Wish upon an artifical star?

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The quest for fusion and the story of a young scientist trying to make sense of it all

By the numbers, 1.6 MegaJoules of laser light is equivalent to the kinetic energy of an SUV barreling down the highway. The energy is, of course, in photons instead of metal and speed, but you get the idea. The plan is to focus this light on a pellet not much larger than a grain of sand, crushing it to densities and temperatures comparable to the interior of the sun and praying that the energy of ten to a thousand SUVs—or say, a couple of high-speed subway cars—comes out in the form of heat and neutrons. Do this hundreds of times a day, somehow, presumably with help from some kind a robotic assembly line, and the age of uranium and plutonium-based nuclear reactors—that is the age of Fukishima's and Chernobyl's and nuclear waste with million-year half-lives—will at least begin to end.

When I told my high school biology teacher last year that I'd finished grad school and taken a research job in fusion, she wasn't thrilled. A somewhat awkward discussion followed. Although I never actually took her environmental science course, I knew simplicity was a core principle of her life and that she was the only teacher at my central Florida high school who rode a bike for most of the year. Despite the heat that day her house was un-airconditioned but relatively cool. I noticed Rachel Carson's Silent Spring on her lamp stand and asked her about it. Required reading for one of her classes. I'd been meaning to read my own copy of the book sitting at home, but I'd been too busy finishing up my astrophysics Ph.D. to do it. I told her that compared to a career in astronomy I was glad to take up a job doing research that might actually help someone. It's harder to argue with that one.

She was right to be skeptical. Most environmentally-minded people have heard of fusion and are aware that it is an old idea with a still-distant payoff, if it even works at all. In 1950 the father of the Soviet H-bomb turned human-rights champion, Andrei Sakharov, along with Russian physicist, Igor Tamm, proposed confining a super-hot plasma with magnetic fields to achieve fusion as a source of civilian power.

Sakharov would later become one of very few scientists who have ever won the Nobel peace prize for the way he used his scientific freedom and prestige to speak out against the human disregard of the Soviet regime. Unfortunately, hot plasmas turned out to be much more difficult to confine than initially believed. Any lack of uniformity in the magnetic field gives the plasma an opportunity to slip away, and the interaction between the fields generated by the plasma itself and the confining magnetic field is difficult to predict and control. Such issues still frustrate efforts to achieve magnetically-confined fusion.

These complications were appreciated by 1961 when, within a year of the discovery of the laser, Sakharov proposed using the technology to spark fusion reactions. His designs were significantly improved upon in 1964 by the German-American theoretical physicist, Freidwardt Winterberg, and around the same time Lawrence Livermore National Laboratory, located east of San Francisco Bay in California and just west of the mountains, carried out some of the first attempts at achieving laser-fusion in the lab and has been improving on those efforts ever since. The interest isn't entirely altruistic. The lab was created in the cold-war climate of 1952 to spur American efforts to develop the Hydrogen bomb. In a quintessentially American solution to the problem of keeping up with the Russians, it was decided to build another weapons laboratory to internally compete with Los Alamos National Lab in New Mexico, where much of the atom bomb development had occurred during World War II. A kind of locker-room camaraderie between the two labs has been in place ever since, but in the opinion of many, Livermore—for many years directed by Edward Teller, one of the real-life inspirations for Dr. Strangelove—is regarded as the better lab. Achieving significant laser-driven fusion in their latest experiment, the so-called National Ignition Facility (NIF) would be the ultimate triumph. The free trip to Stockholm would be another added perk, but it would also be a watershed moment for the nuclear weapons program. Since the Reagan administration, the United States has pledged to uphold the UN's Comprehensive Test Ban Treaty, which disallows and kind of full-scale nuclear weapons tests. To be able to experiment with thermonuclear explosions on this much smaller scale would be very informative for designing and maintaining the nuclear stockpile.[1] That's why the NIF is funded by nuclear weapons money, even though the NIF website is all about telling

