In Pursuit of Technological Innovation*

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Background

The American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME) is one of the five engineering founder societies in the United States. This group includes IEEE (electrical/electronics), ASCE (civils), ASME (mechanicals), and AIChE (chemicals). In turn, AIME's four member societies, the Society of Petroleum Engineers International (SPE), the Association for Iron and Steel Technology (AIST), the Minerals, Metals, and Materials Society (TMS), and the Society for Mining, Metallurgy, and Exploration (SME), represent many different technical disciplines.

Each of these member industries apply highly sophisticated technologies in their operations. These technologies have been important enablers in their continuing drive to improve how they face critical challenges in solving problems encountered in delivering products and services to consumers in an environmentally friendly manner. As such, timely development and rapid application of leading edge technologies are critical for their survival and prosperity and for better service to the communities they serve. Technology makes lives better, and we still have opportunities to improve how we use our planet's resources to meet people's needs.

Commonly, new technologies are first invented, then developed, and finally applied in the field. While inventions are always needed to feed the technology pipeline, innovation opens new opportunities to apply existing technologies in different and new ways and, perhaps, for completely different purposes. Innovation can be an idea, a tool, an algorithm or a practice that is different from its original purpose.

The reuse of obsolete slow computer chips by toy makers is one of the many examples of such innovation. Another interesting example of innovation is the use of excimer laser technology, originally developed by a team of engineers and scientists at IBM in 1976 aimed at etching computer chips. They demonstrated that "smooth grooves could be reproducibly etched into a human hair without burning or otherwise damaging the surrounding portions of the hair strand." After seeing a picture of the etched hair, Stephen Trokel, M.D., an ophthalmologist at Columbia University in New York City, visited the IBM laboratory in July 1983. He followed his visit by laboratory studies and confirmed that a very important technological breakthrough had occurred. Today his innovative laser vision correction is performed around the world. Dr. Trokel's work illustrates how innovation can happen when people look outside their normal 'technical tool box' and see how others have used technology to address problems in different areas.

While invention and innovation are different, they both require appropriate processes to harness human creativity and ingenuity. After publishing his book *The Innovator's Dilemma*, in which he popularized the term "disruptive innovation," Clayton Christensen (1997), a professor at the Harvard Business School, co-authored the book *The Innovator's DNA: Mastering the Five Skills of Disruptive Innovators* (Dyer et al., 2011) in which he and his colleagues list five habits of mind that characterize disruptive innovators: associating, questioning, observing, networking, and experimenting.

The AIME Council of Excellence

To create an environment to nurture these discovery skills, and realizing that innovative breakthroughs most often happen at the intersection of diverse disciplines, AIME recently embarked on a new experiment described later in this article. This exercise is aimed at connecting ideas and problems in different fields that otherwise may seem unrelated. By making it possible to look outside one's normal 'technical tool box,' we hope that we can foster innovation to help everyone make smarter use of the earth's resources.

In 2014, the AIME Board adopted a new governance structure including creation of a committee of eight leading scientists and engineers (two from each member society). This new committee is called the Council of Excellence (COE). The current members of the Council of Excellence are:

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1. Ford Brett | Chief Executive Officer, PetroSkills | SPE
2. Khalid Aziz | Professor, Stanford University | SPE
3. Kevin Zeik | General Manager-Research, U.S. Steel Corporation | AIST
4. Ted Lyon | Managing Director, Hatch Associates Consultants | AIST
5. Robert Shull | Fellow, National Institute of Standards & Technology | TMS
6. Dan Thoma | Professor, University of Wisconsin | TMS
7. Ta Li | Past Vice President, Tetra Tech | SME
8. Ponisseril Somasundaran | Professor, Columbia University | SME

Guest experts can be invited by any of the members to provide the appropriate additional focus expertise when needed. The COE is charged (Figure 1) with three major tasks:

Technology Review and Application

This broad task includes reviewing technology needs/gaps for each industry, identifying technologies with potential application in other industries (crossover), and investigating potential innovative application of the technologies where a gap may exist or where improvement to current processes may be possible. This is where the members engage in associating, questioning, observing, networking, and experimenting. Within this task, they examine the currently employed technologies and look for new and innovative ways to implement them within their own discipline or find novel application across other disciplines. Emerging technologies will also be examined, and technology gaps identified.

