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Mailing Address: *Berkeley Scientific Journal*
5 Durant Hall #2940
Berkeley, CA 94720-2940

Phone Number: *(510) 643-5374*

Email: *bsj.berkeley@gmail.com*
Online: *bsj.berkeley.edu*

Dear Reader,

This issue of the Berkeley Scientific Journal revolves around "waste," seemingly extemporaneous objects left over by nature or human activity. Admittedly, our theme is a bit of a misnomer. A running theme throughout this issue is objects once thought to be "waste" found under further analysis to be of great value. This issue highlights one of my favorite aspects of science, the way once held notions and ideas change as new information arises. Moreover, waste is an incredibly important subject in science today. Technological advances over the last century and a half have greatly improved the quality of life for many, but they also have waste byproducts that must be dealt with. Understanding waste is crucial to building a sustainable future.

Out latest issue combines features articles written by our staff, interviews with Cal professors, and top-quality research performed by undergraduate Cal students. On an interplanetary scale, we have an article looking at space debris left by humans [1], and the role stellar waste plays in human life [4]. Narrowing our focus to human life, we have an article on the body wasting away as a consequence of eating disorders [9], and an analysis on the function of "Junk DNA"[15], how industrial waste enters and affects the human body [22], and a look at telomeres, DNA sequences often tied to aging [29]. Finishing off we have a selection of articles analyzing technological uses of waste, beginning with a look at solid-oxide fuel cells [12], a piece on data fragmentation and how computers handle waste [18], and an article on nuclear power and its subsequent creation of waste [26].

For our interviews we first met simultaneously with Professor Ahn and Professor Carson to talk to them about the technical and social aspects of the problem of nuclear waste management [30]. Then we present Professor von Meier, who talks to us about renewable energy sources [36]. In our final interview, we hear from Professor Hermanowicz on sustainability and water filtration [44]. To conclude we have an excellent paper which highlights original research spearheaded by Cal undergraduate Olivia Cope. We thank you for your readership, and hope you enjoy our foray into the world of waste.

Go Bears!

Ali Palla
Editor-in-Chief

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19(2)

Space Debris: the Hubris of Humanity

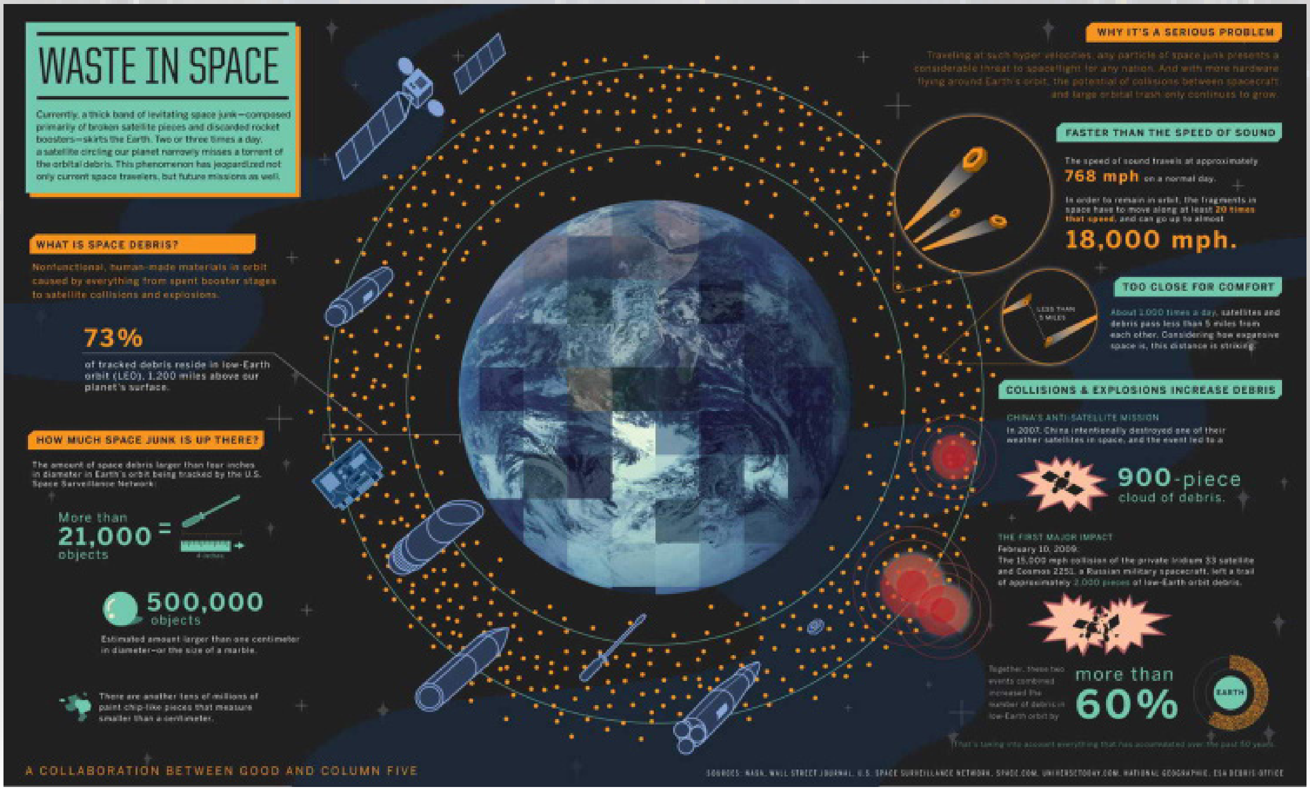
Botao Peng

10 centimeters is not big. 10 centimeters is the average diameter of a bagel. 10 centimeters is even shorter than the length of an average smartphone. So why is 10 centimeters a big deal? Imagine a piece of metal 10 centimeters in diameter orbiting around the Earth in space Yet this piece of metal has enough momentum and force to puncture the International Space Station. A single puncture could effectively destroy all electronics, release all the oxygen, impair the escape vessels, and even kill all members aboard. This is the danger of space debris.

Space debris is junk that orbits the earth. This ranges from abandoned satellites to broken segments from rockets and missiles. It also includes defragmented rocket stages as well as broken equipment from collisions with other debris. The first real serious satellite fragmentation occurred in June of 1961 when two satellites collided with one another[4]. The collision resulted in a break-up of the satellites, sending pieces of both into orbit. This only increases the chances of another collision of occurring. Yet the fragmentation does not stop there. Back in 2007, China conducted an anti-satellite weapon test that destroyed a decommissioned weather satellite, smashing the object into 150,000 pieces each larger than 1 cm [8]. Not only does space junk pose a threat to space travel, it also increases the chance of self multiplication.

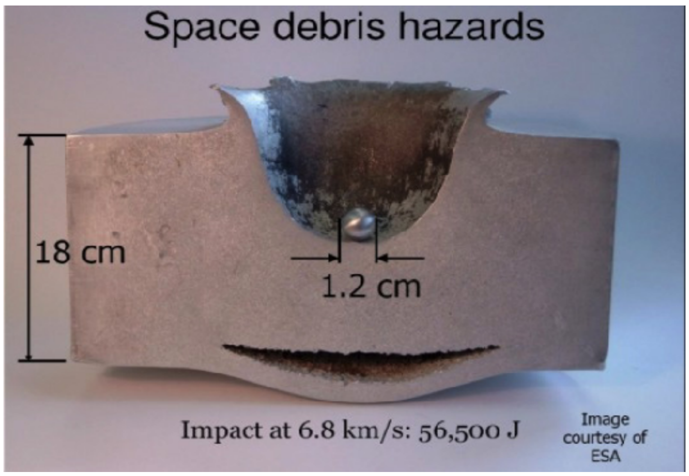
Space debris was not always a problem. In the early years of the space age, scientists would leave abandoned rocket stages in orbit after use. This was not such a bad idea, considering how empty space was at the time. However, over time, the number of space missions increased from simply sending a weather satellite into space to landing a man on the moon. With each mission, more waste was left behind, increasing the amount of debris orbiting the earth. The used rocket stages that once were few and unnoticeable now cloud our view of the heavens. So much in fact, that, 47.7% of debris orbiting Earth is from break-up debris[4] and used propulsion engines cause 45.4% of all satellite break-ups[4]. Such a recent collision occurred in 2005. A 31-year-old U.S. rocket body hit

“A single puncture could effectively destroy all electronics, release all the oxygen, impair the escape vessels, and even kill all members aboard.”



a fragment from the third stage of a Chinese launch vehicle that exploded in March 2000[9]. What once was not even a consideration during missions, now hinders our very ability to travel in space.

Despite the amount of junk floating in orbit, much of the waste is currently tracked by various organizations. Since 1989, NASA and other organizations have been monitoring and measuring debris, especially in low Earth orbit (below 2,000 kilometers from sea level)[5]. According to a 2012 report by NASA Orbital Debris Program Office, more than 21,000 orbital debris larger than 10 cm (large orbital debris) exist[1]



and more than 500,000 orbital debris between 1 and 10 cm exist[1]. The U.S. Space Surveillance Network is currently tracking over 13,000 human-made objects larger than 10 centimeters in diameter, which include operational spacecraft and debris from old rocket bodies[9]. Anything orbiting in low earth orbit (LEO) will be orbiting the Earth at around 7.5 km/s. Anything higher can reach speeds of over 10 km/s or 22,370mile/hr. Imagine getting hit by a metal football at that speed. Imagine the destruction that could cause to any space craft.

during normal operations, minimizing the potential for break-ups during operational phases, limiting probability for collision in orbit, avoiding intentional destruction or harmful actions, minimizing potential for post-mission break-ups from stored energy, limiting long-term presence of launch orbital stages in LEO after missions, and limiting long-term interference from launch orbital stages with satellites[3]. Despite these guidelines, they only serve to minimize the amount of trash produced every mission. What about the trash already in space?

One of the solutions proposed to remove orbital debris is space lasers. Despite how science fiction has characterized them, lasers may prove to be one of our better solutions. These lasers could either destroy fragments of rocket stages by reducing them into smaller pieces without blowing them into many pieces or push the waste out of orbit. Current estimates say ground-based laser facilities could cost around $100 million and would be most likely operated near the equator[6]. Experts also say that such technology could remove all orbital debris up to an altitude of 800 km in two years[6]. It sounds like a promising solution considering the fact that a recent analysis suggests that with the current levels of debris and satellites, there will be approximately one collision per year[6].

Despite how promising a lasers system sounds, the price of such a method is quite a problem. Why not have the rockets bring themselves down, rather than having us remove them? SPOT-1, a French weather satellite, was successfully launched on February 22, 1986 with a 3 year expected lifetime[7]. Officials decided to re-orbit the satellite after a replacement, SPOT-5, was declared operational[7]. Rather than sending someone up into orbit to retrieve the used satellite, experts used its residual propellant to maneuver the satellite into a lower altitude disposal orbit, from which reentry could be completed within 15 years[7]. If this could be the future of space travel, boomerang space engines, then all future debris could be eliminated.

"Despite all the potential disasters that could be caused by the orbital debris, the issue has been far from unnoticed."

Despite all the potential disasters that could be caused by the orbital debris, the issue has been far from unnoticed. As mentioned previously, some nations have developed computer models of space debris based on the large, catalogued population and statistical observations from a wide range of sensors[2]. As a result, many organizations involved in space operations have become aware of the potential threats of space debris, and some of those organizations have initiated efforts to mitigate debris generation and to share the results of those efforts with the international community[2]. In 2007, the United Nations set 7 Space Debris Mitigation Guidelines for future reference. The seven include limiting debris released

Orbital debris has been and probably will be an issue for the next few decades. Our plans of removing all the debris from the past 60-plus years will be a challenge for humanity. Yet, technology that once created the waste is now developing into a method of removing it. Even as you are reading this, humans are making space travel a viable option. And when you are on that spacecraft peering out into the vast heavens, the last thing you want is a piece of metal hurdling at you at nearly 30 times the speed of sound.

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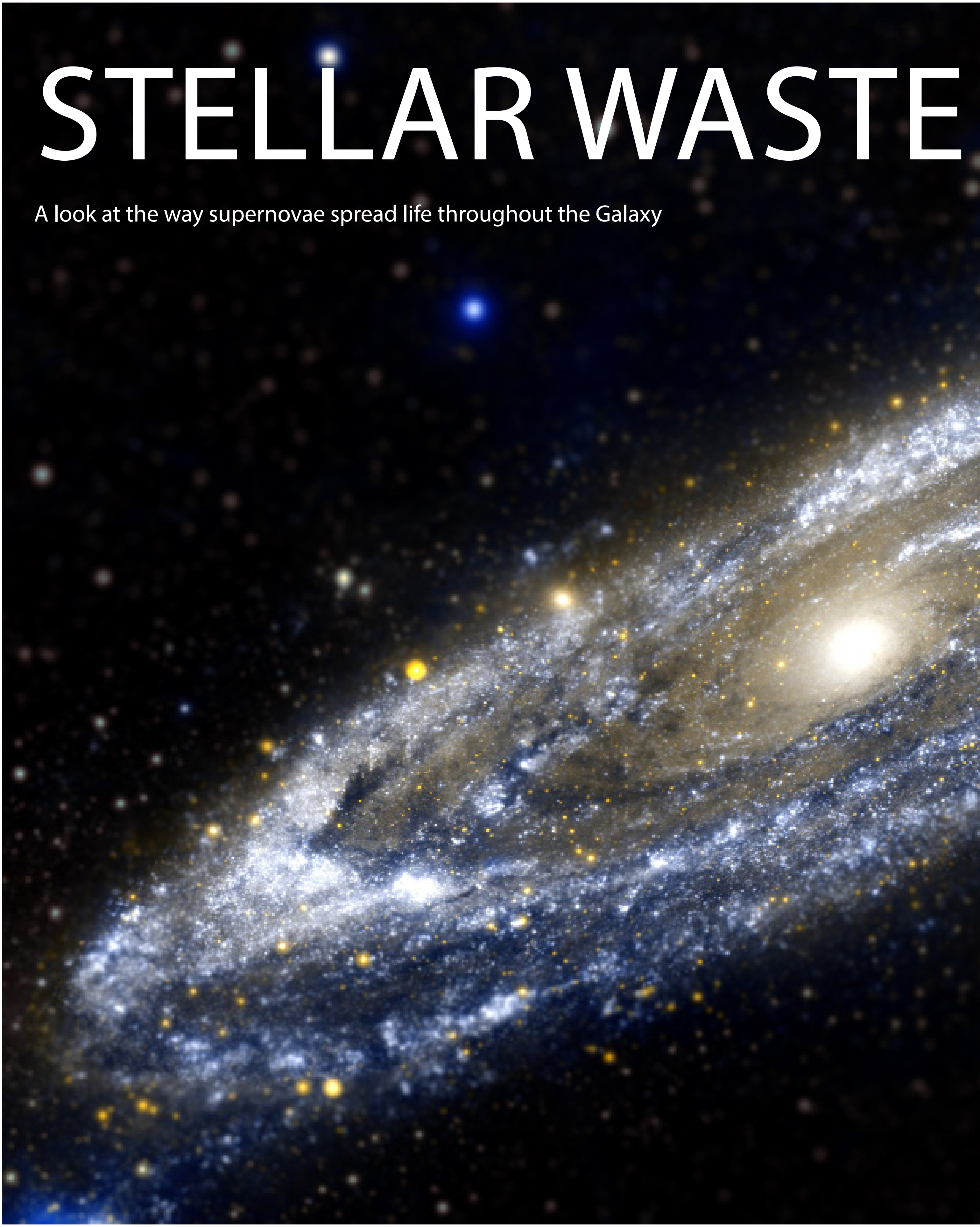
STELLAR WASTE

A look at the way supernovae spread life throughout the Galaxy



Life in the Milky Way: A Galactic Garbage Can

James Pettingell

The story of the human race, the story of you, began with the formation and destruction of the first stars. These ancient and noble progenitors of Earth seeded the Galaxy with every atom that now constitutes your very being: your thoughts and your body. The tree of complexity grows from their fertile technicolor ashes: spread in beautiful array, circles of gold intertwined with strands of sky blue, blood red coursing in veins throughout—iris like—future eyes. Are we the only ones to see ourselves in the stars? "Where are they?" Enrico Fermi famously asked upon considering this quandary of the seeming absence of intelligent life in our galaxy. The Milky Way has reached a mature enough point to form and support life, as evidenced by our only example, the Earth, but evidence suggests that others could have come long before us. Recent research into the chemical evolution of the Galaxy, how it relates to the

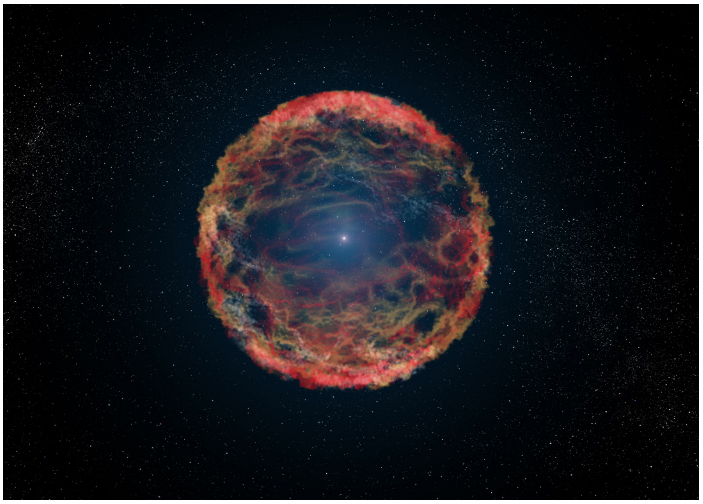


Figure 2. The x-axis along the bottom of the graph depicts the metallicity of the host star in a ration of iron (Fe) to hydrogen (H). The y-axis along the left is the number of stars surveyed. The x-axis along the top is another depiction of metallicity in relation to the sun, Z being the metallicity of the star surveyed, and Z(sub sun) being the metallicity of our sun. The right hand y-axis is the probability of harboring Earth-like planets, or destroying them (as depicted by the hatched curves).

formation of new stars and exoplanets, and the discovery and study of these planets paint an increasingly optimistic future for our understanding of life in the Galaxy.

Stellar waste—or supernova remnants—drive galactic chemical evolution. Early star formation and destruction give a relative idea of when life first became possible in the Galaxy. In 1999, Takuji Tsujimoto proposed a type of star formation as a solution to the problem of calculating the abundance of metal rich stars (in cosmology metal being any element heavier than H/He) in the early stages of galactic formation. Conventional models of star formation stated that stars formed out of well-mixed gas clouds, and would have a metallicity equivalent to the gas out of which they formed. This newer model says that stars are formed out of supernova remnants which sweep up interstellar gas and form a dense inhomogeneous shell. This shell fragments into thousands of pieces, which, under the right conditions can become new stars. However, only about 10 percent of the gas in the cloud comes together to form new stars, the other 90 percent will reintegrate with the Galactic disk (Tsujimoto, 1999). This means that stellar metallicity is different than that of the gas from which it is formed. The interstellar gas, especially in the youth of the Galaxy, is metal poor, therefore stars formed out of the inhomogeneous dense shell incorporate this low metallicity. This process of supernova, dense shell, and star formation continues until a dense shell can no longer be formed due to lack of interstellar gas (Tsujimoto, 1999). This model explains the abundance of metal poor stars throughout the Galaxy, which do not allow for Earth-like planet formation or the complex chemistry required for life (Lineweaver, 2001).

However, some areas can be too metal rich to support life. Solar systems extremely high in metals form massive close-orbiting planets known as hot Jupiters, which are highly disruptive to the formation of Earth-like planets. The relationship between increasing metallicity and increased formation of Earth-like planets is linear until it reaches the point where hot Jupiters are formed, it reverses, and the probability for destroying Earths increases exponentially (Lineweaver, 2001). Around five percent of Sun-like stars harbor hot Jupiters, leaving 95 percent of all others the possibility of possessing Earth-like planets, with the probability of such occurrence measured directly by metallicity (Lineweaver 2001).

But the relationship between metallicity and formation of Earths may not be as drastic as once thought. The difference between metallicities in stars with and without planets can show little variation, and in the case of red giant stars, there is no relationship between metallicity and star formation (Mortier, 2013). Large planet formation requires a

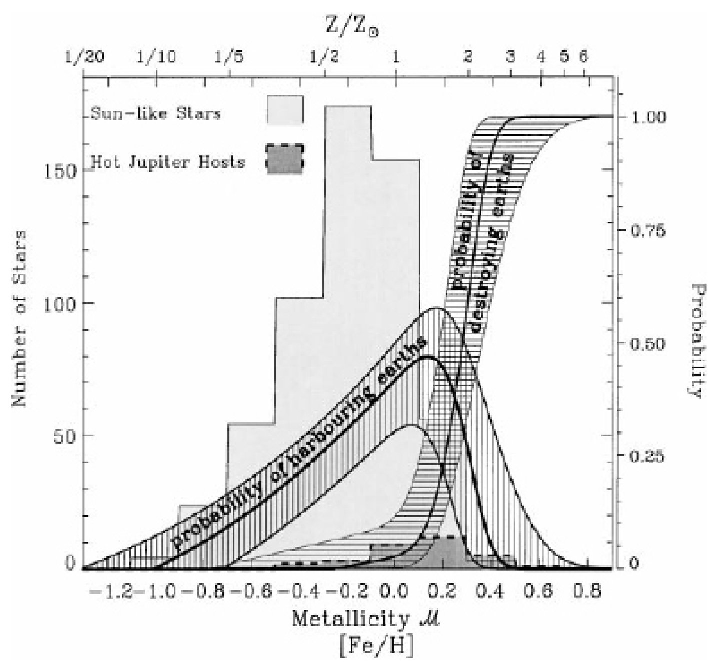


Figure 3. The x-axis along the bottom of the graph depicts the metallicity of the host star in a ration of iron (Fe) to hydrogen (H). The y-axis along the left is the number of stars surveyed. The x-axis along the top is another depiction of metallicity in relation to the sun, Z being the metallicity of the star surveyed, and Z(sub sun) being the metallicity of our sun. The right hand y-axis is the probability of harboring Earth-like planets, or destroying them (as depicted by the hatched curves).

