Alberta Innovates
Energy and Environment Solutions

ALBERTA'S 2 TRILLION TONNES OF 'UNRECOGNIZED' COAL

Alberta Innovates Energy and Environment Solutions

Funded by the Government of Alberta

ALBERTA'S 2 TRILLION TONNES OF 'UNRECOGNIZED' COAL

Recognition by the International Energy Industry of Alberta's Vast Coal Endowment for Very Large Scale Projects (such as in-situ coal gasification)

Client Report to:

Alberta Innovates - Energy and Environment Solutions

By:

R.J. Richardson, M.Sc., P.Geol.

CanZealand Geoscience Ltd.

August, 2010

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Alberta has vast coal reserves and resources that are not internationally recognized. The problem is that geological coal data varies in quantity and quality from nation to nation and part of the definition of reserves involves economics and again change markedly from place to place and from time to time. In addition there is geological complexity to consider in estimating reserves.

In the past it really didn't matter to Canada (or Alberta) that only a small part of a huge coal endowment was internationally recognized as reserves. Canada has a limited domestic market for coal and was relatively successful in the international export market for high quality metallurgical coal. Transport and environmental issues, mining costs and foreign competition in both metallurgical and in particular thermal coal markets were bigger issues for the Canadian coal industry than establishing that large coal endowment existed. In addition gas and oil were easier to transport to the major market in the United States and to eastern Canada.

Things have changed in the last decade with new technology both for in-situ gasification (also known as Underground Coal Gasification - UCG) and Carbon Capture and Storage (CCS), world depletion of oil and concerns over climate change. The recent international interest in in-situ gasification, surface gasification and associated energy technologies such as CTL, GTL, hydrogen and fuel cells has surfaced in a number of jurisdictions

Now with coal being in-situ mined up to 1400m (perhaps deeper) in an Alberta pilot project; the question of how much coal that is available in Alberta has now become important. Already the leading 'recognized' coal nations (USA, China, Australia and India) are promoting their coal resources for in-situ development. Canada and in particular Alberta needs to establish itself as a credible option for large-scale in-situ gasification developments.

In Alberta (the Canadian Province having the largest coal resources) the Alberta Energy Resources Conservation Board (ERCB) estimates the remaining established reserves (similar to WEC's proved recoverable reserves category) of all types of coal in Alberta at December 31, 2008, to be 33.4 Gt. Of this amount, 22.7 Gt (or about 68 per cent) is considered recoverable by underground mining methods, and 10.8 Gt is recoverable by surface mining methods. In addition the ERCB recognize an ultimate potential of 620 Gt and ultimate in place coal resource of 2000 Gt (the Alberta Geological Survey using different methods put the estimate at a minimum of 2500 Gt; Beaton et al., 2006). Alberta's coal resources are vast and at 2000 Gt it is similar in scale to a recent estimate (Rupert et al., 2002) of the total coal resources of the United States.

Alberta does have a substantial amount of publically available geological data that can be used to establish coal resources. In addition to tens of thousands of shallow coal exploration holes and more than 17 thousand recent Coal Bed Methane (CBM) wells there are data from over 350 thousand oil and gas boreholes drilled in Alberta. The database grows by 15-20 thousand boreholes a year.

Many of these oil and gas boreholes intercept deep coals and the coals that are readily indentified on geophysical logs. Industry geologists often use hundreds to thousands of these oil and gas boreholes to outline CBM plays.

A short review of two top coal nations, India and USA indicates that large reserve and resource estimates may be questionable because of dated methodology in the case of India and modern strict focus on economically recoverable resources in the case of the United States. Neither of these two countries appears to have the potential of Alberta for either conventional coal mining or new technologies such as in-situ gasification. However they do have a very large domestic market.

Conclusions and recommendations:

- Alberta has very large coal resources and reserves that are not internationally recognized which hinders Alberta and Canada's position as a major coal nation.
- As a priority Alberta should promote the ERCB remaining reserve figure of 33.4 Gt through its membership (both the Alberta Department of Energy and the ERCB are members) on the Energy Council of Canada to the World Energy Council.
- Through industry and academic conferences promote the reserves and resources of the province stressing the geological data behind the estimates.
- Adopt and promote the ERCB published Ultimate in-place resources estimate of 2000 Gt as the official Alberta estimate noting it is likely to be revised upward in future.
- The ERCB and AGS should review their current reserve/resource estimate methodology and those of other countries such as the USA and also those of industry organizations and societies to insure they meet current government, scientific and industry needs.
- The ERCB and AGS should review what enhanced studies of reserve/resources are needed for in-situ coal gasification regardless of a potential change in estimation methodologies.
- Alberta is a major energy economy and is looking to expand in petrochemical and develop a hydrogen future. Alberta is an emerging "energyplexes".
- Alberta should promote in-situ gasification as way of realizing its position as an energyplex for the following reasons:
    - Alberta strength is in abundant coal resources over vast areas of the province
    - Relatively simple and favourable geology
    - Large market for syngas in the oilsands and in energy and power industries
    - CCS expertise and geological capacity
    - Pipelines and infrastructure available

INTRODUCTION

Reserve and resource estimation methodologies of coal vary greatly from country to country and are based on widely variable quantity and quality of geological data. This study provides a background document (paper) to Alberta Innovates - Energy and Environment Solutions that outlines the issues around coal resource and reserves estimation with a particular focus on Alberta coal, and some comparative observations on India and the United States coal resources.

This study provides a high level overview of the size, depth and quality of Alberta's coal resources and thus their potential for in-situ gasification and other large scale coal-based technologies. As environmental issues related to in-situ gasification are a critical aspect of any future coal development the current technologies will be reviewed with regard to the geological environment and conditions in Alberta and current international best practices.

Finally some conclusions and recommendations will be made.

BACKGROUND AND ISSUES

Historically and currently Canada is considered by the international energy industry to have minor coal reserves (Fig. 1) relative to those of the traditionally accepted major coal nations. Recent estimates by the World Energy Council (WEC) for proved recoverable reserves (that is, the tonnage of coal that has been proved by drilling etc. and is economically and technically extractable) has the United States at 238.308 Gt (gigatonnes or billion tonnes), Russian Federation at 157.010 Gt, China at 114.500 Gt, Australia at 76.200 Gt, India at 58.600 Gt while Canada is listed as having only 6.578 Gt; less than a 1% share of the world coal reserves and a little less than nations such as Poland (7.502 Gt), Brazil (7.059 Gt) and Columbia (6.814Gt).

Figure 1: World coal shown graphically based on WEC data (from Chikkatur, 2008 source http://show.mappingworlds.com/world/).

In Alberta (the Canadian Province having the largest coal resources) the Alberta Energy Resources Conservation Board (ERCB) estimates the remaining established reserves (similar to WEC's proved recoverable reserves category) of all types of coal in Alberta at December 31, 2008, to be 33.4 Gt. Of this amount, 22.7 Gt (or about 68 per cent) is considered recoverable by underground mining methods, and 10.8 Gt is recoverable by surface mining methods. In addition the ERCB recognize an ultimate potential of 620 Gt and ultimate in place coal resource of 2000 Gt (the Alberta Geological Survey using different methods put the estimate at a minimum of 2500 Gt; Beaton et al., 2006). Alberta's coal resources are vast and at 2000 Gt it is similar in scale to a recent estimate (Rupert et al., 2002) of the total coal resources of the United States.

Coal data varies in quantity and quality from nation to nation and part of the definition of reserves involves economics and again changes markedly from place to place and from time to time. In addition there is geological complexity to consider in estimating reserves. Resource estimates can be even more wide ranging.

Alberta does have a substantial amount of publically available geological data that can be used to establish coal resources. In addition to tens of thousands of shallow coal exploration holes and more than 17 thousand recent Coal Bed Methane (CBM) wells there are data from over 350 thousand oil and gas boreholes drilled in Alberta. The database grows by 15-20 thousand boreholes a year.

Many of these oil and gas boreholes intercept deep coals and the coals that are readily indentified on geophysical logs. Industry geologists often use hundreds to thousands of these oil and gas boreholes to outline CBM plays. Almost all of the deeper coals are not extractable (economic) through traditional mining at present.

However traditional coal mining is no longer the only option for coal. Thinking about coal has changed in recent years with new and improved technology for in-situ gasification paired with Carbon Capture and Storage (CCS) and with the current concerns of world depletion of oil and climate change. The recent international interest in in-situ gasification, surface gasification and associated energy technologies such as CTL, GTL, hydrogen and fuel cells has surfaced in a number of jurisdictions including Alberta.

Now with coal being in-situ mined up to 1400m depth in an Alberta coal gasification pilot project; Alberta's huge coal endowment needs to be recognized.

OVERVIEW OF COAL RESERVE AND RESOURCE ESTIMATION METHODOLOGIES

Government agencies, coal companies, security regulators, internal energy agencies, financial organizations are all involved in coal resource and reserve estimation. All these different entities in different jurisdictions around the world have similar but different systems of estimation or criteria. Often the geological data they depend on is dated, sparse or varies greatly in quality. Coal development economics also change over time as does technology so it is not surprising that reserve and resource estimates are not very comparable. Even with efforts to standardize reporting by agencies such as the World Energy Council (WEC) major problems remain. A 2007 report by the *Energy Watch Group* concluded that "The first and foremost conclusion from this investigation is that data quality of coal reserves and resources is poor, both on global and national levels. But there is no objective way to determine how reliable the available data actually are" (Energy Watch Group, 2007).

The WEC periodically collects information from its member countries and despite having published definitions and criteria the data suffers from the issues mentioned above.

The WEC definitions are:
Proved amount in place is the resource remaining in known deposits that have been carefully measured and assessed as exploitable under present and expected local economic conditions with existing available technology.

Proved recoverable reserves are the tonnage within the proved amount in place that can be recovered in the future under present and expected local economic conditions with existing available technology.

Estimated additional amount in place is the indicated and inferred tonnage additional to the proved amount in place that is of foreseeable interest. It includes estimates of amounts that could exist in unexplored extensions of known deposits or undiscovered deposits in known coal-bearing areas, as well as amounts inferred through knowledge of favourable geological conditions. Speculative amounts are not included.

Estimated additional reserves recoverable is the tonnage within the estimated additional amount in place that geological and engineering information indicates with reasonable certainty might be recovered in the future.

The *BP Statistical Review of World Energy* is also widely referenced for coal resource and reserve information but just reproduces the data collected by World Energy Council (Hook et al., 2008). The International Energy Agency uses **Proved reserve** which is equivalent to proved recoverable reserve as defined by WEC (Energy Watch Group, 2007).

The US Energy Information Agency (EIA) uses the following nomenclature (Energy Watch Group, 2007):

Demonstrated reserve base covers publicly available data on coal mapped to measured and indicated degrees of accuracy and found at depths and in coalbed thicknesses considered technologically minable at the time of determinations.

Estimated recoverable reserves (this category corresponds to the proved recoverable reserves according to WEC and to proved reserves according to BP statistics) cover the coal in the demonstrated reserve base considered recoverable after excluding coal estimated to be unavailable due to land use restrictions or currently economically unattractive for mining, and after applying assumed mining recovery rates.

The United States Geological Survey (USGS) approach to coal resource/reserves estimate have evolved substantially over the last couple of decades. In 1975 it was a definition driven ruled based methodology (USGS, 1975; Falkie, and McKelvey, 1976) that became a model for the Canadian, Albertan and other coal reserve/resource systems worldwide. In 2009 the USGS published The National Coal Resource Assessment Overview: U.S. Geological Survey Professional Paper 1625–F (Pierce et al., 2009) in which reserve and resource estimation challenges is discussed in detail (Luppens et al., 2009). The current USGS approach is aimed at identifying "**available coal**" and "**economically recoverable coal resources**" which is essentially a reserve but one that has many limiting criteria attached. The National Coal Resource Assessment (NCRA) system uses digital data bases and geographic information systems (GIS) for coal assessment which forms part of a digital geological model; Figure 2 provides a flow diagram of the many steps involved. Important findings of the NCRA was that the amount of **economically recoverable resources** for all the areas evaluated represents only a relatively small fraction (4 percent to 22 percent) of the original resources and "coal reserve assessments are not a one-time exercise; the assessments need to be redone periodically as conditions such as new data (geologic, restrictions, and so forth) or significant changes in mining economics warrant" (Luppens et al., 2009). New estimates of US coal reserves will be much smaller than those identified in past studies. US coal resources and reserves will be discussed in more detail later in this paper.

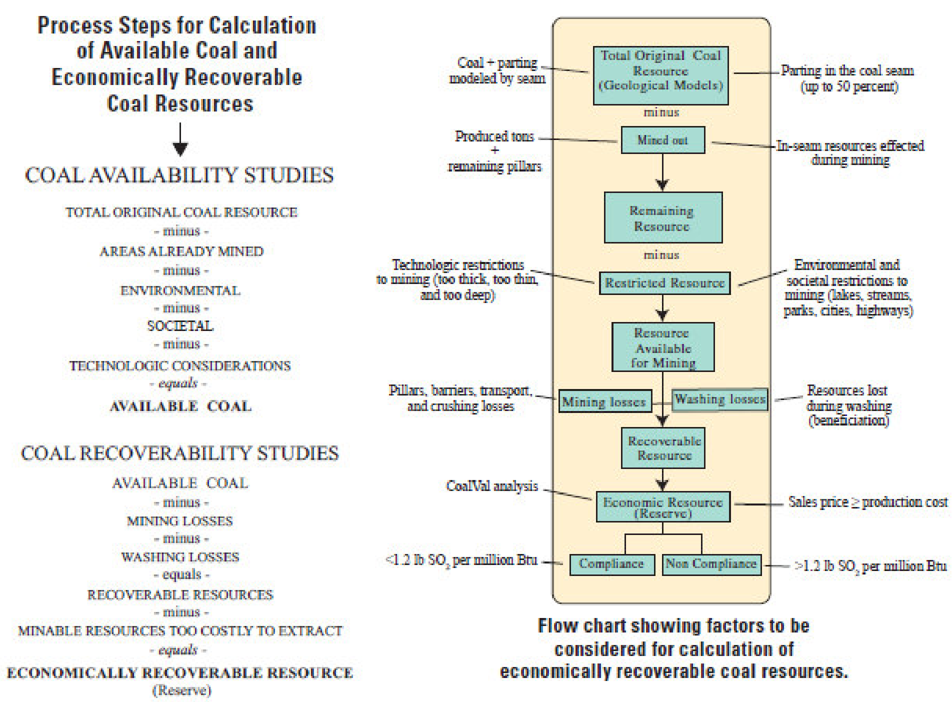

Figure 2: Coal Availability/Recoverability Methodology Flow Diagram (Luppens et al., 2009).

