20A: Essential Infrastructure Systems in Environmental Health: Electricity

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Essential Infrastructure Systems in Environmental Health

• Electricity
  – The common currency.
  – How is it generated?
  – How is it distributed?
  – Systems impact on environmental health.

• US National Academy of Engineering identified the electrical grid as the “the most significant engineering achievement of the 20th Century.”
Health Concerns

- Extraction of raw materials for electrical generation (coal, oil, gas) and their transport.
- Stationary source air, water, soil pollution and waste.
- Climate change.
- Lung diseases, many different cancers, STDs.

Electricity: Essential Vocabulary: Ohm’s Law: $I = V/R$

- **Voltage**: a measure of the “pressure” or push of electrons between two points. Analogous to flow of a liquid moving from point A to point B. (Unit = volt) $(Current \times Resistance)$
- **Current**: a measure of the “intensity” of the flow of the electric charge between two points (Unit = ampere)
- **Resistance**: a measure of the difficulty of an electric current to flow from point A to point B. (Unit = Ohm). Impedance is more complicated and impacts alternating current $(Voltage/Current)$
- The energy dissipated by resistance or impedance is measured as **Heat**. Think light-bulb or toaster.
- **Heat** = $Current^2 \times Resistance$ (note: current squared)
C

- Light travels at a constant, finite speed of 186,000 mi/sec.
- An MPH student, moving at the speed of light, would circumnavigate the equator approximately 7.5 times in one second or 213.8 million times during the class year.

Landmark Discoveries

- **Electromagnetic effect**: One of the great findings of the 19th century (Faraday and Henry, 1830’s). Essentially, a magnet has a “North” and “South” pole and when rotated (e.g. 60 cycles per second, 60Hz) generates and electric current in a stationary wire (often copper) wrapped to interact with the magnet.
- Edison and Tesla: current wars.
Direct Current (DC) and Alternating Current (AC)

- **Direct current (DC):** is a flow of electrical charge that always takes place in the same direction. Think about how a battery works. The circuit must be complete and historically resistance makes transmission work only over “short” distances.

- **Alternating current (AC):** is a flow of electrical charge that periodically reverses direction or cycles (Hertz: 60 cycles per second). Produced by electromagnetic induction.

Alternating Current (AC)

- Modern power plants produce **three phase AC power.** There are three coils spaced 120° apart that generates three separate currents.

- AC voltage oscillates and if the frequency is 60Hz, or 60 times per second as the magnet rotates.

- Electrons actually flow **back and forth** in both directions through devices that are connected to this voltage source, thus light bulbs actually “flash” on and off 60 times every second.
Electricity: The Common Currency

- **Coal, natural gas, biomass and oil**: chemical reactions that generate heat to produce steam.
- **Nuclear**: radioactive decay releases heat that generates steam.
- **Hydroelectric**: water flowing from high point to low point releases potential energy that rotates a turbine to produce electricity.
- **Wind**: Pressure gradient generates power that turns blades to run a generator.
- **Solar**: Photoelectric effect induces the direct flow of electrons or sunlight directly boils water to generate steam.
1 quad = 293,071,000,000 kilowatt-hours (kWh)

https://www.eia.gov/
Baltimore, Maryland

Energy Source (Fuel Mix)

The values shown represent Q1 2018 through Q4 2018 averages for the Mid-Atlantic region.

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>28.68%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>31.13%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>34.53%</td>
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<tr>
<td>Oil</td>
<td>0.21%</td>
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<tr>
<td>Unspecified Fossil</td>
<td>0.04%</td>
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<tr>
<td>Renewable Energy</td>
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<tr>
<td>Captured Methane Gas</td>
<td>0.30%</td>
</tr>
<tr>
<td>Geothermal</td>
<td>0.00%</td>
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<tr>
<td>Hydroelectric</td>
<td>1.50%</td>
</tr>
<tr>
<td>Solar</td>
<td>0.28%</td>
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<tr>
<td>Solid Waste</td>
<td>0.51%</td>
</tr>
<tr>
<td>Wind</td>
<td>2.63%</td>
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<tr>
<td>Wood or other Biomass</td>
<td>0.22%</td>
</tr>
<tr>
<td>Unspecified Renewable Energy</td>
<td>0.00%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.00%</strong></td>
</tr>
</tbody>
</table>

