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Development, maintenance and implementation of the United Nations Framework Classification for Resources:
Petroleum

United Nations Framework Classification for Resources – Draft Guidance for application to Coal Bed Methane

Prepared by a Task Force established under the Petroleum Working Group of the Expert Group on Resource Management

Summary

The application of the United Nations Framework Classification for Resources (UNFC) to all energy sectors is crucial to increasing transparency, reducing risks, and assuring sustainability. Proper classification, reporting, and management of Coal Bed Methane is key to realizing Sustainable Development Goals (SDGs) and accelerating global action on climate change. This draft document provides additional guidance for the application of UNFC to Coal Bed Methane projects so that consistency and coherency can be assured. The draft document will be finalized after review by the Group of Experts on Coal Mine Methane at its seventeenth annual session and the Expert Group on Resource Management at its thirteenth session.

Contents

Acknowledgements

This Draft Guidance for the Application of the United Nations Framework Classification for Resources to Coal Bed Methane was prepared by a Task Force established under the Petroleum Working Group of the Expert Group on Resource Management. Mr. Claudio Virues, Task Force Lead (Alberta Energy Regulator, Canada) and Mr. Harikrishnan Tulsidas (United Nations Economic Commission for Europe (ECE)), are acknowledged for their substantial contributions. The Petroleum Working Group members are thanked for the comprehensive review of the document.

I. Introduction

1. Sustainable development of energy resources has become critical for ensuring the security of supplies and the planet's well-being. The Sustainable Development Goals (SDGs) call for responsible production and consumption patterns, encouraging innovation, increasing productivity, and reducing waste generation, including carbon emissions.

2. Multiple challenges are to be overcome for the energy resources to be utilized sustainably to produce goods and services, improving quality of life. The energy industry has to transform into a new comprehensive recovery model, 'zero waste' and energy neutrality, from extracting only the best quality material available and neglecting the possible by-products.

3. This requires accurate estimation and classification of primary and secondary resources and the currently disregarded "wastes" potentially turned into wealth. The neglected "wastes" often create massive environmental externalities, and industries will bear significant liability to manage external factors. When properly recovered as co-/by-products, such "wastes" are transformed into value for the industry, bring net environmental gains and increase social benefits to the communities in mining regions.

4. For this to happen, four main activities should work in harmony: policy analyses, government natural resource management, business process management and efficient capital allocation. The United Nations Framework Classification for Resources (UNFC) is the only universal standard that considers all required processes for the holistic development of the energy and minerals sector and enables it to deliver socio-economic gains.

A. United Nations Framework Classification for Resources

5. UNFC provides a tool for managing energy and mineral resources. Applicable to renewable energy projects, including geothermal energy, and all extractive activities, including solid minerals, oil, gas and uranium, and injection projects for the geological storage of CO_2, UNFC ensures that resources are developed transparently, efficiently sustainably in a socially acceptable manner.

6. UNFC is a generic principle-based system in which quantities are classified by the three fundamental criteria of environmental-socio-economic viability (E), technical feasibility (or field project status) (F), and degree of confidence (or level of knowledge) (G), using a numerical and language independent coding scheme.

7. The definitions of UNFC Categories and Sub-categories have been simplified, and the most commonly used classes are defined using plain language, providing harmonized generic terminology at a level suitable for global communications. Commonly used words that are widely misunderstood and do not have a unique meaning are avoided.

8. An increasing number of multi-resource companies are today operating in many different countries and jurisdictions. In addition, the development of new types of resources, such as coal mine methane, the mining of bitumen to produce synthetic crude oil, and the development of unconventional gas reservoirs demonstrates that historical boundaries between the minerals and petroleum sectors, reflected in different resource classification systems are no longer sustainable.

9. UNFC captures the universal principles and provides a tool for consistent reporting for these activities, regardless of the industry, covering all energy and mineral sectors. UNFC also uniquely includes all classes of resources. It is a reliable system paving the way for improved global communications aiding stability and security of supplies, governed by understood rules and guidelines.

10. Clear and consistent classification of all resources is the foundation for sound management and development of resources. UNFC uses a unique project maturity model for classification, which in the hands of experienced professionals, can become a powerful tool for the progressive development of resources sustainably. Therefore, it is not just the Class in which a resource falls that is important, but how stakeholders can move the resources to a higher class that determines how, when, and at what cost the resources can contribute to the socio-economic development.

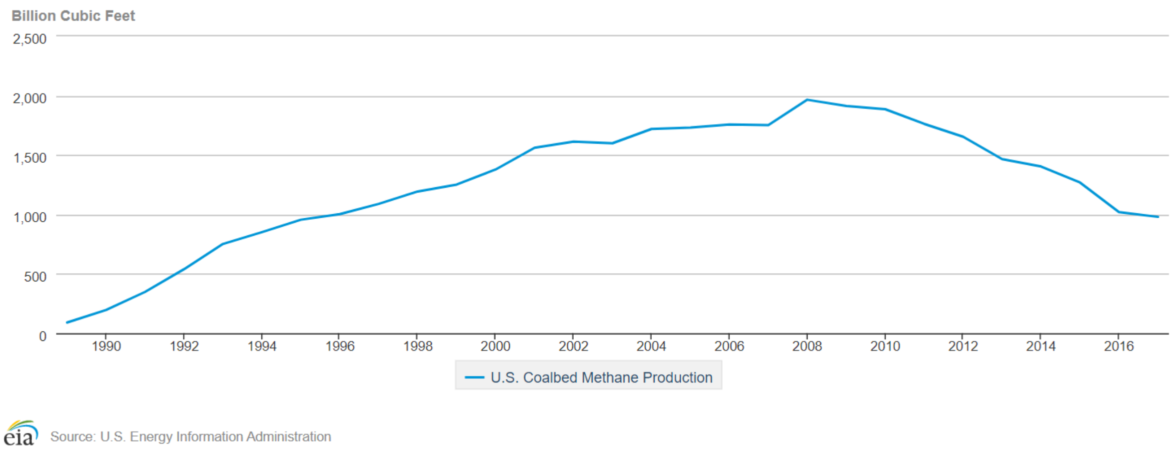
11. Since UNFC emphasizes how much is expected to be produced at a given cost with available technologies, the system is a powerful tool for planning and capital resources allocation.

B. Latest State of Coal Bed Methane in the World

12. Coal is defined as a "readily combustible rock containing more than 50% by weight, and more than 70% by volume of carbonaceous material formed from compaction and induration of variously altered plant remains similar to those in peaty deposits".[1] Coal Bed Methane (CBM), variously referred to as natural gas from coal (NGC, Canada) or coal seam gas (CSG, Australia), is generated either from methanogenic bacteria or thermal cracking of the coal. Since much of the gas generated in coal can remain, primarily because of gas sorption in the coal matrix, coal acts as both the source rock and the reservoir for its gas. Exploration for and exploitation of CBM resources requires knowledge of the unique coal-fluid storage, and transport processes and special techniques (well completions and operations) needed to extract commercial quantities of gas.

13. CBM resources worldwide are immense, with estimates exceeding 9,000 Trillion Standard Cubic Feet (Tscf)[2] in 2008 and up to 6,500 Tscf in 2014.[3] The primary producing countries include the US, Canada, and Australia. More than 40 countries have evaluated the potential of CBM. The U.S. has the most mature production, with commercial production starting in the 1980s. US production of CBM in 2009 was 1.97 Tscf and 0.98 Tscf in 2017.

