MEMBERSHIP UNITS

APS Launches a New Forum on Diversity and Inclusion

BY LEAH POFFENBERGER

In November 8, the APS Board and Council approved the creation of a new forum dedicated to making physics a community where all people feel welcome and heard. A petition to create the Forum on Diversity and Inclusion (FDI) received over 1600 signatures, blowing past the 100 signatures needed for the Council’s consideration, and the petition received a unanimous vote of approval from the Council.

A key tenet of the APS Strategic Plan: 2019 is serving the physics community by providing a welcoming and inclusive environment for all those engaged in physics, and FDI is an integral step to meeting this goal. The formation of FDI will both supplement and expand existing efforts by APS and its member units to promote a culture of diversity, equity, and inclusion in physics, as it will be able to bring together APS members from a variety of backgrounds. FDI will grow the number of APS members who are involved in diversity and inclusion efforts, provide a space for discussing issues within the physics community, and support existing projects.

“The creation of this forum is very timely as the portfolio of APS diversity programs has grown substantially over the last few years,” says Monica Plisch, Director of Programs at APS. “For example, the new APS-IDEA project will network and support physicists working to improve diversity, equity, and inclusion in their physics departments and laboratories, and the Forum is a natural partner in this effort.”

FDI CONTINUED ON PAGE 5

STRATEGIC PLAN

APS Makes Progress on Priorities

T hroughout 2018, APS members, leaders, and staff prepared a new Strategic Plan to guide the Society and lay out priorities for APS in the years ahead. Strategic planning is an opportunity to set priorities, focus resources, work toward common goals, and assess and adjust the Society’s direction in response to a changing environment. “I don’t see strategic planning as a tactical exercise but as a network of diversity leaders; informing and activating the new Strategic Plan 2019.

GOVERNMENT AFFAIRS

Partnering with APS Members in 2019 to Advance the Scientific Enterprise

BY TAWANDA W. JOHNSON

Staff members from the APS Editorial Office in Ridge, NY, recently visited Capitol Hill to advocate for the Keep STEM Talent Act and urge action against EPA rollback of methane emission regulations (J. RY). Darío Corradi, Robert Wimmer, Matteo Rini, Katiucia Cassemiro, and Roslie Barreto worked with APS members and coordinated with other science and technology organizations to respond to those needs.

Federal Research Funding:

In an ongoing effort to achieve sustained and robust support for federal science agencies, APS OGA worked with APS members and coordinated with other science and technology organizations to advocate for physics and physicists.

PARTNERING CONTINUED ON PAGE 7

MEETING NEWS

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In late 2018, astronomers started observing something weird in Jupiter's famous Great Red Spot: It appeared as if large red clouds were being ripped off the giant's planetary feature, leading to predictions that it would disappear within the coming decades. 

Philip Marcus from the University of California, Berkeley, hopes to reassure worried fans of the Great Red Spot with research he presented at the 2019 Division of Fluid Dynamics Meeting in Seattle, Washington. Done work in the lab shows that beneath the swirling red clouds, the vortex that powers the Great Red Spot is still going strong and that the observed flaking was a result of interactions with smaller vortices. Most of the images that astronomers, both professional and amateur, were viewing during the flaking phenomenon actually show the cloud layer on top of the Great Red Spot, and according to Marcus, the clouds don't always give an accurate description of the underlying structure. 

BERNOULLI CONTINUED ON PAGE 7

Daniel Bernoulli came from a family of gifted mathematicians and physicists. He was inspired in part by his medical studies. Some early thoughts on the problem of pressure, work, too, publishing his first treatise on the subject on the side. And he kept up his mathematical work, too, publishing his first treatise on the subject in 1724.

Mathematical Exercises contained some early thoughts on the problem of pressure, inspired in part by his medical studies.

Upon returning home, Daniel received an offer to teach mathematics at the Imperial Academy in St. Petersburg, Russia. His older brother, Nikolas, accompanied him and took a similar position, but died of tuberculosis the following year. Without his brother, Daniel was increasingly unhappy in St. Petersburg and sought to return home to Basel. Instead, his father sent one of his best students, Leonard Euler, to Russia so the two could collaborate. It proved a successful partnership.

