Potential of Tight Gas in Pakistan: Productive, Economic and Policy Aspects*

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Abstract

Tight gas has been defined as "Natural gas produced from a tight formation, one that will not give up its gas readily or in large volumes". Tight Gas - as known popularly, constitute a huge resource potential contained in poor quality reservoirs. The only parameter which classifies a reservoir to be tight (according to literature) is its permeability below or equal to 0.01 mD. The advent of new technologies has greatly advanced the exploration, drilling, and completion. Reservoir engineering and exploitation of tight gas coupled with low cost factors, and higher gas prices has lead to augmented interest in tight gas as a favored alternative or complementary resource globally, in general and in Pakistan in particular.

The production of tight gas is more costly and therefore less attractive to producers owing to the need for fracturing, acidizing, and other expensive treatments to free the gas from the relatively impermeable formations. In view of these constraints, such gas has to be given an incentive price higher than the price of conventional gas. Pakistan can produce a sizeable quantity of gas from tight gas reservoirs to improve power generation. According to rough estimates, Pakistan has approximately 40 trillion cubic feet (TCF) reservoirs of tight gas. This paper has analyzed productive and economic aspects of tight gas coupled with policy aspects.

What Is Tight Gas?

As per the definition from the Glossary of Petroleum Industry, tight gas has been defined as natural gas produced from a tight formation, one that will not give up its gas readily or in large volumes. Technically speaking, it is gas bearing sandstone or carbonate matrix which exhibits in situ permeability to gas of less than 0.01mD. It is the gas found in sedimentary rock that is cemented together so tight that flow rates are very low. Extracting tight gas usually requires enhanced technology like "hydraulic fracturing" where fluid is pumped into the ground to make it more permeable. Reservoirs may also be designated as "tight", if the effective permeability is less than 1 mD and generally the unstimulated gas flow rates are less than 1.0 mmcfd.

Definition of Tight Gas based on permeability

Permeability has been defined as a measure of the ability of the material (such as rocks) to transmit fluids. In other words, it is the ability of rocks to transmit fluids which is measured in Darcies/mDarcies (mD). In the 1970s, the United States government defined a tight gas reservoir as one in which the expected value of permeability to gas flow would be less than 0.1 mD. This definition was a political definition that has been used to determine which wells would receive federal or state tax credits for producing gas from tight reservoirs. Actually, the definition of a tight gas reservoir is a function of many physical and economic factors. The following equation, known as Darcy's Law, relates these physical factors:

$$Q = \frac{-kA\,(Pb - Pa)}{\mu \quad L} \qquad (1)$$

Darcy's formula has also been reported in the literature [5] in terms of following correlation:

$$Qgas = \frac{7.07x10\text{-}4xhxKx(Ps2Pf2)}{\mu \text{ x } ZxTxLnRe/Rw} \qquad (2)$$

Where:

h	=	Pay zone thickness (feet)
K	=	Permeability in Darcies
Ps	=	Static pressure (psia)
Pf	=	Bottom hole flowing pressure
μ	=	Viscosity of fluid in centipoise
Ln	=	Natural log
Re	=	Radius of drainage (feet)
Rw	=	Radius of well bore (feet)
Z	=	Compressibility factor
T	=	Reservoir temperature in rankine

Darcy's law (given in equation 1) is a simple proportional relationship between the instantaneous discharge rate through a porous medium, the viscosity of the fluid and the pressure drop, over a given distance. The total discharge, Q (units of volume per time, e.g., ft^3/s or m^3/s) is equal to the product of the permeability (κ units of area, e.g. m^2) of the medium, the cross-sectional area (A) to flow, and the pressure drop ($P_b - P_a$), all divided by the dynamic viscosity μ (in SI units e.g. kg/(m·s) or Pa·s), and the length L the pressure drop is taking place over. The negative sign is needed because fluids flow from high pressure to low pressure. So if the change in pressure is negative (in the *x*-direction) then the flow will be positive (in the *x*-direction). All variables given in equation (1) play important roles, whether they are directly proportional or indirectly proportional to total discharge, Q. When, definitely after physical and chemical analysis of the reservoirs, it is established that certain variable, for instance, pressure drop is the driving force for improving the total discharge, Q, efforts are made to enhance pressure drop by using advanced technology and the price of gas will depend on how much efforts have been made for tight gas recovery. Thus, to choose a single value of permeability to define “tight gas” is of limited significance. In deep, high pressure, thick reservoirs, commercial completions can be achieved when the formation permeability to gas is in the microdarcy range (0.001 mD). In shallow, low pressure, thin reservoirs, permeability of several millidarcies might be required to produce the gas at economic flow rates, even after a successful fracture treatment.

One way to define tight gas is as “natural gas that cannot be produced at economic flow rates or in economic volumes unless the well is stimulated by a large hydraulic fracture treatment, a horizontal well bore, or by using multilateral well bores or some other techniques to expose more of the reservoir to the well bore”.

Tight gas definition has been defined and fixed differently in various countries. **Table 1** presents standards of permeability in various countries.

From **Table 1**, it is clear that the range for permeability is from < 0.1 mD to < 2 mD. The exploration and production of tight gas from the reservoirs in these countries require the use of the state-of-art and advanced technologies like high performance perforations, hydraulic fracturing, horizontal wells, multilateral wells, and infill drilling of combinations of these technologies. It involves huge investment with recovery period from ten to fifteen years depending upon production rates and prices of gas.