In contrast to the current USGS methodology is that of India where coal resources are "generally reported on the basis of the Indian Standard Procedure 1956, which treats all resources as reserves based on certain stipulations. This is a geological resource-classification system without the assessment of quality, mineability, or extractability of deposits. Such a method of resource reporting tends to present a highly inflated picture, because it has little relationship with economically mineable/ extractable reserves" (Chand and Sarkar, 2006). Bhattacharyya (2010) recently commented "the Indian reserve reporting system appears to misinform the coal potential of the country as the reported reserves do not consider the techno-economic feasibility of the resource extraction, mining inefficiency (i.e. coal not extracted due to mining technology issues) and are based on insufficient exploration information". India's coal resources will be briefly reviewed later in this paper.

The Canadian (federal) methodology is that of the Geological Survey of Canada (GSC) which is set out in GSC Paper 88-21, "A Standardized Coal Resource/Reserve Reporting System for Canada" (Hughes et al., 1989). This is a rule based system, somewhat similar to the old rules based system of the USGS, which has been used as a supporting document for more recent Canadian Institute of Mining, Metallurgy and Petroleum (CIM) CIM Standards on Mineral Resources and Reserves (CIM Standards) and Canadian Securities Administrators (CSA) issued National Instrument 43-101 (in particular NI 43-101CP) methodologies. Changes for NI 43-101 have been proposed on April 23, 2010 (ASC, 2010). The Geological Survey of Canada system is potentially inconsistent with the more recent Canadian CIM Standards, as well as other recent classification systems, which allows for possible confusion when applying these additional guidelines (Stevens, 2004). The data for Canadian coal reserve estimates comes mainly from the GSC's National Coal Inventory which primarily has industry drillhole data from active coal mining areas and adjacent coal fields but supplemented with information on deeper coals where coal bed methane potential was identified. As a result reserve estimates have been very conservative and resource estimates are not widely appreciated (see also comment of Smith, 1989 below).

The Minerals and Metals Sector of Natural Resources Canada report in its *Canadian Minerals Yearbook* that Canada holds 8.7 billion t (Gt) of proven coal reserves, including 6.6 Gt of proven recoverable coal reserves, which will provide more than 100 years of production at the current production rate. In addition, about 193 Gt of coal resources have been identified (Stone, 2008). Smith in his GSC 89-4 paper *Coal Resources of Canada* noted that variations between the GSC estimates of coal resources and those of provincial government agencies reflect differences in criteria used for estimating coal resources and/or categories in which these estimates are reported. The Federal estimates, which are greatly at odds with Alberta's estimates which will be discussed in more detail latter in this paper.

The Alberta Energy Resource Conservation Board (ERCB) coal resource/reserve methodology (ERCB, 2000 ST-31: Reserves of Coal Province of Alberta at December

1999) differs from that used by the GSC although both are based on the old USGS 1975 scheme; the primary definitions and criteria follow:

Resource - A gross quantity of coal calculated, interpreted, or presumed to exist in the ground.

Established Resource - A body of coal that has been specifically delineated by drilling, trenching, driving adits, mine development operations, or other exploratory work, including some coal judged to exist contiguously on the basis of geological, seismic, or similar information. To calculate established resources, a standard error (based on uncertainties in coal thickness, area, and coal specific gravity) is determined for each deposit, and established in-place tonnages were taken to be two standard errors less than the best estimate (as calculated above).' For Mountain and Foothills deposits calculated prior to 1982 a subjectively conservative estimate of tonnages was made. Nevertheless, an assumed standard error of 5 per cent has now been applied to these deposits.

Reserve - That portion of an established resource considered recoverable by current technology under present or anticipated economic and social conditions.

Initial in-Place - The quantity of a resource prior to any production (Initial Quantity in-Place - Several techniques, in particular the block kriging, grid, polygon, and cross-section methods, have been used for calculating in-place volumes, with separate volumes calculated for surface- and underground-mineable coal).

Initial Reserve - A reserve prior to deduction of any production,

Remaining (established) Reserve -The initial reserve less cumulative production (similar to WEC's proved recoverable reserves category).

Ultimate Potential - An estimate of the initial reserves that will have become developed in an area by the time all exploratory and development activity has ceased, having regard for the geological prospects of that area and anticipated technological, economic, and social conditions; includes cumulative production, remaining reserves, and presumed future additions through extensions and revisions of existing deposits, and the discovery or delineation of new deposits.

A large degree of uncertainty is inevitably associated with estimating an ultimate potential, and new data could substantially alter results. Two methods are used to estimate ultimate potential of coal. The first, the volume method, gives a broad estimate of area, coal thickness, and recovery ratio for each coal-bearing horizon, while the second method estimates the ultimate potential from the trend of initial reserves versus exploration effort (ERCB ST98-2009: Alberta's Reserves 2008 and Supply/Demand Outlook / Coal).

Ultimate in Place Resources – Includes all in place initial resources whether considered recoverable or not recoverable (for conventional mining) (Fig. 3).

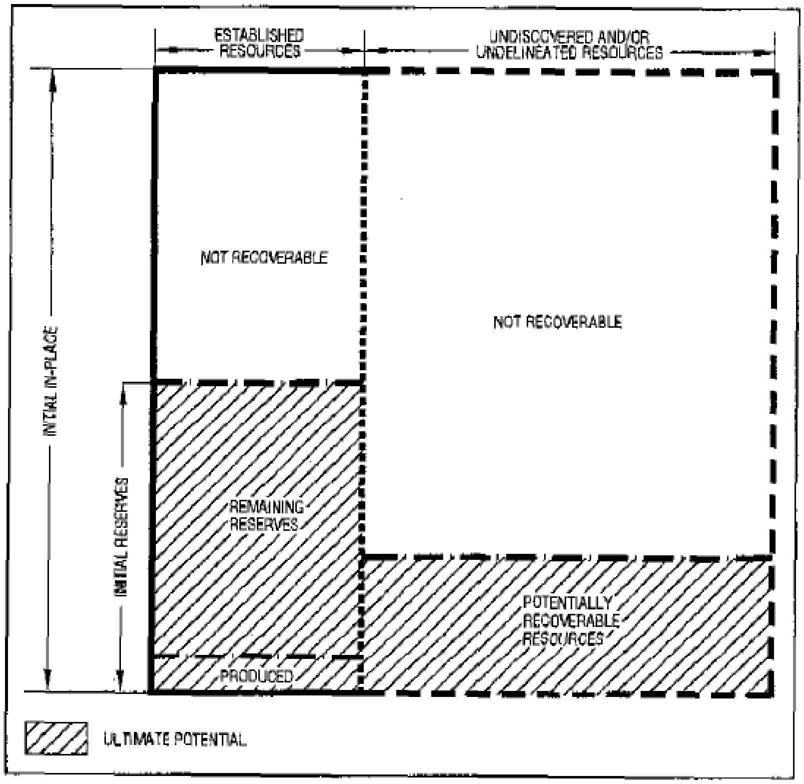

Figure 3: Schematic Representation of ERCB Resource Terminology.

NEW TECHNOLOGY AND IN-SITU GASIFICATION AND WHAT IT MEANS FOR FUTURE COAL RESERVE ESTIMATIONS

Huge resources of coal that can not be economically mined because of great depth, thinness, high ash content, surface constraints etc. may be soon be in-situ mined to produce syngas.

The traditional coal resource and reserve estimation methodologies may not work well for new technologies such as in-situ gasification. The in-situ gasification is more like an unconventional gas project such as coal bed methane, shale gas and perhaps gas hydrates than a traditional coal mining project.

The oil and gas industry has been working on a "project based system" for estimating conventional and unconventional resources. As early as 1930's there was international efforts by the oil and gas industry to standardize the definitions of petroleum resources (SPE-PRMS, 2007). The SPE/WPC/AAPG/SPEE Petroleum Resources Management System (SPE-PRMS) is now used internationally for oil and gas evaluations. Figure 4 outlines the Resource Classification System which is somewhat like many coal resource evaluation systems.

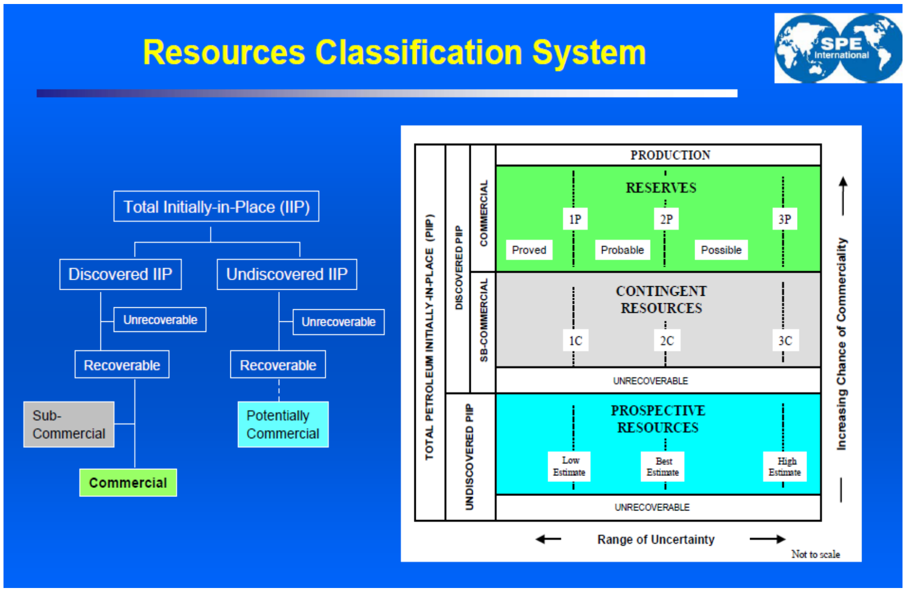

Figure 4: Resources Classification Framework (SPE-PRMS, 2007).

The SPE-PRMS is however more focused on commercial viability though development projects (Fig. 5). As gas is the product in in-situ coal gasification the SPE-PRMS system may be more useful at least for in-situ coal resource estimates and with some modifications may also be applicable for traditional coal resource and reserve estimates if the system was widely adopted by the international coal sector.

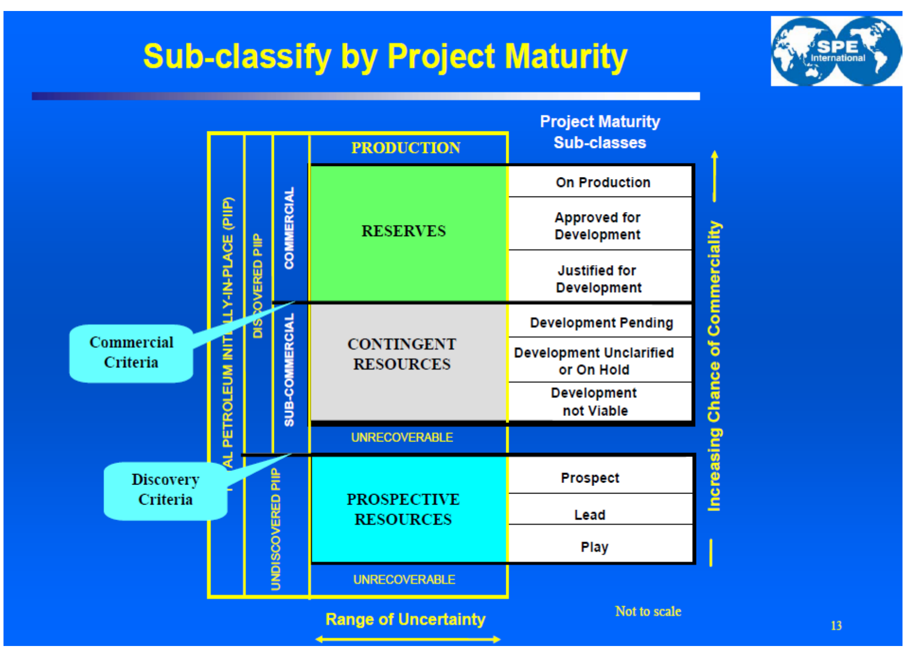

Figure 5: Sub-classes based on Project Maturity (SPE-PRMS, 2007).

OVERVIEW OF WORLD COAL RESOURCES AND RESERVES INCLUDING A DISCUSSION OF "PEAK COAL" AND IN-SITU GASIFICATION.

World coal initial in place resources are poorly known as the data is sparse and the estimates are generally speculative with many assumptions being made. Industry in particular are seldom interested in coal that might not in fact be there or if there likely unmineable. Some governments are interested in looking to the future and security of energy supply and some take comfort in large projected resources. However other governments and certainly some scientific agencies are now more interested in realistic estimates taking into account economic, environmental constraints other resource constraints, social constraints and so forth. A number of researchers have now been looking at the concept of Peak Coal (based on Hubberts Peak Oil theory) where they believe that coal production in many countries has already reached a peak and is declining. They suggest that even some of the nations with the largest reserves many face declining in two or three decades if not sooner. In contrast to this is the introduction of new technology such as in-situ gasification which will likely extend coal usage far into the future.

World coal resources

The international Energy Agency (IEA) have estimated the total world resources of hard coal and lignite at some 21 trillion tonnes (IEA, 2010) but offer no breakdown by country. One slide from a presentation by Sarma, (2008, Directorate General of Hydrocarbons India) provides a breakdown (Table 1) but the source(s) of the information could not be confirmed. The USA figure of ~4 trillion tonnes is that from Averitt, (1975) and for Canada an early estimate from Williams and Murphy (1981) but sources for other country estimates are unknown. However it is interesting that Canada is rated top for coal resources and if ERCB estimates for only Alberta Ultimate in Place Resources (~2000 Gt) are accepted Alberta would still rate in the top five.

