DAKOTA SALTS

STATE OF NORTH DAKOTA

COMPRESSED AIR ENERGY STORAGE FEASIBILITY IN NORTH DAKOTA

INTERIM REPORT

July 18th, 2011

DAKOTASALTS
A Sirius Minerals Project

CONTENTS

1 PREAMBLE

Compressed Air Energy Storage (CAES) is a proven system for the balancing of intermittent electrical generating systems such as wind farm installations. North Dakota has an abundance of wind and therefore it is logical to evaluate this option. Sirius Minerals through its wholly owned subsidiary, Dakota Salts has entered in to a study agreement with the Industrial Commission of North Dakota under its Renewable Energy Program. A grant of $225,000 has been provided to Dakota Salts to support feasibility studies on using salt caverns for CAES from wind energy in North Dakota.

Dakota Salts subsequently engaged as partners in this endeavour, two world class organizations; the Electrical Power and Research Institute (EPRI), and Schlumberger Limited subsidiary Schlumberger Water Services (SWS).

EPRI is a leading authority on CAES and has extensive experience with economic optimal dispatch modelling and strategic planning for all types of energy storage technologies.

Schlumberger is one of the foremost experts in subsurface storage permitting, geological characterization and geo-mechanical modelling.

Through this team of recognized leaders in the field of CAES, Dakota Salts has entered in to an initiative to carry out the CAES feasibility study for North Dakota wind capture utilization and optimal full system integration.

2 OBJECTIVES, METHODOLOGY, SCOPE & DELIVERABLES

2.1 Objectives

The primary objective of this undertaking is to determine the potential, both technologically and economically, for using salt caverns for Compressed Air Energy Storage (CAES) from North Dakota wind energy electrical power generation.

This study aims to estimate the optimal design of the caverns based on the characteristics of the salt/potash beds and further define the total value proposition for bulk energy storage. The desired result will be to stimulate investment in plant construction for wind integration in the region.

2.2 Methodology

Dakota Salts completed a deep exploratory well in Burke County, North Dakota in late 2010. Drill cores were obtained and sent to the Schlumberger subsidiary, Terra Tek in Salt Lake City. Laboratory testing was performed on the samples to generate actual rock and subsurface material properties data. Through this advanced technology, subsurface geo-mechanical characteristics were obtained.

Finite element models, both 2D and 3D were constructed and the material properties obtained from the subsurface cores were entered into the models. Potential cavern geometries were used to develop computer generated storage vaults of various shapes and sizes. This allowed for computer simulations to be run and ultimately determine how the caverns would behave structurally and geomechanically under a variety of depth, shapes, and sizes, loading and cycling conditions.

The Williston Basin is a geological sedimentary structure which extends into the Northwestern portion of North Dakota. This basin is well known as a host for salt and potash mineralization; a critical element in the production of storage caverns for hydrocarbons, hydrogen and compressed air storage in many parts of the United States. A considerable amount of geophysics and exploratory drilling has been completed over this region. From the available data, combined with the Burke County exploratory well, Dakota Salts has performed a regional study to assess the site possibilities for a CAES facility.

EPRI has applied its vast experience in CAES to develop a North Dakota specific, economic optimal dispatch model. The resulting findings have been incorporated into the body of this study and integrated into the physical cavern analysis and geological models.

2.3 Scope

The scope of this study incorporates;

- An evaluation of the geology of the Williston Basin of North Dakota as it pertains to the capability to site salt caverns
- An evaluation of salt formation quality and thickness amenable to solution mining for the creation of storage caverns
- Obtaining fresh salt cores directly from an active drilling program
- Geomechanical laboratory testing of actual North Dakota salt cores and generation of the physical material properties of the rock insitu
- Finite element 2D & 3D modelling through FLAC software to simulate mining and storage capacities and resultant cavern geotechnical behaviour
- Optimal dispatch modelling
- Bulk energy storage technology comparisons
- Determining the economics of CAES in MISO
- Performing a sensitivity analysis

2.4 Deliverables

Through the project scope a number of deliverables have been outlined in the collaborative study including;

