Working Paper

# Barriers to the Commercialization and Adoption of New Underground Coal Mining Technologies in the U.S.

## Interim Results

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# Preface

This report presents interim results of a project characterizing barriers to the development, commercialization, and adoption of new technologies for use in underground coal mining in the U.S. The findings are based on structured interviews with representatives of organizations involved in the U.S. underground coal mining technology market. The full scope of the project includes a workshop in which barriers will be refined and prioritized and options for eliminating barriers will be developed. The results of the workshop will be incorporated into a final report published at a later date.

This research was sponsored by the Mining Program of the National Institute for Occupational Safety and Health (NIOSH). The findings are intended to help the NIOSH Mining Program achieve its goal of enhancing and expediting the development and commercial availability of new mine safety technology and technological applications. The findings are also expected to support the U.S. Mine Safety and Health Administration's ongoing efforts to update mine safety regulations.

RAND Social and Economic Well-Being is a division of the RAND Corporation that seeks to actively improve the health and social and economic well-being of populations and communities throughout the world. This research was conducted in the Community Health and Environmental Policy Program within RAND Social and Economic Well-Being. The program focuses on such topics as infrastructure, science and technology, community design, community health promotion, migration and population dynamics, transportation, energy, and climate and the environment, as well as other policy concerns that are influenced by the natural and built environment, technology, and community organizations and institutions that affect well-being. For more information, email chep@rand.org.

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# Summary


While the U.S. coal mining market has been contracting in recent years as demand for coal has slackened, it remains substantial. The industry produced 706 million short tons of coal in 2019, 38% of which (267 million short tons) was produced in underground coal mines by 32,000 workers in 15 states. Underground coal mining is a highly specialized industry. The combination of the harsh environment, heavy equipment, physical hazards, and toxic and flammable atmospheres creates a challenging operating environment and hazardous working conditions. Because of the inherent challenges in developing reliable and safe mining technology, as well as the historical economic importance of the mining sector, the federal government has long provided both support and oversight for technology development and use in mining.

Three multiple-fatality coal mining accidents in 2006 led Congress to pass the Mine Improvement and New Emergency Response Act (MINER Act) of 2006. Among other topics, the MINER act addresses research and development of safety technology for underground coal mining. An important element of the Act was the establishment the Office of Mine Safety and Health Research within NIOSH to expedite the development and commercial availability of new safety technologies for underground coal mining. While the NIOSH Mining Program has facilitated the development of several new technologies to improve underground coal mining safety and health, it has observed that the commercialization and widespread adoption of technologies faces formidable barriers.

To improve its ability to carry out its charge under the MINER Act, NIOSH desires to better understand these barriers and explore their implications for NIOSH research. The objective of this study was to characterize the barriers to commercial availability and implementation of safety and health protection technology in U.S. underground coal mines. RAND undertook this task by conducting a series of structured interviews with representatives of a sample of organizations having a stake in the U.S. underground coal mining market.

RAND conducted 75 interviews with representatives of 54 organizations that spanned a range of types directly or indirectly involved in the underground coal mining technology market, including engineering, design, construction, and consulting firms; labor organizations; legal firms; mining companies; professional organizations; regulatory agencies; research & development organizations; standard development organizations; suppliers of major equipment; and suppliers of other technology.

Through these interviews we identified and characterized 24 barriers. To help understand the origins of barriers and potential options for addressing them, we distinguished three groups of barriers (economic, regulatory, and other) and several sub-groups within each group. The majority of identified barriers (15, or 63%) are associated with regulatory issues, and fall into 6

sub-groups reflecting different aspects of the regulatory process to approve technology for use in underground coal mines: the cost of approval, the duration of the approval process, the currency of regulations, the prescriptiveness of standards, operator burden, and regulatory culture. Most of the other barriers (6, or 25%) are associated with economic factors, including insufficient demand, insufficient supply, and the specialized market for underground coal mining. The remaining 3 barriers, grouped as "other," are associated with mine operator culture, liability, and federal support.

The individual barriers span a range of specific issues, and in several cases interview participants provided examples illustrating their implications. Most barriers have the effect of dissuading suppliers from developing new technologies, updating existing technologies, or even from entering or remaining in the underground coal mining market at all.

The most commonly cited barrier was cited in 29 of the 75 interviews, while two barriers were cited in just once each. The five most commonly cited barriers and the number of times they were cited were:

- Duration of technology approval dissuades developers (29)
- Small U.S. market makes it difficult for suppliers to recoup investments in new technology (26)
- Shrinking market leads to incumbent dominance (23)
- MSHA-specific standards isolate U.S. underground coal mining market (21)
- Cost of technology approval dissuades developers (19)

The findings have implications for NIOSH. For example, one barrier is that mine operators are reluctant to exceed regulatory requirements for safety technology. In light of this behavior, NIOSH may want to consider potential regulatory requirements when investing in new technology research, avoiding technologies that are unlikely to help operators meet regulatory requirements. Similarly, even in the case of a new technology that could, in principle, help operators meet regulatory requirements, if it is particularly novel, technology suppliers may face challenges in obtaining MSHA approval or decide that it's not worth the effort and risk to even attempt it. In terms of ways in which NIOSH may facilitate the elimination of barriers, NIOSH research on the equivalency between MSHA and IECEx standards has already proven essential to MSHA's willingness to consider granting technology approval according to IECEx standards in lieu of MSHA standards. The majority of barriers, however, relate to issues that are beyond NIOSH's direct influence and NIOSH is likely to play a secondary role in addressing them.

# Abbreviations

| | |
|---|---|
| EIA | U.S. Energy Information Administration |
| IECEx | International Electrotechnical Commission System for Certification to Standards Relating to Equipment for Use in Explosive Atmospheres |
| MINER Act | Mine Improvement and New Emergency Response Act of 2006 |
| MSHA | Mine Safety and Health Administration |
| NIOSH | National Institute for Occupational Safety and Health |
| OMB | U.S. Office of Management and Budget |
| VCS | voluntary consensus standard |

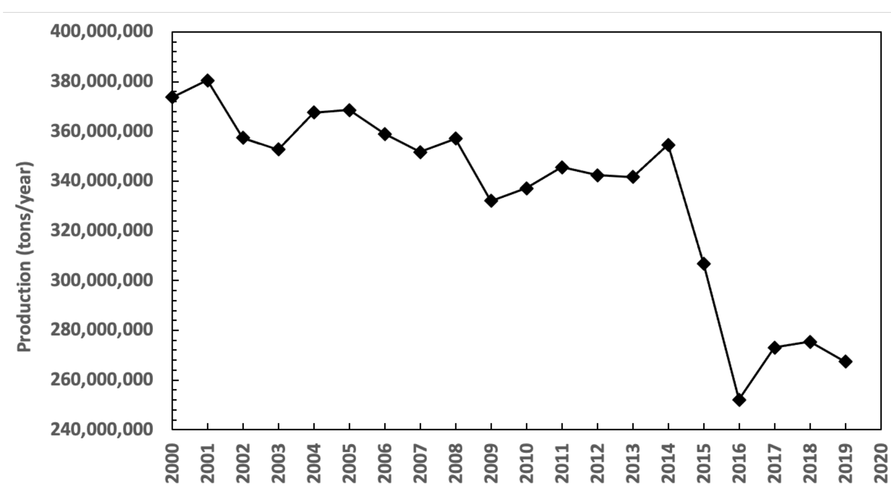
# Introduction

## Underground Coal Mining in the United States

The underground coal mining industry in the United States in 2019 employed approximately 32,000 workers in 226 mines in 15 states and produced approximately 267 million short tons of coal, primarily for electric power generation (U.S. Energy Information Administration (EIA), 2020). This underground production represented 38 percent of the total coal produced in the U.S., with the remaining 62 percent coming from surface mines. About 55 percent of underground production was from mines that use primarily longwall mining operations, 44 percent was from mines that use primarily continuous mining operations, and less than 1 percent was from mines that use conventional or other mining methods (EIA, 2020).

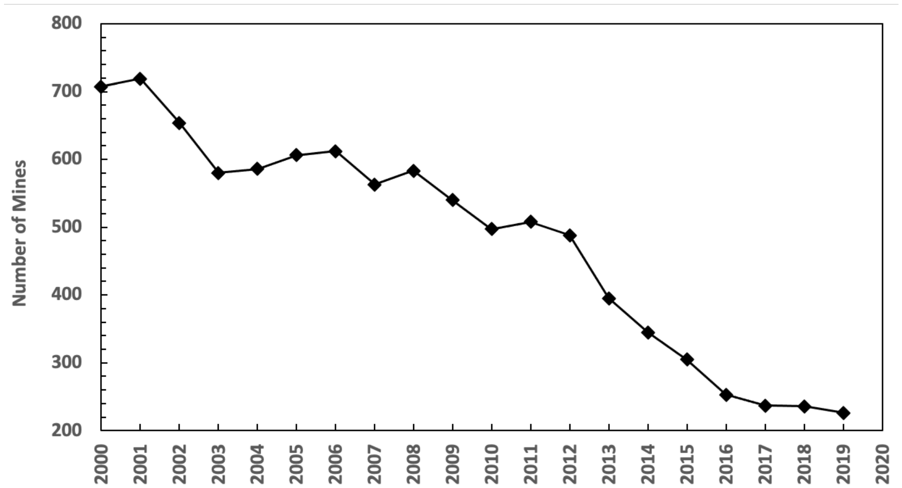
These statistics are in flux, as coal production in the U.S., including both surface and underground, has been declining for several years. Historical trends for underground coal mining production, number of mines, and employment are shown in Figures 1.1. 1.2. and 1.3, respectively. The reason for the increase in employment from 2003–2012, despite decreases in production and the number of mines during this period, is unknown. In addition to reducing employment and production, the contraction of the market has reduced the number of companies through mergers and bankruptcies, among both mine operators (e.g., the bankruptcy of Murray Energy, formerly the largest producing underground coal mining company in the U.S.) and technology suppliers (e.g., the merger of Joy Global and Komatsu Limited).

