Shale Oil and Gas: Lifeline for Pakistan

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Draft Report
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In this report, the Energy Unit of the Sustainable Development Policy Institute looked at shale gas development in Pakistan. Shale gas exploration and production have the potential to transform Pakistan’s economy. Not only is shale gas abundant in Pakistan but also it is also cheap and environment-friendly. Therefore, shale gas definitely offers an opportunity that, if exploited effectively, can help to revolutionize the energy mix existing within the country. The effects of shale gas can be far-reaching, and it, therefore, needs to be given adequate importance at the highest Level. We recommend the convening of a special task force on shale oil and gas development.

Shale makes up more than half of earth’s sedimentary rock, but types and formations differ from shale to shale and even within the same shale. Given the complexities involving the exploration of shale gas, it is not surprising that there is no industry-standard definition for the process. Therefore, the complexities of shale oil and gas reservoirs offer significant challenges, which vary according to the geology of the region. In the case of Pakistan with a geographical area of 796,095 km², the sedimentary basin area is approximately 800100 km² (665500 sq. km Onshore and 134600sq.km Offshore), with Shale formations that have a potential of yielding shale oil and gas. Shale, the bedrock for hydrocarbons is distributed throughout the Upper, Middle, Lower Indus, Baluchistan and Offshore Basins as thick sequences. Most of these shale sequences are at a mature stage for hydrocarbon generation and may form good resource plays.

Energy Information Administration (EIA), a US agency working on energy statistics and analysis, has estimated recoverable shale gas reserves of 105 trillion cubic feet (TCF) and more than nine billion barrels of oil within Pakistan, but this information is contained in a broad-brush study lacking sufficient details on Pakistan’s shale gas play. Hence, there is an urgent need to carry out a detailed assessment of Upper, Middle, Lower Indus, Baluchistan and Offshore basins.

Key reservoir parameters for shale deposits include thermal maturity, reservoir thickness, total organic carbon (TOC) content, adsorbed gas fraction, free gas fraction within the pores and fractures, and transport properties. Data covering thermal maturity and reservoir thickness, mineralogy, faults and seismic fractures and stratigraphy of most areas is available. However, the customization of technology, the development of the right models to suit our needs, defining of geological conditions, setting of criteria for selection of shale gas reservoirs, acreages and size as well as the delineation of lease terms are major considerations in this context.
Before carrying out preliminary exploratory activities of any kind, the Planning Commission or the Ministry of Petroleum needs to compile available geological, petrophysical, geochemical, sedimentological, and geomechanical data as well as to quantify the Total Organic Carbon (TOC), Programmed Pyrolysis, Vitrinite Reflectance (VR), Maceral Analysis, Kerogen Description, Fluid Saturations, Porosity, Grain Density, Pressure Decay Permeability and Mineralogical Analysis etc., of established wells for conventional oil and gas. The concerned Commission or the Ministry can do this by consulting the Pakistan Basin Study conducted by OGDCL.

The Pakistan Basin Study consists of over 550 reports, five regional reports and over 10,000 area reports/research papers. The well data includes summary sheets, log data, petrophysical and geochemical data. The Study also includes 2D seismic data and selected lines from 3D data over 126000 line km. This data will help in assessing the sedimentary basin of Pakistan and in building models for further study on Shale Gas Plays. A geological model will help in the analysis of geological features and interpretation of area for shale oil and gas. The next stage will be to develop a petrophysical model through a detailed core and quantitative well log data analysis for prospective area. After this has been conducted, a geophysical (seismic) model will be developed for studying the Shale Gas reservoir properties. The previously available 3D seismic data and detailed fault delineation provide effective identification of sweet spots, improved drilling results and prospects of shale gas profitability. In addition, drilling hazards are also likely to be reduced. Similarly, the geomechanical model with inputs from logs will help in identifying local stresses for well/casing design, natural fracture density, orientation and distribution. Through data interpretation and analysis, the most promising shale gas areas may be identified before the pilot phase.

The Government of Pakistan (GOP) will have to consider these fundamental steps before Shale Gas production can be materialized. It is important that the background studies and analysis are conducted thoroughly to increase chances of productivity. This process should be driven by the national agenda and should form a top priority for the natural gas sector. Experiences of Poland and China show that geological and other challenges may lead to a slow start in production. However, if countries make concerted and dedicated efforts, the same obstacles may be transformed into opportunities.

The industry, government, NGOs, Media and public have to join hands to bring about a shale gas revolution, which will help to create jobs as well as to produce cheap electricity and fuel for industry. Above all, such a revolution will prevent the country from expending 15 Billion USD on petroleum products and fossil fuel imports from the Gulf. Pragmatically positioned, this report takes as its lead premise the need to take into account certain pressing considerations before shale oil and gas can be harnessed to bring about an economic revival.

Foreword by Executive Director, SDPI

The Energy Unit of Sustainable Development Policy Institute (SDPI) has dedicated its best efforts to the development of practical solutions to address the energy challenges of Pakistan. In the wake of a serious energy crisis in the country, the Energy Team is committed to providing strategic insights, policies and to offering solutions to help decision-makers chart a course towards a prosperous Pakistan. In this pursuit, SDPI is pleased to present its first report on shale gas and oil development at a time when leading global players have already recognized the vast potential of shale gas.

This report highlights the importance of developing shale oil and gas for Pakistan as a step towards reducing energy poverty in the country. It also dilates upon the possibility of gaining an economic edge that exploration of shale gas would entail for Pakistan in South Asia. This is followed by an investigation into the state of shale gas reserves of the country and the difficulties associated with the exploration process along with an environmental impact assessment. Moreover, the report discusses the generation of economic activity through shale gas exploration, and the possible benefits for thousands of Pakistanis who are in need of sources of sustainable livelihoods.

We are proud to present this comprehensive document in the hope that it steers the way towards shale gas development in Pakistan. The country now has an opportunity to exploit its shale resources in an effective and visionary way, which prospect may be realized through the implementation of the findings of this report.

Dr. Abid Qaiyum Suleri, Executive Director

Sustainable Development Policy Institute
Foreword by Engr. Jabbar, Board of Governors, SDPI

Natural gas is one of the principal sources of energy in our economy. The past decade has witnessed substantial changes in the policy use of natural gas. Out of the box, unproductive and inefficient usage of natural gas has nearly exhausted our quantified conventional natural reserves. Paradigm changes in the development of technology have created the potential to recover more natural gas from shale formations, which can be used to meet our growing demand for energy, and to sustain economic development.

When I was taken on the board of SDPI, my first priority was to strengthen the energy unit of SDPI. I am glad that Dr. Abid, Executive Director SDPI, has already chosen a competent team led by Engineer Arshad H Abbasi. I have worked in the heart of the Energy sector as representative of the private sector with interventions implemented as and when needed. This issue is of central importance to me, particularly that of natural gas. Years of experience in this sector have convinced me that for Pakistan to be energy secure, it must look harness its indigenous resources.

This report on shale oil and gas looks at global trends in the natural gas market, and makes some astute observations. Analyzing the 105 Tcf of shale oil and gas potential, and 9.1 bbl of shale oil, the report looks at the economic impact that developing this sector would entail. From the findings of this report, it can be concluded that Pakistan must soon start the exploration for sweet spots of shale oil and gas, and must work closely with the pioneers of this new technology.

As an alternative energy resource, shale oil and gas present a new outlook for Pakistan. We must look ahead to resources that will create energy security in Pakistan, namely sufficient energy supply at affordable tariffs aimed at creating better economic growth. It is necessary, however, to engage in debate over this new alternative fuel.

While the natural gas itself is the same, the methods of drilling, hydraulic fracturing will pose challenges. It is, therefore, necessary to seek technical assistance, and to draw a roadmap that assesses the future and the way forward. This report is essential because of the need for discourse and logical assessments as to the costs and benefits of shale oil and gas.

It is also important that there is adequate dialogue and deliberation on the issue in our country, and that we learn from the lessons of other countries in their quest for shale oil and gas. It is essential to act now, and to develop our natural gas industry, especially in the wake of acute shortages. Natural gas may be the lifeline of Pakistan’s energy sector, and it is, therefore, essential to look into shale oil and gas. This report looks into water consumption for shale, the population density of shale-rich areas, the geology of Pakistan as well as the economic impact of exploring unconventional gas resources in Pakistan. I hope that this study leads to the development of a new area of research on this topic of national and international interest.

Engr. M.A. Jabbar, Board of Governors

Sustainable Development Policy Institute
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<th>Description</th>
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<tbody>
<tr>
<td>ADB</td>
<td>Asian Development Bank</td>
</tr>
<tr>
<td>AEO</td>
<td>Annual Energy Outlook</td>
</tr>
<tr>
<td>ARI</td>
<td>Advanced Resources International, Inc.</td>
</tr>
<tr>
<td>BCF</td>
<td>Billion Cubic Feet</td>
</tr>
<tr>
<td>BTU</td>
<td>British Thermal Unit</td>
</tr>
<tr>
<td>CNG</td>
<td>Compressed Natural Gas</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>D and C</td>
<td>Drilling and Completion Costs</td>
</tr>
<tr>
<td>DOE</td>
<td>Department of Energy</td>
</tr>
<tr>
<td>EIA</td>
<td>Energy Information Administration</td>
</tr>
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<td>Environment Impact Assessment (UK)</td>
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<tr>
<td>FO</td>
<td>Furnace Oil</td>
</tr>
<tr>
<td>Ft</td>
<td>Feet</td>
</tr>
<tr>
<td>FY</td>
<td>Fiscal Year</td>
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<tr>
<td>G</td>
<td>Gram</td>
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<td>Description</td>
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<tr>
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</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GENCO</td>
<td>Generation Company</td>
</tr>
<tr>
<td>GOI</td>
<td>Government of India</td>
</tr>
<tr>
<td>GOP</td>
<td>Government of Pakistan</td>
</tr>
<tr>
<td>GSPA</td>
<td>Gas Sale and Purchase Agreement</td>
</tr>
<tr>
<td>GwH</td>
<td>Giga Watt Hertz</td>
</tr>
<tr>
<td>HDIP</td>
<td>Hydrocarbon Development Institute Pakistan</td>
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<td>IGA</td>
<td>Intergovernmental Agreement</td>
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<tr>
<td>JCC</td>
<td>Japanese Customs Cleared</td>
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<tr>
<td>Kg</td>
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<tr>
<td>LNG</td>
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<tr>
<td>MAF</td>
<td>Million Acre Feet</td>
</tr>
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<td>Millidarcy</td>
</tr>
<tr>
<td>Mg</td>
<td>Milligram</td>
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<tr>
<td>MIT</td>
<td>Massachusetts Institute of Technology (US)</td>
</tr>
<tr>
<td>MMBtu</td>
<td>Million Metric British Thermal Units</td>
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<td>MPNR</td>
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<tr>
<td>NBP</td>
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<td>PML-N</td>
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</tr>
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</tr>
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<td>Ppm</td>
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<td>R&amp;D</td>
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<td>Residual Furnace Oil</td>
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<td>R₀</td>
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<td>SNGPL</td>
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<td>SSGCL</td>
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<tr>
<td>TCF</td>
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<td>TSS</td>
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<td>UFG</td>
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<td>Water Exploitation Index</td>
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## Units Conversion Table

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<tr>
<th></th>
<th>Million Btu</th>
<th>Mcft Gas</th>
<th>Ton FO</th>
<th>Ton Crude Oil</th>
<th>Barrel Crude Oil</th>
<th>Ton Local Coal</th>
<th>Ton Imported Coal</th>
<th>MWh Primary Electricity</th>
<th>MWh Final Electricity</th>
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<td>1 million Btu</td>
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<td>0.024</td>
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<td>7.258</td>
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<td>1 MWh Final Elect.</td>
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## Gross Calorific Value

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<th>Giga Joule per MMCF</th>
<th>TOE/ MMCF</th>
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<tr>
<td>Sui Standard Natural Gas</td>
<td>980</td>
<td>1033.9</td>
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<td>Badin and Condensates Average¹</td>
<td>1.047</td>
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<td>Oil</td>
<td>Million Btu per ton</td>
<td>Giga Joule per ton</td>
<td>TOE/ton</td>
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<td>Indigenous Crude Oil</td>
<td>41.895</td>
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<tr>
<td>Imported Crude Oil</td>
<td>43.313</td>
<td>45.7</td>
<td>1.0338</td>
</tr>
<tr>
<td>Avgas</td>
<td>43.659</td>
<td>46.1</td>
<td>1.0421</td>
</tr>
<tr>
<td>Motor Spirit</td>
<td>44.761</td>
<td>47.2</td>
<td>1.0684</td>
</tr>
<tr>
<td>HOBC</td>
<td>44.541</td>
<td>47</td>
<td>1.0632</td>
</tr>
<tr>
<td>HSD</td>
<td>44.045</td>
<td>46.5</td>
<td>1.0513</td>
</tr>
<tr>
<td>LDO</td>
<td>43.648</td>
<td>46</td>
<td>1.0418</td>
</tr>
<tr>
<td>Furnace Oil</td>
<td>40.792</td>
<td>43</td>
<td>0.9737</td>
</tr>
<tr>
<td>Kerosene</td>
<td>43.218</td>
<td>45.6</td>
<td>1.0316</td>
</tr>
<tr>
<td>LPG</td>
<td>45.326</td>
<td>47.8</td>
<td>1.0819</td>
</tr>
<tr>
<td>Electricity</td>
<td>Million Btu per GWh</td>
<td>Giga Joule per Gwh</td>
<td>TOE/GWh</td>
</tr>
<tr>
<td>As Primary Energy Input for Hydro/Nuclear</td>
<td>10,000</td>
<td>10,550</td>
<td>238.69</td>
</tr>
<tr>
<td>As Final Energy</td>
<td>3,412</td>
<td>3,600</td>
<td>81.44</td>
</tr>
<tr>
<td>Coal</td>
<td>Million Btu per ton</td>
<td>Giga Joule per ton</td>
<td>TOE/ton</td>
</tr>
<tr>
<td>Indigenous</td>
<td>18.74</td>
<td>19.8</td>
<td>0.4474</td>
</tr>
<tr>
<td>Imported</td>
<td>27.56</td>
<td>29.1</td>
<td>0.6579</td>
</tr>
</tbody>
</table>

¹ For Btu values of all other field gases, please see Table 3.1.
Key Findings

The key findings of this report are:

- The development of unconventional gas is estimated to be sufficient to fulfill the natural gas demand for almost 45 years at the rate of eight billion cubic feet per year.
- Similarly, the unconventional oil will be enough for 61 years based on current annual consumption that is 125 million barrel per annum.
- Meeting the current 100% demand of gas and oil, the country would be able to save USD 15 billion thus making trade deficit equal to zero.
- Achieving self-sufficiency in oil gas demand will generate 7,50,000 jobs per annum.
- The largest impact of availability of gas will be on power sector as the electricity will be available at the average rate of Rs. 4 per unit ensuring consistency and reliability in terms of availability.
- The reserve of shale oil and gas located in least development areas, particularly in Baluchistan and Koh-E-Suleman ranges and exploring reserves in these areas will generate economic activity for these undeveloped areas.
- The shale oil and gas will also bring revolution on environmental front. The guar ke phalli, which is used as proppant has minimized the environmental impact of fracturing fluid used during hydraulic fracturing, and it is only cultivated in India and Pakistan thereby making it a useful crop to cultivate.
- The drought resistant guar bean is very helpful to controlling soil erosion in hilly, torrent prone areas such as DI Khan, DG Khan, Rajin Pur and Eastern and Southern Balochistan to mitigate flashfloods.
Commendations

Pakistan Engineering Council
(Constituted under Pakistan Engineering Council Act, 1976 enacted by the Parliament)

Ataturk Avenue (East),
C-2/2, Islamabad.

Unconventional Oil and Gas: The Life Line for Pakistan

Pakistan has been suffering from unprecedented energy crisis for more than a decade now. This has been devastating the economic growth and causing restlessness among the masses. The report entitled as "Unconventional Oil and Gas: The Life Line for Pakistan" is the timely and excellent effort done by SDPI. It has highlighted the alternate sources of hydrocarbon energy within Pakistan which has the potential to meet the growing energy demands of the country.

Pakistan Engineering Council (PEC) as a Think Tank on energy has been closely working with SDPI on energy issues and this report on unconventional energy resources is the constituent of Pakistan Energy Vision-2035 a joint effort of PEC and SDPI. As country currently facing the gas deficit of MBFD urgently needs to look into the alternate energy resources on sustainable lines. PEC has provided full technical support in assessing the potential and prospects of shale for Pakistan. The report has identified that shale exploration being more labor intensive as compared to conventional energy resources will be a source of economic activity for unskilled and semi-skilled labors.

We as an engineering institute intends to provide technical support in terms of skill development required for shale gas development and if necessary will also make relevant changes in engineering curriculum of universities and capacity building facilitation to ensure indigenous support.

(Dr Ashfaq Ahmed Sheikh)
Additional Registrar-CPDI/
Secretary Think Tank energy
Comments on “Shale Oil and Gas: The Lifeline for Economy of Pakistan”

It has been a privilege to read this essential report on Pakistan’s Shale Gas. Looking at Pakistan’s urgent demand for natural gas, and keeping in mind the acute gas shortage, it seems necessary for Pakistan to take clear policy measures to develop its Shale Gas. This report looks at the dynamics of Shale Gas, addressing the economic impact that Shale Gas exploration may have on Pakistan’s economy.

A point to be noted is that this report, which is detailed in its technical aspects, has looked at drilling, horizontal fracturing etc, and has also focused on a roadmap that evaluates Pakistan’s natural gas sector, the state of energy, and the way forward. It has also looked at other important aspects such as seismicity and water consumption that might result from exploring Shale Gas.

I congratulate the Sustainable Development Policy Institute for highlighting this important topic, and the predicted impact of Shale Gas. It should be noted that a pilot project on Shale Gas may have risks, but there needs to be a cost-benefit analysis as well as the identification of sweet spots for oil and gas in Pakistan at the earliest.

(Prof. Dr. Kausar Ali Syed)
Pakistan’s economy has been crippled seriously due to an unprecedented energy crisis and its associated grievances. This catastrophe can be traced back to the gas crisis, which is attributable to a lack of strategic approach in gas utilization and pricing mechanism. Therefore, the country needs to look into alternate resources for filling this swallowing energy shortfall presently creating havoc across the country. The report launched by SDPI titled as “Shale Oil and Gas: The LifeLine for Pakistan” is an excellent effort in view of the current crisis. The report has not only highlighted and demarcated the areas enriched with shale oil and gas but has also provided a detailed, comprehensive policy framework for unlocking this potential.

There is a definite need to augment the supply side of natural gas, and to develop shale gas resource of Pakistan is an essential and a major decision to rely on indigenous source rather than natural gas imports. My concern is more over the efficient utilization of natural gas. The natural gas crisis that we have been going through this winter, where despite closure of Industries and CNG stations, there has been shortage of gas for domestic use is not as much a supply problem as it is the effect of a badly leaking and under capacity natural gas distribution network. Adding more gas to this system is akin to adding more water to a leaking bucket.

While developing Shale Gas is the need of the hour the potential of which the SDPI report has spelled out with clarity, repairing the leaking gas distribution network and removing acute bottlenecks that are chronic and endemic have become imperative. I have written upon this subject many times and explained at many forums that the winter domestic demand compels the gas utility companies to jack up the distribution system pressures, which in turn increases many times over the leakage from the leaking lines. We are blowing away precious natural gas in the air especially in the winter thereby causing an otherwise avoidable crisis.

I wish to congratulate Arshad H Abbasi and his energy team for doing this time consuming job and diverting the attention towards Shale Gas, a vital energy resource.

Dr Faizullah Abbasi, Vice Chancellor, Dawood University of Engineering & Technology, Karachi
The report presented by Engr. Arshad Abbasi and his team at SDPI regarding shale oil and gas highlights the importance and relevance of environmental friendly Shale Gas in detail. It explains the resources and economic part for Pakistan in an effective way.

The technical data and supporting documents presented in this report, Shale Gas resources 586 Tcf (technical recoverable 105 Tcf) and shale oil resources 227 billion barrels (Technical recoverable 9.1billion barrel), make worth exploring this real game changer for Pakistan.

In this report, the SDPI team has skillfully addressed the shortcomings of the Shale Gas policy framework of the Government of Pakistan. The recommendations made by SDPI are worthy of notice and need to be considered seriously otherwise an unsuccessful scenario as experienced by other nations may develop in Pakistan.

In my personal capacity, I have found Engr. Arshad Abbasi’s report very focused and based on the real issues of Pakistan’s energy crises and very visionary.

I congratulate Engr. Arshad Abbasi and his team for presenting such a remarkable report, which highlights the need of the day for Pakistan.

Dr. Najeeb Ullah
Ph.D. (University of Cambridge UK)
Director

Pakistan has been facing worsening energy crisis for about a decade. It has now assumed gigantic proportions posing serious challenges to our national economy and security. Pakistan's energy economy is essentially based on natural gas as it contributes nearly 50% to our primary energy mix. Despite following a dynamic upstream petroleum policy for about 25 years, it has not been possible to find substantially greater reserves of conventional oil and gas to meet our growing needs. The gas demand is increasing about 8% every year, but the indigenous gas supply is now declining as the major fields are depleting naturally. There is a need to exploit all natural resources of hydrocarbons, hydroelectricity, coal, wind and, where economically feasible, solar, biofuels and biomass to meet the whopping energy shortfall.

Unconventional oil and gas now show a big potential as the developments in knowledge and technology have enabled economic extraction of oil and gas from tight reservoirs but more notably from shale. Shale oil and gas revolution in USA is turning the largest importer of oil and gas into a future exporter. Pakistan has sedimentary basins under 85% of its landmass with well-identified shale oil and gas resource plays.
Exploitation of shale plays will pose gigantic challenges of technological as well as financial nature, but there is a promise of energy autarky in the long run. In this respect, I compliment the timely focus of SDPI on our shale oil and gas potential through its Energy Wing led by Mr. Arshad Abbasi. They have painstakingly put together a useful report that provides valuable information about the resource and suggests a framework for its exploitation.

This report was briefly presented in the meeting of the Advisory Committee of the Planning and Development under the Chairmanship of the Federal Minister for Planning and Development. Recognizing the paramount importance of the subject to our economic and national security, it created a Task Force to provide a way forward. SDPI and especially Mr. Arshad Abbasi and his team will play a crucial role of providing a secretariat to the Task Force. I accepted the role of leading the Task Force in great national interest knowing well the seemingly insurmountable challenges that it will entail. With active support of the Government, the Task Force will turn every corner to realize the commercial production of shale oil and gas in a realistic timeframe. I am endorsing the effort put into development this Report and feel proud of being associated with its launching.

Dr. Gulfaraz Ahmed  
PhD Petroleum Engineering Stanford University  
Former Federal Secretary Petroleum & Natural Resources" 

Pakistan’s energy crisis is so severe that it cannot be tackled by merely relying upon traditional sources of energy. Thus, there arises the urgent need for exploring and developing alternative avenues of energy generation. Shale Gas and Oil is one such avenue that can revolutionize the energy sector in Pakistan. This debut report on the subject chalks out a workable plan of action for harnessing the country’s Shale resources without overlooking the social and ecological concerns in the process. It answers why Pakistan has a peculiar advantage in developing the Shale Gas and Oil capacity and how greatly the consequent generation of energy will contribute to economic progress of the nation. Arshad Abbasi’s critical scholarship on issues of energy and ecology has always fascinated me. This pioneering work by him deserves serious attention of the present government, which considers overcoming energy crisis as a topmost national priority.

Last, I would like to congratulate Dr. Abid Executive Director for transforming SDPI into a Genuine Energy Think-Thank 

Dr Ishtiaq Ahmad  
Quaid-i-Azam Fellow, St Antony’s College,  
University of Oxford
Pakistan has been suffering from a terrible energy crisis for more than a decade now. This has been slowing the pace of economic activity and has even caused public unrest with prolonged outages of both electricity and gas. This catastrophe seems to have occurred because of mismanagement of gas resources in Pakistan. The question of affordable and uninterrupted supply of electricity has arisen due to lack of gas availability and increased dependence on oil for electricity generation. Utilizing this high cost fuel for electricity generation has directly translated to high electricity tariffs, creating restlessness among the masses.

In this grave situation, the advent of shale revolution has changed the energy dynamics across the globe and serves as a ray of hope for countries with diminishing gas reserves. SDPI's report Shale Oil and Gas: The Lifeline for Pakistan” is a very good and timely effort contributed by Mr Arshad H Abbasi and his team to give comprehensive analysis and prospects of shale exploration for Pakistan.

