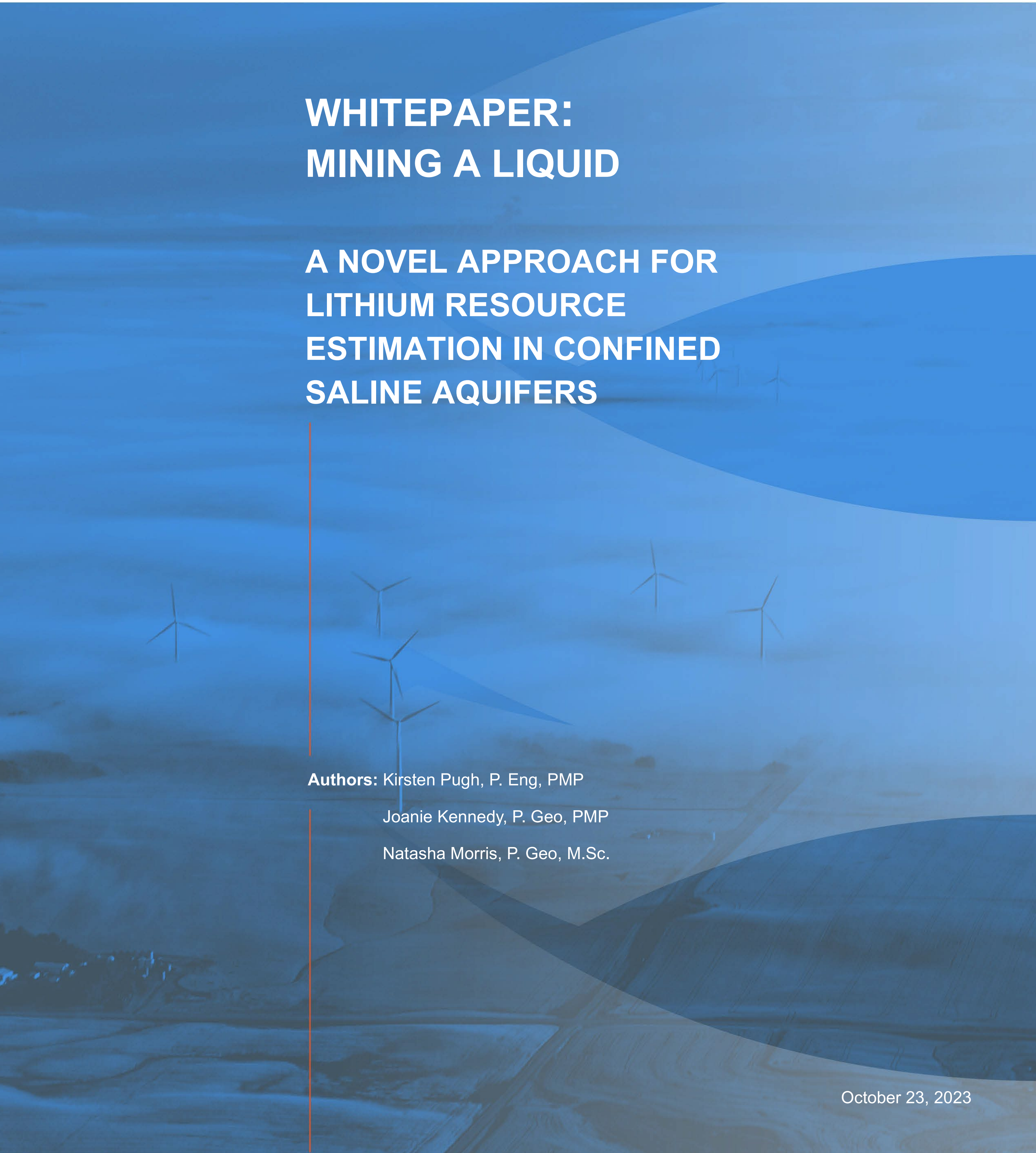
E3 LITHIUM



WHITEPAPER: MINING A LIQUID

A NOVEL APPROACH FOR LITHIUM RESOURCE ESTIMATION IN CONFINED SALINE AQUIFERS

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Executive Summary

Confined saline aquifers are a significant emerging source of lithium in the global market. They represent a distinct resource type for brine-hosted lithium deposits and there is a need to develop standards and guidelines for resource and reserve estimation to account for their unique characteristics and challenges.