**Figure 1.1–U.S. Underground Coal Mining Production Over Time**



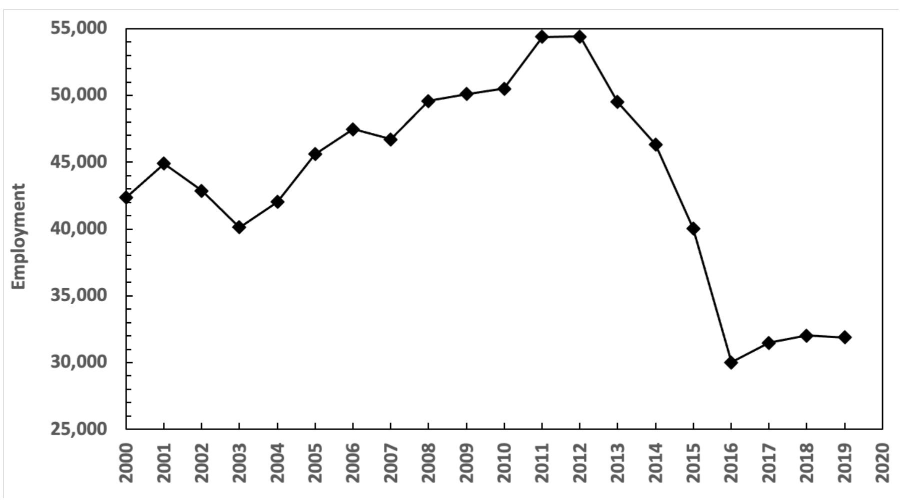

Source: EIA (2001–2020)

**Figure 1.2–Number of U.S. Underground Coal Mines Over Time**




Source: EIA (2001–2020)

**Figure 1.3–U.S. Underground Coal Mining Employment Over Time**




Source: EIA (2001–2020)

Worldwide coal production in 2019 was 8.7 billion short tons (International Energy Agency, 2020). China was the leading producer by far, accounting for 47 percent of the total. India was the second largest producer, with 10 percent of the total, and the U.S. was third with 8 percent. Relative proportions of underground and surface coal production are not available for global coal production, although the World Coal Association notes that, "underground mining currently accounts for a bigger share of world coal production than opencast" (World Coal Association, 2020).

Underground coal mining production in the United States is dominated by a few large companies, with several smaller companies contributing the remainder. As of 2014, five companies (Murray Energy Corporation, Alliance Resource Partners, Alpha Natural Resources, Consol Energy, and Foresight Energy) accounted for 54 percent of the market share for underground coal.[1] It should be noted these companies were not necessarily the top overall coal producers, as production from larger companies, such as Peabody Energy and Arch Resources, Inc., comes primarily from surface mining. The market is dynamic, however, and as it contracts, companies have merged and reorganized. Since 2014, Murray Energy Corporation acquired Foresight Energy, went bankrupt, and reemerged as American Consolidated Natural Resources, Inc. Similarly, Alpha Natural Resources and Contura Energy merged and have become Alpha Metallurgical Resources.

The market for major equipment for underground coal mining in the U.S. is dominated by a small number of companies. While the U.S. coal mining market has declined in recent years, analysts project a 5.5 percent annualized growth rate through 2021, taking the industry from $29.2 billion today to the 2013 revenue level of $38.2 billion in 2021 (IBISWorld Inc, 2016; Whitter, 2016). The main external drivers identified for this growth are increased electricity demand (~90 percent of U.S. coal production is thermal coal, used primarily for electricity generation) and an increase in the global price of thermal coal. The global market is similarly anticipated to grow at an annualized rate of 3.4 percent through 2021, reaching $822.4 billion. As part of this growth, the global market for underground coal mining equipment is expected to grow 7 percent per year and reach over $24 billion by 2019 (Stephans, 2016b).

## Factors Shaping the Underground Coal Mining Technology Market

Technology used in underground coal mining must be able to withstand the harsh physical conditions present in the mining environment. In addition, because of the special safety risks associated with underground coal mines, such as the presence of toxic and flammable gases and dust, equipment must be specially designed to minimize risks to workers. Because of the inherent challenges in developing reliable and safe mining technology, as well as the historical economic importance of the mining sector, the federal government has long provided both support and oversight for technology development and use in mining.

In December of 1907, President Roosevelt called for the creation of a bureau of mines that would "have power to collect statistics and make investigations in all matters pertaining to mining and particularly to the accidents and dangers of the industry" (Roosevelt, 1907). 1907 was (and still is) the most lethal year in U.S. history for underground coal mining disasters, with over 900 workers killed (NIOSH, undated a). Congress established the U.S. Bureau of Mines in 1910 (NIOSH, 2012). The principal activity of the Bureau of Mines was to help develop

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[1] Production data taken from company websites, form 10-K filings, and EIA Annual Coal Reports.

technologies and practices which would ensure the availability of mineral resources and which could be used safely in the presence of flammable gasses and dust.

Mining safety in the U.S. improved significantly over several decades. However, in 1968, after nearly 20 years of relatively few mining fatalities, 108 workers died in mining disasters, including 78 in a single disaster (NIOSH, undated a). In response, the federal government's oversight role was strengthened with the Federal Coal Mine Health and Safety Act of 1969.[2] This act established a suite of mandatory safety standards and mine inspection requirements, which included technology standards and approval authority. This government regulatory function, initially housed in the Bureau of Mines, was expanded and transferred to the newly established Mine Safety and Health Administration (MSHA) in 1977 as part of the Federal Mine Safety & Health Amendments Act.[3]

When the Bureau of Mines was closed in 1996, some of its functions were transferred to other federal agencies, while many activities were discontinued. The health and safety research work was transferred to the National Institute for Occupational Safety and Health (NIOSH), while other functions were transferred to the Department of Energy, the U.S. Geological Survey, and the Bureau of Land Management. Notably, most aspects of technology development, the primary function for which the Bureau of Mines was created, were not transferred to any agency and hence effectively abandoned.

Underground coal mining fatalities and fatality rates have continued to decline steadily over time (NIOSH, undated b). However, after 25 years of one or no underground coal mining disasters per year, three multiple-fatality mining accidents in 2006 at the Sago, Aracoma, and Darby mines led Congress to pass the Mine Improvement and New Emergency Response Act (MINER Act) of 2006.[4] The MINER act amended the Federal Mine Safety and Health Act of 1977 and the Occupational Safety and Health Act of 1970 to improve the safety of mines and mining. The MINER act addresses safety and health topics related to underground mining, particularly in the areas of emergency preparedness, rescue, accident investigations, and safety technology research and development.

Much progress has been attributed to the MINER act. For example, the Assistant Secretary for Mine Safety and Health noted in 2011 that, "We are finally seeing the installation of wireless or nearly wireless two-way communications and electronic tracking systems, as mandated by the MINER Act. I have no doubt that these impressive technologies would not have been developed for coal mines by the private sector had the MINER Act not adopted its aggressive technology-forcing provisions five years ago" (Main, 2012).

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[2] https://arlweb.msha.gov/solicitor/coalact/69act.htm; https://www.govinfo.gov/app/details/STATUTE-83/STATUTE-83-Pg742

[3] https://arlweb.msha.gov/regs/act/acttc.htm; https://www.fmshrc.gov/sites/default/files/response.htm

[4] https://arlweb.msha.gov/MinerAct/MinerActSingleSource.asp.

An important element of the MINER Act was the establishment the Office of Mine Safety and Health Research within NIOSH.[5] This Office, now called the NIOSH Mining Program, was created "to enhance the development of new mine safety technology and technological applications and to expedite the commercial availability and implementation of such technology in mining environments." The NIOSH Mining Program manages a $45 million portfolio of intramural and extramural research addressing key concerns related to safety technology and practices. Research priorities are identified based on assessments of burden, need, impact, stakeholder input, and the regulatory agenda including rulemaking by MSHA (NIOSH, 2021). In addition, the Mining Program engages in partnerships with its stakeholders to share information and solutions about some of the most pressing health and safety issues.

While the NIOSH Mining Program has facilitated the development of several new technologies to improve underground coal mining safety and health (NIOSH, 2019), it has observed that the commercialization and widespread adoption of technologies faces formidable barriers. First, some parts of the market are very specialized in terms of their specific technical needs, so many of the technologies must be purpose-built for underground coal mining. In addition, the working environment is hazardous and physically harsh, which puts extra constraints on the design and performance of technologies to ensure that they can operate safely and reliably. While safety concerns warrant careful regulatory oversight, there are indications that the current regulatory environment presents barriers to technology commercialization. The National Occupational Research Agenda Mining Sector Council (2015) has noted that the current regulatory environment would benefit from impartial review and research on alternative codes of practice and systems of regulation, as well as continued research to promote innovation in technologies to improve health and safety of mining personnel. Finally, as demand for coal decreases and the market contracts, opportunities for innovation, investment, and new entrants are limited.

