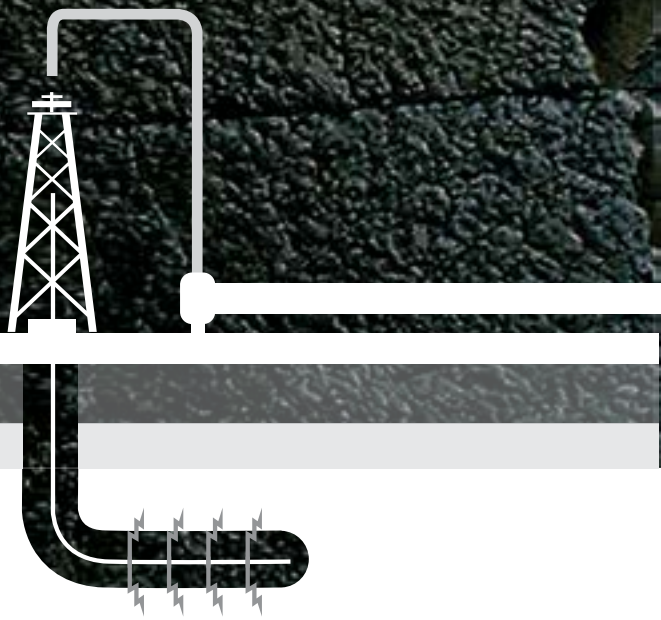
SHALE GAS
AND ITS IMPLICATIONS FOR AFRICA AND THE AFRICAN DEVELOPMENT BANK



AFRICAN DEVELOPMENT BANK GROUP

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2013

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Shale gas and its implications for Africa and the African Development Bank

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ABBREVIATIONS

ARI	Advanced Resources International
BSA	Benjamin Schlesinger and Associates
CNG	Compressed natural gas
EIA	Energy Information Administration
EITAF	Extractive Industries Technical Advisory Facility
EUR	Estimated ultimate recovery
GGFR	Global gas flaring reduction
GHG	Greenhouse gas
GTL	Gas-to-liquids
GWP	Global warming potential
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
KWH	Kilowatt hour
LNG	Liquefied natural gas
MCF	Thousand cubic feet
MMBTU	Million British thermal units
NGL	Natural gas liquid
PTAC	Petroleum Technology Alliance Canada
RPS	Renewable portfolio standards
SCEK	Science and community environmental knowledge
TCF	Trillion cubic feet
TCM	Trillion cubic meters
TCP	Technical cooperation permit

SHALE GAS

Shale gas is the same fuel as that produced from conventional onshore and offshore gas fields, but is found in different geological formations. These formations require new techniques of extraction, which bring environmental problems not found with conventional gas. Shale gas reserves are usually found in different geographical locations from conventional gas reserves, which means that certain countries without conventional gas may be able to produce shale gas.

FOREWORD

The very rapid development of shale gas production in the United States during the past few years, made possible by technological advances, has raised the possibility that shale gas deposits in other countries exist and may be commercially viable. This has far reaching implications for energy markets across the world including Africa. The objective of this study is to assess the impact of the shale gas revolution on Africa.

A number of African countries have already been identified as possessing possible viable shale gas deposits. The additional supplies of gas from such sources have the potential to lower international gas prices and to increase the consumption of natural gas, partly at the expense of coal, thus slowing down the growth of greenhouse gas emissions from power generation while conferring substantial economic benefits to the countries producing the gas. However, the production of gas from shale deposits is accompanied by a number of difficulties, particularly with respect to the amount of water that is required in the use of the technology that has been developed. Good environmental planning and management of shale gas production can reduce these costs associated with its production.

This study reviews the factors that led to the rapid development of shale gas in the United States, the nature of shale gas and the technology required for its commercial extraction, and the issues associated with its production. It places these in an African context by reviewing estimates that have been made for shale gas deposits in certain African countries, some of which are very substantial, and highlighting the challenges that would need to be overcome if such deposits were to be confirmed and developed. It also reviews the potential effects on other fuels, as well as on greenhouse gas emissions, of the global development of shale gas.

The African Development Bank stands ready to support those of its member countries that have shale gas prospects with a range of actions. The study concludes that: (a) if confirmed by exploration, several countries in Africa appear to have reserves of shale gas that could provide a major source of energy for their economies; (b) the development and production of shale gas can present substantial environmental difficulties that need careful monitoring and mitigation; and (c) it is of major importance for governments and the public to reflect on the most advantageous way to proceed, before embarking on a full development of the shale gas resource.

Donald Kaberuka
President
African Development Bank Group

EXECUTIVE SUMMARY

THE SHALE GAS REVOLUTION

Within the past decade there has been a huge increase in natural gas production, much of this within the United States. Most of this increase is from shale gas, which only within that period has been able to be developed economically. The potential impacts of future development are large in global terms, and the advent of shale gas production has been termed a "game changer" both for countries that produce such gas and those that use it. Ernst and Young (2012), in a survey of gas in Africa, emphasized the magnitude of such effects.

Box 1: Global gas supplies and shale gas

Relatively new, "unconventional" supplies of natural gas — including shale gas, tight gas and coalbed methane (also known as coal seam gas) — could transform the world's energy markets. While global gas reserves have been growing steadily for decades, over the past decade the so-called unconventional gas "bonanza" has roughly doubled the resource base that can be economically recovered. A decade ago, the world was estimated to have only 50 to 60 years' worth of gas remaining; with the new unconventional supply, the estimated resource life has risen to more than 200 years. Currently, the unconventional boom has been centered in the United States, but parts of Europe, China, Argentina, Brazil, Mexico, Canada, and several African countries are thought to hold yet unknown huge quantities of unconventional natural gas. Of the world's estimated remaining technically recoverable natural gas resources, unconventional gas accounts for about 44% of the total, and shale gas, in turn, accounts for an estimated 63% of the world's technically recoverable unconventional gas.

Source: Ernst and Young 2012.

To better understand the "shale gas revolution" and its relevance to African countries, this report first describes actual experience with shale gas production in the United States, and then reviews a number of questions concerning shale gas and its production that are relevant to African countries. The report finishes by suggesting how the African Development Bank might work together with its client countries to assess the potential costs and benefits of developing shale gas where present.

Shale gas in the United States

Prior to 1998 there was no commercial shale gas production in the world, but by 2012 production in the United States of almost 8 trillion cubic feet of shale gas amounted to one-third of that country's total gas production, and more than 7% of global gas production. The technological breakthroughs that have made this possible are readily exportable, and now other countries are considering whether to develop their shale gas reserves. The potential for the medium term is for a very substantial increase in global gas production over what would have occurred had the technological breakthrough not taken place.

In the United States the increased supplies of gas have cut spot gas prices by more than half, which has changed the relative attraction of different fuels. Coal for power generation, which had relied on its low fuel costs to offset its high capital costs, can no longer compete with gas, for which the capital costs are lower and the fuel cost has declined so dramatically. Older and less efficient baseload coal-fired stations have been shut down, and combined cycle gas-fired power stations provide baseload generation in their place. Because the emissions of carbon dioxide from the combustion of gas are much lower than that from coal when delivering the same electrical output, the advent of shale gas has been welcomed as making a contribution to slowing US greenhouse gas emissions.

The production of shale gas[1]

The physical difference between shale gas and conventional gas is the location of the resource in rock formations. "Conventional gas reservoirs are created when natural gas migrates from an organic-rich source formation into permeable reservoir rock, where it is trapped by an overlying layer of impermeable rock. In contrast, shale gas resources form within the organic-rich shale rock. The low permeability of the shale greatly inhibits the gas from migrating to more permeable reservoir rocks".[2] This low permeability and shale's tendency to run in horizontal layers mean that conventional drilling techniques with a vertical well are unable to recover commercially viable amounts of shale gas. To overcome this difficulty, an approach using hydraulic fracturing ("fracking") and horizontal drilling has been developed.

Hydraulic fracturing pumps a fluid at high pressure into the well to create fractures in the rock. To hold these open, once the pressure is released, small particles (usually sand) are added to the fluid as "proppants". This then allows the gas to escape into the well. The fracking fluid is predominantly water and proppant, but a small fraction (up to 1%) consists of chemical additives that make the process more efficient. Some, but not all, of the fluid returns as the gas rises to the surface through the vertical section of the well. Horizontal drilling, branching out from the vertical section of the well, makes possible a much larger contact area between the reservoir rock and the wellbore.

[1] A detailed account of shale gas production is given in International Energy Agency (2012).

[2] Energy Information Administration (2012).

Environmental issues associated with shale gas production

The production of shale gas by fracking involves a number of environmental risks, and these continue to be of concern to communities near proposed well sites and groups involved with environmental protection. Four key issues have been identified that governments need to take into account in their decision-making and regulations for the sector.

I. The large use of water required for fracking
Each well requires a large amount of water (several thousands of cubic meters), which has to be either taken from local water sources or trucked in. Where there are local water shortages, this can present a major hurdle to the development of shale gas. Some water is recovered from the well and can, after treatment, be used in subsequent fracking. Governments can require a certain degree of recycling.

II. Water contamination
The chemicals added to the fracturing fluid may escape and pollute water supplies. This can happen at the surface, where better containment can be mandated, or underground through leaks into aquifers, where high-quality well casings can be required in order to prevent leakage. The risk is small that fluid from the fracturing itself, deep underground, will leak into shallow aquifers used for water supply. The depth of drilling can be regulated in order to ensure this separation.

III. Seismic events
There have been a very few low-level seismic events near areas where fracking is underway. Subsequent analysis and investigation have not confirmed a causal link between the two, but governments can regulate fracking to ensure that it does not take place near geological fault lines.

IV. Venting and flaring of gas
If the gas is not all collected during the well completion phase, it will either be flared or, in more extreme cases, vented. The global warming potential of vented gas is so high that allowing a substantial fraction of the produced gas to be vented would raise the total life-cycle emissions of the gas toward those of coal, thus weakening arguments that extra gas production can help to slow global warming. Governments can act to reduce this risk by regulating the venting and flaring of gas from the wells.

Although there are problems associated with the environmental impact of the production of shale gas, particularly with respect to water demand in areas with supply constraints, there are a number of actions the government can take through contracts, regulation, and monitoring that can substantially reduce the environmental risks.

Shale gas in Africa

The US Energy Information Administration (EIA) produced a study in 2011 estimating global technically recoverable shale gas reserves.[3] Technically recoverable reserves are those that can, with a high degree of certainty, be expected to be able to be extracted with current technology and under current economic conditions.[4] To make such an estimate extensive geological data is needed, and it was available for 32 countries. The study ignored the Middle East and Russia, where it was assumed that the conventional gas reserves are so large that there is no immediate prospect of shale gas being produced. Most African countries were omitted from the study for lack of adequate public data, but estimates could be made for six countries and the territory of Western Sahara.

The EIA study estimated that the technically recoverable global shale gas reserves are almost 50% of technically recoverable conventional gas reserves, indicating the very large impact that the technological breakthrough has had on potential global gas production. For Africa, the technically recoverable shale reserves, of the countries for which estimates could be made, are almost equal to the technically recoverable conventional gas reserves of the continent.

For the individual countries, it is possible to compare their technically recoverable shale gas reserves with proven reserves of conventional gas and current production levels of gas. Table 1 indicates the potential importance of shale gas for these countries. If the estimates of the reserves are confirmed by exploration and production drilling, they could make very significant contributions to these economies.

Table 1: Technically recoverable shale gas reserves, proven conventional gas reserves, and current production of gas in trillions of cubic feet

Country	Technically recoverable shale gas reserves[1]	Proven conventional gas reserves[2]	Production of gas in 2010[2]
Algeria	230	158	2.957
Libya	290	52	0.586
Tunisia	18	2.26	0.071
Morocco	11	0.035	0.004
Mauritania	0.4	0.989	0.000
Western Sahara	7	-	-
South Africa	485	0.000	0.035

Sources: 1 = EIA(2011b). 2 = Oil and Gas Journal, cited by Ernst and Young (2012).

[3] EIA (2011b)

[4] Technically recoverable reserves include both proven reserves (those confirmed by exploration and drilling) and unproven (undiscovered) reserves (those whose presence is inferred from broad geological data). See Gene Whitney, Carl E. Behrens, and Carol Glover (2010).

Algeria is a major producer and exporter of gas, but its rapidly increasing domestic consumption will put downward pressure on exports, and shale gas could play an important role in allowing exports to continue on a large scale without slowing domestic growth. The challenge for Algeria will be to determine whether there is sufficient water supply available to permit fracking without damage to other sectors of the economy, such as agriculture. In addition, despite its long experience with developing a gas sector, Algeria does not yet have experience with the regulations and monitoring required to ensure that fracking does not pose an unacceptable environmental risk.

Libya has until now concentrated more on oil production, but is looking to place an increasing emphasis on gas production. This would enable it to supply domestic needs for electricity generation and industry as well as exports. Libya also has experience in managing a gas sector, but will face similar challenges to Algeria on the environmental front, especially with respect to the supply of water.

Tunisia and ***Morocco*** both have very small domestic reserves of conventional gas and limited production. If their shale gas reserves are confirmed, they would significantly change these countries' energy pictures. Imports of gas or other fuels would decline, and the power sector would be able to diversify its fuel source. These countries have very limited experience with managing a hydrocarbons sector, and those difficulties would be added to the struggles of managing the environmental risks. Yet again, the adequacy of water supply and measures that might be taken to minimize its impact on the economy will be important.

