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ALASKA GEOLOGIC CARBON SEQUESTRATION POTENTIAL ESTIMATE: SCREENING SALINE BASINS AND REFINING COAL ESTIMATES

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Alaska Department of Natural Resources

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Arnold Schwarzenegger
Governor

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PIER FINAL PROJECT REPORT

Prepared For:
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Public Interest Energy Research Program

Prepared By:
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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

- PIER funding efforts are focused on the following RD&D program areas:
- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Alaska Geologic Carbon Sequestration Potential Estimate: Screening Saline Basins and Refining Coal Estimates is the final report for the Alaska Geologic Carbon Sequestration Potential Estimate: Screening Saline Basins and Refining Coal Estimates Project under contract number MR-045, conducted by the Alaska Department of Natural Resources. The information from this project contributes to PIER's Environmentally Preferred Advanced Generation Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

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Abstract

Preliminary screening for CO_2 storage potential in Alaska saline basins and coal seams, while following established DOE methodology, failed to account for the uniqueness of the Alaskan environment and economy. Data such as depth, salinity, presence and capacities of seals and traps, porosity, permeability and geochemistry, are all needed to make reasonable quantitative volumetric estimates for CO_2 storage capacity in sedimentary basins. Data such as coal rank, volume, quality, thickness, volume, rank, and permeability are needed to make the estimates for storage capacity in unmineable coal seams. This data is sparse or lacking in most of the vast sedimentary and coal basins in and offshore Alaska. With the exception of the Colville Basin on the North Slope, and the Cook Inlet Basin in south central Alaska, the lack of constraining data makes obtaining reasonable volumetric estimates of saline basin storage potential problematic. Enough data does exist, including economic and logistical factors related to working in extremely remote or offshore environments, to support a more qualitative approach in determining saline reservoir storage potential for those basins, and those results are included in this report.

For coal estimates, sufficient data were available to refine volumetric estimates for the Northern Alaska Province, the Nenana Basin, and the Cook Inlet Basin. Numerous geologic reports, coal studies and geologic maps were compiled, researched and reviewed to obtain the information necessary to revise the previous estimate of Alaska coal seam CO_2 storage capacity.

This report presents the background and analysis resulting in the qualitative summary of the CO_2 storage potential in sedimentary basins in Alaska, and a refined quantitative summary of the sequestration potential in unmineable coal seams in Alaska's major coal bearing basins. The final products discussed in this report are presented in Geographic Information System (GIS) layers, which include:

1) Outlines of sedimentary basins deeper than 1000 meters, with multiple attributes gathered to support an overall Sequestration Potential. Sequestration Potential is a qualitative estimate of how suitable a particular basin would be for CO_2 sequestration, and is based on analysis of the supporting attributes. The most important attributes impacting Sequestration Potential are a) reservoir and seal potential, and b) logistical and economic considerations such as distance from roads, or the need to work in an offshore environment.
2) Outlines of major coal bearing basins with qualitative attributes assigned that collectively determine the potential for CO_2 sequestration and provide revised quantitative estimates for volume of coal seam sequestration. The major factors that affect the storage capacity of coal seams include coal rank, coal volume, coal quality, coalbed methane presence and quantification, coal permeability, and permafrost presence and depth.

The sedimentary basins are shown relative to roads and large CO_2 stationary sources to illustrate proximity of the major sources to the potential sinks. Sources and proven sinks are closely co-located for much of the North Slope and south central Alaska, but very far removed for central (interior) Alaska.

Keywords: Alaska, Carbon capture and sequestration, CCS, carbon dioxide, coal, coalbed methane, saline basins, CO_2 emissions, source-sink matching, West Coast Regional Carbon Sequestration partnership, WESTCARB geologic sequestration

Executive Summary

This report presents refined saline basin screening and improved coal storage capacity estimates which take into account data coverage, geologic and tectonic environments and gross measures of economic feasibility. Its purpose is to augment and improve, as part of WESTCARB Phase II, understanding and estimates of storage potential in saline aquifers and coal seams for Alaska as part of a larger DOE effort to assess carbon sequestration potential nationwide.

Preliminary screening for CO_2 storage potential in Alaska saline basins and coal seams, while following established DOE methodology, failed to account for the uniqueness of the Alaskan environment and economy. Initial studies (Stevens and Moodhe, 2009) indicated very large area with potential for sequestration in northern Alaska and offshore saline aquifers [16,700 Gigatons (Gt)] and onshore coal seams (120 Gt). However, taking the next step and incorporating factors for sedimentary basins such as known and expected water salinity, tectonic environment, offshore environments and distance from infrastructure; and for coal seams, coal rank, cleating, and permafrost, will significantly constrain these resource estimates. Logistical constraints alone of working offshore reduces the storage estimate for saline basins by over 11,000 Gt.

This report provides a qualitative summary of multiple geologic and economic risk factors for both onshore and offshore basins, that impact the storage potential of the basins incorporated into GIS layers (Figures ES-1 and ES-2.)

Improved screening data for saline basins was obtained by integrating:

- Amount and quality of data available to screen the basin
- Likelihood of sufficient porosity and permeability, traps and seals
- Distance from infrastructure and sources of CO_2.
- Likely depositional environment (impacting predictions of salinity)
- Contribution of seismic (tectonic activity) risk to long term storage risk

This report also presents improved volumetric estimates for CO_2 sequestration in unmineable coal seams. Based on recently updated USGS coal resource estimates, preliminary estimates indicated that Alaska has a total geologic CO_2 storage capacity of 120 Gt in deep coal seams (Stevens and Moodhe, 2009). However, it is likely that only a portion of the 120 Gt is considered favorable for CO_2 sequestration, due to low permeability, seam geometry, surface access, faulting, deep permafrost and other site-specific conditions.

Results summarized in this report reflect augmented and refined estimates for storage potential for coal seams in Alaska by:

- Constraining the volumetric estimate of coal distribution and depth using new data and existing mapping,
- Producing a derivative map (Figure ES-2) of coal available for sequestration using filters that include coal rank, depth, lateral distribution, permafrost presence and depth, cleating and availability of infrastructure.

The revised estimate of Alaska coal seam CO_2 storage capacity is significantly lower than the previous estimate of 120 Gt. This study suggests that the combined CO_2 storage capacity deep, unmineable coal in three major Alaska coal basins is 49.24 Gt.

Estimates are in accordance with established methodology unless otherwise documented.

While revised estimates show the saline and coal sequestration potential is much lower than initial estimates, and is "high" only in the Cook Inlet basin in south central Alaska, and in a limited area on the central north slope, the sequestration potential in those two places is still likely to be more than large enough to handle the volumes of CO_2 available for capture in Alaska for many years. The limiting factors for CCS will be the economics of capture, transport (very long distances in the case of interior Alaska) injection, and long-term monitoring, and the establishment of laws and regulations for long term CO_2 storage.

The saline basin screening (Figure ES-1) and the updated estimates of coal storage potential (Figure ES-2, Table ES-1) have both been delivered to the WESTCARB GIS data clearinghouse maintained by the Utah Automated Geographic Reference Center.