- **Residential**: 4.2 KWh per square foot
- **Hospital**: 30-35 KWh per square foot
  - mostly heating and cooling <2% medical imaging
  - Water consumption is also 5-10x higher

Thailand, 2017

<table>
<thead>
<tr>
<th>Type of Fuel</th>
<th>March 2017</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>3,811.15</td>
<td>22.55</td>
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<tr>
<td>Lignite</td>
<td>1,416.49</td>
<td>8.38</td>
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<tr>
<td>Hydropower</td>
<td>501.79</td>
<td>2.97</td>
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<tr>
<td>Fuel oil</td>
<td>10.64</td>
<td>0.06</td>
</tr>
<tr>
<td>Diesel</td>
<td>2.35</td>
<td>0.02</td>
</tr>
<tr>
<td>Renewable</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Purchase</td>
<td>11,157.65</td>
<td>66.02</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>16,900.27</strong></td>
<td><strong>100.00%</strong></td>
</tr>
</tbody>
</table>

www.egat.co.th
Some Basic Electrical Generation Principles

- Coal, oil, nuclear, biomass and concentrated solar power produce steam to drive turbines and generators.
- Natural gas is used for "jet-engine" type power to drive turbines and generators.
- Photoelectric solar generates electricity directly.
- Hydroelectric uses potential energy drop from water to turn turbines to generate electricity.

No matter what the input they all generate electricity.
Largest coal fired electrical plant in US uses 11 million tons of coal a year; 1288 tons per hour.

The Robert W. Scherer Power Plant is located in Juliette, Georgia.
Transformers

- A **transformer** is a device that transfers electrical energy between two or more circuits through electromagnetic induction. A **varying current** in one coil of the transformer produces a varying magnetic field, which in turn induces a voltage in a second coil. This is used to **increase or decrease** the alternating voltage. Only works for **AC** current.

- Transformers have oil or other coolant on the inside that have high dielectric constant and disperses heat. PCBs used to be used in transformer oil.

> https://en.wikipedia.org/wiki/Transformer

Electric arc or Flashover

- An **electric arc** or **flash over** is an electrical breakdown that produces a discharge through a normally nonconductive medium such as air. Arc welding and lightening as examples.

- In some electric devices sodium hexafluorine used as insulator, particularly circuit breakers in transmission lines.

- In a system, this is emergent behavior.
High Voltage DC Transmission

- When benefits behind lower line losses outweigh efficiency shortfalls in voltage stepping (Long distances)
- Undersea cables (no reactive losses)
- Connecting unsynchronized grids
- Use **inverter** to change DC to AC current
- AC to DC uses a **rectifier**

Bath County Pumped Storage Station Virginia: Largest Battery in the World

- 3,000 Megawatts powers 750,000 homes
- Upper reservoir: 105 foot rise and fall
- Lower reservoir: 60 foot rise and fall
- Generating electricity uses 13 million gallons water per min
- Can run for 11 hours at 79% efficiency
Summary

• Electricity is the common currency of our society.
• It is a major system with emergent properties.
• Very sensitive to environmental changes.
20B: Case Studies in Environmental Epidemiology

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Case Studies:
Past: Love Canal
Present: Atrazine in Drinking Water
Future: Biology Century
Where and Why Love Canal

New York State Map

Love Canal

• 1890’s - William Love’s vision for a canal to connect the Niagara River to Lake Ontario, parts built and then abandoned
• 1942 - Hooker Chemical Company begins dumping of chemical wastes
• 1947 - Hooker Corporation buys the 16-acre dump site
• 1952 - City of Niagara Falls disposes of municipal wastes at the site
• 1953 - Hooker Corporation fills the canal and sells the land to Niagara Falls Board of Education
• 1955 - Elementary school (99th Street) opens
• 1959 - Chemical seepage into basement is reported
• 1974 – Surface begins to collapse exposing barrels of chemicals
• 1976 - NYDEC documents widespread contamination of sewers and sumps in the neighborhood
• 1977 - Local reporter begins investigating possible links to illness
This Indenture,