For ***Mauritania***, the potential reserves are much less important relative to known reserves of conventional gas, and the pressure to develop shale gas is likely to be rather modest.

By contrast, the shale gas reserves estimated for ***South Africa*** are the fifth largest in the world. For a country that has virtually no domestic gas production and relies almost entirely on coal for power generation, such a find, if confirmed, could be a game-changer. Although the reserves are believed to be spread over a very wide geographical area, much of it is desert, and water shortages would be a major constraint. For large-scale development, a comprehensive water plan and environmental safeguards would need to be developed before extensive fracking could be allowed.

Already, all of these countries have seen interest from international companies wishing to explore possible development sites. At the same time, civil society groups are expressing concern and even opposition to the production of shale gas. Some governments have placed a moratorium on exploration, while others are permitting exploration (since it does not require fracking) but not development. These decisions must be made in an informed way and be responsive to concerns about possible environmental damage.

A role for the African Development Bank

Shale gas discoveries on the African continent represent an important challenge for the AfDB. On the one hand, reserves, if confirmed, may be substantial enough in some countries to bring major economic benefits. On the other hand, the environmental risks could in some circumstances prove so severe that it would be better for the government to ban the production of shale gas. The decision on whether to go ahead should be made on an informed basis rather than by giving way to excessive optimism or pessimism.

Governments and civil society groups are only just learning of the possible presence of shale gas reserves and the risks of production, and there may be confusion and uncertainty about the costs and benefits. The AfDB could act as an "honest broker" by working to ensure that governments with possible shale gas reserves are better informed, with access to the best information on possible environmental dangers, their possible remedies, and the legislation and regulations that would be needed to minimize the risks.

The AfDB could proceed with a two-step approach. The first step would be to organize one or more regional workshops for the countries where possible shale gas reserves have been identified. The workshops would bring together a group of experts on shale gas production and on the prevention and regulation of associated environmental damage. The experts would be selected in order to provide a balanced view, rather than one that leans pro- or anti-industry. Governments would be invited to send representatives and also to suggest in advance issues that they would find helpful to have discussed. A substantial amount of the workshops could be devoted to question-and-answer sessions in order to maximize the transfer of knowledge. The AfDB would also indicate its willingness to work with governments in determining whether they will go ahead with shale gas production and, if they decide to go ahead, how the Bank would be able to support them.

The second step would depend on governments' reaction. Those that wished to go ahead with shale gas production might require technical assistance for staff training in the specifics of fracking and associated environmental regulations. Beyond this, officials might require assistance in drafting regulations and establishing monitoring procedures. For certain governments that have not previously produced conventional gas (or oil), there would be an additional set of new technical challenges related to the management of the sector. In all these cases, the AfDB could build on its recent experience with a number of hydrocarbon-producing countries and offer technical assistance loans. In some cases, there might even be a role for financing infrastructure associated with gas development.

Some countries may be in possession of unpublished geological data; where this is of sufficient quality, the AfDB could offer technical assistance to hire specialist consultants to make an estimate of possible shale gas reserves. Where such reserves can be identified, this acts as an incentive to the private sector to undertake exploration and, possibly, development.

INTRODUCTION

Shale gas, as a newly exploited energy source, has prompted a revolution in forecasting and planning for energy markets. The discovery and extraction of large quantities of gas from shale formations in the United States is already having an impact on both US and global energy markets, and the prospects of further exploitation in the United States and in many other countries is leading to a reevaluation of the role of natural gas in the global energy picture.[5] At the same time, there has been extensive debate over the environmental costs and benefits of shale gas, leading a number of governments to place a moratorium on drilling in shale.[6] Environmental impacts include the local costs associated with the drilling process, the global benefit of the possible substitution of gas for coal in power stations, and the global cost of potential leakage or venting of gas during drilling.

African countries could be affected in a number of ways by this revolution. Some may turn out to have commercial deposits of shale gas, leading to an increased domestic supply of energy and even to exports. At the same time, existing gas producers that do not find shale gas reserves will face increasing international competition for the export of natural gas.

This report is intended to help start a dialogue in the African context on the possible effects of the shale gas revolution. It seeks to answer seven questions posed by the African Development Bank considering the possible effects on African countries of the development of shale gas on the continent and elsewhere. The second part of the report discusses these seven questions. The first part discusses four key topics relating to shale gas in order to provide the background against which the answers to the questions can be understood. These topics are:

I. The shale gas revolution in the United States
II. The production of shale gas
III. Environmental issues associated with shale gas production and use
IV. Enabling factors of the US shale gas revolution and their transferability to other potential shale-gas-rich regions

PART I: REVIEW OF THE SHALE GAS INDUSTRY

The shale gas revolution in the United States

Although the United States has so far been the only producer of commercial shale gas, the growth of production has been so rapid and so large that the so-called shale gas revolution is of global importance. The US experience provides a number of important lessons for other countries thinking of embarking on a program of exploration and development of shale gas.

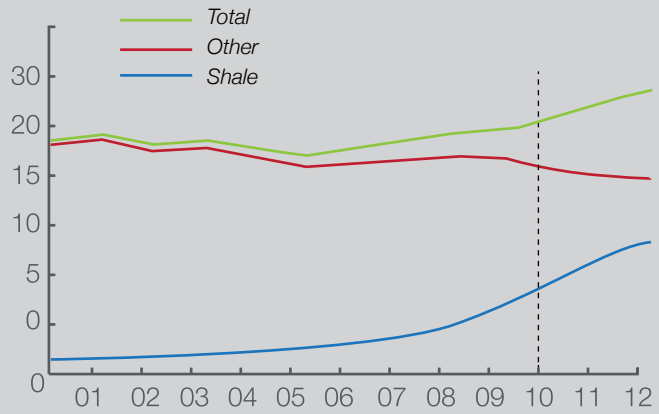
[5] See for example, Der Speigel (1 February 2013).

[6] Detailed accounts of the production and uses of shale gas are available in IEA (2012) and Rao (2012).

The exceptional growth of shale gas production and the comparison with conventional sources of gas in the United States

Since 2005, the development of commercial technologies to produce natural gas from shale deposits in the United States has changed the complexion of the natural gas industry. The size of the increased production and the speed at which it has occurred have been truly revolutionary. Particularly in the past two years, it has become apparent that forecasts and scenarios that do not take account of the presence and potential of shale gas will be seriously misleading. Shale gas was first commercially produced in 1998. By 2005, production had reached 0.75 trillion cubic feet (tcf) per year, or 4% of all US natural gas production; by 2010 it was 5 tcf/year, accounting for one-quarter of total US gas. Estimates (EIA 2012a) for 2011 and 2012 indicate a continuation of that very rapid growth rate, with 2012 seeing almost 8 tcf/year, or one-third of total gas production (Figure 1). For reference, the total US natural gas production in 2010 was 21 tcf, while total world production was 113 tcf (EIA 2011a).

Figure 1: US shale and other gas production 2000–2012 in tcf/year



Source: EIA 2012a

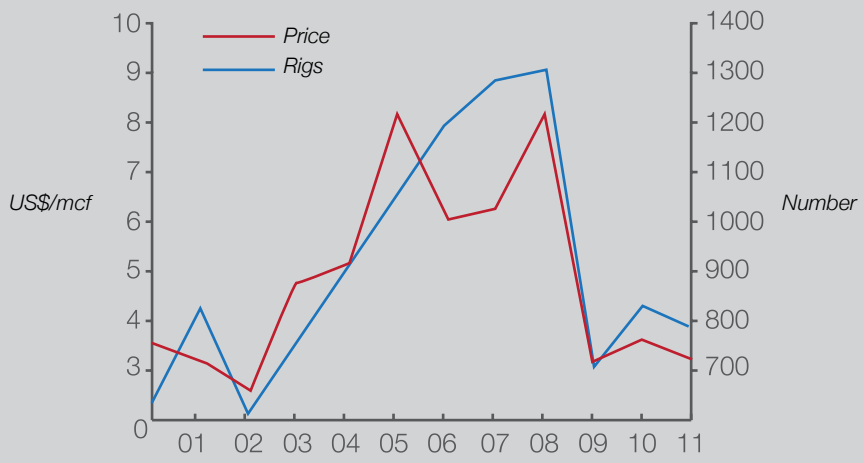
Shale gas production and the changing trade balance for gas in the United States

This enormous increase in shale gas production more than offset the decline in production from other sources of gas, and saw US exports increase while imports decreased. Up to 2007 the net US import of gas had steadily risen to 3.8 tcf, but this then fell to 2.6 tcf in 2010 and is estimated to have been only 1.6 tcf in 2012. This has had a notable effect on the global gas market. Investment decisions made earlier in the decade to supply liquefied natural gas (LNG) to the anticipated growing US import market turned out to be overly optimistic, and accordingly large supplies of LNG have been diverted to the global market, increasing competition among exporters. Imports of LNG to the US market peaked in 2007 at 771 bcf and then fell by more than half, to 349 bcf by 2011. Trinidad experienced the largest fall in export volumes to the US, but Nigeria and Egypt also saw large drops (EIA 2012).

Impact of increased shale gas production on spot US natural gas prices

Within the United States, the unexpected increase in natural gas production led to major changes in the spot price of gas (Figure 2). Such changes were possible because of pipeline infrastructure that could be easily linked to the new supplies of shale gas, as well as third-party access rights that provided immediate market access and allowed the spot market to function, swiftly accommodating variations in supply. A sharp increase in spot prices had accompanied the decline in domestic gas production up to 2007. This increase in turn created greater incentives for the production of shale gas that followed. As a result of the subsequent rapid growth in output, prices then dropped sharply, reaching decade lows by 2012.[7]

Figure 2: US spot Henry Hub annual average natural gas prices per thousand cubic feet and number of natural gas rigs in operation in the United States



Source: EIA 2012b

The relation between spot natural gas prices and exploration in the United States

The decline in spot gas prices had repercussions for the rate of exploration. Initially, the fall in conventional gas supply that led to the rise in gas prices was accompanied by a sharp increase in the number of gas-directed drilling rigs in operation—peaking in 2008 at double the number at the beginning of the decade. As the spot price dropped again, the number of active drilling rigs also declined, and by 2011 the number was only 60% of the 2008 peak (Figure 2).

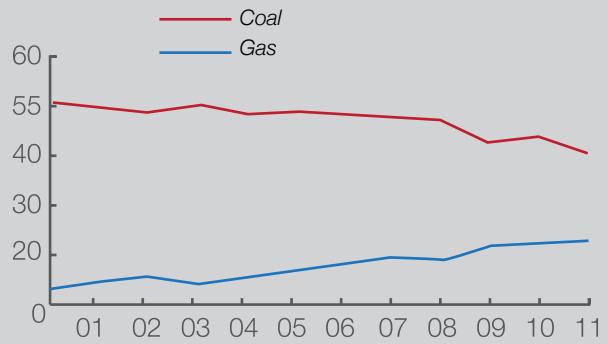
[7] The estimate of the Henry Hub spot price for 2012 is $2.77/mcf or $2.71/MMBtu (using a US-based conversion factor of 1 mcf = 1.023 MMBtu).

Data from the first nine months of 2012 indicates a further substantial fall to a level below that of the year 2000. This relationship between prices and exploration will determine how rapidly the US production of shale gas continues to increase. One important feature of the US scene has been that the gas from certain shale sites is also combined with natural gas liquids (NGLs), whose price is tied to that of oil. These "wet gas" sites are more profitable than the equivalent "dry gas" sites and have remained attractive even at the low gas prices seen at the end of the decade. The IEA (2012) suggested that break-even prices for US dry shale gas range between $5 and $7/MMBtu, while wet shale gas has a lower break-even price, perhaps as low as $3/MMBtu.

Impact on US energy markets in the past decade

The large increase in gas supply coupled with the very large fall in US spot gas prices has had a major impact on the choice of fuels for generation and heating. The impact has been seen most sharply in the role of coal in the energy mix. Over the past decade the share of coal in the number of net kilowatt hours generated fell from 52% to 42%, while the share of gas rose from 16% to 25% (Figure 3). Renewables, excluding hydro, increased their share from 1.4% to 4.2%, while the shares of both oil and nuclear fell slightly.

Figure 3: Percentage shares of gas and coal in net US generation (kWh)



Source: EIA 2012c

Relation to global gas markets

A reduced global price for LNG cargoes has not yet materialized. While there is an immediate link from increased US shale gas production to global gas markets, the expected fall in global prices for LNG cargoes, the vehicle for gas trade, did not occur. As the bulk of such trade is sold under long-term oil-linked contracts, low US prices or increased global gas supply did not affect its price. In addition, the Fukushima disaster prompted Japan to almost completely shut down its nuclear power plants, which led to a rise in the demand for imported gas. This was reflected in rising prices in the fledgling spot markets for LNG in Asian markets through early 2012. As global economic growth stays weak and Japan is able to move to other sources of generation (including coal plants), prices are starting to decline.

