Contract No. G-018-036
"Bakken Water Opportunities Assessment"
Submitted by **Energy & Environmental Research Center**
Principal Investigator: Daniel J. Stepan

PARTICIPANTS

Sponsor	**Cost Share**
Phase I	
North Dakota Petroleum Council	$10,000
EERC/DOE Funds	$25,000
North Dakota Industrial Commission	$25,000
	$60,000
Phase II*	
Industry Match	$ 85,000
North Dakota Industrial Commission	$ 85,000
	$170,000
Total Project Cost	$230,000

Project Schedule – 12 months*
Revised to 22 months**
Contract Date – June 19, 2009
Start Date – April 1, 2009
Completion Date Phase I – March 15, 2010**
Phase II Work Plan Submitted – 3-31-2010**
Completion Date Total Project – 12-31-2011**

Project Deliverables:

Final Report Phase I: March 15, 2010** √
Phase II Work Plan Submitted: March 31, 2010**√
Status Report: July 31, 2010**√
Status Report: January 31, 2011***√
Status Report: July 31, 2011***
Final Report: December 31, 2011***

OBJECTIVE/STATEMENT OF WORK:
To investigate the recycling of water flowed-back after Bakken fracture stimulation. The project has the following two phases under the Northern Great Plains Water Consortium program:

Phase 1: Assess the technical and economic potential of recycling frac flowback water.
Phase 2: Field demonstration of a mobile frac flowback water recycling technology.

*The Council recommended and the Commission approved the funding of Phase I and stated that the applicant did not need to resubmit an application for the funding of Phase II. However, the applicant must show that Phase I has been successful and has obtained industry match funding for Phase II prior to the Council considering, at a future meeting, the funding for Phase II.

** The Council recommended at their January meeting and the Industrial Commission subsequently approved the funding for Phase II noting that the scope of work has been revised from what had originally been proposed. Rather than recycling frac flowback water the focus will be on treatment of nonpotable groundwater. A Phase II Work Plan is to be submitted in March along with confirmation of match funding. A no-cost extension has also been requested and the final completion date has been extended to January 31, 2011. The reporting schedule has been revised to reflect the new project completion date.

*** A no-cost extension has been granted extending the final completion date to December 31, 2011. The reporting schedule has been revised to reflect the new project completion date.

STATUS

The contract has been executed. EERC provided a report at the North Dakota Petroleum Council's meeting in September, 2009 regarding the status of the project. Seven tasks were outlined under this project:

- Task 1 – Inventory Industry Freshwater Use
- Task 2 – Assess Flowback Quality with Time and Location
- Task 3 – Evaluate Current Water Handling Costs
- Task 4 – Evaluate Feasibility of Recycle/Reuse Technologies
- Task 5 – Assess Current State of Existing Recycling Technologies
- Task 6 – Develop Detailed Plans for Phase II
- Task 7 – Project coordination, outreach and reporting

As of the September 2009 Petroleum Council meeting the project status was:

- Samples have been analyzed and/or data has been collected from four of five producers participating in the assessment.
- Extensive, but not comprehensive, frac flowback water chemistry data has been analyzed.
- Technology review and capabilities assessment underway.
- Preliminary economic assessment underway.

A presentation was given at the January 20, 2010 Oil and Gas Research Council meeting. The Principal Investigator Daniel Stepan stated:

- Under Phase I samples have been analyzed and/or data have been collected from five producers participating in the assessment.
- Extensive, but not comprehensive, frac flowback volumes and water chemistry data compiled and evaluated.
- Technology review and capabilities assessment complete.
- Preliminary economic assessment ongoing.
- Phase 1 final report in preparation.

He stated that they are ready to proceed to Phase II. A Frac Flowback Water Treatment system has been identified – Mechanical Vapor Recompression (MVR). It is oil field-compatible, robust, mobile, uses existing technology and shows high treated water recovery.

He noted that Bakken Flowback Water-Recycling has significant challenges:

- Slow recovery of flowback water.
- Relatively low-volume initial recovery.
- Extremely high dissolved salts early in the flowback.
- Treatment very challenging, even with the most robust technologies.
- Treatment very likely not cost-effective in most cases.

He noted that for Phase 2 the following is underway:

- EERC has identified an oil industry partner for a pilot-scale demonstration of marginal-quality water treatment by reverse osmosis.

