

WORLDWIDE GAS SHALES AND UNCONVENTIONAL GAS: A STATUS REPORT

Prepared by:
Mr. Vello A. Kuuskraa, President
Advanced Resources International, Inc.
Arlington, VA USA

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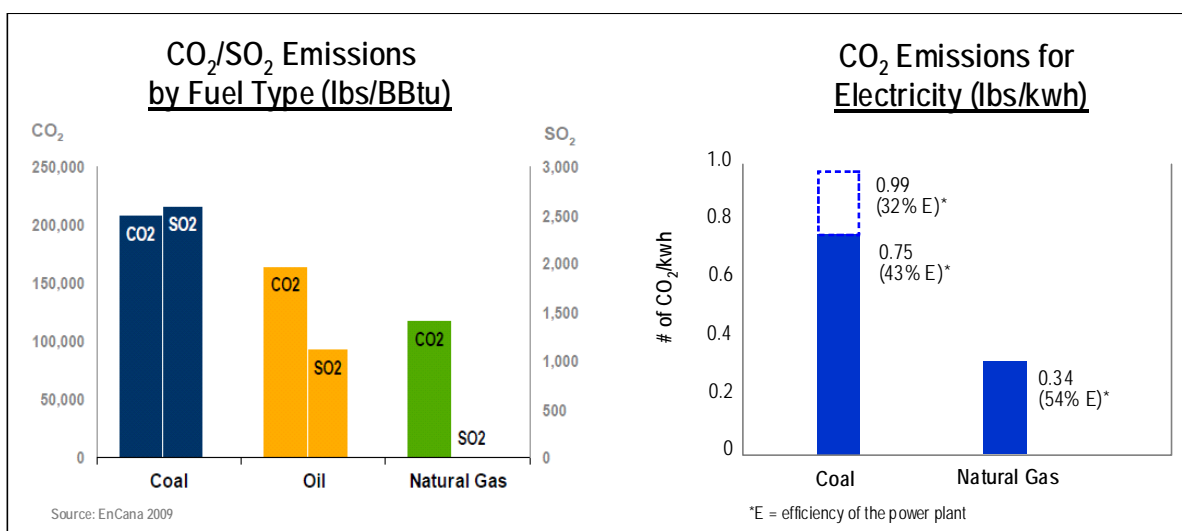
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WORLDWIDE GAS SHALES AND UNCONVENTIONAL GAS: A STATUS REPORT

Vello A. Kuuskraa
Advanced Resources International, Inc.
Arlington, VA USA

INTRODUCTION

Increased use of natural gas for power generation and transportation offers a major option for reducing greenhouse gas emissions. For example, substituting a new, efficient natural gas power plant (with 0.34 pounds CO₂/Kwh) for an older coal-fired power plant (with 0.99 pounds CO₂/Kwh) would reduce CO₂ emissions per Kwh of electricity produced by two-thirds, Figure 1.



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Figure 1. Reducing CO₂ Emissions in the Electric Power Sector

While recognizing the many benefits from greater use of natural gas, serious concerns have been raised as to:

1. Are there sufficient supplies of natural gas in North America and worldwide to support a major shift toward its greater use?

2. *Will the future supplies of natural gas remain economically affordable, particularly with sharp growth in demand?*
3. *Can significantly increased natural gas supplies be produced in an environmentally sound manner?*

This White Paper, “*Worldwide Gas Shales and Unconventional Gas: A Status Report*”, takes some initial steps toward examining these three issues. Ultimately, however, much more in-depth work and broader-scale assembly of information will be required to address the benefits and concerns surrounding greater use of natural gas as a major greenhouse gas mitigation option.

THE “PARADIGM SHIFT”

Driven by a new understanding of the size of gas shale resources and the availability of unconventional gas, a “paradigm shift” is underway on world natural gas supplies. This “paradigm shift” began more than a decade ago in North America with only modest fanfare:

- Low cost coalbed methane in the San Juan Basin of Colorado and New Mexico led the way;
- Next was the introduction of highly productive tight gas sand development from the Jonah and Pinedale fields in Western Wyoming;
- Third was the emergence of the Barnett Shale, followed by the other great gas shale basins/plays of North America, such as the Horn River, Marcellus and Haynesville.

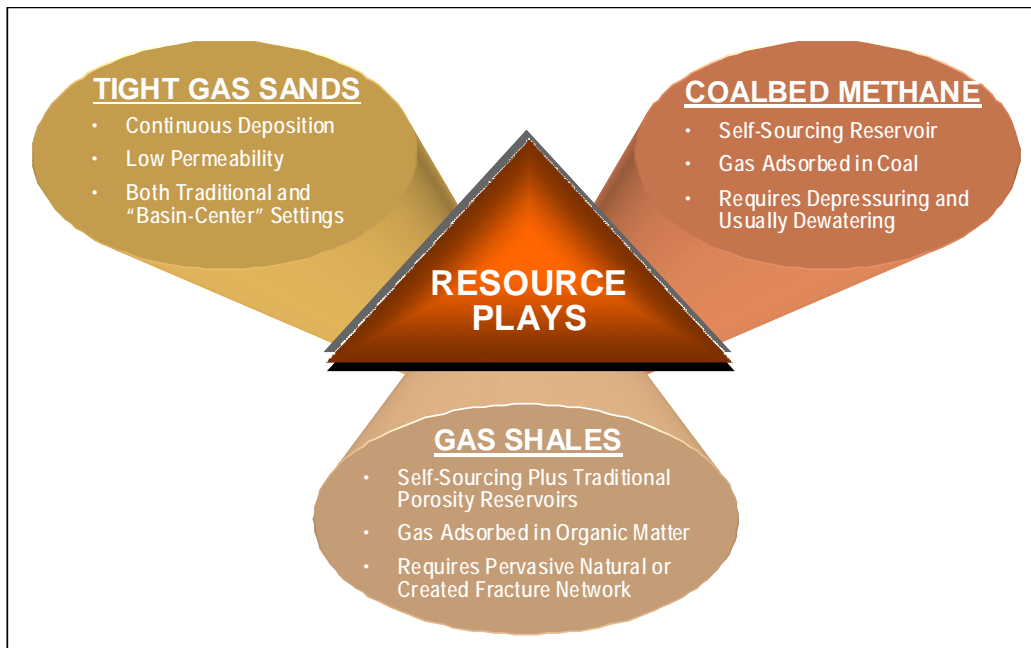
The final segment of this “paradigm shift” - - the worldwide pursuit of gas shales and unconventional gas - - has only just begun, with Australia and China in the lead. Europe’s gas shale geology is challenging, but its resource endowment and supply potential are large.

WHAT IS UNCONVENTIONAL GAS?

Three natural gas sources - - tight gas sands, coalbed methane and gas shales - - comprise today's unconventional gas, Figure 2. Methane hydrates, a future candidate, are not yet ready for "prime time". A number of features distinguish unconventional gas from better understood conventional gas.

- First, the unconventional gas formations are "continuous", deposited over large areas rather than in discrete traps.
- Second, the geologic setting of unconventional gas is several orders more complex and challenging than of conventional gas.
- Third, for two of the unconventional gas types - - coalbed methane and gas shales - - the gas source, trap and reservoir are the same, not three distinct elements as for conventional gas.

Since gas shales are the most abundant depositional rock and today's "hot topic", it will be addressed first.



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Figure 2. What is Unconventional Gas?

WHAT CHANGED THE GAME?

Low rates of gas production from shallow, fractured shale formations in the Appalachian and Michigan basins of the U.S. have been underway for decades. What “changed the game” was the recognition that one could “create a permeable reservoir” and high rates of gas production in deep shale formations by using intensively stimulated horizontal wells, Figure 3.

