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NATURAL GAS: GUARDRAILS FOR A POTENTIAL CLIMATE BRIDGE

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INTRODUCTION

Recent experience in the United States suggests that increasing natural gas supply has the potential to deliver multiple wins: lower energy costs, improved energy security, reduced air pollution, and a significantly less carbon-intensive electricity supply. Over the past decade, the U.S. shale gas revolution has dramatically increased supplies of low-cost natural gas, upended U.S. coal markets, and led many electric utilities to switch from coal to natural gas.[1] Despite continuing concerns about local impacts of hydraulic fracturing ("fracking") practices, natural gas is expected to remain abundant and relatively inexpensive in the U.S.

The U.S. experience has heightened interest in whether natural gas can serve as a "bridge" fuel on the path to a global low-carbon future. Along with rising energy demand, the growing share of coal in the global fuel mix has been the main contributor to the rise in global greenhouse gas emissions in the last decade (IPCC 2014). Under most business-as-usual (BAU) scenarios, coal will remain the backbone of many countries' electricity supplies for the next two decades; the IEA projects that more than 1,000 GW of new coal power capacity will be added in 2013–2035 alone, three-quarters of it in Asia (IEA 2013c). If these plants were to operate for 50 years, they would emit nearly 300 billion tonnes of carbon dioxide (Gt CO_2), about a quarter of the remaining 21st century global carbon budget consistent with a 50% or better likelihood of keeping the global temperature increase below 2°C (see Figure 1).

Slowing the emissions lock-in of new coal power is thus a top priority for climate policy, one that no single resource – whether renewable energy, nuclear energy, or energy efficiency – can accomplish on its own (Eom et al. 2015; IEA 2013b). As the least carbon-intensive fossil fuel, amenable to higher-efficiency generation technology, natural gas could, in principle, make an important contribution. As we discuss further below, producing electricity from natural gas emits about half the GHGs per kWh as coal. Thus, the Intergovernmental Panel on Climate Change (IPCC) has suggested that high-efficiency natural gas combined cycle gas turbine (CCGT) plants could function as a "bridge technology" in the transition to a lower-carbon economy (IPCC 2014).

Yet the climate implications of increased natural gas supply are far from straightforward. While building out new infrastructure for the supply and use of natural gas can support climate goals by avoiding the "lock-in"

1 The U.S. also had an abundant surplus of natural gas generation capacity that enabled a more rapid switch from coal to gas than might have otherwise been possible (Hood 2014).

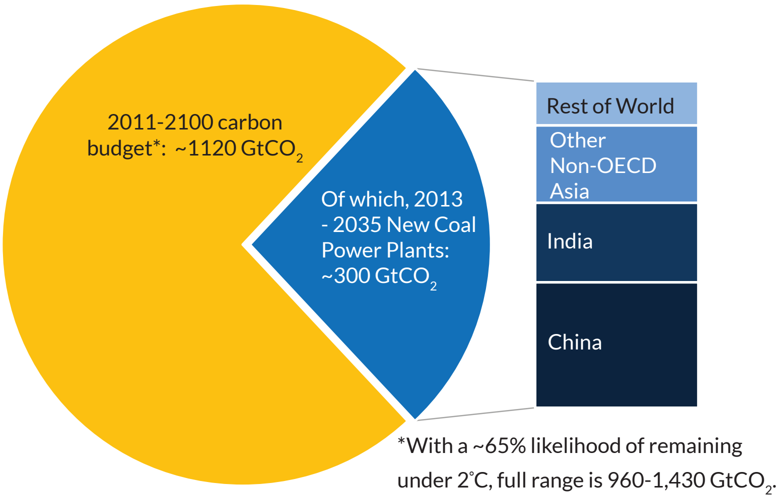


Figure 1: Projected new coal builds could lock in nearly 300 Gt CO_2 of added emissions

Note: The carbon budget given is the IPCC's central estimate of a carbon budget consistent with a 50% or better likelihood of limiting the global temperature increase to 2°C above 1861–1880 levels, after accounting for non-CO_2 gases; the full range of estimates is 960–1,430 Gt CO_2 (IPCC 2013). New coal build projections are from IEA (2013c) New Policies Scenario; CO_2 estimates are based on assumed capacity factor of 70%, 50-year operational lifetime, and 40% efficiency.

of new coal power plants, it also poses risks, for example, of "locking-out" other, lower-emission alternatives. Achieving one while avoiding the other will require careful policy design. In the sections that follow, we explore the viability of this option, as well as key concerns that would need to be addressed to ensure that increased natural gas use will accelerate, not hinder, the decarbonization of electricity around the world. We synthesize published literature, recent modelling studies, and interviews with sector experts, and offer some "guardrails" for potential climate bridge.

In the U.S., the Energy Information Administration (U.S. EIA 2014a) now projects that due in part to low-cost natural gas, carbon dioxide (CO_2) emissions will remain below 2005 levels beyond 2040, while GDP nearly doubles over 2012 levels.[2] Indeed, the natural gas boom, combined with recent and pending U.S. Environmental Protection Agency regulation of CO_2 and local air pollutants, has made it increasingly unlikely that new coal power plants will be built in the foreseeable future.[3] Shale gas is also a thriving business: it has generated over US$60 billion annually in tax receipts and royalty payments (shale oil included), reinvigorated and increased the competitiveness of U.S. petrochemical, steel, and fertilizer industries, and supported the creation of thousands of new jobs (Aguilera and Radetzki 2014; Krupnick et al. 2014).

Many foresee the United States becoming a major gas exporter in coming decades (IEA 2014b; U.S. EIA 2014a; BP 2014), a prospect that has already begun to alter global markets for liquefied natural gas (LNG), improving the prospects for more favourable gas prices as far away as Asia.[4] From all appearances, the newfound abundance and competitiveness of natural gas has been a "game changer" for U.S. energy markets and greenhouse gas emissions, and a positive contributor to the economy. A key question for policy-makers around the world is whether such a phenomenon can endure and spread.