- Determination of geo-mechanical conditions and salt cavern size, shape and depth possibilities specific to North Dakota geology.
- Through the running of a series of computerized geo-mechanical scenarios for a solution mined cavern and cavern field in North Dakota, cavern geometry while maintaining geotechnical stability will be evaluated.
- An assessment of cavern performance and stability during CAES service.
- Identification of operating pressure ranges within potential North Dakota caverns in CAES service.
- An example of a CAES unit design and financial model.
- Presentation on plant characteristics for a Bulk Energy Storage (BES) plant operating in North Dakota including ranges for heat rate, energy ratio, capital costs, variable and fixed O&M costs, up and down ramp rates, maximum discharge capacity and switchover time.
- Information on the optimal dispatch of a BES plant operating in North Dakota; assumptions for CO_2 emissions and savings; and plant capacity factors.
- An economic study utilizing a variety of North Dakota on/off peak cycling and electricity price data.

Deliverables (Continued....)

- Modelling specifics and inputs which will assist in determining the size of a potential BES plant.
- Cost to benefit analysis for a potential BES plant in North Dakota.
- Conclusions, recommendations and presentation of a go forward strategy

3 INTRODUCTION

Since mid-2008, Dakota Salts has been coordinating expertise and efforts to capture the value of North Dakota's large bedded salt deposits for the purpose of solution mined Salt Cavern and Compressed Air Energy Storage (CAES) solutions. Dakota Salts has collectively established a confluence of interested parties that are working together in the realm of Wind Turbine Energy, Salt Cavern CAES and Energy Transmission Infrastructure with the aim of assisting North Dakota in being one of the United States' greatest resources for renewable energy technology and renewable energy storage.

Dakota Salts was the first to pioneer salt cavern storage efforts in the region setting where a comprehensive renewable energy solution is possible via wind and CAES: North Dakota. Dakota Salts has engaged the world's leading expertise surrounding successfully building and operating CAES plants to comprehensively launch a feasibility study and subsequent plant construction. State assistance via the North Dakota Renewable Energy Council Initiative was allocated in 2010 to be used toward an in-depth feasibility studies for the direct purpose of integrating wind utility into energy storage technology in North Dakota via CAES and integrating wind-CAES solutions into existing electrical infrastructure.

In 2010 Dakota Salts, collectively with Schlumberger Water Services and EPRI, began the first phase in developing an overall feasibility study combined with an economic model specific to the State of North Dakota. The general purpose of this project was two-fold:

1. **Perform an Advanced Subsurface Geo-mechanical Feasibility Study Characterizing North Dakota Salts for its Utilization in Bulk Energy Storage**

   North Dakota is the beneficiary of the proper geological and regional setting that allows high wind turbine efficiency and wind storage capability via salt cavern CAES. The depth at which North Dakota's salts are deposited introduces geological and geo-mechanical considerations that are unique to North Dakota. Thereby, the necessity to carefully coordinate and balance deep salt caverns and/or shallower horizontal storage caverns for CAES technology and the implementation of new technologies in salt cavern generation is a consideration that must be completed to address bulk energy storage solutions in North Dakota.

2. **Perform a Cost Benefit Analysis for a Compressed Air Energy Storage (CAES) plant for Wind Integration in North Dakota**

   In North Dakota electrical service territories, there is a need to take advantage of renewable energy generation (in particular, wind generated energy) and to more effectively follow the daily increase and decrease of power requirements providing improved system reliability and efficiency.

   The objective of the economic study is to perform a cost-to-benefit analysis for installation of bulk energy storage (BES) power plant for wind integration service in North Dakota. This will include plant performance and operating cost specifications, expectations for plant capital costs, and optimal dispatch of the power plant.

4 SWS REPORT PRÉCIS

Schlumberger Water Services, in conjunction with Schlumberger Data and Consulting Services, is conducting geo-mechanical analyses of hypothetical CAES system located in North Dakota. These analyses are being performed on a representative “type” cavern configuration which was developed through integration of many public domain and newly acquired data sources;

- Public domain geological and geophysical data
- New geological and geophysical data acquired by Dakota Salts as part of their potash exploration program
- Mechanical testing of core acquired by Dakota Salts as part of their potash exploration program
- Literature on existing CAES facilities and similar gas storage facilities
- Public domain geospatial data on wind resource and transmission infrastructure.

