Arsenic Technology Workshop – Future Research Opportunities

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CONTENTS

CHAPTER 1
PURPOSE/OBJECTIVES

A two-day workshop focusing on arsenic removal technologies was held August 21-22, 2003 in Golden Colorado. The purpose of the workshop was to review the current state of science and engineering on arsenic removal technologies, and identify research needs/opportunities for the Arsenic Water Technology Partnership (AWTP). The expected outcomes from the workshop included identifying gaps and issues, investigating opportunities for improvement, and identifying research priorities for arsenic removal that can be used in developing the research strategy for the AWTP. The focus of the workshop was on technologies and other issues such as management (cost, technology acceptance, training, etc.), improving existing technologies, developing innovative technologies, cross-over technologies, or other approaches. Reducing energy, operating, and residual disposal costs were also considered.

Representatives from utilities, federal and state regulatory agencies, national laboratories, universities, the consulting community, and large and small municipalities attended the workshop which was sponsored by the American Water Works Association Research Foundation (AwwaRF) in collaboration with the Department of Energy's Office of Science (DOE), Sandia National Laboratories (SNL), and WERC: a Consortium of Environmental Education and Technology Development (WERC). Participants included world renowned experts in the treatment of water contaminants. Through the participants' efforts, the workshop identified a path forward for research initiatives in arsenic removal as applicable to point of use (POU) as well as point of source (POS) for small, medium, and large utilities. Furthermore the group identified long term technology solutions that would benefit the efforts undertaken by various participants in the workshop.

Appendix A is a list of attendees and Appendix B contains definitions of current removal technologies.

CHAPTER 2
PROGRAM BRIEFINGS

Several programs presented a detailed perspective of on-going activities in the research, demonstration, and outreach for arsenic contaminated water and removal efforts. The presentation included information from the DOE Water Program, the arsenic partnership that includes AwwaRF/SNL/WERC, and the Environmental Protection Agency's (EPA) arsenic research programs.

DOE Water Program Briefing - Presented by Mike Kuperberg for Teresa Fryberger

The mission of DOE's water program is to enable scientific advances that help solve currently intractable DOE environmental problems, while contributing to the general advance of the scientific fields involved. The goals are to provide: science as a basis for informed decisions about environmental remediation and stewardship; advancement of scientific foundations that enable innovative remediation technologies and methodologies; and synthesis and integration across disciplines to foster new scientific approaches that match the complexity of the problems.

DOE's approaches include development of an understanding of contaminant fate and transport, cutting edge remediation techniques, approaches for managing and treating wastes, scientific basis for long-term stewardship of sites (LTS) where residual contamination remains, and the deterministic risks of DOE wastes and contaminated media to human health and environment.

The details of the presentation are provided in Appendix C.

AwwaRF/SNL/WERC Arsenic Water Technology Program Briefing - Presented by Jeff Oxenford, Malcolm Siegel, and Abbas Ghassemi

This program is expected to be a multi-year effort that moves technologies from the bench-scale to demonstration, and includes assistance that will be provided to utilities for implementation. The overall goal of this program is to enable water utilities, particularly those serving small rural communities and Indian tribes, to implement the most cost effective solutions to their arsenic treatment needs. This goal will be met by accomplishing three objectives: conducting research minimizing operating costs and minimizing quantities of waste; demonstrating the applicability of these technologies to a range of water chemistries, geographic locales, and system sizes; and evaluating the cost effectiveness of these technologies and providing education, training, and technology transfer partnership.

Three organizations with specialized capabilities are partnering to implement this program. AwwaRF has proven research management expertise, a peer-review based competitive research program, and a wealth of water supply community experts and the lead for the bench-scale program. SNL brings technology field-testing expertise and scientific R&D relevant to water treatment and analysis and leads the pilot-scale demonstration program. WERC has extensive experience in education, training, technology development and deployment, economic analysis and outreach activities and leads the training/technology transfer program.

The details of the presentation are provided in Appendix D, E, F and G.

