

# **Introduction to Chemical & Biological Engineering**



당신이 배를 만들고 싶다면  
사람들에게 목재를 가져오게 하고  
일을 지시하고  
일감을 나눠주는 일을 하지 말라.  
대신 그들에게 저 넓고 끝없는  
바다에 대한 동경심을 키워줘라!

-생텍쥐페리-

**If you want to build a ship, don't drum up people to collect wood and don't assign them tasks and work, but rather teach them to long for the endless immensity of the sea.**

**Antoine de Saint-Exupery**



# **The College Degrees With The Highest Starting Salaries In 2016**

(<https://www.forbes.com/pictures/5775434fa7ea436bd18bff25/the-20-college-majors-wit/>)



# **The 25 Bachelor's Degrees With The Highest Salary Potential In 2016-2017**

(<https://www.forbes.com/pictures/fjle45eedfd/the-25-bachelors-degree/>)

# What do Chemical Engineers Do?

<https://www.aiche.org/community/students/career-resources-k-12-students-parents/what-do-chemical-engineers-do>

- Chemical Engineering Touches Everything
  - Petrochemicals, Specialty chemicals, Pulp and paper
  - Biotechnology, Pharmaceuticals, Healthcare, Food processing
  - Electronic and advanced materials, Polymers, Microelectronics,
  - Environmental health and safety industries
  - Manufacturing, Design and construction
  - Business services

# What do Chemical Engineers Do?

- Chemical Engineering Touches Everything
  - Don't make the mistake of thinking that chemical engineers only “make things”.
  - Their expertise is also applied in the areas of law, education, publishing, finance, and medicine, as well as in many other fields that require technical training.

# What do Chemical Engineers Do?

- Math and Science Are Important
  - Chemical engineers rely on their knowledge of mathematics and science—particularly **chemistry** and **biology**—to overcome technical problems safely and economically.
  - And, of course, they draw upon and apply their engineering knowledge to solve any technical challenges they encounter.

# What do Chemical Engineers Do?

- Chemical Engineers are
  - Advancing Biomedicine
  - Developing Electronics
  - Enhancing Food Production
  - Generating Energy
  - Improving Materials
  - Saving Environment

# Chemical Engineers are Advancing Biomedicine



# Chemical Engineers are Advancing Biomedicine

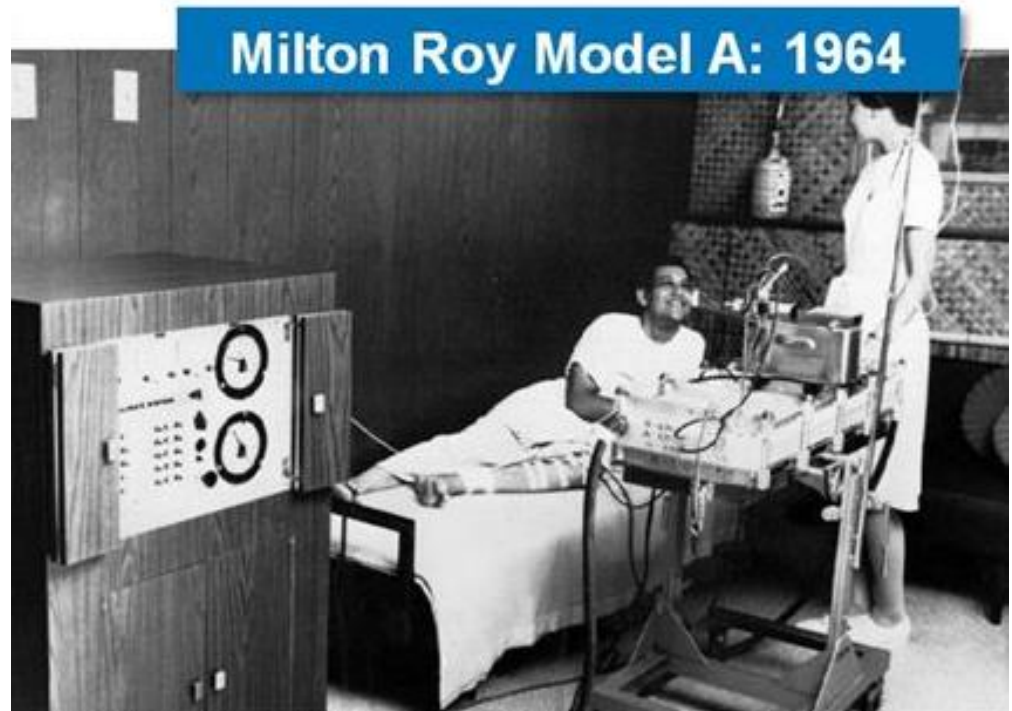
- Chemical engineers have made rich and varied contributions to many biomedical advancements in an effort to
  - Modernize disease diagnosis and treatment options
  - Improve the safety and efficacy of drug-delivery mechanisms
  - Achieve better therapeutic outcomes