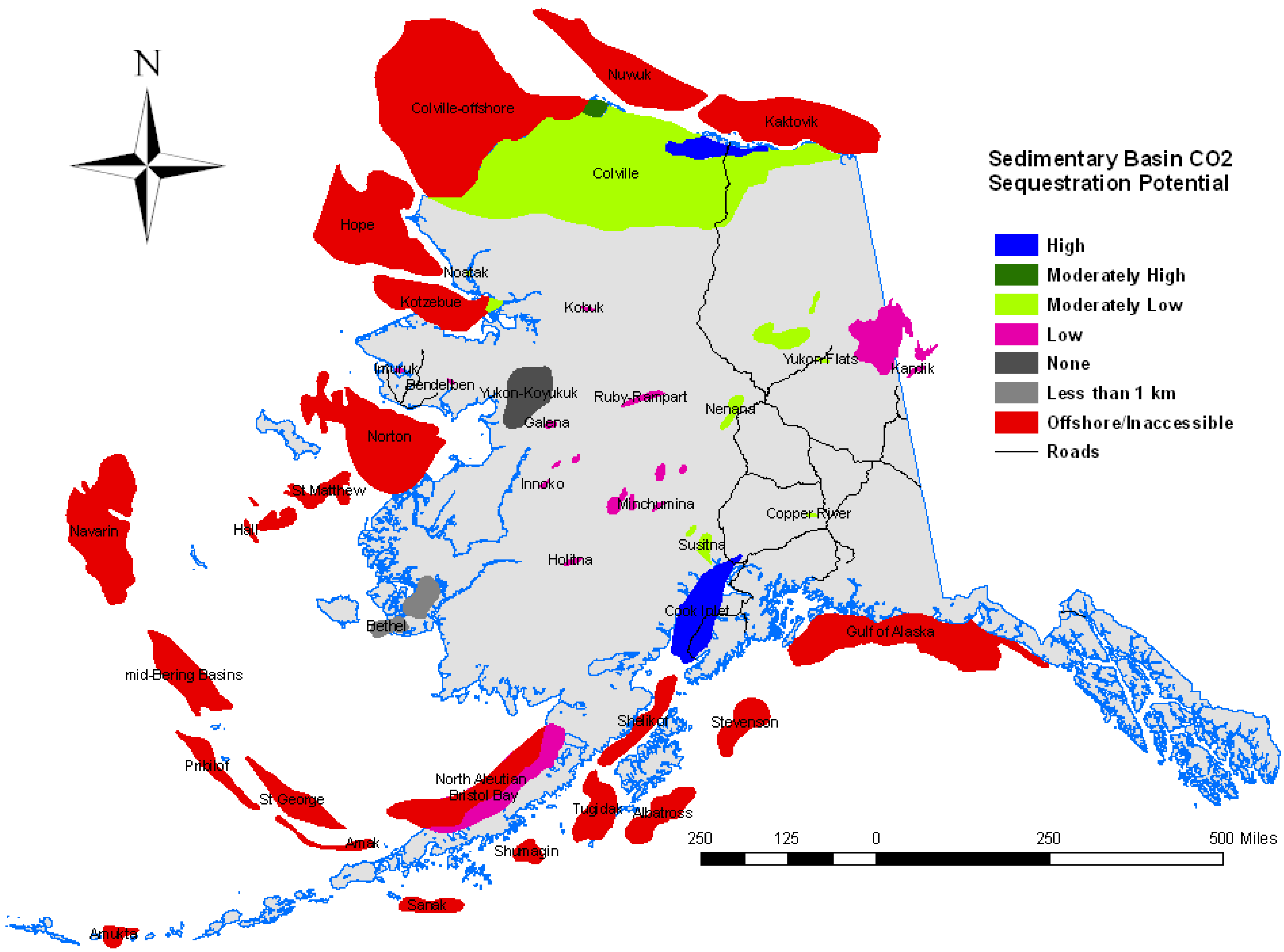

Figure ES-1. Alaska Saline Sedimentary Basin CO_2 Storage Potential

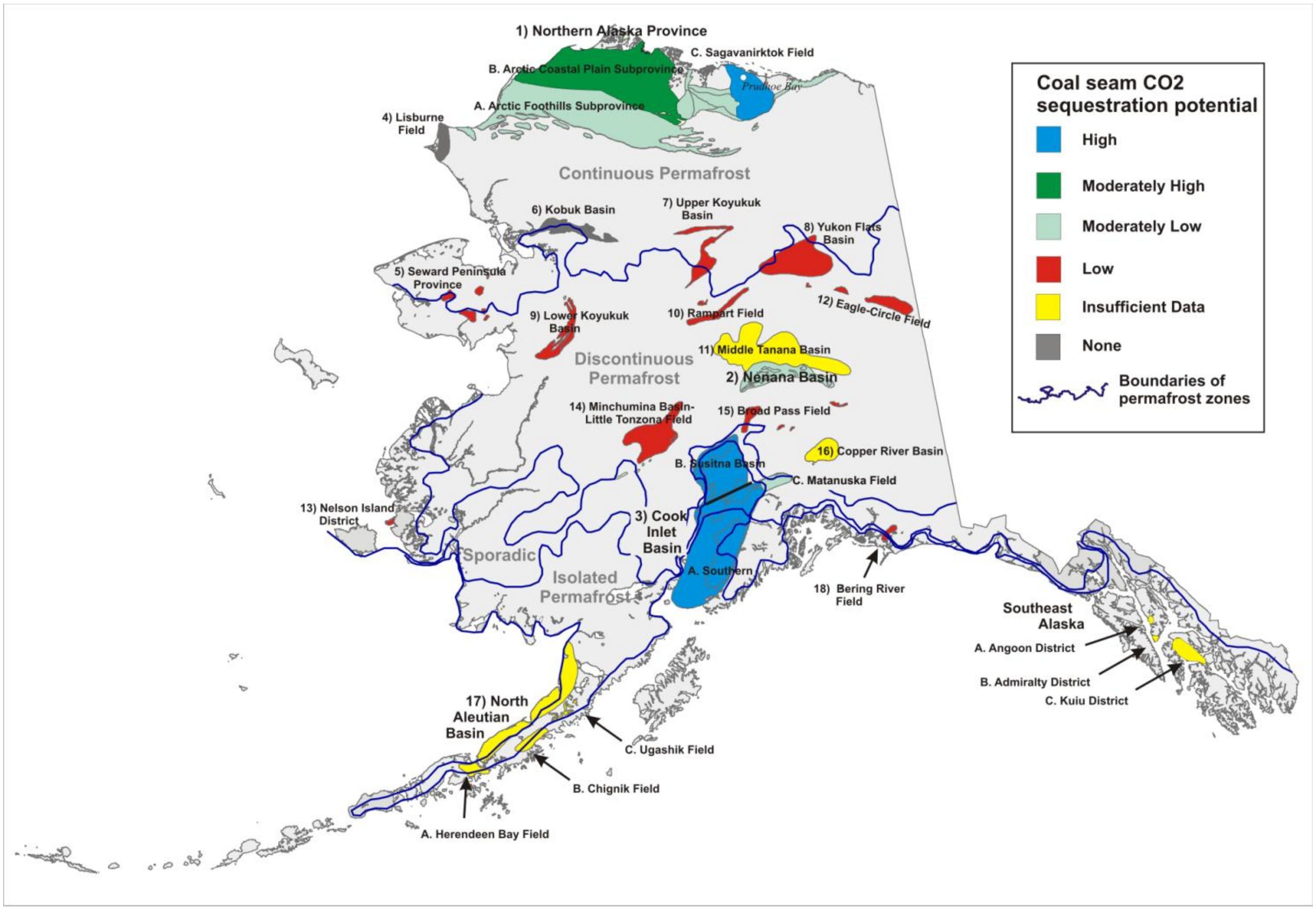

Figure ES-2. Alaska Coal Basin CO_2 Sequestration (storage) Potential

(1) REGION	(2) IDENTIFIED & HYPOTHETICAL COAL RESOURCES (billions of short tons)	(3) AVERAGE COAL RANK	(4) ARI Estimated CBM Resources (based on daf) (Tcf)	(5) ARI Estimated CO2 Storage Potential (Tcf)	(Gt)	(6) USGS Estimated CBM Resources* (Tcf)	(7) CO2 Storage Potential based on USGS CBM Resources* (Tcf)	(Gt)	(8) REVISED ESTIMATE OF COAL SEAM CO2 STORAGE POTENTIAL (this report) (Gt)
1) Northern Alaska Province	3,753.00		621	1,862	98	17.2	120.4	6.32	5.83
A. Arctic Foothills Subprovince	1,290.00	Bituminous							
B. Arctic Coastal Plain Subprovince	1,910.00	Subbituminous	No Data	Not Subdivided		15	105	5.53	5.08
C. Sagavanirktok Field	553.00	Subbituminous				2.2	15.4	0.79	0.75
Total North Slope	**3,753.00**		**621**	**1,862**	**98**	**17.2**	**120.4**	**6.32**	**5.83**
2) Nenana Basin	17.00	Lignite to subbituminous	1	3	0	1	10	0.52	0.41
3) Cook Inlet Basin. Includes A. Southern, B. Susitina and C. Matanuska resources	1,570.30	Subbituminous to anthracite	136	407	21	140	980	50.58	43.00
TOTAL ALL "BASINS"	**5,340.30**		**758.00**	**2,273**	**120.00**	**158.20**	**1,110**	**57.32**	**49.24**

*North Slope based on Roberts et al., 2008

Table ES-1. Summary table of estimates of deep coal seam CO_2 storage potential in Gigatons (Gt) based on attributes evaluated in this report (column 8). Coal resource estimates (column 2) and average coal rank (column 3) compiled from Merritt and Hawley, 1986 and Flores et al., 2004. ARI estimated CBM resources based on dry ash free coal (column 4) and estimated CO_2 storage potential (column 5) from Stevens and Moodhe, 2009. USGS estimated CBM resources (column 6) from Flores, et al., 2004; Montgomery and Barker, 2003; Roberts, et al., 2006; and Roberts, et al., 2008. Column 7, CO_2 storage potential was determined during the course of this study and is based on the 2008 assessment of North Slope recoverable CBM.

1.0 Introduction

Carbon dioxide capture and storage (CCS) technologies could play a critical role in mitigating the impact of fossil-fuel-based energy generation on greenhouse gas buildup in the atmosphere. The U.S. Department of Energy (DOE) is actively engaged in the second phase (CCS technology validation pilot studies) for its network of regional partnerships to determine the CCS technologies best suited for different regions of the country. In parallel, the PIER program is conducting research to define least-cost greenhouse gas mitigation strategies appropriate for California, including an assessment of the potential for carbon sequestration.

The West Coast Regional Carbon Sequestration Partnership (WESTCARB) in partnership with California Energy Commission is identifying and validating carbon sequestration opportunities in California, the surrounding states of Alaska, Arizona, Hawaii, Nevada, Oregon, and Washington, and the Canadian Province of British Columbia. Findings from the first phase of WESTCARB's regional characterization of geologic formations and land management suitable for long-term CO_2 storage (known as "sinks") indicated a lack of data in many key areas. Enhancing the geologic characterization of the WESTCARB region is necessary to be able to produce a robust regional CCS implementation strategy.

Preliminary screening for Alaska, while following established DOE methodology, failed to account for the uniqueness of the Alaskan environment and economy. Previous studies indicated a large area with potential for sequestration in saline aquifers and coal seams. Those numbers, however, need further refinement as many Alaska basins are underexplored, with little to no well control and/or seismic data, or are far from infrastructure or offshore. In offshore basins (estimated at over 11,000 Gt capacity), storage estimates for saline reservoirs are much higher than can currently be realized due to logistical considerations of working in harsh, often ice-covered, waters. In addition, factors such as known and expected water salinity (where fresh waters will be significantly deeper than usual related to fluvial depositional environments) unknown seal capacities, unknown impact of seismicity on sealing capacity in basins without proven hydrocarbons, and most significantly, economic and logistical hurdles related to the long distances between remote interior basins and CO_2 sources and roads or pipelines, will severely constrain saline and coal storage potential.

Coal capacity estimates will also be constrained from initial estimates when a number of factors that include coal rank, cleating, and permafrost are incorporated. It is important to note, that no direct measurement of CO_2 adsorption capacity of Alaskan coal has been measured in the laboratory. Therefore, estimates of coal seam CO_2 storage capacity are based on comparison to coal basins elsewhere as analogues.

The goals of this project were to augment and improve, as part of WESTCARB Phase II, preliminary estimates of storage potential in saline aquifers (qualitatively) and coal seams (quantitatively) in the DOE Carbon Sequestration Atlas for Alaska. The refined saline basin screening and improved coal storage capacity estimates take into account data coverage, geologic and tectonic environments and gross measures of economic feasibility.