Many countries possess considerable untapped gas resources, especially in the form of shale and other unconventional gas deposits, which together could provide nearly two-thirds of incremental gas supply over the next two decades (IEA 2012). Under the International Energy Agency's recent high gas scenario,

2 In the EIA Reference Case, coal, which fuelled 49% of U.S. power generation in 2007 but had declined to 37% in 2012, drops to 32% in 2040, while the natural gas share rises from 30% in 2012 to 35% in 2040, and renewables' share rises from 12% to 16% (U.S. EIA 2014a). CO_2 emissions from power generation thus rise by 11% by 2040, even as generation grows by 25%. The EIA Reference Case also envisions 16% of 2012 coal capacity (50GW) being retired by 2020, as tighter environmental regulations lead operators to retire their older coal power plants rather than upgrade them to meet new standards.

3 For example, the U.S. EIA most recent reference case projects that less than 0.5 GW of 300 GW of in total capacity additions through 2040 will be coal-fired, while more than 50 GW of existing coal capacity will be retired (U.S. EIA 2014a).

4 The first two LNG projects approved by the U.S. Department of Energy (Sabine Pass and Freeport), and other projects yet to be approved, have signed contracts with Asian buyers that depart from traditional oil indexation and instead index to gas-on-gas pricing (U.S. Henry Hub prices) (IEA 2013a). Oil indexation is widely viewed as a contributor to high Asian LNG prices.

Golden Rules for a Golden Age of Gas (IEA 2012), by 2035, China would produce nearly 400 billion cubic metres (bcm) per year of unconventional gas, as much as the United States produces today; in India, production would climb to nearly one-quarter this level. Furthermore, greater globalization of gas markets – currently only 20% of gas is traded internationally (IEA 2013b) – through expanded LNG and pipeline infrastructure would allow abundant, low-cost conventional and unconventional gas resources to reach supply-constrained markets, in China, India, and other locations where much of the world's coal power development is now expected to occur.[5]

IN THE POWER SECTOR, GHG EMISSIONS FROM NATURAL GAS CAN BE HALF THOSE OF COAL

Using natural gas instead of coal for power production can reduce net life-cycle GHG emissions by as much as half (relative to the most efficient coal power technologies now widely in use). As shown in Figure 2, two factors account for much of the difference: the lower carbon intensity of natural gas, which is the least carbon-intensive fossil fuel, and the higher efficiency of natural gas technology. New combined-cycle gas turbines can achieve power conversion efficiencies of around 60%, while the efficiency of most new supercritical coal plant technologies ranges from 39% to 44%.

The emissions associated with three other factors, however, are somewhat higher for natural gas than for coal: energy use for upstream production and processing, energy use for transport, and methane leakage (discussed further below). The use of liquefied natural gas (LNG) instead of pipeline gas can reduce the net life-cycle benefit by about 20% (from 49% to 41%), due to the substantial energy requirements to liquefy and transport gas (typically for longer distances; we assume shipping for 10,000 km plus 1,000 km pipeline transport for LNG, and 2,500 km for pipeline natural gas.

However, as a growing body of evidence shows, the rate of methane leakage in natural gas operations is a decisive factor in any calculation of GHG benefits (see, e.g., Howarth et al. 2011; Brandt et al. 2014). While methane (CH4) has a much shorter lifespan in the atmosphere than carbon dioxide, it also has a much higher global warming potential: 34 times the rate of CO_2 over 100 years (Myhre et al. 2013).

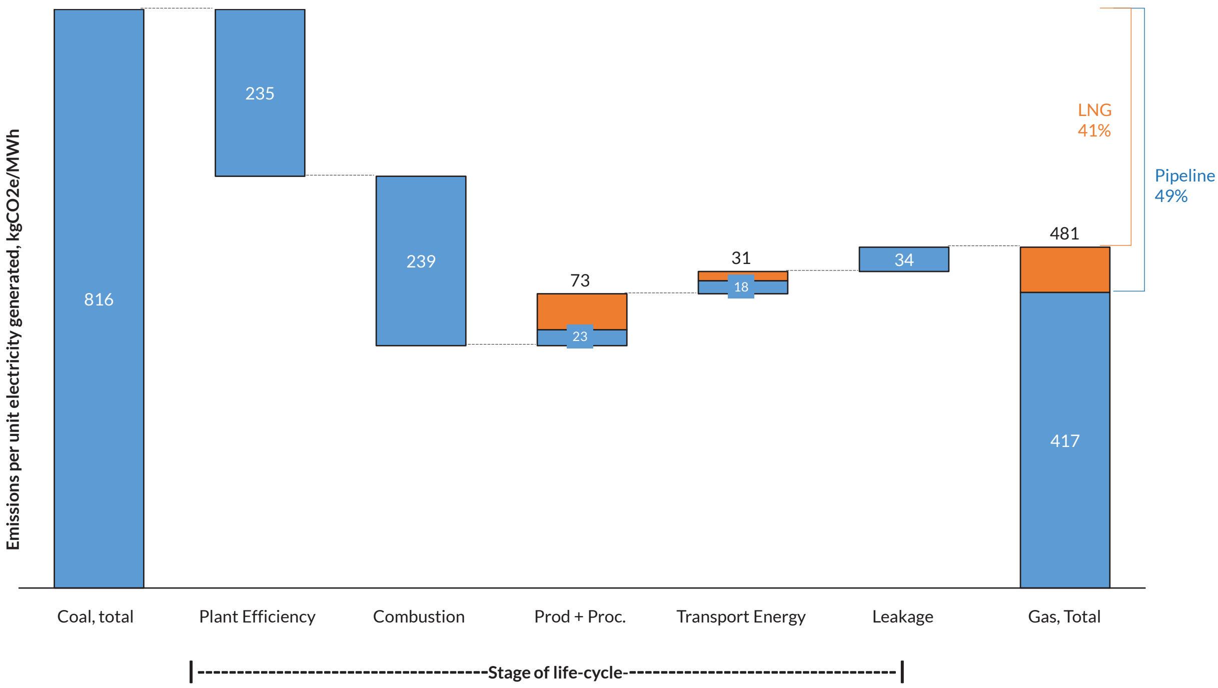


Figure 2: Potential GHG benefits of substituting natural gas for coal in the power sector

Note: Analysis assumes efficiencies of 42% for supercritical coal and 59% for natural gas CCGT, for power plants installed in China in 2020 based on IEA (2013c), and methane leakage of 0.0045 kg CO_2e per MMBtu of coal produced, based on U.S. data (U.S. EPA 2014), for lack of better global estimates. We use a global warming potential for methane of 34, per the latest IPCC assessment (Myhre et al. 2013).