1. Although, for obvious reasons, it's hard to know exactly what the weapons program is doing with NIF, it's likely that one of the uses is in experimentally calibrating how many years a warhead can sit dormant and still successfully detonate. By far the most efficient fusion mixture (for any fusion experiment) involves two isotopes of Hydrogen called Deuterium and Tritium, which happens to ignite at the lowest temperature of any elemental combination. However, Tritium only has a half-life of fourteen years, meaning that warheads may potentially be much less explosive or even defective within a few years of construction. Without experimental tests, it's hard to confirm exactly how rapidly a given warhead will lose its peak explosive power.

schoolchildren about fusion and how they're bringing the energy of the stars to earth.

My research group orbits around Livermore. Of the twenty or so of us, at any given time it seems like at least two of us are at the lab. We have bi-weekly teleconferences, frequent e-mail correspondence, occasional visits. When they speak—drawing upon sixty years of collective and inherited wisdom in plasma and nuclear physics—we hang upon every word. There are people in our group that used to be over there. Former students from our group have gotten staff positions. Other students wish they'll have staff positions when they graduate. We talk about Livermore like it's the promised land. As if the only real consolation to a frenetic life of pushing forward research projects, to the neglect of all else, is the enjoyment of a mild climate year-round, close proximity to California wine country and a scenic, yet traffic-laden drive to and from home.

I've never quite bought into the hype, although I can plainly see the brilliance of the scientists who work there. Having spent a summer studying astrophysics at Los Alamos as an undergrad, which is also surrounded by mountains and considered by many to be a beautiful setting, my mind's eye had a pretty good feeling of what the place might be like. While at Los Alamos I gained a respect for the value of the unclassified work being done in Department of Energy Labs, I went home that summer concluding that a staff position at one of them wasn't for me. I never got used to going to the cafeteria and wondering if weapons engineers were sitting at an adjacent table. I never got desensitized to the van rides I took to the Plutonium division, which is surrounded by barbed wire and other security measures, where I would meet the two office ladies who carpooled me back to Santa Fe. The scarcity of undergrads was also troubling. There's a certain vitality in being surrounded by students—a constant reminder that we are all learners. And, geographically, I began to doubt that a billion-dollar research lab (or, more generally, technocratic westerners) really belonged in the desert at all. Some years later my astrophysics contacts at the Lab, who work solely on unclassified research, actually left and moved to Argonne National Lab near Chicago. Their decision was at least in part from pent-up frustration about Lab culture, which tends to undervalue research that doesn't directly or indirectly serve the Lab's mission.

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In month two of my new job I got a chance to visit the promised land. Before launching into that account, let me explain that my purpose in telling this story is that I think Livermore is the most vivid illustration of two interconnected ideas that have become integral to my sanity as a young scientist. The first is that salvation will not come by technology alone. Stated enthusiastically enough this statement is impossible to disagree with, like a shibboleth at a presidential debate. However, consider how laughable it would be to announce to your local city council, naming some environmental concern, that we should all give up on assuming that technology or the market will slowly but surely bring about a green revolution and take matters into our own hands. Scientists and engineers coming up with new green ways of meeting our needs will be a backup plan. Think of the number of magazines on the newsstand—even environmentally-themed ones—that take up the opposite premise, taking a seat on the grandstand and admiring the ingenuity of those who push forward the state-of-the-art.

For me, this is the first commandment. The second is like unto it: *The legitimacy of the quest for new technology depends upon the diligence and sincerity we apply to making use of already existing technology.* I think about this every time I see people in the physics building putting Aluminum cans in the trash bin (Aluminum being the most easily and efficiently recyclable material of what can be recycled these days and the inhabitants of the physics building having pledged their lives to discovering things that could, eventually, inspire new technologies). On a more serious level than aluminum cans, anyone who has witnessed an F-16 fly overhead or a shuttle launch or any number of the technical feats that our civilization has achieved, instinctively knows that our current capabilities to make and design, apart from any new breakthrough, are spectacularly grand. We've simply chosen to channel those energies towards certain things and not others.