Figure I
Global Coal Bed Methane production



[1] James Morton Schopf; A definition of coal. Economic Geology 1956; 51 (6): 521–527. doi: https://doi.org/10.2113/gsecongeo.51.6.521

[2] Jenkins, C., and Boyer, C. I. I. (2008). Coalbed- and Shale-Gas Reservoirs. J. Pet. Technol. 60, 92–99. doi: 10.2118/103514-ms

[3] Mastalerz, M., 2014, Coal bed methane: reserves, production and future outlook, in T.M. Letcher, ed., Future energy, second edition: New York, Elsevier, p. 145-158

14. Mastalerz[4] included annual CBM production (Figure I), and by country as summarized in Table 1 (original), modified by data from Kelafant[5] in 2016 in Table 2.

Table 1
Annual CBM Production by Country (2010 data)

Annual CBM Production by Country (2010 data) (from Mastalerz, 2014)	
Country	**Production, Bcf**
U.S. (minus Alaska)	1,886
Canada	320
Australia	190
China	50
Alaska	1
Russia	0.5
India	0.4
Kazakhstan	0.4

Table 2
Annual CBM Production by Country

CBM Resources by Country		
Country	**Mastalerz (2014) 2010 Resources, Tcf**	**Kelafant (2016) Tcf**
Russia	2,824	
China	1,100	1,300
Alaska	1,037	
U.S. (minus Alaska)	700	
Australia	500	203
Canada	500	801
Indonesia	435	
Poland	424	
France	368	
Germany	100	
UK	100	
India	70	120
Ukraine	60	
Zimbabwe	40	
Kazakhstan	25	27
Southern Africa		110

Note: Modified by Kelafant in 2016.

15. CBM reservoirs are generally naturally fractured, and the majority of gas storage is through sorption because of the internal surface area provided by organic matter within the coal matrix. The natural-fracture system dictates the transport of natural gas and water to the wellbore. The coal matrix has very low permeability, and the gas transport mechanism is generally considered due to diffusion. The gas diffuses from the coal matrix into the natural fractures and moves under Darcy flow to the wellbore. The production profiles of CBM reservoirs are unique and a function of the various reservoir and operational factors.

[4] Mastalerz, M., 2014, Coal bed methane: reserves, production and future outlook, in T.M. Letcher, ed., Future energy, second edition: New York, Elsevier, p. 145-158

[5] Kelafant, J., 2016, International coal seam gas activities: excerpt from paper in North American Coalbed Methane Forum Coal Seam Gas Quarterly Newsletter, v. 5 issue 3

16. **Research on Primary Mechanisms of gas storage**: The primary mechanisms for gas storage in CBM reservoirs are: (1) adsorption upon internal surface area, primarily associated with organic matter, (2) conventional (free gas) storage in natural fractures, (3) conventional storage in matrix porosity, and (4) solution in bitumen and formation water. In 1999, an experimental study was conducted on coals of various ranks and compositions to measure the free gas stored in coal matrix porosity and its potential contribution to the gas storage capacity of coal. Adsorption and porosity studies show that free gas in coal matrix porosity makes up a substantial component of gas stored in low-rank coals under typical reservoir conditions. The free gas is not determined by adsorption/desorption analyses and is not predicted by lost gas techniques. The presence of substantial free gas in the matrix and possibly fracture porosity explain the higher-than-expected gas production obtained for low-rank coals, such as coals in the Powder River Basin and Tertiary coals in the Western Canadian Sedimentary Basin.[6] Generally, free gas is negligible compared to sorbed gas storage and is usually ignored in CBM reservoirs because of low fracture-pore volumes and high water saturation. The exception is for some dry CBM reservoirs, in which free-gas storage may be more significant.[7]

17. **Research on Sorbed gas storage**: Sing et al. draw attention to the ambiguities which have arisen in connection with the reporting of gas adsorption (physisorption) data. The first stage in the interpretation of a physisorption isotherm is to identify the isotherm type and hence the nature of the adsorption process(es).[8]

18. **Research on Sorbed gas storage**: Sorbed gas storage is the most crucial storage mechanism in most CBM reservoirs. High-rank coals have surface areas on the order of 100 to 300 m^2/g, whereas conventional reservoirs typically have surface areas < 1 m^2/g. Bustin et al. investigated the influence of coal composition and rank on coal bed methane reservoir capacity, gas content and gas saturation for a series of Australian, Canadian and United States coals.[9]

19. **Research on Controls on sorption**: Levy et al. investigated controls upon sorption, in addition to the organic matter pore structure, including pressure, temperature and rank of thermal maturity for Permian coals from the Bowen Basin of Queensland.[10]

20. The adsorption of CBM-reservoir gases is primarily physical vs chemical, meaning that molecular interaction is weak and reversible. Gas is stored in a near-liquid-like state, with a higher density than compressed gas at typical reservoir temperatures and pressures. Joubert al. investigated the controls upon sorption, in addition to the organic matter pore structure, including moisture[11] and mineral matter content (grade).[12]

21. Clarkson et al. investigated the effect of coal composition upon pore structure and adsorption characteristics of four bituminous coals of the Cretaceous Gates Formation coal.[13]

[6] Bustin, R.M., and Clarkson, C.R. 1999. Free Gas in Matrix Porosity: a Potentially Substantial Resource in Low-Rank Coals Coalbed Methane Symposium Proceedings, Tuscaloosa, Alabama, May 1999, p. 197-214.

[7] Bustin, A.A.M. and Bustin, R.M. 2009. Gas in Box: How Much Producible Gas is in the Horseshoe Canyon, CSUG, Calgary, Nov. 2009

[8] Sing, K.S.W., Everett, D.H., Haul, R.A.W, Moscou, L., Pierotti, R.A., Rouquerol, J., and Siemieniewska , T. 1985. Reporting physisorption data for gas-solid systems with particular reference to determining surface area and porosity. Pure and Appl. Chem. 57: 603-919

[9] Bustin, R.M. and Clarkson, C.R. 1998. Geological controls on coalbed methane reservoir capacity and gas content. International Journal of Coal Geology (1998): 3–26

[10] Levy, J.H., Day, SJ, and Killingley, J.S. 1997. Methane Capacities of Bowen Basin Coals Related to Coal Properties. Fuel 74 (1): 1–7

[11] Joubert, J.I., Grein, C.T., and Beinstock, D. 1973. Sorption of Methane in Moist Coal. Fuel 52: 181–185

[12] Mavor, MJ 1996. Coalbed Methane Reservoir Properties. In A Guide to Coalbed Methane Reservoir Engineering. Report GRI-94/0397, Chicago, Illinois: Gas Research Institute

[13] Clarkson, C.R., and Bustin, R.M. 1999. The Effect of Pore Structure and Gas Pressure Upon the Transport Properties of Coal: I Isotherms and Pore Volume Distributions. Fuel 78: 1333–1334

22. Hall et al. studied methane adsorption experimentally on wet Fruitland coal at 115°F. The data elucidated the competitive adsorption behaviour of the individual components in these mixtures.[14]

23. **Research on the primary mechanisms governing gas flow in coals**: Mavor investigated the primary mechanisms governing gas flow in coals, including pressure-driven flow (modelled with some form of Darcy's law) through the fractures and concentration-driven flow (modelled with some form of Fick's law) through the coal matrix.[15]

24. **Research on Permeability and Analytical Models**: Palmer et al. showed that permeability changes could be substantial during depletion of CBM wells: up to 100 times in the San Juan Basin, and those analytical models of permeability increase during depletion are accessible, easy to use, and practical.[16]

25. For situations where a coal deposit might be evaluated for CBM and Coal Mine Methane (CMM), cross-over with the mining industry may occur in estimating in-situ coal tonnage. Indeed, the two sectors may derive different estimates as each industry uses different parameter cut-offs.