5 Even at high levels of increased domestic gas production under a high gas scenario, the IEA projects that China and India would increase gas imports significantly (IEA 2012).

Methane is the primary constituent of natural gas, and leakage can occur at each stage of natural gas extraction and delivery: field production, processing, transportation and storage, and distribution. While low-cost technologies and management practices exist for limiting methane leakage to a small fraction of the produced gas – lower than 1%, per ICF International (2014) – in practice leakage rates vary widely across production and delivery systems. They are also highly uncertain, even in the United States, where considerable research has been conducted in recent years (see Table 1). Estimates from other countries and regions are sparse, so here we rely largely on U.S. literature to estimate the average leakage rate at 1.5% (slightly higher than U.S. EPA (2014) national average leakage rate estimate for 2012 (1.3%), and equivalent to the average of the last four inventory years, 2009–2012). Table 1 shows the implications of different leakage rates found in the literature for the GHG benefits of replacing coal with natural gas for power production.

Table 1: Estimated life-cycle methane leakage in natural gas power plant operations and the impact of GHG emissions benefits compared to coal

Methane leakage scenario/rate (% of gas production)	% emissions reduction, natural gas substitution for coal power	Reference
Base case (1.5% leakage)	45%	
60% reduced leakage (0.8%)	48%	ICF International (2014); Lowell et al. (2013)
EPA estimate for 2012 (1.3%)	46%	U.S. EPA (2014)
1.5 x U.S. EPA estimate for 2011 (2.1%)	43%	Brandt et al. (2014)
U.S. EPA for 2009 (2.5%)	40%	U.S. EPA (2011)
Howarth et al. 2011 average (5%)	24%	Howarth et al. (2011)
Break-even with coal power (10.6%)	0%	Own calculation
High-leak estimates, time and region specific (15%)	-21%	Karion et al. (2013); Caulton et al. (2014)

Note: Emissions reduction is estimated assuming a 50:50 mix of pipeline gas and LNG. Base case and break-even calculations use the IPCC (2013) estimate of methane's 100-year global warming potential as 34 times that of CO_2.

The rise in unconventional natural gas production has heightened concerns about methane leakage. However, although some studies report higher leakage rates from U.S. shale gas (Howarth et al. 2011), others find them to be on par or lower than for conventional gas systems (Argonne National Laboratory 2012; Edwards and Trancik 2014) – even much lower (Littlefield et al. 2012).

THE GHG EMISSIONS BENEFITS DEPEND ON HOW NATURAL GAS IS USED

As discussed above, the emission savings from replacing coal with natural gas in the power sector can be substantial, up to 50%. Yet there is no guarantee that any incremental supply will be used to displace coal in the power sector. In fact, one of the most valued characteristics of natural gas is that it can be used across the economy: for building heat, in industry, and increasingly also in transport. In some of those uses, the emission benefits are significantly lower; in some cases, emissions can actually increase, as shown in Figure 3.

Natural gas substituting for "zero carbon" power (renewables and nuclear) has a large added emissions impact due to larger life-cycle emissions of natural gas relative to the low emissions from non-fossil fuel resources.[6] As a rule of thumb, a net emissions reduction is likely if the amount of coal energy displaced is greater than combined renewables and nuclear energy replaced (Newell and Raimi 2014). Used as a transport fuel, compressed natural gas (CNG) offers a small to slightly negative emissions benefit. Greater emissions benefits may result from substitution for gasoline in passenger light-duty vehicles than for diesel in heavy-duty truck operations– though the literature disagrees to some extent on this (Newell and Raimi

6 We assume a 50:50 mix of pipeline and liquefied natural gas (roughly approximating how incremental natural gas supplies may be delivered). Emissions of approximately 20 $kgCO_2e$/MWh for "zero-carbon" resources are assumed, based on the average values reported for a range of non-fossil fuel energy sources in Table A.II.4 of IPCC (2011).