# **Achievements in Advancing Biomedicine**

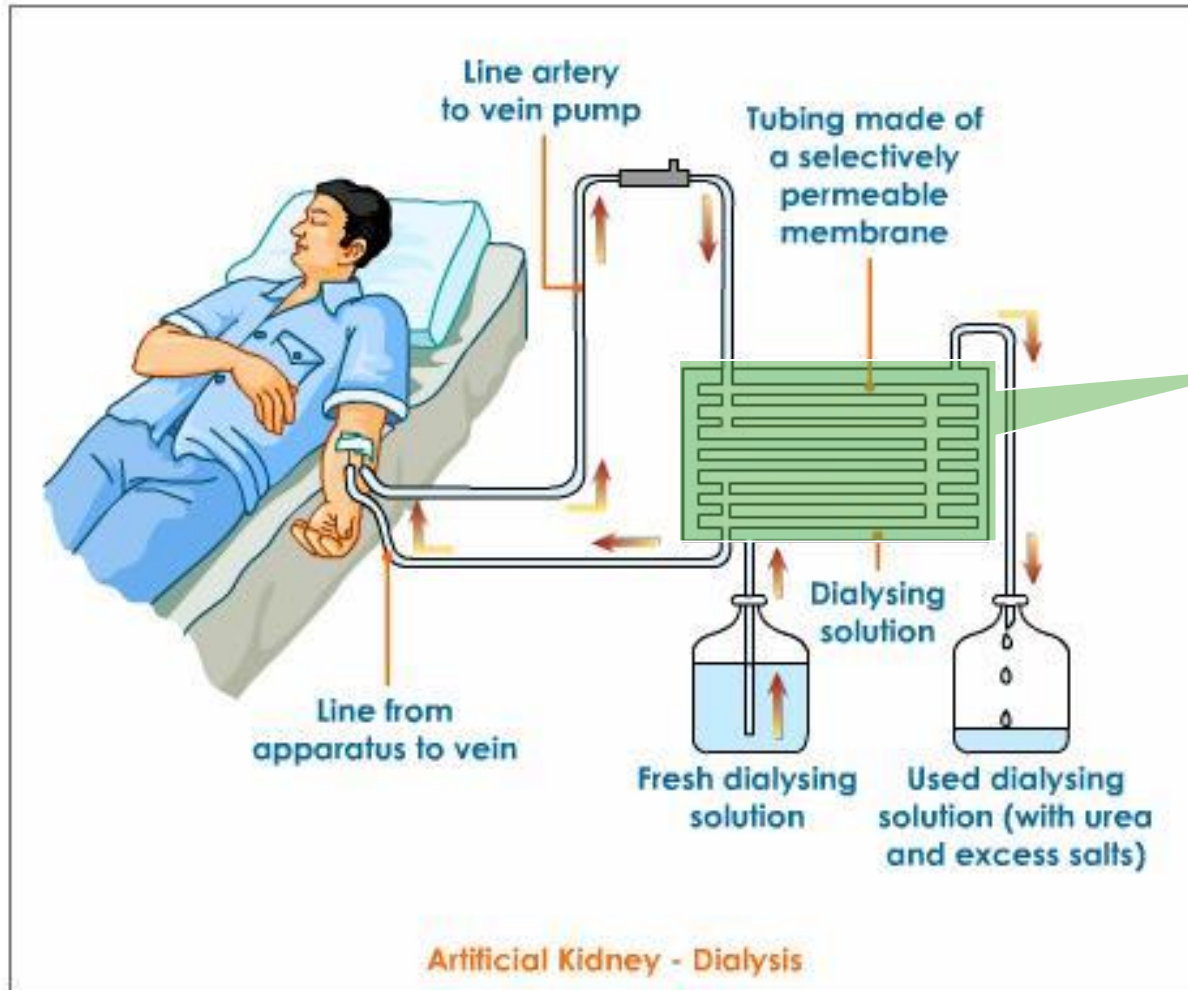
- **Kidney Dialysis (artificial kidney)**
- **Treating Diabetes**
- **Tissue Engineering**
- **Drug Delivery**

