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WHAT ARE THE CONSTRAINTS ON ASSOCIATED GAS UTILIZATION?

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Abstract: With the growing share of natural gas in global energy consumption there is increasingly higher interest in associated gas utilization issues. For a long time, oil producers have simply flared this unwanted by-product of oil, citing various reasons that constrained its utilization. The share of flared gas in total gas output varies among main oil-producing regions and nations. This paper looks at several country cases with different situation of associated gas utilization and available options for associated gas development to define constraints still reining in associated gas utilization.

List of Abbreviations

BBL	Barrel
BCF	Billion cubic feet
BCM	Billion cubic meters
BCMPA	Billion cubic meters per annum
CF	Cubic feet
CCGT	Combined cycle gas turbine
EIA	Energy Information Administration (U.S.A.)
FSU	Former Soviet Union
GOR	Gas-oil ratio
GOSP	Gas-oil separation plant
GTL	Gas-to-liquids
GW	Gigawatt
IEA	International Energy Agency
LNG	Liquefied natural gas
LPG	Liquid petroleum gas
MBOE	Million barrels of oil equivalent
MCF/D	Million cubic feet per day
MTOE	Million tonnes of oil equivalent
NLNG	Nigerian LNG company
ULCC	Ultra large crude carrier
VLCC	Very large crude carrier

1. INTRODUCTION

For a long time natural gas has been oil's poor hydrocarbon relation, with its much lower energy content per volume and dependence on pipeline infrastructure for transportation.

Greater part of today's documented gas reserves have probably been discovered 'incidentally' as a result of oil exploration, and some part may have even been re-discovered, as during earlier years of the industry non-associated gas finds were sometimes considered worthless and not even recorded[1].

If there is no local market or export opportunity, non-associated natural gas is simply left in the ground, being classified as "stranded". Today, more than half of the world's discovered gas is regarded as such[2]. Associated-gas, on the contrary, is a by-product of oil, and, as the history of the industry shows, mostly an unwanted by-product, which needed to be disposed of.

In the light of increased public intolerance to environmentally harmful practices, oil companies become targets of criticism for contributing to greenhouse effect and pollution by flaring their associated gas. Environmental concerns have also served as a base for projections of increasingly important role of natural gas, a relatively clean fuel, in global energy consumption. For example, IEA expects gas use "to surpass coal just after 2010"[3]. Will these developments, along with new technology, overcome the constraints on associated gas utilization and eliminate flaring? To answer this question it is important to understand what the actual constraints are. The aim of this paper is to define the constraints that rein in associated gas utilization.

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[1] Shell (1983), The Petroleum Handbook, (6th ed), Amsterdam: Elsevier.
[2] Johnston, D. (2003), International Exploration Economics, Risk and Contract Analysis, Tulsa: PennWell.
[3] International Energy Agency (2002), Natural Gas Information (2002 edition).

It will first provide a brief introduction to the technical aspects of this resource and the traditional ways of handling it. The second part will look at examples of successful utilization programs and unsuccessful efforts at country levels. The third part will provide brief overview of associated gas utilization methods and new technological developments, and will be followed by conclusions.

1.1 ASSOCIATED GAS AND FLARING

There are two types of associated gas accumulations in oil deposits. Solution gas is dissolved in the oil 'pool[4]'. Cap gas occurs in oil deposits where oil saturation with gas reaches a maximum under existing pressure and temperatures, and the 'excess' gas is pushed to the top, forming a cap[5]. In simplified terms, gas-oil-ratio defines whether the hydrocarbon formation is oil, gas or condensate field (Figure 1).

Figure 1 Gas-oil-ratios for different fields

	Oil	Condensate	Associated gas	Dry gas
GOR, cf/bbl	100-2,500	10,000	20,000	100,000

Source: adapted from Johnston (2003)

For oil production, both solution gas and gas cap are natural drives, maintaining the reservoir pressure at the initial stages of production. However, primary recovery is usually limited to a maximum of 25-35% of hydrocarbons initially in place. Re-injection of extracted gas is used as a secondary recovery mechanism. But this still needs purification of the gas and compression, which means additional costs that increase as reservoir pressure drops in line

[4] A geologist would frown on the use of this word; it is used here for the purpose of simplicity.
[5] Shell (1983), The Petroleum Handbook, (6th ed), Amsterdam: Elsevier

with production increasing[6]. Also, in some fields re-injected gas may actually impair oil production by adversely affecting its flow[7].

