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Who Will Fill the Geoscience Workforce Supply Gap?

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Society needs more geoscientists than there are presently students.

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Society is inextricably linked to the resources and natural processes that exist and occur on our planet. As the global population grows and economic development continues to advance, our dependence on resources and the impact from processes is becoming increasingly apparent. The geosciences will continue to play an increasing role in meeting humanity's needs, as seen during the 2008 spike in energy prices, the recovery from natural disasters such as Typhoon Nargis that caused 146,000 fatalities in Myanmar, the emerging priority of potable water availability for international development, and the complexities that climate change is bringing to the global economy. These issues have created a near-term demand for geoscientists that, on aggregate, is exceeding the available supply. As the issues of resources and hazards become even more central to the global economy, the demand for geoscientists is expected to grow sharply.

Given the various educational pathways geoscientists follow and the varied industries that employ them, the geoscience discipline is difficult to define. Added to this complexity are the different ways in which geoscientists are classified by federal, professional society, and industry classification schema (*1*). However, for the purpose of this article we will follow the definition established in the American Geological Institute's (AGI's) recent report, "Status of the Geoscience Workforce, 2009" in which the geosciences include geology, environmental science, hydrology, oceanography, atmospheric science, geophysics, climate science, geochemistry, paleontology, and geoengineering disciplines (i.e., environmental, geotechnical, geological/geophysical, petroleum, and mining) (*1*).

The expansion of geoscience demand in the traditional employment sectors, such as the natural resources industries, is expected over the near and midterm to exceed the growth of efficiencies from enhanced technology and techniques (*2*). The scale and scope of future growth will further expand with increased global demand for resources, climate change and hazard mitigation, and expansion into non-core areas such as law, finance, and risk assessment to support decision systems for emerging issues in water, climate, and hazards. Additionally, labor intensity, particularly total workforce, will increase to meet the greater challenges of finding scarce resources, managing development as it encroaches upon higher-risk hazard zones, and developing new technologies to facilitate the transfer of geoscience knowledge across industries. Likewise, the application of core geoscience skills will evolve with the changing society and economic priorities. For example, a geoscientist working on reservoir characterization today may in the future use his or her skills to develop technologies for carbon capture sequestration or to characterize new hydrological resources.

The U.S. Bureau of Labor Statistics projects an overall 19% increase in all geoscience-related occupations between 2006 and 2016, which is 9% faster than the growth rate for all U.S. occupations (*1*). The highest growth rates in geoscience jobs will be in the management, scientific, and technical consulting (78%) which includes the majority of natural resource and hazard mitigation opportunities, waste management and remediation (37%), and finance and insurance (35%) sectors (*1*). Considering that a graduate degree is required for the majority of geoscience occupations, and that the number of geoscience graduate degrees conferred per year from U.S. institutions has averaged 1700 since 1995, the supply of new geoscience graduates to the workforce does not meet current demands, much less the projected increase in demand over the coming years (*1*).

Additionally, the aging geoscience workforce, with approximately 50% of geoscience professionals within 10−15 y of retirement, is cause for major concern within geoscience-employing industries (*1*). The concern is not only in the numbers, but also the ability to facilitate the technical and business requirements of employers in the future. With such rapid rates of attrition expected, the traditional mentoring processes in place within most organizations will be strained, undermining the long-term success of future geoscientists in the workplace. Also of grave concern is that a large portion of these impending retirees are in middle and upper geoscience management positions that require years, if not decades, of experience to be successful. The future middle and upper level technical managers are not in the workforce today, and will be placed into these positions more rapidly than their predecessors. These shortages portend wide-ranging negative effects on technical management and the

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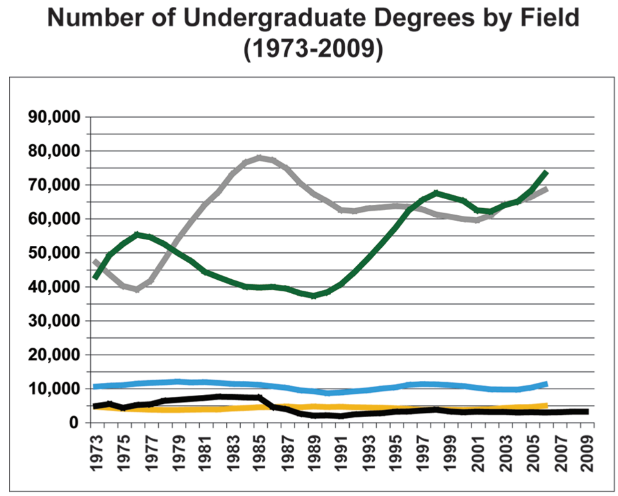
ability for the science to be integrated in the business and policy frameworks of geoscience-dependent activities.