Daniels continued his breakthrough work on hydrodynamics during this period. The English physician William Harvey—who was the first to observe that the human heart worked like a pump to force blood through the arteries so it could circulate through the body—encouraged Daniel to combine his love for mathematics with his medical training to discover the basic rules that govern the movement of fluids.

One day he conducted a pivotal experiment: he punctured the wall of a pipe filled with fluid a small, open-ended straw. He noticed that the fluid would rise up the straw, and the degree to which it would do so was directly related to the fluid's pressure. His technique could circulate through the body—encouraged physicians, as an apprentice and opted to study medicine at Basel University. 

Daniel also did his most groundbreaking work while there, Daniel invented a ship’s hourglass while there, Daniel invented a ship’s hourglass. His technique is still used today. It is called a hydrostatics, and it is still used today. It is called a hydrostatics, and it is still used today. It is called a hydrostatics, and it is still used today. It is called a hydrostatics, and it is still used today. It is called a hydrostatics, and it is still used today. It is called a hydrostatics, and it is still used today. It is called a hydrostatics, and it is still used today. It is called a hydrostatics, and it is still used today. It is called a hydrostatics, and it is still used today. It is called a hydrostatics, and it is still used today.
Each year, around 2,000 undergraduate women in physics make their way to one of the many regional locations for the annual Conferences for Undergraduate Women in Physics (CUWiP). CUWiP began as a grassroots effort launched by the University of Southern California in 2006, growing to six conference sites. In 2012, APS became an institutional home for CUWiP, providing support for a growing number of conference sites: from January 17 to 19 this year, 13 sites across the country will host women seeking undergraduate physics degrees.

CUWiP was founded with the goal of increasing the number of bachelor's degrees awarded to women. Just over 20 percent of bachelor's degrees in physics were awarded to women in 2017, compared to almost 25 percent of bachelor's degrees in all disciplines. Through a weekend of plenary sessions, workshops, and networking events, CUWiP seeks to provide undergraduate women with a supportive community and tools they need to be successful in physics.

"Almost everyone who has a physics degree and a woman will attend one of our CUWiPs. About 2,000 women each year are pursuing physics degrees and [we have] about 2,000 attendees each year," says Renee Michelle Goertzen, Senior Program Manager at APS. "We have a national reach."

CUWiP indeed has a large presence, with 13 sites in the United States and one in Canada, providing geographic ease of access for many of the attendees. These conferences are also remarkably diverse, drawing in underrepresented minorities in physics. The percentage of students who are Hispanic, Black, or Native American and attend CUWiP is high compared to the percentage of physics degrees awarded. For example, Hispanic students make up 10 percent of CUWiP attendees.

"CUWiP is doing very well at attracting students from underrepresented groups, which is important because these are the students who are coming from groups where they are probably less likely to see someone like themselves who is a physicist," says Goertzen. "It is very important that they see that coming to these conferences, meet other people who look and act and have interests like them so that they can say 'Oh, I could be a physicist!'"

Before and after each conference, attendees are surveyed by a team of physics education researchers on a number of areas, from knowledge about what they can do with a physics degree to measurements of persistence—the likelihood they stay in physics. Persistence is tied to a number of factors, such as a sense of belonging in physics, identifying as a physicist, having others recognize you as a physicist, and being part of a physics community. After CUWiP, all attendee groups showed gains in persistence indicators, with women of color showing the largest gains on average.

Each CUWiP site's local organizers have the freedom to set their own conference agendas in order to

The number of women graduating each year with undergraduate physics degrees in the US is nearly equal to the yearly attendance at CUWiP conferences.

Putting the Flu in Fluid Dynamics: Tracking the Transmission of Airborne Disease Particles

BY LEAH POFENBERGER

During the peak of flu season, many people find themselves being wary of their coughing co-workers or sniffling students, but airborne diseases, like cold and flu viruses, can sometimes travel far beyond a sick colleague's desk.