We present a methodology outlining a new approach for estimating resource volumes for confined saline aquifers. The approach honours the existing NI43-101 standards and best practices for estimation of mineral resources and mineral reserves as set by the Canadian Institute of Mining (CIM) and incorporates methodology that has long been utilized in Canada through the NI51-101 framework, the industry and national standard for resource estimation of liquids (or near liquids).

This methodology seeks to become a new standard for confined saline aquifers, to differentiate them from existing unconfined salar-based deposits and standardize the approach for this emerging and distinct resource type.

Introduction

The global lithium industry is evolving, and the methodology for estimating mineral resources and mineral reserves needs to evolve with it.

Following WWII, the lithium industry has been dominated by lithium production from hard-rock mines[1], typically associated with spodumene[2] deposits. Starting in 1995, development in the Lithium Triangle[3] introduced salar[4]-based lithium production. Advances in direct lithium extraction (DLE) technology have unlocked the development potential of lithium enriched brines found in confined saline aquifers within sedimentary basins.

Different jurisdictions maintain their own standards for mineral resources and mineral reserves reporting. The Committee for Mineral Reserves International Reporting Standards (CRIRSCO[5]) enables consistency across National Reporting Organizations and contributes to the development of best practice international reporting.

This novel approach for lithium resource estimation in confined saline aquifers, leveraging NI51-101 methodology and staying NI43-101 compliant, details a methodology that's specific to this emerging resource type, as the industry looks to unlock new sources of lithium production.

Problem Definition

In Canada, E3 Lithium's jurisdiction, the Canadian Institute of Mining (CIM) sets the standards for best practices when writing NI 43-101 technical reports with estimation of mineral resources and mineral reserves[6]. Specifically for lithium, a best practice guideline[7] exists, based on salar-based deposits which are hosted in **unconfined** aquifers subject to significantly different hydrologic processes than **confined** aquifers.

No standard exists for confined saline aquifers, which are a significant emerging source of lithium in the global market.

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[1] Charted: Lithium Production by Country (1995-2020) (visualcapitalist.com): A Brief History of Lithium Mining

[2] Spodumene: Mineral information, data and localities. (mindat.org)

[3] Lithium Triangle - Wikipedia: Region of the Andes rich in lithium reserves; encompassed by Argentina, Bolivia, & Chile

[4] Brine Lithium Deposits | Geology for Investors: Salars are continental lithium deposits, also known as salt lakes or salt flats

[5] CRIRSCO (cim.org): International resource and reserve reporting

[6] https://mrmr.cim.org/media/1146/cim-mrmr-bp-guidelines_2019_may2022.pdf: CIM Estimation of Mineral Resources & Mineral Reserves Best Practice Guidelines

[7] DRAFT 1 (cim.org): CIM Best Practice Guidelines for Resource and Reserve Estimation for Lithium Brines

High-Level Solution

E3 Lithium, Alberta's leading lithium developer and extraction technology innovator has developed a new approach for estimating resource volumes in confined saline aquifers.

Confined saline aquifers can leverage methodology that has long been utilized in oil & gas development, where resource estimation of liquids (including high viscosity near liquids) is common practice and standardized in Canada through the NI51-1018 standard. Brine-hosted lithium resources have more in common with petroleum resources than they do with hard-rock mining – but not all brine-hosted lithium resources are created equal. Unconfined aquifers, which are connected to atmospheric pressure, are under a completely different pressure regime than confined aquifers, which are influenced by both depth and containment. There are often gases (generally dissolved but sometimes free in certain structures) present in confined aquifers that provide pressure support. These pressure regimes, whether gravity-controlled for unconfined aquifers, or mass-balance controlled for confined aquifers, are fundamentally different and therefore different resource estimation methodologies should be applied to each.

Current CIM best practice guidance for lithium brines (CIM 2012)[7] outlines the methodology for unconfined aquifers. For confined aquifers, we propose that an alternative methodology is required as gravitational forces are not the sole, or necessarily even the primary, recovery mechanism9. This is where oil and gas reserve estimation methodology has some applicability in the lithium brine space, based on reservoir engineering methods.

Pressure is the key reservoir engineering principle, as it is a significant factor dictating flow rates. Pressure management is key to maximizing resource extraction over the long term and this will be the same for confined aquifer brine resources.