Of course, this falsely defines technology as anything that has ever graced the pages of Wired magazine. I'm reminded of the quote by Lewis Mumford: "Restore human legs as a means of travel. Pedestrians rely on food for fuel and require no special parking facilities." Technology is everywhere. It's forks and spoons, pavement, traffic signals and road paint.

Livermore is a parable to both of these commandments, first in the ironic sense that achieving laboratory fusion is simultaneously a breakthrough for the weapons program as much as it is a triumph on the road to generating power. Second, isn't it a little odd that we're so eager to tap the energy from an artificial star when, despite huge advances in solar technology, it still seems like little is being done to tap the energy of the star we already have?

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Things came together for me to make a few day-visit to Livermore in the middle of February last year. A bunch of guys from our group had already been there for two weeks running a laser experiment (in a different building than NIF) and I was coming along with a professor who was checking-in on them. Taking an early-morning flight, we flew into San Francisco and drove east across the Bay, having gained time by traveling west. My last visit to the Bay area had been in kindergarten with my family – it had been a while. As I got off the plane I was greeted with a warning that "This area contains chemicals known to the State of California to cause cancer." It was somehow reassuring to know that the State of California had the good sense to tell you like it is, even as I was walking through the carcinogenic haze.

The late-morning traffic was bad but it was a nice tour to go over the Bay and drive a little into the mountains. Upon arrival, my first interaction with the lab was the badge office, where my picture ID was made, which was given to me attached to a small radiation detector. It was designed to silently keep tally of my total radiation dose. As a theorist, there was no reasonable worry that I would really need it, but there it was. With badge in hand, we quickly drove to meet up with the guys running the experiment. On the way I was surprised to notice that none of the buildings had any writings on them except a number for identification. There was little else to distinguish many of the buildings on site. When we arrived at the laser experiment, I was shocked to discover that one of the most advanced lasers in the world was housed in one of the most unremarkable buildings I have ever seen. Someone told me later that the minimalist aesthetic was designed to make the Lab difficult to bomb with any kind of precision.

Things were not going very well at the experiment. Though it was hard for me to follow the discussion, I gathered that they were struggling with getting the laser properly focused and aligned on the hair's width center of the target they were aiming at, and set up had taken considerably longer than originally planned. This conversation was conveyed like auto mechanics reporting back to their floor boss. It was the most masculine conversation between men wearing what were, essentially, shower caps on their shoes that I have ever witnessed.

We returned to the control room and talked more shop, while other members of the team made sure everything was in place for the second and final laser shot that day. The control room itself was likewise unremarkable, with whiteboards, two flat-screen TVs on the walls showing a scant amount of uninformative text about the state of the laser, and no windows into the experiment—a deliberate choice to prevent any possibility of laser light reaching us through it. There were no consoles or other equipment in the room either. What they could adjust remotely they did from their laptops and a band of ethernet cables which came in through the ceiling to a table in the middle of the room. The only interesting feature of the space was the door into the experiment where people would go in or come out and give a status update on the alignment or some other concern. Outside of the door was a collection of what looked like large, granny-style safety glasses, tinted with various colors to exclude certain wavelengths of laser light. Curious as I was, I almost didn't want to go through the door and get the nickel and dime tour of the experiment. It was a compelling enough story as it was. I was content with being guest-access-only forbidden from seeing it.

As things moved closer to taking the final shot of the day, since there is always some uncertainty in the experiment, for kicks they went around and took friendly bets on the exact pulse energy that would be delivered to the target. I thought this was pretty hilarious. I played it safe and picked a number near the middle. Later, they started the ten-minute countdown and a voice that sounded like Stephen Hawking came on the overhead speakers and periodically announced that a shot was about to be fired. I began to wonder what it would actually sound like when the pulse they had spent half the day preparing for would be launched. Some kind of sparking noise? Would the discharge of the capacitor bank make a sound? The pulse hitting the target? 5... 4... 3... 2... 1...