Made the 30th day of April, Nineteen Hundred and Seventy-Five,

Between ELMIRA ELECTROCHEMICAL COMPANY,

a corporation organized under the laws of the State of New York with its office and principal place of business on Buffalo Avenue in the City of Niagara Falls, County of Niagara and State of New York,

party of the first part, and

THE BOARD OF EDUCATION OF THE SCHOOL DISTRICT OF THE CITY
OF NIAGARA FALLS, NEW YORK,

party of the second part,

SUBJECT to the rights of the public in and to any and all streets and highways which cross said premises;

Prior to the delivery of this instrument of conveyance, the grantee herein has been advised by the grantor that the premises above described have been filled, in whole or in part, to the present grade level thereof with waste products resulting from the manufacturing of chemicals by the grantor at its plant in the City of Niagara Falls, New York, and the grantee assumes all risk and liability incident to the use thereof. It is, therefore, understood and agreed that, as a part of the consideration

Love Canal
Barrels Collected During Clean-up

Love Canal: Community Activism

Lois Gibbs and daughter
• **April, 1978** - Lois Gibbs, resident and mother of two children, canvasses the neighborhood with a petition to close the 99th Street School located near the center of the dumpsite.

• **May 19, 1978** - New York State Health Department meets with to explain potential hazards of exposure to toxic chemicals in and around homes.

• **August 2, 1978** - The New York State Commissioner of Health declared a State of Emergency at Love Canal and ordered the 99th Street School be closed.

• **August 7, 1978** - The President of the United States declared an emergency and provided funds to permanently relocate the 239 families who lived in the first two rows of homes that encircled the landfill site. Families living in the remaining 10-block area, including Lois Gibbs' family, were told they were not at risk.

• **October 1, 1980** - President Carter visited Niagara Falls to sign the appropriation bill that provided the funding for permanent relocation for all 900 families who wished to leave.

• **December 20, 1983** - Lawsuit filed by 1328 Love Canal residents was settled for just under $20 million dollars with Occidental Chemical Corporation, a subsidiary of Occidental Petroleum. One million dollars were set aside for a Medical Trust Fund.

• **August 15, 1990** - Love Canal Revitalization Agency renamed a portion of Love Canal, Black Creek Village, and announced that 9 homes were available for sale to the general public.

• **December 22, 1995** - Occidental Petroleum agreed to pay $129 million to cover the federal government's cleanup costs at Love Canal.

• **August, 1998** – A playground was built on the southern section (not habitable) section area of the neighborhood.

1978 - 1998
Chemicals from the Love Canal hazardous waste site were found in stormwater off Briar Avenue near the 18th Street School in Niagara Falls on April 15, 1975. Officials posted signs to keep children and passersby out of the hazard zone. (News file photo)

**Exclusive: Are Love Canal chemicals still making people sick?**

By Dan Herbeck [Link](http://buffalonews.com/author/dan_herbeck/) | Published June 1, 2008 | Updated June 1, 2018
The Toxicological Paradigm

- Exposure
- Internal dose
- Biologic effective dose
- Early biologic effects
- Altered structure & function
- Clinical disease

Susceptibility
- Genetic factors

Effect modifiers
- Diet
- Habits
- Health
- Medication
- Co-exposure

Exposure and Health Risk at Love Canal

- Single or complex exposure? Complex and unknown
- Identity of exposures over time? Not really
- Route of exposures: soil, air, water, food
- Population at Risk: across the whole life-span
- 10,000 people lived within one-mile and 70,000 people lived within three-miles
- If the incidence of a single disease was 20 per 100,000 per year, could you detect a difference by an epi study?
Case Studies:
Past: Love Canal
Present: Atrazine in Drinking Water
Future: Biology Century

Atrazine
• MW 215.68
• Melting point: 175°C
• Boiling point: 200°C
• Solubility in water: 7mg/100 ml
• Herbicide
• Increases crop yield by ~3-5%.
• Mostly used on corn
### Present: Atrazine in Drinking Water

- About 76,000,000 pounds were applied in the United States in 2003.
- Half-life in soil is weeks to months.
- US EPA maximal contaminant level 3 ppb (3 μg/liter and solubility is 70,000 μg/liter). *Yearly average or point estimate?*
- The U.S. EPA said in the 2003, "The total or national economic impact resulting from the loss of atrazine to control grass and broadleaf weeds in corn, sorghum and sugar cane would be in excess of $2 billion per year ..."