Who will fill the geoscience supply gap? Ideally, the answer to this question is a large pool of new, well-trained geoscience graduates, and in the end, this is required to fully meet societal needs. The likely solution is a combination of options to fill the void until geoscience graduation numbers increase to meet demand. Such measures may include incentives for geoscientists to delay retirement, hiring and training scientists from other science, technology, engineering, and mathematics (STEM) disciplines, increased efforts in recruitment and retention strategies, and hiring non-U.S. geoscience graduates. Here we review the history of the workforce shortage and provide insight to the strategies that are currently being implemented to strengthen the geoscience workforce supply pipeline and to recruit more students into university geoscience programs.

History of the Workforce Shortage. Historically, the fortunes of geoscientists have been tied to the boom and bust cycles of the natural resource industries, both oil (and gas) and mining. The fortunes also extended to geoscience programs at universities. From the mid-1950s to the mid-1980s, there was fairly strong correlation between oil prices and undergraduate and graduate enrollments (Table S1), and geoscience degree completion rates were 25% for undergraduates and 29% for graduate students (*1*). National investments in the strategic mineral stockpile during the Cold War, bolstered by domestic economic growth and oil supply fears following the embargos of the 1970s, drove profits and opportunities in the resource industries, leading to high-paying geoscience jobs. Subsequently, enrollments in geoscience departments increased as students saw the promise of successful and lucrative careers in the geosciences. The connections between geoscience departments and industry were strong, and students and faculty recognized the skills needed for new graduates. These skills were centered on rigorous fieldwork and training in core geoscience concepts. After the collapse of commodity prices in the mid-1980s, oil and gas and mining companies laid off thousands of workers, especially in high risk areas such as exploration. The sudden and very public evaporation of high-paying jobs in industry resulted in a sudden and dramatic decrease in geoscience enrollments. One of the key results of this response was that by 1990, geoscience enrollments had largely decoupled from the price of oil, and they have never resumed pre-bust correlation patterns (Table S1). This sudden change required university geoscience programs to adapt or perish.

In a bid to bolster sagging enrollments and to capture an increased public awareness of environmental issues and the emerging environmental industry, universities began to add more environmental science/studies programs (*3*). During this period, many geoscience departments added environmental courses to their curricula to address the changing interests of students. However, even with the upswing in the natural resource industries over the past 5 y and the increased interest in the environmental field since about 1990, the number of geoscience degrees conferred per year has remained low relative to other science and engineering disciplines (Figure 1), with geoscience undergraduate degrees averaging approximately 2700/y and geoscience graduate degrees averaging 1700/y for the past 15 y (*1*).

Furthermore, the current economic recession has further stressed academic departments. Geoscience departments, a critical source of the future geoscience workforce, have been hit especially hard during this global economic crisis. Eighty-five percent of all U.S. geoscience departments expect budget cuts in 2009 and/or 2010, and 15% of geoscience departments expect budget cuts in excess of 10% (*4*). The majority of these cuts are expected to impact support activities (lab equipment, IT, etc.) and faculty (reductions and hiring freezes) (*4*). With



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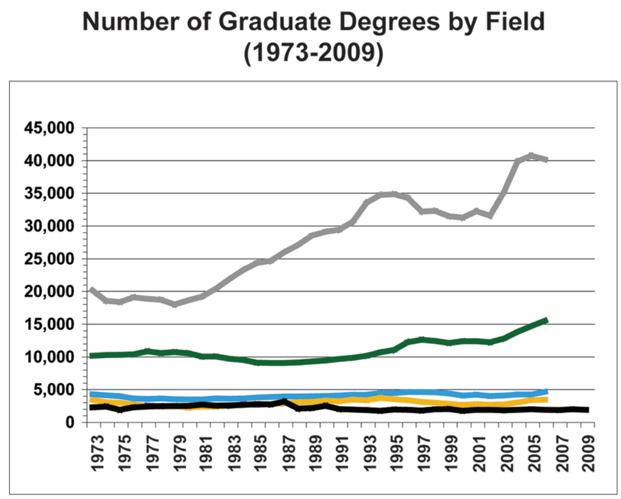