EPA's Arsenic Research Program Presented by Sally Gutierrez

EPA's Office of Research and Development is spearheading a research program with the purpose of providing information to fill-in research gaps that exist for a number of technologies or compliance approaches and provide this information to utilities, engineering firms, regulatory officials and others. The objectives of the program are to identify and evaluate new cost-effective technologies; demonstrate/verify performance of existing and new commercially available technologies; and provide technical guidance to small communities, regulators and consulting firms on selection and design of cost-effective systems to meet the arsenic maximum contaminant level (MCL). The EPA program provides training and technical assistance, demonstration projects, environmental technology verification program, and other advanced research programs.

The details of the presentation are provided in Appendix H.

CHAPTER 3
PERSPECTIVES ON REMOVAL TECHNOLOGIES

Several participants presented information focusing on emerging technologies, technology demonstration, emerging commercial technologies, implementation of technologies, and the current state of science and research needs. The presentations included perspectives by Bruce Thomson from the University of New Mexico's Civil Engineering Department, Bruce Bartley from NSF International, Steve Reiber from Corrosion Control, and Patrick Brady from SNL.

Emerging technologies for arsenic removal Presented by Bruce Thomson

The first presentation focused on arsenic removal technologies currently available, shortcomings and strengths of existing technologies, emerging technologies, and future needs. The discussion on small communities without water treatment plants and technologies relevant to larger plants included topics such as oxidation, removal including adsorption, ion exchange, precipitation and membranes. Outstanding issues such as residuals handling and management, analytical methods and process control were *noted as of great interest*. Details related to each technology including technology description, parameters of concerns, costs, maintenance requirements, shortcomings, applicability to POUs, as well as residual concerns and analytical methods were extensively discussed.

The discussion regarding drinking water treatment technologies included coagulation/precipitation/filtration, ion exchange, adsorption, membrane processes, POU, In-situ technologies, and others. While there is a fairly adequate understanding of these techniques, several challenges and technology needs were noted for each technique.

<u>Coagulation/Precipitation/Filtration</u>

Challenges with Coagulation/Precipitation/Filtration

- Capital cost
- Complexity/requires high level of technical expertise
- Effects of water chemistry on performance (pH and competing ions)

Technology Needs for Coagulation/Precipitation/Filtration

- Demonstrate performance of small plants (<10^5 gal/d)
  - Granular media filtration
  - Membrane filtration
- Develop process automation and control appropriate for small communities

<u>Ion Exchange</u>

Challenges with Ion Exchange

- Process control, especially regeneration issues
- High salt use
- Complexity/requires high level of technical competence
- Brine management and disposal (potential hazardous waste issues)

Technology Needs for Ion Exchange

- Develop media with improved selectivity for arsenic

<u>Adsorption</u>

Adsorption Challenges

- Developing and evaluating new adsorbents
- Effects of water chemistry on performance (pH, PO_4^{3-}, H_4SiO_4, others)
- Process control
- Residuals management

Technology Needs for Adsorption Processes

- Develop media with improved selectivity and arsenic capacity at pH > 7.0
- Develop better understanding, quantitative performance model, of effects of pH and competing ions on media performance
- Develop procedures for rapid evaluation of media performance
- Need for lower cost media

<u>Membrane Processes</u>

Membrane Process Challenges

- Complexity
- Cost
- Water use
- Scaling and fouling (sea water desalination vs. arsenic removal from ground water)
- Residuals management

Technology Needs for Membrane Processes

- Demonstrate performance of nano- and ultra-filtration
- Reduce cost and complexity
- Reduce water consumption

<u>POU Systems</u>

POU Challenges

- Servicing and sampling in the home is enormous challenge
- Implementation uncertainty and what constitutes compliance
- Process monitoring
- Greater capacity media
- New paradigm in U.S. drinking water supply - The water in the distribution system may no longer be safe to drink

<u>In-Situ Technologies</u>

In-Situ Challenges

- Very early stage of development

Specific concerns related to residuals include potential hazardous characteristics (TCLP, CalWET, total arsenic concentration, handling issues, volume of waste, water consumption), as well as the potential for an arsenic release through anaerobic environment in landfill and the effects of stuck pH controller on loaded media. Technology needs for residuals management include developing methods to reduce residuals volume and the need for appropriate technology for dewatering and an improved understanding of long term stability of arsenic residuals.