Table 1: Estimate on World Coal Resources (Sarma, 2008)

CBM RESOURCES GLOBALLY

Sl. No.	COUNTRY	COAL RESOURCES (BILLION TONNES)	CBM RESOURCES (TCM)
1	CANADA	7000	6.5 – 76.4
2.	RUSSIA	6500	13.3 – 73.6
3.	CHINA	4000	16.4 – 34.0
4.	USA	3970	12.7 – 25.5
5.	AUSTRALIA	1700	8.8 – 14.2
6.	INDIA	495 (245 + 250)	1.4 – 2.6
7.	GERMANY	320	1.7 – 2.5
8.	U.K	190	1.1 – 1.7
9.	POLAND	160	1.4 – 2.0
10.	SOUTH AFRICA	150	1.4 – 2.0
11.	INDONESIA	17	0.1 – 0.2
12.	ZIMBABWE	8	0.04 – 0.05

SOURCE : CONFERENCE PROCEEDING OF INTERNATIONAL SEMINAR ON CBM PROSPECTS & POTENTIAL DEC.' 99

World coal reserves

World coal reserves a complied by the World Energy Council through submission of data by its member countries. Table 2 shows the top 19 countries having between 2 GT (Pakistan) and 238 Gt (USA) of **Proved recoverable reserves.** About half (47.9) of the world's reserves are in two countries (the United States and the Russian Federation) while 30.2% is shared by the remaining three countries of the top five (China, Australia and India). This paper reviews in more detail two of the top five countries where there seems to be a reevaluation in the United States and concerns on estimates in India. The Canadian estimates and in particular the coal resources of Alberta are discussed in more detail below. An examination of other countries is beyond the scope of this study but it worth mentioning that China, ranked 3rd with 13.9% of the coal reserves and the world's largest coal consumer, has by one estimate even greater reserves than stated. The Ministry of Land and Resources of China stated the number was actually 188.6 billion tons by the end of 2002 (Bo-qiang Lin and Jiang-hua Liu, 2010 source www.ChinaCoal.org.cn). China is also preparing a new reserve and resource estimation system (Stoker, 2009) where, resources are classified on the basis of geological knowledge, project economics and the project (feasibility) study status (Bo-qiang Lin and Jiang-hua Liu, 2010).

Table 2: World proved reserves (BP Statistical Review of World Energy June 2009; Source of reserves data: World Energy Council, 2009).

Proved reserves at end 2008

(Million tonnes)	Anthracite and bituminous	Sub-bituminous and lignite	**Total**	Share of total	R/P ratio
US	108950	129358	**238308**	28.9%	224
Russian Federation	49088	107922	**157010**	19.0%	481
China	62200	52300	**114500**	13.9%	41
Australia	36800	39400	**76200**	9.2%	190
India	54000	4600	**58600**	7.1%	114
Ukraine	15351	18522	**33873**	4.1%	438
Kazakhstan	28170	3130	**31300**	3.8%	273
South Africa	30408	–	**30408**	3.7%	121
Other Europe & Eurasia	1025	18208	**19233**	2.3%	268
Poland	6012	1490	**7502**	0.9%	52
Brazil	–	7059	**7059**	0.9%	*
Colombia	6434	380	**6814**	0.8%	93
Germany	152	6556	**6708**	0.8%	35
Canada	3471	3107	**6578**	0.8%	97
Czech Republic	1673	2828	**4501**	0.5%	75
Indonesia	1721	2607	**4328**	0.5%	19
Greece	–	3900	**3900**	0.5%	58
Hungary	199	3103	**3302**	0.4%	351
Pakistan	1	2069	**2070**	0.3%	496

Peak Coal

An offshoot of now well known King Hubberts Peak Oil theory (Hubbert, 1956) is the concept of Peak Coal (Rutledge, 2007). There is debate (GSA, 2009) both about the concept of Peak Coal and/or specific predictions. One hand many authors have used history matching to demonstrate where past production peaked in a number of countries and have predicted where and when coal will peak in a number of other countries (Fig. 6 and Höök, 2008). Many others particularly those in industry or government energy departments and scientific organizations point to hundreds of years of supply. Peak Oil seems to be a reality but there are many differences between oil and coal and it might be argued that in some places coal had a false peak due to changing technologies, new more versatile energy options and technology change but in many countries it is now back. Mining coal for the coal to Liquids (CTL) perhaps is impractical as Höök, 2009 suggests. However, in-situ gasification may be another of those new technologies that change the shape of the curves and push an initial peak further into the future.

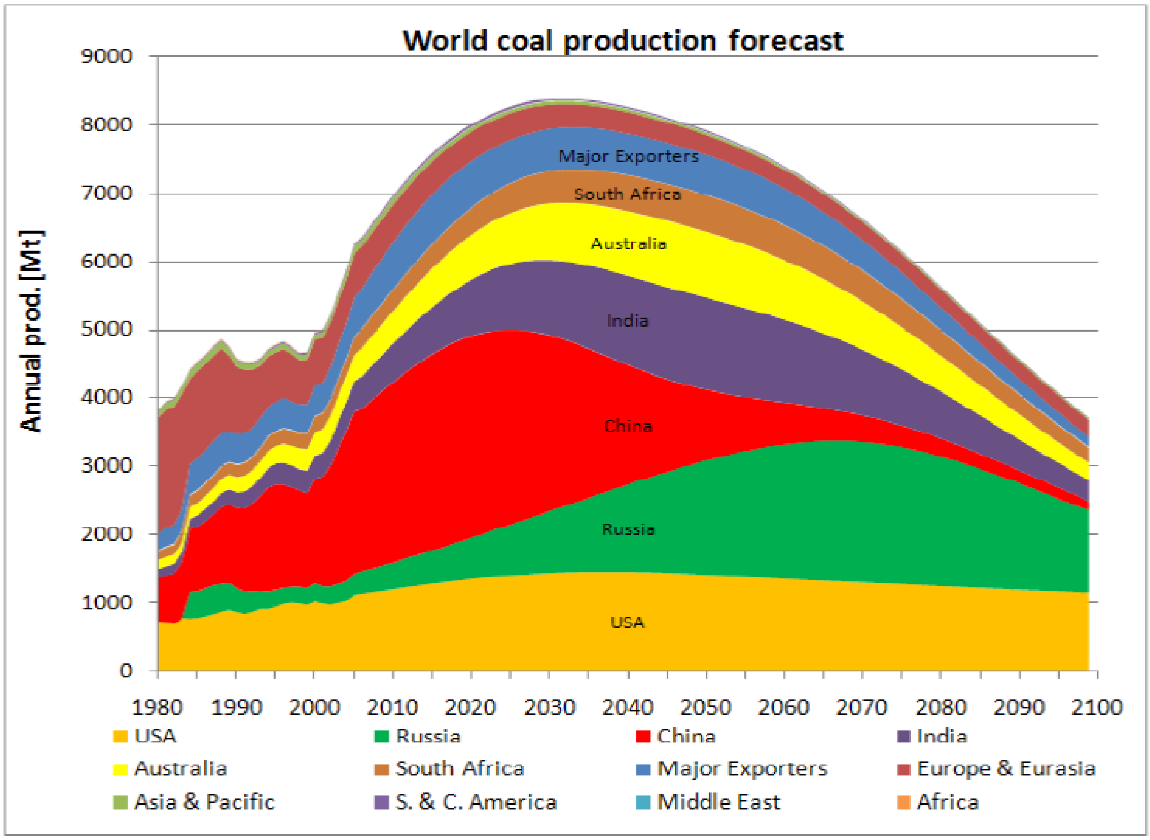

Figure 6: Peak Coal and projected decline in world coal production (Höök, 2008).

In-situ Gasification

In-situ gasification is possible with both coals that are minable and coals that currently can't be minable because of depth, quality, surface or social constraints and remoteness from markets or transport. There may be a number of environmental advantages in not gasifying reserves or minable coal as deep coals offer a greater barrier to possible near surface contamination and benefits from higher pressures as well as offering potential Carbon Capture and Storage (CCS) opportunities.

In addition coal that does not have to be traditional mined offers safety advantages and potential cost savings. The biggest advantage is the most of the **coal in place**, a far larger tonnage than reserves, is now a valuable commodity. The only country where a UCG reserve assessment has been carried out, the UK showed a 17-fold increase in recoverable reserves if UCG was employed instead of mining (DG JRC Institute & Energy Edge Limited, 2007). The 2004 DTI study estimated that there was about 17 billion tons of potentially gasifiable coal onshore in Britain, with a parallel estimate giving a figure at least double that offshore, suggesting a total of over 50 billion tons (Fergusson, 2009). There are a number of planned and proposed in-situ gasification projects currently in the UK.

A geological review of in-situ coal gasification it Alberta has been recently completed by Pana (2009). The report identifies three major coal deposits (the Ardley, Drumheller or Horseshoe Canyon and upper Mannville coal zones) as potential targets for in-situ gasification all of which are of current interest by industry.

In Alberta three companies (other companies may be active but have not made their plans public) have proposed in-situ gasification projects, one of which is in the pilot stage (Fig. 7). The companies have targeted different coal zones; the deep Mannville north of Whitecourt, the near surface area of the Ardley Coal Zone west of Edmonton and the shallow Horseshoe canyon coals near Drumheller.

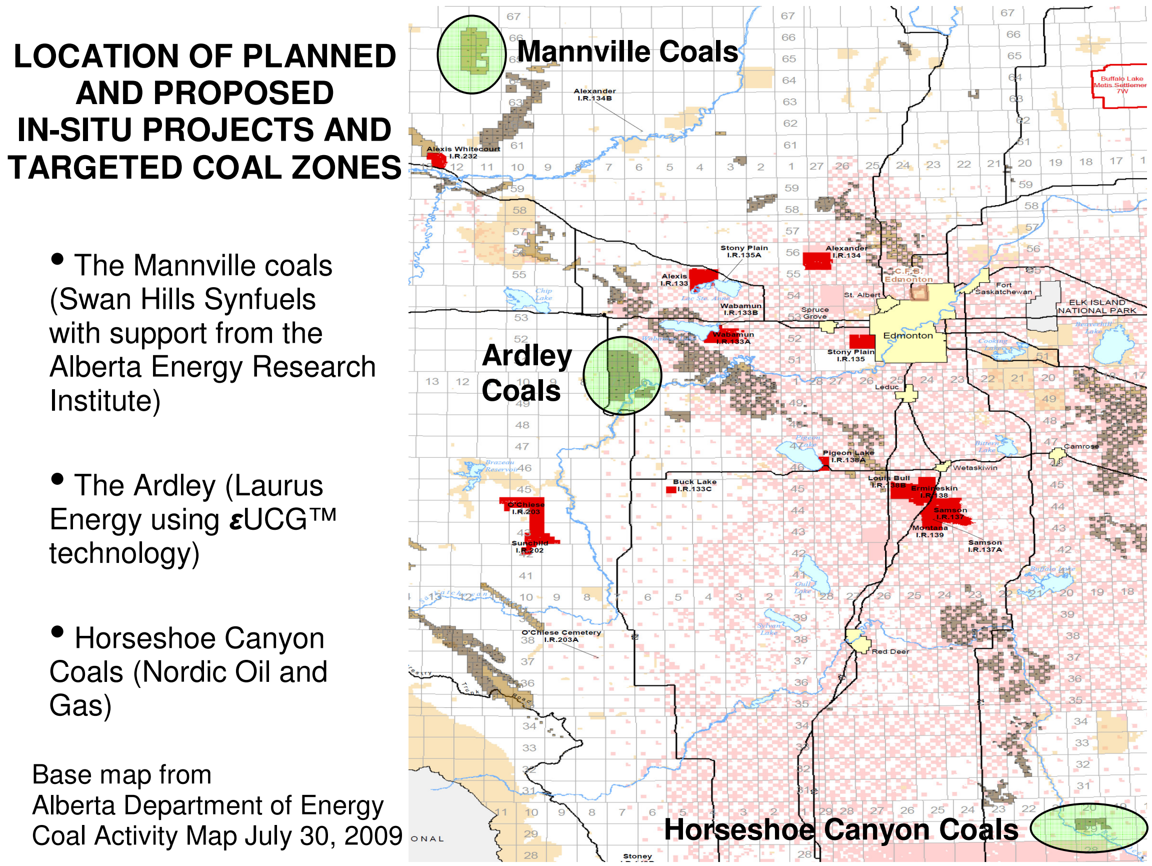

Figure 7: Location of planned in-situ gasification projects in Alberta. The township grid provides scale (9.8 km X 9.8km).

Table 3 provides some information on the planned projects and targeted coals. The Mannville project is the most advanced with a successful test in June and July 2009 (http://www.swanhills-synfuels.com/projects_demonstration.htm). The area under lease contains more coal than the total of coal mined in Alberta's history and that total is tiny in comparison to what is potentially available. The gasification of coals at 1400 m depth is the deepest in-situ gasification to date and indicates much of Alberta's coal to at least this depth can be technically gasified. A modeling study on gasification of deep Alberta coals has recently been carried out by Nourozieh et al., in press *(Simulation Study of Underground Coal Gasification in Alberta Reservoirs: Geological Structure and Process Modeling)* see Figure 8. One of there findings indicate that syngas for deep coals at high pressure will be methane rich (Fig. 9).

Table 3: Summary information on the Alberta proposed in-situ gasification projects.

MANNVILLE PROJECT	ARDLEY PROJECT	HORSESHOE CANYON PROJECT
Demonstration Pilot Project is underway with Alberta Energy Research Institute (AERI), providing $8.83 million for the $30-million project with Swan Hills Synfuels of Calgary. No estimate of tonnage in area under lease. http://www.swanhills-synfuels.com/projects_demonstration.htm	Laurus Energy estimated 2 Gt of resource in 18,688 hectares under lease http://laurusenergy.com/projects/alberta/	Nordic Oil and Gas announced on June 1, 2009 (http://www.nordicoilandgas.com/july209.html) that it had acquired 3,856 hectares (9,528 acres) of coal leases located at Drumheller, and that historical data had determined that the leases contained approximately 54 million tonnes (Mt) of coal
Technology CRIP Type will be deepest UCG project so far at ~1400m	εUCG™ technology (Ergo Exergy Technologies Inc.) to be used	Technology likely a vertical grid type as the coals are shallow likely less than 200 m in depth
Saline water at gasification chamber level	Potable water at gasification chamber level ~ 200 m in depth	Likely brackish to fresh water at gasification chamber level
Rank - High Volatile C Bituminous	Rank - High Volatile C Bituminous	Rank - High Volatile C Bituminous
Thickest seams ~3 - 4 m	Thickest seams ~3 - 4 m	Thickest seams ~1 - 2 m
Total cumulative coal ~4 - 6 m	Total cumulative coal ~4 - 6 m	Total cumulative coal ~8 -12 m

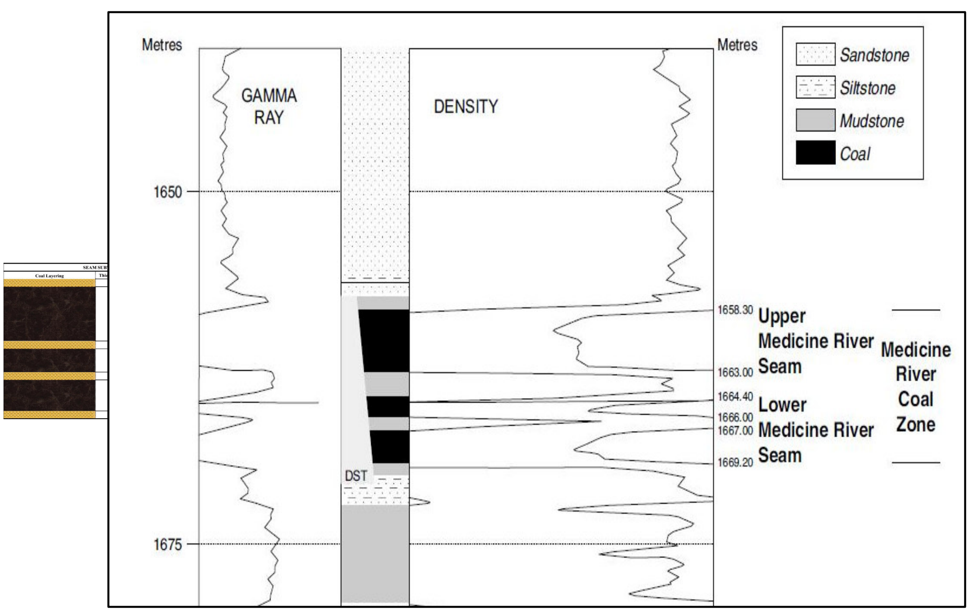

Figure 8: Coal seam layer model Nourozieh et al. and geophysical log of Mannville of a similar coal stratigraphy southwest of Edmonton (7-13-45-1W5M) from Dawson et al., 2000.

