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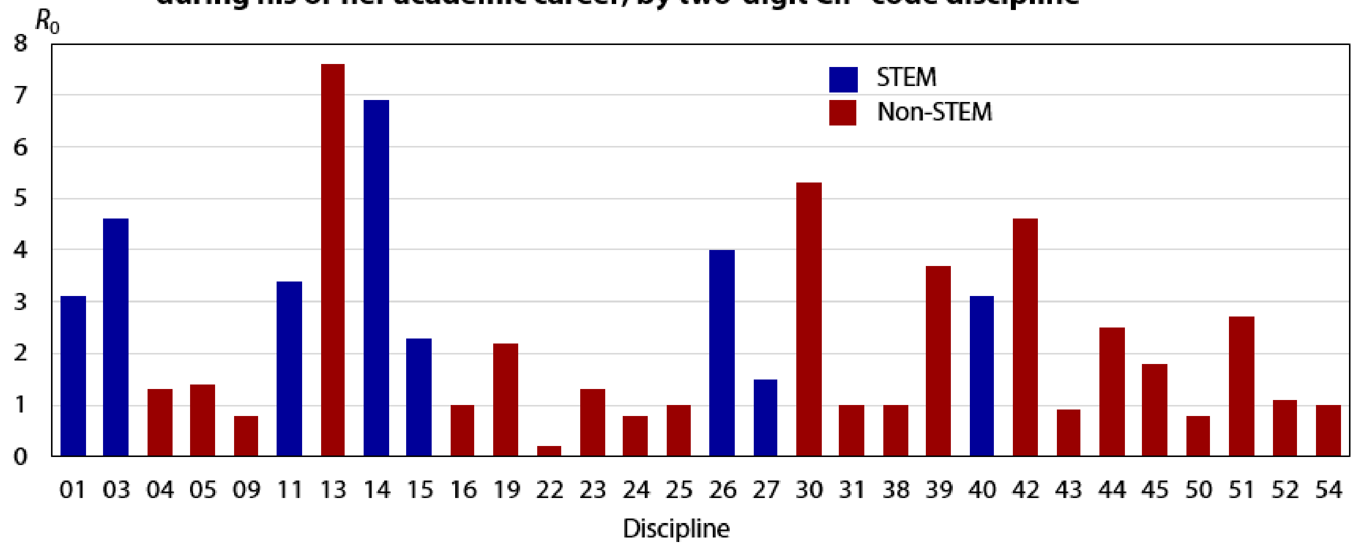
was defined as the mean number of new Ph.D.'s a typical tenure-track faculty member will graduate during his or her academic career. When $R_0 = 1.0$, each professor, on average, graduates one new Ph.D. that can replace him or her. When $R_0 > 1.0$, the number of faculty slots has remained almost constant and there are more workers with doctorates than there are faculty positions.

Figure 1. Mean number R_0 of new Ph.D.'s a typical tenure-track faculty member will graduate during his or her academic career, by two-digit CIP-code discipline



Note: Classification of Instructional Programs (CIP) codes are as follows: 01—Agriculture, agriculture operations, and related sciences; 03—Natural resources and conservation; 04—Architecture and related services; 05—Area, ethnic, cultural, gender, and group studies; 09—Communication, journalism, and related programs; 11—Computer and information sciences and support programs; 13—Education; 14—Engineering; 15—Engineering technologies and engineering-related fields; 16—Foreign languages, literatures, and linguistics; 19—Family and consumer sciences/human sciences; 22—Legal professions and studies; 23—English language and literature/letters; 24—Liberal arts and sciences, general studies and humanities; 25—Library science; 26—Biological and biomedical sciences; 27—Mathematics and statistics; 30—Multi/interdisciplinary studies; 31—Parks, recreation, leisure, and fitness studies; 38—Philosophy and religious studies; 39—Theology and religious vocations; 40—Physical sciences; 42—Psychology; 43—Homeland security, law enforcement, firefighting, and related protective services; 44—Public administration and social service professions; 45—Social sciences; 50—Visual and performing arts; 51—Health professions and related programs; 52—Business, management, marketing, and related support services; 54—History.