In oil and gas reservoirs, varying pressure management commonly changes over the life of the resource development. Typically, the first stage of development, called primary recovery[10], leverages natural energy contained in the system to drive fluids to surface. This stage includes adding artificial lift to enhance production rates, to offset pressure decline in the confined zone. Once primary recovery becomes uneconomic, typically at around 5-10% of the resource volume, a transition to secondary recovery occurs.

During secondary recovery[11], pressure maintenance is undertaken to stabilize or increase production rates. A common mechanism is to inject fluids (typically water) to balance out the produced fluids (typically oil and/or gas + water). The ratio of injected volume (corrected to

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[7] DRAFT 1 (cim.org): CIM Best Practice Guidelines for Resource and Reserve Estimation for Lithium Brines

[8] Regulatory Instrument Details | ASC: Alberta Securities Commission, standards of disclosure for oil & gas activities

[9] Reservoir drive mechanisms - AAPG Wiki: Reservoir Drive Mechanisms

[10] primary production | Energy Glossary (slb.com)

[11] secondary recovery | Energy Glossary (slb.com)

reservoir temperature and pressure conditions) to produced volume (corrected to reservoir conditions) is known as the "voidage replacement ratio". Pressure maintenance is a key parameter for a brine resource or reserve estimate.

Additionally, in a balanced voidage scenario, total system compressibility is not a controlling factor on the producible volume because the reservoir pressure is being maintained. Therefore, the pressure change governing the flow rate into the wellbore is a function of the pressure drop created by the artificial lift. This pushes quantification of the production rate into the realm of economic evaluation, which is only applicable at a reserve estimation level.

It important to note that emerging regulations in some jurisdictions mandate fluid reinjection as part of the brine production scheme[12]. Reinjection brings challenges as well as benefits, as lithium depleted brine will be added to the reservoir and dilution of the resource over time will need to be managed. However, this type of production scheme has been utilized for oil and gas reservoir development for decades and fluid breakthrough can be managed, with the field optimized in real time. These aspects of production need to be evaluated as part of the reserves analysis, as by-passed brine will need to be excluded from the reserves versus the resource. Without pressure maintenance, the reserve volumes will be limited to primary recovery volumes.

Solution Details

In applying this methodology to confined aquifers, the fluid and rock properties are included in the resource estimation, while the reservoir drive mechanisms are included in the reserve estimation by being applied as Modifying Factors[13]. For the purposes of this white paper, the original in place volume, specific to lithium resource estimation, has been termed "Original Lithium In Place", or "OLIP", representing the total volume present in the subsurface. Subsequently, the producible lithium volume has been termed "Producible Lithium In Place", or "PLIP", representing the total volume that can be brought to the plant inlet for processing. The final, recoverable volume, termed "Recoverable Lithium In Place" accounts for any losses during the processing stage, and represents the total sales volume.

The resource estimate is based on a "producible volume", which is calculated by taking the original in place volume and multiplying by a recovery factor[14]. The recovery factor includes a mix of fluid and rock properties (such as viscosity and permeability), as well as reservoir drive mechanisms (particularly pressure regime) that dictate how much brine will be able to be pumped to surface, as a reasonable prospect for eventual economic extraction at a mineral

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[12] Directive 090: Brine-Hosted Mineral Resource Development (aer.ca): See 7 Mineral Schemes

[13] cim-definition-standards_2014.pdf: Modifying Factors are considerations used to convert Mineral Resources to Mineral Reserves. These include, but are not restricted to, mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governmental factors.

[14] Reserves estimation - AAPG Wiki: See Volumetric Estimation

resource estimation confidence level, and economically at a mineral reserve estimation confidence level.

Modifying standard oil equations[15] for lithium, producible volume can be broken down as follows:

$$PLIP = (OLIP)(RF)$$

Where:

OLIP = Original Lithium In Place

RF = Recovery Factor

Given:

$$OLIP = (Pore\,Volume)(S_w)(\frac{1}{B_w})(1 - Sw_{irr})(Li_{conc})$$

Where:

Pore Volume = (Area)(Thickness)(Porosity)

S_w = Water Saturation

B_w = Water Formation Volume Factor

Sw_{irr} = Irreducible Water Saturation

Li_{conc} = Lithium Concentration

The methodology is discussed step-by-step:

1. **Pore Volume**

Pore volume quantifies the space within the rock formation that contains the brine-hosted mineral resource. Pore volume is the basis for any resource estimate, and it can be calculated with varying degrees of certainty as geological confidence supporting the estimate increases over time with data and analysis.