## Purpose and Task of Study

The barriers to technology commercialization and adoption impede the NIOSH Mining Program's ability to carry out its charge under the MINER Act of expediting the commercial availability and implementation of new mine safety technology. As a federal research agency, NIOSH has limited visibility into the technology market. While the Mining Program partners with industry to help develop technologies and share information, the commercialization and adoption of technologies is ultimately up the technology suppliers and technology users (coal

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[5] NIOSH was established under the Occupational Safety and Health Act of 1970. The organization is part of the U.S. Centers for Disease Control and Prevention in the U.S. Department of Health and Human Services. The mission of the NIOSH Office of Mine Safety and Health Research, now the NIOSH Mining Program, is "to eliminate mining fatalities, injuries, and illnesses through relevant research and impactful solutions." (https://www.cdc.gov/niosh/mining/aboutus/aboutus.html)

mine operators). In order to improve the efficacy of the contract and grant awards that it administers under the authority of the MINER Act, NIOSH needs a more complete understanding of the barriers to technology commercialization and adoption from the point of view of the mine operators and technology innovators.

To this end, NIOSH asked RAND to characterize the barriers to commercial availability and implementation of safety and health protection technology in U.S. underground coal mines from the perspective of the organizations that purchase, use, approve, and manufacture these safety technologies. RAND undertook this task by conducting a series of structured interviews with representatives of a sample of organizations having a stake in the U.S. underground coal mining market (stakeholder representatives).

The findings of this work are intended to help the NIOSH Mining Program in two ways:

1. Help make the best use of the funds entrusted to NIOSH in its contracts and grants program to expedite the availability and implementation of technologies. While there are many technologies that NIOSH could fund, the money to do so is quite limited, and NIOSH desires to focus on those that provide the most benefit with some realistic possibility of being adopted by the mining industry. In order to assess the likelihood of adoption, a thorough understanding of the implementation barriers is essential.

2. Identify those barriers that NIOSH may be able to help alleviate in its role as a research organization. The findings will help provide an understanding of which issues are appropriate for NIOSH to try to influence. This is important because some of the suspected issues could require NIOSH to enter into research areas that require addition of new expertise and substantial commitment of resources. Such changes require a compelling justification given the finite pool of resources and the competing budget priorities.

# Study Method

## Study Scope and Interview Population

Identifying appropriate interview participants is important for ensuring that relevant knowledge about and experience with different technologies is considered in our exploration of barriers to commercialization and adoption. The population sampled for the interviews is representatives of organizations that participate in, either directly or indirectly, in the U.S. market for underground coal mining technology. Such stakeholder organizations include those that purchase, use, approve, and manufacture technology, as well as those that advise about or litigate issues related to technology use.

To help identify organizations, we first defined different categories of stakeholders. These include:

- *Engineering, Design, Construction, & Consulting*–companies that design, engineer, and/or construct underground coal mines; or companies and individuals that supply one or more of these services on a consulting or contract basis
- *Labor*–organizations that represent underground coal miners on labor issues (principally the United Mine Workers of America)
- *Legal*–firms or individuals that represent companies in litigation and in filing petitions, appeals, and other legal activities
- *Mining*–companies that own or operate underground coal mines
- *Professional*–organizations that have an interest in the advancement, safety, and regulation of underground mining
- *Regulatory*–government organizations that develop and enforce underground mining regulations
- *Research & Development*–government laboratories, universities, companies, and other entities involved in the research and development of technologies to improve mining operation efficiencies and the safety and health of underground coal miners
- *Standard Development*–non-governmental organizations that develop voluntary consensus standards for technology and procedures
- *Technology- Major Equipment*–suppliers of complete pieces of equipment used for underground coal mining operations (continuous miners, longwall shearers, bolters) or transportation (shuttle cars, personnel carriers)
- *Technology*–suppliers of technology (other than major equipment) used in underground coal mining

This range of types of organizations is intended to ensure that interview participants spanned a wide range in perspectives and experiences related to underground coal mining technology.

NIOSH's responsibility under the MINER Act and in general centers around technology addressing worker safety. However, when considering technology suppliers, we endeavored to cover a broad range of technologies used in underground coal mining that go beyond those strictly focused on worker safety. We took this approach because there are safety aspects associated with all technologies used in underground coal mining and because many safety technologies must integrate or interface with other mining equipment (e.g., proximity detection). In light of the high fire and explosion hazard in underground coal mines and the associated regulatory requirements for electrically-powered equipment used in them, our analysis focused primarily on electrical and electronic technologies. Technologies addressed in our analysis include:

- Air quality control, including powered respirators, ventilation systems, and emission controls
- Air quality monitoring, including gas sensors and dust monitors
- Communications and tracking, including asset and personnel tracking, proximity sensing, and audio and video communications
- Efficiency optimization, such as remote control and automation
- Emergency response, including refuge chambers, back up air supplies, fire suppression systems
- Mining operation, such as continuous miners, longwall shearers, bolters, and shuttle cars

Primarily mechanical or pneumatic technologies and materials, such as hearing protection, brattices and stoppings, rock dusting, and materials used for ground control, conveyer belts, cutting, etc., were not specifically pursued.

An important consideration in our search was to gain perspective on the issues associated with underground coal mining in the U.S. compared to those for underground coal mining in other countries and on issues with underground coal mining compared to those for other industries. To this end, we included organizations that:

- Operate both in the U.S. and in other countries
- Operate both in underground coal mining and in other industries

To identify stakeholder organizations, we drew on searches of technology supplier and mining company websites, mining publications, trade association websites and member directories, federal and state regulator websites, university mining research programs, and other sources. We also drew upon MSHA's List of Approved Products (MSHA, 2021) to identify technology suppliers. Our search was augmented with input from the NIOSH Mining Program staff. In addition, we reviewed 130 stakeholder comments about regulatory reform submitted to MSHA from 2017 to 2019 in response to its call for input as required by Executive Order 13777, "Enforcing the Regulatory Reform Agenda." From these comments we identified candidates that had expressed concerns about market barriers stemming from regulatory issues.

Because the visibility and relevance of organizations is inconsistent, we did not attempt to compile a comprehensive list of stakeholder organizations. We did, however, attempt to identify large, influential, and/or innovative organizations in each of the stakeholder categories. Our search was global, but we restricted our sample to those organizations that conduct operations within the United States.

Our sampling approach was to include essentially as many representatives from each category that we could enlist to participate. We also used a snowball sampling approach, in which we asked interview participants for suggestions for additional individuals or organizations to include.

## Interview Protocol

In order to maintain internal consistency and facilitate comparisons among interview participants, we developed structured interview protocols. The most important stakeholder categories were Technology, Technology- Major Equipment, and Mining (which comprised two-thirds of the interviews), so we developed the main interview protocol targeting representatives of organizations in these categories. For most other stakeholder categories, we used the same protocol, but skipped questions that did not apply to them. One exception was the Regulatory category, for which we developed a separate protocol. Interview protocols are presented in Appendix A.

The overall goal of the interviews was to characterize barriers to commercialization and adoption of new technologies for use in underground coal mining. The main interview protocol began with some general questions about the technology development process and technology awareness and selection. It then raised the question of what the main barriers to technology commercialization and adoption are, and what possible solutions to eliminating them might exist. When asking about barriers, we prompted interview participants to consider barriers stemming from economic, cultural, technical, regulatory, or other issues. However, we never provided examples or other types of prompts for anything more specific than these broad categories. The interviews ended with some questions probing for specific examples of consequences of these barriers, including technologies available in other countries or other industries but not underground coal mining in the U.S., technologies that were developed but never commercialized, and technologies not having a similar alternative that have been discontinued.

The Regulatory protocol was developed during the course of the interviews, based in part on findings from interviews with representatives of technology suppliers. Technology suppliers often cited aspects of the regulatory regime and process as significant barriers, which led to several questions for interviews with regulators. As a result, we deferred interviews with regulators until we had developed a suite of questions for them. Interviews with representatives from the Regulatory category were less focused on identifying barriers than on providing balance and context for the regulatory-related barriers identified by industry representatives. Some of the questions focused on the technology approval process, while others raised more general questions about the use of non-MSHA standards and the standard development process.

Interview candidates were contacted by email. All invitations that went unanswered were followed up with at least two reminder emails. In most cases, invitations were sent to individual representatives that had been identified ahead of time. In other cases, the invitations were sent to the organization's general information email address. The invitation described the objectives of the project and requested a one-hour interview. It also clearly stated that all interviews for this project were being conducted on a not-for-attribution basis, meaning that neither individuals' nor organizations' names would be revealed to anyone outside of RAND, including NIOSH. All reports to NIOSH and the public attribute findings only to the level of stakeholder category. We chose to present the findings anonymously because we anticipated that barriers to commercialization may involve regulatory issues and recognized the potential sensitivities involved in asking technology suppliers and others to discuss their concerns about the regulatory process in a public setting where they may fear retaliation from regulators. The message also noted that this study was not associated with any specific regulatory analysis or decision.

Interviews were conducted by telephone (no video) between January and November 2020. Each interview included a single interview participant and two members of the RAND team. In some cases, multiple individuals from the same organization were interviewed (separately). This usually occurred for larger organizations in which different people had different areas of expertise and experience and the representatives felt that it was important for us to meet with more than one person. Both RAND participants took notes during the interviews. In addition, interviews were recorded to provide an accurate transcript. Transcripts were not shared with anyone outside RAND, including NIOSH.

## Data Analysis

While the interview protocol included a number of different questions (Appendix A), the primary target of the analysis was to identify and characterize barriers to the commercialization and adoption of technologies. Questions 6–11 bear directly on this goal, and consequently were the main focus of both the interviews and the analysis. Questions 1–5 helped to set the stage and explore the technology development process, but typically shed little light on the question of barriers.