### Toxicology of Atrazine

- Endocrine disrupting compound in experimental models. Increases aromatase, a critical enzyme in estrogen production.
- Epigenetic modifier and transgenerational effects in experimental models.
- Concern about impact on elderly with compromised health status, e.g. Type II diabetics.
- Not shown to be a potent carcinogen in experimental models.
Evansville, Kaskaskia, Carlinville, Illinois
Syngenta agrees to $105M settlement of Atrazine litigation

- May 25, 2012, - Syngenta AG, a Swiss chemical company agreed to pay $105 million to settle litigation involving community water systems and Atrazine. (Syngenta formed in 2000 by merger of Novartis and Zeneca Agrochemicals, now owned by ChemChina, a state owned enterprise.)

- Water systems arguing about Atrazine contamination agreeing to the settlement will be eligible for payments from a $105 million settlement funded by Syngenta.

- “Under the terms of the agreement, Syngenta expressly denied liability and the plaintiffs acknowledged that they are not aware of any new scientific studies relating to Atrazine,” the company said.

- Approximately 2,000 water districts in the U.S. may be eligible to make a claim.
The Toxicological Paradigm

Exposure, Effects and Health Risk of Atrazine

- Single or complex exposure? **Single**
- Identity of exposures over time? **Yes**
- Route of exposures: **water**
- Population at Risk: Between 35-40 million people live in the major contaminant areas.
- Carcinogenic or non-carcinogenic effects: endocrine disrupter.
Case Studies:

Past: Love Canal

Present: Atrazine in Drinking Water

Future: Biology Century

Chemistry Century
The Biology Century and Convergence

The Biology Century: At the beginning

- Starting the third generation in the biological revolution.
- The first generation (1953-1970’s) involved intensive studies at the molecular/cellular level.
- The second generation involved genome sequencing and cloning (1980’s-2000’s).
- Convergence is the third generation, merging life, engineering and physical sciences to fundamentally change the approach to disciplinary based strategies in human health at a global scale.
- Public health provides the multidisciplinary training for convergence work. (JDG, 2014)

Science 29 July 2011: 527
The Environment and the Epigenome

What is “Epigenetics”?
What is “Epigenetics”? 

• Classic genetics alone cannot explain the diversity of phenotypes within a population (not to mention phenotypic differences in monozygotic twins) 
• Epigenetics = “above the genetics” 
• Heritable changes in gene expression that are not due to any alteration in the DNA sequence 
  – Heritable = inherited mitotically in somatic cells and/or inherited transgenerationally 
• Best known epigenetic marker = DNA methylation (e.g., hypo-methylation of DNA in human tumors and hyper-methylated tumor-suppressor genes)
Proof of Concept: Agouti Mice

*Coat color in Agouti mice varies from black to yellow due to stochastic methylation of CpG motifs*

Unmethylated agouti (expressed)  
Methylated agouti (not expressed)


Folate and B12 have transgenerational effect on decreased expression of the Agouti gene

Obesity  
Diabetes  
Cancer

Waterland and Jirtle. Mol Cell Biol 2003; 23:5293
Aging and memory.

Genomic Editing, Engineered Synthetic Cells and Self Healing Materials
GMOs and GEOs

- Genetically modified organisms (GMO):
  - According to the World Health Organization, "Genetically modified organisms (GMOs) can be defined as organisms (i.e. plants, animals or microorganisms) in which the genetic material (DNA) has been altered in a way that does not occur naturally by mating and/or natural recombination.