Thus, when gas recycling is not possible for one of these reasons (high costs and negative effect on oil extraction), producers have to dispose it off.

During earlier years of the industry gas was simply vented. Even today this practice is not eliminated. In Alberta, for example, oil producers vent about 0.5 bcmpa, as much as they flare[8]. However, concentrations of vented gas in the surroundings can become high enough to cause explosion[9]. Oil companies came up with the first "solution" – to burn it.

1.2 FLARING

According to various estimates some 10-13 bcf[10] is flared daily in the world. Only two countries, U.S. and Russia, consume more than this amount[11]. Before the 'dash-for-gas', the ratio of flared gas, to gas consumed was even higher: in 1980, total amount of flared was equal to the amount consumed in Western Europe, some 3 mboe[12]. The figure below illustrates world oil production and gas flaring since 1980.

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[6] Harrison, G. (1984), Associated natural gas resource management: a comparative study and techno-economic model, Ph.D. thesis, Heriot-Watt University.

[7] Shell (1983), The Petroleum Handbook, (6th ed), Amsterdam: Elsevier.

[8] Innes D. (2003), *Flaring Performance in Alberta: Statistics, Target Levels, Before and After Guide 60*, Regulatory Capacity Building Workshop, sponsored by the Global Gas Flaring Reduction Partnership of the World Bank and IFC, (Calgary, Alberta, October 21-24, 2003) http://www.worldbank.org/ogmc/ggfrcapacitybuilding.htm [visited on January 20, 2004].

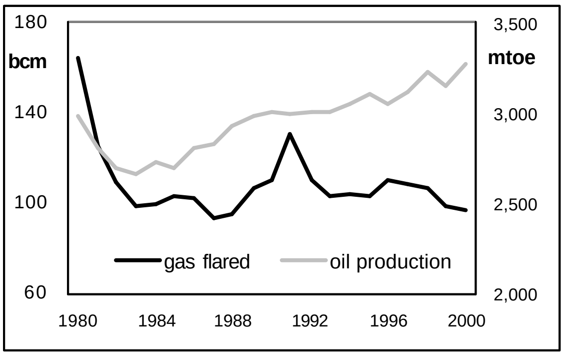
[9] Harrison, G. (1984), Associated natural gas resource management: a comparative study and techno-economic model, Ph.D. thesis, Heriot-Watt University.

[10] Johnston, D. (2003), International Exploration Economics, Risk and Contract Analysis, Tulsa: PennWell and Haugland T. (2002), Results of Stakeholder Discussions, Global Gas Flaring Reduction Initiative Conference, World Bank and IFC, (Oslo, Norway, April 14-16, 2002), http://www.worldbank.org/ogmc/proceedings.htm [visited on January 20, 2004].

[11] International Energy Agency (2002), Natural Gas Information (2002 edition).

[12] Shell (1983), The Petroleum Handbook, (6th ed), Amsterdam: Elsevier.

Figure 2 World oil production and gas flaring



Source: Haugland (2002)

Gas flaring contributes to emissions of carbon monoxide, nitrous oxides and methane, estimated between 1-4% of the total amount of these emissions from all sources[13] and itself is a source of noise and unwanted heat and light, affecting nearby communities and surrounding flora and fauna. Harmful effect on the environment could be reduced by implementing explosion modeling techniques[14]. However, even if by some magic all the flaring becomes harmless, other problems would remain. First, from the society's point of view, an exhaustible resource is being simply wasted, and second, oil producers operate inefficiently by not being able to generate income from associated gas utilization.

The first argument about the waste of exhaustible resource is not very convincing. If flared volumes, estimated 100-130 bcmpa[15] are compared with the global gas consumption – about 2,500 bcm, then the ratio of flared to consumed gas is 4-5%. This could be considered quite a significant amount. However, taking into account the fact that energy consumption is given

[13] Environment Agency (1999), Oil and Gas in the Environment, London: Stationary Office.
[14] Brinded M. (2002), Using associated gas – the Climate Double Dividend, Global Gas Flaring Reduction Initiative Conference, World Bank and IFC, (Oslo, Norway, April 14-16, 2002), http://www.worldbank.org/ogmc/proceedings.htm [visited on January 20, 2004].
[15] Haugland T. (2002), Results of Stakeholder Discussions, Global Gas Flaring Reduction Initiative Conference, World Bank and IFC, (Oslo, Norway, April 14-16, 2002), http://www.worldbank.org/ogmc/proceedings.htm [visited on January 20, 2004].

in terms of useable, rather than useful energy, which depends on the efficiency of transformation or final consumption appliances, global useful consumption of gas is much lower than the statistical 2,500 bcm. Of this, about 900 bcm is used for power generation[16], where fuel efficiency rarely exceeds 40-50%, with more efficient but not widespread CCGT technology providing 70-80%. Thus, in power generation sector alone, more gas is wasted than in oilfield flaring. While flaring essentially is waste, it is small compared to the waste that takes place as a result of inefficient energy transformation and consumption.

