# Building the Next Generation Through 20 Years of Solar Decathlon: From Collegiate Prize to Multifaceted Clean Energy Workforce Program

## Preprint


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*National Renewable Energy Laboratory*



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# Building the Next Generation Through 20 Years of Solar Decathlon: From Collegiate Prize to Multifaceted Clean Energy Workforce Platform

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**ABSTRACT**

The U.S. Department of Energy Solar Decathlon®, initiated in 2002 as a collegiate competition that challenges student teams to design and build high-performance, low-carbon buildings powered by renewables, has always aimed to empower students to become the next generation of buildings professionals. As we celebrate the 20th anniversary of the Solar Decathlon in 2022, this paper highlights the competition's evolution from a singular prize to a multifaceted platform that prepares the broader buildings workforce to address climate change.

The original event encouraged college students to design and construct a residence over a two-year period. To improve the accessibility of the competition, the Design Challenge—a one to two semester, design-only competition for both residential and commercial buildings—was added to the Solar Decathlon platform. The Solar Decathlon has also scaled globally with events in Europe, the Middle East, China, Latin America and the Caribbean, Africa, and India. In 2021, the Solar Decathlon broadened its reach once again by introducing three new programs: Solar Decathlon Professionals (SD Pro), Solar Decathlon Pathways (SD Pathways), and the U.S. DOE Zero Energy Design Designation. Each of these new programs seek to expand the Solar Decathlon mission to learners of all ages. SD Pro provides a zero energy design practicum for architects and engineers, while SD Pathways connects Solar Decathlon alumni with high school students across the United States to promote STEM educational paths. And the Zero Energy Design Designation recognizes post-secondary academic programs that prepare students to tackle climate change through zero energy building designs.

This paper utilizes participation data, alumni profiles, project submissions, and more to understand how changes to the competition have expanded program reach to minority-serving institutions, as well as improved the program's impact on the building industry's capacity to construct or renovate high-performance and zero energy buildings.

As one of the oldest federal government competitions, the Solar Decathlon offers a roadmap for dramatically increasing prize impact and demonstrates continued dedication to pushing boundaries in tackling decarbonization and environmental justice through workforce development.

## Introduction

Global climate analysis has established a goal for every country's energy economy to achieve a standard of net zero emissions by 2050 (EIA 2021), and the United States now has the opportunity to show global leadership in taking action toward this goal. However, to do so requires historic progress in efficiency innovation and renewable energy integration.

The residential sector currently accounts for 17% of energy consumption in the United States, and the commercial sector accounts for 12% (EIA 2021). While both sectors include a range of energy uses, improving building efficiency is a promising path to carbon neutrality.

In 2015, the average annual energy consumption of a U.S. home was 77 million British thermal units (BTUs), double that of a personal vehicle, while also releasing 70% more carbon emissions (EERE n.d.). Due to advancements in energy efficiency, energy consumption of American homes has remained consistent despite houses becoming larger and increasingly dependent on appliances. A home built in 2000, for example, consumed the same amount of energy as one built in 1960, despite being 27% larger (EERE n.d.).

While progress in energy efficiency is encouraging, to achieve the 2050 net zero emissions goal in the residential and commercial sectors, new construction buildings must be constructed to zero emissions standards and existing buildings must be significantly retrofitted to achieve net zero emissions by 2050. This transition can be spearheaded by a growing workforce committed to building zero energy and zero energy ready structures. A zero energy building (ZEB) is "an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy" (DOE 2015). For a structure to be considered zero energy ready, it must maintain a level of energy consumption that can be offset by renewable energy generation (DOE 2013)

The International Energy Agency has set a goal for 85% of buildings to fulfill zero energy standards by 2050; however, incremental goals have also been set by multiple agencies. Milestones set by the American Council for an Energy Efficient Economy (ACEEE) to achieve by 2030 are (ACEEE 2021):

- 25% of existing buildings retrofitted.
- 33% of low-income houses receive efficiency improvements.
- 25% of new construction achieves zero energy (beginning in 2030).