From the economic view point, tight gas may be defined as natural gas that cannot be produced at economic flow rates or in economic volumes without a hydraulic fracture job or special drilling techniques. A reservoir having estimated value of effective permeability up to 1 mD shall be classified as tight gas reservoir, and a reservoir with effective permeability of more than 1 mD shall be classified as a conventional reservoir. With the sharp recent rise in well drilling and particularly well stimulation costs, it is perceived that much of the conventional gas resources, including tight gas in the United States, are becoming uneconomic. However, improvement in the unconventional gas knowledge base and technology progress using industry/government partnerships can maintain the economic viability of this large, often marginally productive resource (Kawata and Fujita 2001).

Availability Development and Production of Tight Gas

The Unconventional Hydrocarbons (UHC) production is available in the specific regions of the world because of its high production cost (Kawata and Fujita 2001). Tight gas energy source is a fast growing market. Stimulation and cementing technologies are providing most significant support for improved economic production. Tight gas reservoirs require advanced technologies to enable reduction of the migration distances from formation to well. During the last decade, development of tight gas reservoirs has occurred outside the United States in Canada, Australia, Mexico, Venezuela, Argentina, Indonesia, China, Russia, Egypt, and Saudi Arabia. **Table 2** presents Worldwide

Unconventional Gas Resources Estimates.

It is clear from **Table 2** that North America has almost quadruplicate tight gas resources as compared to Western Europe, whereas it contains 18.5% of the total World's tight gas resources. The world's share of tight gas resources, in case of South Asia is only 2.65%. The reason for this low value is lack of awareness about unconventional gas resources and the non-availability of latest technologies required to tap these resources. **Figure 1** depicts various basins of tight gas throughout the United States. It is clear from this figure that tight gas resources are very widely distributed. When wells are drilled, there is a very high rate of successful (not necessarily economic, however), approximately 98%. With such widely distributed resources, the challenge is finding "sweet spots" that can be more economically extracted, and developing techniques that will do this in a cost effective manner (Tverberg 2008).

United States natural gas production has been flat for a number of years. It is quite natural that the production should decline in the coming future, but it does not seem to happen in the next few years. The reason production remains level is because unconventional gas production has been rising at the same time that conventional production has been declining. Among the major forms of unconventional gas sources are tight gas, coal bed methane, and shale gas. The productions of all three have been rising in recent years However, tight gas is the largest of the three (**Figure 2**). Tight gas is playing a pivotal role in the production/supply of natural gas in the United States.

It is evident from **Figure 2** that the United States produced 3.6 Tcf of tight gas in 1996, whereas, the production of tight gas crossed 5.7 Tcf in the year 2006, showing a growth rate of 58% during the period of comparison.

Tight Gas Potential in Pakistan

The preliminary tight gas reserves estimate for initial gas in place (GIIP) in various horizons/basins in Pakistan are in the range of 24 TCF to 40 TCF. The tight gas reserves have also been identified in the existing Development and Production Leases granted to various E&P companies operating in Pakistan. These companies are reluctant to exploit tight gas reserves because of high cost with lower return on their investment. **Table 3** presents field-wise details of tight gas resources in Pakistan. Following are five possible candidates for Tight Gas Resource in Pakistan:

- Lower Goru Tight Sands
- Sembar Sands and Siltstones
- Sui Upper Limestone
- Habib Rahi Limestone
- Pirkoh Limestone

Further detail about the above-mentioned possible candidates for tight gas resource may be seen in **Figure 3** depicts total known tight gas resources in Pakistan.

Figure 3 indicates the presence of tight gas resources in Sulaiman Foldbelt, Middle Indus Basin, and Kirthar Foldbelt. In addition to these, tight gas resources are also present in other parts of Pakistan, like: Potwar region, Lower Indus Basin, and Offshore areas near to Karachi. This has been shown clearly in **Figure 4**.

New Technology for Tight Gas Sands

A concerted technology effort to better understand tight gas resource characteristics and develop solid engineering approaches is necessary for significant production increases from this low-permeability, widely dispersed resource. The current understanding of the tight gas resource and past experience in the other countries of the world with production enhancement techniques, from nuclear detonations to hydraulic fracturing, both indicate that significant gas recovery can be achieved, only by positioning a wellbore in the near vicinity of the formation to be produced. To meet the economic requirement of wellbore positioning close to the producing formation, tens of thousands of wells would need to be drilled to reach targeted production levels - a staggering economic and environmental challenge.

The basic components for construction of a tight gas sand well include rotary drilling of a wellbore eventually completed with a hydraulic fracture stimulation. Many technology improvements over past years, while incremental in nature, have combined to allow costs to be reduced while exploration techniques have allowed better well locations to be selected. The incremental improvements have combined to offset the impact of lower quality rock being developed. It is postulated that for a significant increase in tight gas production levels, a greater than "incremental" technology development must be developed.

Further, environmental impact can be minimized by "**Onsite Waste Management**" **–** Nothing leaves the location except saleable product. All waste materials (drill cuttings, drilling fluids, and produced fluids) are safely re-injected into appropriate zones in the same formations. Recycle of materials is maximized.

