

APPENDIX A
HYDRAULIC FRACTURING

INTRODUCTION

The purpose of this appendix is to provide the elements of the preliminary economic analysis for the hydraulic fracturing industry. Hydraulic fracturing is sometimes called “fracking” and the terms will be used interchangeably in this appendix. Hydraulic fracturing operations were not specifically evaluated in the original analysis prepared by OSHA. However, the number of hydraulic fracturing operations has increased rapidly in recent years, and new information indicates that some workers at hydraulic fracturing operations are exposed to significant levels of silica. OSHA finds that sufficient data are now available to provide the main elements of the economic and technological feasibility analysis for this industry.

In 2010 and 2011, investigators from NIOSH conducted eleven site visits to assess chemical exposures at hydraulic fracturing operations, including exposure to crystalline silica dust. These site visits were conducted with the cooperation of the National Service, Transmission, Exploration & Production Safety [STEPS] Network, an industry-sponsored volunteer organization formed in 2003 to improve safety and health in the oil and gas industry. Air monitoring conducted by NIOSH at the fracking sites indicated that some workers were routinely exposed to silica dust in excess of the current OSHA general industry PEL. NIOSH’s reports on these visits contained specific recommendations for control of dust at fracking sites and the use of respiratory protection until feasible engineering controls could be implemented.

In 2011, under STEPS, a focus group on crystalline silica was formed involving representatives from the oil and gas industry and other related industries, along with NIOSH and OSHA, to increase awareness of the potential hazard and promote the development and implementation of controls to protect hydraulic fracturing workers from hazardous exposures to crystalline silica. OSHA and NIOSH worked with the silica focus group to develop and issue a Hazard Alert in June 2012 on silica exposure at hydraulic fracturing operations. NIOSH is continuing to work with industry members on the design and development of engineering controls for fracking sites.

This Appendix includes descriptions of engineering controls recommended by NIOSH for hydraulic fracturing sites, such as misting systems, containment on transfer points, and local exhaust ventilation. It also includes descriptions of engineering controls that have been used at other types of operations, such as control booths used in surface mining and mineral processing, that could potentially be implemented at fracking sites. OSHA is particularly interested in receiving public comment or additional information on the effectiveness of the controls described in reducing worker exposure to silica, the costs and time required to implement controls, and the feasibility of any new technology. Specific questions on these points are included in the NPRM Issues Section on the technical feasibility of engineering controls (#9 through #17), compliance costs (#18), and effect on small entities (#19).

This appendix presents OSHA’s preliminary results with respect to the industrial profile, technological feasibility, benefits, costs, economic feasibility, and regulatory flexibility findings with respect to the hydraulic fracturing industry. The Agency’s analysis in this appendix was supported by the work of its contractor, Eastern Research Group (ERG), as reflected in its final report to OSHA in hydraulic fracturing (ERG, 2013).

INDUSTRIAL PROFILE

In this section, OSHA presents a brief description of the hydraulic fracturing industry and its activities. OSHA then identifies the NAICS industries with potential worker exposure to silica during hydraulic fracturing. Next, OSHA provides summary statistics for the affected industry, including the number of affected entities and establishments, and the average revenue for affected entities and establishments. This information is provided for each affected NAICS industry in total, as well as for small entities as defined by SBA. Finally, OSHA will provide other production estimates that will be useful for the subsequent cost estimates.

Hydraulic fracturing is a process used to extract natural gas and oil deposits from shale and other tight geologic formations. The process begins once well drilling is complete. Workers in the oil and gas industry pump fracturing fluid, composed of base fluid (usually water); a proppant (usually sand); and chemical additives, into the new well bore under extremely high pressures (e.g., 7,000 psi to 9,000 psi) (Esswein, 2012). The high pressure fractures the shale or rock formation, allowing the natural gas trapped in the formation to flow into the well. The large quantity of sand or other proppant in the fracturing fluid holds the fractures in the shale formation open after the pressure is released. Use of this process has increased significantly in recent years due to new horizontal drilling and multistage hydraulic fracturing technologies that improve access to natural gas and oil deposits.

Silica sand that is used as a proppant contains a high percentage of crystalline silica, typically ranging from 60 to 100 percent depending on the source (Halliburton MSDS, 2008; Carmeuse MSDS, 2009). Therefore, when silica sand is used as a proppant in hydraulic fracturing, high concentrations of respirable silica dust can become airborne as workers deliver, convey, and mix the sand with fracturing fluid. An enormous quantity of proppant is involved in the hydraulic fracturing process; each lateral drilling zone radiating from the vertical well bore requires 190,000 to 300,000 lbs. of sand. A vertical well might serve several horizontal zones, each of which is treated sequentially by hydraulic fracturing (involving approximately a half-day of active pumping per zone).¹ More than one vertical well can be drilled at one well pad², and the number of personnel and the amount of sand, equipment, and activity at a site increases when multiple crews hydraulically fracture multiple wells at the same time.

¹ Hydraulic fracturing crews frequently spend several days performing active hydraulic fracturing at a site where a well has several zones, with additional days for equipment setup and removal on the days before and after hydraulic fracturing. The stay can be longer when multiple wells are located at the same site. Once the job is complete, the crew moves onto another site, where the process is repeated. The hydraulic fracturing process is a relatively brief phase of well installation, which can take three or four months, including site preparation, drilling, installing pipelines, and the initial stages of environmental reclamation (Rader, 2102). Over this period, a number of different specialized work crews will occupy the site, often for overlapping periods. During hydraulic fracturing several dozen workers can be on the site, but most work occurs outside the central sand-handling zone, which is only occupied by fracturing sand workers. The number of fracturing sand workers typically ranges from a half-dozen to two dozen, depending on the size of the project and whether multiple hydraulic fracturing crews are involved. A crew of 10 to 12 workers is typical (STEPS, 2012).

² The worksite around the wellhead is known as the well pad. The size of the well pad will vary, depending on the location, but it is typically between 1.5 and 5.7 acres. A well pad may contain one well, but it has become common to drill multiple wells from a single well pad (NYSDEC, 2011).

The hydraulic fracturing process generally proceeds as follows. Sand truck drivers deliver sand to the site and pneumatically pump it from trucks into large pieces of equipment (sand movers) that store sand. Workers regulate the flow of sand out of the sand mover onto a series of associated conveyor belts, which carry the sand to a hopper from which the sand is metered into a blender. The sand, water, and chemical additives are mixed together in the blender before the sand-laden fracturing fluid is pumped through a high-pressure manifold into the well. This final step does not contribute to worker silica exposures because sand is both wet and contained in an enclosed system by this stage; however, up to this step, respirable silica emissions occur at numerous points as the dry sand is moved from the trucks to the sand movers to the conveyor belts to the blender hopper.

Hydraulic fracturing crews work as a team that travels from well site to well site. Individual workers are specialized and have defined roles. Those whose jobs keep them in the central area near the sand-handling equipment can experience high levels of respirable silica exposure. Ancillary workers who have work locations on the perimeter can experience elevated silica exposures, although they are not in the immediate vicinity of the dust emissions. Workers whose jobs either do not require entry into the central work area or only require entry intermittently experience variable exposure depending on the amount of time they spend near dusty activities.

The hydraulic fracturing process occurs in the following main phases for a single well, as shown in Table A-1.

Table A-1: Major Stages of Well Fracturing Work

Phase	Duration	Activities
Well site setup	5-60 days	<ul style="list-style-type: none"> Transporting hydraulic fracturing equipment and materials to the well pad (may begin during the late stages of drilling) Removing drilling equipment from the wellhead Positioning and installing hydraulic fracturing equipment
Well and equipment testing	<1 day	<ul style="list-style-type: none"> Pumping a testing fluid through hydraulic fracturing equipment at high pressure
Fracturing	1-30 days	<ul style="list-style-type: none"> Perforating the well casing Blending fracturing fluid components Pumping fracturing fluid Installing isolation plugs
Flowback	2-8 weeks	<ul style="list-style-type: none"> Removing plugs Collecting used fracturing fluid from the well Treating and recycling used fracturing fluid

Source: ERG, 2013.

Fracturing times can vary from one-half day to a month or more. During this time, the well casing might be perforated multiple times, and different blends of fracturing fluid might be pumped down the well to initiate and spread fractures. Although pumping of fracturing fluid is intermittent during this period, the overall process of perforating, pumping, and plugging requires continuous, 24-hour operation until it is complete.

Wells are typically fractured one segment, or stage, at a time. The well is fractured in stages instead of all at once to provide better control over fracture locations and because of pumping equipment limitations. Typically, a new well is fractured in 10 to 16 stages, but a well can be fractured in as many as 40 stages (Montgomery et al., 2010). Figure 2 in the ERG report illustrates five fractured stages separated by four fracturing plugs in a horizontal well. A horizontal well is a well that has been drilled with a horizontal component, giving it an L-shape.

Each stage is fractured in a series of steps, shown below in Table A-2.

Table A-2: Major Stages for Fracturing of a Specific Stage

Step	Activities
Perforating	<ul style="list-style-type: none"> Configuring the perforator (setting explosive charges) above ground Lowering and then pumping the perforating gun into the well with wireline equipment. (The wireline is a slender, rod-like piece of metal used for lowering special tools into the well.) Setting off charges to create holes in the well casing
Fracturing fluid blending and pumping	<ul style="list-style-type: none"> Blending of fracturing fluid components Pumping fracturing fluid into the well
Isolation	<ul style="list-style-type: none"> Inserting an isolation plug into the well Securing the plug to isolate a stage

Source: API, 2009.

The steps presented in the table are repeated until all stages in the production zone have been fractured. The total length of time it takes to fracture an individual stage varies by well site and well depth. The shortest jobs require approximately one-half day.

Fracturing fluid may be blended and pumped by a company different from the one that drilled the well. Additionally, a diverse contingent of contractors may carry out the multitude of tasks involved during fracturing (e.g., perforation, wireline operations).

Affected Industries by NAICS

Oilfield activities are classified primarily into five NAICS codes:

- NAICS 211111 (Crude Petroleum and Natural Gas Extraction)
- NAICS 211112 (Natural Gas Liquid Extraction)
- NAICS 213111 (Drilling Oil and Gas Wells)
- NAICS 213112 (Support Services for Oil and Gas Operations)
- NAICS 333132 (Oil and Gas Field Machinery and Equipment Manufacturing)

U.S. Census identifies NAICS 213112 (Support services for oil and gas operations), as the industry that includes the establishments involved in hydraulic fracturing. This NAICS code also captures a range of other oilfield service activities (Other oil and gas field services; Oil and gas exploration services; Oil and gas well surveying; Cementing oil and gas well; and Running, cutting, and pulling casings, tubes, or rods) designed to support oilfield exploration or to supplement the production from oil and gas wells. In 2007, hydraulic fracturing represented 10.5 percent of the economic activity in NAICS 213112.

Discussions held by ERG with industry personnel and a review of the available literature confirm the Census data: hydraulic fracturing is performed almost entirely by oilfield service contractors that are classified in NAICS 213112. These contractors are employed by oil and gas firms. Some industry contacts also mentioned that a few oil and gas producers own and deploy their own fracturing crews, but noted that the share of fracturing activity performed by oil and gas firms is negligible. Therefore, for this analysis, OSHA has ignored the portion of fracturing that might be performed by oil and gas production companies. OSHA requests comment on the size and scope of hydraulic fracturing performed by oil and gas production companies. The definition of the fracking industry is blurred by the additional services the fracking companies might provide. At the large firms, extensive engineering and well management services are often provided. Firms also manufacture some well equipment and otherwise reflect the diversity of activities in the oilfield. In an online business publication produced by Dun & Bradstreet, some of the largest entities are classified in multiple NAICS codes (Dun & Bradstreet, 2013).³ For example, the Baker-Hughes operations in Texas are classified as well servicers in NAICS 213112 (Support Services for Oil and Gas Operations) but their Montana operations are classified as a manufacturer of well equipment in NAICS 333132 (Oil and Gas

³ As both the Dun & Bradstreet and Census information are provided voluntarily and are not subject to audit, some of the listings or data might be erroneous and subject to revision at each publication cycle.

Field Machinery and Equipment Manufacturing). Similarly, Schlumberger’s Colorado office appears under the NAICS 238910 (Site Preparation Contractors) and their Los Angeles office is classified under NAICS 237110 (Water & Sewer System Construction). Other relatively large fracking companies’ operations also are classified in other NAICS. These NAICS designations might be accurate, as the various companies engage in a range of oilfield activities. However, the observation also suggests that some establishments might be classified into other oilfield categories.

Even among the smallest firms, fracking companies might also offer various well services (perhaps acidizing, where acid pumped into the formation helps to improve flow) that might help keep low-pressure wells producing. Most of these other activities offered by the smallest firms, however, are within the coverage of NAICS 213112 (Support services for oil and gas operations).

Table A-3: Product Line Breakdown for Support Services for Oil and Gas Operations (NAICS 213112)

Product code	Industry	Value of shipments of this line (1,000)	Percentage of Industry Value (%) ^a
213112	Support activities for oil & gas operations	\$44,200,088	100%
21311235	Other oil & gas field services	\$23,427,308	53.0%
21311211	Oil & gas field exploration services	\$6,312,385	14.3%
21311233	Hydraulic fracturing of oil & gas wells	\$4,646,738	10.5%
21311232	Oil & gas well surveying & well logging	\$1,840,8	4.2%

		40	
21311234	Running, cutting, & pulling casings, tubes, or rods	\$1,583,512	3.6%
21311231	Cementing oil & gas wells	\$1,318,555	3.0%
213112W	Support activities for oil & gas operations, not specified by kind	\$5,070,750	10.5%

[a] Total does not equal the sum of components as result of rounding.
 Source: U.S. Census, 2007⁴

Characteristics of Affected Entities and Establishments

Based on discussions with industry contacts, a review of the literature by ERG, and an examination of websites advertising hydraulic fracturing services, OSHA estimates that approximately 200 entities are engaged in hydraulic fracturing. Three large companies (Schlumberger, Halliburton, and Baker Hughes) account for approximately 30 percent of the fracking market. A second tier of approximately 10 firms serves a substantial share of the remaining market. These firms include Frac Tech Services International (FTSI), Cudd Pressure Control, Pumpco Energy Services, and others. These companies have sufficient equipment to handle the largest fracking jobs, but do not provide the same range of technical services as the largest three firms. A third tier consists of approximately 40 to 50 firms that also have capability for large fracking jobs but are not as widely active across oil and gas regions in the United States.

The final tier consists of small, possibly single-crew, hydraulic fracturing companies that have sufficient capacity to handle only minor, low-pressure refracturing jobs on conventional oil and gas wells.⁵ All of the major oil and gas producing regions host a number of these very small fracking firms, and although no reliable figures were identified, OSHA, based on ERG’s conversation with industry representatives, estimates that there are approximately 150 of them. Employment within these small companies can be as low as 20 or fewer workers, as very small fracking jobs might be accomplished with as few as 5 or 6 workers. With additional administrative and technical support personnel, it is estimated that the smallest firm size would require at least 10 employees. One industry contact noted that it is possible that some operations are run by sole proprietors who then assemble a temporary hydraulic fracturing crew for individual jobs. The frequency of this arrangement is not known and is likely very limited because of the difficulty of assembling a sufficiently experienced crew for individual jobs.

In hydraulic fracturing, even the smallest firm must be fairly capital-intensive because the minimum pumping equipment requirements are substantial, and therefore a modest-sized full-service fracking firm is likely to have at least \$50 million in equipment assets. An industry contact estimated that even the smallest firms need an investment of over \$1 million in pumping

⁴ U.S. Census, 2007. Industry Statistics Sampler <http://www.census.gov/econ/industry/products/p213112.htm>.

⁵ Refracturing is an operation to restimulate a well after an initial period of production. It is performed to restore well productivity to near original or even higher rates of production and to extend the productive life of a well (Schlumberger, 2013)

and other equipment. Very small firms are able to minimize their investments by purchasing second-hand equipment that is in need of servicing and that is sufficient for use on relatively low-pressure jobs.

Firms and Establishments

To estimate the number of establishments in the industry, ERG examined the company websites of some of the largest firms in the fracking industry in order to gauge the approximate number of establishments each firm operated. While the small firms are almost certainly operating in one or two locations, ERG noted that the largest firms operated up to 30 locations in the United States. From these data and discussions with experts on the industry, ERG estimated the number of establishments per entity across various size classes in order to derive the aggregate number of establishments in the industry. Using these judgments, ERG estimated that the 200 entities in hydraulic fracturing operate 444 establishments. The estimates supporting this calculation are shown in Table A-4.

Table A-4: Estimated Number of Hydraulic Fracturing Establishments

Employee Size Category	Estimated Number of Entities in Hydraulic Fracturing	Estimated No. of Establishments per Entity	Total Establishments
10-19	100	1	100
20-99	50	1.2	60
100-499	46	4	184
500+	4	25	100
Total	200		444

Source: ERG, 2013.

Revenue and Profit Estimates

For most industries covered in this PEA, where an industry contained both establishments that used processes causing silica exposures and establishments that did not use such processes, OSHA has assumed that the establishments using processes that cause silica exposures are financially typical of the industry as a whole. In the case of fracking however, such an assumption was not plausible. For example, NAICS 213112 includes some firms with fewer than 10 employees. As discussed above, given that even the smallest hydraulic fracturing firms have substantial equipment requirements, and that minimal crew sizes imply a need for at least ten employees, OSHA believes that the number of fracturing firms with fewer than 10 employees is negligible.⁶ Therefore, the Agency removed firms with 9 or fewer employees from consideration for the analysis.

Even after this adjustment, the revenue data for typical firms in oil and gas well drilling support services was still found to be unreasonable for fracking firms. For example, for the smallest size category considered (10-19 employees), based on ERG's analysis, OSHA estimates that such firms would not be performing any large-scale fracturing jobs but would be restricted to small jobs generating roughly \$5,000 to \$50,000 in revenues. Using an average revenue for the smallest fracturing jobs of \$25,000 per job and the industry-wide Bureau of the Census revenue estimate of \$2.1 million per year per firm, the average hydraulic fracturing establishment with 10-19 employees would, on average, be able to perform only 84 fracking jobs per year in order to meet the Census revenue estimate. ERG estimated that most of the jobs would be single-day jobs and that a firm could do far more than 84 jobs a year. Thus, OSHA concludes that the industry-wide average revenue estimate appears to underestimate the average revenues for hydraulic fracturing firms. OSHA requests comment on the typical lengths of time involved in the major stages of well fracturing work and the range of revenues earned for hydraulic fracturing jobs.

The underestimation of revenues for hydraulic fracturing firms relative to the other oilfield service firms is expected given the high capital-to-labor ratio of hydraulic fracturing relative to the other firms. For example, companies can offer wireline services with relatively light, mobile rigs that are much less expensive than the equipment necessary for hydraulic fracturing.

The Small Business Administration (SBA) defines a small business for this industry as a firm that earns receipts no greater than \$7 million per year. ERG evaluated the percentage of establishments performing hydraulic fracturing who would fall under this level and the upward adjustment to average revenue per establishment that would be necessary to correct for the difference in capital-to-labor ratios among the entities covered. However, limitations to the available data complicate this adjustment process.

Examining the 10-19 employee size category, and noting that an entity averaging only \$25,000 per fracking job could only perform 84 small fracking jobs per year to earn \$2.1 million per year reported, the average revenues attributed to fracturing activity appear too low. If these small

⁶ As mentioned above, NAICS 213112 includes a range of other oilfield service activities, such as other oil and gas field services; oil and gas exploration services; oil and gas well surveying; cementing oil and gas well; and running, cutting, and pulling casings, tubes, or rods. These activities, which do not involve hydraulic fracturing, can more reasonably be performed by firms with fewer than ten employees. Firms that perform these types of non-fracturing services are judged to dominate the smallest size categories in the industry.

fracking jobs typically only require one day to complete, then such a firm would have a utilization rate for its hydraulic fracturing equipment of 23 percent of the days of the year. A firm with a more plausible utilization rate, namely a rate three times as high (69 percent), would generate \$6.3 million per year, or nearly the small business revenue limit.