C. Latest State of CBM in Australia

26. According to the U.S. Energy Information Administration (EIA),[17] Australia has sizeable, untapped natural gas resources in the form of CBM, known as coal seam gas (CSG) in Australia, and shale gas. Commercial production from CBM, which began in 1996, rose to 424 Billion Cubic Feet (Bcf) in 2015, 50% higher than in 2014.

27. This production increase corresponds with the commencement of the country’s first CBM-to-Liquefied Natural Gas (LNG) export terminals in Queensland over the past two years. Several CBM projects in the Surat and Bowen Basins are under development to serve three new LNG projects in Queensland.

28. CBM wells typically produce less gas than conventional wells and at slower rates, requiring upstream partners to develop more fields to fulfil LNG requirements. Investors face challenges with project delays based on increased and more effective public resistance to potential environmental impacts.

29. Australia is attempting to balance its dual interests of increasing investment, exploiting these resources, and developing them sustainably and in an environmentally safe manner. New South Wales (NSW), Queensland, and the Federal Government have established environmental regulations related to water use and disposal and land rights in CBM and shale gas projects.

30. Queensland established more austere water safety and management policies for CBM producers in 2010. In 2013, NSW enacted a natural gas plan that restricts CBM production near residential areas and small industries. Vast shale gas reserves in Australia could boost natural gas production once developed.

31. As noted above, EIA estimates that Australia has 429 Trillion cubic feet (Tcf) of technically recoverable reserves, ranking the country seventh highest in the world, behind Canada, the United States, Mexico, China, Argentina, and Algeria. Most of the exploration activity has focused on the Cooper Basin in the country's interior, where most of the country's onshore conventional gas reserves are located.

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[14] Hall, F.E., Zhou, C., Gasem, K.A.M., Robinson Jr., R.L., and Yee, D. 1994. Adsorption of Pure Methane, Nitrogen, and Carbon Dioxide and Their Binary Mixtures on Wet Fruitland Coal. Paper SPE 29194 presented at the Eastern Regional Conference and Exhibition, Charleston, West Virginia, USA, 8–10 November. DOI: 10.2118/29194-MS

[15] Mavor, MJ 1996. Coalbed Methane Reservoir Properties. In A Guide to Coalbed Methane Reservoir Engineering. Report GRI-94/0397, Chicago, Illinois: Gas Research Institute

[16] Palmer, I. 2009. Permeability Changes in Coal: Analytical Modeling. Intl. J. of Coal Geology 77: 119–126

[17] https://www.eia.gov/international/content/analysis/countries_long/Australia/australia.pdf

32. The basin has attracted many international oil companies with the financing and technical capacities to develop shale reserves and mid-sized companies. Santos drilled the first successful commercial shale gas flow at its Moomba Field in the Cooper Basin in 2012. However, reduced capital expenditures resulting from the low oil price environment have significantly slowed the country's shale gas exploration and development since 2014. Furthermore, Victoria State and the Northern Territory have announced bans on unconventional gas exploration, posing significant risks for Australia's shale gas development.

33. Towler et al.[18] provided an overview of the coal seam gas developments in Queensland, in which they reported in the 2014/2015 fiscal year Queensland production of 469 Bcf of gas, of which 430 Bcf was CSG from the Bowen and Surat basins. The most recent Queensland Government petroleum CSG report is available.[19] Flores[20] included a map showing CSG potential in Australia, noting that the coal beds range in age from Permian to Tertiary in about 30 coal-bearing basins. Blewett[21] included maps showing the distribution of demonstrated black coal and gas resources in Australia. CSG reserves in 2012 were divided into six coal basins in eastern Australia: Surat Basin (69%), Bowen Basin (23%), Gunnedah Basin (4%), Gloucester Basin (2%), Sydney Basin (1%), and Clarence-Moreton Basin (1%). (Flores, 2013).

34. An interactive map of CSG wells in Australia (unknown date) is available.[22] An interactive map of CSG wells in New South Wales is also available.[23]

D. Latest State of CBM in Canada

35. Canada contains diverse CBM resources, which are concentrated chiefly in the Carboniferous strata in the intermontane basins of the Canadian Maritime Provinces, Mesozoic-Cenozoic strata in intermontane basins of British Columbia, and Cretaceous strata of the Western Canada Sedimentary Basin of the Cordilleran foreland in Alberta. The vast majority of the resource and reserve base is in Alberta, where the Alberta Geological Survey estimates Original Gas In-Place (OGIP) on the order of 500 Tcf. The bulk of the production comes from the Horseshoe Canyon play, which is active in various Cretaceous coal-bearing formations. Early production operations focused on vertical wells completed in multiple coal seams, and expansion of the industry between 2005 and 2007 was buoyed by the advent of lateral and multilateral drilling in single seams.

36. According to the Alberta Energy Regulator, the remaining reserves in Alberta are estimated to be about 2 Tcf. Development activity, however, has decreased significantly in recent years in response to low natural gas prices. According to the International Energy Agency (IEA), Canadian CBM production peaked at 8.9 Bcm (315 Bcf) in 2010. Production was 7.2 Bcm (254 Bcf) in 2014, and the annual rate of decline has increased from 3.7% in 2011 to 6.8% in 2014 (Figure II).[24] Accordingly, the current economic climate remains challenging for developing new CBM reserves in Canada.[25]

37. General information on CBM in Alberta is available from the Alberta Energy Regulator and the Alberta Geological Survey.

[18] Towler, B., M. Firouzi, J. Underschultz, W. Rifkin, A. Garnett, H. Schultz, J. Esterle, S. Tyson, and K. Witt, 2016, An overview of the coal seam gas developments in Queensland: Journal of Natural Gas Science and Engineering, v. 31, p. 249-271

[19] https://publications.qld.gov.au/dataset/queensland-petroleum-and-coal-seam-gas

[20] Flores, R.M., 2013, Chapter 9, Worldwide coalbed gas development, in coal and coalbed gas, fueling the future: Elsevier Science, 717 p

[21] Blewett, R., ed., 2012, Shaping a nation: a geology of Australia: Geoscience Australia, 571 p