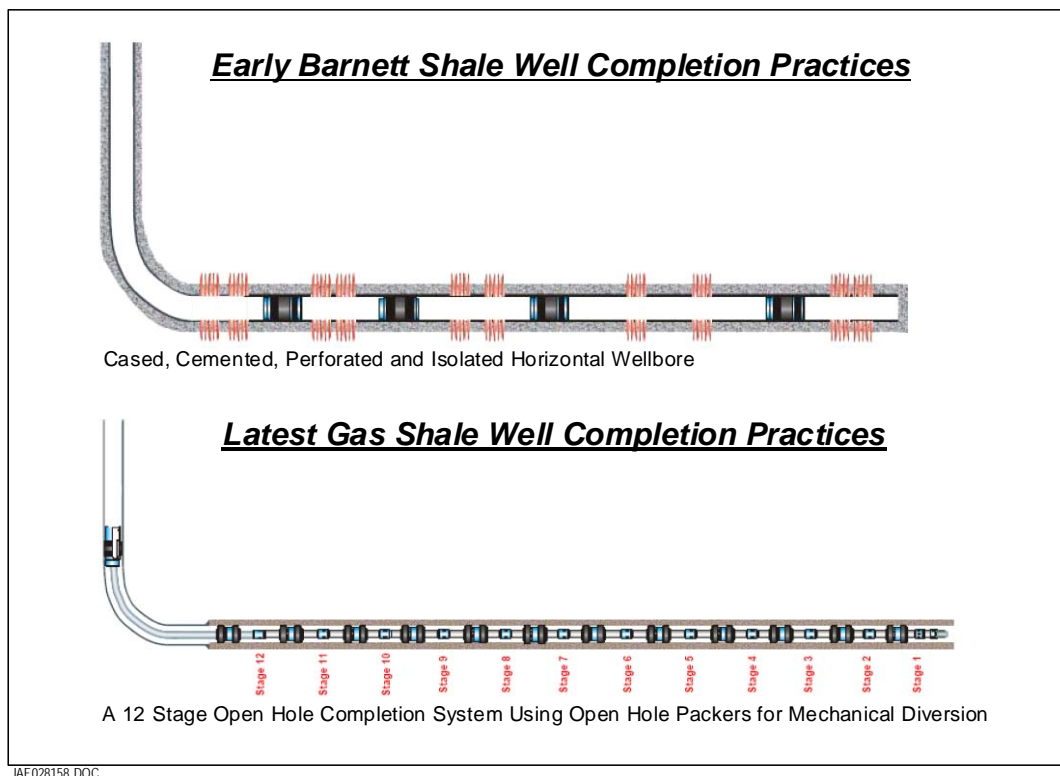


Figure 3. Evolution in Effective Horizontal Gas Shale Well Completions

This break-through in knowledge and technology enabled the numerous deep, low permeability gas shale formations to become highly productive, making the Barnett Shale “the largest natural gas field in Texas”. Today’s active pursuit of the high visibility Haynesville, Marcellus, Horn River and many other gas shale plays/basins could make gas shales the largest undeveloped natural gas resource in the world.

THE NORTH AMERICAN GAS SHALE AND UNCONVENTIONAL GAS EXPERIENCE

How Much Can Gas Shales Contribute? North American gas shales already contribute over 9 Bcfd (billion cubic feet per day) equal to 250 Mcmd (million cubic meters per day), having grown rapidly during the past decade, Figure 4¹. Ten years from now, we expect gas shales to account for a third of overall North American natural gas production, equal to 26 Bcfd (740 Mcmd) assuming sufficient demand, Figure 5².

- With aggressive development of the Haynesville and Marcellus plays, U.S. gas shales are projected to reach 20 Bcfd (560 Mcmd) by 2020.
- Led by the mighty Horn River, Canadian gas shales could exceed 6 Bcfd (180 Mcmd) by 2020.

Emerging North American gas shale plays such as Eagleford, Pierre and Mancos are expected to add to these production projections in future years.

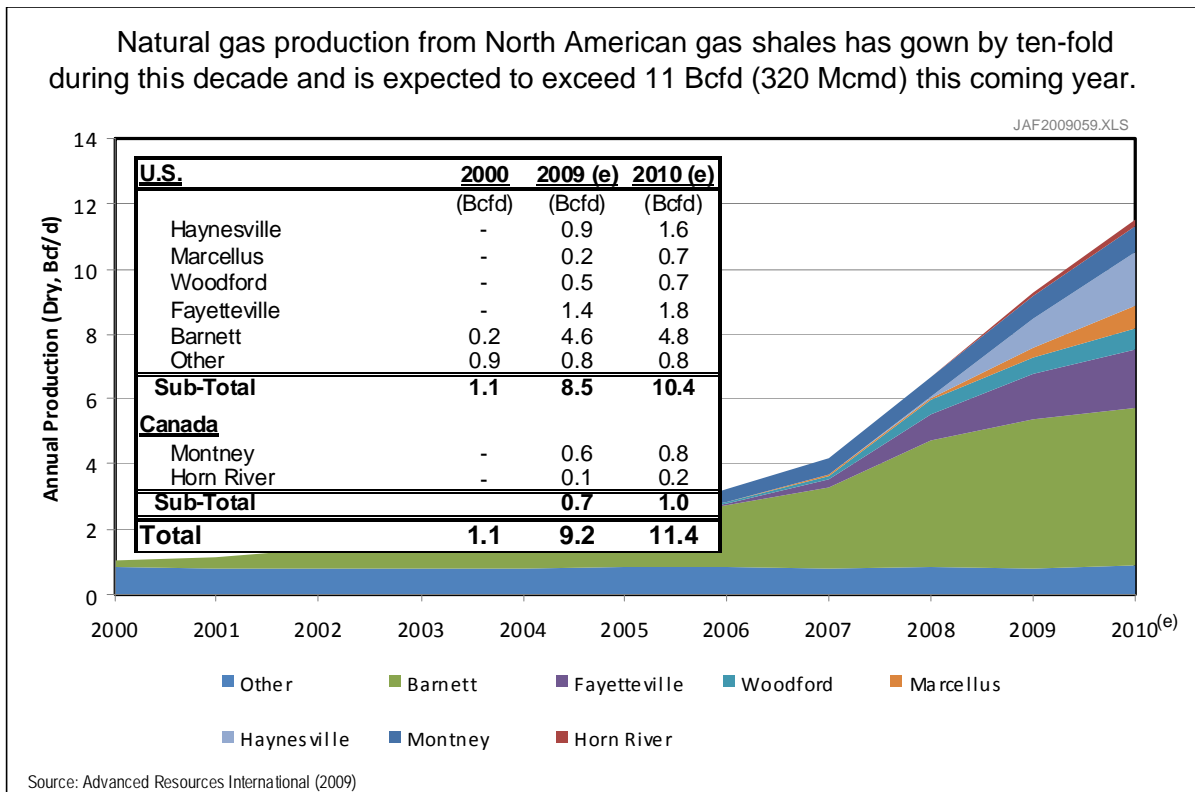
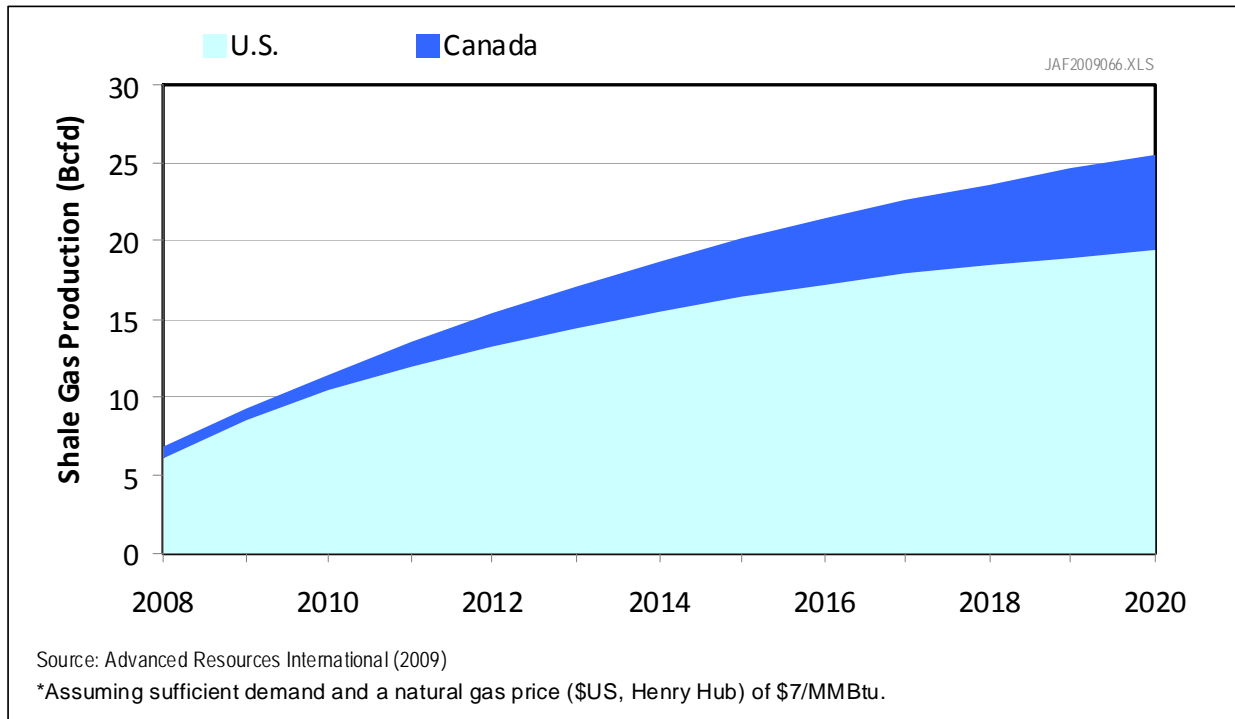