2.0 Results and Discussions

Project results of saline basin screening and updated estimates of coal storage potential have been delivered to the WESTCARB GIS data clearinghouse maintained by the Utah Automated Geographic Reference Center. Significant to interpreting these results is the size and proximity of these potential CO_2 storage locations with CO_2 sources and with infrastructure. Source sizes and locations are briefly described in Section 2.1. Section 2.2 describes the analysis and results of the saline basin screening, and Section 2.3 describes the procedures and results of the analysis of storage potential in unmineable coal seams.

2.1 Stationary CO_2 Sources in Alaska

Stationary sources of greenhouse gas (GHG) account for approximately 21 million metric tons (mmt) of Alaska's 52 mmt total CO_2 equivalent (CO_2e) GHG emissions (ADEC, 2008)[1]. The largest stationary source locations and amounts are displayed in Figure 1. (Emissions were calculated based on fuel burned in all facilities requiring Title V EPA permits. Facilities that did not require a Title V permit were deemed minor emitters.) Of the 21 mmt related to stationary sources, approximately 15 mmt were generated in the production of oil and gas, primarily a result of natural gas combustion in generating power for hydrocarbon extraction, transport, and refining. This industry is focused in the producing fields on the North Slope, and to a lesser extent, the Cook Inlet, and is a critical economic driver in the State. Emissions in interior Alaska, ~ 2 mmt, are predominantly from the combustion of coal and diesel in power generation.

High storage potential exists in the proven oil and gas basins on the North Slope and the Cook Inlet, in depleted fields, in enhanced hydrocarbon recovery, and in saline reservoirs in those basins.
Fortunately, since CO_2 from oil and gas operations produces 75% of Alaska stationary sources, source and sink locations are essentially co-located (Figure 2.) More than half of the remaining 25% of Alaska stationary emissions is from power generation and industry in the Anchorage and Kenai areas, and is relatively close to potential CO_2 storage reservoirs there as well.

Storage of captured emissions in the interior (~10% of stationary emissions) is much more problematic and economically challenged. To date, no high potential saline or coal storage potential have been identified in the area, and any captured CO_2 would have to be shipped (no CO_2 pipelines currently exist in Alaska) to proven oil and gas basins either on the North Slope or in Cook Inlet.

[1] CO_2e values were calculated by the Alaska Department of Environmental Conservation (ADEC) based on 2002 fuel burned in facilities requiring Title V Clean Air Act permits. 52 mmt is ~.7% of all US GHG emissions (US EPA, 2007.)

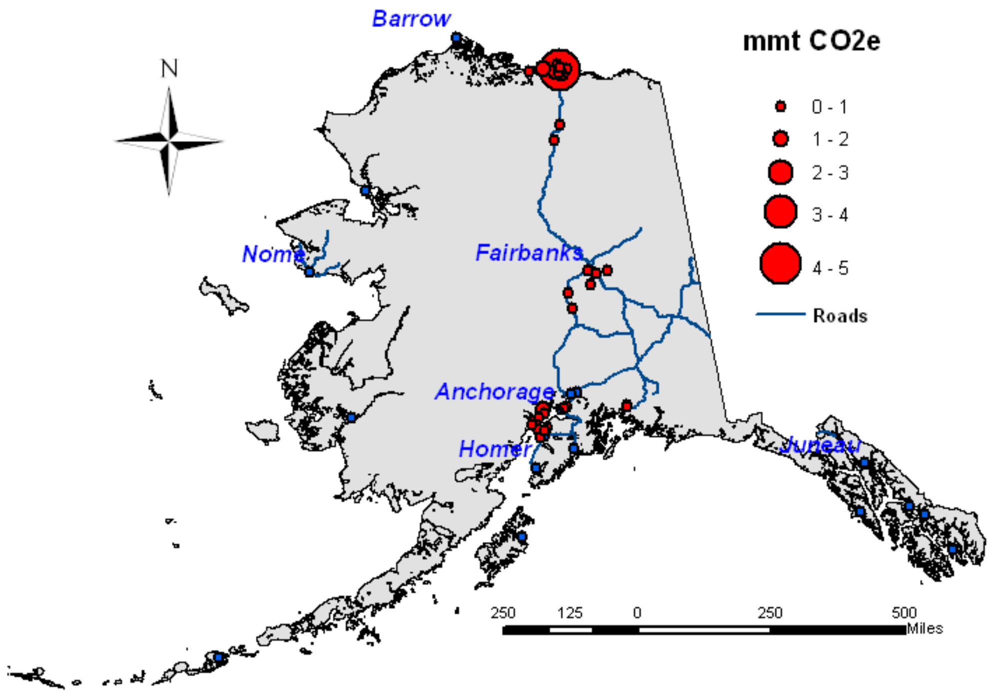

Figure 1: Largest CO_2e emissions (as calculated by the Alaska DEC from fuel burned in Alaska facilities requiring Title V EPA permits) displayed in million metric tons of CO_2 equivalent.

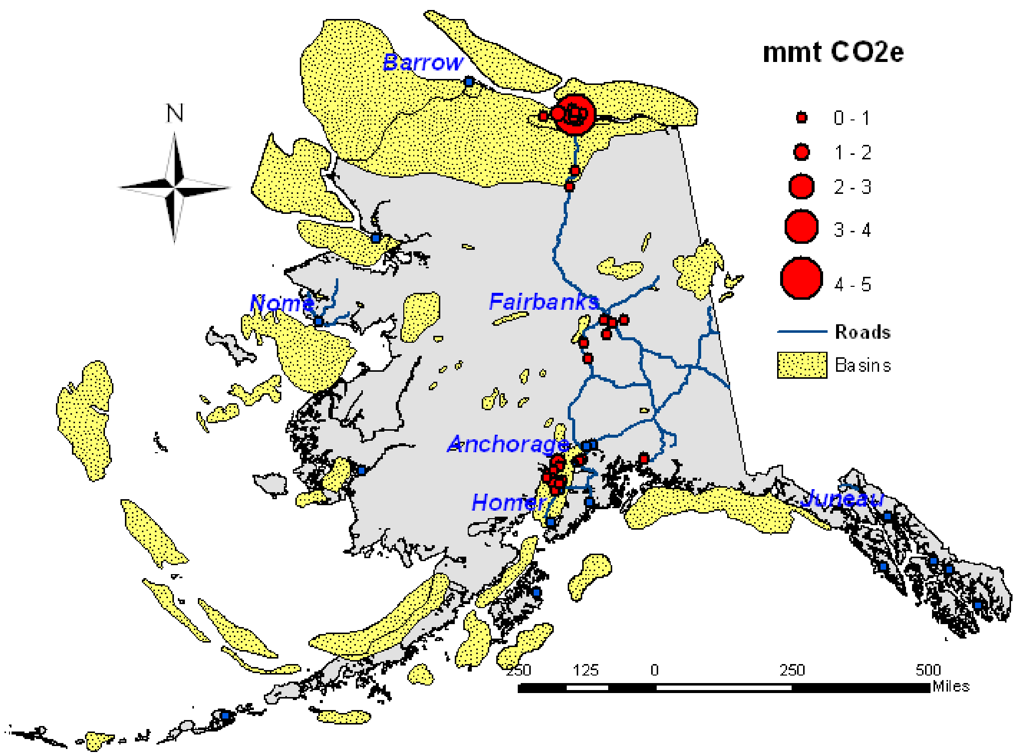

Figure 2: Stationary Sources of CO_2 (red) and deep sedimentary basins (stippled-yellow). Proven hydrocarbon basins are displayed in green.

2.2 CO_2 Storage Potential in Saline Sedimentary Basin Reservoirs

Data such as depth, salinity, presence and capacities of seals and traps, porosity, permeability and geochemistry, are all needed to make reasonable quantitative volumetric estimates for CO_2 storage capacity in sedimentary basins. This data is sparse or lacking in many of the vast sedimentary basins in and offshore Alaska. With the exception of the Colville Basin on the North Slope, and the Cook Inlet Basin in south central Alaska, both which have producing oil and gas fields and have significant seismic and well data coverage, the lack of constraining data in most basins makes obtaining reasonable volumetric estimates of storage potential problematic. Enough data does exist, however, to support a more qualitative approach as an initial step in determining saline reservoir storage potential for those basins.

Refined basin level screening for storage potential in Alaskan saline basins was obtained by assessing and incorporating the following:

- Depth: impact on storage volume potential. At depths greater than 800 meters CO_2 is in its dense, supercritical liquid state. Storing CO_2 in the supercritical state is not required, but is desirable for two reasons. First, significantly more CO_2 can be stored in the same storage volume, and second, the liquid is a less mobile and less buoyant state, and therefore more likely to stay contained.
- Amount of seismic and well data available for basin: impact on confidence and risk. For portions of the Colville Basin on the North Slope, and the Cook Inlet Basin in south Alaska, there is a significant amount of data, including seismic, well logs, gravity, and magnetics. In most other basins the paucity of seismic and well data translates to minimal knowledge of porosity, permeability, seals and traps. Surface mapping, gravity and recent tectonic activity may be the only geological and geophysical measurements available to categorize a basin.
- Environment of deposition (fluvial non-marine vs. marine, sand to shale ratio): impact on depth-salinity relationship and likelihood of seal formation
- Tectonic activity: impact on likelihood of seal integrity where no other information is available, and
- Distance from infrastructure and CO_2 sources: impact on economics. The cost to construct a pipeline over large distances, with no road support, is enormous. Many basins in Alaska are currently economically and logistically unfeasible for this reason. Offshore basins are effectively inaccessible due to the harsh operating environments. Even in the relatively protected waters of the Cook Inlet, seasonal ice and expensive facilities will likely preclude operations in the offshore portions of the basin.

2.2.1 Sedimentary Basin Attributes

Information was gathered from many sources to describe the types and kinds of information that exist for and about sedimentary basins in Alaska. The following attributes, along with a description of their significance and the source of the data, were captured in the GIS basin outline shape file. While all attributes are listed here for completeness, some have significantly more impact than others on overall "Sequestration Potential." The attribute fields are in bold (followed by the actual field name in parenthesis, if different.)

