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# Techno-economic Assessment of Shale Gas Water Management Solutions

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**GTI Technical Contact:**
Tom Hayes, Ph.D.
Coordinator, Environmental Engineering Solutions
847-768-0722
Tom.Hayes@gastechnology.org

**GTI Business Contact:**
Mr. Trevor Smith
Program Manager
847-768-0795
Trevor.Smith@gastechnology.org

**Gas Technology Institute**
1700 S. Mount Prospect Rd.
Des Plaines, Illinois 60018
www.gastechnology.org

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## Abstract

A critical challenge for shale gas development is the cost and environmental acceptance of wastewater and solid waste management solutions. Gas Technology Institute (GTI) has completed a research project that:

- Defined the current sustainable practices and emerging technical solutions from a global perspective.
- Categorized the best in class options for water management according to the flow sheet model developed by GTI.
- Identified gaps in water treatment and handling technology development and additional areas for innovation.
- Determined near and long term water management cost reduction and efficiency opportunities taking into account full life cycle costs.
- Identified potential next steps to reduce the cost of disposal of solid drilling wastes and increase assurance to stakeholders of the environmental sustainability of drill cuttings disposal.
- Integrated the elements of the project scope to focus on emerging unconventional gas markets that are just entering into the exploratory phase of resource development.
- Produced a decisive report with findings and recommendations and a public summary.

The intended benefits of this report include:

- A private report providing a holistic view of what is technically possible, environmentally desirable, and economically practical
- An assessment of commercial risk to help reduce market uncertainty
- Benchmark alternatives ($/bbl plus life-cycle costs), identify areas for cost reduction and innovation
- An opportunity to pursue partnerships with emerging technologies
- A product to help communicate safe, reliable, cost-effective, and environmentally sustainable solutions to regulators, solution providers, and the public.
- A product to help inform the upcoming EPA study and the global conversation on unconventional gas water management

The performing partners on this project included:

- Dr. Thomas Hayes, Trevor Smith, and Guy Lewis — Gas Technology Institute
- Judith Herschell — Herschell Environmental
- Steve Hughes, P.E. — Tetra Tech
- Dr. Radisav Vidic — University of Pittsburgh
- Joe Zuback — Global Water Advisors.

Industry participation the project included:

- Aquatech International Corporation

- Aqua-Pure Ventures Inc.
- Chevron Corporation
- Clean Membranes, Inc.
- Devon Energy
- Energie Beheer Nederland B.V. (EBN)
- Ecosphere Energy Services
- Eni S.p.A – E&P Division
- E.ON Ruhrgas E&P GmbH
- GDF Suez
- Keppel Offshore and Marine Technology Center PTE Ltd
- Marathon Oil Corporation
- Noble Energy
- National Oilwell Varco, L.P. (NOV)
- Orlen Upstream Sp. zo. O
- Range Resources
- Reserved Environmental Services
- Schlumberger/MiSWACO
- Seneca Resources
- Shell Global Solutions
- 212 Resources
- Weatherford/Johnson Screens
- Williams Energy

## Executive Summary

As shale gas emerges as one of the world's most abundant, affordable and clean-burning sources of energy, growth in the development and production of these resources will require greater sourcing and management of water. Shale gas development requires multiple wells being drilled from one or two pads in a well field with hundreds of well fields constructed and completed within each development area. It becomes clear from simple month-by-month rollup computations that the annual generation and quality of water to be handled as well as annual output of solid waste (including drilling waste) becomes highly dynamic --- constantly increasing and decreasing each year. Within each year of the construction stage of the life cycle of a county-size development area (25 mi x 25 mi), billions of gallons of water must be found (sourced), hundreds of thousands of truckloads must transport water to wellheads for performing hydraulic fracturing of the shale as a necessary step for initiating gas production, tens of millions of barrels of brine (collected as flowback water and produced water) must be reused or disposed of in an environmentally acceptable manner, and hundreds of thousands of tons of drilling waste and sludge must be carefully managed. Since water and waste management represent one of the greatest annual costs of shale gas development (an estimated 8 percent of total revenues from gas production over the life of a development area in the Marcellus Shale could potentially be consumed by water and solid waste management), the economical and environmentally-acceptable management of these streams is critical to the sustainable development of shale gas plays in the U.S., Europe, and throughout the world. The purpose of this project was to provide an assessment and planning approach that can potentially enable shale gas developers to reduce the cost of brine, salt and solid waste management over the life cycle of each development area and assess the need for alternative handling options in the future.