Source: Authors' calculations based on data from the College and University Professional Association for Human Resources

Using this method, we estimate R_0 for all fields of study in the United States. (We assume the average career duration to be 20 years.[15] We use 2012–2013 data from the College and University Professional Association for Human Resources (CUPA-HR), which reports the number of tenured and tenure-track faculty at 794 institutions in the United States.[16] We also use data from the National Center for Education Statistics' Integrated Postsecondary Education Data System, which has the number of Ph.D.'s awarded in 2012 at those same institutions. We group disciplines by their Classification of Instructional Programs (CIP) code,[17] a taxonomic scheme devised by the National Center for Education Statistics to track fields of study. Figure 1 shows that R_0 varies considerably across the broad disciplines listed.

Although the number of Ph.D.'s has been climbing steadily, the number of professor positions has remained almost constant in most fields, except for the biomedical sciences and computer sciences.[18] A higher R_0

indicates that more Ph.D.'s are competing for tenured and tenure-track faculty slots, provided that the number of positions remains constant. For example, $R_0 = 6.9$ signifies that a tenure-track position is available for only 14 percent (1 out of 6.9) of new Ph.D.'s in engineering. Our calculations show that $R_0 > 1$ for all STEM fields, indicating that there are more Ph.D.'s eligible for academic positions than there are openings, assuming no growth in the number of tenure-track faculty slots.

These R_0 statistics confirm anecdotal accounts. Faculty openings today often attract hundreds of qualified applicants.[19] Henry Sauermann and Michael Roach studied the preferences of science Ph.D. students (n = 4,109) and found that the majority considered a faculty research career to be an "extremely attractive" career path.[20] However, only a fortunate few go directly from graduate school to a tenure-track faculty position. In 2010, less than 15 percent of new Ph.D.'s in science, engineering, and health-related fields found tenure-track positions within 3 years after graduation.[21] For Ph.D.'s in the life sciences, the figure was an even smaller 7.6 percent. Most who want an academic career join academia as postdocs or adjunct faculty, hoping to vie for a tenure-track faculty position in the future.

Our findings here are consistent with many others in the literature. In 2007, Michael S. Teitelbaum highlighted the poor prospects for recent doctorates and postdocs.[22] Similarly, the RAND Corporation pointed out that the length of postbaccalaureate study for the biosciences has increased considerably, from between 7 and 8 years to between 9 and 12, and that many are unable to secure stable employment with tenure until their late thirties.[23] This finding was substantiated in a National Research Council report, *Bridges to Independence*, which focused on the poor state of biomedical research careers and urged immediate reform to enhance the quality of training and to foster opportunities for young researchers to conduct independent research.[24] Although this academic surplus began in the biosciences, it has now extended to encompass many STEM fields, such as astronomy, meteorology, and high-energy physics.[25]

Thus, in the academic employment sector, we find no evidence of any shortages. To the contrary, it appears that the mismatch is between an oversupply of Ph.D.'s desiring an academic career and the relative paucity of tenure-track faculty positions.[26] Although the degree of mismatch varies according to discipline, we have long queues of Ph.D.'s competing for nearly all STEM-related faculty positions.

The government and government-related sector: For the purposes considered here, this sector comprises different branches of civilian government organizations that require their employees to hold U.S. citizenship and certain security clearances. Examples are the U.S. Department of Energy's National Laboratories and the U.S. Department of Defense (DOD), the military, and a number of defense and aerospace contractors and research institutes.This section synthesizes reports produced by the National Academies that studied the hiring needs of the U.S. Air Force and the DOD with anecdotal accounts from the authors' interviews.

The National Research Council Committee states that the Air Force had a robust supply of personnel with STEM degrees to meet its recruiting goals for STEM positions, with a few exceptions.[27] The Air Force Personnel Center found staffing gaps in electrical engineering, operations research, quantitative psychology, physics, nuclear engineering, and systems engineering, specifically with regard to graduates with advanced degrees. The Aeronautical Systems Center commander also identified shortages, in areas such as electromagnetics, structures, software, reliability and maintainability, and manufacturing engineering.

Similarly, the National Academy of Sciences Committee, charged with identifying the needs of the U.S. DOD and the U.S. defense industrial base, found that DOD representatives almost unanimously stated that there was no STEM workforce crisis, but that there were specific areas in which needs were not being met.[28] For example, 800 funded positions were open for 90 days or more for systems engineers and other

STEM workers, and there were opportunities for cybersecurity and intelligence professionals as well. In addition, the aerospace and defense industry has experienced difficulty in hiring mechanical engineers, systems engineers, and aerospace engineers.