Advocacy

Documenting and publishing the results of the technology review, communication of crossover technologies, and proposing new and innovative applications through applied technology workshops, conference panel sessions, etc. are included in this task. In addition, advising and encouraging scientists, engineers, and technologists to focus on and conduct research in new and innovative utilization of old technologies, as well as demonstrating the feasibility of potential crossover applications will be tackled. Another important consideration is expediting the pace from development to application. Today in the petroleum industry, for instance, it can take up to 16 years on average to move an idea from concept to full field implementation, almost twice as long as many other industries (National Petroleum Council, 2007).

In his book entitled *Diffusion of Innovation*, Everett Rogers (2003) describes a typical technology adoption timeline during which world-class companies with long term vision enter the adoption and application stage first (Figure 2). These are the innovators, seekers and learners, and those who bear a technology leader attitude. After the innovators, early adopters, and early majority, comes the late majority group followed by laggards. The latter group of companies are typically characterized by their short-term vision, passive and slow technology identification, and invent-everything-here attitude.

However, for AIME's COE, these latter groups also provide a significant opportunity to expedite their technology adoption pace. The Council's advocacy strategy will encourage shifting the adoption behavior (Figure 3) from a passive and cautious approach to that of an innovator and a technology leader. Under the flag of advocacy, the Council will engage in creating a vision, and a strategy to incorporate mechanisms for technology awareness, interaction with external knowledge sources, technical knowledge transfer, and knowledge sharing.

Advisory

The Council will also act as AIME's Science and Technology Advisory Team on matters requested by AIME. These can vary from providing input regarding AIME's relationship/collaboration with external entities such as the United Engineering Foundation and National Academy of Engineering and requests for funding to involvement in multi-disciplinary efforts and providing feedback/opinion on the AIME award nomination process and nominees.

The Innovation Process

Rogers (2003) also proposes five stages for the diffusion of innovation and technology adoption process as knowledge, persuasion, decision, implementation, and confirmation. The Council will be involved in the first two elements of knowledge and persuasion. The work of the Council as described above provides an environment for true collaboration by AIME's member societies. The members from all industry disciplines will engage in literature search, brainstorming ideas, and seeking new and novel application of both aged and emerging technologies across multiple industries. However, our industries are huge, and compared to the vast expanse of the four member societies, the work of only a few members of the COE will be constrained by several limiting factors such as their available volunteer time and their focused expertise. It is obvious that additional input by the members at-large will significantly energize the process. The work by COE is only a starter fuel to turning the innovation engine and much wider worldwide conversation by the members of the four AIME member societies. The total process can be described in the following Figure 4.

Recent COE Conversation

The Council has had several conversations in the past year in an attempt to start its innovation process. The four-society, two-member teams have conferred separately, developing an initial list of technologies in the current and emerging categories as well as the perceived technology gaps. The following Figure 5 contains the results of COE's preliminary attempt at identifying, tabulating, and describing selected technology sectors and categories.

All members of any of the AIME member societies (AIST, TMS, SME, and SPE) are also considered as members of AIME by default. AIME's structure, therefore, has created a unique opportunity for all of its roughly 200,000 members to participate in the collaborative work of the COE as described above. The Council of Excellence invites all members to provide ideas that may find a crossover application in one or more of the industries represented by AIME. For this purpose, AIME has created an online submission form available at http://www.aimehq.org/programs/collaborative-efforts/council-of-excellence. Your input may provide for a breakthrough in accelerating the pace of technology advance. Gradually, the COE will engage experts from sister engineering and scientific disciplines in this process as well.