Figure 4. How Much Do Gas Shales Contribute Today?



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Figure 5. How Much Might North American Gas Shale Contribute in the Future?

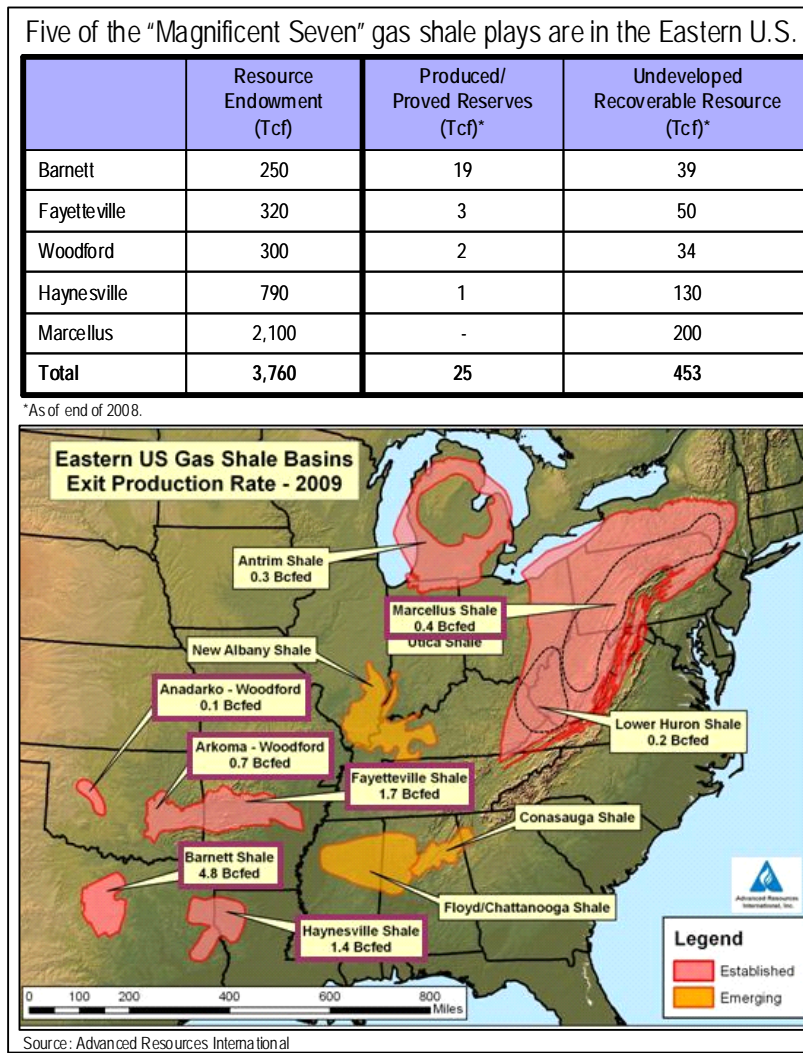
How Large Is The North American Gas Shale Resource? The gas shale resource of North America is huge. We recently completed in-depth, basin-level assessments of the “Magnificent Seven” gas shale basins of the U.S. and Canada. The resource endowment (the gas in-place) in these “Magnificent Seven” gas shales equals 5,140 Tcf (trillion cubic feet) equal to 146 Tcm (trillion cubic meters), with an estimated 715 Tcf (20 Tcm) recoverable, Table 1³. As such, the resource endowment in these “Magnificent Seven” gas shales already exceeds Rogner’s (1997) estimate for total North American gas shale resource endowment of 3,840 Tcf (109 Tcm)⁴.

The natural gas resources contained in the numerous still to be defined and smaller gas shale plays and basins in the U.S. (e.g., Antrim, Huron, Eagleford) and in Canada (e.g., Liard, Cordova and Utica) will add to these totals.

Table 1. How Large is the North American Gas Shale Resource?

Gas Shale Basins	Resource Endowment		Recoverable Resource	
	Tcf	Tcm	Tcf	Tcm
U.S. (5 Basins)	3,760	107	475	13
Canada (2 Basins)	1,380	39	240	7

A closer look at five of the “Magnificent Seven” gas shale plays in the Eastern U.S. gas basins shows, Figure 6:

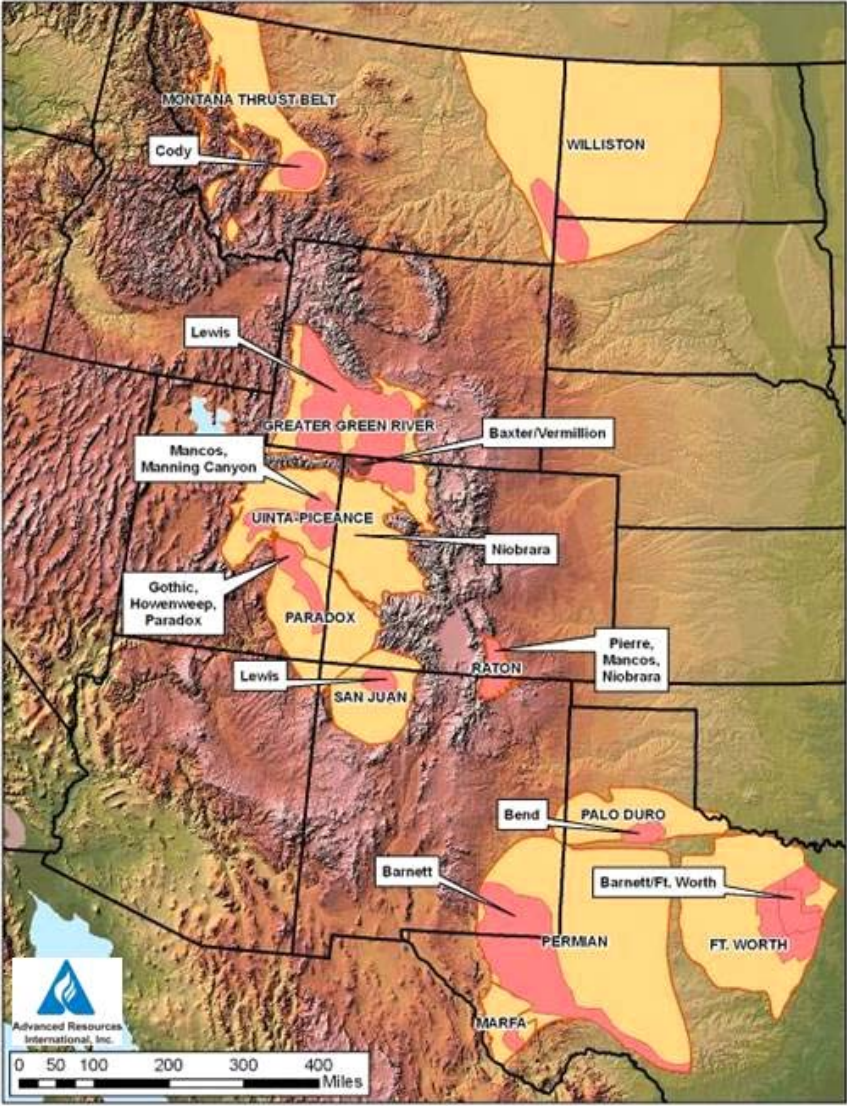


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Figure 6. Eastern U.S. Gas Shale Basins

- The Marcellus Shale, with 2,100 Tcf (59 Tcm) of resource endowment and 200 Tcf (5.7 Tcm) of recoverable resource has the potential to become the dominant North American gas shale play.
- The Haynesville Shale with its highly productive wells offers a glimpse of the benefits of applying modern technology to geologically favorable gas shale settings.
- The Barnett Shale has already provided 5 Tcf (140 Bcm) of gas shale production plus another 14 Tcf (400 Bcm) of proved developed reserves.
- The rapidly growing Fayetteville Shale is expected to soon provide 2 Bcfd of production; the Woodford Shale in the Anadarko, Ardmore and Arkoma basins illustrates the regional diversity of gas shale plays.