The second issue, regarding inability, or unwillingness of oil companies to market associated gas needs more analysis. On the one hand, it is strange that an international oil major in terms of operational efficiency is performing poorer than an average American slaughterhouse, which claims using "every part of the pig except the squeal". On the other hand, it is hard to imagine that an oil company would not try to maximize its revenues, by monetizing as much of its hydrocarbon resources as it can. Thus, the root of the problem lies essentially in the way oil companies treat their associated gas: a nuisance to be dealt with at cost, or a potentially marketable product, capable of yielding actual revenues. Next section looks at how developments in several large oil-producing countries influenced oil companies' approach to their associated gas.

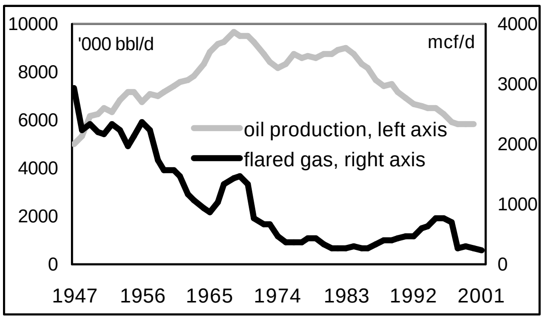
[16] International Energy Agency (2002), Natural Gas Information (2002 edition).

2. ASSOCIATED GAS UTILIZATION: COUNTRY-LEVEL STUDIES

U.S.A.

The U.S., one of largest oil producers in the world, was flaring gas at today's Nigerian rates[17], but it also was the first country to reduce flaring. Its flaring peaked in 1947, when some 3 bcf of gas was burnt daily[18], and has been declining since then. In 2002, American domestic oil industry flared 13 times less gas, although its oil production was higher than in 1947 (Figure 3).

Figure 3 U.S. oil production and gas flaring



Source: EIA (a, b, c)

U.S. gas flaring reduction was essentially Texas Railroad Commission's initiative, as to the oil companies "recovering the gas was a bother…and the cost prohibitively expensive"[19]. The commission's order of 1947 prohibited productions from field without gas recovery and treating facilities[20]. It is difficult, though, to imagine what the success of this regulation would be, had not the U.S been a country with the biggest energy consumption in the world. Between the late 1940s and early of 1970 its energy consumption more than doubled, with oil

[17] See next section.

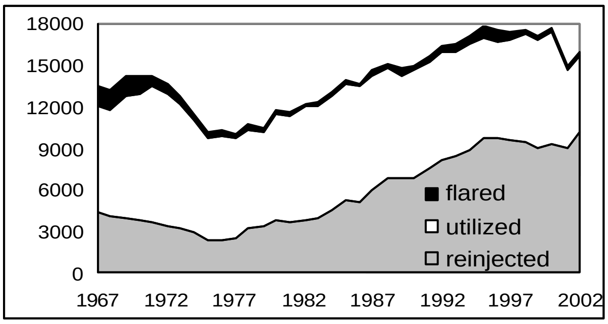
[18] Energy Information Administration, Natural gas website, pages visited:
U.S. Natural Gas Gross Withdrawals from Oil Wells,
http://tonto.eia.doe.gov/dnav/ng/ng_enp_sum_nus_a_d.htm [visited on January 20, 2004].

[19] Shook, B. (2002), Texas Engineer Murray Made Ending Gas Flaring His Life Cause, Oil Daily, January 2.

[20] Ibid.

and gas almost solely accounting for the increase[21]. Associated gas utilization has accounted from half to two-thirds of its production, with the rest being re-injected (Figure 4) or flared.

Figure 4 U.S. associated gas utilization



Source: EIA(a)

Nigeria

Nigeria has long struggled with associated gas utilization. In 2001, according to official information[22], it flared about half of total associated gas production, though some sources put the flared gas ratio as high as 70%[23]. This country has ideal conditions for such problems with associated gas to exist:

- The climate is hot, so there is virtually no heating requirement, although another important constraint on gas use for domestic applications (water-heating and cooking) is the lack of distribution infrastructure.
- Power sector is not big enough (just under 4 GW of gas-fuelled power plant capacity[24]), to increase utilization of associated gas.

