Volume 21 Spring 2011

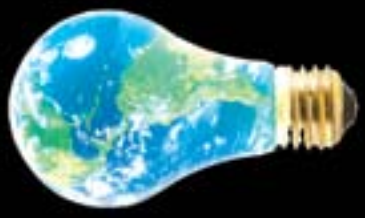
MURJ

Massachusetts Institute of Technology
Undergraduate Research Journal

150 MIT Innovations in the Past 150 Years

p. 9

Massachusetts Institute of Technology



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MIT Undergraduate Research Journal

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murj.mit.edu

May 2011

Dear MIT Community,

We are proud to present Issue 21 of the MIT Undergraduate Research Journal (MURJ), a biannual publication that showcases the groundbreaking undergraduate research being done across campus, across disciplines. As always, the breadth of questions and hypotheses being examined by students is unparalleled; in this issue, we learn about the future of sustainable energy as accessed by different social states, microgel-mediated nucleation, and novel labeling techniques in the brain. These pieces, as well as others in the issue and online at murj.mit.edu, are the newest ideas and technologies to join MIT's long history of creation and innovation.

This spring is especially exciting for our community, as MIT celebrates its sesquicentennial. In our features section, we highlight some of the most interesting research and inventions produced in the past 150 years by MIT professors and students – with some surprising finds – as well as delving into the life and times of the Chemistry department's most recent Nobel Prize winner, Dr. Richard Schrock. As we take time to reflect on the achievements made by our peers and professors over the past century and a half, we are confident that the next 150 years will bring even more triumphs in science, technology, the arts, and society, and hopeful that MURJ will be reporting these discoveries firsthand.

MURJ is a collaborative effort by an extraordinary team of dedicated and hardworking students, and we would like to thank our executive board and department members for their time and effort this semester. We would also like to thank the UROP department, the Office of Undergraduate Advising and Academic Programming, MIT Student Activities Office, and the MIT Publishing Service Bureau for their continued support. Finally, a special thank you to the authors for sharing their research with us and the larger community. We hope you enjoy the issue!

Sincerely,

Omar Abudayyeh
Co-Editor-In-Chief

Ana Lyons
Co-Editor-In-Chief

Evelyn Wang
Co-Editor-In-Chief

MIT Energy Club
MIT Undergraduate Research Journal

Massachusetts Institute of Technology
www.mitenergyclub.org

May 2011

Dear MIT Community,

On May 2nd of this year the price of a barrel of oil dropped by $1.51 due to a random exogenous event – the death of Osama bin Laden. According to the Wall Street Journal this price adjustment reflected the new confidence that markets had in 'greater stability in the Middle East and Central Asia' due to the event. This interpretation can be easily critiqued just as an oil trader's ability to quantify security improvements can. Another, more insightful, interpretation of this event can be summed up as follows: The energy sector is a huge highly interconnected system of markets, technology, and massive infrastructure, therefore singular events matter.

Here at MIT we are primarily concerned with the pursuit of disruptive endogenous events - the development of new energy technologies, systems and management strategies (along with better understanding and dealing with high-impact exogenous events). While the long term effect of exogenous events may decay, the on-going influence of new technological breakthroughs can continue to reverberate in very profound ways. It is through technological innovation that the utilization of so-called unconventional gas reserves has been opened up in the past few years; this technological development will have lasting influence on the natural gas market (and as consequence the domestic electricity industry).This typifies the lasting impact of the research enterprise, in which, we at MIT delight.

The ethos of the student energy community is to approach energy issues with 'fact-based analysis', and UROP students exemplify this. We are honored to have been asked to write an introduction to this bi-annual collection of UROP students' innovative work. It would come as no surprise to us if something truly disruptive came out of the work in the pages that follow.

Sincerely,

Addison Stark
TPP '10, 2 PhD
Co-President MIT Energy Club

Guillaume Fernet
Sloan MBA '11
Co-President MIT Energy Club

Science News In Review

Cell Phone Usage May Be Linked to Altered Brain Activity

Contrary to popular belief, could using cell phones actually be good for us? In a recent study conducted by the National Institutes of Health, researchers obtained data that suggest that less than one hour of cell phone use can accelerate brain activity.

In the study, 47 subjects were each given two cell phones which were placed next to each ear. In the control experiment, both phones were in "off" mode, and no unexpected brain activity was observed. In a subsequent experiment, the cell phone near the right ear was set on a mute call. Surprisingly, after 50 minutes, positron emission tomography- (PET-) scans performed on the subjects indicated increased sugar consumption levels in areas of the brain nearest to where the right phone was positioned.

This study raises several questions regarding the health effects of electromagnetic radiation emitted from cell phones. While cell phone radiation frequency is relatively low, many scientists are now curious if altering brain activity through the use of cell phones is detrimental or beneficial. Many medical groups have been proponents of the safety of cell phones for quite some time, but numerous doctors have supported the idea of using headsets as a precautionary measure. Even though this study presents new data, many have said that the link between cell phone usage and brain activity would need to be further investigated in order to assess the impacts of cell phone-induced brain stimulation.

Cell phone use has become so prevalent that the possibility of beneficial aspects can have a major impact on society.
Credit: Kristen Murphy, Associated Press

—R. Kumar

Source: http://well.blogs.nytimes.com/2011/02/22/cellphone-use-tied-to-changes-in-brain-activity/?ref=research

David Pesetsky Elected to American Association for the Advancement of Science

David Pesetsky, the MIT Ferrari P. Ward Professor of Modern Languages and Linguistics, has been named a Fellow of the American Association for the Advancement of Science (AAAS), an honor bestowed for "meritorious efforts to advance science or its applications."

It is no wonder that David Pesetsky was chosen for this honor, having made significant advances in syntactic theory and forging connections between it, language acquisition, and neuroscience, as well as making links to various other domains of linguistics. At MIT, Prof. Pesetsky is currently working on the relation between language and music and his research interests span morphology (the study of the structural units of words and language that hold meaning), syntax (the study of sentence construction, of which Prof. Pesetsky focuses on that in Russian and, as a recent development, in music), and language acquisition.

Including Pesetsky, five other MIT professors were selected as AAAS fellows: William Boone Bonvillian, Director of MIT's Washington, D.C. Office, Edward F. Delong, Morton and Claire Goulder Professor of the Department of Civil and Environmental Engineering and Department of Biological Engineering, Chris A. Kaiser, MacVicar Professor of Biology, Terry L. Orr-Weaver, Department of Biology and White Institute, and Li-Huei Tsai, Picower Professor of Neuroscience and a Howard Hughes Medical Institute Investigator. In total, 503 members of the MIT community have been awarded this honor.

David Pesetsky, Ferrari P. Ward Professor of Modern Languages and Linguistics, and Margaret MacVicar Faculty Fellow.
Credit: Scott Solomon, http://news.sciencemag.org/sciencenow/2011/01/the-worlds-smallest-farmers.html?ref=hp

—S. Wu

Thunderstorms Make Antimatter

When we hear the word "antimatter", we often think of something foreign and beyond the scope of our regular lives. However, recent observations indicate that antimatter is not as distant from us as we believe.

In January of 2011, scientists at NASA saw something that had never been seen previously: thunderstorms producing beams of antimatter above Earth. Using the Fermi Gamma-ray Space Telescope, newly-produced gamma rays could be measured and observed. Gamma rays are produced when antimatter collides with normal particles, a process which annihilates both the antimatter and the normal particle. It is believed that this occurs during terrestrial gamma-ray flashes (TGFs).

To produce antimatter, electric fields present at the top of thunderstorms sweep a flood of electrons upwards, which form gamma rays upon deflection by the above air. While most of the gamma rays end up colliding with electrons and accelerating, some gamma rays transform in an electron and a positron (the antimatter equivalent of the electron) when passing by nuclei. Since the electron and the positron's source was a gamma ray, they are highly energized.

Following the Earth's magnetic field, the positron may collide with a normal particle at some point and become annihilated, as described previously. This annihilation can be seen using the Fermi Gamma-ray Burst Monitor. Alternatively, the positron may collide with an electron on the Fermi spacecraft and the resultant gamma ray would be measured as well.

Thunderstorm with lightning striking the Earth.
Credit: http://allaboutweather.org/wp-content/uploads/2010/07/Thunderstorm.jpg

This discovery will be useful in determining the mechanism behind TGFs and in understanding what specifically it is about these thunderstorms that allow them to make antimatter.

—C. Wong

Source: http://science.nasa.gov/science-news/science-at-nasa/2011/11jan_antimatter/

Dictyostelium discoideum: The world's smallest farmers

Dictyostelium discoideum, a microorganism found to harvest bacteria.
Credit: Scott Solomon, http://news.sciencemag.org/sciencenow/2011/01/the-worlds-smallest-farmers.html?ref=hp

Amoebas and humans are more alike than you think. A novel study, conducted by Debra Brock, a graduate student at Rice University in ecology and evolution biology, suggests that *Dictyostelium discoideum* can act as a harvester. Commonly known as " Dicty", these microscopic amoebas reside independently as long as they can ingest bacteria from surrounding soil. When this supply of bacteria diminishes, individual Dicty aggregate together to form a sluglike creature nearly half a centimeter in length. These creatures can slide to fertile pastures where they can attain their necessary nutrition. Upon reaching these fertile areas, the sluglike creature creates a stalk with a fruiting bud. This bud then releases tiny spores that each contains a miniscule amoeba – to restart the cycle.

Brock discovered the fruiting buds contained amoeba spores when she extracted the content of

continued on p. 6

"Dictyostelium discoideum" continued from p. 5

the fruit body using a pipette, and spread it on a plate for growing bacteria. After two days, she observed bacteria patches had developed on the plate, suggesting the fruiting bud harbored Dicty amoebas. To ensure that the observed bacterial substance was not just an infection, Brock killed the bacteria with antibiotics and then transferred it to a fresh patch of bacteria. The antibiotic-treated bacteria was in fact picked up by the fresh bacteria indicating the bacteria was not an infection.

Researchers have studied several organisms that farm. Examples include ants and termites that produce fungus, damselfishes that grow algae, and intertidal snails that cultivate fungus. Dicty, however, utilize a much simpler mechanism for growth. It cannot employ methods such as tending to its crops, fertilizing, and killing the pests. The Dicty amoeba simply does not entail the necessary machinery to execute such methods.

This study may open doors to more potential farming micro-bacteria. To some it may be surprising to know humans are not the only organisms capable of farming — little amoebas can cultivate crops too.

—R. Kumar

Source: http://news.sciencemag.org/sciencenow/2011/01/the-worlds-smallest-farmers.html?ref=hp

Possible Universal Marker for Pinpointing Cancerous Cells

We often think that methods developed for detecting cancer in mice would have to be modified in some form to be used accurately in humans. However, researchers at Massachusetts General Hospital (MGH) have uncovered a genetic product made by tumor cells that can be used to distinguish them from normal cells.

David Ting, a postdoctoral researcher in Daniel Haber's lab at MGH, and colleagues found a type of RNA transcript that was present extensively in both mice and human tumor cells. Investigating these transcripts further, the scientists found that the transcripts were coded by DNA satellite repeats, short repeated fragments of DNA. Compared to normal cells, many types of tumor cells contained up to 40 times more satellite repeats. While most of the tests were performed on pancreatic cancer cells, the few samples of prostate, lung, kidney, and ovarian cancer cells tested also indicated high levels of satellite RNA when compared to normal human cells. Although a 40-fold greater manifestation is astoundingly high, this difference between tumor and normal cells was not discovered earlier since satellite repeats do not code for protein and were thus considered to be unimportant, thereby passing below the radar of traditional DNA microarrays.

This discovery is surprising and significant, as it can help elucidate the mechanism behind cancer development. The Haber group discovered a link between high RNA levels and particular embryonic development genes, which may also signify that cancer uses normal functions to develop and spread. What is yet to be determined is whether the high RNA levels are indicative of cancer or whether they are merely byproducts of another natural mechanism. Regardless, studies on high RNA levels and on satellite repeats as markers can be useful in improving current biopsy interpretation procedures.

—C. Wong

Source: http://news.sciencemag.org/sciencenow/2011/ 01/a-universal-marker-for-tumor-cel.html?ref=hp

Tumor cells are caused by mutations in DNA.
Credit: http://singularityhub.com/wp-content/uploads/2010/07/DNA_NIH.jpg

Cima, Griffith and Odoni Elected to National Academy of Engineering

The National Academy of Engineering (NAE) recently announced that three MIT faculty members - Michael Cima, Linda Griffith, and Medeo Odoni - have been selected to join the prestigious institution. The announcement was made on Feb. 8. by MIT President Emeritus and NAE president Charles M. Vest. This honor symbolizes one of the highest professional distinctions accorded to an engineer and membership represents exemplary contributions to "engineering research, practice or education, including , where appropriate, significant contributions to the engineering literature."

Michael J. Cima, the Sumitomo Electric Industries Professor of Engineering in the Department of Materials Science and Engineering, was recognized for his innovations in rapid prototyping, high-temperature superconductors and biomedical device technology. His research focuses on materials and engineered systems aimed at developing treatments for cancer, metabolic diseases and urological disorders.

Linda G. Griffith, the MIT School of Engineering Professor of Teaching Innovation, was honored for her contributions to 3-D functional biomaterials, engineered hepatic tissues and cell transplant devices. Her research is in the field of tissue engineering with applications to the development of polymeric materials, biomaterials and scaffolds.

Michael Cima, Linda Griffith and Amedeo Odoni.
Credit: http://web.mit.edu/newsoffice/2011/new-nae-members.html

Amedeo R. Odoni '65, SM '67, PhD '69, the T. Wilson Professor of Aeronautics and Astronautics and professor of civil and environmental engineering, was acknowledged for his contributions and global leadership in air traffic control and airport systems. His research is aimed at models and tools for exploring demand/capacity and demand/delay relationships in airports and air traffic controls.

MIT now has 162 members in the NAE, 119 of whom are still involved in research on the MIT Campus. Other MIT alumni were also named to the NAE, including Stuart L. Cooper '63; Daniel M. Hancock SM '73; Chris T. Hendrickson PhD '78; Cato T. Laurencin PhD '87; Donald Liu SB/SM '66; Ralph D. Masiello '68, SM '69, EE '70, PhD '73; Donald A. Norman '57; John A. Rogers SM '92, PhD '95; and Thomas J. Richardson, PhD '90.

—S. Wu

MURJ Features

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150 MIT Innovations in the Past 150 Years

Long after the sun has set on Lobby 7, the lights of the Infinite stay on. There is no doubt that we are proud of our hard-working culture and the innovations that it has spawned. Part of the beauty of MIT's sesquicentennial celebration is that it invites us to pause for a moment and reflect on the sea of discovery that defines our past. We have tackled everything from the tiniest quarks to the inflation of the universe. Our history is one that resonates with "inventional wisdom."

