1. **Introduction**

Powering the future is the greatest environmental, economic and social challenge facing any nation. Australia has one of the world's largest per capita carbon footprints, with nearly 70 per cent due to energy emissions. Moreover Australia, with an annual production of 70 PJ, is the second largest coal bed methane (CBM) producing country in the world.

CBM refers to gas that is generated during coalification and stored within coal on internal surfaces. This gas can be generated by microbial processes but is mainly generated through thermal decomposition of coal. CBM production started initially to keep coal mining safe from explosions. A methane air mixture of 5-15% is explosive. The global energy decline, the abundance of this resource, together with the cleanliness of CBM as a burning fuel compared to the conventional fossil fuel and the reducing cost of producing the methane lead this resource to become an important contributor to addressing the world energy needs. CBM has thus attracted worldwide attention as a source of unconventional natural gas supply.

In Australia the reserves mainly occur in high volatile to medium volatile bituminous Permian coals of the Sydney and Bowen basins and subbituminous to high volatile bituminous Jurassic coals of the Surat Basin. Most of the production related to Jurassic coals is from the Walloon Coal Measures of the Surat Basin, and related to Permian coals is from the Fairview/Spring Gully, Peat/Scotia and Moranbah projects in the Bowen Basin and the Camden project in the Sydney Basin (Faiz, 2008).

CBM production in Australia is focussed in Queensland where the first CBM well was drilled near the Leichhardt Colliery in 1980 to drain methane from the seams before mining. There was limited success with this project, and interest in CBM waned until the late 1980s. Between 1990-1999 exploration for conventional petroleum in Queensland slowed in favour of exploring for viable CBM targets in the Bowen-Surat basins. During this period 170 CBM wells were drilled. CBM exploration focused on the laterally continuous, thick Permian coal seams of the Bowen Basin while also testing the Galilee, Ipswich, Surat and Clarence-Moreton basins. The first wells in the Dawson Valley at Moura were drilled in 1992. In 1994, Tri-star Petroleum drilled TPC Fairview 1 into the Bandanna Coal Measures over the Comet Ridge north of Roma, resulting in the discovery of a significant CBM resource. Other CBM fields discovered during this cycle were Spring Gully, Peat and Scotia. All of these fields target Permian-aged Bowen Basin coal measures (Troup and Green, 2011).

From 2000 until now there has been a switch from conventional to CBM exploration in the Bowen-Surat basins. On average, four CBM exploration wells were drilled for each conventional exploration well and exploration for conventional oil and gas resources was coming to an end in these areas until exploration for conventional fields in the Bowen-Surat basins has died off in 2009/2010 financial year as no wells were drilled since then. The focus of exploration in this area has shifted strongly towards CBM.

Following the recognition that the less thermally mature coals in the Powder River Basin in the USA were prospective for CBM the Jurassic Walloon Coal Measures were targeted for CBM exploration which has increased exponentially since 2004.

In this paper we highlight the factors controlling CBM production and focus on the opportunity and the challenges facing CBM production in Australia. We also present an overview of the papers in this special issue.
2. Some of the factors influencing the investment in CBM

In addition to a favourable government policy and gas market and the advancement in directional drilling technology, the following factors impact the CBM investment decision.

2.1 Gas content

Coal seams are characterized by dual porosity. They contain both micropores or primary porosity and macropores or secondary fracture porosity system. Macropores are the space within the cleat system and other natural fractures and are responsible for transport of water and methane through seams while micropores- whose volume does not exceed 10% of the coal bed volume- refer to the capillaries and cavities of molecular dimensions in the coal matrix that are essential for gas storage in the adsorbed state. It is estimated that 98% of the methane is typically adsorbed in the micropores and very little resides in the macropores (Gray, 1987). Their immense storage capability likened them to a sponge as it can store 6 times the volume of natural gas found in conventional reservoirs.