These sentiments were generally echoed in our interviews. One participant, a recruiting manager for a government research institute, said that hiring at the bachelor's level was relatively easy, but hiring those with advanced degrees was proving more challenging because of skill set mismatches.[29] He stated that, although there were many applicants from the mechanical, aeronautical, and bioengineering disciplines, shortages of electrical engineers existed at the doctoral level. Software development skills at all degree levels were also in high demand.

Another recruiting manager for a government research institute found difficulties hiring those with advanced degrees in computer sciences and computer engineering.[30] Because of budget stipulations, salaries his institute offered could not compete with those in the private sector.

Although foreign nationals can generally be brought in to bridge skill gaps in academia and the private sector, that is currently not an option in many areas for government workers and contractors, including defense-related contractors. The International Traffic in Arms Regulations dictate that information and material related to defense and military technologies may be shared only with U.S. citizens unless a specific exemption is obtained. A manager for a large government contractor found substantial shortages in hiring of Ph.D.'s in fields such as nuclear engineering, materials science, and thermohydraulic engineering.[31] This contractor requires only a dozen or so workers in each field, but the supply of U.S. citizens with doctorates in these fields is small.

A recruiter seeking people to work in engineering startup companies told us of problems finding materials science Ph.D.'s who were U.S. citizens.[32] Although the recruiter received dozens of applications from qualified foreign nationals, the government funding involved required U.S. citizenship.

In the government and government-related employment sector, we found no evidence of widespread STEM shortages; however, there may be shortages at the advanced-degree level due to citizenship and security clearance requirements.

Private sector. Much of the literature on the STEM crisis emanates from concerns about shortages or surpluses in the private-sector STEM labor market; however, the crisis is generally discussed in broad terms, referencing the STEM workforce as a whole. For example, the report by the President's Council of Advisors on Science and Technology called for an additional 1 million STEM degrees over the next decade.[33] Similarly, many studies dispute the claim that there are STEM shortages at the aggregate level and point to shortages only in specific fields.[34] However, the disciplines involved and the degree levels at which graduates are actually in demand are unclear.

The findings that follow are from a literature review and interviews.

1. Shortages. There are many accounts based on anecdotal evidence that break down disciplines to a relatively detailed level and identify specific areas with a shortage of STEM talent. For example, Lou Frenzel identified shortages among analog/linear and radiofrequency/microwave design engineers and skilled programmers.[35] Similarly, Jonathan Rothwell analyzed the Conference Board's Help-Wanted Online Series® and found that in 2010 there were seven job openings in computer occupations for every graduate with a relevant computer major.[36] And Abby Lombardi, in *Wanted Analytics*, which aggregates job listings from all over the World Wide Web, reported in 2013 that help-wanted ads for software developers were up 120 percent over the previous year.[37]

From our interviews with recruiters, we also find software development skills to be the most in demand. Experienced mobile application developers are especially coveted.[38] In certain cases, it does not even matter whether a candidate has a bachelor's degree in a specific area: companies[39] are looking for candidates with hands-on experience in software development through "hack-a-thons," extracurricular projects, and internships. These anecdotal accounts are supported by a falling unemployment rate for software developers, from 4 percent in 2011 to 2.8 percent in 2012 and down to 2.2 percent in the first quarter of 2013.[40] Also, the recent "big data" trend has sparked demand for data scientists in all areas, from health care to retail.[41]