For firms in the 20-99 employee size category, average revenues are calculated at \$5.9 million. Most of the firms in this size category are likely to compete for new well completion work, which is considerably more lucrative than the small refracturing jobs. Most new wells require fracturing of multiple stages (sections of the well), with one to three stages often being performed per day. A typical single stage of a new well fracturing job is estimated to generate roughly \$100,000. One large fracking company reported that its annual average revenue per stage for 2011 was \$139,000 (FTSI, 2011).

As a result, the average revenue figures in the Census data again appear to be substantially too low. A firm in the 20-99 employee size category, if performing new well fracturing, would have performed only 52 stages before reaching the average revenue level and 70 stages of work before reaching the small business size limit. While it is possible that a few firms would fall below the SBA size limit, OSHA judged that the large majority of firms in this size category would exceed the small business revenue limit.

OSHA concludes that, for purposes of the regulatory flexibility screening analysis, only firms in the 10-19 employee size category are capable of performing hydraulic fracturing work and yet are small enough to remain below the SBA small business cutoff. Moreover, OSHA concludes that a negligible number of firms in the next larger size category would also be small entities.

Table A-5 summarizes the industry characterization for hydraulic fracturing firms in the hydraulic fracturing portion of the industry and the small business entities in the industry. Because small business entities typically have fewer than twenty employees, OSHA, in this appendix, will not report separately the results for entities with fewer than 20 employees.

Table A-5: Characteristics of Businesses Performing Hydraulic Fracturing Affected by OSHA's Proposed Standard for Silica -- Entities in NAICS 213112 --

Industry Portion	Affected Entities [a]	Affected Establishments [a]	Total Affected Employment [a]	Total Revenues (\$1,000) [b]	Revenues Per Entity (\$1,000)	Revenues per Establishment (\$1,000)
All Hydraulic Fracturing Firms only	200	444	25,440	\$8,219,837	\$41,099	\$18,513
Hydraulic Fracturing SBA-Defined Small Entities	100	100	1,500 [c]	\$547,500	\$5,475	\$5,475

[a] Estimated by ERG.

[b] Calculated from or based on the number of establishments and the per-establishment revenues shown in Table A-6

[c] ERG used the midpoint of the employment range 10-19 to estimate the average employees per entity for entities with fewer than 20 employees and SBA entities.

Source: ERG, 2013.

Applying the following methodology, and as summarized in Table A-6, ERG revised the reported Census figures for revenue per establishment for NAICS 213112 to generate more reasonable estimates of revenues for active hydraulic fracturing firms. ERG first developed estimates of the likely revenue per stage for hydraulic fracturing work. At the low end, ERG estimated that \$25,000 per stage was representative of the work on low-pressure, shallow, conventional wells. At the high end, ERG drew from the average revenue per stage (\$136,335) reported by a large hydraulic fracturing company in its 2011 annual report (FTSI, 2011). The estimate in the second size category (\$50,000) allows for a mix of small fracking jobs with jobs on new wells. Work on new wells dominates the industry activities and typical revenues per stage for hydraulic fracturing work on new wells are estimated to be much closer to the \$100,000 figure. Thus, the \$50,000 average revenue per stage is judged by OSHA to be a conservative estimate.

Table A-6: Derivation of Adjusted Per-Establishment Revenue Estimates for Firms in the Hydraulic Fracturing Industry

Employee Size Category	HF Entities	Estimated HF Establishments	Census-Based Revenue Per Establishment Estimate (a)	Estimated HF Revenue Per Stage (b)	Estimated Establishment Revenues (\$1,000) at Different Utilization Rates (Percent)(d)		
					25	50	75
10-19	100	100	\$2,064,073	\$25,000	\$2,281	\$4,563	\$6,844
20-99	50	60	\$5,158,959	\$50,000	\$4,563	\$9,125	\$13,688
100-499	46	184	\$15,005,003	\$100,000	\$9,125	\$18,250	\$27,375
500+	4	100	\$24,000,429	\$136,335 (c)	\$12,441	\$24,881	\$37,322
Hydraulic Fracturing Industry	200	444				\$15,428	

(a) Estimated by ERG.

(b) Estimated by ERG.

(c) FTSI, 2011.

(d) Utilization is defined as performance of one stage per day for the specified percentage of days in the years. As noted in the text, many hydraulic fracturing jobs will accomplish more than one stage in a day.

Source: ERG, 2013.

ERG then estimated a range of revenues using annual equipment utilization rates of 25, 50 and 75 percent. For simplicity, utilization is defined for this estimate as the completion of one stage in a day. Although in this analysis, very small fracking firms are modeled to engage in a single stage of activity at a time, in fact, hydraulic fracturing firms of all sizes can often perform more than one stage per day. For small firms, this might mean traveling to a second well on a single day to perform a second fracking job. On large wells, the rate at which stages are completed varies with the depth at which stages are performed. Therefore, because of the mobility and flexibility of fracking firms, the definition of utilization applied here is a conservative factor in the definition of revenues.

In the final step of its model, ERG calculated revenues using the range of equipment utilization rates described above. Because the hydraulic fracturing industry has been extremely active for the last several years, actual utilization rates are quite high and many firms have purchased new equipment (PacWest Consulting Partners, 2012). For this analysis, however, to avoid overestimating revenues, ERG selected a 50 percent utilization rate for estimating revenues per establishment. Nonetheless, uncertainty regarding utilization rates for the smallest operators in

the fracking market remains. In addition, while most information suggests that new-well hydraulic fracturing dominates industry activities, OSHA has limited information on the scale of activities among the small hydraulic fracturing firms. The focus on the robust new-well fracking activity might overstate the market and the viability of the smallest fracking operators. Using the 50 percent utilization estimate, ERG estimated average revenues for hydraulic fracturing firms as ranging from \$4.6 million for a 10-19 employee establishment to \$24.9 million for one of the largest establishments, and OSHA has applied those revenue estimates in this preliminary economic analysis. OSHA requests data on equipment utilization rates among fracking firms and information on the scale of activities of all hydraulic fracturing firms, particularly firms defined as small by the SBA definition.

Table A-7 presents OSHA’s preliminary estimate of revenue and profit for firms in the hydraulic fracturing industry affected by the proposed standard.

Table A-7: Profit and Revenue for Entities in the Hydraulic Fracturing Industry Affected by OSHA’s Proposed Standard for Silica - NAICS 213112

Industry Portion	Profit Rate [a]	Revenues (\$1,000)	Profit (\$1,000)	Revenues Per Entity (\$1,000)	Profit Per Entity (\$1,000)	Revenues per Establishment (\$1,000)	Profit Per Establishment (\$1,000)
Total for Entire NAICS	10.31 %	\$34,524,044	\$3,559,429	\$5,044	\$520	\$4,311	\$444
Hydraulic fracturing firms only	10.31 %	\$8,219,837	\$847,465	\$41,099	\$4,237	\$18,513	\$1,909
Hydraulic fracturing entities with fewer than 20 employees	10.31 %	\$547,500	\$56,447	\$5,475	\$564	\$5,475	\$564
Hydraulic fracturing SBA entities	10.31 %	\$547,500	\$56,447	\$5,475	\$564	\$5,475	\$564

[a] IRS, 2002 to 2006.

Source: ERG, 2013.

Other Industry Characteristics

In addition to estimating the numbers of entities and establishments and their revenues and profits, OSHA, in the following sections, derives estimates of the number of fracturing fleets and the wells of various kinds fractured per year. Estimates of the number of affected employees are discussed following the technological feasibility sections, which discusses the kinds of occupations and the associated silica exposure in hydraulic fracturing.

Fracturing Fleets

As another component of the analysis, ERG assembled information on the number of fracking fleets in the industry. Industry publications have estimated the number of individual fleets and the pumping horsepower that operate in the United States. Sufficient work capacity to perform a full-scale fracturing operation can be as low as 30,000 horsepower for a typical fleet, but can also range up to 40,000 to 50,000 horsepower of fracturing capacity. According to one industry source, recent figures indicate that, as of mid-2012, an estimated 503 U.S. fracking fleets operated 14.7 million in hydraulic horsepower (HHP) capacity. The same industry source also forecast that by the end of 2012 the number of fracking crews will have grown to 530 and the aggregate pumping capacity will have grown to 15.6 million HHP. For this cost analysis, OSHA used an estimate of 530 fleets: 100 small fleets, 244 medium fleets, and 186 large fleets. Because most of the costs represent modifications to the fracking equipment, the fleet estimate is a significant driver of the total prospective compliance costs.

Most significant hydraulic fracturing entities maintain sufficient horsepower capacity to allow them to compete for new well jobs. As has been discussed, however, some very small fracturing companies might be competing for only small refracking jobs on relatively low-pressure existing wells.

To accommodate 24-hour well operations that occur in most locations, ERG's model allows for two active shifts at any time. Common arrangements are for crews to work 7 days on and 7 days off, or to work 10-day periods, with a single rest day in the middle of the 10-day work period.

While crew sizes vary with the job, information from industry sources helped ERG model the typical fracturing crew size. Larger crews are needed for fracturing jobs on new deep wells with horizontal components. Because new well fracking occupies more crew time than re-fracturing of existing wells, larger fracking crews will be more common. Large fracking crews employ 15 to 20 workers, while small fracking crews commonly range from 6 to 10 workers. The midpoints of the crew sizes are, therefore, 17.5 and 8, respectively.

ERG estimated that 84 percent of the wells on which fracturing occurs are new wells and 16 percent are existing wells. Applying these relative shares to the estimated mean crew sizes given above, ERG calculated the average crew size for all fracking operations to be 16 workers. Because, as noted above, 24-hour fracking schedules are common, many fleets employ three crews, to allow for a day, night, and rotation shifts. On the other hand, small or less complex projects might be performed only with daytime crews. To allow for multiple crews per shift, ERG estimated that two crews per fleet should reflect the industry average. Thus, based on ERG's model of the fracking workforce, OSHA estimates that there are, on average, 32 crew members per mobile fracking fleet. Multiplying the estimated 530 fleets by an average fleet size of 32 workers, OSHA estimates a total worker population of 16,960 in hydraulic fracturing fleets.

OSHA notes that not all fracking fleets are fully deployed at all times. However, the utilization rate for hydraulic fracturing fleets was not incorporated into this analysis, and OSHA requests comment on fleet utilization rates in hydraulic fracturing.

Besides the well crews, generally, a number of workers in other occupational trades are present around the well during the fracturing operation. This group can include a representative of the oil and gas company, a toolpusher (equipment supplier), a drilling mud supplier, vendors for other well services, and other individuals. The number of these other workers was estimated by ERG to be roughly equivalent to the fracking crew population, at least during daylight hours. However, for the night shift, such participation by other workers cannot be substantiated by expert sources and, according to ERG, is probably somewhat reduced due to turnover and other dynamics associated with employment within the ancillary and fracking well support operations

For the workers present on the well pad who are not directly part of the hydraulic fracturing crews and who therefore are seldom exposed to significant levels of crystalline silica, OSHA has excluded an assessment of control costs in this preliminary analysis. Any compliance efforts for this diverse workforce would be the responsibility of their employers and would not be related to any intrinsic hydraulic fracturing function. OSHA anticipates that silica dust exposures would be limited by the distancing of workers from the fracking equipment during operations, a relatively simple procedure given that the job functions of these workers should not require them to be close to the dust-generating areas. OSHA requests data on the risk of silica exposure for ancillary and support personnel on hydraulic fracturing well pads.

Oil and Gas Wells Fractured

To assess the extent of hydraulic fracturing activities, it is useful to examine the available recent data on the number of wells drilled annually in the United States. The U.S. Energy Information Administration (EIA) reports that 41,118 oil and gas wells were drilled in 2011, including 21,709 for crude oil, 14,917 for natural gas, and 4,492 dry holes (EIA, 2012).⁷ These are overall numbers and include both exploratory and developmental wells as well as those that were not fractured. The total number of natural gas, crude oil, and dry hole wells drilled from 2007 to 2011 is presented below in Table A-8, with details on the number of exploratory and development wells in each of the three categories.

Table A-8: Number of Gas and Oil Wells Drilled in the United States

	Year				
	2007	2008	2009	2010	2011
Natural Gas					
Exploratory and	32,71	32,27	18,23	16,97	14,91

⁷ A dry hole is a well that is drilled but does not produce oil or gas in commercially worthwhile amounts.

Development	9	4	4	3	7
Exploratory	2,794	2,345	1,196	1,044	843
Developmental	29,925	29,929	17,038	15,929	14,074
Crude Oil					
Exploratory and Development	13,361	16,645	11,261	16,254	21,709
Exploratory	806	892	612	668	979
Developmental	12,555	15,753	10,649	15,586	20,730
Dry Holes					
Exploratory and Development	4,978	5,428	3,552	4,277	4,492
Exploratory	1,582	1,715	1,052	1,093	1,011
Developmental	3,396	3,713	2,500	3,184	3,481
Total					
Exploratory and Development	51,058	54,347	33,047	37,504	41,118
Exploratory	5,182	4,952	2,860	2,805	2,833
Developmental	45,876	49,395	30,187	34,699	38,285

Source: Energy Information Administration (EIA, 2012)

The boom in hydraulic fracturing is associated with its use in completion of gas wells. The technique has also proved extremely valuable as a means of stimulating production from certain challenging fields that, until fairly recently, were not major producing fields.

According to 2005 Congressional testimony by the Interstate Oil and Gas Compact Commission, a group that represents governors from oil and gas producing states, hydraulic fracturing was used in 90 percent of all oil and natural gas wells recently drilled in the United States (EWG, 2012). Similarly, FracFocus, a national hydraulic fracturing chemical registry managed by two multi-state governmental bodies, the Ground Water Protection Council and the Interstate Oil and Gas Compact Commission, estimates that of the total wells drilled in 2011 (41,118 wells), 85 percent, or 35,000 wells, were hydraulically fractured (FracFocus, 2012). According to experts, 60 to 80 percent of all U.S. wells drilled in the next ten years will require hydraulic fracturing to continue operating (FracFocus, 2010). These 35,000 hydraulic fracturing jobs for new wells form the bulk of the fracking market.

No oilfield data sources provide national estimates of the number of refracturing jobs performed in recent years. Discussions with several oilfield contacts suggest, however, that refracturing jobs represent a small portion of industry activity (ERG, 2013). However, OSHA cautions that these comments might not capture the activities of the very small fracking firms performing

small refracturing jobs on older, low-pressure conventional oil and gas wells, the volume of which has not been well reported.

According to EIA data, in 2009 the well count totaled 824,847, consisting of 461,388 gas wells and 363,459 oil wells (EIA, 2010). By 2010, the number of gas wells had grown to 487,627 wells (EIA, 2013). Of this total, an estimated 211,706 were unconventional gas wells.⁸ The American Petroleum Institute (API) surveyed producers and, based on the survey results, estimated that 2.31 percent of unconventional gas wells were re-fractured in 2010 (API, 2012).⁹ For conventional wells, the rate of refracturing is even lower. The API survey results indicate that 0.3 percent of these gas wells were refractured during 2010. ERG was unable to estimate the number of oil wells being refractured, although discussions with industry contacts suggest that these wells represent a very small portion of activity (ERG, 2013).

Applying the API survey-based estimate that 2.31 percent of unconventional gas wells and 0.3 percent of conventional gas wells are refractured, OSHA calculates that the combined number of wells refractured annually totals 5,718 gas wells. This estimate of refractured gas wells represents approximately 16 percent of the estimated number of new wells completed with hydraulic fracturing. In discussions with ERG, industry suggested that this level of refracturing appears to be high. However, at this time OSHA lacks data to make an alternative estimate and requests public comment on this estimate of the number of gas wells refractured annually.

GROWTH OF THE HYDRAULIC FRACTURING INDUSTRY

The Department of Energy forecasts that shale gas production will increase almost threefold from 2009 to 2035 (U.S. EIA, 2011a). Tight sand gas and coalbed methane, both of which require hydraulic fracturing in nearly all cases to be released, accounted for approximately 28 percent and 8 percent respectively of total U.S. gas production in 2009 (U.S. EPA, 2011a).

In the very near future, however, the growth of the hydraulic fracturing sector is less certain, as an industry source estimates that fleet utilization rates began to decline during 2012. The U.S. rig count is a leading indicator of the utilization rate for hydraulic fracturing equipment, and based on recent trends in that leading indicator, the utilization rate, estimated at 95 percent in the first quarter of 2012, was projected to fall to 85 percent during the second quarter (PacWest Consulting Partners, 2012).

Production of shale gas grew by an average of 48 percent per year between 2006 and 2010, largely due to advances in hydraulic fracturing combined with horizontal drilling (U.S. EIA,

⁸ Unconventional wells are those that are difficult to develop and can only be produced using horizontal wells that are stimulated by hydraulic fracturing (Kelso, 2012). API (2012) reports that EPA's 2010 well counts include 200,921 conventional wells and 154,161 unconventional wells (including 31,381 shale; 47,371 coal bed-methane; and 75,409 tight). With unconventional wells making up 43 percent of the total, OSHA estimates that, of the 487,627 wells reported by EIA (2013), 211,706 are unconventional.

⁹ The rate at which unconventional wells are refractured is strongly influenced by a large number of refracturing jobs in one particular oilfield. When this oilfield is removed from the data, the share of refractured wells drops to 0.7 percent for unconventional wells (API, 2012). Nevertheless, with no statistical basis to exclude this oilfield from the data, for this preliminary analysis OSHA has retained it in the database and therefore applied the overall rate of refracturing (2.31 percent) instead of the downward adjusted rate.

2011a). Because using the two techniques in combination greatly increases the productivity of unconventional reservoirs, the rise in use of hydraulic fracturing techniques has largely matched the rise in horizontal well drilling (U.S. EIA, 2011a, 2011b). In some fields, the growth in horizontal drilling and hydraulic fracturing are quite dramatic. For example, in the Barnett shale in Texas, the most extensively developed shale gas field in the United States, the number of producing horizontal wells rose from fewer than 400 to over 10,000 between 2004 and 2010 (U.S. EIA, 2011b). The development of shale oil resources is likely to represent a substantial share of oil and gas activity for a number of years

TECHNOLOGICAL FEASIBILITY

Methodology

Defining “Silica” Data

Unless specifically indicated otherwise, all silica exposure data, samples, and results discussed in this technological feasibility analysis refer to personal breathing zone (PBZ) measurements of respirable crystalline silica. The term “respirable crystalline silica” is used as defined in the proposed rule (see “Definitions”).

Data Sources and Source Characteristics

General information on the data sources and source characteristics for the overall technological feasibility analysis is discussed in Section IV.A—Methodology of the Preliminary Economic Analysis. Details regarding the data sources used for this supplemental appendix are presented below under the heading “Baseline Conditions and Exposure Profile.”

Methods to Assess Feasibility of Control Technology

Exposure profiles were developed by job category. OSHA analyzed the distribution of silica exposure data for each job category involved in hydraulic fracturing operations, drawing information from sources such as NIOSH site visits, trade and industry organizations, OSHA site visits, and peer-reviewed journals.

All results in the general industry exposure profiles, including the measurements in this hydraulic fracturing section, are 8-hour time-weighted average (TWA) PBZ samples collected over periods of 360 minutes or more (for the purposes of this analysis, defined as “full-shift”). To determine an 8-hour TWA, the exposure level for the period sampled is assumed to have continued over any unsampled portion of the shift. OSHA has preliminarily determined that this sample criterion is valid because workers in general industry are likely to work at the same general task or repeating set of tasks over most of their shift; thus, unsampled periods generally are likely to be similar to the sampled periods.

For additional information on the methodologies used for this analysis, please consult Section IV.A—Methodology of the Preliminary Economic Analysis.

OSHA has organized activities at hydraulic fracturing sites into three main job categories: fracturing sand workers, ancillary support workers, and remote/intermittent support workers. Table A-9 provides information on these job categories and their source of exposure.

