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Evaluation of Innovative Arsenic Treatment Technologies

The Arsenic Water Technology Partnership Vendors Forums

Summary Report

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Abstract

The lowering of the drinking water standard (MCL) for arsenic from 50 µg/L to 10 µg/L in January 2006 could lead to significant increases in the cost of water for many rural systems throughout the United States. The Arsenic Water Technology Partnership (AWTP), a collaborative effort of Sandia National Laboratories, the Awwa Research Foundation (AwwaRF) and WERC: A Consortium for Environmental Education and Technology Development, was formed to address this problem by developing and testing novel treatment technologies that could potentially reduce the costs of arsenic treatment. As a member of the AWTP, Sandia National Laboratories evaluated cutting-edge commercial products in three annual Arsenic Treatment Technology Vendors Forums held during the annual New Mexico Environmental Health Conferences (NMEHC) in 2003, 2004 and 2005. The Forums were comprised of two parts. At the first session, open to all conference attendees, commercial developers of innovative treatment technologies gave 15-minute talks that described project histories demonstrating the effectiveness of their products. During the second part, these same technologies were evaluated and ranked in closed sessions by independent technical experts for possible use in pilot-scale field demonstrations being conducted by Sandia National Laboratories. The results of the evaluations including numerical rankings of the products, links to company websites and copies of presentations made by the representatives of the companies are posted on the project website at <http://www.sandia.gov/water/arsenic.htm>. This report summarizes the contents of the website by providing brief descriptions of the technologies represented at the Forums and the results of the evaluations.

Acknowledgements

The Vendors Forums described in this report required the work of a large number of people. We thank the members of the Technical Evaluation Teams for their willingness to share their technical experience and insights with the Arsenic Project in our attempts to evaluate a large number of technologies. The contributions of several other coworkers to the conduct of the Forums are gratefully acknowledged. These include: Goldie Piatt, Sandhya Rajan, Charlie Casaus, and Barbara Martens (all Sandia National Laboratories) and Roseann Thompson (WERC). We also are grateful for the cooperation and assistance of the organizers of the New Mexico Environmental Health Conferences in providing the host venue for the Forums. The technical editing assistance of Judy Campbell (GRAM, Inc.) for this report and the skills of Mona Aragon (Sandia National Laboratories) in setting the up the Forum websites are gratefully acknowledged. The management support and encouragement of Tom Hinkebein (Department 06118, Sandia National Laboratories) is also appreciated. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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Acronyms

AWTP	Arsenic Water Technology Partnership
AwwaRF	American Water Works Association Research Foundation
DE	Diatomaceous Earth
EBCT	Empty bed contact time
EBV	Empty bed volume
GFO	Granular Ferric oxide
IX	Ion exchange
MCL	Maximum Contaminant Level
MIT	Massachusetts Institute of Technology
POE	Point-of-entry
POU	Point-of-use
RO	Reverse osmosis
SNL	Sandia National Laboratories
TCLP	Toxicity Characteristic Leaching Procedure
WERC	A Consortium for Environmental Education and Technology Development
WET	California Waste Extraction Test

1. Introduction

The Arsenic Water Technology Partnership (AWTP) is a multi-year, congressionally-funded program to evaluate and develop new technologies that could significantly reduce the costs associated with compliance with the new maximum contaminant level (MCL) for arsenic in drinking water (10 µg/L). The Partnership <http://www.arsenicpartners.org> is a collaborative effort of Sandia National Laboratories (SNL), the American Water Works Association Research Foundation (AwwaRF), and WERC: A Consortium for Environmental Education and Technology Development. Each of the partners develops or evaluates new arsenic treatment technologies in their respective programs. The technologies that show the most promise are then tested at the field scale by SNL at several pilot-plant sites in New Mexico and in other states.

The adoption of the new MCL for arsenic in drinking water in 2006 was accompanied by an explosion in research, development and commercialization of new technologies designed to remove arsenic from surface and groundwater sources. In order to “jump-start” the Pilot Demonstration Program and collect peer-reviewed information about commercially available treatment technologies for outreach efforts, Sandia National Laboratories has sponsored the Arsenic Treatment Technology Vendors Forums as part of the annual New Mexico Environmental Health Conferences in 2003 to 2005.

This annual conference is the largest regional Environmental Health conference in the country (second in size to the National Environmental Health Association Annual Educational Conference). Each Vendors Forum was preceded by a Short Course with invited lectures on a variety of scientific, engineering, public health, and regulatory topics related to the new arsenic MCL. Then, during the first part of each Forum, commercial developers of innovative treatment technologies described project histories that demonstrate the effectiveness of their products. At a subsequent closed session, these same technologies were evaluated by independent technical experts (Technical Evaluation Teams) for possible use in pilot demonstrations to be conducted by Sandia at community sites. In 2005, the scope of the Forum expanded to include other contaminants such as uranium, perchlorate, and nitrate.

The Forums were designed to provide benefit to both water utilities and water treatment companies. Many of the small rural communities that will have to comply with the new MCL for arsenic do not have the technical or financial resources to critically evaluate the many treatment options offered to them by commercial companies and to choose from among them. The Arsenic Water Treatment Technology Vendors Forums and the website that summarizes the results of the technology evaluations provide information useful to these communities and also establish an objective and defensible basis for selection of technologies for pilot testing by SNL in Arsenic Water Technology Partnership.

For some of the small R&D companies that participated, the Forums provided exposure to a larger audience than they normally would encounter and the chance to have their technology demonstrated in a program with a national scope. This effort may thus accelerate the adoption of promising innovative treatment technologies developed by smaller companies by lowering some of the barriers to entry into marketplace.