A discussion on analytical methods included the three types of analytical applications research, compliance monitoring, and process control using the current technologies of optical spectroscopy (GFAA, HGAA, ICP-OES), mass spectroscopy (ICP-MS), colorimetric (including test strips), electrochemical, and speciation. Analytical challenges include methods for process analysis, which are reliable, simple, and cheap.

The details of the presentation are provided in Appendix I.

Technology demonstration and emerging commercial technologies Presented by Bruce Bartley

The second presentation focused on technology demonstrations and emerging commercial technologies. The details of the on-going testing, status and the results were presented. The arsenic technology testing status include a discussion on reverse osmosis (RO), chemical coagulation with rapid filtration skid mounted package plants, adsorptive media and oxidation with rapid filtration of iron laden source waters. The testing was undertaken at Park City, Utah's Spiro Tunnel Water Filtration Plant that remediates groundwater from a silver mine. The current information status for the demonstration projects follow.

Arsenic reduction by RO testing is performed through a minimum of one month of continuous operation, daily sampling for arsenic, iron, Mn, TDS, etc., determination of arsenic species (III and V), total and dissolved arsenic, operation parameters for water production (specific flux) and the impacts of fouling and cleaning. Two systems were studied: A) Koch Membrane Systems TFC® - ULP4 Reverse Osmosis Membrane Module and B) Hydranautics ESPA2-4040 Reverse Osmosis Membrane Element. Both technologies are applicable to small system equipment (5 – 10 gpm) and the pilot units are easily scaleable for medium to larger systems.

The results of the arsenic reduction by RO were:

- Total arsenic feed: mean=65 μg/L, range=49-77 μg/L
- 32 days of testing in March and April 2000
- Product A reduced mean arsenic to < 0.5 μg/L, and Product B to < 0.9 μg/L
- Mean arsenic in waste stream: Product A (60 μg/L) and Product B (62 μg/L)

The results of the operation and maintenance (O&M) of the RO technologies:

- Water recovery was approximately 13-15 percent in both products tested
- Specific flux decreased for one but not for the other throughout the test
- Some accumulation of arsenic and iron on membranes occurred however no significant fouling was observed
- Requires power and skilled operator for O&M, but is simple to operate

Chemical Coagulation Package Plants (CCPP) are skid mounted ready-to-install. Two systems were tested: A) Kinetico Inc. Model CPS100CPT which uses a synthetic ceramic filtration media and B) Watermark Technologies, LLC eVox® Model 5 which uses sand filtration. Both systems are applicable to small system equipment (< 10 gpm). The test plan for arsenic reduction by CCPP involved a minimum of two weeks to establish operations, intense sampling, every 6 hours for 48 hours, daily sampling for arsenic, iron, Mn, TDS, etc., determining arsenic species (III and V), total and dissolved arsenic and chemical and electrical consumption.

The results of arsenic reduction from the CCPP systems were:

- Total arsenic in feed water ranged 60.9-146 μg/L
- Testing occurred in April 2000
- Product A: each arsenic species reduced to average of < 4.7 μg/L
- Product B: each arsenic species reduced to average of < 3.0 μg/L
- Waste produced: solids

The results of the O&M of the CCPP technologies were:

- Power A (359 kWh) and B (516 kWh)
- CCPP requires some technical sophistication
- Chemical usage for
  - Product A: 5.48 mg FeCl3 / L at 1.1 gpm
  - Product B: 8.63 mg FeCl3 / L at 5 gpm

Future technology tests will be focused on adsorptive media in three small communities in Pennsylvania using three technologies (ADI (a regenerative media), Kinetico Alcan iron treated activated alumina, and one to be announced). The testing protocol will include a two-week system integrity, weekly sampling until estimated breakthrough, daily sampling close to breakthrough, and arsenic speciation, interfering and confounding chemicals.

Additional technology tests for oxidation, co-precipitation and filtration will be performed in a small community in Anchorage, Alaska. The technology is ozone followed by a cartridge filter and involves ozone for rapid oxidation and simplistic, disposable cartridge filter. The protocol will be the same as chemical coagulation, however operation will discontinue when a cartridge change is required. Also some additional testing of ozone production, and TCLP and Cal WET tests of solids, and arsenic speciation and iron sampling will be required.