Successfully reaching these milestones relies upon a skilled, engaged, and diverse workforce. Several programs have already been initiated to stimulate the growth of this field. For example, the New York State Energy Research and Development Authority (NYSERDA) has partnered with the New York Department of Labor to increase field training for employees working in clean energy efficiency and deployment (NYSERDA 2021). Government-funded incentives increase the feasibility of hiring and maintaining skilled workers for employers; however, such programs are not aimed at attracting new workers. Independent certification programs, such as the Urban Green Council's Green Professional Building Skills Training, have shown success in technical training while also introducing the field to a new candidate pool (Srivastava, Awojobi, and Amann 2020). Both field training and independent certification provide support for a growing field of ZEBs. However, innovation is required in order to achieve net zero by 2050, and multiple publications have found an increase in innovation with an increase in competition between equitable parties (Bos, Kolari, and van Lamoen 2013; Ahn 2002; Chen et al. 2021; De Bondt and Vandekerckhove 2012), yet there are few competitions offered in building sciences.

Incorporating technical training, workforce growth, and innovation, the National Renewable Energy Laboratory (NREL) organizes the U.S. Department of Energy (DOE) Solar Decathlon, a collegiate competition that challenges students to design and construct zero energy buildings in residential and commercial divisions. The competition has progressed from a single-prize contest to an international workforce platform over the past 20 years (2002 to 2022), and its contribution to the field of building science has progressed as well. The primary focus of this

paper will be to analyze the Solar Decathlon's strategy of support for the growth and diversification of an industry able to produce zero energy structures.

### Solar Decathlon Background

The Solar Decathlon program, outlined in Figure 1, provides participating students hands-on training that prepares them for the clean energy workforce. Through realistic design constraints, students are educated about the latest solutions for zero energy design and high-performance buildings. Throughout the competition, teams engage with local industry partners, sponsors, and nonprofit organizations to apply sound building science principles to create cost-effective, market-ready designs (DOE n.d.).

For the 2022–2023 competition cycle, Design and Build Challenge teams compete in the following 10 Contests: Architecture, Engineering, Market Analysis, Durability and Resilience, Embodied Environmental Impact, Integrated Performance, Occupant Experience, Comfort and Environmental Quality, Energy Performance, and Presentation. Each Contest is equally weighted, so teams must excel in each contest to win.


Figure 1. Solar Decathlon Challenges 2022–2023. *Source*: (DOE n.d.)

Teams select their site location independently and must state how their designs meet their target market and excel within the geographic constraints. In both the Design and Build Challenges, projects are evaluated to determine how effectively teams integrate energy efficiency into well-designed, high-performance buildings that "push the envelope" for consumers and industry.

## Contributing to the Acceleration of Innovation

### Academic Autonomy and Constructive Competition

Already, a community of professionals have dedicated their careers to the research and implementation of clean energy; in the next decade, this community is projected to multiply and accelerate (IEA 2021). DOE and NREL seek to contribute high-impact resources toward the

advancement of a sustainable energy future, and the resources of Solar Decathlon are primarily dedicated to the development of an inspired community of students. These individuals, pursuing the science of zero energy design by their own volition, are well prepared to become primary players in the achievement of a zero energy economy.

Solar Decathlon participants are unified by their interest in energy technologies and their ambition to take on such an intensive extracurricular project. This autonomy allows for heightened personal investment, as well as community building through shared priorities. Classroom learning allows students to receive detailed information; however, four to six years of degree requirements can lead to students forming a perception of learning dominated by obligation (Cardon 2014). Alternatively, the Solar Decathlon is an opportunity for students to dedicate time and energy to a cohesive, self-managed project which can ignite a student's passion for technical material (Barak and Asad 2012).

The Solar Decathlon also offers technical training to contestants, as well as working professionals, through the Building Science Education (BSE) course. This module-based series provides a backbone of substantiated science and allows students and professionals to broaden their understanding of building capabilities. This information supplements prior training by maintaining a narrow focus on ZEB technologies. Beginning with foundational modules to ensure baseline understanding, the BSE then goes into detail about pertinent technology such as passive design strategies, temperature control technologies, and mathematic processes pertaining to envelope efficiency (DOE n.d.). The BSE also includes material focusing on topics pertinent to the zero energy design process, such as embodied environmental impact, grid interaction, and theories of effective design. The program is offered at no cost and acts as a launchpad to the Solar Decathlon challenges.