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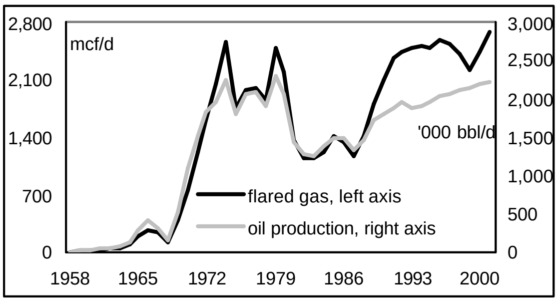
[21] Energy Information Administration, U.S. Energy Production by Source, 1949-2002, http://www.eia.doe.gov/emeu/aer/txt/ptb0102.html
[22] Central Bank of Nigeria (2002), Statistical Bulletin: Real Sector Statistics, Available on http://www.cenbank.org/Out/statbulletin/2001/SbulletinReal-a.pdf [visited on January 19, 2004].
[23] U.N. (2001), Nigeria: Focus on the environmental impact of gas flaring, report from 13/11/2001, accessed through http://www.africaonline.com/site/Articles/1,3,43034.jsp on January 20, 2004.
[24]Erinne, J. (2001), Natural gas offers Nigeria huge potential, challenge, Oil & Gas Journal, July 2, 2001

- Development of gas-intensive industries, which use it either as energy source or feedstock, is slow due to general economic and political situation; existing plants are mostly controlled by the state and have inefficient management and operations[25]. Also, due to small domestic demand gas intensive industries such as aluminum-smelting and petrochemicals are export-oriented and subject to international competition and trade volatility.

Figure 5 Nigerian oil production and gas flaring



Source: for years 1958-1972: Harrison (1984),
for years 1973-2000: Central Bank (2002)

So far, most positive effect on Nigerian gas flaring reduction has come from LNG. Shell set up a team for exploring LNG prospects in Nigeria in 1969[26], but it took 30 years for the project to materialize. NLNG is currently operating three trains with total capacity of 11 bcm. For the first two trains, associated gas accounts for 40% of feedstock, with the rest coming from gas-only fields. With the completion of the third train in 2003 all three trains were supposed to be fitted with necessary gas treatment equipment to switch to 100% associated gas feedstock.

[25] Ibid.
[26] Harrison, G. (1984), Associated natural gas resource management: a comparative study and techno-economic model, Ph.D. thesis, Heriot-Watt University.

While there are not yet data available for the amounts of gas flared in 2002 and 2003, the existing official data[27] on gas flaring contain some discrepancy: between 1999, when NLNG started production, and 2001, associated gas production increased by 60%, with flaring increasing by 20% only. It is not clear where the increase in associated gas production came from, because oil production, according to the same source, increased by 5% only.

Meanwhile NLNG expects gas flaring to reduce to 20% of the amount produced, by 2006, when two more trains will add 10.3 bcm capacity. With this, all five trains will have total capacity of 21 bcm, while current associate gas output is at 28 bcm.

Three other large-scale associated gas utilization projects are at various stages of development, all Chevron-operated and export-oriented: Escravos Gas Project will take 680 mcf/d and export 40,000 bbl LPG and condensate after its completion in 2005, Escravos GTL project is expected to start in 2006 with 33,000 bbl output capacity, and 3.5 bcmpa West Africa Gas Pipeline, designed to be fed by associated gas.

In the meantime, Nigerian government in January 2003 brought its "all flares out" target from previously planned 2008 to four years earlier[28].

Saudi Arabia

Harrison[29] notes that global gas flaring increased dramatically in line with OPEC's share in global oil production These countries, mostly situated in hot climate zones, and without previously developed industrial sectors, lacked two important categories of gas uses –

[27] Central Bank of Nigeria (2002), Statistical Bulletin: Real Sector Statistics, Available on http://www.cenbank.org/Out/statbulletin/2001/SbulletinReal-a.pdf [visited on January 19, 2004].
[28] Petroleum Intelligence Weekly (2003), News brief on Nigeria, January 16.
[29] Harrison, G. (1984), Associated natural gas resource management: a comparative study and techno-economic model, Ph.D. thesis, Heriot-Watt University.

household heating and power generation for industries. They virtually had to build domestic gas markets from scratch, while in other gas producing countries, gas, when available, would take over shares of other fuels. Saudi experience in associated gas utilization could be regarded as one of the most successful.