New Technology Components

- The concept of bringing offshore technology onshore i.e., the multiple-well single location, with many wells being drilled from a single location and with lengths of some wellbores reaching a few miles, allowing wide coverage. This will reduce rig moving costs, location preparation costs and road building costs.
- Drilling the well with real-time near-bit sensors for sending information to the well site geologist who can integrate these data with mud-logging and seismic, and alter the target as the new information dictates: "geo-steering" and look-ahead seismic steering of the drill bit helps to maximize the quality and quantity of pay zone penetrated by the drill bit.
- Use of new fracturing technology to help accessing the pay zones, e.g., with multiple jobs, each optimized to specific formation properties. Each treatment, while not achieving propped lengths once envisioned, can be pumped at significant cost savings and effective propant placement allows for quick and complete well cleanup, enhancing productivity.
- The multiple wellbores may be drilled and completed with the latest "slimhole" technologies and tubulars (coiled tubing) to minimize material and increase speed of drilling. This drilling environment allows for utilization of underbalanced drilling for all wellbores:

this increases rate of penetration, limits wellbore damage, and provides better insight into pay zone selection, primarily through targeting and exploitation of naturally fractured environments.

- One wellbore can be used for disposal of all required materials on site, eliminating the cost of trucking and land filling of these materials. Drill cuttings, drilling fluids, and subsequently produced water never leave the location.
- Operating expenses can be reduced by the centralized location of the wells. Cost of gas compression, metering, well workovers, well monitoring, providing safety, travel and labor are all reduced.
- The environmental footprint can be minimized due to multiple wellbores at a single location. A great deal of activity below the surface coupled with a minimum of surface disturbance and land utilization holds environmental costs down and maintains a positive industry image. Environmental concerns of air emissions, noise, footprint etc., are mitigated by the environmental control enabled by the cluster of wells.

Many of these technologies exist today, although their application is limited to prolific producing areas (e.g., offshore and onshore Alaska) due to the high cost of technology application. A part of the challenge for the future will be to contain these costs, allowing deployment to low permeability environments. Some of the technologies need to be developed and some have not yet been adequately thought about. The future will require a contribution from all participants (Naik).

Economics of Tight Gas

Conventional reservoirs are those that can be produced at economic flow rates and that will produce economic volumes of oil and gas without large stimulation treatments or any special recovery process. A conventional reservoir is essentially a high- to medium permeability reservoir in which one can drill a vertical well, perforate the pay interval, and then produce the well at commercial flow rates and recover economic volumes of oil and gas.

On the other hand, an unconventional reservoir is one that cannot be produced at economic flow rates or that does not produce economic volumes of oil and gas without assistance from massive stimulation treatments or special recovery processes and technologies, such as steam injection. Typical unconventional reservoirs are tight-gas sands, coal-bed methane, heavy oil, and gas shales.

Unlike conventional reservoirs, which are comparatively small in volume but easy to develop, unconventional reservoirs are large in volume but difficult to develop. Increasing gas prices and the improved technology are the key to their development and the future. Unconventional resources are probably very large, but their character and distribution are not yet well understood. It is known to exist in large quantity but does not flow easily toward existing wells for economic recovery. Tight reservoirs contain no natural fractures, but cannot be produced economically without hydraulic fracturing. Fractured, tight and unconventional reservoirs are often perceived as entailing higher costs and risks than conventional reservoirs. Engineers look unfavorably on them because they are difficult to evaluate and recovery techniques must be carefully chosen and applied in order to avoid production problems. However, new technologies developed recently are making more and more of these accumulations economic. Now is the time to carefully examine these reservoirs and new and emerging approaches and technologies are being used to find and develop them. Economic production of natural gas from these resources, including tight gas, is a great challenge in the world in general, and in Pakistan in particular.

In order to find the economic viability of the tight gas production, we need to make an in-depth study of cost elements involved in the production of tight gas and division of revenues. **Figure 5** illustrates the basic elements in the allocation of revenues for recovery of costs and the division of profits (Johnston 2003). In Pakistan, Government take includes royalty (12.5% of sale of product), production bonus, yearly rents, training obligations etc. as per Petroleum Policy, 2009 (DGPC 2009). Marine fee and social development obligations are the expenditures, which a petroleum company incurs for the development of the local community in consultation with Petroleum Marine Development Committee (PMDC) or local MNA.

Economics of Tight Gas in Pakistan

In Pakistan, the drilling cost of a development well varies from US$ 5 million to US$ 13 million per well, depending upon if it is located in the South or North part of Pakistan respectively. Now, it is appropriate to discuss a hypothetical example of drilling fifty development wells with hydraulic fracture stimulation to provide an output of 300 billion cubic feet (Bcf) of gas in twenty years. No exploration expenditures are involved, as it is assumed that these development wells are located in the already discovered gas field and the objective is to recover tight gas using more advanced techniques. Tie-in cost is assumed to be US$ 3 million/well (Heikal 2008). There is a 5% increase per year in the capital cost of the project. For well drilling, completion and fracturing costs, two cases are considered here. In the first instance, it is assumed that a development well is drilled using vertical drilling for which the estimated cost is US$ 13 million per well. In the second case, it is assumed that instead of vertical drilling, horizontal drilling in the already discovered structure through already drilled exhausted vertical well will be carried out for which, it will be required to drill in the direction perpendicular to axial direction for which not more than US$ 3 million per well will be required. OPEX is estimated at US$ 3.5/BOE (Heikal 2008) for both cases.