At an Inferred level, the pore volume calculation can take its simplest form: area * thickness * porosity. Note that thickness can be either *gross* or *net*, provided it is paired with the

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[15] Reserves estimation - AAPG Wiki: Volumetric Estimation of OOIP and ROIP

appropriate porosity value. The author's preference is to begin with the end in mind, by using *net thickness* as it is more directly aligned to producibility, a key Modifying Factor, and applying a single [average or P50] value for effective porosity. Net thickness excludes any pore volumes below a porosity cut-off, while gross thickness includes them. The basis for determining a porosity cut-off, with the intent of excluding non-producible portions of the reservoir, is described below.

Pore volume methodology can and should evolve as geological confidence increases as resource estimation moves from inferred, to indicated, to measured, and eventually to reserve categories through the application of Modifying Factors.

At the Indicated and Measured level, the authors recommend a full-scale geological model, discretized sufficiently in three dimensions to capture changes in both thickness and porosity over the area of interest.

Porosity can be either *total* or *effective*, where total porosity measurements include disconnected pores which are not accessible for fluid flow. This raises the question of which porosity value, total or effective, your dataset is representing. In confined saline aquifers, porosity data is typically sourced from well logs, and core samples and analyses. Well logs are responding to specific physical characteristics of the rock and fluid within their depth of investigation and represent total porosity values as there is no mechanism to differentiate between isolated pore space and connected porosity. Effective porosity can then be calculated from total porosity from well logs. Core porosity, on the other hand, represents effective porosity as the standard measurement relies on physical displacement of an inert gas (typically helium) into the pores, and can only access the connected pore spaces.

Consistent with the recommendation above, the authors recommend using *effective porosity* and pairing it with *net thickness* for the pore volume calculation as this volume represents the fluid volume that is producible and is therefore theoretically available for extraction.

2. Water Saturation

Water saturation refers to the proportion of water contained in the pore space versus other fluids. In oil and gas, reservoirs are typically 3-fluid systems with oil, gas, and water present in the pore space. In confined saline aquifers, water is typically the only fluid present, potentially with a small quantity of dissolved gas, making $S_w \approx 1$.

3. Water Formation Volume Factor

Formation volume factors[16] represent the difference between volume at reservoir conditions and volume at surface conditions. This value is typically ~ 1, as water is largely incompressible. At an inferred level, this is a reasonable assumption. At the measured and indicated level, the

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[16] Produced water formation volume factor - PetroWiki (spe.org): Water Formation Volume Factor

authors recommend physical sampling and measurement to determine the appropriate value for the confined saline aquifer in question, as water is in fact often compressible at pressures observed in confined geological formations, although typically still in the <10% range.

4. Irreducible Water Saturation

As described above, the term effective porosity is used both in hydrogeology and the oil and gas industry to represent connected pores, although there is some inconsistency as to whether effective porosity does or does not include irreducible water (API 1998[17]). Irreducible water is a term used for water that remains bound in pore spaces due to capillary forces in the presence of other fluid phases. In an unconfined aquifer, it would represent water retained in the pore space after gravitational draining of the sample due to capillary forces.

The question of whether or not irreducible water should be excluded from the resource estimation for brine-hosted lithium deposits held within confined saline aquifers is a matter of debate, with precedent on both sides. Specifically relevant to this discussion, several reservoir engineering references discuss that in single-phase systems that are fully saturated, irreducible water saturation be safely ignored[18].

This proposed methodology for confined saline aquifers advocates for excluding irreducible water from the resource estimate on the following basis:

While there is a physical mechanism controlling fluid adherence to grains (typically clays), the rationale for excluding irreducible water saturation is driven by differences in fluid wettability in multi-phase systems, resulting in preferential production or retention of certain fluid types.

In typical confined saline aquifers, the area of interest is almost entirely water saturated, with dissolved gas anticipated to stay in solution provided that the reservoir pressure is maintained above the bubble point.

For a resource estimate, pressure maintenance above the bubble point can be made as an assumption, in support of the resource being a reasonable prospect for eventual economic extraction.

For a reserve estimate, demonstrating the mechanism for maintaining pressure above the bubble point would be required to justify the exclusion of irreducible water saturation from the producible lithium in place value.