2.2 Permeability

Most gases and water in a coal seam move through the naturally occurring micro fractures, the cleats, which provide the permeability essential for bulk fluid flow in coal bed reservoirs. The spacing of the cleats can range from two millimetres to several centimetre, they act as a conduit to the production well. The bulk fluid flow is controlled by their orientation, spacing, compressibility and effective porosity. If the cleats are interconnected and continuously distributed throughout the reservoir, the effective permeability is high. Besides, the presence of larger scale discontinuities, such as fractures, joint and faults can also make a significant contribution in determining the permeability of a coal seam. The permeability of a coal bed ranges between 1 and 10md (Shi and Durucan, 2005 and White et al. 2005).

2.3 Depth and thickness of the coal seam

The cost of drilling and completion increases with the increase in the depth of the coal seams and the corresponding reduction in the natural fracture network and seam permeability restricting the basin consideration for economic production. In most of the productive basins, it is observed that the depth of the coal is less than 1200m. Few examples are: the Fruitland formation of the San Juan basin coal seams are at the depth interval of 762 to 1158m (Ayers and Zellers, 1989); The Powder River basin coal seams are at a depth less than 762m (Larsen, 1989); and the Black Warrior basin coal seams are at a depth of 457 to 915m. Thick coal seam at a reasonable depth (400-800m) is one of the favourable factors in the investment decision for profitable CBM production that can even compensate for thermal immaturity, as is the case in Powder River basin, where coal seams at a shallow depth- 762m or less- are thermally immature and the average gas content of the entire basin is low. Despite that the thick sub-bituminous seams (52 to 91m) hold an estimated 0.85Tm³ of gas which made the basin the second largest CBM producer in USA. Similarly in Australia, high gas content at a shallow depth (<800m) influenced the CBM activities in the South Bowen basin and Surat basin. The shallow depth of the Walloon Coal Measures has made the sequence a highly prospective target.

2.4 Proximity to infrastructure and coal mining history

Access to pipelines, log data from conventional wells and coal mining history is a positive indicator for selecting an economically productive basin. This is evidenced by the case of the Arkoma basin in USA which has produced conventional gas since 1910-1915 where a widespread infrastructure for gas production exists which provided a positive economic indicator for CBM production. The same applies to the Black Warrior basin of Alabama, USA, where coal mining in the previous 100 years provided a source of geologic and engineering data and proximity to gas pipelines and infrastructure in the basin gave
momentum to early development of the CBM industry in that basin (Halliburton, 2007). In Australia, the initial area of exploration interest in the Walloon Coal Measures was adjacent to the Roma-Brisbane pipeline which highlights the importance of proximity to infrastructure for new field developments.

2.5 Well spacing and drainage area

Well to well interference in CBM production is beneficial because of the mutual assistance in water removal and more rapid gas production. Due to the desired interference effect, well spacing, hydraulic fracturing length and permeability are important to know for field development. A five spot pilot project is a minimum requirement to evaluate ultimate field performance where the centre well will be most representative of field performance.

3. Opportunities for Australia

3.1 Providing energy source alternative

Due to the decline of the conventional gas reserves and the increase in the demand CBM is seen to provide Australia with an alternative local energy source. There has been very strong growth in the Australian CBM sector. Production in 1995 was zero and this had only increased to 20 PJ by 2003. In the following five years, a large expansion in CBM occurred. According to figures released by Geoscience Australia (http://www.ga.gov.au/image_cache/GA16805.pdf and http://www.australianminesatlas.gov.au/education/fact_sheets/coal_bed_methane.jsp), total Australian CBM production in 2008 rose to about 138.5 PJ, of which 133.2 PJ came from Queensland and 5.3 PJ from New South Wales. CBM provided about 60 per cent of the Queensland total. With rapid increases in the delineation of CBM reserves and resources, production is projected to increase substantially. In 2004 the total proved CBM reserves were estimated to be double that of the gas reserves (Miyazaki 2005). In that year 4% of the gas consumed was generated from CBM. As at December 2008 the proven and probable (2P) reserves of CBM in Australia were 16 179 PJ, a 116 per cent increase over 2007. The life of these reserves is more than a hundred times greater than the current rates of production. Queensland presently has 94.6 per cent of total 2P reserves with the remaining 5.4 per cent of 2P reserves in New South Wales. In 2010 the CBM gas reserves for Queensland were about 10 times that of conventional gas as per table 10 from Troup and Green (2011).