2. Structure of Vendors Forums

The Forums were comprised of two parts. At the first session, open to all conference attendees, commercial developers of innovative treatment technologies gave 15-minute talks that described project histories demonstrating the effectiveness of their products. During the second part, these same technologies were evaluated and ranked in closed sessions by independent technical experts for possible use in pilot-scale field demonstrations being conducted by SNL. For the Vendors Forums, SNL assembled Technical Evaluation Teams comprised of recognized experts in water treatment technology drawn from the commercial, regulatory, and academic sectors. Each team contained four to five members as described in Appendix A. The technologies were evaluated in six categories: 1) performance, 2) level of maturity and viability of the company, 3) costs, 4) implementability (i.e., regulatory acceptance), 5) effects on the user community, and 6) degree of innovation. Each vendor was scored in each category by each reviewer within the teams that interviewed the vendor. An example evaluation sheet used by the reviewers is shown in Appendix B. Of the twenty-six vendors that have participated in the Forums, fourteen are involved in SNL Pilot Demonstration studies as part of the Arsenic Water Technology Partnership.

3. Results

Table 1 describes the participants that presented information about their technologies at the Forums; the top ranked technologies for each year are identified in Table 2. Appendices C through E summarize the products of each company for each year. Product descriptions were written by the vendors as part of their application to participate in the Forums and have not been altered from the original version.

Twenty-six vendors were evaluated at the three Forums as follows:

- Nine vendors participated in 2003, twelve in 2004, ten in 2005.
 - Four of the 26 vendors attended two Forums.
 - Three universities were among the 26 vendors.
- The highest ranking vendors were HydroGlobe (Graver) in 2003 and Purolite in 2004 and 2005.
 - Most of the vendors were deemed viable candidates for Pilot testing based upon the evaluations.

Table 3 describes the results in each category for each vendor for each year. Percentile scores and ranks were calculated as follows: each vendor was evaluated and scored in each category by multiple reviewers, and all reviewers' scores were summed in each category for each vendor. There was a maximum possible score in each category, but some reviewer scores were not complete; therefore, the maximum possible score differed for each vendor. The **percentile scores** shown in the tables are the sum of the reviewers' scores given to the vendor for a given category, divided by the maximum possible score for that vendor in that category, multiplied by 100%.

Initially, an overall total score was given to each vendor based upon a *weighted* value of each criterion. The weighting factors are shown in the last section of the evaluation form found in Appendix B. Subsequently, it was recognized, that use of the weighting factors introduced an unnecessary element of subjectivity into the rankings. Therefore, in the final analysis presented here, the unweighted scores are used to provide rankings. This allows readers to assign weighting factors of their own choosing and calculate rankings that conform to their interests or priorities. For example, if the Cost of the technology is more important than its Performance, the reader could assign a higher weight to that attribute and recalculate the scores to obtain a new ranking.

Table 4 provides the normalized scores and ranks over all three years. In order to provide a single set of ranks, differences between the judging had to be accounted for. It was observed that the *average* Total Scores increased each year, markedly between 2003 and 2004. Scores for each of the evaluation criteria including Cost increased (improved) over the three year period. Vendors tended to score highest in Performance and lowest in Maturity. Average Innovation scores have been nearly the same each year.

In order to obtain the normalized scores, the following procedure was used:

- The 2005 total scores were not changed.
- The 2003 and 2004 Total Scores for each vendor were multiplied by the average Total Score for 2005 divided by the average Total Score for 2003 or 2004 (a multiplier of 1.337 for 2003 scores and 1.108 for 2004).

$$\text{NormVTS2003} = \text{ActVTS2003} \times \text{AveTS2005/ATS2003}$$

where

NormVTS2003 = Normalized Vendor Total Score for 2003;
 ActVTS2003 = Actual Vendor Total Score for 2003,
 AveTS2003 = Average Total Score for All Vendors 2003, and
 ATS2003 = Average Total Score for All Vendors 2003.

For example, for AdEdge in 2003:

AdEdge Actual Total Score for 2003	=	63.0
Average Total Score for 2003	=	55.5
Average Total Score for 2005	=	74.2
Normalized AdEdge Total Score for 2003	=	63.0 x (74.2/55.5) = 84.2

Hence, the Total Score for each vendor for 2003 and 2004 was increased above the actual Total Score received at the Forum. This allows a ranking of vendors across the three Forums as shown in the table. Vendors listed more than once participated in more than one Forum.

More detailed information about the technologies is found in the individual vendor summary sheets that can be accessed at the Sandia National Laboratories Arsenic Treatment Technology Pilot Demonstration website <http://www.sandia.gov/water/arsenic.htm>. These vendor summary sheets contain brief product descriptions, links to company websites, links to Forum presentations and links to compilations of the review comments by the Technical Evaluation

Teams. Each of the Forum websites also contains links to the presentations given by the vendors, the evaluation criteria used by the Technical Evaluation Teams for that year and brief biographical descriptions of the members of Technical Evaluation Teams.

4. Summary

Each of the members of Arsenic Water Technology Partnership develops or evaluates new arsenic treatment technologies in their respective programs. The primary purpose of the Arsenic Treatment Technology Vendors Forums was to collect peer-reviewed information about commercially available treatment technologies for pilot studies conducted by Sandia National Laboratories. The technologies that show the most promise are being tested at the field scale by SNL at several sites in New Mexico and in other states. The use of independent technical experts and a standardized evaluation process at the Forums established an objective and defensible basis for selection of technologies for the tests. Descriptions of the pilot sites and the results of the tests can be found at the Sandia National Laboratories Arsenic Treatment Technology Pilot Demonstration website <http://www.sandia.gov/water/arsenic.htm>. Other technologies were evaluated by other means for the pilot tests. A description of these evaluations is also posted on the website.