Silence.

"Nothing?! Seriously?" I exclaimed with a boyish grin. Turns out, at least in vacuum, the sound of one of the most intense beams of light mankind has ever made hitting a target and generating a million-degree plasma is also the sound of one hand clapping. If this information ever gets out to elementary school science students, the future of laser physics could be ruined.

"Good shot!" "Nice."

The data streams in from the instruments. The shot looks good—certain to make it into the publication of their results. Things are starting to look up after earlier delays and some of the guys debate pushing back their flights home to take more data. Shutdown is relatively brief and we leave base and head for some food before returning to the "Extended Stay" hotel. This is another unremarkable building, which the guys in the group, in good spirits from a productive day, insult with sarcastic fondness, complaining about the snoring they'll be forced to endure from the others. From my own room I call my wife and collapse into bed, having caught the 6am flight out of Ohio. It had been a big day and more than a little surreal. I've spent most of my waking moments since then running computer simulations and trying to interpret trends in the data from experiments like this that might inform some future upgrade to NIF or the construction of an even larger facility.

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We woke early to head back to the lab and make the most of the remaining time we had on the laser. Too tired to hold a conversation, we listened to heavy metal in the car through long lines of traffic which seemed to be the only kind of music anyone had on their iPhones. It was a less exciting day for me and I spent most of it hanging out in a large administrative building, chatting with other theorists and smirking at the "Unclassified Discussions Only" signs which looked like they'd been there since the Cold War.

The people I met seemed fairly relaxed and I didn't expect to see a volleyball court situated a quarter-mile away from the NIF facility. I was told one of the hotshot theorists—who surprised me by having a tan—was a very skilled player. Despite being a kind of military complex, it was still California.

I also met a number of European scientists who were working on NIF or, like me, were exploring the next steps for laser fusion, assuming NIF works as originally hoped. This was reassuring somehow and I was reminded that foreign scientists played an important role in the Manhattan Project in World War II. Near the center, Hans Bethe (a German) and Enrico Fermi (an Italian) made significant contributions and, famously, the project was birthed by a letter from Albert Einstein (a German émigré to Princeton) to President Roosevelt. Things haven't changed much in this sense and fusion has been an international effort through much of its history.

On our way to the cafeteria for lunch, which was as close to NIF as I've ever been, the professor I was with flagged down one of the NIF scientists he knew as they walked past. We asked him how the experiment was going. He looked a little stressed and reported that the fusion yields were lower than expected, and, frustratingly, the block of time scheduled for fusion experiments had recently run out and the weapons program would be running the NIF for a while. This also meant there would be no chance for me to get a tour of the multi-billion dollar complex. I spent another day at the lab and headed home as planned.

In the next block of time for fusion tests, the NIF team—some of them working strenuously into the night—was able, over a couple months, to optimize the implosion by adjusting the timing of the lasers and subtly changing the chemical mixture of the shell of the fusion pellet. Now, a record- smashing one-tenth of the energy that goes in through laser light gets created in fusion reactions at peak compression, a state that lasts for only a few nanoseconds. Still a long way from powering your toaster, but in the sixty-plus years since fusion was proposed no one has ever gotten this close. It'll be front-page news if they get much closer.

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Whenever I'm torn over the seeming fact that the long history of fusion research is evidence that nature doesn't really want us to bring the energy of the stars down to earth, I remember that so much of our current economy is easily classified as unnatural and that progress is often something that seems like two steps forward and one step back. Fluorescent lights, for example, work by a low-density mercury plasma that would be banished from the public sphere as a potential toxicity hazard were it not one of the most efficient ways of illuminating buildings. Automobiles (which now sometimes seem like a plague) were once a godsend to city streets which, in earlier times, were covered in horse manure. Even the world's most efficient solar cells depend on the coincidence that two heavy metals—one being hazardous if ingested, the other can pretty much only be found and imported from a handful of mines in China—happen to be perfectly sensitive to the wavelengths of sunlight. Our relationship with technology is ongoing, never-ending. The dilemma is always to what extent we allow it to dictate our lives and to what extent we creatively use it and change it to be tools for some human-defined purpose.

