputs, emissions, and water impacts. Consultant report for California Energy Commission.

U.S. Energy Information Administration, 2011. World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States.

U.S. Environmental Protection Agency, 2013. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011. Washington, D.C. EPA 430-R-13-001.

Venkatesh, A., Jaramillo, P., Griffin, W.M., Matthews, H.S., 2012. Implications of changing natural gas prices in the United States electricity sector for SO2, NOx and life cycle GHG emissions. Environmental Research Letters 7.

Venkatesh, A., Jaramillo, P., Griffin, W.M., Matthews, H.S., 2011. Uncertainty in life cycle greenhouse gas emissions from United States natural gas end-uses and its effect on policy. Environmental Science and Technology 45, 8182-8189.

Weber, C.L., Clavin, C., 2012. Life Cycle Carbon Footprint of Shale Gas: Review of Evidence and Implications. Environmental Science & Technology 46, 5688-5695.

World Coal Association, 2013. Coal Statistics. URL http://www.worldcoal.org/resources/coal-statistics/.

For more information

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