The Forums also provided benefit to water utilities and water treatment companies. Many small rural communities affected by the new MCL for arsenic will need technical and financial assistance to comply with the standard. The technology descriptions and evaluations contained in this report and associated website provide information that will help these communities critically evaluate the many treatment options offered to them by commercial companies and to choose from among them. The Vendors Forums may also accelerate the adoption of promising innovative treatment technologies developed by smaller R&D companies by lowering some of the barriers to entry into marketplace. The Forums and the website provided exposure to a larger audience than they normally would encounter and gave them the chance to have their technology demonstrated in a program with a national scope.

Table 1. Vendor Forum Participants (2003 – 2005)

VENDOR	PRODUCT	CONTACT	PHONE	EMAIL	WEBSITE
ADA Technologies, Inc.	Amended Silicate	Craig Turchi	303.792.5615 x285	Craigt@adatech.com	http://www.adatech.com/default.asp
AdEdge Technologies, Inc.	AD33 (E-33 [granular]) E-33P (pellets)	Ley Hathcock Rich Cavagnaro	678.835.0052	ley@adedge technologies.com	http://www.adedge technologies.com
ANCECO	ABCEL / ANCEL	Alexander Blake	732-739-3410	ancecocorp@aol.com	unavailable
APW, Inc.	Isorb, Adsorb, Hedulit, Nanolit	Nitin Kohli	775.829.6883	kohli@apwgroup.us	http://apwgroup.us
ARCTECH, Inc.	HUMASORB	Daman Walia Sid DuMont	703.222.0280	dwalia@arctech.com	http://www.arctech.com/
Argonide	Alfox GR-3; Alfox18; NanoCeram	Fred Tepper	407.322.2500	fred@argonide.com	http://www.argonide.com/
Brimac Carbon Services	Brimac 216	Symon Thomas	734.972.3290	cfttechnologies@earthlink.net	http://www.brimacservices.com/
Dow Chemical	Adsorbsia GTO	Geofrey Onifer Thomas McCandless	989.636.6228 972.491.7104	gponifer@dow.com tmccandless@dow.com	http://www.dow.com/liquidseps/ prod/pt_as.htm
EaglePicher	NXT-1 NXT-2 NXT-CF	Kim Walsh Peter Lenz	775.824.7646	kim.walsh@eaglepicher.com Peter.Lenz@eaglepicher.com	http://www.eaglepicher.com
Edenspace Systems	Phytoremediation technology	Mark Elless	877.961.8777	elless@edenspace.com	http://www.edenspace.com/ index.html
Engelhard	ARM 200	Linda Muroski (Tom Shaniuk)	732.205.5046	Linda.muroski@engelhard.com	http://www.engelhard.com/
Filtronics	Electromedia	Patrick Charlton Bill Hoyer	714.630.5040	pcharlton@filtronics.com whoyer@filtronics.com	http://www.filtronics.com/

Table 1. Vendor Forum Participants (2003 – 2005) (continued)

VENDOR	PRODUCT	CONTACT	PHONE	EMAIL	WEBSITE
Graver Technologies (HydroGlobe)	MetSorb (HMRG); ActivMet; FerriMet/CF	John Schroeder	302.731.3523	jschroeder@gravertech.com	http://www.gravertech.com/ http://www.hydroglobe.com/
HydroFlo (MARTI [Metals & Arsenic Removal Tech, Inc.]	ARTI-64	(Dennis Mast) George Moore	919.772.9925 919.772.6823w 919.889.8458c	dmast@hydroflo.cc gmooremarti@aol.com	http://www.hydroflo-inc.com/ http://www.martiinc.com/
Kinetico, Inc.	UltrAsorb-A, UltrAsorb-T and UltrAsorb-F. (adsorptive media) Resins Macrolite (precipitation/ filtration) Reverse osmosis	Skip Wolfe Art Oakes	440.56.44262 801.364.2001	swolfe@kinetico.com artoakes@kinetico.com	http://www.kinetico.com/
Inotec (University of Utah)	AsTECH	Jack Adams Terrence Chatwein	801.712.2760 801.581.6348	jadams@mines.utah.edu djadams22@sisna.com terrence.chatwin@m.cc.utah.edu	No website
Magnesium Elektron Inc./Isolux Technologies	Isolux	James Knoll	908.782.5800 x1133 908.797.7480c	jknoll@meichem.com	http://www.zrpure.com/
Massachusetts Institute of Technology	Kanchan Filter	Susan Murcott	617.452.3442	murcott@mit.edu	http://web.mit.edu/murcott/www/arsenic http://web.mit.edu/watsan/worldbank_summary.htm

Table 1. Vendor Forum Participants (2003 – 2005) (continued)

VENDOR	PRODUCT	CONTACT	PHONE	EMAIL	WEBSITE
Orca Water Technologies	KemLoop 1000 (Coagulation/ filtration)	Ron Tenny John Crass Mike Monacell	907.350.7697 805.639.3071	rtenny@orcawt.com jcrass@orcawt.com mmonacell@orcawt.com	http://www.orcawt.com
Purolite	ArsenX ^{np} A-530E; A-520E; A- 300E; C100E	Francis Boodoo	610.668.9090	fboodo@puroliteusa.com	http://www.puroliteusa.com/index3.htm
ResinTech	ASM-10-HP	Frank DeSilva Patty Ruggeri Peter Meyers	760.476.9283 856.768.9600 856.768.9600	fdesilva@resintech.com pruggeri@resintech.com pmeyers@resintech.com	http://www.Resintech.com
SolmeteX	ArsenX ^{np} NP33	Owen Boyd	508.393.5115	oboyd@solmetex.com	http://www.solmetex.com/
University of Oklahoma	Polymer – enhanced ultrafiltration	David Sabatini	405.325.4273	sabatini@ou.edu	unavailable
Virotec	Bauxsol Arsenic ProActiv Bauxsol-GAC	Neil Bardach Dave McConchie Will Caldicott	917.868.6912 303.842.9351 617.964.1773	neil@bardach.com dmconch@scu.edu.au wcaldicott@virotec.com	http://www.Virotec.com/usa.htm
Watts Premier	Reverse osmosis	Shannon Murphy	623.505.1514 344.6848c	murphysp@wattsind.com	http://www.wattspremier.com
ZENON Environmental	Membranes (AbMet)	Joy Rueb	925.246.8190	j.rueb@att.net	http://www.zenon.com