Table A-9 Job Categories, Major Activities, and Sources of Exposure of Workers in the Industry Providing Support Activities for Oil and Gas Operations (NAICS 213112)	
Job Category*	Major Activities and Sources of Exposure
Fracturing Sand Workers in the Central Area (e.g., sand mover operator, conveyor belt tender, blender tender, water operator, pump truck operator)	<p>Operate and tend equipment in the central sand-handling area on hydraulic fracturing sites</p> <ul style="list-style-type: none"> • Dust ejected from the thief hatches on the top of the sand movers. • Dust released from the conveyor belt under the sand movers. • Dust created as sand drops into or is agitated in the blender hopper. • Dust released from conveyor belt operation. • Sand released at the top of the end of the sand belt on the sand movers. • Dust ejected from the side fill ports on the sand movers.
Ancillary Support Workers (e.g., chemical truck operator, hydration unit operator)	<p>Operate or tend equipment that is at a fixed location on the perimeter or slightly removed from the central sand-handling area, such as chemical trucks and hydration units.</p> <ul style="list-style-type: none"> • Dust disbursed from processes operated by fracturing sand workers in the central sand-handling area. • Sand and aggregate on the ground, crushed by heavy equipment and disturbed by passing vehicles. • Accumulated dust in vehicle and equipment cabs occupied by drivers and operators.
Remote/Intermittent Support Workers (e.g., roving operator, ground guide, sand coordinator, mechanic, QA technician, fueler, wire-line crew)	<p>Active over a wide area of the site, primarily outside the central sand handling area, but may include brief, occasional excursions into the central sand-handling area. These workers may spend time at a primary base location (truck, trailer) away from sand-handling.</p> <ul style="list-style-type: none"> • Dust disbursed from processes operated by fracturing sand workers in the central sand-handling area. • Sand and aggregate on the ground, crushed by heavy equipment and disturbed by traffic on the site. • Dust released inside trailer while QA/QC techs sieve sand to check sand quality. Normally only QC technicians are exposed in these instances because they are the only workers in the trailer while this work is performed.
<p>*Job categories are intended to represent job functions; actual job titles may differ and responsibilities may be allocated differently, depending on the facility.</p> <p>Sources: NIOSH HF-Site 1, 2010; NIOSH HF-Site 2, 2011; NIOSH HF-Site 3, 2011; NIOSH HF-Site 4, 2011; NIOSH HF-Site 5, 2011; NIOSH HF-Site 6, 2011.</p>	

Baseline Conditions and Exposure Profile

OSHA reviewed the best available exposure monitoring data, consisting of six NIOSH reports on hydraulic fracturing sites.¹⁰ Between 2010 and 2011, NIOSH visited 11 hydraulic fracturing worksites in five states (seven sites in Colorado and individual sites in Arkansas, North Dakota, Pennsylvania, and Texas) as part of an industry-wide effort to identify and characterize exposures to vapors, gases, particulates and fumes among gas and oil field workers (Esswein, 2013). Participation in the program was voluntary, and the sites visited were not selected at random, but rather at the request of industry representatives. OSHA does not have data to evaluate the extent to which these particular sites are representative of all hydraulic fracturing operations; however, according to industry sources, the sites visited are typical of the hydraulic fracturing operations in these different geographic areas.

During these visits, NIOSH collected full-shift air samples to determine the levels of worker exposure to respirable silica on the work sites, and based on the results of the air sampling, NIOSH identified exposure to respirable silica at these sites as an occupational health hazard.

NIOSH spent three days at each of the eleven sites to obtain PBZ air samples and some area samples (OSHA-NIOSH Alert, 2012). Conditions varied between the sites. NIOSH collected samples in diverse seasons, with temperatures ranging from 30° to 113° Fahrenheit, and at elevations ranging from 246 feet to 4,813 feet.¹¹ Well sites included single stage “re-fracs” (rejuvenating old wells), multistage hydraulic fracturing, and “zipper-fracs” (multiple parallel wells) (Esswein, 2013).¹²

Respirable dust at these sites contained a relatively high percentage of silica. Among the 88 samples for which this information is available from all NIOSH site visits, more than half had greater than 41 percent silica in the sample (with a range of 6 to 100 percent silica). An exception was NIOSH’s Site 6, at which a granular ceramic medium containing 1 percent silica replaced half of the silica sand proppant (NIOSH HF-Site 6, 2011). Exposure controls were largely absent during the monitoring periods, representing what are characterized here as baseline conditions.

¹⁰ Sources are NIOSH HF-Site 1, 2010; NIOSH HF-Site 2, 2011; NIOSH HF-Site 3, 2011; NIOSH HF-Site 4, 2011; NIOSH HF-Site 5, 2011; NIOSH HF-Site 6, 2011. Each report covers three days at one hydraulic fracturing site, except “Site 2” which covers one-half day at each of six re-fracking (well renewal) sites; travel time between sites was not sampled. In order to detect even low levels of silica, NIOSH collected personal samples based on large air volumes by using high flow respirable dust cyclones (BGI model GK2.69) and air sampling pumps set to 4.2 liters per minute to collect samples over workers entire shift (NIOSH HF-Site 3, 2011). Many of these shifts exceeded 8 hours. These samples represent the best available silica exposure data for hydraulic fracturing site workers.

¹¹ The Site 5 report describes “gusty wind” conditions on site, “between 5 and 7 mph” (NIOSH HF-Site 5, 2011). Sites 1, 4, 5, and 6 were sampled during summer, Site 2 was sampled during winter, and Site 3 was sampled during spring (NIOSH HF-Site 1, 2010; NIOSH HF-Site 2, 2011; NIOSH HF-Site 3, 2011; NIOSH HF-Site 4, 2011; NIOSH HF-Site 5, 2011; NIOSH HF-Site 6, 2011).

¹² Simultaneous or “zipper” hydraulic fracturing involves “two or more parallel wells [that] are drilled and then perforated in alternate intervals along the well bores and fractured at the perforations This creates a high-density network of fractures between the wells that increases production in both wells” (Gilleland, 2011).

The following sections describe the baseline conditions, and Table A-10 summarizes the exposure information for the affected job categories. Because few controls were in use at the time of the NIOSH visits, and industry work practices have been modified somewhat since that time, OSHA seeks additional information to update both the exposure profile and information related to controls.

Baseline Conditions for Fracturing Sand Workers

OSHA reviewed 51 exposure results for fracturing sand workers from the six NIOSH reports on hydraulic fracturing sites. The exposure profile, provided in Table A-10, shows a full-shift mean exposure of 464 $\mu\text{g}/\text{m}^3$, a median of 330 $\mu\text{g}/\text{m}^3$, and range of 10 to 2,570 $\mu\text{g}/\text{m}^3$ for this group of workers. Nearly 75 percent of the sample results in this job category exceed 100 $\mu\text{g}/\text{m}^3$, which is approximately equal to the current PEL for general industry.¹³ More than half (27 of 51 samples) exceed 250 $\mu\text{g}/\text{m}^3$ and nearly 10 percent (5 of 51 samples) exceed 1,000 $\mu\text{g}/\text{m}^3$.¹⁴ Eight fracturing sand worker samples exceed 820 $\mu\text{g}/\text{m}^3$, which is the highest exposure level of any worker in the other job categories at hydraulic fracturing sites).

Most of the full-shift fracturing sand worker samples that exceed 1,000 $\mu\text{g}/\text{m}^3$ are associated with sand mover operations. For example, one of the highest sample results (2,000 $\mu\text{g}/\text{m}^3$) was collected on a worker at the bottom operator station on a sand mover at a site where “hot loading” occurred and where sand contained a high percentage of silica (most respirable dust samples in which silica was detected contained 50 to 100 percent quartz) (NIOSH HF-Site 3, 2011).¹⁵ Other sample results for sand mover operators exposed above 1,000 $\mu\text{g}/\text{m}^3$ include values of 1,010 $\mu\text{g}/\text{m}^3$, 1,100 $\mu\text{g}/\text{m}^3$, and 1,950 $\mu\text{g}/\text{m}^3$ (NIOSH HF-Site 3, 2011; NIOSH HF-Site 5, 2011). The worker with the highest full-shift sample result (2,570 $\mu\text{g}/\text{m}^3$), however, was not a sand mover operator, but instead worked near sand movers while tending sand conveyer belts in hot, dry, breezy weather at a location where respirable dust samples contained 30 to 65 percent quartz (NIOSH HF-Site 1, 2010). At these three sites where exposure levels exceeded 1,000 $\mu\text{g}/\text{m}^3$, the extremely high silica exposure levels were associated with worker positions immediately down-wind of points from which sand dust was released (e.g., thief hatches, conveyers, sand hoppers).

At the time NIOSH visited these sites, these fracturing sand workers wore either filtering facepiece or half-facepiece respirators. Since then, firms have made efforts to protect workers at hydraulic fracturing sites from exposures to crystalline silica. One such effort is more frequent use of full-facepiece respirators by workers in the central sand-handling areas at hydraulic fracturing sites. (ERG, 2013).

¹³ The exact value for the current PEL varies depending on the silica content of the dust and is calculated based on the equation published in 29 CFR 1910.1000 Table Z-2. For additional information see the discussion in Section IV.B – Technological Feasibility.

¹⁴ Sources: NIOSH HF-Site 1, 2010; NIOSH HF-Site 2, 2011; NIOSH HF-Site 3, 2011; NIOSH HF-Site 4, 2011; NIOSH HF-Site 5, 2011; NIOSH HF-Site 6, 2011.

¹⁵ The term “hot loading” refers to the time-saving practice of continuing the hydraulic fracturing process while refilling the sand mover. This practice involves leaving the sand mover and associated conveyors running while the sand mover is being simultaneously refilled with sand from a sand truck (using a pneumatic conveyance system). The pneumatic transfer of sand into the sand mover adds air to the interior, which then vents through any available openings. The combined activities are visibly dustier than the individual activities (Esswein, 2012). A bottom operator station includes a control panel for the sand mover and a sight line to lower portions of the equipment.

NIOSH documented baseline conditions for fracturing sand workers, which included largely uncontrolled work processes using dry sands from various sources.¹⁶ The work typically occurs at sites that contain numerous trucks, sand movers, and related large equipment that block natural breezes that might otherwise create some air exchange in the area where dust is released in the highest concentration (Esswein, 2012; Rader, 2012). An alternative proppant (e.g., ceramic media) is used occasionally at sites where conditions benefit from the proppant's unique properties (e.g., strength, shape, size, uniformity). The exposure profile represents fracturing sand worker exposure on sites operating under these baseline conditions.

Baseline Conditions for Ancillary Support Workers

The six NIOSH reports on hydraulic fracturing sites also contain exposure data (six samples) for ancillary support workers. Half of the samples exceeded the current PEL, while the remaining samples were 50 $\mu\text{g}/\text{m}^3$ or less. The median exposure level for this job category is 142 $\mu\text{g}/\text{m}^3$, with a mean of 243 $\mu\text{g}/\text{m}^3$ and range of 9 $\mu\text{g}/\text{m}^3$ to 820 $\mu\text{g}/\text{m}^3$.¹⁷ The highest exposure level for a worker in this job category, 820 $\mu\text{g}/\text{m}^3$ obtained for a hydration worker, was more than three times the next highest level for a hydration worker, 240 $\mu\text{g}/\text{m}^3$, obtained at the same worksite, but likely on a different day (NIOSH HF-Site 3, 2011). In contrast, other hydration worker results from a second site were 9 $\mu\text{g}/\text{m}^3$, 26 $\mu\text{g}/\text{m}^3$ and 44 $\mu\text{g}/\text{m}^3$ at a site where fracturing sand worker exposures reached 983 $\mu\text{g}/\text{m}^3$ (NIOSH HF-Site 4, 2011). Fracturing sand worker exposure levels at Site 4 were substantially elevated, although not as high as at Site 3, where the median fracturing sand worker exposure was 625 $\mu\text{g}/\text{m}^3$.¹⁸ This suggests that the most highly exposed ancillary support worker (from HF Site 3) spent markedly more time in close contact with fracturing sand workers and their exposure sources than would normally be the case. Unusual exposure patterns can result from workers temporarily assigned to another job duty (in this case fracturing sand worker), upset conditions or from individual work practices, any of which could cause an ancillary support worker to spend more time than usual in the extremely dusty fracturing sand work area.

Ancillary support worker baseline conditions are also documented by the NIOSH reports. Workers in this job category work at fixed positions just outside the central sand-handling area. The primary sources of exposure for ancillary support workers are the processes controlled by the fracturing sand workers (Esswein, 2012). Variable wind and weather conditions carry airborne silica from the central work area, where controls are largely absent, causing bystander exposure for ancillary support workers (Esswein, 2012). Silica dust accumulated in the vehicle

¹⁶ Sources: NIOSH HF-Site 1, 2010; NIOSH HF-Site 2, 2011; NIOSH HF-Site 3, 2011; NIOSH HF-Site 4, 2011; NIOSH HF-Site 5, 2011; NIOSH HF-Site 6, 2011

¹⁷ Sources: NIOSH HF-Site 1, 2010; NIOSH HF-Site 2, 2011; NIOSH HF-Site 3, 2011; NIOSH HF-Site 4, 2011; NIOSH HF-Site 5, 2011; NIOSH HF-Site 6, 2011.

¹⁸ At HF Site 3, 10 fracturing sand worker exposure levels were 85 $\mu\text{g}/\text{m}^3$, 130 $\mu\text{g}/\text{m}^3$, 330 $\mu\text{g}/\text{m}^3$, 363 $\mu\text{g}/\text{m}^3$, 620 $\mu\text{g}/\text{m}^3$, 630 $\mu\text{g}/\text{m}^3$, 750 $\mu\text{g}/\text{m}^3$, 1,100 $\mu\text{g}/\text{m}^3$, 1,950 $\mu\text{g}/\text{m}^3$, and 2,000 $\mu\text{g}/\text{m}^3$ (average 796 $\mu\text{g}/\text{m}^3$, median 625 $\mu\text{g}/\text{m}^3$ over three days) (NIOSH HF-Site 3, 2011). These sample results for these fracturing sand workers are higher than the mean and median for the fracturing sand worker job category, suggesting that the dust levels at Site 3 were higher than the typical site. Even so, the hydration worker with an exposure level of 820 $\mu\text{g}/\text{m}^3$ (greater than the average fracturing sand worker exposure level at the same site) appears to have performed the job in a way that incurred greater exposure than would otherwise have been expected.

cabs and silica-containing sand and aggregate crushed on the ground by passing heavy equipment contribute to ancillary support worker exposure whenever these sources are disturbed. The exposure profile, based on NIOSH's reports, represents ancillary support worker exposure on sites operating under these baseline, uncontrolled, conditions.

Baseline Conditions for Remote/Intermittent Support Workers

The six NIOSH reports provide 26 sample results for remote/intermittent support workers, who typically had lower daily exposures compared to fracturing sand workers and ancillary support workers. The remote/intermittent support worker exposures are characterized by a median of 51 $\mu\text{g}/\text{m}^3$, a mean of 88 $\mu\text{g}/\text{m}^3$, and a range of 6 $\mu\text{g}/\text{m}^3$ to 630 $\mu\text{g}/\text{m}^3$. Overall, 13 samples (50 percent) are 50 $\mu\text{g}/\text{m}^3$ or less, another 9 (34 percent) are greater than 50 $\mu\text{g}/\text{m}^3$ but no greater than 100 $\mu\text{g}/\text{m}^3$, and four samples (16 percent) exceed 100 $\mu\text{g}/\text{m}^3$ (these four samples range from 140 $\mu\text{g}/\text{m}^3$ to 630 $\mu\text{g}/\text{m}^3$). Among the workers in this job category, only those serving as ground guides periodically experienced exposures greater than 100 $\mu\text{g}/\text{m}^3$ (4 samples, or 18 percent of the 22 samples for ground guides). Although their exposure is intermittent, their duties take them near moving vehicles (which disturb dust) and into the central sand-handling area as they guide sand delivery trucks into positions near sand movers. The single sample for a QA technician was less than 25 $\mu\text{g}/\text{m}^3$,¹⁹ as was one of the three samples obtained for mechanics (the other two sample results for mechanics were between 50 $\mu\text{g}/\text{m}^3$ and 100 $\mu\text{g}/\text{m}^3$).

NIOSH also documented baseline conditions for remote/intermittent support workers, which included the largely uncontrolled work processes of workers in another job category (fracturing sand workers). Sand and aggregate crushed on the ground by passing heavy equipment contribute to remote/intermittent support worker exposure whenever these materials are disturbed. Similar to the other job categories, the exposure profile for remote/intermittent support workers is based on NIOSH's reports and therefore represents the exposure of workers in this job category operating under these baseline, uncontrolled, conditions.

It is important to note that certain remote/intermittent support workers, such as QA technicians who sieve sand as part of quality testing, handle silica-containing materials in a manner that could be a meaningful source of exposure if performed on a large scale. However, OSHA has no evidence that shows that these workers experience significant exposure from the small-scale short-term testing activities in which they are involved at hydraulic fracturing sites.

¹⁹ NIOSH did not document the QA technician's activities. However it is reasonable to assume that sieving of small samples was part of the worker's activities during sampling since it is one of the tasks involved with this job.

Table A-10—Respirable Crystalline Silica Exposure Range and Profile for Hydraulic Fracturing During Support Activities for Oil and Gas Operations (NAICS 213112)

Job Category	Exposure Summary			Exposure Range		Exposure Profile							
	N	Mean (µg/m3)	Median (µg/m3)	Min (µg/m3)	Max (µg/m3)	<25 (µg/m3)	≥25 and ≤50 (µg/m3)	>50 and ≤100 (µg/m3)	>100 and ≤250 (µg/m3)	>250 and ≤500 (µg/m3)	>500 and ≤1,000 (µg/m3)	>1,000 and ≤2,000 (µg/m3)	>2,000
Fracturing Sand Workers	51	464	330	10	2,570	1 2.0%	5 9.8%	7 13.7%	11 21.6%	10 19.6%	12 23.5%	4 7.8%	1 2.0%
Ancillary Support Workers	6	243	142	9	820	1 16.7%	2 33.3%	0 0%	1 16.7%	1 16.7%	1 16.7%	0 0.0%	0 0.0%
Remote/intermittent Workers	26	26	88	51	6	8 30.8%	5 19.2%	9 34.6%	2 7.7%	1 3.8%	1 3.8%	0 0.0%	0 0.0%
Total	83	330	121	6	2,570	10 12.0%	12 14.5%	16 19.3%	14 16.9%	12 14.5%	14 16.9%	4 4.8%	1 1.2%

Notes: All samples are PBZ results for durations of 360 minutes or more and represent 8-hour time-weighted average (TWA) exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Sources: NIOSH HF-Site 1, 2010; NIOSH HF-Site 2, 2011; NIOSH HF-Site 3, 2011; NIOSH HF-Site 4, 2011; NIOSH HF-Site 5, 2011; NIOSH HF-Site 6, 2011.

Additional Controls

Additional Controls for Fracturing Sand Workers

As indicated in the exposure profile, OSHA estimates that slightly less than 12 percent of fracturing sand workers currently have exposures at or below the proposed PEL of 50 $\mu\text{g}/\text{m}^3$. For the remaining workers, additional controls will be required to reduce exposures below current levels.

Dust containing silica is emitted from several points on equipment operated by fracturing sand workers. Based on visual observation, NIOSH identified seven primary sources of emissions affecting workers engaged in hydraulic fracturing. These seven sources, itemized below, were observed at each of the eleven work sites at which NIOSH conducted air monitoring (Esswein, 2013):

1. Dust ejected from thief hatches on top of the sand movers.
2. Dust released from the conveyor belts under the sand movers.
3. Dust generated on site by truck traffic (road dust).
4. Dust created as the sand drops into, or is agitated in the blender hopper.
5. Dust released from the conveyor belt operation.
6. Sand released at the top end of the sand belt (associated with the sand movers).
7. Dust ejected from the fill ports on the side of the sand movers.

Table A-11 shows how these seven primary and two other sources of exposure relate to the three job categories.