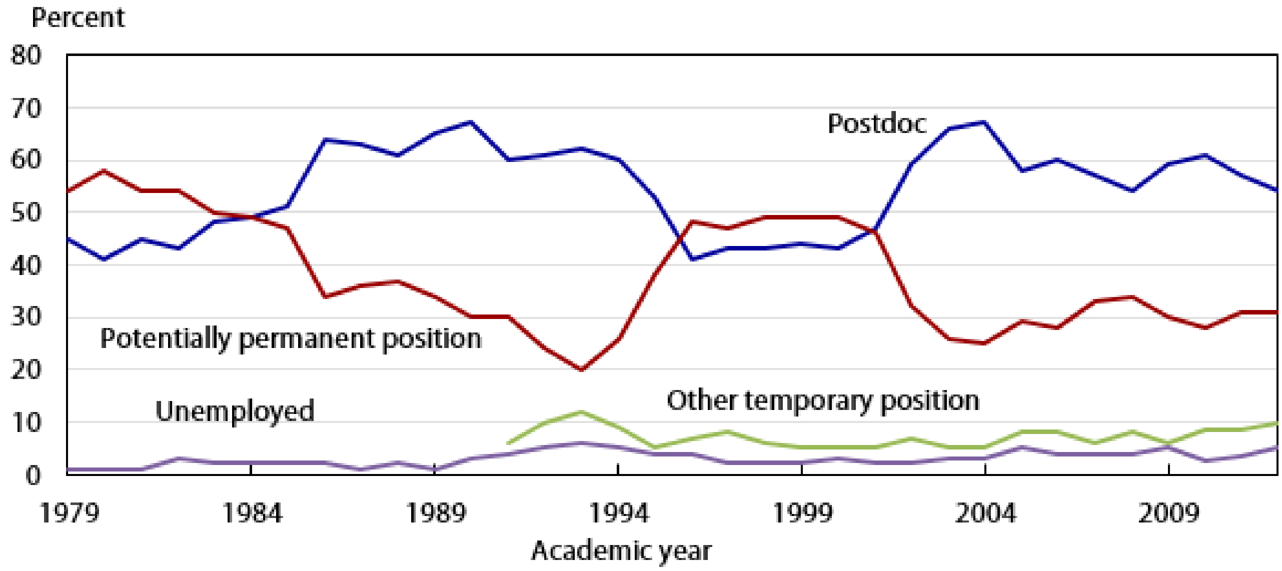
Because energy prices surged in the last decade and new technologies for the domestic extraction of oil and gas emerged, petroleum engineers are now in high demand, even though that occupation was an unattractive and declining one throughout the 1980s and 1990s.[42] As an indicator, the real wages of petroleum engineers have increased.[43]

Demand for STEM skills also exists below the bachelor's level. A 2011 survey of manufacturers found that as many as 600,000 jobs remain unfilled because there is a lack of qualified candidates for technical positions requiring STEM skills—primarily production positions (e.g., machinists, operators, craftworkers, distributors, and technicians).[44] Some are concerned that very few people are pursuing employment in the skilled trades.[45]

2. Surpluses. At the same time that shortages exist, there are areas with surpluses of STEM talent—most notably, biomedical Ph.D.'s. An NIH blue-ribbon panel found an increasing number of biomedical Ph.D.'s working in science-related occupations that do not involve research and even that do not require graduate training in science.[46] Chemistry and biomedical graduates also have taken a hard hit, due to the downsizing and offshoring of biotechnology, chemical, and pharmaceutical jobs.[47] Since 2000, U.S. pharmaceutical companies have cut 300,000 jobs.[48] By 2012, downsizing had increased the unemployment rate among chemists to 4.6 percent, the highest in 40 years. One recruiter we interviewed said he found that many chemical engineering college graduates were seeking employment in software development.[49] Among young Ph.D.'s, the situation was even worse: just 38 percent of newly minted chemistry Ph.D.'s were employed in full-time, nonpostdoc positions in 2011, down from 51 percent in 2008.[50] New chemical engineering Ph.D.'s fared better, with a full-time, nonpostdoc employment rate of 61 percent.

In 2010 and 2011, the unemployment rate for electrical engineers held at 3.4 percent, but it spiked to 6.5 percent in the first quarter of 2013. Although recruiters in the government and government contractor sector had concerns about hiring electrical engineers, these concerns did not surface in our interviews with private sector recruiters, suggesting that the hiring challenge in the government sector is probably due to the U.S. citizenship requirement.