The emerging stakeholder needs include highly credible performance test data by an independent third party which is the result of skepticism of vendor claims and a need for QC documented and a check of the performance data. Other needs include commercially ready technologies, O&M information, data on water production and recovery, and quantified cost factors, such as chemical and electrical consumption.

The lessons learned include:

- States must be involved in development of protocols and test plans.
- O&M is a major consideration for small systems and must be affordable.
- QA – take nothing for granted
  - PE samples of speciation resins
  - Data transfer and transposition errors
- Pragmatic test designs: trade off of cost versus sufficient data for decision makers.

The details of the presentation are provided in Appendix J.

Implementation of technologies for arsenic removal Presented by Steve Reiber

The third presentation focused on the measures required to comply with the arsenic standard that approximately 4,100 systems will need to take. Ninety-five percent of existing systems serve fewer than 10,000 people, and these small systems face unique challenges. Many of the ~3000 community water systems (CWSs) affected by the arsenic rule are very small systems.

The most difficult implementation challenges facing the water systems include selecting a treatment option, considering non-treatment options, addressing POUs as an alternative, handling residuals, source management, the impact of water chemistry, and Safe Drinking Water Act (SDWA) compliance. Additionally issues such as public relations, public safety and expectations, and exemptions must also be considered and have an impact on implementation challenges. The most challenging issue that the CWSs has to address is financing of the treatment options. Also some emerging issues that the CWSs are facing include infrastructure repair and replacement, competitive pressures, source water protection and supply, and newly recognized threats such as terrorism. Recognizing that most small and medium systems consist of only a few well heads, the options for management of the system becomes limited. Towards this effort, communities must consider source inventory which includes number and location of wells, capacity, reliability and replacement cost. In addition to meeting the arsenic standard, communities should also consider other ancillary water quality issues such as fluoride, sulfate, nitrate, silica, hardness, and radon.

Potential non-treatment options include modification of well operations, well modifications, reservoir blending, system blending, and limited well operation. POUs are a viable alternative that can be used in many small systems and are an allowable compliance option. However, states can determine whether POU compliance strategies are a workable option for their systems and whether or not POUs provide the public health protections of the SDWA. Implementation of POU options will require a rigorous maintenance program, consumer participation and education, monitoring strategy, and pilot testing.

Residuals disposal options due to regulatory requirements include direct discharge to receiving bodies, discharge to publicly owned treatment works (POTW), underground injection, land application, and recycling. The land disposal options may include shipping to non-hazardous waste landfills or hazardous waste landfills and possibly land application. The residual management and disposal require meeting regulatory requirements currently in place, under Resource Conservation and Recovery Act (RCWA), Clean Water Act (CWA), and the Drinking Water Act Underground Injection Control (SDWA UIC). Other issues related to residual management include design consideration for public safety including configuration, redundancy, loading rates, and process control monitoring.

Financial assistance for meeting these requirements are vital to the success of the program. The USDA Rural Utilities Service offers limited assistance to small water system communities serving 10,000 persons or less at a low interest rate ranging from market of 5.25 percent to "poverty" rate of 4.5 percent. This assistance is offered through a seven-phase process which includes well characterization and verification, development of a compliance strategy (treatment and non-treatment evaluations), determination of feasibility of preferred options (bench and pilot testing programs), performance of detailed cost evaluations, identification of preferred alternatives, construction, and startup and operations training.

The details of the presentation are provided in Appendix K.

Current state of the science and research needs Presented by Patrick Brady

The fourth presentation examined the emerging science of arsenic removal from drinking water and presented the following three objectives to: 1) describe the underlying chemical and physical controls over arsenic removal from drinking water; 2) consider the performance metrics that arsenic removal technologies must meet; and 3) anticipate where improvements might occur in the next 5 to 10 years.