Results of the stakeholder interviews were analyzed using an adaptive content analysis approach sometimes referred to as recursive abstraction (Polkinghorne and Arnold, 2014; Oun and Bach, 2014; Polkinghorne and Taylor, 2019). This method is characterized by repeated summarization of the data into distinct themes, with the objective of reducing the number of themes and achieving increasingly higher levels of abstraction in each cycle. The appropriate extent of abstraction is driven by the objectives of the analysis. In our case, the primary objective was to identify and characterize individual barriers that are distinct from each other in terms of their origins and/or implications. An economic market such as that being examined here includes strong interdependencies (e.g., demand influences supply), making it sometimes difficult to unequivocally decide whether particular barriers are really distinct from each other. In keeping with the recursive abstraction approach, we endeavored to merge and minimize the number of barriers whenever a clear case for distinction was lacking. However, while this approach did result in defining some barriers that represent composites of multiple descriptions of slightly different issues, the amount of interpretation and abstraction required to characterize them was minimal. This helped us avoid one of the shortcomings of recursive abstraction, which is that final abstracted themes can become disconnected from the raw data and questions about reliability and reproducibility may arise. In effect, our analysis differed little from more conventional coding-based content analysis in which our abstracted themes (i.e., barrier groupings and individual barriers) are analogous to codes with the exception that they were allowed to be refined and merged as data were added.

We used the same approach to sort and group the barriers according to higher-level themes. These higher-level themes help to concisely convey more general sources of barriers, which will be useful when developing options for eliminating barriers and for understanding the roles of different actors in implementing the options.

When describing a barrier, interview participants often provided examples of instances in which that barrier was encountered. In addition, the interview protocol included questions specifically intended to elicit examples of challenges with technology availability that may result from barriers (Appendix A). We have included these examples in our presentation of results to help illustrate the kinds of challenges market stakeholders face.

A challenge with qualitative interviews is verifying the accuracy of the data. Most of the input from the interviews consists of personal experiences and opinions, for which verification is generally not possible or appropriate. But in cases where interview participants described more factual types of information, we did attempt to verify it. In many cases interview participants cited specifics of the regulatory process in their descriptions of barriers. Hence, an important source for verification was regulatory documents and interviews with representatives of regulatory agencies (primarily MSHA). These interviews served to provide context and clarification for statements about regulatory procedures and practices made by industry representatives.

# Results

## Response Rate and Distribution

We sent invitations to 180 interview candidates and conducted 75 interviews. This translates to overall response rate of 42%, which aligns with expectations based on experience from similar types of stakeholder interview projects we have conducted in the past. Of those that were not interviewed, half declined to participate and half did not respond (Table 1). Invitees that declined to participate generally provided no explanation for their decision. While interviews were conducted during the COVID-19 pandemic, interview candidates did not cite the pandemic as a reason for not participating. Most interviews took about an hour to complete.

**Table 1—Individual Interview Responses**

| Response Type | Number | Percent |
|---|---|---|
| Accepted and interviewed | 75 | 42 |
| Declined to participate | 52 | 29 |
| No response or invalid contact | 53 | 29 |
| Total | 180 | 100 |

Responses are presented by stakeholder category in Table 2. The 75 interviews were conducted among 54 organizations. The distribution of interviews among categories is generally similar to the distribution of candidates among categories, with the exception of the Research and Development and Legal categories. These categories are underrepresented in our sample compared to the other categories. This undersampling was deliberate, supported by the finding that most stakeholders in these categories offered relatively little insight into the questions we were pursuing. The interviews were dominated by the Technology, Technology- Major Equipment, and Mining categories, which together accounted for 65% of both interviews and organizations. Because of the contraction of the coal market in recent years, the number of companies operating underground coal mines has decreased substantially, leaving few active mine operators in the market. The number of suppliers of major underground coal mining equipment has also declined through mergers and market exits, leaving a very small pool of active companies.

**Table 2—Interviewee Organizational Demographics**

| Organization Type | Number of Interviews | Percent | Number of Organizations | Percent |
|---|---|---|---|---|
| Engineering, Design, Construction, & Consulting | 5 | 7 | 5 | 9 |
| Labor | 1 | 1 | 1 | 2 |
| Legal | 3 | 4 | 2 | 4 |
| Mining Company | 13 | 17 | 9 | 17 |
| Professional Association | 1 | 1 | 1 | 2 |
| Regulatory | 10 | 13 | 3 | 6 |
| Research & Development | 4 | 5 | 4 | 7 |
| Standards Development Organization | 2 | 3 | 2 | 4 |
| Technology Supplier | 26 | 35 | 24 | 44 |
| Technology Supplier- Major Equipment | 10 | 13 | 3 | 6 |
| Total | 75 | 100 | 54 | 100 |

We did not specifically keep track of which companies conduct business outside the U.S. or outside the underground coal mining market, but many if not most of the technology suppliers do one or both. In fact, several of the companies we met with that had their roots in underground coal mining told us that, as the coal market contracts, they are increasingly expanding to other markets, sometimes maintaining a presence in coal only to serve existing customers that depend on them.

## Barriers to Technology Commercialization and Adoption

Interview participants were generally prepared with thoughts on barriers to technology commercialization and adoption and were forthcoming in describing them. In many cases they provided examples that illustrated the challenges or implications of particular barriers. Many confirmed the sensitivities in discussing this subject and appreciated the fact that interviews were being conducted on a not-for-attribution basis. As described in the methods section, we provided no examples or prompts for barriers while conducting the interviews; all barriers were introduced by interview participants.

Our analysis identified 24 barriers (Table 3). To aid in navigating the origins of barriers and potential options for addressing them, we have divided the barriers into groups and sub-groups. The order in which barrier groups and sub-groups are listed are not significant. Most barriers fall in the regulatory group. Table 3 also shows the number of interviews in which a particular barrier was mentioned. The relative frequency with which a barrier was mentioned provides a measure of the pervasiveness of awareness and impact of that barrier among market stakeholders. Other comparative attributes of the barriers, such as the priority to the community, the magnitude of the impact, or the feasibility of eliminating it, will be addressed in an upcoming workshop and reported in a final project report.

**Table 3—Barrier Taxonomy**

| Barrier Group | Barrier Sub-Group | Barrier | Number of Interviews |
|---|---|---|---|
| Economic | Insufficient Demand | Small U.S. market makes it difficult for suppliers to recoup investments in new technology | 26 |
| | | Shrinking market leads to incumbent dominance | 23 |
| | | Mine operators lack funds to invest in new technology | 14 |
| | | Unwillingness to exceed regulatory requirements for safety technology | 11 |
| | Insufficient Supply | Technology developers lack resources to commercialize | 4 |
| | Specialized market | Harsh physical environment in mines dissuades potential developers | 4 |
| Regulatory | MHSA Approval Cost | Cost of technology approval dissuades developers | 19 |
| | MSHA Approval Duration | Duration of technology approval dissuades developers | 29 |
| | | Technology approval applications are sent to end of queue when discrepancies are found | 5 |
| | | Lack of transparency about technology approval application status | 5 |
| | | Poor coordination between MSHA & NIOSH | 2 |
| | Currency of MSHA Regulations | MSHA standards are out of date | 16 |
| | | MSHA regulatory environment is unequipped to address new technology | 3 |
| | Prescriptiveness of MSHA Standards | Prescriptiveness crowds out novel approaches | 18 |
| | | MSHA-specific standards isolate U.S. underground coal mining market | 21 |
| | | MSHA approval requires revealing proprietary information | 1 |
| | | Reapproval of technology is required for small design or part changes | 14 |
| | Operator Burden | Exceeding minimum safety requirements opens mine operators to citation for failure of non-required features | 6 |
| | | Exceeding minimum safety requirements can reveal unknown risks | 2 |
| | | The regulatory burden of operating some technologies dissuades operators from using them | 1 |
| | Regulatory Culture | Conservative and risk averse culture | 13 |
| Other | Cultural | Mine operators are resistant to change | 11 |
| | Liability | Greater liability risk in U.S. compared to other countries acts as disincentive to enter market | 4 |
| | Federal Support | No federal agency is addressing mining technology needs | 5 |

Below we discuss each of these barriers in more detail. Unless otherwise noted, the material presented is drawn directly from interviews.

## *Economic Barriers*

We identified 6 barriers that we grouped as stemming from economic factors, which we further divided into 3 sub-groups: Insufficient Demand, Insufficient Supply, and Specialized Market. All of these barriers are related to the small and shrinking size of the underground coal mining market.

### Insufficient Demand

#### *Small U.S. market makes it difficult for suppliers to recoup investments in new technology*

Most of the technology suppliers noted that the small size of the available market created a disincentive to invest resources in innovation. This was among the most commonly cited barrier in our interviews (Table 3). A common assertion was that, even if every underground coal mine bought as many as they could use of whatever new technology the supplier was considering developing, the sales revenue wouldn't be enough to recoup the investment that would have been needed to develop the new technology.

Many suppliers explained that the small and shrinking underground coal market was driving them to pursue new customers in other industries. Several companies that historically considered underground coal mining as their primary market had shifted partially or almost completely to other markets. As one supplier put it, “Coal mining sales for the vast majority of our history, say through 2015, were 80%–90% of revenue; now it’s 20%–30%, if that. We have no desire, whatsoever, to develop any new products for the underground coal mining industry.” Another supplier summarized a common sentiment in saying, “If we weren't in it, we probably wouldn't pursue it.” Others were more blunt: “If I was a supplier I wouldn't spend a dime on underground coal mining,” and, “No one in their right mind would be in this market. You would never do it if it was your own money. If you looked for a business loan, the bank manger would throw you out.”