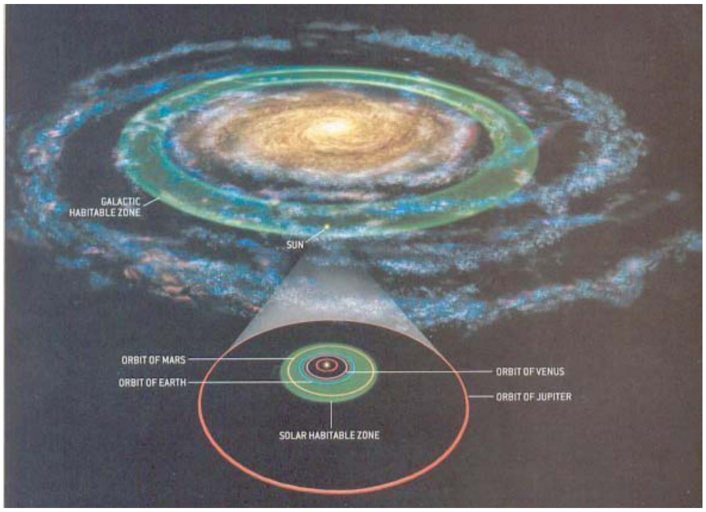


Figure 4. A general depiction (not accurate) of the concept of a galactic habitable zone, with a zoom in on our solar system for comparison.

high metallicity, but formation of Earth-like planets has been observed to require half as much metallicity as previously proposed (four times lower than the metallicity of our Sun), based on analysis of Kepler planet candidates (Buchhave, 2012). This by no means throws out Lineweaver's estimations of Earth-like planet occurrence, it simply lowers the lower bound of metallicity.

Given the strict requisites to the formation of Earth-like planets and the emergence of life, an estimation of the locations in the Galaxy in which these were possible was formulated and called the Galactic habitable zone.

The inner part of the Galaxy generates metals more quickly, as it is denser in gas and creates more stars. This means that the likelihood of planet formation is increased drastically. But the high rate and proximity of supernovae create a dangerous environment for life, ruling it out of the GHZ (Lineweaver, 2004). Through star formation and supernovae, which increased the metallicity of interstellar gas, metallicity spread out from the center to create a habitable zone about 8 billion years ago (Lineweaver, 2004). The radius of the GHZ increases as metallicity spreads and condenses throughout the Galaxy. Within the galactic habitable zone, 75 percent of the stars are older than the sun, and their average age is one billion years older than the sun (Lineweaver, 2004). The average age Earth-like planets in the Galaxy is around 1.8 billion years older than Earth (Lineweaver 2001). Therefore, within the GHZ there is a possibility for the existence of Earth-like planets billions of years older than Earth.

The amount of time needed for an intelligent race to colonize the entire Galaxy, according to Fermi is around 1-100 million years (known as the Fermi-Hart timescale) (Cirkovic, 2008). With the knowledge of the possibility of life in the Galaxy that is billions of years older than life on Earth, the paradox emerges. A possible answer comes in the maturity of the Galaxy, where the evolution of the astrophysical nature yields a more temperate environment for life to exist long enough to reach the point where it can expand out of its home solar system and across the Milky Way. The timescale for understanding the paradox is the astrobiological clock, which may be reset by catastrophic life destroying events. One of the best candidates for such an event are gamma-ray bursts, which could potentially wipe out high-complexity life in regions of the GHZ (Cirkovic, 2008). But as the GHZ expands out of the more perilous regions of the Galaxy, the resets become less frequent, as less stellar density reduces the risk of gamma-ray bursts causing mass extinction. Circovik presents a phase transition model which suggests that there are periods of equilibrium within the Fermi-Hart timescale where intelligent life can flourish due to the amount of time passed since the last reset of the astrobiological clock. The answer to the paradox is that we are in a state of disequilibrium, which is to say that not enough time has passed since the last reset. But a state of equilibrium is supposed to return, and within the Fermi-Hart time scale, complex life should develop again and become commonplace (Circovik, 2008).

The balance required for life is delicate: just the right amount of metallicity, precise proximity to the host and nearby stars, and relative tranquility on a cosmic scale for billions of years. The spread of stellar waste, the chemical evolution of the Galaxy and the growth of its habitable zone suggest a brighter future for life, and a state of astrobiological equilibrium becomes increasingly likely. The point at which the Galaxy is most fertile may still be ahead, but what is certain is that we are alive now. If we face the dangers of mass extinction, which will silence us forever, then time is of the essence, and before the clock flicks back to zero, we must find a way to carry our conscious noise out of the solar system, and through the Galaxy.

"The Galactic habitable zone (GHZ) is the Goldilocks zone of the Milky Way."

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Eating Disorders: The Body Wasting Away

Shirley Shao

When the girl goes to lunch with her friends, she orders a sandwich. She eats all of it, and then later, in the bathroom, she vomits up and flushes it down the toilet. In another case, she eats none of it, and when her friends are not looking, she throws it away in the trash. Or perhaps she does not buy the sandwich at all, saying that she already ate - or maybe she takes tiny bites as she and her friends talk, secretly spitting out what her teeth chewed into mush into a napkin. In fact, she may not be a girl at all, but it is probable that she is, and that she comes from the middle class. This could be the first time she has done this, or this could be just one of many recurring episodes – but if she has just began to walk down this road, she is most likely somewhere from age 15 – 19 (Fairburn, 2003). There are many flavors to an eating disorder, and what the girl displays is only a sampling of the possible variations. It is easy to see the waste in eating, regurgitating, and then flushing a box of Cheez-its down the toilet, or in tossing untouched food aside. But even if the stomach never gets to break down the proteins in that skipped dinner, something else is disintegrating and slowly wasting away.

That something is the body and mind.

The medical diagnosis for these disorders can be roughly sketched to divide eating disorders into three categories: anorexia nervosa, bulimia nervosa, and atypical. Anorexia nervosa, colloquially referred to as anorexia, is one of the most well known and has the most apparent physical symptoms. It is also one of the better understood, having been the subject of more studies than most of the other disorders. Anorexic patients are notably underweight and engage in long-term, severe restriction of their food intake; in addition, they often have difficulty sleeping and experience lethargy. In a sense, anorexia involves the consequences of self-induced starvation. Food and an anorexic's restriction of it becomes an obsession as they seek to control their body, an obsession that grows into a feeling of pride when they are faced with their thinness or low weight. This pride, in turn, nurtures the perception that their eating habits (or lack thereof) are accomplishments rather than a sign that they need help (Fairburn, 2003). There is even a "pro-ana" movement where its members search for self-improvement for their imperfect selves, in this case embracing the restraints and dramatic weight loss embodied in anorexia (Bates, 2015).

Such perceptions are dangerous in a world where an anorexic is more likely to die than a patient afflicted with any other psychiatric disorder, both because of the risk of suicide and as a result of medical complications (Fairburn, 2003). A 2011 study by Jon Arcelus revealed that the SMR (standard

Figure #1. Oftentimes, patients with eating disorders have a distorted view of what their body looks like, and will resort to purges or fasts in order to achieve the weight they desire.

mortality) rate of anorexics is 5.86. As a means of comparison, schizophrenia has a SMR of 2.5 for females and 2.8 for males. For bipolar disorders, males have an SNR of 1.9 and females 2.1 (Arcelus, 2011). Here, SMR refers to the incidence rate of death over a decade.

> "There is even a "pro-ana" movement where its members search for self-improvement for their imperfect selves, in this case embracing the restraints and dramatic weight loss embodied in anorexia"

The other major well-known eating disorder is bulimia nervosa, colloquially referred to as bulimia. This is more common than anorexia and typically has a later age of onset, and is punctuated by periodic binges and purges. Here, purges can refer to the regurgitation of food or obsessive exercise that is intended to "purge" the body of the calories ingested,

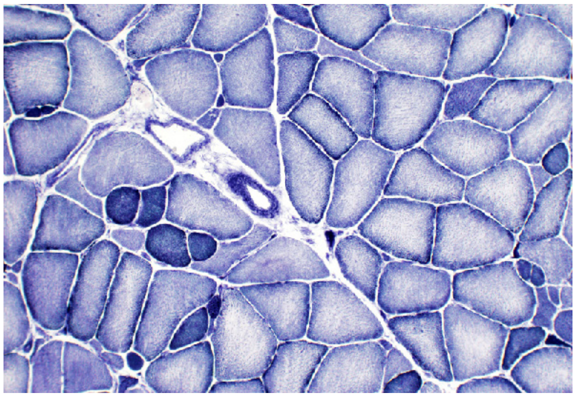

Figure #2. The type 1 fibers have been dyed a darker blue. In a healthy cell, type 2 fibers are not smaller than type 1 fibers. In anorexics (tissue sample not depicted), the type 2 fibers have atrophied to become much less prominent than type 1 fibers.

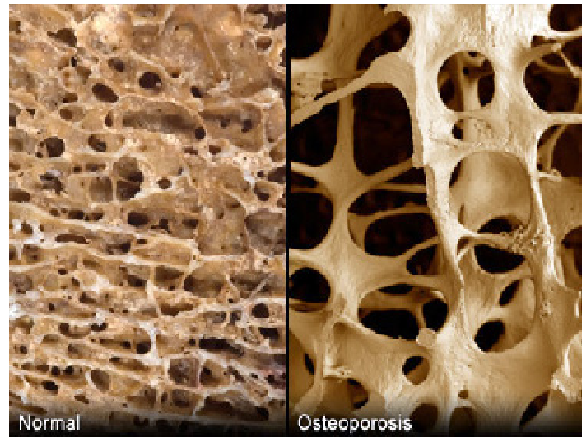

Figure #3. Because of nutrient deficiencies, anorexics and other patients afflicted with eating disorders will suffer a decrease in bone mass density. This puts them at risk for osteoporosis.

while binging refers to an single sitting where the patient eats continuously. Because the purges and binges balance each other out, a bulimic generally has a less emaciated or markedly thin appearance than does an anorexic. The third category of eating disorders consists of "atypical disorders," which, when combined form the largest category of eating disorders. They involve variations on the better-known disorders, but are made unusual with deviations that prevent identification within the two other established categories (Fairburn, 2003).

The reality of the impact self-starvation has on the body is grim. When a patient's "purging" of a patient involves vomiting, the consequences can manifest in his or her mouth. The vomit can cause dental erosion and undermined tooth enamel, at the same time wearing down the contours of the teeth. In these cases, formerly glossy teeth become worn down and uncomfortably sensitive to touch and temperature changes. Other effects include (but are certainly not limited to) damaged mucosal membranes in the mouth and pharynx, and lesions in oral tissue (DeBates, 2004).

In one study by C.F. Lindboe, women from age 19-28, who had struggled with anorexia for an extended period of time, allowed scientists to take a sample from the vastus lateralis of their quardriceps femoris muscle, which is a prominent muscle in the upper leg. Within muscle fibers, there are two main types – namely, type 1 and type 2. Type 1 fibers are "slow-twitch" fibers that are involved in continuous extended muscle contractions, say, those that are needed for a cycling marathon. Type 2 fibers on the other hand, are "fast-twitch" fibers that are involved in shorter intervals of movement. Type 1 relies on oxygen, whereas type 2 can churn out energy using anaerobic respiration. For ordinary people, type 1 and type 2 fibers are the same length and size. In Lindboe's study, the women had experienced 41% weight loss, and both types of fibers have atrophied in the cells of the anorexic women: the type 1 fibers have degenerated by 41%, while the type 2 fibers have degenerated by 75%. These women had no history of neuromuscular disease, and the study implies that the complications of their anorexia that have inflicted this damage on their body. Such a theory is supported by other studies, where samples of muscle taken from boys and girls who had experienced pronounced weight loss (about 25%) were analyzed and found to also exhibit atrophied type 2 fibers (Lindboe, 1982). Beneath the skin, the muscles of the body are wasting away.

"Beneath the skin, the muscles of the body are wasting away"

In these cases, an eating disorder sucks much-needed nutrients away from the body, and as the muscles decay, the bones do not escape unscathed either. They are the casualties of a damaged hormonal system. Depending on when the onset of an eating disorder is, the consequences on a patient's body can vary. For anorexics whose body fat concentration has dipped below a certain level (the precise cut off varies with an individual's body composition), amenorrhea, the absence of menstruation sets in, and with it, decreased bone mass. For a pre-pubescent girl, anorexia can delay the onset of puberty all together, and the implications of amenorrhea in a key time period of bone development are dangerous. The medley of hormones whose levels are forced to climb or drop because of nutritional deficiencies or the lack of a menstrual cycle is frightening long: FSH, estradiol, testosterone, cortisol, growth hormones, insulin-like growth factors, thyroid hormones, leptin, ghrelin, and peptide YY levels are all thrown into disarray by nutritional deficiencies. Of these, FSH, estradiol, testosterone, and growth hormones are related to the growth and development of the body, whereas the final three (leptin, ghrelin, and peptide YY) hint at the chaotic state of the factors that control a person's appetite. For adults, these hormonal abnormalities can contribute to the development of osteoporosis, in which the bones become weak and fragile as they are riddled with increasingly larger holes (caused by bone loss or bone deficiencies). In particular, the hormonal anomalies induce increased bone resorption, as minerals of the bone are broken down and sent into the body. Bone resorption is not unseen in healthy bodies, but is drastically increased in starved bodies. In one study, 92% of the anorexic women had bone densities that were below average, with 38% exhibiting a bone density low enough that certain sites could be classified as osteoporotic. It is telling that the only known methods of restoring bone mass density are through weight gain and the end of amenorrhea (Lawson, 2003).

In a 2014 study by Carolina Bates, she researches the metaphors applied by anorexics on online communities, and titles her article "I am a Waste of Space, of Breath, of Time." Although the paper describes an analysis of the mindsets of more extreme (and moreover, less covert) anorexics, the title alone gives some insight to the reason why eating disorders are psychiatric disorders. The affect of an eating disorder beyond the physical body are undeniable – as a patient becomes obsessed with the thought of food or weight control, they become less productive and their disorder can become an economic burden that increases health costs (Samnaliev, 2014). In this way, waste of the body extends to waste of the mind, branching over wasted time and talent. The psychological effects of a disease can be more difficult to measure than the physical, beyond the criteria for diagnosis. Both clinical and epidemiological studies show that most people with anorexia or bulimia are also burdened by another anxiety disorder, be it OCD or a social phobia (Kaye, 2004). Treatment is much easier when the disorder is discovered and addressed early on, but for people who have engaged in one for so long that the behavior has become entrenched, treatment becomes extremely difficult. The story of an anorexic, of a bulimic, of anyone afflicted with an eating disorder can begin with the waste of food, and end in the waste of human life.

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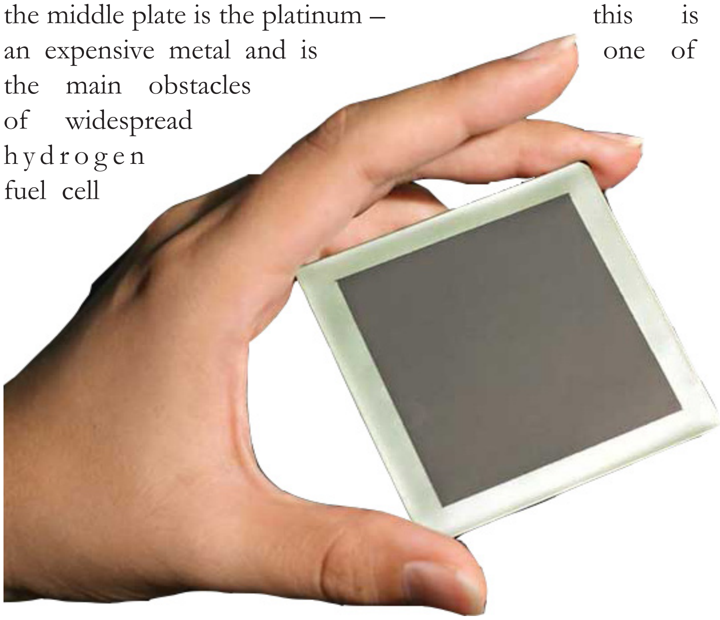
Layout by Jacob Ongaro

Something for Nothing: Solid-Oxide Fuel Cells

Karthik Gururangan

Fuel cells have been a popular contender for the gateway to the hydrogen economy for some time. Indeed, today we can see zero-emission buses and cars powered by a hydrogen fuel cell. Generally speaking, a fuel cell is an electrochemical system that drives the transferred electron occurring in redox reactions through an external circuit to power something. It is really the most straightforward way to convert chemical energy into electrical energy, and provided that the reactants remain in a steady supply, a fuel cell can indefinitely supply a steady current.

By referring to Figure 1 we can understand the setup of a hydrogen fuel cell. At the blue side (anode), hydrogen loses electrons and the resultant protons migrate into a reaction chamber. The green side (cathode) is very often an opening or simple air reservoir. The electrons flow through the circuit and reach the oxygen, completing the chemical reaction to produce water. Using the hydration electrochemical reaction is the basis of our intended hydrogen economy. In reality, one cell of this type hardly produces 1 volt so we combine single cells in series into what is called a fuel cell stack for applications. The main drawback of classical gas or liquid hydrogen fuel cells is that they require a platinum catalyst to speed up the reaction process to usable values (Minh, 2004). In Figure 1, the middle plate is the platinum – this is an expensive metal and is one of the main obstacles of widespread hydrogen fuel cell usage. Recently, scientists have proposed using solid-state diffusion of hydrogen and oxygen ions through an oxide electrolyte to make the hydration reaction (Park, 2000). These fuel cells are called solid-oxide fuel cells, or SOFCs. At high enough temperatures, SOFC diffusion can quickly outpace regular chemical kinetics, give us greater fuel choice flexibility, and eliminate harmful carbon monoxide by-products of common liquid fuel cells (Park, 2000).



"At high enough temperatures, SOFC diffusion can quickly outpace regular chemical kinetics, give us greater fuel choice flexibility, and eliminate harmful carbon monoxide by-products of common liquid fuel cells."

Diffusion is a temperature-controlled exponential law based on two things: the diffusivity of a particular electrolyte and the activation energy of diffusion for that particular solute. The activation energy can be decomposed into the energy needed to move around through the solid and the energy associated with moving around through holes called vacancies in the solid. Figure 2 gives an intuitive idea of what this means.

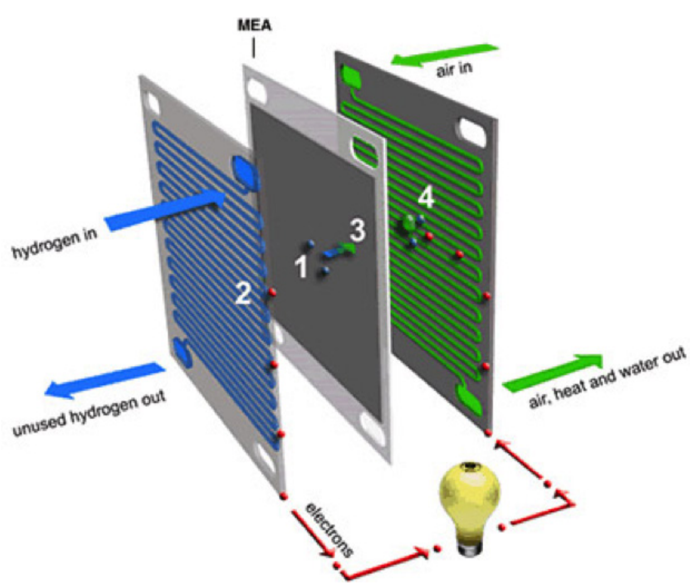


Figure 1. : Simple schematic of a single hydrogen fuel cell

An atom can either push its way past two others to move to another position or it can move through the existing gap defects. By choosing a solid oxide electrolyte, the much larger oxygen ions have an easier time migrating through the lattice, making the overall diffusion rate much faster than it

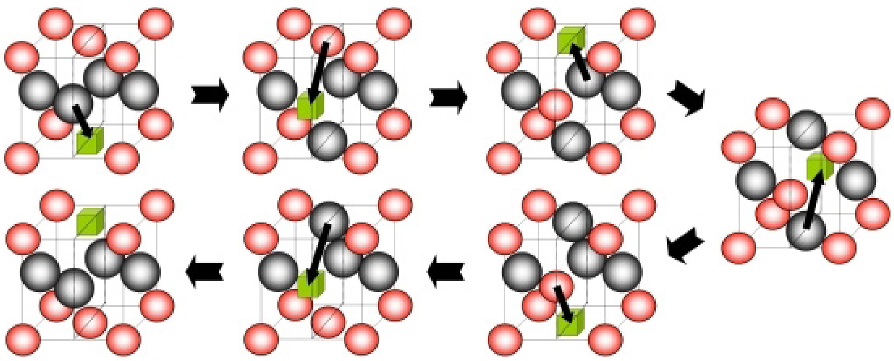


Figure 2. : Diagram of solid-state diffusion by vacancy mechanism with Arrhenius Law equation

would be using other solid electrolytes.

Figure 3 gives us a way to understand the electrochemical system that a SOFC operates on. The hydrogen-containing fuel is oxidized at the anode; the electrons provide power through an external circuit and reach the cathode where it reduces the oxygen atoms via exposure to air (Park 2000, & Hibino 2000). The oxygen ions now migrate through the electrolyte to combine with hydrogen ions at the anode to create water. The important research in SOFC research concerns the materials used for anode, cathode, and electrolyte (Shao & Halle, 2004). The selected electrolyte should be porous to oxygen ions but not oxygen molecules, have high ionic conductivity, resist oxidation, and act as a thermal barrier to combustion (Shao & Halle, 2004). Zirconia (ZrO_2) is a popular oxide ceramic electrolyte because it primarily satisfies these four conditions. Scientists have also found that doping zirconia with yttria (Yr_2O_3) will increase the number of vacancies (gaps) in the crystal, making the diffusion rate of oxygen ions through the electrolyte much faster. This particular electrolyte is called yttria-stabilized zirconia (YSZ) and is currently the most widespread contender for an electrolyte material. The major drawback of this diffusion mechanism is that SOFCs using YSZ must be operated between 600 – 1000 C (Singhal, 2000 & Steele, 2001). Other experiments have confirmed that samaria-doped ceria (SDC) can potentially yield an even greater oxygen diffusion rate at lower temperatures (Hibino, 2000). The key property of anode and cathode materials is a low area-specific resistivity (ASR) (Steele, 2001). This value is inversely correlated to the fuel cell's energy density: the higher the energy density, the more power that can be produced (Steele, 2001). Common electrode materials are nickel for the anode and an alloy of lanthanum, strontium, and manganite called LSM (Steele, 2001). When these electrodes are combined with an SDC electrolyte, engineers have managed to produce sufficient output power at 50 – 60% efficiency at 500 C (Steele, 2001).