FIGURE 1. Number of undergraduate and graduate degrees conferred per year in science and engineering disciplines. The colors indicate degree by discipline: gray for engineering, green for biology, blue for chemistry, yellow for physics, and black for geosciences. Biology, chemistry, physics, and engineering degree data were derived from the National Science Foundation/Division of Science Resources Statistics (NSF/SRS) "S&E degrees: 1966−2006" data set (*29*). Biology, chemistry, physics, and engineering degree data for 1999 were interpolated from the 1998 and 2000 data because no data were listed for 1999. Geoscience degree data were derived from the American Geological Institute's "Geoscience Degrees Granted in the United States" data set (*30*).

29% of geoscience departments expecting the budget cuts to threaten their program's existence within the next 3 y (*4*), geoscience departments in the U.S. will be challenged to sustain the current levels of geoscience enrollments and number of new graduates. The funding challenges are also being seen in the 8% increase in 2008−2009 of undergraduates, but no real increase in graduate students (*5*). The limiter for geoscience graduate enrollments, even with greater demand, is that most students are accepted into funded assistantships. With 9% of geoscience departments expecting budget cuts to reduce graduate student admission and/or support, the flat trend in 2008−2009 geoscience graduate enrollments is likely driven by budget constraints that are not allowing expansion to accommodate demand (*4, 5*).

Student Participation in the Geosciences. The long-term challenge for the geosciences is recruitment and production of geoscientists, especially those who have been brought up in the field through their higher education. Results from a study of student motivations in selecting college majors indicates that lack of exposure to earth sciences in high school is a major reason for low enrollments in undergraduate geoscience programs (*6*). Unlike other sciences (e.g., biology, chemistry, and physics), many students fulfill their earth science education requirement in grades 6−8, and the majority of states do not require earth science for high school graduation (*1*), even though the National Science Education Standards, established in 1996, emphasize the importance of earth science literacy in primary and secondary school students (*7*). Additionally, the percentage of high school graduates taking a 1-semester course in earth science has not exceeded 25% over the past 27 y. When this percentage is compared with the highest percentage of high school students taking other science courses over the same time period (biology [93%], chemistry [66%], and physics [33%]), the discrepancy is startling, especially considering that the percentages for the other sciences are for full-year courses.

Fortunately, there has been progress in earth science education requirements in high school over the past 7 y. In 2007, 7 states required earth science as part of their high school graduation requirements, and 24 states included earth science in their recommended high school curriculum (a 9% increase from 2002) (*1*). Additionally, students who take earth science in high school are allowed to count these courses toward their graduation requirements in 31 states (*1*).

However, the average high school earth science course taker is more likely to not pursue science in college, and these students often score lower in science and math (*6*). The more science-attuned students are often fast-tracked to the other sciences (bypassing earth science in ninth grade and enrolling in biology instead) so they can take Advanced Placement (AP) science courses in their junior and senior years (*8, 9*). In the effort to place them in AP science courses, those students who may be well-suited to a geosciences college major are not exposed to earth science courses.

There are two major present barriers to accessing these potential geoscience majors: (1) the lack of certified secondary school earth science teachers, and (2) the lack of an AP Earth Science course. Over the past decade, several articles have stressed the importance of developing a cadre of well-trained and certified earth science teachers (*10, 11*). These articles have also noted the low certification rates of earth science teachers compared to other science disciplines (*10, 11*). The lack of certified secondary school earth science teachers is an impediment to the geosciences because teachers instructing outside their core competencies do not provide the same content and experiential framework for students as their specialist-trained colleagues (*11*). The broad development of geoscience education degrees would foster a larger corps of well-trained earth science teachers who would provide the quality experiences that could lead to increased enrollments in both high school and college geoscience courses and programs (*10, 11*).