# Artificial Kidney

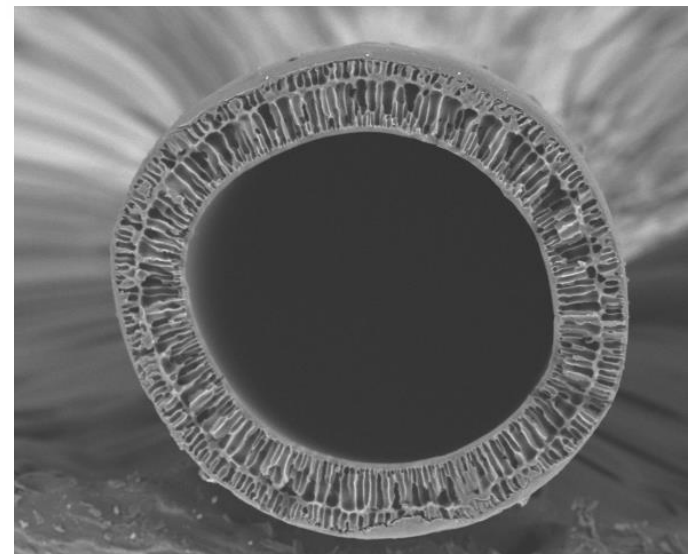
- Milton-Roy Model A
  - designed by chemical engineering professor Les Bab in order to help the daughter of a friend