Case – I: Development well Using Vertical Drilling

Since the objective is to recover tight gas, therefore, a development well has to be drilled. The working for this case has been shown in **Table 4** under the assumptions mentioned above. **Table 5** shows Petroleum Policy-2009 prices of natural gas in the respective three zones of Pakistan at various reference crude oil prices (RPC).

For natural gas price from tight gas field, it is first assumed that 50% premium on the base case of prices given in **Table 5** is to be paid. The results have been shown as under:

NPV@10%	=	$48.00 million;
NPV@15%	=	($79.89) million
IRR	=	12%

Similar exercises were done for 60% and 70% premium prices for tight gas over base case prices given in **Table 5**. Following results were obtained:

For 60% premium price:

NPV@10%	=	$99.45 million;
NPV@15%	=	($43.41) million
IRR	=	13%

For 70% premium price:

NPV@10%	=	$153.62 million;
NPV@15%	=	2.71 million
IRR	=	15%

From these results, it is concluded that the project of tight gas in Pakistan is economically feasible, if the prices of tight gas are kept at 70% higher than normal gas prices in different zones of Pakistan at various RCP.

It is important to note that average (arithmetic mean) price of different zones was used and after every three years different RCP values given in **Table 5** were used. This was true for the case of vertical drilling.

Case – II: Development well Using Horizontall Drilling:

It is assumed that a development drilled well is already there (in the existing D&P lease) and few meters of drilling perpendicular to the axis of the well is required. The objective is to recover tight gas from an already exhausted natural gas well. The only difference between this case and previous case is that drilling cost has been taken as US$ 3 million per well, other items are the same. For this case, the project is feasible at premuim price of 50% of the base case price given in **Table 5**. Following results were obtained:

NPV@10%	=	$107.63 million
NPV@15%	=	$10.95 million
IRR	=	16%

This case is more preferable from the government’s as well as from the investor’s/consumers’ perspectives.

Conclusions and Recommendations

Based on the analysis made in the preceding sections, it is concluded that:

- Permeability should not be the sole criteria for making any decision about tight gas. The decision should be based on Darcy's formula and project economics.
- Estimated total tight gas reserves in the world are 7,406 TCF, of which 18.51% are in the North America.
- Estimated total tight gas potential in Pakistan is in the range of 24 – 40 TCF.
- Latest technology is available in the world, although expensive, to recover tight gas in Pakistan.
- Vertical drilling is more expensive for a new development well to recover tight gas and project is feasible only, if a premium price of at least 70% of Petroleum Policy-2009 RCP is paid, otherwise the project is not worthwhile.
- Re-entry of an already drilled well in the direction perpendicular to the axis of the well is much cheaper, compared to vertical drilling and is economically viable, even if 50% premium price of RCP of Policy-2009 is paid.
- Gas price incentives are prerequisite to promote a tight gas recovery process.
- Sale of gas to third party, especially to power sector, should be encouraged. It will have a multiple effect on the economy of Pakistan.
- Tight gas policy should be announced without any further delay and this policy should be reviewed after every three years.
- The other provisions of Petroleum Policy-2009 should also be applicable to the Tight Gas Policy-2010

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S.No.	Country/ Region	Permeability
1.	USA	< 0.1 mD
2.	German Society for Petroleum & Coal Science and Technology	< 0.6 mD
3.	Saudi Arab	< 2 mD
4.	Algeria	< 1.0 mD
5.	Southern North Sea	< 1.0 mD

Table 1. Permeability of tight Gas defined in different countries/regions (DGPC 2009).

S.No.	Region	Gas in Tight Sands (TCF)[1]
1.	North America	1,371
2.	Latin America	1,293
3.	Western Europe	353
4.	Central and Eastern Europe	78
5.	Former Soviet Union	901
6.	Middle East and North Africa	823
7.	Sub-Saharan Africa	784
8.	Centrally Planned Asia and China	353
9.	Pacific	705
10.	Other Asia Pacific	549
11.	South Asia	196
TOTAL	**World**	**7,406**

Table 2. Worldwide Unconventional Natural Gas (Tight Gas) Resources Estimates (DGPC 2009).

Details	Existing Resources							
Operator	ENI	OMV			OPII	POGC	POL	
Field	Kadanwari	Sawan	Miano	Gambat, Latif etc.	Ratana 1	Block 2667-7, Kirthar E.L.	Pariwali-7	Bela-1
Location	Middle Indus	Sindh	Sindh	Sindh	North Potwar	Sindh	Pindi Gheb Attock	Jund, Attock
License/ Lease	Lease	-	-	-	-	License	-	-
GIIP (TCF)	3	0.9	3.90	0.632	-	-	-	-
Recoverable Reserves (TCF)	1.35	0.360	1.56	0.25	0.092	0.41	0.005	0.013
Effective Permeability, mD	0.5	0.01 – 1.0	0.01 – 1.0	-	-	< 0.2	0.01	-
Timeline for first gas, months (from day dev. Plan gets approval)	2012-13	2012-13	2012-13	2012-13	-	Mid 2011	Producing	2010
Expected plateau prod., mmcfd	150	-	-	-	4	20	1	2
Existing Price (May, 2010)	-	-	-	-	-	-	-	-

Table 3. Field-wise Details of Tight Gas Resources (DGPC based on information provided by Operating Companies).