1) **Basin Name.** Names and outlines are from published sedimentary basin maps (Kirschner, 1988, Troutman, 2007, Meyer, 2008, and Van Kooten, 1997). In most cases, basin outlines reflect estimated depths greater than 1000 meters. Figure 2 shows the basin outlines in conjunction with the largest CO_2 sources.

2) **Exploration Wells (Exploratio).** The number of exploration wells in the basin.The amount and sampling of well log data is critical to describing how much is known about basin porosity, permeability, seal capacity and salinity.
Public well data in Alaska is available though the Alaska Oil and Gas Conservation Commission (AOGCC.)[2]

3) **Seismic Coverage (Seismic_Co)**. Seismic data is needed to determine the presence or absence of significant faulting and regional architecture and potential presence and extents of seals, as well as illuminating any possible trapping mechanisms. Estimates of publicly available data were made from the USGS National Archive of Marine Seismic Surveys website[3], Alaska Department of Natural Resources North Alaska Oil and Gas Resource Map Series (2008), and seismic broker maps.

4) **Depositional Environment (Deposition)**. Depositional environment (Figure 3) is important in understanding likely depth- salinity relationships, especially when little to no well data is available to supply direct measurements. Whereas a non-marine environment of deposition will not necessarily lead to a completely freshwater basin, it is expected that in these basins the depth of non-saline water will be deeper than average, and will impact overall pore-space estimations. Depositional environment can also impact the likelihood of the presence of seals, though that is more difficult to predict. In cases of sparse to no well data, geologic field work documented in literature was used to categorize the basins as marine, marine-non-marine mixed, and non-marine. Where the depositional environment is non-marine or marine-non-marine (represented as "Mixed" in the Expected Salinity attribute defined below), the risk is higher that the depth where salinity reaches 10,000 ppm TDS will be deeper than average. This is known to be the case for the Cook Inlet Basin (completely non-marine, primarily fluvial deposition), where bicarbonate concentrations are high, but salinity is low. Most basins in Alaska are believed to be at fluvial (non-marine) or a mixture of non-marine and marine (Sherwood, 1988 and Kirschner, 1988).

5) **Salinity**. The expected salinity attribute is derived either from measured well data, or qualitatively interpreted from depositional environment (previous attribute.) Qualitative values of Low, Normal, and Mixed were used to describe salinity, with normal being typical marine deposition. Low=non-marine, Mixed=marine and non-marine, Normal=marine.

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[2] Alaska Oil and Gas Conservation Commission (AOGCC) - Public wells in Alaska lands and waters, http://doa.alaska.gov/ogc/

[3] USGS National Archive of Marine Seismic Surveys, (NAMMS) http://walrus.wr.usgs.gov/NAMSS/

6) **Average Depth in m (Average_De).** This estimate is based on well and seismic data where available, or gravity measurements where seismic and well data is sparse (a majority of the interior basins.) The average depth of the basin is equivalent to average thickness where water depths or elevations are small, and are estimated from Kirschner, 1988. Values are in meters.

7) **Basin_Age**. Predominate age (by Era) of sediments in basin (Sherwood, 1988 and Kirschner, 1988.) This attribute did not directly impact any estimates of storage potential.

8) **Porosity and Permeability (Porosity).** Direct porosity measurements are sparse to nonexistent in most Alaska basins. This qualitative attribute (values of unlikely, possible, and proven) was estimated from well data where available, and geologic field work and published maps and literature where well data was not available. This attribute is highly generalized, and is assumed to tie directly to permeability and reservoir quality where no other direct measurements exist.

9) **Oil and Gas Production (Oil_and_Ga).** Identifies those basins where production of oil and gas resources has occurred. Considering the similarity in fluid properties between light oil and supercritical CO_2, and between natural gas and gaseous CO_2, seals and traps suitable for hydrocarbons are deemed likely suitable for CO_2 storage as well. Hydrocarbon production is considered proof of porosity, permeability, reservoir, seal and trap. (Whereas trap is not a factor in the DOE estimates of saline reservoir storage capacity, it is likely that the presence of a trap could lower the risk of eventual leakage.)

10) **Map Unit**. Basins are categorized as either undifferentiated sedimentary or flysch (Kirschner, 1988.) Alaskan flysch basins are mostly Mesozoic, typically lightly to pervasively metamorphosed and deformed, and individual sand and shale layers are typically thin with very poor reservoir quality. Undifferentiated sedimentary basins contain a wide variety of largely non-marine clastic rock types with a variety of reservoir and seal characteristics.

11) **Seismic Risk (Seismicity).** A qualitative estimate (high, medium, low) of seismic risk based on USGS Seismic Hazard Maps for Alaska (Wesson, et al., 2007). Hazard maps (Figure 4) were constructed using historic earthquake activity, paleoseismic information, and current understanding of earthquake potential. A higher seismic risk could be linked to a higher risk of leakage of stored CO_2 where seismic activity might open up fault conduits, or adversely impact seal capacity. However, high earthquake risk is not always indicative of high leakage risk, as is evident in the Cook Inlet where natural gas accumulations indicate that numerous seals have not been breached, even though there continues to be strong and frequent seismic activity in the area.

12) **Distance from infrastructure (Distance_f).** Infrastructure includes CO_2 sources, primary roads and pipelines. This is a qualitative measure of how far, and how expensive, it would be to transport captured CO_2 to the storage site. Attribute values are near, far, and offshore. At this time, logistical

hurdles related to using any offshore basin for the storage of CO_2 are huge, especially when ice is a factor. Figure 2 illustrates that many of the sedimentary basins in Alaska are either located offshore or very far from CO_2 sources and infrastructure.

13) **Reservoir and Seal Potential (Reservoir_)** – A qualitative attribute, based on the best well and seismic data available, of both reservoir and seal potential is shown in Figure 5. A value will be assigned (Good, Fair-Good, Limited, or Poor) if the basin has at least one well. This is highly generalized, as in all but productive hydrocarbon basins, the well control is completely insufficient to describe the reservoir and seal characteristics for the entire basin. With that caveat, this attribute is an attempt to illustrate whether a particular basin could have significant amounts of CO_2 storage capacity, independent of economic or logistical considerations.

14) **Sequestration Potential (Sequestrat)** – A qualitative attribute based on the other attributes, and shown in Figure 6. Values are High, Moderately High, Moderately Low, Low, None, Less than 1 km, and Offshore/Inaccessible. This attribute is further described in Section 2.2.2.

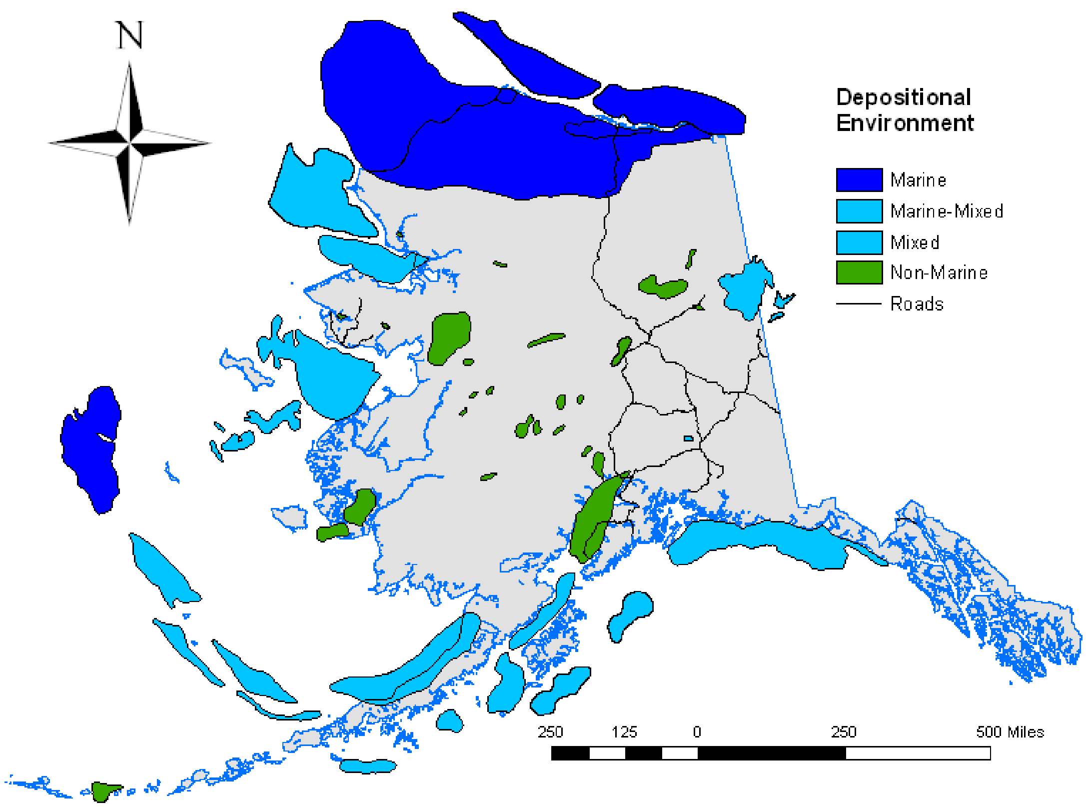

Figure 3: Alaska sedimentary basin "Depositional_Environment" attribute. Those basins deposited in non-marine or mixed environments are likely to have deeper than usual non-saline waters.