Significant gas shale resources also exist in Western U.S. basins - - in Colorado, Montana, New Mexico, Utah and other states, Figure 7. Western U.S. gas shales, while being explored, have yet to be intensively developed. Lower reservoir quality and lower wellhead prices place the Western basins at a disadvantage to Eastern gas shales. Still, the resource endowment and potential in the Western gas shale basins is huge, awaiting advances in extraction technology that would improve their economic viability.



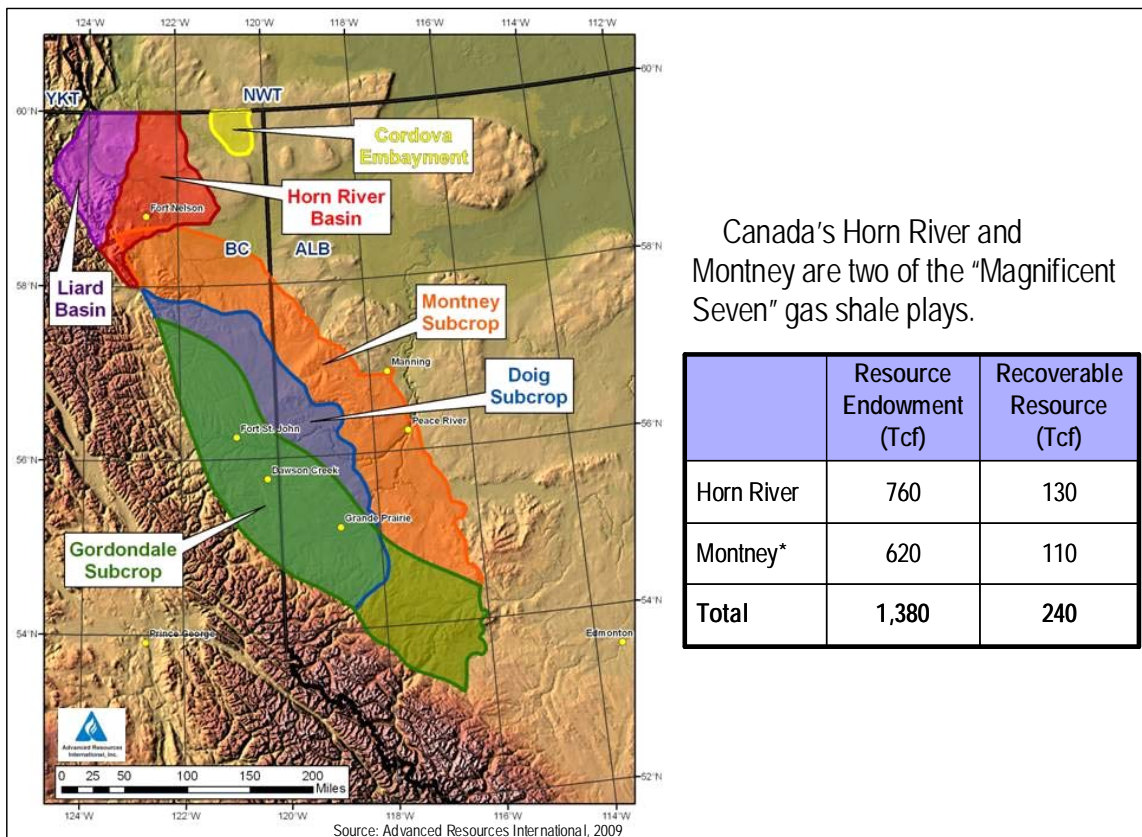
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Figure 7. Western U.S. Gas Shale Basins

Canada holds a number of significant gas shale basins, with two of these - - the Horn River and the Montney - - included within the “Magnificent Seven”, Figure 8:

- The high-graded portion of the geologically attractive Horn River gas shale basin holds 760 Tcf (22 Tcm) of resource endowment with an estimated 130 Tcf (4.6 Tcm) recoverable. The initial horizontal wells drilled into the Horn River gas shales rank amongst the most productive natural gas wells drilled in Western Canada in recent years.
- The Montney resource play contains a hybrid mix of thick gas shales and silty tight gas sands. The resource endowment is 620 Tcf (18 Bcm) with about 20% of this resource endowment technically recoverable. As of mid-2009, 234 horizontal gas shale wells were producing about 360 MMcfd (10.7 million cmd) from the Montney.

A number of other less defined gas shale plays and basins, such as the Cordova, Liard, Doig, Gordondale and the Colorado Group, exist in Western Canada, Figure 8. These geologically more challenging gas shales also await advances in well drilling, completion and operating technologies to unlock their full geologic potential.



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Figure 8. Western Canada Gas Shale Basins

Are North American Gas Shales Economically Affordable? Given the wealth of geologic and reservoir data now available on North American gas shales, there is a growing consensus that the resource endowment and the recoverable resource are, most likely, quite large. However, there is still uncertainty about the costs and affordability of gas shales.

In our view, and consistent with the “paradigm shift”, the higher quality gas shale basins and plays make up the low cost portion of today’s North American natural gas price/supply curve and with advances in technology could offer affordable gas supplies far into the future, Figure 9.

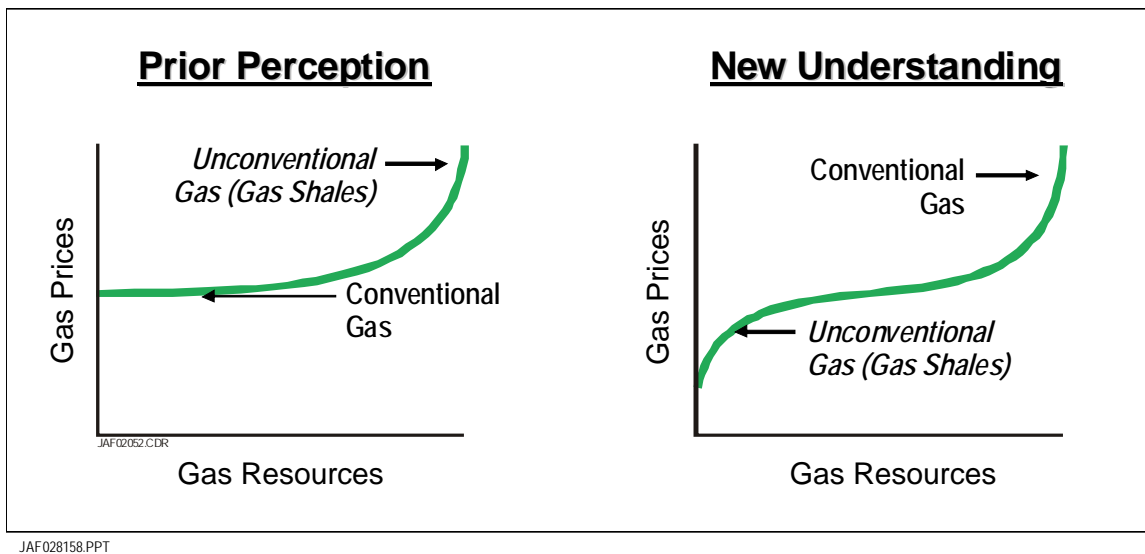


Figure 9. Are Gas Shales Economically Affordable?