Year	No. of Wells	Well Head	Production/ Sales	Annual Sales	CAPEX Drilling	(MMUS$) Facilities	OPEX (MMUS$)
		Mmscfd	Mmscfd	Mmscf			
1	10	-	-	-	130	30	-
2	10	20	18	6,574	136.5	31.5	4.007
3	10	38	34	12,424	143.325	33.075	7.573
4	10	54	49	17,748	150.491	34.729	10.818
5	10	69	62	22,540	158.016	36.465	13.739
6		82	74	26,948			16.426
7		75	67	24,562			14.972
8		69	62	22,690			13.831
9		64	58	21,146			12.889
10		61	55	19,945			12.157
11		58	52	18,947			11.549
12		55	49	18000			10.972
13		52	47	17,100			10.423
14		49	44	16,245			9.902
15		47	42	15,433			9.407
16		43	39	14,158			8.630
17		33	30	10,918			6.655
18		24	21	7,839			4.778
19		15	13	4,915			2.996
20		7	6	2,136			1.302
21		0	0	-			-
Total				300,267	718.332	165.769	183.026

Table 4. Cost Estimation for Vertical Drilling. Source (Data adopted from Heikal, S. 2008 and own assumptions and calculations).

RCP, US$/ bbl	Policy-2009 Price of Zone-I, US$/mmBtu	Policy-2009 Price of Zone-II, US$/mmBtu	Policy-2009 Price of Zone-III, US$/mmBtu
70	4.62	4.32	4.03
75	4.69	4.39	4.09
80	4.76	4.45	4.14
85	4.83	4.52	4.20
90	4.89	4.58	4.26
95	4.96	4.64	4.32
100	5.03	4.71	4.38

Table 5. Respective Zonal Prices of Natural Gas as per Petroleum Policy-2009 at Various RCP (DGPC 2009).

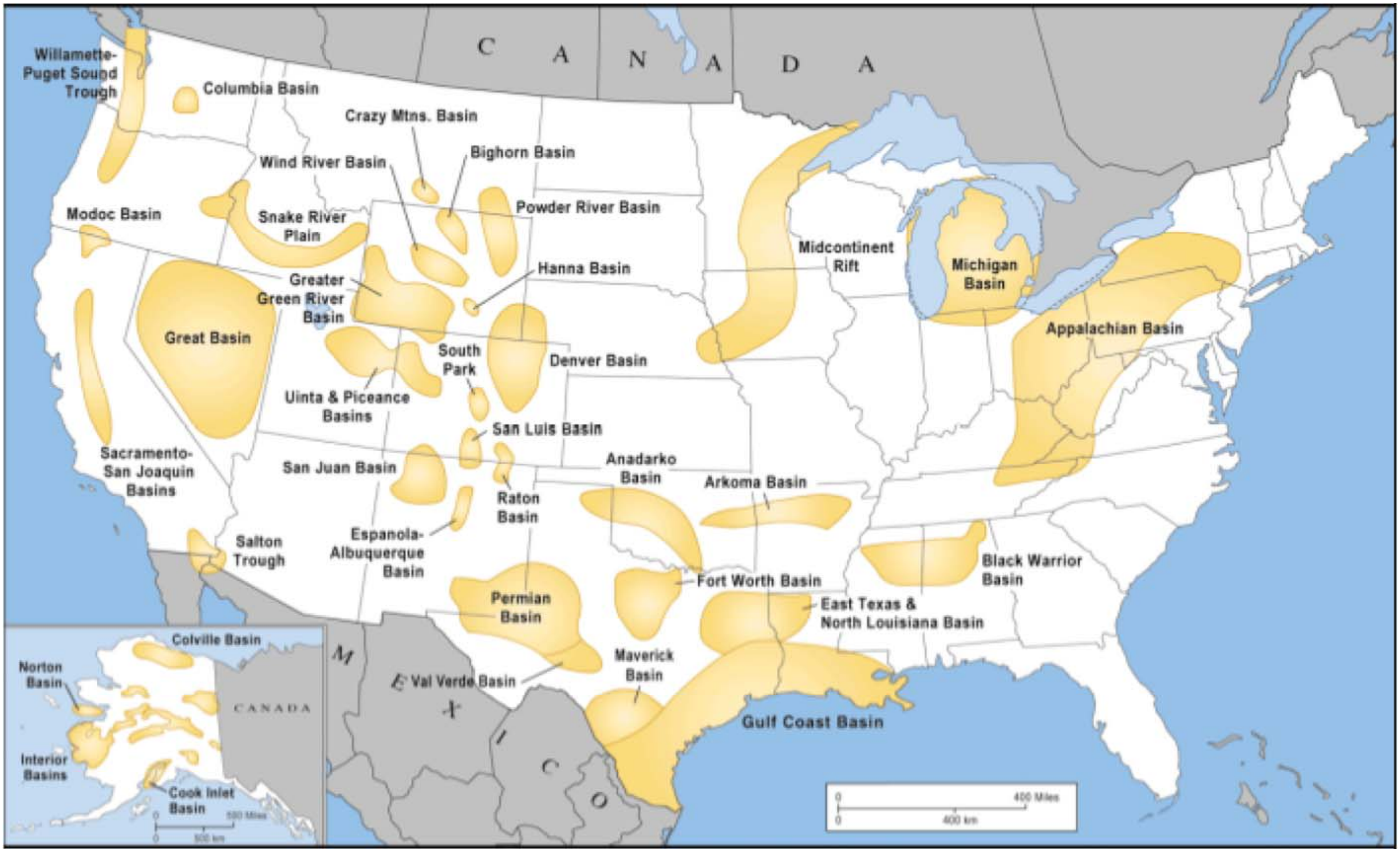

Figure 1. Various Basins of Tight Gas throughout the United States of America (G. Tverberg, 2008).