- Genetically edited organisms (GEO):
  - A genetically edited organism does not contain foreign genes, unlike a GMO. It is edited (mutated) or strain specific genes added, e.g. corn genes into corn.
Genetic Engineering to Make New Materials and Public Health

OR

Biologically directed nanoengineering, cells are good bioreactors.

Angie Belcher and Biological Engineering

• About 500 million years ago organisms started growing hard materials like calcium carbonate and ... bone...These organisms evolved to make exquisite nanostructures like shells.

• Now evolving simple organisms using directed evolution to .... grow and assemble materials ... for solar cells, batteries, and for medical diagnostics...

• Capitalized on ... properties of biology–using only non-toxic materials, employing self-repair mechanisms, self-assembling precisely and adapting and evolving to become better over time.

http://web.mit.edu/be/people/belcher.shtml
Biological engineering occurs at lower temperatures, pressures and with biologically non-toxic materials.
Biomimetics and Bio-inspired Systems

Impact on Space Transportation, Space Science and Earth Science

- Embryonics
- Self Assembled Array
- Biological Mimicking
- Brain-like computing
- Sensor Web
- Biological nanopore
- Low resolution
- Artificial nanopore
- High resolution
- Adapted from NASA nanotechnology program

Mission Complexity

- Extremophiles
- Mars in situ life detector
- Skin and Bone
- Self healing structure and thermal protective systems
- Biologically inspired aero-space systems
- Space Transportation

- 2002
- 2010
- 2020
- 2030

- Cellulose and chitin are the two most common structural biological materials on Earth
- Both biologic materials are 70-80% as strong as Kevlar


Snyder JF¹, Walsh B², Carr PA³, Reschke B ⁴.⁵

Problem:
A torn solar panel array needs to be repaired using straps.

1. Design a custom solution with experts on Earth. Design a set of straps to suture the torn panel back together.
2. Material Synthesis: The crew collects the raw material for the new part from bacteria engineered to produce chitin (structural), rubber (sealant), and hydrogen (optical clarity).
3. Build: 3D printing techniques shape the raw materials into parts. Either the crew or mission control can initiate the automated manufacturing process.
4. Use: Sterilize, stabilize, and integrate the replacement into the system.
5. Recycle: At the end of its life cycle, biological cultures digest the used module to create the next part.
Sequential self-assembly of DNA functionalized droplets

Yin Zhang¹, Angus McMullen¹, Lea-Laetitia Pontan¹,²,³, Xiaojin He¹, Ruojie Sha², Nadrian C. Seeman⁴, Jasna Brusic¹ & Paul M. Chalkin¹

- DNA nanotechnology and self-assembly of crystal structure, drug delivery to brain
- DNA devices at the nanoscale that move
- DNA as “hard-disk” for information storage.
- Moving past 0 and 1 binary units.

Self assembly of complex shapes designed using a molecular canvas of DNA strands

Each image is 150nm x150nm in size.

MULTIDIMENSIONAL DNA ARRAYS

Researchers can also design small DNA motifs that self-assemble into lattices. Shown below is a "tensegrity triangle" motif with three double helical edges (represented as cylinders) that contain complementary sticky ends along one, two, or all three of its edges. The motifs are then cross-linked using DNA nanostaples to form a scaffold for subsequent growth, making it possible to build three-dimensional, multi-layered structures. DNA origami is another example of DNA-based nanotechnology, where long DNA molecules are folded into precise shapes using short, single-stranded "staples." This can be used in various applications, including the study of molecular biology and the development of new materials.
Race Horse First Film Ever 1878 Eadweard Muybridge

CRISPR–Cas encoding of a digital movie into the genomes of a population of living bacteria

Seth L. Shipman1,2,3, Jeff Nivala1,2, Jeffrey D. Macklis2 & George M. Church1,3

Nature, 2017
Engineered Nanobiosensors and Public Health

Epidermal Electronics
The Exposome Project:
Opportunity for Citizen Science and Public Health

Characterizing the exposome. The exposome represents the combined exposures from all sources that reach the internal chemical environment. Toxically important classes of exposome chemicals are shown. Signatures and biomarkers can detect these agents in blood or serum.

S M Rappaport, M T Smith Science 2010;330:460-461