Successful implementation of any arsenic removal technology involves far more than simply removing arsenic from water. To begin with, management alternatives must be identified for any waste solids and/or fluids that are produced. Note that these will typically contain elevated concentrations of arsenic and possibly other hazardous or radioactive constituents, and therefore potentially may be subject to stringent disposal criteria.   If the water requires pretreatment the waste management becomes more complicated. At the same time, most treatments tend to affect effluent levels of dissolved components other than arsenic - sometimes in a harmful fashion. Typically, removal of arsenic through ion exchange also tends to lower bicarbonate levels increasing the corrosivity of the effluent. Coagulation using Al(III) or Fe(III) salts can result in increased concentrations of these metals in the treated water. Finally, all current arsenic treatment technologies work better for arsenate than arsenite, so a preoxidation step is typically a given.

The presenter discussed the technical details as well as the pros and cons of ion exchange, coagulation/filtration, arsenic adsorption (activated alumina, ferric media, Greensand), lime softening and iron removal, reverse osmosis/nano-filtration, and others. A detailed discussion of the future path including new materials, residual stabilization, anion competition, adsorption enhancement, POU treatment, in-situ treatment and others were also presented.

The details of the presentation are provided in Appendix L.

CHAPTER 4
CURRENT STATE-OF-THE-ART GOALS AND OBJECTIVES – BREAKOUT SESSIONS

The purpose of the breakout sessions was to identify the highest priority issues facing water utilities for arsenic removal. The workshop participants were divided into three groups, 1) small utilities serving less than 3,300 users, 2) medium to large utilities, and 3) any size utility with the participants focusing on longer term technology solutions. The focus of the breakout sessions was on technologies however other issues such as management, cost, technology acceptance, training and other issues were also discussed. It was requested that groups one and two focus on technologies and challenges to meet the upcoming regulatory deadlines. Group three focused on longer term issues and more innovative solutions.

Group one was chaired by Steve Reiber and facilitated by Malcolm Siegel. Group two was chaired by Bruce Bartely and facilitated by Abbas Ghassemi. Group three was chaired by Bruce Thomson and facilitated by Albert Ilges. Each group discussed issues that would impact technologies and influence the research focus of the upcoming bench-scale initiatives. Each of the groups focused on the current situation, the current state-of-the-art, challenges that are faced by the utilities and the best way to meet these challenges. The groups looked at technology, water quality, operation, residuals handling and other issues. Furthermore each group identified future needs based on the new arsenic standard. The panels discussed the future of treatment of arsenic, innovative or cross over technologies that could be applied, modifications that could be made to existing technologies, and innovative solutions that could be pursued. Additionally the groups developed recommendations for bench-scale, pilot scale demonstrations, and an implementation program. Also the participants addressed immediate action issues and what technologies would most likely impact the future. This included what needs to be accomplished and a possible description of projects to be funded under a research initiative.

The expected outcome from each of the groups encompassed a list of key challenges to utilities for technology implementation and selection, a list of appropriate technologies, and the pros and cons of technology application, and most importantly, identification of research opportunities. The groups re-convened and presented their findings to the other workshop participants. The workgroup instructions are provided as Appendix M.

Small Utilities Breakout Session

During the breakout session, the group intended to specifically address issues related to Point of Use (POU) as well as Point of Source (POS). The group looked at the two categories as separate issues when considering challenges faced by individual states, disposal of the media, monitoring, economics, automation, barriers, and the proposed solutions.

As a result of their discussion the group identified the following six research priorities:

- Development of better tools to predict capacity of adsorptive media
  - Theoretical and validation protocols
- Development of better adsorptive media
  - Higher arsenic capacity
  - Better/more consistent physical properties in order to optimize flow (less head loss) and have more contact with shorter required empty bed contact time (EBCT)
  - Better co-contaminant removal of V, U, Sb, ClO_4, and F
  - Better performance in presence of interfering anions such as PO_4, and $Si(OH)_4$ as well as having a wider pH range for performance

- Development of mobile water treatment plant
  - Capable of serving multiple communities
  - Requires 7-day community water storage capacity
- Adsorptive media with faster sorption kinetics
- More selective ion exchange resins
  - Less selective for sulfate
- More complete automation of small systems that are applicable to both package plants and POU devices
  - Improved sensor alarms
  - Automated shutdown

The details of the break out sessions as well as other suggestions for research are provided in Appendix N.