Table A-11 – Sources of Worker Exposure to Silica at Hydraulic Fracturing Sites

Job Category	Potential Silica Exposure Sources								
	Thief hatches – sand mover top	Conveyor belt under sand movers	Dust raised by traffic	Blender hopper	Conveyor belt operation	Transfer point from sand belts on sand movers	Sand Fill Ports	Sand sieve (QC laboratory only)	Dust in vehicle cabs
Hydraulic Fracturing Worker (Central Zone)	**	**	*	**	**	**	**	NA	NA
Ancillary Support Workers (Nearby)	*	*	**	*	*	*	*	NA	**
Remote/Intermittent Support Workers	*	*	*	*	*	*	*	**	*

* = Exposure is primarily as bystander; silica dust originates with other workers' activities.
 ** = Exposure is directly associated with the workers' activities and equipment.
 NA = Source of exposure is not applicable to job category.

Sources: NIOSH HF-Site 1, 2010; NIOSH HF-Site 2, 2011; NIOSH HF-Site 3, 2011; NIOSH HF-Site 4, 2011; NIOSH HF-Site 5, 2011; NIOSH HF-Site 6, 2011.

To limit worker exposure to silica, emissions should be reduced from each of the seven primary sources, a process that will require a combination of control methods. Effective control methods include local exhaust ventilation (LEV), wet methods, enclosure (equipment, workers), work practices and administrative controls, and substitution.

Local Exhaust Ventilation (LEV)

Control equipment that encloses and ventilates emission points is used broadly to control silica dust in both general industry and the construction industry. This control method is highly effective when designed to capture dust at the release point and with sufficient suction (pressure and volume) to overcome competing forces, such as turbulence, leakage, other sources of air flow, and dust particles in motion. Captured air released in the work area needs to be treated with an appropriate air-cleaning device to prevent respirable particles from recirculating back into workers' breathing zones. LEV with a tight-fitting or partially enclosing hood is a control option for all the major sources of dust released from sand-handling equipment in hydraulic fracturing work zones.

OSHA identified two commercial providers offering **powered LEV systems** built for the purpose of controlling dust emissions from dust sources associated with filling sand movers (FracSandDC, 2012; NOV, 2012). One is an add-on retrofit option for sand movers (operating at a speed of 3,200 cubic feet per minute ([cfm])). The other is reportedly available installed on new sand movers, retrofit on existing sand movers, or as a dust control service package providing trailer-based equipment (45,000 cfm) and personnel to set up and operate it on a per-job basis. Both draw air from the sand mover

to control dust released while sand trucks pneumatically fill the sand mover (STEPS, 2012; JJBodies, 2011; NOV, 2012; FracSandDC, 2012). Captured dust is held in containers until disposed of (in accordance with local requirements) (STEPS, 2012).²⁰ One of the systems also can be configured to provide LEV at the transfer belt and conveyers (STEPS, 2012; JJBodies, 2011). The manufacturer reports that preliminary test results suggest substantial reductions in airborne dust exposure; however, workers in the area continue to require respiratory protection (STEPS, 2012).²¹

Separately, NIOSH has designed and tested a prototype *mini-baghouse passive dust collection system* that fits over individual thief hatches and deposits collected sand back into the sand mover (STEPS, 2012; Esswein, 2012; NIOSH HF-Site 6, 2011). NIOSH recommends that “baghouse material should be selected to control respirable particles in the size range of 3-5 microns” (i.e., the size of respirable dust) (NIOSH HF-Site 6, 2011). NIOSH reports that the design is promising and may be commercially available in the future (Esswein, 2012).

OSHA notes that with LEV systems that focus on controlling dust from thief hatches or the sand mover in general, other control methods (e.g., additional LEV, wet methods) still will be needed to manage dust released from conveyers, transfer belts, and hoppers.

OSHA has not identified studies or data demonstrating the effectiveness of LEV for controlling silica exposure of fracturing sand workers.²² However, the sections of this technological feasibility analysis covering foundries, pottery, and construction industry activities such as milling, rock and concrete drilling, and rock crushing discuss examples of beneficial ventilation systems currently in use for other large-scale operations involving sand and other silica-containing materials. Although these industries do not handle the same quantity of sand on a daily basis as that used by the hydraulic fracturing industry, several of the industries do use notable amounts of high-silica sands and have achieved marked reductions in silica exposure using LEV systems. The following examples from the foundry industry demonstrate that appropriately designed and maintained LEV systems can have a great influence on silica exposure levels. The reader is directed to Section IV.C—Technological Feasibility of the Preliminary Economic Analysis for additional examples from the industries mentioned above.

The foundry industry includes facilities that handle large quantities of silica sands. Although foundries do not use the extreme tonnage of sand encountered at hydraulic fracturing sites, the handling processes are similar, including extensive use of conveyor

²⁰ For example, at a well location used for tests, sand fines (sand particles) collected by the ventilation system (up to 1,000 pounds per stage) were buried in accordance with local environmental management procedures (STEPS, 2012). Depending on the dust collection system used, fines are collected and held for disposal in barrels or bulk bags.

²¹ OSHA was not able to obtain additional information regarding exposure concentrations or the level of respiratory protection needed during use of this control system.

²² As of November 2012, NIOSH and an LEV system supplier both reported that technical evaluations and exposure studies were in the planning stages (Esswein, 2012; STEPS, 2012).

belts under hot and dry conditions to transport dusty sands returned from the shakeout area for reuse in molds for metal casting. Foundry workers in the sand systems operator job category manage the flow of sand through hoppers and bins before blending it with clay (another silica-containing material) in equipment called mullers. In the ferrous sand-casting foundry industry, exposure monitoring data obtained by OSHA at a foundry showed an 83 percent reduction in sand system operator silica levels (from 231 $\mu\text{g}/\text{m}^3$ to 40 $\mu\text{g}/\text{m}^3$) after the foundry installed LEV and repaired leaks in the mixer (OSHA SEP Inspection Report 122040488). Standards published by the American Conference of Governmental Industrial Hygienists (ACGIH) and the American Foundrymen's Society (AFS) for sand mixers and mullers, bins, hoppers, and screens specify that equipment be well enclosed and exhausted at a minimum rate of 150 cfm (200 cfm in the case of screens) per square foot of opening (ACGIH, 2010; AFS, 1985). ACGIH also recommends an air flow rate of 250 cfm per square foot of opening for toxic dusts, which might be more appropriate for silica-containing materials than the published air flow rates for other materials handled by similar equipment (ACGIH, 2010).

Both OSHA and NIOSH showed that controlling dust from foundry sand-handling equipment could result in low silica exposures. An exposure of 11 $\mu\text{g}/\text{m}^3$ (the concentration limit of detection [LOD]) was obtained for a sand systems operator who was controlling a muller with both muller belts and sand elevator fully enclosed (OSHA SEP Inspection Report 108772377). NIOSH reported exposures less than 30 $\mu\text{g}/\text{m}^3$ at a facility where a sand system operator monitored a pneumatic transport system that moved sand to the mixing equipment (NIOSH ECTB 233-107c, 2000).²³

Although conditions in foundries are substantially different from those found in hydraulic fracturing sites, the principles of enclosure and exhaust ventilation apply equally to both. A well-designed ventilation system associated with an appropriate process enclosure or enclosing hood is highly effective for capturing silica dust before it spreads through the workplace. While no documentation exists showing to what extent the commercial systems currently available or under development control respirable silica exposure, the available evidence suggests that each of those systems likely reduces dust emissions from thief hatches (one of the greatest sources of dust at these sites). The best available evidence OSHA has – photographs and videos of hydraulic fracturing worksites – suggests that thief hatches account for at least half (and likely more than half) of the visible dust released at these sites over the course of a day (FracSand DC, 2012). Visible dust is not a measure of respirable dust concentration, but it is a marker for airborne dust in general, of which respirable dust is typically one component (OSHA 3362-05, 2009).²⁴ The LEV systems currently available or under development for hydraulic fracturing sites

²³ In addition, this facility used specifically sized (A50-grain), pre-washed lake sand for casting, which likely helped reduce exposures (NIOSH ECTB 233-107c, 2000). Pre-washing sand can remove fine respirable-sized particles that might otherwise become airborne when workers use the sand. Washed lake sands contain fewer very fine particles and the grains are more rounded than angular sand types. In the foundry industry, for a variety of reasons (e.g., reduction of fine particles, improved mold permeability, reduced resin use), rounded or partially rounded sands provide better casting results for bonded sand-casting methods. The same characteristics (washed, rounded, reduced fine particles) are beneficial for proppants used in the gas and oil industry (Maslowski, 2012).

are unproven, but available information on these and similar types of equipment suggest that this type of technology has potential as an effective control for thief hatch emissions. If so, the exposures of all workers in the central fracturing sand-handling area could be reduced by half (based on the visual impression that at least 50 percent of total emissions are contributed by thief hatch emissions, as noted above). As a result of this 50 percent reduction, all workers with current exposures between 50 $\mu\text{g}/\text{m}^3$ and 100 $\mu\text{g}/\text{m}^3$ would experience modified exposure levels of 50 $\mu\text{g}/\text{m}^3$ or less. Air monitoring will be required to confirm the actual extent of the exposure reduction that employers achieve by controlling thief hatch emissions. OSHA is interested in receiving additional information from the public on the emissions from individual equipment at sand fracturing sites and by how much these emissions could be reduced through the use of controls.

The supplier of at least one commercially available ventilation system also applies LEV to other dust sources associated with hydraulic fracturing equipment, including conveyer belts, transfer belts, hoppers, and drop points (STEPS, 2012). The available information is insufficient for evaluating the effectiveness of these controls. An analogous situation exists, however, in a study of rock-crushing equipment used to crush pure quartz stone in the Iranian quartz powder production region (Bahrami et al., 2008). Like hydraulic fracturing equipment in the United States, the crushers initially were completely without controls, operating in an extremely high-silica environment (the stone contained 98 percent silica). The investigators compared area samples obtained at uncontrolled, small, mechanized crushing machines to similar samples obtained for equivalent machines fitted with LEV at hoppers, rotary grinders, screeners and conveyor belts (the LEV system was not further described by the investigators). They found that airborne respirable dust concentrations were higher (levels of 111,000 $\mu\text{g}/\text{m}^3$ to 179,000 $\mu\text{g}/\text{m}^3$) for uncontrolled equipment compared to those fitted with LEV, which were 99 percent lower (Bahrami et al., 2008). This study is described in more detail in the Preliminary Economic Analysis Section IV.C—Technological Feasibility discussion of rock crushing machine operators and tenders. Although hydraulic fracturing sand equipment is markedly larger scale, and worker exposure levels tend to be correspondingly higher, the Iranian experience offers insight into the degree of control that might be available from basic LEV installed on previously uncontrolled equipment, where silica can constitute 100 percent of the respirable dust.²⁵ If the hydraulic fracturing silica emissions from conveyors, drop points,

²⁴ A reduction in visual emissions suggests that dusty air is not vented from the thief hatch, and exposure from that particular source is reduced. Visible emissions, however, do not indicate the extent to which respirable particles are captured by or pass through any air-cleaning device (e.g., cyclone, filters) handling that air. Air-cleaning devices that are not effective for respirable-size particles can release those particles at the point where exhaust air is discharged. Depending on the discharge location, exhaust air from an inefficient dust capture system might contribute to worker exposure, as noted by Flanagan et al. (2001), where a low-efficiency vacuum filter contributed to worker exposures after the vacuum was used to collect concrete slurry from wet cutting operations in the construction industry.

²⁵ Fifty of the 51 largely uncontrolled respirable dust PBZ sample results for fracturing sand workers evaluated by NIOSH ranged from 66 $\mu\text{g}/\text{m}^3$ to 3,370,000 $\mu\text{g}/\text{m}^3$, up to 20 times higher than uncontrolled area concentrations (111,000 $\mu\text{g}/\text{m}^3$ to 179,000 $\mu\text{g}/\text{m}^3$) reported by Bahrami et al. (2008). One additional respirable dust result exceeded 8,000,000 $\mu\text{g}/\text{m}^3$ and was excluded from this calculation. Note that these figures represent respirable dust, as opposed to respirable silica, concentrations.

and hoppers were also reduced by the same 99 percent reported by Bahrami et al. (2008), the current maximum hydraulic fracturing worker silica exposure ($2,570 \mu\text{g}/\text{m}^3$) might be reduced by a corresponding amount to $26 \mu\text{g}/\text{m}^3$ (or half this amount if eliminating emissions from thief hatches resulted in a 50 percent decrease in total exposure). OSHA acknowledges that the large scale of hydraulic fracturing equipment might make it more difficult to control than the small Iranian rock crushers (because markedly greater cfm would be required, and temporary equipment might not fit as well). If instead exposures at conveyers, drop points, and hoppers were only controlled by 66 percent (instead of a 99-percent reduction), hydraulic fracturing workers currently exposed to levels that do not exceed $250 \mu\text{g}/\text{m}^3$ would be reduced to $85 \mu\text{g}/\text{m}^3$ or less.²⁶ Similarly, exposures up to and including $290 \mu\text{g}/\text{m}^3$ would also be reduced to a level no greater than $100 \mu\text{g}/\text{m}^3$. When combined with a 50-percent reduction due to control of exposure from thief hatches, these worker exposure levels would be reduced to $50 \mu\text{g}/\text{m}^3$ or less.²⁷

Pneumatic Sand Transport Systems

An additional option is to use pneumatic sand transport to move sand within the hydraulic fracturing site. Pneumatic sand systems currently are successfully used on hydraulic fracturing sites to transfer sand from sand delivery trucks to the sand movers. These systems fully enclose the sand as it is carried by fast-moving air through a system of pipes until it is delivered to its destination (at a hydraulic fracturing site, OSHA anticipates that the destination would be the blender hopper). At that point (the blender hopper), the same type of emissions capture system would be needed as is currently under consideration for the sand mover thief hatches, which now vent excess air used to pneumatically convey sand into the sand mover.

NIOSH recommends pneumatic sand transport systems for use in mines, an industry closely related to the hydraulic fracturing industry in that most worksites are in remote (rather than urban) locations, central processes that involve moving massive quantities of dusty mineral matter with the ultimate goal of extracting natural materials from the earth. Additionally, silica exposure is a notable source of concern for workers in both industries. NIOSH describes pneumatic material transport systems for the mining industry, as follows:

Pneumatic conveyors are tubes or ducts through which material is moved by pressure or vacuum (suction) systems. Positive pressure systems can be

²⁶ This 66 percent reduction represents two-thirds of the effective reduction reported in Bahrami et al. (2008). OSHA is using this reduction percentage because the Agency believes that exposures at hydraulic fracturing sites occur on larger scales and may be more difficult to control than exposures at the rock crushing sites studied by Bahrami et al. (2008). Thus, the reduction from 99 percent to 66 percent is a conservative estimate used in lieu of another reduction factor based on more complete evidence.

²⁷ A control method offering a 66 percent reduction will reduce an exposure of up to $250 \mu\text{g}/\text{m}^3$ to $85 \mu\text{g}/\text{m}^3$ or less (or an exposure of $290 \mu\text{g}/\text{m}^3$ to $99 \mu\text{g}/\text{m}^3$ or less). An additional 50 percent reduction due to controlling emissions from the thief hatches will further reduce these exposure levels by one-half, to $43 \mu\text{g}/\text{m}^3$ or less. The same additional 50 percent reduction will reduce an exposure of up to $100 \mu\text{g}/\text{m}^3$ to a level of $50 \mu\text{g}/\text{m}^3$ or lower.

either dilute phase or dense phase. Dilute phase uses a low (dilute) product to air ratio for transport, while dense phase uses a high (dense) product to air ratio. Dilute phase flow is when the air velocity in the conveyor line is high enough to keep the product being conveyed airborne. Dense phase does not require the product to be airborne. Material being conveyed lies for periods of time in the bottom of a horizontal line and sometimes flows through the line in slugs. Dilute phase systems typically operate at pressures obtainable from a fan and dense phase systems use a high-pressure compressed air source. When material is fed into a pressure system, the material is conveyed to a storage bin with dust collection, cyclone, or filter-type collector. The conveying air then escapes through the cyclone vent or a filter.

Since positive pressure pneumatic systems are totally enclosed, dust emissions do not usually occur unless the system has worn-out areas. Because maximum wear in the conveying ductwork occurs at elbows, long-radius elbows made of heavy gauge material should be used. Numerous styles of wear-resistant elbows are [commercially] available. The elbows can also be lined with refractory or ceramic material to further reduce wear and abrasion. In low-pressure pneumatic systems, dust may also leak through joints. Self-adhesive neoprene gaskets should be used at all joints to provide a dust-tight seal. (NIOSH-RI9689, 2012)

Such a pneumatic system would eliminate all sources of silica exposure from the sand truck to the blender hopper, except that associated with the vent where pressurized air is vented near the ultimate sand delivery point. As noted earlier in this discussion of LEV exposure control options for this job category, NIOSH reported exposures below the limit of detection (in this case less than 30 $\mu\text{g}/\text{m}^3$) for a worker in the vicinity of sand handling areas at a foundry that moved quantities of silica sand via a pneumatic transport system (NIOSH ECTB 233-107c, 2000). OSHA does, however, recognize that using pneumatic sand transport systems, which cannot move the same large quantity of sand per minute as conveyor belts, might result in operational inefficiencies by reducing the rate of sand delivery to the blender hopper. Additionally, pneumatic systems can be costly to maintain because the aggressive action of fast-moving sand acts as an abrasive and can cause system components to deteriorate.

Wet Methods

Wet dust suppression methods have proven effective for controlling silica dust in a wide variety of settings. Water spray, or amended water spray (including additives to extend the functional benefit of the water spray), is widely used to control dust in outdoor storage yards in both general industry and construction. Although OSHA does not have information demonstrating the effectiveness of this method for controlling road dust at hydraulic fracturing sites, numerous examples exist in other industries, where heavy equipment operates constantly on what otherwise would be dusty driving areas. For example, in the structural clay industry (i.e., manufacturing bricks and concrete block

from clay and concrete that contain silica), front-end loaders and other heavy equipment constantly move back and forth on the site. As at hydraulic fracturing sites, spilled sand and related silica materials at structural clay sites are crushed by vehicles and become airborne when disturbed. Workers in the material handler job category are exposed to silica when they operate this equipment; however, wet methods can reduce exposure levels for these workers. Dust suppressants or frequent wetting using a water spray truck can limit the amount of dust that becomes airborne. For example, a brick manufacturing facility described in NIOSH ECTB 233-124c (2000) sprayed the yard (product storage area) with water five times per day. Five of the six results obtained for material handlers operating in the area were below the LOD ($16 \mu\text{g}/\text{m}^3$ in this case), while one result was $43 \mu\text{g}/\text{m}^3$ (NIOSH ECTB 233-124c, 2000).

A study by Addo and Sanders (1995) offers additional support for the application of dust suppressants to work areas and storage yards. The study examined three chemical dust suppressants (lignosulfate, calcium chloride, and magnesium chloride) applied to an unpaved roadway for four and a half months and found that, compared to an untreated roadway, the suppressants reduced fugitive dust emissions by 50 to 70 percent.

Wet methods and dust suppressants, such as foam sprays, can also be applied to process equipment and conveyers to prevent silica dust from becoming airborne as raw materials are transferred within a work area. For example, as noted under baseline conditions for the material handler–loader operator subcategory in the structural clay industry, dust suppression was used at a structural clay facility visited by NIOSH and is associated with a silica result of $56 \mu\text{g}/\text{m}^3$ (NIOSH ECTB 233-124c, 2000). The foam application system consisted of “a drum of citrus-based surfactant, a control panel, hoses, a manifold, and 4 spray heads. This system worked by blanketing the surface of the conveyed material with foam, preventing the generation of silica containing aerosols” (NIOSH ECTB 233-124c, 2000).