This is an evergreen process shown in Figure 4, and the readers' contributions, feedback, and input into the "Technology List" tables are critical to energize this process. The members of the Council of Excellence will review the incoming ideas from members at-large and include them in the Council's future discussions for further processing.

The following is a brief review of some of the technology challenges that each of the AIME member industries are facing:

Steel Industry

Safety, energy and sustainability are three key areas of both current and future innovations within the global steel industry. The industry itself may be considered mature by many, but recent and future innovations will continue to make steel the material of choice in many applications for decades to come.

Over the past century, safety within the steel industry and related fields has improved several fold, and the recognition and elimination of hazards, as well as workplace communications and training, have been the center driving force for improvement. Today, the use of computer modeling to understanding, not only each process step but also the workplace environment and the interaction with employees, is encouraging improvements in robotics and sensors within these processes. Future safety innovations will involve better modeling of the process steps, incorporating improved sensor and imaging technologies, data analytics and 3D visualization technologies to protect and train current and future industry employees.

As the world around us embraces new, green energy supplies, the steel industry must continuously innovate new production methods that take advantage of these clean energy sources. Both competitiveness and product performance as well as differentiation will need to rely on novel production methods that convert iron ore and scrap into high performance materials of choice for use in many industries, from mining, to automotive, industrial, and consumer goods. Innovation of current processes for the production of iron and steel will also utilize advanced sensors and energy recovery methods to reduce traditional energy consumption and greenhouse gas emissions.

Finally, recycling is the backbone of steel's sustainability. Around the world and throughout North America, steel is continuously recycled, which means it can be recycled over and over with no loss of performance. It is the most recycled material on the planet, more than all other materials combined. To improve sustainability, innovative methods to improve recycling of complex multi-material end use products will be required. As more complex steels are incorporated with other metallic and non-metallic materials, methods of design and construction may need to consider end of life separation, challenging current engineering principles. To date, even the most complex advanced steels can make use of recycled steel. As we design future products, we also may need to consider recycling into fundamental alloy design to maintain the competitive edge that makes steel the most recycled material on the planet.

Mining Industry

Preservation and sustainability are important for the continued economic mining of mineral resources. Three major areas in the industry are of particular importance for the future. First is the *environmental impacts of mining* in which various issues of waste management and disposal continue to impact successful mining. Cross technologies in mining will facilitate mitigation and substitution of toxic chemicals and byproducts, water and tailings management (impoundment failures), and zero discharge of mining waste and tailings. Next is the *technology improvements to facilitate enhanced processing economics* for which continuous improvements further the economic viability of mining operations. Identified processes will be adapted to beneficiation in the areas of processing by using saline water, dry processing of beneficiated ores, and increasing energy efficiency (crushing/grinding, pumping, flotation, dewatering). Finally, mining sustainability demands both *examination of existing processes and visionary thinking to meet future materials demands*. Such areas include mining education and training and public awareness, robotic mining and milling (economic and safety considerations), and extraterrestrial mining and recycling (including asteroids, space junk).

Minerals, Metals, and Materials Industry

Nanotechnology has enabled the creation of new functionality in materials due partially to the unusually high percentage of atoms being located at interfaces, like grain boundaries or surfaces. Nanoparticles, which can be placed into very small volumes, are good examples of materials whose properties are specifically sensitive to their external environment because of this high surface to volume ratio. Currently there are a multitude of methods devised for making such materials, and, because of their small size, their application as localized sensors (e.g., for oil field detection, temperature, biological agents, gas detection and concentration, etc.) is just beginning to be realized. Their use for localized heating of cancer cells in hyperthermia treatments has already gone into trials in Europe and for MRI image enhancement is being suggested.