Medium/Large Utilities Breakout Session

During the breakout session, the group intended to specifically address issues related to key challenges faced by medium and large utilities, appropriate technologies to address the challenges, and gaps and opportunities for important research. The issues and challenges were divided into two categories: 1) technological, and 2) administrative, policy and education.

In the technological area, the group identified the following five areas as emerging issues and challenges:

- No break through technologies
- Focus on new research to get technologies to the market rapidly
- Identify technology application and appropriate domains for specific areas such as source chemistry
- On-going epidemiologic studies on low arsenic effects in population (pilot community, cost vs. health effects)

In the administrative, policy and education area, the group identified the following seven areas as emerging issues and challenges:

- Education and training that will facilitate the regulatory approval process
- New approaches to facilitate the knowledge and the confidence of stakeholders with various treatment options
- Broader approaches to meeting MCL requirements which must consider cultural, economic, and technical issues
- A new technology transfer approach including interactive training in order to facilitate acceptance of the technology
- Outreach efforts should recognize limitations on funding which includes travel costs and other constraints
- Best Management Practices (BMP) and a compendium for all various options already available which include technology performance vs. the condition of application
- Include National Rural Water Association (NRWA) in technology transfer and demonstrations

The technologies and practices that could be useful for medium and large utilities were also discussed at great length. Existing technologies and practices that could be altered or adjusted included consideration of: non-treatment alternatives; modification of existing systems (well screens, aquifer storage and recovery (ASR)); stabilization, fate, and long term stability for management of waste and co-contaminants; use of existing water chemistry, i.e., iron; pretreatment options such as silica, controlling redox, sand and acid species; treatment as part of the flow vs. total flow (technology vs. economics); practices such as on–off cyclical operations; as well as minimization of liquid waste.

The group identified the following four priorities as the most appropriate technology needs that will address the arsenic standard:

- Modifications of existing technologies as related to the hydrodynamics of media (uniformity coefficient), modified activated carbon, sulfide based media, and extension of life of current media (optimum performance of additives)
- A real time arsenic detector that is reliable, easy to use, maintainable and simple. One consideration may include detectors developed for arsenic using surrogates such as silica
- Development of flexible treatment solutions that are adaptable to emerging technologies
- Identification of easily disposable media/cartridge that is also affordable.

When developing a technology application for a water system, it was consider vital to look at the operating constraints for medium and large size systems. These considerations include series vs. parallel design, and flexibility of future modifications, as well as the affect of temperature and other environmental conditions such as weather, bio-growth, and aging.

The group also identified several areas of focus for improvement opportunities and future research. The identified areas were modification of surface charge on media, evaluation of old media to design new media, and development of test protocols for media to be used during on-site evaluations by the utilities. They specifically identified the following as short-term research opportunities that could provide near term impact in meeting the arsenic standard. These include:

- Modification of existing technology and operational approaches etc.
- Stabilization of residuals
- Beneficial/alternative use of residuals
- New catalysts to enhance performance of coagulation
- New solid catalyst to assist in pre-oxidation
- Examination of existing technologies for cross over to small systems

The details of the breakout session are provided in Appendix O.

Any Size Utilities - Longer Term Technology Solutions Breakout Session

During the breakout session, the group intended to specifically address issues related to key short-term challenges as well as long term opportunities faced by all utilities. They focused on appropriate technologies to address these challenges, gaps and opportunities for future research. These included evolutionary changes in current technologies, as well as quantum step improvements or innovations. The group also prioritized the technologies based on current and future need.

The panel discussion focused on oxidation/reduction, and treatment technologies such as ion exchange, coagulation with sedimentation, filtration, etc. Additionally, they discussed residuals including handling and management of smaller quantities of high concentration arsenic containing streams rejected from treatment technologies. Ease of handling and long-term stability of the resulting stream would be key factors. They further discussed analytical methods, including detection of arsenic and control of processes, In-situ treatment, including reaction barriers and sub-surface immobilization/treatment, and water source identification, characterization, and selection, including identification of concentrated high level arsenic zones in water sources.

The group agreed to concentrate on technologies that could be proposed for future development. However, if site issues such as management issues were an integral part of this, then this would be identified.