There is another telling example of dust suppression during road milling operations. Road milling machines, which process and convey large quantities of silica-containing asphalt road surface, make use of wet methods during milling (at the cutting drum) and increasingly are applying water spray to the recyclable asphalt product (containing sand and silica rock aggregate) on conveyer belts as a dust control measure. In a study conducted in the Netherlands, a novel wet dust emission suppression system reduced the PBZ respirable quartz exposure of asphalt milling machine drivers to a mean of $20 \mu\text{g}/\text{m}^3$ ($n = 4$), with a range of $9 \mu\text{g}/\text{m}^3$ to $30 \mu\text{g}/\text{m}^3$ (Van Rooij and Klaasse, 2007). The system consists of 24 spray nozzles (located at the picks drum, collection conveyer, and loading conveyer), which spray aerosolized water containing an additive (likely a foam, based on the product name) onto the milled asphalt material (Van Rooij and Klaasse, 2007). The additive foam causes the dust to become tacky and aggregate, and the foam expands rapidly to encompass small particles generated by the tool’s aggressive action. This technology can offer more effective dust suppression than plain water.²⁸ Milling machine

²⁸ Although more costly than a simple water spray, foams are more effective (by volume applied) than water spray. Foam can be adapted to control dust from most tasks, including applications that require a rugged design (Van Rooij and Klaasse, 2007).

tenders also benefitted from the system, having a mean PBZ respirable quartz exposure of $8 \mu\text{g}/\text{m}^3$ ($n = 4$), with a range of $4 \mu\text{g}/\text{m}^3$ to $12 \mu\text{g}/\text{m}^3$. Compared with a standard milling machine, which uses only cooling water (not aerosolized) on the blade, the use of the aerosolized water and foam system reduced the mean exposure for drivers and tenders combined by 97 percent. Without the added controls (i.e., cooling water only), mean exposure was $418 \mu\text{g}/\text{m}^3$ ($n = 2$) for drivers and $509 \mu\text{g}/\text{m}^3$ ($n = 1$) for tenders.

OSHA recognizes that gas and oil companies must use great care to limit the number and type of materials introduced into the well hole; therefore, additives might not be suitable for sands destined for hydraulic fracturing. Investigators Van Rooij and Klaasse (2007) also reported results of using aerosolized water without the additive foam. Aerosolized water alone provided a substantial benefit, resulting in PBZ respirable quartz exposures of $42 \mu\text{g}/\text{m}^3$ and $57 \mu\text{g}/\text{m}^3$ for milling machine drivers and $56 \mu\text{g}/\text{m}^3$ and $104 \mu\text{g}/\text{m}^3$ for tenders. Aerosolized water reduced the mean exposure for drivers and tenders combined by 86 percent compared with cooling water only; however, three of four exposures remained above the proposed PEL of $50 \mu\text{g}/\text{m}^3$. The authors did not report individual sample durations, but the average sampling time for all 15 results was 254 minutes (range: 60 to 388 minutes). The investigators concluded that exposure results were lower when the additive was used in the spray water. NIOSH, in cooperation with an industry group, is evaluating control methods, including water spray and LEV, for road milling machines in the United States.

Wet dust suppression systems can also reduce general dust levels across a worksite when other, more local methods only partially control the emissions source. NIOSH describes this control method as it is used in the mining industry, which, like hydraulic fracturing, handles large quantities of silica materials as sand, rock and ore during processes that, if uncontrolled, generate substantial dust:

Wet suppression systems are probably the oldest and most often used method of dust control at mineral processing operations. In the vast majority of cases for mineral processing operations, the wet suppression system used is a water spray system. Although the use of water sprays is a simple technique, there are a number of factors that should be evaluated to determine the most effective design for a particular application. There are two methods to control dust using water sprays at mineral processing operations:

- Preventing dust from becoming liberated and airborne by directly spraying the ore.*
- Knocking airborne dust down by spraying the dust cloud and causing the particles to collide with water droplets and fall out of the air.*

Most operations use a combination of both methods in the overall dust control plan. When considering the use of a wet suppression system, some general considerations and guidelines apply:

- *The effectiveness of water spray application is dependent on nozzle type, droplet size, spray pressure, spray pattern, spray angle, spray volume, spray droplet velocity, and spray droplet distribution.*
- *Each ore type and application point is a unique situation and needs to be evaluated separately to achieve the optimal design.*
- *Water evaporates and needs to be reapplied at various points throughout the process to remain effective.*
- *Water freezes and its use is limited during certain times of the year and in certain climates.*
- *Wet suppression cannot be used with all ores, especially those that have higher concentrations of clay or shale. These minerals tend to cause screens to bind and chutes to clog, even at low moisture percentages.*
- *Over application in the volume of moisture is a problem in all operations and can impact the equipment as well as the total process. In most cases, a well-designed suppression system will not exceed 0.5% moisture application, which is roughly equivalent to one gallon per ton of ore.*
- *The suppression system should be automated so that sprays are only used during times of production when ore is actually being processed. For dust knockdown, a delay timer may be incorporated into some applications to allow the suppression system to operate for a short time period after a dust-producing event.*

When considering sprays, one of the primary aspects is the droplet size. When wetting the ore to keep dust from becoming airborne, droplet sizes above 100 microns should be used. In contrast, when the goal is to knock down existing dust in the air, the water droplets should be in size ranges similar to the dust particles. The intent is to have the droplets collide and attach themselves to the dust particles, causing them to fall from the air. In these cases, droplets in the range of 10 to 50 microns have been shown to be most effective. [From NIOSH IC 9521, 2010]

As discussed in the section on construction rock crushing, an international report on wet dust control methods for rock crushers in India offers evidence that water mist reduces silica exposure in rock crushing and conveying operations.²⁹ At several small, tightly clustered rock crushing machine sites in India, five initial respirable quartz results obtained during dry crushing operations ranged from 60 $\mu\text{g}/\text{m}^3$ to 360 $\mu\text{g}/\text{m}^3$, with a median of 290 $\mu\text{g}/\text{m}^3$ and a mean of 246 $\mu\text{g}/\text{m}^3$ (Gottesfeld et al., 2008). Although the stationary (movable, but apparently not mobile) crushers were mechanized (powered), the

²⁹ Like hydraulic fracturing, rock crushing involves high-silica (e.g., concrete, asphalt, brick), dusty materials, frequently transported by conveyor belts for hours at a time.

workers loaded the crusher hopper manually and carried off the crushed material by hand in sacks. None of the crushing machines was equipped with an operator's booth. Among the sites evaluated for this study, the bulk stone quartz content ranged from below 4 percent to 27 percent, with an additional 3 to 6 percent cristobalite at some sites.

Results were markedly lower when water spray systems were installed. Of the 150 small Indian crushing mills in the study area, 40 subsequently agreed to install atomizing water spray dust suppression systems.³⁰ The 18 follow-up breathing zone and area samples collected during the monsoon season range from 5 $\mu\text{g}/\text{m}^3$ to 55 $\mu\text{g}/\text{m}^3$, with a median of 11 $\mu\text{g}/\text{m}^3$ and a mean of 14 $\mu\text{g}/\text{m}^3$ (sampling durations not reported).³¹ A second set of follow-up samples was collected during the dry season. These 27 post-control dry season samples (15 PBZ and 12 area samples), obtained over approximately 2 to 5 hours, range from 10 $\mu\text{g}/\text{m}^3$ to 630 $\mu\text{g}/\text{m}^3$, with a median of 20 $\mu\text{g}/\text{m}^3$ and a mean of 63 $\mu\text{g}/\text{m}^3$. Gottesfeld et al. (2008) note that the higher sample results observed after spray systems were installed (29 percent exceeded 50 $\mu\text{g}/\text{m}^3$) might have been due to one or more spray nozzles that did not function and neighboring rock crushing mills that did not have dust control equipment (dust drifted between neighboring operations). Although the wide exposure range indicates that elevated exposure occurred occasionally, both the median and the mean were dramatically lower after the control system was installed. Respirable dust levels dropped by 63 percent. This reduction is based on the difference in respirable dust before controls were applied and after water spray controls were added during the dry season.

A general mist system of the type described above (see Gottesfeld et al., 2008) could provide supplemental dust control at hydraulic fracturing sites where LEV alone does not completely control workers' silica exposure. For example, when combined with LEV controls on thief hatches, conveyors, and other sources of emissions, the installation of a water misting/fogging that provides an additional 63% reduction in dust emissions, would reduce the exposure of fracturing sand workers who are currently exposed to levels as high as 770 $\mu\text{g}/\text{m}^3$ to levels of 49 $\mu\text{g}/\text{m}^3$ or less.

As discussed in Section IV.A—Methodology, employers will benefit from expert advice in selecting a water mist system. For example, the size of the droplets is at least as important as the type and volume of the spray.

Additional exposure reductions can be achieved by moistening the proppant on conveyor belts and at drop points. This method is recommended by NIOSH and typically involves

³⁰ The water spray systems were provided by an international partnership studying silica exposure in the crushing mills, where the workforce primarily consisted of tribal women and adolescent girls (Gottesfeld et al., 2008).

³¹ The researchers intended for both area and PBZ samples to represent individual worker exposures. They placed sampling pumps in a stationary location in the immediate work area when workers were reluctant to wear them. Although sample results are presented individually in the study, it does not differentiate between area and PBZ samples in the post-control data. As such, the range, mean, and median values contain both area and PBZ results. Although OSHA prefers PBZ samples to represent actual worker exposures, the Agency has used this data because it is the best available information.

adding 0.1 percent to 1.5 percent water to the proppant (NIOSH HF-Site 6, 2011; NIOSH RI 9689, 2012). Hydraulic fracturing sites can account for the amount of moisture added as dust suppressant to materials on conveyor belts approaching the blender hopper, so the fluid balance in the fracturing slurry remains predictable. OSHA recognizes that adding moisture at the early stages of the process (e.g., in the truck before sand is delivered) is less practical, as it could interfere with the truck's pneumatic sand delivery system. Because they fully enclose the sand, pneumatic transport systems are a highly effective dust control method, providing the dust controls are available on the receiving vessel (in this case, the sand mover). OSHA also acknowledges that it might be more difficult to account for water added as a dust suppressant between the delivery truck and final conveyers, since more of the water would evaporate under warm and dry conditions than during cool or humid conditions.

Enclosure

Process enclosure limits emissions from areas under positive pressure (e.g., fill ports and unused thief hatches on sand movers) and areas of turbulence (e.g., conveyers, sand drop points from the ends of conveyers). Enclosures used with LEV improve ventilation effectiveness so engineers can design systems with smaller, more energy-efficient fans. Worker enclosures can limit employee exposures by providing clean filtered air to an enclosed, pressurized operator's booth. Several opportunities for reducing exposures by enclosure exist at hydraulic fracturing sites.

NIOSH noted that the fill ports on the sides of the sand movers can be a primary source of silica exposure for all fracturing sand workers in the area during the periods when the sand movers are refilled by the sand delivery truck drivers (NIOSH HF-Site 1, 2010).³² Sand delivery typically involves just one or two of the several nozzles on each sand mover. One component of silica management at hydraulic fracturing sites involves preventing silica release from those fill ports that are not in use. Fill ports are not intended for pressure relief and should be closed with manufacturer-provided or replacement end caps (NIOSH HF-Site 6, 2011). Tight closure with a cap will prevent silica emissions from this source. The ability to tightly close by valve or cap is a typical design feature wherever unused ports are present in pneumatic sand transport system-receiving vessels (i.e., tanks, rail cars, trucks, and process equipment—including sand movers) (Smith and Voges, no date; Dynamic Air, 2011; Bhatia, no date).³³ Replacement

³² Sand delivery trucks connect pneumatic sand transport hoses to the ports to add sand to the sand movers. The ports are designed for filling the sand mover rather than as relief valves for dusty air introduced into the sand mover during pneumatic sand transport from the delivery truck. However, when they are left open during filling, dusty air vents out through any unused fill ports (particularly those on the opposite side of the sand mover) (NIOSH HF-Site 1, 2010).

³³ In pneumatic transport system designs, ports that are not intended to be completely sealed typically are considered part of the air-venting system and usually are vented back to the sand source to minimize product loss, or they are connected to a LEV system that provides dust capture (Smith and Voges, no date; Dynamic Air, 2011; Bhatia, no date). LEV systems are described earlier in this section in the discussion of LEV as a silica control option.

port caps are commercially available (NOV, 2012).³⁴ Installing a leak-proof gasket and closing unused thief hatches will also help ventilation systems function more efficiently and reduce opportunities for exposure.

Exposure reduction can be enhanced by enclosing conveyors and particularly conveyor drop points. NIOSH advocates reducing and enclosing drop points: “Some methods to accomplish this are through the use of rock ladders, telescopic chutes, spiral chutes, and bin-lowering chutes” (NIOSH RI-9689, 2012). These options are applicable to hydraulic fracturing sites, for which NIOSH recommended shrouding or skirting at the end of the sand belt to limit dust released as material falls from the belt (NIOSH HF-Site 6, 2011).³⁵ ACGIH recommends reducing the height of conveyor transfer points so that dusty material falls the minimum distance possible. Ventilated conveyors require extra ventilation when the fall distance is three feet or greater (ACGIH, 2010 [see VS-50-20]).

Enclosing the operator is another practical option for protecting workers who must work in particularly harsh environments. At hydraulic fracturing sites, some of the most highly exposed workers will benefit from operator enclosures (clean air booths) placed at the sand mover and conveyor belt operator work stations. From within an appropriately positioned booth workers can observe operations while breathing filtered air. Silica exposure only occurs when the worker exits the booth (e.g., to adjust a control or address an equipment problem). Therefore, a worker who spends 50 percent of the shift in a well-sealed, pressurized clean air control booth, will experience an approximately 50% reduction in exposure, assuming constant level of exposure outside the booth.

There are several types of operator enclosures that could be used to reduce exposures on hydraulic fracturing worksites. Environmental cabs on trucks and heavy equipment represent one form of mobile control booth. Portable control booths positioned on pallets or a truck bed are also an option. To permit workers to spend a greater amount of time in the booth, the equipment control panel can be converted to a mobile control (on a cord with the controls positioned in the booth interior) or wireless/radio remote control (worker carries the control module into the booth). Mobile and remote control modules are increasingly commercially available for many types of heavy stationary and mobile equipment.³⁶

An example of control booths used to protect workers who otherwise would be exposed to silica comes from the structural clay industry. As in the hydraulic fracturing industry,

³⁴ In calculating exposure reduction OSHA assumes that the step of closing the side ports is taken at the same time as LEV is applied to the thief hatches (together these steps provide the 50 percent exposure reduction described for the thief hatch LEV control option).

³⁵ OSHA assumes that at least partial enclosure is included as part of an efficient LEV system design and installation for conveyors, drop points and hoppers.

³⁶ Examples of remote controls used for dusty equipment in industries that work with silica are provided by Cattron-Theimig (no date), Komatsu America (2010), Pentek-Squirrel-III (1997), NIOSH EPHB 334-11a (2008), and Minnich (2009).

workers in the structural clay industry handle bulk quantities of sand, blending them with clay powder or cement to form batches of bricks or concrete masonry units. In structural clay manufacturing plants, when exposures continue to be elevated during automated mixer charging, the charging system controls can be placed in an enclosed operator booth. At a structural clay facility visited twice by OSHA, an area sample collected inside a poorly sealed ventilated control room resulted in an average silica concentration of 111 $\mu\text{g}/\text{m}^3$ (OSHA SEP Inspection Report 300523396). Before OSHA's next visit, the facility sealed gaps around the main entrance door to the control room. This modification reduced airborne silica levels inside the room to 11 $\mu\text{g}/\text{m}^3$, a 90-percent reduction compared to the earlier sample. The reduced level likely represented an even greater percent reduction compared to the dusty grinding equipment area outside the control room. OSHA notes that low silica levels inside the control room suggest that the room provides a substantial level of protection for any worker inside (OSHA SEP Inspection Report 300523396).

In the *Dust Control Handbook for Industrial Minerals Mining and Processing*, NIOSH analyzed the elements of effective control booths and cabs, reporting that the level of dust protection depends on the adequacy of the following factors: enclosure integrity (well sealed), filtration (sufficiently efficient for respirable particles), pressurization (positive pressure inside to keep dusty outside air from leaking in), work practices to keep doors and windows closed, climate control (so doors and windows can be kept closed), housekeeping in the enclosure (remove any dust that gets inside), and maintenance (including changing outside air filters as necessary) (NIOSH RI 9689, 2012). The NIOSH handbook includes a table summarizing NIOSH studies on personnel enclosures (cabs) associated with mining equipment (routinely used with massive quantities of dusty, silica-containing mineral materials), which shows dust reduced 63 to 98.8 percent by the cabs.³⁷ Ability to maintain a slight pressurization was one of the most important factors in reducing dust. Although some cabs (and related booths) perform exceedingly well in excluding dust (98.9 percent reduction), the amount of exposure reduction they offer decreases when the door is opened frequently (as the worker enters and exits), since dusty air can enter each time. Therefore, OSHA estimates that a cab or booth on a hydraulic fracturing site, which workers might need to enter and exit many times per hour, would offer somewhat less than 98.8 percent reduction, with the 90 percent reduction OSHA found for the structural clay facility booth likely being more typical (OSHA SEP Inspection Report 300523396).³⁸

On hydraulic fracturing sites, workers who can spend even 50 percent of the time in an environmental control/clean air booth that offers a 90 percent exposure reduction could

³⁷ The 63 to 98.9 percent reduction in airborne dust levels reported by NIOSH is equal to protection factors of 2.8 to 89.3. A protection factor of 100 reduces exposure 99 percent and a protection factor of 1,000 reduces exposure 99.9 percent (NIOSH RI 9689, 2012).

³⁸ Booth efficiency also can be reduced if portable equipment is not maintained routinely; seals tend to deteriorate more quickly on enclosures that are moved frequently. Routine housekeeping and maintenance of the booth seals and ventilation system will be necessary to ensure portable equipment retains this level of effectiveness (NIOSH RI 9689, 2012).

have their exposures reduced by 45 percent.³⁹ This means that for a hypothetical fracturing sand worker spending 50 percent of an 8-hour shift in an environmental control booth, a current exposure level up to 1,000 $\mu\text{g}/\text{m}^3$ can be reduced by 45 percent to 550 $\mu\text{g}/\text{m}^3$ or less. Furthermore, an exposure level of 1,400 $\mu\text{g}/\text{m}^3$ could be reduced to 770 $\mu\text{g}/\text{m}^3$ using this method.⁴⁰ Significant exposure reduction can be achieved when other exposure controls are added (i.e., water spray/misting equipment, partial enclosures with LEV, and thief hatch controls, which together reduce exposures of up to 770 $\mu\text{g}/\text{m}^3$ to levels of 49 $\mu\text{g}/\text{m}^3$ or less). These estimates show that fracturing sand workers with current exposures greater than 770 $\mu\text{g}/\text{m}^3$ and no greater than 1,400 $\mu\text{g}/\text{m}^3$ (nearly 10 percent of the samples in the exposure profile for hydraulic fracturing workers) can ultimately experience exposure of 49 $\mu\text{g}/\text{m}^3$ or less through the use of multiple controls.

As noted above, the exposure reduction potential of an operator enclosure or booth is related to both the efficiency of the booth in excluding dust and the amount of time the worker spends in the booth. Workers able to spend 80 percent of the time in a booth that is 90 percent efficient in excluding dust would experience a greater exposure reduction (72 percent) than workers able to spend only 50 percent of work time in the same booth (45 percent). This exposure reduction would have a large effect on the sample result for even the most highly exposed individual in this industry (2,570 $\mu\text{g}/\text{m}^3$ recorded for a fracturing sand worker monitoring conveyer belts). For example, spending 80 percent of the shift in an operator booth (90 percent efficient) could reduce this worker's exposure level to 717 $\mu\text{g}/\text{m}^3$. With the addition of the control combination discussed above, the worker's ultimate exposure level could also be reduced to 49 $\mu\text{g}/\text{m}^3$ or less (46 $\mu\text{g}/\text{m}^3$ in this case). OSHA believes that under current working conditions it is more realistic for fracturing sand workers to spend 50 percent of the time in a booth; however, when an additional level of protection is necessary, increasing time in the booth remains an option.

Worker enclosures, including operator control booths and heavy equipment cabs, are described in more detail in the Preliminary Economic Analysis Section IV.C— Technological Feasibility discussions of concrete products industry mixer operators, foundry furnace operators, structural clay grinder operators, and workers operating rock crushing machines.