Present-day electronics is based on the fact that the electron has a charge, and the vast array of devices (like transistors, diodes, filters, rotators, etc.) takes advantage of the differing density of electronic states possessed by different materials, primarily semiconductors and metals, placed next to each other. A *new paradigm in electronics* is now emerging. It is based on the fact that the electron also has a magnetic spin and that different materials possess different densities of electronic spin states. Consequently, by placing such different materials next to each other, one can obtain quite different electronic behavior, like spin currents without electrons moving, spin filtering, non-volatile memory (i.e., which does not require a battery to maintain) and fast unlimited magnetic switching. In addition, it is becoming more apparent that one may even be able to control magnetic behavior by application of electronic voltages, a long-term elusive objective. Novel stress sensors, quantum computers, fast low energy superconducting computers, tiny high sensitivity magnetic field detectors, energy scavenging devices, and much higher density (perhaps 3-D) magnetic memory are just some of the devices which will result from such developments.

Manufacturing is also currently undergoing a revolution as industries begin to adopt new strategies and techniques for increased functionality in engineering components. One such advanced manufacturing effort is called additive manufacturing. Additive manufacturing conceptually uses printing technology to make objects in 3 dimensions using powders of different materials. Items as big as car bodies are now being experimentally constructed this way. It also enables new combinations of materials with different properties at different locations in the part. For example, one can use this technology to print unusually-shaped bulk magnets having different magnetic anisotropies and softness in different locations of the shape, thereby directing the magnetic flux more efficiently through the part and lowering its energy consumption.

Attention to *infrastructure* is also a continuing focus. Infrastructure is not just highways and bridges-it includes air and shipping ports, railways, buildings, water systems and energy grids, as well as complex monitoring equipment associated with a variety of subsystems. An equitable, safe, and sustainable infrastructure for the future will require a multi-disciplinary approach to address the realistic challenges that impact society. Of course, infrastructure has its roots in the core building materials such as concrete and steel but will also rely heavily on sensors, advanced manufacturing capabilities, and sustainable lifecycles. A resilient infrastructure must include climate effects, human behavior (demand shifts), and equity for safety and impact.

Petroleum Industry

The petroleum industry has historically been both a ‘source’ (a provider) and a ‘sink’ of innovations (a user from other domains). The industry has provided innovations in the area of how the subsurface of the earth functions. These technologies have ‘flowed’ from the petroleum industry to help provide an understanding of aquifers and improved subsurface environmental remediation techniques. Many technologies have also flowed into the industry from other domains including computing, automation, instrumentation, materials, and chemistry. The petroleum industry has benefited from these by improved tools and techniques that have helped make the industry safer and more effective. Sometimes the industry is an early adopter of these other technologies, and sometimes it seems to lag. With continuing advances in these other domains, there is likely no reason that the petroleum industry will not continue to benefit by learning from other areas. Some example technology challenges are *data mining, optimizing field development and operations, drilling rig automation, application of Lean Principles, application of nanoparticles, micro-seismic to characterize the subsurface, use of enhanced polycrystalline diamond,* and *CO_2 separation, transportation, compression, and injection.*

Creating a Network – Your Contributions Needed

Each of our technical societies exists to disseminate technology within their individual sphere. Over the years each has proven able to accomplish that mission by linking up people with similar challenges to see how, by sharing experiences, they can better solve the problems they face. The big idea of the COE is to link more people so that each association can help and benefit from the experience of those who have solved similar problems – but in a different field. By expanding the technology tool-box that we all have available, we will all be able to work smarter and make smarter use of the earth's resources.

Your participation is essential in creating and expanding a network of innovative engineers and scientists to synergize their minds and knowledge to accelerate new technology development and identify new and innovative application of aging or cross-industry technologies. Please submit your ideas at http://www.aimehq.org/programs/collaborative-efforts/council-of-excellence. We look forward to conversing with you on them and thank you in advance for your contributions in pursuit of technological innovation!