To meet current and anticipated challenges in each region, the industry has implemented and/or considered four flow schemes that can be used for shale gas water disposal and reuse. The flow schemes include: FS1) Direct transportation of brines for disposal in a Class II deep well injection facility; FS2) In-field primary treatment primarily for the removal of suspended solids, oils & greases, microbes (through disinfection), and friction reducer polymer prior to reuse of flowback water for the next frac job; FS3) Near-field (within 20 miles of the well fields) primary treatment mainly for the above constituents plus the possible removal of scale forming constituents (e.g. calcium, magnesium, barium, etc.) followed by reuse of flowback water for the next frac job; and, FS4) Primary treatment plus demineralization using thermal evaporation/distillation processes such as mechanical vapor recompression.

This report describes the economics (i.e. envelope of vendor pricing as a function of salinity, scale, and degree of treatment plus associated direct and indirect costs) and niche application of each of these flow schemes to achieve treatment and disposal goals that are protective of human health and the environment (consistent with local, state and federal regulations). For FS1, typical direct costs range between \$1.50-\$3.50/bbl depending on volume and deep injection rate discounts. For FS2, typical direct costs range between \$1.00-\$5.00/bbl depending on volume and level of treatment. For FS3, typical direct costs range between \$0.50-\$4.00/bbl depending on volume and level of treatment. And for FS4, typical direct costs range between \$4.00-\$6.50/bbl depending on volume and salinity concentration. Indirect costs including road bonding and repair, potential carbon footprint levies, and other air emissions generated by truck traffic were also evaluated and estimated.

The importance of assessing the economic and strategic implications of future regulatory changes is also acknowledged in this report, which helps to ensure regulators provide opportunity for sustainable economic development of shale gas resources along with assurance that environmental impact is managed appropriately for environmental sustainability.

This analysis was assisted by GTI's proprietary water-based life cycle computer model which was utilized to forecast the water output, water reuse capacity, salt generation and solid waste output from a development area using more than 30 inputs to describe its characteristics. Some of the inputs used for the model were taken from statistical analyses conducted by GTI on flowback and produced water data

obtained from the Marcellus and Barnett Shale plays. Life cycle analysis was applied to the active Marcellus and Barnett shale plays as well as an assessment of the exploratory phase of Baltic Basin development in Poland. The Marcellus Base Case identified a number of characteristics that could be of considerable help with water management planning through application of the right flow scheme and management options at the right time. The analysis showed that for a development area, certain water management requirements, reuse opportunities, strategies, and options will change significantly from year to year (or from decade to decade) over the water-based life cycle of shale gas resource development. For example, reuse capacity is greatest in the initial years of the life of a development area. When reuse capacity is exceeded by the generation of flowback and produced water brines (the crossover point), reuse opportunities become minimal and the need for non-reuse options for brine disposal become increasingly important. GTI's model also showed that much of the water flow and more than two thirds of the salt output occurs in the last half of the life of a development area, posing significant challenges to economic and environmental sustainability if precautions are not taken in time. However, preparation based on quality forecasting and an ability to respond with a flexible water management approach that allows the right flow scheme and/or technology to be applied at the right time can result in substantial savings and improved economic performance for a development area.

Further savings are possible with the application of advanced next generation technologies. Promising new technologies in terms of relevance, potential capability and fit with the unique requirements of shale gas flowback and produced water treatment needs were discussed and compared by this study. Increased collaboration between shale gas developers, solution providers, and research organizations in evaluation of these technologies in the field can be expected to yield tangible benefits including water management savings for developers, reduced uncertainties for solution providers, and greater levels of confidence in a shale gas industry that is committed to sound water management solutions.