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[17] RP40-1 (energistics.org): Effective porosity in core vs logs, 5.1.1.5-5.1.1.7

[18] Van Rosenberg 1956; Clerke 2008; Coasts & Smith 1964

5. Lithium Concentration

The distribution of the mineral of economic interest is of singular importance for the mineral resource estimate. CIM Best Practice Guidelines[19] discusses a variety of data analysis techniques that can be applied. In all cases, statistical analysis is a critical component in understanding the spatial distribution of the mineral resource in three dimensions. Depending on the geological interpretation, different statistical methods may be used.

One of the unique aspects about confined saline aquifer brines, is that depending on the groundwater flow regime and age of the brine, the lithium concentration can be relatively homogeneous within the permeable portion of the reservoir. The exact emplacement history and evolution of the brines may be speculative in many cases[20] but presumably the lithium has been distributed over long geological timescales via advective and dispersive groundwater flow as well as potentially diffusion.

If the lithium concentration is not homogeneous across the permeable portions of the reservoir, the authors recommend subdividing into zones across which the lithium concentration is homogeneous, on the basis that the characteristics controlling the concentration are varying significantly enough that the resource volumes in the zones should be calculated individually and subsequently summed rather than averaged. The controlling characteristics may be rock-based (such as permeability) or a function of depositional environment (such as aquifer recharge). This is another key distinction between confined saline aquifers and unconfined aquifers, as recharge from confined sources may be introducing new lithium to the system, where as recharge from unconfined aquifers is much more likely to be dilutive to the lithium in the system.

For a homogenous reservoir zone, and an Inferred resource estimate, it is the authors opinion that it is reasonable to apply a single [average or P50] value for lithium grade and apply it full pore volume.

For an Indicated and Measured resource estimate, it’s common to apply kriging variance to differentiate between indicated and measured estimates. Kriging and related methods are implicitly designed to evaluate spatial continuity in datasets that have spatial variance. Because of the low spatial variance in lithium concentration in confined aquifers, or subdivided zone within the aquifer, the authors have applied an alternative statistically based approach to evaluate lithium grade continuity.

As part of the exploratory data analysis of lithium grade, variograms can be built to evaluate the potential variance, spatial continuity, and directional trends in these parameters within the data.

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[19] CIM Estimation of Mineral Resources and Mineral Reserves Best Practice Guidelines

[20] Huff, G.F., 2016. Evolution of Li-enriched oilfield brines in Devonian carbonates of the south central Alberta Basin, Canada; Bulletin of Canadian Petroleum Geology, v. 64, n. 3, p.438-448.

In the case described above with a homogeneous lithium concentration in the reservoir, in the medium to long range of the variogram, variance should be zero. Some near field variance may be noted due to variance in lab sample analysis results due to measurement error; this can become evident from samples collected from the same well or clusters of wells in close proximity. Kriging would not be performed in this case, as the variogram would not be suitable.

Exploratory data analysis should also include basic descriptive statistics to evaluate the data distribution. In the geologic settings described above, lithium grade distributions will be characterized by a very narrow range of P10 to P90 (10th and 90th percentiles) and a low coefficient of variation (i.e. less than 0.5).

Once lithium grade distribution has been sufficiently demonstrated to be homogeneous in the reservoir, or subdivided zone within the aquifer, the uncertainty in porosity and permeability becomes a more significant component of the overall uncertainty in the resource relative to the grade. The authors suggest that a median (P50) concentration for the lithium concentration is sufficiently representative of the regional grade distribution that it can be utilized with sufficient confidence for a measured resource evaluation.

6. Recovery Factor

For a resource estimate (rather than a reserve estimate), the recovery factor is related to whether or not the resource has a "reasonable prospect for eventual economic extraction[21]".