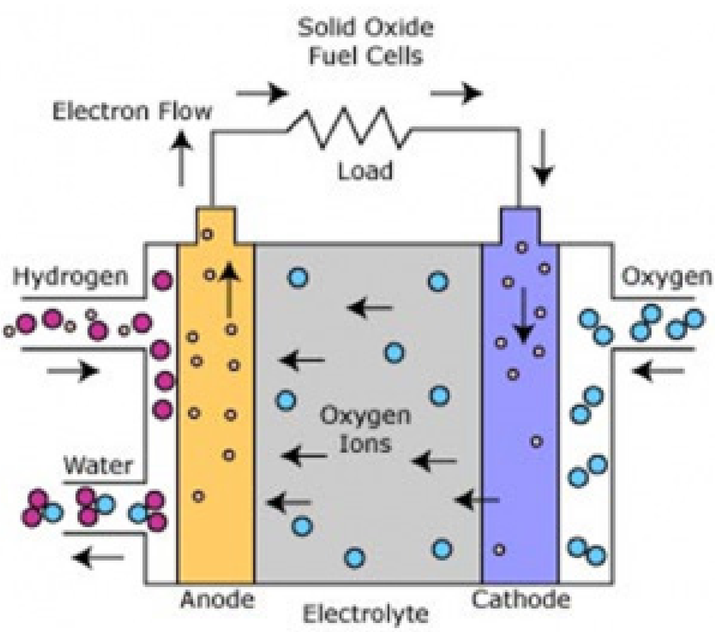


Figure 3. : Schematic of single SOFC operation. The anode, cathode, and electrolyte are solid and the rate of oxygen anion diffusion through the electrolyte is equal to the rate of electron flow (current generated)

The final step in SOFC design is its implementation. Currently, engineers have employed a tubular design:

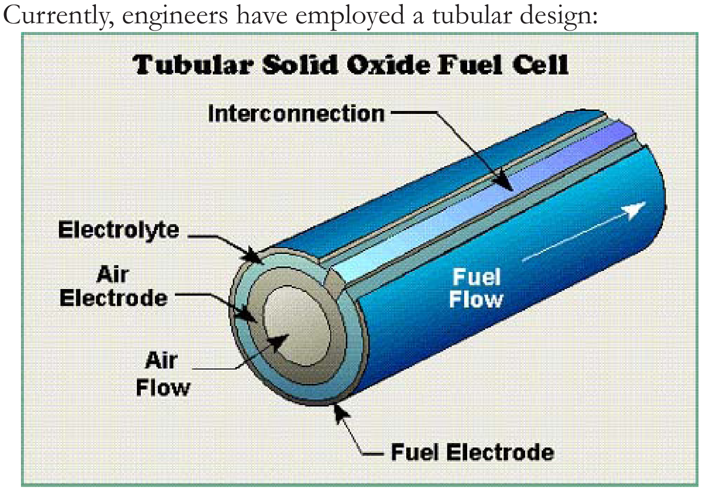


Figure 4. : Hollow SOFC tube. One side is exposed to air (oxygen) and the other is exposed to the hydrocarbon fuel. The electrons flow from fuel electrode to the inner electrode and oxygen ions diffuse outward

This popular layout is compact and amenable to the way these ceramic components are processed (Singhal, 2000). In addition, this design and others are flexible and scientists have managed to alter myriad power plant systems for fuel cell operation. The only barrier to widespread SOFC usage is its unfortunately high operation temperature (Hibino, 2000). While operation at room temperature or even common fuel cell temperatures is unlikely given how thermally-dependent diffusion is, SOFCs provide a zero-emission, innovative gateway to the hydrogen economy. Many power plants and generation schemes accommodate high-temperature operation and with advances in materials chemistry, we are developing components that can sustain high power output at lower and lower temperatures (Singhal, 2000).

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Layout by Karthik Mayilvahanan

Junk DNA

Neel Jani

The DNA that composes humans is made of over 3 billion base pairs, yet close to 99% of these genes do not code for proteins and have been termed as "Junk DNA" (Wong et al., 2000), while a more appropriate name would be non-coding DNA (those that do no code for a specific protein), Junk DNA has stirred significant debate and research in the scientific community namely due to its enigmatic nature. Evolutionarily speaking, why should so much energy be wasted in the production of something of which only 1% will be functional? Growing research in the past couple of decades has thus tried shining light on Junk DNA, namely what it is, why it exists, its functionality, and its future in humans.

History of Junk DNA

The concretized term "Junk DNA" originated with researcher Susumu Ohno in the early 1970's, yet there has been an unintended misrepresentation from the media that the discovery of potential functions of noncoding DNA has only begun now. In fact, the discovery of the term went hand-in-hand with research as to the potential functions for what the term represented. Several researchers dismissed the idea that the vast majority of the genome is completely nonfunctional and were receptive to the idea of a function independent of coding proteins, such as regulation (Gregory and Palazzo, 2014). In fact, after each new type of non-protein coding DNA was discovered, the search for the potential function of these genes was sought. Among the major ones discovered after the 1960's were pseudogenes, transposable elements (TE's), and introns.

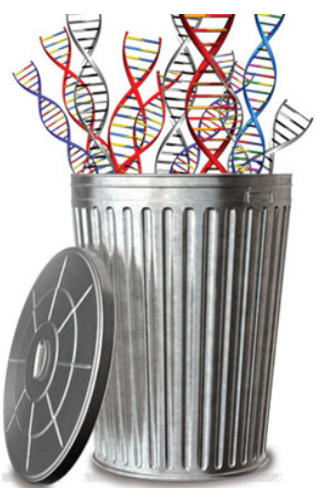


Figure 1. Evolutionarily speaking, why should so much energy be wasted in the production of something of which only 1% will be functional?

Types of Junk DNA and their Uses

Pseudogenes

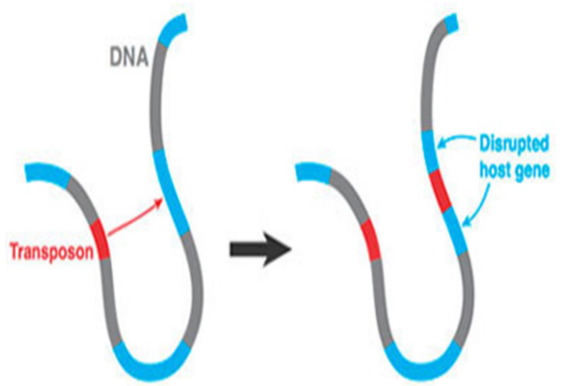
While the preservation of pseudogenes might occur because they induce no harm to the organism, there is growing evidence suggesting that they regulate prominent diseases such as diabetes and cancer.

When Susumu Ohno coined the term junk DNA, it was in reference to the development of pseudogenes. Specifically, Ohno described the phenomena of gene duplication; namely, how the cell of an organism could duplicate its genome, and have modifications and alternations to the newly formed copy rather than the original. Such a process would ensure that potential disastrous mutations to the copied genome could be masked by the original genome (Gregory and Palazzo, 2014). Those mutations that would be beneficial would help the organism survive. Overall, these gene duplication events seem to allow an organism to adapt adequately to potential environmental stressors. However, at times, the mutations undergone by the duplicate cause a non-functional protein to be coded. Hence, the mutation does not provide a substantial benefit or loss to the organism and is thus preserved as a pseudogene. The human genome is home to a large number of these pseudogenes that code non-functional proteins; researchers estimate that they number from 12,600 to 19,700 (Gregory and Palazzo, 2014).

While the preservation of pseudogenes might occur because they induce no harm to the organism, there is growing evidence suggesting that they regulate prominent diseases such as diabetes and cancer. This increase in research pointing out the functionality of pseudogenes has come from the use of next generation sequence technologies over commercial microarrays (Pink et al., 2013).

Transposable elements

Transposable elements were discovered by Barbara McClintock and were thrown under the same veil of Junk DNA as pseudogenes. Transposable elements are DNA Sequences that change their position in the genome. Transposable elements are founds in several groups and even kingdoms and are therefore "highly conserved among distantly related taxonomic groups, suggesting that they must be of some biological value to the genome" (Pray, 2008). With this in mind, specific functions of TEs have been explored. First, like pseudogenes, TEs have been found to assume regulatory functions with respect protein synthesis (Gregory and Palazzo, 2014). Second researchers Roy Britten and Eric Davidson have found that they might be involved in cell differentiation and the specification of the function of biological structures. This specialization is determined by the distribution of these TE's in a given stretch of DNA (Pray, 2008). Overall, however, the evidence for these functions has only been found for a small number of TEs, thus begging the question if these functions are unique to TE's or simply a subset of them (Gregory and Palazzo, 2014).



Transposable elements are DNA Sequences that change their position in the genome.

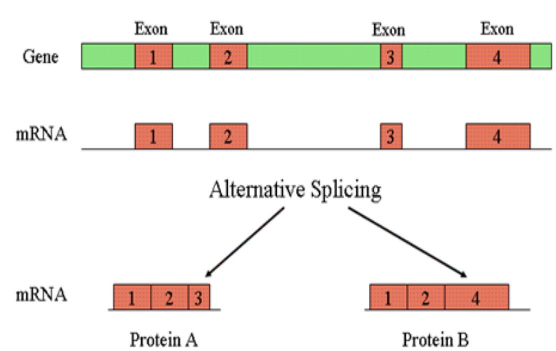
Introns

About 40% of the human genome is comprised of intronic regions, yet these intronic regions also contain pseudogenes and transposable elements (Gregory and Palazzo, 2014). Introns are portions of mRNA that can be removed prior to translation of the mRNA sequence through a process known as alternative splicing. Introns have been found to increase the possibilities of protein products due to alternative splicing, thus increasing diversity and potential adaptations to environmental pressures from one strand of mRNA. Furthermore, researchers have found that introns that are removed from the larger segment of RNA can express themselves later on (Carmel and Chorev, 2012). Thus there, is also the possibility of expression of an intron once it is excised.

Is Junk DNA actually Junk?

While there are several types of Junk DNA and each of them appear to have some use, several arguments suggest that Junk DNA is, in fact, junk. The first is what is termed as the Onion Test. Specifically, organisms with significantly more DNA content than humans, such as the onion whose genome is five times as large as that of a human, might appear to have no real reasons to carry this much more DNA (Gregory and Palazzo, 2014). The complexity of a human and the greater number of metabolic processes required suggest that there is DNA in the onion that is simply not used, though recent attempts have been made to show that it is necessary (Freeling, Xu, & Woodhouse 2015). The arbitrariness of the relationship between the physical amount of DNA and complexity is further highlighted by the fact that "salamander species belonging to Plethodon boast a fourfold range" within the species itself, suggesting that there is DNA that is inherently useless to the organism's function (Doolittle, 2013).

Second, as mentioned earlier with respect to pseudogenes, a variety of evolutionary processes shape the structure of non-coding DNA. Functionally important regulatory sequences will tend to be conserved as a result of negative selection against harmful mutations, whereas positive selection will favor those that benefit the population. However, "a central tenet of the nearly neutral theory of molecular evolution is that extraneous DNA sequences can be present within genomes, provided that they do not significantly impact the fitness of the organism" (Ludwig, 2002). Thus, these mutations in a genome have to be significantly negative in order for these genes to be eliminated from a population.



Introns have been found to increase the possibilities of protein products due to alternative splicing.

Researchers have also found through the evolution of Archaea that there are selective pressures to get rid of junk DNA in them. In fact, the percentage of non-coding DNA with respect to coding elements in the genome of an Archae has been found to have 6-14%, which is significantly less than the amount in humans (Tatusov, Wolf, & Koonin, 2002). Moreover, after having traced the percentage of coding elements in Archae throughout time, and researchers found that "the evolution of non-coding regions appears to be determined primarily by the selective pressure to minimize the amount of non-functional DNA, while maintaining essential regulatory signals" (Tatusov, Wolf, & Koonin, 2002). Essentially, the minimum amount of DNA for regulating transcription is preserved but the rest, over time, will be removed from the population. These ideas have also been proven empirically in eukaryotes, where "a general mutational tendency towards DNA loss… inescapably influence[s] the length of noncoding regions in most eukaryotes" (Comeron 2001).

Conclusion

Junk DNA continues to baffle researchers to this day, and on-going research hopes to demystify the functionality associated with non-coding genes. While most of non-coding DNA that has some function appears to be regulatory, both in terms of protein and larger biological structures, and some possible functions in combating disease, a large percentage of non-coding DNA eludes researchers with regards to function. Moreover, the historic nature of a reduced genome size and the lack of correlation between genome size and complexity suggest that even if some non-coding sequences might have some regulatory function, they are also several sequences that are essentially expendable.

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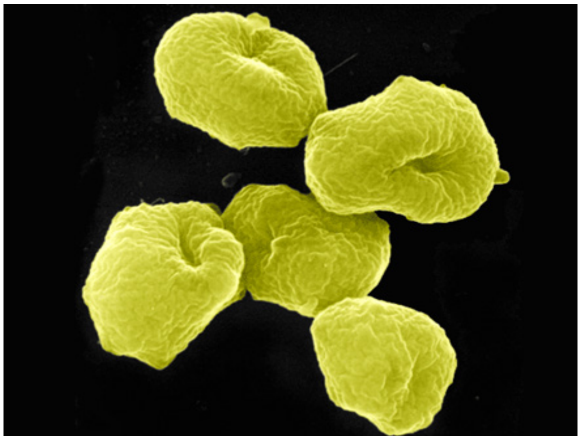

Figure 2. Researchers have also found through the evolution of Archaea that there are selective pressures to get rid of their junk DNA.

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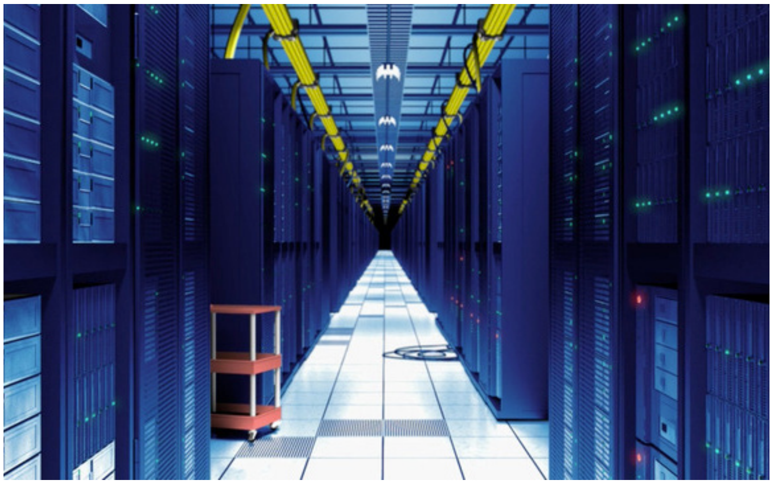
Data Fragmentation

Nisha Balabhadra

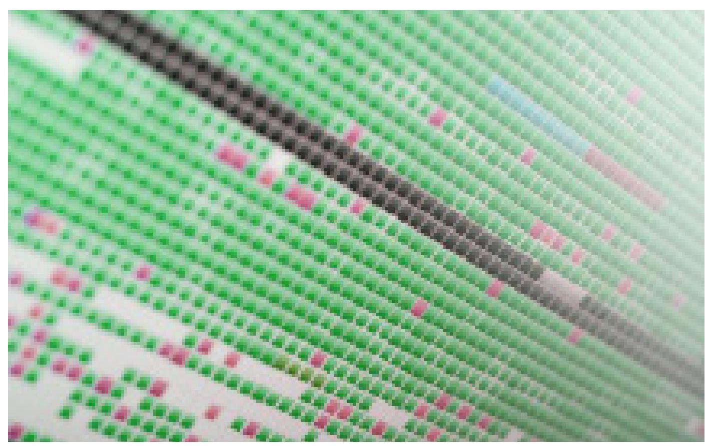


Data fragmentation is a process by which files and data are broken apart into small blocks of memory in order to be stored by the computer. When breaking the data into these blocks, often times the computer will allocate more space than is needed to store the data, and this space will remain empty and unusable by the system. This process by which wasted space is created is called fragmentation. Fragmentation doesn't seem like a huge problem with newer computers and systems, however as time passes the wasted memory space builds up and the computers become our worst nightmares, slow, lagging, and mere shadows of the machines that they were originally.

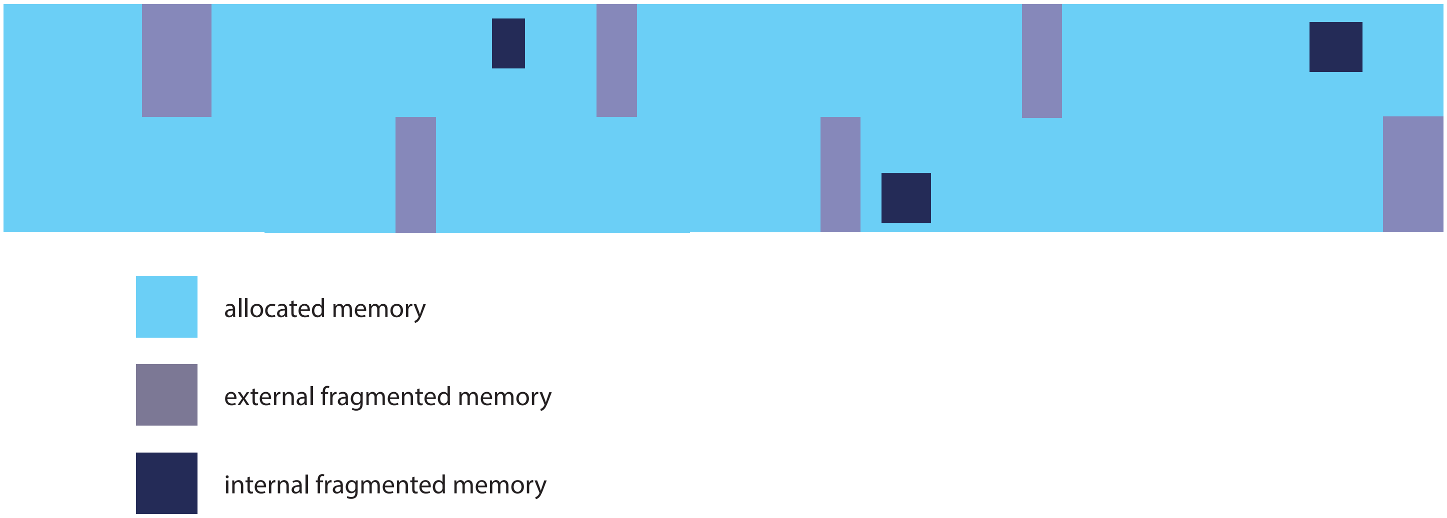
There are two main types of memory fragmentation, internal and external. Internal fragmentation occurs when a certain amount of memory is allocated for a specific job that the computer has to do. The computer overestimates the amount of space needed for that job and within the allocated memory there are blank spots of unused, wasted space that the computer can no longer use (Samanta, 2004). Since the wasted space is within a block of allocated memory it is referred to as internal fragmentation. External fragmentation happens when there are blocks of unused memory in-between already allocated memory blocks (Samanta, 2004). With external fragmentation the unused blocks are still available for use, however they cannot be used for larger jobs as the memory space is no longer continuous (Samanta, 2004).

Files stored on the computer are called fragmented when they are not stored in a continuous block of memory (Pal, 2008). This commonly occurs when there is not enough space in the computer's disk (Pal, 2008). It can also occur due to appending and editing the file (Pal, 2008). File types that are most often fragmented are PST files (that come from outlook emails), Microsoft Word documents and JPEG (image) files (Pal, 2008). Fragmented files are harder for the computer to retrieve as their memory is stored in many different places, and are therefore slower to retrieve (Peterson, 2002).

Some ways to reduce the occurrence of file fragmentation, as well as speed up the time to retrieve files is to store files in larger blocks of memory, ensuring their continuity (Peterson, 2002). This however raises the problem of internal fragmentation, where memory is deemed unusable by the computer. Other solutions involve storing series of files sequentially so that operations can be performed sequentially as well (Peterson, 2002). This begets problems when the clusters of files that are stored together become too large and must be allocated elsewhere (Peterson, 2002). Some even better solutions to file fragmentation include what is called the buddy system (Samanta, 2006). In the buddy system, blocks of memory are split into two "buddy blocks" until one of the blocks is an appropriate size for the operation being performed (Samanta, 2006). Whenever blocks of memory are returned (i.e. are no longer in use) they can recombine with their buddy blocks, and create more new space for new files and jobs to be stored or performed (Chang, 1996). The buddy system significantly improves retrieval speeds of files and improves memory storage in computers (Chang, 1996).



Fragmentation not only reduces speed of file retrieval, but it also reduces performance of systems such as SSD, Solid State Drives, which are similar to hard drives in computers, but utilize flash memory like a USB drive will, and are faster. Fragmentation reduces speed of SSDs by up to fourteen times



(Chen, 2009). In order to prevent aging of the system the SSD needs to be defragmented, or organized and cleaned regularly as a short time fix (Chen, 2009). In addition to reducing performance, fragmentation contributes to software aging. After fragmentation, empty blocks of memory are not used freely until certain processes are finished executing (Macêdo, 2010). This causes higher processing costs, and contributes to aging of the computer (Macêdo, 2010). Additionally this can cause the system to exit user mode to retrieve blocks of unused memory and then return back to it, further increasing process size and therefore aging the computer more (Macêdo, 2010).

Fragmentation can also be applied to resources for the computer to use in executing an operation or a job. Job scheduling involves allocating resources to each job, as well as determining the order in which jobs are executed (Huang, 2009). Resource fragmentation affects job scheduling by reducing performance (Huang, 2009). This problem can be alleviated by algorithms that either work to fit in jobs in a particular order so that the smallest jobs are finished first, or by which jobs need the least resources (Huang, 2009). With proper management of resource fragmentation, systems can run up to five times better than before (Huang, 2009).

Although fragmentation is typically negative, especially for the average user who simply wants a fast computer to store their work, and other files, it has interesting applications in fields such as encryption. Fragmentation can be used to enable privacy over data collections (Ciriani, 2007). In this instance, data can be fragmented over different servers and encrypted where necessary (Ciriani, 2007). This allows data to be highly visible, but at the same time keeping information classified (Ciriani, 2007).

Fragmentation is a pain when it comes to personal computing, but there are new ways of avoiding it being found everyday. And with the advent of cloud technologies, we no longer need to concern ourselves too much with storing and allocating memory for our files on our computer's hard drives and risk diminishing their performance.

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Layout by Henry Hammel

Tiny but Toxic: How Industrial Waste Infiltrates the Body

Rachel Lew

During one of the most devastating episodes of air pollution in history, a 30-mile-wide cloud of smog settled on the city of London, incapacitating its residents. For five days, the smog was so thick that all transportation above ground was halted and Londoners were forced to walk the streets instead, dangerously exposing themselves to the pollution. The Great Smog of December 1952 was estimated to have caused 4,000 deaths within days. (Klein, 2012) Reflecting on the event fifty years later, a woman who lived through the Great Smog said, "It was the worst fog that I'd ever encountered. It had a yellow tinge and a strong, strong smell strongly of sulphur, because it was really pollution from coal fires that had built up. Even in daylight, it was a ghastly yellow colour" (Days of Toxic Darkness, 2002).

Figure 1. The Great Smog of 1952 (London, England)

At the time, the smog was considered more of a visibility problem than a health hazard. Runners from Oxford and Cambridge University even persisted in their annual cross-country race, using track marshals to guide them through the yellow smog (Klein, 2012). Perhaps if they had been aware of the health effects associated with breathing polluted air, they would have decided to stay indoors that day. Exercising in polluted air has been proven to be particularly harmful not only to the throat and lungs, but also, surprisingly, to the heart (Pekkanen, 2002).