Note: Descriptive product names are given in this table; symbols indicating Trademarks, Copyright, Patents or pending patents are not included. Any links to third party web sites are not an endorsement, sponsorship or recommendation of the third parties or the third parties' ideas, products, or services. Similarly, any references in this table to third parties and their products or services do not constitute an endorsement, sponsorship, or recommendation.

Table 2. Vendor Rankings for Arsenic Treatment Technology Forums

Total Score Rank	2003 Forum	2004 Forum	2005 Forum
1	HydroGlobe	Purolite	Purolite
2	MEI	Watts Premier	ResinTech
3	Kinetico (Macrolite)	Zenon	SolmeteX
4	Kinetico (Fe-based)	Engelhard	EaglePicher
5	AdEdge	Filtronics	Orca
6	Filtronics	Dow Chemical	Brimac
7	Argonide	ResinTech	ADA
8	Edenspace	EaglePicher	Inotec
9	U. of Oklahoma	APW	Virotec
10	Arcotech	MIT	Argonide
11		Hydroflo	
12		Anceco	

* Companies in bold font are currently being tested in SNL's Pilot Demonstration Program.

Table 3. Vendor Forum Percentile Scores* (and Rank), by Category, by Year

Vendor 2003 Forum	Performance Score (Rank)	Maturity Score (Rank)	Cost Score (Rank)	Implementability Score (Rank)	Effect Score (Rank)	Innovation Score (Rank)	Total Score (Rank)
AdEdge	61.7 (4)	69.3 (3)	64.4 (4)	64.0 (2)	60.5 (7)	52.0 (8)	63.0 (5)
Arctech	32.0 (10)	32.0 (7)	28.7 (10)	23.3 (10)	26.1 (10)	60.0 (7)	30.2 (10)
Argonide	58.3 (6)	14.0 (10)	51.2 (7)	46.0 (8)	57.5 (8)	78.0 (4)	49.9 (7)
Edenspace	54.6 (8)	14.8 (9)	42.2 (8)	46.7 (7)	61.1 (6)	100 (1)	48.7 (8)
Filtronics	61.4 (5)	71.3 (2)	60.0 (5)	63.5 (3)	62.5 (5)	52.0 (8)	62.5 (6)
Hydro-Globe	74.6 (1)	51.9 (9)	69.8 (1)	60.0 (6)	66.7 (1)	86.7 (2)	67.5 (1)
Kinetico (Fe media)	63.8 (3)	59.3 (4)	65.8 (3)	61.1 (4)	63.9 (4)	62.2 (6)	63.1 (4)
Kinetico (Macrolite)	58.3 (6)	82.7 (1)	56.8 (6)	66.0 (1)	66.0 (3)	52.0 (8)	63.3 (3)
MEI	69.5 (2)	58.5 (5)	67.6 (2)	60.6 (5)	66.1 (2)	77.8 (5)	66.0 (2)
U. Oklahoma	40.3 (9)	24.0 (8)	36.0 (9)	36.0 (9)	54.0 (9)	84.0 (3)	40.8 (9)
Average Scores	57.5	47.8	54.2	52.7	58.4	70.5	55.5

Vendor 2004 Forum	Performance Score (Rank)	Maturity Score (Rank)	Cost Score (Rank)	Implementability Score (Rank)	Effect Score (Rank)	Innovation Score (Rank)	Total Score (Rank)
Anceco	52.1 (12)	46.0 (9)	48.1 (12)	35.0 (12)	11.0 (12)	62.5 (8)	39.7 (12)
APW	77.8 (4)	39.1 (10)	70.0 (5)	63.9 (7)	64.9 (9)	42.2 (12)	62.6 (9)
Dow Chemical	76.0 (6)	68.4 (6)	74.5 (4)	66.5 (6)	76.8 (4)	58.0 (10)	72.2 (6)
EaglePicher	77.0 (5)	46.8 (8)	76.0 (3)	57.5 (9)	72.4 (6)	70.0 (4)	66.5 (8)
Engelhard	80.3 (3)	81.2 (5)	64.5 (9)	78.5 (3)	76.0 (5)	66.0 (5)	76.2 (4)
Filtronics	71.0 (9)	83.6 (4)	65.5 (7)	74.5 (4)	71.2 (7)	60.0 (9)	72.8 (5)
Hydroflo	53.3 (11)	36.4 (11)	57.0 (11)	44.0 (11)	48.4 (11)	80.0 (2)	49.1 (11)
MIT	63.7 (10)	26.8 (12)	62.5 (10)	48.5 (10)	59.2 (10)	82.0 (1)	53.5 (10)
Purolite	88.1 (1)	89.8 (2)	81.1 (1)	85.6 (1)	81.3 (2)	77.8 (3)	85.2 (1)
ResinTech	72.7 (8)	66.4 (7)	65.5 (7)	61.0 (8)	68.4 (8)	66.0 (5)	67.3 (7)
WattsPremier	87.5 (2)	85.6 (3)	77.0 (2)	84.0 (2)	85.0 (1)	48.0 (11)	82.8 (2)
Zenon	75.0 (7)	90.4 (1)	66.0 (6)	74.5 (4)	77.6 (3)	66.0 (5)	76.7 (3)
Average Scores	72.9	63.4	67.3	64.5	66.0	64.9	67.0