- Groundwater samples from a brackish aquifer have been collected, analyzed and shared with several technology vendors.
- EERC is currently awaiting bids from the vendors to supply the pilot equipment.
- Pilot test is tentatively scheduled to begin in March or April.
- Duration: 6 weeks minimum
- After 6 weeks of operation, the EERC will work with the technology vendor to determine projected treatment costs for a large-scale reverse osmosis plant
- EERC will also evaluate this approach as a water supply option for other industrial and/or municipal uses.

The Phase I Final Report was received in April, 2010. A link to the Phase I Final Report is available on this website.

Under Phase I treatment and recycling of frac flowback water was investigated as a means to reduce the demand for freshwater and provide a supplemental supply near drilling and fracturing activities. The character of the frac flowback water with respect to both quantity and quality presented significant challenges for widespread water-recycling opportunities. A relatively small percentage (17% to 47%) of the water used in hydraulic fracturing in the Bakken is typically recoverable in a reasonable time (2 to 10 days). Further, the dissolved solids levels in the frac flowback water increase rapidly and to levels as high as 220,000 mg/L. These factors provide significant challenges for developing cost-effective treatment strategies, even with the most robust technologies. While there will certainly be niche opportunities using certain technologies to recycle frac flowback water, widespread recycling will not likely be economically viable.

The regional and national importance of providing sufficient volumes of water for such an extremely high-value use cannot be overstated. These water supplies will need to come from a variety of resources. One opportunity is to upgrade marginal-quality groundwater resources to satisfy a portion of the demand. An evaluation of a membrane technology for the treatment of nonpotable groundwater to supply water for hydraulic fracturing in the same geographic area is being conducted as a Phase 2 Bakken Water Opportunities Assessment project.

The Commission received the Phase II Work Plan in June, 2010. As noted above rather than recycling frac flowback water which had been done in Phase I the focus will be on treatment of nonpotable groundwater. One potential brackish water supply source for western North Dakota may be the Dakota Aquifer (Dakota). The Dakota is one of the most widespread aquifers in North America, extending from western Iowa to Montana and from the Arctic Circle to New Mexico. The aquifer comprises primarily sandstone, interspersed with layers of shale and siltstone, and is capable of supporting moderate-to-high pumping rates in western North Dakota.

To evaluate the technical and economic feasibility of treating groundwater from the Dakota to provide a freshwater supply for the oil industry in western North Dakota, the EERC teamed up with Hess Corporation (Hess) to conduct a pilot treatment project using reverse osmosis (RO). Hess has identified a specific well and demonstration site. The work plan outlines the EERC's strategy to evaluate a pilot-scale demonstration of Dakota water treatment in partnership with Hess. The ultimate goal is to evaluate the technical and economic feasibility of this approach for providing a freshwater supply source for the oil industry as well as other industrial and/or municipal applications, such as cooling water for coal-fired electrical generation. If the pilot

project is successful and the economics are agreeable, Hess has expressed interest in building a full-scale, 1-million-gallon-per-day (MGD) RO treatment plant.

The Phase II Work Plan includes the following Tasks:

Task 1: Selection of Treatment Technology Vendors
Task 2: Site Preparation
Task 3: On-Site Pilot Test
Task 4: Treatment Technology Performance Evaluation and Cost Assessment
Task 5: Project Reporting

Total cost of the Phase II work plan is **$1,786,404**. In addition to the funding provided by the Commission in the amount of $85,000 Hess has agreed to provide $1,424,930 and the Department of Energy is providing $276,474.

The Phase II Semiannual Progress Report for the January 1 to July 31, 2010 time period was received. This report states the following:

Task 1: Selection of Treatment Technology Vendors – After a review process conducted by Hess and EERC, GE Water & Process Technologies (GE) was selected as the preferred vendor for the project.

Task 2: Site Preparation - The majority of the work during this report period focused on preparing the site for the pilot project which began treating water in July. Specific site preparation activities included:

- Installation of the RO treatment and pretreatment units
- Installation of the feedwater cooling system and heat exchangers
- Construction of a lined and covered pond for storage of the treated water
- Installation of five 400-barrel tanks to store the feedwater, excess permeate (if needed), and RO concentrate. The RO concentrate tank is designed to meet saltwater storage standards.
- Installation of the necessary piping to connect the system components.
- Installation of the electrical power supply and necessary connections.
- Construction of a truck-loading station that will be used to transport the treated water to hydraulic fracturing locations within the Bakken play.
- Installation of corrosion test racks to evaluate the corrosivity of the feedwater, permeate, and concentrate on various metals and metal/alloys.