Upon inhaling the smog, Londoners in 1952 began choking and wheezing as toxic particles infiltrated and irritated their respiratory pathways. Weeks later, many found themselves afflicted with bronchitis, tuberculosis, and other

> Ultra-fine particles not only exacerbate existing lung disease but also increase blood coagulability….clotted or thickened blood can easily clog major vessels.

inflammatory pulmonary diseases. Worse, over the course of six months, more Londoners were plagued by pollution-caused cardiovascular disease, resulting in an estimated 8,000 additional deaths (Klein, 2012).

We now know that particulate matter air pollution, or PM, can damage both the pulmonary and cardiovascular systems of organisms, causing both short- and long-term health problems. In 2002, the number of PM-related deaths per year in the United States was about 60,000 (Verrier, 2002). Though this number only accounts for 2.4% of the total number of deaths in the US, by comparison, about the same number of people died from Alzheimer's disease that year (Kochanek, 2004).

Unfortunately, with the rise of industrialization, the problem of particulate air pollution has only intensified. In the 1900s, air pollution mainly consisted of emissions from coal combustion, such as sulfur oxides, nitrogen oxides, carbon monoxide, other organic compounds, and particulate matter made up of inorganic ash residues (Bituminous and

> In 2002, the number of PM-related deaths per year in the United States was about 60,000.

Subbituminous Coal Combustion, 1998). Modern industrial processes have yielded even more forms of waste that are dispersed into the air. Diesel exhaust from heavy machinery, for example, contains DEP (diesel exhaust particles), which accumulate easily in the lungs and can hang in the air for long periods of time. Desertification in Mongolia and China due to industrial development on the land has given rise to ASD particles (Asian sand dusts), which are blown over as far as North America by wind currents (Takizawa, 2011).

DEP and ASD are examples of pollutant particles that affect the pulmonary system through airway irritation. Specifically, they heighten allergic symptoms; animals exposed in experiments to diesel exhaust exhibited enhanced airway hyperresponsiveness (AHR) and inflammation. Those exposed to ASD also showed inflammation in the mucous membrane of the nose. (Takizawa, 2011). In human children, greater exposure to PM2.5--pollutant particles with a diameter of 2.5 µm--NO_2, and soot is associated with increases in asthma symptoms (Gehring et al., 2010). Moreover, an eight-year study conducted in the Netherlands found that children who lived closer to roads with high traffic, and were thus exposed to higher levels of DEP and other traffic-related pollutants, were more likely to develop asthma during the first eight years of their lives (Gehring, 2010).

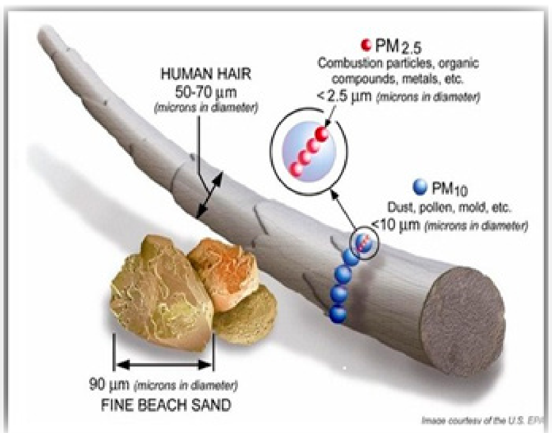


Figure 2. Relative size of particulate matter air pollution

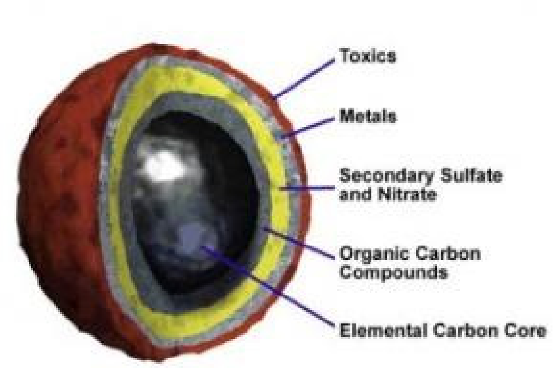
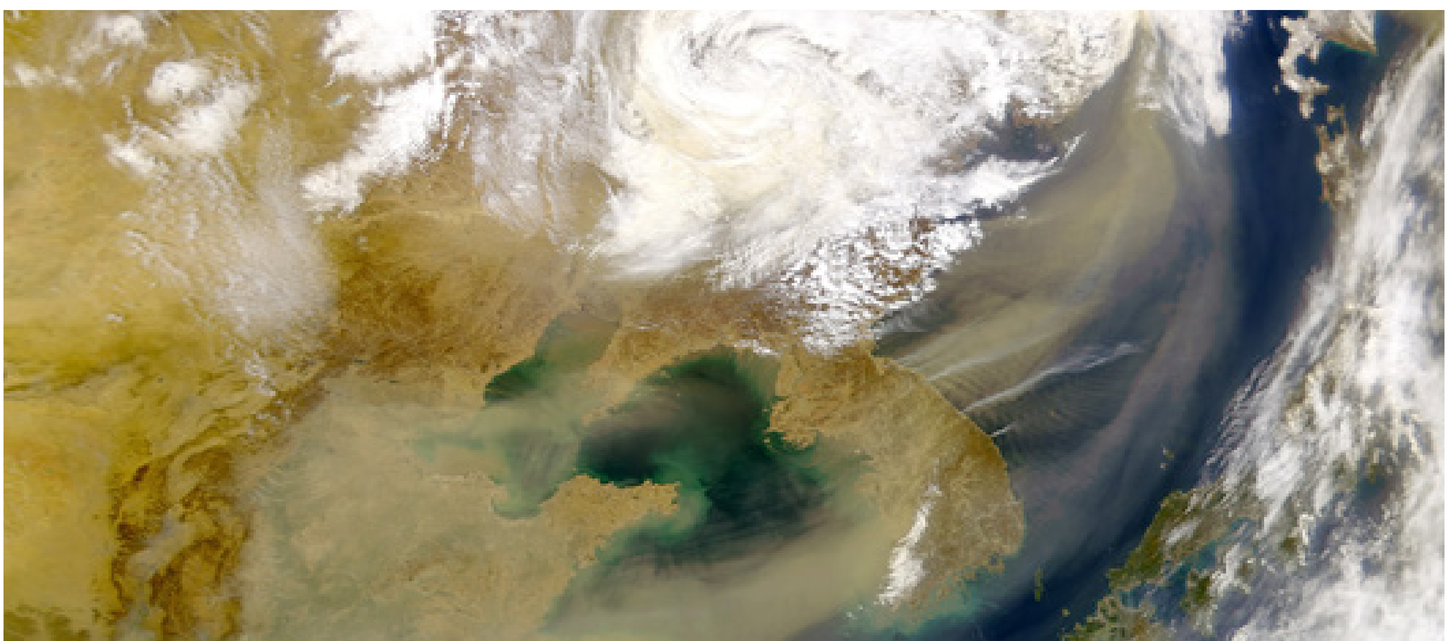


Figure 3. Composition of diesel exhaust particle (DEP)

DEP and ASD are not the only particles contaminating ambient air, or air in its natural state. In general, PM is defined as "a mixture of combustive byproducts and resuspended crustal materials, as well as biological materials such as pollen, endotoxins, bacteria, and viruses" (Verrier, 2002). These particles are tiny; the largest are about 10 µm in diameter, about one-fifth the width of a human hair.

Some scientists believe that the smaller the PM, the more toxic it is to organisms. According to a 1995 article in



Yellow cloud of Asian sand dusts (ASD) blows over from China

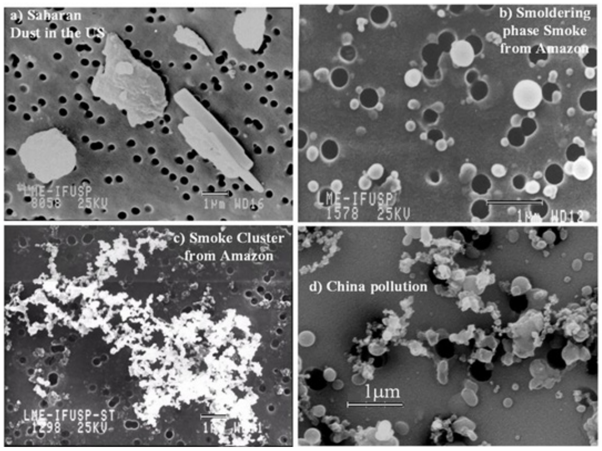


Figure 4. Various airborne pollutants under microscope

The Lancet by Seaton et al., soluble particles absorb water as they travel down the airway, grow in size, and can be easily rejected by the lung's defenses. However, ultra-fine particles penetrate these defenses and go on to cause inflammation in the alveoli of the lungs, "with release of mediators capable... of causing exacerbations of lung disease" (Seaton, 1995). These ultrafine particles are especially dangerous because they can enter systemic circulation. Then, as blood is circulated throughout the body, so are the ultrafine particles, spreading toxicity into areas outside of the lungs (Bhatnagar, 2004). The invasion of PM into circulating blood has been documented to cause constriction of arteries, cardiac arrhythmias, and myocardial infarction--the death of heart tissues as a result of inadequate oxygen supply (Verrier, 2002).

Interestingly, Seaton et al. also hypothesizes that these ultra-fine particles can transport chemicals on their surface, provoking an inflammatory reaction in the body. This low-grade inflammatory reaction would then cause an increase in "plasma viscosity, fibrinogen, factor VII, and plasminogen activator inhibitor" (Seaton, 1995). The protein fibrinogen aids in blood clotting, factor VII is a key initiator of blood coagulation, and plasminogen activator inhibitor inhibits the breakdown of blood clots. Therefore, ultra-fine particles not only exacerbate existing lung disease but also increase blood coagulability. Corroborating this hypothesis, a study that exposed healthy human volunteers to CAPS (concentrated ambient air particles) saw results in which the volunteers' blood contained significantly more fibrinogen 18 hours after exposure (Ghio, 2000). If these hypotheses are correct, then PM inflicts cardiovascular disease indirectly: clotted or thickened blood can easily clog major vessels, and prevent blood flow to the heart--also known as ischaemic heart disease--and other vital organs. Lack of blood flow corresponds to lack of oxygen and nutrients; the resulting tissue death in these regions could manifest in a stroke or heart attack.

In Beijing, for example, a citizen could check the Air Pollution Index one morning and leave the house knowing that he or she has a greater risk of incurring a heart attack that day.

Currently, knowledge of the exact molecular mechanisms surrounding the effects of PM on the cardiovascular system remains limited. However, it is generally believed that this relationship exists. For one, the number of hospital visits for cardiovascular disease has been shown in many studies to be higher on days with higher levels of air pollution (Metzger, 2004; Pekkanen, 2002). Moreover, data collected on 500,000 people in the United States between 1979 and 2000 showed that "for every 10-μg/m3 increase in fine particles (PM2.5), all-cause mortality increased by 6% annually and cardiopulmonary mortality by 9%," a correlation which was also observed to a lesser extent with increases in density of coarser particles (Verrier, 2002). It is disturbing to consider that in highly polluted cities, pollution levels must be reported daily in the news to keep individuals aware of the hazards of going outdoors. In Beijing, for example, a citizen could check the Air Pollution Index one morning and leave the house knowing that he or she has a greater risk of incurring a heart attack that day (Chen, 2015).

In sum, exposure to air pollution can cause not only precipitous cardiopulmonary distress such as asthma attacks, heart attack, and stroke, but also chronic damage to the heart, lungs, and airway. Fortunately, however, it is possible to mitigate PM-related health risks. On the individual level, people living in heavily polluted areas can make lifestyle adjustments such as staying indoors when pollution levels are high. On the


Figure 5. Sunrise over a smog-covered Hong Kong

institutional level, it is important that governments make an effort to control common sources of pollution, since declines in city pollution levels have been shown to cause fewer deaths in the area. In Utah, for instance, a 13-month strike at a steel mill in Utah Valley--one of the most polluted cities in the US--caused PM10 concentrations to decrease and subsequently lower the city's mortality rate by 3%. Similarly, "[r]estrictions on the sulfur content of fuel oil in Hong Kong resulted in a 45% average reduction in SO2, and the average annual trend in deaths from all causes declined 2% and from respiratory causes declined 3.9%." (Laden, 2006). And if the pollution itself cannot be controlled, then efficient city planning can help increase the distance between housing and sites of pollution.

Any country engaging in industrialization necessarily contributes to the problem of pollution, and thus has a responsibility to relieve it. Heart disease and respiratory illness are two of the most common causes of death around the world; by striving to reduce air pollution, we are not only improving the Earth's health, but also securing our own.

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Layout by Abigail Landers

Nuclear Waste: Forever Contaminated?

Andrew Wang

Mention the word "nuclear" and immediately thoughts of Hiroshima, Nagasaki, Three Mile Island, Chernobyl, and Fukushima are elicited. The iconic mushroom clouds and the thought of a nuclear apocalypse during the Cold War have dominated fears for a significant part of the last century. It is no wonder people cringe at the thought of nuclear power. Especially with nuclear disasters like Chernobyl and Fukushima, most people are worried that anything nuclear will lead to an uninhabitable wasteland. However, there is no reason to immediately dismiss nuclear energy. Besides the fact that we are increasingly reliant on nuclear energy, it provides over 10% of the world's energy and data from both Fukushima and Chernobyl show that the land is recoverable ("World Statistics", 2015). Drawing upon both of these infamous nuclear disasters we will examine how nuclear waste affected the environment.

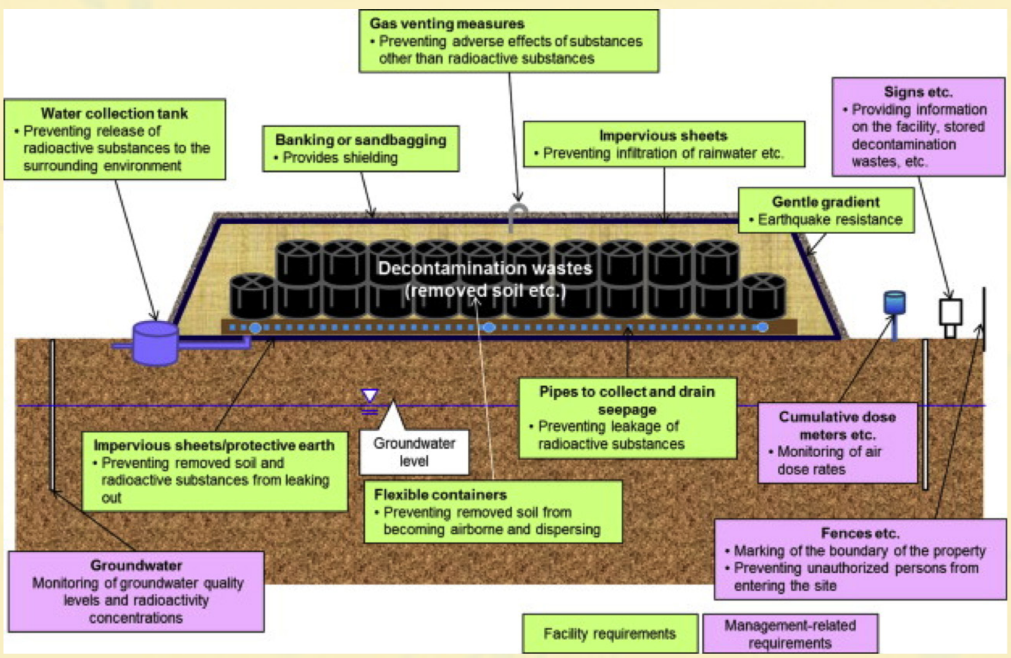

Figure 1. A Schematic of the process to clean-up the topsoil around Fukushima.

It has been almost four years since Fukushima and almost thirty years since Chernobyl, but both still remain in the public conscience. Nuclear Energy is created by a steam turbine, where the heat given off by a nuclear reaction, boils the water surrounding it, which drives the blades of the turbine. A process that does not release a significant amount of carbon dioxide into the atmosphere. However, the Fukushima nuclear meltdown happened on March 11, 2011 when an 9.0 magnitude earthquake caused the nuclear power plant to shut down. However, the earthquake triggered a tsunami that prevented the emergency procedures from being activated, allowing nuclear waste to slowly leak into the environment. The danger was so great that Japan immediately ordered an evacuation of all people within 20 km to 30 km (~12.5-18.6 miles). The Fukushima Daiichi disaster still impacts Japan and cleanup remains underway to this day. This was the second largest nuclear disaster since Chernobyl. Chernobyl happened on April 26, 1986, when a reactor exploded and sent a huge plume of radioactive material into the atmosphere and caused 31 deaths and long term effects that are still being researched today (Danzer, 2014). The public worry increased so much in both cases that people still refuse to eat food such as fruits and berries deemed safe. Moreover, Chernobyl still remains an isolated ghost town due to mass scale evacuation right after the incident and the lack of effort dont to repair it.These two events are the only ones to be rated 7, the highest rating on the INES scale, International Nuclear Event Scale, a scale determining the severity of nuclear incidents. Both of these events, while disastrous, allow us to study the effects of nuclear waste on biological systems, while spurring research into disposing of nuclear waste.

Both nuclear disasters exposed radioisotopes into the environment and since it is unwise to leave radioactive isotopes in otherwise useable land, clean up is very necessary. The most important step was a mass scale evacuation of people living near the reactor and for a temporary ban on food exports from the contaminated region. People who experience high levels of atomic radiation will develop Acute Radiation Sickness, which harms the skin and bone marrow possibly beyond repair, or develop cancer in the long term. In Fukushima, to dispose of the radiation, the clean up crew used high power water pressure to wash off the soil or any other type of debris (Hardie, 2013). They also removed most of the topsoil, which was most likely to be affected by radiation, through ploughing and used heating to reduce the amount of radioisotopes. The topsoil, as well as any organic matter, was taken to a plant, where it is dried and will remain, until the radioisotopes, specifically Cesium, decompose (Hardie, 2013). Similar procedures were used in Chernobyl. It is worth mentioning that this cleanup effort is extremely expensive, costing on the order of billions of dollars. The Fukushima cleanup is still going on today and even behind schedule.

Figure 2. A picture of Fukushima after the disaster.

Generally, when a nuclear meltdown occurs, it is not just the heat that is released from the blast. The greatest danger from a nuclear disaster as previously mentioned are radioisotopes, most common strontium-90 and cesium-137 (Merz, 2015). Cesium can mimic the properties of potassium, while Strontium can mimic the properties of Calcium, which can be taken up by physiological processes and as they further decay, harm the body beyond repair. ("Fission Fragments", 2015) It is not uranium that is dangerous as commonly assumed because it is actually a relatively stable radioisotope, but it is what uranium splits into when undergoing nuclear fission. Iodine -131 is another byproduct of nuclear fission, but that is less of a concern when studying the environment because

"The Fukushima cleanup is still going on today and even behind schedule"

the half life of Iodine-131 is only 8 days and will become relatively harmless Xenon (Buesseler, 2011). In addition, Strontium-90 and Cesium-137 are more of a concern because they each have a half life of approximately 30 years and therefore will be in the environment for potentially hundred of years ("Strontium", 2012).

In the short term, radiation does not affect humans very much. If exposed to radiation it may trigger nausea and other flu-like symptoms. One of the biggest problems is the fact that animal products become contaminated with radiocesium and vegetables become contaminated with radiostrontium (Merz, 2015). For instance, in Chernobyl many children experienced greater radiation because of the milk they drank, which contained an excess amounts of Strontium-90 (Hatch, 2005). People were not aware at the time of the dangers of drinking contaminated milk. This also poses a problem for the government because people still have to eat. Interestingly enough, foods only showed dangerous radioactive levels in the first year, whereas by the second year only deer meat and mushrooms showed significant levels (Merz, 2015). It can be assumed that most of the radiation is absorbed into the crops the first year, so the radioactivity decreases to acceptable levels. Unlike land-locked Chernobyl, Fukushima had a significant amount fallout went into the Ocean and rivers which prevented the water from being immediately drinkable.

In the long term, effects are still being discovered. From Hiroshima, we know that excess cancer risk associated with exposure is known to persist over 50 years (Steinhauser, 2014). In Chernobyl, there was an increase in thyroid cancer in children in the years following the accident. While only 31 people died in the following days, the radiation exposure is 175-3000 times higher than the dose that the average person will receive in a year (Danzer, 2014). In Chernobyl, the winds carried the fallout across Europe, while in Fukushima, the fallout mostly went into the ocean because of Japan's mostly mountainous topography (Steinhauser, 2014). In Fukushima there is a ban on fishing because radiostrontium can remain in the bones of fish and other marine life for a significant time.

Since nuclear power is new and it is hard for scientists to study the effect of radiation over generations, some scientists have decided to study the effect on animals. In Japan, they have noted the wildlife near the the reactor. For instance, the wild monkeys and the pale grass blue butterfly are currently being studied. It has been concluded that the wild monkeys suffer from a low blood count (Hiyama, 2015). Since the life cycle for the pale-blue butterfly is only 2 years, it is easily to study the generational changes between. The study concluded that the worst defects on butterflies occurred during the fifth generation, and then there were gradually less genetic defects (Hiyama, 2015). Extrapolating this data, it will take us into the 2100 for affected people's progeny to no longer suffer the worst of the nuclear meltdown.

One last thing to note is the sociological effect of the meltdown. Upon hearing about the meltdown, people rationally had an anti-nuclear sentiment. Both Germany and Japan attempted to go nuclear free, but Japan eventually had to reverse its decision due to its energy needs (Davies, 2011). The United States remained mostly indifferent as they attributed Fukushima to environmental factors and since the United States has its reactors in a mostly isolated area inland, they did not think it was to change policy. The main lesson

B S J

"...it will take us into the 2100 for affected people's progeny to no longer suffer the worst of the nuclear meltdown."

from Fukushima and Chernobyl is that governments needs to work closely with scientists to plan ahead in case disasters happen. In Fukushima, people were banned from drinking tap water until about two months later, despite the fact that it had been well below unsafe radiation limits after only 30 days (Hamada, 2014).

In the end, we should follow the words of Albert Einstein, who not only contributed significantly to theoretical physics, but helped create the atomic bomb, "A new type of thinking is essential if mankind is to survive and move toward higher levels." Nuclear power is a way to create cleaner energy to meet the demands of the ever industrializing world and while it may be dangerous we need to push forward, but not abandon caution and to learn from the mistakes we have already made.