At the same time, our hearts weigh heavily with the weight of global suffering and uncertainty. Indeed, a common theme connecting MIT's 1949 Mid-Century Convocation to the Next Century Convocation held on April 10th, 2011 is that both occurred when the world was going through great strife. During Winston Churchill's keynote address at the Mid-Century Convocation, the Berlin airlift was underway. He took the opportunity to express his hope that, in the future, science would be used for the betterment of mankind--such as in tackling world hunger. In the same vein, keynote speaker and Archivist of the United States The Honorable David S. Ferriero touched on the importance of science and technology to create a better environment for future generations. His vision was of a world that is sustainable and safe amidst dangers such as oil spills and nuclear weapons. With this in mind, the timeline of MIT's inventions and innovations shows us how far we have come, and how far we have yet to go to improve the human condition. It galvanizes us to undertake more daunting challenges in hopes of creating more inspired solutions. We can revel in the accomplishments of the past as we work towards triumphs in the future.

Features MURJ Volume 21, Spring 2011

MIT +150 INVENTIONAL WISDOM

1. MIT founding, 1861

2. Arthur D. Little, MIT chemist who discovered acetate, 1886

3. First Chemical Lab at MIT founded, Francis H. Storer, 1867

4. First Physics Lab at MIT founded, Edward C. Pickering, 1869

5. Ethernet, Robert Metcalf '68

6. Campbell Soup, John Dorrance, 1895

7. Theory of the inflationary universe, Prof. Alan Guth '68

8. GPS (Global Positioning System), Ivan Getting '33

9. Lego Mindstorms, MIT Media Lab

10. Texas Instruments Inc., Cecil Green '23

11. Artificial Skin, Ioannis Yannas SM '59

12. Hypertext, Prof. Vannevar Bush PhD '16

13. Technicolor, Herbert Kalmus, 1903

14. Evidence of quarks, Professors Henry Kendall and Jerome Friedman

15. Disposable-blade safety razors, William Nickerson, 1876

16. Plan for Canberra, Australia, Marion Mahony Griffin, 1894

17. Fax Machine, Shintaro Asano SM '61

18. Spacewar, the first computer game, Steve Russell '60

19. Rock & Roll Hall of Fame Building, I.M. Pei '40

20. Inertial guidance system, Charles Stark Draper '26

21. Analog Devices, Inc., Raymond Stata '57

22. Discovery of human oncogenes, Prof. Robert Weinberg

23. The Internet Archive, Brewster Kahle '82

24. Modern linguistics, Prof. Noam Chomsky

MIT +150 INVENTIONAL WISDOM

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25. Doppler radar, Bernard Gordon '48

26. Voice recognition technology, Ray Kurzweil '70

27. The field of Marketing Science, Prof. John Little

28. Car Talk - Tom '58 & Ray '72 Magliozzi

29. Credit card holograms, Prof. Stephen Benton '63

30. RSA Public Key Cryptography, Professors Ron Rivest, Adi Shamir and Len Adleman

31. Rockman amplifier, Tom Scholz '69

32. The World Wide Web, Senior Research Scientist Tim Berners-Lee

33. Biogen Inc., Prof. Phillip Sharp

34. The "butterfly effect," Prof. Edward Lorenz

35. Bose stereo, Professor Amar Bose '51

36. Rockefeller Center, Raymond Hood 1903

37. Spreadsheets, Daniel Bricklin '73

38. http://www.popularmechanics.com/technology/gadgets/news/4268172

39. Controlled drug release, Prof. Robert Langer, 1976

Drugs of different sizes can be encapsulated in and released from polymers in controlled amounts

40. First free standing hologram, Prof. Stephen Benton '63, 1986

In 1985, Benton began generating synthetic holograms from 3-D digital databases, initially creating a 3-D image of a green car floating in front of the Boston skyline.

41. Project Daedalus, 1988

Project Daedalus sets distance and endurance records for human-powered aircraft in a flight over the Aegean Sea

42. Airport Surveillance Radar Deployed, Lincoln Labrotories, 1989

Provides air traffic control (ATC) personnel with a display free of clutter and a telephone bandwidth data stream for transmitting information to ATC facilities.

43. Human Genome Initiative, Oct. 1990

MIT is chosen for a key role in the Human Genome Initiative, whose goal is to map all 23 human chromosomes

MIT +150 INVENTIONAL WISDOM

44. Traffic Alert and Collision Avoidance System (TCAS), Lincoln Labrotories, Dec. 1993

Reduces midair collisions by sensing nearby aircraft and issuing an advisory to the pilot. Now mandated on all large transport aircraft, TCAS has been in operation for over a decade and has been credited with preventing several catastrophic accidents.

45. Advanced Land Imager, Lincoln Labrotories, 1995

Validates new technologies that (1) could be utilized in future land-observing satellites and (2) would reduce mass, size, and power consumption while improving instrument sensitivity and image resolution.

46. Human Genome, Whitehead Institute, 1996

Establishes the location of more than 16,000 human genes; the first milestone of the overall goal of the Human Genome Project

47. Bio-Detection Program, Lincoln Labrotories, Nov-96

early-warning sensor that can sense small quantities of airborne biological particles and issue an alarm in less than one minute, and a bioelectronic sensor that can potentially identify a biological agent from a single sensed particle.

48. LINEAR Asteroid Search, Lincoln Labrotories, Mar-98

detect and catalogue near-Earth asteroids (NEAs) that may threaten Earth.

49. MIT-Caltech collaboration, Jun-05

MIT and Caltech join forces to develop an easy-to-use, reliable, affordable and secure United States voting machine that will prevent a recurrence of the problems that plagued the 2000 presidential election

50. Joint Program on the Science and Policy of Global Change founded, Year 1991

Designed to unify natural and social sciences to study environmental problems

51. World Wide Web Consortium (W3C) established at MIT, directed by Timothy Berners-Lee, senior research scientist, Lab for Computer Science, Year 1994

52. Copenhagen Wheel, MIT SENSEable Cities Laboratory, 2011

Originally developed in 2009 by the MIT SENSEable City Laboratory, the now commercially available Copenhagen Wheel on display is a device for sustainable mobility that offers a cost-effective transportation alternative to the automobile. The device transforms existing bicycles into hybrids with regeneration and real-time sensing capabilities.

53. Christening Bottle, S.S. MIT Victory, Year 1945

During World War II, a series of U.S. Navy Victory ship troop transports was named after educational institutions that had contributed to the war effort. MIT's place on that list was assured through large-scale research and the development of radar, inertial guidance, digital computing, reconnaissance photography, and smaller-scale contributions to hundreds of other projects.

54. Fluid Bed Catalytic Cracking, Warren K. Lewis and Edwin Gilliland, Year 1939

The fluid-bed design, combined with the innovations made by Standard Oil researchers, resulted in a refinery design that remains the primary method of high-quality gasoline production. The more immediate result was the introduction of 100-octane aviation fuel that gave a crucial technological advantage to the United States and its allies during World War II.

55. Carlisle Solar House, National Solar Photovoltaics Laboratory, MIT Lincoln Laboratory, 1970s

Lincoln commissioned Solar Design Associates to design and build a 3,200 square foot energy-efficient, passive solar residence powered by photovoltaics. The Carlisle Solar House was the first inhabited energy-independent house ever built.

MIT +150 INVENTIONAL WISDOM

56. MIT Nuclear Research Reactor, MITR II, MIT Laboratory for Nuclear Science, Year 1958

In 1951, Manson Benedict, a key member of the Manhattan Project, was hired to become MIT's first professor of nuclear engineering. In 1958, MIT created a new Department of Nuclear Science and Engineering led by Benedict through 1971.

58. Cavity Magnetron, MIT Radiation Lab, Year 1940

September 1940 resulted in the creation of the MIT Radiation Laboratory or Rad Lab. In five years, the Rad Lab developed 150 different systems for radar, navigation, early warning, gun direction, and blind bombing as well as the LORAN navigation system. It grew from 50 to 4,000 employees, employing about one-fifth of the nation's physicists, and was second in size only to the Manhattan Project. The Rad Lab reshaped MIT in fundamental ways after WWII. It also represents the Institute's single greatest contribution to the nation in response to a crisis during its 150-year history.

57. Virus Battery, Angela Belcher, Year 2009

Launched in 2006, the MIT Energy Initiative (MITEI) follows the Institute's grand tradition of pulling together its innovative powers to tackle society's toughest problems. Researchers built the lithium-ion battery (the silver-colored disc) on the nanoscale, re-engineering viruses to self-assemble materials for both its anode and cathode. This work points toward commercial batteries with high energy densities that can be created inexpensively with non-toxic ingredients. Not surprisingly, when President Obama visited MIT the following October, he talked more about this viral power with Professor Angela Belcher, who leads the project.

59. Mark 14 Gunsight, MIT Instrumentation Laboratory

In the 1940s "Doc's Shoebox" was the nickname for the rectangular black metal prototype of the Mark 14 Gunsight developed during WWII. Sperry Gyroscope had contracted with Charles Stark Draper's Instrumentation Laboratory at MIT to help develop the specialized instrument that would allow a Navy anti-aircraft gunner to keep up with the new fast-flying airplanes. The U.S. Navy ordered 85,000 Mark 14 Gunsights, which have been credited with altering the balance of power in favor of the United States in the Pacific conflict. Draper received the Medal of Merit for his contributions. Most notably, Draper's wartime project work led directly to his famous inertial navigation work and the steady expansion of the Instrumentation Laboratory to serve the nation's defense needs.

60. Project SAGE, MIT Lincoln Lab, Year 1950

The U.S. Air Force collaborated on early tests with radar over Cape Cod, and eventually expanded the project to MIT's new research and development center at Lincoln Laboratory. SAGE was part of a continental warning defense system. Reports from remote radar stations came in over telephone lines, were processed by computer, and displayed flight-tracking information on CRT screens like the experimental prototype displayed here. By the time the SAGE system was fully operational it had been supplanted by ICBM technology. Nonetheless, the system is considered a major milestone. It got IBM into the computer business and made major contributions to that industry's development.

61. CityCar Electric Vehicle, MIT Media Lab, Year 2006

The Smart Cities Group at the MIT Media Laboratory puts its ideas into action. This is a prototype of the CityCar, a lightweight, intelligent, electric vehicle, that the Group believes will one day radically reduce the energy consumption and carbon footprints of cities. The key enabling technology is a "robot wheel" that integrates drive, steering, suspension, and braking inside each wheel. This not only simplifies the design of the chassis and body, but also enables extraordinary mobility. The CityCar is also capable of folding to minimize its urban footprint. A traditional parking space can fit up to three CityCars. Each CityCar can rapidly recharge within 15 minutes at electric charging stations distributed in an urban area. They are most effectively used to form intelligently coordinated, citywide, one-way, shared-use programs, otherwise known as "mobility-on-demand" systems.

62. The Tech, MIT, Year 1881

As befits the oldest newspaper at MIT, The Tech also was the first newspaper to publish online. A massive scanning and OCR project has made nearly the entire archives from 1881 to the present searchable online. Many alumni, including MIT President James R. Killian, Jr., and Arthur D. Little, began their careers of leadership as editors of The Tech. Financially independent from MIT, The Tech is supported by advertising and donations. It reports on news of campus, local, and international interest, giving a unique perspective on current events. The Tech archives form the most comprehensive documentation of MIT student life for the past 130 years. Other student publications include newsletters and newspapers, literary journals, humor and satire magazines, and research journals, as well as a multitude of formal and informal electronic publications.

63. The world's first electromagnet, Francis Bitter, Year 1936

Professor Francis Bitter's revolutionary design of the first electromagnet came to life for the first time in Boston Edison's Scotia Street substation. During the Second World War, he used his pioneering research towards combat advances by demagnetizing Allied battleships to avoid triggering German undersea mines with magnetic sensors.

64. Discovery of tRNA structure, Alexander Rich, Year 1973

Professor Alexander Rich produced high-resolution x-ray diffraction images that determined the precise structure of tRNA.

65. William Shockley, Year 1956

Dr. Shockley won the Nobel Prize in Physics in 1956 for his development of a solid-state transistor capable of amplifying power. He later directed a prominent semiconductor lab in California, which led to the rise of such firms as Intel, National Semiconductor, and Fairchild Semiconductor.

66. Harold Edgerton

In the 1950s Edgerton was a pioneer of strobe imagery, remembered internationally for the brilliant and transformative photos that he produced.

67. Van de Graaff Generators, Robert Van de Graaff, 1931

The largest air-insulated Van de Graaff generator in the world was built by Robert van de Graaff in 1931. The 40-foot machine is still in use today: the star of daily lightning shows at the Boston Museum of Science.

68. Sea Squirt Robot, MIT Sea Grant's Autonomous Underwater Vehicle Lab, Year 1988

The Sea Squirt was the first robot built by MIT Sea Grant's Autonomous Underwater Vehicle Lab; the results of its work have been used to develop more advanced underwater UAVs, conduct naval and scientific research, and pave the way for future oceanic research.

69. Scratch, Mitchel Resnick, MIT Media Laboratory, Lifelong Kindergarten Group, Year 2007 Allows users to combine new and preexisting sounds, graphics, and program pieces

70. Google App Inventor, Hal Abelson, Year 2010

Hal Abelson is a professor at MIT who, during a sabbatical year at Google, invented software that allows us to create our own Google Apps

71. HP-35 Calculator, Hewlett-Packard Company, Year 1972

William Hewlett was an MIT alumni who used his own pocket to set the standard for the first pocket-sized scientific calculator, the HP-35.

72. GNU Manifesto, Richard Stallman, 1985

The GNU operating system is a UNIX-like system that consists of free software, and the manifesto behind the project shaped modern conceptions of public access to computer software.

73. Project Athena

The result of a $100 million collaboration between MIT, IBM and Digital Equipment Corporation to make computers an integral part of the curriculum.

74. First Transgenic Animal Model (Rudolf Jaenisch)

75. Discovery of the Abundance of MicroRNA (David Bartel)

76. Computer Time-Sharing

Professor Fernando Corbató led the pursuit to find our how to allow multiple users to work with a single computer, which today is essential for many systems. 1960s

78. Differential Analyzer, Vannevar Bush, 1931

This innovation mechanized calculus and was used 24 hours a day during World War II to solve problems from MIT's Radiation Lab.