The production of shale gas

The techniques of production of shale gas have a number of features that affect availability, desirability, and environmental impact. Although commercial-scale production so far remains limited to the United States, there is a wide range of experience from that country.[8]

Where shale gas is found

The physical difference between shale and conventional gas is the location of the resource in rock formations. "Conventional gas reservoirs are created when natural gas migrates from an organic-rich source formation into permeable reservoir rock, where it is trapped by an overlying layer of impermeable rock. In contrast, shale gas resources form within the organic-rich shale rock. The low permeability of the shale greatly inhibits the gas from migrating to more permeable reservoir rocks." (EIA 2012a) Hence, the first step in exploration is to locate shale formations. However, a number of other factors must be quantified before even preliminary estimates of the gas in place and recoverable resources can be made.[9] These include the depth at which the shale is found, the thickness of the deposit, reservoir pressure, total organic content, thermal maturity, and clay content. Where there is such information, companies can then decide whether drilling is likely to be worthwhile. Shale gas deposits are not linked to the location of conventional associated or non-associated gas, so the presence of conventional gas reserves is not in itself an indicator of the likelihood of shale gas reserves. Offshore shale gas reserves have also been identified, but as yet the extremely high costs of recovery have prevented their exploitation.

The location of shale gas resources has a number of important consequences for production. First, the general location of shale formations, which are found in sedimentary basins, is often already known from broad geological study, so pure exploration to determine whether shale is present may be unnecessary. The uncertainty lies in the extent of the amount and recoverability of gas from the shale. Second, the low permeability of shale and its tendency to run in horizontal layers mean that conventional drilling techniques are unable to recover commercially viable amounts of shale gas. Two technical developments—hydraulic fracturing and horizontal drilling—were required to overcome these difficulties.

Hydraulic fracturing and horizontal drilling

Hydraulic fracturing, or "fracking," pumps a fluid at high pressure into the well to create fractures in the rock. Once the pressure is released, small particles (usually sand) are added to the fluid as "proppants" to hold open the fractures. This allows the gas to escape into the well. The fracturing fluid is predominantly water and proppant, but a small fraction (up to 1%) consists of chemical additives. These help to keep the proppants suspended in the fluid itself, reduce friction, counter rust in pipes, and kill microorganisms. Some, but not all, of the fluid returns as the gas comes to the surface.

[8] A number of countries besides the United States have issued licenses for shale gas exploration, but these have not yet resulted in commercial levels of production.

[9] The EIA (2011b) published a study by Advanced Resources International (ARI) that explains such steps in detail.

Horizontal drilling was developed to make possible a much larger contact area between the reservoir rock and the wellbore. Often a series of fractures is created at intervals along the horizontal wellbore (multi-stage fracking). The total volume of water use for fracking for a single well may vary from a few thousand to 20,000 cubic meters, and the volume of proppant from 1,000 to 4,000 tonnes (IEA 2012). The need for a large number of wells to supply needed volumes of gas leads to high well density per unit area, and the use of drilling multiple wells from a single site, or pad, is used to reduce the amount of disruption caused by fracking.

Well production profile

Shale gas wells typically exhibit much shorter productive life than conventional gas wells, whose production might last up to 30 years. Shale gas production at a given well starts rapidly but then may decline by between 50% and 75% in the first year (IEA 2009); most recoverable gas is extracted in just a few years. These large swings in production are more difficult to manage commercially than in the case of conventional gas, since a supplier is more likely to experience deviations from expected sales levels.

Global estimates of shale gas in place and recoverable reserves

A study by Rogner (1997) was the first to provide a global estimate of shale gas resources, but predated any substantial commercial exploitation. The EIA study (2011b) carried out by Advanced Resources International (ARI) was able to draw on more than 10 years of production experience in the United States. ARI considered 48 shale basins in 32 other countries, containing nearly 70 shale gas formations, using published data. The study excluded Russia and the Middle East on the grounds that their substantial conventional reserves, cheaper to develop, would make it unlikely that shale gas reserves would be tapped. For Southeast Asia and sub-Saharan Africa (with the exception of South Africa), the lack of adequate published geological data prevented an evaluation.

ARI's methodology first estimated the total gas-in-place resource for a prospective area within the basin. The technically recoverable gas was estimated from the gas-in-place by using a shale gas recovery factor, which was based on a number of geological inputs and reservoir engineering formulae. The recovery factors were mainly between 20% and 30%. Because there has been so little actual exploration for shale gas outside the United States, global recoverable reserves remain largely unproven. As exploration confirms or fails to confirm these estimates, the balance between proven and unproven shale gas reserves will change.[10]

[10] Determining the gas in-place consisted of the following specific steps:

I. Conducting a preliminary review of the basin and selecting the shale gas formations to be assessed.
II. Determining the area of the shale gas formations within the basin and estimating their overall thickness, in addition to other parameters.
III. Determining the "prospective area" deemed likely to be suitable for development based on a number of criteria and application of expert judgment.
IV. Estimating the gas in place as a combination of "free gas" (trapped in the pore spaces of the shale) and "adsorbed gas" (adhering to the surface of the shale).
V. Establishing and applying a composite "success factor" made up of two parts. The first part was a "play success probability factor," which took into account the results from current shale gas activity as an indicator of how much is known or unknown about the shale formation. The second part was a "prospective area success factor," which took into account a set of factors (e.g., geologic complexity, lack of access) that could limit portions of the prospective area from development.

Based on these calculations, the EIA estimated that the total shale gas-in-place for the countries included was 22,016 tcf (623 tcm), while technically recoverable reserves were estimated to be 5,760 tcf (163 tcm).[11] Including ARI's estimate for the United States, shale gas-in-place was 25,300 tcf (716 tcm), and recoverable reserves were 6,580 tcf (186 tcm). Excluding the same countries as in the ARI study, Rogner had estimated total shale gas-in-place as 13,897 tcf (393 tcm).

The IEA (2012) provided estimates for worldwide recoverable reserves of conventional and non-conventional gas, based on the ARI data and including countries excluded by ARI, but making a number of important adjustments. In particular, estimates for India, Poland, China, and the United States were reduced in the light of subsequent geological studies. As well as shale gas, the IEA estimated reserves of coalbed methane (natural gas found in coal seams) and tight gas (gas found in low-permeability formations apart from shales). The IEA estimates for the end of 2011 are shown in Table 2—shale gas recoverable reserves are equal to about half of the remaining recoverable conventional gas reserves. These figures make clear how large the shale gas reserves are, and what a large part they can be expected to play in the future of world energy markets. These technically recoverable reserves are estimated considering present technical knowledge and costs of extraction. Were there to be large changes in either of these factors, the reserves picture would change accordingly.

Table 2: Remaining technically recoverable natural gas reserves by type and region (tcm)

Region	Conventional gas	Shale gas	Tight gas and coalbed methane	Total
E.Europe/Eurasia	131	12	30	173
Middle East	125	4	8	137
Asia/Pacific	35	57	36	128
OECD Americas	45	56	21	122
Africa	37	30	7	74
Latin America	23	33	15	71
OECD Europe	24	16	5	45
World	421	208	123	752

Source: IEA 2012.

[11] 1 cubic foot = 0.0283 cubic meters.

In Africa, individual estimates of shale gas reserves could be made for Algeria, Libya, Tunisia, Morocco, Mauritania, and South Africa, as well as the territory of Western Sahara. Details are provided in the second part of this report.

Environmental issues associated with shale gas production and use

A number of environmental impacts are associated with producing and using shale gas. These include the need for large supplies of water for fracking, the risk of water contamination from fracking fluids and materials brought to the surface by returning fluids, the venting and flaring of the gas, and the possibility of inducing seismic shocks. In its brief commercial history, these factors have generated a large number of studies and considerable controversy. The governments of countries such as France, Britain, and South Africa, observing this debate as it has evolved in the United States, have placed moratoria on exploration and production drilling for shale gas, preferring to wait until more evidence has been collected both internationally and locally.[12] Reviews of environmental impacts and associated regulations are contained in IEA (2012) and in the study by Petroleum Technology Alliance Canada and Science and Community Environmental Knowledge (2012).

Large supply of water required for fracking

As noted above, each well may require several thousand cubic meters of fracking fluid, for which the water may be drawn from local surface sources or boreholes or trucked from further afield. Even though some of the water used can be recycled as the fracturing fluid flows back, there is still a large net withdrawal required. In areas where water resources are scarce, the loss of value (for example, of agricultural production) from the diversion of water increases the total cost of the fracking operation to the economy, and may bring drilling into conflict with communities that depend on the same water supplies. The portion of the water used for fracking that returns to the surface as flow-back contains chemicals used in the fracking fluid, as well as metals and minerals leached from the reservoir rock. This wastewater requires secure storage and then treatment. A portion may be available for recycling to be used again as fracking fluid, or may be reinjected into deep rock layers, but it is likely that some of it will need industrial treatment to enable it to be safely reused for other purposes (irrigation, etc.).

Considerable interest is being shown in methods of fracking that do not use water, but rather other materials. Such alternatives have not yet been widely adopted, and there will need to be a good understanding of their environmental impacts.

[12] The South African and British governments subsequently lifted their moratoria after considering the possible benefits of going ahead with exploration and production. France passed its ban in July 2011, and the present government confirmed in September 2012 that the ban would continue.

Potential water contamination

There has been considerable debate about the risk that water supplies (surface or subsurface) could be contaminated by fracking operations. This could occur through accidental spills or the discharge of untreated wastewater, the leakage into aquifers through the well casing, or leakage of fracking fluids from the deep hydrocarbon zones into shallower aquifers through the rock separating the two. Good practices in designing and operating water containment schemes, and ensuring that cement seals on the wells are correctly made and are inspected over time, can reduce the risks of the first two, while the third is unlikely because the producing zone is typically much deeper (1,000 meters or more) than the sources of drinking water (200–300 meters at most). Regulating and monitoring the treatment and discharge of wastewater plays an important role in reducing the risks of water contamination.

Venting and flaring of gas from the well operations

As with all gas production, there is the possibility that some gas will be either flared or vented, thus adding to global greenhouse gas emissions. Shale gas tends to emit more GHGs per unit than conventional gas, for two reasons (IEA 2011):

I. More wells and fracking are needed per cubic meter of gas produced. The energy associated with this leads to higher CO_2 emissions and lower production efficiency than conventional gas.

II. Venting and flaring happen during the well completion stage unless care has been taken to recover and market the gas during this phase. Because the completion phase accounts for a higher fraction of the total gas recovered, the leakages will tend to be higher than for conventional gas wells on a basis of each unit of gas recovered.

The possibility that larger quantities of methane could be emitted than in conventional gas operations is very serious for GHG emissions because of the short-term potency of methane as a contributor to global warming. Regulations to control gas flaring and venting by collecting the gas emitted at this stage are therefore even more important for shale gas than for conventional gas (Chesapeake Energy 2012).

Possible seismic effects caused by fracking

There have been a few instances where small earthquakes have been attributed to the presence of fracking in the vicinity. Rao (2012) mentions seismic events in three locations—the British county of Lancashire; Cleburne, Texas; and Greenbrier, Arkansas—where there was speculation that nearby fracking was the cause. Investigations concluded that the fracking itself was likely not the cause, but that deep disposal wells could be to blame. Detailed studies suggest that that the levels of induced seismic activity are low. Given that there are very many small earthquakes felt each year in the United States, the occurrence of one or two events near fracking operations of up to 3.0 on the Richter scale is not thought to indicate strong evidence that fracking has led to increased seismic activity (Rao 2012). However, it is generally agreed that before fracking begins, surveys should be carried out in order to ensure that it is not taking place in an area where there are substantial geological fault lines. This could be mandated as part of the environmental regulations that apply to shale gas production.

Effect on GHG emissions of use of shale gas

One of the most striking aspects of the increased production of shale gas in the United States has been its displacement of coal as a fuel for power generation. Although this has been due to the superior economic performance of new combined-cycle gas stations, supplied with lower-cost gas, compared with that of old coal-fired power stations, an added bonus has been the reduction in CO_2 from combustion. However, a number of studies have argued that the full life cycle of emissions of shale gas, including venting and flaring during well development, as well as leakages along the production and transportation chain (pipelines etc.), produce total GHG emissions almost as high, or even higher, than those due to the use of coal in power stations. That said, more recent studies that have reevaluated such claims tend to take the view that shale gas confers a substantial benefit, reducing GHG emissions by almost half. The review by the IEA (2012) points to the need for ongoing research, and to two crucial factors in the comparison of the two fuels—the percentage of methane emissions in the total gas produced, and the global warming potential (GWP) of a unit mass of methane.[13] Again, better regulation of the production and transportation of the gas can help to reduce its potential to add to global warming.

Enabling factors of the US shale gas revolution and their transferability to other potential shale-gas-rich regions

The speed and magnitude of the growth in shale gas production in the United States raises the question of whether this experience could be duplicated elsewhere, or whether there were special factors that made it possible and whose absence elsewhere would lead to a more modest growth in production.

Knowledge of shale deposits and potential gas resources

The existence of shale formations and potentially substantial recoverable shale gas reserves was well known in the United States before the onset of fracking, thanks to extensive geological surveys and drilling for conventional gas, oil, and other resources. Indeed, it was the detailed knowledge of the likely scale of shale gas resources that encouraged the US government to subsidize research into drilling and recovery techniques that could become commercially viable. Companies could be fairly confident that shale gas was present at drilling sites, even though the quantities were uncertain. This made the risks of using the new technologies more manageable. While a number of other countries have sufficient data to encourage drilling for shale gas, many appear to be less fortunate. The ARI study could cover only 32 countries and did not include the Middle East and Russia, where adequate data may exist but the incentive to produce shale gas is small because conventional gas reserves are large and cheaper to exploit.

