The Foundations of the Resource Pyramid: Canada's Other Petroleum Reources

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Summary

Almost 40 years ago the CSPG embarked on an ambitious project to characterize "The Future Petroleum Provinces of Canada – Their Geology and Potential". The results were published under the same title as Memoir 1 (McCrossan, 1973). As well as initiating the CSPG's Memoir publication series Memoir 1 provided a synoptic overview of Canadian Petroleum Potential. That work, although still a useful reference, is superseded by events and changes in geoscience knowledge, technology and commerce.

It remains important to identify and characterize Canada's potential petroleum resource endowment, but it has also become increasingly important to provide sufficiently specific and detailed geological resource characterizations that are proxies for reservoir performance as a function of technology applied and commodity price. The derived scientific understanding should also feedback into engineering and business disciplines to improve practice and to identify new technological needs that will improve the economic performance and competitiveness of Canada's petroleum resources. Despite the "prophets of doom" (i.e. peak oil), the increases in production, the commercialization of new resource types and historical petroleum price behaviour are completely contrary to that of a scarce resource. Global petroleum supply, especially crude oil, remains subject to geopolitical risks, such that crises of supply cannot be entirely ruled out, but beyond those marginal risks the future challenge for the upstream Canadian petroleum industry will depend, among other things, on whether Canada remains a competitive petroleum producer in an environment characterized by rapid technological change.

Introduction

CSPG Memoir 1 (McCrossan, 1973) provides an assessment of Canada's conventional petroleum resources in the early 1970's. Memoir 1's authors identified 38 "unmetamorphosed" sedimentary basins that covered an area of 2.476×10^6 mi^2 of which 1.064×10^6 mi^2 underlay the continental shelves and which were attributed a total volume of 3.538×10^6 mi^3 of sedimentary rocks that were attributed 96×10^9 barrels of oil equivalent recoverable ultimate potential. That number was more pessimistic than a prior estimate of 121×10^9 BOE recoverable that the Canadian Petroleum Association had estimated previously (Canadian Petroleum Association, 1972).

Much has changed since the publication of Memoir 1.

1. There are new standards and classifications for reporting both reserves and resources (National Instrument 51-101 in 2003 and the Petroleum Resources Management System in 2007).
2. A number of economically and geographically oriented methods and applications of qualitative and quantitative petroleum resource assessments were developed and applied (e.g. Procter et al., 1984; Podruski et al., 1988; Reinson et al.1993; Lee, 1998).

3. The concept of the petroleum system and its impact on resource appraisals were introduced to better characterize and compare resource potential and exploratory risks.
4. As a result of both scientific and technological progress the unconventional resources, lightly mentioned in Memoir 1, have grown significantly in number and importance and redefined the word "reservoir".
5. While some production has been established in the geographic frontiers most remain undeveloped just as,
6. Canada enlarges its territory and defines its exclusive economic zone on the continental margins in response to its adoption of the United Nations Convention on the Law of the Sea.

Currently the petroleum potential of Canada has been revised upward significantly. For example, in less than 30 years after Memoir 1 was published, the bituminous resources of the three major Alberta oil sands deposits (Athabasca-Wabiskaw, Cold Lake, and Peace River; Marsh, 2006) which alone cover >140,000 km^2 (54,000 mi^2) — an area larger than England — were attributed proven in place reserves of 1.75 trillion barrels (280×10^9 m^3) of which 173 billion barrels (27.5×10^9 m^3) were estimated recoverable at contemporary prices, using established technology, where Parsons (1973) had attributed 0.3×10^{12} barrels (4.8×10^9 m^3) in place, almost a six-fold increase. It is both important and timely to revise and update our strategic overview of petroleum opportunities in Canada, both as a strategic tool and as a handbook for a new generation. Similarly, at the start of this century, prior to the identification of major "shale-hosted" or coal-bed petroleum resources, the amount of conventional natural gas produced from the Western Canada Sedimentary Basin was approaching 100 Tcf, which was the approaching the ultimate potential of 129.8 Tcf assigned in Memoir 1 (McCrossan and Porter, 1973) while the ultimate potential of the basin had increased to more than 232 Tcf (6.5×10^{12} m^3; Reinson et al., 1993).