80. Stair-Climbing Wheelchair, Ernesto Blanco, 1962

In 1962, Blanco submitted a design to National Inventors Council for a stair climbing wheelchair. Although the design never became a reality, Blanco continues to share his "inventional wisdom" with students today.

77. TX-0 Computer, MIT Lincoln Laboratory, 1953–1957

The TX-0 was used in diverse applications; it was originally developed for testing transistor circuitry and very large magnetic core memory but later was used in developing speech and handwriting recognition programs.

79. Whirlwind Computer 1947–1953

Whirlwind was the first digital computer at MIT and it was the first that could operate in real-time.

81. Low-Cost Prescription Eyeglass Lens Fabricator, Saul Griffith, 2004

The fabricator is a simple lens molder that makes prescription lens on the spot. It was designed to benefit third world countries and won the Lemelson-MIT Student Prize in 2004

82. H.M.'s Brain, Suzanne Corkin, 1953–Present

H.M. suffered from epilepsy so part of his hippocampus was removed; Corkin studied how his memory changed and discovered which parts of the brain are important for long-term memory

84. Lyon, Hilda M. The effect of turbulence on the drag of airship (Aero 1932 M.S.)

86. Shannon, Claude Elwood. A symbolic analysis of relay and switching circuits (E.E. 1940 M.S.)

88. Sutherland, Ivan Edward. Sketchpad, a man-machine graphical communication system (E.E. 1963 Ph.D.)

83. Fisher, Alvan. Control of street lights by solar radiation (E.E. 1925 M.S.)

85. Herrera, Rodolfo Eduardo. Amino acid utilization by aerobacter aerogenes and Escherichia coli (Biol 1938 B.S.)

87. Gallager, Robert G. Low density parity check codes. (E.E. 1960 Sc.D.)

89. Fermino, Jessie Little Doe (Jessie Little Doe Christobal). An introduction to Wampanoag grammar. (LingPhil 2000 S.M.)

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90. Strain Gage Denture Tenderometer

In the 1950s, the MIT Food Technology Department's food irradiation research was at the cutting edge of the field; Brody in particular led the way towards objective measurement of food properties with the Tenderometer such as texture and tenderness. This helped food manufacturers design foods with particular qualities. Invented by Aaron Brody in 1956

91. PowerFoot One Prosthetic Foot

While climbing on Mount Washington, Hugh Herr got caught in a severe blizzard and ultimately lost both his legs to frostbite. He engineered his own prosthetics and showed how well designed prosthetics could prevent any appearance of disability. Invented by Hugh Herr in 2007

92. Boston Arm Prototypes

MIT Professor Norbert Wiener broke his hip in 1962, and during his recovery, he speculated that servomechanisms (systems that control motion automatically using feedback) could be used to link the brain to an artificial limb. Turning his idea into reality, the "Boston Arm" was created and was the first artificial limb that used electrical signals from the brain to control its movement. Invented by Robert Mann in 1966–1973

93. "Minksy Arm"

Professor Marvin Minsky created a robotic arm that used a video camera and computer to build with children's blocks and was inspired by his idea that the mind is able to accomplish advanced tasks through a series of simple processes. Invented by Marvin Minsky in 1967–1973

94. OpenCourseWare

An immediate global hit, OpenCourseWare was an idea built on the Institute's core values of accessible learning and academic innovation for the greater benefit. 2000—Present

95. Karl Taylor Compton Lecture Series Yr 1969

In addition to the typical class lectures, MIT campus organizations sponsor several lecture series that bring noted speakers to campus. One of the most prestigious, the Compton Lecture Series, named for MIT President Karl Taylor Compton, originally brought one lecturer to campus for a residency of at least a week, giving three lectures on a general subject for the entire campus community and several more specialized seminars.

96. WMBR 88.1 Radio Station 1946–Present

MIT established the oldest college amateur radio station in the United States with W1MX in 1909; it began broadcasting to the campus in 1946. Students continued to experiment with the technology and made the station the first all-transistorized console in 1961, just in time for MIT's centennial celebration. It continues its broadcast today, and you can tune in to its eclectic musical selections and groundbreaking public affairs programming.

97. MIT Science Reporter, MIT and WGBH Boston 1950s–1960s

In its early days, Boston public broadcasting was supported by MIT which gave WGBH space rented near the Stratton Student Center. A product of that collaboration came as MIT Science Reporter, a unique program in which MIT researchers explained their work in an understandable way to the public.

98. MIT Press 1926–Present

The MIT Press has published 9000 influential works predominantly, but not exclusively, on science and technology. For example, Michael Gazzaniga's classic reference, The Cognitive Neurosciences, was a defining text in his field that moved the discipline towards new areas of research.

99. MIT's World's Fair Photographic Albums 1893–1904

In 1893 and 1904 MIT was invited to participate at the Columbian and Louisiana Purchase World's Fair expositions and took photo albums full of images of its cutting edge research laboratories, the campus, and student life.

101. Soundstair (Christopher Janney, Yr 1978)

Soundstair is Janney's master's thesis project when he was a graduate student at MIT's Center for Advanced Visual Studies. It generates a series of sounds as people traverse the stairs and if you visit the MIT Museum and go to the MIT150 exhibit you will get to hear his work in action!

103. Plasma Sculptures (William Parker, William Parker)

Electricity + Plasma = Light. Nicola Tesla discovered this more than a century ago, but then-undergraduate William Parker "rediscovered" it while doing a physics UROP! This led him to designing plasma globes where the colorful streams of light result from high-frequency alternating current which excites valence electrons that jump to higher energy orbitals and then fall back by releasing the colorful photons of light.

100. Flame Orchard, Gyorgy Kepes, 1970–1972

In the early 19th century, opera houses were lit with gas foot lamps and people began to notice that the flames seemed to jump and leap according to the singer's voice. To study his pheonomena, Kepes built Flame Orchard which was made of units housing gas containers and a sound speaker that vibrated the gas which was lit to show how the flames indeed moved according to the vibrations of sound.

102. Digital Holography (Stephen Benton, Spatial Imaging Group, MIT Media Laboratory, and Brigham and Women's Hospital, Yr 1985)

Professor Stephen Benton was the first to generate a holographic image from a digital database and recognized its value for medice. With the Brigham and Women's Hospital he generated unique images of the human brain from MRI data, and gave doctors a very effective means of viewing the brain in greater context.

104. Analog Music Synthesizer (Lawrence Stabile, 1971–1974)

Larry Stabile built the analog music synthesizer out of his passion of engineering and arts and this led the way to today's digital home audio systems.

106. One Laptop per Child XO Laptop (Nicholas Negroponte, yr 2002)

Professor Nicholas Negroponte kicked off the effort to provide a complete laptop for $100 to the world's poorest children so that education could transcend economic circumstance. more than one million of its elegant designs are in the hands of children across the globe.

108. "Silk Purse" (Arthur D. Little, yr 1921)

"Making silk purses from sows' ears and flying a lead balloon are timeworn clichés for impossibility. This made it all the more stunning when Arthur D. Little, Inc., announced they had succeeded at both." (From MIT Museum placard) The silk purse is spun from gelatin fibers made out of pigs' ears.

105. MIT $100K Entrepreneurship Competition 2010 Winner (C-Crete Technologies)

aims to change radically how the world makes cement; the competition encourages entrepreneurship and innovation

107. Invention of the Strain Gauge (Arthur Ruge, yr 1938)

It is a tiny piece of high-resistance filament bent in a zigzag pattern and fixed in a rigid base (glue). It measures stress on any surface by measuring the changes in electrical resistance of the current running through the wires of the gauge. It is used in virtually all commercial weighing scales, in every structural stress test—and it even allowed astronaut Neil Armstrong to declare: "The Eagle has landed."

109. American Research Development Corporation (1946)

ARD was the first publicly traded venture capital firm, and MIT president Karl Compton was key in supporting its establishment

110. Perfect Cup of Coffee Research (Samuel Cate Prescott, 1930s)

" In 1920, the National Coffee Roasters Association gave Professor Samuel Cate Prescott $40,000 to establish a new laboratory devoted to perfecting coffee. The resulting guidelines—one tablespoon of coffee per eight ounces of water, just short of boiling, in glass or ceramic containers, never boiled, reheated, or reused—were the result of three years of study." MIT Museum placard

111. Technicolor Film Camera (Herbert Kalmus, 1930s)

Alumni Herbert Kalmus and Daniel Comstock founded Technicolor in 1915 and developed several different processes for making color films. MIT put the "Tech" in Technicolor.

112. Boston Wind Tunnel Models (Frank Durgin and Wright Brothers Wind Tunnel, 1970s)

In the 1960s, the windows of the Green Building cracked and fell many stories and whenever it was windy, it was nearly impossible to enter or exit the building. The AeroAstro Department conducted extensive wind tunnel investigations to analyze the problem and they were subsequently engaged by the city of Boston to do similar work on the other side of the Charles River.

113. Studies of Boston's Geology (William O. Crosby, 1878–1907)

"As an undergraduate at MIT in the 1870s, William O. Crosby fell in love with the rock collection at the Boston Natural History Society." (MIT Museum) Later, as a professor, he introduced his students to the geology of the Boston Basin and he was engaged to evaluate the foundation conditions for the new MIT campus in Cambridge.

114. Boston's Central Artery/ Tunnel Plan (Frederick Salvucci, 1970s)

"The megaproject buried the aging Central Artery elevated highway, reconnected the city with its waterfront, opened a third harbor tunnel, cut back pollution, and gave Boston a new landmark—the Leonard Zakim Bunker Hill Memorial Bridge." (MIT Museum) It was sheperded by MIT alumni and now senior lecturer Frederick Salvucci.

115. Boston Chinatown Master Plan (Tunney Lee, y 2010)

"MIT architects and urban planners have shaped many features of Boston. The most recent compelling effort is the Boston Chinatown Master Plan released in the spring of 2010 following a two-year process led by the Chinatown Gateway Coalition." (MIT Museum)

116. Braille Typewriter (Ernesto Blanco, 1970s)

"Blanco designed a model that provided electric power for the embossing force, and applied the force only once per letter rather than once per indentation. Blanco's Braille typewriter was commercialized and is still widely used. "

117. Seaswarm (Senseable City Lab, 2010)

The Seaswarm robot is an easily maintained, autonomous robot that is designed to skim the surface of contaminated water and collect as much as 20 times its weight in oil - without collecting any water.

118. Apollo Block II Computer Guidance, Navigation, and Control System Simulator (Draper Lab, 1960s)

This simulator was used to train astronauts and to test the hardware and software for every Apollo mission.

119. Voyager Plasma Science Experiment (MIT Space Plasma Group, 1977-present)

"The Voyager I and II spacecraft are now the human-made objects farthest away from Earth on the longest exploratory mission in history. Aboard the two spacecraft are five instruments supporting five ongoing experiments."

120. Brainwave Correlator Computer (Research Laboratory of Electronics, 1955)

"Walter Rosenblith started the Communications Biophysics Laboratory at RLE to apply modern electronics and Norbert Weiner's mathematical work to the poorly understood phenomenon of electromagnetic waves in the brain. This unit is one piece of a large computer built in collaboration with groups at MIT and at Massachusetts General Hospital"

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121. Adaptive Optics (MIT Lincoln Laboratory, 1980s)

"Adaptive optics systems use linked sensors, computers, and deformable mirrors to constantly adapt to the changing conditions of the atmosphere. The sensor measures aberrations in the atmosphere, and the computer uses this information to reshape the mirror to provide a more accurate image. MIT Lincoln Laboratory was among the leaders in developing this technology. The two mirrors on display are from larger apparatus developed for highly classified military research projects."

122. Atomichron, Cesium-Beam Atomic Clock (Jerrold Zacharias and National Company, 1953–1956)

"The Atomichron was the first piece of quantum electronics equipment sold commercially but, more important, its introduction would greatly aid future work on missile guidance, navigation, and control systems."

123. Elements of Linguistic Structure (Noam Chomsky, 1955)

"This manuscript from 1955 is one of Chomsky's first works on his influential concept of generative grammar: the idea that humans have some innate knowledge of grammar from birth, and that language acquisition cannot totally be explained by the relatively sparse stimuli they are exposed to as pre-verbal children."

124. Numerically Controlled Milling Machine (MIT Servomechanisms Lab, 1950s)

125. "Viruses harnessed to split water" (Belcher et al, 2010)

"MIT team's biologically based system taps the power of sunlight directly, with the aim of turning water into hydrogen fuel."

126. "Rapid analysis of DNA damage now possible" (Engelward et al, 2010)

"Now a team of MIT bioengineers has devised a new way to rapidly reveal DNA damage under a variety of conditions, promising to make such analysis a routine aspect of applications such as drug screening and epidemiological studies of the effects of environmental agents."

127. "Canned, good" (Samuel Cate Prescott, 1895)

"More than 100 years ago, 2 pioneering scientists figured out how to keep canned food safe."

128. "Cold asteroids may have a soft heart" (Department of Earth, Atmospheric and Planetary Sciences, 2005)

"Partially molten small bodies may be abundant in space, and may have given the Earth its oceans."

129. Charles River, Side Scan Sonar Towfish (Martin Klein and Klein Associates, Inc., yr 1970)

Harold Edgerton. Famous for his high-speed photographs, Edgerton made equally important contributions to underwater exploration, including the development of side scan sonar technology. In the early 1950s, Edgerton began experimenting with sonar to focus deep-sea photographs.

130. Weather Radar Research (Spiros Geotis, 1960–1963)

"MIT's pioneering role in weather radar began at the Radiation Laboratory during WWII.Geotis prove one could use radar to predict the location of hailstorms, and the quantity and detail of citizen data also showed that it was possible to estimate the size of the hailstones." MIT Museum

131. Jamaica Pond notes/Sanitation research (Ellen Swallow Richards, late19th century)

"When you turn on the tap in the United States, you can be sure the water you drink is safe. For that, you can thank Ellen Swallow Richards, MIT's first woman graduate (1873) and woman faculty member. Richards' work led to the first state water-quality standards in the United States, the first municipal sewage treatment plant (located in Lowell), and standards for the use of chlorine to maintain water quality." Museum

132. Maps for the Perceptual Form of the City Study (Professors Kevin Lynch and Gyorgy Kepes, 1954, 1960)

"MIT researchers for "Perceptual Form of the City" went into Boston to investigate citizens' mental maps, asking passersby questions such as, "How do I get to the Public Garden?" This research helped Lynch form his early theories of city planning, "

133. *"Turning windows into powerplants" (Vladimir Bulović, Richard Lunt, 2011)*

"If a new development from labs at MIT pans out as expected, someday the entire surface area of a building's windows could be used to generate electricity — without interfering with the ability to see through them."