This barrier is well-illustrated by the situation with the availability of surveying equipment. Surveying equipment transitioned from manual to electronic several decades ago, yet there is currently no electronic surveying equipment approved for use in underground coal mining on the market. In fact, the last (and possibly only) approved electronic surveying device was retired by the supplier in the 1980s. Evidently no suppliers deem it worthwhile to develop a product for this market. As a result, mine operators must either use manual surveying equipment or seek permission from MSHA to use non-approved electronic surveying equipment. Few, if any, suppliers still provide or support manual surveying equipment, making that option increasingly difficult to pursue. The market has thus left the industry in the difficult position of relying on non-approved technology for something as essential as surveying.

Suppliers of general technologies like surveying equipment have large markets in other industries and hence can choose to move out of underground coal mining with relative ease. However, for suppliers of technologies that are unique to underground coal mining, such as most coal production equipment, moving to new industries may not be an option.

#### *Shrinking market leads to incumbent dominance*

Beyond the small size of the market, the fact that it's shrinking led technology suppliers to note that there are no new customers among mine operators and that existing customers are disappearing. Existing customers have long-standing relationships with existing suppliers. Having no new entrants on the demand side reduces the opportunity for new entrants in the technology supplier side to gain a foothold in the market.

#### *Mine operators lack funds to invest in new technology*

With demand for coal decreasing, mine operators have decreasing revenue, forcing them to cut costs. This results in mine operators having few resources to invest in new technology. Some participants noted that, even if the investment may reduce operating costs over the long-term, up-front investment funds are often not available.

#### *Unwillingness to exceed regulatory requirements for safety technology*

With regards to technologies specifically focused on worker safety, some interview participants claimed that worker safety is not an inherent driver for the technology market. This was far from a consensus view, with some feeling that regulatory requirements represent a minimum standard, and that an argument could be made that exceeding the regulatory requirements with innovative safety technologies could increase a company's competitiveness. In practice, however, our interviews revealed that mine operators will generally only invest in safety technologies that are specifically mandated by regulation. Reasons cited for this position are that worker safety is so highly regulated that employers feel that the regulatory system acts as a de facto safety and health program, the poor state of the coal market, and that the workers' compensation system largely shields employers from the cost of worker injuries.

### Insufficient Supply

#### *Technology developers lack resources to commercialize*

In parallel with reducing demand for new technology, the shrinking coal market in the U.S. has also stifled innovation through reduced revenues for technology suppliers. As with mine operators, technology suppliers are facing shrinking sales, forcing them to reduce costs. This reduces the resources available to innovate and commercialize new technologies. Further, limited available innovation resources are being focused on pursuing alternative markets where there are signs of growth.

#### Specialized market

##### *Harsh physical environment in mines dissuades potential developers*

The underground coal mining environment is unusual in that it places special physical demands on technology. This makes the market specialized and some interview participants speculated that this specialization dissuades new entrants who are unfamiliar with the demands. We note that this barrier is closely associated with the specialized regulatory requirements of underground coal mining technology discussed below, and it may be difficult to distinguish the two.

### *Regulatory Barriers*

Interview participants described 15 barriers stemming from regulatory issues, making regulatory barriers the most common group of barriers by a wide margin. While states have important regulatory oversight over many aspects of underground coal mining, the vast majority of regulatory requirements related to technology commercialization and adoption come from the Federal government through MSHA, and all the barriers raised in our interviews stem from the federal regulatory environment.

MSHA's regulatory role with regards to underground coal mining is extensive, but the primary area relevant to this study is the approval of technology for use in hazardous atmospheres. Any electrically-powered technology used within the active working areas of an underground coal mine must be "permissible," meaning that it has been certified to be compliant with particular safety standards intended to minimize the risk of ignition of flammable or explosive atmospheres. The standards were developed by MSHA or its predecessors and all technologies used in such "permissible" areas must be approved for use by MSHA. This requirement applies to any electrically powered equipment for use in hazardous atmospheres, whether it be for coal production or support activities, such as atmospheric monitoring, computing, communications, transportation, or lighting.

Other environments in which workers may encounter hazardous atmospheres, such as petroleum, shipyards, and agriculture, also have safety requirements for equipment. However, these industries are regulated by OSHA, which uses a regulatory approach in which equipment must meet internationally recognized standards and does not need to be certified by OSHA.

The 15 regulatory barriers fall into 6 sub-groups reflecting different aspects of the MSHA approval process: cost, duration, currency of regulations, prescriptiveness of standards, operator burden, and regulatory culture. Our interview participants included multiple representatives from MSHA, who were included in order to help ensure accuracy of claims and to balance industry views with those of MSHA.

## Approval Cost

*Cost of technology approval dissuades developers*

Obtaining approval for new technology entails an expense for technology suppliers. Costs include the time required to prepare the initial application and revisions to the application in response to feedback from MSHA, the resources required to redesign the technology in response to feedback from MSHA, and the MSHA application fee. Because the extent of revision and redesign required to obtain approval is unknown, the total cost is uncertain, making it difficult to account for in project planning. In addition, uncertainty in the duration of the approval process represents an indirect cost in the form of impeding business planning. These costs can dissuade technology developers under certain conditions. One such situation is that suppliers considering developing a first-of-a-kind technology felt that the cost of seeking MSHA approval (and uncertainty about ever obtaining approval) was too uncertain to merit moving ahead. Another is that suppliers with stable revenue in non-U.S. underground coal mining markets noted that the cost of obtaining MSHA approval was not worth it to them. A third is that, based on anticipated sales revenue resulting from a new technology development effort, the added cost of MSHA approval is sufficient to shift the effort from profitable to unprofitable. Finally, some small companies noted that the cost of MSHA approval was simply unaffordable. All of these situations are exacerbated by the relatively small size of the U.S. market, which minimizes the potential sales revenue that would be gained with approval, further dissuading suppliers.

In addition to acting as a barrier to technology commercialization, the cost of MSHA approval may also be a barrier to technology adoption. Mining company representatives noted that MSHA approval costs increase technology prices for customers, with one estimating that an MSHA-approved product costs operators 3–4 times more than an equivalent non-MSHA-approved product.[6] This could dissuade mine operators from upgrading to newer technology even when available.

Multiple MSHA representatives confirmed that the cost to applicants of the technology approval process dissuades investment in new technology development and commercialization.

## Approval Duration

*Duration of technology approval dissuades developers*

A barrier closely related to the cost of MSHA approval and often cited in conjunction with it is the duration of the MSHA approval process. This was the most commonly cited barrier in the study (Table 1). Many interview participants stated that the generally long and uncertain duration of the MSHA approval process frustrates product development and business planning efforts. Several technology suppliers that work in multiple countries noted that approval of their

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[6] This estimate likely depends on the total cost of the technology in question (i.e., the proportional price increase resulting from MSHA approval costs will be greater on low-cost items than high-cost items).

technology in the U.S. under MSHA takes much longer than the approval of similar technologies in other countries. Interviews revealed multiple ways in which approval duration presents a barrier to innovation and commercialization.

In the same way that approval cost does, many participants noted that the long and uncertain duration of MSHA approval dissuades efforts to develop or introduce new technologies. They claimed that the involved and time-consuming approval process stifles innovation and drives potential new entrants "to industries with no or less onerous approval requirements." Experiences with the time required for approval ranged from 1–6 years. And because the MSHA approval process is unique relative to other countries' processes, the duration is independent of whether or not a technology has already been approved for use in other countries. Some participants stated that the uncertainty in the duration is as great a barrier as the length of it. One noted that if they knew how long it would be, they could plan around it, but being both slow and unpredictable makes it very difficult to work with.

Multiple MSHA representatives confirmed that the long and involved technology approval process dissuades investment in new technology development and commercialization.

Another way in which the long approval duration (in conjunction with cost) presents a barrier is that it makes it difficult to keep technology current. Once a technology is approved, any changes to the design or components requires a new approval, which suppliers are reluctant to undertake. As a result, approved technologies can be quasi-static and not updated as the state of the art evolves.

*Technology approval applications are sent to end of queue when discrepancies are found*

A recent change in MSHA's technology approval process may extend the approval process for some applicants. Prior to the change, after reviewing an application, if the technology was not approved, MSHA presented the applicant with a list of "discrepancies" that needed to be addressed in order to obtain approval. Upon the applicant addressing the discrepancies, MSHA would immediately review the revised application. This cycle could be repeated multiple times. Since the change in late 2019, all applications are closed after one review.[7] Applicants that fail are provided with a list of discrepancies and may then reapply for approval with a new application. The essential difference is that, prior to the change, an application review would remain active until the technology was approved or the application was withdrawn. Since the change, an application that fails is "sent to the end of the line." MSHA's rationale for this change, described both in a letter to technology suppliers and in interviews with us, is that applications from underprepared applicants or that otherwise required substantial revision were tying up MSHA investigators for long periods of time, creating a large backlog of new applications waiting for review.

[7] Applications with minor discrepancies may be given a single opportunity to quickly revise the application.

Although this change is relatively recent, several technology suppliers complained that this will make the application process even longer for any complex or first-of-a-kind technology.

#### *Lack of transparency about technology approval application status*

Several technology suppliers claimed that the lack of transparency about the status of their technology approval applications added to the length of the approval process. While suppliers praised MSHA's willingness to provide guidance about preparing an application, they noted that, once an application has been submitted, MSHA does not provide any feedback on the application status. So applicants have no insight into the shortcomings of an application until the review is complete and MSHA presents the discrepancies. Suppliers noted that this can occur years after the application was submitted, during which time they could have been working on addressing discrepancies if MSHA had conveyed them to the applicant as soon as they were identified. MSHA confirmed that the lack of communication with an applicant is an established practice, though not mandated in any policy. It also noted that it is aware of the criticisms and is trying to address them.