Other North American Unconventional Gas Resources. While the most visible, gas shales are only one of the unconventional gas resources under development in North America.

- Coalbed Methane, which had its start in the U.S. San Juan coal basin, provides over 5 Bcfd (150 million cmd) in North America.
- Tight Gas Sands, still the largest of the unconventional gas sources, provide nearly 18 Bcfd (500 million cmd) in the U.S. and another 5 Bcfd (140 million cmd) in Canada.

Adding coalbed methane and tight gas to our expectations from gas shales, by year 2020 we look for unconventional gas to have the capacity to provide 52 Bcfd (1.5 Bcmd) and account for nearly two-thirds of total North American natural gas production, Figure 10².

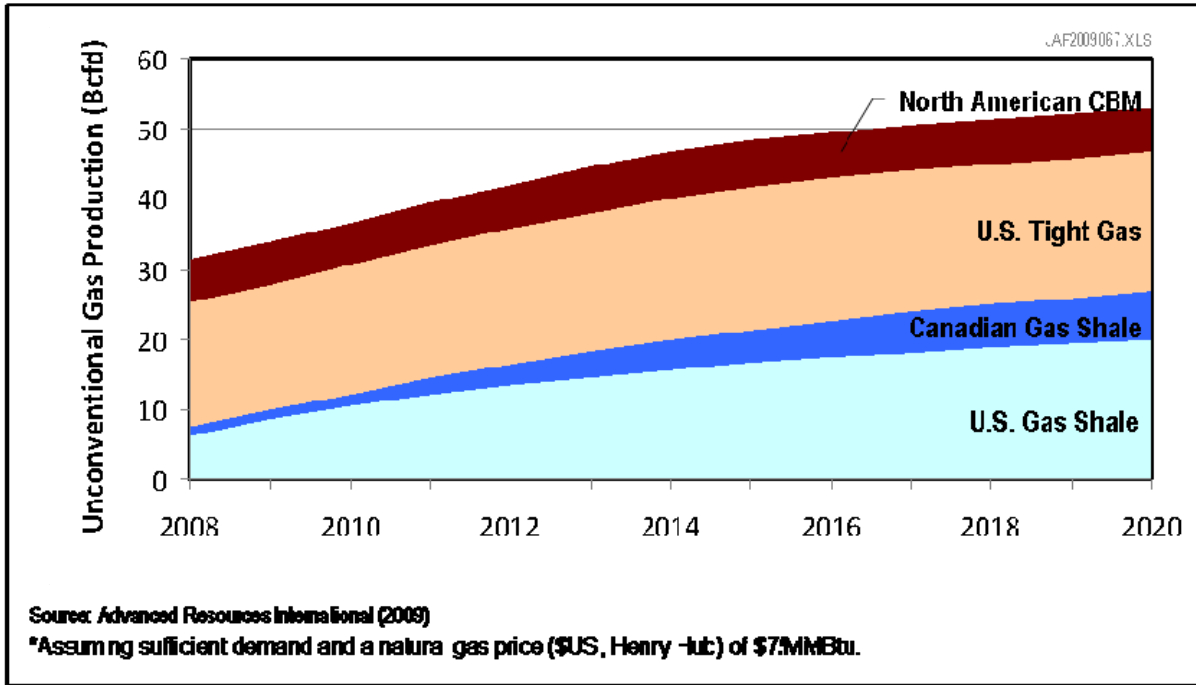


Figure 10. Projected North American Gas Shale and Unconventional Gas Production

WORLD GAS SHALE RESOURCES

Current Resource Endowment and Recoverable Resources. All currently published resource endowment estimates for world gas shales start with Rogner’s 1997 “top-down” study of world hydrocarbon resources⁴:

- Gas Shale Resource Endowment: 16,110 Tcf (456 Tcm)

The International Energy Agency in their “World Energy Outlook (2009)” assumed that about 40% of Rogner’s resource endowment estimate would become recoverable⁵:

- Gas Shale Recoverable Resource: 6,350 Tcf (180 Tcm)

While undoubtedly large, only basin- and play-level (“bottom up”) appraisals of the diverse gas shale basins of the world will build confidence on the true size, quality and producibility of this important natural gas resource.

European Gas Shale Resources. Gas shale exploration is underway in many of the European basins. Three of these stand out - - the Alum Shale of Sweden, the Silurian Shales of Poland and the Mikulov Shale of Austria. Our preliminary resource assessment for these three gas shale basins is 1,000+ Tcf (~30 Tcm), with a potential recoverable resource of 140 Tcf (4 Tcm)³. Our preliminary estimate for the gas resource endowment for Western and Eastern Europe, which we anticipate to grow with time and new data, is already twice Rogner’s estimate of 550 Tcf (15.6 Tcm)⁴.

- **Sweden – Alum Shale.** The Late Cambrian/Early Ordovician organic-rich Alum Shale, while generally about 40 m thick, reaches 200 m of thickness in western Sweden and has high TOC, from 2 to 20%, Figure 11. Shell is drilling shallow coreholes at Skane, an area with relatively mature shales. Our preliminary estimate of the unrisksed resource endowment for the currently leased acreage is 60 Tcf (1.7 Tcm) with a risksed recoverable resource of about 10 Tcf (0.3 Tcm).
- **Poland – Silurian Shales.** Lane Energy, EurEnergy, BNK, ExxonMobil and ConocoPhillips have leased gas shale acreage and are exploring for gas shales in Poland, Figure 12. Gas shales in the large Baltic Basin of northern Poland appear to be prospective. More speculative are the prospects for gas shale production in the Podlasie Depression and the Lublin Basin, although the thermal maturity in these two basins appears to be favorable. Our preliminary estimate of the unrisksed resource endowment, within currently leased areas of these three gas plays, is 710 Tcf (20 Tcm) with a risksed recoverable resource of 100 Tcf (3 Tcm).