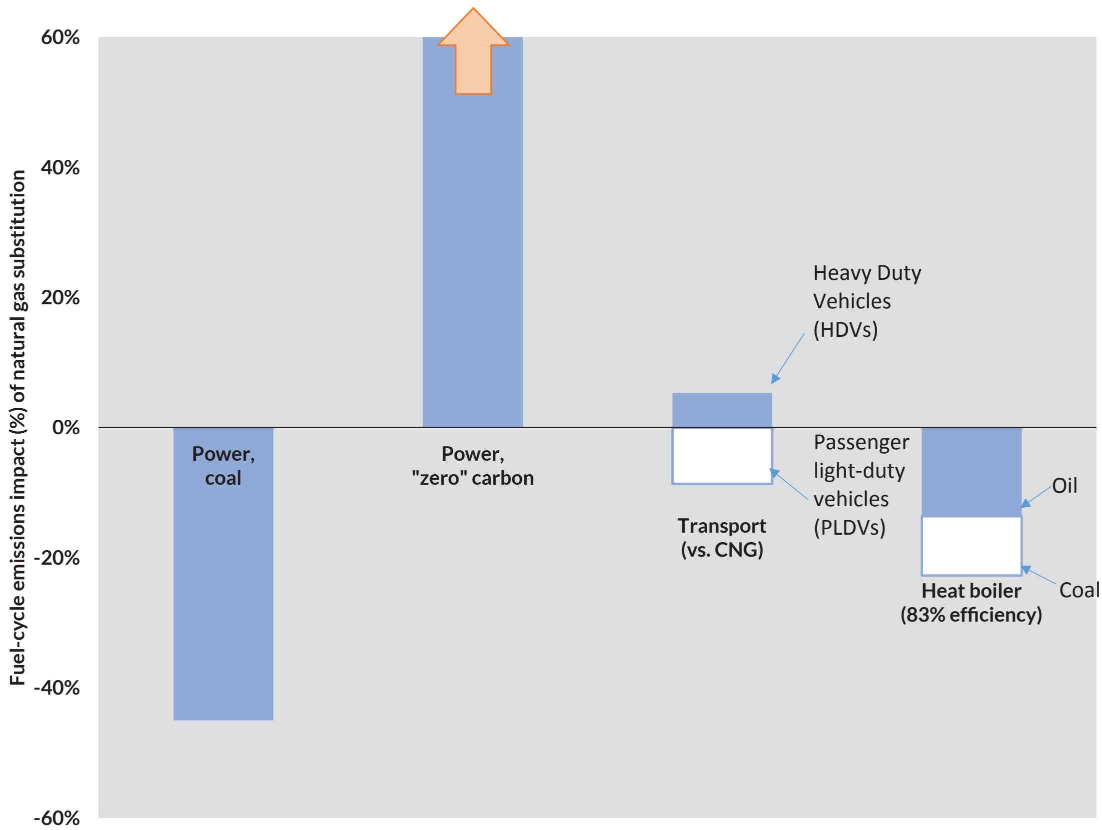


Figure 3: GHG emissions benefit of natural gas substitution depends on sector

2014).[7] For heat applications in buildings and industry, the relative emissions benefit impact for natural gas substitution is 14% compared with oil and 23% compared with coal.[8]

As this makes clear, the contribution of increased natural gas use to reducing GHG depends on how it is used, with the greatest benefits achieved when gas substitutes for coal in the power sector. However, the actual uses of natural gas are likely to vary significantly, depending on local circumstances.[9] Furthermore, it can be difficult to know with any certainty, even for gas introduced into the power sector, the extent to which coal rather than other resources might ultimately be displaced. Important factors include the relative availability and price of natural gas compared with other fuels and energy sources in different sectors. Policies from local air pollution regulations to carbon pricing can also strongly influence how gas is used.

LARGE VOLUMES OF NATURAL GAS ARE NEEDED TO MAKE A DENT IN THE GROWTH OF COAL

Under what are generally viewed as optimistic estimates for natural gas, drawn from the IEA's Golden Rules for a Golden Age of Gas report (IEA 2012), global natural gas production could increase by 50% over 2011 levels by 2035, to 5,100 bcm per year, assuming increasing development of unconventional natural gas resources (such as shale gas). By contrast, the IEA (2012) projects 10% lower gas production in 2035, relative to the optimistic scenario, in a corresponding scenario with low development of

7 Calculations based on data from Alvarez et al. (2012), Table 1, but scaled for lower methane leakage (1.5%) assumed here.

8 Heat-only boiler efficiency assumed to be 83% for all fuels, based on IEA data cited in Bruckner et al. (2014). Natural gas in practice can have slightly higher boiler efficiencies. Natural gas use in space or water heating in the US may emit 50-60% less CO_2e than electric furnaces, given average grid electricity mix (Newell and Raimi 2014), although electric heat pumps can provide even lower-GHG heating, including when combined with natural gas power, but are yet to be widely deployed.

9 For example, in Lima, Peru, nearly 200,000 vehicles have been converted to use compressed natural gas (CNG), for fuel cost savings and to reduce air pollution; see http://www.ngvglobal.com/peru-ngv-conversions-may-reach-20-thousand-for-2014-1124 and http://www.minem.gob.pe/minem/archivos/gasnatural.pdf. In Beijing, China, meanwhile, natural gas for heating has been a priority (in homes and commercial buildings, replacing coal), to reduce air pollution in the winter, but the supply has not always sufficed; see http://www.reuters.com/article/2013/10/29/us-china-pollution-idUSBRE99S1A520131029.

A Marcellus Shale drilling site in Pennsylvania © Penn State

unconventional resources. As McGlade et al. (2012) note, however, a "golden age of gas" is "subject to multiple uncertainties, particularly with regard to the size and recoverability of the physical resource" (p. i). Furthermore, while some short-term increase in gas use may be compatible with a 2°C trajectory (IEA 2013b), the level of natural gas production envisioned in the "golden age of gas" scenario is consistent with a probable temperature rise of 3.5°C.

There are also several supply-side challenges to increasing natural gas production and international gas trade, from lack of technical capacity to financial risks. Expanded gas production, particularly for unconventional gas, depends upon expertise and capacity to drill and service thousands of wells; appropriate legal and regulatory frameworks; favourable investment environments, and access to markets through gas transportation infrastructure, among other requirements.

Gas transportation infrastructure – from LNG terminals to distribution pipelines – is particularly capital-intensive, with significant lead times and considerable financial risk unless future gas flows can be relatively guaranteed (e.g. through upfront long-term contracts). Furthermore, greater reliance on natural gas that could come with added production (e.g. building natural gas rather than coal power plants) may not necessarily be viewed as an energy security asset. While many countries in Asia and Europe may stand to greatly expand unconventional gas production, their overall trade balance may remain negative. The IEA (2012) has estimated they could still face gas import bills, on the order of 0.2–0.7% of GDP.

In addition, for the gas industry to maintain a "social license to operate" (IEA 2012), particularly for unconventional gas production, it must more effectively address local environmental concerns. Unconventional gas production – a key element of an abundant gas future – is by nature a land- and water-intensive process that presents serious potential risks for local communities and water resources.[10] Instances of poor practice, inadequate attention to local concerns, and lack of transparency, especially

10 A recent report from the World Resources Institute describes the challenge of freshwater availability for shale gas production (Reig et al. 2014), finding that nearly 40% of the area containing shale gas resources are in arid or significantly water-stressed locations where nearly 400 million people reside.

in relation to hydraulic fracturing ("fracking") – a technology instrumental to shale gas production – have damaged the industry's reputation. Nonetheless, similar to the U.S. Department of Energy (U.S. DOE 2011), the IEA suggests that "the technologies and know-how exist for unconventional gas to be produced in a way that satisfactorily meet these challenges, but a continuous drive from governments and industry to improve performance is required if public confidence is to be maintained or earned."[11] Indeed, the prospects and merits of abundant gas future depend on whether such a drive is successful.

How does this fit with power sector needs? Figure 4 shows IEA projections of new coal power capacity to be added in 2020–2035, the period in which new gas supplies could potentially make the most pivotal impact on global emissions (IEA 2013c). Under the IEA's Current Policies Scenario, where fewer actions are taken to address CO_2 emissions, new coal plant builds in 2020–2035 exceed 900 GW. Under its New Policies Scenario, the IEA projects that 550 GW of new coal power would be built, roughly 80% of it in China, India, and other developing Asian countries. With far lower emissions of local air pollutants, natural gas also offers a means to help address growing air quality concerns in these countries.