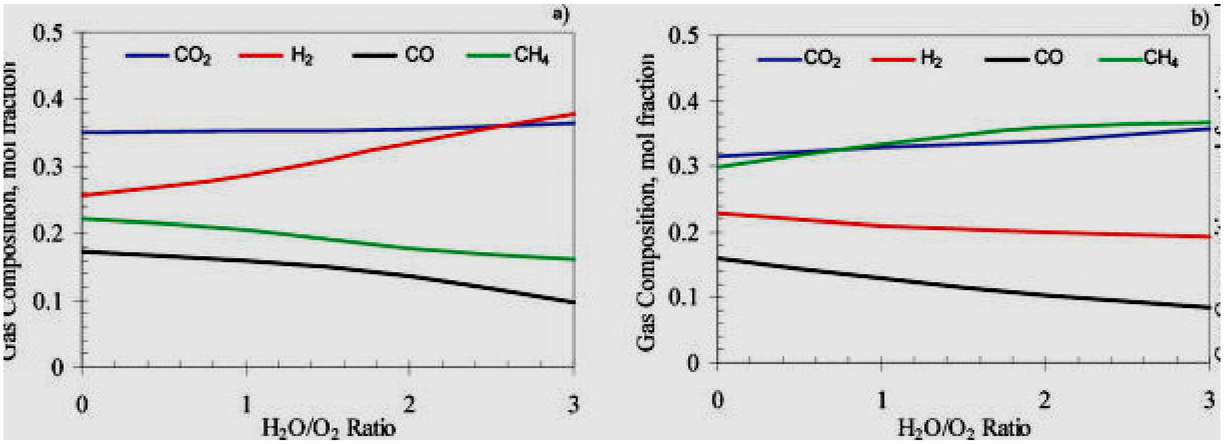

Figure 9: Effect of the water/oxygen ratio on the gas composition: (a) 1 MPa and (b) 11.5 MPa. (Nourozieh et al., in press).

ENVIRONMENTAL CONSIDERATIONS FOR IN-SITU GASIFICATION AND THEIR RELATIONSHIP TO ALBERTA'S GEOLOGICAL CONDITIONS

The three major environment issues are 1) groundwater contamination, 2) surface subsidence, and 3) CO^2 emissions. In addition there are public concerns about explosions underground fires and possible gaseous emissions (Shackley et al, 2004). All issues can be addressed through regulatory control and oversight and are for the most part little different from issues around the conventional hydrocarbon industry.

Alberta has a mature hydrocarbon and mining industry with strong regulatory oversight. In addition the geology of the Alberta Basin is well known and publically available databases are very good by world standards while the geology is favorable:

Groundwater contamination:

Groundwater contamination for shallow in-situ gasification can be controlled through maintaining reaction chamber pressures slightly below isostatic pressure. Geological knowledge of local stratigraphy and hydro geology information can also help in prediction of areas where special care must be taken. In particular areas that have been glaciotectonically disturbed. Alberta has good information on surficial geology (many parts of the world that haven't been glaciated and this is less of an issue) and shallow hydrogeology in many areas.

Much of Alberta's coal is at great depth and the associated aquifers are saline. In most areas there are thick capping rocks. Groundwater contamination of shallow aquifers is very unlikely.

Surface subsidence:

With shallow in-situ gasification surface subsidence is controlled through leaving supporting pillars of coal; similar to conventional underground mining. Understanding

the local bedrock and surficial geology is necessary to decide on pillar width at particular depths.

With great depth surface subsidence is less of a concern as cavities will not propagate to the surface. However geological knowledge of the stratigraphy is still important.

CO^2 emissions:

In-situ gasification produces substantial amounts of CO and CO^2 that can be somewhat reduced in surface facilities but substantial amounts of CO^2 remain and need to be captured and stored.

With shallow in-situ gasification the remaining coal, chars and cavity space are at too low a pressure to store CO^2 and cap rock would be limited. Captured CO^2 would need to be stored in deeper coals, saline aquifers or depleted or depleting oil and gas reservoirs after compression of the CO^2.

Deep in-situ sites the gas is already at high pressure offering better options for processing, storage or pipeline transport. The CO^2 may be stored in the same seams that were gasified and/or in adjacent seams using much of the gasification infrastructure. Other options are saline aquifers or depleted or depleting oil and gas reservoirs. In general the environmental issues around in-situ gasification of deep coals will be less than those of shallow projects.

Alberta's unique geology offers an unusually large number of very large storage options. In addition the provinces' energy activity in particular the oil sands developments and government support for CCS will provide opportunity for CCS that other jurisdiction looking at in-situ gasification will lack.

SYNOPSIS OF COAL RESERVES AND RESOURCES OF THE UNITED STATES

The United States has the world's largest recognized coal reserves (238 Gt) and has also been a world leader in resources and reserve estimation system development with many countries copying the McKelvey type reserves system (Falkie, and McKelvey, 1976) that was the basis for many jurisdictions coal evaluation systems. The current USGS approach is aimed at identifying "**available coal**" and "**economically recoverable coal resources**" which is essentially a reserve but one that has many limiting criteria attached. The evaluation of US coals under the new criteria is underway but new estimates of US coal reserves will be much smaller than those identified in past studies (Fig. 10) with some coal fields having between 4% and 22% of original coal remaining for economic recovery (Luppens et al., 2009). How this will impact on the current WEC reserve numbers is uncertain but a much lower estimate is likely.

Looking at the original coal resources in place in 1999, the USGS/EIA estimated the total conterminous U.S. United States coal resource to be 3.97 trillion short tons (National Coal Council, 2010 and Averitt, 1975). In 2002 a report *The US Geological Survey's national* *coal resource assessment: the results* (Ruppert et al., 2002) determined through a GIS-based USGS coal resource assessments of 27 top producing coal beds, coal zones, and coal basins an estimated 1,600,000 mst (million short tons) or roughly 1450 Gt of coal resources remained. This is a substantially smaller estimate than that of Averitt (1975). This estimate does not include coals in Alaska and number of basins in the US that were not included. The hypothetical coal resources of Alaska are estimated (Flores et al., 2003) to be as much as 5,500 billion short tons (4,990 billion metric tons or 4990 Gt). However most of the resource is hypothetical (undiscovered) with minimal drilling information compared to that available in Alberta.

The US coal resources for in-situ gasification is likely very large and remaining "**economically recoverable coal resources**" are still very significant and the US is likely to hold its first place rank for coal reserves at least in the short term.

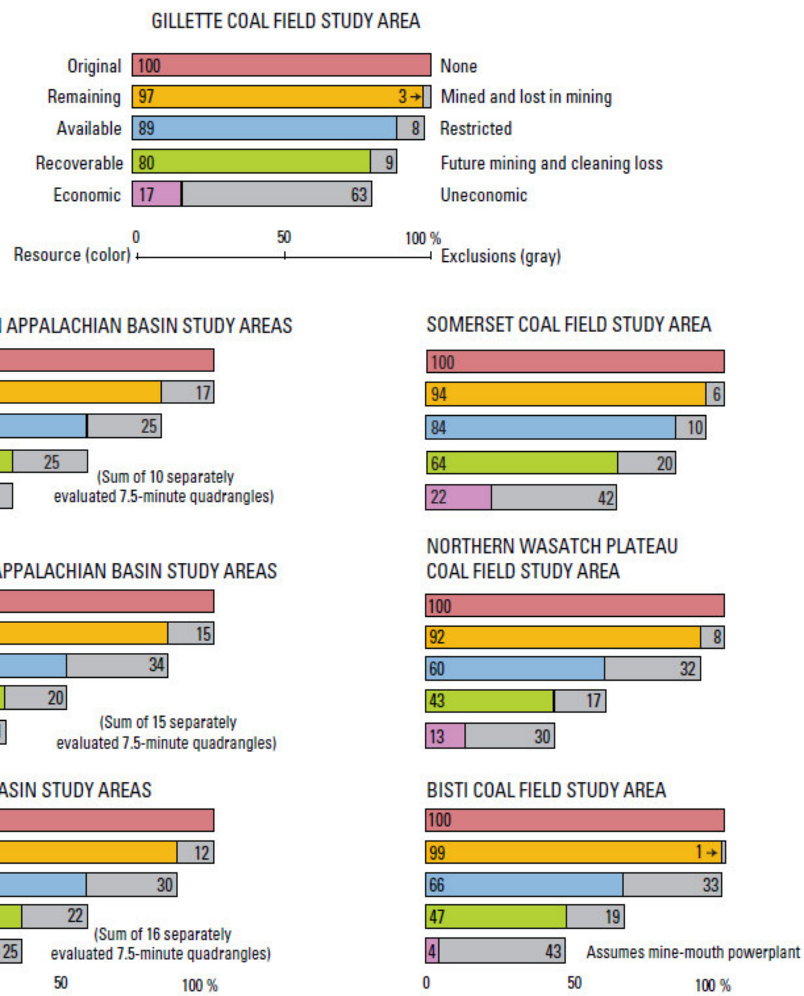

Figure 10: Coal availability/recoverability summary of coal basins resource evaluations from USGS Professional Papers 1625 A, B, C, and D. (Luppens et al., 2009).

SYNOPSIS OF COAL RESERVES AND RESOURCES OF INDIA

The Permian age Gondwana coal fields (Fig. 11).in India are located in basins that formed in linear areas of weakness (rift basins) as a result of the break-up of Gondwanaland. The bulk of India's coal is from the Gondwana basins coal and has been mined in for more than 230 years. There are also some younger Tertiary aged lignites although reserves and resources are estimated separately at around 36 GT of resources with only 323 Mt in 0-300 m proved category (Table 4), most of which occur in Tamil Nadu. Other states with lignite deposits are Gujarat, Jammu and Kashmir, Rajasthan, Kerala, and the union territory of Pondicherry.

The Gondwana basins have very thick coal seams although much of it is of high ash and low quality. The geology of the basins can be complex geologically with faulting, rapid changes in seam geometry and orientation and in places igneous intrusions making mining challenging. The basins are restricted in size which also presents problems in mining. The coal basins are not extensive in area "out of this total potential coal bearing area of 22400 sq km, only about 10200 sq km or 45% has been systematically explored through regional/promotional drilling. In the remaining 12200 sq km area that is still to be systematically explored, prognosticated resources of 143 billion tonnes have been estimated by GSI and CMPDI" (Source; Ministry of Coal, Government of India, 2005)**.** The Geological survey of India (GSI), Central Mine Planning and Design Institute (CMPDI) and Mineral Exploration Corporation Limited (MECL) have been pursuing coal exploration and have increased m in 2009 the Geological Resources of Coal to a depth of 1200 m to 267 GT (Table 5) there isn't a breakout of depth in the table but information from 2007 (Table 4) indicates in the depth range of 0-300 m there are estimated to be somewhere in the order of 76 Gt of coal in the **proved** category.

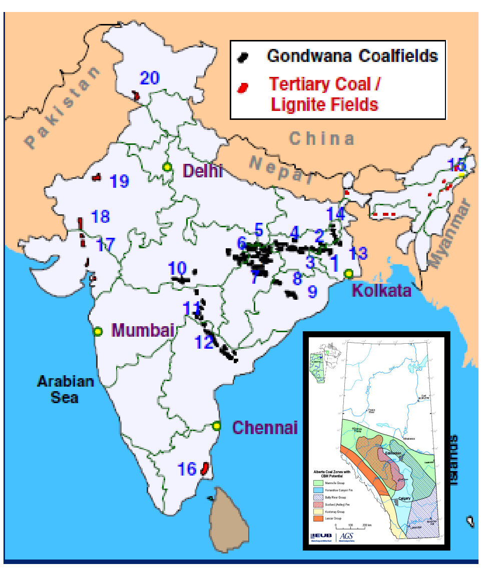

Figure 11: Major coal fields and basins in India (Verma, 2006) and inset map (see also Fig. 12) at the same scale showing the areal extent of the major coal zones in the Alberta Basin.

Table 4: Coal resource data broken out on the basis of depth. In the depth range of 0-300 m there are estimated to be somewhere in the order of 76 Gt of coal in the proved category (India Geological Survey, 2007).

RESOURCE OF DIFFERENT TYPES OF INDIAN COAL

(As on 01-04-2007)

(Figures in million tonne)

Depth range	Proved	Indicated	Inferred	Total
GONDWANA COAL				
Coking				
0-300	6705.26	4246.77	66.77	11018.80
0-600*	8103.59	6.83	0.00	8110.42
300-600	980.32	4630.52	819.21	6430.05
600-1200	1159.96	4419.22	1215.93	6795.11
0-1200	***16949.13***	***13303.34***	***2101.91***	***32354.38***
Non-Coking				
0-300	69686.56	61216.91	13870.59	144774.06
0-600*	5606.74	495.26	0.00	6102.00
300-600	5841.66	37968.70	17211.00	61021.36
600-1200	509.22	7086.79	4591.50	12187.51
0-1200	***81644.18***	***106767.66***	***35673.09***	***224084.93***
TERTIARY (High Sulphur) COAL				
0-300	323.49	96.54	367.58	787.61
300-600	143.59	9.85	1.19	154.63
0-600	***467.08***	***106.39***	***368.77***	***942.24***

Table 5: As a result of exploration carried out up to the depth of 1200m by the GSI, CMPDI and MECL etc, a cumulative total of 267.21 Billion tonnes of Geological Resources of Coal have so far been estimated in the country as on 1.4.2009 (Ministry of Coal, 2010).