Figure 2. Initial employment of physics Ph.D.'s, 1979–2012

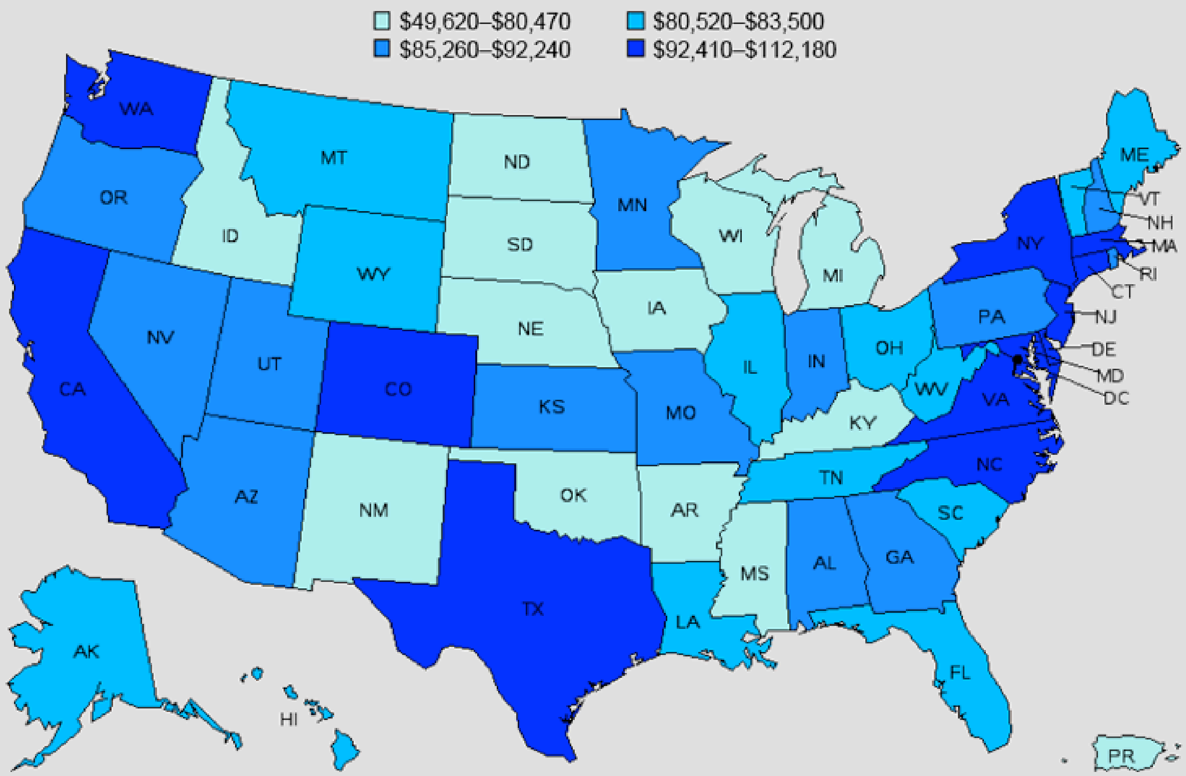


Note: In 1991, the survey questionnaire was changed to measure "other temporary" employment as a separate category. Data are limited to Ph.D.'s who earned their degrees from a U.S. university and remained in the United States.

Source: American Institute of Physics, Statistical Research Center.

Because the unemployment rate for STEM Ph.D.'s is generally low, a more useful indicator of job market strength is the number of STEM Ph.D.'s who accept potentially permanent positions, compared with those who accept postdocs. A considerable number of physics Ph.D.'s are unemployed, accepting postdocs and other temporary positions (69 percent in 2010, as opposed to 51 percent before the dot-com bust), indicating that the demand for physics Ph.D.'s is not high. (See figure 2.)

Figure 3. Annual mean wage of software developers of applications, by state, May 2013



Source: U.S. Bureau of Labor Statistics.

3. Geographic differences. There are also regional differences in the labor markets for STEM workers. For example, software developers are in much higher demand in California, Washington State, and New York, a fact that is reflected in their higher wages in those states. (See figure 3.) This trend is seen across different STEM occupations, and areas of demand vary. Petroleum engineers, for instance, are clustered in Texas and Oklahoma. A recruiter for a company in Connecticut stated that one of the primary challenges he faced in hiring software developers was the location of the office, because many qualified candidates were reluctant to relocate to Connecticut.[51] Another recruiter mentioned that his company relocated to the Boston area specifically to gain access to the local talent pool, a move that improved recruitment.[52]

Summary

Across all the different disciplines, yes, there is a STEM crisis, and no, there is no STEM crisis. It depends on how and where you look.