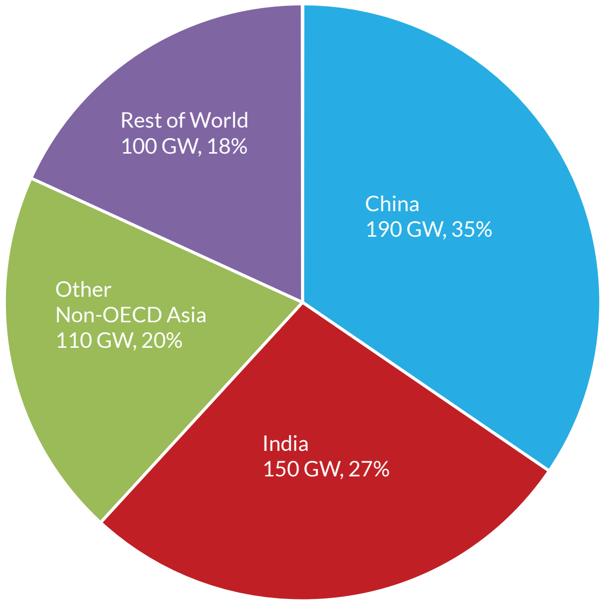


Figure 4: Coal power capacity additions, 2020–2035, IEA New Policies Scenario (IEA 2013c)

As a rule of thumb, the power supplied from a 1 GW coal plant can be replaced annually by 1 bcm of natural gas, saving nearly 3 million tonnes of CO_2e per year.[12] If 10% greater natural gas production could exclusively replace roughly 500 GW of new coal power capacity, emissions reductions would total 1.3 Gt CO_2e per year by 2035.[13] For China, increased domestic natural gas production, if directed solely to displacing coal in the power sector, could replace nearly half of the almost 200 GW of new coal capacity expected from 2020 through 2035, directly reducing emissions by up to 300 million tonnes CO_2 per year by 2035.[14]

11 IEA (2012), p.10.

12 Assumes a 70% coal plant average operating capacity with 42% average conversion efficiency, and an average conversion efficiency of 59% for CCGT power plants.

13 10% represents a 535 bcm increase in gas supply, similar to production increases envisioned by IEA (2012), or outlooks from major energy producers relative to IEA (2013a) baselines: BP (2014); ExxonMobil (2014); Shell (2013).

14 While the potential benefits of replacing coal with natural gas are particularly great in Asia, the opportunities and challenges of using natural gas as a climate bridge and economic engine are widely shared across many regions of the globe. An abundant and less expensive natural gas future that enables a significant displacement of China and/or India's new coal builds will also have corresponding impacts on energy use, energy supply, and economic development in other countries. Therefore, our analysis takes a global, rather than Asia-specific, perspective.

DEMAND-SIDE DYNAMICS AND THE SCALE EFFECT AFFECT NET EMISSIONS SAVINGS

A critical question for policy-makers is whether expanding the natural gas supply would actually displace new coal builds. The answer would depend on several factors, including the market competitiveness of natural gas vs. coal and low-carbon alternatives, what other demand there is for the incremental gas, and whether the gas can be delivered to regions of projected coal power growth. Figure 5 shows how natural gas and coal prices compare in different regions, and how a carbon price might change the equation for new power plant investments.