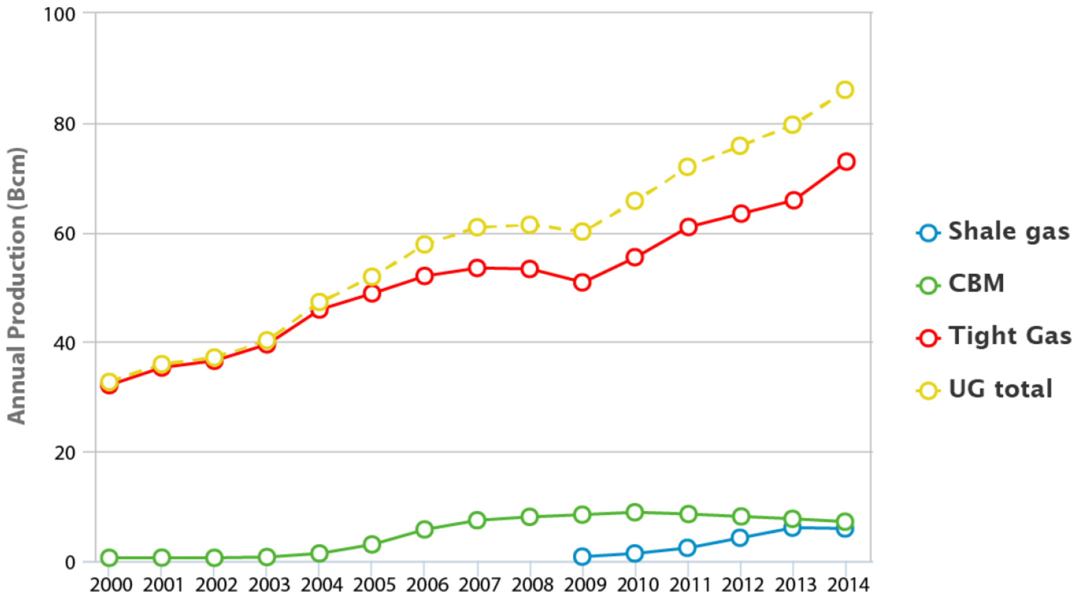
[22] http://www.abc.net.au/news/specials/coal-seam-gas-by-the-numbers/

[23] http://www.resourcesandenergy.nsw.gov.au/landholders-and-community/coal-seam-gas/facts-maps-links/map-of-csg-wells

[24] EMD Annual Meeting Committee Coalbed Methane

[25] EMD Coalbed Methane Committee Report 2017 EMD Annual Leadership Meeting April 1, 2017

Figure II
Canadian unconventional gas production, 2000-2014



Source: International Energy Agency.

38. CBM production peaked in 2010, and the rate of decline has been increasing since 2011 as Canadian natural gas markets are challenged by decreasing natural gas prices (Figure II).

39. The Alberta Geological Survey estimates there may be up to 500 Tcf of natural gas in Alberta's coals.

40. In 2012, nearly all CBM wells drilled in Alberta had targeted the thinner coal seams in the Horseshoe Canyon (ultimate gas in place 179 Tcf) and Belly River coal zones along the Calgary-Red Deer corridor. Wells targeting these seams tend to produce gas with little or no water, with production referred to as "dry CBM". The first commercial production of CBM in Alberta was from these coals, and they constitute the majority of CBM reserves booked. The depth range of these coals is 200 to 800 metres.[26]

41. The remaining CBM wells have targeted the deeper Mannville coals (ultimate gas in place 321 Tcf). These coals tend to be thicker, more profound, and more continuous with substantial saline (salt) water production. The depth range of these coals is 900 to 1,500 m.

42. Most CBM wells in the Horseshoe Canyon Formation are vertically drilled wells, whereas most wells in the Mannville Group are horizontal wells.

E. Latest State of CBM in the United States of America

43. Production and natural gas reserves from coal beds in the United States of America (U.S.) continued to decline in 2016. CBM is still though a vital resource globally.

44. EIA[27] shows a map of the U.S. lower 48 States CBM fields. U.S. annual CBM production peaked at 1.966 Tcf in 2008 (EIA).[28, 29] CBM production declined to 1.269 Tcf in 2015 (EIA), [30] the lowest level since 2001, representing 4.7% of the U.S. total natural gas

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[26] https://www.alberta.ca/coalbed-methane.aspx

[27] EIA, 2009a, Coalbed methane fields, lower 48 states: US Energy Information Administration. http://www.eia.gov/oil_gas/rpd/coalbed_gas.jpg

[28] EIA, 2009b, US crude oil, natural gas, and natural gas liquids reserves, 2007 annual report: US Energy Information Administration, DOE/EIA-0216(2007), 145 p.

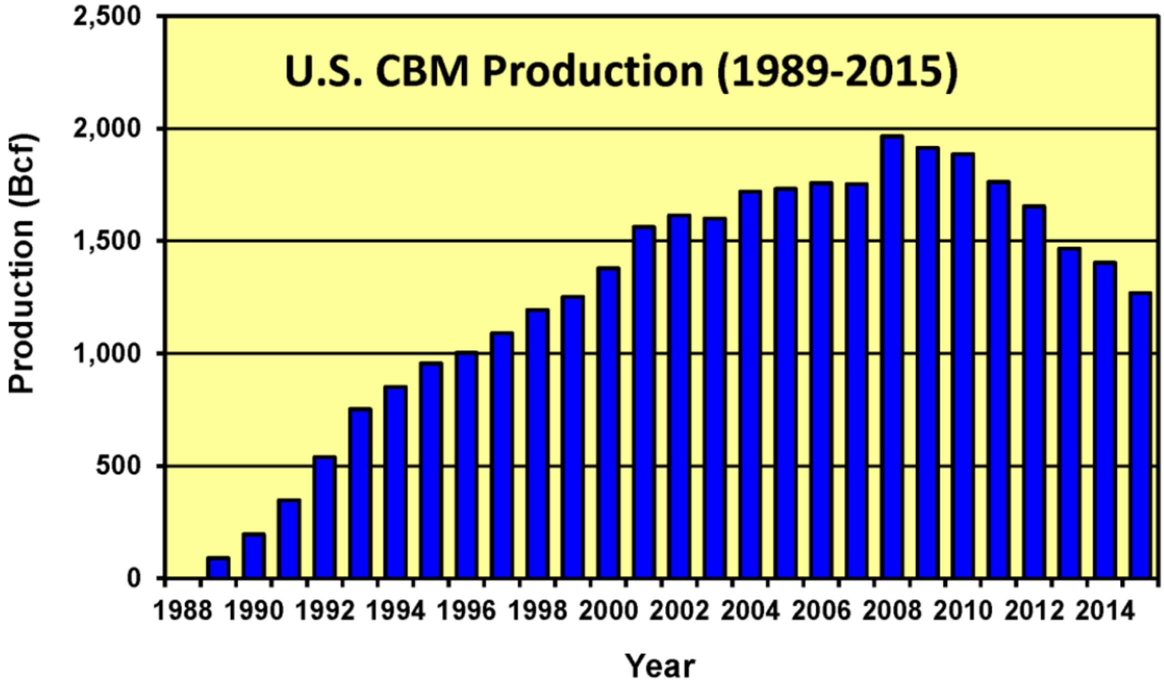
[29] EIA, 2010, Summary: US crude oil, natural gas, and natural gas liquids proved reserves 2009: US Energy Information Administration, 28 p.

[30] https://www.eia.gov/dnav/ng/NG_ENR_COALBED_A_EPG0_R52_BCF_A.htm

production of 27.1 Tcf (EIA 2016f). According to EIA (2016a), the top 8 CBM producing U.S. States during 2015 (production in Bcf) were Colorado (392), New Mexico (344), Wyoming (207), Virginia (106), Alabama (72), Oklahoma (48), Utah (42), and Kansas (25). Annual CBM production decreased for each State over the previous year (EIA 2016a, c). Cumulative U.S. CBM production from 1989 through 2015 was 34.7 Tcf (Figure III). CBM production continues even though few new wells are being completed, reflective of the very long productive lives of CBM wells. As many U.S. CBM fields approach late maturity in an environment of low commodity prices, operators are working to optimize operations and reduce lifting costs.