The other barrier, a lack of an AP Earth Science course, is also a steep challenge to overcome since AP courses are sought after by college-bound students because they can often count toward college credit and represent an achievement that can help in competitive college admissions. Additionally, high school students who pass their AP exams are likely to continue in that field of study at the university level (*12*). To date there are AP courses in every major STEM discipline (Biology, Calculus, Chemistry, Computer Science, Environmental Science, Human Geography, Physics, and Statistics) except geoscience (i.e., technology and engineering are covered by the computer and physical sciences).

In 2000, representatives of the professional geoscience societies met with the College Board to propose an AP "Geology" course (*8*). As a result, the College Board surveyed high school teachers in 2001to determine their interest in such a course (*8*). However, to date, no formal AP Earth Science course has been proposed by the College Board.

In 2002, the National Research Council released a report "Learning and Understanding: Improving Advanced Study of Mathematics and Science in U.S. High Schools" (*13*) which examined the state of current advanced study programs, such as the AP and International Baccalaureate (IB) programs, and made recommendations for improvement of these programs. The report suggested restructuring advanced study programs to increase the depth of subject knowledge and extending student preparation for advanced study through middle school curriculum. The report catalyzed the redesign of AP Biology, Chemistry, Physics, and Environmental Science courses, supported through a $1.8 million grant from the National Science Foundation (*14*). The commission assigned to redesigning the AP Environmental Science (APES) course recognized the course's existing strong focus on social science and policy content, and that integrating additional earth science content would prove difficult (*14*). As a result, the APES commission recognized that earth science needed a separate standards track, and one with parity to the AP Chemistry, Physics, and Biology courses (R. Ridky, personal communication). Recently, the College Board released its report "Science College Board Standards for College Success" which gives detailed guidelines for aligning middle and secondary school curricula to prepare students for AP courses and postsecondary education as well as to be successful in college and the workforce (*16*). These guidelines specify the essential discipline-specific core principles and concepts that students need to understand, as well as performance expectations for students in middle school and those in secondary school. The report separately identifies Earth Science key skills and knowledge that middle school and secondary school students need to be prepared for introductory college-level earth science and environmental science courses, as well as for the current AP Environmental Science course and any AP Earth Science courses that may be added in the future (*16*).

University Program Outreach and Recruitment. To increase exposure of earth science to high school students, geoscience university departments have taken on a variety of strategies (*14, 15, 17*). Whereas several departments have developed outreach that provides workshops and lectures for professional development for K−12 teachers and increase awareness of the geosciences within the local community, others have focused specifically on recruiting high school students (*14, 15, 17*). Some examples of outreach efforts include the geoscience departments at Clemson University, Western Michigan University, Texas A&M University, and the University of Texas at Austin. Clemson University provides geology professional development workshops for K−12 teachers. Western Michigan University's Michigan Geological Repository for Research and Education (MGRRE) has a geoscience outreach program, called CoreKids, whose staff and scientists visit local classrooms to give lectures, facilitate visits to the MGRRE Core laboratory, and provide online resources to educators and the community. The geosciences department at Texas A&M provides a 2-week geology field camp specifically designed for 4th−12th grade science teachers. Additionally, the Jackson School of Geosciences at University of Texas at Austin has an active outreach program that provides public lectures via webcast, a professional development program for teachers, and a summer earth science college preparatory program for high-achieving middle and secondary school students.

Other departments have filled the "AP gap" by recruiting high school students to take advanced geoscience courses at their high schools for college credit (*14, 15*). Models for such arrangements between secondary schools and universities are increasingly common (*14, 15, 17*). In New York

State, ten high schools currently allow students to earn undergraduate credit from the State University of New York College at Oneonta's Earth Science Outreach Program (ESOP) by taking advanced geoscience courses taught by high school teachers at the students' high school (*14, 15, 17*). At ESOP's inception in 2005, only two schools participated with a total of 40 students, compared to 91 students today (*17*). Furthermore, data for the most recent year for five schools indicates that 13 of 67 students (19%) decided to major in the geosciences as a result of participating in the program (*17*). SUNY-Oneonta is just one example of connecting secondary schools with university geoscience programs. Other examples include Bellarmine College Preparatory School in San Jose, where students enrolled in Richard Nevle's Geology Honors course can earn up to three credits from the University of California, San Jose (*13*). At Harvard-Westlake School in California, Wendy van Norden's year-long honors geology course, in which students can earn college credit from UCLA, provides students with field experience through various field trips (*17*).