Contestants then begin their design process working within a team and against groups of similarly ambitious peers. This coupled competition and collaboration pushes contestants to apply their knowledge in creative and logical ways, opening the door for innovation.

**Solar Decathlon Build Challenge**

The Build Challenge began in 2002 with the inaugural Solar Decathlon and has evolved through 10 editions over the past 20 years. In its original format, teams were challenged to design and build houses that could be powered by rooftop solar. The competitions culminated with teams transporting their houses to a centralized event location, where they were assembled and displayed for measurement, evaluation, and public exhibition. These temporary Solar Decathlon Villages fostered a sense of community among competing teams and inspired hundreds of thousands of visitors with visions of the future of buildings.

The 2023 Build Challenge introduced a new "Local Build" format where teams build or renovate permanent structures in their local communities. Rather than transporting houses to a centralized event location, the team projects are built and exhibited in their communities, showcasing their work to members of the public, regional industry, local governments, and more. This marks a shift from research, development, and temporary demonstration of innovative building technologies to the deployment of market-ready, innovative technologies and building techniques that provide lasting impact in communities around the world. The figure below depicts the program schedules of both the Design and Build Challenges over the course of a Build Challenge cycle.

Figure 2. Project schedules for Solar Decathlon Build and Design Challenges, 2022–2023. *Source*: (NREL 2020)

Structured as an 18-month design/build project over the course of two academic years, the Build Challenge runs in parallel with the Design Challenge, with major milestone events that bring the entire Solar Decathlon program together. The first six months of the Build Challenge comprise the design phase, in which teams submit various deliverables to the competition organizers that are meant to facilitate the development of their building design, from concept to detailed construction drawings and plans. Build Challenge teams present their designs and their plans for construction to a jury of industry members at the competition event in April, with the goal of receiving "Approval to Proceed" to the construction phase. For 2023, this Approval to Proceed is paired with $50,000 in DOE prize funding.

From this point, the Approval to Proceed and associated prize funding kickstart the next 12 months of activity. Teams must secure proper building permits and begin construction in order to complete their houses and obtain certificates of occupancy by the construction completion deadline in mid-February.

Upon completion, the houses enter the measured evaluation period. In the Build Challenge, 4 of the 10 Contests are scored based on the measured performance of each house: Integrated Performance, Occupant Experience, Comfort & Environmental Quality, and Energy Performance. With houses located in various climate zones around the globe in the new Local Build format, these Contests have been revised to evaluate the overall functionality of the house rather than absolute measurements such as energy consumption, energy production by rooftop solar panels, etc. For example, these measurements evaluate each house's ability to maintain a comfortable indoor environment for its occupants, provide amenities, produce on-site renewable energy, charge an electric vehicle, and more.

To complete these measurements, the competition organizers send a measurement and instrumentation kit to each team. Equipment is selected, calibrated, and set up to capture the data required for the measured Build Challenge contests. The installation and measurements are overseen by the competition organizers to ensure consistent evaluation across all teams. Using virtual meeting software, the organizers observe various components of the measurement process and provide supervision on the proper execution of each activity. Once measurement data is captured, points are awarded according to the rules of the competition.

Teams then open their houses to their communities for the local exhibition period. Each team hosts tours, open houses, media engagement sessions, and VIP visits to showcase their

work and educate the public on the technologies and design decisions incorporated in their house. Leading up to this exhibit period, the competition organizers provide specific guidance and resources for teams to create a community outreach and engagement strategy that will maximize the influence of these student projects.

The remaining points are awarded in the six juried contests during the final Competition Event, during which students present to juries for Architecture, Engineering, Market Potential, Durability & Resilience, Embodied Environmental Impact, and Presentation. Each Contest is evaluated individually by juries consisting of experts in the specific subject area. The teams present an overview to all juries together, followed by individual jury presentations focused on each Contest. Juries then determine scores for each Contest, basing evaluation on presentation materials, virtual tours, photography of the houses, and technical documentation. Adding these points to the score earned in the measured Contests, overall scores are tallied, and final standings are announced. The Build Challenge awards first, second, and third place in the overall competition, as well as first, second, and third place in each of the 10 Contests.