# Artificial Kidney



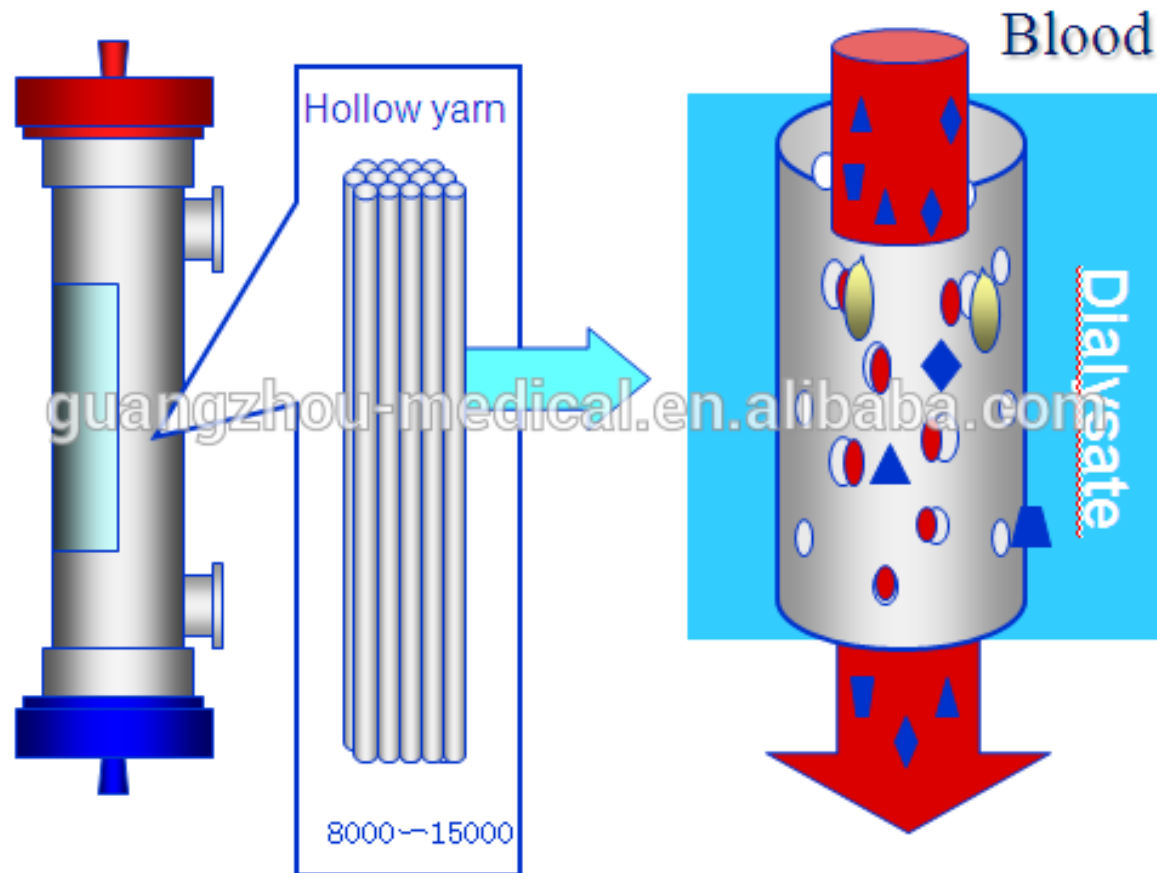
# Artificial Kidney



TM-1000

x180 500 um

# Artificial Kidney



# Artificial Kidney

- Chemical engineers have continued to create smaller, more effective, and more affordable dialysis machines.
- An excellent example of the life-enhancing synergies that result when chemical engineers join forces with physicians and biomedical researchers
- One of the “Ten Wonders of Biomedical Eng.”
- Essentially mass-transfer device (Mass Transfer)

# Treating diabetes

- Combined efforts of chemical engineers, physicians, and biomedical researchers
- Glucose level monitoring (**Biosensor**)
  - Microanalytical techniques (small blood samples)
  - Continuous monitors implanted beneath the skin
  - Use of implanted microchips to control insulin addition
- Insulin Injection (**Process Control**)
  - Continuous-infusion insulin pump

# Artificial pancreas at a glance

## 1 CGM sensor

Continuous glucose monitoring (CGM) sensor is inserted under the skin to continuously measure glucose concentrations in the patient's cells

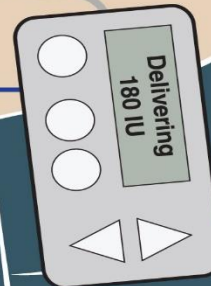
## 2 CGM receiver

CGM receiver displays the updated readings as graphs and trends minute-by-minute, and translates the readings from USB to Bluetooth



## 4 Insulin pump

The CAD communicates with a body-worn insulin pump that automatically administers the correct insulin dose via a cannula inserted under the skin



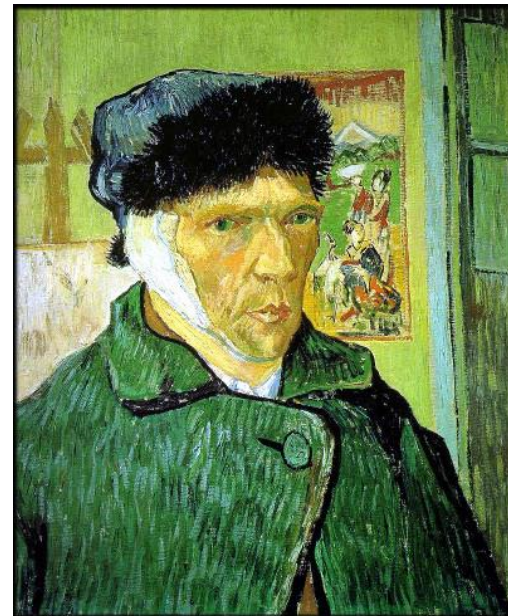
## 3 Control algorithm device (CAD)