At the 2019 Division of Fluid Dynamics meeting, Sima Asadi from the University of California Davis presented research on tracking what activities cause a sick person to expel the most virus-laden droplets and modeling how these particles can spread in an indoor environment. Asadi's research, done as part of a partnership between the University of California Davis and the Kahn School of Medicine at Mount Sinai in New York, shows the disease-spreading potential of speaking loudly. Asadi studied the spread of disease-carrying aerosol particles at various distances.

Coughing and sneezing are the two most obvious behaviors people think of when it comes to the spread of airborne diseases; since both give off large, easily visible droplets and a large number of microscopic particles—and both can carry pathogens. However, simply breathing and speaking can give off tiny particles capable of carrying infections, too. And since breathing and speaking can happen continuously, versus coughing and sneezing which happen more infrequently, it’s possible these activities have a higher probability of disease transmission. Previous studies of infectious disease transmission have identified talking as a notable particle emission mechanism but did not account for differences in speech volume.

"(Other studies involved) counting from one to 100 and saying 'okay, we observed this much of a particle, so talking is important,'" said Asadi. "We performed more diverse activities to get better results, we reported was the particle emission rate. We basically concluded that, whatever you say, if you speak louder, you will release more aerosol particles."

In addition to finding that speaking louder emits more particles, Asadi's research identified a subset of people who emit more particles while speaking in general, called "speech superemitters." This group consistently produced an order of magnitude more aerosol particles than their counterparts in the study, even after months had passed. Asadi's group is currently unable to say why certain people are so-called superemitters—age, gender, weight, and lung capacity don't seem to be factors—but knowing this subset of people exists could play a role in different disease transmission research.

"For influenza virus transmission, usually there are some people who infect more people than others, and we call them 'super-spreaders,'" Asadi said. "We have a long tradition here in mathematics," he said. "We have a hypothesis that some people might be super-spreaders because they are super-emitters." After establishing volume of speech as a parameter for aerosol emission and disease transmission, the next step for Asadi's research group was to use this data while examining the role of distance: what is the likelihood that someone in an enclosed space, like a classroom or an airplane, gets others sick through airborne particles?

Classical modeling of disease transmission has made use of what is known as the Wells-Riley model, which assumes all air in a room is perfectly mixed—meaning the aerosol particles are assumed to be part of that mixture. This fails to account for both time and location in the room, which limits the model's usefulness for short-
BERNOULLI CONTINUED FROM PAGE 2

servation of energy. According to kinetic theory of gases, applying the also provided a foundation for the various hydraulic machines. He discussions of water flowing conservation of energy and included behavior culminated in his most speed of the fluid increases. A similar phenomenon occurs with potential energy as it gains height. body exchanges kinetic energy for Newton's laws of motion, a moving • January 2020

Despite Daniel’s success, or rather, because of it, his relationship with his father continued to worsen, coming to a head in 1734, when both Daniel and Johann sub- mitted winning entries for the Paris Academy’s Grand Prize, and were jointly awarded the honor. A jealous Johann was furious, banning his son from his house—how dare the student he deemed the master’s equal—oblivious to how his bad behavior mirrored his late brother’s jealousy of him. Johann went so far as to publish his own book on hydrodynamics in 1739, one year after the work of his son, but deliberately predated it to 1731 in order to claim credit for Daniel’s work. Their relationship never recovered from the insult, and a dispirited Daniel never quite showed the same enthusiasm for his mathematical studies after the rift. Yet Daniel continued to con- tribute to various different fields for the remainder of his life, such as the study of the oscillation of air in organ pipes. He was elected as a fellow of the Royal Society and won the Paris Academy’s Grand Prize nine more times. He died on March 17, 1782, his scientific legacy assured.
The Nobel Lectures in Physics and Chemistry: The View from Stockholm

BY ABIGAIL DOVE

n a cold December day in Stockholm, Sweden, the doors to a conference hall opened mercifully just as an icy wind started to fall, and there were barely any empty seats to be found when APS Fellows James Peterson and Stéphane Guéron kicked off the dinner in Physics and Chemistry Lectures. Peebles is credited with developing the theoretical framework for modern particle physics.