Regardless of final standings, teams the complete the Build Challenge walk away with an intense, hands-on educational experience that uniquely prepares them for careers in the buildings industry. And with a permanent, locally built house, the Build Challenge project creates lasting impact beyond the competition, resonating outward into the community and local industry.

**Solar Decathlon Design Challenge**

In collaboration with the DOE Zero Energy Ready Home Program, the Design Challenge began in 2014 as the Race to Zero competition. In the original format, collegiate teams competed to apply sound building science principles to create market-ready residential designs.

Today, the Design Challenge has expanded to include residential and commercial building divisions, as well as zero energy retrofits, while competing in the same 10 contest areas as the Build Challenge. Students are encouraged to work in multidisciplinary teams to simulate real workplace groups that they will likely encounter in their professional careers.

Engagement with industry professionals during the Design Challenge provides real-world perspective on proposed solutions. Industry professionals provide support in completing calculations and integrating building systems, and teams work with architects, engineers, building energy modelers, codes professionals, product manufacturers, local officials, and contractors to inform their design.

Design Challenge Rules are issued each year with the opening of the team application period. Teams must register in the fall, noting their intended Division. The first deliverable before the end of the calendar year requires students to describe the project goals and location in a 2-page Project Summary; this document is revised for each deliverable throughout the competition. Throughout the Design Challenge, organizers offer competition webinars for the teams to cover rules and best practices for competing. Regular check-ins are also held for teams to ask questions.

In mid-February, teams virtually presented their preliminary design work to a jury of external reviewers to compete for 10 finalist slots in each Division. This process allows for all teams, whether they advance as finalist teams or not, to gain experience presenting to professionals. External reviewers and organizers at NREL provide comments to the teams to assist in improvement before the final submission.

The final deliverable, which division jurors review prior to the competition event, consists of a report detailing the project's compliance with each of the Solar Decathlon Contests,

along with supporting documentation and images. The event—which has taken place in person, virtually, and in a hybrid format—provides teams with an opportunity to deliver a short presentation to Division jurors and defend their project choices during a question-and-answer period. This engaging conversation is viewed by both students and jurors as the most valuable interaction of the competition as found through surveys and post-discussion. Jurors then deliberate to select first-, second-, and third-place winners in each Division.

Awards are given to the top three teams within each Division. After these awards are announced, the first-place teams in each Division give a short presentation to all competition attendees, including a panel of new jurors called "Grand Jurors." This gives non-winning student teams the opportunity to learn the qualities of winning projects. From these presentations, Grand Jurors select a Residential Grand Winner and a Commercial Grand Winner.

Top team presentations and project summaries are shared via the Solar Decathlon website after the competition for team recognition and to inspire the public with the design projects and ideas. Although every team does not walk away with an award, teams that complete the competition cultivate valuable industry experience that cannot be gained in the classroom.

## Increasing Growth in the High-Performance Buildings Workforce

### Buildings Industry Landscape

Since 2002, residential building employment has increased by 12.4%, while commercial employment has only increased by 0.47% (U.S. BLS 2022). Since then, residential and nonresidential building employment have increased by 58.6% and 23.4%, respectively (U.S. BLS 2022).


Figure 3. Progression of residential and non-residential/commercial building employment (2002-2021). *Source*: (U.S. BLS 2022)

Over the same time period, Solar Decathlon has also grown. In 2002, the Solar Decathlon offered its inaugural Build Challenge consisting of a single 10-contest event with 14 teams. During the current 2022 competition cycle, the Solar Decathlon is now hosting the 10th Build Challenge and the 9th Design Challenge with a total of 119 collegiate teams. Three international Solar Decathlon events are also taking place this year.

## Growing the Zero Energy Building Workforce

The combined buildings workforce has increased 3.26% each year since January 2012 (U.S. BLS 2022). This rate accounts for the retirement of professionals in the field; however, to quantify the number of new workers hired, an equal replenishment must be included to account for retirees. This replenishment amounts to 48,000 new hires in the first year of simulation.[1]

Three scenarios are displayed in Table 1. The first scenario represents industry growth projections maintaining the growth rate of the past decade (3.26%), while the second scenario follows the national average (8%); however, achieving zero energy performance requires more than average growth. The IEA has set a number of 2030 milestones, including (IEA 2021):

- Electricity accounts for 50% of energy use in buildings (up from 33% in 2020)
- 10 million homes retrofitted per year by 2030 (up from 4 million in 2020)
- 35% of homes use electricity for heat (up from 20% in 2020)
- 5 million heat pump installations per month (up from 1.5 million per month in 2020)
- All new homes are zero energy ready from 2030 onward.