The NIF, in my opinion, can not be said to uniformly fall into one or the other side of this dilemma. If it works I will raise my glass with the rest of my research group and drink the champagne that my supervising professors are likely to purchase in celebration. If it doesn't I am liable to join the voices that agree that it was never, in itself, going to rescue our power-hungry world from its own implosion. Whatever the outcome, the story of NIF – the experiment that got closer to realizing fusion energy than any that came before it – will carry the bittersweet theme that it never would have been built or survived its multi-billion dollar delays without the full pork of the US nuclear weapons program behind it. It was realized this way instead of being a victory for a trans-nationally-funded collaboration of scientists working towards an altruistic goal – the kind of internationalism Einstein and Sakharov often spoke of as integral to the character of science. During their careers – in a much less- globalized world with plenty of conflict – science was often a common ground which, somewhat like the Olympics, offered a positive venue for crossing national divides.

The world's other great fusion experiment—the ITER project—which aims to achieve fusion with something akin to Sakharov & Tamm's original proposal of magnetic plasma confinement at least, on paper, follows this internationalist model. However in practice the collaboration has been rife with nationalist infighting (e.g. which country will the multi-billion dollar experiment be built?). The US withdrew its funding this year in protest and despite planning for as long as I've been studying physics it is only now that the first bricks are being laid. From this perspective NIF is a Pyrrhic victory and ITER is a sign of the times.

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In truth, though, the international character of science is doing quite well. I'm reminded of this as a visiting professor from China moves into the vacant seat in my office. There are dozens of examples of healthy international collaborations (though mostly with far less world-changing ramifications than fusion) that are feathers in the cap of the nations involved and evidence that we really can get along, so long as the goals are limited to things like seeking obscure particles, mapping the sky, or watching the polar ice caps melt. I'm obviously a bit of a pessimist in my view on this class of high-flying projects, but it's gotten to the point where, in a given year, it's unlikely that two professors in the same field and living in adjacent cities will interact with each other except at national or international conferences. Perhaps as fuel costs rise and budgets tighten in the coming years this may change.

In any case, the overwhelming success of science has become the hubris that fuels the collective wisdom that technology really will solve society's woes. It's a tradition that traces its roots to Kepler & Newton's heroic re-centering of the universe and Darwin's stunning rewrite of the story of how we came to be. The overconfidence generated by these achievements hovers like a ghost over the university, whispering in our ears, and the message somehow gets wrapped up in a manifesto of economic progress that even the philosophy department is supposed to be able to contribute to. The NIF (or at least the NIF website) is just another part of this appeal. As a scientist—and incidentally with an academic mentor-lineage that can be traced back to Newton himself—it's painful to watch it all. It's even more painful to speculate how much your funding comes from some high-level, childlike faith in technology-driven progress. I mean are we really trying to bring about an age of reason by founding hundreds of science and technology magnet schools when thousands of household chemicals have never been subject to basic toxicity tests, or is it just another attempt to spur the economy without addressing any of the fundamental problems that have led us to this point? And in Ohio it's been shocking to see how little science-based hesitation there has been to move forward with natural gas fracking and oil drilling in our state parks. Meanwhile, despite the ingenious re-birth of Northwest Ohio's glass industry as one of the most productive solar cell manufacturing centers in the world, nearly all the solar cells get shipped to Germany where subsidies have made it worthwhile to go solar. It makes me want to occupy the state science fair. Maybe I will.

When I see the wind-power generators on the hills behind the NIF spin around happily in the California breeze I'm reminded there is another way. I wish it was more than a metaphor. I wish the current push towards alternative energy had begun twenty years ago. If only it were enough. If only we could learn to live within its supply. Or maybe the billions flowing into the experiment in the foreground are worth the expense—the culmination of a sixty-year-old hail Mary to save the environment that just might work. Time will tell.