Pakistan, suffering from unprecedented gas shortfall, needs to pursue this unconventional resource as an urgent national concern. The gas obtained from these unconventional reservoirs may be able to address the grievances of the masses in the form of optimized energy mix and uninterrupted supply of electricity. I once again congratulate SDPI for this timely effort and agree that moving towards alternate energy resources is the need of the hour for Pakistan.

**Tahir Basharat Cheema**
President, Institute of Electrical Engineering

The Sustainable Development Policy Institute’s report on” Shale Oil and Gas: The Life Line for Economy of Pakistan” comes at a time of a grave energy crisis gripping Pakistan. With the country facing a terrible gas shortage, it is necessary to look for alternative solutions. One panacea that emerges from this report on Shale Oil and Gas is the fact that Pakistan may have indigenous natural oil and gas reserves in our Shale plays.

This report explores the environmental and economic impact that Shale Gas development will have in Pakistan. It closely analyzes the “Shale Gas Revolution” in North America, and its impact on global natural gas sector. From that vantage point, it zooms into the Pakistani scenario, giving a clear roadmap and policy recommendations to develop this natural resource. What emerges from this is the fact that Pakistan will have to look into this emerging resource, simultaneously learning from global successes and failures, and adopting a strong policy towards energy security.

I would therefore like to congratulate Engr. Arshad H. Abbasi and his energy team for highlighting this issue of national importance. I hope that Pakistan may be able to exploit its
high potential of Shale natural oil and gas reserves thereby not only creating more jobs but also meeting our high energy demands.

Imtiaz Gilani  
Vice Chancellor  
University of Engineering and Technology, Peshawar  
Chairman, Higher Education Commission

I would like to congratulate Mr. Arshad H. Abbasi and his team for identifying and analyzing the shale oil and gas resources in Pakistan. This report has compiled most important information regarding the shale-enriched areas in Pakistan. The report also contains a comprehensive policy framework required to initiate the development process of shale oil and gas resources with the consideration of environmental hazards. I agree with the suggestion that Pakistan should learn from the experience of other countries in exploitation of shale oil and gas resources of the country.

The report has rightly pointed that exploration of these resources have become necessary in view of current endemic energy crisis. Moreover, the exploration of unconventional reservoirs being more labour intensive (unskilled & skilled) has the potential to adequately address the issue of unemployment in Pakistan. After successful Shale Gas reservoir deliverability test, a new venue of investment will be opened for the investor from inland and abroad. Hence, the report titled as “Shale Oil and Gas : The life line for Pakistan” is a good effort by SDPI, and the recommendations floated in this report are quite relevant to the subject.

Dr Saeed Jadoon,  
Executive Director, OGDCL Institute of Science & Technology Islamabad.

The report titled as Shale Oil and Gas : The Life Line for Economy of Pakistan” is an excellent effort contributed by SDPI in demarcating and highlighting the shale oil and gas potential in Pakistan. The report has rightly highlighted that these unleashed shale oil and gas resources may serve as hope to address the dearth of energy availability for masses, which is creating havoc across Pakistan. The report has also defined the comprehensive framework required to step forward in exploring these resources provided the technological assistance and support from US. Moreover, in order to increase the success factor in revealing these unconventional sources, a thorough and deep understanding of reservoir geochemistry is very pivotal for determining the time required for sweet spot identification. Once the sweet spot is identified, then the gas and oil locked within these unconventional reservoirs can be pumped up within short period of time.
I once again congratulate SDPI warmly for putting in such tremendous effort and diverting the attention toward these resources, the exploration of which seems to be a panacea for the current, endemic energy crisis.

Dr Shazia Asim  
Department of Earth Sciences  
Quaid-e- Azam University

Pakistan is amongst the countries facing severe energy shortage. The statistics reveals that there is a wide gap between petroleum and natural gas demand and local production. To fill this gap, the only option is to import from other countries by spending huge amounts of foreign exchange. It is the need of the hour to tap out and utilize indigenous natural resources. This will ensure self-reliance on one hand and save foreign exchange on the other.

The petroleum and gas demand of the country can be met either by speeding up exploration and exploitation activities using conventional methods or by developing unconventional / innovative techniques as mentioned in the proposal to recover oil and gas from shale formations. Before proceeding toward large-scale activities for oil and gas extraction from shale, I humbly suggest conducting a pilot scale study by selecting shale formation of a particular area and adopting hydraulic fracturing and directional drilling. The cost and profit from the pilot project should be assessed and evaluated before initiating the next the project. If it proves feasible, then the proposed activity should be executed at full scale even by engaging relevant foreign companies. However, Oil and Gas Development Corporation Ltd. (OGDCL), Pakistan may be taken in the loop so that duplication of the activity, if any, can be avoided.

Prof. Dr. Noor Muhammad,  
Chairman, Department of Mining Engineering,  
University of Engineering and Technology, Peshawar

I would like to congratulate Engr. Arshad H Abbasi and his team for doing such a marvelous job in the oil and gas sector. Our country at present is facing this worst energy crisis due to the lack of strategic approach while carrying out resource allocation. The economy at large has also been collapsed seriously due to this severe energy crisis.

However, the report prepared by SDPI titled as “Shale Oil and Gas : The Lifeline for Pakistan” is a ray of hope for Pakistan in this gloomy situation. The energy obtained through these unconventional resources will not only satisfy the mounting energy needs of growing population but will also address the challenge of expensive energy mix.
The report has also brought good news for unskilled and semi-skilled labors as exploration of unconventional resources are usually more labor intensive as compared to conventional resources, which would not only provide unskilled labors an opportunity to raise their standard of living but also generate economic activity within the country.

Hence, moving towards unconventional reservoirs has become inevitable in prevailing situation and Pakistan needs to pursue towards this option at earliest for its survival. I once again congratulate SDPI and hope that the recommendations of the report, if taken up seriously, will relieve the gas starving country.

Dr. Salahudin Rafai,
Former Chairman, NTDC

It is encouraging to see that efforts such as this report have begun in earnest to determine the status of Shale Gas reserves in Pakistan.

The Shale-Gas technology has so far succeeded and commercially applied mostly in the USA – not surprisingly, since the latter has historically taken a lead in introducing many novel technologies.

The limited success of shale gas elsewhere is indicative of a technology in its infancy. With major oil companies now beginning to take serious interest on a worldwide basis, it won’t be very long before the technology matures, with more reliable means of exploring, testing, and exploitation.

The question of Shale-Gas exploitation in Pakistan is not “if” but “when” to jump in the act, at what cost, and by-whom. Such decisions are better left to the policy makers. However, a world of caution or two would not be inappropriate here.

Pakistan, with its limited financial and technological resources, should approach with extreme caution. A few ill-thought, under-financed, poorly-managed, and/or politically-driven projects could cause more harm than good. Shale-Gas exploitation requires extreme (most advanced) technology and a few false dry wells could seal the fate of Shale-Gas in Pakistan for a long time to come.

A safe bet would be to wait till the technology matures to a high success-to-failure ratio. Otherwise, the highly effective US approach of Govt./industry/academia partnership can be taken.
In any event, the petroleum industry is very capable and experienced in innovation; and if shale gas can be successfully exploited, it eventually will be done by the industry alone. Providing some meaningful incentives to the industry could possibly expedite the process.

Dr. Syed Muhammad Mahmood- (PhD Petroleum Engineering)  
Stanford University, USA  
Chairman- Department of Petroleum & Gas Engineering  
University of Science & Technology, Lahore

I would like to congratulate Engr. Arshad H. Abbasi and his team for their report titled” Shale Oil and Gas: The Lifeline for Pakistan”. We are energy starved. Our industrial growth is at a historical low. Our national security is also dependent on our energy security. We are energy starved because we lack a strategic approach. Our industrial growth is at a historical low because we lack a strategic approach. We are energy insecure because we lack a strategic approach. “Shale Oil and Gas: The Lifeline for Pakistan” is the strategic approach that has long been missing.

As of December 2011, Pakistan’s proven reserves of natural gas stood at around 30 trillion cubic feet (Tcf). According to a State Bank of Pakistan report, “Pakistan is left with only 50 percent natural gas reserves as high consumption in different sectors has exhausted 50 percent of the overall reserves of 54 Tcf by financial year of 2011-12.” Pakistan, as per the SBP, has “sufficient reserves to last just over 20 years.” Pakistan has 586 Tcf of “risked Shale Gas in-place.” For Pakistan, that is 400 years worth of gas supply. Of the 586 Tcf, Pakistan’s “technically recoverable Shale Gas resource is estimated at 105 Tcf.” For Pakistan, that is 73 years-worth of gas supply.

The two shale formations have already been identified: the Sembar Shale formation and the Ranikot Shale formation. Within the Sembar Shale, dry gas in 31,320 square miles, wet gas in 25,560 square miles and oil in 26,700 square miles. Within the Ranikot Shale, oil in 26,780 square miles, 4 Tcf of wet Shale Gas and 3.3 billion barrels of shale oil. Pakistan has the ninth largest shale oil reserves on the face of the planet. This gift of God can be a game-changer – abundant, cheap source of energy.

My congratulations, once again. And, I hope that the recommendations of “Shale Oil and Gas: The Lifeline for Pakistan” are taken up seriously.

Dr. Farrukh Saleem  
Eminent economic theorist, Financial Analyst
Executive Summary

Given that the “Shale Oil & Gas Revolution” in North America has transformed the global oil and gas sector, countries across the world are looking to explore their shale oil and gas reserves for better economic growth. In the light of this, the Sustainable Development Policy Institute (SDPI) seeks to look at the viability of shale oil and gas in Pakistan, and to provide substantial policy recommendations as the latter stands poised to embark on a new journey in energy technology.

Pakistan is currently in the midst of a grave energy crisis, which threatens not only the economic but also the national security of the country. The Government of Pakistan faces challenges to its writ as citizens take to the streets to protest energy shortages, industries come to a standstill and unemployment spirals out of control. Under the weight of these challenges, the Government has been led to seek a reliable energy supply at an affordable price. A review of the history of Pakistan’s energy sector shows that mismanagement of resources and an unhealthy reliance on imported oil to meet our energy needs have exacerbated the crisis.

Immediately after independence, the Government of Pakistan with scarce oil and gas resources at its command sought to expedite the process of gas exploration, and the first discovery was made in 1952 at Sui with proven reserves of around 4,000,000 million cubic feet (MMCF). The use of gas and its contribution to power generation increased with augmented development in

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4 Total Gas Demand and Energy Crisis. 2013. The Internal Documents of Ministry of Petroleum and Natural Resources
thermal power generation. Indeed, the sale of gas to the power sector increased from 29% in 1955 to 37% in 1960.\(^6\)

Uptill the early 1990s, the energy mix in Pakistan reflected a greater contribution of hydroelectricity at a percentage of 45% as considered against 55%\(^7\) for thermal energy. This green track was lost with the advent of the Power Policy 1994\(^8\), which came up with robust investment in thermal power plants. Consequently, the share of hydrocarbon based energy resources gained dominance and in 2012, this rose to a level of 65% with that of hydropower hovering around 32\(^9\). The trends in power generation through gas, oil and hydropower are reflected in Figure 1.

In 2002-03, all hydrocarbon-based energy generation in the transport and the power sectors was shifted to gas in the optimism that the country’s projected gas reserves would be sufficient to meet the requirements of both the sectors. However, when this decision led to gas curtailment, it was rolled back; the Figure 1 shows that in 2007 the use of oil surpassed the gas consumption\(^10\).

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\(^8\) Internal Documents of Ministry of Water and Power (MOWP)


As electricity generation began to rely more on Furnace Oil (FO), prices became vulnerable to external shocks in the international oil market. This increased dependency on oil imports has led to the perpetuation of circular debt and subsidies, which have collectively drained the national exchequer\textsuperscript{11}.

Hence, it is evident that successive policies have had a significant impact on oil and gas resources, which has been discussed in detail in Chapter 1 of this report. It is estimated that Pakistan’s natural gas demand is growing at an exponential rate while the gas supply is dwindling at a similar pace. Currently Pakistan’s daily gas requirement is around 6.5 billion cubic feet per day (bcfd) against its current supply of 4 Bcfd leaving a shortfall of 2.5 Bcfd\textsuperscript{12}. Moreover, over the next ten years, gas demand is projected to rise to almost 8.58 Bcfd. As gas supplies deplete, domestic supplies are expected to reach the level of 2.11 Bcfd\textsuperscript{13}, and result in a demand-supply shortfall of about 6.47 Bcfd by the year 2022.

The current state of the natural gas sector thus shows a high demand for natural gas as well as the need for action and alternatives. The economy of Pakistan depends mainly upon oil and gas resources to fulfill energy requirements. Indigenous resources of oil, and the now depleting gas reserves, are not enough to quench the energy thirst of a growing economy. As a result, Pakistan has to import large quantities of oil from the Middle East \textsuperscript{14}. Pakistan is exploring the option of gas pipelines through the Iran-Pakistan gas pipeline and the Turkmenistan-Afghanistan-Pakistan-India pipeline. Both gas pipelines, while excellent as propositions to meet the high demand of gas, have their own shortcomings. Unless prices are renegotiated, oil-indexed gas prices may prove to be unaffordable as IP is estimated to be around USD 15/mmbtu and TAPI to end up costing 13 USD/mmbtu\textsuperscript{15}. Security challenges, geopolitical

\textsuperscript{11} Malik, A. 2007. How Pakistan is coping with the challenge of high oil prices? PIDE.
\textsuperscript{12} Total Gas Demand on System.(2013). Ministry of Petroleum and Natural Resources (MPNR). Islamabad. Pakistan
\textsuperscript{13} Energy Supply & Demand.(2013). Hydrocarbon Development Institute (HDIP). Islamabad. Pakistan
\textsuperscript{14} Malik, A. 2007. How Pakistan is coping with the challenge of high oil prices? PIDE.
\textsuperscript{15} Iran-Pakistan Gas Pipeline Project: Current Status of Agreements, MMM-AAA, 2013
considerations and economic feasibility are some of the factors which need to be considered in building gas pipelines.

Another alternative is Liquefied Natural Gas (LNG), and there are talks of Pakistan importing LNG from Qatar. With prices that are currently hovering around $17/mmbtu\textsuperscript{16}, excluding the additional cost of shipping and transportation, import expenses, regasification etc (which will add an estimated additional $2/mmbtu)\textsuperscript{17} LNG may also prove to be an expensive source of energy for Pakistan, and may not solve the problem that expensive thermal fuel has presented.

In policy decisions in the natural gas sector, Pakistan needs to consider the most efficient and affordable path towards energy security as it aims to meet its growing energy demands. In the past, gas sector strategies had revolved around exploring new avenues to import natural gas, but the exploration for indigenous resources was limited. However, with Pakistan potentially having shale oil and gas, it may be seen as a gamechanger. In fact, Shale Gas has the potential to stimulate economic activity and also result in a saving of $15 billion, which was previously spent on importing petroleum products.

The shale gas revolution in North America changed the global energy landscape. The US and Canada became leading players in producing commercially viable natural gas from Shale plays\textsuperscript{18}. It is worth mentioning here that now China plans to boost its shale gas production from 7 Bcf (200 million cubic meters) in 2013 to 52.95 Bcf (1.5 billion cubic meters) this year. The nation plans to produce a total of 229.45 Bcf (6.5 billion cubic meters) of shale gas by 2015. Because of this achievement, China has placed its 30-year gas pipeline project to import Natural gas on the backburner. The Ministry of Land and Resources has also said that the central government would push forward natural gas pricing reforms this year\textsuperscript{19}. In comparison, the share of shale

\textsuperscript{17} Ibid.
gas in total natural gas production in 2012 was 39% in the United States and 15% in Canada\textsuperscript{20}. Shale gas production in the United States averaged 25.7 billion cubic feet per day (Bcf/d) in 2012, while total dry production averaged 65.7 Bcf/d\textsuperscript{21}.

Pakistan has more than 827,365 Km\textsuperscript{2} sedimentary basin area (611,307 Km).\textsuperscript{2} This sedimentary area is naturally enriched with a thick sequence of shale formations as a source and has a proven petroleum system. A significant amount of gas has been trapped within the unconventional reservoirs including Tight gas, coalbed methane and shale oil and gas apart from oil and gas resources within the conventional reservoirs. The conventional gas reservoirs have been explored and developed in Pakistan; however, very little work has been done so far in developing these unconventional reservoirs. It is estimated that apart from proven conventional gas reserves, the country has been bestowed with approximately 200 Tcf of shale gas resources within the shale formations\textsuperscript{22}. Studies suggest that 70% of Pakistan’s total area may have Shale\textsuperscript{23} rock.

Energy Information Administration (EIA) IA estimates that Pakistan has a shale gas potential of 105 Tcf, and a shale oil potential of 9.1 billion barrels. In view of growing energy demands and the joint challenge of energy security and climate change, the country needs to take an initiative in developing unconventional reservoirs such as Tight gas and shale gas and oil etc. As Pakistan moves towards exploring this indigenous natural resource, a clear policy framework will become crucial. The principal focus of this report is an assessment of the prospects and socioeconomic viability of developing shale oil and gas resources in Pakistan.

Pakistan opened the door for the US and USGS in October 1955\textsuperscript{24} and signed an agreement to intensify the mapping and appraisal of the geological resources of Pakistan. By the time the

\begin{itemize}
\item[\textsuperscript{21}] EIA, 2013. “North America Leads the World in Production of Shale Gas.”
\item[\textsuperscript{22}] Unconventional Resources in Pakistan.(2012). Internal Documents of Ministry of Petroleum and Natural Resources (MPNR).
\item[\textsuperscript{23}] PacWest Consulting Partners, 2011
\end{itemize}
sixteen-year long project ended in 1970, USGS, in collaboration with the Geological Survey of Pakistan, had extensively surveyed the Petro-geology of Pakistan. At the same time, American and other European oil and gas companies, such as Standard- Vacuum Oil Company (1956), Hunt International Oil Company (1955), Shell Oil Company (1956), Sun Oil Company (1957) and Tidewater (1958) reached agreements with Pakistan for Oil and Gas exploration. Now the same American companies are the biggest players in the shale oil and gas sector. The initiative taken by Pakistan in the ‘50s and ‘60s may pay off now when the same companies and USGS use data in the resource assessment of shale oil and gas in Pakistan. The most vital data such as stratigraphic columns and well logs, depth, structure, including major faults, gross shale interval, organically-rich gross and net shale thickness, total organic content (TOC) and thermal maturity (Ro) was compiled during almost two decades. Yet, only a pilot project may be able to tell the true picture. Insipite of this extensive geological survey by USGS in Pakistan, the country faces unique challenges in unleashing this resource potential. The play and prospective area success factor assessed by EIA for Sembar and Ranikot is around 30-40%. The play success probability factor identifies the likelihood of shale oil and gas production at attractive flow rates. But as exploration wells are drilled, tested and produced and information on viability of shale oil and gas play is established, the play success factor will change. Moreover, the success/risk factor of prospective area for shale oil and gas needs to be analyzed on the basis of structural complexity, total organic carbon (TOC), thermal maturity etc.

The USGS has disseminated information about shale oil and gas based on geological information and reservoir properties assembled from the technical literature and log data from reports and presentations.

The other challenges include:

- Data Management and Data Interpretation
- Comprehensive core analysis through geological, petro physical, geo physical and geo-mechanical model

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The Pakistan Basin study, an investment of millions of dollars and expert data collection, covering important and relevant data may be used to make initial assessments of Pakistan’s shale formations, and shale oil and gas plays. A good understanding of the stratigraphy and geological properties of shale-rich areas may help determine the sweet spot of shale oil and gas in the future. Shale makes up more than half of the earth’s sedimentary rock, but its types and formations differ from shale to shale, and even within the same shale. In view of the complexities, it is not surprising that there is no industry-standard definition for the process, and differences exist in experiences of countries involved in shale gas and oil development.

Once the already available data is gathered and evaluated, a comprehensive geological, petrophysical, geophysical and geo mechanical modelling of selected wells is required. The modeling is done by taking the samples either in the form of fluid or rock cuttings, while, in some cases, the whole core is extracted and analyzed for modeling. The samples are taken from wells at varying sites to check the rock geology, chemistry and hydrocarbon content present in them. After this, the well with successful vertical drilling having substantial hydrocarbon content is selected for horizontal drilling and hydraulic fracturing. It is important to note here that this comprehensive core analysis is a prerequisite for moving ahead in shale plays development.

Moreover, the challenge of establishing well depth criteria can be addressed by assembling the log data and stratigraphy of conventionally drilled oil and gas wells particularly in shale enriched basins. As the critical depth for acquiring the shale oil and gas has been surpassed at many wells, detailed analysis of their log data and stratigraphy can play a very important role in

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27 Ibid
establishing the depth and thickness of the shale and identifying the prospective area per basin for detailed shale oil and gas activities\textsuperscript{29} (See Table 1).

<table>
<thead>
<tr>
<th>Zone Formation</th>
<th>Province</th>
<th>No of Wells</th>
<th>Total Depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chorgali/Sakessar</td>
<td>Punjab</td>
<td>44</td>
<td>4,643-15,300</td>
</tr>
<tr>
<td>Lower Goru</td>
<td>Sind</td>
<td>1016</td>
<td>5.2-11,844</td>
</tr>
<tr>
<td>Ranikot</td>
<td>Punjab, Sind &amp; Balochistan</td>
<td>498</td>
<td>853-3,667</td>
</tr>
<tr>
<td>Sakessar/Sakeesar Datta</td>
<td>Punjab</td>
<td>316</td>
<td>951-1,777</td>
</tr>
<tr>
<td>Sembar</td>
<td>Punjab</td>
<td>15</td>
<td>10,039-11,076</td>
</tr>
<tr>
<td>Khewra &amp; Khewra/Tobra</td>
<td>Punjab</td>
<td>46</td>
<td>1747-1863</td>
</tr>
</tbody>
</table>

Source: (Pakistan Energy Yearbook, 2012)

The challenge of skill gaps can be overcome by revising the curriculum of engineering universities and Pakistan Engineering Council (PEC), and the statuatory body needs to play a leading role in this regard.

In order to address the technology challenges, the country needs to strengthen its ties with US for developing the shale plays in Pakistan by becoming a part of Unconventional Gas Technical Engagement Program (UGTEP), formerly known as Global Shale Oil & Gas Initiative (GSGI). The gas industry will need to learn from and share the U.S. experience, in terms of technical trainings and in terms of establishing regulatory and fiscal frameworks and environmental protection for shale. Some key points require deliberation, particularly lessons from China and

\textsuperscript{29} Ibid
Poland. These nations have invested ample time and financial resources and have been able to overcome unique challenges and to convert them into opportunities.

Chapter 4 of this report looks at the environmental impact of shale oil and gas development. One major difference between production of conventional oil and gas and unconventional gas development is water consumption during hydraulic fracturing, which is a unique drilling process (discussed in Chapter 2). Unavailability of water sources for the awarded blocks may pose logistical risks and additional costs. It will therefore be essential for guidelines to be established to prevent the contamination of aquifers, establish limits on well pads, and target areas of low population density. An advantage that Pakistan may have on the environmental front of shale oil and gas is the availability of a drought resistant guar bean, which is used as a proppant in the hydraulic fracturing process\textsuperscript{30}. The cultivation of the guar bean in hill torrent prone areas may also help mitigate flash floods in DI Khan, DG Khan, Rajin Pur and Eastern and Southern Balochistan\textsuperscript{31}.

Chapters 5-7 explore the policy implications of shale oil and gas, assessment of a roadmap, the economic benefits and impact, and the way forward. Pakistan will need to strengthen its existing infrastructure, and to develop regulatory policies that are favorable to exploration and production of shale oil and gas, while addressing social and environmental concerns. Moreover, there will be a need for an increased focus on the technical and educational understanding of not only our indigenous shale, but also on the technology and petrochemical processes used in assessments of shale gas plays.

In conclusion, Pakistan is fortunate to be blessed with abundant natural resources. Only our policy decisions and planning regimes can now set the course for the future of our natural gas sector thereby allowing for a possible shale gas revolution to successfully occur, bringing in its wake much needed economic revitalization and allied social change.