Type of Coal	Proved	Indicated	Inferred	Total
(A) Coking :-	(in Million Tonnes)			
-Prime Coking	4614	699	0	5313
-Medium Coking	12449	12064	1880	26393
-Semi-Coking	482	1003	222	1707
Sub-Total Coking	**17545**	**13766**	**2102**	**33413**
(B) Non-Coking:-	87798	109614	35312	232724
(C) Tertiary Coal	477	90	506	1073
Grand Total	**105820**	**123470**	**37920**	**267210**

"CMPDIL (Central Mine Planning and Design Institute Ltd) has reported that the total extractable reserves for India as in the year 2005 — out of the total geological resource base of about 250 Gt *(units changed from BT in original text)* — stands at 52 Gt (Table 6). In other words, only about 21% of the total geological resources of 250 Gt may be extractable. Interestingly, GSI/CMPDIL while reporting the inventory of coal resources do not take into consideration the depletion due to more than the past 200 years of mining in India, the coal that has been sterilized due to various reasons like fire, inundation, etc., or the reserves, which have already been projectised (and are no more available for constructing a new mine thereon). The locked coal in partially developed/abandoned mines, mine barriers, under rivers and other water bodies, below towns, roads, railways, reserve forests, etc., also remain included in the reported figure of resources" (Chand and Sarkar, 2006). A more recent estimate of about 44 Gt (Chikkatur et al., 2009) of is even lower. In Alberta for roughly the same depth and certainty criteria there is ~33 Gt of reserves.

Table 6: Indian extractable reserves (source Ministry of Coal Government of India, 2005).

Tentative Extractable Reserves of the National Coal Inventory

Area	Geological Reserves				Extractable Reserves
	Proved	Indicated	Inferred	Total	
CIL Blocks	67.71	19.42	4.56	91.69	30.03
Rest	25.25	97.66	33.24	156.15	22.21
Total	92.96	117.08	37.80	247.84	52.24

The total of **resources** 0-1200 m in depth in India is stated as 267 Gt. (Table 5) while in Alberta the estimate for coal **resource in place** of ~2000 Gt is more than 7 times as much as in India although the Alberta estimate includes deeper coals. In terms of reserves in the range of 0-300 m India has ~ 44-52 Gt and Alberta ~33 Gt or roughly 60% of India's shallow minable coal reserves.

India does have substantial high ash, low quality coal at depths beyond surface mining >300 m the there are no environment constraints the coal could be in-situ gasified. The small footprint, increased safety and potential for a pipeline ready product would present many advantages and help meet India's future energy needs. However Carbon Capture and Storage (CCS) will be a major issue that will need to be addressed.

COAL RESERVES AND RESOURCES OF ALBERTA

Geological Overview

Alberta is sited on a large foreland basin in which coal-bearing formations underlie some 303 000 km^2, or approximately 46 per cent of Province's area of 661 848 km^2 (Fig. 12).

Coal seams can be traced in the subsurface over 10's of kilometers and coal zones over 100's of kilometers.

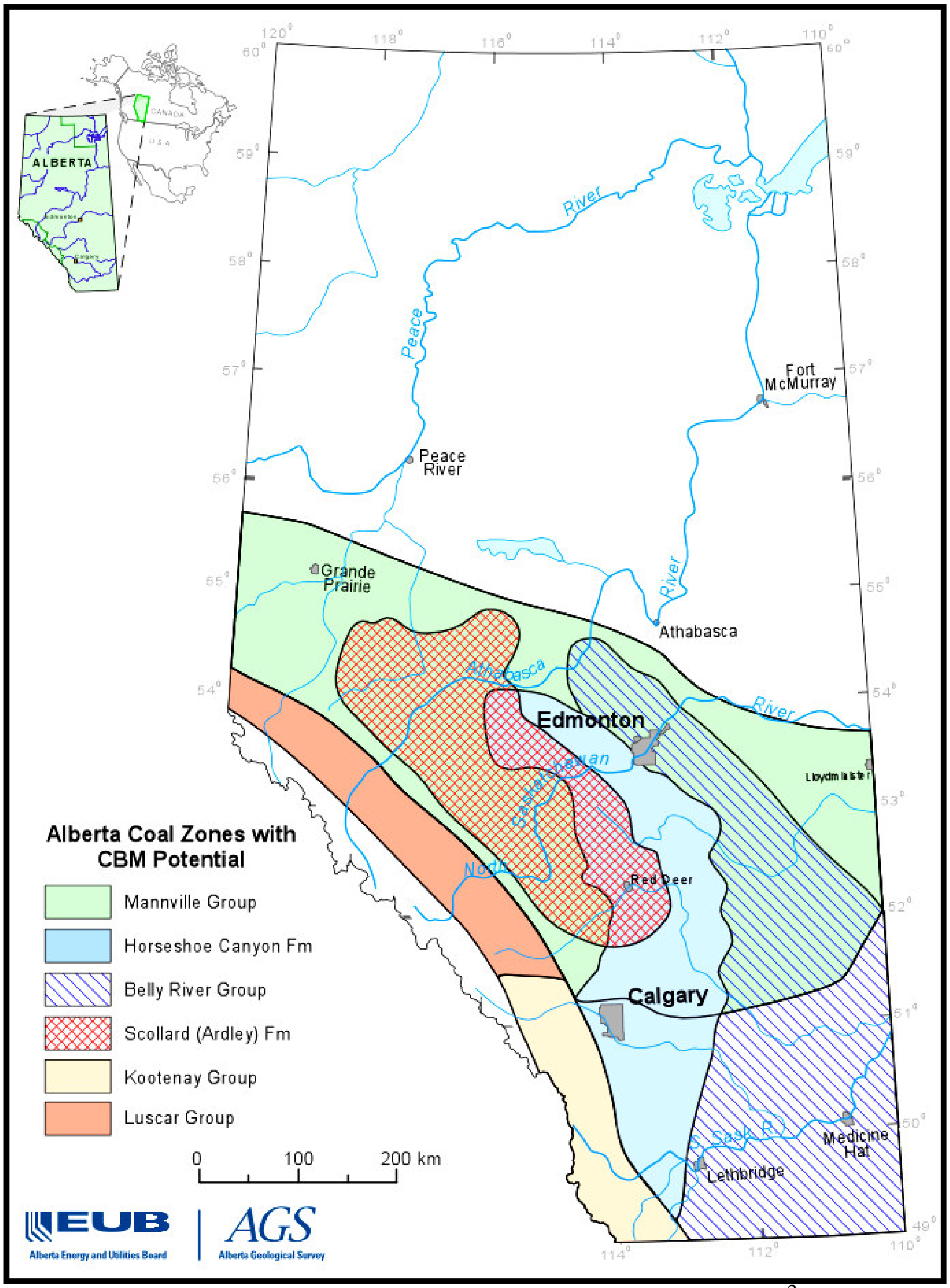

Figure 12: Coal-bearing formations underlie some 303 000 km^2, or approximately 46 per cent of Alberta's area of 661 848 km^2.

The coal-bearing strata of Alberta were deposited in a sedimentary basin along the eastern edge of the evolving Rocky Mountains. They form part of a clastic wedge ranging in age from late Jurassic to mid-Tertiary. In the plains the coal-bearing strata are gently dipping, whereas in the mountains and foothills these strata have been deformed and are dipping at varying angles. The oldest coal-bearing rocks belong to the Jurassic-Cretaceous Kootenay Group of the mountains and foothills; the youngest are in Tertiary strata of the Paskapoo Formation in the plains.

Coal deposits can be found in a wide variety of geological settings, but in the Alberta basin most coals are associated with alluvial plain and coastal plain settings. The alluvial plain environment is characterized by widespread mires and very low gradients. Coal zones in this setting include the Ardley zone in the Scollard Formation, the Coalspur in the Saunders Group, the Carbon-Thompson in the uppermost Horseshoe Canyon Formation, the Kakwa, Cutbank and Red Willow Coal Measures of the Wapiti Group, and the Obed coal zone in the uppermost Paskapoo Formation. For the Carbon-Thompson and portions of the Ardley coal zones, these coals are commonly associated with lacustrine deposits.

Coal zones associated with coastal plain settings include the Upper Mannville coals, Cadomin-Luscar coals (Jewel Seam), Lower Horseshoe Canyon Formation coals (Drumheller coal zone), Belly River Formation coals (Lethbridge, Taber and McKay coal zones) and the St. Mary River Formation coals (Richardson, 2006).

The major coal zones of the plains area are the Ardley coal zone, Drumheller coal zone and Mannville and equivalent coal zone each of which will be discussed in more detail (Fig. 13).

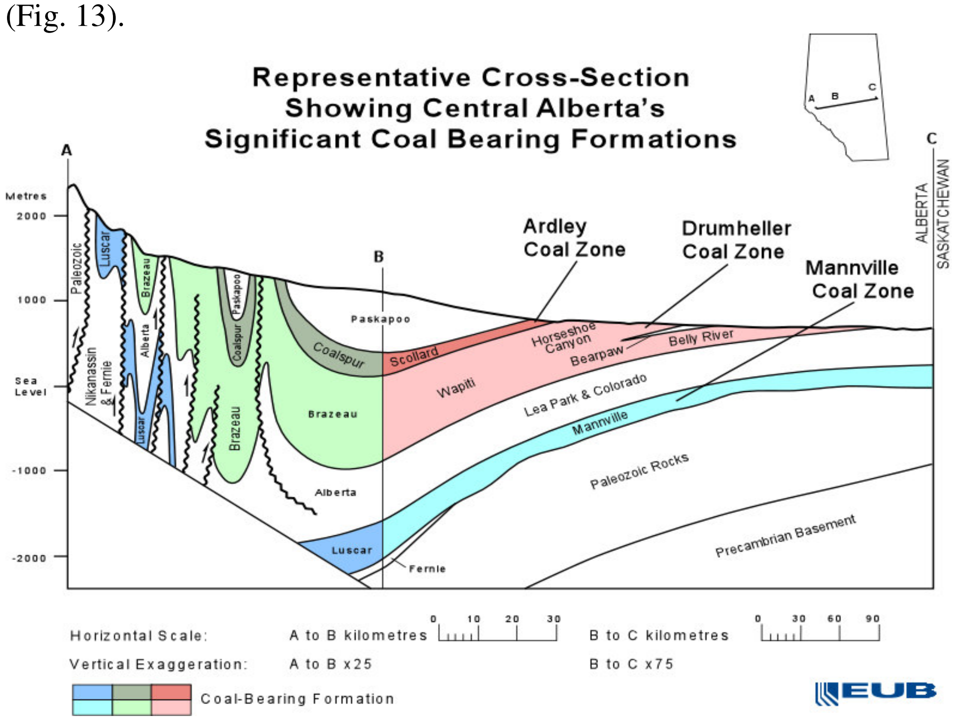

Figure 13: Major Coal Zones of Alberta.

Geological Database

A large publically available geological database exits in Alberta primarily because of extensive oil and gas exploration. Over 350 000 oil and gas boreholes have been drilled to date and which grows by 15-20 thousand boreholes a year (Fig.14). Since 1997 the number of boreholes has doubled in number. The coals below casing are recorded on the geophysical logs of many of those boreholes. In the last decade some of the boreholes have been drilled for Coal Bed Methane (CBM) exploration and development. The ERCB's report *ST109: Alberta Coalbed Methane Well Locations as of March 5, 2010* lists 17 336 CBM well locations. Most of the CBM wells are vertical with some horizontal and a number multi laterals having more than 5000 m of reservoir contact (Fig. 15). In addition to the oil, gas and CBM boreholes there are about 68 000 boreholes specifically drilled for coal that are close to outcrop where oil and gas boreholes are cased and the coals hidden.

In the mid 1980's the Alberta Geological Survey used the oil and gas borehole geophysical logs to map and quantify the coal in the Ardley, Drumheller and Belly River coal zones of the Alberta Plains and the boreholes locations can be seen in Figure 16. Although in the mid 1980's there were fewer (about 1/3 of today) oil and gas boreholes available, a good first estimate of coal resources could be made (Strobl et al., 1987).

Using oil and gas boreholes the deep Mannville coal resources were studied by Yurko (1975), Williams and Murphy (1981) and Langenberg et al. (1997).

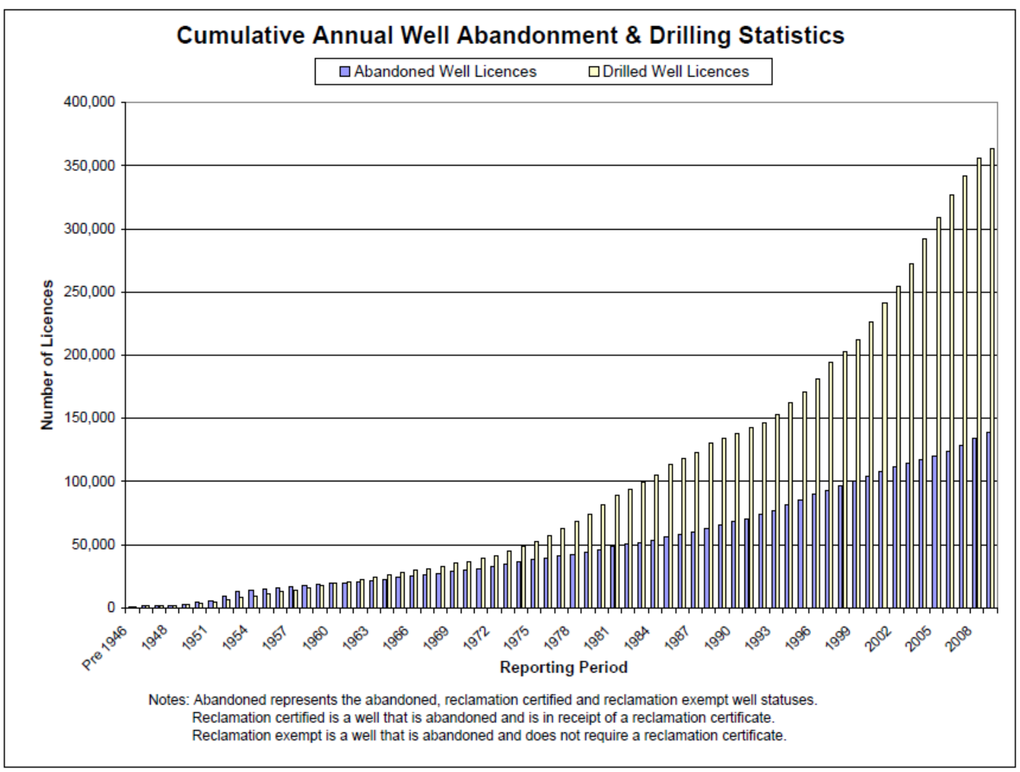

Figure 14: Cumulative oil and gas boreholes in Alberta (ERCB, 2010).