134. *"The bouncing gas" (Martin Zwierlein, 2011)*

"Clouds of gases that bounce off each other could help physicists model the behavior of high-temperature superconductors and other unusual materials."

135. *"Nano-sized vaccines" (Darrell Irvine, 2011)*

"MIT engineers have designed a new type of nanoparticle that could safely and effectively deliver vaccines for diseases such as HIV and malaria. "

136. *"A new spin on superconductivity?" (Young Lee and Daniel Nocera, Tianheng Han, 2011)*

"MIT scientists have synthesized, for the first time, a crystal they believe to be a two-dimensional quantum spin liquid: a solid material whose atomic spins continue to have motion, even at absolute zero temperature. It could help to unlock the mystery of high-temperature superconductors."

137. *"The code for survival" (Thomas Begley, Peter Dedon, 2010)*

"Cells fight stress by reprogramming a system of RNA modifications, researchers find."

138. *"Going nature one better" (Markus Buehler, 2010)*

"MIT researchers aim to learn biology's secrets for making tough, resilient materials out of simple components, and then improve on them."

139. *"Enhancing the power of batteries" (Paula Hammond, 2010)*

"They found that using carbon nanotubes for one of the battery's electrodes produced a significant increase — up to tenfold — in the amount of power it could deliver from a given weight of material, compared to a conventional lithium-ion battery. "

140. *Tunable Vancomycin Releasing Surfaces for Biomedical Applications (1. Anita Shukla; 2. Sareena N. Avadhany,; 3. Jean C. Fang,; 4. Paula T. Hammond, 2010)*

Work led to "layer-by-layer assembly of polymer multilayer films is applied to create vancomycin delivery coatings." Vancomycin is an antibiotic

141. *"Teasing out malaria's genetic secrets" (Jacquin Niles, 2010)*

"Biological engineer's new approach to studying gene control could lead to new drug targets."

142. *"Imaging fish on the fly" (Mehmet Fatih Yanik, 2010)*

"New MIT technology allows high-speed study of zebrafish larvae, often used to model human diseases."

143. *"Building organs block by block" (Ali Khademhosseini, 2010)*

"Tissue engineers create a new way to assemble artificial tissues, using 'biological Legos' — cells transformed into bricks."

144. *"New way to grow microwires" (Tonio Buonassisi, 2011)*

(there is a REALLY!!! awesome picture and subtitle about this at http://web.mit.edu/newsoffice/2011/silicon-microwires-0204.html) "Researchers find simple, inexpensive method to produce silicon wires for sensors, batteries and solar cells. Molten droplets of copper dissolve silicon out of a surrounding silicon-rich gas, and then the silicon precipitates out at the bottom of the drop to gradually build up a silicon microwire. "

145. "New hope for terahertz" (Sushil Kumar;Chun Wang I. Chan; Qing Hu; John L. Reno, 2011)

"Terahertz rays — radiation between microwaves and infrared rays on the electromagnetic spectrum — are a promising means of detecting explosives, but they've proven hard to generate cost effectively. However, a laser that generates terahertz rays operates at higher temperatures than some thought possible making it a viable option."

146. "Selection by size and substance" (Karen Gleason, Ayse Asatekin, 2011)

"Technique could produce filters that select molecules according to their chemical properties and dimensions."

147. "Graphene electrodes for organic solar cells" (Vladimir Bulović; Jing Kong, 2011)

"A promising approach for making solar cells that are inexpensive, lightweight and flexible is to use organic (that is, carbon-containing) compounds instead of silicon. The problem is making electrodes that can carry current to and from the cell that are equally flexible, and researchers may have found the solution in graphene electrodes."

148. "Detecting whether a heart attack has occurred" (Michael Cima, 2011)

"new implants can detect three proteins whose levels spike after a heart attack. Such devices could be used to monitor patients who are at high risk of heart attack"

149. "Hidden in plain sight" (George Barbastathis,Baile Zhang,Yuan Luo,Xiaogang Liu, 2011)

"A new approach to invisibility cloaking gets much closer to the science-fiction version, using simple and inexpensive materials such as calcite crystals."

150. "The surprising physics of cats' drinking" (Roman Stocker, Pedro Reis, Sunghwan Jung (Virginia Tech), Jeffrey Aristoff (PRinceton))

"A new study reveals that even the way cats lap up liquid displays the perfect balance for which they're known."

Nobel Spotlight:
Professor Richard Schrock
MIT Chemistry Department

Introducing a new MURJ special feature article: Nobel Spotlight. Each issue, an MIT faculty member who has won the Nobel Prize will be interviewed.

Recently, MURJ had the opportunity to sit down and talk with the recipient of the 2005 Nobel Prize in Chemistry, Richard R. Schrock of MIT's Chemistry Department. Schrock won the prize for his work in clarifying the structure and mechanism of olefin metathesis catalysts, used in reactions that redistribute alkylene fragments. There are widespread applications of this research, including their use in the production of medicines, polymers, and enhanced fuels.

See what you have in common with Professor Schrock under "Quick Facts" or read up on some of his other research interests here too.

MURJ: Do you have any hidden talents?

Richard Schrock: Well, that depends on what you call a talent! I don't sing, I don't play an instrument, I don't perform in plays – I don't have any of those talents. I do woodworking – in my basement; I got my own shop.

MURJ: If you could meet anyone in the world – dead or alive – who would it be?

RS: Albert Einstein.

MURJ: What is your favorite class to teach?

RS: Well, I like 5.112!

MURJ: The coolest thing about MIT is….

RS: The undergraduates!!

MURJ: What is your favorite memory about MIT?

RS: Hmmm… being offered to come here.

MURJ: If I wasn't a Nobel Prize researcher I would be a….

RS: Well, I think I would still be a chemist at MIT…so I guess I would be a non-Nobel Prize winner. I'm not going to be a lawyer, or you know – well one always dreams about other lives, like being a concert pianist or something.

MURJ: Can you give us a summary about the research that won you the Nobel Prize [in layman's terms for those don't know what olefin metathesis is]?

RS: Sure – well, carbon forms bonds to itself; single bonds, double bonds, triple bonds. Now, the double bonds are very common in nature, and they are found in natural products and so on. What I did was discover how a catalyst – unknown what it was actually – "chopped up" those double bonds and made other double bonds. A double bond chopping reaction.

MURJ: How did you get involved with that research?

RS: Oh, well it started in about 1974 – when I was at DuPont – and I made a compound that does that reaction.

MURJ: So was winning the Prize always a goal for you?

RS: No – I mean, I never thought about winning the Nobel Prize.

MURJ: How did you find out you won?

RS: A phone call. 5:30 AM.

MURJ: What was your first reaction?

RS: Saying "thank you!" A lot!

MURJ: Who was the first person you told?

RS: Well, a lot of people found out, but the first person I told besides my wife was my mother…she didn't actually know what it was.

MURJ: The coolest thing about winning a Nobel Prize is…

RS: You are always a Nobel Prize winner… even if you aren't here anymore.

MURJ: So where is your prize right now?

RS: Well the prize consists of three parts. A medal, a certificate that looks just like that [points to a copy on his wall], and then you get some money. Well, here is one – the medal [takes out replica from display case]. The real one looks exactly like this one but this one is gold plated… I bring in the real one of those [the certificate; for 5.112]… it's a hand-drawn, bound, painted certificate. [The cash prize] is personal money, and I put it in the bank… a good place to put money.

MURJ: What is your favorite memory from the ceremony?

RS: My favorite memory, boy… my favorite memory… actually seeing my wife and family in the audience. My extended family – her brothers and sisters; my brothers and sisters. Well, I don't have any sisters – 2 brothers.

MURJ: What is your current research? Are you pursuing a second prize possibly?

RS: Well, one doesn't pursue ANY prize; but I am not currently pursuing a second prize. My research is similar to what I got the prize for – but only much, much better. Many more implications.

MURJ: For our readers out there – do you accept UROPs?

RS: Yes. I have two right now.

MURJ: Do you have any advice for any MIT students who may one day want to win the Prize or go into chemistry?

RS: Well, if you want to go into chemistry – sure go into chemistry – it's great. Everything is chemistry. And… don't think about winning the Nobel Prize.

MURJ: Anything last thoughts you want to share with our MURJ readers?

RS: Science is great. It's our future.

For more information on Professor Schrock, visit http://www.mit.edu/~chemistry/faculty/schrock.html

Quick Facts:

Birthplace: Indiana
High School: Mission Bay High School (San Diego, CA)
Alma Matter: University of California, Riverside
Favorite Sports Team: Celtics
Favorite Restaurant in Boston/Cambridge: Troquet (Where he Celebrated his Nobel Prize Win)
Favorite Song: Classical Music Pieces
Length of Time at MIT: 36 years (Since 1975)
Favorite MIT eatery: Under the Small Dome – Looking Up
Favorite MIT Eatery: Café 4
Number of Papers Published: 510

Professor Richard Schrock, MIT Chemistry Department

MURJ UROP Summaries

Layer-by-Layer (LbL) Assembly on Stimuli-Responsive Hydrogels[1]

Margaret Lloyd[2], Paula Hammond[3], Eunice Costa[4]

1. Department of Chemical Engineering, MIT, 2010-2011
2. Student Contributor, Class of 2012, Deparment of Chemical Engineering, MIT
3. Principal Investigator, Department of Chemical Engineering, MIT
4. Supervisor, Department of Chemical Engineering, MIT

The aim of this project is to produce temperature- and pH-sensitive hydrogels on two-dimensional (2D) surfaces in order to have a high-throughput platform that would optimize thin-film build-up of biocompatible polyelectrolytes. Overall, it is hoped these constructs will promote cell adhesion and introduce moieties for a biosensing application that will aid the understanding of cell behavior in tissues and during cell development. This 2D platform will be used to mimic the 3D thermo-responsive behavior of hydrogel microparticles, or microgels.

Hydrogels are flexible polymers known for their significant water content and applications in various biomedical processes. LbL assembly is a common technique to create surface coatings with fine control over film composition and nanostructure by alternating layers of anionic and cationic polymers. In the 2D study, we are copolymerizing thermo-responsive N-isopropylacrylamide NIPAAm with the pH-sensitive methacrylic acid (MAA) in water to form hydrogels on functionalized silicon surfaces; these hydrogels are thus sensitive to both temperature and pH. The outer layers are alternating biocompatible polyelectrolytes known to promote cell adhesion; we hope to control diffusion of cell-secreted factors into the hydrogels by not only manipulating the surface chemistry, but also by taking advantage of the responsive behavior of our hydrogels to external stimuli. Ultimately, these gels could be used as fluorescent sensors to identify when certain factors are released by cells or as stimuli-responsive "gates" to regulate diffusion rates of factors at various pH and temperature conditions.

There are three parts to this project: polymerization of hydrogels on silicon slides and microgels; LbL assembly of polyelectrolytes on these hydrogels; and characterization of the constructs. In the Fall, my project supervisor and I tested various methods of silanization and polymerization in order to find the optimal protocol for our project. Silanization is used in order to create reactive groups on a silicon slide that will enable the synthesis of the polymer on the surface. It was discovered that washing slides sequentially in 1.0M NaOH, 0.1M HCl, and DI water, followed by silanizing in an ethanol solution with 5%(v/v) 3-Trimethoxysilyl methacrylate prepared slides most effectively for our project. Successful silanization was confirmed by X-ray photoelectron spectroscopy (XPS).

In parallel to the 2D platform, microgels were used as a 3D spherical model of hydrogel behavior. One of the main issues we faced in this UROP was losses of within LbL assembly on the microgels during washes. This process is imperfect, so a small fraction of the microgels were removed along with excess polymer and impurities in solution. In December, we worked on optimizing the assembly of Poly (Allylamine Hydrochloride) (PAH) and polyacrylic acid (PAA) polyelectrolyte layers, but found that maximizing the number of bilayers also increased losses with each wash between layers. In an attempt to offset losses, we increased our polymer solution volume from 10mL to 50mL, but this increased the centrifuge time for washes nearly 6-fold. Our protocol for a 10mL solution was used thereafter, calling for three washes of each layer after centrifuging for 30 minutes.

During IAP, I constructed a four-bilayer assembly of poly-L lysine (PLL), a cationic polymer, and poly-L glutamic acid (PGA), an anionic polymer. In the Spring, I continued to silanize silicon surfaces to optimize our polymerization protocol, and started another LbL assembly of four Chitosan/Dextran sulfate (DS) bilayers in order to test a variety of polymer assemblies with our silicon slides. In the end, the Chitosan/DS assembly was not stable enough for continued study.

Once we produced the hydrogels via our optimized polymerization protocol, we assessed the characterization of the constructs; this characterization included evaluating the thin-film build-up and composition in the characterization stage also sought to assess the potential cell-interactive properties of the microgels by optimizing the integration of the microgels onto 3D agarose gels used for 3D tissue engineering. A range of agarose hydrogel concentrations was used to generate varied gel physical structures, as it has been shown that agarose gel mesh size, or the size of pores within the gels, decreases with increasing concentration. For the integration of our microgels, it was found that only agarose concentrations below 0.5 wt% would not deform microgel structure significantly. An ideal gel percentage that was low enough to maintain the microgels' spherical shape but high enough to remain solid at a variety of temperatures remains unidentified.

We observed that the polyelectrolytes' response to an increase in temperature from 24 to 37° C depends on whether the last layer is positively or negatively charged irrespective of the actual polyelectrolytes involved. In the PLL/PGA system, for example, microgels with layers ending in cationic PLL decreased in size with increasing temperature. The same behavior was observed in the PAH/PAA system for assemblies ending in cationic PAH. For assemblies ending in anionic PGA and PAA, microgel size did not change with changing temperature.

Future work will expand our studies to other polyelectrolyte systems, such as anionic poly-D (sodium 4-styrenesulfate) and cationic poly (dialyl dimethyl ammonium chloride). We also plan to study the localization of polyelectrolytes in microgels to better understand the "on-and-off" thermo-responsive behavior. Fluorescently labeled polymer layers will be tracked to observe whether they form defined layers around the microgels or fit inside the polymer meshes within the gels. Whereas PAH has been shown to form defined layers, more study is needed to understand the behavior of our other polyelectrolytes. Furthermore, cell studies will be performed with the integration of these microgels into 3D engineered tissues.