\textsuperscript{30}ChemTotal. (2013). \textit{Guar Gum and Guar Derivatives in Fracturing}
\textsuperscript{31}West Texas Guar, Inc., (2013). \textit{Guar and its Uses}
Chapter 1

THE STATE OF ENERGY IN PAKISTAN

Energy is the primary and most important of factors determining the economic condition of a country. There is a close link between the availability of energy and the future growth of a nation as energy development is an integral part of sustainable economic growth. With energy demand rising at a tremendously fast pace and Pakistan’s natural gas reserves depleting, there is a dire and urgent need to develop unconventional energy resources.

This report elucidates the viability of shale gas exploitation in Pakistan by giving a comprehensive overview of successful shale gas exploitations in the world as well as of technical and economic considerations for shale gas extraction and utilization in Pakistan.

This chapter explores the historical background of Pakistan’s energy sector and necessary context, which need to be considered before practical decisions are taken regarding shale exploration in Pakistan.

Energy supply in Pakistan consists of two major segments that are commercial and non-commercial. In 1947, the per capita energy consumption in terms of oil equivalent (TOE) was around 0.02 TOE. The crude oil and coal production was only around 0.49 million barrels and 0.24 million tons respectively. The sectors consuming the most significant portion of the supply of energy were industrial, transport, domestic, agriculture and commercial. At that time, the industrial sector was almost non-existent and motorized travelling was not very common. The agriculture sector had also not yet been mechanized. The total installed capacity of the

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32 Record from Planning Commission of Pakistan
public utilities in 1947, excluding those owned by private industrial establishments, was around 68.1 MW\(^3\). Within this total, 30 MW\(^3\) was based on ‘Steam Electric Power Plants’ while the rest relied on diesel electric plants.

With scarce resources to meet energy demands, in 1948, the Government of Pakistan (GOP) promulgated the “Regulation of Mines and Oilfields Act-1948” to explore indigenous hydrocarbon resources. The aim of this Act was to provide regulatory certainty for exploration and production business, which was essential to encourage and accelerate exploration activities.

In this regard, a well was drilled at Sui in Baluchistan in 1952\(^3\), which led to the discovery of large reserves of natural gas. The estimates of proven reserves at Sui (October 1955) were around 4,000,000 million cubic feet (MMCF), roughly equivalent in heating value to 143 million tons of coal at the time\(^3\). The discovery of Sui Gas Field was the first major milestone in the search for hydrocarbons in Pakistan.

In 1955, the Sui field began commercial production. Initially, natural gas was delivered to consumers through a transmission line from Sui to Karachi.\(^3\) At that time, a 406.4 mm (16 inches) gas transmission line was laid from Sui to industrial city of Karachi with a length of 599\(^3\) km, and the initial consumers of this gas were the power stations in Karachi. Following the discovery of natural gas at Sui, several foreign oil

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33 Internal Documents (WAPDA)
34 Ibid
36 Ibid
38 Ibid
companies took active interest in carrying out exploration in Pakistan, and the GOP reached various agreements with international oil and gas exploration companies for carrying out further exploratory activities in prospective areas.  

By the end of 1956, the total sale of natural gas amounted to 6,866 MMCF, and the production of gas remained confined only to Sui Field. In 1957, Pak Stanvac discovered Mari, another large gas reserve located 40 miles east of Sui. The recoverable reserves from this gas field were about 3.942 MMCF, and natural gas from Mari was used solely for fertilizer factories. Natural gas had multiple advantages over alternative fuels like coal and oil as it was more readily available and cost-effective. Within two years, all large and small industries in Sukkur, Hyderabad and Karachi started using gas, which led to a boom in industrial activities.

In addition to industrial development, the use of gas and its share in power generation also expanded with increased development in thermal power generation, and gas sales to the power sector increased from 29% in 1955 to 37% in 1960. Despite significant new gas discoveries during this period, the exploration activities registered a downward trend because of a lack of oil discoveries, which led to decreased oil production. The fall in oil production and increase in energy demands led to increased oil imports. The import bill increased from Rs. 75 million in 1954-55 to Rs. 404 million in 1963-64, which led to the draining of the foreign exchange reserves. Low production of oil led policymakers to declare gas as the primary fuel for power generation and industrial use. Consequently, the consumption of natural gas rose from 1,375 MMCF in 1955 to 51,900 MMCF in 1964. During 1962-63, the industrial sector was given prime importance as 55% of gas was consumed by industries as a fuel, 36% for power

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42 Planning Commission of Pakistan. (1977-83). Fifth Five year Plan  
generation and about 9% was consumed for commercial and domestic purposes\textsuperscript{47}, thus driving strong economic growth within the country. However, after the 1970s, the consumption pattern reflected a shift in usage by industries to increased usage by the power and the domestic sectors\textsuperscript{48}. It is pertinent to highlight that the power sector became the largest consumer of gas in 1971 followed by industrial, fertilizer, cement and domestic sectors. However, as the gas reserves at Sui began to deplete, it was realized by policymakers that gas needed to be conserved for manufacturing fertilizer and other priority uses. There was an effort to shift from gas to alternative fuels in the case of cement and other industries\textsuperscript{49}.

However, the discovery of condensate oil and gas at Dhodak in 1976, wrongly estimated reserves of 4.5 trillion cubic feet, with an immediate 35% increase in gas reserves,\textsuperscript{50}. As a result of this misleading data, there was increased dependence on gas for meeting energy needs, and domestic gas connections were provided at an exponential rate\textsuperscript{51}. As a result of an excessive dependence on gas and projected demand and supply gap, it was proposed by the Planning Commission of Pakistan in the late Eighties to not extend the gas supplies to new industries and to limit new connections until more gas could be developed and realistically priced\textsuperscript{52}. "Keeping in view an expected gas shortfall at the time of the Seventh Five Year Plan (1988-93), it was decided that gas allocation in the future would be supply driven instead of demand driven.\textsuperscript{53}

In a similar vein, development plans for Seventh Five year Plan (1988-93) focused on expediting the exploratory activities\textsuperscript{54} and the utilization of gas in various sectors was also prioritized. It was decided that gas would be allocated in the following priority manner:\textsuperscript{55}:

1. Feedstock for Fertilizer
2. Replacement of High Speed Diesel (HSD)

\textsuperscript{47} Ibid.
\textsuperscript{50} Ibid.
\textsuperscript{51} Ibid
\textsuperscript{55} Ibid.
3. Replacement of Kerosene in Domestic sector
4. Replacement of Furnace oil (FO) in Industrial Sector
5. Substitution of Furnace oil (FO) in Power Generation

This prioritization led to increased gas consumption in the fertilizer sector. In 1992, fertilizer industry consumed 23%\textsuperscript{56} of total gas (See Table 1). The table identifies that the fertilizer sector in 1992 was the second to the power sector in its dependence on gas, consuming 36% of the existing gas supply. The gas consumption in domestic sector also rose from 12% in 1987-88 to 15% in 1992-93\textsuperscript{57}, which was attributed to the replacement of kerosene oil with natural gas in domestic sector. It is estimated that during 1992-93, in view of abovementioned priority order for gas allocation, the fertilizer sector was allocated gas at the price of Rs 22/MMBtu while the industrial and power sectors were charged around Rs 62.75/MMBtu\textsuperscript{58}. The domestic consumers on the other hand were facilitated through the introduction of a slab system. The price of natural gas for the domestic sector was around Rs 35.6/MMBtu for gas up till 3.55 MMCF, and Rs 46.5/MMBtu for consuming 10.64MMCF\textsuperscript{59}, the cheapest amongst consumer prices after fertilizer sector.

| Table 2: Percentage Share of Natural Gas Consumption (1987-93) |
|-----------------|---------|---------|---------|---------|---------|---------|
| Commercial      | 2.65    | 2.72    | 2.52    | 2.65    | 2.68    | 2.80    |
| Cement          | 1.36    | 1.33    | 1.80    | 2.80    | 2.42    | 2.33    |
| Power           | 36.85   | 35.96   | 38.14   | 37.91   | 39.85   | 36.53   |

\textsuperscript{56} Hydrocarbon Development Institute of Pakistan(HDIP).(1993). Pakistan Energy Year Book.(1992-93). Islamabad. Pakistan
\textsuperscript{57} Ibid.
\textsuperscript{58} Economic Survey of Pakistan(2010). Ministry of Finance. Islamabad
\textsuperscript{59} Ibid
During 1993-98, a new petroleum policy was envisaged to enhance the investment in energy sector, and there was a decrease in dependence on oil imports. The fundamental purpose of the policy was to privatize the fuel sector for promoting developmental and exploratory activities within this sector and to maximize the use of available indigenous resources. When this petroleum policy came into action and the private sector became involved, dependence on natural gas rose to 30% during 1994-95. At that time, it was decided that manufacturing industries would be given priority for gas allocation over power generation as these industries had continuous operations for instance, glass, textile, ceramics, pharmaceutical manufacturing units etc. Within one year, 19% of the gas was consumed in industrial sector and 33% was consumed in power sector in 1994-95 against 18% and 35% in the industrial and the power sectors in 1993 respectively.

In 1994, there was paradigm shift in the power sector when the Government of Pakistan (GOP) formulated a power policy for permitting the private sector to invest in the power sector to help in the commissioning of 19 IPPs, fossil fuel based projects. This power policy attracted investment in thermal power plants and increased dependence on imported oil and consumption of domestic gas, which had serious repercussions on oil and gas consumption. After this power policy was launched in 1996-97, around 37.68% of energy needs were fulfilled through gas and natural gas. Consumer prices since 1993-1999 highlight that the fertilizer sector acquired gas at the cheapest rate followed by the domestic and the industrial sectors (Annexure-1).

It is estimated that 48% of the energy needs were met through oil, and of this percentage, 31% of the oil was consumed for power generation. This increased dependence on oil for...
power generation continued and in 1997-98, 36.4% of the oil was consumed for power generation.

In addition to increased dependence on imported oil, the GOP offered generous tariff for purchasing electricity from IPPs i.e. $0.060/Kwh for the first 10 years. It was subsequently increased to $0.065/KWh, which was almost twice as much as KESC’s thermal generation or four times WAPDA’s average hydro-thermal generation. The high front-end tariffs to meet the cash flow of IPPs had resulted in tariffs in the initial years being as high as $0.083/KWh. An additional premium of $0.0025/KWh for the first ten years was also offered for projects commissioned until 1997. Hence, according to ADB Report-2000, the inclusion of IPPs under Power Policy 1994 had ruined the financial performance of both WAPDA and KESC, and instead of any improvement, had enlarged the burden on the national exchequer through increased furnace oil consumption in power generation.

Box 1: Depleting Natural Gas Reserves in Pakistan

The total gas reserves in Pakistan were 52 TCF. The country is left with 23 TCF only. It is estimated that these 23 TCF will be exhausted soon in view of the excessive dependence on this reserve, and there will be no gas by 2025. The oil reserves in Pakistan are also depleting gradually, and it is estimated that oil reserves would last for 6-7 years against the daily average oil production of 385000 barrels/day, where 85% of the needs are met through oil imports.

Source: Economic Survey of Pakistan, 2010

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66 Ibid
68 Ibid.
69 ADB. (2000). *Pakistan Power Sector Assessment*
During 2002-03, a large portion of Pakistan’s hydrocarbon based energy production (both for transportation and electricity) was converted from oil to gas as it was thought that the country was blessed with abundant domestic gas reserves, and that it should avoid expensive oil imports. In addition to this, the transport sector was also shifted to gas; this was in addition to an increase in domestic consumption due to increased urbanization and inauguration of gas schemes during election campaigns. Consequently, the share of gas consumption for fulfilling the primary energy needs increased as compared to other sources of energy and touched the value of 48% in 2007 as compared to 34% in 2003 and the power sector with 44% share in gas consumption became the biggest consumer of gas followed by increasing usage in the fertilizer, industries and transport sectors. This shift from oil to gas did not lead to fruitful results; rather, it aggravated the energy crisis in terms of gas curtailment for power generation. Domestic and industrial consumers also suffered equally in terms of non-availability of gas. In 2007, the curtailment in gas availability for power generation again changed the consumption pattern of oil and gas in the power sector. Error! Reference source not found. shows that the use of oil surpassed gas consumption in 2007, thus augmenting the

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70 Oil and Gas Consumption in Power Sector. (2010).
import bill of Pakistan. The prices charged to natural gas consumers from 2000 to date are shown in **Annexure-2**

Annexure -2 identifies that a new price slab for domestic consumers consuming units greater than 10.64 and 14.2 was introduced in 2000, and rates for these slabs were even less than those charged to the industrial consumers. Another new price slab covering domestic consumption above 17.8 units was introduced in 2008, and domestic consumer price in this slab was greater only than the industrial consumer price. It is worth noting that in EU member States, unlike the situation in Pakistan, the domestic consumer price which is around Rs. 994/Kwh\(^73\) is deliberately kept higher as compared to the industrial consumer price i.e. Rs 823/Kwh\(^74\) in order to restrict and optimize the use of gas amongst domestic consumers and to prioritize its use in industries for spurring industrial growth. However, in Pakistan, the consumer price is highest for industrial and commercial consumers as compared to domestic consumers, which is a contributory factor in the current gas crisis. Thus, lack of a concrete natural gas policy\(^75\) and rationalized gas pricing mechanism\(^76\) form some fundamental reasons for this energy crisis, which has currently become one of the

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\(^{74}\) Ibid


largest threats to energy security in Pakistan. It is estimated that currently the total gas demand in the system is around 6.5 Billion Cubic Feet (BCF/D) against a total supply of 4 BCF/D, thus presenting a shortfall of around 2.5 BCF. Nevertheless, 44% of the energy needs are met through gas (see Figure 3), which is the largest contributor as compared to other sources of energy. The power sector with 27.5% share is the largest consumer of gas, followed by industries, household, and fertilizer, transport as well as commercial sectors. Hence, the lack of gas availability in all these sectors has hampered economic growth within the country.

In order to meet these mounting energy needs of the country, the GOP is pursuing a multipronged strategy focused on the import of natural gas through gas pipelines and of Liquefied Natural Gas (LNG). Thus, the following sections will discuss the components of the multidimensional strategy adopted by the GOP to overcome this energy crisis and its ramifications.

i. Import of Liquefied Natural Gas (LNG) from Qatar

LNG is a liquefied natural gas, which is a colorless, non-toxic and clear liquid that forms when natural gas is cooled to -162°C. This reduces the volume of gas 600 times from its original volume, which makes it easier for storage and transportation. Pakistan in its drive to address gas shortages has decided to give priority to importing LNG from Qatar in a government-to-government arrangement. The Economic Coordination Committee (ECC) recently approved the import of 500 MMCFD at the price of $19/MMBtu and it is estimated that Pakistan will have to spend at least $200 million to build infrastructure for importing LNG from Qatar. In order to facilitate this import, various options are under consideration by GOP which include encouraging the LNG supplier to construct LNG storage and regasification terminal for receiving LNG on tolling basis, entering into an agreement with an independent LNG terminal owner or

77 Total Gas Demand on System.(2013). Internal Documents of Ministry of Petroleum and Natural Resources. Islamabad Pakistan
79 Ibid
81 Nation. (2013). US Firms Set Conditions for LNG Import to Pakistan. Pakistan
operator for acquiring all services and developing LNG terminal or regasification facilities on public-private partnership basis.

Nevertheless, Pakistan, while pursuing LNG imports, needs to take into account the fact that large scale investments in LNG projects are subject to a number of risks including sources of gas supply, escalating cost in investment stage, changes in global oil prices and impact of unconventional gas production i.e. shale gas upon the LNG market\textsuperscript{82}. It is important to note that increased gas production from unconventional reservoirs has already resulted in a large fall in expected LNG import demand and changed the energy dynamics\textsuperscript{83}, which facts are worth considering by the GOP before the LNG deal is formalized.

\textbf{ii. Turkmenistan-Afghanistan-Pakistan-India Pipeline (TAPI)}

The Turkmenistan-Afghanistan-Pakistan-India Pipeline (TAPI) is a natural gas pipeline project that will transport Caspian Sea natural gas from Turkmenistan.\textsuperscript{84} Under this program, Turkmenistan will export 1164.9 Bcf of natural gas per year through a 1800 km\textsuperscript{85} pipeline that will originate in Turkmenistan and reach India after passing through Afghanistan and Pakistan. According to the original plan, Pakistan and India will get 494.2Bcf each from Turkmenistan, while 176.5 Bcf will be allocated for use in Afghanistan.\textsuperscript{86} The Intergovernmental Agreement (IGA) was signed by the Heads of all member countries in 2010 during the TAPI Summit.\textsuperscript{87} The initial cost estimates of the project based on the pre-feasibility study was $7.6 billion\textsuperscript{88}, which could escalate further due to delay in finalizing various necessary issues. The gas prices have

\begin{thebibliography}{88}
\bibitem{82} Ernst and Young.(2013). Global LNG: Will New Demand and New Supply means New Pricing
\bibitem{83} The LNG Industry in 2012, GIIGNL, Editorial, 2012,
\bibitem{84} Foster, J. (2008). \textit{A Pipeline Through a Troubled Land, Foreign Policy}. Canadian Centre for Policy Alternatives
\bibitem{85} Palau,G.R.(2012).The TAPI Natural Gas Pipeline: Status and Sources of Potential Delays. Civil Military Fusion Center(CFC).
\bibitem{86} PetroMin Pipeliner, 2011, “Turkmenistan-Afghanistan-Pakistan-India Gas Pipeline: South Asia’s Key Project”
\bibitem{87} Inter State Gas Systems (Pvt) Limited. (2013). \textit{Turkmenistan-Afghanistan-Pakistan-India- Gas Pipeline (TAPI)}
\bibitem{88} Palau,G.R.(2012).The TAPI Natural Gas Pipeline: Status and Sources of Potential Delays. Civil Military Fusion Center(CFC).
\end{thebibliography}
been negotiated bilaterally, given the different economic conditions and energy deficits among the member countries. Pakistan has signed the bilateral Gas Sale and Purchase Agreement (GSPA) at the price of 70% of the Brent crude oil.\textsuperscript{89} It is estimated that gas price for TAPI in case of Pakistan is around $14/MMBtu\textsuperscript{90} that is very high especially in view of current energy dynamics strongly impacting natural gas prices across the globe. In addition to this, the infrastructure cost and security concerns associated with this project are not only challenging in terms of the timely execution of this project but also in terms of the economic viability of this project for Pakistan.

iii) Iran Pakistan Gas Pipeline (IP)

The Iran-Pakistan Pipeline is another vital component of a multipronged strategy for curbing the energy crisis in Pakistan. Pakistan inked an agreement with Iran in 2009 for importing 750 MMCFD of gas through 1100 km long pipeline, afterwards to be increased to 1 BCFD\textsuperscript{91}. Iran, in this regard, has constructed more than 900 km (out of 1100 km) of the pipeline on its territory at a cost of $700 million, while the Pakistani portion of the pipeline is to be constructed at an estimated cost of $1.5 billion\textsuperscript{92}. A 2013 Memorandum of Understanding had indicated that Iran might provide a $500 million loan to partially finance the construction, while the remaining cost was to be paid by Pakistan. However, by the end of 2013, Iran signaled that it might not be able to lend the amount of $500 million,\textsuperscript{93} which was to have been paid through the cost of gas after the commissioning of the IP gas pipeline project. The state owned SSGCL and SNGPL are to initiate the mechanical work while the FWO, a subsidiary of the armed forces, has been contracted to carry out the civil work of the project by laying down the pipeline from Gabd to Nawabshah in Pakistan. Pakistan aims to capitalize on the gas imported through this pipeline mainly for power generation of around 4000-5000MW, and this is considered important in

\begin{itemize}
\item \textsuperscript{89} Ibid.
\item \textsuperscript{90} Iran-Pakistan Gas Pipeline Project: Current Status of Agreements, MMM-AAA, 2013
\item \textsuperscript{91} Project Financing, MMM-AAA, 2013
\item \textsuperscript{92} Contract
\item \textsuperscript{93} Project Financing, MMM-AAA, 2013
\end{itemize}
helping to end the energy crisis in Pakistan. The imported price of gas, determined through a formula linking the delivered gas price to a basket of Japanese Customs Cleared (JCC) crude, at agreed crude oil parity turns out to be $14/MMBtu. This import price in light of Iran’s situation in international market and the “Shale Gas Revolution” may need to be re-evaluated and revisited in view of broader national interests.

Not all projects for importing natural gas can cater to Pakistan’s increasing energy demands, and the economic viability and security risks associated with the former need to be assessed. Moreover, the advent of shale gas has not only transformed the energy landscape of the US but it has also influenced international energy markets and changed the priorities of countries across the globe. As this report will highlight, Pakistan is endowed with reserves of shale gas. What it needs to do is to step forward and unlock its reservoirs. Shale Gas, if exploited successfully, may be able to reduce Pakistan’s dependence on energy imports and make it self-sufficient in terms of energy.

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94 Gas Shortfall Mitigation Strategy, MMM-AAA, 2013
95 Iran-Pakistan Gas Pipeline Project: Current Status of Agreements, MMM-AAA, 2013
Chapter 2
Shale Gas as a Game Changer

Shale Gas is no different in composition from conventional gas. However, Shale Gas is found in concentrated reservoir and is trapped in much smaller pockets throughout Shale rocks, a type of sedimentary rock. As Shale Gas is locked tightly, it is not extractable through conventional methods\(^{97}\).

2.1 History of Shale Gas

The first Shale Gas extraction was carried out in 1821 in a shallow, low pressure fracture in Fredonia, New York.\(^ {98}\) However, the industrial scale production of Shale Gas started

\(^ {97}\) Shale Gas Background Note.(n.d.). Department of Energy and Climate Change. UK
\(^ {98}\) US Department of Energy.(2011). NETL

The Shale Gas Revolution in North America changed the global energy landscape. The US and Canada are fundamental
no earlier than 1970\textsuperscript{99}. In 1976, investments were made in Eastern Gas Shales Project\textsuperscript{100} and the US Department of Energy (DOE) collaborated with private gas companies, to drill the first multi-fractured horizontal well of shale in 1986\textsuperscript{101}(See Figure 4).

This was followed by further incentives by US government and in 1991, the US Department of Energy, subsidized Texas Gas Company i.e. Mitchell Energy for better process operation.\textsuperscript{102} These incentives by US government led to the achievement of the first economically viable shale fracture, under a novel process called “slick water fracturing” by Mitchell Energy in 1998.\textsuperscript{103} Development in the unconventional reservoirs continued, and in early 2000\textsuperscript{104} vast new natural gas fields were developed from Shale formations such as Marcellus and Utica in Pennsylvania and Barnett, Haynesville and Eagle Ford in Texas.

\textsuperscript{102} Ibid.
\textsuperscript{104} Vello. A. K. (2007). Reserves Production Grew Greatly During Last Decade. Oil and Gas Journal
Figure 4: History of Shale Gas Development

1821
First Shale Gas produced from the Natural Gas well in Ferndina, New York, US

1859
US Oil Industry launched when Edwin Drake demonstrated that oil can be produced in large volumes

1860s-1920s
Natural Gas was produced from shallow, low pressure and fractured shales in Illinois and Appalachian basins was limited to use in cities that were close to producing fields

1930s
Technology developed, large diameter pipelines for carrying large volumes was made from midcontinent and southeastern oil fields to northeastern cities. Natural Gas industry started blooming

Late 1940s
First hydraulic fracking treatment was pumped in 1947 on a gas well operated by Pan American Petroleum Corporation in Grant County, Kansas

Early 1970s
Development of downhole motors, key component of directional drilling technology. Drilling capabilities continue to advance for next three decades

Late 1970s and Early 1980s
Research was conducted to develop methods to estimate the volume of unconventional natural gas reservoirs such as tight gas, shale gas and coal seams and to

1980s to Early 1990s
Mitchell Energy combined larger fracture designs, rigorous reservoir characterization, horizontal drilling and lower cost approaches to hydraulic fracking to make Barnett Shale economic

2003-2004
Barnett Shale gas play overtook the shallow shale gas production from historic shale plays like Michigan Basin Antrim and Appalachian Ohio. Shale. About 2.8 bcf/d of gas was produced from US shales

2005 to 2010
Barnett Shale gas production increased by 5 Bcf/d

2010
Marcellus Shale gas contains about half of technically recoverable shale gas resource
This enhanced investment was attributed to a technological breakthrough, bolstered by a period of rising natural gas prices\(^\text{105}\) (See Figure 5). The figure highlights that since 2000, the natural gas extracted from shale has been the fastest contributor to the gas industry and that it currently accounts for 34% of US natural gas production, which figure is expected to touch 60% by 2035\(^\text{106}\).