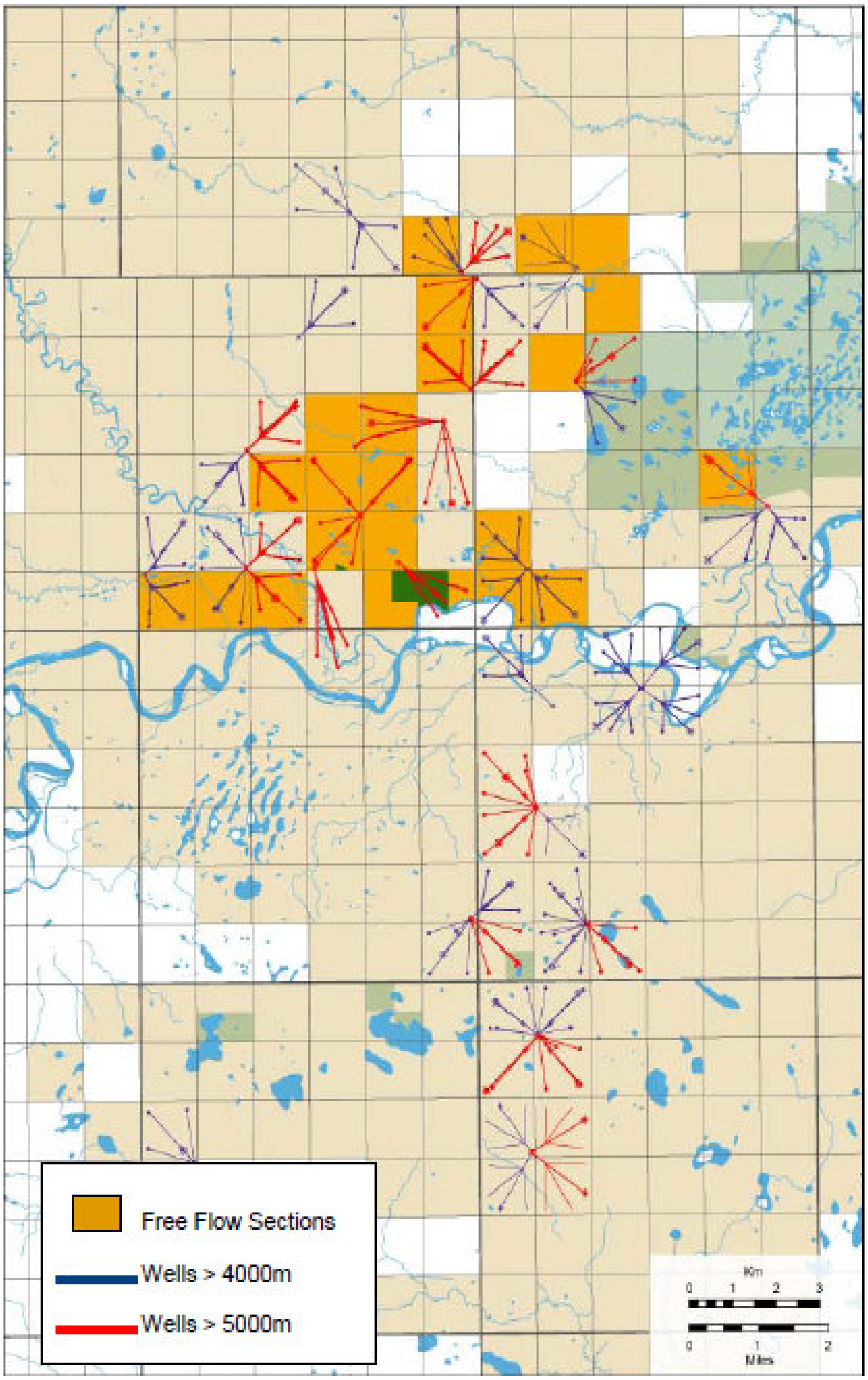

Figure 15: Multilateral - Maximum Reservoir Contact (MRC) CBM wells in the Mannville coal zone (Finn et al., 2009).

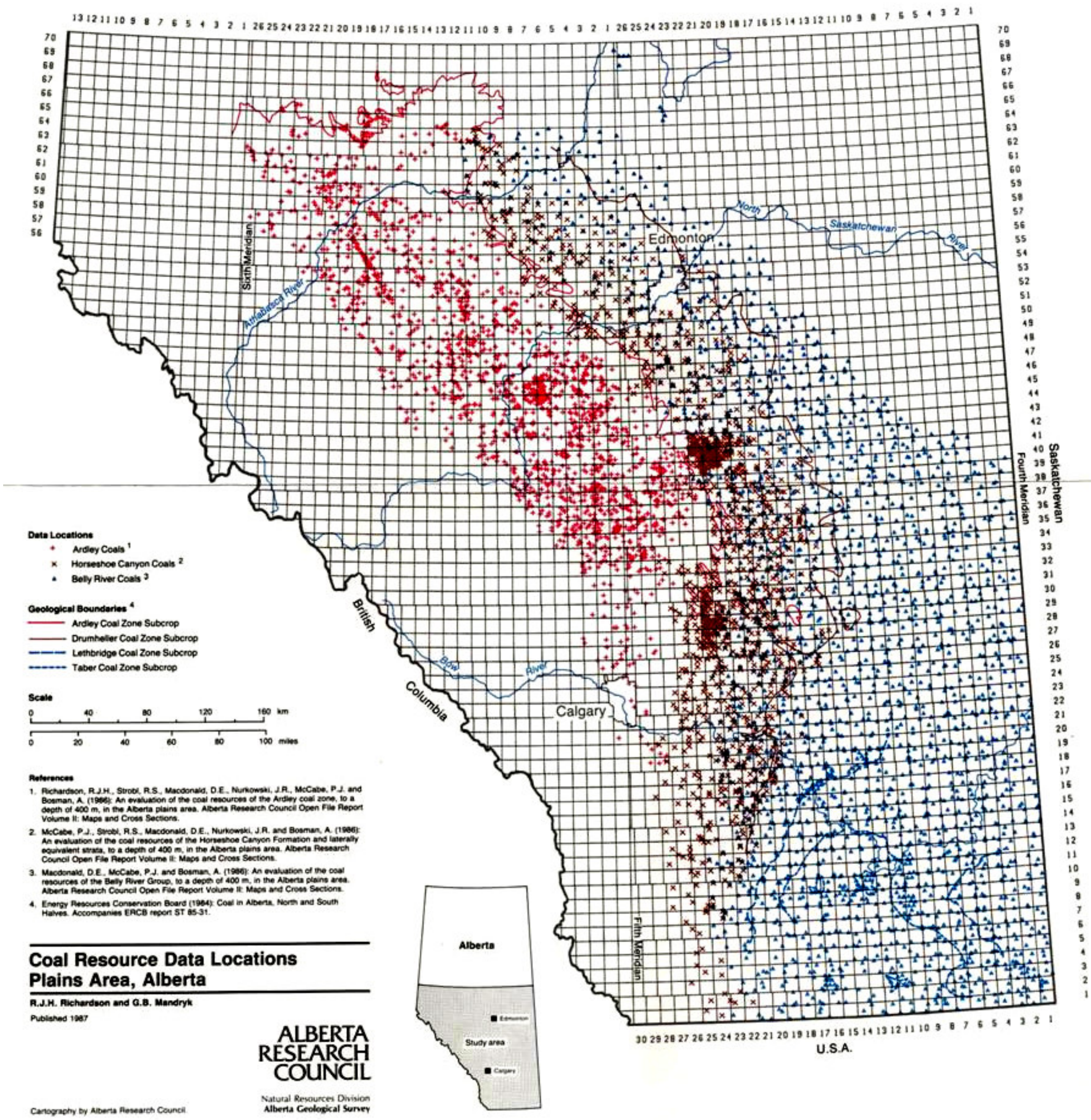

Figure 16: Oil and Gas boreholes locations used in study of deep Ardley, Drumheller and Belly River coal zones of the Alberta Plains (Richardson and Mandryk, 1987).

Resource estimation, depth and quality by coal zone

Ardley coal zone

The Ardley coal zone underlies 59 000 km^2 of Alberta (Beaton et. al., 2002) and is characterized by laterally continuous and thick coal seams (Richardson et al., 1988). The coal zone dips southwestward from outcrop to about 1000 m at the edge of the disturbed (thrust and fold belt) part of the basin. Seams vary in thickness up to 10 m and the coal zone contains up to 30 seams. In general there are more seams and thicker seams towards the axis of the basin in the west reflecting increased accommodation there during the period peat swamp formation. Total cumulative thickness reaches 20m (Fig. 17) while the coal zone (coals and other sediments) increases from a few metres at the outcrop to more than 250 meters in the west. The coal rank ranges from subbituminous C near the outcrop to high-volatile bituminous B at depth.

The total coal resource for the Ardley coal zone has been estimated at 596 Gt (Table X). There are about 100 Gt of thick (>2.5 m) coal between 400 and 800 m that would be a good target for in-situ gasification (Fig. 18).

Table 7: Summary of area and tonnage of the Ardley and Drumheller coal zones.

Coal Zones	Area (Km^2)	Coal Tonnage (Gt)	Reference
Plains Area			
Ardley	59 000	596	Beaton et al., 2002
Drumheller	128 000	564	Beaton et al., 2002

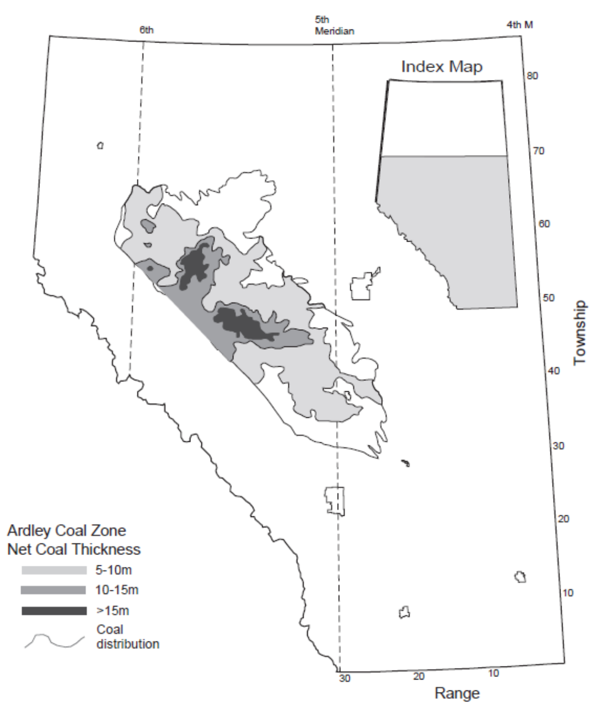

Figure 17: Ardley coal zone thickness map (Beaton et al., 2006).

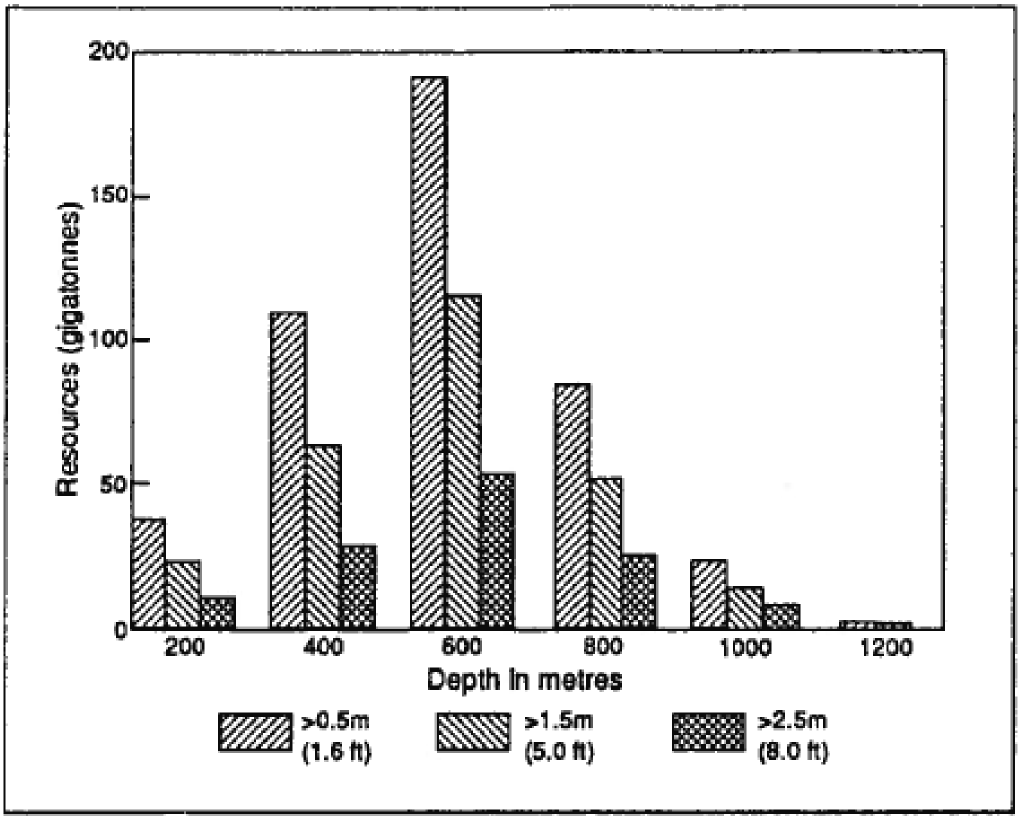

Figure 18: Coal resources at various depths and seem thickness in the Ardley coal zone (Richardson, 1991).