[13] Global-warming potential (GWP) is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. A GWP is calculated over a specific time interval, commonly 20 or 100 years.

Absence of extensive public geological information is a strongly limiting factor for individual countries. With so many opportunities globally to acquire gas reserves in areas where their presence appears likely, companies may be reluctant to undertake the much more elaborate survey and exploration work required when information on the location and physical/chemical characteristics of shale formations is lacking. The presence of conventional gas itself is not an indication of the presence of shale gas, so gas-producing countries that have been only partly geologically mapped may continue to be uninteresting to potential shale gas producers. Indeed, the IEA (2012), in considering the alternative of a low development path for unconventional gas because of resource uncertainty and absence of supporting policies, assumed that until 2035, shale gas would be produced only in the United States, Canada, China, India and Australia.

Subsidized research by government into techniques of drilling and recovery

Starting in 1976, the US federal government supported research into shale gas production through its own activities and support to industry. Tax credits to the equivalent of $3 a barrel of oil production or Btu equivalent for four years were provided for shale gas in the 1980 Energy Act. In 1991, the Department of Energy subsidized Mitchell Energy's first horizontal well, and in 1998 Mitchell Energy drew on all this experience and knowledge of new technologies to achieve the first commercially viable shale fracture (Breakthrough Institute 2011). Knowledge of these technologies and their subsequent improvements has become widespread, and government subsidies are no longer required.

These technologies are easily transferable, and it is not likely that shale gas exploration or development in other countries would require government financial assistance in order to provide an initial impetus if there are recoverable shale gas reserves. Indeed, the private sector has already applied for permission to explore or even develop in countries where it appears that there may be substantial shale gas reserves, and several governments have issued licenses to do so (Der Speigel 2013).

Role of small independent exploration and production companies

The early stages of the shale revolution were dominated by the activities of some small independent companies that were willing to take the risks associated with a new activity. These companies tended to be highly specialized in exploration and production and operated on a scale that allowed them to be highly mobile—even moving rigs to new geographical locations if exploration did not succeed. The experience of these early participants served to improve techniques of recovery, while regulators also learned from early experiences about some of the environmental risks associated with shale gas. As the perceived risks have declined, some larger companies have entered the US market, and experience gained there will be important for activities elsewhere.

Outside of the United States, large companies, including super-majors and national oil companies, are joining in the search for shale gas. For large-scale developments, these companies' access to substantial financial resources will be crucial. It is also unlikely that other countries will have the conditions to encourage a large number of small companies to explore for and produce shale gas, as happened in the United States.

Quality and quantity of resource and cost of production

In the United States, the greatest initial uncertainty associated with shale gas formations was the recoverability factor. As experience was accumulated, better estimates of recoverability could be made. The more extensive the geological information that was available, the better the estimates were likely to be; these estimates could effectively guide where drilling should take place.

The amount of gas that can be produced from a well and the associated volume of NGLs, if any, must be weighed against the cost of drilling, as well as other costs and revenues from sale of the gas. The estimated ultimate recovery (EUR) varies greatly from one well to another, and until experience is gained with a particular shale formation, it is difficult to predict. The presence or absence of NGLs (with their high sale value) is also an uncertain factor in the early experience of a shale gas formation.

The costs of drilling for shale gas are higher than for comparable onshore conventional gas wells because of the expense associated with the fracking. In the Middle East, for example, countries with adequate conventional reserves will have break-even prices for conventional gas well below those for any shale gas that may exist; hence, the presumption is that such countries will not exploit possible shale gas resources. In countries that are running out of reserves, conventional gas yet to be recovered is likely to be in less accessible regions and to have higher costs similar to those of shale gas. Costs of offshore conventional gas are comparable to that of onshore shale gas, while offshore shale gas remains prohibitively costly.

An established market for gas

A crucial factor in the development of US shale gas was the existence of markets for natural gas. There were established markets not only for power generation and home heating, but also for industrial use (for conversion to ethylene and hence to many chemicals and associated products) and transportation (compressed natural gas vehicles).

In any country, in order to make the production of shale gas worthwhile there must be a market for it, in which it can compete while covering risk-adjusted costs. One important source of demand can be the local market in both the power and industrial sectors. The advent of new lower-cost sources of gas can change the domestic market for fuels. Where that market is growing, the use of gas depends on its total costs (both capital and fuel) versus those of competing fuels. Where the market is not growing, gas must compete against other fuels whose capital costs have already been incurred. However, there can be other reasons why the local market might prefer gas even if it does not have an absolute cost advantage:

I. Energy security. Energy markets that are highly dependent on one or more sources of other fuels whose suppliers have monopoly power may wish to diversify, seeking to protect themselves against future price increases of these other fuels. European countries have shown considerable interest in diversifying the source of their natural gas supplies and Poland and Ukraine in particular are looking to encourage domestic shale gas production.

II. Climate change considerations. Where there are emissions from competing fuels such as coal, whether GHGs or those with more localized effects such as sulfur, regulations to reduce such emissions in effect raise the capital costs even on existing plants. This gives gas, with its lower GHG and negligible local emissions, an important advantage even against existing plants, and a stronger advantage against new plants. If shale gas can be produced without large-scale venting or flaring, it can make a contribution to reducing the growth of GHG emissions when substituting for other fossil fuels.

In some countries, the actual or potential domestic market for gas is very limited and would be unable to absorb the total amounts that might be found. Even the small amounts of gas a market might be able to absorb initially would require gas gathering, storage, and transportation facilities, and these have strong economies of scale such that per unit, the total cost of delivered gas is higher in small markets. Without the presence of another source of demand, the domestic market by itself may not provide a case for developing shale (or conventional) gas reserves.

Where gas producers have access to export markets, either by pipeline or in the form of LNG, the large potential volume of sales improves the economics of gas production. Pipelines or liquefaction plants have important economies of scale that help to make the gas internationally competitive. In such cases, the location of the gas reserves becomes crucial. Landlocked countries, or countries where the gas deposits are far from the coast, face high transportation costs of moving the gas to export terminals. This explains the interest in offshore exploration blocks and planned LNG terminals in African countries such as Cameroon, Equatorial Guinea, Tanzania, Nigeria, and Mozambique. The existence of an export market helps to reduce the unit cost of the gas, so that a domestic market, even if small, can be supplied at cost-recovery prices.

For countries that are far from actual or potential export terminals and that have only a small domestic market, the incentives to explore for and produce shale gas would be weak, just as they would be for conventional gas. Unfavorable geography can be a major roadblock to the development of shale gas, at least until the domestic market becomes sufficiently large to obviate the need for an export market.

Pipeline and storage infrastructure

The United States already had in place an extensive pipeline infrastructure to move the gas to users. Gas-transport pipelines are very expensive to build, so the fact that only the relatively short links from shale-gas-gathering points to the pipeline network needed to be constructed was important in allowing smaller companies to go ahead with their development programs. Very large quantities of shale gas were thus not necessary to make its delivery to market cost-effective, and third-party access to pipelines and storage made it possible to utilize the existing delivery mechanisms.
Similar to the US experience, countries that already have a gas pipeline network and storage facilities

have lower development barriers to accommodate extra supplies from shale gas discoveries. Although some infrastructure will be needed to connect the new production to the network, the incremental cost of this will generally be small compared to the cost of having to establish an entire new network. If the latter were necessary, it is likely that government would have to take on the initial costs of the gas infrastructure, since it is unlikely that the private sector would do so before abundant gas is discovered, and they would be unlikely to look for such gas without a guaranteed pipeline system. Where the pipelines are owned either by a government or by another company, the right to access the pipeline and storage and the existence of fair tariffs to do so are essential. Third-party access regulations will need to be established and to be clear and transparent, and the presence of an independent regulator will be important.

The discovery of shale gas in remote areas reduces its chance of exploitation because of the increased transportation cost, while discoveries near demand centers increase the likelihood that it can be produced at a cost that would compete with other fuels. One important way in which the costs and risks of gas transportation might be mitigated is to build a gas-fired power station near the well sites, then use high-voltage power lines to transmit the electricity to the grid.

The existence of a spot market for gas sales

Shale gas production tends to be less predictable than production from a conventional well. The very high decline rates characteristic of production make it difficult for a producer to guarantee to supply a certain amount over time, as might be specified in a long-term contract. Therefore, a gas spot market is advantageous. Producers can sell excess production and purchase deficits in order to deliver an agreed amount to a purchaser. The United States has well-developed spot and futures markets, which can facilitate commercial arrangements for companies that may have only a small portfolio of producing wells.

Few other countries have spot markets for gas, and such markets cannot be expected to emerge in most countries that find shale gas. Alternative methods of sale will be required, and contracts will have to be tailored to the more variable production profile of shale gas wells. There will be considerable interest in watching the development of shale gas markets in the first group of countries that join the United States as producers.

Favorable mineral extraction rights

In the United States, individuals or companies, not the government, own the mineral rights below the surface of the land, so it is possible to purchase such rights from an existing owner. This made it very simple to start exploration once it was generally realized that commercialization of shale gas was possible. Where governments own the resource, it is likely that the procedure to start drilling will take longer, reflecting public concerns for a transparent and competitive bidding process and environmental safeguards. Because the US regulatory authorities for oil and gas were well-established, it was not thought necessary to hold up shale gas exploration until new regulatory codes were drawn up. Nevertheless, subsequent experience and concerns over environmental effects have led to calls for tighter regulation of the sector.

Adequate supplies of water and a means of safe wastewater disposal

Shale gas is quite distinct from conventional gas or oil production in that it requires large quantities of water for fracking, and the fraction of this water that is returned to the surface will contain fracking chemicals and minerals leached from the rocks.

Without a local source of water, the costs of trucking in the several hundred loads of water required for fracking a single well can be prohibitive. Where there is local water available (surface or subsurface), it usually has a value and, even if not paid for by the drilling companies, will be reflected in public and economic evaluation of the drilling. Where local water is scarce, either seasonally or year-round, the economic costs may exceed the benefits and considerable hostility to fracking can be expected from the local population.

The process of treating wastewater from the well, so that it is safe for irrigation or other uses, is improving but adds costs to production. Poorly regulated operations can result in wastewater that not only is unusable in itself, but can pollute other sources of clean water.

The most attractive sites are those where there is adequate water supply and where the regulations for treating wastewater are clear and reasonable. These could include requirements to recycle at least a certain percentage of the water for fracking in other wells and build containment areas, as well as specifications of how clean the water must be before it can be released for another purpose, such as irrigation.

Reasonable fiscal terms

The fiscal terms that apply to the production and sale of natural gas are crucial in incentivizing the private sector for shale gas exploration and production. First, companies need to believe that the fiscal terms will remain stable. Dealing with governments that have a reputation for altering fiscal terms in their favor at later dates may be viewed as a high-risk proposition that may not be worthwhile if the expected margin on the gas is too small. Second, fiscal terms need to be reasonable, but not overly generous. With private-sector hydrocarbons companies looking for exploration acreage and facing increased competition from state-owned enterprises, the new market for gas is likely to prove attractive for the foreseeable future.

Where shale gas is discovered in a country that has little experience with gas contracts, designing the initial concession and purchasing contracts is important and requires specialist help in order to avoid being too generous to the private sector.

Clear and comprehensive regulatory system

All gas projects require regulations that cover exploration, development, production, and marketing. There is considerable international experience with such regulations, much of which is summarized in the EITAF (2012) sourcebook. Without clear and comprehensive regulations, potential entrants into the sector cannot be certain of what limitations they may later face. Lack of regulation is in itself a source of risk.

For shale gas, the special nature of fracking raises a number of important issues not normally met with in conventional gas production, and the US experience suggests that there is an important need for regulation of certain aspects of drilling and production activities. The IEA (2012) suggests a number of "golden rules" for addressing the environmental effects of shale gas production, and indicates how these might be implemented through purpose-designed regulation. These rules are grouped around the following categories of action:

I. Measuring and disclosing relevant variables that affect local communities, and engaging with them in planning to ameliorate the impact
II. Choosing the drilling site to minimize local effects and to avoid fracturing where there is a risk of triggering seismic events
III. Isolating wells from other strata, in particular aquifers
IV. Reducing water usage and treating, storing, and disposing safely of wastewater
V. Eliminating venting and minimizing flaring

Governments that do not have wide experience with environmental legislation, monitoring, and enforcement will need to develop such capacity, because the lack of such rules and capacity adds to uncertainty about future conditions and reduces the attractiveness of investment for potential producers.

As mentioned, once gas has been produced, it has to be transported, either to export terminals, or to domestic market offtakers. Given that the existing pipelines will be owned either by the government or by another company, the right to access pipelines and storage and the existence of fair tariffs to do so are essential. This requires clear, transparent third-party access regulations.