Table 3. Vendor Forum Percentile Scores* (and Rank), by Category, by Year (continued)

Vendor 2005 Forum	Performance Score (Rank)	Maturity Score (Rank)	Cost Score (Rank)	Implementability Score (Rank)	Effect Score (Rank)	Innovation Score (Rank)	Total Score (Rank)
ADA	84.2 (4)	55.6 (8)	62.2 (8)	56.4 (9)	76.0 (5)	70.9 (7)	68.1 (7)
Argonide	77.0 (8)	32.4 (10)	59.6 (9)	58.2 (7)	74.9 (6)	60.0 (8)	61.1 (10)
Brimac	78.3 (7)	76.0 (5)	65.6 (7)	74.0 (5)	74.0 (7)	76.0 (3)	73.8 (6)
EaglePicher	80.7 (6)	66.0 (6)	80.4 (3)	70.5 (6)	88.0 (4)	74.0 (4)	77.4 (4)
Inotec	82.7 (5)	55.3 (9)	66.9 (6)	50.9 (10)	60.7 (10)	87.3 (1)	65.5 (8)
Orca	75.5 (9)	82.2 (4)	85.5 (1)	76.8 (4)	62.9 (9)	52.7 (10)	75.6 (5)
Purolite	89.3 (2)	95.2 (1)	84.4 (2)	92.5 (1)	91.6 (1)	84.0 (2)	90.2 (1)
ResinTech	87.0 (3)	83.6 (3)	80.0 (4)	89.0 (2)	89.2 (2)	72.0 (6)	85.2 (2)
SolmeteX	89.7 (1)	84.4 (2)	72.4 (5)	81.0 (3)	88.8 (3)	74.0 (4)	83.2 (3)
Virotec	69.7 (10)	56.8 (7)	58.0 (10)	58.0 (8)	64.0 (8)	60.0 (8)	61.7 (9)
Average Scores	<i>81.4</i>	<i>68.7</i>	<i>71.5</i>	<i>70.7</i>	<i>77.0</i>	<i>71.1</i>	<i>74.2</i>

*Each vendor was evaluated and scored in each category by multiple reviewers. All reviewers' scores were summed in each category for each vendor. There was a maximum possible score in each category. But, some reviewer scores were not complete; therefore, the maximum possible score differed for each vendor. The **percentile scores** shown in the tables are the sum of the reviewers' scores given to the vendor for a given category divided by the maximum possible score for that vendor in that category multiplied by 100%.

Table 4. Normalized Total Scores*, All Vendors, All Years

Normalized Total Scores – All Forums	Vendor Rank
94.3	1. Purolite
91.6	2. WattsPremier
90.2	3. Purolite
90.2	3. HydroGlobe
88.2	5. MEI
85.2	6. ResinTech
84.9	7. Zenon
84.6	8. Kinetico (Macrolite)
84.4	9. Kinetico (Fe-based)
84.3	10. Engelhard
84.2	11. AdEdge
83.6	12. Filtronics
83.2	13. SolmeteX
80.5	14. Filtronics
79.9	15. Dow Chemical
77.4	16. EaglePicher
75.6	17. Orca
74.5	18. ResinTech
73.8	19. Brimac
73.6	20. EaglePicher
69.3	21. APW
68.1	22. ADA
66.7	23. Argonide
65.5	24. Inotec
65.1	25. Edenspace
61.7	26. Virotec
61.1	27. Argonide
59.2	28. MIT
54.6	29. U. Oklahoma
54.3	30. Hydroflo
43.9	31. Anceco
40.4	32. Arctech

*In order to compare and rank the vendors between the three Forums, the Total Scores given to the vendors were normalized as follows. The 2005 Total Scores were not changed. The 2003 and 2004 Total Scores in Table 2 for each vendor were multiplied by the average Total Score for 2005 divided by the average Total Score for 2003 or 2004 (a multiplier of 1.337 for 2003 scores and 1.108 for 2004). Vendors listed more than once participated in more than one Forum. See text for more details.

APPENDIX A. Members of Technical Evaluation Teams

*Technical Evaluation Team; Arsenic Treatment Technology Vendors Forum
October 22, 2003*

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APPENDIX B. Vendor Evaluation Sheet for the 2004 Vendor Forum

**ARSENIC PILOT DEMONSTRATION TECHNOLOGY
VENDOR FORUM
REVIEW COMMITTEE EVALUATION FORM
OCTOBER 19 - 20, 2004**

VENDOR NAME _____

TECHNOLOGY NAME _____

TYPE OF TECHNOLOGY _____
(e.g. Adsorption, Coagulation/Filtration, Membrane)

REVIEWER NAME _____ DATE _____

SCORING Rate each subcategory from 0 to 5 with 0 representing poor and 5 indicating optimal. **Enter only one number in each box even if there are multiple subquestions.**
Please use the space beneath each subtotal to make notes associated with scoring.