#### *Poor coordination between MSHA & NIOSH*

While NIOSH generally has no formal regulatory role related to underground coal mining technology, it does have a role in the testing of at least one particular technology type as part of the MSHA approval process. Technology approval therefore requires coordination between MSHA and NIOSH. Developers of this technology type felt that the required coordination between agencies extended the duration of the already protracted approval process, especially because the relationship between the agencies was perceived as poor.

### Currency of Regulations

#### *MSHA standards are out of date*

A commonly cited barrier to getting current technology into underground coal mines is that MSHA technology approval standards are very out of date. One reason for this is that MSHA standards are embedded in regulations. Changing a standard therefore requires a formal rulemaking process, which triggers an involved series of actions, including a regulatory analysis, soliciting and responding to public comment, and approval from the Office of Management and Budget in some cases. Doing so requires substantial attention and resources. MSHA must prioritize limited resources to regulatory concerns that go well beyond updating technology approval standards, and many standards have fallen out of date. As one participant put it, "MSHA only goes to rulemaking when it's a big deal. It tends not to deal with lesser issues."

As a result, several aspects of technology approval are based on knowledge and best practices that are many years or even decades out of date. Interview participants noted several examples of technology standards that have remained unchanged since the early 1970s. An implication of this is that, in order to receive approval, underground coal mining technologies require features and capabilities that are antiquated, which hinders effective design and increases size and cost. For example, all circuit breakers still require a reset handle external to the enclosure, despite the emergence of small, low-voltage circuit breakers that are integrated into control boards. Another example is that regulations still require that all motor controllers allow access for maintenance, even though new controllers require no maintenance.

MSHA representatives confirmed that outdated regulations are a real problem. One noted that "we have approval regulations still on the books that were promulgated in the 1930s…. Our inspectorate is saddled with the 1968 version of the electrical code." He noted that MSHA has limited resources for updating regulations, and as a result such efforts target more urgent matters such as black lung and silica.

*MSHA regulatory environment is unequipped to address new technology*

A related barrier to the commercialization of new technologies is that, through a combination of being out of date and prescriptive, "the system is not welcoming to new technology." Regulations apply specifically to particular pieces of technology used for specific purposes, in many cases in ways that are no longer in use. Multiple interview participants highlighted that a source of reluctance to develop or introduce new technologies is that it's unclear what part, if any, of the regulation is relevant to the new proposed technology. One technology supplier, in pre-application consultation with MSHA about the relevant regulatory requirements of a potential new product, was told by MSHA that, because it hadn't seen any technology like the proposed idea before, it was unwilling to provide any guidance until it had some experience from going through the approval process with an applicant. In effect, MSHA wanted a test case before advising about how to approach an application. While perhaps understandable, it suggests that MSHA perceives the technology approval process to be as unadaptable as applicants do. This creates great uncertainty about how the already long and difficult technology approval process can become even more so for a first-of-a-kind technology.

Interview participants cited examples of this regulatory uncertainty, leading to reluctance to apply or even failed approval applications, ranging from lithium-ion batteries to automation to novel roof control technologies.

The challenge of wariness at MSHA towards new technology goes beyond technology approval. One interview participant noted that, among mine operators, there is a "reluctance to be first because of perceived heightened scrutiny and challenges from MSHA for a first adopter."

It should be noted that the challenge of shepherding a new technology through the regulatory approval system is not a new problem. Until 2002, only low- and medium-voltage longwall shearers were permitted under MSHA regulations. However, the first high-voltage longwall shearers entered the market in 1985 (MSHA, 2002). Because they could not meet MSHA regulations, they were brought into service through a regulatory alternative known as a petition for modification of mandatory safety standards (informally referred to as a 101(c) petition, which refers to the section of the Mine Safety and Health Act that prescribes the process). This process allows a mine operator (not a technology supplier) to petition MSHA to be allowed to use a non-approved technology in a particular mine.[8] Over the next 16 years, MSHA granted over 100 101(c) petitions to use high-voltage longwall shearers (MSHA, 2002). In 2002, MSHA finally revised the regulation to allow high voltage shearers to be approved through the normal process.

A nearly identical sequence of events occurred between 1997 and 2010 for high-voltage continuous miners (MSHA, 2010). In both cases, the reasons that the new technology was not able to be approved was that (a) the regulation was written very prescriptively around the existing technology at the time and (b) the regulation was not updated as new technology emerged.

These examples are notable for a few reasons. First, the technologies in question were merely evolutionary and far from novel or revolutionary, and yet still faced barriers. Second, because mine operators file 101(c) petitions for equipment produced by third party technology suppliers, there is risk either to the supplier of developing a new technology that it doesn't know it will be able to sell or to the operator of investing in something that it could not sell or use.[9] Finally, such widespread and long-term use of a laborious and risky technology approval process nominally designed for special cases, even if it became somewhat streamlined through repeated use, is tacit acknowledgement that the technology is safe and hence that the fact that it cannot be approved through the normal technology approval process has little to do with safety concerns.

One factor that may have made this approach less laborious and risky than it sounds is that the suppliers may have already developed the technologies for markets in other countries with more flexible and receptive technology approval systems. Thus, they did not necessarily develop the technology entirely for a U.S. market for which approval was uncertain.

### Prescriptiveness of MSHA Standards

Interview participants repeatedly called out the highly prescriptive nature of MSHA standards and several barriers that this creates.

#### *Prescriptiveness crowds out novel approaches*

A general complaint about the prescriptiveness of MSHA regulations is that they can be so specific to existing technology that they effectively crowd out novel approaches. Best practices and federal policy for standard development is to develop standards that specify performance characteristics (performance-based standards) as opposed to design and construction characteristics (prescriptive standards) (U.S. Office of Management and Budget, 2016). One

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[8] Section 101(c) of the Mine Safety and Health Act allows mine operators to petition for modification of mandatory safety standard if "(1) an alternative method of achieving the result of the standard exists that will at all times guarantee no less than the same measure of protection afforded by the standard, or (2) Application of the standard will result in a diminution of safety to the miners."

[9] We don't know if final sales were contingent upon approval of a 101(c) petition or if customers bought the technology outright without knowing whether they would be allowed to use it. In other words, it's not clear who was left "holding the bag" if the petition was not approved.

participant stated that "MSHA is tied to out-of-date, overly prescriptive legislation that doesn't allow for safety solutions other than those specified." Another said that MSHA had informally told him that if the design of a technology meets the construction requirements, it will get approved, effectively implying that the approval system weights prescriptive factors more than performance.[10]

One interview participant highlighted examples of specific required design details such as bolt spacings and flange widths, which he viewed as unnecessarily prescriptive. Others highlighted the impact of prescriptiveness specifically on the development of novel safety technologies. Because regulatory requirements for protecting worker safety are so strictly prescribed, any technology designed to improve worker safety that isn't "counted" within the regulatory framework is unlikely to sell. As a result, technology suppliers have little incentive to develop and commercialize novel approaches to safety.

One example of this is technologies that reduce workers' exposure to dust, such as ventilated canopies on bolters and shuttle cars. MSHA regulations apply to the control and measurement of area-wide dust levels and hence any exposure reduction to an individual worker inside a canopy is not considered for dust exposure limits. Another example is safety approaches that focus less on engineering and more on training and practices, such as the National Mining Association's Core Safety Principles (National Mining Association, 2021). One participant noted that adoption of such approaches is known to be associated with improved safety, yet they are not recognized in the MSHA regulations. A third example we heard about was that a regulation requiring that methane measurements be made manually creates a disincentive to develop automated methane detection technology, even though automated technology may be desired and beneficial. One somewhat special case is related to a technology that was being developed in conjunction with a new MSHA regulation mandating the use of that technology. Because the regulation and technology were developed together, the details of the regulation are closely tied to the details of the technology, essentially requiring any new entrant to produce a nearly identical technology.

#### *MSHA-specific standards isolate U.S. underground coal mining market*

Several interview participants noted that MSHA's technology approval system is an outlier in the global coal mining market. Other countries with major coal mining markets use a similar set of voluntary consensus standards (VCSs) rather than government-unique standards. These standards, as the name implies, are developed through a consensus-based process that includes representatives from all relevant market stakeholders and technical experts. This process ensures that a standard reflects the needs of all stakeholders and the most current research and other knowledge. VCSs are, by themselves, voluntary and unenforceable, but government agencies routinely adopt VCSs by reference into regulations, making them mandatory for the regulated population.

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[10] MSHA approval requires performance testing.

Most relevant VCSs for underground coal mining technology are produced by the International Electrotechnical Commission System for Certification to Standards Relating to Equipment for Use in Explosive Atmospheres (IECEx). These standards are adopted by reference into mining safety regulations by regulatory agencies around the world. Agencies sometimes include "country deviations" when adopting IECEx standards, though these deviations are relatively minor, such that, outside the U.S., there is a largely uniform regulatory framework for underground coal mining technology.

While MSHA regulations do reference several VCSs, these are primarily standards from standards development organizations such as ASTM International and the National Fire Protection Association and refer to issues other than the fire and explosion hazards in environments such as underground coal mines. For the latter, MSHA regulations rely on MSHA-specific standards.

One implication of this situation is that MSHA standards are developed in relative isolation from the national and international standards development communities. MSHA confirmed that it "does not collaborate in rulemaking; it's not like the process for VCSs." As a result, MSHA does not necessarily incorporate input from all relevant stakeholders and/or follow best practices for standards development (e.g., the American National Standards Institute's essential requirements[11]). For example, most standards development organizations and regulatory bodies, as well as U.S. policy for federal agency standards, support developing standards based on performance criteria rather than design criteria when appropriate (U.S. Office of Management and Budget, 2016).