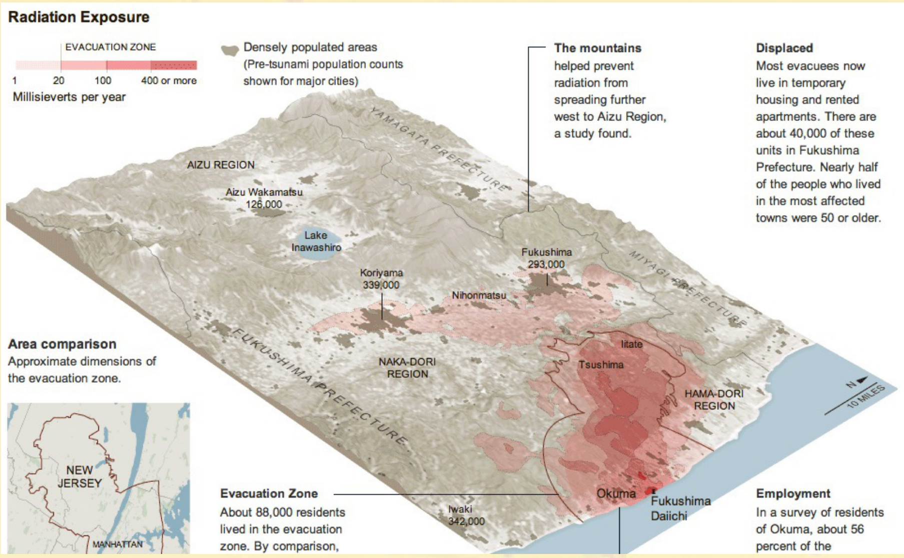

Figure 3. Image of the Fallout that spread across Fukushima

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Telomeres Hold the Key to Understanding Aging and Cancer

Shruti Koti

In 1953, James Watson and Frances Crick described the structure of DNA and made history. However, just a few years later, a scientist from the other side of the world was conducting research in the field of molecular evolution that would shape our understanding of genetics. Susuma Ohno was born in Korea to Japanese parents in 1928. From a young age, he showed a love for animals, particularly horses, that would eventually take him to veterinary school. But rather than practicing as a vet, Ohno got pulled in a different direction: experimental science. As he was studying the chromosomes of mammals, he noticed that while there was great variation in the number of chromosomes in different species, the amount of chromosomal material (DNA bases) was the same. So whether there were 17 pairs of chromosomes in the creeping vole, or 84 pairs in the black rhinoceros, they shared the same amount of chromosomal material. This was not the case in lower phylogenetic species. Ohno hypothesized that there had been successive doublings of the amount of chromosomal material over evolutionary time, and recognized that most of the DNA in higher organisms did not contain coding sequences. He collectively called these regions 'junk DNA' (Beutler, 2002). We have since realized that there must be an evolutionary reason for its existence, but the name stuck.

"Junk DNA *does* exist for a reason."

The term junk DNA is used nowadays to describe any DNA sequence that does not play a functional role in development, physiology, or some other organism-level capacity. However, junk DNA does exist for a reason. Highly repetitive DNA regions may play a role in gene regulation and chromosomal maintenance, while some transposable elements are thought to be remnants of defective viruses that now permanently reside in our genome (Palazzo & Gregory, 2014). A telomere is a special kind of repetitive nucleotide sequence found at each end of a chromatid that plays a role in protecting against degradation.

DNA polymerase, the enzyme that carries out DNA replication, can only synthesize new DNA in the 5' to 3' direction, so duplication cannot be carried out through the whole length of a chromosome. This is because in eukaryotic DNA replication, an RNA primer is required for each segment of DNA that is being replicated, so a primer cannot be placed at the very end. Thus, in each duplication, the end of the chromosome is shortened (Levy et. al., 1992). Telomeres therefore act as buffers to prevent genes from getting truncated. Over time, due to each cell division event, telomeres get shorter. Eukaryotic cells use the enzyme telomerase to elongate telomeres, but telomerase has not been detected in normal somatic cells. Therefore the typical response of cells to dysfunctional telomeres is to undergo a senescence growth arrest.

"In each duplication, the end of the chromosome is shortened."

Biologically, senescence is the phenomenon that occurs when telomeres reach a critically short length, and normal cells irreversibly stop multiplying and acquire a range of altered functions. Evidence suggests that the senescence response evolved as a failsafe mechanism to prevent proliferation of tumor cells, because as telomeres shorten, the chance that an actual gene may get truncated or mutated increases exponentially (Kim et. al., 2002). Therefore it is advantageous to halt the proliferation of these compromised cells rather than risk the multiplication of damaged cells. As senescent cells accumulate, their altered cellular functions may disrupt the surrounding tissue microenvironment crucial for suppressing the growth of oncogenic cells (cells with mutations in genes that have the potential to cause cancer).

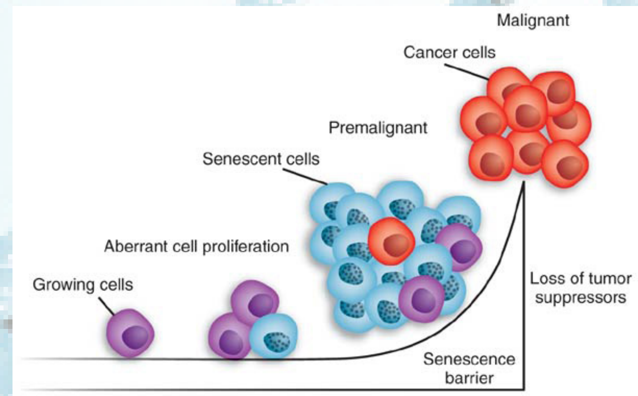

Figure #1. Cells that pass the senescence barrier may transform into malignant cancer cells.

BSJ

Though telomerase activity can in theory compensate for short telomeres (which would reduce the amount of senescent cells, decreasing the likelihood of cancer), young healthy adults actually have very little telomerase activity (Buffstein, 2005). Even if we were one day able to take telomerase injections to keep our telomeres long and healthy, it turns out that, ironically, telomerase is more likely to promote cancer than suppress it (Kim et. al., 2002).

In an experiment measuring telomerase in mouse tissue compared with human tissue, somatic expression of telomerase was found to be higher in mice. When these values were standardized for differences in cell number, mice were found to be more cancer-prone than humans (Kim et. al., 2002). While telomerase expression itself doesn't cause a transformation, telomerase cooperates with potentially oncogenic changes to promote tumorigenesis, but "fixing" a cell that would have been senescent. A better understanding of telomerase function would suggest strategies for preventing cancer and other diseases, but as of now, it is clear that there is a definite link between telomere length and aging.

Generally, there are several theories that attempt to explain the phenomenon of aging. The evolutionary theory states that aging is a nonadaptive result of the declining power of natural selection to favor advantageous alleles, or to

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eliminate deleterious ones after sexual maturity. Mechanistic theories of aging attempt to illuminate processes involved in aging, implicating somatic decline with age. These include the rate of living theory, the telomere length theory, and others such as oxidative damage and membrane pacemaker theory (Buffstein, 2005). The hope, going forward, is that telomere length may serve as a biomarker of aging: a quantifiable parameter that reflects biological aging, and could potentially identify those at risk of age-related conditions and diseases (Mather et. al., 2011).

There are many issues in trying to extend the human lifespan, the most logical one being that the only ones who will be able to afford life-extending medicine or treatments are those who are already privileged. Others make more philosophical arguments, claiming that humans miss the essence of life by focusing on the preservation of their "ego" (Pijnenburg & Leget, 2007). Even so, attempts have been made to extend the lifespan of cells.

In 2007, a health maintenance program launched a natural product-derived telomerase activator, TA-65. Low levels of TA-65 moderately activated telomerase in keratinocytes, fibroblasts, and immune cells in culture. However, the most striking effects were the declines in the percentage of senescent cytotoxic T cells and natural killer cells at 6 and 12 months following the dosage. The protocol lengthened critically short telomeres and remodeled the relative proportions of circulating leukocytes towards a more "youthful" profile (Harley et. al., 2011).

Such studies have shown promising results, implying that not only drugs, but also lifestyle changes, may be able to maintain long telomeres. Once we understand how we can manipulate telomere length and telomerase to predict aging, it is only a matter of time before research elucidates our understanding of cancer and age-related disease.

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A Joint Interview with Professor Joonhong Ahn and Professor Cathryn Carson on Nuclear Waste Management: a Technical and Social Problem

By: Manraj Gill, Juwon Kim, Daniel Miller, Harshika Chowdhary, Kevin Nuckolls, Philippa McGuinness

Dr. Joonhong Ahn is a professor in the department of Nuclear Engineering and Dr. Cathryn Carson is an associate professor in the department of History at the University of California, Berkeley.

Professor Carson's interests in nuclear history and the relationship between scientists and non-scientists developed into a collaboration with Professor Ahn that led to the organization of an advanced summer school in social-scientific literacy. They have been working together to bridge the gap between society and engineers, a gap that was evident during the 2011 Fukushima-Daiichi nuclear disaster. In 2015, they published together, along with other experts of nuclear engineering and education,* "Reflections on the Fukushima Daiichi Nuclear Accident: Toward social-scientific literacy and engineering resilience" *depicting various accounts of what transpired in leading up to and in response to the event.

We got the opportunity to talk with both of them in a joint interview discussing topics ranging from technical aspects of nuclear waste and energy to the challenges surrounding the lack of communication between society and engineers.

Berkeley Scientific Journal: How did you involved in your field of research?

Professor Joonhong Ahn: I became interested in the field of radioactive waste management at the beginning of my career. I thought that nuclear power utilization was a crucial issue that needed further research in any country. Just like nuclear fusion, in the 1970s and the 1980s, people said that at the turn of the century we would solve this issue. I started my career around the 1980s, so I thought that would be the best topic for me to tackle because around the middle of my career I expected to see major accomplishments in this field! The issue of nuclear energy is socially very important and technically very challenging, so I thought, "Why not?" The turn of the century actually [happened to be the beginning] of [a lot of advances in the field] which was good for me as well!

Figure 1. Professor Joonhong Ahn teaches courses in radioactive waste management and the nuclear fuel cycle at Berkeley.

BSJ: You mentioned that you were interested in nuclear energy at the beginning of your career. How were you exposed to this field?

JA: I read a book for the general public about nuclear power utilization when I was in high school. I was fascinated by the fact that the nuclear waste issue was not solved or even considered at that time, so I knew that was what I wanted to pursue.

Professor Cathryn Carson: I didn't really get to know Professor Ahn until 2007-08. I was given a year off by the history department to sit in on courses in nuclear engineering as I had a long term history research project on the specialty of nuclear engineering waste management that Professor Ahn was working on. I was in a lot of his classes asking lots of non-technical questions because, for me, nuclear engineering was a perfect example of a problem that was both technical and social at the same time.

CC: I also found it wonderful to have a professor of nuclear engineering who understood where those questions were coming from and why they mattered. I was supposed to be in there learning the technical stuff, which was useful to me as a historian of nuclear waste. However, it was just a pleasure to get to know Professor Ahn and realize that we could have a conversation across the disciplines on the basis of both a shared interest in his technical specialty and these larger societal questions of how nuclear power fits in in our future.

BSJ: How did you get started on your current collaboration?

CC: As a historian of science, I'm interested in how our thinking of problems can radically change. Back in the 1950s when nuclear waste first became an issue, people were thinking it was a simple problem and by the time I started getting interested, in around 2000, it was a much more complex problem. As a historian, I want to understand how that sense of what makes it complicated changed and getting to know what it looks like now is really important for that.

Figure 2. Professor Carson has been interested in a broad array of topics at the intersection of science, government, philosophy and history.

I can't recall how it was that Professor Ahn drew me into the University of Tokyo and Berkeley collaboration which led over several years to the summer schools he organized. It was just an amazing experience for me to work not just with nuclear engineers around Fukushima but with Professor Ahn, in particular, given the unique position he plays in that debate.

Figure 3. The tsunami from the March 2011 9.0 earthquake led to a nuclear meltdown at the Fukushima Nuclear Power Plant.

BSJ: After an accident like the Fukushima-Daiichi nuclear disaster, what do the societal aspects of recovery entail?

CC: Understanding that there are both technical and societal aspects is key. The effects on people are not just due to exposure from radiation but also from being evacuated from their homes. People died from evacuation, not just from the accident. The uprooting and the emotional upheaval from having their social network destroyed, having their relationships to their homes completely ripped out, being in a state of fear and dislocation for months at a time… All of those societal aspects are so important to understanding the Fukushima-Daiichi accident even though they don't get counted in casualties.

JA: The costs are enormous. Already \$100 billion has been spent for the recovery and more money will be put into that region with the hope that the region will recover from the accident. However, before the accident the total GDP of the area was not very large. This has caused the public opinion to be split – "Why are we spending such a large amount of money for just that region? Even if they fully recover, the economic benefits will not be that great. So rather than trying to recover the same lives as before why don't we just relocate those people and let them start a different life?"

BSJ: What exactly was the time period for recovery?

JA: That's a good question, nobody knows yet. I think this is going to be long term damage, so we won't see an endpoint in the near future. For TEPCO (Tokyo Electric Power Company), it is very likely it will take more than half a century, at least, for the decommissioning of the damaged reactors. For people, there isn't enough time for them to fully recover. It depends on how you define recovery and how you define damage. We'll have a workshop next week and some philosopher participating in that workshop submitted a paper to me where, interestingly, he said there is only damage when someone claims there is damage.

BSJ: From an engineering perspective, how would you counter a delayed response to a nuclear accident?

JA: A hundred thousand people are still evacuated from their homes and would like to go back. So, decisions have to be made as soon as possible. However, because of complex societal discussions compounded by some scientific uncertainties decisions simply couldn't be made in a timely manner.

BSJ: How can we measure the harmfulness of nuclear radiation to humans? How are different types of exposure considered in determining the malignance of nuclear radiation?

JA: If the radiation level is very high we can measure the effects very precisely, and there is very good regulation based on that measurement. If radiation levels are lower, more specifically 100 milli-Sieverts or lower, the effects are not so clear and the uncertainty becomes bigger. The uncertainty is so significant that you cannot draw a decisive relation between the amount of radiation you are exposed to and the negative effects it causes.

Currently there are various hypotheses. Some say that within a range of low radiation levels, there are actually positive effects on the human body. For example, you can invigorate cell activities which make you healthier than without radiation. Others say that the low dose range is the same as higher doses. Under this hypothesis, you can extrapolate the line established for a dose greater than 100 milli-Sieverts into the lower range and to zero. Some say it is more complicated, so it is a mistake to say the relationship is linear. We should also be aware that, in some regions, like India or Iran, the natural radiation levels are very high. Radiation levels in these regions can be 50-100 times higher than in the United States.

BSJ: What contributes to these high natural radiation levels?

JA: Naturally occurring radioactive materials, such as uranium in granite and potassium in salt. In fact, salt is the major contributor of natural radiation. People have been living in high radiation dose areas for many years. Many research organizations have been to those areas and conducted epidemiological studies and have not found any viable differences between populations from those areas and other reference populations. This serves as evidence for the idea that certain levels of radiation have low biological effects. Indeed, some researchers have claimed that this high natural radiation has some positive effects as well. It is an uncertain situation.

I do not think that problem will be solved purely scientifically because the lower the dose the more subtle the effects. In order to have a statistically decisive conclusion regarding the effects of low dose radiation you need a huge sample size; a statistically reliable sample size could be greater than the population of the world! Even though you know how to prove something scientifically, you cannot prove it practically. This is known as a trans-scientific problem. A problem can be defined scientifically but the solution requires more than just scientific knowledge. Maybe in the future molecular biologists will find a more mechanistic way and better modeling systems to approach this problem. Even so, we have many different factors affecting the low dose radiation effects.

BSJ: Back to the idea of responding to a nuclear disaster, the desire is for 'strategic prioritization', the ideal that there should be a threshold which should determine the action that you should take from a waste containment point of view. How exactly do you come up with this model and determine the thresholds?

JA: I think there are two sides. The first is the technological prioritization. Prioritization should be made to decrease the volume of waste to be generated from the decontamination activities. For the reduction of waste generation, technology is certainly very helpful, but it has to be applied in the right place and in the right way. That is what I meant by prioritization. Then, how do we know where is the right place to apply technology? That can be determined with the help of environmental sciences, i.e., how cesium migrates through the environment, and so on. For that, we already have some knowledge but it is not complete [and] we have to improve it.

The second is societal aspect. The social side should be described by Professor Carson! But what I see is that even if you have a technology, you cannot apply that technology if you do not have a public agreement. Often, the question of "right place" or even "right way" is answered societally. Right now it seems to me that the local people have not reached an agreement for whether this decontamination is necessary or which part should be done first.

BSJ: From a quantitative point of view, would you want a fixed definition of this threshold? Is this the right way of convincing other participants in the community?

JA: That is definitely part of the process. Without technology, there is no way of convincing people. But on the other hand, even if you have the technology and perfect knowledge of cesium behavior, that's not enough.

CC: I want to underline this point so that you don't miss it. It's one of the most powerful things Professor Ahn has said to the nuclear engineering community. Having the engineering solution alone and trying to persuade the public of it is not the way forward. Understanding what the engineering options are is a part of it. But you need societal input, communication from society to engineering, not just from engineering to society. If you don't have listening on the part of engineers your solution is not going to work.

BSJ: In your chapter you define this situation as "socio-technical system"…

CC: A socio-technical system is a technology in its societal setting. You can't imagine a technology, such as radiation technology, without a society around it. That jargon doesn't work with engineers, but the concept is exactly what Professor Ahn is helping to articulate. Yes, you must have the technology, but if you want it to work you can't forget about the society around it.

BSJ: How did an accident like Fukushima Daiichi highlight the importance of work between both engineers and society?

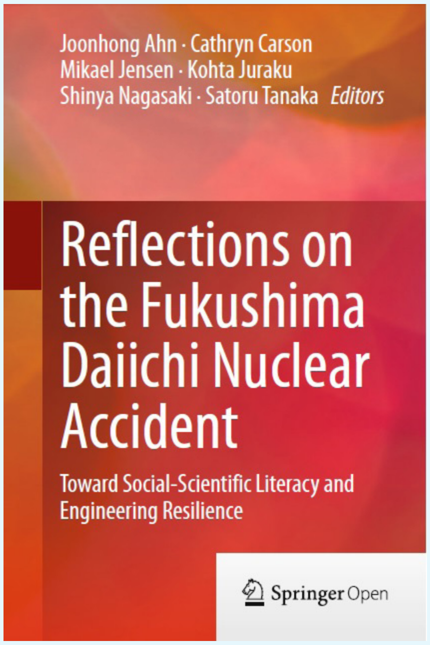

Figure 4. In the book (see introduction) that Professors Ahn and Carson co-edited, the importance of the idea of integrating social-scientific literacy in nuclear engineering education is highlighted in the post-Fukushima era.

JA: Nuclear engineers try to invent something interesting or powerful, and tend to realize it regardless of what society thinks about it. I think that the beginning the Manhattan project was like that. The nuclear bomb was so powerful that nobody would actually object to it, not at the time. So we tend to think that if we invent something we think to be good, it will be good for society and that should be realized.

I think that is applicable for the nuclear reactor. But for waste issues, this is no longer applicable. One technology can satisfy part of society, but not the rest. We need some mechanism to sense what the agreeable solution is. For other industries, I think the market has been the mechanism to know what is best accepted. However, the market doesn't really function like this for nuclear technology. But people are becoming more sensitive about impacts on themselves, and values are more diverse within society and across countries than before. We cannot simply select or impose one technology on the entire society. We need some mechanism to know what is most agreeable, and that is why solving this waste disposal issue has taken so long.

BSJ: You mention in your book that both social scientists and engineers feel powerless. What do you think leads to that sense of powerlessness in both groups?

CC: That's an interesting question. I think it's different for each case. It was amazing to me to realize that engineers felt powerless! I had always imagined that they were powerful, because they could invent and then impose technologies. At least that's how I saw it. It startled me to learn that they felt that there were so many societal obstacles to realizing what they thought was right. So the feeling of powerlessness for engineers is not knowing how to work with a society that doesn't behave like a bunch of engineers.

Society has other criteria, other forms of decision making which are very different from that of the engineering profession. So, in that case, the powerlessness is where society is complex. Engineering teaches you to make problems solvable, and many societal problems are not solvable like they are in engineering. For social scientists, the powerlessness is much more about the challenges for social scientists to offer clear solutions to anything explicitly and exactly because society is complex.

Social scientists often come in and say "This is too complex to solve', which is the exact opposite of what the engineers want to hear. Social scientists are very used to engineers telling them "Go away, you're not helpful." Social scientists and engineers can be like oil and water when you mix them.

BSJ: From what you've said it sounds like the two disciplines can't be reconciled because their mindsets are so fundamentally different. You did, however, attempt to bridge this gap. How did that turn out?

CC: They don't seem to be totally unbridgeable if you look empirically (*looking over to Professor Ahn*)! We don't think alike, but I think we've both moved a bit closer towards the other. It takes acknowledging, either as a social scientist or as an engineer, that your way of tackling a problem is not the only one and you may have to change. That's as hard for me as a social scientist as it is for the engineers that Professor Ahn works among.

I have to find a way to be helpful, because otherwise there is no partnership. If I just say "Oh no, can't do it that way!" that is not respectful of their expertise and it is not helpful in moving things forward. So, in my case, I've found my way to be helpful: not by proposing solutions but by listening, by educating, and by being there for students. I don't know how to solve the problems that Professor Ahn is tackling, but I do know how to help engineers get more clarity for themselves about the character of the problem.

BSJ: And Professor Ahn, how did you get closer to bridging the gaps with social scientists?

JA: : Let me give you two episodes. I had a very interesting discussion with one of the authors here, a Japanese sociologist. After the accident many sociologists wrote books about the accident, criticizing how silly nuclear engineers were. Particularly, some of them pointed out that the way the company managed the regulatory system was bad. In comparison, years ago a seismologist pointed out that there was a big earthquake there about 1000 years ago. The major difference is that the seismologist pointed out the fact before the accident happened, and sociologists pointed out theirs after the accident happened.

So you can criticize us, but why don't you do it before the accident happens so we can change! I could not get any clear answer from sociologists for that part… I'm not criticizing sociologists! I'm just pointing out the difference in how we consider the same things.

The second is related to rationality. We had a long discussion amongst students in the summer school about rationality. Nuclear engineering students have very clear and stiff ideas about what is rational. It is rational to have nuclear power in a country and continue it because it is good for reducing carbon dioxide emission, which is good for energy independence, etc. They have all kinds of reasons for why they think that nuclear power is very rational. They brought their idea of rationality to this discussion with non-nuclear engineering students, and immediately got an objection from other students. So we had a very interesting discussion. I think some nuclear engineering students started to think of rationality in a very different way than they had before the accident. I'm sure that is going to affect their design in the future which makes me optimistic.

BSJ: Outside of nuclear accidents, how do you think engineers get a better understanding of the social aspect of nuclear engineering, and how does that affect how they manage nuclear waste?

JA: I think this accident should affect the way we design everything. The reactor, the fuel, and the waste disposal. The paradigm for safety has been fundamentally questioned by this accident. Nuclear engineers have to consider the social aspects and the safety more fundamentally.