Drumheller coal zone

The Drumheller coal zone underlies 128 000 km^2 of Alberta (Beaton et. al., 2002) and is characterized by linear parallel pods of coal that can thicken and thin over relatively short distances. "Peat accumulation occurred in conjunction with intermittent regressive-transgressive pulses of the Bearpaw Sea, where water-table levels allowed peat accumulation for short periods in north-trending, shoreline-parallel mires, commonly 30–50 km inland from the shoreline. Thick net coal accumulations are present in the Drumheller Coal Zone, with local accumulations up to 18 m (Fig 19), but the coals are discontinuous. A north-trending zone of thick net coal, which averages 8 m, occurs in the southern region of the Drumheller Coal Zone. Individual seams average 1 to 2 m thick, although seams may be up to 5 m thick in areas of greatest net coal" (Beaton, 2003; McCabe et al., 1989; Rottenfusser et al., 1991). The coal rank ranges from subbituminous B at shallow depths with the majority of coals having a rank of high volatile C bituminous in the central Plains region while coal rank increases both westward and northward, where a rank of high volatile B bituminous is attained (Beaton et al., 2006),

The total coal resource for the Drumheller coal zone has been estimated at 564 Gt (Table 7).

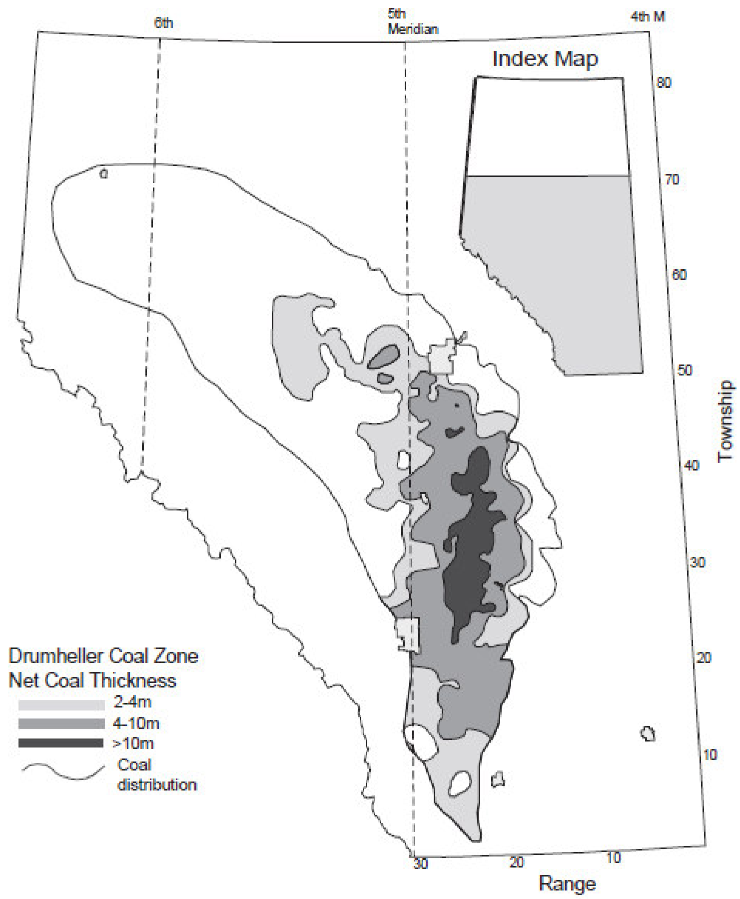

Figure 19: Drumheller coal zone thickness map (Beaton et al., 2006).

Mannville and Equivalent coal zones

The deep Mannville and equivalent coal zones underlie most (253 000 km^2; Beaton et al., 2006) of southern Alberta (Fig.20) and extend past the British Columbia border in the west and the Saskatchewan border in the east. Depth to the top of the Upper Mannville Coal Zone varies from 264 m the northeast to 3590 m in the southwest at the Rocky Mountain deformation front reflecting basin structure. The coals are thick and seams are laterally continuous similar to those of the Ardley coal zone. Total Cumulative coal ranges from 0.2 to 16.5 m with individual seams up to 12.2 m thick (Langenberg et al., 1997). Coal Rank varies from lignite in the northeast and east and with increasing at depth in the west and southwest along the deformed belt to medium-volatile bituminous to low-volatile bituminous rank (including some semi-anthracite). About half the Mannville coal resources is low-volatile bituminous and the other half is high-volatile bituminous coal (Langenberg et al., 1997).

Some early estimates of Mannville coal resources >2 feet in thickness (Williams and Murphy, 1981) were largely responsible for the large coal resources estimates for Canada of > 7000 Gt (Table 1). An earlier estimate by Yurko (1975) is 628,000 million tons or about 570 Gt. In a more recent study by Langenberg et al. (1997) using more data points but only considering seams more than 4 m thick (because of a CBM focus) produced a minimum resource estimate of 500 Gt.

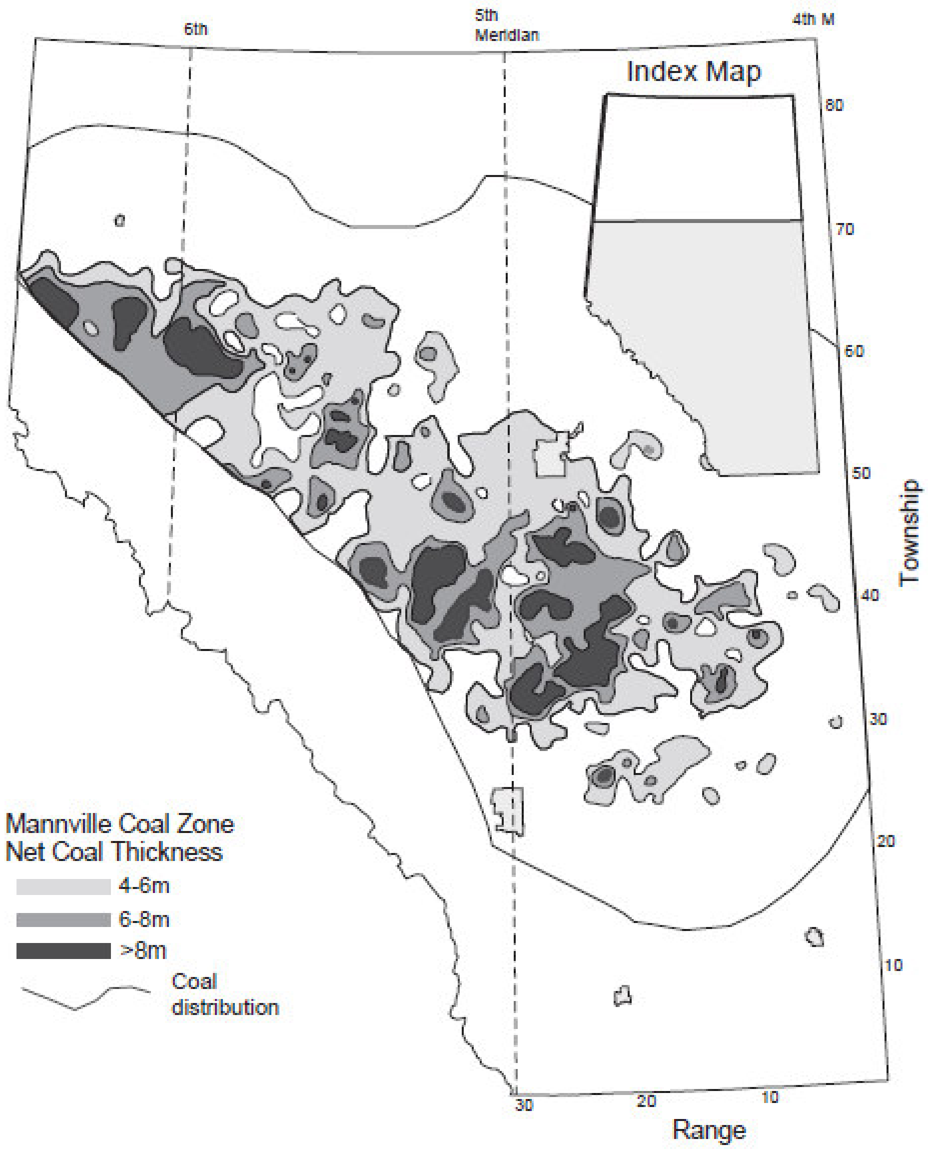

Figure 20: Mannville coal zone thickness map (Beaton et al., 2006).

Alberta Coal Reserve and Resource Estimates Summary

The ERCB and AGS approach coal resource estimation differently which makes direct comparison impossible. However there is good justification for the different approaches.

The AGS does not estimate coal reserves are essentially focuses on Ultimate in-place resources (whether considered recoverable or not recoverable) from a coal zone perspective. The reason for this approach is it is easier to work geological models, sedimentology, stratigraphy, when looking at packages of coal. In this approach a coal zone will included a range of coal ranks. The approach works well for initial resource exploration and development but is of more limited use in mine production. The approach has recently been useful in helping to establish Alberta's CBM industry and will be useful in development of an in-situ coal gasification industry.

The ERCB approach on resource and reserve estimation is based on its regulatory function. It has primarily been based on coal rank and mining method classification of coals (Table X) regardless of coal zone (although the ERCB has this data as well). The data is now also used for CBM reserves and resources estimation ERCB using three-dimensional block models and a number of other data related to gas estimation.

The ERCB has a far greater focus on data within the coal fields/deposits and minable areas than does the AGS. That high level of data allows for reserve estimation. In addition more intensive geological and mining models are used while the regional approach of the AGS provides context.

Table 8 provides the established initial in-place resources and remaining reserves of raw coal in Alberta. The key remaining reserve figure is 33.4 Gt. which should be recognized in the WEC coal reserve figure for Canada.

Table 8: Established initial in-place resources and remaining reserves of raw coal in Alberta as of December 31, 2008[a] (Gt) (ERCB, ST98-2009).

Rank Classification	Initial in-place resources	Initial reserves	Cumulative production	Remaining reserves
Low- and medium-volatile bituminous[b]				
Surface	1.74	0.811	0.235	0.576
Underground	5.06	0.738	0.108	0.630
Subtotal	6.83[c]	1.56[c]	0.343[d]	1.217[c]
High-volatile bituminous				
Surface	2.56	1.89	0.166	1.724
Underground	3.30	0.962	0.047	0.915
Subtotal	5.90[c]	2.88[c]	0.213[d]	2.667[c]
Subbituminous[e]				
Surface	13.6	8.99	0.754	8.236
Underground	67.0	21.2	0.068	21.132
Subtotal	80.7[c]	30.3[c]	0.822	29.478[c]
Total[c]	93.7[c]	34.8[c]	1.379	33.421[c]

[a] Tonnages have been rounded to three significant figures.
[b] Includes minor amounts of semi-anthracite.
[c] Totals for resources and reserves are not arithmetic sums but are the result of separate determinations.
[d] Difference due to rounding.
[e] Includes minor lignite.

Table 9 shows the Ultimate in-place resources (whether considered recoverable or not recoverable) and ultimate potentials (may be recoverable by surface or subsurface methods). The key figures are the totals of 2000 Gt and 620 Gt. It should be noted that this is estimated for mining and not in-situ gasification although the numbers might provide some general guidance for in-situ gasification.

Table 9: Ultimate in-place resources and ultimate potentials[a] (Gt) (ERCB, ST98-2009).

Coal rank Classification	Ultimate in-place	Ultimate potential
Low- and medium-volatile bituminous		
Surface	2.7	1.2
Underground	18	2.0
Subtotal	21	3.2
High-volatile bituminous		
Surface	10	7.5
Underground	490	150
Subtotal	500	160
Subbituminous		
Surface	14	9.3
Underground	1 400	460
Subtotal	1 500	470
Total	2 000[b]	620

[a]Tonnages have been rounded to two significant figures, and totals are not arithmetic sums but are the result of separate determinations.

[b]Work done by the Alberta Geological Survey suggests that the value is likely significantly larger.

The AGS has stated that there is more at 2500 Gt of coal in Alberta (Beaton et al., 2006) The estimate if from a number of studies that although similar criteria was used in the estimation the approach varied over time and thus the estimates are not directly comparable. However the numbers are very large and the over or under estimation in any study will not be significant. The present paper has looked at the three major coal zone of the plains are of Alberta but has not included the Foothills and Mountain coal zones or minor coal zones of the plains area. Some estimate of the coal resources of the five major

Foothill and Mountain coal zones (Coalspur, Brazeau, Gates, Gething and Kootenay) can be deduced for a CBM focused study by Langenberg et al. (2001). However the geology is more complex than in the plains area and drilling data is sparse making resource estimation even more challenging.

Table 10 provides a compilation from published AGS studies on the majority of Plains area coal zones in Alberta. The total coal resource (Ultimate in-place resources) in the Alberta plains is > 3000 Gt.

Table 10: Area and coal resources (Ultimate in-place resources) of the major coal zones in the Alberta plains area from AGS studies.

Coal Zones	Area (Km^2)	Coal Tonnage (Gt)	Reference
Plains Area			
Ardley	59 000	596	Beaton et al., 2002
Carbon-Thompson	76 000	183	Beaton et al., 2002
Daly-Weaver	76 000	178	Beaton et al., 2002
Drumheller	128 000	564	Beaton et al., 2002
Lethbridge	170 000	277	Beaton et al., 2002
Taber	190 000	335	Beaton et al., 2002
MacKay	212 000	403	Beaton et al., 2002
Mannville	253 000	>500	Langenberg et al., 1997; Beaton et al., 2002
Gething	4 650	13	Langenberg et al., 1997
Subtotal		***>3049***	

CONCLUSIONS AND RECOMMENDATIONS

- Alberta has very large coal resources and reserves that are not internationally recognized which hinders Alberta and Canada's position as a major coal nation.
- As a priority Alberta should promote the ERCB remaining reserve figure of 33.4 Gt through its membership (both the Alberta Department of Energy and the ERCB are members) on the Energy Council of Canada to the World Energy Council.
- Through industry and academic conferences promote the reserves and resources of the province stressing the geological data behind the estimates.
- Adopt and promote the ERCB published Ultimate in-place resources estimate of 2000 Gt as the official Alberta estimate noting it is likely to be revised upward in future.
- The ERCB and AGS should review their current reserve/resource estimate methodology and those of other countries such as the USA and also those of industry organizations and societies to insure they meet current government, scientific and industry needs.

- The ERCB and AGS should review what enhanced studies of reserve/resources are needed for in-situ coal gasification regardless of a potential change in estimation methodologies.
- Alberta is a major energy economy and is looking to expand in petrochemical and develop a hydrogen future. Alberta is an emerging “energyplexes”.
- Alberta should promote in-situ gasification as way of realizing its position as an energyplex for the following reasons:
    - Alberta strength is in abundant coal resources over vast areas of the province
    - Relatively simple and favourable geology
    - Large market for syngas in the oilsands and in energy and power industries
    - CCS expertise and geological capacity
    - Pipelines and infrastructure available

ACKNOWLEGEMENTS

The project was funded by **Alberta Innovates - Energy and Environment Solutions** and was managed by Surindar Singh (AI-EES). Brian Hudson (Alberta Energy), Curtis Evans and Andrew Beaton (Energy Resources Conservation Board) provided advice on this project and made technical and editing improvements to the final document and are thanked for their support and input.