### 2.2 Shale Gas and its Impact on International Market

In 2013, the US DOE’s Energy Information Administration (EIA) evaluated and identified 137 shale formations in 41 countries outside US\(^\text{107}\). The report “Technically Recoverable Shale Oil and Shale Gas Resources” highlighted the geochemical characteristics of these shale formations and quantified technically recoverable reserves in shale formations across the globe. The Figure 6 shows the global recoverable shale reserves.

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\(^{107}\) US. Energy Information Administration (EIA). (2013). Technically Recoverable Shale Oil and Shale Gas Resources. US Department of Energy
As the **figure 6** shows and according to the EIA assessment it has been identified that globally, the risked Shale Gas in place ranges from 30,000 - 31,138 Tcf while technically recoverable resources are estimated to be around 7,299 Tcf. Currently, the US has been leading the world in shale exploration. A natural gas boom through the development of shale plays in US has revolutionized global energy politics and abundant natural gas obtained through unconventional methods has created a deep impact on the structure and dynamics of natural gas markets. The shale gas revolution in the US has not only increased gas availability but has also created employment opportunities on a massive scale and also lured foreign investment. Inspired by the economic impact and growth driven by shale gas in the US, other countries outside the North America are now actively pursuing the development of unconventional resources to decrease their dependence on oil imports. However, China, Poland and Canada are the only countries outside North America that have been successful in producing natural gas through shale plays. Nevertheless, countries like Argentina, India and Mexico are striving to develop these unconventional beds yet they face several challenges in doing so.

It is estimated that shale oil and gas production has decreased the well head prices of natural gas from nearly US$8 per thousand cubic feet (MMBtu) just before the shale gas revolution in 2008 to around US$2.66 per thousand cubic feet (**See Figure 7**). This has led to a 10% decrease in electricity prices. There has also been a considerable decrease in US natural gas prices, which has prompted electricity generators to switch to gas from coal. The US gas is trading at $ 4 per
MMBtu\textsuperscript{108}, which is 2.5 times cheaper than the rate in Europe and four times cheaper than the rate in Asia. Power production through coal, which is easy and cheap to transport, has declined sharply due to its competition with Shale Gas.

In Europe where the coal prices were predicted to be around $100 and $130 per ton\textsuperscript{109}, the prices are standing around $80 per ton. It is estimated that US coal which is unwanted at home is increasingly finding its way to European markets, where it has displaced more expensive gas as feedstock for power stations\textsuperscript{110}. Europe has increased coal power generation and substituted natural gas with coal in power generation. This trend has emerged due to low coal prices of imported coal primarily of US origin as compared to the prices for natural gas. The UK is one of the European countries where coal is being used as feedstock for power stations and this has significantly increased Greenhouse Gas Emissions (GHGs), estimated to be more than 3% in 2012\textsuperscript{111}. However, many experts believe that coal’s European revival will be short lived, and that it is essentially the last gasp of a fuel without a long-term future.

Moreover, the revolution has also provided immense opportunities to the US, as it has now become an exporter of Liquefied Natural Gas (LNG) through the Gulf of Mexico, which was originally designed for importing natural gas to US. The flooding of natural gas due to abundance of gas available at cheaper rate has led to discount in LNG prices as compared to oil indexed LNG prices. The current margin between North American gas on gas and oil indexed prices is driving the Asian LNG buyers to go for cheaper option. Moreover, the move to secure

\textsuperscript{109} Ibid.
\textsuperscript{111} World Wild Life Fund(WWF).(2013). Parliamentary Briefing: Is There really a Coal Renaissance in EU.WWF UK. Panda House, Weyside Park
the Henry Hub prices is an attempt by Asian buyers to put pressure on existing suppliers to move away from oil-indexed contracts\textsuperscript{112}.

### 2.3 Characteristics of Shale Oil and Gas

Shale is a collection of fine-grained, laminated sedimentary rocks consisting of silt and clay sized particles. It is the most abundant of sedimentary rocks, constituting about 60\% in the Earth’s crust\textsuperscript{113}. Shale is often found within layers of sandstone or limestone, several meters thick and is typically formed within the environment where mud, silt and other sediments are deposited gently by transporting currents, and become compacted over the years. Shale sediments are deposited in the deep ocean floor, basins of shallow seas and river flood plains\textsuperscript{114}.

Shale characteristically constitutes around 30\% clay minerals and a substantial amount of quartz. The small amount of carbonates, feldspars, iron oxides, fossils and organic matter are also found amongst these. These shale formations serve as source rock for hydrocarbons and act as a seal for trapping oil and gas in underlying sediments\textsuperscript{115}.

Shale Gas is a part of a continuum (Figure 6) of unconventional gas productivity from tight gas sands, Shale Gas to coal bed methane (CBM). The gas in shale reservoirs is of two types i.e. adsorbed gas and free gas as compared to other reservoirs (See Figure below). The adsorbed gas is attached to the rock surface and is gradually released to the well bore as the pressure is released, while, the free gas is located in pores in shale rock and behaves in a similar manner as in conventional reservoirs. Both gases will be produced over time but at varying rates.\textsuperscript{116} Hence it is necessary to distinguish between adsorbed and free gas and to quantify the Total Organic Content (TOC), which is the foremost quality explored in the petro-physical field. The TOC is a direct estimation of gas content and adsorbed gas volume available.

\textsuperscript{112} LNG Unlimited.(2013). LNG Journal
\textsuperscript{114} Ibid.
\textsuperscript{115} Shales, BRITANNICA
Another target in shale gas exploration is Kerogen, which is natural, solid insoluble organic matter in shale source rocks that can yield oil upon heating\textsuperscript{118}. The organic matter present in the sedimentary rocks is insoluble in ordinary organic solvents\textsuperscript{119}. The physical and chemical properties of Kerogen are strongly influenced by the type of biogenic molecules from which the Kerogen is formed. The chemical composition of Kerogen is also affected by the processes of thermal maturation i.e. catagenesis and metagenesis, which alter the original Kerogen. Subsurface heating causes chemical reactions that break off small fragments of the Kerogen as oil or gas molecules. The Kerogen has been categorized into four types depending on their chemical composition\textsuperscript{120}.

**Type I Kerogen:** It is quite rare and derived from lacustrine algae. The occurrence of type I Kerogen is limited to anoxic lakes and a few unusual marine environments, as they have high generative capacities for liquid hydrocarbons\textsuperscript{121}.

**Type II Kerogen:** This originates from different sources including marine algae, pollen and spores, leaf waxes and fossil resins. This includes contributions from bacterial cells and lipids.

\textsuperscript{117} Harvey, T and Gray, J.(2013). The Unconventional Hydrocarbon Resources of Britain’s Onshore Basins Shale Gas, Department of Energy and Climate Change, UK
\textsuperscript{119} Ibid.
The type II Kerogen is mostly present in marine sediments and is deposited under reducing conditions\textsuperscript{122}.

**Type III Kerogen:** It is composed of terrestrial organic material which lacks in fatty or waxy components. The cellulose and lignin are the major contributors in forming this type of Kerogen. It is estimated that type III Kerogen has low hydrocarbon generative capacity as compared to type II Kerogen and, unless they have small inclusions of Type II material, they are normally considered to generate gas\textsuperscript{123}.

**Type IV Kerogen:** This principally contains organic debris and highly oxidized material of various origins. Type IV Kerogen is generally considered to have no hydrocarbon resource potential\textsuperscript{124}.

Kerogen undergoes very important changes, when subjected to high temperature and pressure over long periods of time. It is formed through thermal decomposition reactions called catagenesis and metagenesis, which break off small molecules and leave behind a more resistant Kerogen residue. These small molecules eventually become petroleum and natural gas. The term catagenesis refers to the stage of Kerogen decomposition during which oil and wet gas is produced while metagenesis, which follows catagenesis, represents dry gas generation\textsuperscript{125} (See Figure 9).

As Kerogen catagenesis takes place, small molecules are broken off the Kerogen matrix. Some of these are hydrocarbons, while others

\textsuperscript{122}Ibid
\textsuperscript{124}Ibid
are small hetero-compounds.

These small compounds are comparatively more mobile than the Kerogen molecules and are the direct precursors of oil and gas. Moreover, the hydrocarbon generation potential of Kerogen depends on the hydrogen content. The greater the hydrogen content, the greater the hydrocarbon yielded during cracking process.

It is estimated that erogen I, which is very rare has the highest hydrogen content. The type II Kerogens are also enriched with hydrogen content\textsuperscript{126}. However, the type III Kerogen has comparatively low hydrogen content as it contains extensive aromatic systems. The Type IV Kerogens, which mainly contain polycyclic aromatic systems, have the lowest hydrogen contents.

Therefore, type II and III Kerogens, which are prevalent in case of most shale depositions across the globe are considered as good potential source of hydrocarbon generation\textsuperscript{127}.

The identification of prospective area for Shale Gas formations is the most challenging step in identifying the recoverable shale gas resources. The criteria used for establishing the prospective area are dependent on the geochemical properties of the shale formations. The specific geochemical properties that are considered while identifying the production potential of shale gas include Total Organic Carbon (TOC), Gas Volume, Thermal Maturity, Permeability, Mineralogy, Depth and Petro-physical Data.

a) **Total Organic Carbon:** TOC is the total amount of organic material (Kerogen) present in the rock and expressed as a percentage (%) by weight. TOC governs the resource potential of shale. Hence, rocks having higher TOC values mean that it is rich in organic content. Generally, the exploration targets have TOC values in range of 2-10% (see Table 3) but rocks having TOC beyond 10% are usually too immature for development \textsuperscript{128}

\textsuperscript{126} Ibid
\textsuperscript{127} Leuschen, H. (2011). Black Sea Sediments
Table 3: Relationship between Total Organic Carbon and Resource Potential

<table>
<thead>
<tr>
<th>Total Organic Carbon, Weight (%)</th>
<th>Resource Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.5</td>
<td>Very Poor</td>
</tr>
<tr>
<td>0.5 to 1</td>
<td>Poor</td>
</tr>
<tr>
<td>1 to 2</td>
<td>Fair</td>
</tr>
<tr>
<td>2 to 4</td>
<td>Good</td>
</tr>
<tr>
<td>4 to 10</td>
<td>Very Good</td>
</tr>
<tr>
<td>&gt;10</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

b) **Thermal Maturity:** Thermal maturity is a measure of the degree to which Kerogen has been heated over the time and converted into liquid or gaseous hydrocarbons. Kerogen is the part of the organic matter present within the sedimentary rocks that is insoluble in organic solvents. The details of Kerogen and its types will be explained in detail in later part of the report. The thermal maturity is measured in vitrinite reflectance (Ro). Values of Ro vary from 0% to 3%. Ro values that exceed 1.5% indicate dry gas-generating source rocks indicate a positive sign of gas shales. However Ro range of 0.6% to 0.8% shows oil and ranges of 0.8% to 1.1% points to wet gas. However, Ro value below 0.6% shows that Kerogen is immature which means that the Kerogen has not been sufficiently exposed to thermal conditions over time that could have converted the organic material to hydrocarbons.\textsuperscript{129}

c) **Permeability:** The permeability to gas is one of the most complex properties to consider while characterizing the shales. It is the function of efficient porosity, mineralogy and hydrocarbon saturation. The permeability in case of unconventional reservoirs varies from 0.001 milliDarcies (mD)\textsuperscript{130} to 0.0000001 mD. The conventional reservoirs have


\textsuperscript{130} This is the unit of permeability
permeability that lies between hundreds of mD, which is many times greater than observed permeability in shales or unconventional reservoirs (See Figure 10).

**Figure 10 Permeability of Unconventional Resources, Source: Pour and Bryant, 2011**

**Mineralogy:** The mineralogy of the basin also plays a pivotal role in understanding the relation between fracture complexities, fracture conductivity, thereby determining the potential for gas recovery from the reservoir. The lesser the clay content, the greater will be the fracturing ability of shale or, in other words, the easier it would be to recover shale gas. Clay tends to absorb most of the pressure and bends under applied hydraulic pressure without breaking; however, the presence of silica or hard minerals enhances the ability of shale to fracture more easily.

**Depth:** The depth criterion for prospective area is greater than 1,000m, but less than 5,000m. Areas shallower than 1,000m have fundamentally low pressure and lower gas concentration coupled with the risk of high water content in their natural fracturing system. On the other

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hand, areas deeper than 5000m have risks of decreased permeability and higher drilling and development cost. Therefore, a depth greater than 1,000m and less than 5,000m is an ideal condition for shale gas development.\textsuperscript{134}

**Reservoir Pressure:** The pressure of fluids within the pores of reservoir is known as reservoir pressure or hydrostatic pressure. The reservoirs with abnormally high pore pressure are known as over pressured reservoirs. This phenomenon can occur in areas where the burial of fluid filled sediments is quite rapid and pore fluids cannot escape thus increasing the pressure of pore fluids. It is estimated that drilling in an over pressurized reservoir can be hazardous as excess pressure can cause the well to blow out or become uncontrollable during drilling. On the other hand, the reservoirs having pore pressure less than hydrostatic pressure are referred to as under pressured reservoirs. It is worth noting here that though the under pressure and normal pressure zones are considered as common areas or formations that have hydrocarbon production but severe under pressured reservoir can cause the drill pipe to stick to the formation. Hence, the reservoir pressure plays a pivotal role in recovery of hydrocarbons from these impermeable rock formations and in determining the intensity of fracturing pressure.\textsuperscript{135}

**Geophysics:** This plays an important role in planning of well path. It is estimated that high quality 3D seismic is critical for drilling the lateral in zone and achieving success in lateral placement. It is estimated that well performance is proportional to lateral length, at least for laterals up to 5000 m in length. Hence, the longer a well stays in zone, the higher the expected rate and reserves for that well. 3D seismic also plays an important role in mapping of the horizon below the objective shale. Therefore, a thorough understanding of the formation below the target shale is critical to successful extraction from the well.

**Petrophysical Data:** Petrophysical analysis plays an important role in understanding the low permeability reservoirs, enabling in turn the estimation of the hydrocarbon potential of these reservoirs. The primary data required for petro-physical analysis of shale formations are same as those used for analyzing the conventional reservoirs. The data includes gamma ray, resistivity and porosity. Like conventional reservoirs, the shale formations with significant hydrocarbon potentials indicate specific characteristics, which distinguish them from other shales having little or no hydrocarbon potential.\textsuperscript{136} 

\textsuperscript{134} KPMG. (2013). \textit{Shale Gas: A Global Perspective}. Global Energy Institute International

\textsuperscript{135} Reservoir Pressure. (2013). Oil Filed Glossary. Schlumberger

count in excess of 150 gAPI\textsuperscript{137}. However, some shale formations of Cretaceous, Mesozoic and Tertiary age may not display this property.

The other measurements include resistivity and porosity measurement enabling log analysts to identify potential gas bearing shales. It is estimated that the resistivity measurements in case of gas bearing shales are usually greater than the shales with little or no gas potential. Similarly, the porosity measurements also exhibit distinct characteristics in case of gas bearing shales. The organic shales exhibit high density porosity and low neutron porosity which are attributed to the presence of gas within the reservoir. The high density porosity is attributed to the presence of Kerogen which has lower bulk density than sandstone or limestone. This high density porosity is attributed to presence of Kerogen The low neutron porosity on the other hand is due to the presence of low clay-mineral content in organic rich shales as compared to conventional and other typical shales with little or no hydrocarbon potential\textsuperscript{138}.

The formation evaluation for characterizing the unconventional reservoir is heavily dependent on understanding the mineralogy of the rocks. This mineralogy and geochemical data can be analyzed using neutron induced gamma ray spectroscopy tools. This spectroscopy data also provides information regarding the clay types, which is then used to predict sensitivity to fracturing fluids and to understand the fracturing characteristics of formation. The clay type also indicates whether the rocks are ductile or brittle. The presence of smectite\textsuperscript{139} usually indicates the presence of ductile clay while the presence of illite\textsuperscript{140} identifies brittle rocks vulnerable to fracture.

Hence, these geologic and reservoir properties are used to provide a first order overview of the geologic characteristics of the major shale oil and gas formations and to help in selecting the shale oil and gas basins deemed worthy of more intensive assessment.

**Reservoir Engineering:** Reservoir engineers must forecast estimated ultimate recovery (EUR) for wells with limited production data from reservoirs with nano-darcy permeability and poorly understood fracture patterns. This is in contrast to the traditional micro-darcy tight gas sands with more predictable fracture half lengths. Development patterns vary from 20 acres to 160 acres, with variation even within the same shale. Typically, the reservoir engineer is asked to

\textsuperscript{137} Ibid.
\textsuperscript{138} Jiang,S.(2012). Clay Minerals from the Perspective of Oil and Gas Exploration. Chapter.2. INTECH
\textsuperscript{139} It is a type of Clay Mineral
\textsuperscript{140} Illite is non-expanding, clay sized micaceous mineral. It is phyllosilicate or layered alumino silicate
run the economics for the play. Even though shales are widespread over very large areas, not all areas are commercially attractive.\textsuperscript{141}

2.4 Developing Shale Gas

With reference to the characteristics and features of Shale Gas as discussed above, the exploration and development of Shale Gas consists of the following steps:

2.4.1 Drilling and Completion

A shale gas well is drilled in stages of decreasing diameter and increasing depth. The process of well drilling and completion is typically of several weeks duration. The holes are bored into the ground at a depth of 1,000-13,000 ft,\textsuperscript{142} thus allowing the production of natural gas from reservoir. There are two common types of drilling techniques used for natural exploration which are vertical drilling, directional drilling/horizontal drilling. These techniques have been explained briefly below:

**Vertical Drilling (Vertical Wells)**

The vertical wells are conventional wells that have been used extensively by the industry. It is estimated that vertical wells are cheaper to drill as compared to horizontal wells but the production from vertical wells may not be as economically lucrative in comparison to horizontal wells.\textsuperscript{143}

**Horizontal Drilling (Horizontal Wells)/Directional Drilling**

It is the process of drilling wells from the surface to a subsurface location above the target reservoir called “Kickoff Point”. The well bore is then deviated from a vertical plane around a curve to intersect the reservoir at the “entry point” with a near horizontal inclination and remaining within the reservoir until the desired bottom hole location is reached.\textsuperscript{144} Directional drilling on the other hand is more or less similar to horizontal drilling and drilled to achieve the same goals and objectives. Although both kinds of wells may be used to extract natural gas from shale, operators are progressively relying more on horizontal wells due to more exposure to a formation that achieved with a vertical well. For instance, typically in shale formations, a

\textsuperscript{142} Zurich.(2011). Balancing the Opportunities and Risks of Shale Gas Exploration. Zurich American Insurance Company
\textsuperscript{144} Zurich. (2011). Balancing the Opportunities and Risks of Shale Gas Exploration. Zurich American Insurance Company
vertical well may be exposed to 50 ft of formation while a horizontal well may be exposed to a lateral length from 2,000 to 6,000 ft\textsuperscript{145} of the formation, thus allowing the gas to be produced from various zones in the formations, which increases the rate of production considerably.

However, the selection of drilling technique depends on a number of factors, which have to be analyzed by drilling engineers before the process begins. These factors include objectives of the project, location of the target reservoir, target depth, budget, and geology of reservoir system, permeability and anticipated environmental constraints.\textsuperscript{146} It is estimated that horizontal wells are a preferred choice when the reservoir is located beneath a major surface obstruction, such as mountain or other topographical features that may hinder with the preparation sites required for vertical drilling. Similarly geology of reservoir also determines the type of drilling technique to be used. A horizontal well is less effective than a vertical well when the geology of a reservoir is lenticular. In the same manner, if the reservoir is of a blanket type then vertical well is less effective than a horizontal well.\textsuperscript{147} The drilling process for shale gas development is explained in detail in \textbf{Figure 11}:


2.4.2 Hydraulic Fracturing

Hydraulic fracturing (commonly known as “fracking”) or stimulation is a process of transmitting pressure by fluid or gas to create cracks or to open existing cracks in hydrocarbon bearing rocks. The need for this technique has evolved due to low permeability of hydrocarbon bearing rocks. Therefore, the fundamental purpose of hydraulic fracturing is to enable oil and gas to flow more easily from the formation to well bore. This stimulation technique intends to improve the permeability of rocks from about 0.0001 millidarcy (mD) to about 1,000mD for

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enabling the hydrocarbons to flow easily. The type of hydraulic fracturing used depends on a number of variables:

- Type of the well that has been drilled (horizontal or vertical)
- Rock Properties of the potential reservoir
- Depth, thickness, temperature and pressure of reservoir
- Well Construction: Type of well bore and cementing
- Number of fractures to be completed in the well bore
- Choice of fracturing fluids and materials
- Cost of fracturing and material

Once the well is drilled and cased to the target depth, perforations are made in production casing to make entry points through which the fracturing fluid and proppant can enter into the targeted hydrocarbon zone. The number and orientation of perforations are predetermined and pre designed to intersect the natural fracture system and later on similar perforations allow the gas to enter into the well. The hydraulic fracturing equipment is then brought to the surface and connected to the well bore to initiate the process.

The process of hydraulic fracturing is extremely equipment intensive. The fracturing equipment consists of pumping units, blending units, control units and adequate supplies of fracture fluid and proppant material. The selection of hydraulic fracture fluid is directly related to the reservoir properties. Although water based fluids are more common, some reservoir rocks have water sensitive clays and in that case other fluids are used. Other types of fracturing fluids include gases such as carbon dioxide, nitrogen, propane and other oil based fluids. 99.5% of the hydraulic fracturing fluid consists of mostly water and sand or ceramic particles (proppant) and 0.5-1% constitutes chemical additives (See Figure 12). The number of chemicals and their concentrations added to the fluid proppant mixture can vary greatly and can also depend on specific properties of the reservoir.


\[150\] Canadian Society for Unconventional Gas.(2010). Understanding Hydraulic Fracturing. Canada


\[152\] Ibid.
The process includes mixing the fluids with a small amount of chemicals and then feeding it into fluid pumpers from where it is injected into the well bore. The fluid is injected into the well bore by an array of trucks fitted with high-pressure pumps, at a pressure of 50 Milli Pascals (MPa) or greater. The fracturing pressure must be greater than the stress within the reservoir rock (known as tectonic stress) but within the pressure rating of the wells and the fracturing equipment. Once a fracture has been initiated, an increasing amount of power is required to extend the growth of fracture\(^{153}\). It is worth noting here that this increasing power is supplied by the rate at which fluid is pumped and the fracture fluid’s ability to keep the crack open as the fracture grows in length (See Figure 13).

\(^{153}\) Canadian Society for Unconventional Gas.(2010). Understanding Hydraulic Fracturing. Canada
Figure 13: Hydraulic Fracturing Process (Source: Bipartisan Policy Center and American Clean Skies Foundation, 2011)

After this initial fluid fracture load, a fluid/proppant mixture is pumped in to open fractures to keep them open by depositing the proppant in the fractured network. The fractured fluids then flow back to the surface when the treatment is completed. It is estimated that around 15-50%\textsuperscript{154} of the hydraulic fracturing fluid is recovered and that it is either recycled for other hydraulic operations or disposed according to environmental rules and regulations.

After fracturing, the well is depressurized to create a gradient so that the gas flows out of the shale reservoir into the well. The fracturing fluid flowing back to the surface at the same time (flowback water) also constitutes saline water from dissolved minerals in shale formations (Formation Water). Afterwards, the fracturing fluid and formation water returns to the surface over the lifetime of the well (produced water) and gas flows into the well.\textsuperscript{155}

2.5 Life Cycle

The life cycle of Shale Gas consists of six major steps for the production of gas. These steps are discussed below.

\textsuperscript{154} Canadian Society for Unconventional Gas.(2010). Understanding Hydraulic Fracturing, Canada

Table 4 Life Cycle of Shale Gas

<table>
<thead>
<tr>
<th>i. Site Preparation</th>
<th>ii. Drilling</th>
</tr>
</thead>
<tbody>
<tr>
<td>This activity deals with clearing the site for building of access routes, excavation, construction and installation of well pads.</td>
<td>Natural gas does not flow to vertical wells because of low permeability of shales. This is overcome by drilling horizontal wells where drill is steered from vertical trajectory to horizontal trajectory (for 1 to 2km), thus exposing the wellbore to as much of reservoir as possible.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>iii. Completion</th>
<th>iv. Flow back</th>
</tr>
</thead>
<tbody>
<tr>
<td>As the drilling ends, multiple cement and metal layers are placed around the wellbore. After the completion of well, a fluid consisting of water, chemical is injected at high pressure to crack shale, which increases the permeability of the rock and the flow of natural gas.</td>
<td>A portion of the fracturing fluid is returned through the well to the surface due to the pressure at subsurface. The volume of fluid reduces gradually and is then replaced with natural gas production.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>v. Production</th>
<th>vi. Distribution of Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fissures created during the fracking process are kept open by the sand particles so that the natural gas within the shale can flow through the well. Once the gas is released through the well, it is captured, stored and then transported for processing.</td>
<td>Natural gas is distributed within the region to fulfill the energy demands.</td>
</tr>
</tbody>
</table>

Source: Accenture, 2012

The life cycle activities of Shale Gas are further explained in the Figure 14 along with the expected time required for the production of shale gas. Site preparation takes the maximum time whereas drilling time can vary from 15 to 60 days\(^{156}\). The fracking process takes even

\(^{156}\) Accenture. (2013). *Water and Shale Gas Development: Leveraging the US Experiences in New Shale Developments*
fewer days than drilling and the flowback activity is purely for the treating the fracking fluids and to capture and store the natural gas that is produced by fracking.