Work Practices and Administrative Controls

³⁹ When a booth offers 90 percent efficient protection from airborne dust exposure and a worker spends 50 percent of the shift in the booth, the worker's exposure will be reduced by 45 percent ($0.9 \times 0.5 = 0.45$). In the second example, the worker spending 70 percent of the time spent in a booth that is 90 percent efficient would have a 63 percent decrease in exposure ($0.9 \times 0.7 = 0.63$). Following the same calculation method, a worker spending 80 percent of the shift in the booth (still 90 percent efficient) will experience 72 percent exposure reduction.

⁴⁰ An exposure reduction of 45 percent will leave a residual exposure 55 percent ($1 - 0.45 = 0.55$). For the hypothetical worker with a current exposure of 1,000 $\mu\text{g}/\text{m}^3$, exposure after the control will be equal to 550 $\mu\text{g}/\text{m}^3$ (calculation: $0.55 \times 1,000 \mu\text{g}/\text{m}^3 = 550 \mu\text{g}/\text{m}^3$). Using the same procedure, OSHA calculates that a 45 percent reduction in an exposure level of 1,400 will result in an exposure of 770 $\mu\text{g}/\text{m}^3$.

Work practices and administrative control options provide workers with standard operating procedures that help workers cover fill ports and close any thief hatches that do not need to be open during sand mover filling and hydraulic fracturing processes, require workers to stand back from dust emission points unless necessary, minimize hot-loading unless adequate controls are in place to protect workers, and limit personnel in the areas where greatest exposure tends to occur.⁴¹

Another work practice control option involves adjusting equipment to minimize the height from which proppant falls from conveyer belts during transfers (to other conveyors or to the blender hopper). Reducing the drop distance minimizes the influence of competing air currents and reduces the amount of dust that becomes airborne as proppant transfers between conveyors or from conveyor to blender hopper. Design “VS-50-20” in ACGIH (2010) recommends that drop distances be less than 3 feet. For ventilated systems, additional ventilation is required to compensate for dust released during greater falls. NIOSH also recommends that fall heights for materials be minimized whenever possible (NIOSH RI-9689, 2012).

Combination of Controls

The massive quantities of sand and high silica content mean that a combination of controls likely will be necessary to reduce silica dust at fracturing sites. Control options such as LEV, general misting wet methods, road wetting with amended water, full enclosure (sealing unused side ports), and work practice/administrative controls are not mutually exclusive and can be used in any combination.

As determined in the discussions of LEV, wet methods, and enclosures above, exposure levels can be reduced dramatically by installing effective combinations of controls. In summary, in the preceding discussion of control options OSHA has shown:

Operator enclosures: For a hypothetical fracturing sand worker spending 50 percent of an 8-hour shift in an environmental control booth (90 percent efficient against dust, as identified in OSHA SEP Inspection Report 300523396), a current exposure level up to 1,000 $\mu\text{g}/\text{m}^3$ can be reduced by 45 percent to 550 $\mu\text{g}/\text{m}^3$ or less. Furthermore, an exposure level of 1,400 $\mu\text{g}/\text{m}^3$ could be reduced to 770 $\mu\text{g}/\text{m}^3$ using this method. Five (10 percent) of the samples in the exposure profile for fracturing sand workers exceed 770 $\mu\text{g}/\text{m}^3$ but do not exceed 1,400 $\mu\text{g}/\text{m}^3$. All but three (6 percent) of the 51 samples used in the exposure profile for fracturing sand workers are less than 1,400 $\mu\text{g}/\text{m}^3$.⁴²

Wet methods: When a misting/fogging system that provides a 63-percent reduction in exposure level, as demonstrated by Gottesfeld et al. (2008), is installed at a hydraulic

⁴¹ OSHA recognizes that the practice of hot-loading reduces otherwise unproductive time spent refilling the sand mover.

⁴² The remaining three fracturing sand workers with exposures that exceed 1,400 $\mu\text{g}/\text{m}^3$ would also have their exposure reduced to levels below 770 $\mu\text{g}/\text{m}^3$ if the workers were able to spend 80 percent (rather than 50 percent) of their time in the booth; however, OSHA does not have evidence that this amount of time in the booth is as realistic as 50 percent under current site conditions.

fracturing site, fracturing sand workers who are currently exposed to levels greater than $290 \mu\text{g}/\text{m}^3$, but no more than $770 \mu\text{g}/\text{m}^3$, could have their exposures reduced to between $108 \mu\text{g}/\text{m}^3$ to $285 \mu\text{g}/\text{m}^3$ or less. Eighteen (35 percent) of the 51 samples used in the fracturing sand worker exposure profile are already in the range of $290 \mu\text{g}/\text{m}^3$ to $770 \mu\text{g}/\text{m}^3$. This control option will also benefit workers whose exposure can be reduced to $770 \mu\text{g}/\text{m}^3$ or lower through the use of operator enclosures.

Partial enclosure and LEV: If exposures at conveyers, drop points, and hoppers are reduced by 66 percent (two-thirds of the 99-percent reduction reported by Bahrami et al. (2008)), hydraulic fracturing workers currently exposed to levels that do not exceed $250 \mu\text{g}/\text{m}^3$ would have exposures of $85 \mu\text{g}/\text{m}^3$ or less. Similarly, exposures up to and including $290 \mu\text{g}/\text{m}^3$ would be reduced to a level no greater than $100 \mu\text{g}/\text{m}^3$. Workers whose exposures are reduced to $290 \mu\text{g}/\text{m}^3$ or less by other control options (operator enclosures and wet methods) will also benefit to the same extent. Twelve samples (nearly 24 percent) in the fracturing sand worker exposure profile are already greater than $100 \mu\text{g}/\text{m}^3$, but do not exceed $290 \mu\text{g}/\text{m}^3$.

LEV control at thief hatches: Based on a visual assessment of video and photographs (FracSand DC, 2012), OSHA estimates at least a 50-percent exposure reduction due to control of emissions from thief hatches. This would cut worker exposures in half. Once the exposure of a worker is reduced to a level of $100 \mu\text{g}/\text{m}^3$ or less (by the control options listed above or any other methods), OSHA anticipates that the addition of LEV on thief hatches will further reduce the exposure to $50 \mu\text{g}/\text{m}^3$ or less. Seven samples in the fracturing sand worker exposure profile are currently greater than $50 \mu\text{g}/\text{m}^3$ but not greater than $100 \mu\text{g}/\text{m}^3$. When the exposure of more highly exposed workers can be reduced to this same range (greater than $50 \mu\text{g}/\text{m}^3$, but not more than $100 \mu\text{g}/\text{m}^3$) using the control options described above (partial enclosure with LEV, wet methods, operator enclosures), the same LEV control at thief hatches will further reduce the exposure of those workers to $50 \mu\text{g}/\text{m}^3$ or less.⁴³

Combination of controls: In summary, OSHA's analysis above shows that different combinations of controls can be used to reduce exposures of up to $1,400 \mu\text{g}/\text{m}^3$ to levels below the proposed PEL of $50 \mu\text{g}/\text{m}^3$. For workers with current exposures above $770 \mu\text{g}/\text{m}^3$ but no greater than $1,400 \mu\text{g}/\text{m}^3$, all the controls discussed above – operator enclosures, wet methods, partial enclosure and LEV, and LEV control at thief hatches – will need to be applied to achieve exposures below $50 \mu\text{g}/\text{m}^3$. For workers with current exposures greater than $290 \mu\text{g}/\text{m}^3$ but not exceeding $770 \mu\text{g}/\text{m}^3$, the use of wet methods, partial enclosure and LEV, and LEV control at thief hatches should control exposures to below $50 \mu\text{g}/\text{m}^3$. Where current exposures are still lower – up to $290 \mu\text{g}/\text{m}^3$ – only partial enclosure and LEV, along with LEV control at thief hatches, will be necessary to reduce exposures below the proposed PEL. Finally, where worker exposures are

⁴³ The highest fracturing sand worker sample result is $2,570 \mu\text{g}/\text{m}^3$. Applying a 45 percent reduction for using a 90-percent-efficient control booth 50 percent of the time results in $2,570 \mu\text{g}/\text{m}^3 \times 0.55 = 1,414 \mu\text{g}/\text{m}^3$. Applying the 63 percent reduction reported by Gottesfeld et al. (2008) for water mist dust control results in $1,414 \mu\text{g}/\text{m}^3 \times 0.37 = 523 \mu\text{g}/\text{m}^3$. An additional estimated 66 percent reduction based on the study of LEV applied to Iranian rock crushers (Bahrami et al., 2008) yields $178 \mu\text{g}/\text{m}^3$. Applying an estimated 50 percent reduction based on a visual assessment reduces this value to $89 \mu\text{g}/\text{m}^3$.

already at or below the current PEL of 100 µg/m³, exposures below the proposed PEL could be achieved simply through LEV control at thief hatches.⁴⁴

Substitution

Substitution is another option for reducing silica exposures at hydraulic fracturing sites. Oil and gas extraction worksites present two opportunities for substitution: work zone surfacing materials and proppant.

NIOSH reported that spilled silica sand and aggregate crushed by heavy equipment in the work zone contribute to worker silica exposures (Esswein, 2012). This source of exposure can be reduced by covering the work zone with substitute materials such as low-silica or granite aggregate (which contains silica, but is very hard so less subject to crushing).

The second substitution option involves the proppant. Hydraulic fracturing requires a granular media proppant—typically sand. To function as a proppant, the sand must stand up to considerable pressure in the well, and the physical properties of quartz make this type of sand particularly useful. However, alternate media are available and widely used for this purpose under certain circumstances. Commercially available alternatives include sand of other mineral content (reduced silica sand, usually mined from a different source than pure silica sand), coated sand (resin over sand grains to improve durability), and low-silica clay or ceramic granules. NIOSH observed a hydraulic fracturing crew using ceramic sand containing less than 1 percent silica (NIOSH HF-Site 6, 2011).⁴⁵ Substituting such a proppant for silica sand would reduce silica exposure levels by up to 99 percent or more (depending on the amount of silica in the alternative proppant) compared to pure silica sand.

OSHA acknowledges that these substitute materials are more costly than natural sands. Due to their cost, alternate proppants tend to be reserved for special circumstances (particularly high-pressure wells) where the special characteristics (increased durability, uniformity, or roundness) are needed to help extend well life.

Low-silica alternate media can also be used in combination with (high-quartz) natural sand media. NIOSH obtained PBZ samples at a hydraulic fracturing site that used a mixture of natural sand and ceramic proppant (58 percent of the total proppant used that day was the low-silica ceramic proppant, while the remaining 42 percent was silica sand). PBZ samples indicated that the silica content of the samples was lower (3 to 25 percent silica) than at sites using only high-silica sands (typically between 50 and 100 percent

⁴⁴ OSHA chose to discuss these specific combinations of controls for purposes of analyzing the technological feasibility of achieving the proposed PEL in the hydraulic fracturing industry. The Agency recognizes, however, that different combinations of controls than those specified here may also be appropriate for achieving needed reductions in exposure.

⁴⁵ NIOSH reported that the proppant's MSDS listed less than 1 percent quartz in the product. NIOSH analysis confirmed that the percentage was slightly lower than 1 percent (NIOSH HF-Site 6, 2011).

silica) (NIOSH HF-Site 6, 2011). Although reducing the silica content of the proppant does reduce the silica in the airborne dust, worker exposures can still be significant; at this NIOSH site 9 of the 11 PBZ samples exceeded 50 $\mu\text{g}/\text{m}^3$. None exceeded 100 $\mu\text{g}/\text{m}^3$.

In an example from the foundry industry, which also processes, conveys, and blends quantities of high-silica sand, substituting non-silica granular media (that is less toxic than silica) for silica sand used for molds and cores virtually eliminated the silica exposures of all foundry sand system operators. A report from the Industrial Commission of Ohio shows that exposures dropped below the LOD for all workers when the foundry used a non-silica substitute: olivine sand (ERG # OH-1460).⁴⁶ Another aluminum foundry reported respirable dust levels of 300 to 1600 $\mu\text{g}/\text{m}^3$ but no exposure to silica when using olivine sand (Foundry Engineering Group Project – Case History H, 2000).⁴⁷ These examples from the foundry industry support NIOSH’s findings, discussed above, showing marked reductions in respirable dust silica content at a hydraulic fracturing site using a low-silica alternate media as a portion of the proppant (NIOSH HF-Site 6, 2011).

Before using an alternate material, employers must evaluate the health hazards associated with it and take any necessary steps to protect workers from the hazards.

Additional Controls for Ancillary Support Workers

The exposure profile, presented in Table A-10, provides information on ancillary support workers, including OSHA’s estimate that half (50 percent) of the workers in this job category are currently exposed to silica levels of 50 $\mu\text{g}/\text{m}^3$ or less. Because ancillary support workers primarily are exposed to dust drifting into their work areas from the central fracturing sand zone, the additional controls necessary to reduce the exposure of fracturing sand workers to 50 $\mu\text{g}/\text{m}^3$ or less also are expected to reduce the exposure of all ancillary support workers to 50 $\mu\text{g}/\text{m}^3$ or less.

Following the control process outlined above for fracturing sand workers, all workers with exposure levels of 770 $\mu\text{g}/\text{m}^3$ or less will have their exposure levels reduced by an estimated 63 percent (to 285 $\mu\text{g}/\text{m}^3$) when site misting is applied, and by another estimated 66 percent (to 96 $\mu\text{g}/\text{m}^3$) by LEV applied to conveyors, transfer belts, drop points, and hoppers. Exposures will be reduced by an additional 50 percent (to 48 $\mu\text{g}/\text{m}^3$) through effective LEV on thief hatches. If these estimates prove to be correct, no additional controls will be necessary for ancillary support workers.

The unusually high exposure of a single ancillary support worker is presumed to have been influenced by either an upset condition or work practices.⁴⁸ This worker’s exposure

⁴⁶ Olivine is a magnesium-iron ortho-silicate mineral that contains little or no quartz and is commercially available as sand for foundries.

⁴⁷ Samples were collected over 3- to 6-hour periods.

⁴⁸ The worker was a hydration worker with a sample result of 820 $\mu\text{g}/\text{m}^3$, more than three times greater than any other worker performing the same job. Because all other hydration workers in the exposure profile had markedly lower exposures, the data suggests an atypical scenario in this worker’s work day.

of 820 $\mu\text{g}/\text{m}^3$ suggests several possible scenarios: 1) an upset condition; 2) the worker was performing the role of another job category (fracturing sand worker); or 3) work practices kept the worker in intensely dusty areas longer than is typical of this job category. The exposure value is more typical of the fracturing sand worker job category than an ancillary support worker. Respiratory protection should be used when upset conditions cause a situation where overexposure could occur. Information that the worker will receive under other provisions of this standard and the hazard communication standard would permit the worker to understand the benefits of minimizing time in extremely dusty areas when not required to work there by scenarios 1 and 2. A modest 6 percent reduction in the worker's exposure (from 820 $\mu\text{g}/\text{m}^3$ to 770 $\mu\text{g}/\text{m}^3$) would mean that the exposure of this worker too could be reduced to 50 $\mu\text{g}/\text{m}^3$ or less by the combination of controls that would reduce fracturing sand worker exposures from 770 $\mu\text{g}/\text{m}^3$ to 50 $\mu\text{g}/\text{m}^3$ or less. This can be accomplished by seeking lower dust areas (at a greater distance from intense dust sources) when not actively making water connections.

In the event that any workers in this job category remain exposed above the proposed PEL of 50 $\mu\text{g}/\text{m}^3$, other control methods are available, including improved closure and housekeeping in vehicle cabs to prevent tracked or settled dust from becoming a source of exposure. NIOSH recommends several cab design features and emphasizes the importance of maintenance and cleanliness (NIOSH 2009-123, 2009). Cabs employing several of these recommendations regularly achieve exposure reductions (inside versus outside the cab) exceeding 90 percent (Cecala et al., 2005; NIOSH 528, 2007).

Furthermore, ancillary support workers will also benefit from yard dust controls, as discussed for remote/intermittent support workers.

Additional Controls for Remote/Intermittent Support Workers

The exposure profile, summarized in Table A-10, presents OSHA's estimate that 50 percent of remote/intermittent support workers have current exposures of 50 $\mu\text{g}/\text{m}^3$ or less. Further controls will be needed to reduce the exposure levels of the 50 percent of workers in this job category whose exposures are above the proposed PEL of 50 $\mu\text{g}/\text{m}^3$.

Like the ancillary support workers, the remote/intermittent support workers primarily are exposed when dust drifts into their work areas from the central fracturing sand zone or when they enter this zone as part of their job duties. Controlling silica emitted from fracturing sand-handling equipment will, therefore, reduce most exposure experienced by remote/intermittent support workers.

Following the control process outlined above for fracturing sand workers, the exposures of all remote/intermittent support workers (all of whom had exposure levels of 770 $\mu\text{g}/\text{m}^3$ or less) will be reduced by an estimated 63 percent (to 285 $\mu\text{g}/\text{m}^3$) when site misting is applied, and all exposures less than 290 $\mu\text{g}/\text{m}^3$ will then be reduced by another estimated 66 percent (to 99 $\mu\text{g}/\text{m}^3$) by LEV applied to conveyors, transfer belts, drop points, and hoppers. Exposures will be halved (i.e., reduced by an additional 50 percent to 48 $\mu\text{g}/\text{m}^3$)

through effective LEV on thief hatches. If these estimates prove to be correct, no additional controls will be necessary for ancillary support workers.

Based on this information, OSHA preliminarily concludes that no additional controls are necessary for remote/intermittent support workers. However, additional potential sources of exposure exist for these workers and if employers observe that exposure levels remain elevated, they should consider options for reducing dust disturbed by passing vehicles on the site.

Wet dust suppression methods for yard dust are described above in the discussion of wet methods for controlling fracturing sand worker exposures. To reiterate, water spray or amended water spray (including additives to extend the functional benefit of the water spray) are widely used to control dust in outdoor storage yards in both general industry and construction. As noted previously, Addo and Sanders (1995) examined three chemical dust suppressants (lignosulfate, calcium chloride, and magnesium chloride) applied to an unpaved roadway for four and a half months and found that, compared to an untreated roadway, the suppressants reduced fugitive dust emissions by 50 to 70 percent. NIOSH provides a detailed discussion of factors that influence the effectiveness of dust suppression methods for yards and roads (NIOSH RI9689, 2012). Citing a study conducted in 1981 by Midwest Research, NIOSH notes that “There is very little information about the use of surfactants to extend the effective life of watering haul roads. However, observations have noted that the time between watering roads can be extended 33–50 percent when surfactants are used” (NIOSH RI 9689, 2012). Other options for reducing dust from passing vehicles include speed control (slower vehicles kick up less dust), traffic control, and surface roughness (a rougher aggregate or “cloddy” soil surface prevents wind from picking up as much dust).

Certain remote/intermittent support workers (e.g., Q/A technicians who sieve sand as part of quality testing) handle silica-containing materials in a manner that could be a potential source of exposure if performed on a large scale. However, no evidence exists that these workers experience measurable exposure from the small-scale short-term testing activities in which they are involved at hydraulic fracturing sites. As indicated in Table A-10, the single sample that NIOSH obtained for a Q/A technician (who sifted sand samples) had a result of 10 $\mu\text{g}/\text{m}^3$ (below the LOD).

Feasibility Finding

Feasibility Finding for Fracturing Sand Workers

Based on the best available information, OSHA estimates that 88 percent of fracturing sand workers require additional controls to reach the proposed PEL of 50 $\mu\text{g}/\text{m}^3$ or below. OSHA preliminarily concludes that silica levels of 50 $\mu\text{g}/\text{m}^3$ or less can be achieved for 94 percent of the workers in this job category (those with current exposures that do not exceed 1,440 $\mu\text{g}/\text{m}^3$).⁴⁹ These levels can be achieved by using a combination of control

⁴⁹ In addition to the exposure distribution presented in the exposure profile for fracturing sand workers, the following supplemental distribution of the same 51 samples is also useful for applying control options

options, with a greater number of controls necessary for more highly exposed workers. These controls include installing a fully effective LEV system on thief hatches and sealing fill ports on sand movers; installing LEV on conveyors, transfer belts, drop points, and hoppers; adding a site water misting/fogging system; and, for the most highly exposed workers, providing operator booths.

