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Environmental Impacts of Industrial Silica Sand (Frac Sand) Mining

By Isaac Orr and Mark Krumenacher*

Introduction

Sand has been mined for industrial processes across the United States for more than a century. Referred to as silica sand or industrial sand, it is used for a variety of essential industrial purposes, including as feedstock for glassmaking, cores for molding metal castings at foundries, metal production, and household and industrial cleaners; construction supplies such as concrete; bedding for livestock; an abrasive in toothpaste; filtering drinking water; and hydraulic fracturing, a technique used in oil and natural gas production.¹

In recent years, the use of silica sand for hydraulic fracturing using horizontal drilling techniques has been the largest factor driving growth in the industrial sand market. Industrial sand, commonly referred to as “frac sand,” is crucial to the process of recovering oil and natural gas from shale, tight sandstones, and other unconventional rock formations.² Growing demand for frac sand has led to an increase in volume and value of industrial sand produced in the United States.

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Before the rapid growth of hydraulic fracturing, industrial sand was a relatively small market. In 2005, for example, U.S. Geological Survey (USGS) data indicate 31 million metric tons of

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¹ National Industrial Sand Association, “What is Industrial Sand?” 2011, <http://www.sand.org/what-is-industrial-sand>.

² U.S. Geological Survey, “Silica [Advance Release],” *2012 Minerals Yearbook*, August 2014, <http://minerals.er.usgs.gov/minerals/pubs/commodity/silica/myb1-2012-silic.pdf>.

industrial sand were mined in 35 states. That sand was valued at \$700 million, averaging roughly \$22.6 per metric ton. Approximately 35 percent was used for glassmaking, 19 percent at foundries, 12 percent in hydraulic fracturing using vertical drilling techniques, and 10 percent in the construction industry.³

By contrast, in 2014 75 million metric tons of industrial sand and gravel were mined, nearly 2.5 times more than just a few years ago. That sand was valued at \$4.2 billion, averaging about \$56 per metric ton. Hydraulic fracturing, not the glassmaking industry, is now the leading use for industrial sand, as 72 percent of the sand mined in 2014 was used for hydraulic fracturing and well-packing. Thirteen percent of the industrial sand mined in 2014 was used for glassmaking, 6 percent at foundries, and just 3 percent as whole-grain fillers and for building products.⁴

Much of the growth in industrial sand production has occurred in the Midwest: 68 percent of the industrial sand mined for hydraulic fracturing was mined in this region in 2012, and that figure has grown in recent years. The leading industrial-sand-producing states in 2014 were, in order of volume produced, Wisconsin, Illinois, Texas, Minnesota, Arkansas, Oklahoma, Missouri, and Iowa, together accounting for 78 percent of the industrial sand mined in the United States.⁵

In Wisconsin, industrial sand mining employed 189 people in the state in 2002. That figure will grow to nearly 3,000 when existing and proposed mines become fully operational.

Increasing demand for industrial sand has become a significant driver of economic growth, particularly in areas where frac sand is mined, resulting in substantial growth in employment in the industrial sand industry. In Wisconsin, the leading supplier of industrial sand in the nation, data from the federal Bureau of Labor Statistics (BLS) indicate

industrial sand mining employed 189 people in 2002.⁶ The Wisconsin Economic Development Corporation estimates this figure will grow to nearly 3,000 when existing and proposed mines become fully operational, representing a 15-fold increase in employment in the industry.⁷

Although industrial sand and gravel have been mined safely in the United States for more than a century, the recent growth in scale has raised concerns about the potential environmental impacts of industrial sand mining. These concerns have been perpetuated by environmental special-interest groups, many of which are ideologically opposed to oil and natural gas

³ U.S. Geological Survey, "Mineral Commodity Summaries," January 2006, <http://minerals.er.usgs.gov/minerals/pubs/commodity/silica/sgindmcs06.pdf>.

⁴ U.S. Geological Survey, "Mineral Commodity Summaries," February 2015, <http://minerals.usgs.gov/minerals/pubs/commodity/silica/mcs-2015-sandi.pdf>.

⁵ *Ibid.*

⁶ Kate Prengaman, "Frac Sand Boom Creates Thousands of Jobs," *Appleton Post Crescent*, August 20, 2012, <http://archive.postcrescent.com/article/20120820/APC0101/308200091/Frac-sand-boom-creates-thousands-jobs>.

⁷ *Ibid.*

development and therefore to the use of hydraulic fracturing regardless of data establishing its safety. These advocacy groups have authored a series of reports raising concerns about the potential environmental, economic, and societal impacts industrial silica sand mining may have in areas where it occurs.

These advocacy documents, such as the *Communities at Risk* report published by Boston Action Research, do not give the reader a realistic understanding of the issue. They are based on anecdotal evidence, not credible scientific data. The reports are overly alarmist, downplaying the positive impacts of industrial sand mining while exaggerating the possibility of negative impacts and neglecting to inform the reader those negative impacts are unlikely to occur.

Federal, state, and local regulators are responsible for developing rules and guidelines to protect the public interest, and these policymakers must have access to the best-available information to fulfill this responsibility. This *Heartland Policy Study* serves to provide a data-driven, not anecdotal, analysis of the potential environmental effects of industrial sand mining. Parts of this study will be dedicated to addressing the many misleading claims made about industrial sand mining in various environmental reports in an effort to develop better tools for policymakers on the subject matter.

Every society utilizes natural resources, and doing so may have an impact on the environment. In the United States, a great deal of time and effort is expended, in both the public and private sectors, to ensure environmental impacts are kept to a minimum. Citizens and policymakers must

Those raising fears of the effects of frac sand mining have taken advantage of the public's limited understanding of the industrial sand mining process.

weigh the costs of developing a resource against the benefits derived from doing so, and they should develop that resource in the most environmentally friendly way.

For an informed discussion to take place, the public must have access to the best-available information. Unfortunately, those raising fears of the effects of frac sand mining have taken advantage of the public's limited understanding of the industrial sand mining process, limited recognition of the precautions taken to minimize potential environmental impacts, limited knowledge of geology, and lack of awareness of state and local regulations on silica sand production. This *Heartland Policy Study* is the first in a series explaining the advantages and disadvantages of industrial silica sand mining and providing information so a better-informed discussion can take place.

Part 1 of this *Policy Study* cuts right to the chase, considering the environmental costs and benefits of frac sand mining as they pertain to air quality, water quantity, water quality, and reclaiming mines after mining is completed. In Part 2, the authors review the background and potential of industrial sand mining in the United States and put that potential in the context of supply and demand for silica sand, now and into the future. Because demand for frac sand has been the main driver of growth for industrial sand production, Part 2 also briefly discusses the role of silica sand as a proppant for oil and natural gas recovery.

Throughout this *Policy Study*, the authors may use the terms silica sand, quartz sand, and industrial sand interchangeably to refer to sand that has the chemical composition of silicon dioxide, or SiO₂, and is used for commercial purposes unless otherwise specified. The term frac sand will refer to industrial silica sand that is used specifically for hydraulic fracturing.

This *Policy Study* concludes silica sand mining can be done in a safe and environmentally responsible manner with proper oversight and environmental protections. State and local governments have done a commendable job working with environmental and industry leaders to craft legislation that protects the environment while permitting industrial sand production to move forward. Regulations crafted to specifically regulate industrial sand mining would be duplicative, resulting in higher costs without tangibly increasing environmental protections.

Part 1 Environmental Impacts

The benefits of industrial silica sand mining are realized in economic terms, whereas the costs are merely theoretical, in the form of potential environmental impacts. Although there are more than 2,500 sand and gravel pits in Wisconsin, and probably several thousand more throughout the Upper Midwest, the prospect of large-scale silica sand mining has evoked fears about air and water pollution.⁸ These fears have led several counties in Illinois, Iowa, Minnesota, and Wisconsin to enact moratoria on permitting new sand mines. Some of those bans are still active, while others have expired.

Reasonable measures can be taken to mitigate environmental damage and protect the public health while allowing for responsible development of industrial silica sand resources.

The potential for environmental damage from industrial silica sand mining is a legitimate concern, but it must be viewed realistically and in terms of cost-benefit analysis, not merely in absolute terms. Among the key areas of environmental concern are air quality (especially as it pertains to the lung disease silicosis), groundwater depletion,

contamination of surface waters and groundwater aquifers, and potential long-term land damage, especially on land previously used for agriculture.

This study assesses each of these impacts and concludes reasonable measures well short of moratoria and bans can be taken to mitigate environmental damage and protect the public health while allowing for responsible development of industrial silica sand resources.

⁸ Wisconsin Department of Transportation, "Non-Metallic Minerals Commodity Profile," WisDOT Multimodal Freight Network 2012, accessed March 9, 2015, <http://www.dot.wisconsin.gov/business/freight/docs/profile-nonmetallic.pdf>.

Air Quality

One of the most widely cited environmental concerns associated with industrial sand mining is air quality, especially as it pertains to particles of crystalline silica small enough to be inhaled, particles measuring below 10 micrometers in diameter. Prolonged exposure to such particles, known as respirable crystalline silica (RCS), can cause silicosis, a preventable but potentially fatal lung disease, in occupational settings.⁹

Silicosis is an inflammation of the lung and other respiratory tissues that eventually causes fibrosis, a hardening of the lungs, reducing the ability to breathe efficiently. Symptoms include shortness of breath while exercising, fever, fatigue, and loss of appetite. Silicosis also renders the victim more susceptible to infection and diseases such as tuberculosis and lung cancer.¹⁰

The American Lung Association reports the silicosis death rate in the United States is generally low. Between 1996 and 2005, the age-adjusted death rate due to silicosis was 0.8 per million population. Even that low death rate is higher than necessary, considering deaths caused by occupational exposure to RCS can be prevented by complying with safety procedures and preventative measures outlined by the Mine Safety and Health Administration (MSHA) and Occupational Safety Administration (OSHA).^{11,12}

In mining and other industrial environments, comprehensive silicosis prevention programs include substituting less-hazardous noncrystalline silica alternatives when possible; implementing engineering controls such as blasting cabinets, local exhaust ventilation, not using compressed air for cleaning surfaces, using water sprays to control airborne dust, and using surface wetting to prevent dust from becoming airborne when cutting, drilling, grinding, etc.; administrative and work practice controls; personal respiratory protective equipment; medical monitoring of exposed workers; and worker training.¹³

The concentrations of dust at a typical industrial sand mining operation are far lower than what is considered an occupational health hazard.

⁹ Carson Thomas and Timothy Kelley, "A Brief Review of Silicosis in the United States," *Environmental Health Insights* 4: 21–26, May 18, 2010, <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2879610/>.

¹⁰ Occupational Safety & Health Administration, "Silica and Silicosis," accessed March 10, 2015, <https://www.osha.gov/dsg/etools/silica/silicosis/silicosis.html>.

¹¹ American Lung Association, "Occupational Lung Disease," *State of Lung Disease in Diverse Communities 2010*, <http://www.lung.org/assets/documents/publications/solddc-chapters/occupational.pdf>.

¹² National Institute for Occupational Safety and Health, "A Guide to Working Safely with Silica," Mine Safety and Hazards Administration, accessed March 10, 2015, <http://www.msha.gov/S&HINFO/SILICO/SILICAX.pdf>.

¹³ Dr. Ki Moon Bang, *et al.*, "Silicosis Mortality Trends and New Exposures to Respirable Crystalline Silica—United States, 2001–2010," *Morbidity and Mortality Weekly Report*, February 15, 2015, <http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6405a1.htm>.

The concentrations of dust at a typical industrial sand mining operation are far lower than what is considered an occupational health hazard. Most sand handling is done when the sand is wet or moist, and workers who may be exposed to dust are not in confined buildings near the source of dust, where concentrations may be relatively high if building ventilation is inadequate. Residences near mines are typically exposed to more dust from gravel roads and agricultural fields than from sand mine processes.¹⁴

The best available air monitoring studies show respirable crystalline silica concentrations in Wisconsin and Minnesota have been within the range of normal “background levels” and far below levels considered hazardous.

Although silicosis is an occupational hazard for workers in industries that involve exposure to RCS, fears of a public outbreak of the disease as a result of sand mining have not been supported by air monitoring data gathered by the Minnesota Pollution Control Agency (MPCA), the Wisconsin Department of Natural Resources (WDNR), or studies conducted by Dr. John Richards of Air

Control Techniques (ACT), whose research has provided the best available dataset on RCS levels near sand mines and processing sites in Wisconsin.