Table 1. Comparison between total initial reserves and cumulative production in 2010 for the 3 sources of hydrocarbons from Troup and Green (2011)

<table>
<thead>
<tr>
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<th>Total Initial Reserves</th>
<th>Cumulative Production to June 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>million cubic metres</td>
<td>bcf</td>
</tr>
<tr>
<td>Conventional Gas</td>
<td>73,447</td>
<td>2,594</td>
</tr>
<tr>
<td>CBM</td>
<td>767,916.13</td>
<td>27,118</td>
</tr>
<tr>
<td>Liquids: oil &amp; condensate</td>
<td>37,853.17</td>
<td>238.38</td>
</tr>
</tbody>
</table>

3.2 Leading Producers

Australia Pacific LNG (a joint venture between Origin Energy and ConocoPhillips) is presently the leading producer of CBM in Australia and holds the country’s largest CBM reserves (http://www.aplng.com.au) with three objectives: 1) Further development of Australia Pacific LNG’s gas fields in the Surat and Bowen
Basins in south-west and central Queensland; 2) Construction of a 520km gas transmission pipeline from the gas fields to an LNG facility on Curtis Island off the coast of Gladstone; 3) An LNG facility on Curtis Island off the coast of Gladstone, with the first two gas production trains processing up to 9 million tonnes per annum. During 2008–09, the company produced 71 petajoule-equivalent (PJ e) of CBM. Production capacity at the end of 2010 is estimated at 128 PJ per annum. The Talinga Stage 2 gas production facility was commissioned in early 2010 while Spring Gully gas production facility belonging to the company continues to be developed, while the Australia Pacific LNG also has interests in producing projects operated by others in the Bowen and Surat basins.

3.3 Supportive government policies

The boost in CBM exploration and production in Queensland was supported by the year 2000 state’s Cleaner Energy Strategy that dictated that by January 2005 13% of the electricity sold to retailers should be powered by gas. This target increased to 15% by 2010 which lead the companies to explore and produce CBM in Moranbah Bowen Basin and Walloon Coal Measures in the Surat Basin. That requirement has been increased to 18% by 2020 (http://www.ga.gov.au/energy/petroleum-resources/coal-seam-gas.html).

3.4 Gas prices and LNG market developments

Australia is known for its cheap gas. The large potential resources of the CBM industry in Queensland have created the possibility of an export CBM to LNG industry in Queensland. Less than a decade ago, there was concern that Eastern Australia was rapidly running out of natural gas reserves and that gas may have to be either shipped or piped from Western Australia. A realisation of the enormous potential of growth in the CBM sector in Eastern Australia has led to a number of proposed LNG developments, which to some extent parallels the huge offshore LNG developments in the North West Shelf and Browse Basin in Western Australia. Supplies of natural gas (as CBM) appear assured in Eastern Australia, and the potential for large reserves is such that a number of LNG export projects have been proposed to cater for production in excess of domestic needs. By June 2009, eight proposals for LNG plants in Queensland had been announced, most involving partnerships between Queensland companies with coal seam gas resources and international petroleum companies. If all eight proposals reach full capacity, it would represent a potential LNG market for the state of about 43 million tonnes per annum. By mid-June 2011, three of the eight proposals had received Federal Government approval, and LNG exports are expected to begin in 2015.