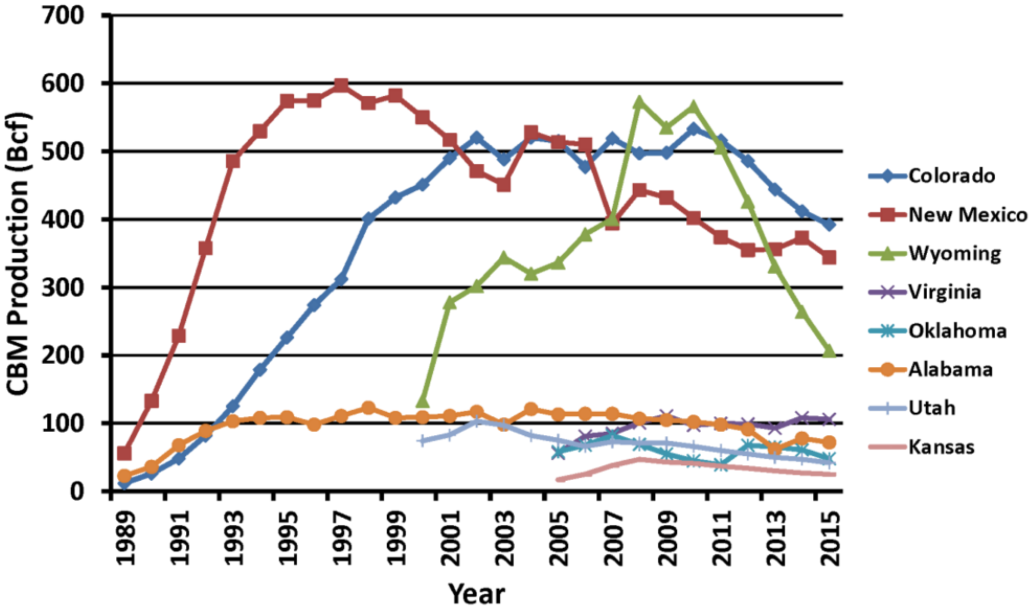
45. According to EIA (2016c, data through 2015), annual peak CBM production in the top 8 CBM producing U.S. States during 2015 occurred in the following years: Colorado (533 Bcf in 2010), New Mexico (597 Bcf in 1997), Wyoming (573 Bcf in 2008), Virginia (111 Bcf in 2009), Oklahoma (82 Bcf in 2007), Alabama (123 Bcf in 1998), Utah (103 Bcf in 2002), and Kansas (47 Bcf in 2008) (Figure IV). The website provides a history of Wyoming CBM production.[31] The United States Geological Survey (USGS) includes hyperlinks to USGS CBM assessment publications and web pages.

Figure III
United States CBM Production 1989-2015



[31] http://www.wyohistory.org/essays/coalbed-methane-boom-bust-and-hard-lessons

Figure IV
Annual CBM Production of the top 8 United States of America States



F. CBM Gas as a Product

46. In the context of this document, CBM gas products include, but are not limited to, any of the following:

- Unconventional natural gas, e.g. shale gas, coal bed methane (CBM – also called coal seam gas (CSG))
- Gas hydrates
- Synthetic gas
- Coal mine methane (CMM)
- Other sources.

II Classification CBM

A. CBM classification guidelines

47. UNFC classifies projects based on three sets of basic Categories:

(a) The E Categories designate the degree of favourability of environmental-socio-economic conditions in establishing the viability of the project, including consideration of market prices and relevant legal, regulatory, social, environmental and contractual conditions;

(b) The F Categories designate the maturity of technology, studies and commitments necessary to implement the project. These projects range from early conceptual studies through to a fully developed project that is producing, and reflect standard value chain management principles;

(c) The G Categories designate the degree of confidence in the estimate of the quantities of products from the project.

48. These Categories are numbered, with one being best. They combine to form classes identified by Hindu-Arabic numerals. For example, E1, F1, G1, (or 1,1,1 for short) is equivalent to "proved reserves", i.e. there are no contingencies in the economic and social

domain blocking the implementation of the project, the project has advanced to a stage where performance or extraction can take place, and the quantities have been determined to a degree of certainty that is high enough to attest that they will be reached or exceeded.

III. Environmental-Socio-Economic Viability (E Axis) CBM

49. The environmental-socio-economic viability axis (E Axis) Categories encompass all non-technical issues that could directly impact the development viability, including product pricing, capital and operating costs, legal/fiscal framework/regulations and environmental or social impediments.

A. CBM Environmental Criteria

50. Environmental factors are not defined in UNFC nor in any of the resource-specific guidelines.

51. A practical application would be the physical, chemical, and biological impact on or changes to the project area and surroundings, due to a project (e.g. contamination in soils or water, disruption of wildlife habits and migration characters, etc.).

52. Additional environmental factors include safeguard zones, protected natural areas, wetland sites, flora and fauna protected by legislation, and critical land use in the area.

53. As with social criteria, a matrix can classify the likely environmental impacts on petroleum projects.

IV Technical Feasibility (F Axis) CBM

A. General overview and principles

54. The feasibility of extraction for a development project is evaluated and represented by the F Axis. This includes maturity of the gas recovery technology, development plan, producer ability, and commitment necessary for the project execution.

55. In general, the feasibility of the project development is categorized into four major Sub-categories:

- F1 - Defined development project with confirmed feasibility of extraction
- F2 - Defined development project with the feasibility of extraction to be confirmed (requires further evaluation or approval) or a not viable defined project
- F3 - Conceptual development project to which the feasibility of extraction cannot be evaluated, given the limited data
- F4 - Absence of a development project (defined or conceptual) to evaluate
- It should be noted that the feasibility of extraction and the F-axis are defined considering only the maturity status of the development projects. All projects are evaluated based on the robustness and maturity of the future development project (which may be conceptual) at the effective date.

56. This approach facilitates a single evaluation framework to categorize the likelihood of project production at all stages of exploration, appraisal and development.

B. Consideration of Risk

57. The primary risk associated with CBM production is economic – will gas rates and gas contents be sufficient to justify capital costs? To effectively evaluate a CBM asset, the evaluator must address the following questions:

- Is the reservoir at equilibrium, saturated, or undersaturated?
- If dewatering is required, how long will dewatering take?
- What volumes of water will need to be handled?
- What disposal method will be required for the water?
- What is the composition of the gas?
- What peak production rate can be expected for a typical well?
- What well density will be optimal?

58. All CBM gas projects before development have an associated chance (probability or risk) of viability, which is equivalent to the possibility of commerciality (Pc), being the product of the case of productive reservoir discovery (Pg) and the chance of development (Pd). The Pd includes the demonstration of viable recovery technology. For conventional CBM resources, the most significant risk is usually the chance of discovery. The most critical risk for unconventional CBM gas resources is typically the chance of development.

59. There is generally a well-accepted methodology for assessing Pg. CBM system risk factors such as source, migration, reservoir, seal and trap are typically combined to generate a Pg. For Pd, the technical and commercial aspects that need to be overcome before a viable project must be considered. These include subsurface (resource quality and continuity), recovery technology, surface (well locations and infrastructure), project execution (financing and capability), economics, approvals (government and regulatory) and timing. Dependency between factors should be considered. These factors can be used in a methodology that combines them in a matrix or scorecard.