The production of natural gas from a single well is likely to be five years or if a shale reservoir is rich in organic material, natural gas is likely to be produced natural gas for about 40 years\textsuperscript{157}.

\begin{figure*}[h]
\centering
\includegraphics[width=\textwidth]{figure14.png}
\caption{Life Cycle Activities of Shale Gas}
\end{figure*}

\textsuperscript{157} Ibid.
Chapter No 3
Shale Resources of Pakistan

3.1 Geology of Pakistan

Pakistan is blessed with a diverse topography encompassing different forests, plateaus, deserts and hills. It encompasses two main sedimentary basins i.e Indus Basin and Baluchistan Basin. These basins developed during different geological episodes, which were finally welded together during Cretaceous/Paleocene along Ornach Nal/Chaman Strike slip faults (see Figure 16).\(^{158}\) There is another newly identified

basin named as Kakar Khorasan Basin which is also termed as Pishin Basin. The geological history of Indus basin comes from the Precambrian Age. The Indus Basin consists of the Upper Indus Basin, Kohat sub-Basin, Potwar sub-Basin, Lower Indus Basin, Central Indus Basin, Southern Indus Basin, as tabulated below. The generalized stratigraphy of the above mentioned basins of Pakistan is shown in Figure 16.

<table>
<thead>
<tr>
<th>ERA</th>
<th>BASIN</th>
<th>SOUTHERN INDUS</th>
<th>CENTRAL INDUS</th>
<th>NORTHERN INDUS</th>
<th>BALOCHISTAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>CENOZOIC</td>
<td>QUATERNARY</td>
<td>Kirolak</td>
<td>Siwalks</td>
<td>Omara</td>
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<tr>
<td></td>
<td>Pliocene</td>
<td></td>
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<td>Chatti</td>
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<td>TERTIARY</td>
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<td>Kamlial</td>
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<td>Kirthar</td>
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<td></td>
<td>Ranikot</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lockhart / Hangu</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rakshani</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mesozoic</td>
<td>Upper</td>
<td>Pab</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cretaceous</td>
<td>Mughal Kot</td>
<td>Mughal Kot</td>
<td></td>
<td></td>
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<tr>
<td></td>
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<td>Parh</td>
<td>Parh</td>
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<td></td>
<td>Lumshiwal</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Sinjrani</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower</td>
<td>Goru</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jurassic</td>
<td>Upper</td>
<td>Takatu / Chiltan</td>
<td>Samana Suk</td>
<td>Samana Suk</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Middle</td>
<td>Loralai / Delta</td>
<td>Shinawari</td>
<td>Shinawari</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower</td>
<td>Shirinab</td>
<td>Data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Triassic</td>
<td>Upper</td>
<td>Wulgai / Alozai</td>
<td>Kingriali</td>
<td>Kingriali</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Middle</td>
<td>Tredian</td>
<td>Tredian</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower</td>
<td>Mianwali</td>
<td>Mianwali</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Paleozoic</td>
<td>Permian</td>
<td>Zaluch</td>
<td>Wargal</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sardhai</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Nilawhan</td>
<td>Warcha</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dandot</td>
<td>Tobra</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cambrian</td>
<td>Baghanwala</td>
<td>Baghanwala</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Juttana</td>
<td>Juttana</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Kussak</td>
<td>Kussak</td>
<td>Khewra</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Precambrian</td>
<td>Khewra</td>
<td>Khewra</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Salt Range</td>
<td>Salt Range</td>
<td>Salt Range</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jodhpur</td>
<td>Jodhpur</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Basement</td>
<td>Basement</td>
<td>Basement</td>
<td></td>
</tr>
</tbody>
</table>

Figure 16: Stratigraphy of Pakistan, Source: University of Karachi, 2009

Figure 16 shows the different formations present within the Pakistan basins. Unconventional rocks are highlighted in orange while conventional rocks are highlighted in green. However, the unidentified or the absent rocks have been highlighted in maroon. The figure 16 indicates that the major formations are Sembar and Ranikot Formations, which are found in Southern and Central Indus Basins. Moreover, a number of other formations indicating unconventional rocks are also present within Northern and Baluchistan Basins. The most important Basin in terms of unconventional rocks is within the Central Indus. The following section will give more details of each Basin found in Pakistan so that a better understanding is gained of shale-based gas production with reference to the geology of each basin.

a) Upper Indus Basin

This Basin is situated in the North of Pakistan and is separated from Lower Indus Basin by Sargodha High. The eastern and northern boundaries coincide with the Main Boundary Thrust (MBT)-the southern most of the major Himalayan thrusts. The MBT runs through Kohat Ranges, Margala Hills and Kala Chitatta. The Western boundary of this Basin is marked by an uplift of Pre-Eocene sediments. The Basin is additionally subdivided into Potwar, River Indus (in west) and Kohat (in east) (see Figure 17).^{160}

Potwar and Kohat sub basins are smaller in size but they show significant variations. Potwar sub-basin preserves the sediments from Quaternary and Precambrian age in the subsurface. However, the Trans-Indus Ranges that are to the south of Kohat sub-Basin shows sediments from Pliocene and Cambrian age. In other words both the sub-basins are characterized by an non conformity between the Permian and the Cambrian.\footnote{Fatmi, A.N. (ed.). (1974). Lithostratigraphic units of the Kohat Potwar Province, Indus Basin Pakistan. Geological Survey of Pakistan} The generalized stratigraphy of Upper Indus Basin in terms of oil and gas production, source rock potential and limestone, gypsum, sandstone, shale and granite deposition is shown in Figure 18.
Figure 18: Generalized Stratigraphy of Upper Indus in terms of Oil and Gas Production, Source: US Geological Survey, 2004

b) **Lower Indus Basin**

The Central and Southern Indus Basins are separated by Mari Kandhkot highs and Jacobabad which is together known as Sukkur Rift. Mari Kandhkot Highs has been active since Jurassic times and at least up to Paleocene. The Basin is subdivided into Central and Southern Indus Basin.

i. **Central Indus Basin**

This Basin is separated from Upper Indus Basin by Sargodha High and Pezu uplift in north. It is locked by Indian Shield present to the east with marginal zone of the Indian Plate in West and Sukkur Rift in the South. It contains oldest rocks from Triassic age but the oldest rocks that have been pierced through drilling are of Precambrian Salt Range

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Formation on Punjab Platform. In the trough areas, the depth to the basement is about 15,000m. This Basin from East to West comprises three main units which are Punjab Platform, Sulaiman Depression and Sulaiman Foldbelt. Figure 19 clearly shows the cross section of Central Indus Basin.

Figure 19: Regional Cross Section of Central Indus Basin, Source: US Geological Survey, 2004

- **Punjab Platform**
  Punjab Platform is the eastern segment of the Central Indus Basin. From tectonics standpoint it is a broad monocline that dips gently towards the Sulaiman Depression. However it is the least affected area (tectonically) because of the greater distance from the collision zone. This results in larger stratigraphic variations.

- **Sulaiman Depression**
  This depression like any other depression was also formed as a result of the collision between two plates. To the Western flank of the depression is located the Zindapir Inner Folded Zone with Mari Bugti Inner Folded Zone to the South and merging in to the Punjab Platform to the East. The seismic data of the area reveals that there are some buried anticlines (e.g Ramak) which may have been formed at the expense of flow of Eocene shales.

- **Sulaiman Fold Belt**
  Sulaiman Fold Belt has the main tectonic feauture in proximity of the collision zone. The decollement zone in this part is possibly due to shales which are unlike those seen in Upper Indus Basin. The most significant lithostratigraphic variations seen in Sulaiman

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Depression and the Fold Belt are in Paleocene/Eocene. This period marks the facies that changes from North to South and then from East to West.\(^{165}\)

ii. Southern Indus Basin

The Southern Basin as the name indicates is located just in the South of the Sukkur Rift-a divide between Central and Southern Indus Basins. This Basin is bounded by the Indian Shield to the East with the Indian Plate located to the West. The oldest rocks in this area are from the Triassic age.\(^{166}\) This Basin contains four main units which are as follows:

- **Thar Platform**

  Thar Platform is different from Punjab Platform as it shows that the buried structures are formed due to extension tectonism which resulted because of the counter-clockwise movement of Indian Plate. The East side of Thar Platform is bounded by Indian Shield, which merges into Kirthar and Karachi. Similarly troughs are present in the West while in the North it is bounded by Mari-Bugti Inner Folded Zone. Additionally, this platform has a fine development of Early/Middle Cretaceous Sands which are the reservoirs of oil and gas fields.\(^{167}\)

- **Karachi Trough**

  Karachi Trough is characterized by thick Early Cretaceous sediments and also marks the last stages of marine sedimentation. Moreover this area preserves Early, Middle and Late Cretaceous rocks.\(^{168}\) The most intriguing feature is that it has continuous deposition across Cretaceous/Tertiary (K/T) boundary wherein Korara Shales were deposited, the basal part of which represents Danian sediments. The common feature of K/T boundary are the deposits of laterites, coal, bauxite etc.\(^{169}\)

- **Kirthar Foredeep**

  It has a faulty eastern boundary with Thar Platform. Sedimentation has been continuous in this depression. Paleocene seems very well developed in this depression but is missing from Khiarpur-Jacobabad High area. Moreover it is similar to Sulaiman Depression as it has considerable potential for the maturation of source rocks.\(^{170}\)

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167 Ibid.
170 Ibid.
• **Kirthar Fold Belt**

Kirthar Fold Belt in North-South has same trending tectonic characteristics like the Sulaiman Fold Belt in terms of stratigraphic equivalence and structural style. However, the West part of this fold is adjacent to Balochistan basin while Western boundary is associated with hydrothermal activities which resulted in the formation of economic mineral deposits of Lead, Manganese, Fluorite, Zinc and Baryte.\(^{171}\)

• **Offshore Indus**

Offshore Indus is part of passive continental margin which appears to have gone through two distinct phases of geological history i.e Cretaceous-Eocene and Oligocene-Recent. Sedimentation in offshore Indus area started in Cretaceous time.\(^{172}\) Moreover, it is divided into Platform and Depression along Hinge Line.

**Kakar Khorasan Basin (Pishin Basin)**

This Basin is separate from Baluchistan and Indus basin, which has evolved through different geological processes. It is located between the Chaman Fault in North and the Indian Plate in the South. This Basin was formed between the leading edges of Eurasian and Indian Plates during the path of their coalescence and the Tertiary sedimentary fill which is most likely underlain by the oceanic crust. This is definite with the presence of ophiolites and its southern border and existence of Precambrian basement in the North in Helmund and Kabul blocks. As the Basin is very immature, the majority of the sedimentary sequence is dominated by younger (Post-Eocene) flysch like the stratigraphic units of the Balochistan Basin.\(^{173}\)

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\(^{172}\) Butt, A.A. (1986). *Plate Tectonics and the Upper Cretaceous biostratigraphic synthesis*. Mineralogical Pakistan

3.2 Shale Resources in Pakistan

Pakistan has more than 827,365 Km\(^2\) sedimentary basin area(611,307 Km\(^2\) Onshore & 216,058 Km\(^2\) off shore) against the total area of 796,095 Km\(^2\). This sedimentary area is enriched with thick sequence of shale formations as a source and has a proven petroleum system. A significant amount of gas has been trapped within the unconventional reservoirs including tight gas, coal bed methane and shale gas apart from oil and gas resources within the conventional reservoirs. The conventional gas reservoirs have been explored and developed in Pakistan; however very little work has been done so far in developing these unconventional reservoirs. It is estimated that apart from proven conventional gas reserves, the country has been bestowed with approximately 200Tcf of unconventional gas resources within the shale formations. The studies conducted by PacWest Consulting Partners(2011) have identified that approximately 70% area of Pakistan is covered by Shale Gas (See Figure 20).

Box 2: Shale Gas and Future of Pakistan

The recent estimates of Shale Gas reserves in Pakistan are enough to cater to the energy needs of Pakistan for the next 44 years (including current gas reservoir) while shale oil is enough for 61 years (including domestic oil production), provided the strategic and wise allocation of these resources, thus bringing prosperity within the country.

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174 The assessment has been made on the basis of gas demand of 2.9TCF/annum and Oil demand of 125.54 million barrels/annum
175 Sedimentary Area in Pakistan,(2010), Internal documents of Ministry of Petroleum and Natural Resources (MPNR).
176 Ibid
177 Unconventional Resources in Pakistan,(2012). Internal Documents of Ministry of Petroleum and Natural Resources (MPNR).
178 Assessment of Unconventional Resources in Pakistan,(2011). PacWest Consulting Partners
The study highlights that shale has been distributed throughout the upper, middle, lower Indus, Baluchistan and Offshore basins as thick sequence. It is estimated that most of the shale resources are in mature stage for hydrocarbon generation and are estimated to be thicker than the shale plays in North America. Therefore, these shale resources in Pakistan have potential to become good resource play. Jadoon (2011) in his study on Sembar, Ghazij and Talhar formation identifies that Pakistan on average has Shale Gas ranging from 180-210 Tcf.

The Exploration Department in Pakistan is also concerting their efforts towards harnessing this resource potential, and they are especially focusing on shales of Lower Goru Formation namely Turk Shale, Badin Shale, Jhole Shale, Upper Shale, Shales of Middle Sands, Lower Shale, Shales of Basal Sand, Talhar Shale and Shales of Massive Sands in Lower Indus Basin. It is estimated that based on the available data (mu log, gas logs, wireline logs and geochemistry), most of the shales indicate encouraging results regarding Shale Gas, Shale Oil, Oil Shale and Tight Gas Potential\textsuperscript{179}.

In addition to the abovementioned formations, initial work regarding wells for Shale Gas, Shale Oil, Oil Shale and Tight Gas has been started on Patala, Chichali, Datta, Kingriali, Mianwali, Dandot/Sardhai, Kussak, Shales of Salt Range(upper Indus Basin), Warchha, Sembar, Shales of Lower Goru(Middle Indus Basin), Shales of Rakhshani, Wakai, Kharan, Hosab and Panjgur Formations(Baluchsitian Basin) and Shales of Sembar and Ranikot(Off Shore).

The recent estimates by EIA Assessment have shown that the total Shale Gas reserves in Pakistan are estimated around 586 Tcf. However, the technically recoverable shale gas resources are close to 100-105 Tcf. In addition to this, the shale oil reserves of approximately 227 billion\textsuperscript{180} barrels have also been found in Pakistan, and the technically recoverable shale oil reserves for Pakistan are estimated around 9.1 billion barrels (See Figure 21).

\textsuperscript{179} Internal Documents of Ministry of Petroleum and Natural Resources (MPNR).
\textsuperscript{180} EIA. (2013). EIA/ARI World Shale Gas and Shale Oil Resource Assessment: Technically Recoverable Shale Gas and Shale Oil Resources: An Assessment of 137 Shale Formations in 41 Countries outside the United States, Advanced Resources International, Inc
It is worth mentioning that a comprehensive and rigorous analysis of the available data of the shale source rock and petroleum systems needs to be carried out in detail. In addition to this, a detailed and inclusive assessment of Upper, Middle, Lower Indus Basin, Baluchistan and Offshore Basins by developing geological, petrophysical, geophysical and geo mechanical models are required for identifying the prospective areas for developing shale plays.

### 3.3 Resource Assessment Methodology

The assessment of shale oil and gas resources has been adopted from a joint study conducted by U.S. Department of Energy and Advanced Resources International (ARI). The methodology for conducting the basin- and formation-level assessments of Shale Gas and shale oil resources includes the following steps:

1. Conducting preliminary geological and reservoir characterization of shale basins and formation(s).
2. Establishing the areal extent of the major shale oil and gas formations.
3. Defining the prospective area for each shale oil and gas formation.
5. Calculating the technically recoverable shale oil and gas resource.

Box 3: Shale Reserves in Pakistan

Recent estimates have identified that Pakistan has approximately 11,720 MillionTons of Oil Equivalent (MTOE) of Shale Gas and of 31,780 MTOE shale oil reserves, which need to be confirmed by the companies operating in the respective areas. These reserves, if tapped, have the potential to determine a new economic era in the history of Pakistan, by not only catering the mounting energy demands, but also making it a self-sufficient and energy secure country. Interestingly, shale oil and gas and reserves in Pakistan, if recovered are greater than the collective reserves of all Central Asian States (See Table below).

<table>
<thead>
<tr>
<th>States</th>
<th>Gas Tcf</th>
<th>Gas MTOE</th>
<th>Oil Million Barrels</th>
<th>Oil MTOE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kazakhstan</td>
<td>85</td>
<td>1700</td>
<td>30,000</td>
<td>4200</td>
</tr>
<tr>
<td>Krgystan</td>
<td>0.2</td>
<td>4</td>
<td>40</td>
<td>5.6</td>
</tr>
<tr>
<td>Turkumanistan</td>
<td>280</td>
<td>5600</td>
<td>600</td>
<td>84</td>
</tr>
<tr>
<td>Tajistiskan</td>
<td>0.2</td>
<td>4</td>
<td>10</td>
<td>1.4</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>66</td>
<td>1320</td>
<td>594</td>
<td>83.16</td>
</tr>
<tr>
<td>Total</td>
<td>431.4</td>
<td>8,628</td>
<td>31,224</td>
<td>4,374.16</td>
</tr>
<tr>
<td>Pakistan</td>
<td>586</td>
<td>11,720</td>
<td>227,000</td>
<td>31,780</td>
</tr>
</tbody>
</table>

This would eliminate the need of importing the energy from these states. It is also pertinent to highlight here that the energy sovereignty of Pakistan lies in strategic use of these unrecovered resources, rather than consuming them recklessly as we did with ‘Natural Gas’. The strategic and wise use of these resources could mark a new economic era leading to peace and prosperity in Pakistan.

The shale reserves in Pakistan are restricted to Southern and Central Indus Basin (Lower Indus Basin), which is located along the Western border with India and Afghanistan. The Basins are bound by the Indian shield on East and highly folded mountains on the West.

Hence, the Lower Indus basin has two types of shale formations, which are Sembar and Ranikot formations and each is discussed in detail below:

3.4 Geological Characteristics of Shale Basins in Pakistan

At the beginning of the chapter, it has been discussed that the unconventional rocks are mostly found in the Lower Indus Basin. This section details the properties of both Sembar and Ranikot formations located within the Lower Indus Basin.

3.4.1 Sembar Formation

The Sembar Formation was deposited in a passive margin setting with sediments supplied from Indian Continent to the South East. It mainly consists of clastic rocks, typically shale with lesser quantities of siltstone and sandstone in the Lower Indus. The sand content increases towards the Southeast in the Lower Indus Basin. However, in the Middle Indus Basin, the formation is composed of siltstone with few marl and shales. Similarly in the Eastern part of the Sulaiman Foldbelt, it becomes sandy within the lower part while in the basal section, phosphatic nodules,
pyritic and sandy shales are developed. Shale in Sembar Formation is basically medium hard, pyritic, moderately indurated and slightly calcareous in the area. The gross thickness varies from >50m to <800m. This thickness increases from East to the West. On the other hand the subsurface depth varies from >1000m to <5000m, and this depth increases towards Foredeeps\(^{183}\). In Punjab Platform and Lower Indus, the depth varies from 1000 to 4000m\(^{184}\). Likewise, Sulaiman and Kirthar Foredeeps have <5000m depth while the depth of Sulaiman and Kirthar Forebelts ranges between 1000 to 3000m.

Hence, the lower Cretaceous Sembar Formation shales tend to have low clay content and high brittle component responding more favorably to hydraulic stimulations as compared to the formations with higher clay content (See Table 5). The recent estimates by EIA have assessed approximately 31,320 mi\(^2\) prospective area for dry Sembar Shale Gas (Ro >1.3%), a 25,560 mi\(^2\) prospective area for wet and condensate (Ro between 1.0% and 1.3%), and a 26,700-mi\(^2\) prospective area for oil (Ro between 0.7% and 1.0%) against the massive area of 91,000-mi\(^2\) covered by Lower Indus Basin.

<table>
<thead>
<tr>
<th>Basin/Gross Area</th>
<th>Properties of Shale Gas</th>
<th>Properties of Shale Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shale Formation</td>
<td>Sembar</td>
<td>Sembar</td>
</tr>
<tr>
<td>Basic Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geologic Age</td>
<td>L. Cretaceous</td>
<td>L. Cretaceous</td>
</tr>
<tr>
<td>Depositional Environment</td>
<td>Marine</td>
<td>Marine</td>
</tr>
<tr>
<td>Physical Extent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prospective Area(mi(^2))</td>
<td>31,320</td>
<td>25,560</td>
</tr>
<tr>
<td>Organically Rich Thickness(ft )</td>
<td>1,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Net</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Interval</td>
<td>10,000-16,400</td>
<td>6,000-10,000</td>
</tr>
<tr>
<td>Average</td>
<td>13,000</td>
<td>8,000</td>
</tr>
<tr>
<td>Reservoir Properties</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>Reservoir Pressure</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>Average TOC (wt.%)</td>
<td>2.00%</td>
<td>2.00%</td>
</tr>
<tr>
<td>Thermal Maturity (% Ro)</td>
<td>1.50%</td>
<td>1.15%</td>
</tr>
<tr>
<td>Clay Content</td>
<td>LOW</td>
<td>LOW</td>
</tr>
</tbody>
</table>


\(^{185}\) Ibid
It is estimated that TOC is the fundamental characteristic defining the hydrocarbon potential of the reservoir. The Table 5 identifies that the TOC and thermal maturity (Ro) of Sembar formation as per exploration targets is around 2% and 1%-1.6% respectively. The thermal gradients in the basin increase from east to west, from 1.31°F/100 ft on the Thar Slope in the east to 2.39°F/100 ft in the Karachi offshore in the west. The average thermal gradient in the Basin is 2.1°F/100 ft. It is apparent from Table 5 that the properties of the reserves are subjected to variation with reference to changes in the depth of the reservoir. The greater the depth, the better is the thermal maturity likely to be as in the case of shale oil within the Sembar formation where the depth of 10,000-16400 m is characterized by thermal maturity (% Ro) of 1.15% (see Error! Reference source not found.) which is greater than 1.15% and 0.85% obtained at the depth of 6000-10,000 m and 4,000-6,000 m. A similar trend has been observed in gas reserves within Sembar formation. However, the TOC (wt.%) and clay content of the reservoir do not undergo any change with varying depth. The oil and wet gas windows within the Sembar Shale are present in the Lower Indus portion. The lower limit of the oil window is around 3500-4,000 ft, of the wet gas/condensate window at 6,000 to 10,000 ft and of the dry gas window at 10,000 ft (See Error! Reference source not found.).

**Box 4: Geology of Kohat-Potwar**

In the Kohat Basin of Upper Indus, sediments were selected for analyzing the TOC and HI to determine the type of kerogen. Among these, Patala and Hangu Formations were found with good TOC and HI indicating Kerogen type II and III. Patala Formation has an HI in the range of 182-347 mg/g. Similarly Hangu Formation showed rich organic sediments with TOC of 2.3% and HI was 257 mg/g.¹⁸⁷

<table>
<thead>
<tr>
<th>Resource</th>
<th>Porosity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Phase</td>
<td>5-7%¹⁸⁶</td>
</tr>
<tr>
<td>GIP Concentration (Bct/mi²)</td>
<td></td>
</tr>
<tr>
<td>Risked GIP(Tcf)</td>
<td>82.7</td>
</tr>
<tr>
<td>Risked Recoverable (Tcf)</td>
<td>57</td>
</tr>
</tbody>
</table>

Source: EIA/ARI, 2013

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¹⁸⁷ Chapter 2. 2009. Geological Settings and Descriptions of Samples


The recent estimates by EIA have identified the oil and gas prone areas in Sembar formation depending upon the Kerogen type present within the area. It is estimated that the oil window is present in areas of Jacobabad, Shikarpur, Sukhur, Khairpur, Larkana and Dadu. The wet gas window is concentrated in Sibi, Nawabshsh, Mirpurkhas and its surrounding areas (See Figure 20).