Advocacy reports such as *Communities at Risk* have relied on anecdotal evidence (which can be subject to cherry-picking of data and other biases) in their discussions of the public health risks of silicosis due to RCS associated with industrial silica sand mining. That report left local citizens without objective, scientific evidence on the health risks posed by sand mining operations, causing some to become unnecessarily alarmed.

Below, we summarize the best available air monitoring studies, which show RCS concentrations in Minnesota and Wisconsin have been within the range of normal “background levels” and far below the levels considered hazardous by MPCA.

Air Monitoring Studies

Emissions Generated by Sand Mining Facilities

In Wisconsin, mining operations with production averaging more than 2,000 tons per month are required to install and operate ambient air monitors. Facilities can apply for a variance from this requirement if they can demonstrate the general public will not be exposed to significant levels of particulate matter. Variance requests must be submitted to WDNR in writing.¹⁵

¹⁴ Jim Aiken, “Exploring Environmental Impacts Related to Frac Sand Mining and Processing- Minnesota Focus,” 2012, <https://www.barr.com/download/244>.

¹⁵ Kristen Hart, “Air Pollution Requirements for Industrial Sand Mines,” Wisconsin Department of Natural Resources, June 8, 2012, <https://s3.amazonaws.com/s3.documentcloud.org/documents/695606/wdnr-silica-regulations.pdf>.

Sand mines may be granted a waiver from conducting air monitoring because, according to WDNR, quarries and sand mines typically have few point source emissions and modeling has shown there is little chance industrial sand mining activities would cause emissions to approach or exceed the National Ambient Air Quality Standards (NAAQS) established by the U.S. Environmental Protection Agency (USEPA).

State regulatory agencies do not always require modelers to take into account fugitive dust emissions from non-point sources, but fugitive dust control plans are almost always required.¹⁶ Additionally, although sand mine operators may be exempted from monitoring the air around their facilities, they must be in compliance with all Wisconsin air quality standards.

In the case of industrial sand mining in the Midwest, particulate matter (PM) has been monitored in three sizes: PM₁₀, which is 10 micrometers (also called “microns”) in diameter, PM₄ (4 microns), and PM_{2.5} (2.5 microns). As a point of reference, a typical human hair is about 100 microns thick.

PM₁₀ is monitored by WDNR at various facilities throughout the state, and the agency reports no instances in which facilities exceeded PM₁₀ standards.¹⁷ PM₄ and PM_{2.5} are of greater concern because these particle sizes are small enough to be inhaled directly into the lungs, bypassing the filtration function of the human body’s nasal passages, and could therefore put an individual at greater risk of contracting silicosis. Studies have investigated concentrations of PM₄ crystalline silica in Minnesota and Wisconsin, allowing for an evidence-based discussion about the potential for a public health threat from RCS and industrial silica sand mining activity.

After collecting more than three years of sampling data, Dr. John Richards of Air Control Techniques found ambient air concentrations at four Wisconsin frac sand facilities for PM₄ crystalline silica particles were well within the range of background concentrations.

Dr. John Richards of Air Control Techniques (ACT) investigated levels of PM₄ particles at two locations each for four EOG Resources, Inc. frac sand facilities (one processing plant and three mines) in Chippewa County and Barron County, Wisconsin, to ascertain whether the facilities were producing hazardous levels of PM₄ particles. Richards used stringent scientific sampling and analytical methods in accordance with guidelines established by the National Institute for Occupational Safety and Health (NIOSH).¹⁸ He modified existing USEPA methods for

¹⁶ Jason Truetel, “Sand Mining Monitoring in Wisconsin,” presented at SME Wisconsin Annual Conference, October 7, 2014, <http://higherlogicdownload.s3.amazonaws.com/SMENET/1b517024-bb1c-4b2c-b742-0136ce7a009c/UploadedImages/TCjointConference/Jason%20Truetel%20-%20Ambient%20Air%20Monitoring%20at%20WI%20Sand%20Mines.pdf>.

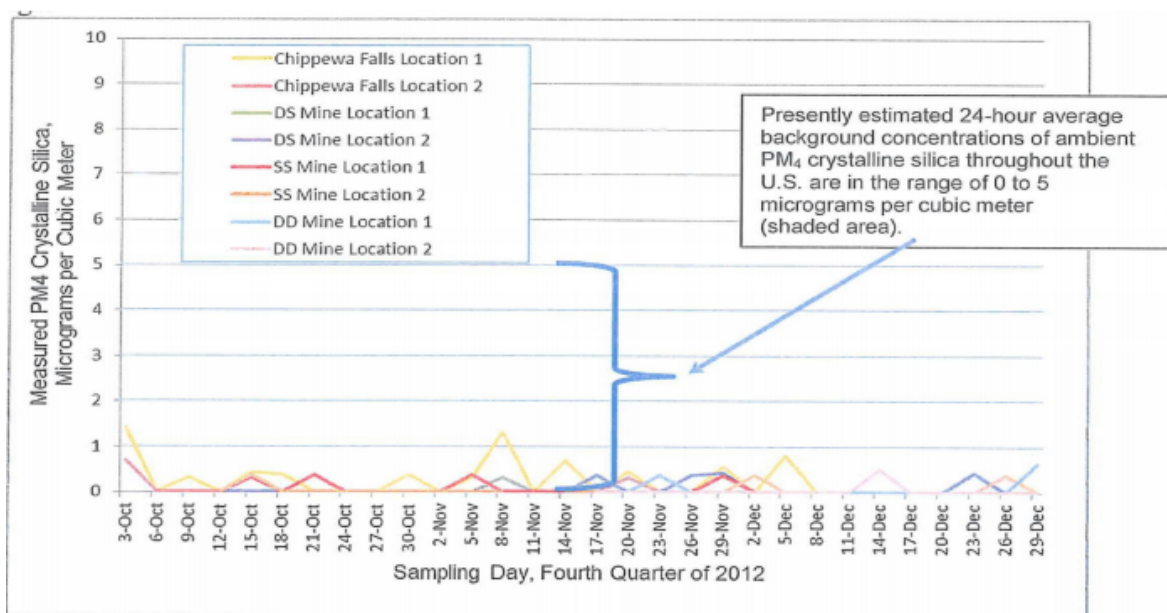
¹⁷ *Ibid.*

¹⁸ Dr. John Richards, “Ambient PM₄ Crystalline Silica Concentrations at EOG Sand Producing Facilities in Wisconsin,” Frac Sand Mining Environmental Research Webinar, Current Status of Research Findings, pp. 85–104, June 18, 2014, <http://www.uwsp.edu/cnr-ap/clue/Documents/Mining/FracSand2014WebinarFinal.pdf>.

measuring similar small particles to account for the specific particle size being studied and analyzed for crystalline silica.

After collecting 1,176 days – more than three years – of sampling data at the eight locations, ACT found ambient air concentrations for PM₄ crystalline silica particles were well within the range of background concentrations in agricultural, rural, and urban areas throughout the United States. The PM₄ crystalline silica concentrations, when detected, were less than 10 percent of the California reference exposure level of three micrograms per cubic meter (µg/m³), meaning emissions of silica dust at these facilities were far below concentrations considered conservatively protective of human health. (See Figure 1.)

Figure 1
PM₄ Levels at Four Wisconsin Frac Sand Facilities

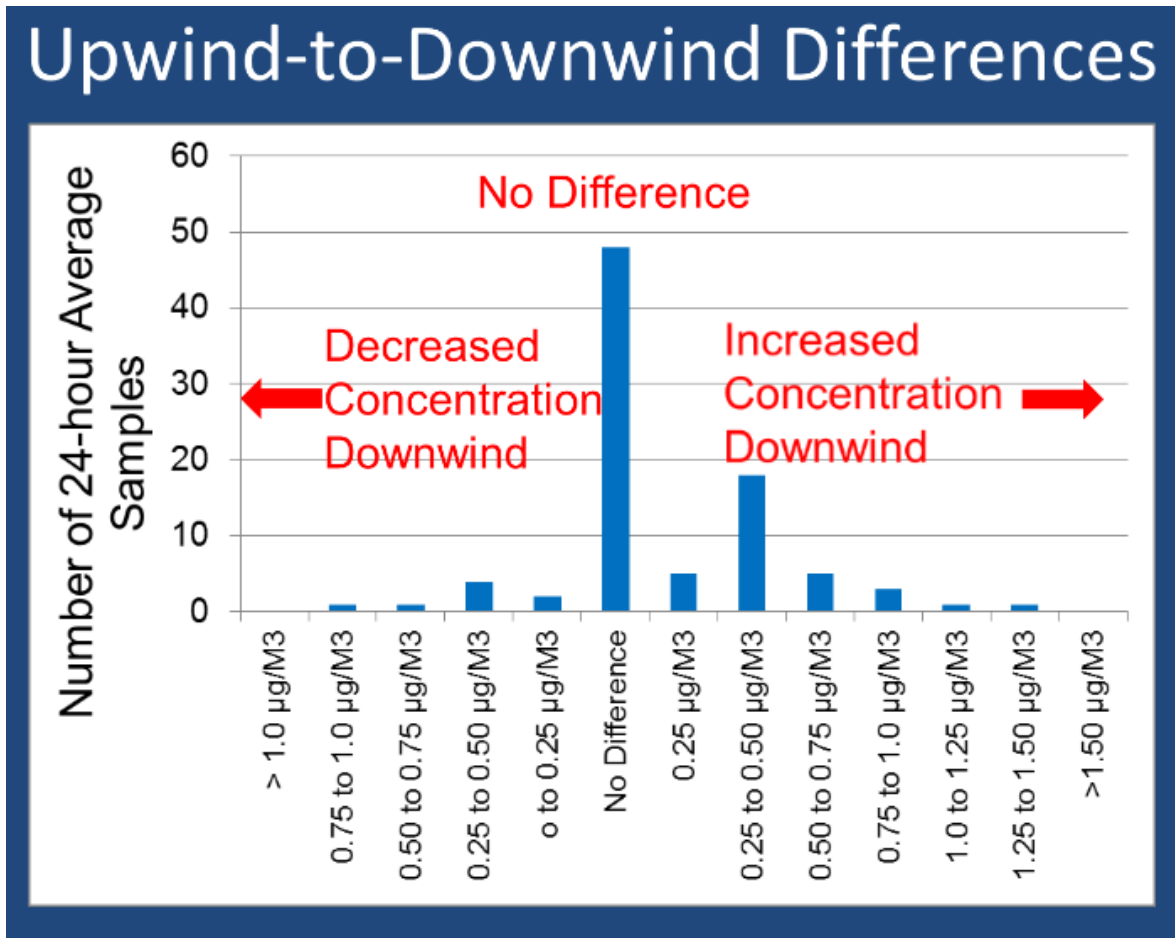


After collecting 1,176 days of sample data, researchers determined levels of respirable crystalline silica measuring four micrometers in diameter (PM₄) were far below levels considered hazardous to human health. PM₄ levels detected were less than 10 percent of the California reference exposure level.

Richards also conducted upwind/downwind monitoring at the eight locations, allowing researchers to determine whether differing concentrations of PM₄ crystalline silica at each monitor were the result of activity at the frac sand facility. The vast majority of samples showed no observed difference in ambient crystalline silica concentrations between the upwind and downwind monitors. Where concentrations did differ, the differences were small and well below

levels considered harmful, suggesting the industrial sand mine and processing plants are not a source of hazardous levels of respirable crystalline silica particles.¹⁹ (See Figure 2.)

Figure 2
Upwind/Downwind PM4 Levels at Four Wisconsin Frac Sand Facilities



There were no observed differences between upwind and downwind monitors in the vast majority of samples collected at four frac sand facilities in Barron and Chippewa Counties in Wisconsin. When differences were observed, they were small, suggesting the facilities are not sources of hazardous levels of respirable crystalline silica particles.

¹⁹ *Ibid.*

Comparison of the PM4 data collected by ACT at the eight Wisconsin locations and PM2.5 data collected by WDNR in Eau Claire, Wisconsin showed a consistent match across the state. Those comparisons indicate regional background concentrations of ambient PM4 crystalline silica largely determined the measured concentrations, regardless of the prevailing wind direction. The regional background concentrations are due to a variety of well-known sources of ambient PM4 crystalline silica, including agricultural operations, unpaved roads, construction activity, industrial sources, and the global transport of dust from the Gobi (China) and Saharan (Africa) deserts.

Crystalline silica comprises 12 percent of Earth’s crust, and any activity that disturbs rock or soil can contribute to ambient PM4 crystalline silica concentrations. Richards noted, “there is a little crystalline silica everywhere, but not a lot anywhere.”