Before 1980s, Saudi Arabia was flaring most of its associated gas production, from less than 1 bcf/d in 1950s to 4.5 bcf/d in 1970s[30]. According a Saudi oil ministry official, quoted by Harrison[31], Saudi Aramco was not undertaking any utilization projects, because "even if market was found for all of its associated gas, it would add just 1% to its revenues". This was before the first oil shock. In 1975 the country's government ordered Saudi Aramco to construct a gas gathering system, using cash from increased oil revenues.

By 1982 first phase of the Master Gas System came on-stream with three gas processing plants, which reduced gas flaring to 64%[32]. In 1985 flaring was virtually eliminated[33], but this was due to the slump in oil production: a 66% reduction in oil production from 1980 to 1985 resulted in the same scale reduction in associated gas output. Thus, due to its role as a swing oil producer, Saudi Arabia in 1985 had half the amount of gas it was utilizing in 1982 and had to come up with unusual measures to restore gas output without increasing its oil exports. In summer 1985 Saudi Arabia chartered three ULCC/VLCC tankers as floating

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[30] Al-Shibani A. (2002), Eliminating Gas Flaring in Saudi Arabia, Global Gas Flaring Reduction Initiative Conference, World Bank and IFC, (Oslo, Norway, April 14-16, 2002), http://www.worldbank.org/ogmc/proceedings.htm [visited on January 20, 2004].

[31] Harrison, G. (1984), Associated natural gas resource management: a comparative study and techno-economic model, Ph.D. thesis, Heriot-Watt University.

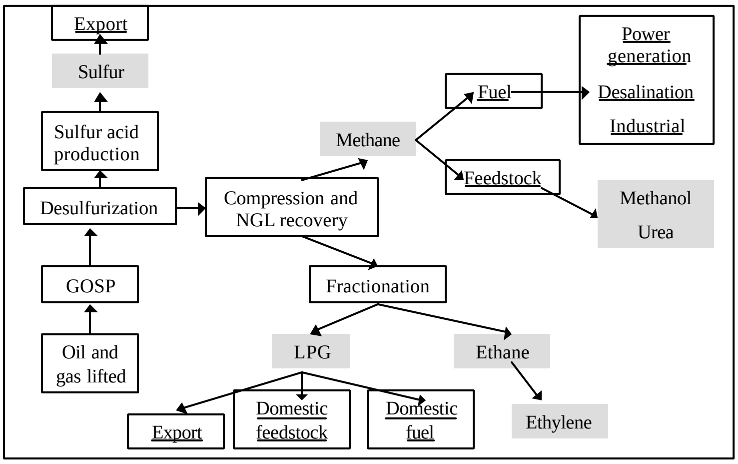
[32] Abushihada (1986) Arab Gas in Stevens, P. (ed.) International Gas Prospects and Trends, Basingstoke: Macmillan.

[33] Al-Shibani A. (2002), Eliminating Gas Flaring in Saudi Arabia, Global Gas Flaring Reduction Initiative Conference, World Bank and IFC, (Oslo, Norway, April 14-16, 2002), http://www.worldbank.org/ogmc/proceedings.htm [visited on January 20, 2004].

storage to load excess amounts of Arabian Light from gas-rich fields, production of which it was going to increase for associated gas[34]. This situation also prompted the country to tap its non-associated gas reserves[35].

Gas fed into Master Gas System was delivered to developing petrochemical industrial complexes, which now comprise the core of Saudi Basic Industrial Corporation (SABIC). This company now accounts for 10% of the world's petrochemical production (EIA, d). Figure 6 provides a brief overview of Saudi associated gas utilization scheme.

Figure 6 Saudi Arabia associated gas utilization scheme



Source: adapted from Harrison (1984)

In Saudi Arabia associated gas utilization helped to start monetizing non-associated gas reserves as well, which first acted as "swing supply…to assure steady rates…should crude

[34] MEES (1985), Saudi Arabia Adds to Floating Storage to Boost Availability of Associated Gas for Domestic Requirements, 28 Middle East Economic Survey 42, July 29.

[35] Al-Naimi A. (2001), Natural Gas and Economic Growth in the Kingdom, Symposium of Investment for the Development of Medina Area (Yanbu, Saudi Arabia, April 2001), http://www.mopm.gov.sa/archive/speechs/e_speeches_yanbu170401.pdf [visited on January 20, 2004].