The Nobel Prizes

VIETNAM CONTINUED FROM PAGE 3

Vietnam’s Institute of Physics (IOP) has long been recognized for its research in theoretical physics, which it makes available to outside users. The IOP is one of the private schools in Hanoi. In 1965, the Vietnamese government established the IOP—part of the Ministry of Science and Technology (MST), and the Institute at Phenikaa University, which is one of the private schools in Hanoi. The IOP is a renowned research institution in theoretical research, collectively publishing around 100 papers per year in national and international journals.

One of the positive signs for the IOP and other physics institutions in the government’s Program of Development in the Field of Physics by 2025. This program (and a similar one from the Vietnamese National Foundation for Science and Technology Development (NAFOSTED), similar to the National Science Foundation (NSF) of the US), “has been providing valuable financial support to Vietnamese scientists in multiple disciplines,” said Phan Pedoat, an expert in theoretical physics who is currently an associate professor at VNU.

Collaborations with the West are a fairly new thing. After several years, several private universities have opened, often with direct support from industry. Compared to public institutions, the pay for professors can be considerably higher at these private schools.

The author is a Corresponding Editor for Physics Based in Lyon, France.
METHANE CONTINUED FROM PAGE 4

natural gas has less than half the natural gas’ license to operate. So, we must strive to sphere than carbon dioxide (CO₂), primary component of natural gas.

other people,” says Goertzen. “It’s workshops where you can talk to community connections by having time at all CUWiP sites. The creation of dedicated networking as a result of these surveys is the different programs, the results allow students to receive the right messages and this system could be based in physics. As a result of Industry Engagement to further enhance the collaboration between the Society and both members and non-members in industry.

Member Attraction and Retention Study: In December, the APS Committee on Membership and the APS Membership Department convened a study group to evaluate membership perceptions of APS. With the help of APS, the ultimate goals of CUWiP are to give undergraduate women in physics the opportunity to experience a professional conference, learn information on graduate programs in the physics field, and gain access to a community of women in physics. The purpose of CUWiP, Goertzen emphasized, isn’t to produce students who have advanced degrees in physics.

“the goal of CUWiP is to get students to complete their undergraduate degree and go on to postgraduate options that are physics-related,” she said. “It could be a PhD or a master’s, but it could also be working in B&D or working in a lab, or high school teaching,” says Goertzen. “I want [women in physics] to graduate with a degree and to think they can use physics in their future and to know that there are many options.” CUWiP also strives to build community among women in physics, especially for those who come from smaller physics departments without a strong network of mentors.

“Smaller schools and departments may only have one to two female students in physics, and they may not feel like they’re included (in the physics community).” CUWiP shows them that there are more than just these two people in your department,” says Wright. “CUWiP shows students that they’re not alone in the undergraduate community.”

NOBEL CONTINUED FROM PAGE 5

understanding of how the universe evolved after the Big Bang. His lecture provided a journey through cosmic evolution, from the microwave background radiation from the Big Bang, the existence of dark matter, and the discovery of a large part of the cosmos, and the structure of the universe as a whole, to the unification of 10**9 galaxies. He emphasized that “on occasion we’re driven by the brute weight of the evidence and the need for natural laws operate by rules we can discover by pure thought, which can be remarkably effective.”

The laureate of this year’s physics prize was jointly awarded to University of Geneva’s Michel Mayor and University of California’s Didier Queloz, who in 1995 made the first discovery of a planet outside our solar system, the Jupiter-sized 51 Pegasi b, located about 50 lightyears from Earth. Mayor emphasized that the discovery of this planet brought with it the implication that many of the hundreds of billions of stars in the Milky Way should have planets as well, opening up new possibilities for studying our place in the universe. Queloz explained that to identify such planets, new techniques were developed to detect the slight wobbles they impart to their host stars. By analyzing these data, the group was able to discover many more planets, which are now a common observation in astronomy.

Goodenough subsequently doubled the lithium battery’s energy density by using cathode material based on an oxide of lithium and magnesium, which he termed “lithium oxide.” This new material allowed batteries to store more energy than previous designs, leading to significant improvements in battery performance.