Dust Generated by Transportation of Sand

Residents of communities near industrial sand sites have raised concerns that dust blowing from trucks hauling sand could be a source of hazardous respirable silica particles along transportation routes. Those concerns prompted authorities from the Minnesota Pollution Control Agency (MPCA) to conduct ambient air monitoring along a busy truck route in Winona, Minnesota.

Air monitoring conducted by the Minnesota Pollution Control Agency along a busy truck route found dust levels were so low monitors could not detect any at all on 94.7 percent of the days sampled over seven months.

Using the PM4 data gathered from this monitor, MPCA concluded dust from hauling industrial sand near the air monitoring location was not a threat to public health.

MPCA data show dust levels were so low the air monitors could not detect any at all on 94.7 percent of the days sampled over seven months. When air monitors did detect dust, it was in concentrations near 15 percent of the chronic health benchmark used by MPCA.²⁰

MPCA selected the town of Stanton, Minnesota as a reference site against which to compare RCS levels it recorded in Winona. Stanton does not have silica sand facilities or transportation but does have other sources of RCS, such as farm fields and unpaved roads. Stanton registered higher levels of RCS than did Winona.²¹ MPCA concluded, “Airborne silica is a fairly ubiquitous pollutant and is not unique to silica sand mining and processing facilities.”

²⁰ Zahra Hirji, “Trucks Hauling Frac Sand Not a Source of Lung Disease Dust, Data Shows,” *Inside Climate News*, October 16, 2014, <http://insideclimatenews.org/news/20141016/trucks-hauling-frac-sand-not-source-lung-disease-dust-data-shows>.

²¹ Minnesota Pollution Control Agency, “Air Monitoring at Minnesota Silica Sand Facilities,” accessed March 10, 2015, <http://www.pca.state.mn.us/index.php/air/air-quality-and-pollutants/air-pollutants/silica-sand-mining/air-monitoring-data-at-minnesota-silica-sand-facilities.html#winona>.

Conclusion: Sand Mining Doesn't Hurt Air Quality

The data compiled by Richards at ACT and MPCA, which together comprise about 2,000 samples from Minnesota and Wisconsin, indicate industrial sand operations do not generate hazardous levels – or anything approaching hazardous levels – of small silica particles in the ambient air near these operations. This research provides a positive starting point for understanding the real and perceived risks of mining, processing, and transporting industrial sand in the Upper Midwest. These findings are important, and they should not be surprising.

The reason the sand in the Upper Midwest is sought-after for hydraulic fracturing is because it is well-rounded, has a high crush strength (meaning it is strong and resistant to fracturing), and is well-sorted. PM4 silica particles are generally created by processes that fracture silica particles into smaller pieces; the industrial sand mining process does not and cannot do that, or there would be no industrial sand business. Doing so would be analogous to a tomato farmer smashing all the tomatoes during harvest.

PM4 silica particles are generally created by processes that fracture silica particles into smaller pieces; the industrial sand mining process does not and cannot do that, or there would be no industrial sand business.

Additional information will be valuable in assessing the potential public health impact, from an air quality perspective, of industrial sand mining. Air quality monitoring should continue. At present, fears of a public outbreak of silicosis are simply not supported by the available data gathered from recent and ongoing ambient air monitoring studies conducted at nine active and one proposed industrial sand operation in Wisconsin and two communities in Minnesota. With respect to air quality, frac sand mining does not put the public's health at risk.

Water Quality

Surface Water Quality Impacts

Industrial sand mines have several potential interactions with water. Surface water may be present at or near mining operations in the form of wetlands, ditches, streams, ponds, or lakes, and water from silica sand facilities may infiltrate downward and encounter groundwater. Because they are generally the most visible, surface water and groundwater quality are two of the most commonly cited environmental concerns expressed by the general public.

The most obvious surface water quality impacts arise when untreated storm water or process water, which is used to cleanse the sand of fine clay and silt particles, is discharged directly to surface water bodies. Such accidental discharges can occur when storm water retention ponds or components of the process water system fail. Structural failures have occurred on more than one occasion and have resulted in the discharge of clay, silt, and fine sand into nearby waterways. Some of the affected waterways appeared cloudy for a few days until the fine silt and clay

particles settled out of the water. Fortunately, because of the nontoxic nature of these particles, the impacts of these discharges were temporary.

Although the discharge of sediment into surface waters is a form of pollution, it differs from other forms of pollution in that sand, silt, and clay particles are naturally transported by water systems on a daily basis. Accidental discharges do not represent catastrophic events from which streams cannot recover once the discharge has been stopped and the suspended particles have settled. In fact, these sediments are found in substantially larger proportions during and after natural rain events.

While bad actors should be identified and punished, the vast majority of companies that respect and adhere to applicable standards and best practices should not be condemned in the process.

Wisconsin has several environmental regulations intended to restrict mining activities to protect the state's waters. The two main regulations are the Wisconsin Pollutant Discharge Elimination System (WPDES) Storm Water Permits and the Chapter 30 and 31 Wisconsin Statutes waterway permits. These permits adequately protect surface water in the state but cannot

prevent all accidents or the results of inadequate designs, construction, or procedures. Accidental discharges previously mentioned presumably occurred because systems were improperly designed or constructed or operators failed to follow established procedures. The incidents could have been avoided by better engineering practices and strict adherence to applicable standards and industry best practices.

Unfortunately, there have been and presumably always will be bad actors in virtually any industry, and their actions can have a negative impact on the environment. The existence of a bad actor should not serve as indictment of an entire industry sector. For example, would an environmental organization argue metals recycling should be banned because a few metals recycling companies have been found to be in violation of environmental standards?²² The same logic should apply to the sand mining industry. While bad actors should be identified and punished, the vast majority of companies that respect and adhere to applicable standards and best practices should not be condemned in the process.

Groundwater Pollution Concerns

Private wells are the primary source of drinking water in many rural areas, and as new industrial sand mines have been announced or begun operations, local citizens have sought to understand the potential impact of those operations on the quality of their groundwater.

²² See Ingrid Lobet, "Danger in air near metal recyclers," *Houston Chronicle*, December 29, 2012, updated January 9, 2013, <http://www.houstonchronicle.com/news/houston-texas/houston/article/Danger-in-air-near-metal-recyclers-4154951.php>.

The main concerns regarding groundwater quality are the potential for pollution from the use of polyacrylamide and acid mine runoff from operating and reclaimed sand mines. There have been no documented cases of contamination of groundwater aquifers or potable water supply wells from industrial sand mining operations. Nevertheless, these concerns merit serious discussion.

To recycle the water used in frac sand processing, operators use water-soluble polymers to remove small clay particles from the water. One of those polymers is polyacrylamide, the same safe chemical used by most municipal drinking water and wastewater treatment facilities. Polyacrylamide gets the clay particles to “clump together” and settle out of the water faster than they would otherwise.²³ Polyacrylamide can contain trace amounts of the chemical acrylamide, a known neurotoxin and carcinogen.

Although acrylamide is a neurotoxin, it does not present a threat to public health because it degrades into carbon dioxide, ammonia, and nitrogen oxides quickly in the environment. In oxygen-rich soils, 74 to 94 percent of the acrylamide breaks down within 14 days. In oxygen-poor soils, 64 to 89 percent breaks down in 14 days. In river water, 10 to 20 ppm levels of acrylamide degrade completely in 12 days.

The rapid degradation of acrylamide greatly reduces – in fact essentially eliminates – the chances of adverse human health impacts from polyacrylamide use at industrial sand mining operations.

Because horizontal groundwater flow velocities are very slow – typically on the order of centimeters per day – acrylamide does not persist in groundwater.²⁴ For example, consider that groundwater velocity at most sand mining areas is less than 1 foot per day. Over the course of 14 days, the time it takes the vast majority of acrylamide to break down in the environment, the groundwater will have moved less than 14 feet. Over the course of 28 days, the groundwater will have moved less than 28 feet.

Considering mines are sited further than 100 feet from drinking water wells, the trace amount of acrylamide that may be present in the groundwater is highly unlikely to contaminate the aquifer and neighboring drinking water wells. The rapid degradation of acrylamide greatly reduces – in fact essentially eliminates – the chances of adverse human health impacts from polyacrylamide use at industrial sand mining operations.

Again, this reasoning applies to a great many industrial processes. Consider, for example, polyvinyl chloride, commonly known as “PVC.” PVC is used in plumbing, medical applications,

²³ Dr. Kent Syverson, “Environmental Impacts of Sand Mining in Wisconsin,” presentation, December 2012, https://www.wicounties.org/uploads/legislative_documents/kent-syverson-wi-counties-frac-sand-commision-talk-dec-2012.pdf.

²⁴ Dr. Kent Syverson, “Water Resource Impacts Associated with the Sand-Mining Boom in Western Wisconsin: A Comparison Between Agricultural Activities and Sand Processing,” Geological Society of America, Abstracts with Programs 45:4, p. 69, May 2013, <https://gsa.confex.com/gsa/2013NC/webprogram/Paper218689.html>.

and a wide variety of other familiar products. PVC tubing is ubiquitous in the medical sector because it is easily sterilized, durable, and provides a strong protective barrier from potential contaminants. Thus PVC polymer has significant value to the public.

Production of PVC also involves the use of vinyl chloride, a highly toxic and carcinogenic chemical. Any batch of PVC will contain a very small, but measurable, concentration of “free” vinyl chloride monomer. This concentration is so small, and breaks down so quickly in the environment, that no rational judge would say the tiny risks presented by minute concentrations of residual vinyl chloride monomer in freshly produced PVC outweigh the many benefits of PVC products.

The same holds true with respect to polyacrylamide. Acrylamide is a potentially toxic compound that may be present in exceedingly small concentrations in polyacrylamide for a short period of time. Environmental organizations may attempt to inflate this particular “risk” to monumental proportions, but the real risk is hardly worth considering.

Standards and Regulations Protect Water Quality

The water-soluble polymers used at industrial sand operations are approved by the National Sanitation Foundation (NSF) and American National Standards Institute (ANSI) Standard 60 for treatment of drinking water. For comparative purposes, it is worth noting municipal drinking

WDNR regulations protect surface water and groundwater by regulating storm water and surface water discharges, well drilling, and application of materials to the land surface.

water treatment facilities add polyacrylamide directly to drinking water; industrial sand operations add polyacrylamide to the sand wash water, which is part of the industrial sand process and not a source of drinking water.

Additionally, WDNR regulations protect surface water and groundwater by regulating storm water and surface water discharges, well drilling, and application to the land

surface of materials with the potential to impact groundwater. Any storm water or surface water discharge of industrial sand wash water is regulated by WDNR under Ch. NR 216. WDNR approves the application of products containing polymers for sediment control purposes under DNR Conservation Practice Standard 1051 to protect surface waters.

WDNR has not established specific groundwater standards for polymers under Ch. NR 140, but there is minimal danger of groundwater pollution if the wash water is held in a pond. WDNR reports: “Sealed ponds will have very little potential for groundwater impacts. Unsealed ponds will likely seal themselves with the fines [silt and clay particles] that are removed from the frac sand.”²⁵

²⁵ Wisconsin Department of Natural Resources, “Silica Sand Mining in Wisconsin,” January 2012, p. 28, <http://dnr.wi.gov/topic/Mines/documents/SilicaSandMiningFinal.pdf>.

One report on silica sand mining suggests sand mine sites could lead to acid mine drainage, but frac sand mining does not generate acid mine drainage.²⁶

Wisconsin has a long history of nonmetallic mining and a large number of nonmetallic mines already in operation. There is no evidence those mines, including industrial sand mines, have degraded groundwater quality. Industrial sand mining has proven compatible with the state's goal of protecting groundwater quality. Aquifers, private water supply wells, municipal wells, springs, trout streams, and exceptional and outstanding resource waters are protected through USEPA and WDNR regulations and permits. In many instances, community-oriented industrial sand mining companies take their own steps to enhance and improve upon these efforts.

Wisconsin has a long history of nonmetallic mining and a large number of nonmetallic mines. There is no evidence those mines have degraded groundwater quality.

Water Quantity

Silica sand mining is often portrayed as a water-intensive industry due to the volumes of water used for washing, processing, suppressing fugitive dust, and, at some facilities, transporting sand as a slurry. The amount of water used varies greatly depending upon the facility and the extent to which water is recycled. Closed-loop systems that recycle 90 percent of the water they use can consume as little as 18,000 gallons per day, whereas open-loop systems can consume as much as two million gallons per day.²⁷

The growth of the industrial sand industry in recent years has generated concern among some members of the public that mining and processing operations will permanently alter groundwater aquifers and the industry will compete with residential, municipal, and agricultural uses of groundwater and ecological systems such as springs, streams, rivers, and lakes.