The areas including Quetta, Karachi, Hyderabad and including other nearby areas are characterized by dry gas window. There are also some areas enriched with both wet and dry gas; these areas include Dera Gazi Khan, Rahim Yar khan and Sadiqabad.

Thus, the EIA assessment highlights that the Sembar in Lower Indus Basin has an estimated resource potential of 83Bcf/mi$^2$ of dry gas, 57 Bcf/mi$^2$ of wet gas and 9 million barrels/mi$^2$ of condensate against the 31,320-mi$^2$ dry gas prospective area and 25,560-mi$^2$ wet gas and condensate prospective area. In the case of shale oil, a resource potential of 37 million barrels/mi$^2$ has been estimated in Sembar Shale within the 26,700 mi$^2$ oil prospective area. Within the overall prospective area of the Lower Indus Basin, the Sembar Shale has risked Shale Gas in-place of around 525- 531 Tcf, with 90-101 Tcf as the risked, technically recoverable Shale Gas resource. In addition, the Sembar Shale has a potential of 145 billion barrels of shale oil in place, with 5.8 billion barrels as the risked, technically recoverable shale oil resource, which estimates need to be confirmed by companies operating in respective areas.

Figure 22: Sembar Shale Formation, Source: EIA/ARI, 2013
3.4.2 Ranikot Formation

The shale in Paleocene Ranikot Formations is primarily upper carbonate unit, which is tailored with fossiliferous limestone inter-bedded with dolomitic shale, calcareous sandstone and abundant bituminous material. The upper unit has been deposited in a restricted marine environment, and therefore, the Ranikot formation in West of Karachi Trough axis is predominantly shale (Korara Shale) with deep marine deposition. The southern portion of the Lower Indus Basin for Ranikot Shale has been characterized by 26,780 mi² for prospective oil (Ro of 0.7% to 1.0%). While the Eastern, Northern and Western boundaries of the Ranikot Shale prospective area are set by the 300 misopach contour; the Southern boundary of the prospective area is the offshore\textsuperscript{190}.

The prospective area of the Ranikot formation has a thickness of around 1,000-3,000ft with net shale thickness of 200 ft (See Table 6).

<table>
<thead>
<tr>
<th>Table 6: Properties of Shale Gas and Oil within Ranikot Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Basic Data</strong></td>
</tr>
<tr>
<td>Shale Formation</td>
</tr>
<tr>
<td>Geologic Age</td>
</tr>
<tr>
<td>Depositional Environment</td>
</tr>
<tr>
<td><strong>Physical Extent</strong></td>
</tr>
<tr>
<td>Prospective Area(mi(^2))</td>
</tr>
<tr>
<td>Organically Rich Thickness(ft)</td>
</tr>
<tr>
<td>Net</td>
</tr>
<tr>
<td>Interval Depth(ft)</td>
</tr>
<tr>
<td>Average</td>
</tr>
<tr>
<td><strong>Reservoir Properties</strong></td>
</tr>
<tr>
<td>Reservoir Pressure</td>
</tr>
<tr>
<td>Average TOC (wt.%)</td>
</tr>
<tr>
<td>Thermal Maturity (% Ro)</td>
</tr>
<tr>
<td>Clay Content</td>
</tr>
<tr>
<td>Porosity</td>
</tr>
</tbody>
</table>

The TOC in this type of shale formation is estimated around 2% and thermal maturity is around 0.75-1.0%\textsuperscript{191}, placing the Ranikot formation in oil window (See Figure 23).

According to an EIA assessment, the Ranikot Shale has estimated resource concentration of around 17 Bcf/mi\textsuperscript{2} of wet gas and 25 milion barrels/mi\textsuperscript{2} of shale oil/condensate against the 26,780 mi\textsuperscript{2} wet gas and condensate prospective area. Within this prospective area of the Lower Indus Basin, the Ranikot Shale has 52- 55 Tcf of risked Shale Gas in-place and 80-82 billion barrels of risked shale oil in place. The risked, technically recoverable shale resources of the

\textsuperscript{191} Ibid
Ranikot Shale are estimated around 4 Tcf of wet Shale Gas and 3.3 billion barrels of shale oil/condensate. It is important to note that the estimates of resource potential should be further confirmed by companies operating in these respective areas.

In addition to resource identification, the EIA has also assessed the play and prospective areas success factor for Ranikot, which is estimated to be around 40% and 30%. The play success probability factor identifies the likelihood of significant portion of oil and gas at attractive flow rates form shale formations and the possibility of developing these shale plays. The formations with limited geologic and reservoir data may have a success factor of 30-40% but as exploration wells are drilled, tested and produced and information on viability of shale oil and gas play is established, the play success factor will change.

The prospective area success factor is the estimation of concerns as to whether a portion of prospective area could turn out to be unsuccessful or unproductive for shale oil and gas. These concerns include areas with high structural complexity (e.g., deep faults, upthrust fault blocks), areas with lower thermal maturity (Ro between 0.7% to 0.8%), the outer edge areas of the prospective area with lower net organic thickness and other information appropriate to include in the success (risk) factor. The prospective area success (risk) factor also captures the amount of available geologic/reservoir data and the extent of exploration that has occurred in the prospective area of the Basin to determine what portion of the prospective area has been sufficiently “de-risked”. As exploration and delineation proceed providing a more rigorous definition of the prospective area, the prospective area success (risk) factor will change. These two success/risk factors are combined to derive a single composite success factor with which to risk the OIP and GIP for the prospective area. For instance, the composite success factor for Sembar and Ranikot is estimated around 12% . However, the history of shale oil and gas exploration has shown that with time the success/risk factors improves, especially the prospective area success factor. As exploration wells are drilled and favorable shale reservoirs setting and prospective area are established, there is probability that the size of shale oil and gas in place will change.
3.4.3 Comparing Pakistan’s Shale formations with US Shale Plays

Each shale basin, play and zone, due to its unique nature may require unique treatment. However, a brief comparison of Pakistan prospective formations with US shale plays will help to illustrate the likelihood of developing these prospective formations within Pakistan.

A brief comparison of Pakistan formations with US shale plays identifies that Total Organic Content (TOC), the characteristic defining the hydrocarbon potential of shale formations, is within the exploration targets i.e. 2-10%. The Haynesville Shale Gas Play, a proven shale play in East Texas, having TOC of 2.2% has been developed and has been producing on average 15 Bft/day as calculated in 2012. The depth of this shale play is also close to the depth of Sembar and Ranikot formations which is on average 5000-13000ft. Moreover, the prospective formations in Pakistan seems comparatively thicker i.e. 1000 ft as compared to Haynesville Shale Gas play with a thickness of 250 ft (See Table 7).

<table>
<thead>
<tr>
<th>Country</th>
<th>Shale Plays</th>
<th>Area (mi²)</th>
<th>Depth (ft)</th>
<th>Thickness (ft)</th>
<th>TOC (% wt)</th>
<th>Well Cost $ million</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>Haynesville Shale Gas Play</td>
<td>3574</td>
<td>12000</td>
<td>250</td>
<td>2.25</td>
<td>6-7</td>
</tr>
<tr>
<td></td>
<td>Eagle Ford Shale Gas and Oil Play</td>
<td>2233</td>
<td>7000</td>
<td>200</td>
<td>4.25</td>
<td>2-3</td>
</tr>
<tr>
<td></td>
<td>Fayetteville Shale Gas Play</td>
<td>9000</td>
<td>4000</td>
<td>110</td>
<td>6.9</td>
<td>1-3</td>
</tr>
<tr>
<td></td>
<td>Bakken Shale Oil Play</td>
<td>6522</td>
<td>6000</td>
<td>22</td>
<td>68</td>
<td>5.5-8.5</td>
</tr>
<tr>
<td></td>
<td>Barnett Woodford</td>
<td>2691</td>
<td>10200</td>
<td>400</td>
<td>5.5</td>
<td>2-3</td>
</tr>
<tr>
<td>Pakistan</td>
<td>Sembar Oil and Gas Formation</td>
<td>26,700-31,320</td>
<td>5000-13,000</td>
<td>1000</td>
<td>2</td>
<td>Exploration has not started yet</td>
</tr>
<tr>
<td></td>
<td>Ranikot Oil and Gas Formation</td>
<td>26780</td>
<td>9000</td>
<td>1000</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

Source: EIA, 2011

Similarly, Eagle Ford with a TOC of 4.25% has been producing 24 Bft/day as recorded in 2012. However, the depth and thickness of this shale play is less than that of the shale formations in Pakistan.

\[\text{\textsuperscript{195}}\] Ibid
As far as the well cost is concerned, it varies significantly with the geology and mineralogy of wells. As in case of Haynesville shale play, the average well cost is around $6-$7 million at the depth of 12000 ft while in case of the Fayetteville shale play, the well cost was within the range of $1-3 million\textsuperscript{197} at the depth of 4000ft. Thus, due to this variability, it is difficult to estimate the well cost for Pakistan, but the resource potential available in Pakistan enriched with unique characteristics thus providing favorable conditions for developing these resources for broader national interests.

3.4.4 Unique Characteristics of Shale Formations in Pakistan

Pakistan shale oil and gas reservoirs are located in a barren land where there is almost negligible cultivation, thereby minimizing the probability of loss of agricultural productivity and displacement issues\textsuperscript{198}. Furthermore the population density in Pakistan is also far less i.e. 225 km\textsuperscript{2} as compared to India, which apparently provides favorable condition for developing unconventional resources. Figure 24 highlights that most of the shale prospective areas including Shikarpur, Sukkur, Larkana, Dera Gazi Khan, Nawabshah and Hyderabad, characterized with unconventional oil and gas windows have on average a population density of around 25 persons per square km\textsuperscript{199}, thereby eliminating the displacement issues being observed in India.

Moreover, the natural gas and oil sector in Pakistan is already equipped with pipeline infrastructures (see Table 8 & Figure 25).

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
Gas Fields & 156 \\
\hline
\end{tabular}
\end{table}

\textsuperscript{198} Ibid

which is sufficient for the development of unconventional resources providing another suitable condition for exploiting this resource potential

$\textbf{Table 8: Natural Gas Infrastructure}$

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSGC Lines</td>
<td>44,887</td>
</tr>
<tr>
<td>SNGPL Lines</td>
<td>94,915</td>
</tr>
<tr>
<td>Compressor Stations</td>
<td>11</td>
</tr>
<tr>
<td>Total Consumers</td>
<td>6.7 Million</td>
</tr>
<tr>
<td>Transmission Network</td>
<td>11,045km</td>
</tr>
<tr>
<td>Distribution Network</td>
<td>128,758 km</td>
</tr>
<tr>
<td>No of Cities and Towns on Gas</td>
<td>597 MMCF</td>
</tr>
<tr>
<td>No of villages on Gas</td>
<td>4989</td>
</tr>
</tbody>
</table>

*Source: MPNR, 2013*
The table below identifies that India and China have 0.001 per Km\(^2\) and 0.004 per km\(^2\) of pipeline infrastructure which is less well established in comparison to that possessed by Pakistan that has been calculated at around 0.17 per Km\(^2\).

<table>
<thead>
<tr>
<th>Table 9: Pipeline Infrastructure of India and China</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Countries</strong></td>
</tr>
<tr>
<td>India</td>
</tr>
<tr>
<td>China</td>
</tr>
</tbody>
</table>


\(^{201}\) Energy Overview of India.(2013). Analysis Brief. Energy Information Administration(EIA)

Additionally some of Pakistan’s reservoir characteristics are comparatively better than those of Poland, China and India. The reservoir properties such as the TOC, pressure, depth and clay content are shown in Error! Reference source not found.

### Table 10: Reservoir characteristics of Shale Gas in different countries

<table>
<thead>
<tr>
<th>Countries</th>
<th>Reservoir</th>
<th>Total Organic Content (TOC)</th>
<th>(\text{Depth}^{203}) (ft)</th>
<th>Clay Content</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poland</td>
<td>Lublin</td>
<td>3%</td>
<td>7000-16000</td>
<td>Medium</td>
<td>Slightly Overpressure</td>
</tr>
<tr>
<td></td>
<td>Podlaise</td>
<td>3%</td>
<td>6000-16000</td>
<td>Medium</td>
<td>Slightly Overpressure</td>
</tr>
<tr>
<td>China</td>
<td>Greater Subei</td>
<td>1.1%</td>
<td>3300-13500</td>
<td>Low</td>
<td>Normal</td>
</tr>
<tr>
<td></td>
<td>Tarim</td>
<td>2.1-3%</td>
<td>8610-16400</td>
<td>Low</td>
<td>Normal</td>
</tr>
<tr>
<td>India</td>
<td>Damodar Valley</td>
<td>3.5%</td>
<td>3300-6600</td>
<td>High</td>
<td>Slightly Overpressure</td>
</tr>
<tr>
<td>Pakistan</td>
<td>Sembar</td>
<td>2%</td>
<td>4000-6000, 6000-10,000, &amp; 10,000-16,400</td>
<td>Low</td>
<td>Normal</td>
</tr>
</tbody>
</table>

Source: EIA, 2013

The Table 10 identifies that Sembar fulfills the minimum TOC required for exploration targets. However, Sembar is characterized by low clay content and normal pressure which when exceeded beyond certain limit can create problems during hydraulic fracturing as has been the case in some countries.

Similarly, depth has played a significant role in the exploration and excavation being carried out by countries developing shale plays. This is because the mountainous terrain and deep shale deposits have either resulted in low production of shale gas or in complete failure. It is estimated that shale reserves in China are difficult to extract as they are buried deep below. But

\[203\] Specific to reservoir
despite the difficult terrain and other challenges, it is argued that China has found ways to use the technology to produce shale gas and oil. However, in Pakistan, the depth may not be a hurdle towards exploration as critical depth for acquiring shale gas/oil has already been surpassed at many conventionally drilled oil and gas wells in the basins enriched with shale oil and gas. Detailed analysis of their log data and stratigraphy can play a very important role in establishing the depth and thickness of the shale and identifying the prospective area per basin for details of shale gas activities (See Table 11 for details)

<table>
<thead>
<tr>
<th>Zone Formation</th>
<th>Province</th>
<th>No of Wells</th>
<th>Total Depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chorgali/Sakessar</td>
<td>Punjab</td>
<td>44</td>
<td>4,643-15,300</td>
</tr>
<tr>
<td>Lower Goru</td>
<td>Sind</td>
<td>1016</td>
<td>5.2-11,844</td>
</tr>
<tr>
<td>Ranikot</td>
<td>Punjab, Sind &amp; Balochistan</td>
<td>498</td>
<td>853-3,667</td>
</tr>
<tr>
<td>Sakessar/Sakeesar Datta</td>
<td>Punjab</td>
<td>316</td>
<td>951-1,777</td>
</tr>
<tr>
<td>Sembar</td>
<td>Punjab</td>
<td>15</td>
<td>10,039-11,076</td>
</tr>
<tr>
<td>Khewra &amp; Khewra/Tobra</td>
<td>Punjab</td>
<td>46</td>
<td>1747-1863</td>
</tr>
</tbody>
</table>

Source: (Pakistan Energy Yearbook, 2012)

However, irrespective of some of the favorable properties discussed above, close evaluation, appropriate knowledge management and understanding about the reservoir are key factors that need to be considered while taking an initiative in developing unconventional resources.

### 3.6 Challenges in developing Shale Plays outside US

At present, the shale gas industry has been dominated by the development of unconventional resources in United States. The shale gas development activities, which are credited for transforming the energy scenario in US, are now also being taken up in other parts of the world. Currently, the major locations for shale gas exploration activities beyond US include India, China, Poland, Australia, Argentina and South Africa\(^{204}\). In the following section, challenges faced by India, Poland and China during shale exploration will be discussed in detail.

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\(^{204}\) EIA. (2013). EIA/ARI World Shale Gas and Shale Oil Resource Assessment: Technically Recoverable Shale Gas and Shale Oil Resources: An Assessment of 137 Shale Formations in 41 Countries outside the United States, Advanced Resources International, Inc
India’s first shale exploration was done in the eastern portion of the Damodar Valley.\textsuperscript{205} The Damodar Valley Basin consists of sub basins (from west to east) i.e Hutar, Karanpura, Daltonganj, Ramgarh, Auranga, Bokaro, Raniganj and Jharia. All the sub basins share same tectonic events, geological history and erosion since early Triassic, but each basin has extensive variability in terms of depth and thickness of Barren Measure Shale\textsuperscript{206}.

In September 2010, the Indian National Oil and Gas Company (ONGC) drilled the first Shale Gas well in Raniganj (RNSG-1) sub basin of the Damodar Valley. The well was completed in January 2011, but continuously encountered problem with the gas flow from Barren Measure Shale at approximately 5600ft.\textsuperscript{207} This is because the exploration in Damodar Valley focused mainly on coal deposits as little geological data was available regarding Barren Measure Shale. On the other hand, the data on thermal maturity, organic content and depth was assumed on the basis of coal formations surrounding the Barren Measure Shale. Furthermore, the burial depth and low pressure was a main limitation in the gas flow\textsuperscript{208}.

Other fundamental reasons for these failures were attributable to a lack of skilled engineers, knowledge of fields and population density. West Bengal in India is one of the most populous areas having the population density of around 1035km\textsuperscript{2}\textsuperscript{209}, almost three times than that of India’s average population density, which is about 370km\textsuperscript{2}. More than 61% of the land in West Bengal is arable land. It is estimated that the development of the unconventional oil and gas resources requires a large number of wells to be drilled, which involves extensive use of land as compared to conventional resources. As conventional oil and gas reservoir requires one well per square Kilometer (km\textsuperscript{2}) while unconventional reservoir typically requires around 2-6 wells per square km.\textsuperscript{210} Therefore, the development of unconventional reservoir in this populous and arable land faced severe resistance from locals as it interrupted their agricultural activities. These challenges led to the failure of the first shale well drill in Damodar Valley.

After this failure, ONGC recently has successfully managed to drill an exploratory well in Jambusur around 60 km from Vadora, which has led to former drilling more wells in the Cambay region of Gujarat\textsuperscript{211}.The first shale gas and oil well drilled in Jambusar by ONGC is

\begin{itemize}
  \item \textsuperscript{205} Ibid.
  \item \textsuperscript{207} EIA. (2013). EIA/ARI World Shale Gas and Shale Oil Resource Assessment: Technically Recoverable Shale Gas and Shale Oil Resources: An Assessment of 137 Shale Formations in 41 Countries outside the United States, Advanced Resources International, Inc
  \item \textsuperscript{208} Ibid
  \item \textsuperscript{209} Maps of India, 2013, West Bengal Population
  \item \textsuperscript{210} EIA. (2013). EIA/ARI World Shale Gas and Shale Oil Resource Assessment: Technically Recoverable Shale Gas and Shale Oil Resources: An Assessment of 137 Shale Formations in 41 Countries outside the United States, Advanced Resources International, Inc
  \item \textsuperscript{211} Shale Gas Exploratory Well in Cambay Region.(2014). http://www.thehindubusinessline.com/economy/ongc-to-explore-shale-gas-in-cambay-basin/article5167074.ece
\end{itemize}
estimated to have a shale potential of 20 Tcf, and the data form the first well near Jambusar has given ONGC more leads for further exploration. This will help the company to ascertain the parameters in taking up commercial production. Thus, the results of this exploratory well will open a new chapter in shale gas and oil exploration in the country. Apart from Cambay, the ONGC will explore Krishna-Godavari, Cauvery and Vindyan sedimentary basins for shale oil and gas in near future. India is also taking up the issue of enhanced cooperation with US on shale gas and oil exploration, collaboration on strategic petroleum reserves, energy policy, export of LNG to India and partnership in the field of renewable energy.

However, a recent report released by International Energy Agency (IEA), has highlighted that the prospects of shale in India are becoming distant\textsuperscript{212}. Geological research suggests that India lacks the type and volume of shale reserves discovered in the US. Moreover, the facts that India is a densely populated area, and that it has issues of water availability as well as problems in land acquisition pose significant hurdles in exploiting shale reserves in the country. As a result, India will continue to depend on imported energy and is set to become the biggest driver of global oil demand by year 2020, according to IEA. For this purpose, India needs a comprehensive energy policy to determine the growing domestic demand in medium to long term at affordable prices and without any disruption risks.

• **Poland**

Poland has the most favorable infrastructure and public support for shale development. The Baltic Basin in Northern Poland is the most prospective area with relatively simple structural setting as compared to Lublin and Podlasie basins, which are structurally complex with narrowly spaced faults imposing limits on horizontal drilling.

Around 30 vertical exploration wells and six vertical and two horizontal production test wells have been drilled to date.\textsuperscript{213} However, the production rates were lower than anticipated by oil and gas companies exploring shale and gas oil. Recently, a major ‘milestone’ is about to be reached. Commercial shale gas and oil production, which is attributed to the successful testing at one of its Polish Lewino wells in a shale formation in the Baltic basin in Northern Poland, is about to be initiated. The natural gas flowed


from the well at around 60,000 cubic feet per day during tests\textsuperscript{214}. Hence, the United Oil Field Services will start drilling more productive horizontal wells in July.

- **China**

China has abundant shale oil and gas resource potential and the Chinese government has prioritized shale development on commercial, legal and technological fronts. The Twelfth Five Year Plan for Shale Gas Development in 2012 foresees large scale development of China’s shale resources, while subsidies and incentives to support shale investment are under contemplation.

The shale industry of China has been very cautious in its shale development yet shale basins of China have geological issues. Subei and Jianghan Basins and Yangtze Platform are structurally complex with poor data control. Similarly the southwestern area of Sichaun Basin has TOC less than 2\% and is a brittle faulted area. Tarim basin shales are deposited too deep with low TOC along with high contamination of Nitrogen (~20\%). Furthermore, Ordos Basin has high clay content (80\%), which makes it less favorable for hydraulic stimulation. However, China has turned these challenges into an opportunity, and the production of gas from shale plays in China rose to 7 Bcf (200 million Cubic Meters) in 2013. The National Energy Administration of China stated that shale gas and oil production was expected to reach 54 billion cubic feet this year, which indicates that China's shale gas and oil production will increase seven times compared to that of last year. The capacity of China’s shale gas and oil exploitation is expected to achieve a significant breakthrough during next two years. The Ministry of Land and Resources (MLR) has predicted that country’s shale gas and oil output could reach 229.45 billion cubic feet per annum by 2015, and by 2020, this could touch the figure of 35.3 trillion cubic feet per annum\textsuperscript{215}. Although, the shale reserves in China are buried deep below, making them difficult to extract commercially, China has nevertheless endeavored to discover different ways to use technology to produce commercially viable shale gas and oil, despite the difficult terrain and other challenges.

Sinopec\textsuperscript{216} has discovered a shale gas and oil well in South West China at a depth of 4,417 meters and with a maximum daily output of 3706500 Bcf (105,000 cubic meters). The MLR has highlighted that this discovery is the deepest well found so far in the


\textsuperscript{216} China Petroleum & Chemical Corporation
country, and its exploration would mark a technological breakthrough in China’s deep Shale Gas & Oil drilling\textsuperscript{217}.

China is also working in closer collaboration with US on alternate energy, which would further help China in accelerating the exploration of its shale gas and oil reserves \textsuperscript{218}.

Pakistan

OGDCL, on behalf of Pakistan has taken some preliminary steps towards developing its shale oil and gas resources apart from the formulation of preliminary regulatory framework and inviting bids from international Exploration and Production (E&P) companies. Notable are those taken by Dr. Saeed Jadoon. However, in view of the challenges faced by other countries credited for exploring Shale Gas, Pakistan needs to be mindful of the upcoming challenges while unleashing this resource potential. It should also consider that every reservoir or well due to its unique nature might pose different challenges, which may be specific to that reservoir only depending on its mineralogy and geochemical properties. Yet, these challenges are not insurmountable providing the right technology and experience in hand are available.

Lack of technology and lack of experienced personnel are fundamental challenges that the producers of Pakistan may face while initiating the exploratory process. Despite the realization of available hydrocarbon potential in these reservoirs, the country lags far behind in enhancing the availability of appropriate technology through bilateral cooperation with US on these terms and conditions. Additionally, the appropriate regulatory and policy framework is also flawed, which requires serious attention, as it is the focal point of shale exploration. Strong regulatory and policy framework plays a significant role in rationalizing and streamlining the drilling and exploratory activities.