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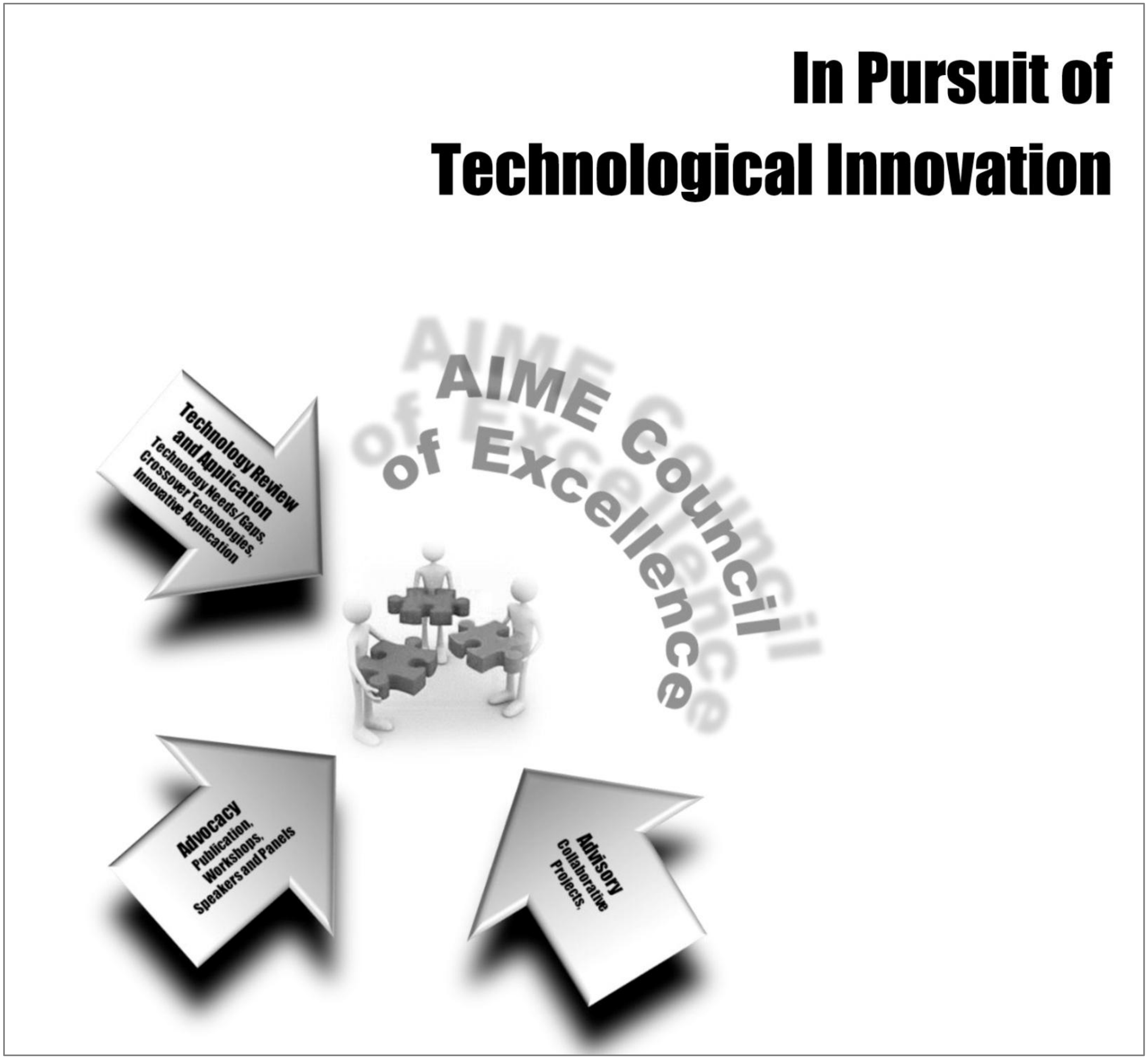

Figure 1. The Council of Excellence charge.