Those concerns are mostly unfounded. Silica sand mining accounts for a very small percentage of the water used in the state. WDNR data show all nonmetal mining operations in the state – including quarry dewatering, washing sand and gravel, and industrial sand mining – accounted for just 0.71 percent of all water withdrawals in 2013.²⁸ Other uses of water in Wisconsin, such as power generation, municipal public water, and agriculture, use far greater amounts of water. (See Figure 3.)

²⁶ Dr. Kent Syverson, *supra* note 23.

²⁷ Kate Prengaman, "A sand plant by the numbers," Wisconsinwatch.org, August 19, 2012, <http://wisconsinwatch.org/2012/08/a-sand-plant-by-the-numbers/>.

²⁸ Robert Smail, "Mining and Water in Wisconsin: Water Use for Non-Metallic Mining," presentation at SME Wisconsin Annual Conference, October 7th, 2014, <http://higherlogicdownload.s3.amazonaws.com/SMENET/1b517024-bb1c-4b2c-b742-0136ce7a009c/UploadedImages/TCjointConference/Robert%20Smail%20-%20Water%20Usage%20in%20Non-Metallic%20Mining.pdf>.

Figure 3



Water Use in Wisconsin: 2013 Total Withdrawals

In 2013, total withdrawals exceeded 2.12 trillion gallons of water from over 14,000 wells, ponds, streams, rivers and lakes.

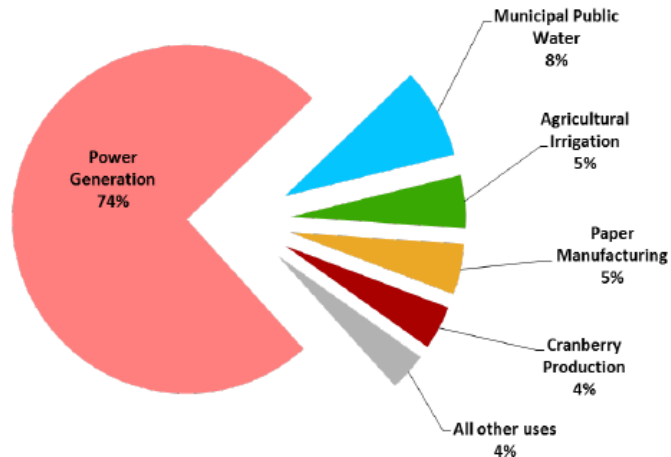
- This is roughly equal to 3 times the water in Lake Winnebago
- Enough water to cover the surface of Wisconsin in about 2" of water.

Total 2013 withdrawals were up 6% from 2012.

Non-metallic mining ranked 8th in total withdrawals with 15 bGal or .71% of the total withdrawal.

2013 Withdrawals by Use

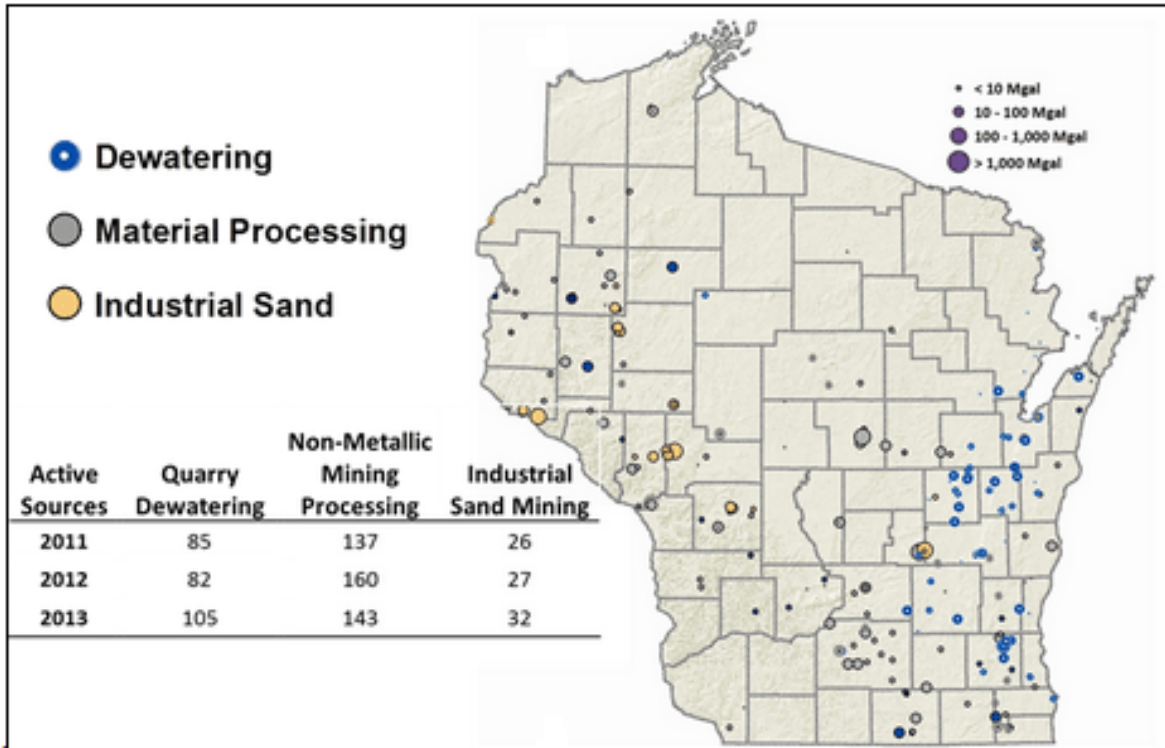
Total Withdrawals = 2.121 Trillion Gallons



Total water withdrawals in the state of Wisconsin in 2013 were 2.121 trillion gallons. Power generation accounted for 74 percent, meaning more than 100 times as much water was used to generate electricity as was used by all nonmetallic mining operations, including quarries and gravel pits in addition to industrial sand mines.

Water consumption by industrial silica sand operations constituted just a fraction of the already-small amount used by all nonmetallic mining operations. Water withdrawals associated with industrial sand activity were only 1.99 billion gallons in 2013, just 0.09 percent of the 2.121 trillion gallons consumed for all purposes in the state. (See Figure 4.) By comparison, agricultural irrigation accounted for 5 percent of total water withdrawals, using 55 times more water than industrial sand operations for mining and processing.

Figure 4



Industrial sand washing, transporting, and dust suppression accounted for 0.09 percent of all water consumed in the state of Wisconsin in 2013. Because industrial sand mining accounts for such a small percentage of total water consumption in Wisconsin, by far the largest producer of industrial sand in the country, these numbers suggest industrial sand operations will not deplete water resources in other states with humid climates.

One reason industrial sand mines use so little water is the majority of plants operate closed-loop systems, which is why industrial sand washing and processing was only the sixth-largest source of water use in the ten counties reporting presence of industrial-sand washing operations.²⁹ Modern, efficient closed-loop systems recycle 90 percent of the water used on site. Water consumption at such sand facilities can vary between 18,000 and 250,000 gallons per day. The 10 percent of water lost in these systems results primarily from evaporation from ponds, drying moist sand, and placement of wet sand and fines (silt and clay particles) during mine reclamation.

²⁹ Emily Chapman *et al.*, "Communities at Risk: Frac Sand Mining in the Upper Midwest," September 2014, [www.civilsocietyinstitute.org/media/pdfs/092514_CSI_BAR_frac_sand_mining_report_FINAL2 - EMBARGOED.pdf](http://www.civilsocietyinstitute.org/media/pdfs/092514_CSI_BAR_frac_sand_mining_report_FINAL2_-_EMBARGOED.pdf).

Except for relatively small amounts of water that evaporate during sand mining and processing, essentially all the groundwater pumped from the aquifer is retained in the geographic basin that comprises the surface water–groundwater aquifer system. For example, water discharged from a mine during dewatering (lowering the water table around an area to be mined) is kept within the basin, under a permit issued by WDNR. There is no material net loss of water from the surface water–groundwater system.

Additionally, groundwater quality and quantity are carefully considered in every stage of a mine’s existence: before permitting, while operating, and after mine closure. Groundwater experts (hydrogeologists) study the groundwater for federal, state, and local governments as well as the sand mining industry, and WDNR hydrogeologists and engineers evaluate all permits for high-capacity wells.

Sand processing operations operating high-capacity wells (wells capable of pumping more than 100,000 gallons per day) must pump groundwater in accordance with a high-capacity well permit from WDNR. In addition, the local mine permitting authority requires scrutiny of groundwater during development of Conditional Use Permits and reclamation plans.

The available data from Wisconsin, the largest producer of industrial sand in the nation, show sand mining will not deplete water resources in the communities in which it occurs.

Ultimately, the impact of groundwater pumping is site-specific and based on ground surface and groundwater elevation, geology, hydrogeologic characteristics of the groundwater aquifer, proximity to surface water, and presence of other nearby groundwater users. The available data from Wisconsin, the largest producer of industrial

sand in the nation, show industrial sand production accounted for just 0.09 percent of all water use in the state, demonstrating sand mining will not deplete water resources in the communities in which it occurs.

Land Reclamation

Wisconsin state law requires all nonmetallic mines be reclaimed in accordance with NR 135 Wisconsin Administrative Code, implemented and administered by Wisconsin counties. Counties are required to implement a nonmetallic mining reclamation permit program in accordance with the administrative code, including adoption of an ordinance and administration of a mining reclamation program. The purpose of this program is to ensure mining sites are reclaimed to a post-mining land use, which can be agricultural, wildlife habitat, prairie, a cranberry bog, or another use upon which the mining company and property owner agree.

Nonmetallic mining permits are subject to uniform reclamation standards provided in NR 135 Wisconsin Administrative Code. Those standards require the replacement of topsoil to minimize compaction and erosion, stabilization of soil conditions and slope, establishment of vegetative cover, control of surface water flow and groundwater withdrawal, prevention of environmental pollution, and development and restoration of plant, fish, and wildlife habitat if needed to comply with an approved reclamation plan.³⁰

NR 340 Wisconsin Administrative Adm. Code also includes mine reclamation requirements administered by WDNR, which apply to a mine or portions of a mine that affect or are adjacent to navigable waterways.

Because large industrial sand mines are designed to be mined in phases (typically 30 to 40 acres of permitted mine are actively mined at a given time)³¹ there will, in most cases, be ongoing reclamation in some areas of the mine while mining continues in others, resulting in a type of “reclaim-as-you-go” strategy.

Mine owners or operators are also required to post with the county a bond or some other form of financial assurance as a condition of the NR 135 permit. In the event an operator fails to fulfill its obligation under the reclamation plan, the county will have sufficient funding to carry out the reclamation plan itself. The financial assurance must be in place before initiating mine development.

Although activists occasionally raise concerns about the quality of reclamation plans, Wisconsin administrative code ensures mines are reclaimed and vegetated to protect air quality and prevent wind erosion of the reclaimed area. Wisconsin is typical of the way other states address land reclamation issues, whether related to sand mining or myriad other human activities.

Reclaiming Farmland

Because agriculture is such a vital industry in rural communities across the Upper Midwest, there has been a considerable degree of concern about whether industrial silica sand mining will cause permanent damage to the quality of soil for agricultural purposes, such as providing pasture for livestock and growing row crops.

Reclaimed sand mine sites produce crop yields of 73 to 97 percent of their original yields within three years of reclamation, suggesting silica sand mining may not cause a long-term decline in farmland productivity.

Studies investigating agricultural productivity have found reclaimed sand mine sites produce crop yields of 73 to 97 percent of their original yields within three years of reclamation,

³⁰ N.R. 135 Nonmetallic Mining Reclamation, Wisconsin State Legislature, January 2012, http://docs.legis.wisconsin.gov/code/admin_code/nr/100/135/11/10.

³¹ Dr. Kent Syverson, *supra* note 23.

suggesting silica sand mining may not cause a long-term decline in farmland productivity.³² The best yields were achieved in areas where the original topsoil was returned to the land.

Yields on reclaimed mine sites vary depending on the type of crop grown, with certain crops faring better than others. On average, corn yields achieved 73 percent of the control group productivity, average winter wheat yields were 77 percent of control, and soybean yields were 97 percent of control. Average cotton yields were 80 percent of control, but the quality of the cotton was reduced in all the reclamation treatment scenarios.³³

These findings are of particular interest in regard to silica sand mining in the Upper Midwest because corn, soybeans, and wheat are among the major row crops planted in the region.