Traditionally, the nuclear safety has been established based on the concept of defense in depth with 5 levels of defense to protect people from negative consequences of accidents. Very simply, levels 1 to 4 are about hardcore nuclear engineering. So, if you do better in design, you can improve the defense at these four levels. But the 5th level is about mitigation, evacuation and recovery from the severe accident. And that is more fundamentally related to societal factors. But because we have a mindset that the nuclear accident would never happen by improving defense between levels 1 and 4, number 5 has been severely overlooked.

But now we have had at least 3 major accidents in the past! And very clearly, we will have accidents in the future. We just don't know the where and when. So, I think that we now have to address this level 5 defense very seriously. That is the integration of engineering and social sciences. While we don't know now what to do and how to do it, that's something we have to develop [very quickly and in the near future].

BSJ: How is waste from nuclear reactors typically created and then dealt with in a safe manner?

JA: Well, the nuclear waste is generated from various stages of nuclear power utilization. But 99% of radioactivity is included in the spent nuclear fuel after irradiation in the reactor. And for that, we have options of either reprocessing or not reprocessing, depending on how we utilize those irradiated fuels. At the end of utilization, we will have to make a final disposal to make sure that the future generations do not get any significant harm. That's the basic objective of having geological disposal. Negative harm includes radiological effects and also economic effects. If you just carry over the treatment and management to future generations, even though the future generations do not get any benefit from this nuclear power, they have to pay some cost to deal with it.

To avoid that situation, the idea of geological disposal was established. With the geological deposal, we think that the negative effects on human beings will be made negligible.

BSJ: What kind of timescales are we talking about in regards to these future generations?

JA: We are talking tens of thousands of years and even millions of years.

BSJ: So, they probably have to be quite deep?

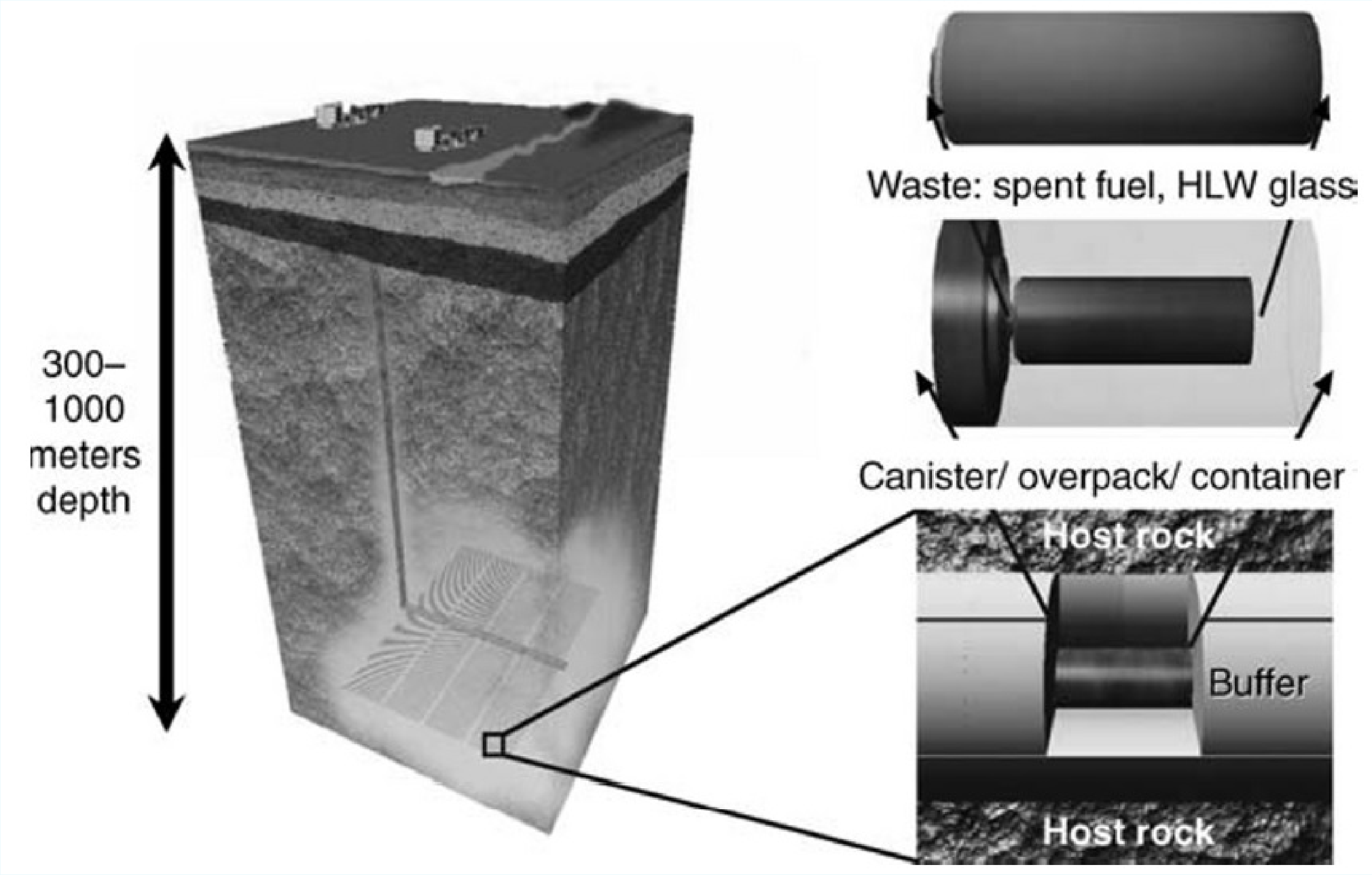

Figure 5. Illustration of a deep geological repository system consisting of various levels of barriers

JA: Yes, very deep! Many repository designs available adopt a depth of a few hundred to thousand meters.

BSJ: We read about the implementation of the Archimedes filter. What is the basic principle behind using this filter in nuclear reactors?

JA: The Archimedes filter was developed for the treatment of harmful wastes generated from the past weapons production activities. I like the idea very much… it is a separation process based on physical process and not chemical process! It's very interesting and probably very effective if it is applied in the right place and in the right application. I understand the DOE (Department of Energy) decided not to use it. The company was resolved some time ago, and the technology was transferred to some other company. So, some day in the future it would be utilized. [But] in principle, it is a very interesting idea!

BSJ: There's the idea that there are issues of establishing trust between nuclear engineers and the general public. What kind of steps have been taken to improve this trust and have they been effective? And what do you think can still be done to improve this situation?

JA: Nuclear engineers took traditionally the so-called 'Decide, Announce and Defend' (DAD) approach and it had been working but not anymore. Particularly, in the back-end fuel cycle issues. Some countries are trying to take into account more participatory processes. But, I've been wondering the following:

The processes taken in this country for the development of the Yucca Mountain Repository followed the due process. In a democratic society, if the President and Congress agree, then that's the reflection of public opinion! But it was turned around by a different President later on. So, democracy and addressing public opinion seems to be different. The decision process isn't just a political process. But more complicated. I don't know how different they are and why they are different.

BSJ: What do you think, then, can be taken towards this?

CC: I think there are two steps that can be worked on. One is, given that societal decision making is more complex that getting a political decision from the President or Congress and given that empirically having a law come out of Congress is not enough, the nuclear engineering profession needs to find ways to work with society that don't simply involve lobbying Congress and lobbying the executive branch. And that involves a different relationship to the larger public. Whether that's a voting public or an opinion public.

So, that entails a mode of communication that is much less about, "We know the truth and you should accept it," and towards engaging in dialogue with the public. Now, that's very easy to say but hard to do in practice. But I think you have seen some shifts in that. Particularly, in the aftermath of the Fukushima-Daiichi accident. In part, Professor Ahn has done that by modelling a different way of engaging with the public: not just working within the political power structure but being available for public lectures and going to schools. And not simply saying, "I know the truth," but being open to conversation.

So that's one part of it, changing modes of behavior. The other is educating nuclear engineering students to realize that they are going to be working in a world where the problems are as much social as they are technical. It's in the nature of the technology. It is part of being a nuclear engineer post-Fukushima.

BSJ: What would you say is the role of the regulatory agencies for nuclear waste management both from the technical and social standpoint?

JA: I think the Nuclear Regulatory Commission of the United States has been doing a good job. It is not a matter of regulation. I think it is a matter of making decisions beyond regulation. Regulation gives a guarantee that this is a safe action. As far as those facilities are complying with those regulatory guidelines, the facilities are safe, meaning adding negligible impacts on public health. But once you know that it is a safe action, it's not a sufficient condition to start some project. You have to satisfy many other conditions. For example, there must be some clearly understood objective for achieving some project, and it seems to me that, for geological disposal, people don't have a good agreement or understanding about what they want to achieve through it.

BSJ: Education for engineers would helps them factor these social aspects into the implementations that they propose. But do you think that in terms computations like strategic prioritization, these aspects can be directly factored into these models that they have? Or is it more of the broader mindset?

CC: It's more of an attitude. It's less "Here's a piece to stick into your model" and more an attitude of "You want to be thinking about this" and "You will want to learn how to do that kind of thinking and engaging." It will be different in every case, but it has been really inspiring to watch how the graduate students who you have brought through this process have now realized that. Though there is no plug-in to the engineering solution, there is a set of behaviors and mindsets that they take away from it.

It's not disconnected from engineering ethics, it is a substantive form of engineering ethics. Engineering ethics that is not about checking off the requirement but actually about understanding yourself as a human actor with responsibility to the people you're serving. And that really is the educational transformation that can get worked here.

JA: So actually, after the accident, many Japanese universities tried to incorporate such social scientific aspects in their nuclear engineering programs. Several universities in Japan have gotten a lot of grants from the minister of education of the Japanese government to realize this goal. They have started comprehensive education programs for graduate students, including social sciences, multiple foreign languages, humanities, and philosophy, in addition to the core nuclear engineering curriculum. But without the attitude that Professor Carson mentioned, it can easily be very much formal and superficial. They can remain the same old nuclear engineers while coping with this on a superficial level.

BSJ: So, where do you see your individual and your collaborative research going in the future?

JA: That's exactly what we are trying to find in the workshop next week! We are trying to find research questions and a research plan. The ideas have emerged from the observations and discussions made in the book because if you read it, you may notice that all these questions are open-ended. No questions were answered in the book!

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Layout by Jingting Wu

BSJ

An Interview with Professor Alexandra von Meier on an Efficient Electric Grid: Improving Visibility and Integrating Renewable Sources

By: Manraj Gill, Saavan Patel, Harshika Chowdhary, Daniel Miller, Philippa McGuinness

Dr. Alexandra von Meier is an adjunct associate professor in the department of Electrical Engineering and Computer Science at the University of California at Berkeley and is co-director of the electric grid program of the California Institute for Energy and Environment (CIEE). Her interest in electric energy spans from making distribution systems more efficient to improving the integration of renewable energy sources into the electric grid. We got the opportunity to talk with Dr. von Meier about her passion for energy, the current and future power distribution grids, micro-synchrophasor technology and the challenges with optimizing the incorporation of renewable energy into the pre-existing system.

Figure 1. Professor Alexandra von Meier teaches courses in electric power systems at UC Berkeley.

Berkeley Scientific Journal: How do you find yourself here, in this research field?

Professor Alexandra von Meier: I was a physics major as an undergraduate at Berkeley. Then I taught high school physics and chemistry for two years. I came back here and as a master's and PhD student in energy and resources here at UC Berkeley. Then I did a postdoc in electrical engineering here with Felix Wu, during which time I started writing a textbook, which has done pretty well. The book is called "Electric Power Systems." It's a little atypical as an engineering text. The idea [with the book] was to teach people who are interested in energy and electricity but who don't have an electrical engineering background about essentially how the system works. Not dumbing it down, but not starting with a bunch of phasor diagrams that would be immediately unintelligible. So, the goal was to write something that would qualitatively explain what's happening and what are the constraints when you're operating the electric grid. That was a labor of love, and I started it during my postdoc.

Then I did another postdoc in nuclear engineering, also at Berkeley. I studied plutonium, in the context of nuclear materials management: what to do with spent fuel from nuclear reactors and what to do with plutonium that comes out of dismantled nuclear warheads. Long story, but then I got a job as a professor at Sonoma State University where I taught in the Environmental Studies and Planning Department. I taught energy management and design. This is a wonderful program, where I was for about twelve years, and taught a curriculum that's really pretty unique. It spans renewable energy, energy efficiency, green building. It's not really an engineering program, but it's quite technical and quantitative so it

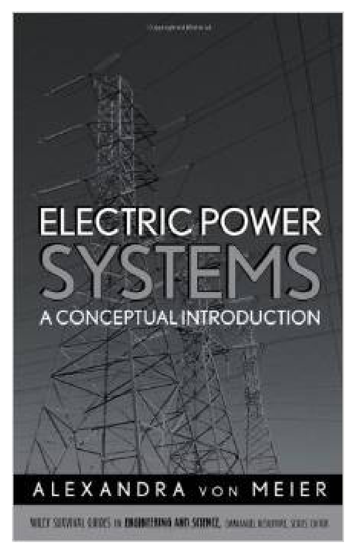

Figure 2. Professor von Meier's book, "Electric Power Systems: A Conceptual Introduction," is used in her 'Introduction to Electric Power Systems' at Berkeley.

enables students who graduate from it to have a really intelligent conversation with an engineer about such things as solar power, wind power, passive solar building.

Then I came back in 2010 to work part time here at CIEE. One reason for that was personal, that I wanted to move back into the Bay Area, and another reason was my interest in doing active research, which is hard to do within the California State University system where you have a big teaching load. And there wasn't really so much of a critical mass of electric power researchers. So I came here to refocus on the electric grid. So now I'm full time here, split between CIEE and the EECS department.

BSJ: When you first went after teaching two years in high school, why did you want to go into energy and power?

AvM: You know, I had actually decided at a really early age that I was interested in energy. In 1979, there was a big accident here in the United States at a nuclear reactor, Three Mile Island. And this made big headlines in Germany, where I was living. There was a big anti-nuclear movement. I was fourteen at the time, but I was really interested in this. People were starting to talk about solar energy as an alternative and I sort of had this idea of, "Oh I want to be an energy expert when I grow up." But there wasn't really an established career path for that, so I actually was going to be a chemistry major. But then I became a physics major…

I took two classes from John Holdren in energy and resources while I was an undergraduate here. John Holdren, who's one of the founders of the Energy and Resources Group here at Berkeley and is now President Obama's Science Advisor, taught ER100-200, Energy and Society, and he taught ER102, which is Quantitative Methods in Global Environmental Issues, and those classes blew my mind! I was like, "This is so cool! This is exactly what I want to study!" So I decided that I wanted to come back to grad school. I was really lucky to get a job teaching at a private high school without having a teaching credential [and it was] a great experience, so then I was ready [to come back for graduate school].

I always knew that I was fond of energy, that I had a passion for it. It was pretty clear that there's a need for finishing up with this whole era of fossil fuels as the mainstay of our energy supply. So, [there's need for] doing something different. And there are a lot of interesting puzzles about how do we do something different. How do we organize ourselves technically and socially around using different energy sources? Because energy touches every aspect of our life. It's really impossible to analyze in isolation.

BSJ: What would you say are some of the problems within the existing power grid today?

AvM: The most fundamental problem is that we're burning fossil fuels for energy. And we can't do that in the long run because we cannot keep taking carbon out of the ground and put it into circulation in the atmosphere, where it will change our climate in a way that will be catastrophic if we keep going. So, the big problem with the electricity grid is that while it's working ok right now, it is working ok with the help of fossil fuel resources. There are some challenges with maintaining very high reliability under all kinds of scenarios. We can improve the robustness and the resilience of the grid to be able to reliably provide high quality electricity to everyone.

The big driver in my mind is that we need to address those technical challenges while primarily addressing the question of how do we make the electricity and how do we get away from the fossil fuel sources. It turns out that some of the most obvious and economical replacements, the sustainable and affordable replacements, are really solar and wind power. Of which we have, for all practical purposes, unlimited resources. It's about where is it, how do we convert it efficiently, how do we transmit it efficiently, and then the big challenge is how do we coordinate the timing because you can't decide when the sun shines and when the wind blows.

Figure 3. Variability in the span of a day in the energy that is generated from wind farms

There are basically three approaches to addressing this variability or intermittency of solar and wind resources.

The first one, which has been our standard strategy ever since [we have had the electric grid, the last 100 years], is: Whenever there is a mismatch between generation and demand, you call on some reserve power plant and you say, "Turn up the knob, give us some more megawatts. Make it equal, make demand and supply equal." Those are called dispatchable power plants. Mostly they're dispatchable because they're burning fuel. So, they have in their backyard a big storage pile of coal, or a pipeline of gas. They have chemical fuel storage essentially. They can make electricity whenever we want. If we start to have less of that, then we have really a shortage of generation resources that can step in and compensate for the intermittence.

The second strategy is to use energy storage. There's a whole field of research on different storage technologies, and the question of the economics, and the control strategies and the coordination for storage – that is, for storing electric energy while the wind is blowing and then using it at another time. And right now, we're actually implementing a pretty aggressive program on building storage, electric storage, in the state of California. But it's not something that will happen right now just on the basis of economic incentives. There's a little bit of help because we think strategically this is a good idea. But if you're just comparing the price of electricity during high and low demand hours, the difference in itself, buying low and selling high, isn't quite enough to justify the expense of installing a huge battery plant.

Now, the third approach to mitigating this variability is to have intelligent, responsive demand. And that's what a lot of people on campus are working on. It encompasses a range of techniques for saying, "How can we use more or less electricity at particular times that doesn't really inconvenience people or make them terribly uncomfortable?" For example, have your air conditioner or water heater kick in at slightly different times or have some delay. This is the area of intelligent loads and demand responses.

So, you kind of have these three strategies for addressing the intermittence.

To do all this well, one big challenge is having visibility and situational awareness of how exactly power is flowing in the electric grid. My research is centered on techniques for measuring and observing what is going on electrically on the grid, so that we can operate intelligently and reliably, and so that we can make use of the resources that are called distributed resources, whether it's rooftop solar or smart water heaters or community scale batteries. These distributed resources can be coordinated and integrated in an intelligent way.

To do that, I believe it's necessary to have a good visibility of the electrical conditions on the wires. There are constraints right now that aren't exactly noticeable. For example, your utility company doesn't really know the voltage! They know it's supposed to be within some range, some nominal value plus or minus 5%, but they don't have a good way of knowing in real time about who is close to violating that. So, if you're integrating more solar and you might have reverse power flow and might be violating some of those constraints, you can feel a lot better about integrating these distributed resources if you have better visibility! That goes for real and reactive power flow and voltages. And the project that I've been working with, the micro-synchrophasors (μPMUs), that's a really advanced way to look at the power distribution system and be able to have visibility of what's going on.

BSJ: Regarding this data collection through micro-synchrophasors, how exactly do you use the data? What can you then tell the power supplier?

AvM: For example, one of the things is that you want to manage is the voltage on a distribution circuit. You would want to include the rooftop solar into this. Really, it's the inverter which is the gadget that sits between the DC (direct current) solar panel and AC (alternating current) grid that has the brains to respond. Now the inverter can do two things. It can inject real power to the grid or it can inject what we know in electrical engineering as "reactive power" into the grid. Reactive power is a phenomenon that has to do with the relative timing between AC voltage and current. It's not a real energy transfer on average, but reflects a kind of circulating energy. So a smart inverter can adjust the power factor and inject different amounts of reactive power. We would like to know what the right amount of real and reactive power that the inverter should be injecting at a particular time is. So as to [not only] optimize the resource use but also the voltage profile.

Our hypothesis it that by having a very precise measurement of the voltage phasor along the distribution system, which includes information not only about the magnitude of the voltage but also the timing, will allow the inverter to make better informed decisions. For instance, you can avoid situations that would be very inefficient or maybe you're maintaining the voltage within bounds but by having relatively high real and reactive power flow in opposite directions which leads to large losses. Our work focuses on specifically identifying the operating states to make the best decision with regard to what you're demanding from your resources.

BSJ: Do you see there is a lack of efficiency currently due to a lack of data? And where is this problem most profound?

AvM: Well, I think many observers of the electric power industry would say that the most pressing issue is reliability and not having data about the operating state. Not having observability of the grid makes you more vulnerable and exposes you to more risks of power outages and makes it longer to restore services to customers. Some of the work in recent years has focused on just getting the data from smart meters to help utilities bring back service quickly.

For the electric utility companies, they feel this pressure where their performance is being evaluated: "How many minutes or hours are the customers out of power?" In my mind, the question that is just as important is: "What exactly is the hosting capacity for renewable resources?"

This capacity is measuring how much solar we can get away with in a neighborhood on a particular circuit serving some thousands of houses. Think of this area being served by a network of transformers and infrastructure and there is a limit to how much solar can be installed without creating a threat of violating constraints of the infrastructure. Reverse power flow can confuse the protection systems

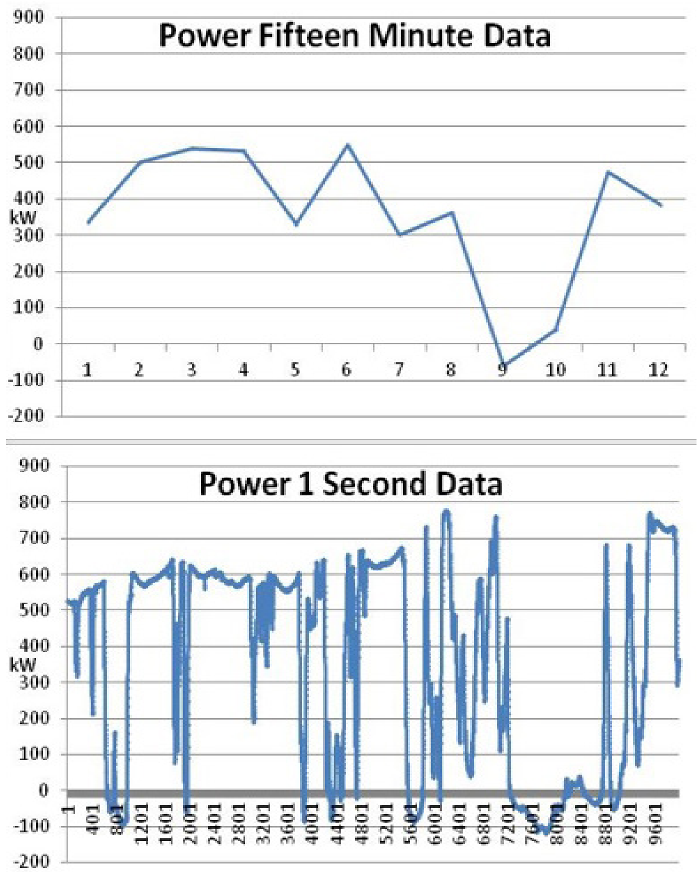

Figure 4. Portraying the variability in a distribution system that is lost in the absence of real time data.