Conclusion: The story of lithium batteries and the impact of Goodenough’s work is a testament to the power of scientific collaboration and the importance of interdisciplinary approaches to solving complex problems. The development of lithium batteries has had a profound impact on the world, enabling the widespread use of electronic devices, electric vehicles, and renewable energy technologies. Goodenough’s legacy serves as a reminder of the potential impact that innovative research and collaboration can have on advancing technology and improving our quality of life.
vortex below. Using high resolution imaging and computer analysis, Marcus and his team were able to measure what’s happening in the vortex underneath the cloud layer. “We determined the actual boundary of the underlying vortex, which is the machine that drives the red spot, and it’s not completely correlated with the clouds,” said Marcus in a press conference. “It’s not at all clear that the shrinking of one has to do with the shrinking of the other; you can’t just conclude that if the cloud is getting smaller that the underlying vortex is getting smaller.”

The mismatch of clouds and vortex is possibly what started the worry about the Great Red Spot in the first place: the small vortices that interacted with the red spot don’t always have their own clouds, allowing them to attract less attention from astronomers as they move across the planet, until they moved too close to the Great Red Spot. The spot is a high-power system that turns in the opposite direction of the planet, making it an interesting study in storms and vortices that are also anti-cyclones, but low-pressure cyclones that turn in the direction of the planet also exist—they just don’t reliably produce clouds announcing their presence. The existence of invisible non-cloud producing cyclones can be inferred when they come close to an anti-cyclone, causing the visible anti-cyclone to act differently.

According to Marcus, the observation of the Great Red Spot flaking was simply a result of the strong anti-cyclone interacting with both a smaller anti-cyclone and a cyclone. “There are two phenomena that I believe led to the observation last spring of these flaking events, and one of them is mergers,” said Marcus. “Anti-cyclones attract each other, while anti-cyclones and cyclones repel each other. It’s like the opposite of electric charges.”

When two anti-cyclones interact, the smaller of the two will be absorbed by the other, but the merger isn’t instantaneous; a visible bulge in the boundary of the anti-cyclone’s clouds can be seen until it is fully absorbed. In the case of anti-cyclones and cyclones, as the outer boundaries of their vortices interact, it creates what’s called a stagnation point.

Typically this causes an anti-cyclone to be observed as slightly altered by the passing of one of the other clouds, but when two other clouds associated with the other anti-cyclones, the clouds don’t immediately get digested,” said Marcus. “We know for sure that, about every ten years, a cyclone meets a visible anti-cyclone. They get these stagnation points. When we have two of them together, which happened last spring, it produces a bloom of their own and the bladestones (are) very normal healthy activities for a red spot and its colleagues, so we do not believe at Berkeley that the red spot is dying.

When the Great Red Spot simultaneously encountered an anti-cyclone (which it tended to merge with) and a cyclone (which created a stagnation point) the undigested anti-cyclone was thrown off by the stagnation point, creating the bladestones or flakes observed by astronomers.

“Many mergers occur, it’s a perfectly normal thing. They were first seen by Voyager in 179 and, they’ve been seen very frequently after that. When they merge with other clouds associated with the other anti-cyclones, the clouds don’t immediately get digested,” said Marcus. “We know for sure that, about every ten years, a cyclone meets a visible anti-cyclone. They get these stagnation points. When we have two of them together, which happened last spring, it produces a bloom of their own and the bladestones (are) very normal healthy activities for a red spot and its colleagues, so we do not believe at Berkeley that the red spot is dying.

To advocate for increased federal funding for science. For instance, APS member Dan Weller, a student at the University of Washington in St. Hayes, a chemistry professor at Colorado State University, authored a paper, urging US Senator Mitch Gardner to support legislation that would make “the F-1 student visa dual intent” and provide a path to citizenship for international STEM graduates. Combating Sexual Harassment in STEM: Within seven months, the Combating Sexual Harassment in STEM (CSHS) policy was introduced in the House—timed with the APS Congressional Visits Day in January—to passing the full chamber in July. FSGA and APS OGA contributed to the outcome by partnering with APS members across the country to contact congressional representatives about the legislation. “The passage of the House bill is a success as a policy proposal that was funded by the federal government (after all) is the result of the sustained efforts of APS members’ work,” said FSGA Chair Tiffany Nicolas, a PhD student at Harvard University. APS members also held local meetings on this issue in several key states, most notably with the staff of US Senator Lamar Alexander, chair of the Senate Commerce, Science, and Transportation and Legislation Committee, which now has jurisdiction over the bill. Climate Change: Climate change continues to be a top concern among six key issues voted on by APS members. A June 2020, April, and DAMEP Meetings. In response to members’ concerns, APS submitted a public comment opposing the EPA’s proposed policy amendments to curtail regulation of methane—a significant contributor to climate change. Recent scientific results indicate that the negative environmental impacts of the EPA’s rollbacks were higher than previously estimated. APS members were encouraged to submit their own comments on the proposed amendments before the EPA November 25 deadline. This will be a substantial issue for APS throughout 2020.