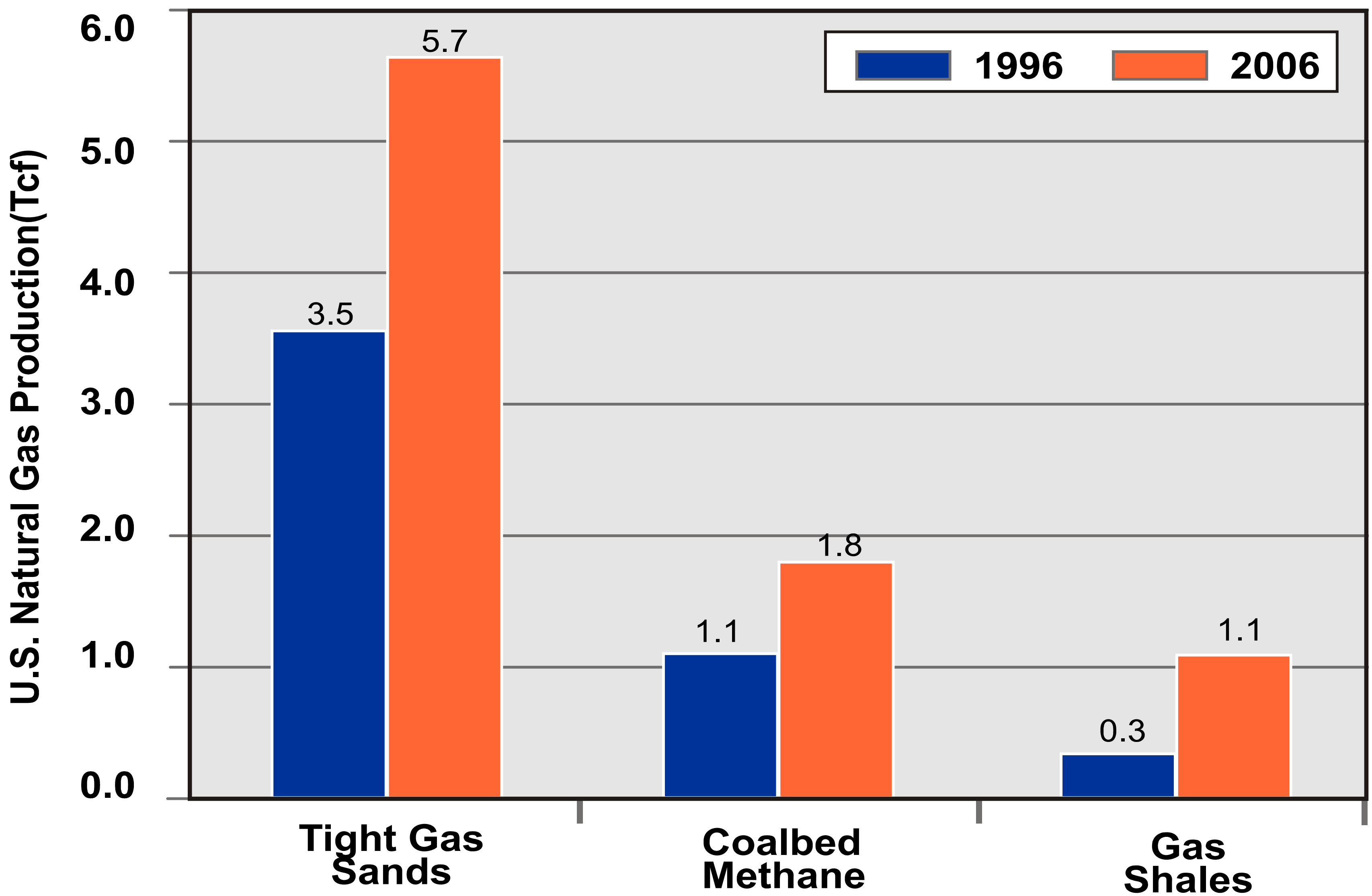

Figure 2. All the three Unconventional Gas Resources have seen Production Growth in the United States (G. Tverberg, 2008).