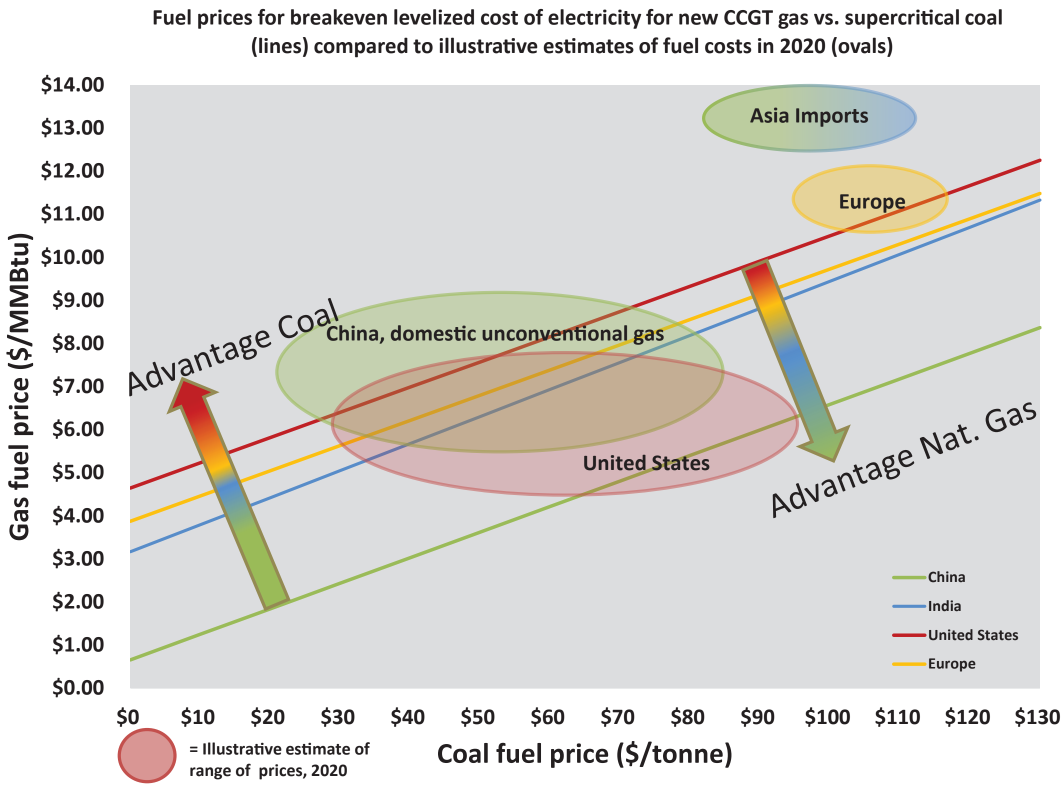


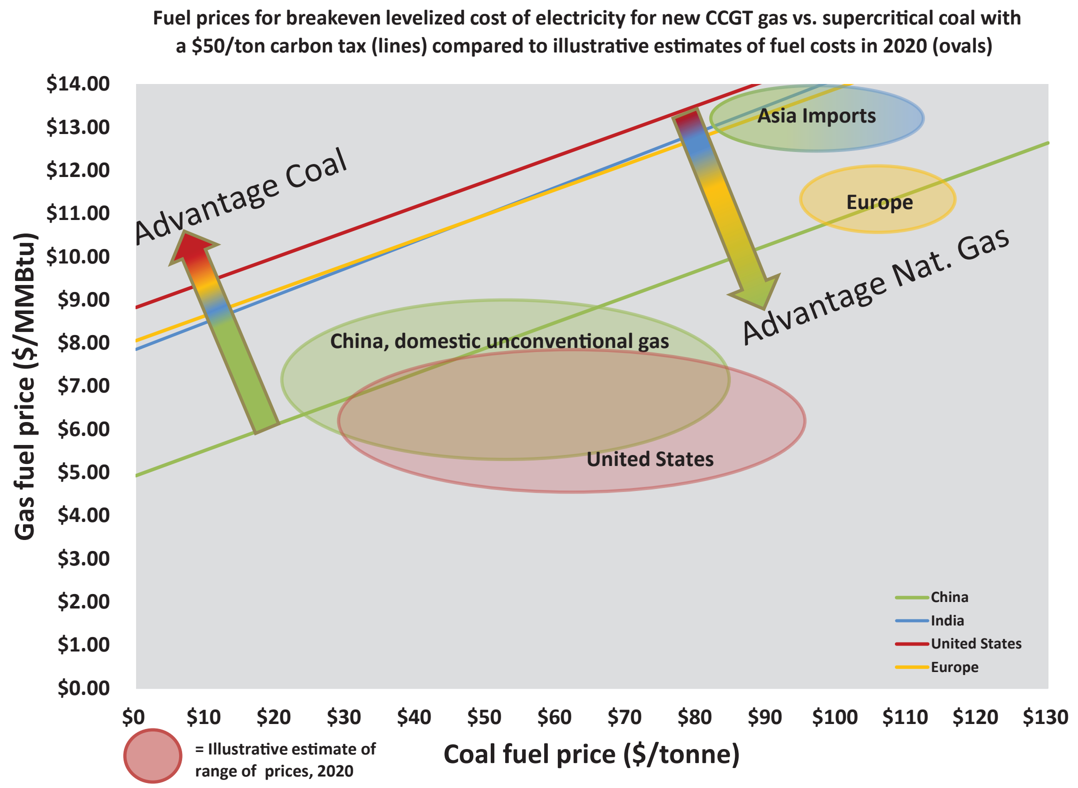
Figure 5: Natural gas competitiveness vs. coal based on market prices alone and with a carbon price, 2020

As shown above, in many regions, coal has a market advantage over natural gas due to its lower price. The United States presents a notable exception (red bubble falls below corresponding red line).[15] Even under optimistic projections for 2020, the price gap between natural gas and coal indicates an advantage for coal power in Europe and major importing regions in Asia. In China, a similar outcome is likely: even under high production scenarios with low unconventional gas prices in China, power from coal plants remains the cheapest option. Policies such as a carbon price, as illustrated in the figure below for a price of US$50/t$CO_2$, can help to close the gap or favour gas over coal.[16]

In the United States, where the recent shale gas boom has made natural gas particularly competitive, the share of coal in power generation dropped from 49% in 2007 to 37% in 2012, while the natural gas share rose from 22% to 30% (U.S. EIA 2015), contributing to a 12% decrease in U.S. energy-related CO_2 emissions in that period (U.S. EIA 2013). In 2013, with higher natural gas prices, coal's share rose to 39%, while natural gas dropped to 27% (U.S. EIA 2015), contributing, with increased demand, to a 2.5% rise in energy CO_2 emissions (U.S. EIA 2014b). In the same 2007–2013 period, natural gas has overtaken oil as the top energy source in industry, with a 43% share (up from 38% in 2007; oil's share declined from 44% to 39%; coal's share dropped from 9% to 7%); in buildings, natural gas's share increased from 75% to 78% (oil's

15 The United States is also notable for the availability of surplus natural gas plant capacity, which remained at a utilization rate below 50% in 2011 (IEA 2013b), facilitating rapid replacement of existing coal powered generation given low gas prices (IEA 2013b; Hood 2014).

16 In the New Policies Scenario of the World Energy Outlook 2014 (IEA 2014b) Table 1.3, carbon prices in the EU approach US$40 per tonne CO_2 by 2030. In the 450 Scenario, however, carbon prices rise to US$100 per tonne in OECD countries and US$75 in China by 2030.



Notes: Illustrative gas prices drawn from IEA Golden Rules case (IEA 2012), Tables 2.2 and 2.3: gas production and development costs are US$3–$7 for the United States and US$4–8 for China, before a $1 mark-up to reflect wholesale prices; gas import wholesale prices are US$10.50–11.60 per MMbtu for the EU and US$12.40–14.30 for Asia (assumed similar to Japan). Coal prices are much more difficult to estimate and generalize given large variation of production costs within each country. Values shown for domestic coal reflect author judgment, based on a review of multiple data sources. EU steam coal import prices are drawn directly from IEA (2013c).

share decreased from 18% to 14%); in transport, natural gas's share has grown from 2.3% to 3.4% (U.S. EIA 2015), partly displacing oil.

There is broad agreement, however, that the U.S. experience of the last few years is unlikely to be replicated elsewhere. Global projections for high natural gas scenarios through 2050 indicate natural gas is most likely to substitute primarily for coal (accompanied by an increase in overall energy consumption), with smaller substitution for biomass, nuclear, other non-fossil fuel energy sources, and transport oil (McJeon et al. 2014). However, the global totals mask regional variations (Edmonds and McJeon 2013). For the United States, natural gas substitution for non-fossil fuel energy (mainly nuclear, biomass and wind) is greater than for coal, and similar to that for coal plus oil substitution. Similar results are reported for Africa, with some differences in the mix of non-fossil fuels replaced by natural gas (especially wind post-2030). By contrast, in China, the substitution of coal by natural gas is expected to dominate the change in fuel mix, with smaller substitution effects of natural gas for nuclear, oil, and other renewables – primarily wind (Edmonds and McJeon 2013).

