The Science Institutes at Yale’s West Campus

Energy Sciences  Cancer Biology  Chemical Biology  Microbial Diversity  Nanobiology  Systems Biology
The need for cheap, abundant energy is among the defining issues of our time. In the twentieth century, coal and oil helped to fuel decades of economic expansion, population growth, and rising standards of living. They also brought formidable problems like pollution, climate change, and geopolitical conflict. In the twenty-first century, as populations and economies continue to expand, the world needs clean, affordable alternatives.

Yale University is deeply invested in the science of clean energy. More than sixty laboratories across Yale’s chemistry, physics, geology, engineering, and biology departments are conducting innovative research with direct implications for sustainable energy. Many efforts are interdisciplinary, bringing together faculty and students from diverse fields to develop novel approaches to energy production—for example, new biofuels and efficient solar technologies—and better ways to use existing fossil fuels and lessen their impacts. Now this work has a new focus in Yale’s Energy Sciences Institute.

Established in 2012 on Yale’s West Campus, the Energy Sciences Institute is dedicated to two overarching questions: Can clean energy sources be improved and implemented on a scale that will replace fossil fuels? And in a world still dependent on oil, coal, and gas, can better technology support the transition from a carbon-based economy to one grounded in sustainable fuels and practices?
Sunlight has long been among the most promising—and most elusive—of clean energy sources. Every hour, the sun showers 120,000 terawatts on the earth, enough to power the planet for a year, but capturing, converting, and storing this energy remain daunting challenges.

Overcoming these hurdles is the first mission of the Energy Sciences Institute. Under the direction of Gary Brudvig, the Benjamin Silliman Professor of Chemistry, the Institute is seeking better methods and materials to make solar cells, fuel cells, and storage options. “Solar power has grown at an average pace of 40 percent per year in the past decade,” notes Brudvig, “but it still produces less than 1 percent of the nation’s energy and is too expensive to introduce on a large scale. We want to focus on new approaches to solar energy, so that this clean, sustainable energy source can be widely adopted.”

Another branch of research within the Energy Sciences Institute seeks to address the world’s existing investment in fossil fuels. As people continue to burn coal and oil, we will need “transitional” technologies to reduce waste and mitigate environmental damage over the next few decades. To this end, Yale scientists are identifying more efficient ways to use existing fuels and creating methods to capture and store waste carbon.
Building a powerful, far-reaching institute

This two-pronged approach to energy sciences inspired Kathryn A. Taylor and Thomas F. Steyer ’79 to make a $25 million seed grant to fund the Institute during its first two years of operation. When it is fully staffed, the Institute will unite up to twelve principal investigators and a supporting team of 100 postdoctoral fellows, graduate students, and staff focused on the fundamentals of clean energy. Already, many of Yale’s top scientists have joined this enterprise, bridging the research capabilities of West Campus, Science Hill, and the School of Engineering & Applied Science.

Donors are vital to the continuing work of the Energy Sciences Institute, particularly in an era when government funding is unpredictable. This research requires cutting-edge laboratories, sophisticated computing, and, above all, the ability to attract and retain the world’s best scientists. Giving in all these areas will advance the Institute on its path to finding clean, sustainable energy sources for people around the world.
Yale innovators in energy science
Following nature’s example
Gary Brudvig, director of the Energy Sciences Institute, has committed his own research laboratory to making solar energy conversion more efficient. The need is urgent: Today’s commercial solar cells, which convert sunlight directly into electricity, operate at an efficiency of just 15 to 20 percent. These rates must triple if solar energy is to become cost-competitive with fossil fuels.

With a team of chemists known as the Yale Solar Group, Brudvig has been working to imitate—and improve upon—photocatalysis, the process used by plants, algae, and some bacteria to convert sunlight into chemical energy. On a global scale, photocatalysis in nature generates six times the energy consumed by human activity every year, without the dangerous by-products that have proven so harmful to human health and the environment. But the natural process, which is deceptively easy to describe as a chemical equation, is very difficult to replicate in the laboratory, involving hundreds of steps and many components.

In 2009, with collaborators Robert Crabtree, Victor Batista, and Charles Schmuttenmaer, Brudvig found a water-splitting catalyst that mimics energy production in living plants—when exposed to sunlight, the catalyst converts water into oxygen and hydrogen. Now, the group hopes to refine their process and translate it into a commercially viable source of “green” fuel.

Brudvig sees the Energy Sciences Institute as the perfect place to meet this challenge. “We have the people and infrastructure here to get at some fundamental questions: What can we learn about bond-forming and bond-breaking reactions? Can we do this work more efficiently?”

Getting to green with transitional technologies
With field investigations in California, Papua New Guinea, and South Africa, Jay Ague has studied the processes that release and transport greenhouse gases in the Earth’s crust. Today he is turning that expertise to the question of sustainable energy—in particular to finding ways to capture man-made carbon emissions and store them in rocks and underground reservoirs. Many rocks existing in nature store carbon permanently and safely, giving researchers confidence that this natural process can be mimicked to our advantage; the immediate challenge is making sure that the process itself is safe and affordable.

In a bunker at West Campus, Ague works closely with Zhengrong Wang, an assistant professor of geology and geophysics, and an interdisciplinary team of faculty, students, and post-doctoral researchers. Their goal is to reproduce the conditions within the earth and simulate how waste carbon dioxide injected into the subsurface would react with minerals there. Ideally, Ague says, it would remain safely sequestered for very long periods of time. Within the next year or two, Ague and Wang plan to move into field work. “Before you go out there you need to know what’s going to happen,” Ague says. “We need to do this responsibly. But we envision that there is an extremely large capacity for the earth to absorb carbon dioxide benignly.”