3.5 Reducing greenhouse effects

Methane is considered as a strong greenhouse gas. It accounts for 3.4% of GHG emissions in Australia. In 2000 Australia ranked number 5 in GHG emissions per capita (Wikipedia greenhouse gas, 2007). It is estimated that more than one billion m³ of methane has been vented to the atmosphere from Australian coal mines annually. Producing CBM is expected to reduce the amount of gas emitted to the atmosphere.

4. Challenges

The nature of CBM production poses potential environmental impacts with consideration of competing natural resources and their management. Environmental considerations are pivotal for the success of CBM industry. Companies are required by law to produce an environmental impact assessment study before they can proceed with CBM production. The most important environmental factors can be summarised as follows.
4.1 Water production and disposal constraints

Water production and disposal is the most important factor for the profitable CBM production. Large quantities of water must be removed from the coal to lower the pressure and to initiate methane desorption. This amount gradually decreases with time. In Queensland over 400 ML of water has been produced every year from Bowen, Galilee and Surat Basins from 1998 to 2003 (Department of Natural Resources and Mines, 2004). As such in marginally economic projects, the cost of water production and disposal is so critical in the investment decision and can make or break a marginal project.

Water management options include: surface discharge; underground injection; impoundment with no re-use (evaporation, recharge); and beneficial uses (Department of Natural Resources and Mines, 2004). Water purity and the quantity produced determine the means and cost of water management option. Despite the option of surface disposal, strict regulations are imposed on the treatment, disposal and monitoring of water in surface streams. A series of treating ponds in any producing field of the basin serve as staging points for the treatment process. Suspended solids, total dissolved solids (TDS) and oxygen demand of produced water have the most impact on water treatment.

The water management issue is a sensitive subject that involves many stakeholders: the gas production companies, the government which is ultimately responsible for the management of the country’s resources and the protection of the environment, the landholders and agricultural industry. Produced water from CBM operations could provide water for landholders and nearby communities and industrial users. A major stakeholder in the management of produced water is the environment. Disposal of water whether it is directly from produced water or post treatment for beneficial use will impact on the environment. This impact must be minimised and managed effectively.

4.2 Contamination of the air and water resources due to wellbore integrity issues

Wellbores- whether deep offshore or onshore- can have integrity issues. When these wells are not well sealed gas leakages can take place in forms varying from a major blowout in an offshore well to a gas contamination of the air or other aquifers overlying the coal seam. Well design and control becomes an important component of a CBM production project and is governed by a code of practice for well head emissions in terms of the maximum leakage allowed (in Australia the limit is less than 10% of the flammable level).

4.3 Contamination of water resources by hydraulic fracturing liquids

In many of the cases the coal beds require stimulation by induced fractures. Either CO₂ or N₂ can then be injected in these fractures either because they have higher affinity to adsorb to the coal matrix in the case of CO₂ or because they merely reduce the tendency of methane to adsorb to the coal by reducing its partial pressure, in the case of N₂. Hydraulic fracturing poses 2 issues: the first is contamination of the well and the aquifers with the fracturing liquid; the other is loss of control of the fracture path which if it reaches the aquifers can lead to water contamination by the harmful fracturing fluids and by the desorbed gas. Fracturing fluids that may contain harmful organic volatile material (BTEX) commonly used in the conventional oil and gas industry are not allowed in the CBM industry. Traces of BTEX were detected in water samples at a CSG project in Queensland in October 2010, raising concerns of risk to water supplies and human health (http://aplng.com.au/pdf/APLNGMediaRelease20102010.pdf). Investigations showed that the incident was minor and localised and arose from contamination during exploratory drilling for CBM.

4.4 The surface footprint of coal seam gas infrastructure

Unlike the production of conventional oil and gas, CBM production requires drilling many wells at a very small spacing, can go down to 200m. The proximity of wells is necessary to facilitate depressurizing the seam and driving the desorption of methane from the coal matrix. While well interference aids the flow of
water from the seams and the production of the gas it presents a large footprint that can have social impact that needs to be carefully assessed before legislative authorities can provide the necessary permits for companies to produce. This has been an issue with the farmers in Australia.