These production trends have been affirmed by other studies examining the long-term results of crop production on reclaimed sand mine soils from 2005 to 2012. These studies found reclaimed mine soils consistently exceed local countywide five-year average yields for all crops (corn, wheat, soybeans, and cotton) but are typically 15 to 20 percent

lower than adjacent prime farmland under identical management.³⁴ In 2012, soybean yields on reconstructed mine soils were higher than on the unmined, adjacent prime farmlands and higher than the five-year county average, for the first time.³⁵

These findings are of particular interest in regard to silica sand mining in the Upper Midwest because corn, soybeans, and wheat are among the major row crops planted in the region, whereas the climate is unsuitable for growing cotton.³⁶ Lower corn yields were attributable to low levels of nitrogen, which were the result of the researchers' desire to study the long-term nitrogen supply of the reconstructed soil by not adding additional supplies of nitrogen-based fertilizer.³⁷

³² W. L. Daniels, *et. al*, "Reclamation of Prime Farmland Following Mineral Sands Mining in Virginia," SME Annual Meeting, February 25–27, 2002, <http://landrehab.org/UserFiles/DataItems/5A706850676C79516461343D/Daniels%20et%20al%202002%20SME%20Reclamation%20of%20Prime%20Farmland.pdf>.

³³ *Ibid.*

³⁴ Comparisons between reclaimed mine soils and countywide production are complicated by the fact reclaimed soils received irrigation, whereas some but not all crops throughout the county were irrigated.

³⁵ W. Lee Daniels and Z. W. Orndorff, "Indicators of reclamation success for mineral sands mining in the USA," 6th International Conference on Sustainable Development in the Minerals Industry, June 30, 2013–July 3, 2013, <http://landrehab.org/UserFiles/DataItems/71702B51452B63547134343D/Daniels%20and%20Orndorff%20Indicators%20for%20Mineral%20Sands%202013.pdf>.

³⁶ U.S. Census Bureau, *Statistical Abstract of the United States*, Agriculture, 2012, <https://www.census.gov/compendia/statab/2012/tables/12s0859.pdf>.

³⁷ W. Lee Daniels and Z. W. Orndorff, *supra* note 35.

A likely factor in the high levels of soybean production is the fact soybeans are nitrogen fixers, meaning they are able to create their own supply of nitrogen by converting nitrogen from the air into a form the plant can use.³⁸ Thus, sand mining's impact on soil nitrogen supplies would have little effect on soybeans.

Although the studies cited here did not investigate alfalfa growth on reclaimed sand mine soils, alfalfa is also a nitrogen-fixing plant, which suggests alfalfa too may be highly productive on reclaimed soils. Additionally, because alfalfa is a perennial plant, it develops a deeper root system than annual crops such as corn and soybeans. Such a root system can help prevent soil compaction, which has been recognized as a challenge for reclaiming farmland.

Faculty and students from the University of Wisconsin River Falls are undertaking additional studies that will examine reclamation best practices and provide valuable information for silica sand mining companies' future reclamation efforts.

These findings should bring comfort to Midwesterners concerned about their region's agriculture. Soybeans are a vital component of crop rotation in the Midwest and alfalfa is important feed for dairy cows, which are the basis of the western Wisconsin economy.

In all of these studies, soil compaction has been recognized as a limiting factor for crop yields, as compaction can limit the extent to which roots can grow downward in the soil, thus limiting the growth of grain, particularly wheat. Chisel plowing and disking the fields, as well as growing crops with longer root systems, can be an effective way to reduce soil compaction and crusting at the surface and can also increase water retention.

Faculty and students from the University of Wisconsin-River Falls are undertaking additional studies of the effectiveness of land reclamation in Chippewa County, Wisconsin. These studies will examine reclamation best practices and provide valuable information for silica sand mining companies' future reclamation efforts.

Part 2

What Is Industrial Silica Sand?

We suspect most readers came to this report seeking assurances that silica sand mining can be done in a safe and environmentally responsible manner. Part 1 was written with those readers in mind.

Part 2 is for the reader seeking more: Not just assurances about the safety of sand mining, but a deeper understanding of what industrial silica sand is and why it is so valuable.

³⁸ University of New Mexico State University, "Nitrogen Fixation by Legumes," May, 2003, accessed February 28, 2015, http://aces.nmsu.edu/pubs/_a/A129/.

Industrial silica sand is simply silica sand used for industrial purposes. This sand is composed of the mineral quartz, which comprises 10 percent of Earth's crust by mass, making it the most common mineral found on the surface of the Earth.³⁹ Industrial sand has the same chemical composition as the sand found in sandboxes, riverbeds, and beaches throughout the world; it is no coincidence that the most sought-after industrial sand deposits were formed in beach environments over millions of years, some 400 to 500 million years ago.

Certain physical characteristics make some sand deposits more attractive for industrial uses, and thus industrial sand mining, than others. Among these properties are size (the size of the grains can affect which uses it is best suited for) (see Figure 5), shape (whether the sand is angular or spherical), uniformity of the grain sizes (whether the grains are all relatively the same size), purity of the deposit (how much of the material is silica sand compared to other, noneconomic minerals), and durability (measured by the sand's ability to resist crushing at high pressures and withstand high temperatures).

Figure 5
Industrial Sand, Penny for Scale



Figure from the *Minneapolis Star Tribune*.

Industrial Sand Supply and Demand

The United States is the leading producer, and a major consumer, of silica sand in the world and is self-sufficient in this mined mineral commodity. Every state produces industrial sand and

³⁹ Minnesota Department of Natural Resources, "DNR and Silica Sand," 2015, accessed February 28, 2015, <http://www.dnr.state.mn.us/silicasand/index.html>.

gravel for aggregate and construction purposes.⁴⁰ Unlike other minerals and commodities, the United States Geological Survey (USGS) does not have specific reserve estimates for sand and gravel for construction and industrial purposes because these resources are so abundant accurate reserve numbers are difficult to calculate. Development of these reserves is largely influenced by land use and environmental considerations, not a limit of supply.⁴¹

Although deposits of industrial sand and gravel are widespread across the country and all states mine these resources to some extent for construction and aggregate, sand deposits in certain states are better-suited for more specialized industrial purposes, such as glassmaking and hydraulic fracturing. As mentioned previously, much of the nation's industrial sand is mined in the Upper Midwest. Many of these industrial sand mines are located in or near an area commonly referred to as "the Driftless Area."

Sand deposits in certain states are better-suited for more specialized industrial purposes, such as glassmaking and hydraulic fracturing.

The Driftless Area is a region spanning 10 million acres, twice the size of Massachusetts, in central and western Wisconsin, southeastern Minnesota, northeastern Iowa, and northwestern Illinois.^{42,43} It is called the Driftless Area because it was not covered by glaciers during the previous glaciation, 10,000 to 12,000 years ago. (See Figure 6.) Because this region was never glaciated, many of the most-desirable sandstone formations for industrial sand production are near the surface with minimal overburden. Consequently, mining in these areas is more cost-effective than in areas where sandstone formations are buried underneath deep deposits of glacial sediment that would have to be removed prior to mining.

The Driftless Area is experiencing rapid growth in industrial sand mining because it is home to some of the highest-quality deposits of silica sand for hydraulic fracturing. This sand, referred to as "Northern White" by oil and gas operators because it comes from northern states and has a white color, derives from four major sandstone formations, the Jordan, Wonewoc, St. Peter, and Mt. Simon.

Another type of silica sand used for fracking in certain areas of the country is found in Texas and other southern states and is referred to as Brady Brown. This sand is generally of lower quality than the Northern White found in the Upper Midwest as it is less resistant to crushing

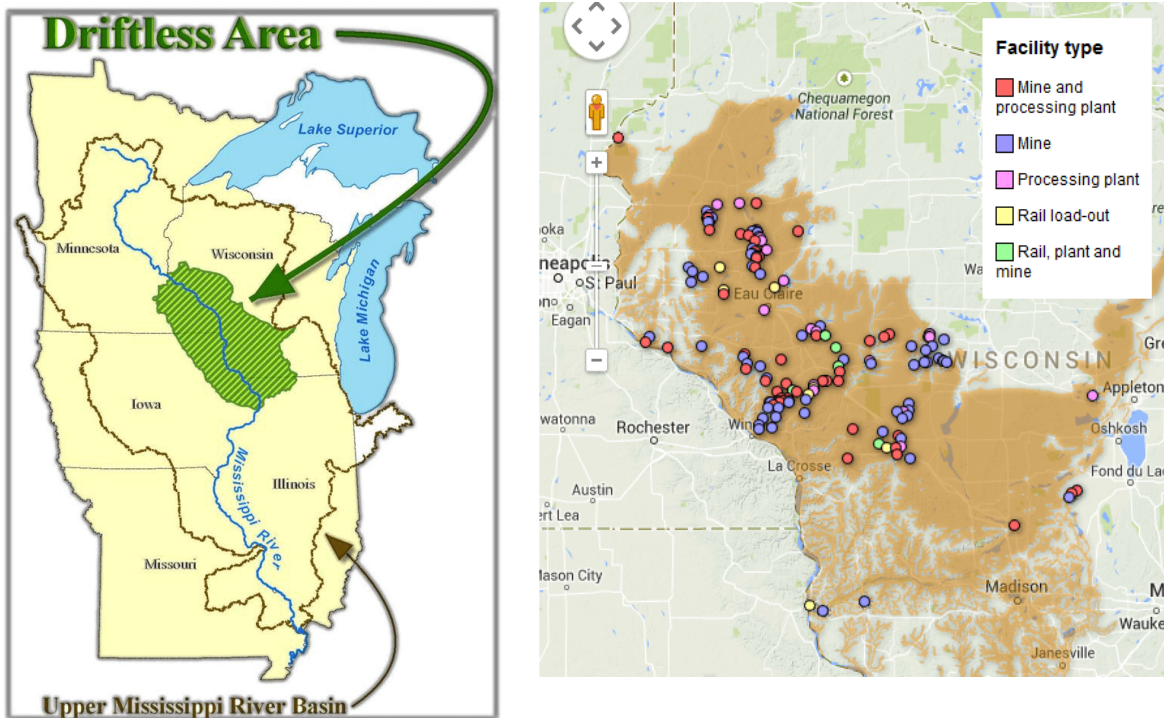
⁴⁰ Minerals Education Coalition, "Sand and Gravel," 2013, <http://www.mineralseducationcoalition.org/minerals/sand-and-gravel>.

⁴¹ U.S. Geological Survey, "Mineral Commodity Summaries 2014," February 28, 2014, <http://minerals.usgs.gov/minerals/pubs/mcs/2014/mcs2014.pdf>.

⁴² Rodney Jacobs and Robert Wray, "Managing Oak in the Driftless Area," University of Minnesota Extension, 2013, <http://www.extension.umn.edu/environment/trees-woodlands/managing-oak-in-the-driftless-area/>.

⁴³ *Statemaster.com*, "Geography Statistics, Land Acreage," accessed February 28, 2015, http://www.statemaster.com/graph/geo_lan_acr_tot-geography-land-acreage-total.

Figure 6
The Driftless Area and Industrial Sand Mining Facilities in Wisconsin



Left: The Driftless Area is an area of the country that was not covered by glaciers during the previous ice age. Right: A map of industrial sand mining facilities in the state of Wisconsin. Many of the mining facilities are located in the Driftless Area of the state, as these sandstone deposits were not covered by glacial sediment during the previous ice age and are near the surface. Figure from the Wisconsin Center for Investigative Journalism.

under high pressures. The Brady Brown is well-suited for lower-pressure hydraulic fracturing needs in the southern states. It is less expensive, as it is close to market – approximately two-thirds of the cost of frac sand paid by energy producers comes from transporting it to the oil or gas fields.

Because the Upper Midwest has vast deposits of industrial-quality silica sand, supply is not likely to be limited by a physical shortage. However, government policies such as zoning laws can affect supply. According to USGS, local shortages of industrial sand and gravel are expected to increase due to land development alternatives and local zoning regulations that will impede the ongoing development and permitting of operations producing hydraulic fracturing sand.⁴⁴

⁴⁴ U.S. Geological Survey, *supra* note 4.

Local zoning regulations can include limits on production, town- and county-wide bans, and moratoria similar to those enacted in municipalities and counties in Illinois, Iowa, Minnesota, and Wisconsin.

Laws in many states consider nonmetallic mining a local land use issue, so county and local governments will continue to play important roles in siting and permitting silica sand mines.