[oil] and associated gas production vary"[36] and now is expected to supply the increase in gas demand growth.

Russia

Publicly available data on associated gas production in Russia are very poor, and it is not possible to track the developments. According to one estimate, only 20% of associated gas is flared, with 40% going to power generation and another 40% sold to gas processing plants[37]. Haugland[38] puts associated gas flaring in FSU at 17-32 bcm a year. If, very straightforwardly, it is assumed that gas flaring could be distributed among FSU countries pro-rata to their oil production, then Russia accounts for about 80% of flared gas, (oil production data from BP[39]), or something between 13-26 bcm[40]. According to Johnston[41] about 2 bcf is flared daily "in Samotlor"[42], which translates into 21 bcm annually. Official figures, quoted in Interfax[43], are much lower. They put associated gas production in 2001 at 37.4 bcm, of which 7.7, or 20% was flared. In 2002, 44 bcm was produced, of which 11 bcm (25%) was flared. This is a 20% increase in associated gas production, while oil production increased by 10% (BP, 2003). Although a 10% increase in associated gas utilization (from 30 bcm to 33 bcm) does indicate some progress, flaring of 11 bcm (or more, according to other sources) must call for some action.

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[36] Al-Naimi A. (1997), The Achievement and the Future of Saudi Arabian Natural Gas, 2nd Saudi Arabian Conference on Gas Utilization for Power & Industrial Development (Yanbu, Saudi Arabia, October 1997), http://www.us-saudi-business.org/alnaimi.htm [visited on January 20, 2004].
[37] Rayisin A. (2001), Gas mixed, 1 Oil of Russia (Neft' Rossiyi).
[38] Haugland T. (2002), Results of Stakeholder Discussions, Global Gas Flaring Reduction Initiative Conference, World Bank and IFC, (Oslo, Norway, April 14-16, 2002), http://www.worldbank.org/ogmc/proceedings.htm [visited on January 20, 2004].
[39] BP (2003), Statistical Review of World Energy, http://www.bp.com/centres/energy [visited on January 19, 2004].
[40] This figure though should be lowered, because in percentage terms, other FSU producers should be burning more of their associated gas produced, as they evidently have even less opportunities to utilize it.
[41] Johnston, D. (2003), International Exploration Economics, Risk and Contract Analysis, Tulsa: PennWell.
[42] Samotlor is just one oil producing region in western Siberia. Johnston probably uses this name to refer to all Western Siberian oil production.
[43] Interfax (2003) Petroleum Report from September 10, 2003

Russian oil companies, while acknowledging that they do flare gas, put the blame on the government and the market. In summary, constraints stated by oil company officials in newspaper interviews[44] are as follow:

1) In selling as feedstock – government regulation of gas prices sold to gas-processing plants, owned and operated by Sibur gas-processing monopoly. These are set by the Ministry of Economy and currently range between 73-442 rubles per 1000 cm ($2.6-15.8)[45] depending on the liquid fraction content. Oil companies claim this barely covers gathering costs and call for price deregulation.

2) In selling as fuel (dried gas) – depressed domestic gas prices. Federal Energy Commission sets wholesale prices for gas sold by Gazprom and some other gas-only producers to utilities and household suppliers. Currently the median price[46] is 912 rubles per 1000 cm ($32)[47]. Although the prices for gas sold by oil companies to non-processing buyers are not regulated, they have to compete with Gazprom in the internal market. Besides, oil companies claim that the costs they have to bear to meet Gazprom's specification for feeding gas into its trunklines and the transportation fees paid to the monopolist are discouraging from larger utilization.

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[44] Bushuyeva, Y. (2003), TNK and Rosneft ask the government to deregulate associated gas prices, Vedomosti, July 4, 2003, Fokina, Y. (2003), Interview with Viktor Zagvozdkin, Lukoil's chief of environmental security department, Russian Focus, October 27, 2003, Pravosudov, S. (2003), Long road to the pipe, Russian Focus, April 14, 2003.

[45] Ministry of Economy (2002), Order of the Ministry of Economic development and trade of the Russian Federation N 117 from April 30, 2002, "On wholesale prices for petroleum associated gas supplied to gas processing plants" Available on http://www.rg.ru/oficial/doc/min_and_vedom/min_ec_torg/117_p.shtm [visited on January 23, 2004].