The combination of outreach programs that bolster the professional development of high school earth science teachers and fill the current "AP gap" through college credit for advanced high school earth science courses are making local inroads in building awareness of the geosciences, and increasing geoscience enrollments at the undergraduate level. These measures along with the standards recently released by the College Board will help to increase the earth science literacy among middle and secondary school students and teachers, and help pave the way for the implementation of an AP Earth Science course at some point in the future (*14*). Furthermore, expansion of these initiatives nationwide would likely make inroads toward solving the issue of insufficient incoming university geosciences students. In addition, AGI in cooperation with its member societies are bolstering geoscience student engagement in professional activities as a means to enhance student retention. In the geosciences, approximately 13% of all majors graduating with a geoscience degree work in geoscience professions, and this is half of the average for other STEM fields (*1*).

Where Graduates Go. The career decision process of students and how perceptions and opportunities influence that process is central to the task of moving a student to graduate with a propensity to work in the field. In the 1970s and mid-1980s, geoscience graduates typically sought careers in the natural resource industries. This is in sharp contrast to today when the three top career preferences for geoscience students are the federal government, state and local government, and the environmental industry (*18*). Furthermore, academic advisors generally advise students toward careers in the environmental industry more than in the petroleum or mining industries (*18*). Master's geoscience students have a preference for government jobs, environmental jobs, and academia, and to a lesser degree, jobs in the petroleum industry or continuing their education (Figure 2). Unsurprisingly, doctoral students indicate an overwhelming preference for academic jobs (Figure 2), but also for government jobs and postdoctoral employment (Figure 2). Unfortunately, as noted earlier, the major job-growth areas are in the private sector, yet two of the three core private employment sectors (petroleum and mining) suffer from low interest by both undergraduates (petroleum: 34%, mining: 29%) and graduate students (petroleum: 35%, mining: 17%) (*18*). A study of employment sectors of recent geoscience graduates indicates that the majority of doctoral geoscience graduates take positions in academia and the government while a small percentage work in the private sector (Figure 2). Half of master's geoscience graduates find work in the private sector (21% in the petroleum industry, 20% in the environmental industry, and 9% in other private industries), while the other half work in academia and government positions (Figure 2).