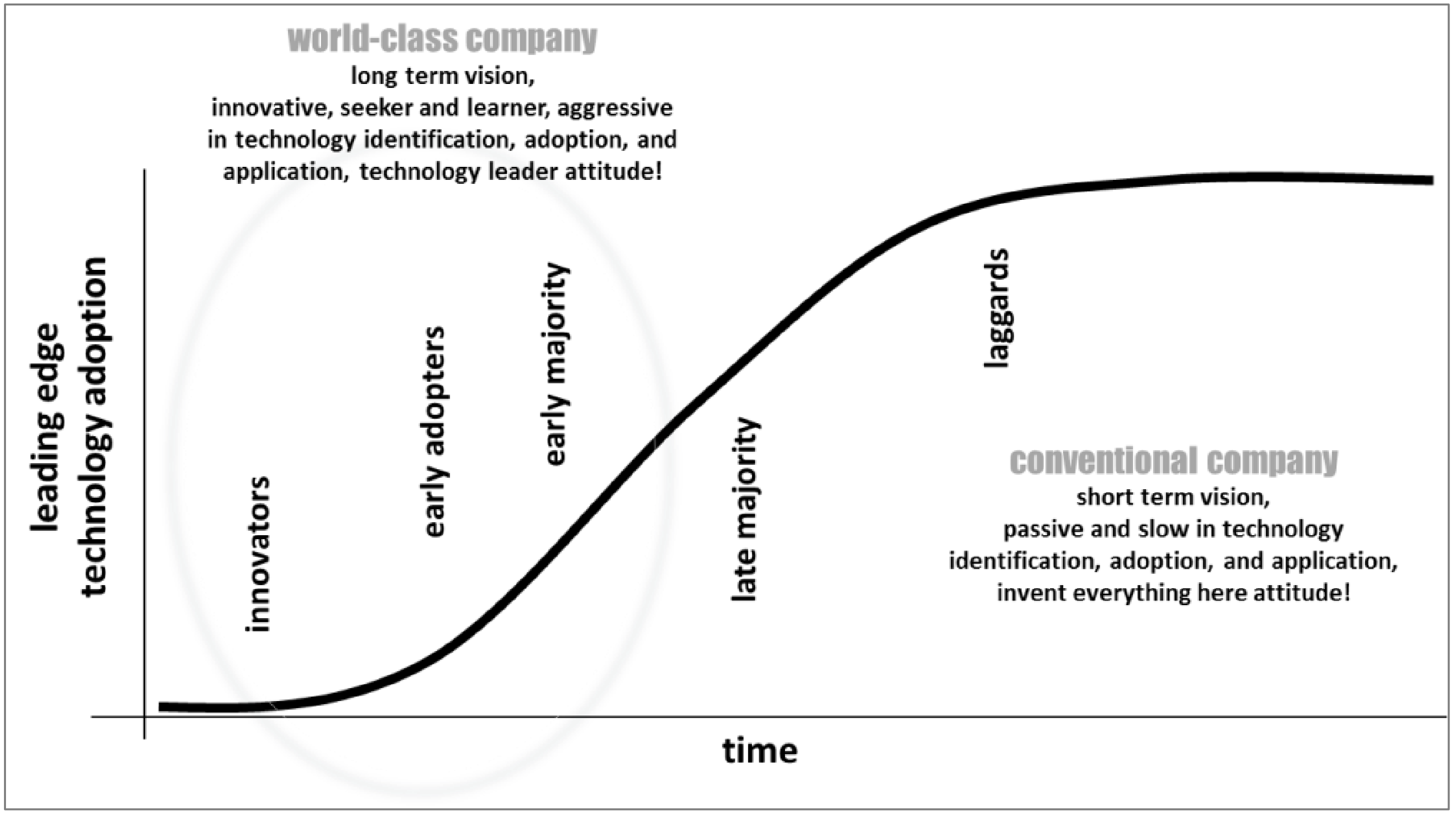

Figure 2. Technology adoption timeline.