For most Ph.D.'s, the United States has a surplus of workers, especially in tenure-track positions in academia. The exceptions are certain fields within industry, such as petroleum engineering, process engineering, and computer engineering, and other fields in the government sector, such as nuclear engineering, materials science, and thermohydraulic engineering. Academia tends to absorb the Ph.D.'s who are unable to find positions in industry into postdoc positions. At the bachelor's and master's levels, there is consistent demand for employees in software development, as well as in high-growth areas such as mobile application development, data science, and petroleum engineering. There is also demand below the bachelor's level in the manufacturing industry, which needs workers in the skilled trades, such as machinists and technicians. Hence, we have a *heterogeneous* mixture of supply and demand for different occupations: some have a queue of workers, others a queue of unfilled positions.

Our findings are supported by the National Center for Education Statistics' longitudinal study of baccalaureate holders, a survey which found that 69.7% of graduates who had not enrolled in advanced-degree studies after they completed their bachelor's degrees in the 2007–2008 academic year were employed in a full-time job with an annualized median salary of $46,000 between graduation and 2012.[53] For STEM majors, the full-time employment rate increased to 77.2 percent and the median salary was $60,000. However, not all STEM majors were equally in demand: computer and information sciences majors and engineering and engineering technology majors had full-time employment rates of 77.1 percent and 83.2 percent, respectively, and corresponding median salaries of $66,000 and $67,000, while graduates who majored in the biological and physical sciences, science technology, mathematics, or agricultural sciences had a full-time employment rate of 71.4% with a median salary of $46,800, closer to that of non-STEM majors. These data are consistent with our conclusion that there is significant variation in the demand for graduates, depending on the STEM discipline.

Conclusion

This article draws upon a variety of data sources—professional science and engineering societies, labor market data, the National Science Foundation, literature reviews, and anecdotal accounts—to understand the supply-and-demand landscape for the STEM labor market. The analysis presented offers a first cut at identifying disciplines and degree levels that are either in demand or oversupplied. A clearer picture of the supply and demand of the STEM workforce will require better data and consistent monitoring of both employer requirements and STEM worker availability.

We introduced the taxicab queuing model as a metaphor for the STEM labor market. Depending on the STEM job segment, we can either have a queue of positions waiting to be filled (cf. taxis) or a queue of STEM workers waiting for jobs (cf. passengers). The characteristics of the queue depend on different factors: the rate of job turnover (cf. taxi service rate); the STEM worker arrival rate (cf. passenger arrival rate); the number of positions available (cf. the number of taxis in the fleet); the location of the job; the degree held by the worker (cf. type of taxi); and the worker's citizenship status. The model also highlights the probabilistic nature of the supply-and-demand market: random fluctuations can cause job segments that traditionally have a shortage of workers to have a surplus, and vice versa. Although we currently lack the data to operationalize the model, it presents a novel approach to characterizing the variation across STEM job segments.

Our central question is whether there is a "STEM crisis" or a "STEM surplus." The answer is that both exist. Our analysis yields the following findings:

- The STEM labor market is heterogeneous. There are both shortages and surpluses of STEM workers, depending on the particular job market segment.
- In the academic job market, there is no noticeable shortage in any discipline. In fact, there are signs of an oversupply of Ph.D.'s vying for tenure-track faculty positions in many disciplines (e.g., biomedical sciences, physical sciences).
- In the government and government-related job sector, certain STEM disciplines have a shortage of positions at the Ph.D. level (e.g., materials science engineering, nuclear engineering) and in general (e.g., systems engineers, cybersecurity, and intelligence professionals) due to the U.S. citizenship requirement. In contrast, an oversupply of biomedical engineers is seen at the Ph.D. level, and there are transient shortages of electrical engineers and mechanical engineers at advanced-degree levels.

- In the private sector, software developers, petroleum engineers, data scientists, and those in skilled trades are in high demand; there is an abundant supply of biomedical, chemistry, and physics Ph.D.'s; and transient shortages and surpluses of electrical engineers occur from time to time.
- The geographic location of the position affects hiring ease or difficulty.

As our society relies further on technology for economic development and prosperity, the vitality of the STEM workforce will continue to be a cause for concern.

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Notes

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[30] Research institute B, involved primarily in U.S. government projects that require U.S. citizenship.

[31] Engineering company A, a government contractor that requires U.S. citizenship and hires no dual-citizenship holders.

[32] Engineering startup.

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