Low perceived impact on local communities

The considerable antagonism shown by some groups toward shale gas exploration is reflected in certain governments taking a very cautious stance on whether to allow fracking to take place. The implementation of moratoria on prospecting and producing shale gas, while the government seeks to be better informed on the total costs and benefits, is likely to have been accompanied by pressure from potentially affected communities to forbid it altogether. Where such movements are strong, and there has been no attempt to open a dialogue to understand their concerns and to indicate how they could be addressed, the hostile climate will make potential investors more cautious in proceeding. In countries where the potential negative effects on communities and livelihoods seem to be smaller, there will be greater willingness to go ahead.

PART II: SHALE GAS AND AFRICA

The recent conventional gas discoveries in East Africa, occurring at the same time as the US shale gas revolution and possible discoveries elsewhere, prompted a number of questions for gas producers and non-producers in Africa. Part II of this report discusses these.

1. What are the estimates for the amount of shale gas in Africa and the rest of the world, and what portion is recoverable?

Global estimates

The estimates for gas-in-place and technically recoverable shale gas reserves provided by EIA (2011b) specify the countries for which estimates were made. For Africa, these include Algeria, Libya, Tunisia, Morocco, Mauritania, and South Africa, as well as the territory of Western Sahara. The specific reasons for not making estimates for each of the other countries was not given, but lack of published data was a determining factor. Egypt was omitted because it is considered part of the Middle East, for which estimates were not made on the grounds that countries in the region have sufficient conventional gas and would not need or wish to develop shale gas, with its typically higher cost of production. This may not be the case for Egypt; it is likely that were shale gas to be discovered on its territory, Egypt would wish to develop it.

Table 3 presents the estimates made by ARI for gas-in-place and technically recoverable shale gas reserves for these countries. Each of these is based on detailed information about the shale formations and their geological properties, using field engineering formulae. For comparison, the proven conventional gas reserves and production for each of these countries are included.

Table 3: ARI estimates of technically recoverable shale gas reserves, proven conventional gas reserves, and current production of gas in trillion cubic feet

Country	Shale gas-in-place[1]	Technically recoverable shale gas reserves[1]	Proven conventional 2012[2] gas reserves	Production of conventional 2010[2] gas in
Algeria	812	230	158	2.957
Libya	1147	290	52	0.586
Tunisia	61	18	2.26	0.071
Morocco	68	11	0.035	0.004
Mauritania	2	0.4	0.989	0.000
Western Sahara	37	7	-	-
South Africa	1834	485	0.000	0.035
Total Africa	3962	1042	504	7.313

Sources: 1 = EIA (2011b). 2 = Oil and Gas Journal, cited by Ernst and Young (2012).

The comparison of technically recoverable shale gas and proven conventional gas reserves in Africa indicates just how important the former will be. The data in Table 3 indicates that at the continent level, if shale gas reserves were to be confirmed by exploration they would be double the current proven reserves of conventional gas. For the largest conventional gas producer, Algeria, shale gas reserves if proven would be 50% larger than the conventional reserves. The shale gas reserves in Libya and South Africa would also be larger than the conventional gas reserves for any of the continent's major producers. As firmer data becomes available on the offshore conventional gas reserves in Mozambique and Tanzania, the total proven conventional gas reserves for Africa will be revised upward, but it is likely that the shale gas volumes as estimated will continue to be a very large portion of the total reserves picture.

It is important to note that other countries in Africa, for which ARI did not have access to published detailed geological data, might have shale gas reserves—thus increasing the total for the continent. However, it is also important to reiterate that shale gas is found in different geological formations from conventional gas, so that established conventional producers cannot be assumed to have shale reserves commensurate with their conventional reserves.

Both ARI and IEA provided data for the shale gas reserves of the rest of the world (selected countries only for ARI), which are summarized in Table 4. These suggest that, on the basis of countries included in both studies, Africa contains about 15% of the shale gas reserves that are likely to be of interest for commercial exploitation. This contrasts with the continent's 7% share of global conventional gas reserves as estimated by BP (2012). These figures serve to emphasize that shale gas is likely to prove of major importance for African countries that have the resources.

Table 4: Technically recoverable shale gas reserves (tcf)

	ARI	IEA
Africa	1042	1060
Rest of the World	5538	6291

Sources: EIA (2011b), and IEA (2012).

The country-by-country situation

The ARI data was estimated in a consistent fashion and is valuable for comparative purposes. However, the study was published in April 2011, and some developments may have occurred since then. Comments on individual countries drawn from the EIA (2011b) report are combined with material from Internet searches for more recent information. The latter may not be established on the same scientific basis as the ARI data, but can give intimations of recent trends.

Algeria

The ARI study estimated gas-in-place at 812 tcf and technically recoverable reserves at 230 tcf, the latter located in the Ghadamas Basin (195 tcf) and the Tindouf Basin (35 tcf) in southwestern Algeria. A newswire report by Jens Alic of Oilprice (11 November 2012) reported 321 tcf of recoverable shale gas, while Agence France-Presse (11 November 2012) quoted Algerian officials as saying that reserves were as large as 500 tcf.

A number of companies, including ENI, Shell, and Talisman, have already signed exploration agreements, and ENI has started exploration. The Algerian national oil company, Sonatrach, drilled its first shale wells in 2011. The government has also announced a new taxation package that would encourage exploration and development of unconventional gas and oil, but parliament has not yet approved it. Bauerova and Patel reported in Bloomberg (26 November 2012) that Algeria would be unlikely to produce commercial shale gas before 2020.

Algeria is a likely place for shale gas production to develop. First, although the country is currently a major gas exporter, local demand is growing to the extent that conventional gas exports are likely to decrease. Because Algeria is heavily dependent on gas for export revenue (90% of which comes from hydrocarbons), extra gas reserves would enable exports to keep fueling the country's development.

Second, Algeria is a longtime major gas producer and has both the infrastructure and technical expertise to manage a substantial expansion in the scale of the sector. It has a regional natural gas pipeline, as well as international export pipelines and an LNG terminal, demonstrating the established nature of its domestic and export markets. Algeria, with its lengthy history of gas production and export, is likely to be regarded as an attractive environment by potential investors, and this is reflected in the interest major companies are already showing in its shale gas reserves. However, the attack on the gas plant at In Amenas is likely to make companies more cautious in the immediate future.

The one unfamiliar aspect of the development of shale gas will be the various environmental risks associated with its production. The need for large quantities of water for fracking, in areas where water supplies are scarce, is likely to be a major concern. Regulations to ensure that waste water is correctly treated and that spills are avoided will be needed. In this area Algeria will need to learn from changing practices in the United States, which have been driven by environmental groups and public concern. As regards the flaring and venting of gas, although this is a particular issue at the early stages of shale well development, Sonatrach has for several years been a member of the Global Gas Flaring Reduction (GGFR) partnership and is already actively involved in reducing such emissions.

Libya

The ARI study estimated that for Libya the gas-in-place is 1,147 tcf, while the recoverable reserves are 290 tcf. The latter is more than five times larger than the country's proven conventional reserves. Of the gas-in-place, 57 tcf are in the Ghadames basin and 1,090 tcf in the Sirt basin. The prospective shale gas formations in the Sirt basin lie in deep subsided troughs and so are very lightly explored.

The long-term prospects for shale gas production in Libya seem to be highly promising based on such large reserves. The country has familiarity with the sector, is already producing gas, and has a pipeline structure. About two thirds of its gas production is exported, mainly by pipeline to Europe. However, the country's recent political instability has reduced its attractiveness for investment in the short term. Gas production dropped dramatically in 2011, but has now reached 80% of its full capacity level of 106 bcf per day. The government has recently announced that it is now making gas production a priority and is talking to partners about shale gas, but there are no reports of shale drilling yet. Two factors are likely to lead to a slow approach to the development of shale gas. First, the lack of exploration in the Sirt basin, where most of the reserves are thought to lie, will lead to a cautious approach until more evidence is accumulated. Second, the past and present political climate will make potential investors reluctant to make major investments until the situation has stabilized.

If Libya were to see a major increase in gas production from its shale reserves, it is likely that two issues might drive the government to seek outside assistance. First, the increased use of gas revenues for domestic development could present problems for an economy that has previously been run on dirigiste lines. Experience from the domestic economic strategies being developed in other new gas producers might also be applicable to the case of Libya. The second issue would be fracking: water supply and water recycling and treatment are both likely to be important in the Libyan context, and the government would certainly have little relevant experience with the problems, solutions, and monitoring required.

Tunisia

The ARI study estimates the shale gas-in-place at 61 tcf, and the technically recoverable reserves at 18 tcf. These are substantially smaller amounts than in Libya or Algeria, but nevertheless are a substantial increase over the small proven conventional gas reserves of less than 3 tcf. The projected reserves are in the Ghadames basin, and a first shale gas well was drilled with fracturing in 2010.

Tunisia produces a small amount of gas but consumes somewhat more, necessitating imports. Further domestic supplies would be a valuable addition to the economy. Pipelines link to the international network and to domestic demand centers. Traditionally, Tunisia has attracted many international exploration and production companies, thanks to a favorable regime of investment incentives. In mid-2012 Shell submitted to the government a request for an exploration permit for shale gas, which is still under consideration.

In many ways Tunisia seems a very attractive country for the development of shale gas. It has a large need for extra gas reserves, it has some experience with the sector (both export and domestic markets), and it has some of the needed infrastructure. The government has some experience with dealing with gas, although not on the scale that might occur if the shale gas reserves were fully utilized.

The environmental issues potentially arising from fracking have already generated a lively debate in Tunisia. Articles published on 7 November 2012 by online media Tunivisions and Tunisia Live raised concerns over the possible local pollution of water supplies, as well as the problem of water scarcity. Shell replied to this, emphasizing that it "adheres to a set of global onshore operating principles that provide a framework for water, air, wildlife, and respecting the communities in which it works." (Tunisia Live, 23 November 2012). The next day, Tunisia Live reported that the International Public Services Union was coordinating a national campaign opposing the extraction of shale gas (Tunisia Live, 24 November 2012). The online comments on these articles illustrate the public's worries. Many said they felt unable to trust an international company whose primary goal is profit; others condemned fracking itself as inevitably harmful, especially in a country where water is in short supply. Others stressed the sector's potential for generating employment, and several commented on the need for an informed public debate.

Morocco

Morocco has a complex and discontinuous distribution of shale deposits that requires substantial data gathering for an accurate resource assessment. ARI based its estimates on two basins that appeared to have the highest potential for shale gas. The Tindouf basin (extending into Algeria, Western Sahara, and Mauritania) and the Tadla basin were estimated to have 68 tcf gas-in-place, providing total recoverable reserves of 11 tcf.

Morocco produces a very small amount of gas (0.004 bcf in 2010) and has proven conventional reserves of 0.035 bcf. As such, it does not have the advantages of existing large gas producers in dealing with new potential supplies. The Moroccan national oil and gas company, ONHYM, has been studying shale gas potential since 2010, and US-based San Leon Energy has drilled a number of exploration wells.

The lack of gas experience coupled with Morocco's complex geology make it likely that progress with shale gas will be slow. However, the projected reserves are such that, if confirmed, they could make an important long-run contribution to the economy. Morocco would probably need support in all areas of gas production, including the environmental aspects.

Mauritania

Mauritania does not yet produce or consume gas, although the Banda field is expected to come into production by 2015. ARI estimated that there is 2 tcf of shale gas-in-place, of which 0.4 tcf could be technically recoverable. Given that proven reserves of conventional gas are estimated at 1 tcf, it is not likely that there will be any urgency to explore for or develop the limited amount of shale gas that may exist.

Western Sahara

The area known as Western Sahara was estimated to contain 37 tcf gas-in-place, of which 7 tcf would be recoverable. At present, there is no prospect of this being actively developed.

South Africa

The ARI study estimated that total shale gas-in-place amounts to 1,834 tcf, and recoverable reserves are 485 tcf. This places South Africa among the most important sources of shale gas in the world, with recoverable reserves almost as large as the total of proven conventional gas reserves for the whole of Africa. The resources are located within the Karoo basin, a huge area stretching over much of the country.

South Africa consumed about 180 bcf of gas in 2011, of which one-quarter was domestically produced and the rest imported by pipeline from Mozambique for use in a gas-to-liquids (GTL) plant. The dominant source of energy is coal, of which the country has very large reserves. Coal accounted for more than 90% of electricity generation in 2009, and is a major feedstock for the synthetic coal-to-liquids program.

Although the overall electrification rate is 75%, almost half of rural households are still not connected to the grid, and as the economy continues to grow, rolling blackouts are imposed at times. Despite pressure from environmental groups, coal use is expected to increase. However, the possibility of large domestic gas supplies adds a new factor to the country's energy equation.

A number of companies—Shell, Falcon, Challenger, Sasol/Chesapeake/Statoil, Sunset, Anglo Coal, and Anglo-American—have already applied for technical cooperation permits (TCPs). The government imposed a moratorium on exploration drilling in 2011 in order to study issues raised by fracking, but this was lifted in September 2012 to permit exploration, but not actual fracking.

Gas infrastructure and domestic production are limited, but South Africa, although not a major hydrocarbon producer, has some experience in this sector and would be capable of ramping up the level of technical expertise required to manage the creation of a domestic gas industry. The government will face two issues. The first is the scale of infrastructure that might be required to gather the gas and transport it to demand centers. This would certainly require close cooperation with the state power utility, ESKOM, whose current expansion plan is looking at further large coal stations and even additional nuclear plants (Financial Times, 24 September 2012). The second issue is the environmental impact of fracking. Already, environmental groups such as the Treasure the Karoo Action Group and the Karoo Shale Gas Community Forum are raising questions about

the advisability of allowing fracking in an area where water is in short supply and where there would be competition for its use (Good Governance Africa 2012). The prospect of increased employment (creating an estimated 350,000 to 850,000 direct and indirect jobs), and the likelihood that the government can apply strict regulatory standards to future fracking, may lead to public acceptance as more information is disseminated.