Industrial Sand Mining and Processing

As noted earlier, industrial sand and gravel mining has occurred in the United States for more than a century. According to USGS, in almost all cases silica mining uses open pit or dredging mining methods with standard mining equipment. Except for temporarily disturbing the immediate area while mining operations are active, sand and gravel mining usually have limited environmental impact.⁴⁵

The first step in constructing an industrial-sand mine is to remove any vegetation, topsoil, and other noneconomic soil or rock, often referred to as “overburden,” from the mining site. Vegetation, such as trees and woody shrubs, is typically fed into a wood chipper, the byproducts of which are stored on-site to decompose into mulch, which is mixed with the topsoil and any fill material used to reclaim the mining site to restore organic matter to the soil after mining activity has ended.

The topsoil removed from the mining area is typically used to construct earthen berms that are seeded with vegetation to create a visual barrier and make the mining process more aesthetically pleasing while preserving topsoil by preventing wind and water erosion. Mining opponents often describe this process as “strip mining” to conjure up imagery of mountaintop removal and strip mining for coal. Removal of vegetation and overburden is not strip mining: It is a necessary and routine first step in a variety of activities, from building a road, to constructing a high-speed rail line, to constructing a new home.

Removal of vegetation and overburden is not strip mining: It is a necessary and routine first step in a variety of activities, from building a road, to constructing a high-speed rail line, to constructing a new home.

After the vegetation and overburden are removed, mining operations begin. Industrial sand is typically found in sandstone formations, which must be disaggregated, or broken apart, in order to mine and process the sand. The disaggregation process varies based on local geological factors, mainly how well-cemented the sand grains are to one another.

Well-cemented sandstones have sand grains that are more “stuck together,” making them harder to break apart. These sandstone formations may require blasting to break up the sand grains and

⁴⁵ U.S. Geological Survey, “Silica Statistics and Information,” February 5, 2015, <http://minerals.usgs.gov/minerals/pubs/commodity/silica/>.

crushing during the processing phase to achieve disaggregation. Loosely cemented sandstone formations are more easily disaggregated, and thus may be broken apart using only heavy machinery, such as a bulldozer or large shovel, without the need for blasting or crushing.

Most industrial sand formations that are mined are 99 percent silica. The marketable share of the sand is generally 75 percent to 85 percent, though some formations may sell 50 percent or less. Sand processing involves a physical separation of grains followed by washing, drying, and sorting of the desired grain sizes.

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After blasting, the sand may be hydraulically mined and pumped to a “wet plant.” Alternatively, the sand may first be placed in a crusher or sent through a scalping screen to remove blocks of rock or coarse sand, after which the sand will fall into a hopper where it is mixed with water and hydraulically

pumped as a slurry to the wet plant. The wet plant separates finer silt material from the sand and cleans the sand grains.

Equipment in the wet plant may include scalping screens to remove oversized materials, attrition scrubbing to loosen and remove certain coatings from sand grains, hydrosizers and hydrocyclones to separate the fine and coarse materials, and dewatering screens or vacuum belts. Using an upward flow of water, hydrosizers remove fine sand and silt and separate the medium and coarse sand into concentrates. The attrition scrubbers break up agglomerated particles and remove coating on the surface of the sand particles using a sand/water slurry.

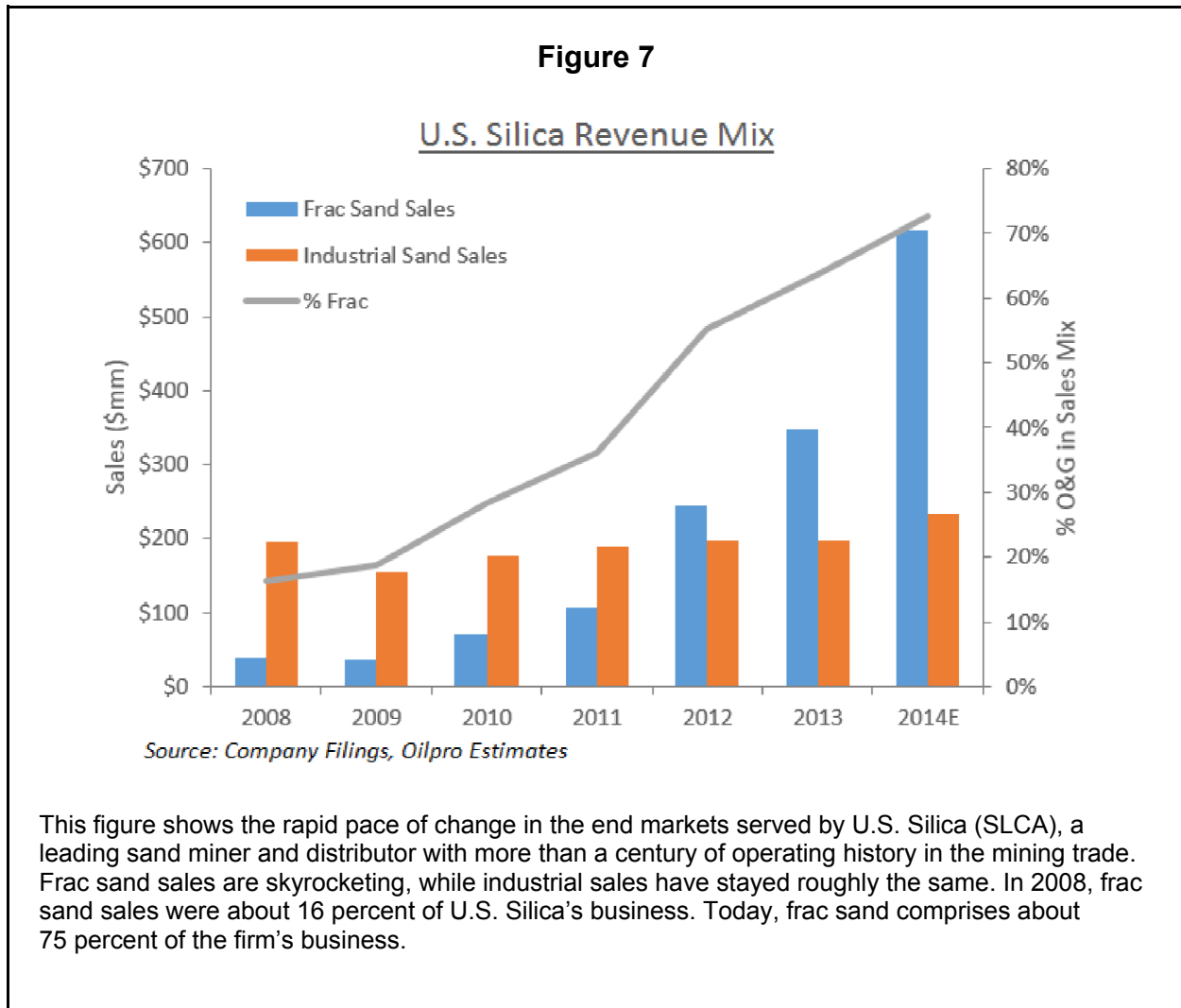
Water from the washing process is typically pumped to a treatment system using ponds to allow fines (silt and clay particles) to settle or using water-soluble polymers and a clarifying tank where fine materials settle and the clean water is returned to the plant. A portion of the water that passes through the wet plant will be used to make a slurry with the fine sands, which may be pumped back to the reclamation area where it can be used as reclamation fill. After dewatering, the sand is transferred by conveyor to a stockpile or directly to a dry plant for processing.

A wet plant may operate on a year-round basis. The amount of water it uses depends on the plant’s capacity and production. While water used in the wet plant is commonly recycled, make-up water may also be required to replace water lost to the product itself and waste, known as tailings. For production levels of about one million tons per year, an estimated 250 to 500 gallons per minute of make-up water, obtained from quarry dewatering or high-capacity wells, may be required.

The final stage of the industrial sand production process is the dry plant, equipped with state-of-the-art pollution control equipment. Natural gas or propane is used as fuel for the dryer. It includes a rotary drum dryer or fluidized bed dryer system and a series of screens to produce the necessary gradations of marketable sand product. The finished product is conveyed to a series of storage silos. The silos use conveyor belts to transport sand to the truck and railcar load-out, where the finished product is transferred into covered trucks and railcars for shipment to market.

Industrial Sand and Hydraulic Fracturing

The demand for highly specialized sand required for hydraulic fracturing, also known as “frac sand,” used to increase the recovery rates of oil and natural gas wells, has grown dramatically in the past several years, becoming the largest segment of the industrial sand market. (See Figure 7.)



Hydraulic fracturing was first conducted in 1947, and USGS data indicate sand has been commonly used as a proppant for hydraulic fracturing since the early 1950s. Sand has been used

in 99 percent of hydraulic fracturing treatments and has become increasingly important for oil and natural gas production in recent years.⁴⁶

Hydraulic fracturing was first conducted in 1947. Sand has been commonly used as a proppant for hydraulic fracturing since the early 1950s and has been used in 99 percent of hydraulic fracturing treatments.

Because the combination and widespread application of hydraulic fracturing and horizontal drilling technology are relatively recent phenomena, it may be beneficial for the reader to have a general understanding of how hydraulic fracturing works and the important role of industrial sand in the process. Understanding this relationship is especially important because some of the

opposition to industrial sand mining stems from environmental groups attempting to prevent industrial sand mine development because they are ideologically opposed to any technology that increases production of domestic oil and natural gas reserves.

Hydraulic fracturing is the process of breaking up low-permeability oil- and gas-rich source rocks, such as shale and tight carbonate and sandstone formations, enabling the oil and gas to flow freely toward the well. It is accomplished by injecting a mixture of water and silica sand, at pressures of 10,000 to 15,000 pounds per square inch (psi) into wells drilled in the source rocks thousands of feet below the surface, to create small fractures in the rocks.⁴⁷ (See Figure 8.) Small amounts of chemicals of the sort typically used in drilling operations to prevent biological fouling, inhibit rust formation, enhance lubrication, etc. are also used during the drilling and well-completion steps, along with an even smaller amount of other chemicals unique to fracking operations.

The high pressures used in the fracking process are produced by a fleet of trucks on the surface pumping the mixture of water and sand – referred to as “fracking fluid” – into the wellbore. That increases the fluid pressure within the wellbore until it is high enough to exceed the breaking points of the oil- and gas-bearing source rocks. When their breaking point is reached, the rocks fracture suddenly, and water rapidly rushes into the fractures, expanding and extending them deeper into the rock.⁴⁸ Each hydraulically fractured well uses between 2,500 and 10,000 tons of sand, and the sudden surge of water from the fracturing of the rocks carries billions of sand grains into the fractures.⁴⁹

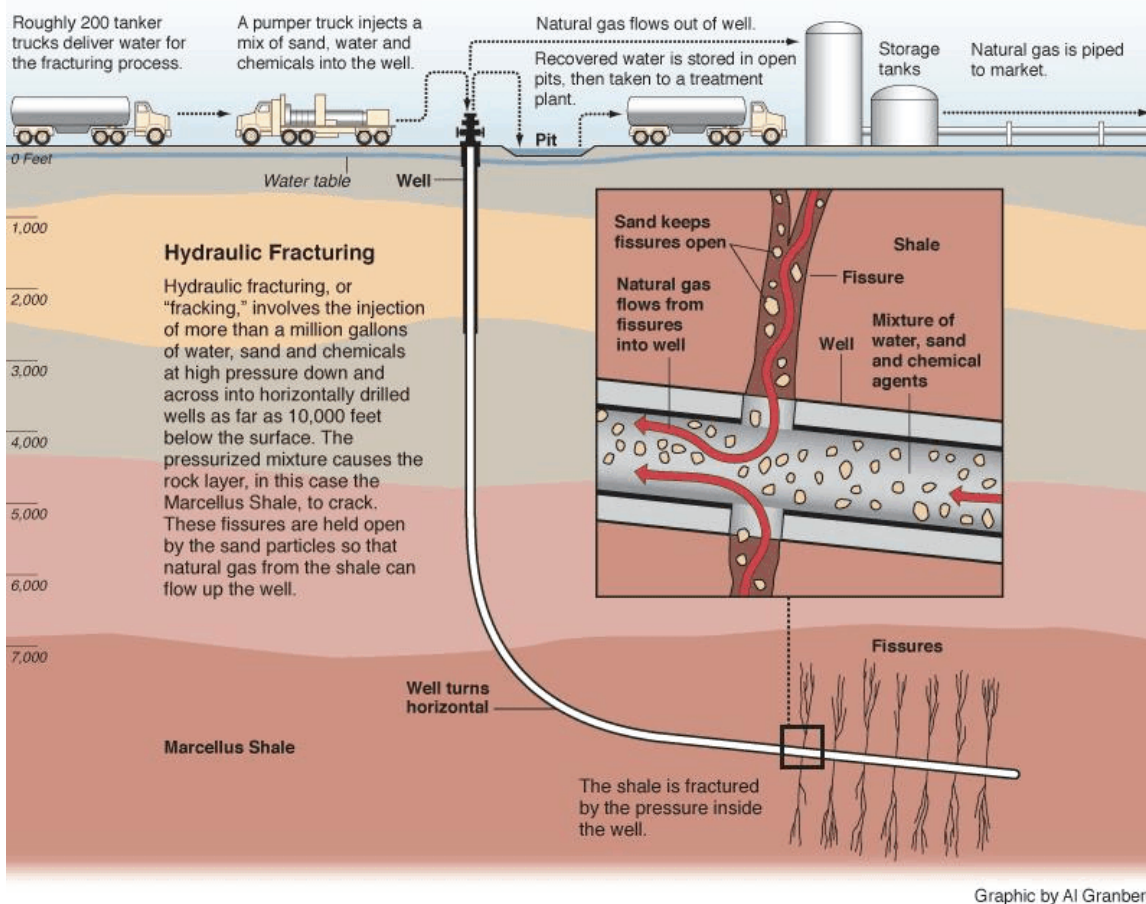
⁴⁶ Tanya J. Gallegos and Brian A. Varela, “Trends in Hydraulic Fracturing Distributions and Treatment Fluids, Additives, Proppants, and Water Volumes Applied to Wells Drilled in the United States from 1947 Through 2010—Data Analysis and Comparison to the Literature,” *U.S. Geological Survey Scientific Investigations Report* 2014-5131, <http://pubs.usgs.gov/sir/2014/5131/pdf/sir2014-5131.pdf#>.