The study is being conducted in 5 main phases:

- Phase 1: Storage Target Location Assessment - A scoping study was performed to evaluate the most suitable location for CAES in North Dakota. Geological and geophysical data were integrated with wind resource and infrastructure data to develop a 3-Dimensional regional model which served as the basis for the scoping study. Magnitudes and trends of depth and thickness of the target formations were used to identify potential storage zone locations and thicknesses.
    - ***This phase is 100% complete***
- Phase 2: Geological Parameter Estimation - Geophysical logs from wells proximal to these the zones identified in the first phase were evaluated to estimate representative non-mechanical material properties (impurity types and quantities) and to further refine the estimated thickness available for storage.
    - ***This phase is 100% complete***
- Phase 3: Geomechanical Parameter Estimation – Mechanical testing was performed on cores taken from the Prairie Evaporite formation in exploration well EBY-1. Testing included triaxial test, unconfined compressive strength tests, cyclic fatigue tests, and creep tests. These tests provided the key mechanical material properties needed for numerical modelling.
    - ***This phase is 100% complete***

- Phase 4: Initial Cavern Geometry Selection – initial cavern model geometry was computed using estimates of operating pressure ranges, required mass flow rates, and desired energy output. These estimates were derived from information provided by EPRI about the North Dakota project, and from available literature on existing CAES sites (Huntsdorf and Macintosh).
    - ***This phase is 100% complete***
- Phase 5: Numerical Simulations – Flac-3D numerical geo-mechanical modelling code is being used to asses various cavern geometry and power plant operational scenarios. Cycle rate, cycle pressure ranges, and cavern geometries are being systematically varied to assess potential trade-offs between operational efficiency and cyclic stress induced cavern failure mechanisms.
    - ***This phase is 90% complete***

5 EPRI REPORT PRÉCIS

As stated earlier in the description of this undertaking, EPRI (Electrical Power Research Institute) was engaged to evaluate the economics of bulk energy storage (CAES) in the North Dakota MISO system. *The detailed report is currently in draft form awaiting group evaluation of the findings and recommendations. The full report complete with the go forward strategy will be included as Appendix 2*

The scope of the study includes;

- Bulk energy storage technology comparisons
- Plant characteristics for the model
- Historical data for 2006, 2007 and 2008 from MISO and US EIA
- Arbitrage based on real-time spot prices
- Capacity service credits, ancillary services & CO_2 savings
- Sensitivity analysis
- Recommendations & conclusions

The results of the study conclude;

- Optimal dispatch for the CAES plant is based on historical 2006-2008 real-time MISO data. Additional revenues from spinning reserve, frequency regulation and backstart services are also included. These ancillary and capacity benefits will be critical components of the benefit mix.
- Benefit/cost ratios range from 4.07 to 7.26. This value of CAES in MISO is largely due to a latent economic value of bulk storage in MISO, and not a result of wind penetration levels (which are around 4%). Higher wind penetration levels will tend to further improve the cost effectiveness of CAES systems.
- Average capacity factors are 30% to 50%, so that CAES runs like an intermediate-duty plant. A capacity of 30-50 hours appears suitable for this application in MISO.
- The annual average CAES CO2 savings are estimated as 256,000 short tons of CO_2 per year, compared to a high performance combustion turbine (CT).
- Bulk energy storage (BES) provides grid damping, enhances grid reliability and avoids higher operating costs. CAES systems are the most economical solution for bulk storage.

Recommendations to proceed include site selection, development of preferred design of an advanced CAES plant, refined cost estimates for this system, and comparison of CAES plant performance to a combustion turbine (CT) based plant providing similar generation services.

6 PROJECT BUDGET

The following matrix contains a summary of project spend for Phase 1;

CAES Actions & Deiverables	Resource	Cost
PHASE 1:		
Project Management	Dakota Salts, LLC	$67,000.00
R&D - Technology Tools	Dakota Salts, LLC	$7,500.00
Salt Creep Data Review	Schlumberger	$19,800.00
Digitization of Logs	Schlumberger	$17,800.00
PetroPhysical Review	Schlumberger	$12,600.00
Project Review	Dakota Salts, LLC	$5,000.00
Phase 1 - Total Spend		**$129,700.00**