5. **Articles in this special issue**

This special issue consists of 15 invited papers in 4 areas that cover the main types of unconventional hydrocarbon sources. Two papers are presented under the area of Coal Bed methane. The paper by Song et al examines the pressure, temperature and structural controls on the accumulation of CBM in synclines and the importance of hydrodynamic sealing in CBM accumulation and preservation. The paper by Chen et al presents a study showing the impact of the stress dependent anisotropic coal permeability on well design through numerical modeling and reservoir simulations.

Four papers are presented in the area of gas hydrates. Navalpakam et al discuss the utilization of the strength of the BSR from the base of the gas hydrate stability zone as a lithology indicator in Hikurangi Margin, a subduction zone east of New Zealand.

The paper by Trung estimates the gas hydrate potential in the South China Sea and predicts large thicknesses of hydrate stability zones in waters deeper than 600ms for various hydrate structures.

The paper by Rajput et al discusses two-dimensional seismic full waveform modeling for multilayer, complex gas hydrate models and studies the converted mode characteristics together with the real data analysis. It concludes that hydrate and free-gas interface acts as principal boundary for mode conversion and that the overburden significantly influences the P-wave amplitude of BSR and identifies key seismic indicators.

The paper by Seo and Kang evaluates the inhibition of hydrate reformation using kinetic hydrate inhibitors (KHI) (PVcap) in the scenario of hydrate production and transportation. The successful role of KHI in inhibiting the reformation of hydrates is demonstrated.

Seven papers are presented in the area of tight gas. The paper of Chen et al presents a novel approach whereby the permeability of tight gas samples is increased by introducing damage and microcracks in the sample using dynamic shock waves utilizing Pulsed Arc Electrohydraulic Discharges (PAED). CT scanning is used to view the damage initiation in the samples.

The paper by Ostojic et al discusses numerical modelling of hydraulic fracturing to improve productivity in tight gas reservoirs and explores the impact of varying the fracture number, orientation and length.

The paper by Zou et al presents an overview of the characteristics of tight gas reservoirs in Chinese basins and a set of criteria for recognizing and evaluating tight gas reservoirs including factors controlling pore throat structures and dimensions and the coupling of sedimentary and diagenetic effects on tight sandstone formation.

The paper by Rezaee et al presents an experimental study on the permeability of tight gas sands using mercury measured pore throat sizes and NMR relaxation spectra and deduces new relations between permeability and pore throat size.

The paper by Bahrami et al evaluates the damage mechanisms associated with water invasion and phase trapping in tight gas reservoirs by performing single well reservoir simulation based on typical West Australian tight gas formation data, in order to understand how water invasion into the formation affects well production performance in both non-fractured and hydraulically fractured tight gas reservoirs.

The paper by Josh et al discusses an improved workflow for systematic gas shale characterization whereby a suite of shales from a number of sedimentary basins around the world are tested using various
techniques petrophysical techniques and correlations between petrophysical and geomechanical properties are found.

The paper by Zeinijahromi et al discusses the physical mechanisms and the governing equations of fines detachment by fast flow near the wellbore during gas production, their mobilisation and capture. It presents an analytical model for constant rate gas production accounting for fines migration and formation damage and an explicit formula for well deliverability decline due to gas production with fines.

Two papers are presented in the area of hydraulic fracturing. The paper by Chen discusses the implementation of cohesive finite element modelling technique to simulate viscosity-dominated plane strain and penny-shaped hydraulic fractures. The study shows excellent agreement between the finite element results and analytical solutions.

The paper by Le et al discusses gel damage in hydraulically fractured gas wells and presents results of physical modelling of the treatment of fracture damage due to gel deposition including dry gas injection and solvent treatment using alcohols. It also develops a mathematical model, based on drying front theory, to predict the rate of recovery of gas flow rates through the sand and fracture packs.

6. References