The most striking change between 1973 and today is where the new supply has come from. With the exception of offshore Newfoundland, where annual crude oil production which began in 1998 is currently about 100 million barrels annually, the promise of the geographic frontier basins has been muted. Where Memoir 1 implies that the future of Canadian petroleum supply was to be found in the conventional resources of the geographic frontiers the reality is that the Western Canada Basin continues to dominate supply as a result of innovation in geological knowledge, engineering practice and technological invention. What will the resource, reserve and supply models of 2050 be like?

Method

McKelvey (Anonymous 1972; 1980; Voelker et al 1979) is attributed the method of classifying natural resource potentials as a function of both economic situation and certainty of occurrence, resulting in the attribution of his name to the McKelvey diagram. It appears that J.K. (Jim) Gray of Canadian Hunter was the first to recognize the strong tendency for resource classes to increase in size with decreasing economic competitiveness and uncertainty in characterization such that they could be illustrated using a pyramidal diagram (attributed by Masters, 1979 as cited in McCabe, 1998, thanks to T.R. Klett, USGS Denver for helping to track this down). Ahlbrandt and McCabe (2002) recognized the value of this concept and promoted it effectively for petroleum resources, although the National Petroleum Council also laid claim to this method, albeit later (NPC, 2003).

The development of the resource pyramid is more than an effective graphical image; it is a conceptual recognition of fundamental characteristics of both natural resource endowments and their conversion to supply. These key characteristics are:

1. The total resource base is immense.

2. At a given moment only a fraction, usually a small fraction of the resource base is economically exploitable with existing technology.
3. With time and effort the development of technology and the augmentation of knowledge make a larger proportion of the total resource endowment accessible.
4. Geoscientists should change from identifying and characterizing resources using current technological and economic constraints as “cutoffs” to identifying and characterizing the total resource endowment as a function of both their current commercial potential as well as their knowledge and technology barriers to current commercial development.

If we are to, and we should, look forward to whether Canada will be an economically competitive source or petroleum supply we need to identify, characterize and analyze our current state of knowledge regarding the total resource endowment with a totally different approach. Not only must we understand how change could or will affect the competitiveness of our own production, but we need to be aware of the impacts these changes can have on the resources of others elsewhere, as “shale gas” production in the USA has taught us. This competition can be internal and external. It may be as important to know how “shale oil” production growth will affect synthetic crude oil production from bitumen. How will eastern European shale gas developments affect planned LNG exports to Asia?

Resource Types and Their Often Overlooked Potentials:

The following resource types also need to be considered when attempting to understand total resource endowment.

1. Enhanced recovery or performance from identified conventional and unconventional accumulations (improvements in recovery factor and cost reductions in the production of existing contributions to supply).
2. Contributions from established unconventional resources as a function of technology and economics (e.g. coal bed methane; shale gas; tight oil; gas hydrates).
3. Synthetic petroleum supply from non-established resources (oil shales, coal to petroleum technologies).

Improved Recovery from Identified Resources:

Most conventional production occurs with natural depletion-primary recovery, or secondary recovery, the most common secondary method being pressure maintenance. Primary recovery factors vary geographically with accumulation type, reservoir geology and oil composition. The average WCSB primary recovery factor is ~14%. The average is reduced for heavy oils, where primary recovery can be 5% or lower. More typically, primary recoveries are ~16% for Paleozoic carbonates and even higher, exceeding 19%, for non-biodegraded production from Mesozoic reservoirs. Secondary recovery commonly adds an incremental 4%-10% recovery. Secondary recovery can be spectacularly effective, as in the Northwest Territories, where production comes primarily from Devonian carbonates and most of that from the Norman Wells reef. The secondary recovery increased the recovery from the 16% typical of Paleozoic carbonates to 46%, adding an incremental 15.2 x $10^6 m^3$ (96 x 10^6 bbls). Elsewhere secondary recovery results are more modest. Most of the incremental 957.8 x $10^6 m^3$ (6,034 x 10^6 bbls) from secondary recovery is from Alberta, where secondary recovery identified an incremental 652.0 x $10^6 m^3$ (4,108 x 10^6 bbls). In Saskatchewan 4% or 233.9 x $10^6 m^3$ (1,473 x 10^6 bbls) has been added mostly from Carboniferous subcrop pools. The use of secondary schemes in Manitoba has been negligible and only 1% or 1.3 x $10^6 m^3$ (8 x 10^6 bbls) is attributable to secondary recovery.