REFERENCES

ASC, 2010, Canadian regulators seek comment on proposed changes to national mining rule, Apr 23 2010, http://www.albertasecurities.com/news/Lists/ASC%20News/DispForm.aspx?ID=783&RootFolder=%2Fnews%2FLists%2FASC%20News

Averitt, Paul, 1975, Coal resources of the United States, January 1, 1974: U.S. Geological Survey Bulletin 1412, 131 p.

Beaton, A., 2003. Production potential of coalbed methane resources in Alberta. EUB/AGS Earth Sciences Report 2003- 03. Alberta Energy and Utilities Board. 59 pp.

Beaton, A., Pana, C., Chen, D., Wynne, D., Langenberg, C.W., 2002. Coalbed methane potential of Upper Cretaceous- Tertiary strata, Alberta Plains. Alberta Energy and Utilities Board, EUB/AGS Earth Sciences Report 2002-06, 76 p.

Beaton Andrew, Langenberg Willem, Pana Cristina, 2006, Coalbed methane resources and reservoir characteristics from the Alberta Plains, Canada International Journal of Coal Geology 65 (2006) 93–113

Bhattacharyya, S.C., 2010, Shaping a sustainable energy future for India: Management challenges. Energy Policy (2010), doi:10.1016/j.enpol.2010.03.045

Bo-qiang Lin and Jiang-hua Liu, 2010, Estimating coal production peak and trends of coal imports in China Energy Policy 38 (2010) 512–519

BP Statistical Review of World Energy June 2009, http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2009_downloads/coal_table_of_proved_coal_reserves_2009.pdf

Chand S K & Sarkar S K, 2006, Demystifying coal security, The Economic Times, 14 April, 2006 http://www.teriin.org/upfiles/pub/articles/art131.pdf

Chikkatur Ananth, 2008. Presentation Coal Use in India and China: Supply, Demand, and Generation Platts Coal Marketing Days September 16, 2008 http://belfercenter.ksg.harvard.edu/publication/18629/coal_use_in_india_and_china.html

Chikkatur Ananth P., Sagar Ambuj D., Sankar T.L., 2009, Sustainable development of the Indian coal sector Energy 34 (2009) 942–953.

CIM DEFINITION STANDARDS - For Mineral Resources and Mineral Reserves Prepared by the *CIM Standing Committee on Reserve Definitions* Adopted by CIM Council on December 11, 2005 http://www.cim.org/committees/CIMDefStds_Dec11_05.pdf

Dawson, F.M., Marchioni, D.L., Anderson, T.C. and McDougall, W.J. (2000): An assessment of coalbed methane exploration projects in Canada; Geological Survey of Canada, Bulletin 549, 218p.

DG JRC Institute & Energy Edge Limited, 2007, COAL OF THE FUTURE (SUPPLY PROSPECTS FOR THERMAL COAL BY 2030-2050), Prepared for the European Commission –DG JRC Institute for Energy by Energy Edge Limited February 2007 EUR 22644 EN http://ie.jrc.ec.europa.eu/publications/scientific_publications/2007/EUR22644EN.pdf

DTI, 2004. *Review of the feasibility of underground coal gasification in the UK*, DTI Cleaner Fossil Fuels Programme, October 2004 (DTI/Pub URN 04/164c) http://webarchive.nationalarchives.gov.uk/tna/+/http://www.dti.gov.uk/files/file19145.pdf/

ERCB, 2000 ST-31: Reserves of Coal Province of Alberta at December 1999

ERCB ST98-2009: Alberta’s Reserves 2008 and Supply/Demand Outlook / Coal

ERCB, 2010, Webpage http://www.ercb.ca/docs/programs/Lmp/CumulativeAnnualAbandonmentReclaimedDrilledStatistics.pdf

Energy Watch Group, 2007**,** Coal: resources and future production, EWG-Paper No. 1/07, http://www.energywatchgroup.org/

Falkie, T.V., and McKelvey, V.E., 1976, Coal resource classification of the U.S. Bureau of Mines and U.S. Geological Survey: U.S. Geological Survey Bulletin 1450–B, 7 p

Fergusson Kenneth J. A , 2009 A cleaner, cheaper, indigenous fuel for combined cycle plants, Modern Power Systems August 2009
http://www.ucgp.com/images/uploadedFiles/Fergusson.pdf

Finn Mike, *, Seely Don, Martin James, 2009 Maximum Reservoir Contact (MRC) Wellsfor Coal Bed Methane Exploitation; Presentation CSUG Meeting Calgary Nov. 2009.

Flores Romeo M., Stricker Gary D., and Kinney Scott A., 2003) Alaska Coal Resources and Coalbed Methane Potential U.S. Geological Survey Bulletin 2198
http://pubs.usgs.gov/bul/b2198

GSA, 2009, U.S. Coal Peak Production: Point and counterpoint, 20 October 2009
GSA Release No. 09-58R **http://www.geosociety.org/news/pr/09-58r.htm**

Höök Mikael, 2008, Presentation, Coal future of China and the World Peak coal is coming!, http://www.tsl.uu.se/uhdsg/Personal/Mikael/ChinaCoalFuture.pdf

Höök Mikael, Zittel Werner, Schindler Jörg, Aleklett Kjell, 2008, A supply-driven forecast for the future global coal production, Contribution to ASPO
2008.

Höök, Mikael, 2009 Presentation Evangelische Akademie Tutzing, Bavaria, Germany 2009-11-16 Recoverable coal volumes-do supply assessments really provide a reasonable picture? http://www.tsl.uu.se/uhdsg/Personal/Mikael/Tutzing_20091116.pdf

Höök, M., Aleklett, K., 2009. *Historical trends in American coal production and a possible future outlook*, International Journal of Coal Geology, 78, 201-216
http://www.tsl.uu.se/uhdsg/Publications/US_Coal_NRR.pdf

Hubbert, M.K., 1956. Nuclear energy and the fossil fuels. In: Drilling and Production Practice first ed The American Petroleum Institute, New York, pp. 7–25.

Hughes, J D; Klatzel-Mudry, L; Nikols, D J. 1988, A standardized coal resource/reserve reporting system for Canada / Méthode d'évaluation normalisée des ressources et des réserves canadiennes de charbon; Geological Survey of Canada, Paper 88-21, 1989; 17 pages.

India Geological Survey, 2007, INVENTORY OF GEOLOGICAL RESOURCE OF INDIAN COAL **(As on 01.06.2007)** Coal Wing, Geological Survey of India, Kolkata http://www.gsi.gov.in/coal.htm

IEA, 2010, Resources to Reserves, (To be released Autumn 2010) http://www.iea.org/papers/2010/Flyer_RtoR2010.pdf

Langenberg, C.W., Rottenfusser, B. A. And Richardson R.J.H., 1997, Coal and Coalbed Methane In the Mannville Group and Its Equivalents, Alberta, Canadian Society of Petroleum Geologist, Memoir 18, 1975

Langenberg, C.W., Rottenfusser, B.A., Richardson, R.R., 1997. Coal and coalbed methane in the Mannville group and its equivalents, Alberta. In: Pemberton, S.G., James, D.P. (Eds.), Petroleum Geology of the Cretaceous Mannville Group, Western Canada, Memoir, vol. 18. Canadian Society of Petroleum Geologists, pp. 475–486.

Langenberg, C.W., Beaton, A., Berhane, M., 2002. Evaluation of the coalbed methane potential of the foothills/mountains of Alberta. EUB/AGS Earth Sciences Report 2002-05. Alberta Energy and Utilities Board. 30 pp.

Luppens, J.A., Rohrbacher, T.J., Osmonson, L.M., and Carter, M.D., 2009, Coal resource availability, recoverability, and economic evaluations in the United States—A Summary, *in* Pierce, B.S., and Dennen, K.O., eds., The National Coal Resource Assessment Overview: U.S. Geological Survey Professional Paper 1625–F, Chapter D, 17 p.

McCabe, P.J., Strobl, R.S., Macdonald, D.E., Nurkowski, J.R. and Bosman, A. (1989): An evaluation of the coal resources of the Horseshoe Canyon Formation and laterally equivalent strata, to a depth of 400 m, in the Alberta Plains area; Alberta Research Council, Alberta Geological Survey, Open File Report 1989-07A, 75 p.

Ministry of Coal Government of India 2005, Report (Part-I) The Expert Committee On Road Map for Coal Sector Reforms, December 2005 http://coal.nic.in/expertreport.pdf

Ministry of Coal Government of India, 2010) Coal reserves, http://coal.nic.in/reserve2.htm

National Coal Council, 2010, ***Coal: Energy Security for Our Nation's Future*** http://www.nationalcoalcouncil.org/Documents/Coal_Energy_Security.pdf

NI 43-101CP COMPANION POLICY 43-101CP TO NATIONAL INSTRUMENT 43-101 STANDARDS OF DISCLOSURE FOR MINERAL PROJECTS http://www.albertasecurities.com/securitiesLaw/Regulatory%20Instruments/4/Standards%20of%20Disclosure%20for%20Mineral%20Projects/43-101CP.pdf

Nourozieh Hossein, Kariznovi Mohammad, Chen Zhangxin, Abedi Jalal, In Press,

Simulation Study of Underground Coal Gasification in Alberta Reservoirs: Geological Structure and Process Modeling ***Energy & Fuels*** **Article ASAP**
DOI:10.1021/ef9013828

Pana C., 2009, Review of Underground Coal Gasification with Reference to Alberta's Potential ERCB/AGS Open File Report 2009-10

Pierce, B.S., and Dennen, K.O., eds., 2009, The National Coal Resource Assessment Overview: U.S. Geological Survey
Professional Paper 1625–F, 402 p.

Richardson, R.J. H., 1991, coal resources and Coalbed Methane Potential of a Major Alberta Coal Zone, In Schwochow, S. D.; Murray, D. K.; Fahy, M. F., editors, Coalbed methane in western North America: Rocky Mountain Association of Geologists 255-263.

Richardson R.J. H. , 2006, Coal – Buried Sunshine in Alberta Beneath our Feet, Brian Hitchon editor p. 126-129

Richardson, R.J.H., Strobl, R.S., Macdonald, D.E., Nurkowski, J.R., McCabe, P.J., Bosman, A., 1988. An Evaluation of the Coal Resources of the Ardley Coal Zone, to a Depth of 400 m, in the Alberta Plains Area—Volume 1. Alberta Research Council, Alberta Geological Survey. Open File Report 1988-02. 96 pp.

Richardson R J. H., and Mandryk G.B., 1987 Coal Resource Data Location Plains Area, Alberta; Alberta Geological Survey Map 214.

Rottenfusser, B., Langenberg, W., Mandryk, G., Richardson, R., Fildes, B., Olic, J., Stewart, S., Eccles, R., Evans, C., Spelrem, M., Sprecher, B., Brulotte, M., Gentzis, T., Wynne, D., Yuan, L.P. 1991. Regional evaluation of the coal bed methane potential in the Plains and Foothills of Alberta, stratigraphy and rank study. Alberta Research Council, Alberta Geological Survey. Special Report 7. 95 pp.

Ruppert Leslie F., Kirschbaum Mark A., Warwick Peter D., Flores Romeo M., Affolter Ronald H., Hatch Joseph R., 2002, The US Geological Survey's national coal resource assessment: the results International Journal of Coal Geology 50 (2002) 247–274.

Rutledge David, 2007, with revisions in 2008, 2009 and 2010, Presentation, Hubbert's Peak, The Coal Question, and Climate Change
http://rutledge.caltech.edu/

Sarma, (2008) Presentation Development of CBM in India, Directorate General of Hydrocarbons India
http://www.cmmclearinghouse.cmpdi.co.in/Development%20of%20CBM%20in%20India_DGH.pdf

Shackley Simon, Reiche Alexander and Mander Sarah, 2004, The Public Perceptions of Underground Coal Gasification (UCG):A Pilot Study Tyndall Centre for Climate Change Research, Working Paper 57.

Smith,G.G., 1989 Coal resources of Canada, GSC Paper 89-4, 146 p.

SPE-PRMS, 2007, SPE/WPC/AAPG/SPEE Petroleum Resources Management System (PRMS)
http://www.spe.org/industry/reserves/docs/PRMS_Development_Process_Slides.pdf and www.spe.org/industry/reserves/docs/Petroleum_Resources_Management_System_2007.pdf

Stevens Mark G., 2004, Current Perspectives On Coal Reporting Guidelines, Pincock Perspectives ISSUE NO. 61 — December 2004
http://www.pincock.com/perspectives/Issue61-Coal-Reporting.pdf

Stoker Peter,2009,Progresson the revision of the Chinese Mineral Resources and Mineral Reserves Reporting Standard.
http://www.jorc.org/pdf/progress_revision_chinese_mineral1.pdf

Stone Kevin, 2008 Canadian Minerals Yearbook, 2008 Coal Section Minerals and Metals Sector, Natural Resources Canada http://www.nrcan-rncan.gc.ca/mms-smm/busi-indu/cmy-amc/2008revu/pdf/coa-cha-eng.pdf

Strobl, R.S., McCabe, P.J., MacDonald, D.E., Richardson, R.J.H, 1987Estimate of Inferred Resources of Coal in the Plains Region of Alberta to a Depth of 400 Metres Alberta Geological Survey, Open File Report 1987-05

USGS, 1975 COAL RESOURCE CLASSIFICATION SYSTEM OF THE U.S. BUREAU OF MINES AND U.S. GEOLOGICAL SURVEY GEOLOGICAL SURVEY BULLETIN 1450-B http://pubs.usgs.gov/bul/b1450b/b1450.htm

VERMA, ASHOK, 2005, *Experience & Opportunities For Methane Projects in India.* Presentation at 2nd Annual Methane to Markets Partnership Meeting, Palacio San Martin, Buenos Aires, Argentina, 2-4 November 2005.

Williams, G D; Murphy, M C, 1981, Deep Coal Resources of the Interior Plains, Estimated From Petroleum Borehole Data Geological Survey of Canada, Paper 81-13, 1981; 15 p.

World Energy Council, 2009, Survey of Energy Resources Interim Update 2009

Yurko J.R., 1975 Deep Cretaceous Coal Resources of the Alberta Plains Alberta Geological Survey Earth Sciences Report 1975-04