Another crucial issue that is starting to gain attention is how increased natural gas supply and resulting lower prices might affect overall energy consumption – the "scale effect". As shown in Table 2 below, several studies using energy-economy models to reflect interactions between energy supplies, prices and consumption have suggested that more abundant, inexpensive gas supplies would lead to increased energy consumption, partly or fully offsetting the GHG benefits from substitution of other fuels.

Moreover, natural gas infrastructure can create lock-in effects of its own. Longer-lived investments in LNG and pipeline systems and building and transportation systems could hinder or lock out lower-carbon alternatives, and are less suited (than power plants) to carbon capture and storage. Infrastructure for shale gas production can also be readily transferred to shale oil production, potentially leading to increased oil

The Lakeside Power Station in Vineyard, Utah © arbyreed / flickr

supplies and further lowering energy prices (Aguilera and Radetzki 2014).[17] This, is turn, could amplify the scale effect noted above. This means that even if in the short term, expanded natural gas supply creates a climate benefit, it could delay the transformation of energy systems that is crucial for a safe climate. Indeed, the IEA (IEA 2014a, p.20) finds that under a 2°C scenario, the average global emission rate of new power investment this decade needs to average well below that of efficient gas plants (200 gCO_2/kwh vs. 350 gCO_2/kWh) and near zero thereafter (less than 50 gCO_2/kWh), leaving limited room for expanded infrastructure for gas power (absent carbon capture and storage).

MANY STUDIES SUGGEST ABUNDANT NATURAL GAS DOES NOT CUT GHG EMISSIONS ABSENT POLICY SUPPORT

Considering all the factors discussed above, how do we measure the net climate impact of more abundant, less expensive, gas supplies? Our discussion highlights three key effects to consider: substitution, methane leakage, and scale. Much of the discussion of the climate impacts of natural gas to date has focused on the first two issues.

The substitution effect, or the direct one-for-one (useful energy basis) replacement by natural gas of a different energy source, depends on where incremental gas flows in the economy. As discussed above, if it flows to the power sector, and substitutes for coal in electricity generation, the GHG emissions benefits are greatest – roughly 40% or 50%, depending on whether the gas is supplied from long-distance LNG or shorter-distance pipelines, respectively. If gas flows to buildings or industries and is used instead of oil or coal in typical boiler applications, the benefits are more modest, on the order of 15% or 30%, respectively.

As shown in Figure 3 above, in transportation applications, displacing oil products with natural gas, the impact is only slightly positive, and possibly even slightly negative, if and where the methane leakage associated with natural gas more than offsets its lower carbon intensity. Finally, to the extent natural gas displaces nuclear or renewable energy in power or other applications, it will increase emissions, and to some extent retard development and possibly lock-out these low-carbon technologies. Past experience and modelling of future scenarios suggest a mix of substitution effects, which can be affected by policy, e.g. binding requirements for renewable energy can limit natural gas displacement effects (Brown et al. 2009). Taken together, however, the net substitution effects tend to be positive, lowering GHG emissions.

17 In fact, Aguilera and Radetzki (2014) argue that "the most important implication of a successful shale revolution would arguably a downward pressure on gas and coal in regional market and on the global oil price" (p.75).

The *methane leakage* effect is a function of practices that lead to venting or accidental losses of natural gas to the atmosphere during drilling, extraction, processing, and transport. As we noted earlier, methane leakage rates, especially those related to production activities, remain highly uncertain. Where leakage is high, it can undermine the climate benefits of coal substitution.

Finally, the *scale effect* occurs to the extent that added gas supplies lead to lower energy prices, thereby increasing economic activity, promoting more energy-intensive activities, and reducing incentives for energy efficiency. These effects in turn can result in increased energy use and CO_2 emissions. The scale effect has been noted for several years (Brown et al. 2009), but has only more recently come into focus with a number of modelling exercises that have investigated the impact of more abundant gas supplies.

Recent studies employing energy-economy models capable of reflecting all three effects – substitution, leakage, and scale – tend to come to similar conclusions: They find that both globally and for the United States, the increase in emissions from the scale effect fully offsets the emission benefits from the substitution effect, net of methane leakage. As a whole, they suggest more abundant and less expensive natural gas supplies are, on their own, unlikely deliver a significant climate benefit. Table 2 summarizes the findings of these studies.

Table 2: Net climate impact of more abundant, cheaper natural gas supplies

Study	Description of Modelling Exercise	Findings
Global studies		
Golden Rules for a Golden Age of Gas (IEA 2012)	More abundant, less expensive gas scenario compared with the IEA's New Policies Scenario.	Global GHG emissions in 2035 are 1.3% lower in abundant gas scenario.
Gas Price Convergence Case (IEA 2013c)	Gas Price Convergence Case (lower prices in Europe and Japan; higher in United States) vs. reference New Policies Scenario.	Global GHG emissions in 2035: 0.1% higher in (mostly) lower gas price scenario.
Implications of Abundant Natural Gas (Edmonds and McJeon 2013; McJeon et al. 2014)[18]	More abundant, less expensive gas scenario versus expensive unconventional gas supply scenario, run with and without climate policy assumption using a global IAM (GCAM). Regional results not published.	Global CO_2 emissions are virtually unchanged (slightly higher in 2030 due to increased energy use, slightly lower in 2050 due to coal displacement). Reduced CO_2 emissions in Asia mostly offset by increases in other regions.
BA Economics (Fisher 2013)	Workshop presentation of high gas scenario.	Global GHG emissions: 1% lower in 2030, 1.5% lower in 2050
U.S.-only studies		
EMF-26 (Energy Modelling Forum 2013)	Coordinated, multi-model energy-economy study of abundant gas scenarios for the U.S.	Suggest approximately no change in CO_2 emissions through 2050: scale effects roughly offset substitution benefits.
NEMS-RFF (Brown et al. 2009)	High gas and low gas assumptions compared with and without climate policies.	CO_2 emissions increase in high gas, no climate policy scenario, (increased energy use and displacement of zero-carbon energy dominant factors).
Implications of Shale Gas Development for Climate Change (Newell and Raimi 2014)	Use High Oil and Gas Case from U.S. EIA *2013 Annual Energy Outlook* (doubling domestic production relative to baseline) with 45% decrease in 2040 natural gas. Increased oil production main driver of transportation emissions.	Increased natural gas production has a small effect on aggregate 2010 to 2040 emissions (0.4 to 1.6% lower emissions, ignoring transport).[19]
The effect of natural gas supply on US renewable energy and CO_2 emissions (Shearer et al. 2014)	Power sector focused energy-economy model. Low, reference, and high natural gas supply scenarios impact over 2013-2055 time period (with and without policies such as moderate carbon price or cap to reduce emission over 80% relative to 2005 by 2050).	Absent climate policy, 2% emission reduction in high supply scenario (range from marginally lower to equal). Policies, particularly renewable portfolio standards are necessary for significant reduction in future CO_2 emissions from U.S. power generation.