To realistically meet these milestones, the third scenario tracks the number of new hires at a workforce growth rate twice the national average (16%). Retirement rate in all scenarios remains constant at 2.86% and the number of new hires is incorporated into the findings.

Table 1. Projected new hires (thousands) in the combined buildings industry, 2022–2030, under current growth rate, average U.S. growth rate, and accelerated growth rate.[2]

| | | 2022 | 2024 | 2026 | 2028 | 2030 | Total |
|---|---|---|---|---|---|---|---|
| Current Growth Rate | 3.26% | 102.9 | 122.1 | 131.6 | 149.2 | 169.1 | 1097.8 (1.09 million) |
| Average Growth Rate | 8% | 182.7 | 205.5 | 248.9 | 305.9 | 376.0 | 2155.8 (2.16 million) |
| Accelerated Growth Rate | 16% | 317.3 | 377.1 | 532.8 | 752.7 | 1063.5 | 5019.8 (5.02 million) |

Based on these calculations, between 3 million and 5 million new buildings professionals are needed by 2030 to achieve net zero by 2050. In order for such growth to take place, action must be taken promptly.

## Engaging the Workforce over the Next 10 Years

The Solar Decathlon aims to provide technical training and professional development to anyone interested in building science. The most common demographic seeking training in this

[1] Assuming the average employee retires after 35 years, 1 in every 35 workers retires annually (2.86% of an industry). In the combined buildings industry, this equates to more than 48,000 professionals retiring each year.
[2] The equation used in Table 1 is: $NW = (WF_P * (1 + GR + RR)) - WF_P$
Variables: NW = new workers; $WF_P$ = workforce of previous year; GR = scenario growth rate; RR = retirement rate.

area are degree- or certificate-seeking students. The Solar Decathlon focuses on supplementing the education of collegiate young professionals.

While college degree programs provide substantial technical education, students are seeking increased human connection and active collaboration in their academic experience (Cardon 2014). The Solar Decathlon looks to provide this for students through team-based objectives. Contestants work within their team to carry out a comprehensive design process and, in the case of the Build Challenge, to organize construction efforts. Support is provided to these students through both the Solar Decathlon and their universities; however, these are student-driven projects, and contestants rightfully take pride in the work they've completed together.

Another significant obstacle many students face is finding organized information about possible career paths (Wild and Ebbers 2002; Mishra 2004). The Solar Decathlon looks to solve this by providing contestants multiple methods of career forecasting. The first is a linked system of career mapping developed by the Interstate Renewable Energy Council (IREC). which offers the chance to analyze career options based on experience (entry to advanced) as well as primary sectors of the workforce (IREC 2022). The Solar Decathlon also presents 10- to 15-minute-long career profile videos featuring recent Build Challenge alumni. These resources provide information and commonality between the contestants and early-career professionals.
Further engagement of Solar Decathlon participants focuses on accentuating the connection between students and professionals. Contestants are able to discuss their work with industry experts through in-person networking and industry partnerships within their community. Through these partnerships, teams can build relationships with companies who aim to develop zero energy designs for planned construction or retrofit projects. This is a draw to the competition as 81% of teams cite "building connections with industry professionals" as an important opportunity in the competition.

The Solar Decathlon mentorship program, an optional pairing between teams and competition alumni currently working in the industry (DOE n.d.), is another bridge offered between contestants and professionals. Although this opportunity is tailored to first-year teams who may lack the experience of returning teams, all teams can apply to be paired with a mentor and further connect with industry

**Expanding Solar Decathlon's Impact**

To build on the positive impact Solar Decathlon has had on the buildings industry over the last 20 years, as it enters its third decade it is time for the program to expand. Three new programs were launched in 2022 to bring the Solar Decathlon mission to learners of all ages: SD Pro, SD Pathways, and the DOE Zero Energy Design Designation.