A second implication is that, because MSHA standards are so different from those used in the rest of the world, technology suppliers effectively must produce a separate product for the U.S. underground coal mining market. This creates a disincentive for technology suppliers to coal mining operations in other countries to enter the U.S. market. Several such suppliers expressed frustration with the challenge or inability to get products that are approved and well-accepted in other countries approved for use in the United States. Some simply decline to attempt it. For example, following a supplier's decision to permanently cease production of a popular MSHA-approved helmet with an integrated powered air purifying respirator, a supplier of a similar product approved in several other countries opted to not seek MSHA approval, deciding that, even with nearly assured new sales in the United States, it was not worth the time and cost that MSHA approval would require. As a result, this technology is no longer available to the U.S. underground coal mining industry.

This problem extends beyond coal mining-specific technology. The Occupational Safety and Health Administration, which regulates safety in most U.S. industries other than underground coal mining, also accepts IECEx standards.[12] This means that suppliers of technology for other

[11] American National Standards Institute (2021)

[12] OSHA accepts a set of UL standards that are identical to IECEx standards.

U.S. industries with hazardous atmospheres (e.g., petroleum) must also often produce separate products for underground coal mining. This impacts a wide range of products, such as sensors, lights, radios, tablets, etc. Thus MSHA's "go-it alone" approach requires that virtually any product used in the permissible areas of U.S. underground coal mines be specially designed and produced specifically for that market.

This barrier was highlighted in a National Research Council report on improving self-escape from underground coal mines (National Research Council, 2013), which called for "…convening a joint industry, labor, and government working group to identify a range of mechanisms to reduce or eliminate any barriers to technology approval and certification, which should include exploring opportunities to cooperate with other international approval organizations to harmonize U.S. and international standards without compromising safety."

In an effort to alleviate some of barriers associated with MSHA-specific standards, MSHA in 1994 proposed and in 2003 promulgated a rule that "permits manufacturers to have their products approved based on non-MSHA product safety standards once MSHA has determined that the non-MSHA standards are equivalent to MSHA's applicable product approval requirements or can be modified to provide at least the same degree of protection as those MSHA requirements" (MSHA, 2003; Code of Federal Regulations, 2021). While seemingly a major reform, in practice this rule has had almost no impact. The main reason for this is that MSHA has thus far determined equivalency for only two non-MSHA standards (IECEx standards 60079-0 and 60079-1) and, as part of its equivalency determination, has imposed so many modifications that the adopted versions of these standards are nearly as prescriptive and cumbersome as the original MSHA standards (MSHA, 2006; Code of Federal Regulations, 2021). According to MSHA representatives, this rule "has failed." "Maybe one or at most two" approvals have been granted using these modified non-MSHA standards since they were approved for equivalency in 2006.

More recently, in 2020 MSHA proposed a new rule that would accept six IECEx standards that provide protection against fire or explosion dangers in place of existing MSHA approval standards in its regulations (MSHA, 2020). The proposed rule does not require a determination of equivalency and the standards would be incorporated in their entirety without modification. As of June 2021, the rule was in the public comment phase.[13] If promulgated, this rule could have a major impact on the ability to incorporate modern technology in U.S. underground coal mines.

*MSHA approval requires revealing proprietary information*

One mine operator said that some technology suppliers are unwilling to seek MSHA approval because of concerns about the need to submit proprietary information to MSHA. He claimed that this was one reason that large IT suppliers, such as Apple, are not involved in the

[13] Comments are available at https://arlweb.msha.gov/regs/comments/2020-1219b/

market. Though raised only once, this appears to be a barrier to at least some technology suppliers that do not wish to reveal proprietary information to the federal government. It is unclear what conditions, if any, could lead MSHA to release this information to outside parties.

*Reapproval of technology is required for small design or part changes*

A significant aspect of the prescriptiveness of MSHA's technology approval process is that any changes to the design or components of an approved technology requires a new approval. As noted above in the *Approval Duration* section, several interview participants said that the time and overall burden of obtaining such a new approval creates a disincentive to making any changes to approved technologies unless absolutely necessary. As a result, underground coal mining technologies tend to be "locked in" to the state-of-the-art at the time they were approved and not updated as technology evolves. Participants emphasized that the requirement for reapproval was overly prescriptive, including such changes as brands or models of LED bulbs and batteries, and applies even if a supplier only slightly revises or even simply updates the name or model number of a component. While this barrier affects all types of technology, it is particularly problematic in areas of rapid development, such as information technology, where technology evolves so rapidly that approved products can quickly become outdated or obsolete.

A corollary of this barrier is that, if a component becomes unavailable, technology suppliers are forced to either find a replacement and apply for MSHA approval or simply stop supplying the product for the U.S. underground coal mining market (which was the case for the integrated helmet-respirator described above).

Applying for reapproval carries risks beyond the barrier of wanting to avoid the time and cost of the MSHA approval process. One technology supplier described a case in which, upon submitting an application for reapproval for certain specific modifications, the MSHA reviewer rejected other aspects of the design that had already been approved by a different MSHA inspector during the original approval process. MSHA representatives confirmed that MSHA inspectors have substantial autonomy and such a scenario is possible.

As an example of the lengths technology suppliers will go to avoid undertaking the MSHA reapproval process, one technology supplier has twice acquired suppliers of components essential to its approved technology that were on the brink of going out of business just so that it could sustain access to those components and stay compliant with its existing MSHA approval. In essence, the approval process is so involved and time-consuming that the industry chooses to operate with antiquated technology to avoid facing it. This results in widespread use of outdated technologies in underground coal mining. In some particularly fast-moving technology areas (e.g., LED bulbs), the long approval time leads to situations in which technologies can literally "be obsolete before they're approved."

### Operator Burden

Beyond barriers to the development and commercialization of technologies, our interviews revealed regulatory-related issues that act as barriers to the use of approved technologies by mine operators.

#### *Exceeding minimum safety requirements opens mine operators to citation for failure of non-required features*

Several interview participants expressed frustration with the risk of being cited for a violation related to voluntarily safety technologies that augment the minimum regulatory requirements (i.e., the operation is fully compliant without the voluntary technology). This risk, they claimed, creates a disincentive to invest in safety and health technology that goes beyond the minimum regulatory requirements. This barrier applies to both the adoption of available technologies and the development of new technologies. One example relayed by a mine operator involved a potential back-up lighting system. The operators had considered installing back-up lights on a piece of equipment so that operations could continue if a light failed. However, they chose not to proceed because they were concerned that operating the equipment with a failed light (even though the equipment would be operating with compliant lighting) would open them up to a citation for an equipment violation. Another example involved an operator being cited for an inoperable emergency escape capsule because they kept a second capsule on site (only one is required) for spare parts.

MSHA representatives confirmed that citations for non-compliance associated with optional safety technologies are possible. Although the technology may not be required, once installed it becomes subject to citation for violations, particularly when the issue represents a safety hazard. However, the examples noted above demonstrate that MSHA's position on this point may not be completely consistent.

#### *Exceeding minimum safety requirements can reveal unknown risks*

Another barrier to the adoption of non-required safety technology is that some operators expressed concern that using more than the minimum required amount of detection equipment might lead to the discovery of hazards that could halt operations or result in violations that otherwise might have gone undetected. For example, one operator noted that increasing the number of points at which methane measurements are taken increases the chances of discovering conditions that exceed allowable levels. It is unclear whether operators believe that exceeding allowable methane levels is a small enough risk that they're not concerned for the workers' safety or that market conditions are so poor that they're willing to risk worker safety in order to avoid costly delays or citations.

#### *The regulatory burden of operating some technologies dissuades operators from using them*

In some cases, MSHA regulations impose certain requirements when using particular technologies. This leads some mine operators to not use some available technologies, even if potentially beneficial to their operations. This barrier was raised in the context of mine-wide monitoring systems, for which documentation requirements (associated with siting, inspections, maintenance, etc.) can be such a burden and expose the operator to the risk of citation for violation that some mine operators opt to not adopt them.

### Regulatory Culture

#### *Conservative and risk averse culture*

A final aspect of the regulatory environment that interview participants highlighted as a barrier was the culture at MSHA. Most of the technology suppliers and many of the mining operators that we interviewed have experience with regulatory environments outside of U.S. underground coal mining and felt that working with MSHA in relation to underground coal mining was far more difficult than working in other regulatory settings. While descriptions of concerns varied, the overall sense was that MSHA's approach is conservative and risk-averse and that it takes an adversarial approach to regulation and enforcement. Expressions of frustration were very common, with MSHA and the approval process described with such terms as "bureaucratic," "painful," "unpredictable," "inconsistent," "overbearing," "onerous," "unbelievable," "dysfunctional," "tribal," "insular," "inflexible," "meddling," "out of touch," "intransigent," "stifling," "non-transparent," "not welcoming," "completely broken," "disaster," "nightmare," "driven by power," and "center of the universe."

One participant said that representatives from MSHA had told him that "MSHA is the worst detriment to new technology coming into the industry." Another claimed that "MSHA approval engineers have little oversight and applicants are fearful of retaliatory behavior. The government has them under their thumb." Other examples participants cited include MSHA's effective unwillingness to determine the equivalency of VCSs, its general unwillingness to grant exceptions to standards at its discretion as is often allowed in the regulations, its unwillingness or inability to update regulations to bring them in line with current technology, the lack of transparency about an application's status, the ability for an inspector on an application for approval of a modification to overturn prior approvals, inconsistent application of approval requirements, and an unwillingness to tackle applications for novel technologies that don't "fit" into the current regulatory structure.