The nearly 14 percent of fracturing sand workers with exposure levels that meet the current PEL, but exceed $50 \mu\text{g}/\text{m}^3$, can be protected by adding emission controls on sand mover thief hatches (and ensuring that the side ports on sand movers are closed when not in use). Based on visual estimates, effective emission controls on the thief hatches will reduce the exposure of these workers by at least half (FracSand DC, 2012). This 50 percent reduction will reduce exposures that are at the current PEL or less to the level of the proposed PEL ($50 \mu\text{g}/\text{m}^3$) or less.

Because the current exposure level of most fracturing sand workers (nearly 75 percent) exceeds the current PEL, further control methods will be needed to control the exposure of these workers to the level of the current PEL. Once the current PEL is achieved for these workers, the option described above (adding emission controls to the thief hatches and closing unused side ports) will bring their exposure down to the current PEL or less, in the same manner as for the workers who currently have exposures greater than $50 \mu\text{g}/\text{m}^3$, but not exceeding $100 \mu\text{g}/\text{m}^3$.

The following supplemental controls will reduce the exposure of most remaining workers in this job category to the level of the current PEL, or less.

Providing LEV on conveyers, drop points, and hoppers is anticipated to reduce exposures 66 percent. A study of LEV by Bahrami et al. (2008) demonstrated a 99-percent difference between controlled and wholly uncontrolled exposure associated with small-scale, high-silica rock crushing, conveying, screening, and hopper operations. OSHA has preliminarily estimated 66 percent effectiveness rather than 99 percent for the larger scale, but otherwise similar conveying and hopper operations at largely uncontrolled high-silica hydraulic fracturing worksites. Using this method, the exposures of the 24 percent of hydraulic fracturing workers currently exposed to levels greater than $100 \mu\text{g}/\text{m}^3$, but less than or equal to $290 \mu\text{g}/\text{m}^3$, can be reduced to the level of the current PEL or less.

For the 35 percent of workers in this job category that are currently exposed between $290 \mu\text{g}/\text{m}^3$ and $770 \mu\text{g}/\text{m}^3$, site water misting/fogging system will reduce airborne silica levels by 63 percent, to a level of $285 \mu\text{g}/\text{m}^3$ or less. Gottesfeld et al. (2008) reported an average 63 percent reduction in silica concentrations when water misting/fogging systems were installed an Indian rock crushing site. Once the exposures of these workers are no greater than $290 \mu\text{g}/\text{m}^3$, same controls described above (i.e., LEV on conveyors, transfer belts,

to this group of workers: Exposure ranges: group $<25 \mu\text{g}/\text{m}^3$: 1 sample (2 percent); group $\geq 25 \mu\text{g}/\text{m}^3$ to $\leq 50 \mu\text{g}/\text{m}^3$: 5 samples (10 percent); group $>50 \mu\text{g}/\text{m}^3$ to $\leq 100 \mu\text{g}/\text{m}^3$: 7 samples (14 percent); group $>100 \mu\text{g}/\text{m}^3$ to $\leq 290 \mu\text{g}/\text{m}^3$: 12 samples (24 percent); group $>290 \mu\text{g}/\text{m}^3$ to $\leq 770 \mu\text{g}/\text{m}^3$: 18 samples (35 percent); group $>770 \mu\text{g}/\text{m}^3$ to $\leq 1,400 \mu\text{g}/\text{m}^3$: 5 samples (10 percent); Group $>1,400 \mu\text{g}/\text{m}^3$: 3 samples (6 percent).

drop points, and hoppers) will reduce their exposure levels to the current PEL. From the current PEL, exposures can be halved (to the proposed PEL of 50 $\mu\text{g}/\text{m}^3$) by adding emission controls on sand mover thief hatches.

For fracturing sand workers that are currently exposed to levels above 770 $\mu\text{g}/\text{m}^3$, additional controls will be necessary. Environmentally controlled operator's booths are an option for these workers who must monitor sand movers and conveyer belts. Although the booths themselves can be 90 percent efficient (or more) in excluding dust (OSHA SEP Inspection Report 300523396; NIOSH RI 9689, 2012), OSHA estimates that the workers might need to spend as much as 50 percent of their time making adjustments and corrections to equipment outside the booth. Therefore, the booths will reduce worker's exposure levels by 45 percent, rather than the full 90 percent. This control option will reduce the exposure level of workers currently exposed up to 1,400 $\mu\text{g}/\text{m}^3$ to a level of 770 $\mu\text{g}/\text{m}^3$ or less, from which point a combination of the misting/spray system and partial enclosure with LEV can bring exposures to the current PEL. Once reduced to this extent, the fracturing sand worker exposures can be reduced to the level of the proposed PEL (50 $\mu\text{g}/\text{m}^3$), or less using thief hatch emissions controls as described above.

OSHA finds that the available information presented in this analysis suggests that, using these control methods, levels of 50 $\mu\text{g}/\text{m}^3$ or less might not be achieved for the 6 percent of fracturing sand workers (3 out of 51 samples) that currently have exposures in excess of 1,440 $\mu\text{g}/\text{m}^3$, unless they are able to spend more than 50 percent of their time in the control booth. When combined with the other controls presented here, the resulting exposure level for the most highly exposed worker in this job category (with an exposure of 2,570 $\mu\text{g}/\text{m}^3$) would be 89 $\mu\text{g}/\text{m}^3$ (see section (3)(vi) of this chapter for details of this calculation). Although above the proposed PEL of 50 $\mu\text{g}/\text{m}^3$, this level is well within the MUC for respirators that have an APF of 10 (e.g., a half-face piece elastomeric respirator with P-100 filters).

OSHA preliminarily concludes that the proposed PEL of 50 $\mu\text{g}/\text{m}^3$ can be achieved for 94 percent of fracturing sand workers. The remaining 6 percent (with exposures above 1,440 $\mu\text{g}/\text{m}^3$ and up to 2,570 $\mu\text{g}/\text{m}^3$) will require respirator protection until such time as enhanced controls are available for this operation. Thus OSHA's preliminary finding is that the proposed PEL is feasible for most fracturing sand operations most of the time.

Where practical, further reductions can be achieved by using 0.1 percent to 1.5 percent water to moisten the proppant on conveyer belts and drop points (NIOSH HF-Site 6, 2011; NIOSH RI 9689, 2012). However, additional information is needed to confirm that this method does not interfere with the water ratio in the hydraulic fracturing slurry. As an alternative, an exposure level of 50 $\mu\text{g}/\text{m}^3$ can be achieved for all fracturing sand workers by using an alternate non-silica proppant instead of silica sand. Another option for eliminating all exposure between the sand delivery truck and the sand blender involves replacing the sand moving equipment with a pneumatic sand transport system. An LEV emission control (similar to that proposed for thief hatches) would still be needed at the point where dusty air from the pneumatic system is released at the blender.

However, this method would likely reduce the rate of sand transfer into the blender, increasing the amount of time it takes to prepare a hydraulic fracturing site.

Feasibility Finding for Ancillary Support Workers

Based on the best available information, OSHA estimates that the proposed PEL of 50 $\mu\text{g}/\text{m}^3$ or less can be achieved for all ancillary support workers. Exposures of 50 $\mu\text{g}/\text{m}^3$ or below have already been achieved, based on the exposure profile, for 50 percent of workers in this category. For the 50 percent of ancillary support workers who currently experience elevated exposures (above 100 $\mu\text{g}/\text{m}^3$), the proposed PEL will be achieved when employers implement the additional controls described above (those which reduce the exposure of fracturing sand workers from 770 $\mu\text{g}/\text{m}^3$ to less than 50 $\mu\text{g}/\text{m}^3$). Ancillary support workers are primarily exposed to dust drifting into their work areas from the central fracturing sand zone, as shown in Table A-11. OSHA estimates that the steps employers take to control silica concentrations in the fracturing sand zone will affect ancillary support workers similarly, reducing their highest exposure level from 770 $\mu\text{g}/\text{m}^3$ to below 50 $\mu\text{g}/\text{m}^3$.

Following the control process outlined above for fracturing sand workers, all workers with exposure levels of 770 $\mu\text{g}/\text{m}^3$ or less will have their exposure levels reduced by an estimated 63 percent (to 285 $\mu\text{g}/\text{m}^3$) when site misting is applied, and by another estimated 66 percent (to 96 $\mu\text{g}/\text{m}^3$) by LEV applied to conveyors, transfer belts, drop points, and hoppers. Exposures will be reduced by an additional 50 percent (to 48 $\mu\text{g}/\text{m}^3$) through effective LEV on thief hatches. If these estimates prove to be correct, no additional controls will be necessary for ancillary support workers.

The exposure of a single ancillary support worker exceeding 770 $\mu\text{g}/\text{m}^3$ (a hydration worker with a sample result 820 $\mu\text{g}/\text{m}^3$, more than three times greater than any other worker performing the same job) is presumed to have been influenced by either an assignment to work with fracturing sand workers, an upset condition, or work practices. OSHA anticipates that this worker would be provided with a respirator if upset conditions were to contribute to future exposure, or instructed to spend more time working in low dust areas if work practices contributed to the exposure (even 6 percent lower exposure would mean that a level of 50 $\mu\text{g}/\text{m}^3$ or less could be achieved for this worker).

OSHA preliminarily concludes that employers can reduce exposures below 50 $\mu\text{g}/\text{m}^3$ for the 50 percent of ancillary support workers who require additional controls using the same combination of engineering controls as described for fracturing sand workers. These controls would include ventilated equipment for conveying and transferring proppant in sand movers, conveyors, transfer belts, and blender hoppers. Wet site-misting methods will also be required. Thus OSHA's preliminary finding is that the proposed PEL is feasible for most ancillary support operations most of the time.

Feasibility Finding for Remote/Intermittent Support Workers

Based on the best available information, OSHA estimates that the proposed PEL of 50 $\mu\text{g}/\text{m}^3$ can likely be achieved for all remote/intermittent support workers. Exposures of 50 $\mu\text{g}/\text{m}^3$ or below have already been achieved for 50 percent of workers in this category. For the 50 percent of remote/intermittent support workers who require additional controls, OSHA preliminarily concludes that employers can reduce exposures below 50 $\mu\text{g}/\text{m}^3$ by using the same combination of engineering controls as described for fracturing sand workers.

Such controls include wet site-misting as well as ventilated equipment for conveying and transferring proppant in sand movers, conveyors, transfer belts, and blender hoppers. Effective LEV needs to be installed on thief hatches. This combination of controls will reduce the exposure of the most highly-exposed worker in this job category from 630 $\mu\text{g}/\text{m}^3$ to levels below 50 $\mu\text{g}/\text{m}^3$. OSHA notes that the exposure levels of all workers exposed at or below 770 $\mu\text{g}/\text{m}^3$ can be reduced to exposures of 50 $\mu\text{g}/\text{m}^3$ or less. As such, OSHA believes that even the highest exposed worker in this job category can achieve levels of 50 $\mu\text{g}/\text{m}^3$ or less. Given these estimates, OSHA's preliminary finding is that the proposed PEL of 50 $\mu\text{g}/\text{m}^3$ is feasible for most remote/intermittent support operations most of the time.

COSTS

OSHA estimated the cost to the hydraulic fracturing industry in three steps. OSHA first estimated the total number of employees in the industry, their job classifications and existing exposures. OSHA then estimated the costs of the necessary engineering controls. Finally, OSHA applied the costing methodologies, respirator unit costs, and program unit costs developed in Chapter 5 of this PEA to the exposure profile to develop estimates of the program costs and then added the total engineering control cost to these program costs to estimate total costs to the hydraulic fracturing industry.

Employment and Exposure Profile

The first step in developing the estimates of costs for the hydraulic fracturing industry was to determine how many workers are exposed to silica at what levels. To do this, OSHA first estimated the number of workers in various job categories and then applied the exposure data presented in the technological feasibility section of this appendix to estimate the number of workers subjected to various levels of silica exposure.

Based on data from the NIOSH site visits and discussions with several industry contacts, ERG estimated the distribution of workers at a representative hydraulic fracturing job site.

Table A-12 summarizes this representative job site by the number of workers performing various tasks and the workers' locations relative to dust exposures. As indicated, the workers most likely to have primary silica exposures, the operators of the sand moving, conveyance, and blending equipment, total 8,480 workers, or just over 50 percent of crew members nationwide.

The other fracking crew members generally can perform their functions without spending extended periods of time close to the sand moving and blending machinery – the site of the highest levels of respirable silica exposure. During the active (pumping) phases of hydraulic fracturing, which generally last two or three hours at a time, many of the fracking crew (as well as other oilfield workers present at the well site) can distance themselves from the immediate work vicinity and will typically congregate in control equipment or in trailers on site, well apart from (and preferably upwind) of the well pad.

Table A-12. Distribution of a Typical Hydraulic Fracturing Crew by Function

Estimated No. of Workers Per Site	Percent of Total	Primary Function	Classification Used in NIOSH Sampling Work	Aggregate Number of Workers
5	31.3%	Sand mover operator	Fracturing Sand Worker in the Central Area	5,300
1	6.3%	Conveyor belt tender	Fracturing Sand Worker in the Central Area	1,060
2	12.5%	Blender tender	Fracturing Sand Worker in the Central Area	2,120
1	6.3%	Hydration unit operator	Ancillary Support Worker	1,060
2	12.5%	Water/chemical hands	Ancillary Support Worker	2,120
3	18.8%	Pump operator technicians	Ancillary Support Worker	3,180
1	6.3%	Supervisor	Remote/ Intermittent Worker	1,060
1	6.3%	Ground guide (Sand coordinator)	Remote/ Intermittent Worker	1,060
16	100.0 %	Total—Fracking Crew		16,960

Source: ERG, 2013.

Table A-13 combines data on exposure from the technological feasibility section of this appendix with the data in Table A-12 to provide the estimated total number of workers currently at risk from respirable silica exposure in the hydraulic fracturing industry, as well as the estimated number of workers at risk of silica exposure at or above 25 µg/m³, above 50 µg/m³, and above 100 µg/m³. An estimated 15,385 workers currently have silica exposures at or above the proposed action level of 25 µg/m³; an estimated 11,964 workers currently have silica exposures above the proposed PEL of 50 µg/m³; and an estimated 10,792 workers currently have silica exposures above 100 µg/m³ (the principal alternative to the proposed PEL under consideration by OSHA).

Table A-13. Number of Hydraulic Fracturing Workers Exposed to Silica, by Exposure Level

Category	Number of Affected Employees	Numbers of Affected Workers Exposed to Silica by Level			
		>0 µg/m ³	≥25 µg/m ³	>50 µg/m ³	>100 µg/m ³
Support Activities for Oil and Gas Operations	16,960	16,960	15,385	11,964	10,792
1) Hydraulic Fracturing Workers					
Sand Mover Operators	5,300	5,300	5,141	4,828	4,362
Conveyor Belt Tenders	1,060	1,060	1,060	1,060	1,060
Blender Tenders	2,120	2,120	2,120	1,836	1,130
2) Ancillary Workers					
Hydration unit operator	1,060	1,060	883	530	530
Water/chemical hands	2,120	2,120	1,766	1,060	1,060
Pump operator technicians	3,180	3,180	2,649	1,590	1,590
Supervisor	1,060	1,060	883	530	530
Sand coordinator	1,060	1,060	883	530	530
Remote/Intermittent Support Workers	8,480	8,480	5,868	4,893	1,306

Source: ERG, 2013.

Costs of Engineering Controls

To determine the costs of the engineering controls necessary to go from the existing general industry requirement of a PEL of 100 µg/m³ to a PEL of 50 µg/m³, OSHA first examined what engineering controls would be necessary to go from the existing exposure baseline shown in Table A-13 to a PEL of 50 µg/m³. OSHA determined that a combination of wet methods and partial enclosure and LEV controls would be sufficient to meet a PEL of 100 µg/m³. The engineering control costs of going from 100 µg/m³ to 50 µg/m³ are then the costs of LEV controls at thief hatches and operator enclosures. These engineering control costs are shown in Tables A-14, A-15 and A-16 for large, medium, and small fleets, respectively (the full derivation of the results in these tables can be found in ERG, 2013). OSHA emphasizes that there is considerable uncertainty in the cost estimates because most of the relevant engineering controls have not yet been deployed in oil fields or on the types of mobile equipment used in oil fields.

Table A-14. Summary of Costs of Controls for Large Fleets

Cost Element	Cost	Units	Baseline Compliance	Cost Factor	Cost/Cost Factor Explanation	Per Well or Sand Mover or Fracturing Fleet	Total Capital Cost	Aggregate Per Year; With Annualized Capital Costs	Comment
						Extrapolated Value			
LEV Controls at Thief Hatches									
NOV APPCO Baghouse Add-On to Sand Mover Equipment	\$45,000	Per Sand Mover	10%	4	Unit cost based on mid-point of \$40,000 to \$50,000 cost range. Cost factor—number sand movers per fleet.	\$180,000	\$33,480,000	\$4,766,799	\$40K to 50K depending on the machine (Galindo, 2012). The estimated cost is the installed cost.
<i>Operating and Maintenance Cost</i>	\$4,500		10%	4	Estimated at 10% of the equipment cost	\$18,000	\$3,348,000	\$3,348,000	
NOV APPCO Baghouse Add-On - Total Cost						\$198,000	\$36,828,000	\$8,114,799	
Dust Booths									
Dust booth for highly exposed workers	\$10,605.49		0%	1	A booth per sand mover is allocated	\$42,422	\$7,890,485	\$1,123,428	Cost per booth estimated by ERG, based on Cecala, et al., 2002, 2005, and BLS, 2011.
<i>Operating and Maintenance Cost</i>	\$1,060.55		0%	1	Estimated at 10% of the equipment cost	\$4,242	\$789,049	\$789,049	

Table A-14. Summary of Costs of Controls for Large Fleets (continued)

Oil and Gas Extraction (Hydraulic Fracturing)

Cost Element	Cost	Units	Baseline Compliance	Cost Factor	Cost/Cost Factor Explanation	Per Well or Sand Mover or Fracturing Fleet	Total Capital Cost	Aggregate Per Year; With Annualized Capital Costs	Comment
						Extrapolated Value			
Cost per well to deploy booths	\$37.25		0%	14,251	Applied to new and refractured deep wells per year			\$2,123,453	<p>Total refractured wells (5,718) and new fractured wells (35,000) were distributed across fleet size by percentage for each size category. Thus, for large fleets, 35% (=186/530) of total refractured wells (2,001 fleets) plus 35% of new fractured wells (12,250 fleets) sum to 14,251 as the cost factor shown.</p> <p>The percentages applied for small and medium fleets were, respectively, 19% (=100/530) and 46% (=244/530), producing cost factors of 7,736 (small fleets) and 18,730 (medium fleets).</p>
Dust Booths - Total Cost								\$4,035,929	

Source: ERG, 2013.

Table A-15. Summary of Costs of Controls for Medium-Sized Fleets

Cost Element	Cost	Units	Baseline Compliance	Cost Factor	Cost/Cost Factor Explanation	Per Fleet	Total Capital Cost	Aggregate Per Year; With Annualized Capital Costs	Comment
						Extrapolated Value			
LEV Controls at Thief Hatches									
NOV APPCO Baghouse Add-On to Sand Mover Equipment	\$45,000	Per Sand Mover	10%	3	Unit cost based on mid-point of \$40,000 to \$50,000 cost range. Cost factor—number sand movers per fleet.	\$135,000	\$29,646,000	\$4,220,923	\$40K to 50K depending on the machine (Galindo, 2012). The estimated cost is the installed cost.
<i>Operating and Maintenance Cost</i>	\$4,500		10%	1	Estimated at 10% of the equipment cost	\$13,500	\$2,964,600	\$2,964,600	
NOV APPCO Baghouse Add-On - Total Cost						\$148,500	\$32,610,600	\$7,185,523	
Dust Booths									
Dust booth for highly exposed workers	\$10,605.49		0%	1	A booth per sand mover is allocated	\$31,816	\$7,763,219	\$1,105,308	
<i>Operating and Maintenance Cost</i>	\$1,060.55		0%	1	Estimated at 10% of the equipment cost	\$3,182	\$776,322	\$776,322	
Cost per well to deploy booths	\$37.25		0%	18,730	Applied to new and refractured medium-depth			\$2,093,118	See Table A-14 for explanation of cost factor calculation.