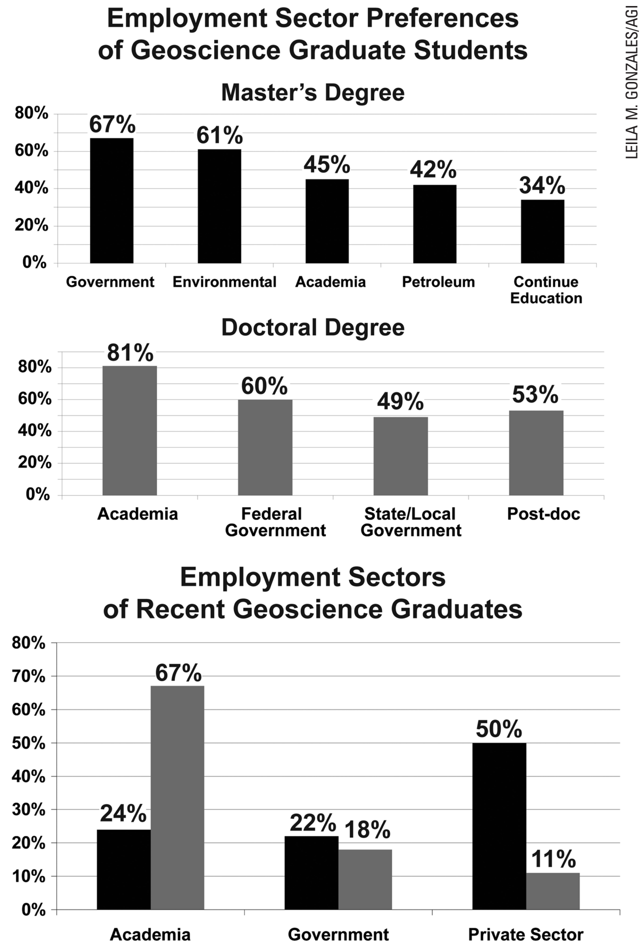

FIGURE 2. Preferences and employment of geoscience graduates. Top: Employment sector preferences of geoscience graduate students. Data derived from the American Geological Institute's *Student and Faculty Employment Attitudes in the Geosciences* (*18*). Bottom: Employment sectors of recent geoscience graduates. Black bars indicate master's degree recipients, and gray indicates doctoral degree recipients. Data derived from the American Geological Institute's *Status of the Geoscience Workforce 2009* (*1*).

Salaries for most geoscience-related professions have outpaced the national mean salaries of all other science occupations for the past decade (*20, 21*), and the most recent salary information (2008) published by the U.S. Bureau of Labor Statistics shows the mean salary for all science occupations was $64,280 while geoscience-related occupations salaries ranged from $65,280 for environmental scientists to $119,140 for petroleum engineers (*21*). Although the average salary growth for all science occupations over the past decade was 43%, some geoscience-related occupations grew faster, namely environmental science (49%), geoscience (49%), geography (56%), and petroleum engineering (116%) (*21*). Furthermore, whereas employment levels for all science occupations are expected to grow by 14% between 2006 and 2016, some geoscience-related occupations are expected to grow much faster: environmental scientists and environmental engineers (25%), geoscientists (22%), and hydrologists (24%) (*19*). Whereas academia and the government are expected to generally maintain staffing levels through replacement of natural attrition, the natural resource industries, which employ substantially more geoscientists than government agencies, are expected to increase their demand for geoscientists over the coming decades (*1, 19*).

Looking To the Future. The convergence of a supply shortage of skilled geoscientists, an aging geoscience workforce, and growth in the energy and environmental sectors means a bright future for well-trained geoscience graduates in the coming decades. Between 2000 and 2007, the petroleum industry, other private sector companies, and the federal government invested $188 billion into the energy industry to meet the projected 19% growth in energy demand over the next 20 y (*22*). The oil and gas sector is expected to continue to provide the majority of the world's energy supplies throughout the coming decades, and increasingly challenging environments for exploration and production within the petroleum industry will result in demand for skilled geoscientists (*2, 23, 24*). New regulations and the increasing importance of water resource management and conservation practices will boost the number of jobs in the environmental sector by 25% by 2016 according to the U.S. Bureau of Labor Statistics (*19*).

Employers across all industries have stressed that geoscience professionals in the future need strong quantitative skills and core geoscience fundamentals that they can apply across disciplines as industries evolve to meet the changing needs of society (*24*−*28*). These inevitable dynamics will also require an ability to work collaboratively and flexibly adapt to the changing directions of the science and the work environment. For example, a geoscientist engaged in discovering new oilfields today may be required to use those same skills to develop technologies to discover groundwater resources in the future.

Who Will Fill the Gap? Given the current trends in geoscience graduates and the expected changes in geoscience workforce demographics, the question remains, "Who will fill the gap, both in the near-term and in the future?" Ideally, a large pool of new, well-trained geoscience graduates would meet the future demand, driven by successful recruitment of students into university geosciences programs. However, a suite of solutions will most likely meet this demand by combining enhanced recruitment strategies to bolster degree production along with incentives for delayed retirements, retraining of professionals from other STEM fields, and hiring non-U.S. geoscience graduates.

With continued insufficient enrollment levels and a depressed rate of degree production, coupled with the near-term budgetary damage to departments in the current recession (*1, 4*), near to midterm growth in geoscience degree production will be challenging. However, despite the difficult situation, recent renewed efforts by academia, professional associations, nonprofit organizations, industry, and government have done much to increase public awareness about geoscience careers and have initiated focused recruitment strategies for increasing geoscience enrollments. Although these efforts will take time before their full effects can be seen, some efforts are already showing promise on a local level, while the key challenge remains of bringing these efforts to a national-scale implementation.

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Supporting Information Available

Table S1: decoupling of oil prices and geoscience enrollments. This information is available free of charge via the Internet at http://pubs.acs.org/.

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