[46] Prices are set for seven different zones, increasing according to the distance between Zero zone, which is Yamal, the main gas-producing province, and the corresponding consumption region.

[47] FEC (2003), Regulation N 89-e/6 of Federal Energy Commission of Russian Federation from October 29, 2003 "On Wholesale Prices for gas produced by Gazprom and its affiliates for selling to all buyers except households" available at http://www.fecrf.ru/cmd/images/pr1.pdf [visited on January 19, 2004]

3) Exports to more attractive foreign markets are de facto monopolized by Gazprom.

In the light of these constraints, it is interesting to look at associated gas utilization of Surgutneftegas Oil Company, which claims the highest level of utilization among Russian oil companies, some 95%[48]. It produces 13 bcm, or third of all oil companies' total gas output. This is helped by three facts:

1) Gas from Surgutneftegas oilfields has higher methane content[49] (94-96%) and needs little and cheaper treatment to comply with Gazprom specification.

2) The company's two biggest utilization outlets are in the same region with its production, which means lower transportation costs. Surgutneftegas has arranged supplies to the biggest gas-fuelled electricity station in the world, Surgutskaya GRES (4.8 GW installed capacity), which takes 7 bcmpa of gas from Surgutneftegas. Also, the company operates production facilities of Surgutsky gas processing plant, which takes the bulk of remaining gas[50].

3) The company has launched two onsite power generators and plans to increase own power production. In 2002, though, it used less then 1% of its gas for power generation.

3. GAS UTILIZATION OPTIONS

Technically, there are several options for gas utilization: preparing it as fuel in various forms (dried pipeline gas, LPGs, LNG, or gas-by-wires – onsite electricity generation) or processing for petrochemical industry feedstock. Johnston[51] provides analysis of natural (non-associated) gas development options, excluding direct sales as dried gas. These could be considered as options for associated gas as well.

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48 Surgutneftegas Annual Report 2002.
49 More usually, methane content in associated gas is around 80% (Harrison, 1984).
50 Surgutneftegas website, http://www.surgutneftegas.ru/rus/show_company_month_news.xpml?mds_objectid=3753.
51 Johnston, D. (2003), International Exploration Economics, Risk and Contract Analysis, Tulsa: PennWell.

Table 1 Gas development options

	LPG plant	**Gas cycling**	**Power generation**	**Methanol**	**Ammonia/ Urea**	**LNG**
Product	LPG, condensate	Reinjection	Electricity	Methanol, hydrogen	Granulated Urea	Liquefied methane and ethane
Threshold field size to feedstock (BCF)	300-400	250-400	650	500	600	5000
Minimum feed (mcf/d)	60-80	40-75	85	60	80	385/train
% produced a year of project life	5-10%	7%	5%	5%	5%	4%
Project life, years	10-20	13	20	20	20	25
Capacity	60 mcf/d	30 mcf/d	500 MW	2000 tonnes/day	1,750 tonnes/day	5.5 mln tonnes/year
Markets	Local, export	Local	Local, grid needed	Export	Local	Export
Plant location	Local, port city	Local	Local	Port city	Local	Port city
Plant capital cost ($M)	50-60	75-100	350-400	250-300	300-400	2,500-3,000
Lead time	>3 years	>2-3 years	>1 years	4 years	5 years	7-10 years

Source: adapted from Johnston (2003)

Other development options, currently under commercialization studies, include Gas-to-Liquids and Gas-to-Solids. A big gas-to-liquids project is currently under way in Qatar. This project, however, utilizes the country's North gas field reserves. Chevron has completed front-end engineering for Escravos project in Nigeria, set to utilize 300 mcf/d of associated gas. GTL technology provides a wide range of end-products with advantages over their conventional petroleum alternatives: clean diesel and jet fuel, middle distillates, lubricants, olefins and methanol.

Gas-to-solids is a relatively new method with commercialization of operations expected to be reached in the coming years[52]. This technology, being developed specifically for offshore gas production, converts gas to hydrates to allow easier transportation to markets, where it is regasified at receiving terminal. One variation of this technology, the slurry method, requires

[52] Bybee, K. (2002), Offshore gas-to-solids technology, Journal of Petroleum Technology, April 2002.

minimal processing, does not involve extreme temperatures (unlike LNG) or oxidants and catalysts, and can have the processing facility installed on a floating barge for mobility.