(fusers and circuit breakers). There's a very delicate coordination among the protection devices. The topology of the network is a very subtle system. The protection system can be confused through power flowing in the reverse direction. This is because everything was designed decades ago with [one-way flow], from the power plant to the customer. The reverse power flow is one concern and then the voltage limits are another. In order to be on the safe side and not have violations, that would then maybe cause problems, there are rules how much solar could be hosted on a particular distribution circuit. One number that's been worked with is 15% as the maximum. There are revisions but it gives you the sense that you want to be a little cautious.

So, there are conservative rules about these hosting capacities. I want these hosting capacities to be dramatically increased! Because if people are willing to pay money to put solar on their roof tops, we should be encouraging that! That's great and all this helps us avoid burning fossil fuels. But the visibility is really a crucial piece of the infrastructure. It would help us get rid of the constraints that are currently in place regarding what is allowed. If people are eager to put them on their houses, then it's too bad if we have to restrict it!

BSJ: How [does the information from the micro-synchrophasors help] protect the grid from the reverse flow? [How would it ensure] that integration of renewable energy is smooth?

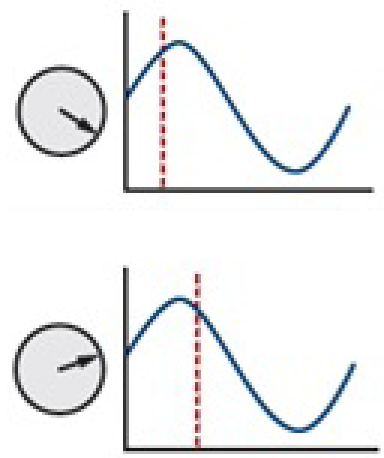

Figure 5. Phase angle (ϕ) differences.

AvM: Let's go into the actual math a little bit. In an AC system, it's really an alternating voltage. To a first approximation, we imagine this sine wave and if you just look at the voltage from your outlet, then it goes from positive to negative sixty times a second. 120V might be the root-mean-square value. But we imagine that, to a first approximation, as being exactly synchronous across everywhere across the western United States which is connected as a "synchronous" AC network. When you learn about AC power flow through transmission lines, you realize that they're not exactly synchronous. For the power to be transmitted, there's actually a shift in the timing of the sine wave. It's not just $\sin(\omega \cdot t)$ but it is $\sin(\omega \cdot t + \phi)$. And that phase angle ($\phi$) of the voltage is actually a state variable. There are two state variables: voltage magnitude and phase angle. So, if you know the angle at every node in the network, you have complete information about the state of power flow.

BSJ: And how small are these phase angle differences?

AvM: Very good question! If you are comparing phase angle differences across the transmission grid, between San Francisco and Seattle or San Francisco and LA, you might see tens of degrees. If you are looking at the angle differences in the distribution system, such as nearby locations, it'll be 1 degree, or 1/10th of a degree, or even less than that. Now, what do we mean by a degree? Well, 360 degrees = 1 cycle or 1/60th of a second. You can do the math, and very quickly when you're talking about fractions of a degree you're talking about microseconds rather than milliseconds.

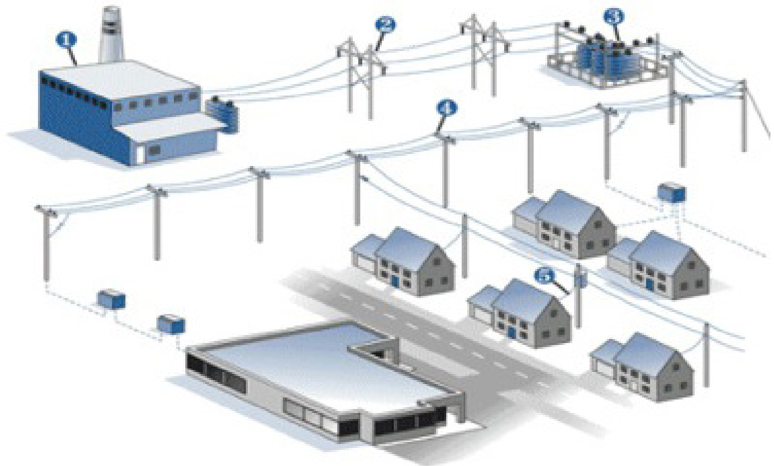

Figure 6. Micro-synchrophasors (µPMU's) at every node in a distribution grid

frequency and measuring the voltage phase angle difference and the voltage magnitude difference, you can get a picture of what the power flow looks like with relatively few measurements compared to all the other measurements you'd have to install conventionally. The hypothesis is that this gives you a more precise insight and that will be more economical.

So the micro-synchrophasors [are designed specifically] for the purpose of discerning these very small phase angle differences down to 1/100th of a degree. We've tested them in the lab to make sure they are precise and accurate. We've installed them on some of the distribution circuits on campus and the Lawrence Berkeley National Lab to observe actual phasor differences between locations. The differences are about what we'd expect, on the order of 10ths of degrees, with some small variations. Synchrophasors for transmission have been around for a few years and really in the last 10 years there has been an enormous increase in deployment and applications for making sense of the measurements. They've never had to be incredibly accurate; down to plus or minus a degree is perfectly fine if what you're looking at is big power oscillations across the western grid. These differences actually exist and are actually a threat to the reliability of the grid, making this a very important use case for synchrophasors: to detect these oscillations and to observe the stability of the network.

In this research project, we asked the question "Could there be a use case for looking at these phasor measurements at the distribution level?" Really, we didn't start with our minds made up, we didn't know if there would be practical value to it. There's a null hypothesis that says, "Maybe we could measure it, but so what? There's nothing useful in it." But we are beginning to see useful things that it tells you, and we have plans for a whole lot more research to really articulate which applications make the most sense.

One of the things we were able to do [was distinguish between] whether [a disturbance came from] the local distribution system or from the transmission system. There's also something really fundamental about measuring the voltage phasor, which is that you can get information about power flow on the network by measuring only voltage and not current. You can get information about power injection elsewhere, not just at your location. Between measuring the

BSJ: What are the current costs of implementing these micro synchrophasors, and how could these costs be reduced? Is cost as an issue?

AvM: Cost will definitely be an issue. But what's interesting is that in the world of electric utilities, the cost of the individual gadget might not be the decisive factor. So let's say each µPMU costs several thousand dollars, but what is the really decisive factor is how many person hours did you spend installing it and running all the wires safely where they have to go, and what else did you need to do get the data back to your computer where you can look at it. So the whole engineering of the monitoring system is a lot more than just the sensor device. For example, one thing that we're seeing in our measurements is that the accuracy of the voltage measurement depends on the transducer, that is, the potential or current transformer. That is the piece of equipment that sits between 12,000-volt piece of aluminum or copper and the 120-volt piece that you're actually touching with the sensor, that makes it safe to touch it. In the end, the transformer has some accuracy that is stamped on it like ± 0.3%. If you're trying to make an exquisitely accurate phasor measurement, that is affected by the accuracy of the instrument transformer. One of our research questions is [finding out to what extent you can] use the existing instrument transformers, and to what extent can you use the service transformer, which are also serving load, in between your µPMU and the primary distribution system you are actually trying to measure, and perhaps correct for the error with the right mathematical algorithm.

If you can just take the µPMU and plug it into the wall, then the deal is done! This is cheap, this is easy, and nothing competes with it! The challenge is how to measure the primary voltage, and you don't just go touching 12,000V, there's an expensive transformer in between. So, it comes down to how much can you take advantage of the instrument transformers that already exist and deal with the errors on the analytic side. That's a critical piece of the distribution monitoring problem.

BSJ: So would you say public policy and bureaucracy provide a hurdle to adoption of these new technologies?

Figure 7. µPMU concept (along with size reference) and implementation in the grid around Berkeley.

AvM: With these technologies, not really. The main reason these technologies have not been adopted yet, or haven't really been developed is that there hasn't been a need for it historically. There are sensing technologies that you can buy off the shelf, like really good voltmeters, but the reason they are not all over the place is that there's never been a need to track how this system is behaving. That's what is really changing. What's different today is that we're interested in the time series behavior of distribution systems, and we're interested in two-directional flow, and we're interested in controlling things actively. If we want to make intelligent decisions, we need better information. This is a completely new set of circumstances that have never existed.

BSJ: In future, 20-30 years from now, what do you want the smart grid to look like?

AvM: We will want to use our distributed resources during times of disturbance or crisis, like a big storm. In a situation like Hurricane Sandy, if some major interruption happened in a place where you have a lot of rooftop solar panels installed and the power is out for some number of days, people are going to start asking the question, "How come I cannot use the power I have on my roof right now?"

By code, solar panels are required to be shut off safely when there is a power outage in the neighborhood. What people are going to want to do is to use those local resources in a standalone mode, which is known as "intentional islanding." Operating power islands safely requires some technical changes in what is in the infrastructure now because you have to balance generation and demand on your island. You need knobs that you can turn up or down so that the load and generation match each other. This may require storage, but in any case a coordination task needs to happen. The process of opening and closing the switch at the point of common coupling, or the connection between the power island and the mainland, is also a challenge. For AC, you need to match the frequency and the phase angle of the voltage before you close the switch, otherwise you damage things. This is an area where I think the µPMUs are going to be very helpful.

I envision we will have pieces of the electric grid that are capable of operating as power islands by themselves, but also seamlessly connect with each other or the backbone of the transmission grid for the purpose of sharing and getting good deals on bulk energy. The transmission system is good for importing less expensive energy from far away. We do not want to do away with the transmission system, but I think we want to become less dependent on it. Power quality and reliability will be provided more locally and allow us to have a grid that is more flexible. The topology can change and you can have small connected pockets that can mix and match as conditions demand in the future.

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Layout by Jingting Wu

An Afternoon with Professor Hermanowicz: Exploring Sustainability and Water Filtration

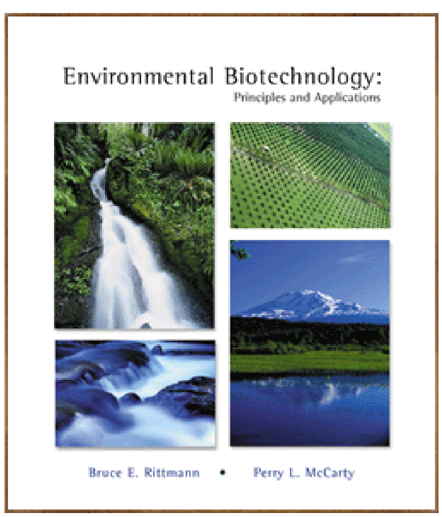
By: Harshika Chowdhary, Luis Castro, Phillipa McGuinness, Juwon Kim, Saavan Patel, Kevin Nuckolls, and Manraj Gill.

BSJ had the distinct pleasure and honor of interviewing Dr. Slav Hermanowicz. Dr. Slav Hermanowicz is an Environmental Engineering professor at the University of California Berkeley. His research focuses on the process of water quality treatment so that wastewater can be reused. Another aspect of Dr. Hermanowicz's research is centered on improving the quality of stored water. In this interview, Dr. Hermanowicz talks about the process of wastewater filtration and how filtration techniques have changed over time. He also discusses the implications of environmental engineering and what constitutes sustainability. BSJ thanks Dr. Hermanowicz for his time.

B S J

Berkeley Scientific Journal: How did you get involved in your field of research?

Professor Hermanowicz: To give you a background, I was born and brought up in Poland. I also went to college there. The focus of environmental engineering was a little bit different than what it is today. At that time, environmental engineering was focused on public health, on providing safe water, sanitation, and cleaning the aquatic environment. The focus was on people, but the focus has evolved today to encompass the broader picture. I wanted to be an engineer because engineers are "doers". Environmental engineering is unique such that it cuts through many different sciences. Unlike civil engineers, I had to take microbiology, structure, and chemistry classes. Today, we encourage our students to study sociology or psychology because they will interact with communities and people. I like to compare civil engineering and environmental engineering with the following example. You are using an iPhone to record me. If this iPhone does not work properly, it is not such a big deal; you can buy a new phone. On the other hand, if we build a treatment facility or a bridge, the scale is larger and affects more people. There is perhaps a different perspective when considering the field of environmental engineering. The consequences of environmental engineering are not necessarily bigger, but they are consequences that last longer. These consequences are felt by very broad groups of society. What really drew me into the field of environmental engineering was that it is useful to large groups of people and allows the engineer to regard problems in many different scales. This turns out to be true. In my research, students are looking at the nanoscale of catalysts with modified properties to the scale of a whole building and then perhaps even larger scales, like the Colorado River. There is a huge range of topics and opportunities in this field.



BSJ: How exactly do you measure and define sustainability in the water reuse cycle?

Professor Hermanowicz: First of all, no one knows the answer to that question. Sustainability is a term that is defined differently by every person. When pressed, people fall back to the definition of the Bruntland Report, which is now 30 years old. People quote a passage about meeting the needs of the current generation and allowing future generation to have a range of choices. This is more a process or a path, rather than a destination. We're trying to implement and find solutions in a way that will not preclude future generations from finding their own solutions. I mean, imagine if we were to exhaust natural resources, like some of the rare Earth metals, given that they are now used in phones and such technologies. We can probably recycle these phones, but at a certain level, it becomes not only non-economical, but also physically very difficult. People in the mining industry and many others know that it is much easier to mine and process rich ore than a very dilute ore. So, we were actually looking at this from the cell phone perspective and the rare Earth metals, such as gold, for there are gold contacts within cell phones. Depending on how you calculate, you can treat the disposed phones as a kind of mineral deposit that is distributed over a city area. Unfortunately, it turns out that this deposit is orders of magnitude lower in concentration than even the poorest ores that are mined now. So if we were going to do this without limitation, then we would be precluding future generations from using gold for their applications. Thus, we are trying to minimize this obstruction of the future. However, this is a very difficult concept. Sustainability originated in Germany around the eighteenth century, when they were approaching forest management. They realized that one cannot simply cut down the forest without limitation. Cutting down forests presents a very short-term solution, so they tried to create a system using replanting and selective cutting that continues forever. I think this is a good analogy. How do you measure that your system is working properly? Well, there are no simple measurements or indicators. Currently, there exists a list of about 120 different metrics used by different groups. Everyone has their own way of measuring this. It also depends on what background you come from. Some people have looked at this problem from a social perspective, by considering factors of social sustainability. These factors make sure that society, as a whole, does not collapse in the future. Historically, there are examples of societies that have collapsed rather quickly. There are people who consider economic sustainability, looking at the abilities to finance related activities. There are also people who consider physical sustainability. My interests in this problem lie in this final piece, primarily, looking at the physical sustainability aspects in the context of engineering solutions for these projects. We try to consider certain factors, such as energy and entropy. There are, in fact, tools that have been developed that are used for such matters, such as a life cycle assessment. Their effectiveness is still in question. I think what is important is that we are moving in a positive direction. There are a lot of embedded values that one must consider. Many times, engineers and others working on this problem do not talk about values. For example, how would you value a potential detrimental environmental effect that could happen 100 years from now versus the effects of environmental damage that is happening now? Is there a discount to consider? If so, how does this discount vary with time? I think we're not talking enough about these issues. It would be very nice to just invest in an agenda concerned with protecting the future environment and future generations without having to make difficult decisions today. That would be lovely! Sadly, this is not possible. So, how do we make these difficult decisions? I believe that we would be much better at making these decisions if we invested more time in discussing values, which may sound strange coming from an engineer. The issue we are dealing with concerns the values and ethics behind an environmental engineering problem.

"For example, how would you value a potential detrimental environmental effect that could happen 100 years from now versus the effects of environmental damage that is happening now?"

BSJ: How have the standards for the "purity" of water evolved over time with new methods being developed to detect impurities?

Professor Hermanowicz: Since the end of the 19th century and particularly since the discovery of germs and microbes, by Pasteur and later Koch, water quality was placed on more of a scientific basis. The first regulations were related exactly to pathogenic microbes or, to be precise, to indicators of potential pollution. In the US the first federal regulation by at that time, what was called the US Public Health Service, was in 1912. Interestingly, they regulated water quality on cross-country trains, which had water containers from which people could drink. They believed that the role of the government was limited and that the role of the federal government was in interstate trade and commerce. This idea was taken very seriously at that time and therefore the federal government did not feel it was possible for them to regulate local water quality. However, since trains crossed the state boundaries they could regulate those and by default the expectation was that the local water would follow that quality. Hence, microbial water quality was first and the response to that was the introduction of disinfection in drinking water, which was probably one of the largest public health victories in our history. Typhoid, cholera and dysentery are practically non-existent in the developed world, unlike other parts of the world, where these diseases continue to plague the public. The regulatory process was progressing relatively slowly; there were only a few other parameters added. However, from the 1970s, when there became a large awareness of the environmental problems credited to a book by Rachel Carson called The Silent Spring, there was a push to regulate more contaminants, particularly chemicals. Advances in analytical chemistry, regarding the detection and identification of compounds at even lower concentrations, matched this new environmental awareness. We used to talk about concentration in parts per million, milligrams per liter, but then it was possible to go three orders of magnitude lower to micrograms per liter. In current times we are talking about parts per trillion. There is a cycle of being able to detect ever-lower concentrations of more exotic contaminants, and then a corresponding push to regulate. This push is moderated by costs; ideally it would be moderated by the cost-benefit ratio. The Environmental Protection Agency is trying to do that in some way but it is a difficult process. The regulatory process is cumbersome, especially in the US. We had a huge explosion of regulatory mandates, starting with the Safe Drinking Water Act and the regulations that followed, early in the 1980s and throughout the 1990s. This is now a little tapered because we cannot expand this list forever. There are new emerging contaminants such as pharmaceuticals, endocrine disruptors, etc. I don't know where this will go, but it is an interesting area.

BSJ: Once you determine cleanliness, how do you determine what level of cleanliness you need for the different functions in terms of, for example, which chemical you need to eliminate?

Professor Hermanowicz: Scientifically, we should do that based upon a risk assessment, and there is a push in that direction in the regulatory framework. You consider the exposure of people, aquatic animals, flora, and fauna to a particular chemical and you will assess what damage is being done. Then you can tie this exposure to concentrations and limit it at that stage. One thing that we do not perhaps talk about much is the whole issue of 'underlying' science and that science is not yet fixed. You are talking about one extra cancer over the lifespans of a million people, which statistically is a very, very small effect because people get cancer from many different causes and identifying that marginal additional contribution is difficult; thus, the science is difficult. This is true even for toxicity. For example, we have a lot of data on toxicity of cyanide, but only at the lethal doses. We do not have data for lower doses because it has not been done and maybe cannot be done. However, one issue is that at some point in that process we need to define what an acceptable risk is and that is a very difficult subject. 1 in 1,000,000 is a very abstract number, but if you talk about it in a public meeting - this is where I think my plea for students to learn more about psychology comes from - and say this facility will only have a 1 in 1,000,000 additional risk of cancer, then somebody will stand up and say "So you want my child to be that one case?" How do you answer that? I mean it's a legitimate concern! You cannot just say that somebody is ignorant! How do you handle that? There is a risk-assessment process because these actions cost money and there will always be a limit. In practice, I think the system is a little imperfect because, at least in the United States, there seems to be a general policy that industry and the judicial court control an actual process. Enough groups are involved in the process that things spin away from what the scientists would think is the ideal pathway. However, I think generally we are moving in that direction.

> *"One thing that we do not perhaps talk about much is the whole issue of 'underlying' science and that science is not yet fixed."*

BSJ: You have mentioned this timeline from detection to regulation. How long does this regulatory pathway take?

Professor Hermanowicz: That is a very good question. I think it varies a lot historically. It started with the idea that you have pathogenic microbes in water, and there the response was actually before the regulations came on board. In the late 19th century, around 1885, was when Robert Koch discovered chlorine could kill germs. Twenty years later, chlorination was a mainstream technique for treating water, even before regulation, so the time here is negative. Another example is the discovery of disinfection byproducts. The mid-1970s was when chemists discovered chloroform and bromoform at federal concentrations (tens of micrograms per liter) in drinking water and the scientists were positive that they were byproducts of the reaction of chlorine with natural organic materials. Therefore, by mixing chlorine in the water to prevent typhoid and cholera, which are very big issues, you are introducing this extra, much smaller risk. From 1975, I think it took around eight to ten years for the regulatory process to kick in and have the first regulation on these processes. However, that is not the end because we are still going through the process of making and discovering new compounds and putting them on the list. Originally it was only chloroform because it was easily identified and now we're talking about other compounds all coming from the same source. This is a process that takes certainly years and maybe longer. This also ties in with the fact that new facilities will be built or existing ones upgraded and this will take around the same amount of time.

BSJ: For our next question, we were hoping that you could explain how the definition of clean water has evolved over time with the improvement of detection methods. How would you measure how clean the water really is?

Professor Hermanowicz: That question is very relevant to what we are doing. Historically, people had some kind of notion for what clean water was. Primarily, people would determine the quality of water by its appearance and taste, but this method is obviously inadequate. Until the end of the nineteenth century, society still had no scientific definition of what clean water was. Some water can appear to be very clean, but can also contain many pathogenic microorganisms. For example, cholera was endemic in London. London was a leading metropolitan area in the nineteenth century, yet they still suffered from frequent outbreaks of cholera. Since the end of the nineteenth century, particularly since the discovery of germs and microbes by Pasteur and Koch, the study of water quality has become more scientific. The first regulations of water quality were directly related to this research concerning pathogenic microbes. Specifically, they related to the indicators of potential pollution. In the United States there has been always an expressly stated philosophy that drinking water should be of the highest available quality. That is one reason why we have the Hetch Hetchy built here, or the Los Angeles aqueduct. There are also other reasons, like the availability of water. Obviously every time we use water we degrade the quality of it, although we are trying to bring this up through treatment processes. But I think the major point is that water is in some way an ultimately sustainable product that is not really destroyed; it just cycles through nature and through the engineered processes. What we are trying to do is essentially make the best use of it. In some way, we have technology with which we can purify even the most polluted water to the highest quality. The question is how much money we are willing to spend and how much energy this takes. Geographic locations in many cases is a reminiscence of history: people settled along rivers because that was convenient—it was a mode of transportation, and a mode of having a water supply, but at the same time people settled Los Angeles which has no water and the water has to be brought to them. In the United States there has been always an expressly stated philosophy that drinking water should be from a source of the highest available quality and that is one of the reasons why we had the Hetch Hetchy built here and the Los Angeles aqueduct.