60. The assessment of the Pg and Pd should reflect the local project subsurface, surface and development risks and uncertainties. Pc uncertainty increases when data quality or quantity is limited or numerous socio-economic or environmental contingencies.

C. General overview and principles

61. The confidence in estimates is represented on the G Axis. This axis corresponds to the uncertainty inherent to any CBM gas development project production estimates. The G Axis is fundamentally different from the E and F Axes, which focus on the environmental-social-economic viability and the technical feasibility. The fundamental principles of the G Axis are:

- Full range of outcomes - while any project will be associated with one class or subclass (E and F Categories), the G Axis represents the range of project outcomes assessed at defined technical and forecast economic conditions based on the available data the effective date. A corresponding G1, G1+G2 & G1+G2+G3 should be provided for any given project and represent the associated low, best and high cases. For viable or potentially viable projects, the range of uncertainty means the outcomes that would be economically recoverable. It is only acceptable not to provide a range of products for a given task if the values have been computed in a system with a lower granularity and transferred to UNFC using the relevant bridging process. Today, only the Russian and the Chinese evaluation bridging documents are operational and may lead to this situation
- Uncertainty versus Maturity - the uncertainty and the range of outcomes for a given project is represented by the range between G1 (low), G1+G2 (best) and G1+G2+G3 (high). The higher the uncertainty, the more extensive the range. While the G Axis remains independent from the E and F Axes, a correlation may be expected between

the project maturity (E and F) and the range along the G Axis: generally, with more data available, the narrower the uncertainty range.

D. Estimation Procedures

62. A CBM gas accumulation may contain one or many projects. The sum of all categories associated with all development projects as well as any cumulative production + unrecoverable volumes (F4) will always be equal to the volume-originally-in-place (VOIP) for the Low, Best and High cases (material balance). With:

- Low Case = G1
- Best case = G1+G2
- High case = G1+G2+G3.

$$production + \sum_{project=1}^{n} low\ case\ estimates + F4G1 = Low\ caseVOIP = G1VOIP$$

$$production + \sum_{project=1}^{n} Mid\ case\ estimates + F4G2 = Mid\ caseVOIP = G1 + G2VOIP$$

$$production + \sum_{project=1}^{n} High\ case\ estimates + F4G3 = High\ caseVOIP = G1 + G2 + G3VOIP$$

E. Analytical procedures

63. The estimation of recoverable quantities associated with a given project can be evaluated using (i) volumetric, (ii) material balance, (iii) analogy and (iv) performance-based procedures. These can be used individually or in combination.

F. Volumetric analysis

64. A volumetric estimate of CBM reserves is the simplest method, as well as the most potentially error-prone, because of the uncertainty in basic parameters such as recovery efficiency and parameters in the total gas initially in-place (TGIIP) calculation [such as bulk volume of the reservoir (*Ah*), and in-situ gas content]. Estimated ultimate recovery (EUR) may be obtained from TGIIP simply by multiplying TGIIP by recovery efficiency (*Rf*). The most commonly used form of the GIIP equation for coal is:

$$G_i = Ah\left(\frac{43560\phi_f(1 - S_{wi})}{B_{gi}} + 1.3597\bar{\rho}_c\bar{G}_c\right)$$

where
G_i = GIIP, Mscf
A = reservoir area, acres
h = reservoir thickness, ft
ϕ_f = natural-fracture porosity, dimensionless, fraction
S_{wi} = initial water saturation in the natural fractures, dimensionless, fraction
B_{gi} = initial gas formation volume factor, Rcf/Mscf
1.3597 = conversion factor
$\overline{\rho}_c$ = average in-situ coal-bulk density corresponding to the average in-situ coal composition, g/cm^3
$\overline{G}_c$ = average in-situ coal-gas content corresponding to the average in-situ coal

65. The guide by the Zuber and Gas Research Institute is the product of more than a decade of CBM research sponsored by the Gas Research Institute. It provides practical methods for evaluating and developing CBM reservoirs. The guide describes the unique properties of coal reserves and explains how to determine these properties. It covers the geology of coal reservoirs, the principles of CBM reservoir engineering, the testing techniques, the basics of simulating reservoir performance and evaluating the economics of CBM projects. It also provides practical approaches to solving various CBM reservoir analysis and development problems. Many of the evaluation techniques presented are applications or modifications of conventional gas reservoir techniques. Others have been developed specifically for CBM reservoir engineering. Though the guide draws extensively on CBM experience for basins in the United States, many reservoir engineering concepts can also be applied to other basins.[32]

G. Material Balance

66. King presents the development of two material balance methods for unconventional gas reservoirs. One approach is appropriate for estimating gas-in-place, while the second is suitable for predicting future reservoirs. These techniques differ from the material balance methods for conventional gas reservoirs in that the effects of adsorbed gas are included. Both ways are developed using the assumptions traditionally associated with the material balance approach.[33]

67. Jensen was the first to develop an approximation that eased material balance for CBM reservoirs without sacrificing significant accuracy.[34];

68. Seidle[35] and Clarkson[36] developed a material-balance equation that included adsorbed gas storage.

69. Ahmed presented three contributions to the mathematical development of material-balance-based methods for analyzing unconventional gas reservoirs, particularly CBM reservoirs. These three contributions are a generalized material balance equation (MBE) that

[32] Zuber, M.D. 1996. Basic Reservoir Engineering for Coal. A Guide to Coalbed Methane Reservoir Engineering, Report GRI-94/0397, Chicago, Illinois: Gas Research Institute.
[33] King, G.R. 1993. Material Balance Techniques for Coal Seam and Devonian Shale Gas Reservoirs. Paper SPE 20730 presented at the 1993 Annual Technical Conference and Exhibition, New Orleans, 23–26 September. DOI: 10.2118/20730-MS.
[34] Jensen, D. and Smith, L.K. 1997. A Practical Approach to Coalbed Methane Reserve Prediction Using a Modified Material Balance Technique. Paper 9765 presented at the International Coalbed Methane Symposium, Tuscaloosa, Alabama, 12–16 May.
[35] Seidle, J.P. 1999. A Modified p/Z Method for Coal Wells. Paper SPE 55605 presented at the SPE Rocky Mountain Regional Meeting, Gillette, Wyoming, USA, 15–18 May. DOI: 10.2118/55605-MS.
[36] Clarkson, C.R. and McGovern, J.M. 2001. Study of the Potential Impact of Matrix Free Gas Storage Upon Coalbed Gas Reserves and Production Using a New Material Balance Equation. Paper 0113 presented at the International Coalbed Methane Symposium, Tuscaloosa, Alabama, 14–18 May.

accounts for and incorporates the Langmuir isotherm, initial free gas, water expansion, and formation compaction; prudent CBM reservoir management and optimization requires knowledge of reservoir pressure.; and a final contribution designed to provide an efficient iterative scheme that incorporates the gas-water relative permeability data to predict the future performance of the CBM reservoir. The paper documents the practical applications of the proposed MBE and verifies its accuracy through comparison with results of numerical simulation on several field examples.[37]

H. Analogues

70. One of the chosen methods of evaluation is an analogy. CBM development in Australia and Canada and its maturity provide enough examples which can be used for analogies.