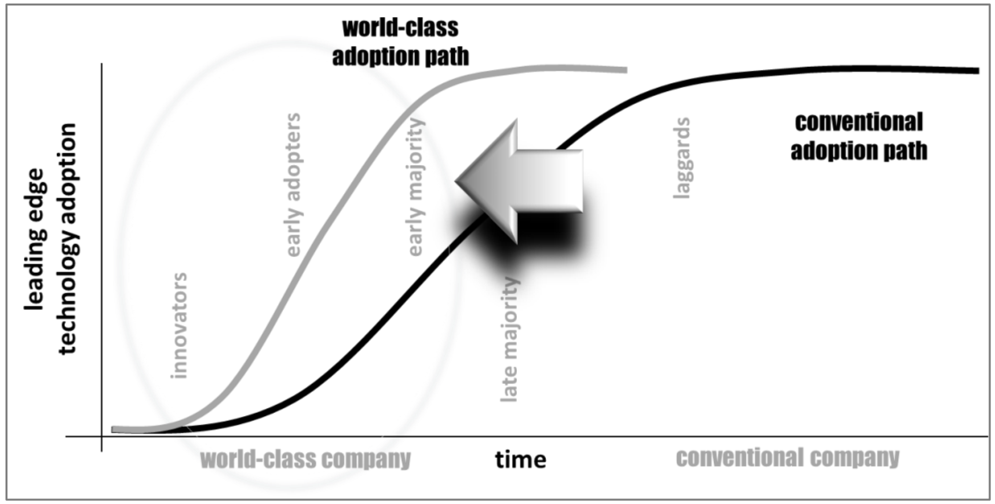

Figure 3. A shift in technology adoption timeline.

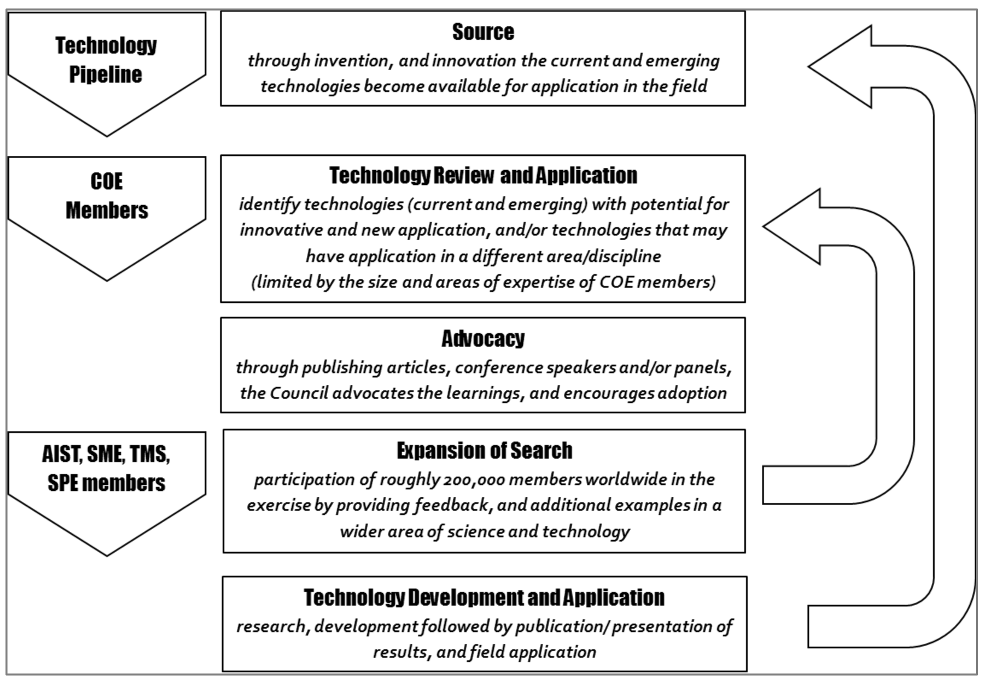

Figure 4. AIME Council of Excellence innovation process.