Launching in fall 2022, SD Pathways will connect Solar Decathlon alumni and high school students across the United States. Alumni will share their personal pathways to careers in the clean energy workforce with the goal of encouraging STEM educational paths for the next generation and increasing awareness of zero energy career opportunities.

Aimed toward mid-career learners on the other hand, SD Pro brings a zero energy building design practicum to industry professionals through a 10-week course in partnership with the American Institute of Architects. The intent of SD Pro is to increase the number of design professionals able to provide and advocate for zero energy building designs.

The third new initiative, the DOE Zero Energy Design Designation, recognizes collegiate institution programs that prioritize preparing their students to contribute to a zero-carbon future

through zero energy building design. To qualify, schools must provide education on building sciences as well as a zero energy design practicum. The first group of schools receiving the Zero Energy Design Designation will be announced in August 2022.

### Increasing Representation in the Buildings Industry

As a part of broadening the accessibility of ZEB training and awareness, the Solar Decathlon prioritizes partnerships with minority serving institutions (MSI). Approximately 5 million students are enrolled at more than 700 MSIs in the United States, accounting for 30% of total undergraduate enrollment and 20% of undergraduate degrees in STEM (Medicine et al. 2019). Working with these universities acts as a catalyst in developing diversity in the buildings industry landscape, and the resources provided by the Solar Decathlon contribute to the pursuit of equity in technical training and professional guidance. The competition has included 22 teams from MSIs since data collection began in 2020.

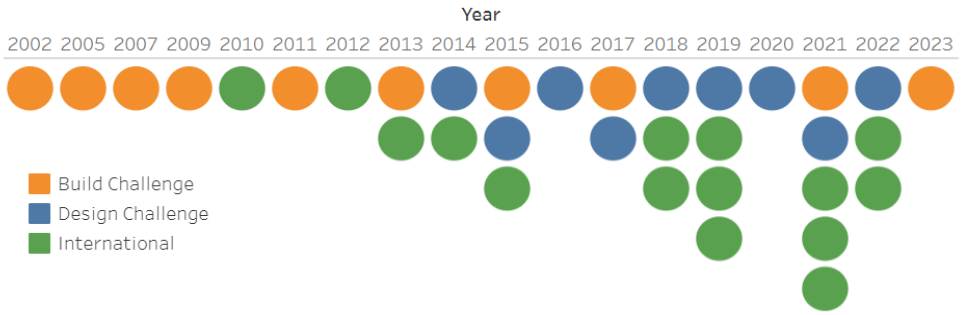


Figure 4: Solar Decathlon competitions 2002–2023, domestic and international. *Source*: (DOE 2022)

Internationally, DOE has extended the Solar Decathlon to countries in all regions of the world, and in return, contestants have contributed to the growing knowledge and excitement of zero energy design. The first international competition was held in 2010 and hosted by the Spanish government in Madrid. Since then, there have been 17 international competitions: 5 in Europe, 2 in India, 3 in China, 2 in the Middle East, 2 in Latin America, and 1 in Africa. Figure 4 shows the progression of competitions administered by the Solar Decathlon, with international competitions highlighted in green.

## Looking Ahead to Zero Energy Communities

### Technology and Market Integration

Introducing transformative technology into open markets requires two things: able producers and willing consumers. Communities on both sides have developed significantly in recent years, resulting in promising deployment of zero energy projects. As of 2020, nearly 8,000 zero energy buildings (28,000 residential units) have been constructed in North America (Edminster 2021). As seen in Figure 5, the last five years have seen the number of zero energy units more than quadruple since 2015.