In addition to this, Pakistan currently confronts serious constraints in data management and data interpretation with respect to shale oil and gas, which is necessary for a better understanding of mineralogy and geochemistry of the reservoirs. There is a dire need for interpreting the already available data from the Pakistan Basin Study keeping in view the need for assessing hydrocarbon potential within the unconventional reservoirs at first. This may be followed by further data collection and analysis, which is done through comprehensive geological, petrophysical, geophysical and geomechanical modeling of selected areas. The modeling is done by taking samples either in the form


\textsuperscript{218} US-China Collaboration. (2014). http://www.globaltimes.cn/content/841151.shtml#.UwruFfmACk9
of fluid or rock cuttings. While, in some cases, the whole core is extracted and analyzed for modelling. The samples are taken from wells at varying sites to check the rock geology, chemistry and hydrocarbon content present in them. After this, the well with successful vertical drilling having substantial hydrocarbon content is selected for horizontal drilling and hydraulic fracturing. It is worth mentioning here that this comprehensive core analysis is a prerequisite for moving ahead in shale play development.

As far as the cost of developing these shale plays is concerned, cost in recovering hydrocarbons from shale is would be high as compared to conventional reservoirs due to new hydraulic fracturing and complex geology; however, it will still be less than the cost incurred due to increasing import bill, heavy subsidy and mounting circular debt. Hence, the development of unconventional resources requires unconventional solutions, but these have the potential to change the fate of the Pakistani nation.

Chapter No 4

The Environment and the Development of Shale Oil and Gas
In the sustainable development of shale oil and gas, environmental and health considerations must be taken into account. While a detailed assessment on health lies beyond the scope of this report, it has explored water consumption, seismicity, impact on water quality and waste water management has also been discussed in some detail. Moreover, the report also considers the use of Guar ki Phalli as a proppant, and its usage in shale oil and gas exploration. In developing Pakistan’s unconventional hydrocarbons, environmental integrity must be taken into account, thereby minimizing health and environmental risks.

4.1 Guar Ki Phalli and Shale Oil & Gas Revolution in Pakistan

Guar gum is a versatile product with various applications such as that of functioning as a natural thickener, thickening and sizing agent, wet-end strength additive, gelling agent and water barrier, flocculation aid, emulsifier, stabilizer, hydrocolloid, fracturing agent and binder\textsuperscript{219}.

As far as shale oil and gas exploration is concerned, Guar gum with its unique properties is used as gelling agent to increase the viscosity of proppant, which is a material that is forced into shale fractures to enlarge their permeability so that the oil and gas can be extracted. It also helps to reduce friction, which in turn decreases the energy consumed; it is considered safer for the environment than other alternatives.\textsuperscript{220}

It is interesting that the global production of Guar gum is estimated at around 10 lakh tons annually\textsuperscript{221} and the increased consumption of guar is characterized by demand from petroleum industry of US and oil fields in Gulf States. At least over 100 countries import guar products, including Canada, China, Chile, Australia, Brazil, Germany, Italy, Japan, UK and US, etc. The export of guar gum by US, the leader in shale gas production nowadays has enabled the former to deploy this material to improve the viscosity and flow of water in the fracking process thereby making a significant contribution to gas development.

It is estimated that India and Pakistan are the leading producers and exporters of guar gum and guar has become an important cash crop for both Pakistan and Indian economies. India being the largest producer of guar gum in the world has 85% of the export global market share out of which 80% of the country’s output of guar is contributed by western desert state of

\textsuperscript{219}West Texas Guar, Inc., (2013). Guar and its Uses
\textsuperscript{220}ChemTotal. (2013). Guar Gum and Guar Derivatives in Fracturing
\textsuperscript{221}Arfeen.M.(2013). Reap Gold, Sow Guar. Financials Daily
Last year, India exported Guar seed worth 5 Billion USD, and the prices of these seeds are now hovering at Rs 8750 per 100 kg.

Pakistan with 10-15% share in world guar gum production and exports is ranked second in the world. According to estimates by local marketers, the production of guar in the country averages 70,000 tons annually, ranging between 50,000 to 110,000 tons per year. About 90 per cent of guar gum processed in Pakistan is exported, and one ton of guar makes 300 kilogram (kg) of gum. The guar gel makes up around thirty percent of the fracking costs in some shale basins. The price of guar has increased from about PKR 13/kg in 2008 to PKR 450/kg, which is attributed to the phenomenal increase in exports to US. There has been a sharp increase in the exports of Guar and Guar products between July 2009 to July 2011 (see Table 12) and the unit values are also increasing likewise.

However, July 2012 showed a distinguished trend as compared to previous years as the export quantity reduced from July 2011 with the unit value doubling in July 2012. The statistics shown in Table 12 indicate that there is a high demand for Guar and Guar products and that the unit value is increasing over the years.

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Qty</th>
<th>Unit value($/unit)</th>
<th>Qty</th>
<th>Unit value($/unit)</th>
<th>Qty</th>
<th>Unit value($/unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guar and Guar products</td>
<td>M.T.</td>
<td>1624</td>
<td>946.4</td>
<td>1675</td>
<td>1373.1</td>
<td>16161</td>
<td>3279.5</td>
</tr>
</tbody>
</table>

Source: Federal Bureau of Statistics, (2010-12)

Interestingly, the Shale Oil & Gas potential in Pakistan has been identified in areas where “Guar Ki Phalli” has been cultivated for many centuries. Guar grows well in arid to semiarid areas of country and 75% of the guar crop is concentrated in central Punjab. The areas where guar gum has been planted for many years in Pakistan include Cholistan, Kharan, Thar and Umer Kot, Dadu and Tharparkar Districts in Sindh province, and Layyah, Bhakkar, Mianwali and Khushab in

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223 Ibid
225 Ibid
the Punjab province, Lasbela and Makran in Baluchistan Province\textsuperscript{229}. It is estimated that the shale oil and gas initiative will help to revive the arid and dry region of Baluchistan, Sindh and Potohar region of Punjab.

This will change not only the livelihood of the poorest of area but also help to bring more barren land under cultivation, which will enhance the green area. The photograph above is taken from the Dera Gazi Khan and Dadu districts, which shows the enthusiasm of farmers to export Guar seeds.

Another advantage of having Guar ki Phali is that it is drought resistant, and it has the ability to prevent soil erosion. Due to flash flooding, the watershed areas of D I Khan, DG Khan and Rajin Pur have been exposed, but the cultivation of Guar ki Phali can help to avert this flash flooding. In Indian states like Bihar and Andhra Pradesh, Guar has been successfully used to contain the menace of flash floods. The abundant use of Guar has now proved it to be the most exported foreign item as it is used for Shale gas fracturing.

4.2 Water Consumption

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{GUAR Ki Phalli in Pakistan}
\caption{GUAR Ki Phalli in Pakistan}
\end{figure}

\begin{box}
\textbf{Box 5: KEY POINTS}

- Natural gas (Shale) production uses significantly less water per BTU of energy produced than other fuel sources such as coal, oil or ethanol. Shale Oil & Gas consumes about 0.6-1.8 gallons of water per million BTUs of energy produced. If Shale Oil & Gas is used to generate electricity at a combined cycle gas plant
\end{box}

Water is used in several stages of the shale gas life cycle. However, a major quantity of water is consumed during the production stage. The drilling and hydraulic fracturing for exploration of shale oil and gas well requires an average of 5 million US Gallons (15-Million Acre Feet (MAF)) of water. This volume of water is equivalent to that used in seven and half Olympic size swimming pools. The extensive production of shale gas in the US has been effectively utilizing various water resources for the purpose of drilling and fracturing of shale gas.

Once the fracturing is performed, 5 to 20% of the original volume of water returns to the surface within the first 10 days, known as flowback water. An additional volume of water, varying from 10% to almost 300% of the injected volume, returns to the surface as produced water over the life of the well. The rate at which water returns to the surface is highly dependent upon the geology of the formation. In US, the major shale player i.e, Marcellus recycle 95% of the flowback water, while two other shale producers that are Barnett and Fayetteville recycle 20% of the flowback water. It is assessed that over a period of 30 years, a typical well if hydraulically fractured may consume between 22 and 51 MAF of water per well. The common steps in which water is used during hydraulic fracturing is illustrated in Figure 26

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230 In one Acre-Feet there are 325851 US Gallons
231 Accenture. (2013). Water and Shale Gas Development: Leveraging the US Experiences in New Shale Developments
232 Standard size of Olympic-size swimming pool is (162x82x9.8 Ft). FINA or Federation International Nation (International Swimming Federation)
234 Accenture. (2013). Water and Shale Gas Development: Leveraging the US Experiences in New Shale Developments
237 Ibid.
4.3 Water Quality

In the United States, where shale gas production has brought about a revolution, environmentalists have expressed concern about possible contamination caused by hydraulic fracturing fluid which when injected under high pressure into the ground and then returned to the surface causes a problem. The US EPA in 2011 reported that there is no proven case of direct contamination by the hydraulic fracturing process.\(^{238}\) When environmentalists in the US pointed out the use of water for shale gas production, Massachusetts Institute of Technology (MIT) conducted a study called the “The Future of Natural Gas: An Interdisciplinary MIT Study”, which concluded that the environmental impacts of shale development are challenging but manageable. Later in 2012, EPA tested the drinking water quality wells in Dimock and found

that water treatment systems were enough to reduce hazardous substances if any were to be found in groundwater due to fracking.\textsuperscript{239}

However, some studies have indicated that there is a potential risk in the contamination of drinking water by methane or fluids.\textsuperscript{240} The possible pathways for this contamination are either through underground leakage from the wellbore to drinking water aquifers or through improper disposal or accidental leakage of hydraulic fracturing fluids to surface water bodies. Owing to the depth of most shale plays, it is unlikely that a credible pathway (independent of the wellbore) exists for fluids to flow from the fractures within the shale through thousands of feet of overlying rock into the drinking water aquifer. Nevertheless, in deep formations, contamination may occur if there are defects in the wellbore. Similarly when the annulus-present between the well casing and surrounding geology- is not properly sealed during well installation then methane gas can migrate from shale resource to the outside of the wellbore to shallow aquifers where it can dissolve in drinking water\textsuperscript{241}.

Additionally, another manner in which contamination can occur is when there is a defect in the casing at a shallow depth; this gives gas a passage to flow from inside the wellbore to the aquifer. Faulty well constructions have caused several instances of water contamination such as in the Bradford County of Pennsylvania where wells were drilled before the hydraulic fracturing took place\textsuperscript{242}.

Furthermore, not only faulty well constructions can be responsible for migration of methane but also abandoned wells can provide pathways for methane. The most evident pathway for contamination is deliberate dumping or accidental spilling of flowback water on the surface; it is also the most easily prevented. A regular cause of accidental spillage is the overflow of retention ponds during rain events. Contaminants of flow back water and additives of hydraulic fracturing fluid can be a health concern if present in large concentrations.

\begin{flushright}
BOX 6: SHALE REVOLUTION IN US
\end{flushright}

In year 2011, approximately 27,000 Shale Oil & Gas wells were drilled and completed in the US and this process consumed approximately 135 billion gallons of water (Or 0.45 MAF), to produced 7,994 BCF of Gas (Shale).\textsuperscript{243}

\begin{flushright}
\textsuperscript{241} Ibid
\textsuperscript{243} EIA. (2013). EIA/ARI World Shale Gas and Shale Oil Resource Assessment: Technically Recoverable Shale Gas and Shale Oil Resources: An Assessment of 137 Shale Formations in 41 Countries outside the United States, Advanced Resources International, Inc
\end{flushright}
4.4 Induced Seismicity

Seismicity refers to the earthquake activity of given area i.e. frequency and magnitude of seismic events. The induced seismicity is referred as micro seismicity which results from human activity such as 1) mining, 2) construction of large water reservoir impoundments with dam, 3) fluid injection into rock formations for waste water disposal or 4) stimulation of fluid flow through hydraulic fracturing in hydrocarbon or geothermal reservoirs\textsuperscript{244}. All these activities involve changes in stress, pore pressure, volume and load in underground rock formations, which can lead to sudden shear failure in sub surface thereby releasing pre-existing shear stress on weak zones such as fault structure or fractures. The majority of induced seismicity events are of small magnitude, which is below the maximum magnitude of naturally occurring seismicity and cannot be felt by humans at surface (See Box below for details)

Induced Seismicity may occur when the conditions in the subsurface are altered in such a manner that stress acting on the pre-existing faults reaches the breaking point for slip. If the stress in rock formation are near the critical stress for fault rupture, it is estimated that relatively modest change of pore fluid pressure\textsuperscript{245} can induce seismicity. Generally, such events are not damaging, but if the preexisting stress condition or the elevated pore fluid pressures are substantially high over a large fault area, then earthquakes with enough magnitude or intensity to cause damage can potentially take place\textsuperscript{246}.

The hydraulic operation during the drilling may induce micro seismic events due to injection of high-pressure fluids into the sub surface. These minor earthquakes are thought to be caused by an increase in pore pressure leaking off into the rock surrounding the hydraulic fracture. The increased pore pressure induces small natural fracture in the formation to slip causing micro earthquakes. These micro earthquakes are a thousand times smaller than the typical earthquakes that can be felt by humans\textsuperscript{247} (See Box below for more details).

In addition to the direct fluid injection for recovering the trapped hydrocarbons form unconventional resources, the drilling of injection wells to dispose of wastewater during oil and gas production is very common. Although only a few seismic events have been linked to disposal wells, such cases have generated serious public concerns. The need for examination of

\textsuperscript{244} Induced Seismicity Potential in Energy Technologies: Report innBreif,(2012). National Academy of Science.
\textsuperscript{245} Pore fluid Pressure: It is defined as pressure of fluids within the pores of a reservoir usually hydrostatic pressure or the pressure exerted by column of water from the formation's depth to sea level.
\textsuperscript{246} Induced Seismicity Potential in Energy Technologies,(2013). National Research Council of the National Academies. Washington, D.C.
\textsuperscript{247} Induced Seismic Activity in Canada,(2013). Canadian Association of Petroleum Producers
these cases regarding causal links between the injection zone and previously unrecognized faults in the sub surface has been suggested\(^{248}\).

**Box 10: What does scientific research say about hydraulic fracturing and seismic activity?**

<table>
<thead>
<tr>
<th>B.C. Oil and Gas Commission, August 2012</th>
<th>U.S. National Research Council, June 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Investigation of Induced Seismicity in the Horn River Basin</em></td>
<td><em>Induced Seismicity Potential in Energy Technologies</em></td>
</tr>
<tr>
<td>• None of the events caused any injury, property damage or posed any risk to public safety or the environment.</td>
<td></td>
</tr>
<tr>
<td>• More than 8,000 high-volume hydraulic fracturing operations have been performed in northeastern B.C. with no associated seismicity.</td>
<td></td>
</tr>
<tr>
<td>• Fractures developed during the hydraulic fracturing operations studied for the report had no effects on shallow aquifers or the environment.</td>
<td>• The process of hydraulic fracturing used for recovery of shale oil and gas does not pose any high risk seismicity</td>
</tr>
<tr>
<td></td>
<td>• A small seismic event has been reported due to hydraulic fracturing at one location near Blackpool, England (2.3 ML) but this did not cause any structural damage.</td>
</tr>
<tr>
<td></td>
<td>• Around 35,000 hydraulically fractured Shale Oil &amp; Gas wells exist in the U.S. But only one case of “felt seismicity” in the U.S., in which hydraulic fracturing “is suspected, but not confirmed, as the cause” (Oklahoma, 2.8 ML).</td>
</tr>
<tr>
<td></td>
<td>• Seismic events of a magnitude greater than 2 ML can possibly be felt, particularly if they occur at shallow depths. Seismic events of a magnitude smaller than 2 ML generally are not felt.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Royal Society and Royal Academy of Engineering, June 2012</th>
<th>Preese Hall Shale Oil &amp; Gas Fracturing panel report, April 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Shale Oil &amp; Gas extraction in the UK: A review of hydraulic fracturing</em></td>
<td><em>Review and Recommendations for Induced Seismic Mitigation</em></td>
</tr>
<tr>
<td>• There is emerging consensus that the magnitude of Seismicity induced by hydraulic fracturing can be felt by few people and the risk of surface impacts, if any, is negligible.</td>
<td></td>
</tr>
<tr>
<td>• “Micro-seismic events are a routine feature of Hydraulic fracturing and are due to the propagation of engineered fractures.”</td>
<td></td>
</tr>
<tr>
<td>• Larger seismic events due to hydraulic fracturing are rare but can be induced in the presence of a pre-stressed fault.</td>
<td></td>
</tr>
<tr>
<td>• Seismic events of magnitude 3 ML at a depth of 2,000 to 3,000 meters are unlikely to cause any structural damage.</td>
<td>• Concludes hydraulic fracturing can proceed if the process is carefully monitored and appropriate precautions are taken.</td>
</tr>
<tr>
<td></td>
<td>• “Observed seismicity” at Preese Hall was “induced by the hydraulic fracture treatments.” The largest of these seismic events had a magnitude of 2.3 ML.</td>
</tr>
<tr>
<td></td>
<td>• A seismic event of a magnitude of 3 ML at a depth of two to three kilometers “is unlikely to cause structural damage.”</td>
</tr>
</tbody>
</table>

Source: Canadian Association of Petroleum Products, 2013

The recording and analysis of micro seismicity is used by well operators in determining the geometry of hydraulic fractures in formations. Micro seismic mapping is a useful tool in planning a well development program such as horizontal well direction, spacing between the

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\(^{248}\) UK On shore Shale Gas Well Guidelines: Exploration and Appraisal Phase,(2013),United Kingdom Onshore Operator Group(UKOOG)
wells and guiding the design of hydraulic fracturing procedure such as injection rate and fluid volume.

The micro seismic data in this regard is obtained with either an array of seismic instruments in one or multiple well bores or with a large number (100 or more than 1,000) of geophones near or on the surface\textsuperscript{249} (See Figure below).

Specialized data processing techniques are used to precisely locate the micro seismic events in time and space and to compute source parameters such as seismic moment, magnitude and moment tensors\textsuperscript{250}. With emerging concerns over induced seismicity while drilling and hydraulic operations for recovering shale oil and gas, new control techniques have been introduced to mitigate these seismic risks. Methodologies like Detailed Hydraulic Fracturing Program (HEP) can be developed for quantitative, probabilistic hazard assessment of induced seismicity risk\textsuperscript{251}. These kinds of assessment should be undertaken before the operation begins in an area with known history of felt seismicity, and assessment should be updated in response to observed, potentially induced seismicity.

As a first step, the operators are required to review the available information on faults in the area of the well to confirm that wells are not drilled into or near the existing faults, which can trigger off any seismicity. This seismicity data should be monitored for a period of several weeks before the operations commence to provide a baseline against which the activity detected during and after fracturing operations can be compared\textsuperscript{252}.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{micro_seismic_monitoring.png}
\caption{Micro Seismic Monitoring. Source: National Research Council of National Academies, 2013}
\end{figure}


\textsuperscript{250} Induced Seismicity Potential in Energy Technologies. (2013). National Research Council of the National Academies. Washington, D.C.

\textsuperscript{251} Guidance about Shale Gas and Hydraulic Fracturing. (2013). Department of Energy and Climate Change. UK

\textsuperscript{252} Ibid.
Each stage of the fracking process should be carefully designed to use only the amount of fluid needed to fracture the rocks sufficiently to trigger the gas flow. A flow back period needs to be routinely incorporated into the design so that after each stage the pressure is reduced immediately to further reduce the risk of tremor.

Once fracking and flowback are complete, monitoring should continue for at least 24 hours in order to identify any abnormally induced events among the normal background seismicity. A permanent tiltmeter and seismometer system should be installed to understand the characteristics of fracking in a particular formation. The installed system will record micro seismic events having a magnitude of less than ML 0.5 that usually accompany all fracking activities\textsuperscript{253}. This information can be used to establish the extent of penetration of fractures into the surrounding rocks and to evaluate the effectiveness of the fracture\textsuperscript{254}.

Hence, before initiating the drilling and exploratory activities, comprehensive geological surveys should be undertaken in order to identify the faults and to drill wells in low risk locations. Moreover, the wells spacing should be evaluated with a view to avoid unplanned interaction between the drilled wells\textsuperscript{255} as illustrated in Figure 28.

\textsuperscript{254} Guidance about Shale Gas and Hydraulic Fracturing.\textsuperscript{(2013). Department of Energy and Climate Change. UK}  
\textsuperscript{255} National Research Council. \textsuperscript{(2013). Induced Seismicity Potential in Energy Technologies. The National Academic Press
4.5 Shale Oil & Gas and Potential Water Usage in Pakistan

Undoubtedly, with increased population, Pakistan is fast heading towards a situation of water shortage. Per capita surface water availability was 5260m$^3$ in 1951 when population was 34 million, which decreased to 1118m$^3$ in 2012 when the estimated population figure hit 184 million$^{256}$. Consequently, Pakistan is becoming a water-scarce country with significant gaps between water requirements and available resources. There is a strong possibility that the water economy will run dry leading to severe water crisis. However, there are countries with even less quantity of water than Pakistan, but with much stronger water economies. To avert this situation, Pakistan needs to realign its strategies to optimize its water productivity. In order to achieve a growth rate of 7 to 9%, water availability has to be ensured for agriculture, industry and urban use.

$^{256}$ Mustafa, K. (2012). *Pakistan’s per capita water availability dwindling*. The News
Figure 29 shows the river system of Pakistan, highlighting the serious challenges on the waterfront including the water storage efficiency of Pakistan, which is 9% as compared to 40% of the world on average. Therefore it is imperative to improve the water efficiency and enhance agricultural productivity in order to contribute to GDP growth as well as to tap the huge potential of shale oil and gas for larger benefits to Pakistan.

The precedent of water use in shale gas production in the US, where in fiscal year (FY) 2011, 135 billion gallons of water (or 0.45 MAF) were used for drilling of approximately 27,000 shale gas wells to produce 7,994 BCF of shale gas. However, in Pakistan, the daily production of 8 BCF of shale gas will consume about 0.152 MAF of waters annually. This potential usage of water for shale gas production constitutes only 0.001% of total average annual surface water

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net inflow of the Indus Basin, which is 142 MAF. According to WAPDA, the usage of water for gas production is only 0.004% of total fresh water that escapes to sea. According to WAPDA, an average of over 35.2 MAF annually escapes below Kotri varying from 9 MAF to 92 MAF. However, this surplus water in the river system is available for about 70-100 days of summer only. To save and utilize available water, construction of additional storage facilities is essential for sustainable irrigated agriculture, which supports about 70% of the population.

Another advantage for shale gas exploration and production for Pakistan is that it will promote water conservation techniques. The authors of this report strongly recommend that community based rainwater harvesting technology needs to be adopted (an old established art) of which knowledge has not been applied in Pakistan. This is due to the lack of awareness on the part of planners and policy makers.

The majority of people in areas and local communities in areas where shale gas potential is identified, local communities largely depend on rain-fed agriculture and livestock for their livelihoods. Water for agriculture and livestock has always been a major concern, especially for the farmers of Baluchistan. Lately, rainfall has become more erratic, and summer temperatures have increased. Only prosperous farmers can afford to extract groundwater by sinking borewells. However, in dry periods marginal farmers have to sell their livestock to get temporary monetary relief as they do not have enough fodder for their animals. The shale gas exploration companies can initiate community based rainwater harvesting for gas production and also educate locals with this simple technique so that farmers can cultivate Guar, locally known as ‘Guar Ki Phalli’, used as gelling agent in hydraulic fracturing (shale oil and gas).

4.6 Waste Water Management

Shale gas and oil exploration and production needs to be managed as fractured water from the well can contain brine and minerals making up a significant portion of the original fracture fluid. Moreover, natural formation water flowing in the well may also require treatment. This produced water can be managed through underground injection, recycling and wastewater management.

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261 WAPDA. (2013). Pakistan Hydropower Potential. Pakistan
If a large volume of flow-back water is recycled, it can have two main positive effects. Firstly, it may help to reduce the demand of freshwater in the process. Secondly, it can help reduce wastewater, preventing excess wastage.