Current Tertiary Recovery:

Aside from a few projects, often technology demonstrations, tertiary recovery has not been applied widely. Overall, to the end of 2004, tertiary recovery produced only an incremental 209.0 x $10^6 m^3$ (1,317 x 10^6 bbls) accounting for less than one percent increase in recovery. Some regions, notably Manitoba, British Columbia and the Northwest Territories have effectively no contribution from tertiary programs. This is not indicative of the tertiary programs, but rather it indicates the lack of their application. Tertiary programs have been historically restricted to Alberta, where projects added an incremental 176.9 x $10^6 m^3$ (1,071 x 10^6 bbls), resulting in a 2% increase in reserves.

These Alberta tertiary recovery projects do not include in situ oil sands projects, such as cyclic steam stimulation project at Cold Lake, or Steam Assisted Gravity Drainage (SAGD) projects, which produced 203.5 x $10^6 m^3$ (1,282 x 10^6 bbls) bitumen by the end of 2004 (CAPP, 2005), all of which is attributed to tertiary recovery. The recoverable reserve of in situ oil sands 534.8 x $10^6 m^3$ (3,369 x 10^6 bbls), about 20% of the initial in place bitumen (ibid.).

In Saskatchewan, the small incremental volume, 32.0 x $10^6 m^3$ (202 x 10^6 barrels) from tertiary programs conceals the importance of the Weyburn CO_2 sequestration and tertiary recovery project. The project, in a Carboniferous carbonate pool, is expected to produce an incremental 20.6 x $10^6 m^3$ (130 million barrels), using miscible or near-miscible CO_2 displacement from a pool that has produced 53.2 x $10^6 m^3$ oil (335 million barrels) since 1955. Important recovery improvements accompanied the in-fill drilling program that preceded CO_2 flood. The project extends field life by ~25 years, and it improves recovery factor ~28%, from the CO_2 flood alone. In addition, it will permanently sequester ~20 million tonnes CO_2.

Future Recovery:

Clearly the WCSB is a potential target for application of established and new recovery and stimulation technologies, including, miscible floods, simulated horizontal wells, and SAGD. A recent oil supply model (NEB, 2006) suggests WCSB oil supply will increase from 2005 volumes of 365 x $10^3 m^3$/day (2.3 x 10^6 bbls/day) to 613 x $10^3 m^3$/day (3.9 x 10^6 bbls/day) by 2015. That increase is due to increased bitumen production alone. The model suggests that conventional oil production will decline in spite of improved recovery (NEB, 1999; 2003). Still, the model suggests that future improvements in conventional light and heavy recovery will additionally contribute between 722 x 10^6m3 to 794 x 10^6m3 (4.55 x 10^9 bbls to 5.00 x 10^9 bbls), compared to NEB (1999; 2003) and CAPP (2005) ultimate recovery estimates, respectively. This represents an incremental 16%-19% increase in recovery and a volume comparable to the remaining established reserve. It implies that average recovery factor increases from 21%, currently, to 27.5%. The NEB (2001) heavy oil estimates increased the conventional heavy oil 30% over previous resource potential (Lee, 1998), and both heavy oil and oil sand resource bases may increase as technology develops. In addition, shale oil and oil shale are not yet a part of supply, and their commercialization could also add significantly to recovery growth. While technological improvements and demonstration projects are encouraging, several new ones of which are planned, it will require much study and many more projects to know if the inferred recovery improvements from both conventional and non-conventional crude oil resources can be realized commercially.