⁴⁷ “Fracking,” Marcellus Shale, <http://www.marcellus-shale.us/fracking.htm>.

⁴⁸ Hobart King, “What Is Frac Sand?” *Geology.com*, accessed March 1, 2015, <http://geology.com/articles/frac-sand/>.

⁴⁹ Mike Ivey, “DNR Reports No Slowing In Wisconsin Frac Sand Mining Despite Oil Slump,” *The Capitol Times*, January 11, 2015, http://host.madison.com/news/local/writers/mike_ivey/dnr-reports-no-slowing-in-wisconsin-frac-sand-mining-despite/article_99ed073f-6d8d-599d-9771-57688e1e76c9.html.

Figure 8

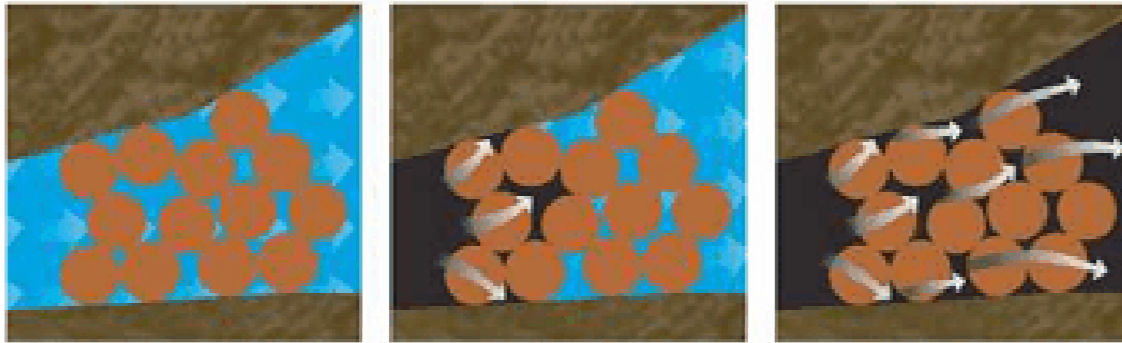


Hydraulic fracturing occurs thousands of feet below the surface of the earth, where water, frac sand, and chemical additives are used to create tiny fissures in shale formations, allowing the oil and natural gas trapped within them to flow up to the well. Despite claims to the contrary, peer-reviewed scientific research from universities and the federal government have found hydraulic fracturing does not contaminate groundwater.

When the pumps are turned off, the fracking fluid flows back up to the surface, and the fractures deflate, much like letting the air out of a balloon. The fractures do not close completely because the billions of sand grains wedged between the cracks serve to “prop” them open, which is why frac sand is referred to as a “proppant” in the oil and gas industry. These new fractures in the rock, propped open by the durable silica sand grains, form a network of pore space that allows petroleum fluids and gas to flow out of the rock and into the well.⁵⁰ (See Figure 9.)

⁵⁰ Hobart King, *supra* note 48.

Figure 9
Resource Flow Through Proppant



Proppant prevents the fissures created during the fracking process from collapsing and allows oil and gas to flow freely to the well. Source: Image modified from momentivefracline.com.

To optimize the flow of oil and natural gas through the fracture system, specific physical properties are necessary for frac sand that are not necessarily required for other industrial purposes, such as glass, bedding for livestock, or cores for foundries. Frac sand grains must be a particular size (typically between 8 and 140 mesh⁵¹) and shape (the sand grains are well-rounded, almost spherical), well-sorted (the sand grains are generally the same size), and durable (able to withstand compressive stresses of 4,000 to more than 10,000 psi).⁵²

The size of the grains is important because frac sand must be small enough to fit into the fissures but large enough to optimize recovery rates. Shape is important because rounder grains have a higher hydraulic conductivity and durability than angular grains. Frac sand grains must be well-sorted (generally all the same size) to create as much connected space (porosity and permeability) between the sand grains as possible for the oil and natural gas to flow through. (See Figure 10.)

Finally, durability, or the strength of the frac sand, is important because sand lacking the proper strength will shatter into smaller particles in the high-stress environment of the shale formation thousands of feet below the surface. When the grains shatter, they produce fine particles,

⁵¹ Mesh size is U.S. measurement standard related to the size of the openings in the mesh and thus the size of particles that can pass through these openings. An 8 mesh screen has eight square openings across one inch of screen. http://www.industrialspec.com/micron-chart.html?gclid=C12Z_syrnsUCFZWCaQod_jlAtg.

⁵² Horiba Scientific, "Frac Sand and Proppant Applications," accessed March 1, 2015, <http://www.horiba.com/scientific/products/particle-characterization/applications/frac-sand/>.

plugging the pore spaces and reducing the ability of oil and natural gas to flow through the well, creating a problem similar to having poorly sorted frac sand.

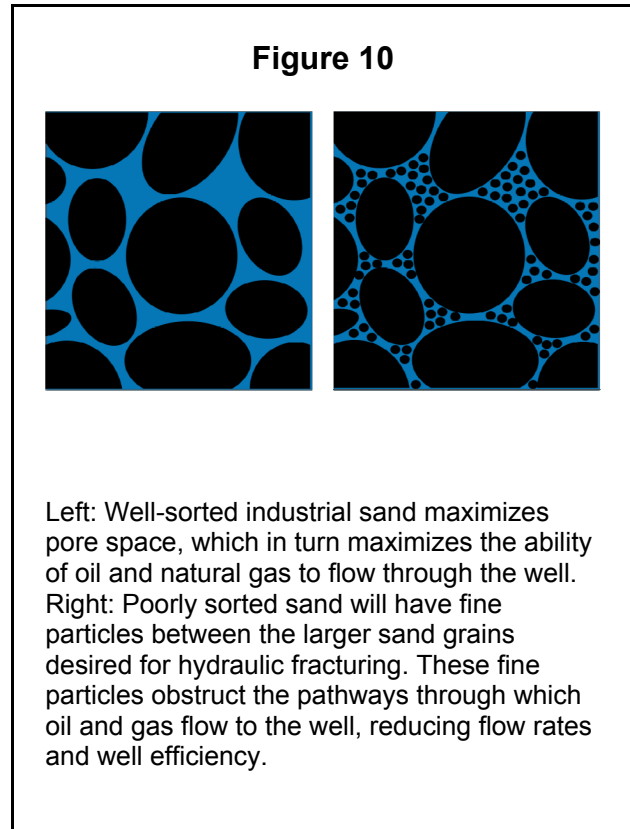
As recently as a few years ago, fracking fluid was 90 percent water, 9.5 percent silica sand, and 0.49 percent chemical additives, but sand can now represent up to 20 percent of the fracking fluid, as oil and gas producers have discovered using more sand results in higher oil and natural gas yields.

It is estimated demand for silica sand has been growing at a compound annual growth rate of 30 percent per year since the early 2000s.⁵³ In September 2014, PacWest Consulting Partners estimated demand for frac sand would again grow by 30 percent in the coming year; since then, oil prices have fallen substantially, causing the consulting firm to revise its 2015 estimates, now estimating an 8 percent decline in demand for frac sand.⁵⁴

Ceramics

In addition to frac sand, oil and natural gas producers use ceramic proppants in the hydraulic fracturing process. These ceramics are made from a type of clay known as bauxite, which is mined and processed into small, ceramic beads. Ceramic proppants provide certain advantages over sand, as they are stronger, withstand greater pressures without breaking, and are more uniform in shape and size. Ceramics are more expensive, however, often costing two to three times as much as silica sand.

As a result of these cost differences, producers have overwhelmingly chosen frac sand as proppant source. USGS reports show sand has been the most common proppant for hydraulic fracturing since proppants became widely used in the 1950s. Less than 1 percent of the records in the datasets indicate the use of ceramics, resin-coated ceramics, resin-coated sand, and bauxite.⁵⁵



⁵³ Joseph Triepke, "2014 Is The Year Of Sand In US Shale Plays [Analysis & Slides]," *Oilpro*, September 2014, <http://oilpro.com/post/5981/1-trillion-grains-per-well-sand-shale-ultimate-consumable>.

⁵⁴ Tanya J. Gallegos and Brian A. Varela, *supra* note 46.

⁵⁵ *Ibid.*

Sand satisfies the vast majority of hydraulic fracturing needs; thus ceramics, although physically superior, are not worth the cost at current sand prices and hence have limited application. Additionally, the bauxite used to make ceramics must also be mined, raising similar permitting, social, economic, and environmental concerns.

Although opposition to industrial silica sand development comes in many forms for a wide variety of reasons, certain groups are motivated by a belief they can prevent or inhibit hydraulic fracturing by limiting the supply of frac sand by enacting local moratoria and bans on silica-sand mining. They are likely mistaken in that belief. Forcing oil and gas producers to switch from silica sand to ceramic proppants is unlikely to bring an end to hydraulic fracturing, as proppants account for only a small portion of the total cost of fracking an oil or natural gas well (approximately 7 to 28 percent). Most drilling operations would be able to pay the higher costs of using ceramics instead of frac sand.

Long-Term Demand for Frac Sand

Several factors suggest there will be strong long-term demand for industrial silica sand for hydraulic fracturing. Among the key factors are gains in drilling and production efficiencies, as these enable producers to continue to increase production when prices fall; increasing demand for natural gas for electricity generation; and liquefied natural gas (LNG) exports.

Several factors suggest there will be strong long-term demand for industrial silica sand for hydraulic fracturing.

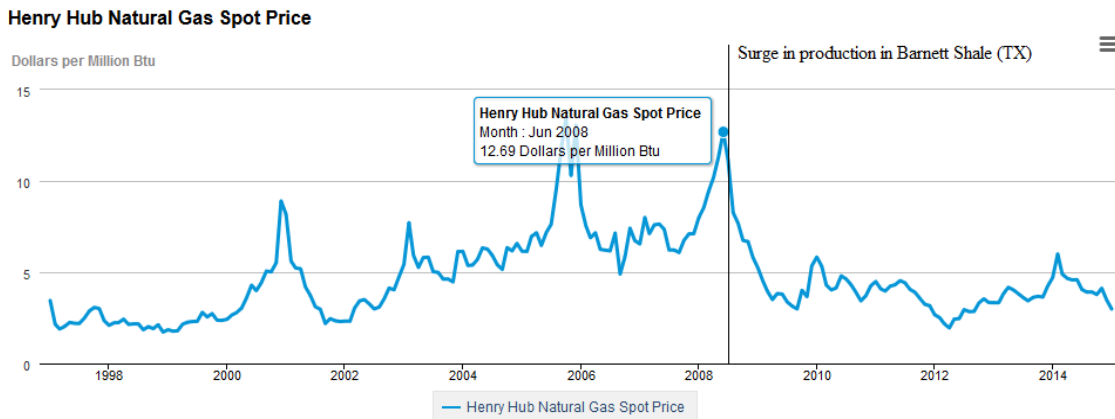
Techniques such as longer well laterals (the distance the well is drilled horizontally underground), multi-well drilling pads, and closer well spacing practices have enabled energy producers to spend less capital on oil and natural gas production. Additionally,

producers have discovered increasing the amount of frac sand pumped into the rock formations has resulted in greater recovery rates, increasing profitability for oil and gas operators as well as silica sand suppliers.