1. Performance (30%)	Score (0 – 5)
1. Can the technology remove As below the 10 ppb MCL?	
2. <u>Residuals disposal</u> A. What is the volume and hazard level of process residuals? B. Will residuals pass TCLP test? C. Will residuals pass California WET test?	
3. How much water is wasted during the treatment process?	
4. Does the process remove other co-contaminants such as perchlorate or radionuclides?	
5. Does the treatment process require the use of chemicals, and if so what volumes and their associated hazards. Are there any other potential safety issues?	
6. A. What is the quality of the treated water? B. Will the technology increase TDS, affect pH or other water quality parameters?	
PERFORMANCE SUBTOTAL	

2. Level of Maturity of Technology and Viability of Company (15%)	Score (0 – 5)
1. Does the technology (process and chemicals used) meet NSF Certifications?	
2. How many treatment systems using this technology have been installed?	
3. <u>Scale-up/upgrade issues</u> A. At what scale has the technology been implemented? B. Can the process be scaled up? C. Can the process be upgraded or modified to use newer technology or media?	
4. <u>Viability of company for long-term survival</u> A. Size of company? B. Manufacturing capability?	
5. A. Is the technology process equipment and materials (chemicals, media, etc.) readily available? B. Are there concerns about availability of materials from foreign vendors or manufacturers?	
LEVEL OF MATURITY SUBTOTAL	
3. Cost (20%)	Score (0 – 5)
1. <u>Capital Costs.</u> A. What are the construction/installation costs? B. What are the land requirements for the process? C. What are the infrastructure requirements? (power, sewer)	
2. <u>Operations and Maintenance</u> A. What are the energy requirements? B. What is the cost of chemicals including transportation, and storage?	
3. <u>Monitoring and automation</u> A. What level of monitoring does the technology require? Associated costs?	

<p>B. What are expected labor activities and costs?</p> <p>C. What is the ease of automation? (to minimize labor costs and level of training.)</p>	
<p>4. <u>Pre/post treatment costs</u></p> <p>A. Does the process remove fluoride to a level where it is necessary to add fluoride to the treated water? Estimated cost for fluoridation/1000 gal treated water?</p> <p>B. Is pre-oxidation of Arsenite to Arsenate required? Cost/1000 gal treated water?</p> <p>C. Is pH adjustment required ? How? Estimated cost/1000 gal treated water?</p> <p>D. Is pre-filtration required for turbidity or suspended solids?</p>	
<hr/> <p>COST SUBTOTAL</p>	
<p>4. Implementability (10%)</p>	<p>Score (0 – 5)</p>
<p>1. Has the technology previously been permitted?</p>	
<p>2. Public Acceptance. Will the treatment process cause</p> <ul style="list-style-type: none"> • Visual impact • High traffic • Storage of hazardous material on site • Noise • Odors • Affect taste and odor of treated water • Other adverse affects to water 	
<p>3. How simple is the treatment process operation? Maintenance requirements, such as; little to no maintenance?</p>	
<p>4. What level of training is required to operate the technology?</p>	
<hr/> <p>IMPLEMENTABILITY SUBTOTAL</p>	

5. Effect on User Communities (10%)	Score (0 – 5)
1. A. What are the potential environmental impacts from the treatment process? B. Does the technology require transportation of hazardous chemicals via City streets?	
2. How can the quantities and hazard level of residuals be minimized?	
3. <u>Water Quality</u> A. Can the treatment system handle variations in influent water quality? B. Is the pH of the treated water acceptable to blend with raw water without adverse affects?	
4. Could the technology affect the operation of wells supplying raw water?	
5. Will the public understand and trust the technology reliability and safety?	
EFFECT ON USER COMMUNITIES SUBTOTAL	

6. Innovation (15%)

1. Is this an innovative technology that would lead to cost or energy savings?

INNOVATION SUBTOTAL

RECOMMENDATIONS

Would you recommend this technology for future studies?
To AwwaRF for further bench-scale studies?
To SNL for Pilot Studies?

ALTERNATIVE WEIGHTING FACTORS

The weights initially assigned to the different Criteria are indicated below. If you wish to suggest an alternative set of weighting factors, please enter the weights below (they must sum to 100% or 1.00) and calculate an alternate Technology Score.

Criteria Parameter (old weight %)	Reviewer Score (A)	New Weight (B)	Technology Score AxB
1. Performance (30)			
2. Level of Maturity (15)			
3. Cost (20)			
4. Implementability (10)			
5. Effect on Communities (10)			
6. Innovation (15)			
OVERALL TECHNOLOGY SCORE			

APPENDIX C. Participating Vendors - 2003

Arsenic Treatment Technology Vendors Forum
 October 22, 2003
 Albuquerque, New Mexico

Company Name/ Product Name	Type of Technology	Product Description by Vendors
AdEdge Technologies/ AD33	GFO Adsorptive Media	Arsenic Removal Description = Granular ferric oxide, applied in point-of-use, point-of entry and pre-engineered skidded community systems
Argonide Corp./ Aflox GR-3	Alumina Adsorptive Media	Under a Phase I EPA SBIR we have developed a sorbent for Arsenic III and V consisting of a nano alumina fiber enhanced with a form of iron. The sorbent has a high dynamic capacity @ 50 ppb over pH ranges of 6.5-8.5. Dynamic sorption capacity has been modeled and there is good agreement between experimental and predicted data over the concentration and pH range of interest, and as a function of bed depth and flow velocity.
ARCTECH, Inc./ HUMASORB	Humic Adsorptive Media	Humasorb (2), a U.S. patented technology based on natural organic humic acid removes arsenic and other multiple toxic metals and organics in a low cost system for small scale and home use.
HydroGlobe/ Metsorb	TiO ₂ Adsorptive Media	MetSorb is a patent pending nonregenerable adsorbent, with extremely high capacity (20%) for removal of both Arsenic III and V from water. The kinetic performance is also excellent with over 40,000 bed volumes of capacity at 50 ppb As and 1 minute EBCT.
Magnesium Elektron, Inc./ Isolux	ZrO ₂ Adsorptive Media	MEI has developed a series of novel adsorbent media for the purification of contaminated water. These zirconium-based media exhibit a wide range of improved performance in removing arsenic, chromium (III & VI), copper, and other metal and non-metal ions from drinking water, industrial process streams, and groundwater applications.
Filtronics Cline Sales, Inc./ Electromedia	Coagulation/ Filtration	Process is oxidation, filtration with or without addition of less than two mg/L iron and without pH adjustment
Kinetico, Inc./ UltrAsorb-A, UltrAsorb-T and UltrAsorb-F Macrolite	Coagulation/ Filtration	Kinetico provides several technologies including Coagulation Macrolite ceramic media filtration, iron based and modified activated alumina adsorptive media, Ion exchange and POU cartridges and RO. This wide variety of products allows us to evaluate a water supply and determine the best fit.