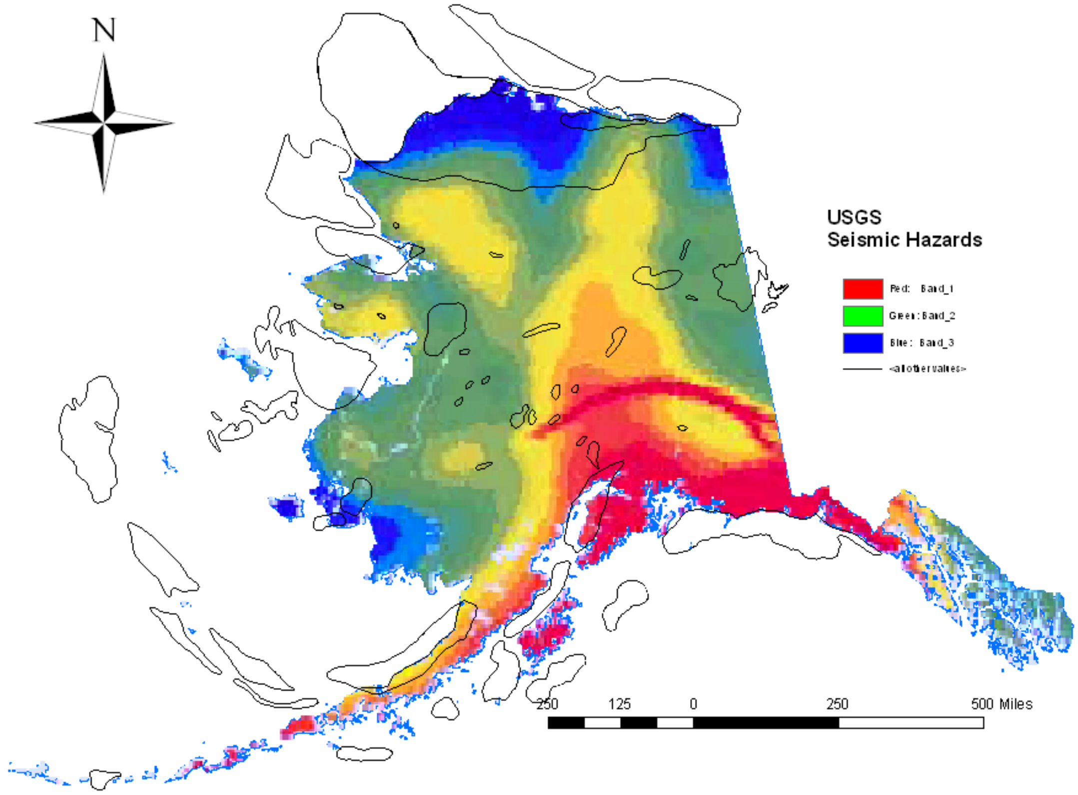

Figure 4: USGS Seismic hazards map with basin outlines. (From Wesson, et.al. 2007, Revision of time-Independent probabilistic seismic hazard maps for Alaska)

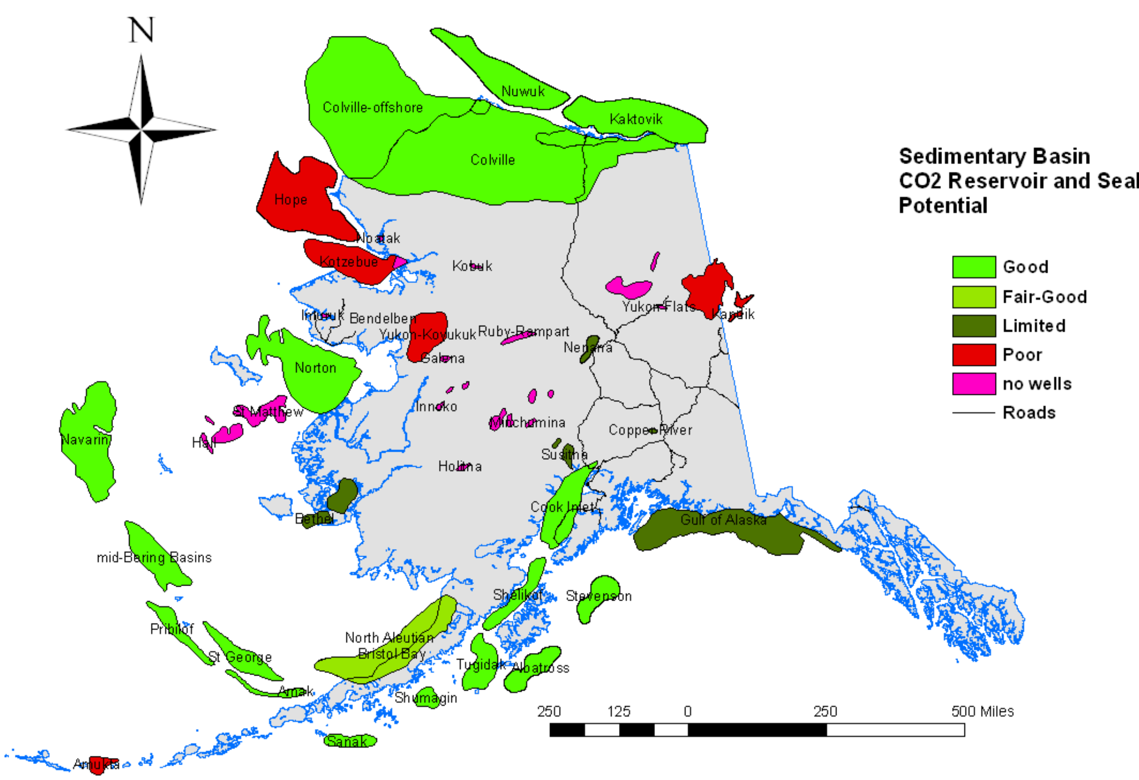

Figure 5: Alaska sedimentary basin “Reservoir_ Seal_Potential” attribute.

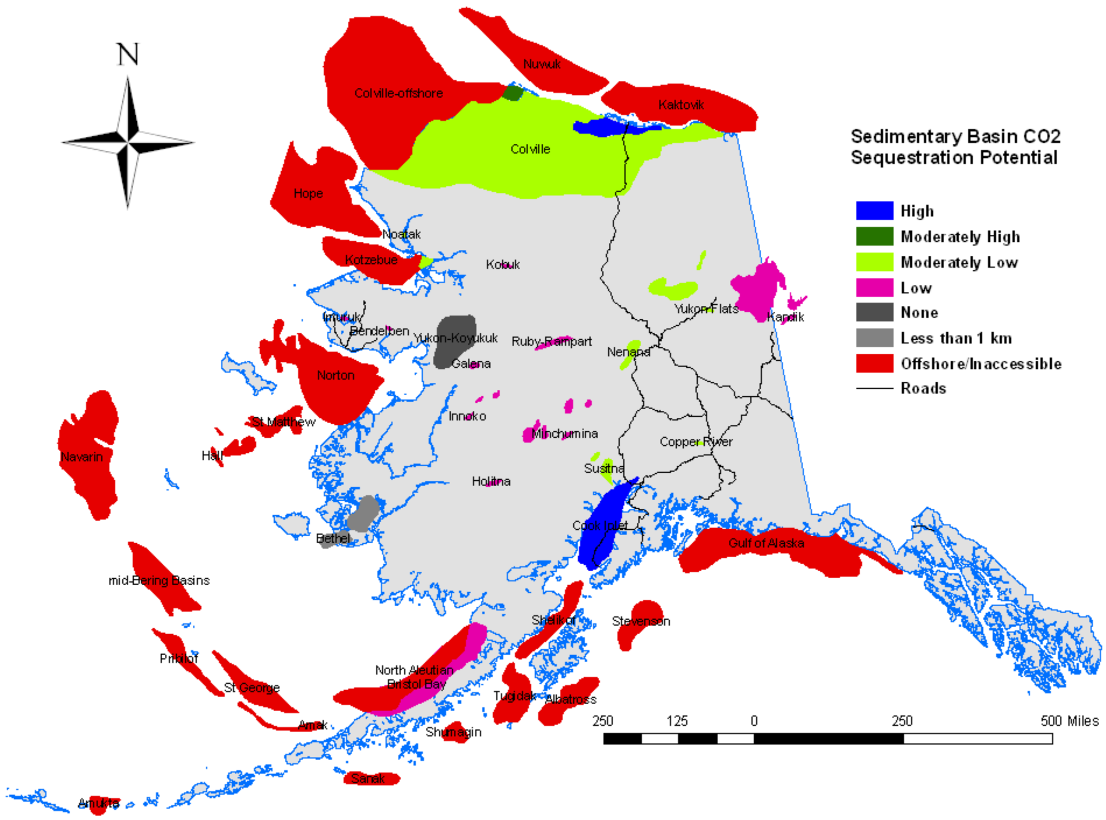

Figure 6: Alaska sedimentary basin storage potential GIS shape file, illustrating the "Sequestration_Potential" attribute, which incorporates logistical and economic factors such as lack of infrastructure, scarce knowledge of reservoir and seal, and challenges in working in an offshore environment

2.2.2 Saline Basin Sequestration Potential Attribute

Sequestration Potential, as shown in Figure 6, is a qualitative estimate of the likelihood a particular basin will be suitable for geologic sequestration of CO_2, and is based on the analysis of the other attributes as described in Section 2.2.1. Factors that most impacted the ranking were:

1) Degree of uncertainty on the presence of reservoir, seal and trap. This follows from the kinds and types of data available to describe a basin. The attributes describing the number of exploration wells and amount of seismic data were key in determining the degree of uncertainty. For the many basins defined primarily on gravity data (little or no well or seismic data collected), the degree of uncertainty is very high. If the knowledge of reservoir, seal or trap is very low this leads to a sequestration potential categorization of 'Low'.

2) Hydrocarbon exploration activity. If wells are being drilled or planned in a basin, the sequestration potential is rated higher, as oil and/or gas exploration success would provide both a confirmation of reservoir, seal and trap as well as improvements to infrastructure. For those basins with current exploration interest, further exploration with well log and seismic data will increase the knowledge

base leading to higher ranking of potential, , i.e.. For the Nenana, Yukon Flats, and much of the Colville basin the sequestration potentials were raised from 'Low' to 'Moderately Low' based on exploration interest.