Egypt

Egypt was not included in the ARI study, so there are no comparable data available. However, the government has indicated that it is interested in encouraging the search for shale gas. US-based Apache announced in 2011 that it would drill some test wells in its search to identify whether shale gas was present in commercial quantities. Egypt is a major gas producer, but domestic demand has been increasing so rapidly that it recently had to import gas from Algeria in order to fulfill its export obligations. Any shale gas could be a welcome addition to reserves.

The country's recent political uncertainty may have discouraged potential investors who otherwise might have been tempted to explore for gas in a country where there is already infrastructure and experience in dealing with the gas industry. In Egypt, as in other countries in the region, water shortages would be a concern, and the government as yet does not have experience with the management or regulation of fracking.

2. What have been the effects of shale gas production on energy markets in general?

To date the principal effects of increased shale gas production have been felt within the United States, because only there has actual commercial-scale production occurred. The effects can be looked at:

I. From within the domestic gas industry, which has faced a very large increase in supply within a very short period;
II. From the standpoint of the international gas industry, which has been affected by a reduction in US net imports of gas; and
III. From the standpoint of other energy industries within the United States that compete with natural gas for various uses.

The domestic gas sector

The domestic gas industry exhibited classic responses to a rapid increase in supply. Prices were driven down sharply as a large stimulus was required in the short run to persuade energy users to switch to gas. New producers responded to earlier prices and continued to see profitable opportunities even as prices stated to decline. This resulted in an oversupply situation in which prices were driven below cost, and investment started to pull back sharply by 2011. As competing sectors adjust to the reality of larger gas supplies and lower long-term gas prices, more substitution can be expected and increased volumes of shale gas will be absorbed without the price of gas being driven below costs. The future of US gas prices depends on the long-term productivity of shale gas development. The EIA (2012d) took as a reference case for its forecasts to 2035 a scenario

in which spot gas prices rose slightly from the $4.39 per MBTU in 2010 to 2020, followed by a stronger rise to 2035. However, if resources proved larger than the base case, the EIA simulated a scenario in which spot gas prices hardly rose at all in real terms.

These relatively lower prices affect demand in two ways. First, existing users of gas may consume more of it at lower prices (ie, households run their central heating at a higher temperature). Second, users of other fuels start to switch to gas because it is now cheaper (ie, power stations using coal are shut down and utilities build gas-fired stations or operate existing stations for more hours). Both effects become larger over time—long-run elasticities are greater than short-run.

The increased domestic supply of gas was not entirely absorbed by an equivalent increase in domestic demand brought about by lower prices. Instead, imports of gas started to fall, thus lessening the amount of inter-fuel substitution required. The EIA foresees a continued drop in gas imports, with the United States even becoming a net exporter after 2020. Were a high production scenario to emerge, the country would become a net exporter earlier, and larger volumes would appear on the world market at equivalent dates. These scenarios raise the possibility of the United States starting to export LNG to Europe and other markets, increasing competition among international suppliers and placing downward pressure on international gas prices.

The international gas industry

The decrease in gas exports to the United States has had important effects on the global gas market. In the short run, the extra supply available from countries exporting less to the United States has been available to meet increased demand, notably from Japan. Given that at present most gas in the Asian markets is sold on long-term contracts, the average price paid for LNG did not fall substantially. However, for certain countries selling into the Atlantic basin, the loss of the US market may be difficult to offset except at much reduced prices. For example, exports of LNG from Nigeria to the United States peaked in 2007 at 95 bcf, but had fallen to only 2 bcf in 2011.

The IEA in 2012 analyzed the longer-term pricing effects of increased output of US and other producers of unconventional gas. The analysis argues that, although the use of long-term contracts indexed to international oil prices will become less prevalent, even by 2035 there will not be full gas-to-gas competition, in which gas prices in various regions differ only by transportation costs. The IEA's assumed prices for a basic reference case and for a low unconventional gas production case are shown in Table 5. The additional unconventional gas production is expected to have substantial effects in reducing global gas prices. In turn, this will have large effects on encouraging the switch towards gas use and away from competing fuels. The difference in gas supply between the IEA's two scenarios is due to the slow development of unconventional gas in the low-gas case.

This difference, caused by various constraints, amounts to 535 bcm in 2035, out of a total of 5.1 tcm in the base case, corresponding to a low gas production scenario of 4.6 tcm. It is important to note that even in the base case, where a considerable volume of unconventional gas comes onto the market, real gas prices are expected to rise substantially by 2020, and even more by 2035. Prices are lower than in the low-gas case, but they are still higher than in 2010.

Table 5: Natural gas price scenarios (2010 US$ per MBtu)

		Base case		Low unconventional gas case	
	2010	2020	2035	2020	2035
US	4.40	5.40	7.10	6.70	10.00
Europe	7.50	10.50	10.80	11.60	13.10
Japan	11.00	12.40	12.60	14.30	15.20

Source: IEA (2012). Wholesale supplies in US, and import prices in Europe and Japan.

A handful of countries account for most of the world's recoverable shale gas reserves, as shown in Table 6 based on the estimates made by ARI. The IEA base case used the ARI figures to estimate the extra shale gas coming on to the market. Hence, its base-case scenario has shale gas production heavily concentrated in the Americas and Asia. Because of the fragmentation of international gas markets, these two areas are likely to feel the strongest effects of the increased supplies.

Table 6: Top seven technically recoverable shale gas reserves (tcf)

Country	Recoverable reserves	Country	Recoverable reserves
China	1,275	South Africa	485
US	820	Australia	396
Argentina	774	Canada	388
Mexico	681	Global total	6,586

Source: EIA 2011b.

Competing energy industries

In the United States, gas is used by a number of sectors, as shown in Table 7. Gas is used for power generation, residential and commercial heating, industrial processes, and various other end-uses, including a small amount for compressed natural gas (CNG) vehicles. The largest single use is in the power sector, and it is here that the use of gas is expected to increase most rapidly, partly at the expense of coal.

Gas has been seen primarily as a peaking fuel—able to follow the load curve thanks to the ability of gas-fired power stations to ramp generation up and down quickly—while coal has been seen as the dominant baseload fuel thanks to its low cost. The capital cost advantage of gas-fired combined-cycle power stations was not sufficient to overcome the fuel price advantage of coal. The shale gas revolution has changed this balance—gas can now also be used as a baseload fuel. Coal-fired generation also requires expensive pollution control equipment, which has given firms the incentive to close older coal stations and replace them with modern gas-fired stations. Rao (2012) argued that in the United States, the cost of gas-fired generation breaks even with a new coal facility at a gas price of $8/MMBtu, assuming that the costs of production for a new coal plant meeting emissions standards would be between 6 and 6.5 cents per kWh. Coal with carbon capture would be considerably more expensive. Since gas prices are likely to remain well below this level, and because of the ease of increasing shale gas production when prices rise above costs, the inference is that gas-fired generation will increase its market share in the United States and in other countries where there is similar pressure to reduce coal-fired emissions.

Table 7: US natural gas consumption by sector, current and forecast (tcf)

Sector	2010	2020	2035
Electric power	7.4	7.9	9.0
Residential	4.9	4.8	4.6
Commercial	3.2	3.4	3.6
Industrial	6.6	7.1	7.0
Other	2.0	2.3	2.4
Total	24.1	25.5	26.6

Source: EIA 2012d.

The EIA (2012e) carried out a study of the impact of a change in relative fuel prices in the United States. This estimated that a 10% rise in the price of coal relative to delivered natural gas would lead on average to a 1.4% increase in the use of gas relative to coal. The rapid changes in the prices of coal and natural gas between 2008 and 2009 provides one scenario for illustrating the interpretation of this elasticity estimate. Over the course of that two-year period, the average price of coal delivered to electric generators increased from $2.07/MMBtu to $2.21/MMBtu, while the average price of delivered natural gas declined from $9.01/MMBtu to $4.74/MMBtu. With this change in relative prices of 103%, the estimated elasticity of substitution predicted that the change in the ratio of generators' consumption of natural gas to consumption of coal (as measured on a Btu basis) would be expected to be about 14%, while in fact it was 16%. These results are directly relevant only to the United States, because they are determined by the exact structure of the generation industry (the proportion of generators of different ages and efficiencies). However, they do suggest that in countries where the power sector relies on old and inefficient coal-fired stations, there could be room for substantial inter-fuel substitution.

A recent article in the Economist (2013) pointed out that, with the domestic fall in demand for coal in the United States, exports of coal to Europe have been rising, with coal prices more competitive

than gas imported to that region. As a result, coal consumption has been rising at a time when governments had been assuming that it would decline. It is not clear how long this trend will persist, but for the present it is having an adverse impact on Europe's GHG emissions. Markets for residential and commercial use of gas are much smaller in the majority of developing countries, but industrial sectors also may have potential for fuel substitution.

The competition between oil and gas is relatively weak. Oil is predominantly linked to transportation fuels, for which gas at present is little-used. In the United States, about one-tenth of 1% of natural gas consumed is used as a vehicle fuel. However, fleet users such as buses, trash trucks, and delivery services see great advantages in natural-gas-powered vehicles. The fall in prices means that natural gas currently costs between $1.50 and $2 less per gallon equivalent than gasoline or diesel. The predictable routes of such vehicles also make it possible to provide an efficient refueling infrastructure and to benefit from the lower fuel costs. For the car market, it is more difficult to provide a refueling system that is as easily accessible as that for gasoline; for that reason, the use of natural gas in cars is likely to increase very slowly.

In some countries, diesel and fuel oil are used for power generation, and were gas to become locally available these might be squeezed out of the market by cheaper gas-fired combined-cycle power stations. However, this effect would be small in global terms and, because the price of oil is largely determined on a single international market, there would be little effect on international oil prices or the cost of imported petroleum products.

3. What effects does the discovery of large volumes of shale gas mean for investment in low-carbon energy technologies?

The introduction of larger supplies of gas and the consequent fall in prices interact in a complex way with the demand for renewables. Solar and wind, when used for the power grid, are intermittent forms of generation, so far largely lacking storage capabilities. Since their generation pattern does not necessarily follow the load pattern, it is necessary to complement them with plants that can rapidly cycle up and down. Combined-cycle gas plants can fill this role, meeting the gap between baseload generation and demand that cannot be met by renewables at a given time. Hence, the availability of more domestic natural gas may make it easier to introduce renewable energy sources into the grid.

However, the fall in gas prices has been steep and is expected to remain so. This may mean that in some countries, as in the United States, gas would become the fuel of choice for baseload as well as for peaking. Its combined capital plus fuel cost is superior to that of wind or solar. However, certain US states have renewable portfolio standards (RPSs), which require utilities to buy and sell certain quantities of renewable energy. Gas is not included in an RPS, so even its availability at lower prices does not threaten the part of the market covered by the RPS (Head 2011).

Two factors are likely to support the continued steady growth of renewables in the on-grid market. First, the actual costs of renewable technology are falling as manufacturing volumes continue to increase. The Economist (2012) called attention to the so-called Swanson's law, in which the costs of photovoltaic cells tend to fall by 20% for each doubling of global manufacturing capacity.

Costs per watt of capacity have fallen to about 75 US cents, and although construction costs add another $4 per watt, these too are falling. The fuel itself is free. By contrast, US coal-fired plants cost about $3 per watt and natural gas plants about $1 a watt, but fuel costs must be added to that. In sunny parts of the United States, where gas plants are kept on standby for peak generation, solar can compete without subsidy. The drive for cost reduction through improved technology is likely support to the renewables industry, but the exact dynamics are uncertain.

The second factor that could continue to encourage the use of renewables is the attitude taken by governments. Where officials continue to be concerned with global warming and push utilities to include a certain amount of renewable generation, the prospects for solar and wind continue to be promising. However, where a country is able to substitute gas for coal, the government may see this as a sufficient contribution to slowing down the rate of increase of GHG emissions and hence reduce its support (financial or otherwise) for renewables. As pointed out by the IEA (2012), cheaper gas prices will reduce the cost of electricity generation, and this may make it more palatable to users to pay for some expensive renewable generation if is mandated by the government. On balance, the IEA assumed that existing policies to support renewables would remain in place and that globally their increased market shares of primary energy demand in 2020 (2%) and 2035 (4%), relative to a 1% share in 2010, would be unaffected by the increased volumes of unconventional gas. At present, the consensus appears to be that where a country has increased access to natural gas or is facing lower import prices, renewables use is likely to slow down unless the government intervenes to promote it. For countries that do not have access to gas supplies, the position of renewables will remain unchanged.

4. What are the implications of increased shale gas production for energy development in Africa?

The increased global production of shale gas will affect countries in Africa differently, according to whether they are already gas producers and consumers, whether they export or import, and/or whether they are potential shale gas producers. Data on reserves, consumption and production for 26 countries are shown in Annex 1. For the other countries in Africa, there is no data on any of the variables, indicating that gas is of negligible importance. Fifteen countries produce and/or consume natural gas and, as indicated above, five or six of those may also have commercially viable shale gas deposits. Countries that do not produce or consume natural gas will feel only secondary effects via the effect on global prices of other sources of energy.