Some participants felt that MSHA's hands are tied by the specificity of the Mine Safety and Health Act and associated code of federal regulations, while others claimed that "MSHA hides behind the Mine Act." While we have not conducted an analysis of the Mine Act or the associated federal regulations (Title 30), we note that the Mine Act grants MSHA broad authority to define standards for permissibility.

### *Other*

While the majority of barriers raised in the interviews stem from economic and regulatory issues, participants raised a few additional barriers that fall outside these categories.

#### Cultural

##### *Mine operators are resistant to change*

While our analysis revealed multiple reasons why mine operators may be reluctant to invest in new technologies (limited resources, unwillingness to exceed regulatory requirements, and regulatory burdens associated with operating some technologies), according to several participants, mine operators are also often unwilling to explore new technologies because of a general resistance to change. While certainly subjective and difficult to separate from other barriers to technology adoption, because resistance to change was cited specifically and in the context of all technology types (i.e., not just safety technology), we include it as a distinct barrier. Some suppliers claimed that this resistance persists even in the face of evidence for economic & productivity benefits.

Participants offered few insights into the source of this resistance, though noted it is most prominent among older workers and in association with digital technologies. Suppliers noted that this resistance to adoption has upstream impacts by reducing the incentive to develop and commercialize new technologies.

Such resistance to change, particularly among older workers in relation to digital technologies, is likely not specific to underground coal mining, but rather a barrier common to many industries. However, its effects will be stronger in a shrinking market where there are decreasing numbers of young workers entering the workforce.

#### Liability

##### *Greater liability risk in U.S. compared to other countries acts as disincentive to enter market*

Some technology suppliers of underground coal mining technology that operated overseas noted that one reason they were reluctant to enter the U.S. market is that there is a greater risk of liability losses in the U.S. market relative to others. The extent to which this is true is impossible to substantiate without some dedicated analysis, which is out of scope for this analysis. However, even if it is no more than a perception it may act as an actual barrier.

#### Federal Support

##### *No federal agency is addressing mining technology needs*

A number of interview participants noted that no federal agency is pursuing or supporting advances in mining technology overall. While NIOSH's work was generally viewed positively, participants noted that it is restricted to protecting worker safety and health and does not address coal production technologies more generally. Some lamented the passing of the U.S. Bureau of Mines in this respect. As noted in the introduction, while several of the Bureau of Mines' functions were transferred to other federal agencies when it was dissolved, most aspects of technology development were not transferred to any agency and hence effectively abandoned.

The general view from industry is that the Bureau of Mines had the mining industry's best interests at heart, while MSHA and NIOSH do not, and may even impede progress. As one participant put it, "agencies need to work with industry to help rather than hinder." The loss of the Bureau of Mines was not only a loss of support to technology development, but restricting federal support to safety and health has created barriers to industry's trust in and receptiveness to NIOSH. One participant noted that when he was with the Bureau of Mines, mine operators were generally receptive to the Bureau's requests to test technology in mines. However, mine operators are wary of helping NIOSH test technology because of the possibility that they may be unwittingly supporting the development of another mandatory regulatory burden. As another participant put it, there is a need for collaboration between government and industry "without agendas" related to new regulatory requirements.

## Summary and Next Steps

Our analysis identified and characterized 24 distinct barriers to the development, commercialization, and adoption of new technology in the underground coal mining market. The majority of barriers are related to regulatory issues (63%), followed by economic issues (25%) and other issues (13%). Regulatory barriers are associated with the approval of technologies for use in permissible environments in underground coal mines and cover the cost and duration of approval, the currency and prescriptiveness of the regulations, the burden on operators, and the regulatory culture. Economic barriers are related to insufficient supply and demand and the specialized market of underground coal mining. Other barriers include a mining culture that is resistant to change, liability risks, and a lack of federal support.

The findings have some useful implications for NIOSH. For example, given that mine operators are reluctant to exceed regulatory requirements for safety technology, NIOSH may want to consider potential regulatory requirements when investing in new technology research, avoiding technologies that are unlikely to help operators meet regulatory requirements. Similarly, even in the case of a new technology that could, in principle, help operators meet regulatory requirements, if it is particularly novel, technology suppliers may face challenges in obtaining MSHA approval or decide that it's not worth the effort and risk to even attempt it. In terms of ways in which NIOSH may facilitate the elimination of barriers, NIOSH research on the equivalency between MSHA and IECEx standards has already proven essential to MSHA's willingness to consider granting technology approval according to IECEx standards in lieu of MSHA standards. The majority of barriers, however, relate to issues that are beyond NIOSH's direct influence and NIOSH is likely to play a secondary role in addressing them.

The type of barrier has implications for the prospects of and options for eliminating it as well as the roles of different actors in implementing those options. In general, economic barriers may be the most challenging to address, as they are inherently linked to the global energy economy and energy policy. Addressing them would involve national policy decisions and the coordination of a large number of different stakeholders. Addressing the regulatory barriers, on the other hand, would involve more localized efforts and fewer stakeholders. In particular, addressing regulatory barriers will necessarily require substantial involvement of MSHA.

The most commonly cited barrier was cited in 29 of the 75 interviews, while two barriers were cited in just once each. The five most commonly cited barriers and the number of times they were cited were:

- Duration of technology approval dissuades developers (29)
- Small U.S. market makes it difficult for suppliers to recoup investments in new technology (26)
- Shrinking market leads to incumbent dominance (23)

- MSHA-specific standards isolate U.S. underground coal mining market (21)
- Cost of technology approval dissuades developers (19)

Three of the five most commonly cited barriers are regulatory and two are economic. The frequency with which barriers were mentioned reflects the pervasiveness of stakeholders' awareness of them and/or the breadth with which their impact is felt across the market. While the relative frequency of mentions provides one useful of ranking among barriers, other attributes, such as the magnitude of the impact, the cost and feasibility of eliminating it, which stakeholder groups it impacts, interdependencies among different barriers, and priority within the community are important factors in discussions about which barriers to address first. Planning is underway for a workshop with market stakeholders in which barriers will be further refined and characterized, prioritization criteria will be developed and applied, and potential options for eliminating barriers will be proposed.

# Appendix A—Interview Protocols

## Main Interview Protocol

Note: Questions 1 and 2 were for mine operators only. Questions 3 and 4 were for technology suppliers and researchers only.

1) How do you learn about new technologies?
2) What factors influence your organization's decisions to use or not use particular technologies? Please rank each factor in terms of its relative importance (multiple factors can have the same ranking).
   a) Regulatory requirements
   b) Impacts on worker safety and health
   c) Worker acceptance
   d) Effects on productivity
   e) Cost- upfront investment or operations & maintenance (including reliability)
   f) Other
3) Please walk us through the technology development, approval, and commercialization process
4) When considering recent technologies you've developed for underground coal mining,
   a) How is technology development financially supported?
      i) Internal funds
      ii) Partnerships with operators
      iii) Outside investors
   b) What are the worker safety and health-related implications of the new technology relative to existing technologies?
   c) What are the productivity or profitability implications of the new technology relative to existing technologies?
   d) Is the technology intended for environments beyond underground coal mining? Beyond mining? If yes, which environments?
5) In what environments are new technologies tested & demonstrated?
   a) Laboratories
   b) Test mines (non-producing)
   c) Non-production areas of working mines
   d) Working mines
   e) Other
6) What are the main considerations and barriers involved in introducing new technologies?

    a) Are there distinct barriers for technology development, commercialization, and adoption?
7) Do you have any observations or recommendations about ways to reduce these barriers?
8) What technologies available in other countries or other industries (e.g., explosion-proofing methods) would you like to see available for underground coal mining in the U.S.?
    a) What prevents them from being available for U.S. underground coal mining?
    b) What are the worker safety and productivity implications of them not being available?
9) Are you aware of new technologies that were proposed or developed but were never investigated further or commercialized?
    a) Why are some ideas pursued and others not?
    b) What are the worker safety and productivity implications of them not becoming available?
10) Are you aware of any technologies not having a similar alternative that have been discontinued?
    a) Why are some technologies retained and others discontinued?
    b) What are the worker safety and productivity implications of them not being available?
11) How is technology development and adoption affected by the industry economic upswings and downswings?

## Protocol for Regulators

**Technology Approval Process**

1) Please walk us through the technology approval process
2) How do approval criteria for experimental permit, field modification, 101(c) petition, and full approval differ from each other?
3) How do re-applications and applications for modification differ from new applications?
4) What happens when an application involves technology for which no clear standard applies or for which the evidence base is lacking?
5) How does your agency consider experience and data from manufacturers, NIOSH, or others in its evaluations?

**Approval Based on Non-MSHA Standards**

6) What is your understanding of MSHA processes of verifying and accepting non-MSHA standards?
7) Why did MSHA begin allowing approval evaluation according to non-MSHA standards?
8) How does a non-MSHA standard get considered for equivalency?
9) About what fraction of applications seek approval based on the IEC flameproof enclosures standard?
10) Are there plans to increase reliance on IEC and other voluntary consensus standards?

**Policy and Rule Development**

11) How does MSHA develop new standards?

    a) What is the motivation?
12) Who reviews and makes decisions about comments submitted in response to EO 13777 on regulatory reform?
13) What research are MSHA standards based on?
14) Are there MSHA-specific rules or policy on collaboration in the rulemaking process?
15) Are there rules or policy on transparency about the status of an application?
16) Why did MSHA eliminate discrepancy letters? What have the implications been?
17) What is the pricing structure for applications?

**Overall Impressions**

18) When considering MSHA's technology approval system overall
    a) What aspects work well?
    b) Which aspects need improvement?
    c) What would you change?

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