3) Distance from infrastructure. Many basins are far from CO_2 sources and the road system (Figure 2). Offshore basins (with the exception of the Cook Inlet Basin) are categorized as 'Offshore/Inaccessible' to reflect that working offshore in harsh weather environments and ice coverage is currently not economically feasible. However, oil or gas exploration success in one of those basins could also prove up sequestration potential for CO_2 emissions generated as part of oil and/or gas production operations.

4) Hydrocarbon production. Current evidence of hydrocarbon accumulations is weighted heavily. For example, the Cook Inlet Basin is categorized as 'High' sequestration potential, in spite of the fact that it is also in the highest category of seismic risk. The trapped hydrocarbons are proof that the high current seismicity does not impact the sealing capacity for reservoirs in this basin.

2.3 Coal Seam CO_2 Storage Potential

Alaska has enormous deposits of coal, with hypothetical coal resources estimated to be in excess of 5 trillion metric tons (5.5 trillion short tons). The map of Alaska's coal resources by Merritt and Hawley, 1986 was utilized as the base to define the numerous coal basins screened for determining CO_2 coal seam storage potential. This map divides coal-bearing basins into a loose hierarchy of "coal provinces", "subprovinces", "coal fields," and "coal districts." This study only considered nineteen onshore coal-bearing sedimentary basins, shown on Figure 7 (areas 1-19), and did not evaluate the numerous small "single-point" coal occurrences delineated on the 1986 Merritt and Hawley map. These single-point coal occurrences lack subsurface data that provides any information on the presence or thickness of any deep coals. With the exception of the Cook Inlet Basin, the apparent offshore counterparts to onshore coal basins were reviewed but due to the absence of sufficient drill hole data, the offshore coal is very poorly delineated. Several coal-bearing basins were further subdivided into A, B and C. The coal basins reviewed are:

1. Northern Alaska Province: A–Arctic Foothills Subprovince, B–Arctic Coastal Plain Subprovince, C–Sagavanirktok coal field;
2. Nenana Basin and A and B;
3. Cook Inlet Basin, A–Southern, B–Susitna Basin, C–Matanuska Field;
4. Lisburne Field;
5. Seward Peninsula Province;
6. Kobuk Basin;
7. Upper Koyukuk Basin;
8. Yukon Flats basin;
9. Lower Koyukuk Basin;
10. Rampart Field;
11. Middle Tanana Basin;
12. Eagle-Circle field;

13. Nelson Island District;
14. Minchumina Basin-Little Tonzona Field;
15. Broad Pass Field;
16. Copper River Field;
17. North Aleutian Basin–A. Herendeen Bay Field, B–Chignik Field, C–Ugashik District;
18. Bering River Field;
19. Southeast Alaska, A–Angoon District, B–Admiralty District, and C–Kuiu District.

The screening process involved examining the coal seam CO_2 storage attributes (described below in section 2.3.1) for each of the 19 coal areas. The coal areas were then placed into six categories of potential for coal seam CO_2 storage (shown in Figure 7), High, Moderately High, Moderately Low, Low, Insufficient Data, and None.

After reviewing publically-available geologic and coal resource data for these 19 coal areas, only the Northern Alaska Province (area 1), the Nenana Basin (area 2) and the Cook Inlet Basin (area 3) have sufficient and reliable subsurface and coal quality data to make reasonable estimates of CO_2 coal seam storage capacity and are in proximity to existing or potential future infrastructure. These areas have also demonstrated coalbed methane potential from both published reports and unpublished information. The North Aleutian Basin (area 17), including the Herendeen Bay, Chignik and Ugashik fields, may have CO_2 potential, but it is considered low due to extensive faulting and lack of lateral continuity in the region (Tyler, et al., 2000). Particularly in the Chignik region, the coals are extensively folded and thrusted and structurally discontinuous (Smith, 1995). Even though there are anecdotal reports of methane from onshore underground mine adits in the Herendeen Bay (area 17A), there is no directly measured coalbed methane content data. Here, the subsurface volume of deep coals is unknown and the coals are likely structurally discontinuous.

Coal rank and ash content affect the capacity of a coal seam to hold gas, whether it is methane or CO_2. Coal has a higher adsorption affinity for CO_2 than for methane. The ratio of CO_2 adsorbed versus CH_4 desorbed at any given pressure is known as the storage ratio (Massarotto, et al., 2005). For higher rank medium to high volatile bituminous coals the storage ratio is about 2:1 at low to medium pressures, decreasing to some extent at higher pressures. As the coal rank decreases, the storage ratio for CO_2 increases, and has been measured for subbituminous coal between 7:1 and 10:1. For the lowest rank coals, lignite the ratio is as high as 13:1 (Burruss, 2002).

2.3.1 Coal Seam CO_2 Storage Attributes

Numerous geologic reports, coal studies and geologic maps were compiled, researched and reviewed to obtain the information necessary to revise the previous estimate of Alaska coal seam CO_2 storage capacity. Sixteen attributes (1-16 listed below) assigned to GIS shape files were selected for the process of screening coal "basins" for their CO_2 storage potential and to provide quantitative estimates for CO_2 coal seam storage capacity in the coal basins with sufficient data to permit a reasonable estimate. These attributes were selected after reviewing available literature deemed important to CO_2 coal seam storage capacity assessment. Attributes 17 and 18 provide information on the area (in meters^2) and the length (in meters) of the polygons. The following list show the attributes assigned to the GIS coal basin outline shape files shown in Figure 7.

1) **CoalBasin** – Coal Province/Basin/Field or District Name – Names and outlines from Merritt and Hawley, 1986 Special Report 37 map. Outlines are of coal basins, coal provinces or coal field and districts basins that contain coal. These outlines delineate the 19 coal basins evaluated.

2) **BasinAge** – Predominate age (by Era) of coal-bearing formation, Tertiary, Cretaceous or Mississippian (Kirschner, 1988; and Merritt and Hawley, 1986). Basin age is generally related to coal rank and structural complexity. The Cretaceous and Mississippian age coals tend to be higher in rank and have undergone greater tectonic stresses.

3) **DepoEnviro** – Coal depositional environment: fluvial, lacustrine, fluvial deltaic system. Certain coal-forming environments develop into coal deposits that are much more laterally continuous. Fluvial-related coals form in smaller, often truncated coal swamps. (Ahlbrandt , et al., 1979; Burke, 1965; Flores, et al., 2004; Merritt and Hawley, 1986; Reifenstuhl and Decker, 2008; and Wahrhaftig, et al., 1994).

4) **StructSet** – Structural setting of the basin or coal forming swamp if known (Kirschner, 1988; Merritt and Hawley, 1986; and Swenson, 1997). There exists a wide range of structural settings that range from simple depressions, to more complex grabens and transpressional foreland basins. For the older "precursor" Cretaceous basins, the structural setting is poorly understood. The structural setting is related to the tectonic forces that created the coal basin and subsequently affected the sediments in the depocenter. The older and especially more complex settings contain coals that are more highly deformed, and less suitable for CO_2 sequestration.

5) **Map_Unit** – Outlines of coal-bearing geologic map units, based on available and numerous geologic maps (Merritt and Hawley, 1986). The geologic maps can provide information on coal outcrops, strike and dip of beds and specific details on the outline of surface exposures of nonmarine coal-bearing rocks. The strike and dip of a coal-bearing unit provides information on the potential for subsurface coal at depth.

6) **Rank of coal** – Rank of coal, qualitative value based on published coal analyses. This is the main factor in determining CO_2 sequestration potential of an area (Merritt and Hawley, 1986; Flores, et al.2004; U.S. Geological Survey, National Coal Resources Data System, US Coal Quality Database; and unpublished data files). The rank of coal affects the CO_2 storage capacity of coal seams in two ways. Lower rank coals have greater storage ratios of CO_2 to methane. However, higher rank coals have greater capacity for cleating and thus have higher permeabilities than lower rank coals.

7) **NetCoalThk** – Net coal thickness in the stratigraphic section, where known. (Flores, et al., 2004; McGee, 1973; McGee and O'Connor, 1975; Merritt and Hawley, 1986; Roberts, 1991; Roberts, et al., 1992; Wahrhaftig, 1973; and Wahrhaftig, 1987). A greater net coal thickness in beds 1 feet or thicker equates to greater potential CO_2 gas storage.

8) **CoalVolume** – Volume of coal (in short tons) in a particular coal basin or province if known for that specific area. (Flores, et al., 2005; McGee, 1973; McGee and O'Connor, 1975; Merritt and Hawley, 1986; Roberts, 1991; Roberts, et al., 1992; Wahrhaftig, 1973; and Wahrhaftig, et al., 1994). .

9) **QualData** – Whether coal quality data exists for a particular polygon (Yes or No.) (Affolter, et al., 1994; Rao, 1980; U.S. Geological Survey, National Coal Resources Data System, US Coal Quality Database, and unpublished data). Coal quality is determined by analyzing coal for calorific value (or heat content), ash (the non-burnable portion), moisture, and sulfur. These factors affect the gas storage capacity of coals, higher ash coals has a lower gas storage potential than low ash coal.

10) **CBM_Data** – If CBM data is published or available for a particular coal basin, province field. (Bailey, 2007; Clark, et al., 2009; Flores, et al., 2004; Montgomery and Barker, 2003; ,Roberts, et al., 2006; Smith, 1995; Thomas, et al., 2004; and Tyler, et al., 2000). Where data is published or available, volume is reported in standard cubic feet per ton (sfc).

11) **CO2_Stor** – CO_2 storage capacity in Gt derived in this study and based on data resulting from numerous sources and methodology provided in Brennan and Burruss, 2003; Clarkson and Bustin, 1997; Reeves, 2001; Roberts, et al., 2008; Stanton, et al., 2001; Stanton, et al., 2002; Stevens and Moodhe, 2009; and Stricker and Flores, 2003.