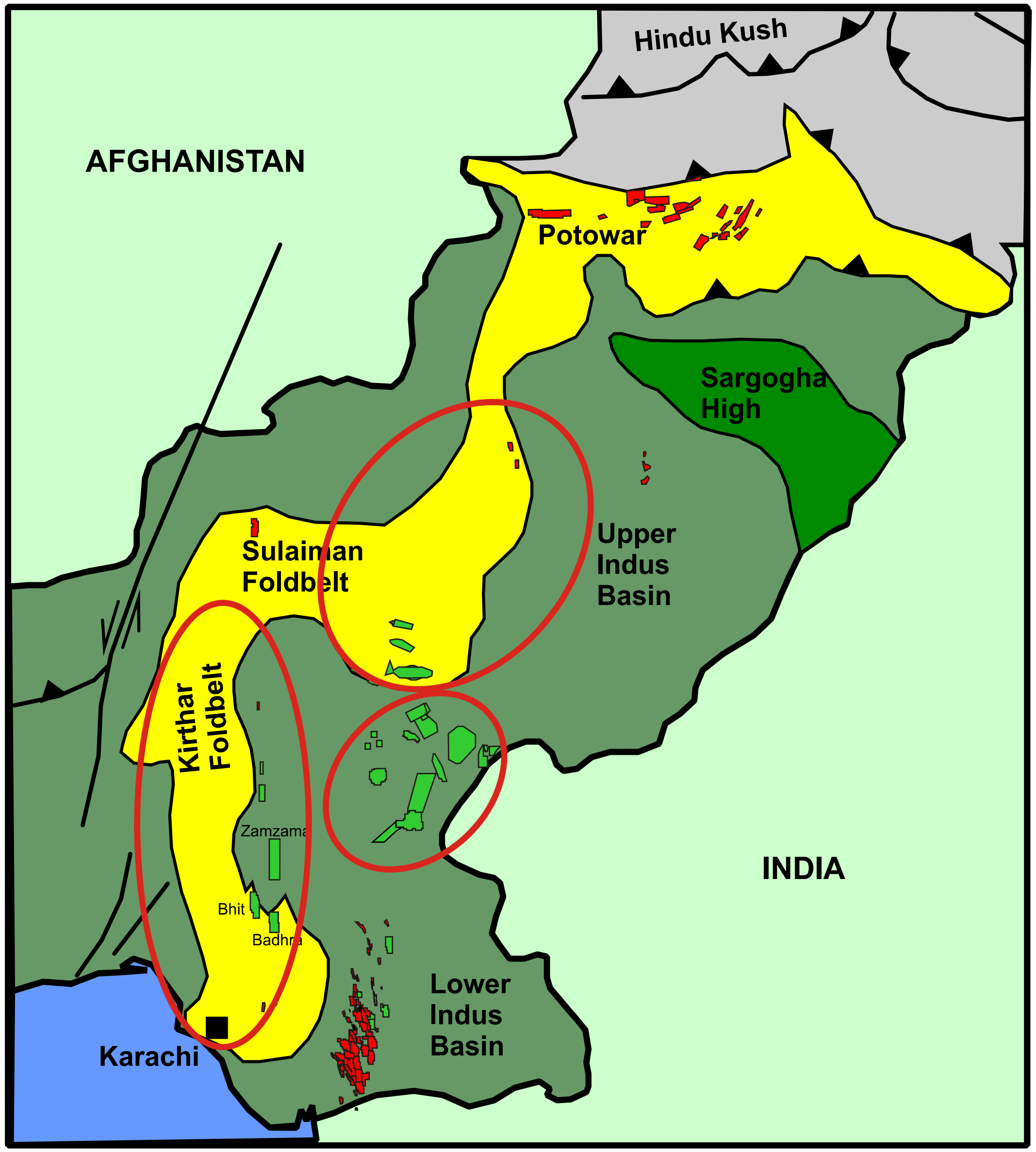

Figure 3. Total known Tight Gas Resources in Pakistan (S. Heikal, 2008 and DGPC 2009).