JUPITER CONTINUED FROM PAGE 2

CALL FOR NOMINATIONS: APS HISTORIC SITES

You are hereby invited to call attention to significant contributions to the history and science of physics. The Friends of the American Physical Society (FAPS) and the APS Congressional Visits (CIV) program would like to bring to the attention of the public the United States’ rich historic record in physics.

Propose sites that you feel should be officially recognized for their historical significance to physics.

Deadline: January 31, 2020

Correction:

In the letter to the editor, Dr. Wells-Riley assumed that the concentration of respirable droplets, or the virus that is being transmitted, was a function of time or location. So you assume that the concentration of the virus could decrease from the source to meters away," she said. "In our model, we are going to consider the concentration function and also location: We expect to have higher concentrations close to the source of infection versus away. While the direct transmission is typically translated to a higher pathogen load, and thus a higher probability of contracting an infection. In her talk, Asadi shared a sample probability created from the transient eddy diffusion model. Assuming a source is in the center of a four meter by four meter room and speaking for 60 minutes, one meter away from the speaker have a ten percent probability of contracting the disease.

Using data from different exploratory activities like breathing or speaking, the model shows that the emission rate of the virus is the same probability. But since talking can happen continuously, "it can be significantly higher," said Asadi. This model for probability of disease transmission can be modified to fit a myriad of situations and groups of people performing various respiratory activities, provided they’re in an indoor space. A matter of the correct parameters that we use. The data that we currently have for particle emission rates are between 0.2 to 14, but if we had data available for children we can definitely apply the model. But we could consider other cases—there can be more than one person if you are in a bigger environment or in a smaller environment. This is what we can say.

So, during this flu season, in addition to washing your hands regularly, you might do yourself a favor—talk softly and carry a big box of tissues.
Integrative Design for Radical Energy Efficiency

BY AMORY B. LOVINS

Note: This article is adapted and excerpted from an invited talk by the author at the APS April Meeting in Denver in 2019 in a session organized by the APS Forum on Physics and Society (APS News, October 2019). The full presentation, with the slides to which the remarks refer, can be viewed at: aps.org/2019mbm.

A round 1975 our government and industry all said that the energy needed to make a dollar of gross domestic product (GDP) could never drop. A year later, I heretically suggested it could drop 7% in 50 years (1). So far, it’s dropped 58% in 43 years, but just the innovations already added by 2020 can save another threefold, or twice what I originally thought. A third of the cost. Today that looks conservative because optimizing buildings, vehicles, and factories as whole systems—not 25 parts of parts—can often produce very large energy savings cost less than small or no savings, turning diminishing returns into increasing returns.

Depleting only stupidity

Economic geologists know that a mineral’s reserves—the identified deposits profitably extractable with current technology—are only a small part of the resource base. Most energy analysts also narrowly define reserves of energy efficiency like mineral reserves, but the actual energy efficiency reserves are several-fold larger than those now typically recognized and captured. The “missing majority” is hiding in plain view and is exploitable by integrative design, as I will describe. But this geological analogy breaks down on cost: orebodies are finite assemblages of ideas, whereas energy efficiency reserves are infinitely expandable assemblages of ideas. Exploiting ideas depletes only stupidity, a very abundant resource. All of this is documented in a peer-reviewed paper [2] called “How Big is the Energy Efficiency Resource?”