Although oil prices have recently become volatile, due in part to the decision of the Organization of Petroleum Exporting Countries (OPEC) to maintain current production levels in order to preserve market share, natural gas prices have not experienced the same volatility. Unlike oil, natural gas is not easily transported, as it must be either compressed or liquefied to be bought and sold over great distances. Domestic demand for natural gas must be met by domestic supply, and thus increased demand for natural gas may increase demand for frac sand regardless of the international price of oil

In some ways, shale gas producers have become victims of their own success, as natural gas prices have remained consistently low since hydraulic fracturing and horizontal drilling achieved their first major commercial success in 2008 in the Barnett Shale of Texas. (See Figure 11.) Despite these low prices, natural gas production from shale has increased dramatically in recent years, largely due to the gains in drilling efficiencies mentioned above. (See Figure 12.)

Figure 11



Source: U.S. Energy Information Administration

A modified figure from the Energy Information Administration demonstrates natural gas prices have been consistently low since hydraulic fracturing became commercially viable in the Barnett Shale in Texas. Despite these low prices, natural gas production from shale formations has increased dramatically, as gains in efficiency have made it profitable for energy companies to produce more gas at lower prices.

Approximately 40 percent of the natural gas currently produced in the United States results from hydraulic fracturing in shale or tight sandstone formations. The Energy Information Administration (EIA) estimates shale gas will account for 53 percent of all the natural gas produced in the United States by 2040, to meet growing consumer and industrial demand for gas and to make up for declines in conventional gas fields.⁵⁶

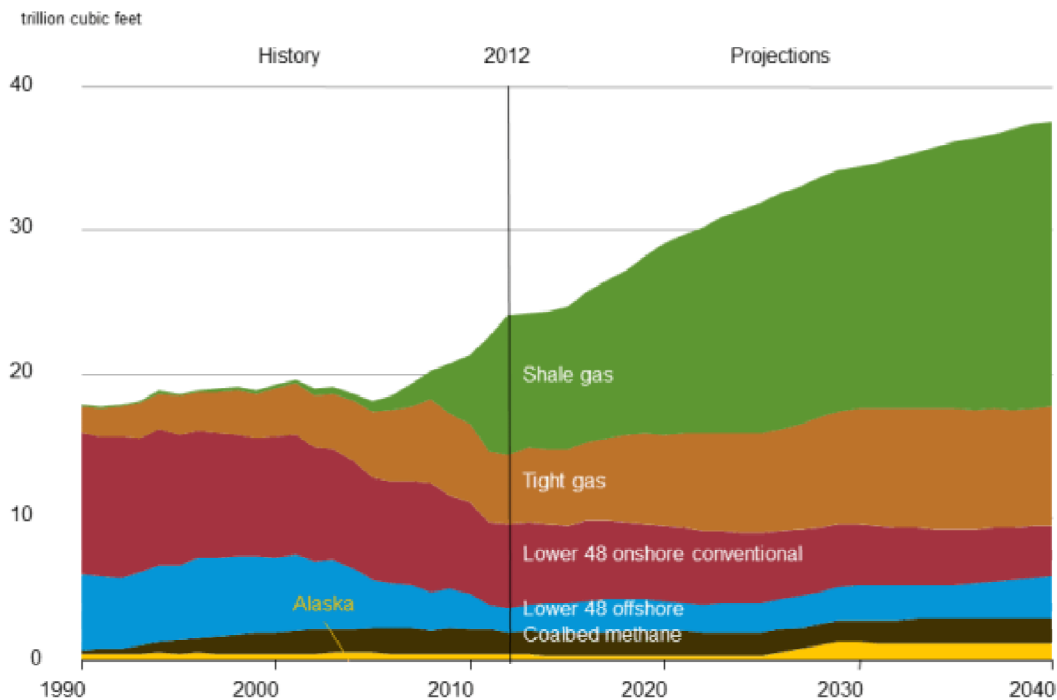
The Energy Information Administration predicts natural gas will become increasingly important as a source of fuel for generating electricity in the coming decades, accounting for 35 percent of U.S. electricity generation by 2040.⁵⁷ (See Figure 13.) As conventional sources of natural gas become less productive and total energy demand increases, use of hydraulic fracturing to produce natural gas will become increasingly important in meeting the nation's demand for electricity.

⁵⁶ Energy Information Administration, "Market Trends: Natural Gas," *Annual Energy Outlook 2014*, http://www.eia.gov/forecasts/aeo/mt_naturalgas.cfm.

⁵⁷ *Ibid.*

Figure 12

Figure MT-44. U.S. natural gas production by source in the Reference case, 1990-2040



Energy Information Administration data indicate shale gas will become increasingly important as a share of total natural gas supply, with production from conventional wells becoming less significant over time. This obviously has important implications for frac sand demand and growth.

Government regulations also could increase demand for shale gas. If proposed USEPA rules known as the Clean Power Plan are enacted, existing power plants will be required to reduce their carbon dioxide emissions by 30 percent from year-2005 base levels by 2030. These emissions cuts will be achieved largely by retiring coal-burning power plants and replacing their generation capacity with natural gas. These regulations are estimated to cost between \$41 billion and \$73 billion per year, raise electricity prices for consumers by double-digit percentage points in 43 states, reduce the diversity of the fuel supply for electricity, which could increase the risk of brownouts or blackouts, and further drive up demand for natural gas, increasing the need for

shale gas and the frac sand used to produce it.⁵⁸

Finally, demand for shale gas also will be driven by natural gas exports. The first export terminals are scheduled to begin exporting gas in late 2015. The U.S. Department of Energy has fully approved five export facilities and 28 others are awaiting decisions.⁵⁹ Additional natural gas export terminals are currently in the permitting phase. When these terminals come online, the United States will become one of the most important exporters on the liquefied natural gas (LNG) market.⁶⁰

According to *Bloomberg Business*, Cheniere Energy claims it will be the largest buyer of U.S. natural gas by 2020, with its liquefaction plant in Louisiana and another planned for Texas allowing it to ship approximately 6 percent of all the gas produced in the United States. As countries in Asia and Europe import increasing volumes of LNG, there will be expanded opportunities for frac sand producers as natural gas producers tap shale formations for export markets.

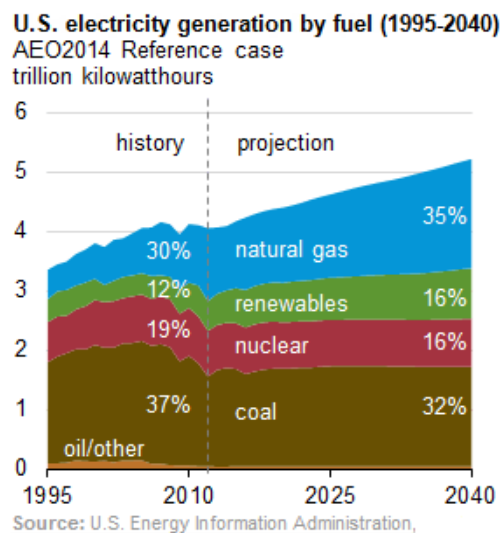
Increasing demand for natural gas will keep demand for frac sand high, and a recovery in oil prices could bring a further dramatic increase in demand for frac sand, as oil producers have continued to drill wells but have decided not to fracture them. Should OPEC reduce production (at present Saudi Arabia seems determined to maintain market share) or should instability affect major oil-producing countries such as Libya, Russia, and Venezuela, the resulting price increases could make fracturing of some of these wells economically viable. All these factors suggest demand for frac sand will likely be strong in the years to come.

⁵⁸ NERA Economic Consulting, "Potential Energy Impacts of the EPA Proposed Clean Power Plan," October 16, 2014, http://americaspower.org/sites/default/files/NERA_CPP%20Report_Final_Oct%202014.pdf.

⁵⁹ Tim Puko, "Funding Dries Up for New U.S. Gas Export Terminals," *The Wall Street Journal*, February 17, 2015, <http://blogs.wsj.com/moneybeat/2015/02/17/funding-dries-up-for-new-u-s-gas-export-terminals/>.

⁶⁰ Zain Shauk, "U.S. Natural Gas Exports Will Fire Up in 2015," *Bloomberg Business*, November 06, 2014, <http://www.bloomberg.com/bw/articles/2014-11-06/u-dot-s-dot-natural-gas-exports-will-fire-up-in-2015>.

Figure 13



The U.S. Energy Information Administration predicts natural gas will supplant coal as the most important fuel for electricity generation by 2040. As conventional sources of natural gas become less productive, the demand for natural gas will have to be met with increasing amounts produced using hydraulic fracturing. As a result, demand for frac sand is likely to remain significant.

Conclusion

Industrial silica sand mines have been active in the Upper Midwest for more than a century and can be operated in a safe and environmentally responsible manner.

The United States has achieved dramatic growth in industrial silica sand mining since the technological breakthrough of horizontal drilling combined with the established technique of hydraulic fracturing transformed once-uneconomic oil and gas deposits into profitable drilling operations. Silica sand production more than doubled between 2005

and 2014, increasing from 31 million metric tons in 2005 to more than 75 million in 2014. Sand for hydraulic fracturing, or “frac sand,” now accounts for 72 percent of all industrial silica sand mined in the United States.

Despite fears that industrial sand mining will generate hazardous amounts of respirable crystalline silica, studies from the Minnesota Pollution Control Agency, Air Control Techniques, and other organizations have found concentrations of silica dust near frac sand facilities and transportation routes were far below levels considered hazardous to human health.

Additionally, concerns of industrial sand mining depleting groundwater and surface water resources are not supported by the data, as industrial sand operations use only a small fraction of the amount of water used for other, more prevalent, purposes, such as power generation and agriculture. Water quality is also unlikely to be seriously degraded by industrial sand operations, because the polymers used in the sand production process break down quickly. Stormwater runoff events involving sand mining and other industries have temporarily reduced surface water quality with suspended particles of silt and clay, but these incidents are short-lived and can be mitigated by enforcement actions directed at operators who fail to adhere to state and federal standards, and improved stormwater runoff plans.

Wisconsin N.R. Code 135 requires all nonmetallic mines to be reclaimed, and concerns that sand mining will have negative, long-term impacts on agricultural land have not been supported by scientific research. Studies have found reclaimed sand mine sites produced 73 to 97 percent of their original crop yields within three years of reclamation.

Industrial silica sand mines have been active in the Upper Midwest for more than a century and can be operated in a safe and environmentally responsible manner. State governments and environmental protection agencies are capable of enforcing reasonable rules – already in place – designed to protect the environment and public health while allowing for the responsible development of silica sand resources.

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About the Authors

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Isaac Orr is a research fellow at The Heartland Institute. He previously worked as a research analyst and writer in the office of Wisconsin state Senator Frank Lasee, and prior to that interned with the Rancher's Cattleman Action Legal Fund. He graduated in 2010 with honors from the University of Wisconsin-Eau Claire, with a B.A. in political science and a minor in geology.

Orr is the author of *Heartland Policy Study* No. 132, "Hydraulic Fracturing: A Game-Changer for Energy and Economies" (November 2013), and his letters to the editor and op-eds have been published in *USA Today*, *The Houston Chronicle*, *The Washington Times*, *The Hill*, *American Thinker*, and *Human Events*. He is the author of "Frac Sand Study: Lots of Scare, Little Science," published in the *Milwaukee Journal Sentinel* in October 2014. He has spoken to nearly a dozen audiences and recorded more than a dozen podcasts on energy and environment topics for The Heartland Institute, available on Heartland's YouTube channel at HeartlandTube.

Orr writes, "I grew up on a dairy farm, and I want to preserve rural America, and rural American values. Along with agriculture, I am fascinated by geology, mining, groundwater, and other environmental issues."

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Krumenacher is a professional geologist with licensure nationally and in several states and is a certified hazardous materials manager. He has managed and conducted geologic, hydrogeologic, and engineering studies, remedial investigations, environmental assessments, pre-acquisition environmental due diligence, and hazardous waste management at various properties including surface and underground mines; large industrial, commercial, and urban redevelopment projects; federal Superfund sites; and state-lead environmental projects.

He has provided testimony regarding aggregate and industrial mineral mining before municipal, township, and county units of government as well as nongovernment organizations, local environmental groups, and community advisory councils to help address residents' concerns about mining.

Krumenacher is actively involved with several mining associations, including the National Stone Sand and Gravel Association, Illinois Association of Aggregate Producers, National Industrial Sand Association, Industrial Minerals Association–North America, Wisconsin Industrial Sand Association, and Society for Mining Metallurgy and Exploration.

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