71. Offsetting projects producing from the same coal zone at approximately the same depth and under the same geological conditions may be used as a guideline for estimating area assignments.[38]

I. Performance-based Estimates

1. Production Data Analysis (Decline analysis or Type Curve Matching)

72. CBM reservoirs commonly exhibit two-phase flow (gas+water) characteristics. However commercial CBM production is also possible from single-phase (gas) coal reservoirs, as demonstrated by the development of the Horseshoe Canyon coals of western Canada. Clarkson et al. showed that using simulated and field examples, reasonable reservoir and stimulation estimates can be obtained from production data analysis of coal reservoirs only if appropriate reservoir inputs are used in the study.[39]

73. Recent advances in production data analysis (PDA) techniques have greatly assisted engineers in extracting meaningful reservoir and stimulation information from good production and flowing pressure data. Applying these techniques to CBM reservoirs requires that the unique coal storage and transport properties be accounted for. In recent work, Clarkson et al. have demonstrated how new techniques such as the flowing material balance (FMB) and production type curves may be adapted to account for CBM storage mechanisms (i.e. adsorption).[40]

74. Clarkson et al. demonstrated that modern production analysis methods, modified for CBM reservoir behaviour and combined with analytical (or numerical) modelling, can be used to extract quantitative reservoir information from CBM reservoirs that exhibit a wide range of production characteristics are completed in a variety of styles.[41]

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[37] Ahmed, T., Centilmen, A., and Roux, B. 2006. A Generalized Material Balance Equation for Coalbed Methane Reservoirs. Paper SPE 102638 presented at the SPE Annual Technical Conference and Exhibition, San Antonio, Texas, USA, 24–27 September. DOI: 10.2118/102638-MS.

[38] Canadian Oil and Gas Evaluation Handbook Section 6.4.4.2.1.

[39] Clarkson, C.R., Bustin, R.M., and Seidle, J.P. 2007. Production-Data Analysis of Single-Phase (Gas) Coalbed-Methane Wells. SPE Res Eval & Eng 10 (3): 312–331. SPE-100313-PA. DOI: 10.2118/100313-PA.

[40] Clarkson, C.R., Jordan, C.L., Gierhart, R.R., and Seidle, J.P. 2008. Production Data Analysis of CBM Wells. SPE Res Eval & Eng 11 (2): 311–325. SPE-107705-PA. DOI: 10.2118/107705-PA.

[41] Clarkson, C.R., Jordan, C.L., Ilk, D., and Blasingame, T.A. 2009. Production Data Analysis of Fractured and Horizontal CBM Wells. Paper SPE 125929 presented at the SPE Eastern Regional Conference, Charleston, West Virginia, USA, 23–26 September. DOI: 10.2118/125929-MS.

75. Rushing et al. presented results of a simulation study designed to evaluate the applicability of Arps' [1945] decline curve methodology for assessing reserves in CBM reservoirs.[42]

2. Production decline methods

76. Decline analysis coupled with a volumetric determination of gas in-place remains the most common performance-based method of determining ultimate recovery for a producing CBM well. Still, it is only used once a production-depletion trend has been established.

77. Advanced production data analysis methods such as production type curves and flowing material balance have been adapted recently to include adsorbed gas storage and more complex CBM reservoir behaviour, such as two-phase flow, non-static absolute permeability and multilayer effects.

78. There are two main decline analysis techniques: curve fitting and type curve matching. Each is discussed in the following text.[43]

3. Curve Fitting

79. The production curve of a CBM well will depend on several factors, including:

- The saturation condition of the reservoir
- The saturation medium of the reservoir
- The grade of coal
- The development of permeability (cleat network) within the reservoir
- The presence or absence of free gas
- The composition of the adsorbed gas
- Relative permeability relationship
- Matrix shrinkage
- Regional structural influences
- Completion methods.

80. For a conventional gas well, the gas rate will generally decline from the first day of production, barring certain circumstances such as choked flow or a very active aquifer. A Cartesian graph of production rate versus cumulative production will often yield a straight line (exponential decline) from which a reasonable estimate of the ultimate expected recoverable gas volume (reserves) can be extrapolated. For wet CBM wells, the gas rate will incline during the dewatering phase, during which decline analysis cannot be used. Even after the production begins to decline and a declining trend has been sufficiently established to employ decline analysis, several effects can cause deviation from the straight-line study. The evaluator must therefore take special care in using decline analysis for CBM.

81. In the case of dry coals, such as the Horseshoe Canyon coals of Alberta, economical gas rates can be produced immediately at the onset of production. Production rates from dry coals may decline from inception, similar to conventional gas wells, or can be characterized by a slight inclining or extended flat production period. This phenomenon is usually attributed to permeability enhancement due to matrix shrinkage. Again, decline analysis can only be used once enough gas production data has been collected to establish a predictable decline trend (a minimum of six months is recommended).

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[42] Rushing, J.A., Perego, AD, and Blasingame, T.A. 2008. Applicability of the Arps Rate-Time Relationships for Evaluating Decline Behavior and Ultimate Gas Recovery of Coalbed Methane Wells. Paper SPE 114514 presented at the CIPC/SPE Gas Technology Symposium, Calgary, 16–19 June. DOI: 10.2118/114514-MS.

[43] Canadian Oil and Gas Evaluation Handbook Section 6.4.5.

82. Seidle[44] indicated that although early gas and water production rates from a coal well are often erratic, at the late time, these wells typically exhibit gentle declines in both gas and water.

4. Type curve Matching for dry or dewatered CBM

83. This analysis method has several different types of analysis:

- Agarwal-Gardner estimates fluids in-place volumes, drainage area, reservoir permeability, the skin around the well or fracture half-length/fracture conductivity for hydraulically fractured wells
- Blasingame estimates skin, formation permeability, in-place fluid volumes, and reservoir drainage area. Blasingame has several families of advanced type curves such as finite conductivity, elliptical, water drive, open-hole horizontal well type curves, in addition to classic radial and fracture type curve models
- Fetkovich estimates EUR, skin, and formation permeability from the rate history of the well
- NPI is the inverse of the Agarwal-Gardner type curves. This analysis method is often preferred by those from a pressure transient analysis domain. Outputs are the same as Agarwal Gardner
- Transient is useful for datasets containing long-term transient flow. Outputs are the same as other modern type curve-match techniques
- Wattenbarger is well-suited for reservoirs that exhibit a long-lasting transient linear flow regime. This method is beneficial for the analysis of tight and shale gas wells.[45]

5 Reservoir Simulation

84. Reservoir simulation includes the use of analytical and numerical flow models that are "calibrated" by history-matching, well production, and flowing and static (shut-in) pressures and are then used to forecast single or multiwell production under a variety of operational and development scenarios. Various commercial simulators now exist for analyzing CBM reservoir behaviour, including many aspects of the storage and transport mechanisms unique to CBM. Reservoir simulation may be performed at the single- or multi-well level. In either case, for reserves-booking purposes, reservoir simulators must be appropriately calibrated to existing well performance using proper constraints on static and dynamic data.[46]

J. Resources Assessment Methods

85. (Contingent) Resources should be demonstrated by drilling, testing, sampling or logging hydrocarbon gas content (e.g., coal sample or gas flow) and coal thickness sufficient to establish the existence of a significant quantity of potentially moveable hydrocarbons (i.e., there should be data indicating adequate permeability to flow within the coal seam). Gas rates may be undemonstrated or uneconomic, the gas composition may or may not support marketability, a significant distance from existing well locations that have demonstrated commercial potential, outside coal fairway or acceptable depth limits (typically 200 to 1000 m) may require as yet unproven well technology, (e.g., novel stimulation techniques or horizontal/multilateral wells), outside areas that can be accessed legally (e.g., protected land), development plan immature or subeconomic, market not assured, lack of approvals.