Readings are sent to a control algorithm device (CAD) - eg a smartphone, tablet or PC - where an algorithm analyses them and calculates the correct insulin dose, if required



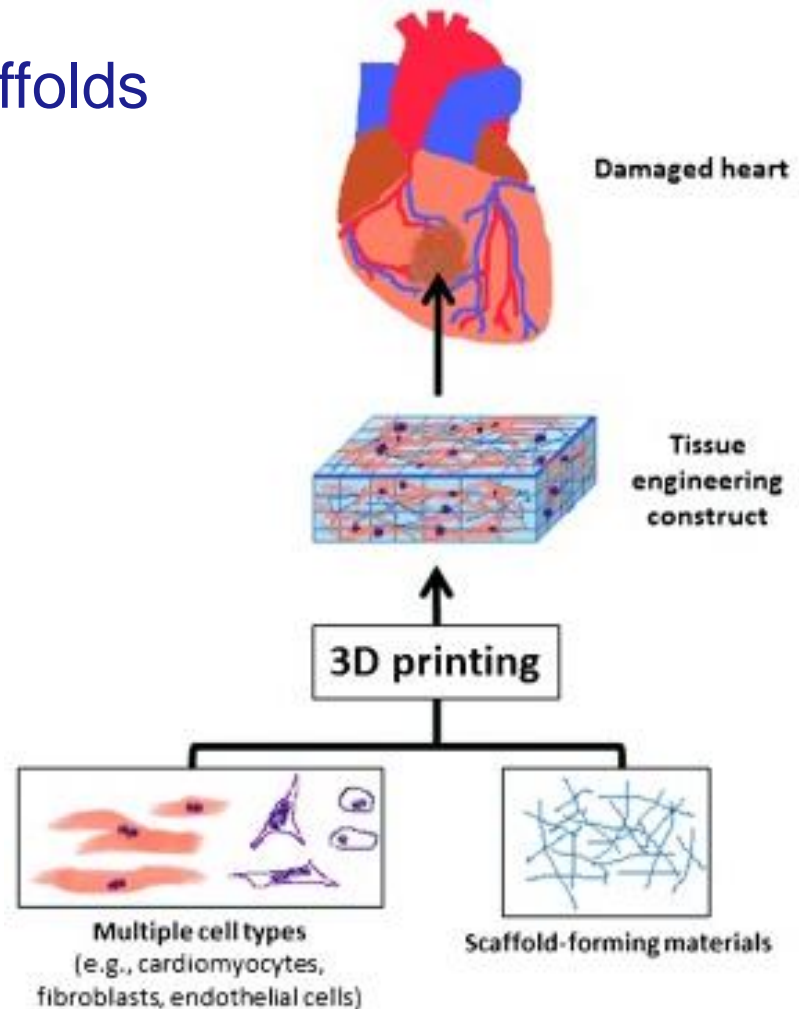
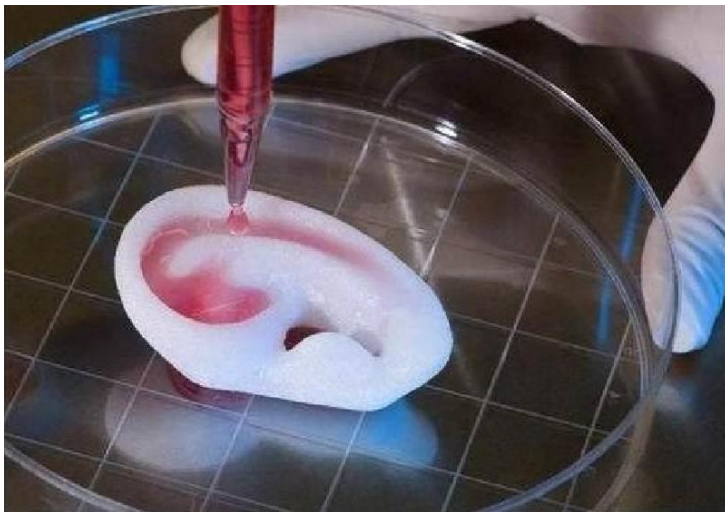
# Tissue Engineering