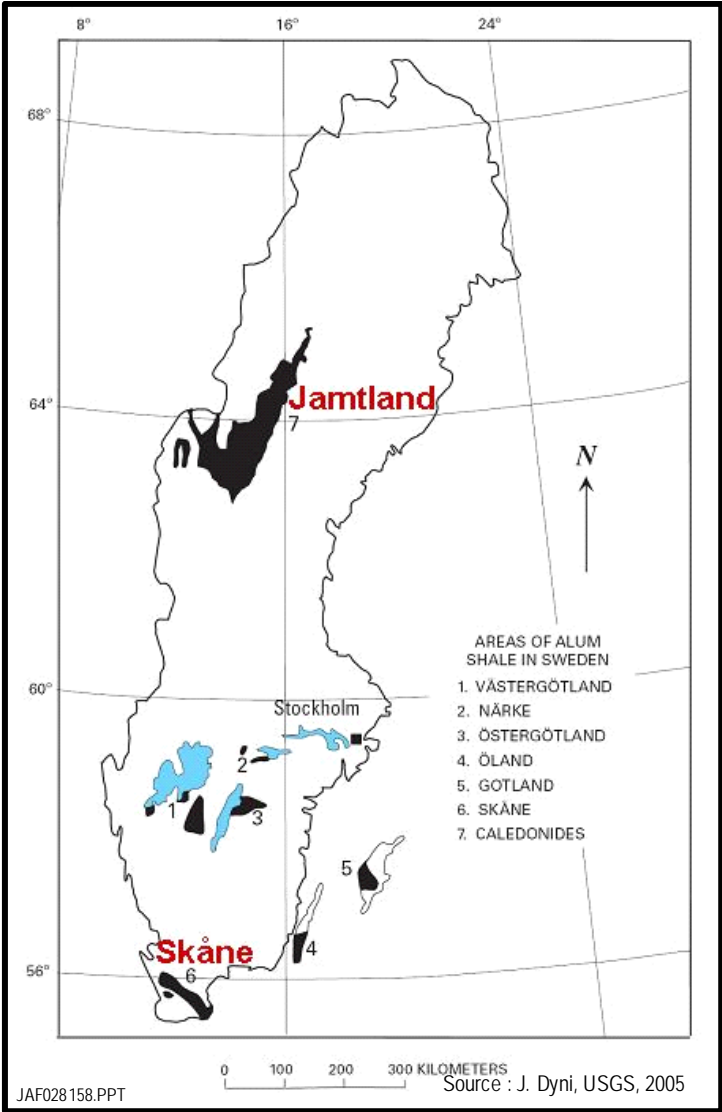
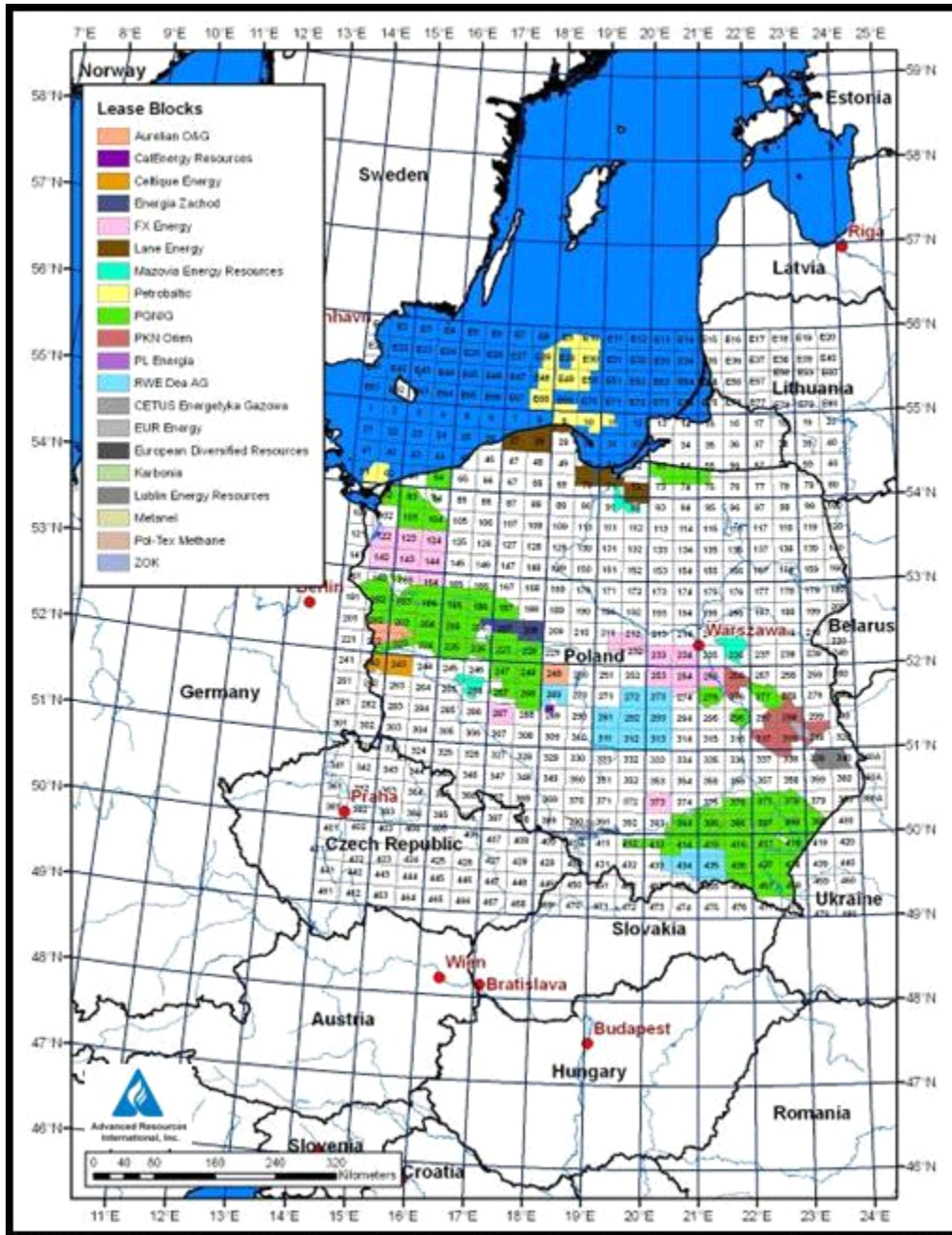


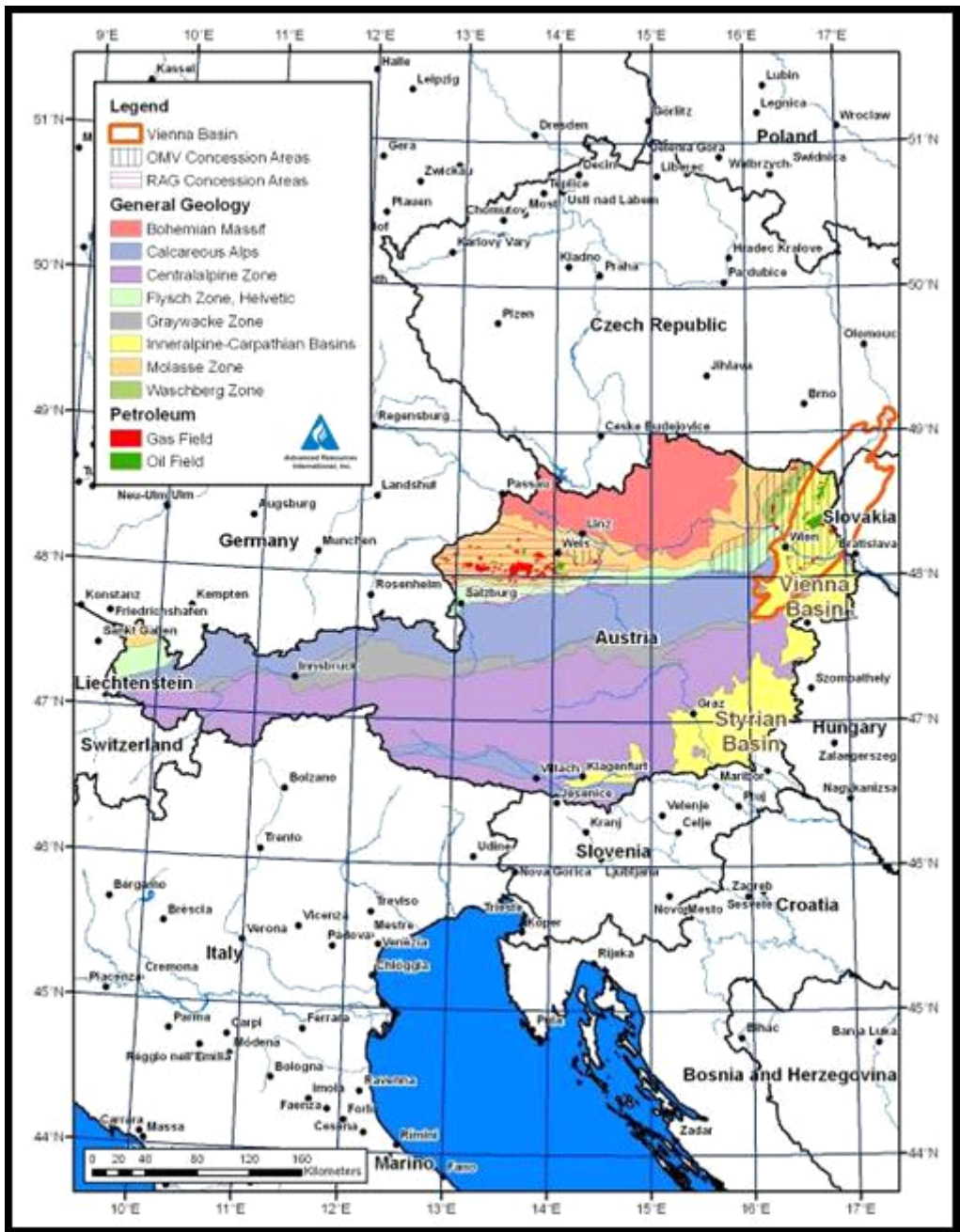
Figure 11. Sweden – Alum Shale



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Figure 12. Poland – Silurian Shales

- **Austria – Mikulov Shale.** With benefit of information from earlier 1970s/80s test wells, OMV is returning to explore the deep Jurassic Mikulov Shale in the Vienna Basin, Figure 13. The University of Vienna is conducting an in-depth study, funded by OMV, to further characterize these shales. Hydraulically fraced horizontal wells are being considered for exploring this challenging and deep gas shale play. Our preliminary estimate for the unrisksed resource endowment for the Mikulov Shale is 240 Tcf (7 Tcm) with a risksed recoverable resource of about 30 Tcf (1 Tcm).