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[44] Seidle, John P., Coal Well Decline Behavior and Drainage Areas: Theory and Practice, 2002, Society of Petroleum Engineers, Inc., SPE 75519.

[45] Canadian Oil and Gas Evaluation Handbook Section 6.4.5.2.

[46] Canadian Oil and Gas Evaluation Handbook Section 6.4.6.1.

86. As with other conventional and non-conventional oil and gas resources, the estimation of CBM resources and reserves can be determined using deterministic or probabilistic methods.[47]

[47] Canadian Oil and Gas Evaluation Handbook Section 6.4.1.

Annex 1

Taskforce on Nature-related Financial Disclosures

Proposed technical scope and implications for CBM

1. Across science, public opinion, non-financial companies and financial institutions, there is a fast-growing cognizance of both the impact and dependency that businesses have on nature. In September 2020, an international financial sector-led Informal Working Group (IWG) was formed to develop a Taskforce on Nature-related Financial Disclosures (TNFD).[48]

2. The TNFD will build up a framework for organizations (non-financial companies and financial institutions) to inform and take action on growing nature-related risks. The framework will direct both how nature may influence the organization but also how the organization influences nature and will serve well as a mechanism to assist organizations in appreciating, disclosing and dealing with the financial risks and opportunities3 related to the weakening state of nature.

3. The goal of the TNFD is to offer a framework for organizations to inform and take action on changing nature-related risks, to sustain a shift in global financial flows outside of nature-negative outcomes and concerning nature-positive consequences. The TNFD framework will embrace a four-pillar methodology organized around how organizations operate: governance, strategy, risk management, metrics and targets. This is the equivalent structure used by the Task Force on Climate-related Financial Disclosures (TCFD) context.

4. The usage of the term “nature-related risks and opportunities” is recommended to broadly refer to the risks and opportunities to an organization caused by the relationships between its activities and nature. This methodology to risk follows TCFD's comprehensive approach to financial materiality that stretches beyond urgent threats to consider transition risks through the use, for example, of scenarios.

5. The TNFD structure will parallel and draw from current initiatives, frameworks and standards applicable to its scope. The Taskforce, when established, will be concerned about how best to work together with significant standard setters and with whom.

6. When collecting TNFD-aligned coverage material, financial institutions will utilize data from corporate disclosure and third-party data sources.

7. For the financial sector to respond to nature-related risks and opportunities, the TNFD framework should be instantaneously usable by non-financial companies and financial institutions and constantly enhanced over time.

8. There are two examples of how TNFD-aligned reporting could be used:

- To report and supplement financial statements and the resolve of the valuation of companies, credit risk, market risk and business risk
- To establish impacts and dependencies on nature.

9. Potential (internal and external) users include non-financial companies, financial institutions, research, rating and data providers, financial supervisors and prudential authorities.

10. The term “nature-related risks and opportunities” is recommended to generally refer to the risks and opportunities to an organization put forward by the relationships between its activities and nature. In addition to shorter-term financial troubles, this includes longer-term risks signified by their impacts and dependencies on nature.

48 https://tnfd.global/

11. The TNFD assumes the definition of *impacts* offered by the Science-

12. Based Target Network (SBTN): "*positive or negative contributions of a company or other actor toward the state of nature, including pollution of air, water, soil; fragmentation or disruption of ecosystems*

13. The TNFD accepts the definition of *dependencies* offered by the SBTN: "*aspects of nature's contributions to people [ecosystem services] that a person or organization relies on to function, including water flow and quality regulation; regulation of hazards like fires and floods; pollination; and carbon sequestration*

14. The TNFD will set forth an adaptable, staged approach for reporting entities to line up with the framework increasingly. The staged process will explain three stages of requirements that grow in complexity:

- The first stage – "basic" – describes a fundamental evaluation of nature-related risks, impacts and dependencies and geospatially explicit wherever possible that should be deemed vital but with significant room for improvement in terms of coverage and precision.
- The second stage – "intermediary" – identifies a halfway path, delivering a further thorough assessment of nature-related risks through limiting generalizations.
- The third stage – "comprehensive" – specifies full placement with the TNFD framework and a comprehensive appraisal of nature-related risks. This stage delivers the best opportunity for the TNFD to realize its goal.

15. What is recommended to be involved in the technical scope of the TNFD? Living (biotic) nature; water, soil and air; and mineral depletion as it relates to other aspects of nature: specifically, the latest as an examination of the impact of quality minerals (including oil and gas (CBM)) on the health and vitality of living nature, water, soil and air is in the scope.

16. The staging below reveals the understanding that nature-related risks coupled with living nature, water, soil and air are of higher importance than risks associated with mineral depletion (gas from CBM):

17. **Basic** - priority types of nature-related risk in priority industries associated with living nature, water, soil and air.

18. **Intermediary** - priority types of nature-related risk in priority industries associated with living nature, water, soil, air and mineral depletion (as it relates to other aspects of nature).

19. **Comprehensive** - all nature-related risks in all industries associated with living nature, water, soil, air and mineral depletion (as it relates to other aspects of nature).

Annex 2

Coal Bed Methane Definitions and Associated Terms

Associated Term	*Definition*
Conventional natural gas	Natural gas that occurs in a standard, porous, permeable reservoir rock and that, at a particular time, can be technically and economically produced using standard production practices.
Conventional resources	A general term for petroleum is in accumulations. The primary trapping mechanism is related to hydrodynamic forces and localized structural or depositional geological features and can be recovered and processed for sale using typical oil field practices.
Isotherm	A connecting line points of equal temperature.
Material balance methods	Engineering methods of analyzing project performance based on mass-balance concepts, wherein expansion of in-situ rock and fluids is related to influx-efflux and production-injection streams. Material balance methods are commonly used to determine or predict production performance fluids in place.
Methane	In addition to its ordinary scientific meaning of CH4 (a light, odourless, colourless gaseous hydrocarbon), a mixture mainly of methane that ordinarily may contain some ethane, nitrogen, helium, or carbon dioxide.
Natural fracture	A discontinuity in the rock is caused by diastrophism, a deep erosion of the overburden, or volume shrinkage. Examples include shales that lose water, igneous rock's cooling, and sedimentary rock's desiccation.
Non-conventional natural gas	Natural gas is not classified as conventional natural gas. An example would be CBM. Also referred to as unconventional natural gas.
Unconventional resources	A general term for petroleum is in accumulations that are pervasive throughout a large area and not significantly affected by hydrodynamic influences. Examples include coal bed methane (CBM), basin-centred gas, shale gas, gas hydrate, natural bitumen (tar sands), and oil shale deposits. Typically, such accumulations require specialized extraction technology (e.g., dewatering of CBM, massive fracturing programmes for shale gas, steam or solvents to mobilize bitumen for in-situ recovery and, in some cases, mining activities). Moreover, the extracted petroleum may require significant processing before the sale (e.g., bitumen upgraders). Also known as "non-conventional resources" and "continuous deposits."