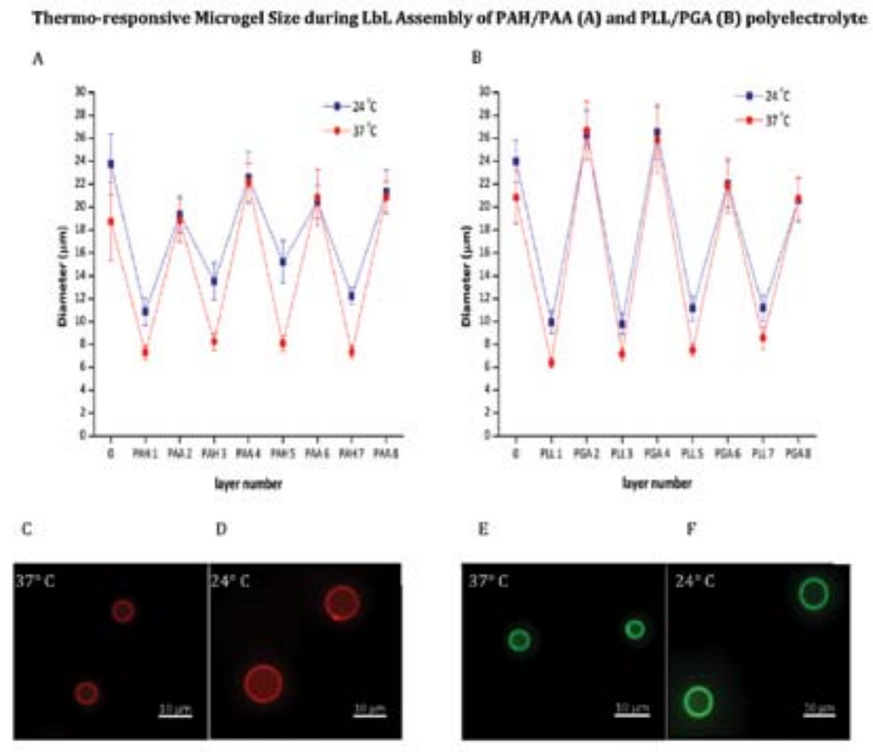

Figure 1. Thermo-responsive behavior of PLL/PGA and PAH/PAA Layer-by Layer assemblies. At the end of anionic polyelectrolyte layers (PAA and PGA), microgel diameter does not change with temperature (A and B). At the end of cationic layers (PLL and PAH), microgel diameter increases with decreasing temperature. Confocal microscopy micrographs show that microgels ending in positively-charged Rhodamine-B labeled PAH respond to temperature change from 37° C (C) to 24° C (D); similarly, E and F show how microgels ending in positively-charged FTIC-labeled PLL increase in size due to a temperature change from 37° C to 24° C, respectively.

Enhancing the Nucleation of Aspirin Using Polymer Microgels of Designed Chemistry[1]

Zeina Ali Siam[2], Ying Diao[3], Professor Bernhardt Trout[3]
1. Department of Biological Engineering, MIT, 2011
2. Student Contributor, Class of 2012, Deparment of Biological Engineering, MIT
3. Supervisors, Department of Chemical Engineering, MIT

Developing a continuous manufacturing process to replace the currently used batch-based processes in the pharmaceutical industry is a emerging area in the field of chemical engineering with the motivation of enhancing the efficiency of the process and the quality of the final product. One fundamental step towards achieving this aim is promoting nucleation, the initial stage of crystal formation, of a drug while maintaining high quality production and controlled dosage. Yet, nucleation is very difficult to control because the crystal formation is contingent upon experimental conditions and properties of interfaces present in a chemical system. The weak intermolecular interactions and flexible molecular conformations of organic molecules pose further challenges towards efficient nucleation.

The project, which was conducted in Trout and Hatton Labs at MIT Chemical Engineering Department as part of the Novartis-MIT Center for Continuous Manufacturing, aimed at utilizing polymeric microparticles to control the crystallization of pharmaceutical compounds by tuning the polymer chemistry. The nucleation kinetics of model compounds, such as Aspirin and acetaminophen, were investigated and correlated with the underlying molecular interactions. Previous work at MIT studied the nucleation properties of these compounds in the presence of crosslinked polyethylene glycol diacrylate (PEGDA), a derivative of the extensively employed polyethylene glycol (PEG) in the pharmaceutical industry, and showed that the variation of mesh or pore size of the crosslinked polymer (a.k.a gel) significantly affected the nucleation rate of the compounds [1]. The next stage after this discovery, which this UROP was about, involved *rational chemical modification* of the PEGDA microgels to enhance the nucleation of the model compounds, one of which, Aspirin, will be discussed below.

To enhance the nucleation of the model drug, PEGDA microgels were modified by crosslinking with 4-acryloylmorpholine monomer (AM). The kinetic properties of Aspirin nucleation before and after chemically modifying PEGDA microgels were investigated, with the hypothesis that by functionalizing the microgels, the Aspirin nucleation barrier would be reduced. The experiments aimed at quantifying the extent of polymer-drug intermolecular interactions by measuring the equilibrium partitioning coefficient of drug in the gel from solution, as well as measuring the nucleation induction time, or the time needed for the formation of a detectable amount of crystals, to assess the effectiveness of the PEGDA microgels in promoting nucleation.

Experimental results presented in Table 1 below show that before functionalizing PEGDA microgels, the induction times for Aspirin were long, and markedly affected by the gel mesh size. Upon chemically modifying the gel, however, the induction times for Aspirin crystallization fell dramatically overall, and the optimal mesh size for the fastest nucleation shifted to a lower value. The data also shows that Aspirin crystallization became less sensitive to the gel mesh size, as the induction times for crystallization were within an order of magnitude for most mesh sizes. This result may be attributed to a stronger polymer-drug interaction, which leads to higher local concentration around the microgels to trigger Aspirin nucleation more rapidly. This hypothesis was further verified by the partitioning coefficient measurement, which revealed an Aspirin concentration much higher in the gel compared with that of the bulk solution.

Table 1 below shows the Aspirin average nucleation induction time (τ) for different mesh sizes of PEGDA before and after chemically modifying the gel.

M_n (g/mol)	130	200	400	575	700
Gel type | τ (min)					
PEGDA	∞	910±40	63±3	1900±100	6600±1100
AM-co-PEGDA	770±70	93±1	227±9	230±10	210±15

Enhancing the crystallization of drugs is a breakthrough in the field of pharmaceutical industry. Whereas drugs are currently synthesized in batches, employing functionalized materials can speed up nucleation, promising a new route to control the crystallization process. Future directions for the current work would be enhancing crystallization along with controlling the crystal morphology, the crystal size distribution, etc.

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Nonparametric Estimation of Gasoline Demand[1]

Scott Landers[2]

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Municipal organic waste (MOW) management is an unresolved challenge in urban areas across developing countries. Waste-picking, or scavenging of recyclable materials from mixed solid waste, is a source of livelihood for a significant portion of the population, especially marginalized groups. A large fraction of plastic, glass, metal and paper waste is successfully diverted by the informal recycling sector and formalized cooperatives. However, organic waste is usually considered to have no economic benefit. Accounting for more than 50% of total municipal waste production, the vast majority of organic waste is left to degrade anaerobically in landfills or in open accumulations that pose serious threats to human health. This uncollected organic material that humans consider to be waste is actually a viable source of energy and nutrients for a myriad of organisms. Yet, there has been limited research on the implementation and control of biological treatment of municipal organic waste. My UROP project is GrubCycle, which aims to create a market for recycling this waste by turning it into a value-added product. The social business model allows individuals to invest in the GrubCycle system, then use it as a small business venture to generate personal income. This improves the local community both by reducing the volume of organic waste and by increasing the net income. Both of these effects increase the standard of living for the residents of these slums. The GrubCycle project will be implemented in the largest urban slum in the world, Kibera, in Nairobi, Kenya. Marginalized communities such as those in the slums of Nairobi often bear the consequences of MOW management shortcomings. They live and work in the most contaminated environments and have the least access to resources (e.g. nutrition and preventative health measures) that could protect them from diseases associated with this contamination. For the technical solution, black soldier fly (BSF) grubs are used to digest 50 to 80 percent of the waste. Once the grubs metamorphosize into prepupae, they are self-selecting. This means they will climb out of the feeding bin onto a dry surface where they can then be harvested. After harvesting them, they are then sold to local vendors who will process them as a source of protein in animal meal. The final product of the UROP will be a self-housed, low-tech system that includes completely encloses the digestion site of the BSF. Here, they will be able to breed and digest the waste in a complete cycle, a GrubCycle.

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Neuronal Labeling in Ventral Tegmental (VTA) by Viral Gene Delivery through Cre-dependent Targeting *in vivo*[1]

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The ventral tegmental (VTA), a small nucleus of the brain located in the midbrain, plays a role in the reward system, motivation and several psychiatric disorders. Approximately, 60% of the VTA is comprised of dopaminergic neurons that produce the neurotransmitter dopamine upon activation [1]. These neurons compose much of the reward circuitry in the brain and are involved in mesostriatal and the mesolimbic pathways. Disruptions in these pathways cause disorders such as schizophrenia, Parkinson's disease, and attention deficit hyperactivity disorder. However, the detailed connectivity of these neurons is not well understood. The small size of the VTA, previous technical limitations and restrictions in the imaging of synaptically connected neurons has prevented much progress in specifically targeting this structure.

To this end, by a project of my own design, we have taken advantage of the capabilities of the Cre recombinase protein (henceforth, Cre) to specifically target fluorescence to dopaminergic neurons in the VTA. Cre, a Type I topoisomerase, has the ability to homologous align and recombine DNA between loxP sites [2]. When a STOP sequence, a sequence that prevents further transcription, is positioned between two loxP sites, any flanking coding sequences will be expressed in the presence of Cre due to the excision of the STOP. We have used transgenic mice that express Cre specifically in VTA dopaminergic cells (henceforth, vtaCre) and an adeno-associated virus serotype 8 (AAV8) to show expression of enhanced yellow fluorescent protein (EYFP) specifically in VTA neurons [3]. The AAV8 contains a plasmid with a loxP-STOP-loxP sequence flanked by EYFP, which then expresses EYFP specifically in VTA neurons of the vtaCre mice [4]. To infect neurons, 200 nl of the AAV8 was injected directly into the VTA of the vtaCre mice and allowed to survive for 14 and 21 days. The animals were sacrificed and perfused with 4% paraformaldehyde (PFA) for 20 minutes. The brains were excised and permitted to post-fix in 4% PFA for 48 hours. The brains were cryo-protected in 30% sucrose/PBS for 24 hours and sectioned to 50 µm sections. Immunohistochemistry was performed with primary antibodies (Millipore) against tyrosine hydroxylase (TH), a marker for dopaminergic neurons, and red fluorophore-conjugated secondary antibodies (Invitrogen). The sections were stained for DAPI, mounted to slides and cover slipped.

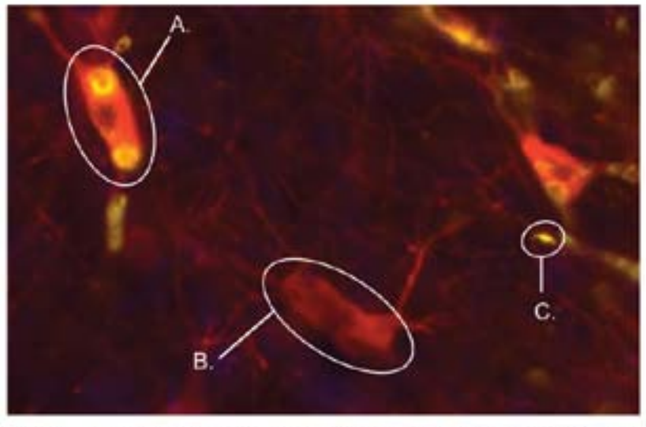

Figure 1. A. Doubly labeled – Cre positive cells infected with AAV8-EYFP (yellow) and labeled by anti-TH immunostaining (red). B. Singly labeled – AAV8-EYFP negative cells labeled only by anti-TH immunostaining (red). C. EYFP aggregate from apoptotic event hypothesized due to cytotoxicity of AAV8.

Upon fluorescent imaging, three neuron types existed in the VTA: (1) unlabeled, (2) only labeled red and (3) doubly labeled red and yellow (Figure 1). Unlabeled cells were non-dopaminergic cells. The red-only cells were neurons that did not express EYFP, either through lack of infection or lack of Cre, and thus only fluoresced due to the anti-TH immunostaining. The doubly labeled cells were Cre cells that were infected by AAV8 and labeled by anti-TH immunostaining. The fact that only these three cell types existed is evidence that the EYFP was expressed only in VTA cells. Furthermore, due to the anterograde movement of the AAV8, axonal projections were seen in both the hippocampus and amygdala, which agrees with current literature [5]. We did notice some portion of VTA cell death in proximity to the injection site, which we hypothesize was due to AAV8 cytotoxicity. As a result, there were some aggregates of EYFP outside of cell bodies due to apoptotic effects.

We have so far shown a method for specifically targeting VTA neurons based on viral gene delivery that is Cre-dependent. This method will allow us to further identify the detailed connectivity that is involved in the dopaminergic pathway that the VTA is involved in. We have already begun experiments to increase transsynaptic specificity with the introduction of a second virus.

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Quantifying Promoter Strength through GFP Expression in E. coli[1]

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A promoter sequence precedes a gene, and serves to regulate gene expression. Cells can moderate protein expression levels through the binding of transcription factors and polymerases to promoter sequences. Synthetic regulation of gene expression can lead to more efficient incorporation of recombinant enzymatic pathways vital to reactions in the pharmaceutical and biofuel industries. We are currently examining several constitutive and inducible promoter systems to quantify promoter strength for use in these pathways.

By altering merely several bases in a promoter sequence, one can drastically change gene expression levels [1]. The ability of a promoter sequence to influence its corresponding gene's expression is referred to as a promoter's strength, with strong promoters yielding lots of mRNA transcript. Promoter libraries such as the Anderson and Stephanopoulos libraries contain promoter sequences of varying strengths derived by random mutagenesis of several bases within a constitutive promoter [2]. Inducible promoter systems, which are commonly used in metabolic engineering to externally control expression, have not been compared to these systems.

We are comparing the strength of commonly used inducible promoter systems, such as Trc, T7, and Tet, to each other and to characterized promoter libraries, such as the Anderson and Stephanopoulos libraries. Quantifying promoter strength in these systems can lead to more efficient expression of and greater flux through recombinant enzymatic pathways. Using standard molecular cloning techniques, we have positioned various promoters directly upstream of GFP and cloned the plasmids into E. coli cells. By measuring fluorescence as a function of turbidity, or cell concentration, we can derive the steady-state fluorescence, F_{ss}, which is directly proportional to promoter strength. Using this method, we can compare the strengths of various promoters.