12) **CoalPerm** – Published data on permeabilities of coal bearing units in millidarcies. Permeabilities can only be determined by pressure testing a seam which has only been reported and published for only two sites in Alaska. Unfortunately, coal permeabilities could not be determined empirically from coal quality data because there are too many undefined variables in the existing data for Alaska coal. The permeability of a coal seam depends upon a number of factors including ash content, mineral inclusions, fractures, maceral types, and confining coal seam pressure. Both maceral type (determined through coal petrography, and this data is lacking) and confining coal seam pressure are unknowns for most coal deposits in Alaska. (Clarkson and Bustin, 1997 and Dawson and Esterle, 2009)

13) **InfraStruc** – Infrastructure within or adjacent to coal basin, field or district. Roads, pipeline, rail, marine.

14) **Permafrost** – Type of permafrost extent in coal basin, field or district. (Ferrians, 1965 and Jorgenson, et al. , 2008). Permafrost is frozen soil or rock, at or below 0 °C and is classified as continuous, discontinuous, sporadic, or isolated zones. In the continuous zones, permafrost occupies the entire area (except below large rivers and lakes), notably present in the northern half of Alaska. On the North Slope, depths to the base of the permafrost are as great as 660 meters in the Prudhoe Bay region. In the discontinuous zone, 50% to 90% of the surface is underlain by permafrost with depths to the base of the permafrost highly variable but as great as 119 meters in the northern Yukon Flats basin. In sporadic

permafrost zones, the percentage of the surface underlain by permafrost is less than 50% with depths to the base of the permafrost as great as 184 meters in the lower Kuskokwim River area in southwest Alaska. The isolated zone of permafrost contains patches of permafrost, with depths to 53 meters (Jorgensen, et al., 2008). The presence of permafrost impacts the storage of CO_2 in coal seams that are frozen by clogging the pores and fractures with ice crystals. Gas storage in coal seams in areas of thick permafrost must occur below the base of the permafrost.

15) **PFrostDepth** – Depth to base of permafrost based on contours derived from oil and gas exploration wells (North Slope) and boreholes in Interior Alaska and Seward Peninsula. (Collett, et al., 1989; Deo, 2008; Ferrians, 1965; Jorgenson, et al., 2008; Osterkamp and Payne, 1981).

16) **CO2_Poten** – Potential for CO_2 sequestration based on depth of coals and permafrost (Bachu, 2003; Flores, et al., 2004; Gunter, et al., 2004; Roberts, et al., 2006; and Stevens and Moodhe, 2009). Areas are ranked High, Moderately High, Moderately Low, Low or Insufficient Data. Areas of Insufficient data lack information to make a reasonable estimate of CO_2 storage capacity. Areas of Low potential have potentially thick coal seams, but their subsurface presence and extent is unknown. The Moderately Low area in the Brooks Range foothills contains thickest coals at shallow depths within the zone of continuous permafrost. The Moderately High area contains known CBM resources at the far western end and coals beneath the permafrost zone, however a large portion of the coal resources are based on hypothetical estimates. The High areas have proven CBM resources and are close to sources of CO_2 generation from Oil and gas combustion and gas, coal and diesel electrical power generation.

17) **Shape_Area** – Area of polygon in meters squared.

18) **Shape_Length** –Length of polygon in meters.

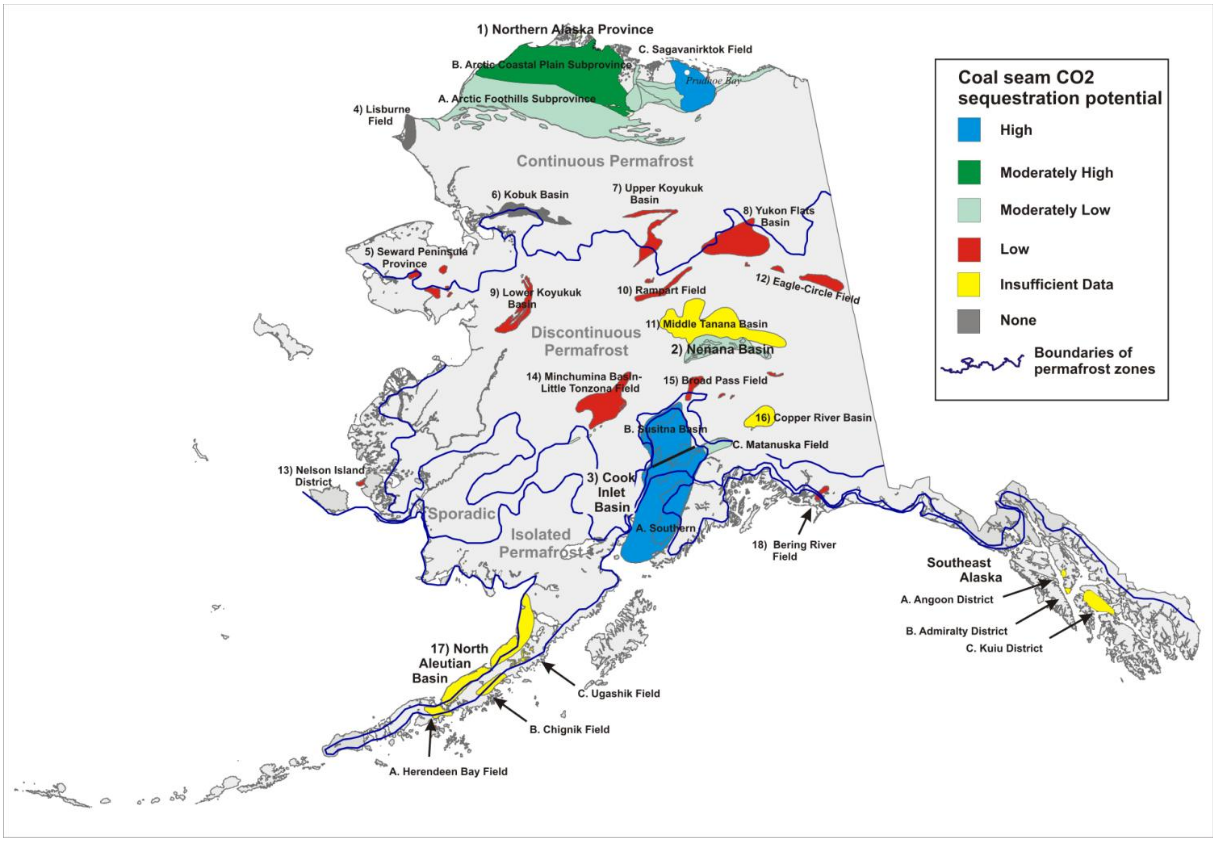

Figure 7: Alaska coal basin storage potential GIS shape file, illustrating the qualitative sequestration potential (CO2_Poten) attribute

3.0 Conclusions and Discussion

3.1 Saline Basin Sequestration Conclusions and Discussion

Using established DOE methodologies, huge potential volumes for CO_2, estimated at 16,700 Gt, have been reported for saline basins on the North Slope and offshore Alaska (Stevens and Moodhe, 2009). When these volumes are further constrained with additional geological and logistical variables, estimates will decrease dramatically (by at least a factor of 10.) The most significant factors are:

a) Logistical hurdles in transporting and working offshore in harsh, often ice covered, environments make it unlikely that offshore basins, over 11,000 Gt of initial estimated storage capacity, will be a resource in the foreseeable future.
b) Prohibitive costs to transport CO_2 long distances between remote basins and infrastructure (including roads) and CO_2 sources, and
c) Insufficient knowledge of porosity, permeability, and seal in the basins to ensure that CO_2 could be injected, and once injected, would not leak.

Additional factors that would diminish, but not necessarily eliminate a basin's sequestration potential, are:

a) Depth of 'fresh' water likely to be deeper than usual in basins deposited in non-marine environments
b) Interaction between faulting, seal capacity and tectonic activity in the next 100-1000 years.

Of more significance, while actual storage potential could be at least an order of magnitude lower than initial estimates made without logistical and additional geologic constraints, the known areas of "high" potential shown in Figure 6 are still likely to provide more than enough storage space for all the CO_2 available for capture in Alaska at current and projected CO_2 emission volumes. Pore space will not be the limiting factor in the successful implementation of CCS in Alaska, it will be the economics of capture and transport. The high storage potential that exists in the proven oil and gas basins on the North Slope and the Cook Inlet (in enhanced hydrocarbon recovery, in depleted fields, and in saline reservoirs near, above and below hydrocarbon reservoirs) needs to be further delineated in order to maximize the potential of geologic sequestration in Alaska. [Preliminary studies show that there is significant potential for EOR in Alaska oil and gas basins (ARI, 2005; Patil, 2006, and Patil, 2008).] Detailed studies are needed to further delineate the sequestration potential in:

a) Enhanced oil recovery in the existing North Slope oil fields
b) Enhanced oil recovery in Cook Inlet oil fields
c) Depleted oil and gas fields
d) Saline reservoirs already delineated in and around the existing North Slope and Cook Inlet fields, and
e) Undiscovered saline reservoirs, using the USGS reserves estimation methodology

It is important to obtain realistic estimates for storage potential in Alaska's saline basins. That information, along with significantly improved economics for CO_2 capture, transport, injection, and long-term monitoring, and the establishment of laws and regulations for CO_2 storage, will maximize the chances of effective implementation of CCS technology in Alaska.