As a result of their discussion the group identified the following ten research priorities:

- Develop inorganic sorbets based on elements other than iron and aluminum
- Identify and develop analytical methods that could be applied for control of arsenic treatment processes
- Develop novel engineered methods for in-situ immobilization of arsenic
- Develop hybrid technologies such as chelation combined with membranes, nanopourous materials or ion exchange with membranes highly selective for arsenic removal
- Develop ion exchange systems that minimize the effect of other co-contaminants on arsenic removal
- Develop systems for extraction and recovery of arsenic from residuals, especially brine
- Understand and develop systems for removal of arsenic as arsenic (III) (e.g. sulfur based systems or zero valent iron)
- Develop and design innovative effective engineering systems (i.e. improved design/delivery/scaling)
- Develop anion binding/chelating resins with enhanced selectivity for arsenic
- Develop systems for mobilization of arsenic in groundwater thus resulting in removal of concentrated arsenic streams and separation of a cleaner water stream.

The group recommended that all the requests for proposals be broad-area or topic-oriented and even encourage exploratory research so that innovation is not limited by being overly restrictive. The group also recommends that it may be appropriate to not require financial match from the utility for truly exploratory projects.

The details of the breakout session as well as proposal guidelines and additional suggestions for research are provided in Appendix P.

CHAPTER 5
CONCLUSIONS

As a result of the two-day workshop the current state of science and engineering on arsenic removal technologies was reviewed and discussed. Additionally, the group identified emerging research areas, research needs, and opportunities for AWTP. Furthermore the workshop participants identified gaps and issues, opportunities for improvement, and research priorities for arsenic removal that can be used in developing the research strategy for the AWTP. The participants also provided guidance on other issues such as management (cost, technology acceptance, training, etc.), improving existing technologies, developing innovative technologies, cross-over technologies, or other approaches. Through the participants' efforts, the workshop identified a path forward for research initiatives including reducing energy, operating, and residual disposal costs for arsenic removal as applicable to point of use (POU) as well as point of source (POS) for small, medium, and large utilities.

APPENDIX A

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APPENDIX B

DEFINITIONS OF CURRENT REMOVAL TECHNOLOGIES

The current technologies for arsenic removal can be categorized as follows: oxidation, sedimentation, coagulation/precipitation, filtration, adsorption, ion exchange, membrane/reverse osmosis, and biological techniques. There are usually two soluble forms of arsenic in water: arsenate (As V) and arsenite (As III). Typical treatment processes are effective at removing arsenate, but not arsenite due to pH levels in groundwater.

Oxidation

Treatment for the removal of arsenic often includes an oxidation step to convert arsenite to arsenate. Oxidation alone does not remove arsenic from solution but must be combined with an arsenic removal process. Oxidation can be accomplished by the addition of oxygen to a compound, or more generally, any reaction involving the loss of electrons from an atom. For example, oxygen in an aeration process oxidizes arsenic, converting arsenite to arsenate. Arsenic can also be oxidized by a number of other chemicals including chlorine, ozone, hypochlorite, hydrogen peroxide, permanganate, and Fenton's reagent (H_2O_2/Fe^{2+}). Photochemical oxidization proceeds from the reaction of radiant energy and a chemical system.

Sedimentation

Sedimentation is the gravity separation of solids from liquid by settling. It is generally used in conjunction with coagulation/precipitation.

Coagulation/Co-Precipitation

Coagulation encompasses all reactions, mechanisms and results in the overall process of particle growth (floc formation) and particle aggregation within a water being treated. Coagulation involves the removal of colloidal and settleable particles. However, the term also commonly refers to the removal of dissolved ions, which is actually precipitation. Chemical precipitation is the process by which dissolved ions in solution form an insoluble solid via a chemical reaction. Co-precipitation occurs when an inorganic contaminant forms an insoluble complex with the coagulant. Both the valence of the inorganic contaminant and the pH of the solution are important to removal by co-precipitation. There are four types of co-precipitation: inclusion which involves mechanical entrapment of a portion of the solution surrounding the growing particle; adsorption which involves the attachment of an impurity onto the surface of a particle or precipitate; occlusion which involves a trapping of a contaminant in the interior of a particle of precipitate; and solid-solution formation which involves occlusion where a particle of precipitate becomes contaminated with a different type of particle that precipitates from the solution.