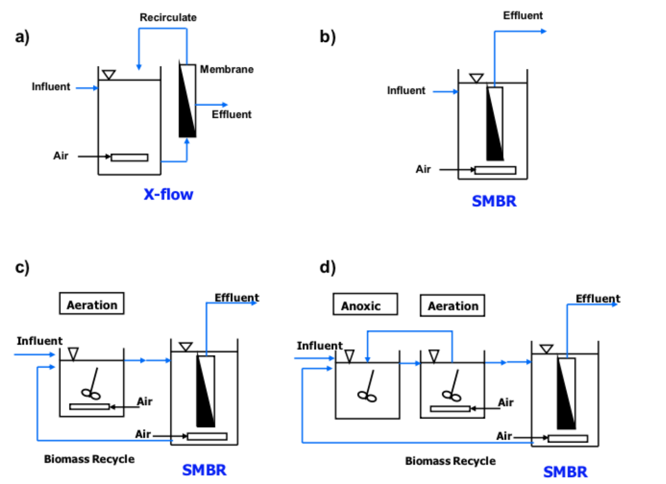


Figure 1. Various MBR configurations .

So considering geography is important because in some cases it allows for people to have cleaner water and in some cases it is more difficult, but we have solutions for both.

BSJ: You have talked a lot about cycling the water. A lot of your research focuses on new filtration technology for wastewater. Could you talk a little bit more about what a Membrane BioReactor is and what sort of issues led to its need?

Professor Hermanowicz: Essentially what happens is that we use water and this water becomes polluted. Although if you look at this from a scientific perspective even the highly polluted water is still 99.5% water, but we do not want to drink that 0.5% or it is harmful for the environment. Throughout history, civilization relied on a natural ability of nature to clean up water, which worked, as long as we do not abuse that natural ability and overload the system. I think that there were two issues that brought this problem to focus: one was the increasing population in urban centers, and therefore, concentrating this pollution in a much bigger fashion; the second was the introduction of xenobiotic compounds, primarily organics that were not present in nature, and were synthesized (pesticides, chemical solvents and so on) that nature has a much more limited ability to handle and sometimes cannot handle.

I am not going to use the term wastewater, as we now think about it as a resource. Treating wastewater as a resource is a big paradigm shift. We can recover water, nutrients, and energy. We found that one of the methods to treat the affluent is a biologically treatment process using microorganisms. This is the most efficient and efficacious way to deal with this problem. Because of this, we now have books such as Environmental Biotechnology, which is the text for a class dealing with this issue that I teach. We use biological processes; in some way we mimic, we intensify the processes that occur naturally in the

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environment. A prime example is when you put untreated waste in a river, bacteria that are already in the river utilizes the waste as food. Bacteria utilize the "food" and consume oxygen. However, this leads to the depletion of oxygen from the river causing the fish to swim belly up. What we do is we take these bacteria and concentrate them in a concrete box. We provide them oxygen at much higher rates. We take a process that would be detrimental to the environment and shift it into a controlled, intensified system. We also use natural systems such as wetlands and soil aquifer treatments, which work fine as long as they are not overloaded. In nature, however, if you want to have nice wetlands, you cannot engineer them to the extent that you can engineer the concrete box. So that is why they are biological processes and it is fun to work with bacteria. Membranes are an additional element that provide for separation of biomass and enhance the final effluent quality. You get a much better quality using membranes. Membranes are an additional element that provide for separation of the biomass and enhance the final quality so that you eventually have a higher quality using membranes. That's where that fits in.

BSJ: You talked about the problems that using bioreactors solves, could you go into some detail about its benefits?

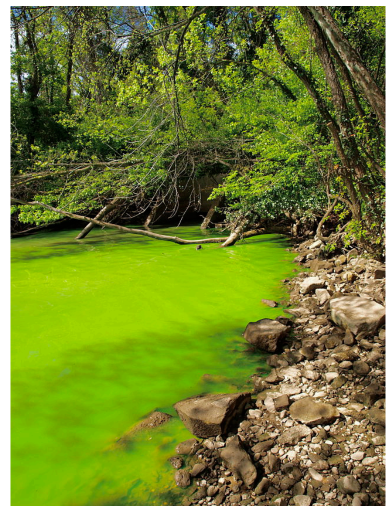
Professor Hermanowicz: It is a new tool in the toolbox of engineers to deal with water reuse. There are two advantages: One is that we process the same amount of dirty water in a much smaller box. We can intensify the process by an order of magnitude of 10 folds. It is much smaller and compact. There is some additional price to pay because bioreactors consume more energy. But if space is an issue, then bioreactors play an important part. Also, the facility has a capacity of tens of millions of gallons per day, which is better from an industrial aspect. Just to give you a perspective, I was looking up the total beer production in the United States annually and it is somewhere in the order of two million gallons. You have a plant in Chicago and they process three hundred million gallons per day. The scale of biotechnology operations in the environmental area is huge! So, reliability is an important part with the membranes. They provide an extra level of protection and make effluent of a higher quality; hence, they can be used much more easily and more widely.

BSJ: What were the unique benefits of the Fluidized Bed Reactors?

Professor Hermanowicz: Well, with the fluidized beds, there was a bit of excitement early in the 1990s. They have a bed of granular material, like sand, put in a column and the water flows upwards. If the water velocity is high enough, then the grains of sand become suspended in the flowing liquid. The major advantage was that it allowed a much higher concentration of microorganisms attached to the surface of the sand granules. So, when you have this pile of sand, the biomass fills the voids and the plugs of the filter. It is really very technical, but the engineers get excited about relatively small technical advances! This excitement is present in every research field! Like, in computer science, if your code is three lines smaller, you are a genius! So, these turned out to be useful, but were highly energy consuming.

BSJ: So, you're looking for means that also optimize energy consumption?

Professor Hermanowicz: Yes, absolutely! That has always been a dogma for engineers. Do things better and cheaper. Cheaper entails lower energy cost and material cost. Engineers have evolved to focus on sustainability, but they did not use this word until very recently. The word, "sustainability," has come about in their attempts to vocalize and sell the idea.



BSJ: So, you are constantly looking for sources with lower energy consumption?

Professor Hermanowicz: Of course! There has always been a dogma for engineers: do things better and cheaper. Cheaper includes lower energy costs and lower material costs. In some ways, engineers have always been involved and focused on sustainability; they just never used the word until recently. They were never able to vocalize this idea and sell it, but this is exactly what we're doing.

BSJ: What are the alternative forms to fluidized bed reactors and MBRs? What are used in treatment facilities today? What do you see used in the future?

Professor Hermanowicz: MBRs are now a hot technology. They are growing by leaps and bounds. There are certain fashions in engineering, and this is very fashionable right now because they provide very high quality effluent with very high reliability. It has other problems, however, that people are trying to solve. Fluidized beds have been used for a while and they have a niche, particularly for industrial waste treatment. However, I do not work on them anymore, in some way they have not become obsolete, but they are a technology that has already found its niche. For example, car manufacturers use them to treat the waste from their painting operations. This is because there is a very high concentration of organics, and you can treat the water in a very small footprint. However, they don't reuse this water so they just have to meet the regulatory standards for wastewater. If you need a high quality, membrane technology is certainly the answer now.

BSJ: So you mentioned the idea of using lakes and natural sources to discharge water into. What are the benefits vs. the costs, for example eutrophication, associated with their usage?

Professor Hermanowicz: Eutrophication is certainly a problem. This is primarily due to non-point pollution. The two culprits are agriculture and atmospheric deposition. With atmospheric deposition you have high temperature processes, such as internal combustion, which release nitrogen oxides into the atmosphere. Nitrogen oxides return to the ground through as rain. With agriculture, it is essentially the use of fertilizers. In some ways, it is just economic. It is much easier for farmers to overdose in fertilizer, which is still very cheap, to increase yield. Agriculture, however, is moving in the right direction, in what is called precision farming. In this method, nutrients and fertilizer are deposited to plants in a much more precise and controlled fashion. The combines and applicators have GPS systems and measure and map local pH levels, becoming high tech and high science. At the same time, it is much simpler to just spread fertilizer, with plants absorbing some of it, and the rest goes into the water. That is the major problem with eutrophication. In this country, we have already solved the issue of point source pollution from pipes and wastewater. The big problem is, especially with things like the hypoxia in the Gulf of Mexico, is that it is coming from other sources. This is a difficult problem to solve because there is no end pipe to treat, so we have to rely on conservation techniques on the different farms. The change is happening though, in 1920s and 1930s, for example, there were very few people who knew about erosion control in farming; now, this is a common practice.

BSJ: Now, how would you see your research going in the future?

Professor Hermanowicz: That's a really good question! The part of doing research, and the fun of doing research is that it is a never-ending story. You think you solved the problem, but in reality you have opened up new areas and think of new questions. As you learn more, very rarely are you completely satisfied with what you have done. I am definitely very interested in a few areas in the future. One is the usage of biological processes, primarily in controlling microbial community structure. We are just learning how to do this with things like QPCR and fish techniques. The difference between biological technology in pharmaceuticals and us is that we have relatively little control over what we get into our systems, like the type of bacteria. We are trying to understand these problems in large scale, open systems. Certainly, the area of sustainability and trying to push some metrics into current regulations would be interesting. We are also going into the area of water reuse and water acclimation on the small scale. We have this project together with two of my colleagues from bioengineering and architecture for greywater reuse in the facades of buildings. Here, it will be interesting to combine different approaches for sustainability and to look at heat recovery. We will see! On a very practical level, it really depends on where the funding is. This is the reality these days, especially in the areas of science and engineering.

BSJ: Thank you for your time!

Image Sources

http://www.ce.berkeley.edu/~hermanowicz/hermanowicz.jpg

http://ecx.images-amazon.com/images/I/51BUD6L02bL.jpg

http://upload.wikimedia.org/wikipedia/commons/thumb/3/36/Potomac_green_water.JPG/640px-Potomac_green_water.JPG

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BSJ

Transpiration effects and inquilines in a lepidopteran stem gall

Olivia Cope
Department of Plant and Microbial Biology
University of California, Berkeley
Keywords: insect galls, plant-insect interactions, ecology, plant physiology

Abstract

I measured transpiration rate and cross-sectional xylem area of *Conostegia oerstediana* branches with and without stem galls induced by *Mompha* sp. Xylem area was reduced from an average of 2.61mm2 in an ungalled stem to an average of 0.31mm2 at the widest point of the gall, but transpiration did not differ significantly between galled (0.11 mL/30min/100cm2 leaf area) and ungalled (0.13 mL/30min/100cm2 leaf area) branches. This could be due to contributions to transpiration rate by gall lenticels. Many of the galls (46%), including those still occupied by *Mompha* sp., had peripheral cavities likely made by other insects; I found the arboreal ant *Procryptocerus batesi* nesting in one of these.

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Introduction

Galls are common but very specialized structures: atypical plant growths induced by organisms that then live inside and feed on the gall. They arise on all plant organs and can be induced by a variety of organisms including microbes, nematodes, and insects (1). In most insect-induced galls, an insect oviposits on plant tissue and the plant's growth response is dependent on the feeding of the hatched larva (1). The gall is a defense by the plant, in the sense that it isolates an herbivore, but it is also a protective and nutrient-rich environment for the galling insect. In addition to the galling insect, other insects can be found living in galls as parasitoids or inquilines (2).

The effect of galls on the flow of water and mineral nutrients in the xylem is not clear. Fay *et al.* (3) found that galls on apical meristems increase water movement and photosynthesis, perhaps as a compensatory response to the loss of nutrients to the galls. However, results in general have not been conclusive (4) and galls that occur on xylary tissues such as stems could actually have the potential to disrupt and slow conduction of water in the plant.

The stems of the Central American melastome *Conostegia oerstediana* are galled by *Mompha* sp. moths. My study aims to answer this question: what effect do insect galls have on the flow of water through plants? *Mompha* galls have numerous lenticels and my initial hypothesis was that these would cause an increase in water loss by *C. oerstediana*. I was also interested in the route of the xylem through or around the gall.

Materials and Methods

I studied stem galls on the tree *Conostegia oerstediana* (Melastomataceae) induced by *Mompha* sp. (Lepidoptera, Momphidae). The galls are round, 11-29mm in diameter and have a green surface with numerous lenticels. My field site for collections was premontane wet forest adjacent to the Estación Biologica Monteverde in Monteverde, Puntarenas, Costa Rica.

I collected 20 pairs of branches with and without stem galls, each branch structurally similar and cut from the same plant; in total I sampled from eight individual trees. After cutting I immediately placed the branches in water to maintain the xylem water column. Upon returning to the lab, I cut the stems again under water and put each stem into a watertight potometer consisting of rubber tubing and a calibrated pipette. The potometers were filled with a 0.5% acid fluorescein solution to dye the xylem tissue for later sectioning (A.H. Sanjuan, pers. comm.). After a 1-minute equilibration, I tracked the movement of both pipettes' water columns for 30 minutes to measure transpiration. The pairing of galled and ungalled branches was necessary to control for other variables that influence transpiration rate such as light intensity, humidity, and wind speed (5); both branches in the pair experienced the same conditions so their transpiration rates could be directly compared.

To further standardize my transpiration data, I traced each leaf of each branch on paper and used the weight of the cutouts divided by the weight of a square centimeter of paper to determine total leaf area of each branch (6).

Next I cut thin stem sections, sampling both galled and ungalled portions if the stem had a gall. I measured the cross-sectional area of the dyed xylem tissue for each stem section, as well as the maximal diameter of each gall, under a dissecting microscope. I used a paired t-test to analyze differences in transpiration rate and xylem area between the branches in each pair, and a binomial test to check for effects of the time of day on transpiration rates.

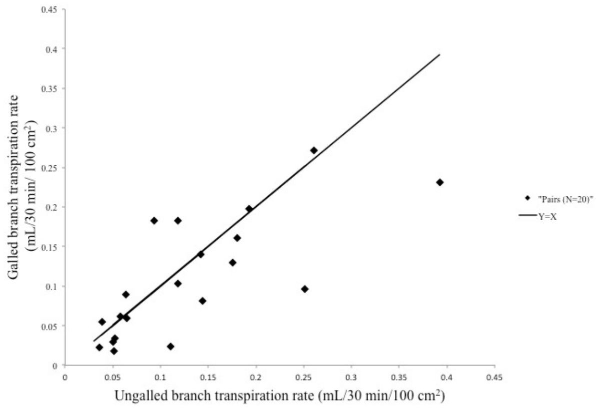


Figure 1. Transpiration rates for pairs of ungalled and galled C. oerstediana branches in mL/30min/100 cm2 leaf area.

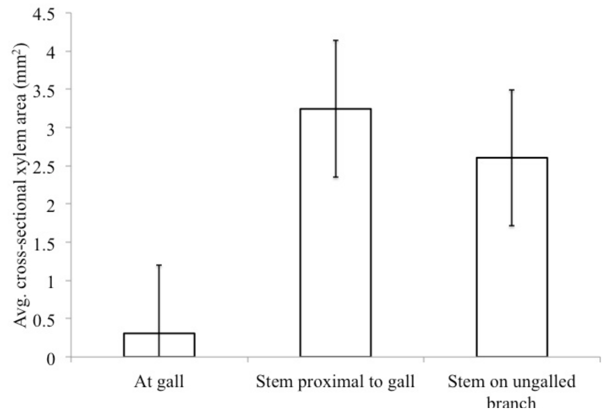


Figure 2. Average cross-sectional xylem area, in mm2, in sections made at the widest point of the gall, in the stem proximal to the gall, and in the stem of an ungalled branch (N=15).

Results

The transpiration rate of *C. oerstediana* branches with stem galls did not differ significantly from that of branches without galls. However, in any pair the ungalled branch was more likely than the galled branch to have the higher transpiration rate (binomial test: N=17, k=5, p=0.07). In 30 minutes, galled branches transpired an average of 0.11 mL per 100 cm2 of leaf area and ungalled branches transpired an average of 0.13 mL per 100 cm2 of leaf area (Fig. 1).

The xylem in a galled *C. oerstediana* stem does not go through the gall, but in fact flattens out and skirts around the gall mass, with the *Mompha* sp. moth larva or pupa occupying the center of the gall (Fig. 6). There was no significant difference between the cross-sectional xylem area of a galled stem immediately before the gall, which averages 3.24 mm2, and that of an ungalled stem, averaging 2.61 mm2. However, the xylem area at the widest point of the gall was always significantly reduced compared to the stem before the gall ($t(14)=9.98$, $p<0.0001$) and averaged only 0.31 mm2 (Figs. 2-3).

The time of day at which data collection occurred ranged from 09:00 to 14:00 and did not significantly affect transpiration rate differences within pairs; however, variation between pairs was greater earlier in the day (Fig. 4).

Twenty-three of the 26 galls collected (88%) were occupied by a living Mompha sp. larva or pupa. Twelve galls (46%) had some sort of cavity surrounding the moth's central chamber. Nine of the 12 galls with cavities (75%) were occupied by a moth larva or pupa.

Most of the cavities were filled with frass but no insects (Fig. 5); however, one contained a small colony of the arboreal ant Procryptocerus batesi (Hymenoptera: Formicidae, 7) including worker adults, eggs, larvae, and pupae (Fig. 6). Of the galls with cavities, all had a hole in them; every gall without a cavity except one did not have a hole like this. Essentially, galls with holes had cavities dug out of them and galls without holes did not ($\gamma^2(1, N=21)=17.36$, $p<0.001$).

Discussion

In this study galled branches transpired at the same rate as their ungalled counterparts (Fig.1). Galled branches were more likely to be the slower-transpiring branch in a given pair, but there was a lot of variation in the transpiration rate differences between galled and ungalled branches so the overall effect was not significant (Fig. 4). The highest amount of variation occurred in pairs sampled during the morning,

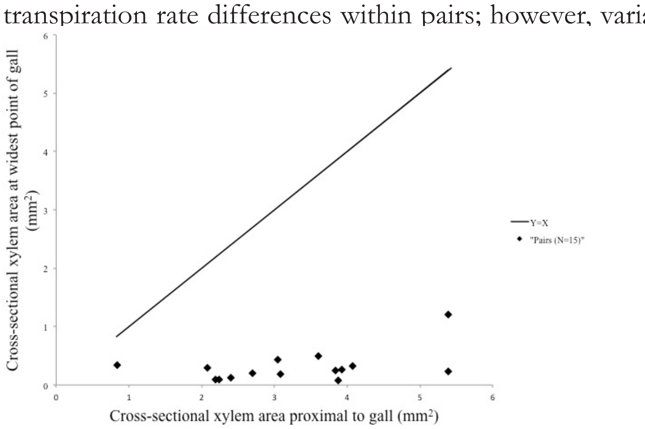


Figure 3. Paired cross-sectional xylem areas in mm2 of galls and stems proximal to galls.

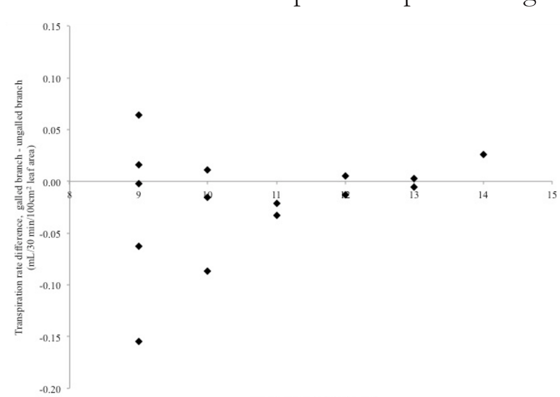
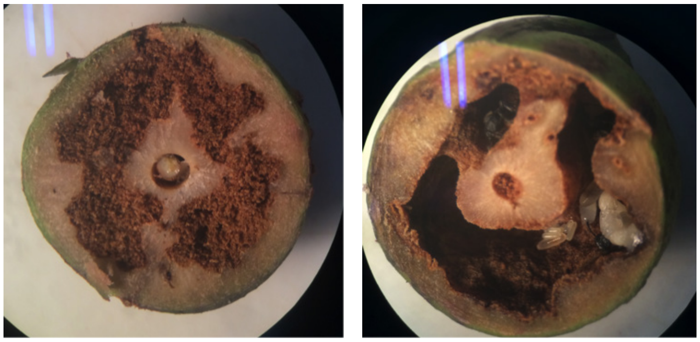


Figure 4. Difference in transpiration rate (mL/30min/100 cm2) between galled and ungalled branches in pairs tested at different times of day. Data collection start times range from 09:00 to 14:00. Negative rate differences represent pairs in which the galled branch had a lower transpiration rate than the ungalled branch.



Figures 5 and 6. Cross-sections of stem galls induced by Mompha sp. on C. oerstediana. 5: Gall with a frass-filled cavity and Mompha sp. larva at center. 6: Gall with P. batesi nesting in an open cavity and Mompha sp. larva at center. The flattened xylem column is visible at the top of the gall (see arrow).

when stomatal openness is peaking; this variation could have been caused by differing rates of change in stomatal water conductance between paired branches (8).

Because they use the plant's resources and have lenticels through which water is lost (5), I had expected the *Mompha* sp. galls to increase the amount of water transpired by C. oerstediana branches. However, there was an unexpected and significant reduction in xylem area due to displacement by the gall tissue (Figs. 2-3). Reduction in xylem area likely reduced flow (9) and offset or trumped any increase in transpiration caused by the gall and its lenticels. The largely neutral effect of the stem galls on transpiration reflects a gall morphology that maximizes the gall's growth while minimizing its effects on plant water needs. This benefits *Mompha* sp. because it reduces the selective pressure on *C. oerstediana* to evolve defenses against the gall. It also suggests that morphological diversity among galls may preclude a universal theory about galling and water use in plants.

Similar methods to those used in this study could be used to determine whether the lenticels on the gall surface are indeed offsetting reduced xylem conductance by releasing more water. Transpiration rates could be compared between branches without galls and branches with their galls sealed with wax. Sealed galls would not be able to transpire through their lenticels and would show the effects of reduced xylem in isolation.

Another outcome of this study was the discovery of a colony of *P. batesi* ants living in the hollowed-out periphery of a gall still occupied by its inducer. *P. batesi* often nest in live, ungalled stems (7) and other ants are known to colonize abandoned galls of similar size (10), but this species has not been reported as a gall inquiline.

I only found one gall with ants nesting inside it, but almost half of the galls collected had a similar cavity. The cavity was generally filled with frass and always had an exit hole too small for the moth but large enough for other insects. P. batesi do not leave frass-filled nest sites (J.T. Longino, pers. comm.) and are opportunistic stem nesters. This leads me to believe that the ants did not dig out that gall cavity themselves but instead moved in after the cavity-making inquiline, whose identity is unknown, had eaten out the gall pith and departed. The cavity appears to be dug in avoidance of the moth's chamber (Fig. 5). Though not typical of ants (11), using the gall while it is still occupied by a moth may be nutritionally and structurally beneficial for both *P. batesi* and the cavity-making inquiline because the gall's tissue growth is most likely maintained by its inducer (1). Further study could reveal the identity of the cavity-making inquilines and the frequency of subsequent ant colonization.

Conclusion

The relationships between gall-inducing insects, their host plants, and other gall-associated fauna are complex. Resultant transpiration rates in this system were not significantly different in galled branches, even though galls had a profound effect on stem vascular anatomy and anecdotally resulted in herbivory by secondary gall users. This combination of heavy use by the inducing insect and mild effects on the specific host plant's fitness gives insight into the success of galling as a life history strategy.

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