Certain sequences approximately 100 base pairs upstream of the promoter can also affect transcription, possibly by permitting additional factors to bind or escape. We have attached various lengths of Trc and Tet upstream sequence to a mid-strength Anderson promoter, Pcon56, and cloned these systems into E. coli as well. Using the same technique as above, we can compare the strength after addition of the upstream sequences to determine how strong the influence is and where the influence of the pre-promoter region ends.

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MURJ Reports

Who is Sustainable?[1]

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Tightly coupled to resource and energy conservation, reducing greenhouse gases that pollute and imbalance the environment is absolutely essential to achieving global sustainability. This cross-sectional and time-analysis study averaged over years 2004-2005 models C02 emissions with key world development indicators to conclude that wealth, energy consumption and industrial activity, and population growth are positively correlated with C02 emissions. A model removing the confounding effects of these variables shows that C02 emissions have decreased in this time frame in countries characterized by highest revenue and highest public education expenditures. An increase in x indicates an increase in social democracy within a nation and a negative dy/dx manifests the presence of working sustainable policies there. Therefore, the countries that are most successful at implementing renewable energy policies are social democracies or welfare states. This paper concludes with a policy recommendation that states can solve the energy crisis by transitioning to a social democracy or welfare regime type. States should also use energy taxes as a mechanism to promote renewable energy usage and teach all its residents how and why to act sustainably; both endeavors also are most easily achieved under the all-encompassing infrastructure of a social democracy or welfare state.

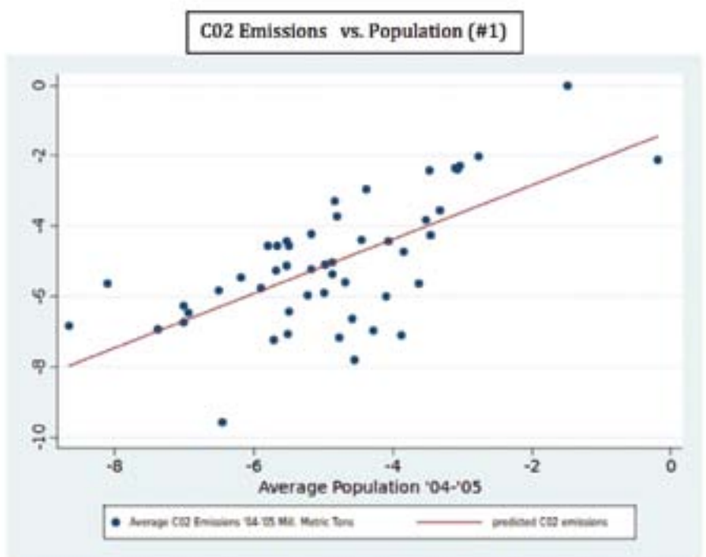
Evidence of sustainable behavior is quite visible in social-democratic and welfare nations. Visit a Nordic state or Germany, for example, and see the windmills dotting the landscape. Most houses and buildings sport solar panels. Observe all the bicycles ridden, the small autos driven, the automatic timers on showers and lights. You can't find a disposable grocery bag in Germany, and if you want beer, you've got to carry your reusable crate to the supermarket. Coming home to America from a Euro-trip, I wonder, "Why don't we have these initiatives here?" There are probably many reasons for this difference, but it begs the question: Are left-leaning countries in general more prone to implementing renewable energy policies? Are they the best at encouraging sustainable behavior, and if so, why?

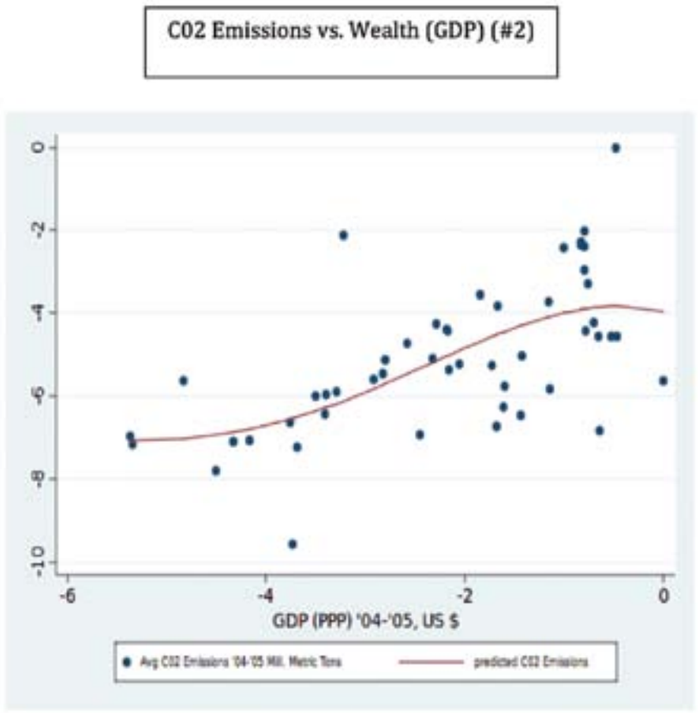
Political ideology and market orientation play critical roles in shaping energy policies. Political orientation influences economic activity and population trends, which are two main drivers of the global energy crisis. Economic competition especially in the liberal market often has compelled businesses to use environmentally harmful practices in order to get the upper hand or to make a profit. Those enterprises, focusing on short term gain, operate mostly in centrist or rightward leaning nations; and their governments, encouraging competition and money-making as the first and foremost route to power, do not stop them from being wasteful. The latest research on global warming and current demographic and economic trends shows that unless we intervene to alter drastically our current behavior, our society is on a trajectory towards collapse. Consequently, sustainable development is a priority for policy makers, a concern for citizens, and a focal point for researchers in hard and soft sciences.

I predict that the effectiveness of sustainable policies in center-right regimes pales in comparison to sustainable efforts in welfare regimes, which support a mixed economy of socialism and capitalism and prioritize maximizing the welfare of their citizens. Citizens and leaders of social democratic nations appear to have a more sustainable attitude: realizing that we are all in this world together, citizens and businesses cooperate with one another more than they compete and keep the long-term perspective in mind. I want to test the positive correlation between renewable energy policies and social democracy. With knowledge of a useful relationship like this, I can recommend that countries transition to social-democracies or welfare states if they want to become sustainable, or that sustainable developers and policy makers support a switch to social democratic or welfare-type policies and infrastructure.

There are a variety of studies on the general relationship between society and renewable energy. The following literature shows that a sustainable perspective necessitates public involvement in sustainable efforts, depends upon a cooperative, long-term focused business ethic, and a desire to employ renewable energy technologies in the global economy while becoming aware of resource efficiency. These forming factors of sustainable development already are in place in social democratic nations and popular their citizens. Therefore, this literature provides support for my causal claim that the success of a nation's renewable energy policies depends upon how social democratic it is.

Kenneth Boulding concludes that the energy industry is best controlled by public hands [1]. This analysis is useful to my research because social democracies support public control and influence whereas republican-democracies and conservative states favor liberal competition between private enterprises. Boulding's analysis of knowledge and transportation with respect to energy suggests that globalization and the liberal market increase energy dependency. Implying that liberal market competition has led to overuse of exhaustible energy supplies, this causal link illuminates the urgency with which politicians may want to rework market orientation and corresponding political ideology.





Other authors discuss how ideology and market orientation influence sustainable development. Fergus illuminates the need for cooperation and mutual responsibility among citizens, governments, and businesses in order to solve the energy crisis [2]. Perelman argues that countries will switch from democratic-republican systems to social-democratic systems because of the global transition to renewable energy [3]. Noll shows how promotion of renewable energy, efficient and shared resource use, clean technology, and sustainable mobility are most typical in social democracies [4]. In Energy for the New Millennium Goldemberg tries to detect countries that are switching to sustainability by using variables like energy use while considering economic, industrial, and population growth among nations [5]. Concluding that the attitudes of those who enforce and adhere to renewable policies is the crucial determinant for their success, Goldemberg recommends a long-term outlook and a comprehensive approach, such as the ones typically employed by public enterprises characteristic of social democracies, as most conducive to sustainable development.

In summary, this portion of literature is indicative of a mutual relationship between renewable energy policies and social democratic management and mindset. It appears to support the claim that a sustainable future requires a transition away from the business-oriented approach characteristic of market economies dominated by private industries, such as the United States, and towards a public-benefit-oriented approach characteristic of a modern social democracy, which champions a combination of both socialism and capitalism. In the latter type of nations, which support mixed economies while guarding and advancing their citizens' economic and social well-being, it does look like sustainable policies would be more easily implemented and citizens would more willingly adhere to and approve of them.

Analysts can use C02 emission rates as an indicator of where renewable energy policies are working. Scientists have shown that humans must endeavor to curb the rate of C02 emissions from industrial activity, because the current emissions rate threatens the balance of our ecosystem by overloading the environment's capacity to reabsorb C02 [6]. A common finding in research about society and C02 emissions is that economic output as measured in GDP is strongly and positively correlated with increasing C02 emissions [6,7]. Studies like those by Raupach and Tucker go on to show that C02 emissions have decreased in recent years in the wealthiest of the wealthy countries. Throughout the literature, different authors hypothesize why this happens. It is an important question to answer because if we can identify a common cause or set of causes for these decreasing C02 emissions rates, then we can use this as a basis for formulating policies designed to reduce emissions throughout the world, overtime. Tucker hypothesizes that countries with wealthier citizens are more likely to implement environmental protection policies, which is why the rate of increasing emissions decelerates.

Dietz developed a stochastic model to estimate how anthropogenic forces change the globe by producing polluting greenhouse gases [8]. Dietz's study finds that population and economic growth exacerbate C02 emissions. He recommends the IPAT: Impact = Population*Affluence*Technology equation as a good way to model human impact on the environment. Similarly to Raupach's and Tucker's articles, the effects of affluence, as measured by GPD per capita, on C02 emissions reach a maximum but then decline at highest levels of affluence. Dietz suggests that this trend occurs because more affluent countries can spend more money to teach its citizens about the benefits of using renewable energy sources.

In addition to energy consumption, industry, and GDP, the literature shows that population and taxes are important to the analysis of C02 emissions and emissions reductions programs. C02 emissions are apportioned differently across populations and the sum of individual C02 emissions aggregate to produce large national, and ultimately global, effects. Using the idea of "common but differentiated responsibilities" of individuals, Chakravarty consequently concludes that successful emissions reductions policies must target individual behaviors [9]. By weighing monetary estimates of environmental damage with economic costs, Boyd assesses the net benefits and disadvantages of energy taxation as a way to curb C02 emissions and concludes that the economy will benefit from reducing energy consumption and C02 emissions via energy taxes [10]. The challenge to using policies like taxes to curb pollution is to find the level of energy reduction that is environmentally beneficial without being economically harmful.

Overall, the literature on C02 emissions tries to make recommendations for how policy makers should maximize the number of efficient countries, defined to be countries that have large economic output, as measured by GDP, but emit less carbon dioxide than countries with similarly sized economies. Because social democracies implement more taxes, are very wealthy, and spend more on government programs that target individual behavior in order to cultivate a nation-wide cultural norm, my literature review supports my claim that social democracies are the most efficient. The literature leaves a question unanswered that, if explored, may shed light on my hypothesis. Since the wealthiest of wealthy countries have successfully reduced C02 emissions rates in recent years, is there a commonality among them that could be the crucial variable in successful sustainable development, and if so, what is it?

I think social democratic government is the shared and key factor. So, I perform the following data analysis in order to determine if social democracies implement the most effective renewable energy policies. I measure the effect of sustainable energy programs by analyzing the presence of fossil-fuel based C02 emissions, a greenhouse gas pollutant that imbalances the environment. A decreasing rate of C02 emissions in a region where economic output remains constant indicates the presence of successful renewable energy policies there. My model verifies that with an increase in population and economic activity there is an increase in C02 emissions, and shows that the wealthiest of wealthy nations have decreased their rate of C02 emissions in recent years. Then, I build a second model that considers some indicators of social democracy to see if these countries share that political ideology. I use variables like annual public education expenditure and annual average revenue both as percent of GDP because social democracies reputably tax their citizens very highly and spend the most on public education. I use variable similar though not identical to those found in the literature: in my case I choose primary energy consumption, industrial intensity, GDP per capita, and average population within

each nation [5,6,7,8]. Wanting to consider ecological and social policy effects as well, I throw in land area and primary enrollment rate as another control variable. My dataset is both a cross-sectional and time series analysis. My model show that as education expenditures and revenues go up C02 emission rates go down. Therefore, I conclude that the countries where renewable energy policies are working are social democracies.

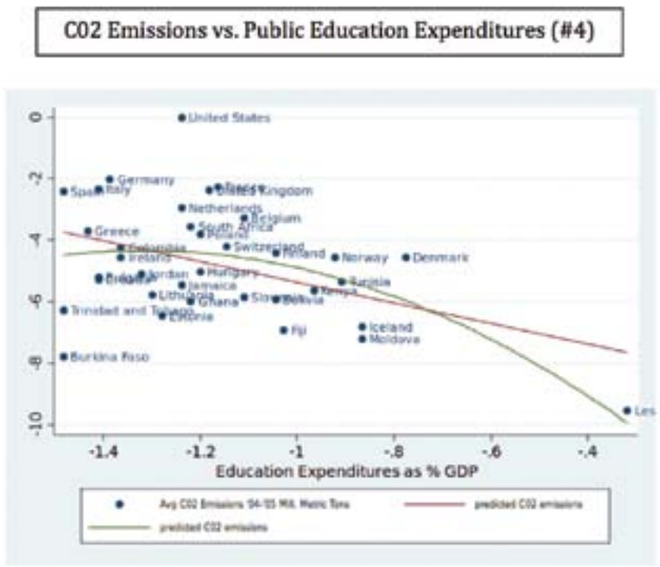
Since C02 emissions are largely created by human activity, I plot C02 emissions averaged over years 2004 and 2005 across 50 randomly selected countries with respect to economic and world development indicators. The Energy Information Administration supplies my C02 emissions data, measured in million metric tons averaged over years 2004-2005. I also take from the Energy Information Administration data on Total Primary Energy Consumption per US dollar of GDP Purchasing Power Parity (PPP) in Quadrillion BTU and population in millions, both averaged over 2004-2005. Taken from the International Monetary Fund database (IMF), Gross Domestic Product (GDP) per capita based on purchasing-power-parity (PPP) is measured in US dollars and averaged over years 2004 to 2005. I retrieved my data on total revenue, excluding grants, measured in percent of GDP averaged over 2004-2005 from the World Bank Organization database. I also created a measure of industrial intensity by dividing industrial share of GDP by agricultural share of GDP data, averaged over 2004-2005, which I retrieved from the World Bank Organization. The CIA World Factbook supplied my data on public education expenditures as percent of GDP over years 1990-2006 and land area in km2. Data on total national annual percentage net enrollment rate at the primary level, averaged over 2004-2004, is taken from the World Bank Organization. All variables are logged after being converted to a 0-1 scale. For means and dispersions, see tables 10-16.