Contributions from established unconventional resources

Several new resources have, or have the potential to contribute to the reserve base. These include:

1. Additional Coalbed methane plays.
2. Shale hosted petroleum including shale gas, shale oil and tight oil.
3. Gas Hydrates

Technological developments, particular horizontal drilling and hydraulic fracturing have made it possible to commercial extract natural gas from 'shales'. This has transformed the natural gas resource potential and supply, decoupling crude oil and natural gas and prices. Yet, some of these "new" Shale Gas technologies were applied early to crude oil plays most notably Upper Devonian and lower Carboniferous Bakken Formation in the Williston Basin, where Shale Oil exploration and exploitation continues.

We will discuss these potentials in more detail during the presentation. However consider the Colorado Group Total Petroleum System (Creaney et al., 2003). Recognizing the potential of these technological developments we re-evaluate Colorado Group crude oil potential, by combining a probabilistic conventional crude oil resource model for the coarse clastic parts of the succession with deterministically mapped crude oil content in “shalier” parts of the succession. Our work also indicates that the anhydrous pyrolysis yield at 300^{o} C (RockEval/TOC S1 peak) can be employed to quantify shale oil content and identify exploratory leads with improved reservoir porosity. Accurate formation pressure data might also help with the identification of the best targets for technology application and development. The resulting map of Colorado shale crude oil content is both well correlated with existing production and a leading indicator for other regions where Colorado shale should be tested and evaluated. Our analysis suggests that Colorado Gp. sources generated ~3.5 $X10^{11} m^3$ of which ~95% was expelled. Commercial conventional plays contain ~2.3 billion m^3 IOIP in 1095 pools. The conventional plays are inferred to also have additional potential for 601 $X10^6 m^3$ IOIP. In addition, we recognize and classify a Colorado Group Shale Oil resource that includes:

- 8 $X10^6 m^3$ IOIP in rocks 0.05 < φ (porosity) < 0.06 that may be currently commercial.
- 680 $X10^6 m^3$ IOIP in rocks 0.03 < φ< 0.04 that are probably technologically accessible and which may be commercial currently, as well as,
- 17.6 $X10^{10} m^3$ IOIP in rocks φ<0.02 that are currently neither accessible nor commercial, but which could be the target of technological development.

Clearly there is a significant undiscovered potential in the Colorado Group. Note that our analysis suggests that there is as much to be found by a more intensive exploration of the conventional plays as is currently attributed to the potential of the shale hosted resources.

Synthetic petroleum supply from non-established resources

As prices increase new resource could also be developed. The two most obvious are oil shales and synthetic petroleum from coals. Both resources have histories of use and commercial performance elsewhere and both have been the subject of continued research, particularly for in-situ methods of petroleum synthesis which have indicated promising potential. As Canada is well endowed with both these resource types (MacCauley, 1984; Smith, 1984) it seems reasonable to consider the possibility of and conditions for these two resources to make contributions to petroleum supply.

Conclusions

Much has changed since Memoir 1 (McCrossan, 1973) presented a synoptic overview of Canadian petroleum resources. The Canadian petroleum resource endowment has grown, primarily in the historical conventional producing areas, as the result of the application of geological and engineering science in conjunction with new technological developments. The Western Canada Sedimentary Basin has served as “post-child” for the resource pyramid concept, as new technologies applied innovatively to previously non-commercial resources have relentlessly augmented reserves and supply. The promise of new commercial supply from conventional plays in the geographic frontiers has not effectively materialized, except for offshore Newfoudland and Labrador. Looking forward we would be wide to adopt the resource pyramid concept to all Canadian resources. The challenge of the future is probably not one of secure supply, but one of developing a commercial competitive resource base, as the same technologies are applied elsewhere in competition to Canadian production. A better knowledge of our resource endowment, better characterized to understand its likelihood of commercial development should be the future task of our national Geoscience community.

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