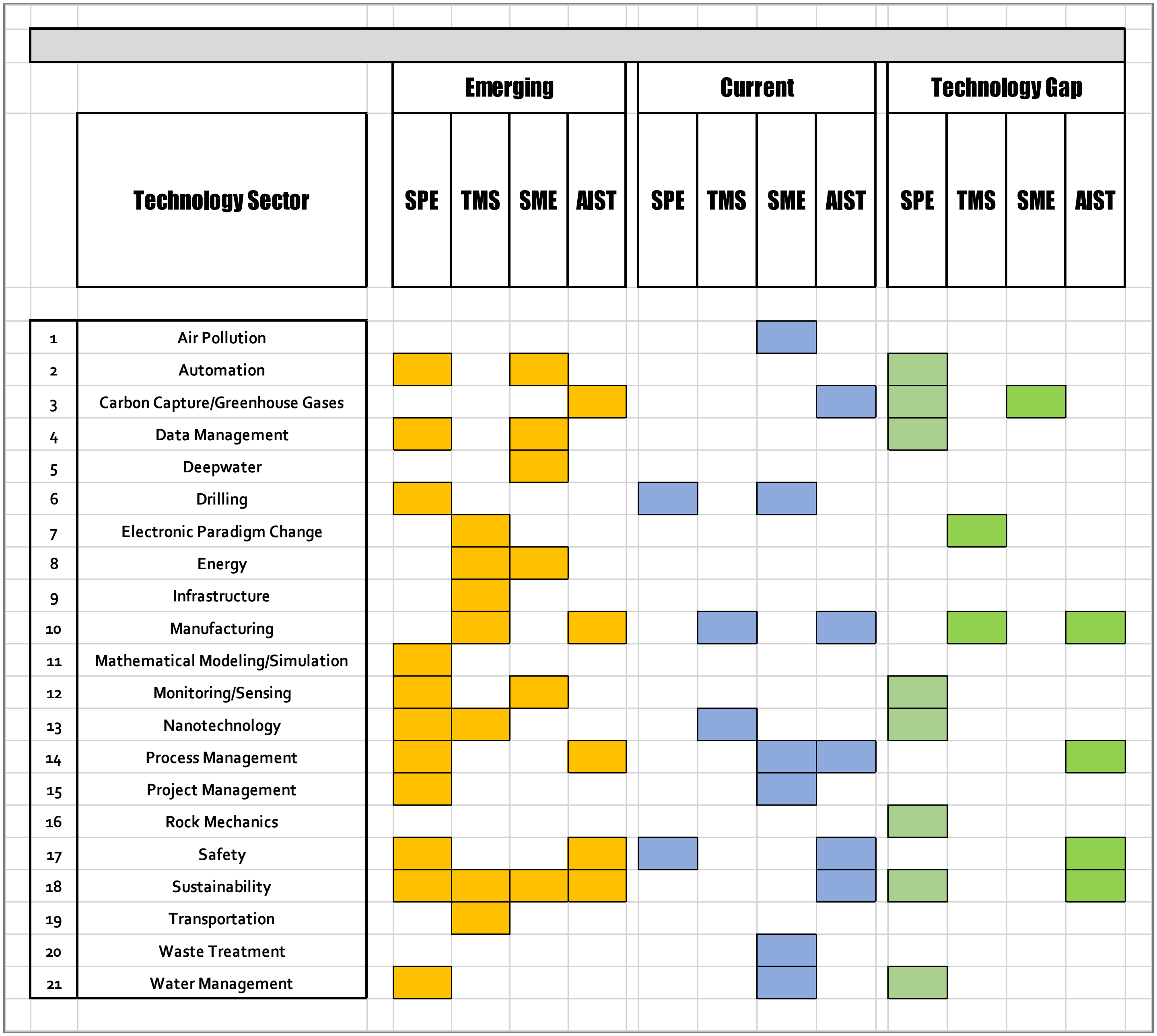

Figure 5. Preliminary technology sector and category listing identified by COE.