The report notes that one of the more challenging aspects of the pilot is the cooling of the feedwater, which exits the production well at a temperature of approximately 150° to 160°F, down to the required 90° to 95°F prior to membrane treatment. After discussion with Hess and GE, it was decided to include heat exchangers as part of the cooling system. Throughout the course of the pilot test, the EERC will evaluate the heat recovery component of the process to determine whether or not a cost savings was achieved through avoided costs to heat frac water makeup.

Another issue of concern related to treatment of brackish groundwater (especially when dealing with elevated temperatures) is corrosion of piping, pumps, cooling system components, and other

materials that come in contact with the water. As part of this project the EERC will be conducting corrosion rate testing of the feedwater, concentrate, and permeate streams to determine proper heat exchanger, piping and valve material selection for a full-scale plant.

Task 3: On-Site Pilot Test – The pilot plant began treating water in mid-July of 2010. It is anticipated that the pilot test will likely be operated for at least 12 months and possibly up to 18 months. The MobileRO® water treatment system provided by GE is a trailer-mounted RO system that has a total flow capacity of approximately 215 gpm. The mobile RO unit and associated cooling system are being operated by GE personnel for the duration of the pilot test. Initially the RO system operated at a reduced capacity (80 gpm permeate) and at reduced permeate recovery rate (50%). The permeate recovery rate will be increased to 70% to 75% recovery in August. Once the system has been successfully operating at the higher recovery rate for approximately 3 to 4 weeks, the system will then be run at the full capacity of 160 gpm permeate. Once the system is fine-tuned and has produced sufficient permeate, the water will be used by Hess to supplement the freshwater supplies used for its hydraulic fracturing operations. Once the system is running full capacity and full recovery, feedwater, permeate and concentrate samples will be collected by the EERC and analyzed by the EERC and/or a commercial lab for detailed chemical characterization. Samples will be collected multiple times in the first few months of system operation and once a month thereafter.

Task 4 – Treatment Technology Performance Evaluation and Cost Assessment – No activities related to this task were performed at this time.

The Phase II Semiannual Progress Report for the August 1, 2010 to January 31, 2011 time period was received. This report states the following regarding the work done during this time period:

Task 3 – On-Site Pilot Test – The pilot project system began treating water on July 21, 2010, at a permeate flow rate of 80 gpm and 50% recovery. Higher permeate recovery rates were not achievable until GE performed system modifications (specifically orifice plate replacement) that were made on August 3, 2010, at which time the recovery rates increased to approximately 70%. GE continued to operate the RO system at a reduced flow rate (80 gpm of permeate production) to be consistent with the truck hauling cycle demands and to maintain a more constant, steady operation. On July 23, 2010, EERC personnel installed six corrosion racks at the subject site. The results of the corrosion studies were that of all the materials tested, the carbon steel and copper-nickel coupons exhibited higher rates of corrosion in all the water streams than did the titanium, Hastelloy, and stainless steel coupons. With that said, the most severe corrosion observed for carbon steel was around 2 mils a year. This corrosion rate may not be considered excessive if it occurred evenly on the surface of a material; however, that does not appear to be the case, as localized pitting was observed and may be of concern in a long-term application. Corrosion results do indicate that stainless steel should withstand contact with the respective feedwater, and concentrate streams quite well. Investment in more exotic (and expensive) materials such as Hastelloy and titanium are not likely warranted.

Task 4: Treatment Technology Performance Evaluation and Cost Assessment – For a variety of unforeseen reasons, the RO system was not operated continuously through the late summer and fall of 2010. While frustrating, this shakedown period provided important insight with respect to the operation and maintenance of the full-scale RO plant that Hess anticipates constructing. The EERC has sufficient data to conduct a preliminary evaluation of the system

performance to date. We believe that a much more robust assessment of the system performance and economics will be achieved using data collected from steady-state operating conditions over a longer period of time. Hess plans to run the RO system continuously through the winter and into the spring of 2011 (and possible next summer) to provide an opportunity to collect additional RO performance data and information on membrane backwash and cleaning cycles. The extended duration of the pilot project also allows the EERC to conduct additional corrosion testing. The corrosion test racks and metal coupons will be reinstalled at the site in the spring of 2011.

6/30/11