3.2 Coal Seam CO_2 Sequestration Conclusions and Discussion

A preliminary published estimate of Alaska CO_2 coal seam storage capacity for the WESTCARB project, based on an estimate of 776 Tcf CBM resources, was 84 Gt (Stevens and Bank, 2007). This estimate was subsequently revised to 120 Gt of CO_2 storage capacity (Stevens and Moodhe, 2009). These studies further noted that it was likely that only a portion of their estimate would be "considered favorable for CO_2 sequestration, due to permeability, seam geometry, surface access, faulting, and other site-specific but currently unknown conditions" (Stevens and Bank, 2007, p. 1). This report addresses those aspects, as well as revised estimates of North Slope CBM resources detailed in Roberts, et al., 2008, improved estimates of thickness of permafrost on the North Slope (Deo, 2008), and distance from sources of anthropogenic CO_2. For both distance from infrastructure and lack of data, we excluded the offshore areas of Alaska, where, with the exception of Cook Inlet, subsurface data on coal seams is lacking and reliable estimates of coal volume is not possible. The Northern Alaska Province (area 1 on Figure 7), the Nenana Basin (area 2 on Figure 7), and the Cook Inlet Basin (area 3 on Figure 7) have a combined deep, unmineable coal seam CO_2 sequestration of 49.24 Gt based on our study of available data (Table 1).
Our revised estimate of CO_2 storage potential is based largely on the 2006 and 2008 assessment of North Slope by Roberts, et al., 2008. Their study took into consideration the thick continuous permafrost extant throughout the North Slope region. Roberts, et al., 2008, concluded that coalbed methane production from within the permafrost would be very unlikely due to lack of permeability in frozen coal seams. This removed a significant portion of the coal seams from consideration, resulting in about only about 6% of the storage potential reported by Stevens and Moodhe, 2009. This permanently frozen coal is not suitable for CO_2 sequestration under current technology. Additionally, we utilized revised estimates of the depth to base of permafrost determined from exploration revisions of well bottom hole temperatures by Deo, 2008. Finally, we utilized CO_2:CH_4 storage ratios based on varying coal rank, as outlined in Burruss, 2002 and Massarratto, et al., 2005 to determine our revised estimate of CO_2 storage potential in Alaska coal seams presented in column 8 of Table 1. Unfortunately, we found throughout the literature compilation process that details on coal cleating and fracture density, along with coal seam porosity is totally lacking in the available literature. Until the advent of coalbed methane exploration, these details were not considered important parameters of data to collect and analyze. Availability of this data would enable further refinement of the CO_2 coal seam storage potential for Alaska.

Estimates of CO_2 sequestration potential in Alaska can be improved through laboratory measurements of CO_2 adsorption and permeability of coal cores collected from exploration wells that penetrate deep coal seams.

(1) REGION	(2) IDENTIFIED & HYPOTHETICAL COAL RESOURCES (billions of short tons)	(3) AVERAGE COAL RANK	(4) ARI Estimated CBM Resources (based on daf) (Tcf)	(5) ARI Estimated CO2 Storage Potential (Tcf)	(Gt)	(6) USGS Estimated CBM Resources* (Tcf)	(7) CO2 Storage Potential based on USGS CBM Resources* (Tcf)	(Gt)	(8) REVISED ESTIMATE OF COAL SEAM CO2 STORAGE POTENTIAL (this report) (Gt)
1) Northern Alaska Province	3,753.00		621	1,862	98	17.2	120.4	6.32	5.83
A. Arctic Foothills Subprovince	1,290.00	Bituminous							
B. Arctic Coastal Plain Subprovince	1,910.00	Subbituminous	No Data	Not Subdivided		15	105	5.53	5.08
C. Sagavanirktok Field	553.00	Subbituminous				2.2	15.4	0.79	0.75
Total North Slope	**3,753.00**		**621**	**1,862**	**98**	**17.2**	**120.4**	**6.32**	**5.83**
2) Nenana Basin	17.00	Lignite to subbituminous	1	3	0	1	10	0.52	0.41
3) Cook Inlet Basin. Includes A. Southern, B. Susitina and C. Matanuska resources	1,570.30	Subbituminous to anthracite	136	407	21	140	980	50.58	43.00
TOTAL ALL "BASINS"	**5,340.30**		**758.00**	**2,273**	**120.00**	**158.20**	**1,110**	**57.32**	**49.24**

*North Slope based on Roberts et al., 2008

Table 1. Summary table of estimates of deep coal seam CO_2 storage potential in Gigatons (Gt) based on attributes evaluated in this report (column 8). Coal resource estimates (column 2) and average coal rank (column 3) compiled from Merritt and Hawley, 1986 and Flores, et al., 2004. ARI estimated CBM resources based on dry ash free coal (column 4) and estimated CO_2 storage potential (column 5) from Stevens and Moodhe, 2009. USGS estimated CBM resources (column 6) from Flores, et al., 2004; Montgomery and Barker, 2003; Roberts, et al., 2006; and Roberts, et al., 2008. Column 7, CO_2 storage potential was determined during the course of this study and is based on the 2008 assessment of North Slope recoverable CBM.

3.2.1 Northern Alaska Province Coal Seam CO_2 Storage Potential

The Northern Alaska Province, comprised of the Arctic Foothills subprovince, Arctic Coastal Plain Subprovince and the Sagavanirktok Field is underlain by the Lower to Upper Cretaceous-age fluvial-deltaic Nanushuk Formation and the Tertiary-age Sagavanirktok Formation. Coal rank ranges from lignite A to high-volatile A bituminous, with a mean rank of high-volatile C bituminous. These coals are within the optimum rank for thermogenic coalbed methane generation (and hence CO_2 storage potential) and cleating has been demonstrated in both coal cores from exploration wells and in outcrop.

Initial estimates of the coalbed methane potential for this region were as high as 800 Tcf. However, a recent detailed evaluation by Roberts, et al., 2008 based on the Total Petroleum System concept indicated a coalbed methane potential of 17.2 Tcf (mean value).

Permafrost zones underlie 80% of Alaska, and include continuous (32%), discontinuous (31%), sporadic (8%), and isolated (10%) permafrost (Jorgenson, et al., 2008). The Northern Alaska Province lies entirely within the continuous permafrost region, where depths to the base of the permafrost are as great as 660 m in the vicinity of Prudhoe Bay to 20 m or less near the base of the Brooks Range. Of all of the factors influencing storage of CO_2 in deep, unmineable coal seams, the presence of a thick permafrost cap has the greatest impact in reducing potential storage capacity. A permanently frozen coal reservoir detrimentally blocks permeability pathways due to incipient ice-filled cleat fracture system. Therefore, the CO_2 storage capacity of the Northern Alaska province is significantly reduced in areas of currently deep permafrost conditions.

It should be noted that studies are underway to examine the potential for creating carbon dioxide-hydrates in these environments as a stable gas hydrate to be sequestered in various reservoir geological formations (see Uddin, et al., 2008). Whether this will be possible in deep frozen coal seams remains to be evaluated. Based largely on the presence of thick permafrost, the volume of available deep, unmineable coal seams for CO_2 sequestration is reduced to between about 6% of the available 98 Gt of CO_2 storage reported by Stevens and Moodhe, 2009. CO_2 storage capacity in the Northern Alaska Province is estimated to be 5.83 Gt (Table 1). Stevens and Moodhe, 2009 did not consider the vast and thick and continuous permafrost on the North Slope in their assessment of CO_2 coal seam storage potential. We reviewed the available data and found, like Roberts et al., 2008 that coal within a large portion of the Northern Alaska Province is within the permafrost zone. Where the coal is thickest, it is also shallowest in the western part of the basin and contained by permafrost (moderately low on Figure 7). In the deeper portion of the basin, the coals are either within the permafrost zone, or a great depth. Roberts, et al., 2008 took this into consideration in their evaluation of the CBM potential.

Unfortunately, while the Prudhoe Bay region has excellent access to infrastructure and large sources of CO_2, it also has the deepest permafrost zones in Alaska (up to 660 m thick). CO_2 sequestration potential in that area, the Sagavanirktok Field, is likely very small, on the order of 0.75 Gt.

3.2.2 Nenana Basin Coal Seam CO_2 Storage Potential

The Nenana Basin contains Tertiary-age coals ranging from lignite to subbituminous in rank. There is little available data on the coalbed methane content of these lower rank coals. Although lower rank coals are more favorable for CO_2 sequestration, having up to a 10:1 replacement for methane, they are higher in ash and poorly cleated and the total resources are small, compared to the Northern Alaska Province and the Cook Inlet Basin. The CO_2 storage potential in available coal seams in the Nenana Basin is estimated to be 0.41 Gt (Table 1). Although the volume of coal in the Nenana Basin is small, about 17 billion short tons, it has lower rank coals that have a potentially higher CO_2:CH_4 ratio, on the order of 10:1. Stevens and Moodhe, 2009 used a lower CO_2 to methane ratio of 3:1 in determining that CO_2 storage potential within coal seams in the Nenana Basin is nil. Recent oil and gas exploration in the deeper portion of the Nenana Basin indicates the presence of a fairly thick section of coal-bearing rocks[4] with the potential for CO_2 sequestration in an enhanced CBM production process. Should storage be found to be feasible in coals in the Nenana basin, they could provide storage for CO_2 captured in and near Fairbanks, including the existing coal-burning power plant in nearby Healy.

3.2.3 Cook Inlet Basin Coal Seam CO_2 Storage Potential

The Cook Inlet Basin contains extensive Tertiary-age coal resources in the Tyonek Formation at favorable depths for CO_2 sequestration. Coal rank ranges from subbituminous to high-volatile bituminous coal. Montgomery and Barker, 2003 indicated potential coalbed methane resources at 140 Tcf. We estimate the CO_2 sequestration potential in deep, unmineable coal seams to be 43.0 Gt (Table 1). This estimate includes both onshore and offshore Cook Inlet subsurface coal seams. Our estimate is higher than the 21 Gt reported by Stevens and Moodhe, 2009. We utilized a different CO_2:CH_4 coal storage ratio (approximately 7:1) and our review of available data resulted in a higher coal resource (1,570 billion short tons) than Stevens and Moodhe, 2009 who reported 1,292 billion short tons of coal.

Of the three coal-bearing basins evaluated, the Cook Inlet Basin has the greatest potential for near term CO_2 sequestration in deep, unmineable coal seams (43.0 Gt, Table 1). Infrastructure consisting of numerous roads and pipelines surrounds much of the northern and eastern portion of the basin, and it sits adjacent to major CO_2 emission sources. As oil and gas development moves westward across the Northern Alaska Province, this region is likely to become more prospective for injecting CO_2 emissions from oil and gas activities into deep coal seams.

[4] Confidential communication

4.0 References

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