Cost Element	Cost	Units	Baseline Compliance	Cost Factor	Cost/Cost Factor Explanation	Per Fleet	Total Capital Cost	Aggregate Per Year; With Annualized Capital Costs	Comment
					wells per year				
Dust Booths - Total								\$3,974,748	

Source: ERG, 2013.

Table A-16. Summary of Control Costs for Small Fleets

Cost Element	Cost	Units	Baseline Compliance	Cost Factor	Cost/Cost Factor Explanation	Per Fleet/Per Well	Total Capital Cost	Aggregate Per Year; With Annualized Capital Costs	Comment
LEV Controls at Thief Hatches									
NOV APPCO Baghouse Add-On to Sand Mover Equipment	\$45,000	Per Sand Mover	10%	1	Unit cost based on mid-point of \$40,000 to \$50,000 cost range. Cost factor— number sand movers per fleet.	\$45,000	\$4,050,000	\$576,629	\$40K to 50K depending on the machine (Galindo, 2012). The estimated cost is the installed cost.
<i>Operating and Maintenance Cost</i>	\$4,500		10%	1	Estimated at 10% of the equipment cost	\$4,500	\$405,000	\$405,000	
NOV APPCO Baghouse Add-On - Total Cost						\$49,500	\$4,455,000	\$981,629	

Oil and Gas Extraction (Hydraulic Fracturing)

Cost Element	Cost	Units	Baseline Compliance	Cost Factor	Cost/Cost Factor Explanation	Per Fleet/Per Well	Total Capital Cost	Aggregate Per Year; With Annualized Capital Costs	Comment
						Extrapolated Value			
Dust Booths									
Dust booth for highly exposed workers	\$10,605.49		0%	1	A booth per sand mover is allocated	\$10,605	\$1,060,549	\$150,998	
<i>Operating and Maintenance Cost</i>	\$1,060.55		0%	1	Estimated at 10% of the equipment cost	\$1,061	\$106,055	\$106,055	
Cost per booth to deploy to well	\$37.25		0%	7,736	Applied to new and refractured shallow wells per year			\$288,183	See Table A-14 for explanation of cost factor calculation.
Dust Booths- Total Cost								\$545,236	

Source: ERG, 2013.

Total Costs

This section summarizes the total engineering and program costs for hydraulic fracturing establishments using discount rates of 0%, 3% and 7% respectively. Program costs are disaggregated into five categories – respirator costs, exposure monitoring, medical surveillance, training, and regulated areas. ERG noted that current respirator use for hydraulic fracturing establishments was very high and estimated current respirator compliance rates to be 98 percent (ERG, 2013, p. 6-14). With the exception of respirator usage and other fracking-specific inputs as noted in ERG (2013), costs were estimated by applying the methods and estimates presented in Chapter 5 for program costs to the industrial profile and exposure profile data presented in this appendix for the hydraulic fracturing industry. The total cost for reducing worker exposures from the current silica dust Permissible Exposure Limit (PEL) to the proposed PEL is \$28.2 million per year at 7% discount rate. Table A-17 presents the combined control and program costs. The table shows that program costs are the highest for exposure monitoring, followed by respiratory costs, medical surveillance, training and regulated area, in that order. The net control costs and program costs range from \$24.5 million per year to \$28.2 million per year with the discount rate assumptions given. Table A-18 presents, over a ten-year period, the undiscounted stream of compliance costs for hydraulic fracturing.

Table A-17. Total Costs for Hydraulic Fracturing Establishments Affected by the Proposed Silica Standard

Items	Rate		
	0%	3%	7%
Engineering Control Costs	\$21,282,804	\$22,728,276	\$24,837,864
Program Costs			
<i>Respirator Costs</i>	\$6,732	\$7,312	\$8,158
<i>Exposure Monitoring</i>	\$2,616,582	\$2,635,204	\$2,662,381
<i>Medical Surveillance</i>	\$397,877	\$415,845	\$442,936
<i>Training</i>	\$182,647	\$190,251	\$201,349
<i>Regulated Areas</i>	\$414,194	\$415,613	\$417,683
Total	\$24,900,837	\$26,392,500	\$28,570,371

Source: ERG, 2013.

Table A-18: Compliance Costs in Hydraulic Fracturing by Year After Promulgation of the Silica Standard (over 10-Year Period): Undiscounted Values

Year	Engineering Controls	Program Requirements [a]	Total
1	\$96,784,033	\$6,150,807	\$102,934,840
2	\$12,893,779	\$3,145,522	\$16,039,301
3	\$12,893,779	\$3,145,522	\$16,039,301
4	\$12,893,779	\$3,879,585	\$16,773,364
5	\$12,893,779	\$3,217,315	\$16,111,094
6	\$12,893,779	\$3,217,315	\$16,111,094
7	\$12,893,779	\$3,402,773	\$16,296,552
8	\$12,893,779	\$3,255,149	\$16,148,928
9	\$12,893,779	\$3,255,149	\$16,148,928
10	\$12,893,779	\$3,348,686	\$16,242,465

[a] Includes costs for respirators and respirator programs.
ERG, 2013.

BENEFITS AND NET BENEFITS

Introduction

Earlier in this Appendix, OSHA estimated the number of workers exposed to silica at various exposure levels currently in the hydraulic fracturing industry. In the cost section, OSHA derived the estimated costs of reducing respirable crystalline silica exposures from the existing PEL of 100 to 50 mcg, as required by the proposal. In this section of this appendix, the Agency applies the benefits models described in Chapter VII, Benefits, and estimates the benefits specific to lowering exposures to fracking operations. The Agency then estimates the net monetized benefits of the rule for this industry (the monetized benefits minus the costs).

Fatalities and Cases Avoided

Applying the risk models introduced in the Benefits chapter, the Agency estimates that between 9 and 14 lives will be saved, and 41 silicosis morbidity cases prevented annually as a result of the proposal. The results are presented in Table A-19. OSHA notes that these estimates are based on an assumption of a 45-year working life and thus do not reflect the point made in the ERG report that “long-term exposures to silica during

fracking might be mitigated to some extent by the mobility of the workforce” (ERG, 2013, p. 4-14).⁵⁰

Table A-19
Estimated Avoided Fatal & Nonfatal Illnesses, by PEL, Resulting from a Reduction in Exposure to Crystalline Silica Exposure of At-Risk Workers over a 45-Year Working Life Due to Proposed PEL of 50 µg/m³

	Total Avoided Cases	Annual Avoided Cases
Lung Cancers		
High	225	5.0
Midpoint	130	2.9
Low	34	0.8
Silicosis & Other Non-Malignant Respiratory Diseases	285	6.3
Renal Disease	103	2.3
Total Number of Fatal Illnesses Prevented		
High	613	14
Midpoint	518	12
Low	423	9
Total Number of Silicosis Morbidity Cases Prevented*	1,836	40.8

*Assessed at 2/1 or higher X-ray, following ILO criteria
 Source: U.S. Department of Labor, Occupational Safety and Health Administration, Directorate of Standards and Guidance, Office of Regulatory Analysis.

Monetized Benefits and Net Benefits

Monetizing the benefits shown above, using the approach described in Chapter VII of the PEA, the Agency estimates that the proposal will provide annualized benefits from avoided silica-related mortality and morbidity in the fracking industry of between \$39 and \$171 million, with a mid-point annualized value of \$104 million employing a 3 percent discount rate.

As shown in Table A-20, the Agency also estimated the benefits using four other discount rate functions. Applying the cost estimate of \$28.2 million described earlier in

⁵⁰ For a discussion of working lives, see this PEA’s Chapter VII: Benefits and Net Benefits.

this appendix, the Agency also derived the net benefits of the proposal for this industry. Under any of the five discount rate scenarios estimated, the proposal generates net benefits. As shown in Table A-20, at the 3 percent discount rate, this implies net benefits of \$76 million at the midpoint. Table A-21 presents undiscounted monetized benefits by year for the sixty-year time horizon after promulgation of the standard. These benefits reach a steady-state peak of \$412.2 million in the 60th year.

**Table A-20
Total Annual Monetized Benefits and Net Benefits Associated with a Reduction in Exposure to Crystalline Silica Due to Proposed PEL OF 50 µg/m³**

		Incremental Monetized Benefit	Net Benefit
Undiscounted (0%)	Low	\$51,971,217	\$27,070,380
	Midpoint	\$140,337,272	\$115,436,435
	High	\$228,703,326	\$203,802,490
Discounted at 3%, with a suggested increase in monetized benefits over time	Low	\$47,725,658	\$21,333,158
	Midpoint	\$128,437,316	\$102,044,815
	High	\$209,148,973	\$182,756,473
Discounted at 3%	Low	\$39,465,202	\$13,072,701
	Midpoint	\$105,429,325	\$79,036,825
	High	\$171,393,448	\$145,000,948
Discounted at 7%, with a suggested increase in monetized benefits over time	Low	\$32,340,540	\$3,770,169
	Midpoint	\$85,737,078	\$57,166,708
	High	\$139,133,617	\$110,563,247
Discounted at 7%	Low	\$28,525,979	(\$44,392)
	Midpoint	\$75,070,378	\$46,500,008
	High	\$121,614,777	\$93,044,407

Source: U.S. Department of Labor, Occupational Safety and Health Administration, Directorate of Standards and Guidance, Office of Regulatory Analysis.

Table A-21: Benefits in Hydraulic Fracturing by Year After Promulgation of the Silica Standard (60-Year Time Horizon): Undiscounted Values

Year After Promul-gation	Undiscounted Value of Cases Prevented by Year After Promulgation (\$M)					
	Lung Cancer	Lung Diseases Other Than Cancer	End-Stage Renal Disease	Total	Value of Morbidity Cases Prevented	Grand Total
1	\$0.0	\$1.5	\$0.6	\$2.1	\$2	\$4.4

Oil and Gas Extraction (Hydraulic Fracturing)

2	\$0.0	\$3.0	\$1.1	\$4.1	\$5	\$8.8
3	\$0.0	\$4.5	\$1.7	\$6.2	\$7	\$13.2
4	\$0.0	\$6.0	\$2.3	\$8.3	\$9	\$17.7
5	\$0.0	\$7.5	\$2.9	\$10.4	\$12	\$22.1
6	\$0.0	\$9.0	\$3.4	\$12.4	\$14	\$26.5
7	\$0.0	\$10.5	\$4.0	\$14.5	\$16	\$30.9
8	\$0.0	\$12.0	\$4.6	\$16.6	\$19	\$35.3
9	\$0.0	\$13.5	\$5.2	\$18.7	\$21	\$39.7
10	\$0.0	\$15.0	\$5.7	\$20.7	\$23	\$44.1
11	\$0.0	\$16.5	\$6.3	\$22.8	\$26	\$48.6
12	\$0.0	\$18.0	\$6.9	\$24.9	\$28	\$53.0
13	\$0.0	\$19.5	\$7.5	\$27.0	\$30	\$57.4
14	\$0.0	\$21.0	\$8.0	\$29.0	\$33	\$61.8
15	\$0.0	\$22.5	\$8.6	\$31.1	\$35	\$66.2
16	\$0.8	\$24.0	\$9.2	\$34.0	\$37	\$71.5
17	\$1.7	\$25.5	\$9.8	\$36.9	\$40	\$76.7
18	\$2.5	\$27.0	\$10.3	\$39.9	\$42	\$82.0
19	\$3.4	\$28.5	\$10.9	\$42.8	\$44	\$87.2
20	\$4.2	\$30.0	\$11.5	\$45.7	\$47	\$92.5
21	\$5.0	\$31.5	\$12.1	\$48.6	\$49	\$97.8
22	\$5.9	\$33.0	\$12.6	\$51.5	\$51	\$103.0
23	\$6.7	\$34.5	\$13.2	\$54.4	\$54	\$108.3
24	\$7.6	\$36.0	\$13.8	\$57.4	\$56	\$113.5
25	\$8.4	\$37.5	\$14.4	\$60.3	\$59	\$118.8
26	\$9.3	\$39.0	\$14.9	\$63.2	\$61	\$124.0
27	\$10.1	\$40.5	\$15.5	\$66.1	\$63	\$129.3
28	\$10.9	\$42.0	\$16.1	\$69.0	\$66	\$134.6
29	\$11.8	\$43.5	\$16.7	\$71.9	\$68	\$139.8
30	\$12.6	\$45.0	\$17.2	\$74.8	\$70	\$145.1
31	\$13.5	\$46.5	\$17.8	\$77.8	\$73	\$150.3
32	\$14.3	\$48.0	\$18.4	\$80.7	\$75	\$155.6
33	\$15.1	\$49.5	\$19.0	\$83.6	\$77	\$160.8
34	\$16.0	\$51.0	\$19.5	\$86.5	\$80	\$166.1

Table A-21: Benefits in Hydraulic Fracturing by Year After Promulgation of the Silica Standard (60-Year Time Horizon): Undiscounted Values (continued)

Year After Promul-gation	Undiscounted Value of Cases Prevented by Year After Promulgation (\$M)					
	Lung Cancer	Lung Diseases Other Than Cancer	End-Stage Renal Disease	Total	Value of Morbidity Cases Prevented	Grand Total
35	\$16.8	\$52.5	\$20.1	\$89.4	\$82	\$171.3
36	\$17.7	\$54.0	\$20.7	\$92.3	\$84	\$176.6
37	\$18.5	\$55.5	\$21.3	\$95.3	\$87	\$181.9
38	\$19.4	\$57.0	\$21.8	\$98.2	\$89	\$187.1
39	\$20.2	\$58.5	\$22.4	\$101.1	\$91	\$192.4
40	\$21.0	\$60.0	\$23.0	\$104.0	\$94	\$197.6
41	\$21.9	\$61.5	\$23.6	\$106.9	\$96	\$202.9

Oil and Gas Extraction (Hydraulic Fracturing)

42	\$22.7	\$63.0	\$24.1	\$109.8	\$98	\$208.1
43	\$23.6	\$64.5	\$24.7	\$112.8	\$101	\$213.4
44	\$24.4	\$66.0	\$25.3	\$115.7	\$103	\$218.7
45	\$25.2	\$67.5	\$25.9	\$118.6	\$105	\$223.9
46	\$26.1	\$67.5	\$25.9	\$119.4	\$105	\$224.8
47	\$26.9	\$67.5	\$25.9	\$120.3	\$105	\$225.6
48	\$27.8	\$67.5	\$25.9	\$121.1	\$105	\$226.4
49	\$28.6	\$67.5	\$25.9	\$122.0	\$105	\$227.3
50	\$29.5	\$67.5	\$25.9	\$122.8	\$105	\$228.1
51	\$30.3	\$67.5	\$25.9	\$123.6	\$105	\$229.0
52	\$31.1	\$67.5	\$25.9	\$124.5	\$105	\$229.8
53	\$32.0	\$67.5	\$25.9	\$125.3	\$105	\$230.6
54	\$32.8	\$67.5	\$25.9	\$126.2	\$105	\$231.5
55	\$33.7	\$67.5	\$25.9	\$127.0	\$105	\$232.3
56	\$34.5	\$67.5	\$25.9	\$127.8	\$105	\$233.2
57	\$35.3	\$67.5	\$25.9	\$128.7	\$105	\$234.0
58	\$36.2	\$67.5	\$25.9	\$129.5	\$105	\$234.9
59	\$37.0	\$67.5	\$25.9	\$130.4	\$105	\$235.7
60	\$37.9	\$67.5	\$25.9	\$131.2	\$105	\$236.5
Total - 60 Years				\$4,418	\$4,002	\$8,420.2

**Annualized over 60
years:**

\$140.3

Source: ERG, 2013.

Economic Feasibility and Regulatory Flexibility Findings

Economic Feasibility

This section presents the total costs of the proposed silica standard on establishments and entities as a percentage of their revenues and as a percentage of their profits. The estimated costs are presented in Table A-22 at a discount rate of 7%.

As noted in the industry profile, OSHA judged that there are virtually no firms with fewer than 10 employees performing hydraulic fracturing. The Agency also judged that the firms in the second smallest employee size category, those with 10 to 19 employees, comprised the totality of the firms that would be sufficiently small as to fall under the Small Business Administration (SBA) definition of a small entity for the industry – defined as a firm with \$7 million or less in annual revenues. Thus, ERG estimated, and OSHA concurred, that these two groups of firms – those with 10 to 19 employees and those that meet the definition of an SBA-defined small entity - were the same. OSHA estimated that nearly all firms with over 20 employees were generating over \$7 million per year in the current market conditions and therefore would not be considered to be small entities based on SBA definitions.

OSHA calculated that, if the control technologies that have been used in other industries can be successfully transferred to the hydraulic fracturing setting, the compliance costs would equal less than one percent of average revenues and less than five percent of average profits for recent years for the hydraulic fracturing sector as a whole and for small entities. Costs of this magnitude are small enough that, as explained in the economic feasibility section, there will be no significant impact on the economic viability of firms in this sector. Specifically, any price increases or output reductions resulting from compliance with this standard would not be of a magnitude sufficient to threaten the survival of a significant number of affected entities.

The demand for hydraulic fracturing services is derived from the demand for oil and gas production. Hydraulic fracturing firms are hired by oil and gas lease holders and production companies to facilitate the recovery of oil and gas. As such, the benefits of hydraulic fracturing services are often quite large, namely the flow of production or the enhanced flow of production from the well. In this context, the expected value of the hydraulic fracturing services is quite large and provides substantial surplus value to upstream production companies in light of the enormous energy reserves released at modest cost.

Industry contacts noted that hydraulic fracturing firms would generally be able to pass the costs of silica dust control on to their customers, the oil and gas producers. The large bulk of the hydraulic fracturing work is occurring as part of the completion of large oil and gas drilling operations. The incremental cost of the hydraulic fracturing work is very small in the context of the overall well completion costs, which frequently run from \$1 million to

\$3.5 million. This range corresponds roughly to the cost of hydraulic fracturing services for 10 to 25 stages at a total cost of \$100,000 to \$140,000.

Table A-22: Costs as a Percentage of Revenues and Profits for Hydraulic Fracturing (at 7% Discount Rate)

NAICS	Industry	Total Costs	Total Affected Establishments	Cost per Affected Estab.	Revenues per Estab. [a]	Profit Rate [b]	Profits per Estab.	Cost as % of Rev.	Cost as % of Profits
All Establishments									
213112	Support Activities for Oil and Gas Operations	\$28,155,401	444	\$63,413	\$18,513,145	10.31%	\$1,908,705	0.3%	3.3%
SBA Entities									
213112	Support Activities for Oil and Gas Operations	\$2,630,358	100	\$26,304	\$5,475,000	10.31%	\$564,473	0.5%	4.7%

[a] Revenues inflated from 2006 to 2009 dollars based on the GDP implicit price deflator.

[b] IRS, 2002 to 2006

Source: ERG 2013

Regulatory Flexibility Findings

OSHA conducted a SBREFA panel and presented an initial regulatory flexibility analysis in the PEA. For regulatory flexibility purposes, OSHA defines costs in excess of one percent of revenues or 5 percent of profits as constituting a significant economic impact. OSHA thus determines that the proposed rule would not have significant economic impacts on small entities in the hydraulic fracturing industry. Nevertheless, OSHA considered the regulatory flexibility issues for the industry and modified the proposed general industry rule with respect to regulated areas to allow a more flexible approach that may be better suited to the changing nature of the fracturing worksite.

Though the costs do not represent a significant impact on small firms in the hydraulic fracturing industry, small firms in the industry commonly do very small re-frac jobs on the most marginal oil and gas properties. As was noted above, some small hydraulic fracturing operators have much smaller budgets and the re-frac, while useful to restore or enhance existing production, will generate much smaller returns to the oil and gas producer. It is possible that some of the incremental costs in this context might not be as recoverable as for larger firms. OSHA welcomes additional information on very small fracturing firms and any comments on this issue.

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