18 A draft modelling study (Edmonds and McJeon 2013) was presented and discussed at an "Abundant Gas Workshop" of the Global Technology Strategy Project of the Join Global Change Research Institute in April 2013, and , subsequent analysis conducted with the participation of five international modelling groups was published in Nature (McJeon et al. 2014).

19 Higher industrial emissions encouraged by inexpensive fuel may be offset by reduced industrial output in regions outside the United States. In addition, the authors consider the emissions impact of decreasing domestic coal consumption being offset by increasing exports, concluding: "Such a large production decrease demonstrates that increased coal exports has not negated the GHG benefits associated with

Cove Point LNG pier in Maryland © Wikimedia

A NATURAL GAS 'CLIMATE BRIDGE' NEEDS FIRM GUARDRAILS

The need to reduce greenhouse gas emissions is substantial and immediate, and expanding natural gas production and use appears to have already yielded economic and carbon emission reduction benefits for the United States. The fact that the expansion has been driven by market forces, not climate policy, may add to its appeal as a potential "bridge" technology at a time when ambitious climate action faces many challenges.

Yet the discussion above makes it clear that, for all its potential benefits, a natural gas expansion can also have substantial negative effects – perhaps enough to offset its expected benefits. Thus, if policy-makers want to use gas as a "bridge", they need to add "guardrails", to:

- Limit energy demand growth (the scale effect);
- Manage and reduce methane leakage;
- Direct added gas supplies to the applications that yield the greatest substitution benefit (displacement of coal in the power sector); and
- Restrict the extent of lower-carbon technology lock-out.

Fortunately, the policies that decision-makers may elect to pursue for broader climate and economic reasons could accomplish many of these goals. These include carbon pricing, energy efficiency standards, measures that internalize some or all of the full environmental and health costs of coal, and technology-forcing requirements (such as renewable portfolio standards) for renewable energy, and possibly nuclear or carbon capture and storage (CCS) technologies. In addition, methane leakage needs to be measured throughout the gas supply chain, and efforts to reduce leakage supported through incentives and regulation.[20]

A more difficult – but crucial – challenge is how to plan for the end of any natural gas bridge. Scenarios compatible with limiting warming to 2°C require a rapid transition towards net zero emissions for the global energy system. If gas supplies are increased in the next decades, how would this affect future continued efforts to reduce emissions? The answer depends on several uncertain factors, including whether (and when) CCS could be available at scale, and also whether sufficient renewable energy can be built out and energy efficiency achieved in time, even if there is first a turn to natural gas instead. If, absent CCS, global natural gas use must plateau and decrease in the coming two to three decades, it also may be difficult to justify the investment that would be required to build out supply in the first place; it is hard to envision an LNG terminal being built for just 15–20 years' use. There is a risk such assets would have to be "stranded", or otherwise that a future transition to sources with lower emissions than natural gas is in turn delayed. It is possible that a steadily rising carbon price or ever-stricter environmental standards could help achieve this transition, but lock-in and path dependency should be taken very seriously. The viability of natural gas as a bridge may hinge on this trade-off.

decreasing U.S. coal consumption" (Newell and Raimi 2014, p.8365).

20 The United States has recently initiated rule-making on what may be the first regulations directed at controlling methane emissions in the oil and gas sector; see http://www.epa.gov/airquality/oilandgas/.

CONCLUSION

This analysis, based on a review of the research literature and of recent modelling studies, as well as interviews with sector experts, has weighed the potential benefits of risks of relying on expanded natural gas expansion and use as a "bridge" to a lower-carbon energy future. It has also examined the extent to which natural gas could play such a role, and the conditions that would be required. We can summarize our conclusions in two points:

- **Countries should not count on natural gas as a "climate bridge"**: Recent U.S. experience was unique in terms of delivering significant benefits to both the climate and the economy (Burtraw et al. 2012; Aguilera and Radetzki 2014). Despite such a best-case scenario, current research suggests that a more enduring climate-economy "win-win" based on increased natural gas supply is far from guaranteed, even in the United States (Newell and Raimi 2014; Energy Modelling Forum 2013). Efforts to build out gas infrastructure and production capability or to establish policies that promote gas production or improved market function (e.g. creation of a gas trading hub in Asia) should not assume that by default, there will be a net GHG emission benefit.
- **Public policy needs to create the enabling conditions if gas is to make a positive contribution**: Proactive policies and oversight systems are needed in order for natural gas to offer major benefits to the economy, the climate, and overall well-being. In order for the "climate bridge" to assist in a sturdy transition to a climate-compatible future, certain "guardrails" are necessary. In particular, approaches for addressing substitution, methane leakage, and scale effects will be required to achieve any significant climate benefits. Climate-specific policies must also create expectations of increasing stringency over time (e.g. rising carbon prices or stricter emissions standards) so that gas infrastructure investment does not effectively lock out lower-emissions technologies and futures.

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ABOUT THE NEW CLIMATE ECONOMY

The Global Commission on the Economy and Climate is a major international initiative to analyse and communicate the economic benefits and costs of acting on climate change. Chaired by former President of Mexico Felipe Calderón, the Commission comprises former heads of government and finance ministers and leaders in the fields of economics and business.

The New Climate Economy is the Commission's flagship project. It provides independent and authoritative evidence on the relationship between actions which can strengthen economic performance and those which reduce the risk of dangerous climate change. It reported in September 2014.

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