Development options listed in the above table could be, perhaps with some risk of oversimplification, divided into two groups: an oil company's business, and none-of-oil-company's business. As Johnston[53] notes: "Oil and gas are separate industries". Of course, it would depend on the individual oil companies how far they would choose to go in associated gas utilization, but arguably not many of them would consider operational integration with fertilizer manufacturers, for example. It is one thing when oil company supplies associated gas through an existing pipeline to someone else's processing plant, as it is the case with Russian associated gas utilization scheme. In this case the company has to make relatively simple calculations involving its cost of associated gas initial treatment and transportation to the plant and the price it receives for it. And it is a totally different case when the only way the oil company can utilize its associated gas is to create the whole processing and transportation chain as well as find markets. As Lane[54] explains, "Producing LNG is not the difficult piece – selling it is!"

[53] Johnston, D. (2003), International Exploration Economics, Risk and Contract Analysis, Tulsa: PennWell.
[54] Lane, A. (2002), Untitled presentation at Global Gas Flaring Reduction Initiative Conference, World Bank and IFC, (Oslo, Norway, April 14-16, 2002), http://www.worldbank.org/ogmc/proceedings.htm [last visited on January 20, 2004].

4. CONCLUSIONS

In the light of country cases and utilization methods studied it makes sense to divide constraints on associated gas utilization into three groups: market-level, company-level and technical constraints.

Market constraints

1. Absence of a local market. It is, above all, absence of gas market or gas consumption as such, and secondly, lack of opportunity to replace other fuels by gas, either because of low energy consumption, or due to high share of relatively cheap traditional energy. In this case, efforts of government for creating, or supporting markets are crucial. An existing and expanding energy market in the U.S. was able to absorb associated gas made available for consumption. Saudi Arabia's government undertook expansive gas utilization projects, while Nigeria has yet to see significant breakthrough in its efforts to increase domestic gas consumption and relies on export options for gas utilization.

2. Uncompetitive downstream energy markets constrain associated gas marketing. Russian oil companies face this type of constraint, while the country's oil and gas industry enjoys relatively well-developed gathering and processing infrastructure. Coupled with this constraint is government regulation of prices.

3. Prohibitive costs of delivering gas to consuming regions. This could be true for both international and intranational trade. Gas, when arrived to the market, naturally has to compete with locally available, or other imported energy. Long-distance pipelines and LNG, though proving quite viable for some cases (Russia-Europe pipelines, several existing LNG supply regions), have not yet become routine gas delivery methods. Also, if LNG industry's much anticipated move from supply-contract-backed towards speculative development happens, this would have adverse effects on nations yet to enter LNG business, because

speculative development apparently requires experience in the industry and financial strength and confidence.

Company-level constraints are those factors affecting an oil company's bona fide intention to utilize its associated gas. Assuming that the company does not face the constraints from the first group, it may come across following difficulties:

1. Lack of expertise in dealing with associated gas and lack of ability for developing them.
2. Associated gas utilization projects compete for financing with other proposals within the company. Svennson[55], while pointing at this, notes also that some utilization projects, though providing "reasonably high rate of return", can still fail to meet the financial target in the companies.

Technical constraints

These result from characteristics of associated gas at given oilfields. If a company favors a specific utilization project and considers financing, the features of its gas reserves may not allow implementation of the project:

1. Low gas stream may not provide sufficient feed for utilization undertakings and will be just flared or vented.
2. Volatile producing gas-to-oil ratio makes associated gas an unreliable feedstock. It is commonly sold on the markets under the so-called seller's option contracts, which give favorable price terms to the buyer, as they take the risk of accepting

[55] Svennson B. (2002), Innovative financing mechanisms for gas flaring projects,
Global Gas Flaring Reduction Initiative Conference, World Bank and IFC, (Oslo, Norway, April 14-16, 2002), http://www.worldbank.org/ogmc/proceedings.htm [visited on January 20, 2004].

unstable supplies. This could be mitigated by pooling arrangements, where producers from adjacent fields would sell the gas under one contract. To the outsiders, however, pooling arrangements would look like cartel agreements and could be challenged on this ground.

3. Gas may be too sour, (ie with higher contents of H_2S), or too high in liquids, thus presenting problems for equipment operations and maintenance.

Problems of associated gas utilization are thus not confined to just one constraint, although the mixture of the constraints that the companies face will vary from one country or oil province to another. Governments may well have their own constraints on implementing stricter policy for associated gas treatment. If they restrict flaring in circumstances where oil companies do not see viable utilization options, they may discourage investment and activities in their oil industries. It is debatable though who is in the end responsible for creating gas markets: the governments or the companies?

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