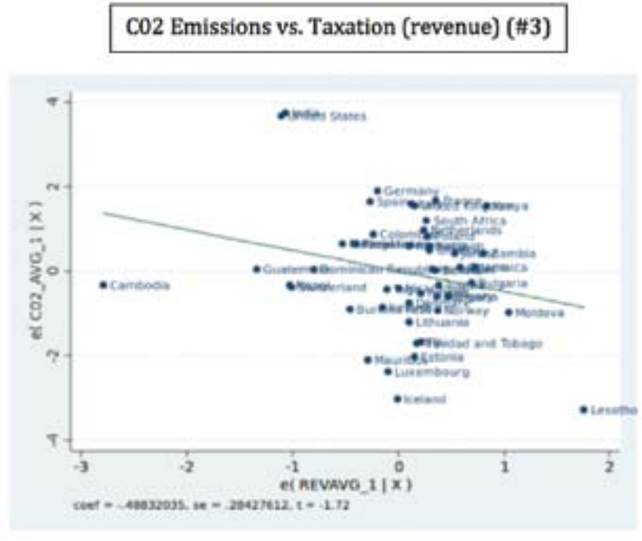
In accord with the literature review, my model shows that higher populations and larger economies lead to statistically higher rates of C02 emissions. My first bivariate regression with 50 observations and 48 degrees of freedom shows that for every 1% increase in average population there is a 76.8% increase in C02 emissions (fig. 1, tab. 1). My second bivariate regression, but with GDP per capita instead of population as the explanatory variable, shows that for every 1% increase in GDP per capita there is a 78.9% increase in C02 emissions (fig. 2, tab. 2). A tight confidence interval, high t ratio, large R2 and P value of 0.000 for both regressions shows that the data is statistically significant, practically eliminates the possibility of the null hypothesis, and increases the confidence in the accuracy of my sample. Using the concept of individual behavior aggregating to produce large global effects, these findings make sense: Firstly, the more people there are in one place, the greater the sum of individual C02 emissions, and secondly, larger economies consume more fossil fuel, which consequently produces more C02 emissions. My second regression also corroborates my literature review, in which other social scientists have found that C02 emissions in recent years hit a maximum and then level off and begin to decrease among the wealthiest of wealthy nations.

A multi-regression analysis with 41 degrees of freedom, 50 observations, and 8 explanatory variables, namely industry intensity, public education expenditure, land area, energy consumption, average revenue, GDP per capita, primary education enrollment, and population average removes some of the confounding effects of the variables (tab. 3). Revenue and education spending look promising because they show a negative relationship, with coefficients of -.6% and -23.5% respectively. Neither land area nor industry intensity show substantively significant correlation. For every 1 % increase in industry intensity there is a 2.4 % increase in C02 emissions, and for every 1% increase in land area there is a 3% decrease in C02 emissions. The negative coefficient for land area is surprising because one might expect larger countries to have a more extensive transportation infrastructure that would require fossil fuel use. Let it be noted that this negative relationship between land size and C02 emissions in no way indicates that actual C02 emissions decrease. Larger land implies an increase in the size of forests and lakes that act as carbon sinks, which means that more of the region's C02 is absorbed before it can be measured. Therefore, C02 emissions data in larger countries could be an underestimate of the actual value, so land area's negative coefficient does not at all mean that larger countries have more successful renewable energy programs. Strangely, the industry intensity regression coefficient is smaller than anticipated, since industrialization corresponds with high use of fossil fuels like coal. This may be due to confounding effects from other variables, but is more likely due to measurement or sampling error: the t- and p-values for both industry intensity, as well as land area, are not ideal.

The multivariate regression shows that GDP per capita is now less substantively significant than population average, but both regression coefficients jump to the 80%-range due to interaction effects from other variables in the dataset. The relationship between energy consumption and C02 emissions is also statistically and substantively significant, as for every 1 % increase in energy consumption there is a 40% increase in C02 emissions. On average, in sample predictions will be off the mark by about 45% and this model explains about 94% of the increase in C02 emissions. There is less than a 0.001 probability of observing the relationship between average population and GDP by chance and less than a 0.002 probability of observing the energy consumption relationship by chance. Tight confidence intervals and T-values of 8.00, 12.63 and 3.35 for GDP, energy consumption, and average population respectively allow me to be fairly confident in the accuracy of my sample and to reject the null hypothesis.

The multivariate regression's conclusions about C02 emissions with respect to large economies and populations are roughly the same as the bivariate's. Accordingly, an increase in energy consumption and industry intensity also has a positive effect on C02 emissions. This relationship directly recommends that economies must shrink in order to decrease C02 emissions. However, most nations would be adverse to this recommendation because they want to pursue an aggrandizement of power via augmenting their economy. So, in order to avoid collapse, nations must delicately balance their goals for national economic profit and power with environmental conservation. Since both population and industry have a positive effect on C02 emissions, policy makers could make national economies more efficient by encouraging industries and individuals to shift from a dependence on fossil fuel and coal and





shift towards a dependence on alternative or renewable energy sources.

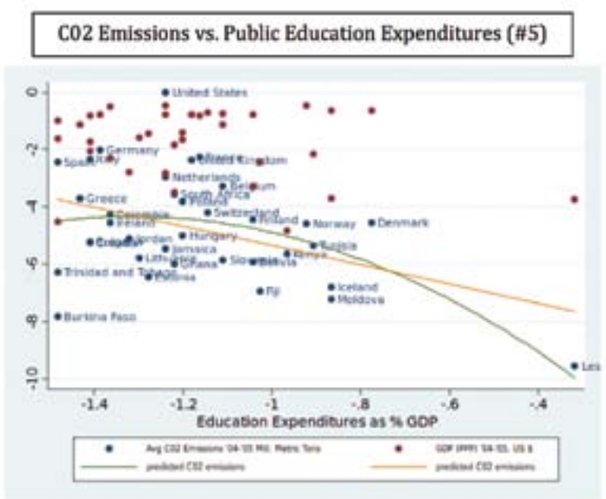
The revenue variable is an indicator of welfare because average revenue means higher taxes, and welfare states tax the most. After dropping Slovenia, an outlier, from my cross-sectional dataset, I ran a bivariate regression of average revenue as percent GDP and C02 emissions with 49 observations and 47 degrees of freedom (tab. 4). With every 1% increase in revenue there is a 47.4% increase in average C02 emissions. This relationship is to be expected because as revenue increases national wealth increases, which I have already shown to be positively correlated with C02 emissions.

Consequently, I run a multivariate regression of C02 emissions, revenue, and GDP per capita in order to isolate revenue from overall wealth. Controlling for GDP per capita, for every 1% increase in revenue there is a 48.9% decrease in C02 emissions (figure 3, tab. 5). In this sample with 49 observations and 47 degrees of freedom, I am 95% sure the true effect of revenue on C02 emissions lies between 8.3% and 106%. This model predicts 42.7% of the data, and on average in sample predictions about percent C02 emissions are off the mark by 140 percentage points. The probability of observing this relationship by chance is less than 0.093 and I am fairly confident in the accuracy of my sample representation. The avplot that controls for GDP clearly shows that C02 emissions rates decrease as revenue increases.

Since high revenue is a social democratic indicator, this regression supports my hypothesis. The negative coefficient for revenue also indicates the presence of well-working energy taxes. Taxing industries, transportation systems, and individuals on the amount of C02 they emit is one way that countries encourage people to switch to using systems that run on renewable energy, like electricity or water power. However, high and widespread energy taxes may not be a globally applicable solution to the energy crisis. Energy taxation may work well in a welfare state where high taxes are accepted already as a norm, but implementing these same high taxes in a republican democracy like the United States would likely not be as successful at curbing C02 emissions because the United States lacks the all-encompassing infrastructure of a welfare state that would incorporate and encourage such a widespread and ingrained policy action. Third world countries might not welcome energy taxes because rapid economic development is their foremost priority.

One must keep in mind that an increase in overall revenue may not necessarily indicate the presence of energy taxes in particular; instead, it could mean only that citizens are subject to higher income and residential taxes. If this is the case, an alternative explanation is that citizens have less money to spend on commodities like big cars, which use lots of fossil fuel. To address this explanation I would have to break down the components of average revenue within each country to see what portion, if any, comes from energy taxes.

Welfare states are famous for their free education, especially their free higher education, while non-social-democracies like the United States are notorious for their universities' volcanic price tags. So, I use public education expenditure as percent of GDP as another indicator of welfare states. Controlling for wealth (GDP per capita) and population, for every 1% increase in public education spending there is a 32.7% decrease in C02 emissions (tab. 6A). There is less than a .1 probability of observing this relationship by chance and I am 95% sure that the effect of public education spending is between -71.9% and 6.6%. The model explains 92.4% of the data and on average in sample predictions are off the mark by 51.2%. Given the breadth and scope of this project, these numbers show fair strength in the accuracy of the sample representation and the model accounts for a good portion of the data. Re-adding Slovenia and removing population as a control variable bring the effect of public education spending to -94.4% (tab 6). Both results are highly substantively and statistically significant so I analyze this further.



Since both the literature and my model show that C02 emissions decrease at highest levels of affluence, I want to focus in on the wealthy states. So from my 50-observation sample, I dropped countries whose education expenditures fell roughly below the mean. A bivariate regression with 35 observations and 33 degrees of freedom shows that for every 1% increase in annual public education spending there is a 334% decrease in C02 emissions. In addition to being substantively significant, this is statistically significant due to its high t-value of 2.74 and low P value of 0.01 (fig. 4, tab. 7).

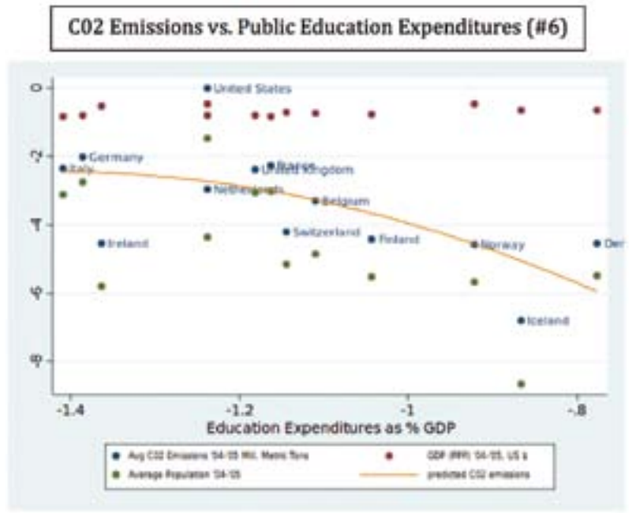
Removing the confounding effect of wealth causes the coefficient to decrease almost one hundred percentage points, yet it is still extremely substantively significant (fig. 5; tab. 8). On average, in sample predictions about C02 emissions are off the mark by 136%, and we are 95% sure that the true effect of education expenditures on C02 emissions is between 53.4% and 132.5%. The model explains

about 52% of the data, and there is less than 0.017 probability of observing this relationship by chance. Therefore, I am fairly confident in the accuracy of my sample representation and can reject the null hypothesis, namely that an increase in public education expenditure when controlling for wealth has no effect on C02 emissions.

Because welfare states are known to have sky-high public education expenditures, I conclude that welfare states are most effective at reducing C02 emissions. An increase in public education spending may lead to better, widespread education that results in higher knowledge levels throughout the nation. Superior education programs emphasize teaching about current problems like the global energy crisis, which increases awareness of the need for sustainable behavior, so in such nations there is pervasive appreciation for the values of conserving energy, like by walking to work or eating low on the food chain, and so less C02 is emitted from these societies.

An alternative explanation is that these countries spend so much on education that they cannot support their industry and economy as much. If industry and manufacturing suffer then C02 emission rates will suffer too. As a corollary, another alternative explanation may be that an increase in education expenditure means more people are spending time in school or pursuing jobs in academia rather than joining the industrial labor force, so as education expenditure goes up, economic production, and therefore C02 emissions, goes down. To eliminate this possible alternative explanation I control for economy size and activity and drop countries whose GDP per capita fell below the mean. This creates a sample with 13 observations and 8 degrees of freedom. Controlling for GDP per capita, average population, and energy consumption, for every 1% increase in education expenditures there is a 57.3% decrease in C02 emissions (tab. 9). A scatter plot with a curvilinear fit shows again that disregarding population size, among the wealthiest nations with similar energy consumption, as government spending on public education increases C02 emissions decreases (fig. 6). This further corroborates my hypothesis that welfare states have the most successful renewable energy policies, and that education encourages sustainability.

Using recent decreases in C02 emissions as an indicator of working sustainable initiatives is a possible threat to construct validity. I assume that recent decreases in C02 emission rates in large economies are due to the implementation of policies that encourage renewable energy usage and sustainable behavior. However, this trend could happen because some countries are treating the symptoms instead of the cause of the energy crisis: maybe they have created a way to absorb C02 emissions quickly, such as by planting more trees or by creating some new, sci-fi-like technological machine that intakes C02. This results in an undervalued measure of C02 emissions. Reabsorbing emitted C02 is a step towards mitigating global warming but it is not a step towards solving the energy crisis by reducing the amount of energy a society uses. If this were the case, I would not be able to conclude that countries with decreased



C02 emission rates have successful renewable energy policies. I can address this threat to validity by controlling for land area and searching within each country for evidence of symptomatic rather than causal remedies to global warming.

Using revenue and public education expenditures as indicators of social democracy is another possible threat to construct validity. Modern social democracies tax highly and spend larger proportions of their funds on education, but the assumption that all countries that do so are social democracies could be in error. Perhaps there is a country that does these two things but lack all other indicators of a social democracy, so is therefore not a social democracy. I could address this threat to validity by investigating countries for additional indicators of modern social democracy.

Reverse causation in my model is highly unlikely. It is doubtful that an increase in C02 emissions would somehow cause GDP per capita or population to grow. It is also highly implausible that a decrease in C02 emissions would lead to a transition to liberal ideology. I also include several explanatory variables in my multivariate regression, but of course there could be other variables that I omitted from my study that are worth considering, such as internal conflict, or religious makeup of society.