For any mineral resource, the prospect for eventual economic extraction lies in the production estimates, which brings us back to the beginning of this white paper: *Brine-hosted lithium resources have more in common with petroleum resources than they do with hard-rock mining – but not all brine-hosted lithium resources are created equal. Unconfined aquifers, which are connected to atmospheric pressure, are under a significantly different pressure regime than confined aquifers, which are influenced by both depth and containment. These pressure regimes, whether gravity-controlled for unconfined aquifers, or mass-balance controlled for confined aquifers, are fundamentally different and therefore different resource estimation methodologies should be applied to each.*

Darcy's Law[22]

As the flow rate is the key factor of producibility, the components governing flow rate become the key factors that guide recovery factor at a resource estimate level. Of the parameters in Darcy's equation, pressure is the most critical, and is a clear differentiator between confined and unconfined aquifers, as discussed above. Permeability is the most challenging to quantify,

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[21] cim-definition-standards_2014.pdf: Definition of Mineral Resource

[22] 2.5: Darcy's Law - Flow in a Porous Medium - Geosciences LibreTexts

and some discussion below is provided on how this evaluation can be approached for brine resource evaluations.

Permeability

After pressure drive, permeability is the most critical key factor governing producibility of a brine-hosted mineral resource. Absolute permeability – a rock characteristic measuring the ability of a fluid to travel through the connected porosity – is typically excluded in favour of relative permeability to a specific fluid. However, a confined saline aquifer with brine-hosted mineral resource is typically a single-phase system, so the absolute permeability is equivalent to the relative permeability of the water.

For the purposes of a resource estimate, the method used needs to be sufficient to demonstrate that there is sufficient permeability to economically produce the brine resource.

For an Inferred resource estimate, it's reasonable to rely on analogue production, or leverage a hydrogeological calculation for transmissivity, such as the Farvolden equation[23].

For an Indicated and Measured resource estimate, physical measurements of permeability are required.

Permeability can be measured in several ways, but all are subject to uncertainties. In hydrogeology, hydraulic testing is typically the preferred method for permeability estimation. One of the most significant uncertainties in inferring reservoir properties from hydraulic testing is that it is difficult to infer the specific rock volume or facies associated with the hydraulic response. It is typical to conduct small scale permeability measurements from core, which is then correlated with porosity measurements. Using this correlation, large datasets of porosity measurements from core and downhole wireline well log measurements can be leveraged for inferring permeability in reservoir models, across the area of interest. However, correlations in carbonate reservoirs are less clear due to the multiple types of porosity typically present (matrix porosity, vuggy porosity, and fracture porosity). Due to these uncertainties, permeability should also be validated using hydraulic testing such as drill stem tests (DSTs) or full production / injection flow testing in the field, such as was done for the flow test performed by the authors[24]. The measured permeability data can then be integrated into a full-scale geological model, discretized sufficiently in three dimensions to account for permeability changes throughout the area of interest, and be used to support the resource estimate.

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[23] Farvolden R.N., 1959. "Groundwater Supply in Alberta." Unpublished report, Research Council of Alberta

[24] bashaw-technical-report.pdf (e3lithium.ca): See 7.8 Reservoir Dynamics, P. 45

Business Benefits

Canada has identified lithium as one of the six prioritized critical minerals (of thirty-one total) with its critical minerals strategy[25]. E3 Lithium's resource estimate for its Bashaw District is 16.0 million tonnes of lithium carbonate equivalent (LCE) is significant on a global scale. As additional resources are estimated, a standardized methodology specific to confined saline aquifers will support the development of this important, emerging resource.

Summary

No standard exists for confined saline aquifers, which are an emerging source of lithium in the global market. E3 Lithium, Alberta's leading lithium developer and extraction technology innovator, and Matrix Solutions, who are Qualified Persons[26] under CIM's NI43-101, have collaborated on a new approach for estimating resource volumes from confined saline aquifers.

Confined saline aquifers can leverage methodology that has long been utilized in Canada through the NI51-101 framework, the industry and national standard for resource estimation of liquids (or near liquids).

Call to Action

Lithium in confined saline aquifers represent a distinct resource type for brine-hosted lithium deposits and there is a need to develop standards and guidelines for resource and reserve estimation to account for their unique characteristics and challenges.

This methodology seeks to become a new standard for confined saline aquifers, to differentiate them from existing unconfined salar-based deposits and standardize the approach for this emerging and distinct resource type while honouring the existing NI43-101 standard.

Current resource estimation methods do not account for the critical differences between traditional unconfined and emerging confined saline aquifers. The proposed methodology will yield more accurate and quantitatively consistent resource estimate reporting for emerging, globally significant confined saline aquifers.

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[25] The Canadian Critical Minerals Strategy - Canada.ca: Critical Minerals in Canada

[26] cim-definition-standards_2014.pdf: Canadian Institute of Mining, definition of Qualified Person

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