Coagulation converts soluble arsenic into insoluble reaction products, allowing separation by sedimentation and/or filtration. Factors affecting arsenic removal by coagulation/precipitation include pH, mixing time and speed, coagulant type and dose, presence of inorganic solutes, and arsenic oxidation state and concentration.

It should be noted that the use of coagulation for arsenic removal typically involves: precipitation which causes the formation of insoluble compounds $Al(AsO_4)$ or $Fe(AsO_4)$; Co—precipitation which incorporates of soluble arsenic species into the metal hydroxide flocculation; and adsorption which uses electrostatic binding of soluble arsenic to the external surfaces of the insoluble metal hydroxides.

Filtration

Filtration is the separation of solid particles from water by passing the solution through a medium. Particles are removed during filtration as a result of any one or combination of mechanisms: mechanical straining, sedimentation, flocculation, adsorption and/or biological metabolism. The filter medium may be of various materials, including, sand, activated carbon, etc.

Adsorption

Adsorption is a mass transfer process where a substance is transferred from the liquid phase to the surface of a solid and becomes bound by chemical or physical forces. Typically adsorption occurs on suspended particles, as part of the process of coagulation/co-precipitation, or on a fixed media. Adsorption, a surface phenomenon, is a function of surface area. Adsorbent media have different associated properties, performances, and costs. Arsenic is adsorbed onto the surface of various granular, activated, clay and celluosic adsorbents, etc.

Ion Exchange

Ion exchange is the reversible interchange of ions between the solid and the liquid phase where there is no permanent change in the structure of the solid. Synthetic ion exchange resins are based on a cross-linked polymer matrix. Redox potential and pH are important factors with regard to arsenic removal by ion exchange.

Membrane/Reverse Osmosis

Membrane separation involves use of semi-permeable membranes that are selectively permeable to water and certain solutes in order to separate impurities. Membranes are able to remove many different kinds of dissolved solids, including arsenic, from water. There are many different membrane alternatives including micro-filtration, reverse osmosis, ultra-filtration, electro-dialysis, and nano-filtration.

Biological

Biological treatment utilizes microorganisms in order to stabilize and/or remove arsenic. This is typically accomplished by oxidation/reduction, detoxification, or mineralization. Critical factors include energy and carbon sources, aerobic or anaerobic conditions, temperature, pH.

APPENDIX C

DOE – OFFICE OF SCIENCE, ENVIRONMENTAL REMEDIATION SCIENCE DIVISION

APPENDIX D

ARSENIC WATER TECHNOLOGY PROGRAM

APPENDIX E

BENCH-SCALE STUDIES - Awwa RESEARCH FOUNDATION

APPENDIX F

ARSENIC TREATMENT TECHNOLOGY DEMONSTRATION PROGRAM

APPENDIX G

ARSENIC TECHNOLOGY PARTNERSHIP PROGRAM

APPENDIX H

OVERVIEW OF EPA'S ARSENIC TREATMENT OUTREACH

APPENDIX I

EMERGING TECHNOLOGIES FOR ARSENIC TREATMENT FOR SMALL COMMUNITIES

APPENDIX J

ARSENIC TREATMENT TECHNOLOGIES & ETV PERSPECTIVES

APPENDIX K

ARSENIC TREATMENT IMPLEMENTATION – THE HARD, THE SOFT, THE UGLY

APPENDIX L

THE EMERGING SCIENCE OF ARSENIC REMOVAL

APPENDIX M

WORKGROUP INSTRUCTIONS

APPENDIX N

GROUP ONE
– SMALL SYSTEM RESEARCH PRIORITIES –
DAY ONE AND DAY TWO

APPENDIX O

GROUP TWO
– UTILITIES WITH RESOURCES (LARGE, MEDIUM, AND SMALL) –
DAY ONE AND DAY TWO

APPENDIX P

GROUP THREE
– ANY SIZE SYSTEM AND LONGER TERM TECHNOLOGY SOLUTIONS –
DAY ONE AND DAY TWO