The economics of producing shale gas

For countries that have shale gas reserves, confirmed by exploration, it does not follow automatically that it will be economic to develop these reserves. The larger the reserve, and the nearer it is to the markets for the gas, the lower will be the unit cost of production. Where there is existing gas infrastructure that can be utilized, costs will be lower still. The price at which the gas could be sold will depend on whether it is solely for export (international traded prices) or for domestic consumption (prices of competing forms of energy). Where economic costs are below potential market prices, there will be a case for the development of the gas. If there are external costs

(environmental damage, water scarcity etc.) that are not internalized in the cost of production of the shale gas, then these will have to be weighed against the pure financial benefits of production before a decision is made to proceed.

Countries that have developed a gas sector have benefited from export revenues; lower domestic fuel costs and hence increased access to power; and employment created within the gas sector, the power sector, and other sectors that supply these industries. In addition, where gas is used as a feedstock for industrial processes, there is potential for wider economic development and job creation.

Conventional gas producers that neither import nor export

According to the data quoted by Ernst and Young (2012), Angola, the Republic of Congo, Gabon, Cote d'Ivoire, and Tanzania produced gas solely for domestic consumption in 2010. Because these supplies are not in competition with the international market, prices can remain independent of external events, including the increased availability of shale gas via the LNG trade. Only if import facilities were constructed could the falling international prices start to put downward pressure on domestic gas prices, as well as to bring benefits to those sectors using gas, such as the power sector. Other imported sources of energy, mainly oil products, are not in direct competition with natural gas and are unlikely to see a reduction in import costs. None of the countries in this group was indicated to be a potential source of shale gas, but this could change if successful exploration takes place. Such exploration is more likely to happen sooner in countries where studies, such as that by ARI, have identified large potential recoverable reserves. A further possibility is that the falling international gas prices and increased availability of gas might persuade some countries to invest in import facilities and begin to import gas rather than other fuels. Competition with these other fuels would be an important factor. For countries that have access to the sea, the possibility of an LNG terminal, or for others a pipeline from a neighboring producer, would be required to open the way for gas to be used in the domestic market, possibly to complement domestic sources.

Tanzania is about to become a gas exporter and should be considered together with other exporting countries.

Conventional gas producers that are net importers

Four African countries (Ghana, Morocco, South Africa, and Tunisia) were net importers of gas in 2010, and the latter three have all been identified as having recoverable shale gas reserves. Countries that are net importers of gas will find that the impact of increased global shale gas production will lower the cost of their import bills below where it would otherwise have been. The degree of this price effect will depend on the regional market from which they are purchasing

imported gas. For example, Tunisia is supplied by Algeria, and South Africa by Mozambique, both by pipeline. In these cases, there is little effective competition from other suppliers and the gas exporters may be able to extract a monopsony rent from their supplies, resulting in only a small price reduction. The onset of domestic shale gas production would change this picture completely. The domestic supplies, if and when they arrived, would tend to reduce the demand for imports, and at the same time their production costs could be competitive with import costs, allowing for transport. The ability of suppliers to extract rent would be reduced, and import prices could fall along with quantities. This aspect makes it more likely that the three latter governments will pursue the development of their possible shale gas reserves. However, it would take several years to bring them to the commercial market even if they can be identified, so in the next few years there may be only minor benefits from lower import prices.

Conventional gas producers that are net exporters

Six countries were net gas exporters in 2010 (Algeria, Egypt, Equatorial Guinea, Libya, Mozambique, and Nigeria), and this group is likely to be joined by Tanzania in the near future. Algeria, Libya, and possibly Egypt have also been identified as potential shale gas producers. For net exporters, the increased competition from the increased shale and other unconventional gas supplies means that they will face downward pressure on prices. The degree of downward pressure will depend on the competition in the market to which they are selling. For example, the IEA estimated that prices into Europe in 2020 would be about $1/MMBtu lower under the baseline unconventional gas expansion case compared to the low expansion case, whereas prices into Japan would be about $2/MMBtu lower. Nigeria has already seen its exports of LNG to the United States almost dry up by 2011, while Algeria, exporting to Europe, will face competition from other suppliers now being shut out of the US market. Equatorial Guinea, which exports mainly to Asia, will face the large decrease in prices expected to be seen in these markets. Countries such as Mozambique and Tanzania, whose net exports will increase as production increases, will see a fraction of their expected gains reduced by the lower prices brought about by competition for the Asian market. However, estimates made by Wood Mackenzie (Ernst and Young 2012) suggest that for the East African producers, the breakeven price would be around $7/MMBtu, while Australia, a major competitor of LNG in the Asian market, may have a breakeven price of around $10/MMBtu. This indicates that even with the increased volume of shale gas that may reach this market, the East African producers will remain competitive.

Countries that become shale gas producers

The maturing of shale gas recovery technology may result in some countries in Africa producing gas that had not been expected to do so. For countries such as Algeria and Libya, which already export substantial volumes of conventional gas, the attraction of shale gas would be to replace declining domestic production. Only if the shale gas volumes were very small would the fall in prices for conventional exports more than offset the benefits from increased domestic production. Since the estimated reserves are very substantial relative to conventional reserves, it is likely that the shale gas revolution could produce a major benefit for such countries.

The development of large shale gas reserves by countries that hitherto had little or no domestic

gas production (such as Tunisia, Morocco or South Africa) will bring about a number of problems associated with the discovery and exploitation of any form of hydrocarbons.

I. The management of a natural resource industry, including licensing and fiscal terms
II. The management of revenues from the rents received through the fiscal terms
III. The development of the economy once a dominant sector emerges
IV. The use of the resource for export or to support domestic production in other sectors
V. The distribution of the created wealth in an equitable fashion
VI. The management of public expectations and aspirations following the announcement of large recoverable reserves

Added to these will be the environmental problems associated with shale gas production and fracking. A particular issue that could arise in Africa is the development of shale gas resources by neighboring countries. Where the resources are sufficient only for domestic consumption, the impact of a neighboring gas discoveries and production is likely to be small. However, if there is sufficient gas for export, but in limited quantities, there could be competition for capital and for the technical know-how required to establish a gas export business. Countries with very large reserves are likely to be the most attractive for establishing LNG terminals or export pipelines, and smaller producers may find they have to wait until the larger neighboring projects are developed.

5. What are the local environmental risks of shale gas with reference to Africa?

As explained in Section 3 of Part I of this report, there are three areas of concern with respect to local environmental pollution caused by exploration and development of shale gas wells. The first two—water supply and the risk of contamination—are of major importance, while the third, seismic risk, is of less concern, even though it is frequently mentioned in public debate.

The supply of water for fracking

Fracking works by using large quantities of water to fracture the rock in which the shale gas is trapped. As the IEA (2012) pointed out, the use of water per unit of energy produced is orders of magnitude higher than for conventional gas. Each well requires a large initial supply of water while the fracturing is carried out, and the short life of an individual well means that many wells are required to obtain a steady supply of shale gas. Even with improving efficiency due to recycling of wastewater, large quantities of water will be required for any substantial shale gas production program. All the countries in Africa that have been identified as having technically recoverable shale gas reserves would likely face potential water shortages and intense competition for water use in agriculture and household consumption. For this reason alone, it is of the utmost importance that governments carry out full environmental surveys, including the sources of water and the effects of their utilization, before giving permission for shale gas development. Even where water is trucked into the drilling areas, the number of truckloads required for a single fracture will be large and have noticeable local impact.

There are methods of reducing water demand, either by improved recycling of water recovered from other wells or addition of other chemicals to the fracking fluid, but the latter brings its own problems.

Water recycling can be partly managed by regulation and contract so that drilling companies must economize on water use from the beginning. The treatment of the "flowback" wastewater from a previous fracture, in order to use it for subsequent fracking, requires it to have the same properties as the initial fluid with its mixture of purpose designed chemicals. This may be costly to achieve and can reduce the attractiveness of drilling for shale gas.

Water contamination

Water contamination caused by fracking can happen in a number of different ways, and much attention has been paid to these possibilities. They include:

I. **Accidental spills of fluids, including chemicals used for fracking, and flowback fluid.** This probability of such a spill that reaches the conventional water supply can be reduced by following strict guidelines for the containment of all fracking fluids, training of staff, and ensuring that control equipment is available. All of these activities can be effectively controlled by government regulation and inspection.

II. **Leakage of fracturing fluids into a shallow aquifer through the cement column around** the well casing. This possibility can be mitigated by following best practice in well design and construction, especially ensuring that cement seals are properly made. The quality of the initial seal and its durability over time can be checked, and this too can be controlled through regulation.

III. **Leakage of fluids or hydrocarbons from the producing zone to shallow aquifers through the intervening rock.** This possibility is generally unlikely, since shale layers are often found at depths of 1,000–3,000 meters, while underground sources of drinking water are a few hundred meters at most. Also, the intervening rock tends to be highly impermeable. Restrictions on drilling depths can reduce this risk, and ensuring a full understanding of the local geology can identify cases where the rocks seals are not perfect.

IV. **Discharge of contaminated wastewater into groundwater or underground aquifers.** This possibility is potentially the most serious, but also can be easily regulated. Governments must set standards for the treatment and permissible discharge of wastewater, and ensure that there is a monitoring system that enforces compliance.

Inducing seismic events

The evidence that fracking causes noticeable seismic events is based on a few instances where modest shocks have been felt in the vicinity of drilling operations, as well on the recognition that the fracturing of rocks is in effect a very small seismic event. Where a fracture intersects with a fault in the rock, a larger event may be caused. Similar issues occur with geothermal and deep mining projects. Because shale gas drilling requires fracking for every well, the geology of the proposed drilling area must be carefully surveyed for the existence of deep faults. Careful monitoring for increased seismic activity is also a necessary precaution so that operations can be suspended if there appears to be an increase.

These environmental risks are not peculiar to Africa; they are likely to be a concern wherever fracking is carried out. Regulations and official monitoring of compliance and performance can avoid unnecessary environmental damage. Countries in Africa tend to have limited experience with environmental regulation and enforcement, yet in the case of shale gas this needs to be in place before any development drilling can take place, because the worst risk of environmental damage is when the initial fracking takes place. The US experience suggests that early practices were more damaging, as less care was taken with the very stages of drilling, and local communities and pressure groups were unaware of the potential damage that could occur. Lessons can be learned from the decade of US experience, and a series of good practices and associated regulations and monitoring can be articulated, as suggested by the IEA (2012).

6. What is potential impact on climate change objectives of greater use of shale gas?

The impact of the greater use of shale gas on GHG emissions depends largely on which, if any, fuels it is replacing. As pointed out above, the lowering of the price of a fuel has two effects. First, more of the fuel is used, thus adding to the total amount of GHGs emitted. However, at the same time, the lower price caused by extra supplies of shale gas will lead to some fuel substitution. Depending on which fuel is substituted, there may be a reduction in the amount of GHGs emitted. The main inter-fuel substitution in the United States was the replacement of coal-fired generation from older and less efficient plants by modern gas-fired combined-cycle plants. Such substitution may have almost halved the emissions of GHGs associated with the production of a given amount of electricity.

Two major factors help determine the extent to which there is a net reduction in GHG emissions from this type of fuel substitution. First is the age and efficiency of the coal (or other) plants that are retired or mothballed. The United States is notable for having many old and inefficient coal plants. BSA (2012) reported that only 12% of plants located in “coal country” (20 Northeast and Midwest states) were less than 30 years old. Natural gas emits less CO_2 when burned to achieve a given thermal heat output, giving an advantage on the order of 40% (Hone 2011). When combustion efficiencies differ between old coal-fired stations (around 30%) and new gas-fired stations (around 55%), this provides an overall reduction of more than 50% in GHG emissions. This factor is influenced by the choice of fuel to be substituted.

The second factor, over which there is also some control, is the extent to which gas being recovered from a well is flared or vented. In particular, venting, which releases methane into the atmosphere, is seen to be especially damaging from a climate-change perspective. There is some uncertainty about the total emissions of methane from the life cycle of a shale gas well, and also about the exact contribution of methane to global warming. Methane stays in the atmosphere for a much shorter time than carbon dioxide (with a half-life of about 15 years, as opposed to 150 years) and it can be argued that the relevant comparison for current emissions is a time period of closer to 20 years than 100 years, as was used by the Fourth Assessment Report of the Intergovernmental

Panel on Climate Change. On this basis, the global warming potential (GWP) of methane would be 72, rather than 25, and this higher figure, combined with a high percentage of methane emissions as a percentage of total gas production, moves gas towards being as serious for GHG emissions as coal. The IEA (2012) shows that at a GWP of 72 and high methane emissions amounting to more than a 3% share of total gas production, gas breaks even with coal. At the normally accepted GWP of 25 and a methane share between 2 and 3%, gas has only 60% of the impact of coal. These figures indicate the importance of controlling venting and flaring of gas from any well. The best practice would be to recover and market gas produced during the completion phase of a well, and restrictions on venting and flaring can be utilized to reduce the GHG emissions. This also serves to emphasize that the GHG net emissions will be location-specific, depending both on the strictness of controls over gas flaring and venting, the combustion efficiency, and the emissions characteristics of fuels that are replaced by gas.