Company Name/ Product Name	Type of Technology	Product Description by Vendors
Univ. of Oklahoma Norman, OK/ PEUF	Coagulation/ Filtration	Polymer enhanced ultrafiltration (PEUF) consists of complexating arsenic ions with a cationic water-soluble polymer, followed by removal of the complex by an ultrafiltration membrane. The retained complex is precipitated with barium chloride to regenerate the polymer. This technology can remove up to 99% of the arsenic while achieving permeate concentrations below 10 ppb and wasting less than 5% of the water.
Edenspace Systems/	Other technologies	Arsenic phytofiltration using hydroponic systems of ferns

APPENDIX D. Participating Vendors - 2004

Arsenic Treatment Technology Vendors Forum
 Wednesday, October 20, 2004
 Albuquerque, New Mexico

Company Name/ Product Name	Type of Technology	Description of Technology by Vendor
APW, Inc./ Adsorb; Hedulit	GFO & TiO ₂ Adsorptive Media	We have two products; one is Adsorb (Ferric Hydroxide) and the other is Hedulit (Titanium Oxhydrate). These products, as of now, are being manufactured in Germany where they have been tested and used for years with ground and industrial waters. Our testing facility is in the University of Nevada, Reno. Our preliminary results have been very encouraging. Our main goal is to apply this low cost and highly efficient filter media in the U.S. as there is a huge demand for these media.
ANCECO Corporation/ ABCEL; ANCEL	Coagulation/ Filtration	Water is entered into an ANCECO treatment system where a pre-determined dosage of ABCEL/ANCEL, non-toxic, chemical is added to the water which is then agitated for 4 minutes. The contaminants are adsorbed onto the chemical phase, the supernatant and sludge are discharged.
Dow Chemical/ Adsorbsia GTO	TiO ₂ Adsorptive Media	Dow has developed a patent pending granular media that is being designed for single use operations based from technology developed at the Stevens Institute of Technology. Our internal testing has shown that this titanium based product, formulated in our development labs, shows an improved capacity for arsenic over commercially available iron-based media
EaglePicher Filtration & Minerals/ NXT-1, NXT-2, NXT- CF	La-Coated DE Adsorptive Media	The nano-crystalline media removes both arsenite and arsenate without the need for chemical pretreatment. The media is a ferric/lanthanum hydroxide compound deposited onto a diatomaceous earth substrate to provide a high surface area and more efficient removal. The arsenic also forms a permanent bonds with the media. Removal is irreversible.
Engelhard Corporation/ ARM 200	GFO Adsorptive Media	With ARM 200, Engelhard introduces a safe, efficient and cost-effective water purification treatment for the removal of arsenic from water. Key advantages of ARM 200 include: Effective removal of low levels of arsenic from drinking water. Certified safe for drinking water use under NSF 61. Removal of both forms of AsIII & AsV with no preoxidation or pretreatment required. Demonstrated arsenic removal capacity of greater than 99% even in the presence of competing ions. Engelhard ARM 200 is a specially tailored adsorbent designed for use in household filters, industrial, and water utility filtration systems.
HydroFlo, Inc./ ARTI-64	Cu-Oxide Adsorptive Media	Metal and Arsenic Removal Technology (MARTI) a subsidiary of HydroFlo, Inc. distribute ARTI-64, an adsorbent media that removes both arsenate and arsenite to levels below EPA and WHO limits. It requires with no pH adjustment, has rapid kinetics and produces no harmful byproducts. Performance is not affected by sulfates and the media can be regenerated.

Company Name/ Product Name	Type of Technology	Description of Technology by Vendor
Isolux Technologies - Division of MEI/ Isolux	ZrO ₂ Adsorptive Media	Isolux Arsenic Removal Technology - A patented adsorption technology based upon the long standing zirconium expertise of MEI. Attributes include; very quick kinetics, high adsorption capacity, no hazardous waste generation, no backwash, and "Returnable Cartridge" design.
Massachusetts Institute of Technology and Stanford University/ ABF - Arsenic Biosand Filter	Adsorptive Bio-Filter	The ABF removal technology has won one of the 45 prizes for arsenic and bacteria removal at the World Bank Development Marketplace Competition last December. There were 2,500 applicants from 130 countries in the competition. It was the only arsenic treatment system to win a prize at the international development competition. Since then, we have continued our field work and are implementing the technology in the Terai region of Nepal.
Purolite/ ArsenX ^{np} ; A-530E; A- 520E; A-300E; C100E	Fe-IX Adsorptive Media	Adsorptive media based on Iron-impregnated Ion Exchange Resin. Equal or better capacity than competitive iron-based media. Simple lead-lag vessel operation No fines generation. No need for frequent backwash. Regenerable/Disposable - cost effective. Sluiceable for offsite regeneration. Suitable for Central, POE, POU, use, NSF-61 certified. Patent pending.
Watts Premier/ Zero Waste Reverse Osmosis	Reverse Osmosis	Zero Waste (point of use) Reverse Osmosis. Watts Premier has been working with small systems for arsenic and other contaminants through the use of, point of use, reverse osmosis. Incorporating the patented Zero Waste reverse osmosis, we have been able to reduce arsenic levels in small communities to non-detect.
ZENON Environmental, Inc./ AbMet	Ultra Filtration/ Coagulation	This paper will present the application of immersed ultrafiltration membranes using enhanced coagulation for arsenic removal. It will also present pilot scale data including spike testing evaluating the significance of arsenic speciation and coagulation dosages for arsenic removal. It will also review basic design concepts for the layout of new/or the retrofit of existing treatment facilities.