As the Energy Sciences Institute ramps up, Ague particularly looks forward to forging closer ties with faculty in the School of Engineering & Applied Science, who could help make tools and machines for carbon capture.

“What I like about Yale is that we have a very collaborative culture,” Ague says. “There’s a liberal arts spirit that carries through the way the whole University
works. I think that with this Institute, we will take the interaction up to a whole new level.”

**Tackling the storage problem**

Robert Crabtree is interested in using chemical bonds to store solar energy. The C. P. Whitehead Professor of Chemistry, Crabtree is working on the problem of how to best manage hydrogen, the energy-storing medium produced by Yale’s water-splitting catalyst.

By itself, hydrogen gas is notoriously difficult to contain and transport. The diffuse substance easily leaks away, and because it reacts with many metals, making them brittle, hydrogen requires storage tanks and pipelines made of exotic, expensive materials.

In a collaborative effort with General Electric, Crabtree is developing a virtual hydrogen storage system, which bonds the hydrogen with organic compounds to create a liquid fuel. A catalyst is used to extract the hydrogen when needed; the spent liquid fuel is cycled back into the system to be rehydrogenated, eliminating waste. The ultimate goal is a safe means to transport hydrogen, which can be further catalyzed into free electrons to power an appliance, car, or other device.

“Because this is such a difficult problem, we have to develop new chemistry,” Crabtree says. But he is optimistic that a better understanding of catalysis, combined with advances that lower the cost of materials, will set the stage for a viable photo-electrochemical cell that can compete with fossil fuels.

“We actually have to beat nature in terms of robustness,” he says. “Fortunately, Yale has extremely good graduate students and infrastructure.”

**At the atomic level, discovering nature’s secrets**

Theoretical chemist Victor Batista plays a special role at Yale’s Energy Sciences Institute, with calculations and deductions that test the limits of molecular and electronic structure theory. His insights help guide and interpret the efforts of experimental chemists like Brudvig, Crabtree, and Schmuttenmaer, while opening new avenues for investigation.

Batista runs a laboratory with ten postdoctoral researchers, five graduate students, and several undergraduates dedicated to understanding the chemical processes behind solar energy conversion. One of his current efforts is to develop “molecular rectifiers.”

When a molecule in a solar cell absorbs light, Batista explains, it dispatches electrons that can be channeled through a circuit as a useful flow of energy. But sometimes the electrons bounce back, undoing the process. If scientists could make molecules that prevent the electrons from coming back, efficiencies would be higher. “It’s an important aspect in the design of photocatalytic cells that could drive ‘multi-electron’ reactions, because in all of these devices, once you...”

Postdoctoral fellows and graduate students bring deep knowledge and innovation to bear on the questions of clean energy.
move electrons one way, they tend to come back and induce efficiency loss,” Batista says.

In the past few years, Batista’s group has used mathematics and computer simulations to describe molecules that could serve as rectifiers, stopping the electrons from bouncing back. Now, as they refine their calculations, Brudvig, Crabtree, and Schmuttenmaer have taken up the experimental and computational work needed to explore that these molecules will work in practice.

This work is picking up speed, Batista says, thanks to demand from students. “Most of the students who approach me about doing research come with tremendous knowledge of what’s going on—it’s the reason they came to Yale in the first place,” he says. “It excites them to work collaboratively because they see their work in context.”

**Better materials, better energy**

As a member of the planning committee that shepherded the Energy Sciences Institute into existence, Charles Ahn has a keen sense of why materials engineering is such an important part of the Institute’s work.

“There are all kinds of ways of getting to clean energy, and many of these approaches are going to rely on a material at the end of the day,” he says. Catalysts such as the ones created by Crabtree and Brudvig need to be placed onto semiconductors in order to be useful; today, several faculty members at the School of Engineering & Applied Science are working to refine the use of silicon and other materials for use in improved photovoltaic cells.

Ahn points out that rapid advances in materials science have given us smaller, faster, and more efficient mobile devices in the electronics arena—items that were impossible a decade ago and which seem indispensable today. “You have these devices because specialized materials were initially discovered and developed and are now being manufactured on a large scale. What we do at Yale is fundamental materials science with the hope of motivating applications. Through our feedback process with engineers working on energy applications, we will end up with the material we want, and this Institute is critical for enhancing and speeding up that process.”

Ahn leads Yale’s Center for Research on Interface Structures and Phenomena (CRISP)—a Center of Excellence for Materials Research and Innovation, supported by the National Science Foundation. Its basic aim is to discover and develop novel materials that have been engineered at the scale of individual atoms. Yale is among the best in the world at growing crystalline materials atomic layer by atomic layer—and Ahn points out that the most effective new materials are going to be created at this scale. “I’m delighted for Yale because as the Energy Sciences Institute gets ramped up, the faculty there will plug into our center, which will make it much stronger, and vice versa, helping the broader science and engineering mission of the University.”

**AN INTEGRATED APPROACH TO SCIENCE RESEARCH**

The 136-acre West Campus is home to an integrated cluster of research institutes in the areas of chemical biology, cancer, nanobiology, systems biology, microbial diversity, and energy sciences. Supporting this work are four core facilities shared by Yale’s science faculty:

- Yale Center for Molecular Discovery
- Yale Center for Genome Analysis
- High Performance Computing Center
- West Campus Analytical Chemistry Core

These interrelated institutes and core facilities sustain a multidisciplinary approach to today’s most pressing questions of human sustainability—health, the environment, and energy—and advance Yale University as a national leader in scientific teaching and research.
To learn more

For more information about Yale’s West Campus, please visit:
www.yale.edu/westcampus

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