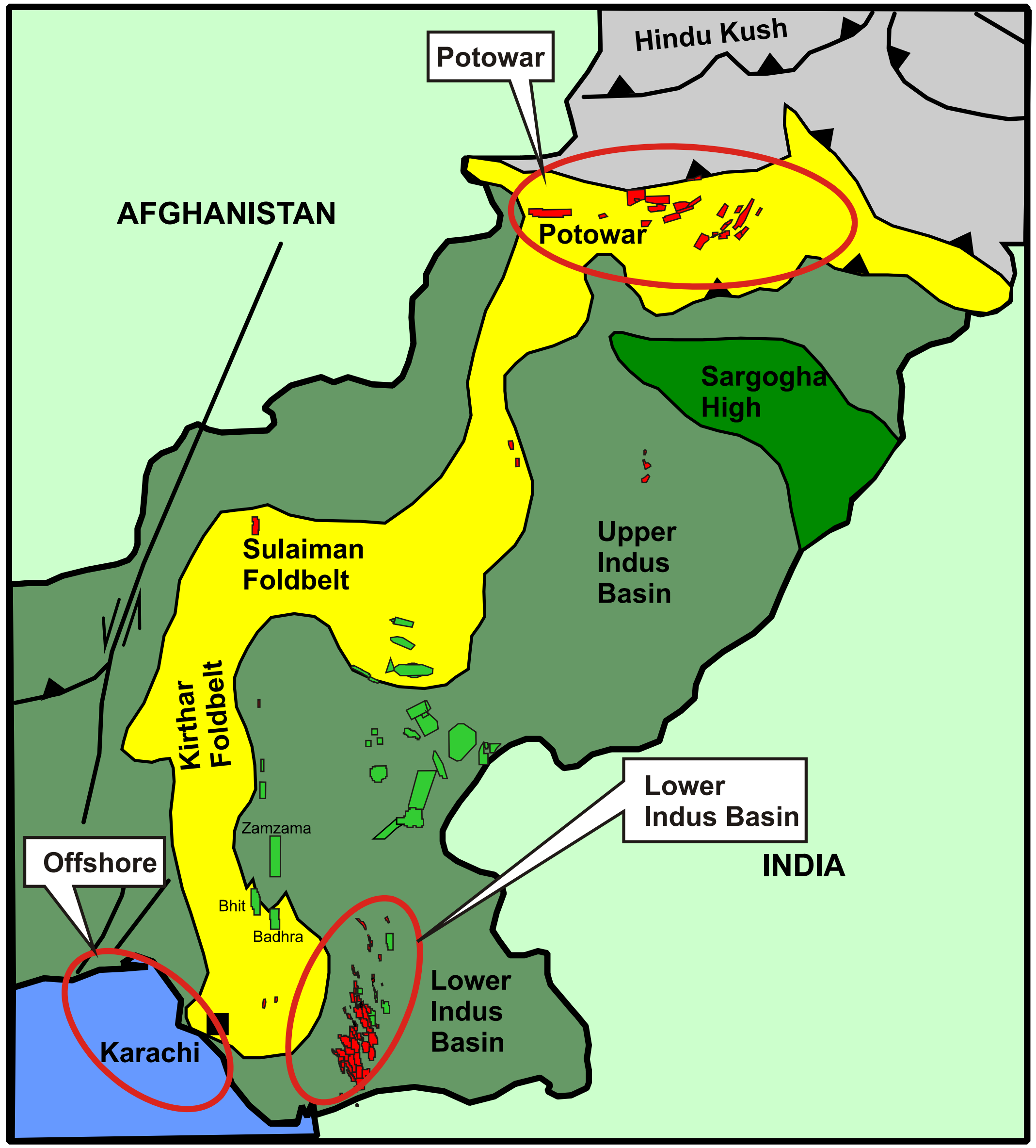

Figure 4. Tight Gas in other parts of Pakistan (S. Heikal, 2008 and DGPC 2009).

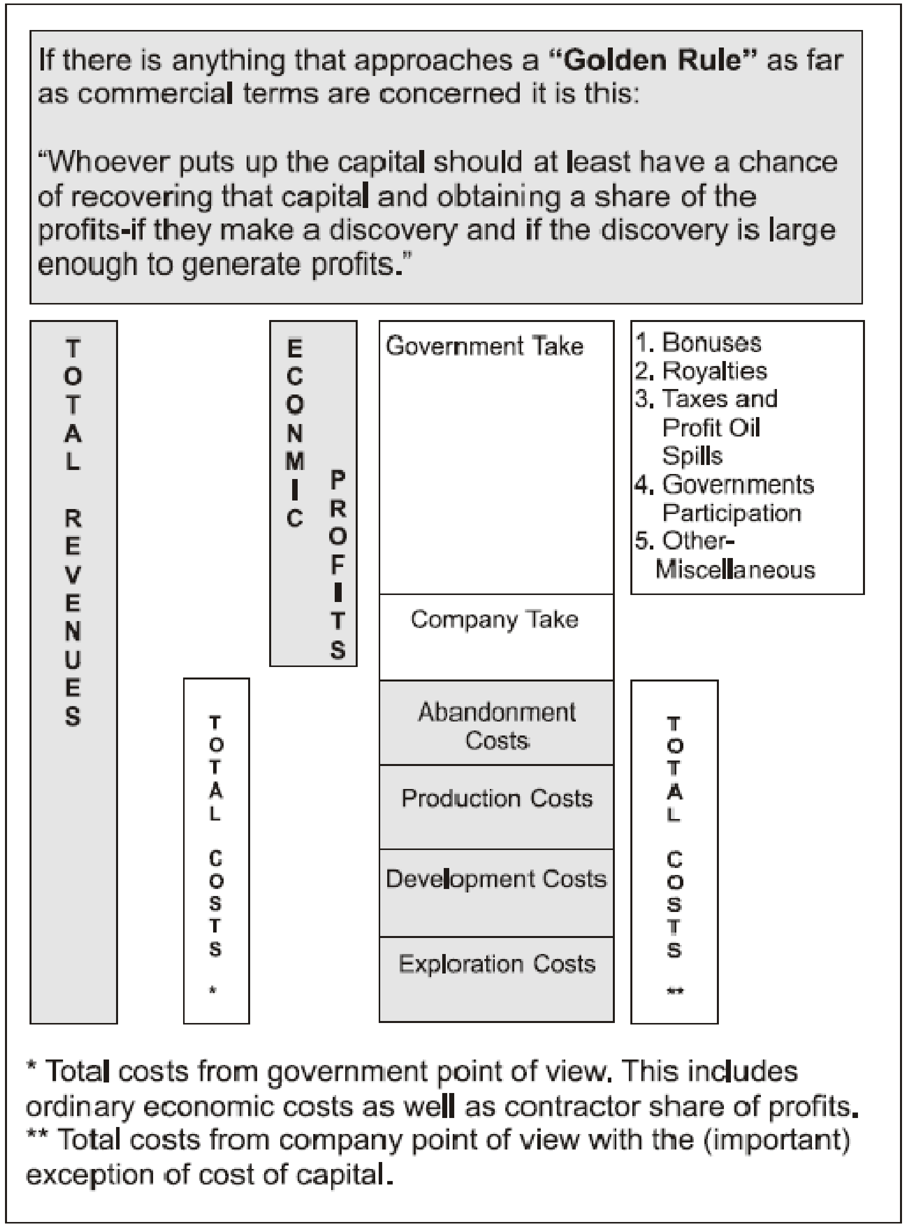

Figure 5. Division of Revenues (D. Johnston, 2003).