These factors, considered in the global context, will help to determine the future path of GHG emissions. In the base case considered by the IEA (2012), the combination of fuel substitution, particularly to coal, and the total increase in energy use due to the relative fall in prices of natural gas means that overall there will be only a small net reduction in the trend of GHG emissions, compared to earlier forecasts that ignored the growth in unconventional gas. The upshot of this is that the shale gas revolution, once the initial euphoria about it has been tempered by more extensive analysis of the type carried out by the IEA, is not likely to change concerns about global warming or to reduce pressure to take action.

At a country level, the effect will depend heavily on the nature and size of fuel substitution. The United States and China, both heavily dependent on coal-fired generation, are likely to see the trend of emissions growth slow down, whereas countries that replace imported gas with domestically produced gas may see a slight growth in energy use and emissions due to lower gas prices. Within Africa, the possible advent of shale gas production used for export (such as might be the case for Algeria, Libya, and Egypt) would not add substantially to those countries' GHG emissions, provided that venting and flaring are constrained. To the extent that the extra gas supplies permit faster domestic growth, energy demand would rise and emissions would follow. Tunisia might tend to replace imported gas with cheaper domestic production, leading to small increases in growth, energy use, and emissions.

Morocco may face a more difficult situation. It has been following an ambitious program of increasing the share of power generation obtained from wind, solar, and hydro in order to reduce its dependence on expensive imported oil. The possibility of shale gas as an alternative source of production—cheaper than either oil or renewables—could slow the adoption of these renewable technologies. However, any shale gas production is likely to take several years to start and then to build up slowly. There is no immediate threat to the renewables program, and in the longer run it could be well complemented by the load-following characteristics of combined-cycle gas plants fueled by domestic production.

South Africa is the country on the continent where the domestic production of shale gas could make the largest difference to GHG emissions. Coal accounts for more than 90% of fuel for power generation, with a small amount coming from nuclear and the rest from hydro and other renewables. At the same time, South Africa is looking to increase its power generation and has considered building more coal-fired power stations as well as nuclear plants. The availability of very large quantities of domestic gas could change this picture dramatically. The gas could even be competitive with modern coal-fired stations, without making allowance for the emissions differences between the two types of plants. The government has also expressed an ambition to make electricity generation "greener," and gas could help support this goal.

7. What role should the African Development Bank play with respect to shale gas, and what does this mean for its energy/strategy/policy with regards to future investment in the Africa energy industry?

The presence of shale gas has the potential to revolutionize the energy sector in several countries in Africa. This will present new opportunities for the AfDB to work with these countries to maximize the benefits of successful development of the shale gas resources. These countries can be divided into four groups for the purposes of considering AfDB strategy.

Existing large gas producers that may have shale gas prospects

The first group of countries that would be affected by development of domestic shale gas are the current substantial conventional gas producers: Algeria, Libya, and Egypt. Were shale gas to be found in large commercially recoverable quantities in any of these countries, it would make a considerable difference to their development strategies. All three presently see exports of gas slowing down as reserves decline and domestic demand increases. Large additional supplies of gas would reverse this trend and lead to increased exports as well as boosting economic growth. The increased international gas competition would reduce revenue somewhat, but volume gains should offset gas prices that rise less rapidly than would otherwise have been the case. All of these countries have considerable domestic gas infrastructure that would make further development relatively simple, and have considerable experience with managing a gas industry.

The need for further advice on how to expand and develop the sector would be limited in the case of Algeria and Egypt, but in the case of Libya the recent regime change may present an opportunity for technical advice on management aspects of the sector. As the country regains political stability, it will be possible to discuss training needs with authorities. A broad approach, similar to that taken with Mozambique and Tanzania to support their newly developing sectors, can assess needs and potential support from other multilateral and bilateral development agencies. This could lead to a lending program similar to that being developed elsewhere, with emphasis on technical assistance and capacity building. The slow path to stability in Libya suggests that this scenario is not likely to happen soon, although even without shale gas discoveries there may be need for support in certain areas.

All three countries lack experience with the environmental issues that would be raised by fracking. A first step for any government has to be to inform itself on the possible dangers and likely impact of fracking, good practices that could minimize such effects, the type of regulations that can be imposed in order to compel such practices, and monitoring to ensure that regulations are obeyed. The need for improved information will be shared by all countries in Africa that develop shale gas, and this presents a unique opportunity for the AfDB to offer guidance and assistance that could lead to a lending program. A detailed review of these environmental issues, their probabilities, and possible solutions could be prepared for a regional workshop to which officials of these countries could be invited. A manual of good fracking practices, based on US experience, could provide a balanced view of the dangers and the steps needed to mitigate possible damages. This review could also serve as the basis for a public information campaign to help win acceptance for a fracking program. Once a government is willing to go ahead with exploration for and possible development of shale gas, it would also need to develop crucial environmental regulations and monitoring tools. This could require technical assistance in training of staff; drafting the appropriate environmental regulations, including environmental provisions in contracts and licenses; and working with geophysical and other specialists to avoid fracking in areas susceptible to environment damage. An integrated work program would be needed before substantial development of shale gas can take place.

Countries that produce little or no gas but have shale gas prospects

A second group of countries (Tunisia, Morocco, Mauritania, and South Africa) have been identified as having shale gas prospects. In South Africa, the reserves may be so large that the country could become a substantial gas producer, while in Tunisia and Morocco the identified reserves would dominate their current limited conventional reserves. These countries' lack of experience with developing and sustaining a large-scale gas sector would provide a new challenge, especially in the case of South Africa, where the whole economy could feel the impact of a major energy discovery. Just as with more established gas producers, the potential environmental effects are already under public discussion, and the governments need to rapidly equip themselves to hold a public debate, then to establish an action plan for regulations and staff training that would have to accompany any substantial development of shale gas.

These countries have twin needs—a technical assistance program of the traditional form aimed at sustainable development of the sector, and an environmental safeguards program similar to that suggested for existing large gas producers. The danger for such countries is if, in their need to develop a gas sector and support the economy, too much early emphasis is placed on development while environmental protection is delayed. This could run the risk of environmental "incidents," such as water shortages, water contamination, or large-scale venting, that are difficult to address once they have occurred and drawn the attention of the public and the government. A key role for the AfDB could be to enter into the debate at an early stage in order to persuade a government to simultaneously prepare for the development of a gas sector—and to ensure that development does not lead to substantial environmental damage.

An important issue arises in the case of Morocco, where a plan to substantially increase the share of renewables in power generation is underway. The advent of domestic shale gas could have a

large impact on this plan. The government would need to understand the extent to which shale gas would tend to undercut renewables because of its low costs and load-following characteristics, and the extent to which gas as a baseload fuel could support greater use of renewables. Assistance with the development of an expansion plan, allowing for the presence of gas, could become a high priority if shale gas is discovered in commercial quantities.

In all these countries, the development of large amounts of domestic gas production would also require the government to create a business plan for the use of the gas. Choices among export, power generation, and other domestic industrial uses have to be considered, and governments might welcome technical assistance in creating a gas master plan and linked industrial strategy.

Gas producers without shale gas prospects

The third group of countries consists of those that are already producing conventional gas but have not yet been identified as likely sources for shale gas. The principal way in which the shale gas revolution might affect them is through the international market for traded gas. Already some international prices are reflecting the increased US production of shale gas, and it can be anticipated that this trend will continue. The production of shale gas in other countries is much less certain, particularly as regards timing, but it appears likely that international prices will tend to be lower than they would have without shale gas. This will reduce the revenue anticipated from new gas finds, but estimates suggest that this effect will be modest, especially in the near future. Gas-producing countries such as Mozambique and Tanzania, which are anticipating increasing their production in the next few years, will need to do market analysis in order to ensure that their gas development strategies are robust to such price changes. Such countries may require assistance to better understand the future development of the various gas markets into which they sell.

Countries that do not produce or consume gas and have no shale gas prospects at present

A final group of countries, mainly concentrated in the interior of the continent, neither produce nor consume natural gas and have not been identified as having prospective shale gas reserves. These countries will be largely unaffected by the shale gas revolution, seeing only marginal changes in the prices of those fuels they import and of investment flows to the energy using sectors. One area of considerable interest to such countries is to improve their knowledge of their own geology and the potential for the presence of shale or conventional gas reserves. It is likely that interest will center on those countries with the best prospects, as indicated by the ARI study. Only where there is local information already available to the government or to exploration companies would there be immediate prospects for encouraging further efforts to improve the database and from there to possibly lead to exploration and development.

The AfDB and environmental safeguards

This report has noted at several points that the environmental risks from fracking require governments to develop regulations to minimize potential damage. It has also suggested that the AfDB could play an active role in supporting governments' drafting and implementation of such regulations.

There is also an issue of whether the AfDB's own safeguards for lending and technical assistance projects adequately address all the risks peculiar to shale gas and fracking. For example, could the Bank support a fracking project where no geological survey has been carried out to ensure

that the proposed well does not intersect a major seismic fault? It may be that such a safeguard should be insisted on before assistance is provided for shale gas exploration or development of shale gas. Clearly, the Bank would need to ensure that its own project safeguards take these risks into account.

Possible first steps for the AfDB

The potential discovery of shale gas reserves in a number of African countries presents an important challenge for the AfDB. On the one hand, such reserves may be substantial, or indeed very substantial, in some countries. Were they to be confirmed and developed, they would have the potential to bring major benefits to the countries' economies. On the other hand, the development and production of shale gas presents major environmental challenges to an economy, and these could in some circumstances prove so overwhelming that it would be better for the government to ban the production of shale gas in high-risk areas. The decision on whether to go ahead should be made on an informed basis rather than giving way to excessive optimism or pessimism.

Governments and civil society are only just learning of the possible presence of shale gas reserves and the problems that may be attendant on production, and there may be confusion and uncertainty about the benefits and costs. The AfDB could act as an "honest broker" by working to ensure that governments with possible shale gas reserves are better informed and have access to the best information on possible environmental dangers, their possible remedies, and the type of legislation and regulations that would be needed to minimize the risks.

The AfDB could proceed with a two-step approach. The first step would be to organize one or more regional workshops for the countries where possible shale gas reserves have been identified. The workshops would bring together a group of experts on shale gas production and on the prevention and regulation of associated environmental damage.The experts would be selected in order to provide a balanced take, rather than pro-industry or anti-industry views. Government officials would be invited to attend and also to submit in advance issues that they would find it helpful to discuss. A substantial amount of the workshop could be devoted to question and answer sessions in order to maximize knowledge transfer. The AfDB would also indicate its willingness to work with governments in determining whether they would go ahead with shale gas production and, if they decided to go ahead, how the Bank could support them.

The second step would depend on the governments' reactions. Those that wished to go ahead might require technical assistance for staff training in the specifics of shale gas production and the associated environmental regulations. Beyond this, they might require assistance in drafting regulations and establishing monitoring procedures. For certain governments with no experience in producing conventional gas (or oil), there would be a series of new technical issues related to the management of the sector. In all these cases, the AfDB could build on its recent experience with a number of hydrocarbon-producing countries and offer a technical assistance loan. In some cases there might even be a role for financing infrastructure associated with the gas development.
A separate area for assistance could be for governments that have geological information not available to ARI. In some circumstances this data might be sufficient for expert consultants, financed through a technical assistance loan, to provide the same sort of estimates for the country

in question as ARI was able to do for others. The value of such an exercise would be in the public release of the results, which could prompt the private sector to start exploring in areas the analysis finds to be promising for the presence of substantial quantities of shale gas. [2]

Annex 1: Proven reserves, consumption and production of natural gas by country (bcm)

Country	Proven reserves as 1 January, 2012	Consumption in 2010	Production in 2010	Trade status
Algeria	4,452	28.5	83.7	NE
Angola	307	0.7	0.7	NT
Benin	1	0.0	0.0	NDP
Cameroon	134	-	-	-
(Congo (Brazzaville	90	0.9	0.9	NT
(Congo (Zaire	1	0.0	0.0	NDP
Egypt	2,162	45.6	60.6	NE
Equatorial Guinea	36	1.6	6.7	NE
Ethiopia	25	0.0	0.0	NDP
Gabon	28	0.1	0.1	NT
Ghana	22	0.1	0.0	NI
Ivory Coast	28	1.6	1.6	NT
Libya	1,478	6.8	16.6	NE
Mauritania	28	0.0	0.0	NDP
Morocco	1	0.6	0.1	NI
Mozambique	126	0.1	3.1	NE
Namibia	62	0.0	0.0	NDP
Nigeria	5,053	4.9	28.7	NE
Rwanda	56	0.0	0.0	NDP
Senegal	0	-	-	-
Somalia	6	0.0	0.0	NDP
South Africa	0	4.0	1.0	NI
Sudan	84	0.0	0.0	NDP
Tanzania	6	0.8	0.8	NT
Tunisia	64	3.2	2.0	NI
Uganda	14	0.0	0.0	NDP
Total Africa	14264	100	207	NE

Source: Ernst and Young (2012). Reserves taken from Oil and Gas Journal, consumption and production data from US Department of Energy.
Notes: NI = net importer, NE = net exporter, NT = no trade but domestic gas use; NDP = no consumption or production of gas. - = no data.

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