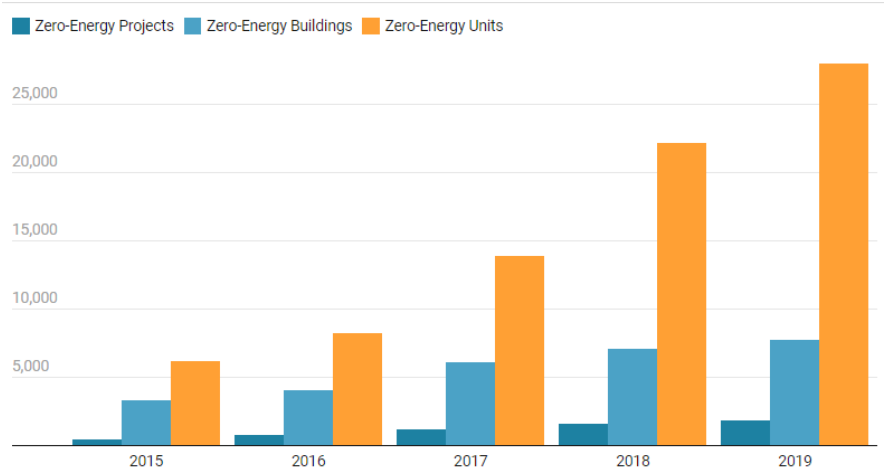

Figure 5. North American growth of zero energy projects, buildings, and units.
*Source*: (Edminster 2021).

While this growth is encouraging, reaching net zero is still a considerable task; the 28,000 zero energy units account for just over 0.005% of units in North America. The federal government has invested in technologies for buildings throughout the nation's history; the national and industry will need to continue that investment for continued growth.

**Industry Progression**

According to the U.S. Energy and Employment Report (DOE 2021), the energy sector is exhibiting forward-thinking priorities, even in economically unstable periods. Over the course of 2020 and 2021, global markets saw declines in commerce and employment.[3] However, this did not stop workforce development for renewable energy and sustainable technologies:[4]

- Wind generation added 2,000 jobs **(2%).**
- Battery storage added 800 jobs **(1%).**
- Hybrid electric vehicles added 6,000 jobs **(6%).**
- Fully electric vehicles also added 6,000 jobs **(8%).**

Trends such as these are indicative of new environmental policies and commitment by producers to transition to clean technologies. The portion of professionals dedicated to high-efficiency building design has grown consistently. In the 2015 single-family market, 31% of builders were dedicated to at least 60% of their projects achieving high-efficiency standards (Edminster 2018). In 2022, involvement has grown to 44% of builders, and the majority of those involved have now committed 90–100% of their projects to utilize zero energy technology (Edminster 2018). As for the multifamily housing market, commitment has increased from 23% in 2015 to 47% in 2022 (Edminster 2018).

The Solar Decathlon aims to connect these dedicated builders to future professionals participating in the competition. The industry partner program allows collaboration among specialists actively working in the field and college students interested in pursuing potentially similar lines of work. This collaboration provides students with educational experience in

[3] The U.S. energy sector saw a 10% decline in jobs during 2021 (DOE 2021).
[4] Percentages show the increase relative to the number of employees at the beginning of 2021.

overcoming industry obstacles and opens hiring pathways to companies pursuing a net zero future.

**Community Acceptance**

Early in the Solar Decathlon's history, Build Challenge teams transported their projects to the National Mall in Washington, D.C. More than 100,000 people visited the "Solar Village" in 2002 to learn about the designs and feasibility of green building technology. This exhibition, including construction, house tours, speeches, and celebrations, lasted only two weeks; but houses built in this inaugural contest continue to impact communities to this day. Ten of the original 14 houses remain living laboratories for building science in their communities 20 years later. Figure 6 shows the 132 active zero energy houses designed, built, and presented by Solar Decathlon teams.