APPENDIX E. Participating Vendors - 2005

2005 Arsenic Treatment Technology Vendors Forum
 November 2-3, 2005
 Albuquerque, New Mexico

Company Name/ Product Name	Type of Technology	Description of Technology by Vendor
ADA Technologies/ Amended Silicate	Amended Silicates Adsorptive Media	Amended Silicate sorbents are based on a process wherein active adsorption sites are distributed onto an inert, inexpensive silicate substrate. This amendment process can be tailored for the contaminant(s) of interest. The arsenic variant utilizes a ferric hydroxide amendment and has properties similar to other iron-based materials. However, the use of the inexpensive silicate substrate allows for efficient distribution of the iron at a low cost.
Argonide Corporation/ Alfox GR-3	Nano iron / alumina Adsorptive Media	Alfox is a granular material consisting of a proprietary nano alumina/nano iron hydroxide mixture. Laboratory testing shows it has about 2 to 2.5 times the EBV v. Bayoxide E-33. It is a higher bulk density and improved attrition resistance v. E-33.
Brimac Carbon Service Products/ Brimac 216	Adsorptive media	Brimac's adsorption media is a granular bone char adsorbent with dual components: carbon and hydroxyapatite $[Ca_{10}(PO_4)_6(OH)_2]$. The carbon surface adsorbs hydrophobic, lipophilic and weakly anionic molecules while the hydroxyapatite adsorbs strongly charged molecules together with many inorganic ions (metals).
Graver Technologies HydroGlobe Division/ MetSorb G	TiO ₂ Adsorptive Media	HydroGlobe MetSorb G is a nonregenerable titanium based media, available in a range of mesh sizes from powder to 16/60 mesh. Compared to competitive media, MetSorb G is less sensitive to common interferences such as silicates, phosphates, pH, and sulfates. It exhibits rapid kinetics, and hence low operating cost per thousand gallons of water treated. Disposal of the material is simple as a nonhazardous waste by TCLP and California WET tests.
EaglePicher Filtration & Minerals/ NXT-2; NXT-CF	Adsorptive Media and Coagulation/filtration	The NXT-2 and NXT-CF are lanthanum hydroxide based medias for adsorption and coagulation/filtration arsenic removal, respectively. The lanthanum hydroxide provides pH stability up to pH10 and removes both As(III) and As(V) without the need for chemical pretreatment. Both medias also remove other contaminants such as phosphate, fluoride, selenium and others.

Company Name/ Product Name	Type of Technology	Description of Technology by Vendor
Inotec/ AsTECH	Chemical/biological	The AsTECH process uses immobilized functional groups and microorganisms to bind and remove arsenic from concentrated and dilute solutions to levels at or below detection. Arsenic is removed by chemical binding and biological transformation. Pilot-scale tests in mining waters have demonstrated arsenic removal to below detection. Additionally, the AsTECH process can be configured to simultaneously remove other metals and inorganics such as nitrates, Se, Zn, Mg, Cr, and others - also to near or below detection. Scalable to treat large flow, low capital and operational costs - operational costs are expected to be in the \$0.10 to \$0.35/1000-gallon range.
Orca Water Technologies/ Kemloop 1000	Coagulation/Filtration	Orca Water Technologies presents the Kemloop 1000. The system will remove arsenic and multi-contaminants using a partially recirculating coagulation conduit combined with direct filtration.
Purolite/ ArsenX ^{np} ; A-530E; A-520E; A-300E; C100E SolmeteX, Inc/ ArsenX ^{np} McPhee Environmental Supply, LLC/ AsX ^{np} /ArsenX ^{np}	Ion exchange and adsorptive medias	<p>Purolite: Purolite's iron-impregnated anion resin, ArsenX^{np}, will remove arsenic and uranium. Modifications incorporating A-530E, our perchlorate selective resin, and/or our C-100E cation resin will selectively remove perchlorate and radium as well. Brine regenerable SBA resins (A-520E and A-300E) will remove arsenic, nitrate, and uranium simultaneously.</p> <p>SolmeteX: ArsenX^{np} is a hybrid polymeric media impregnated with iron nanoparticles. Media has excellent capacity, flow dynamics, and is regenerable.</p> <p>McPhee Environmental Supply offers arsenic removal systems featuring AsX^{np}/ArsenX^{np}. Benefits of this technology are smaller footprint, regenerable media, high pressure capacity, no backwashing, no pH adjustment, no waste, and virtually no O&M. Systems available for POU as well as small and large municipal applications.</p>
ResinTech, Inc./ ASM-10-HP	Hybrid resin/adsorbent	Iron-based adsorbent monatomically dispersed in the gel phase of a strong base anion resin. Arsenic removal first occurs by ion exchange, and then arsenic is adsorbed into the iron. The hybrid resin has very rapid kinetics and is significantly more robust than competitive granular medias.

Company Name/ Product Name	Type of Technology	Description of Technology by Vendor
Virotec International Limited/ Bauxsol, Arsenic ProActiv	Adsorptive Media	Arsenic Removal Description:=Bauxsol has a high acid neutralizing capacity and an excellent ability to trap trace metals and metalloids. Trapped ions are tightly bound by mechanisms that include: precipitation of low solubility minerals, isomorphous substitution, solid-state diffusion, and adsorption. Bauxsol™ has an excellent ability to remove As(V) from water and field trials show the addition of Bauxsol™ to sulfidic rock reduced the As concentration in leachate from 35 to less than 0.005 mg/L. Arsenic concentrations have remained below 0.005 mg/L for five years since the treatment and concentrations of trace metals have remained well below regulatory limits.

Distribution:

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