Source : F. Hanot, First Break, 1992

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Figure 13. Vienna Basin – Mikulov Shale

Other World Gas Shales Resources. A number of major and independent oil and gas companies are circling the globe looking for high quality gas shales. Based on the experience to date in North America and Europe, it is likely that Rogner's initial resource endowment estimate for world gas shales of 16,110 Tcf (456 Tcm) will prove to be conservative⁴.

- **China and India.** China and India have numerous gas shale basins that are only now starting to be evaluated. Rogner attributed 3,530 Tcf (100 Tcm) of gas shale resource endowment to China and India. Recently, Shell and PetroChina announced plans to jointly evaluate and develop the gas shales in Sichuan Province. In addition, China and the U.S. Department of Energy have recently entered into a "U.S.-China Shale Gas Resource Initiative" to support gas shale development in China⁶.
- **Southern Africa.** Statoil, Chesapeake and Sasol recently announced joint plans to assess the gas shales of South Africa. Rogner attributes 270 Tcf (7.6 Tcm) of resource endowment to sub-Saharan Africa. To date, we have appraised the gas shale potential in only one of the southern African countries, namely Botswana. We estimate an in-place resource of 136 Tcf (3.9 Tcm) for the carbonaceous shales of Botswana with approximately 35 Tcf (~1 Tcm) potentially recoverable³.
- **Other Countries.** Gas shale exploration is underway in many other parts of the world. Australia has numerous prospective gas shale basins, including the Amadeus, Cooper and Georgina among others, Figure 14. New Zealand has two organically rich shale deposits in the East Coast Basin, North Island. The deeper Whangai Shale appears to have reservoir properties somewhat comparable with the Barnett Shale, Figure 15.

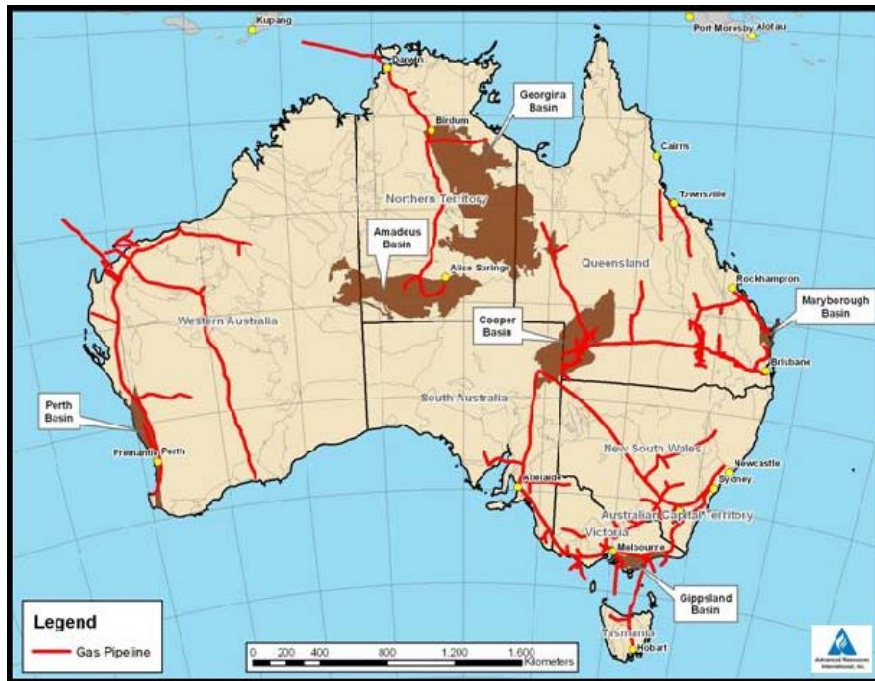


Figure 14. Major Gas Shale Basins of Australia



Figure 15. Gas Shale Prospects of New Zealand

WORLD UNCONVENTIONAL GAS RESOURCES

In addition to gas shales, two other unconventional natural gas supply sources deserve their place on the world gas resources stage.

Coalbed Methane (CBM). This unconventional gas resource once enjoyed the same level of enthusiasm and spotlight as the gas shales of today.

- Our company, along with many others, toured the world looking for the next “San Juan Basin Fairway” and its highly productive, low cost CBM resources. After nearly two decades of exploration, significant CBM basins have been defined in Australia, China and Indonesia.
- A number of LNG export terminals are being planned and constructed in Australia using gas supplies from the world class Comet Ridge (Bowen Basin) and Walloon Fairway (Surat Basin) CBM plays in Queensland.
- Our estimate of the CBM resource endowment in Indonesia is 450 Tcf (13 Tcm) mainly in Sumatra and Kalimantan, Figure 16. The coals are mostly low to moderate in rank, but deeper and thicker than the coals currently being produced for methane in the Powder River Basin. Initial CBM lease blocks were recently awarded to BP, ENI, Arrow and others.
- China holds an estimated 1,270 Tcf (36 Tcm) of CBM resource endowment. It has drilled over 3,000 CBM wells to date and has announced plans to reach 3 Bcfd of CBM production by 2020⁷. Recently drilled horizontal CBM wells show promise in the Qinshui Basin, Figure 17.

Our country-by-country assessment for the CBM resource endowment of the world is 3,540 to 7,630 Tcf (100 to 216 Tcm) with an estimated 830 Tcf (24 Tcm) potentially recoverable, Table 2⁸.