An example—my house

I’d never built a house before, so I didn’t know what was impossible. My wife Judy and I live near Aspen, Colorado, at 2,000 meters elevation. Temperatures there used to dip as low as minus 44 degrees Celsius. We saw up to 39 days of continuous midwinter cloud, but our house uses no combustion. (That’s so 20th century.) Instead, we use superinsulation, ventilation, heat recovery, and supersmart windows that insulate like 16 or even 22 sheets of glass but look like two and cost less than three, making the house 99 percent passive solar heated and 1 percent active solar.

Eliminating the heating system more than paid up front for the efficiency that displaced the heating system, slightly reducing total construction costs and then saving also 90 percent of the flow friction. And if everybody did it six years ago with the carbon-fiber electric car that I did it six years ago with the carbon-fiber electric car that I drive, the 13. The 13 reportedly made money from the first unit off the assembly line. Its carbon fiber is paid for by the smaller batteries that its lightness saves, and fewer batteries also means faster recharging. Its integrative design decreases mass a lot more than normally assumed. Its manufacturing is radically frugal, eliminating conventional body and paint shops, which are the two hardest and most costly steps in making a normal car. Making the 13 needs one-third the normal capital and water, and one-half the normal energy, space, and cost.

You can keep going around the design spiral, making components smaller as their structural loads shrink, because the less weight you have, the less weight you need. Lightness begets lightness. Many big parts then disappear. A good hybrid design, for example, can eliminate transmission, clutch, flywheel, drivetrain, shock absorbers, axles, differentials, starter, and alternator. That’s nine things, each saving even more mass and then you go around the cycle some more and take out more mass. At first it might seem like the special materials and unusual design may raise your manufacturing costs, but after more mass removal, you need less carbon fiber and powertrain. The advanced composite structures can get so much simpler that these savings pay for the carbon fiber, making the ultralighting roughly free, as BMW proved. Start downstream

My team’s latest—$40 billion dollars of industrial retrofit designs typically found about 30 to 50 percent energy savings, paying back in a few years on retrofits. And then in newbuilds, we find savings of typically 40 to 90 percent with generally lower than normal capital costs. These results come not only from rethinking manufacturing processes and redesigning basic elements like pipes, fan, and motors. For example, in both buildings and industry, better pipe and duct design can save about 80 or 90 percent of the flow friction. And if everybody did this, it could save roughly half the world’s coal-fueled electricity because it’s a technology; it’s a design method. And most people don’t yet think of design as a scaling vector, or way to make things big, fast.

And the methods are simple—it’s just physics. Use big pipes and small pumps, not small pipes and big pumps. Friction drops as the fifth power of diameter. Yet in practically every new building or factory, the piping is normally laid out so the flow always goes through right-angle elbows—friction. But why not lay it out so that the main flow has no bends and fewer valves? The only obstacle is force of habit. We should bend minds, not pipes. What do such savings mean for the motors that use over half the world’s electricity? From the fuel burned in the power plant to the end use, there are so many compounding losses that only a tenth of the fuel energy comes out the pipe as flow. But every unit of lower friction you save at the pipe leverages back to 10 units of fuel cost, emissions, and global warming saved at the power plant and as you go back upstream, the components get smaller and cheaper, so the total capital cost goes down. If you know an engineering textbook that mentions this “start downstream” principle, I would love to see it.

The big picture

What can integrative design do for a big economy? Well, seven years ago our business and design synthesis, Reinventing Fire ([1], rigorously showed how to triple US energy efficiency and quintuple renewables by 2050 needing no oil or coal or nuclear energy and at least a third less natural gas, while saving $5 trillion, growing the economy 2.6–fold, strengthening national security and cutting fossil carbon emissions by 82 to 86 percent. This needed no new inventions or Acts of Congress, but instead, with smart city and state policies, could be led by business for profit. The first eight years of this 40-year journey are nicely on track, because the private sector smells the $5 trillion on the table.

That’s exactly what should be happening. I hope these examples will encourage you to rethink how to use your end-use efficiency so far from Second Law limits—and how better design, not only better technology, can help close that gap if we turn integrative design from rare to common.

The author is Cofounder and Chairman Emeritus of Rocky Mountain Institute (rmi.org).

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