**Box 7: Saline Water for Hydraulic Fracturing**

In the United States, the saline water can be used for hydraulic fracturing in shale basins that are of marine origin and have salinity (35,000 ppm, predominantly sodium chloride, but for drilling and cementing, fresh water will still be required. However, as the hydraulic fracturing consumes the most water so a large volume of fresh water will be saved through this. One remarkable example is of Apache Corporation’s British Columbia Shale Oil & Gas pad development, which used saline water for hydraulic fracturing of 12 wells. This minimized the use of fresh water, minimized water storage, waste transport and also reduced the need for a number of chemicals.265

Realistically, however, recycled water can depend on freshwater availability and the cost of wastewater disposal as well as the quantity (and quality) of wastewater in the process. The cost can depend on the processes used for water-treatment, which can be as simple as filtration or settling or more expensive distillation, reverse osmosis or thermal treatment266.

The shale industry is also looking into alternative methods of creating fractures, which do not use water. One of the alternatives is a mixture of propane gel and sand267 that can help to create fractures during the fracking process. The propane gel268 can be derived from a natural gas such as NGL or LPG.

The gel becomes a vapor under pressure and can return to the surface as natural gas, and is then recaptured at that point. Innovative methods like these show a potential of minimizing water use in the fracturing process.

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267 Bullis, K. (2013). Skipping the Water in Fracking. MIT Technology Review

Chapter No 7

Economic Activity Generated through Shale Oil & Gas Exploration

6.1 Background

Unemployment is one of the major issues that Pakistan has been dealing with for over a decade. The recent Labor Force Survey for second quarter of 2012-13 revealed that unemployment rate in Pakistan had increased from 6% to 6.5%\textsuperscript{269} during October-December period of 2012.

It has been identified that in urban areas the unemployment rate has increased by 2% to 10.1% while in case of rural areas the unemployment has risen from 4.3% to 5%, showing an increase of 16.3%\textsuperscript{270}. In other words, one out of ten individuals is unemployed in Pakistan. The inability to access basic necessities of life has created havoc and distress among the masses. Poverty and unemployment are also fueling various other ills within the society, and it is argued that the country has been confronting the war against terror due to poverty and unemployment within the country\textsuperscript{271}.

The industrial sector, which is the second largest sector of Pakistan, contributes 19%\textsuperscript{272} of the Gross Domestic Product (GDP) and out of this, a large proportion is that of the labor class. However, due to the prevalent energy crisis, many industries have either closed their businesses or have moved abroad, thus leaving millions of people unemployed and halting economic growth within the country. Therefore, the solution of this unprecedented energy crisis must be on the priority list.


\textsuperscript{270} Ibid

\textsuperscript{271} Jawahar., K. (2013). Key Causes of Unemployment in Pakistan. Pak Economy

Keeping in view the nexus between employment generation and energy, US has resolved its problem of unemployment by developing its unconventional energy resources. The development of unconventional energy resources is more labor intensive as compared to conventional resources and most of the jobs generated require basic skills, thereby acting as a potential source of employment for unskilled laborers. Shale gas development has not only transformed the outlook for US energy supplies but has also had a profound impact in terms of creating jobs, reducing consumer costs of natural gas and electricity as well as bolstering federal, state and local tax revenue. It has been observed that shale industry alone generated around 600,000 jobs during 2010 against the production of 5.87 Tcf, thus decreasing the unemployment rate from 8.4% to 7%. Shale Gas currently accounts for 34% of US natural gas production, and it is expected to reach 60% by 2035. Pakistan having a rich resource potential of 105 Tcf of Shale gas and 9.1 billion barrels of shale oil, can also address severe concerns of energy crisis and related unemployment through the development of these resources.

Moreover, the organic rich shale formations in Pakistan seem significantly thicker than the shale formations in North America. This thick resource play could be a potential site for the energy companies to invest in exploration and production program as well the best possible way of generating employment for skilled and unskilled laborers. Therefore, international energy companies will most likely be interested in developing the unconventional resources of Pakistan because it provides thicker shale formations and attracts no issues in land acquisition as shale resources are embedded within the barren land. This is a favorable scenario in comparison with the situation in India where shale deposits are in fertile land thereby triggering land acquisition as well as displacement issues. Additionally, existing roads, transportation and other infrastructure also gives a competitive edge to Pakistan enabling it to venture forward in developing this resource as compared to other resource plays. Therefore, this chapter focuses on key insight in to the possible economic activities that can be generated through developing shale reserves in terms of direct and indirect jobs.

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6.2. Workforce Requirement in developing Unconventional Resources

The development of unconventional reserves differs significantly from extracting oil and gas from conventional reservoirs. The extraction of oil and gas from unconventional reservoirs requires a large number of employees and greater input as compared to conventional reservoirs due to large differences in geology, technology as well as related developmental challenges. The processes involved in developing these resources include directional drilling and hydraulic fracturing, which are comparatively more labor intensive and demand more advanced technology than those used in conventional shallow oil and gas development.

The estimation of workforce in shale development is quite a challenging task as natural gas development trends, commodity price and technological changes are difficult to project.

6.3 Methodology for Workforce Assessment

The economic activity that can be generated by developing Shale Gas in Pakistan has been assessed by benchmarking the employment generated through shale industry in US against the volume of gas. It has been estimated that Shale Gas industry has created 600,000 jobs against the production of 5.7 Tcf.

In view of the profound impact of shale gas development on the economic development of the state in US, it is anticipated that if shale gas is tapped accordingly in Pakistan then it will be able to meet the annual demand of 2.9 Tcf and to generate jobs for 320000 skilled and unskilled personnel. Similarly, economic activity generated through shale oil production has been assessed by benchmarking employment generation in US through shale oil production. It is estimated that tapping into the shale oil resources in Pakistan will create employment for 210000 skilled and unskilled laborers against an annual production of 125.54 Million barrels.

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BOX 8: ECONOMIC IMPACT OF DEVELOPING SHALE RESOURCES IN PAKISTAN

Current estimates have identified that developing shale resources in Pakistan will create massive economic activity in terms of generating significant number of employment (for both skilled and unskilled laborers). It is expected that development of shale gas and oil will generate around 320000 and 210000 jobs against an annual production of 2.9 Tcf gas & 125.54 Million barrels respectively, and 98% of these jobs will be concentrated during the pre-drilling and drilling phase while around 2% of these jobs will be created during the production phase.\(^\text{283}\)

6.3.1 Direct Jobs through Development of Shale Plays

The development of shale resources is a great source of economic activity in terms of both direct and indirect jobs. Direct employment refers to the individuals working in exploration and production of natural oil & gas.\(^\text{284}\) A large number of these direct jobs are concentrated within the drilling phase, while a small number of workers are required for the long-term production phase.\(^\text{285}\) The jobs during each phase of development are explained in detail below.

6.3.2 Pre-Drilling & Drilling Phase Jobs

The pre-drilling and drilling phase is the most labor-intensive process during the entire Shale Oil and Gas development cycle. It is estimated that around 98%\(^\text{286}\) of exploration & development jobs are found in pre-drilling

\(^{283}\) Calculations are done by authors based on per well production


\(^{286}\) Ibid.
and drilling phase as compared to the production phase, which means that around 310000 and 210000 jobs will be generated against the production of 2.9 Tcf gas and 125.54 million barrels oil annually (See Figure 30 & Figure 31).

However, this segment of labor force will no longer be required once the wells have been drilled and associated infrastructure is completed. The drilling phase is often considered as “the Boom” phase as a vast workforce is required to perform the activities associated with natural gas development. On the other hand, the production phase is referred to as “the Bust”, because the workforce declines sharply. The workforce required in the drilling phase is subject to the duration of drilling phase, which cannot be projected easily, thereby reflecting the uncertainty in estimating the exact number of workers required during this phase.
6.3.3 Production Phase Jobs

In contrast to drilling phase, the jobs associated with production phase are well defined in terms of efficient management of the operations in a fixed geographic area. These kinds of jobs constitute 2% of the total number of jobs generated during shale gas development cycle and last the lifetime of a producing well. This phase often results in local residency as mostly local workers are employed for this phase (See Error! Reference source not found.).

The jobs during this phase are going to sustain as long as the well is producing natural oil and gas, even if the pre-drilling and drilling activity is completed. In some cases, geologists argue that the wells created are likely to produce for 30 years or more, as in the case with Marcellus well. Therefore, the jobs during this phase are referred to as long term or permanent jobs.

It is also important to highlight that the occupations during the production phase tends to be less labor intensive, with fewer hazards and more specialized work than that available during the drilling phase. Such work is also coupled with excellent salary and benefits.

Most importantly, most of the jobs during the shale oil/gas development cycle require basic skills offering a source of employment for unskilled laborers.

However, some advanced trainings and skill development courses will be required for 6% of the semi-skilled technicians, which will enhance their capacity and provide them an opportunity to raise their standard of living (See Table 13).

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288 Ibid.
Table 13: Shale Gas & Oil Resources Training Requirement

<table>
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Source: NEXT, 2013, Oil & Gas Technical Training & Career Development, Schlumberger

6.3.4 Indirect Jobs through Development of Shale Play

Indirect employment refers to the jobs created in response to increased natural gas production and its use in gas intensive industries as well as employment generated while planting Guar ki
Phali (see Chapter 3) for developing shale gas and oil. These indirect opportunities can be in the form of progressive economic growth by producing inexpensive electricity that can lead to improved industrial development, generation of tax revenues, increased output. These can also catalyze other industries creating more employment opportunities (indirect jobs). The role of development of shale in creating indirect jobs in manufacturing industries in US has been analyzed in the case study below (See Box 9).

**Box 9: ADDITIONAL OUTPUTS ACHIEVED DUE TO DEVELOPMENT OF SHALE PLAYS: A CASE STUDY OF EIGHT MANUFACTURING INDUSTRIES IN US**

US is expanding its capacity in terms of development of Shale Gas resources. The enormous new supplies from the untapped resources of Marcellus (along the Appalachian mountain chain) have given an exceptional advantage to the US chemical and manufacturing industries. The development of Shale Gas will engender the wider availability of low cost domestic energy as well as improve the competitive environment. Research conducted to quantify the economic impacts of this wider availability of gas due to the development of shale plays identified substantial increase in the output of gas intensive industries. The eight key industries selected for analysis included: Paper, Plastic & Rubber, Chemical, Glass, Iron & Steel, Aluminum, Foundries & Fabricated Metal product industries. The analysis found that increased output would:

- Directly generate 200,000 new, high-paying jobs in these eight manufacturing industries
- Generate an additional 979,000 jobs in the supply chain and elsewhere in the economy through the indirect and payroll-induced economic effects of expanded production from these eight manufacturing industries, leading to a total 1.2 million jobs generated from the effects of expanded production
- Generate 1.1 million jobs in construction, capital goods manufacturing, in their supply chains and elsewhere in the economy over the course of the investment phase
- Generate $26.2 billion in annual federal, state, and local tax revenue from the growth in output
- Directly generate a $121.0 billion increase in the output of the paper, chemicals, plastic and rubber products, glass, iron & steel, aluminum, foundries, & fabricated metal products industries
- Directly generate $72.0 billion in capital investment and construction activity by the eight industries to build &/or expand capacity, leading to a $207.6 billion one-time boost of economic activity

Looking at the bigger picture, shale gas development in Pakistan will not only create jobs for the

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drilling and production phases of this important resource, but it will also generate economic activity at the industrial level in Pakistan, which has suffered an immense blow during recent years given the ramifications of the severe energy crisis of the country. Currently, Pakistan is an oil importing country and the impact of irregular fluctuations quickly alters the balance of our domestic economy, adversely affecting macroeconomic parameters such as inflation rate, BOP and net exports. The widening gap between imports and exports has caused the current account to persistently report a deficit, which is growing at alarming levels. Rising fuel prices also have a drastic effect on electricity prices in the country further deteriorating industrial development in Pakistan.

Shale Gas will help businesses restore their vigor and give rise to the establishment of factories that were previously producing export quality products, which can have a directly positive impact on the balance of payments of Pakistan. Shale gas exploration and development will also attract foreign investments by providing a supportive investment and business environment, provided a reasonable level of government support, tax incentives and benefits are available to companies that decide to invest. Since gas is a vital resource that will help to create a boom in the trade volumes of Pakistan, the government can benefit from the resulting tax revenue generation. Consequently, Shale Gas development can allow for energy security, fiscal stability, sustainable development and economic growth, which are all developments desperately needed by Pakistan to overcome its existing economic crisis.
Energy Security is essential for a nation’s growth, and different avenues will need to be explored in order to meet the growing energy demands in Pakistan. Energy security is defined as the capability of a country to secure its energy supplies and to meet energy needs at reasonable price in a sustainable manner. In view of the advantages that shale gas exploration and production may generate for Pakistan, it is essential for the GOP to develop a concrete roadmap and a national policy for Unconventional Oil and Gas. In this regard, this report makes the following recommendations:

- **Shale as a National Agenda**: Pakistan has the potential to revolutionize its energy sector by putting Shale Gas with its estimated reserve of 105 TCF of Shale Gas and 9.1 billion barrels of Shale Oil on the national agenda. With the current natural gas consumption rate of 8 BCF/year, this unconventional source of energy is likely to meet the gas demand of Pakistan for 45 years. Similarly, the consumption of oil in the country is 125 million/annum, which is most likely to satisfy projected demand for 61 years. These figures show that if GOP takes concrete steps based on national interest for the exploration and development of shale oil and gas, then the demand for energy can be easily satisfied provided that expert analysis and consultation are used during the process. Although Pakistan has formulated a Shale Oil and Gas Regulatory Framework through the efforts of OGDCL and the Ministry of...
Petroleum and Natural Resources (MPNR), it still needs further strengthening, as suggested in Chapter 4. It is important to place shale gas high on the government’s energy priorities not only because it is a more environmentally friendly solution than Coal and other non-renewable options but also because this indigenous resource will reduce the burden on the national exchequer.

- **Responsible Shale Development:** Pakistan will need to approach cautiously in Shale Gas, learning from the examples of countries like China and Poland, which have failed to achieve the expected benefits from Shale despite heavy investments. Pakistan will have to analyze existing data and formulate risk evaluation of Pakistan’s shale plays to avoid the challenges that were faced by China and Poland. It will be essential for Pakistan to make careful and thorough assessments of the country’s terrain and geography of shale basins. In fact, the extensive data available under the Pakistan Basin Study (2009) may need to be reanalyzed in the light of Shale Gas Development. Data will have to be analyzed for characterization of the source rock through log data and identification of Total Organic Carbon (TOC). In the past, extensive stratigraphical analysis has been conducted in the Indus basin, and petrophysical models may also help in a better understanding of Shale Gas plays. Moreover, the properties of rock i.e. the mineralogy, petrography and petrophysical properties should be understood for the identification of sweet spots. In this regard, a Hydraulic Fracturing Program (HEP) that would create feasibility reports on Shale reservoirs needs to be formulated. Moreover, factors like fracture containment and induced seismicity should also be factored into the evaluation. Similarly, extensive geological mapping of fault lines will have to be carried out so that wells are not drilled near seismic zones and seismicity will have to be monitored at the pre and post drilling stages.

- **Unconventional Gas Technical Engagement Program (UGTEP) and Other Technical Assistance:** This report strongly recommends that Pakistan should engage with the US on Shale Gas, and conduct diplomatic consultations to become a part of the Unconventional

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293 Wall Street Journal, 2013
Gas Technical Engagement Program\textsuperscript{294} (UGTEP), which was formerly known as the Global Shale Gas Initiative (GSGI). The MPNR will need to learn from and share the U.S. experience, in terms of technical trainings and in terms of establishing regulatory and fiscal frameworks and environmental protection for shale. Before Pakistan can prepare for shale gas bidding, the country will need to strengthen ties with the US State Department’s Bureau of Energy Resources. Moreover, Pakistan will need to build greater cooperation on technical knowledge and training with key shale countries.

- **Effective Regulatory Mechanisms:** Pakistan will need to ensure that the regulatory and licensing policies regarding the unconventional oil and gas sector are favorable for investment. It is recommended that the Ministry of Finance, the MPNR, and the Planning Commission work in collaboration with the Oil and Gas Regulatory Authority (OGRA) to create favorable fiscal and regulatory policies for ensuring investment in unconventional resources so as to initiate the development of these reservoirs. Three key areas of shale gas development that is exploitation, environment and trade should be explored by the GOP. Efficient regulatory mechanisms will need to be developed to speed up the process and to ensure that private investment is not deterred through extensive bureaucratic processes. Moreover, clear division of responsibilities will need to be made, so that the investment process is streamlined.

- **Creating Fiscal Incentives:** Pakistan needs to create an effective fiscal regime for shale gas if it wants to replicate the US Shale Gas Revolution. In similarity to the UK government’s recommended proposal\textsuperscript{295} on fiscal incentives on Shale, Pakistan too will have to create tax incentives for a long-term tax policy on shale. For example, shale gas projects may receive a pad allowance for early investment. Furthermore, the process will have to be clarified, and a positive impact on communities that host projects will have to be ensured. Such consultations will need to be led by the Shale Gas Industry.

\textsuperscript{294} US State Department, 2013, Unconventional Gas Technical Engagement Program (UGTEP)

\textsuperscript{295} Government of the UK, 2013, Harnessing the Potential of UK’s Natural Resources: A Fiscal Regime for Shale Gas
• **Knowledge Management of Hydrocarbons:** Shale gas and oil as a new area of study for Pakistan will require thorough analysis and knowledge management. It is suggested that Pakistani institutes should create a database on the different aspects of the shale oil, and the gas sector should be provided with the geological aspects of the exploration of unconventional resources. Furthermore, existing laboratories will need to be equipped to meet new academic demands. Hence, there is a need to carry out detailed surveys and studies to create understanding of reservoirs with the help of academic and research institutes in Pakistan.

• **Including Shale in the National Curriculum:** Engineering universities and institutes in Pakistan will need to include shale gas technology in their curriculum to develop professionals who have a good understanding of Shale Gas. Furthermore, vocational trainings in this area of study would help to create a skillset on Shale Gas. Additionally, Pakistan Engineering Council (PEC), as a statutory body will be required to play a pivotal role in creating this backbone of knowledge.

• **Environmental Assessment:** Pakistan’s Environmental Protection Agency (EPA) is recommended to work in close collaboration with all regulators of Shale Gas in the region, and to conduct detailed environmental analysis of the impact of Shale Gas technology, including the addressing of concerns on water management, rain water harvesting, land management etc.

• **Community Engagement:** Although most of Pakistan’s higher TOC shale basins are located in low population density areas, it is still essential to engage the communities where exploration and drilling will be conducted from the beginning of the process. Moreover, the public will have to be engaged so that they can understand the facts about shale gas; in this context, local authorities will need to play a key role.

• **Shale Gas Best-Practices:** Regulating authorities are recommended to observe and improve their policy through regular review and revamping in the light of global best practices on shale. The government will have to offer contractors a policy cover and allow for co-development in operations. Furthermore, it is recommended that for
unconventional oil and gas, separate financial and contractual accounts should be maintained to avoid disagreements.
## ANNEXURES

### Annex 1: NATURAL GAS PRICES RS/THOUSAND CUBIC FEET

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GLOSSARY

**Adsorbed Gas** – Gas which is on the surface of a solid material, such as a reservoir rock. Measurement of adsorbed gas helps in calculation of gas in reservoir.

**Biostratigraphic** – The study of the rock strata and the spatial distribution of fossil organisms

**Bitumen** – Inflammable organic matter that naturally occurs in rock that can be extracted through organic solvents.

**Catagenesis** – This is a term that describes the process of converting Kerogens into hydrocarbons for the petroleum industry.

**Continuous Reservoir** – An area that contains hydrocarbon extensively; continuous shale reservoirs can be as large as a sedimentary basin.

**Conventional Reservoir** – Distinct from unconventional reservoir (shale), in which buoyant forces seal hydrocarbon content below a cap-rock.

**Deviated Drilling** – A technique of drilling which deviates from its natural path intentionally and allows drillers to place the borehole in contact with most productive reservoir rock.

**Diagenesis** – A stage in Shale Oil & Gas geological process when alteration of sediments and maturation of Kerogen occurs at temperatures less than 50 degrees centigrade.

**Frac Fluid** – Abbreviated form of fracturing fluid, which usually contains water, proppant and nonaqueous fluids, which reduce friction pressure in the pumping process.

**Fracture** – A crack or surface of breakage within rock. In shale gas and oil and oil extraction, a fracture also refers to a stimulation treatment in low-permeability reservoir.

**Geochemical** – This describes the properties of the earth’s crust and its chemistry

**Grain Density** – Matrix density is the unit volume of rock matrix at zero porosity in grams per cubic centimeter

**Heterogeneity** – Differences in variation in rock properties.
**Horizontal Drilling** – the practice of drilling a horizontal section in a well (used primarily in a shale or tight oil well), typically thousands of feet long.

**Hydraulic Fracturing** – the process of injecting fluid and proppants under high pressure through a [horizontal] well into a Shale Oil & Gas, tight oil or other formation to stimulate production.

**Kerogen** – Natural, solid insoluble organic matter in shale source rocks that can yield oil upon heating.

**Maturation** – The process in which a source rock becomes capable of generating oil and gas under appropriate pressures and temperatures.

**Metagenesis** – In steadily increasing pressure and temperature, sedimentary rocks are buried deeper in the Earth’s strata in the lithosphere and this stage is referred to as metagenesis.

**Mineralogy** – The scientific study of minerals, their distribution, properties, crystal structure etc.

**Natural Gas Liquids (NGLs)** – components of natural gas in gaseous form in the reservoir, but can be separated from the natural gas at the wellhead or in a gas processing plant in liquid form. NGLs include ethane, propane, butane, and pentane.

**Original Gas-in-Place** – the amount of natural gas in a reservoir (including both recoverable and unrecoverable volumes) before any production takes place.

**Original Oil-in-Place** – the amount of oil in a reservoir (including both recoverable and unrecoverable volumes) before any production takes place.

**Oil and Gas Value Chain**

- **Upstream Oil and Gas Activities** – all activities and expenditures relating to oil and gas extraction, including exploration, leasing, permitting, site preparation, drilling, completion, and long term well operation.

- **Midstream Oil and Gas Activities** – activities and expenditures immediately downstream of the wellhead, including gathering, gas and liquids processing, and pipeline transportation.

- **Downstream Oil and Gas Activities** – activities and expenditures in the areas of refining, distribution and retailing of oil and gas products.
Oil and Gas Resource Terminology

- **Conventional gas resources** – resources associated with higher permeability fields and reservoirs. Usually, such a reservoir is characterized by a water zone below the oil and gas. These resources are discrete accumulations, typified by a well-defined field outline.

- **Economically recoverable resources** – that part of technically recoverable resources expected to be economic, given a set of assumptions about current or future prices and market conditions.

- **Proven reserves** – the quantities of oil and gas expected to be recoverable from the developed portions of known reservoirs under existing economic and operating conditions, and with existing technology.

- **Technically recoverable resources** – the fraction of gas in place expected to be recoverable from oil and gas wells without consideration of economics.

- **Unconventional gas resources** – low permeability deposits more continuous across a broad area. The main categories are Shale Oil & Gas, coalbed methane, and tight gas, although other categories exist, including methane hydrates and coal gasification.

- **Shale Oil & Gas and tight oil** – gas, condensate, and crude oil produced from shale plays. Tight oil plays are those shale plays dominated by oil and associated gas, such as the Bakken in North Dakota.

- **Shale Oil** – Another word for tight oil. Unconventional oil produced through bituminous shale.

- **Coalbed methane (CBM)** – gas produced from coal seams (also known as coal seam gas, or CSG).

- **Tight gas** – gas and condensate produced from very low permeability sandstones.

Oil Shale – A type of rock, also known as Kerogen shale which is organic-rich sedimentary rock, with a high Carbon content.

**Petro-physical** – A process for data interpretation, for example to calculate shale volume, total porosity, water saturation etc.

**Petrographic** – A study of detailed descriptions of rocks

**Produced Water** – Water produced in a wellbore that is not a treatment fluid.
**Pyrolysis** – A rock analysis through controlled heating in inert gas or past the point of generating hydrocarbons to assess source rock quality. It breaks large hydrocarbon molecules into smaller ones and determines quality of shale source rock.

**Sedimentology** – The study of sediments for example shale rock, clay, sand etc.

**Sweet Spot** – The target location within a play or reservoir that represents the best production or potential.

**Thermal Maturity** – The heating degree of a source rock in the process of transforming Kerogen into Hydrocarbon.

**Total Organic Content (TOC)** – The weight percent of organic carbon that shows concentration of organic material in source rocks. The higher the TOC, the more effective the source rock. 0.5% TOC is the minimum for an effective source rock.

**Vitrinite Reflectance** – A measure of the thermal maturity of organic matter.