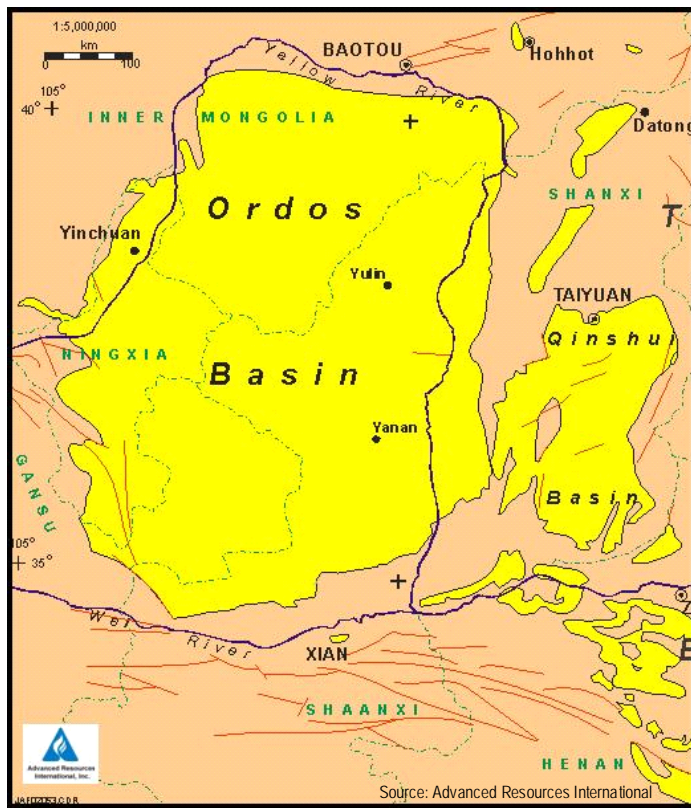


Figure 16. China's CBM and Tight Gas Sand Resources

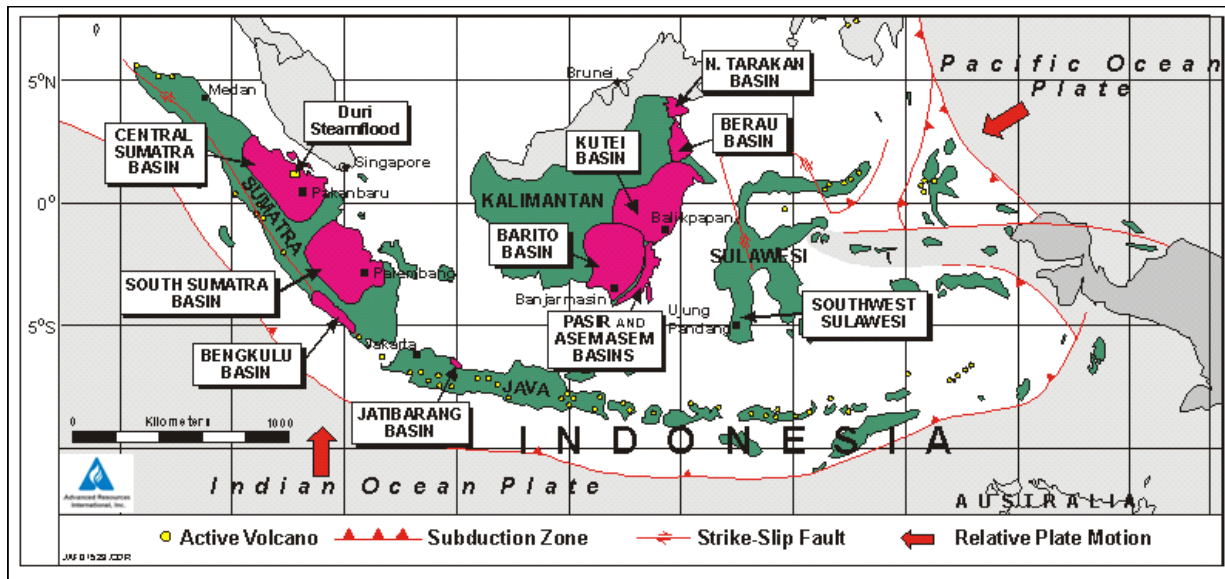


Figure 17. Indonesia's CBM Resources

Table 2. World Coalbed Methane Resources (Tcf)

Country	CBM Resource	CBM Recoverable
	In-Place (Tcf)	Resource (Tcf)
Russia	450-2,000+	200
China	700-1,270	100
United States	500-1,500	140
Australia/New Zealand	500-1,000	120
Canada	360-460	90
Indonesia	340-450	50
Southern Africa*	90-220	30
Western Europe	200	20
Ukraine	170	25
Turkey	50-110	10
India	70-90	20
Kazakhstan	40-60	10
South American/Mexico	50+	10
Poland	20-50	5
TOTAL (Tcf)	3,540-7,630	830
TOTAL (Tcm)	(100-216)	(24)

* Includes carbonaceous gas shales of Botswana.

Tight Gas Sands. Low permeability sand and limestone formations are today still the largest source of North American unconventional gas. Worldwide this resource is only now starting to be defined and developed, with prospective tight gas sand basins in South America, the Middle East and China.

- China currently produces about 400 MMcfd (11 million cmd) of tight gas sand resource from the Ordos Basin.

- The Mako Trough tight gas sand/gas shale play in Hungary has resource concentrations estimated at up to 700 Bcf/mi², Figure 18. The operator, Falcon Oil and Gas, estimates 40 Tcf (~1 Tcm) of contingent recoverable resource. However, the latest exploration well, while testing notable volumes of gas, encountered strong flows of water.

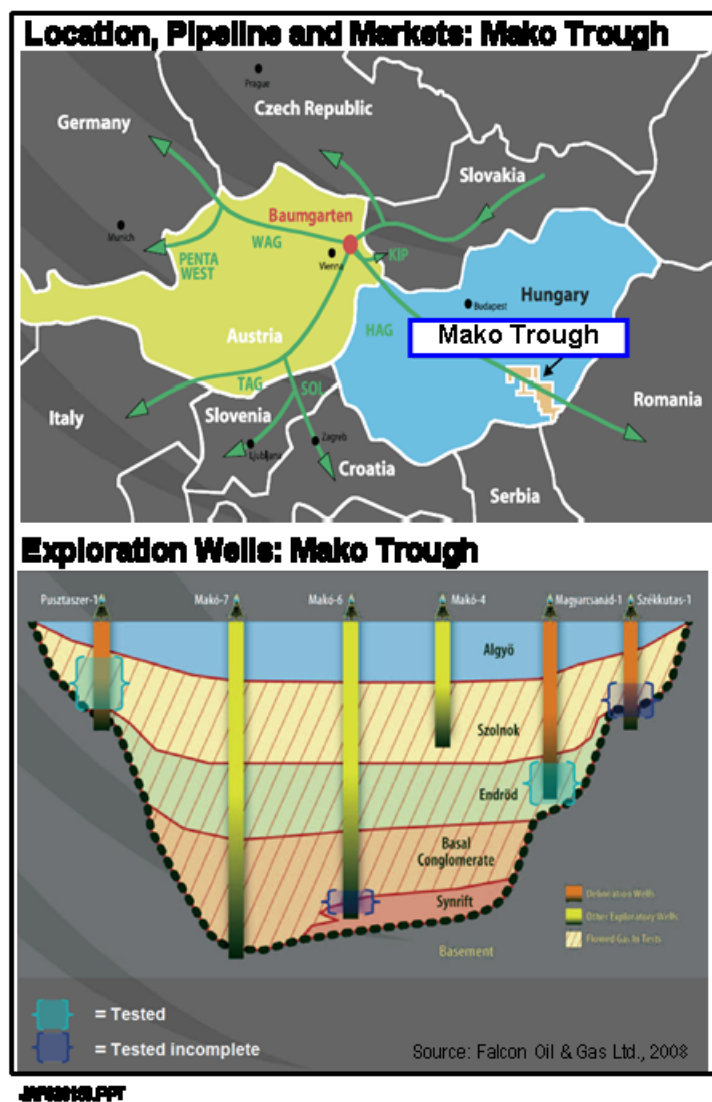


Figure 18. Tight Gas Sand Resources of Hungary

- Rogner's resource endowment estimate for worldwide tight gas sands is 7,400 Tcf (210 Tcm). The IEA's estimate of worldwide recoverable tight gas resource (starting with Rogner's in-place values) is 390 Tcf (110 Tcm). Both of these estimates can and need to be improved with more in-depth study.

KEY CHALLENGES FACING INCREASED USE OF NATURAL GAS

Three challenges need to be addressed if increased use of natural gas (particularly unconventional gas) is to become one of the major pathways to a low-carbon economy.

Challenge #1. Building Confidence in Adequate and Robust Natural Gas Supplies. Considerable skepticism still exists on the abundance of world unconventional natural gas supplies. Pronouncements that we are “running out of natural gas supplies”, voiced by M. King Hubbert in the 1970s, can still be heard for North America.

Detailed basin-level assessments of gas shales and unconventional gas are essential for building confidence that sufficient supplies of natural gas exist to serve as a major climate change mitigation option.

Challenge #2. Addressing the Environmental Barriers to Greater Natural Gas Development. As drilling increases and production grows in areas not used to hydrocarbon production, a harsher “spotlight” will fall on unconventional natural gas development. “Green natural gas development” - - capturing methane emissions, reducing surface impacts, pursuing environmentally acceptable hydraulic fracturing and re-using produced water - - will help make this activity more environmentally friendly.

Challenge #3. Building Demand For Natural Gas In A Carbon Constrained World. The unconventional gas resource base of North America and the world is large. Our view is that with aggressive pursuit of unconventional gas, the worldwide natural gas resource base will prove to be sufficiently large to provide a major, lower CO₂ emissions option for power generation and possibly for transportation.

LIST OF ACRONYMS AND ABBREVIATIONS

Bcfd	Billion cubic feet per day
Bcmd	Billion cubic meters per day
Btu	British Thermal Unit
CO ₂	Carbon dioxide
kWh	Kilowatt-hour
lb	Pound
Mcmd	Million cubic meters per day
MMbtu	one thousand British Thermal Units
SO ₂	Sulfur dioxide
Tcf	Trillion cubic feet
Tcm	Trillion cubic meters

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