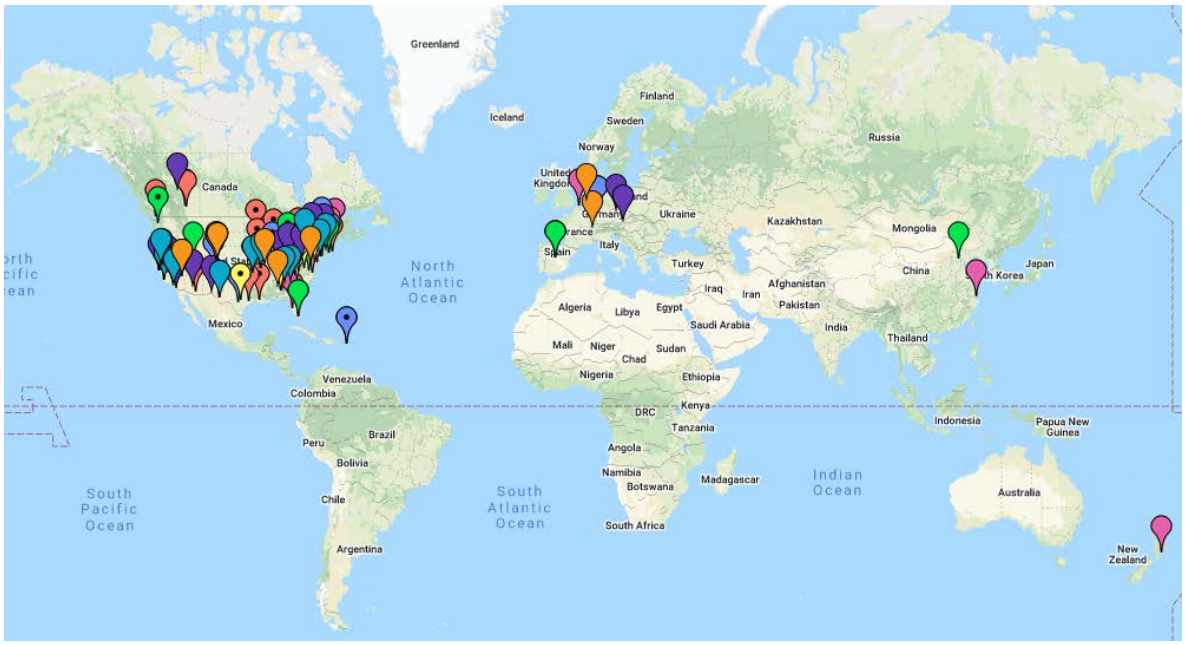


Figure 6: Map of Build Challenge ZEB community installations. *Source*: (DOE n.d.)

The Solar Decathlon creates positive public engagement through student presentations during the house's public exhibition period. During public tours for their community, students explain the technical aspects of their design, demonstrate cutting-edge components, and show homeowners ways to improve the energy efficiency of their own homes. Through student surveys and communications with partners, the mode of delivery has been shown to further enhance the community experience; residents can witness a team of bright young minds, often from a local university, display their technical findings as well as their excitement and pride in their project. This enthusiasm, coupled with the hope of highly driven young professionals, provides communities with a "first-follower" in the transition to net zero by 2050.

The first-follower theory predicts community norms based on sequential decision-making (Hughes 2019). When a leader introduces a novel concept or technology to a group, collective thinking is delayed until the first action of someone other than the leader. In the case of Solar Decathlon, NREL and DOE can be considered the leaders in terms of zero energy design and the collegiate presenters can be considered first-followers. These students are not motivated to make

any sales of the technologies, nor do the residents have any obligations, providing an environment of sincere interest and impartial information sharing.

The continued presence of each Build Challenge home in a community serves as a reminder of zero energy feasibility, and the first-follower dynamic of this ZEB is accentuated by the efficiency, consistency, and proximity of performance. Barriers that often inhibit adoption of clean technologies include initial cost, lack of information, and tendency toward uniformity (Seetharaman et al. 2019). Lack of information is directly addressed by the collegiate presenters, with the Solar Decathlon website providing access to additional information. For the initial cost barrier, teams present their homes in terms of zero energy (with installed renewables) and in terms of zero energy ready (same efficiency without renewables). This introduces an incremental step for communities, which makes the transition between technologies more financially accessible. The Solar Decathlon offers examples of successful ZEBs at no risk or cost to residents, and these examples then become real-world homes through partnerships with private builders, local governments, or nonprofit organizations. As an educational platform and a facilitator for zero energy homes being integrated into communities, the Solar Decathlon projects help instill a belief that achieving net zero is possible.

## Conclusion

Over the past 20 years, the Solar Decathlon has made a considerable impact on developing and educating a clean energy workforce. The competition's past, present, and future stand as a framework for other professional development programs, showing the importance of hands-on learning and student-led projects to spark innovation. The approximately 25,000 alumni of the Solar Decathlon have gone on to work in nearly every area of the public and private sectors, impacting research, industry, and policy across the U.S. and globally. The connection between current contestants and industry continues to strengthen as more and more alumni enter the workforce and maintain their ties to the competition through mentorship, career networking, and more. By fostering a connected group of buildings professionals with a passion for clean energy, the Solar Decathlon ultimately aims to help solve the challenges of climate change: one building, one student, and one innovation at a time.

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