GDP per capita is a possible confounding variable. With respect to the observation that the wealthiest of countries have decreasing C02 emissions, one could consider that wealthy countries may have transitioned from manufacturing to knowledge based economies. Consequently they have less domestic industry and manufacturing so their C02 emissions decrease. However this may not be the case because wealthier people tend to adopt more extravagant lifestyles, whereby they typically consume more energy and as a result emit more C02. A more likely concern is that GDP may change ideology: perhaps as countries grow wealthy, they become more liberal and homogenous and transition to social democracy. Another argument is that wealthier countries can better afford to implement renewable

energy policies, so that is why I controlled for GDP per capita and sometimes focused on only the wealthiest nations.

Though my model assumes that my data was collected accurately, I must keep in mind that measurement errors in data collection are a threat to internal validity. Instrumentation discrepancies when measuring C02 emissions across countries, and variations across the globe in data collection methods on revenue and education, could cause inconsistencies. I try to account for other threats to internal validity, like maturation of subject and history, by averaging almost all variables across two years. Throwing away outliers, like Slovenia, also is a crucial part of my methodology because it enables the regression to be a more accurate representation of the sample as a whole.

A way to improve external validity of the method is to increase the sample size. However, data availability limits the size of the sample. Some countries as of yet did not have data for one or more of my key explanatory variables: the 50-country sample I used for the first few regressions was essentially randomly selected because it was what remained after merging all datasets. Ideally, one hundred or more countries would provide larger statistical significance.

My research supports my hypothesis that modern social democratic governments are best at solving the energy crisis. The most important finding leading to this conclusion is that C02 emissions go down as annual national public education spending and taxation go up. Since high x-values equate to social democratic countries and a negative dy/dx indicates successful renewable energy policies, this negative relationship means that social democratic regimes are making the most successful effort to promote sustainability and enforce renewable energy policies. One possible explanation for this relationship is that social democracies, built around a collaborative ideology, possess an infrastructure and mentality more conducive to encouraging sustainability and enforcing renewable energy policies. Their citizens visibly adhere to sustainable practices and do not seem at all begrudging towards using renewable energy sources. Additionally, my research supports the conclusion that energy taxes and education themselves may directly increase the success of sustainable policies. With this knowledge, I can make a policy recommendation that nations switch to a modern social-democratic system so that they can better implement sustainable policies, use energy taxation to promote renewable energy usage, and educate their citizens as to how to live sustainably.

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Codebook and Data Sources:

country_name = country name

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C02_AVG_1 = Average C02 Emissions '04-'05 Mill. Metric Tons

YEAR_2004_C02 = C02 Emissions 2004

YEAR_2005_C02 = C02 Emissions 2005

C02_AVG = Average C02 emissions in 2004 and 2005

C02_AVG_1 = Average C02 emissions over 2004 and 2005, converted to a 0 to 1 scale, and logged

International Energy Information Administratin, EIA. 2004-2005. “Population (millions)”. http://tonto.eia.doe.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=93&pid=44&aid=33

POPAVG_1 = Average Population '04-'05 POPAVG_1 = Average Population '04-'05

pop2004 = population in millions in year 2004

pop2005 = population in millions in year 2005

POPAVG = average population over 2004 to 2005

POPAVG_1 = average population over 2004 to 2005, converted to a 0 to 1 scale, and logged

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GDPPCAP_AVG_1 = Gross Domestic Product PPP '04-'05, US $

YEAR_2004_GDPPCAP = GDP based on PPP per capita GDP 2004

YEAR_2005_GDPPCAP = GDP based on PPP per capita GDP 2005

GDPPCAP_AVG_1 = GDP based on PPP per capita GDP averaged over 2004 to 2005, converted to a 0 to 1 scale, and logged

CIA World Factbook, CIA.1990-2006. “Public Education Expenditure as percent GDP”. https://www.cia.gov/library/publications/the-world-factbook/rankorder/2206rank.html

education_expenditure_1 = public education expenditure as percent GDP

education_expenditure = education expenditure as percent GDP

education_expenditure_1 = education expenditure recoded from 0 to 1, logged

Education and education_1 are variables in the dataset that are not used in any regressions

Energy Information Administration, 2004-2005. “Total Primary Energy Consumption/US dollar GDP PPP, Quadrillion BTU” http://www.eia.doe.gov/emeu/international/energyconsumption.html

ECAVG_1 = Total Primary Energy Consumption/US dollar GDP PPP, Quadrillion BTU, '04-'05

EC2004 = Energy Consumption in year 2004

EC2005 = Energy Consumption in year 2005

ECAVG = Energy Consumption averaged over 2004 to 2005

ECAVG_1 = Energy Consumption averaged over 2004 to 2005, converted to a 0 to 1 scale, and logged

World Bank Organization, World Bank. 2004-2005. "Revenue Excluding Grants as Percent GDP." http://ddp-ext.worldbank.org/ext/DDPQQ/showReport.do?method=showReport

REVAVG = Revenue, excluding grants % GDP

revenue04 = average revenue as percent GDP in 2004

revenue05 = average revenue as percent GDP in 2005

REVAVG = average revenue in 2004 to 2005

REVAVG_1 = average revenue recoded from 0 to 1 and logged

CIA World Factbook, Central Intelligence Agency. 2010. "Land Area KM Squared." https://www.cia.gov/library/publications/the-world-factbook/rankorder/2147rank.html

land_area_1 = Land Area KM Squared

land_area = land area in KM squared

land_area_1 = land area recoded from 0 to 1 and logged

World Bank Organization, World Bank. 2004-2005. "Industry, value added as percent GDP." http://ddp-ext.worldbank.org/ext/DDPQQ/member.do?method=getMembers

INDAVG_1= average industry as % GDP

ind_2004 = industry, value added as percent GDP 2004

ind_2005 = industry, value added as percent GDP 2005

INDAVG = average industry over 2004 – 2005 as percent GDP

World Bank Organization, World Bank. 2004-2005. "Agriculture, value added as Percent GDP." http://ddp-ext.worldbank.org/ext/DDPQQ/member.do?method=getMembers.

AGRAVG_1= average agriculture as % GDP, logged.

agr_2004 = agriculture, value added as percent GDP 2004

agr_2005 = agriculture, value added as percent GDP 2005

AGRAVG = average agriculture over 2004-2005 as percent GDP

industrial_intensity = measure of industrial intensity = industry, value added as percent GDP/ agriculture, value added as percent GDP

industrial_intensity_1 = Industrial Intensity = average industry as % GDP/ average agriculture as % GDP, converted to 0-1 scale, logged

Education Atlas of World Bank Organization, World Bank, 2004-2005, “Gross Enrollment Rate, Percent Primary” http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTEDUCATION/EXTDATASTATISTICS/EXTEDSTATS/0,,contentMDK:21603536~menuPK:4580850~pagePK:64168445~piPK:64168309~theSitePK:3232764,00.html

education_1 = total national annual net enrollment rate at the primary level in %, averaged over 2004-2004, converted to 0-1 scale

TABLE 1 C02 emissions and population regression

Number of obs = 50 DF = 49 R^2 = 0.4407 Root MSE = 1.364

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Population	.767	.125	6.15	0.000	.516	1.018
Constant	-1.309	.639	-2.05	0.046	-2.59	-.024

TABLE 2

regress C02 emissions and GDP Per Capita (PPP)

Number of obs = 50 DF = 49 R^2 = 0.376 Root MSE = 1.44

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
GDP Per Capita (PPP)	.788	.146	5.38	0.000	.494	1.08
Constant	-3.34	.378	-8.84	0.000	-4.104	-2.58

TABLE 3

regress C02 emissions, GDP Per Capita (PPP), Energy Consumption, Population, Public Education Expenditure as % GDP , Land area, Industrial Intensity, Revenue as % GDP

Number of obs = 50 DF = 41 R^2 = 0.947 Root MSE = .4517

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
GDP Per Capita (PPP)	.816	.102	8.00	0.000	.609	1.02
Energy Consumption	.396	.118	3.35	0.002	.157	.634
Population	.891	.070	12.65	0.000	.749	1.033
Land area	-.029	.063	-0.46	0.651	-.157	.099
Industry Intensity	.024	.099	0.24	0.810	-.177	.225
Education expenditure	-.235	.206	-1.14	0.262	-.652	.182
Education enrollment	.201	.285	0.71	0.483	-.373	.776
Revenue	-.006	.009	-0.64	0.524	-.025	.013
Constant	1.873	.632	2.97	0.005	.598	3.149

TABLE 4

regress C02 emissions and GDP Per Capita (PPP) dropping Slovenia, an outlier

Number of obs = 49 DF = 47 R^2 = 0.056 Root MSE = 1.787

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Revenue	.474	.283	1.67	0.101	-.096	1.044
Constant	-4.503	.412	-10.93	0.000	-5.33	-3.67

TABLE 5

regress C02 emissions, GDP Per Capita (PPP), Revenue, without Slovenia, an outlier

Number of obs = 49 DF = 46 R^2 = 0.427 Root MSE = 1.407

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
GDP Per Capita (PPP)	1.001	.183	5.46	0.000	.632	1.37
Revenue	-.488	.284	-1.72	0.093	-1.061	.083
Constant	-3.401	.382	-8.90	0.000	-4.169	-2.631

TABLE 6

regress C02 emissions, Public Education Expenditure, GDP Per Capita (PPP)

Number of obs = 50 DF = 47 R^2 = 0.416 Root MSE = 1.408

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Education Expenditure	-.944	.527	-1.79	0.080	-2.004	.117
GDP Per Capita (PPP)	.886	.153	5.78	0.000	.577	1.194
Constant	-4.438	.715	-6.21	0.000	-5.87	-3.00

TABLE 6A
Regress CO2 emissions, Public Education Expenditure, GDP Per Capita (PPP)
Number of obs = 50 DF = 46 R^2=.924 Root MSE = .51

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Education Expenditure	-.326	.195	-1.68	0.100	-.719	.0656
GDP Per Capita (PPP)	.927	.056	16.62	0.000	.815	1.039
Population	.843	.048	17.58	0.000	.747	.939
Constant	.624	.388	1.61	0.115	-.157	1.40

TABLE 7 regress CO2 emissions, Public Education Expenditure
Number of obs = 35 DF = 33 R^2 = 0.185 Root MSE = 1.74

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Education expenditure	-3.347	1.22	-2.74	0.010	-5.837	-.859
Constant	-8.704	1.467	-5.93	0.000	-11.69	-5.719

TABLE 8 regress CO2 emissions, GDP per Capita (PPP), Public Education Expenditure
Number of obs = 35 DF = 33 R^2 = 0.518 Root MSE = 1.359

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
GDP Per Capita (PPP)	.924	.199	4.70	0.000	.524	1.32
Education expenditure	-2.45	.974	-2.52	0.017	-4.44	-.471
Constant	-6.020	1.28	-4.70	0.000	-8.63	-3.41

TABLE 9 regress CO2 emissions, GDP Per Capita (PPP).Population, Energy Consumption, Public Education Expenditure
Number of obs = 13 DF = 12 R^2 = 0.986 Root MSE = .242

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
GDP Per Capita (PPP)	.856	.551	1.55	0.159	-.415	2.12
Population	.927	.049	18.67	0.000	.813	1.042
Energy Consumption	.671	.222	3.02	0.017	.159	1.18
Education Expenditure	-.573	.477	-1.20	0.264	-1.67	.526
Constant	2.37	.864	2.74	0.025	.377	4.36

TABLE 10 CO2 emissions

Mean	Std. Dev.	Min	Max
-5.04	1.81	-9.56	0

TABLE 11 GDP Per Capita (PPP)

Mean	Std. Dev.	Min	Max
-2.18	1.40	-5.37	0

TABLE 12 Population

Mean	Std. Dev.	Min	Max
-4.88	1.56	-8.66	-.185

TABLE 13 Land Area

Mean	Std. Dev.	Min	Max
-4.81	1.731	-9.036	-.554

TABLE 14 Education Expenditure

Mean	Std. Dev.	Min	Max
-1.39	.408	-2.46	-.318

TABLE 15 Revenue

Mean	Std. Dev.	Min	Max
-1.52	2.83	-20.13	0

TABLE 16 Energy Consumption

Mean	Std. Dev.	Min	Max
-2.53	.705	-4.46	-.996

TABLE 17 Industrial Intensity

Mean	Std. Dev.	Min	Max
-3.06	1.38	-5.83	0


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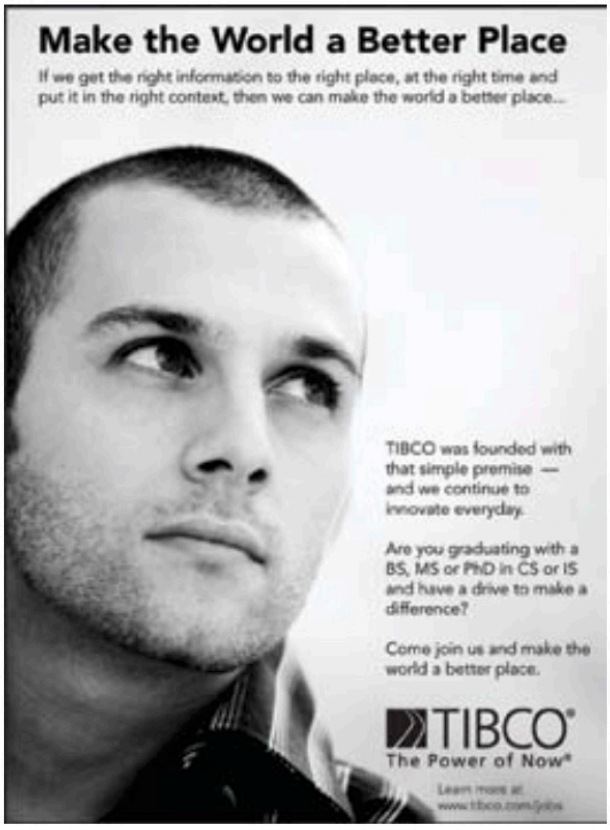
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Seeing the impact of disease drives me to find tomorrow's medical breakthrough.

Brian Hodous
Senior Principal Investigator
Medicinal Chemistry
EMD Serono, Cambridge, USA

As a medicinal chemist working in the first stages of drug discovery, I strive to create new molecules in the laboratory that could someday become an innovative treatment for a serious disease. It is a marathon process that requires perseverance and teamwork.

As a medicinal chemist, it's important to get professional satisfaction from the small, everyday successes. Synthesizing a molecule that makes it all the way to clinical trials is exceptional, and only less than 1% of medicinal chemists have developed a compound that actually becomes an approved drug. What motivates me is thinking about what a medical breakthrough could mean for patients.

I had a good friend who died of pancreatic cancer. It was shocking how quickly this vibrant, healthy person deteriorated before my eyes. When I see those images in my mind, it makes me want to work even harder.

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