- To repair or replace damaged or diseased organs and tissues
- Use of living cells as building materials



# Scaffold & 3D Printing

- Biocompatible polymer scaffolds
- Biodegradable polymer
  - e.g. nerve-guide conduits
- (Polymer Materials)



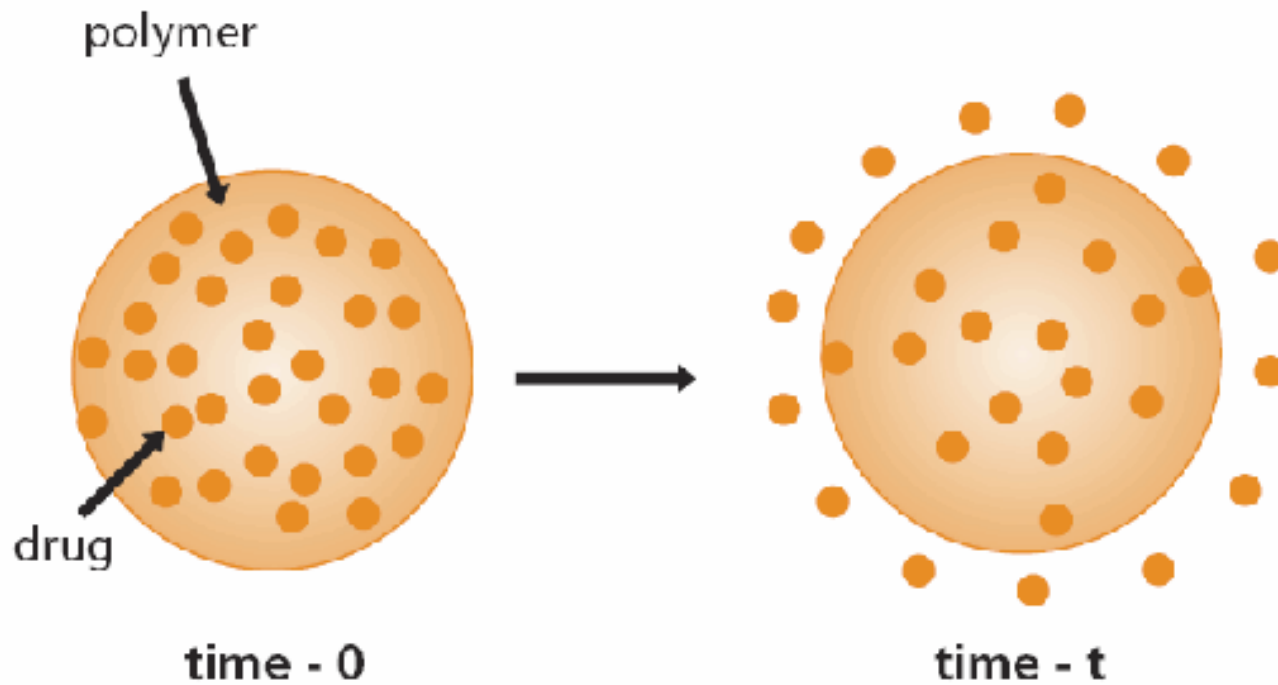
# Tissue Engineering

- Transplantation cells for specific biochemical functions
  - improving pancreas, liver, or bladder functions
- Replacement tissues
  - artificial skin, bones, cartilage, blood vessels, tendons, and ligaments
- Stem cells
  - able to regenerate functional human tissues.

# Drug Delivery

- Conventional method
  - by mouth or injection
- Early advancements using chemical principles  
(Mass Transfer & Polymer Materials)
  - Nasal sprays that deliver finely atomized amounts of a drug via inhalation
  - Transdermal patches that deliver controlled doses through the skin, and
  - Controlled-release capsules and wafers that deliver drugs over an extended period.

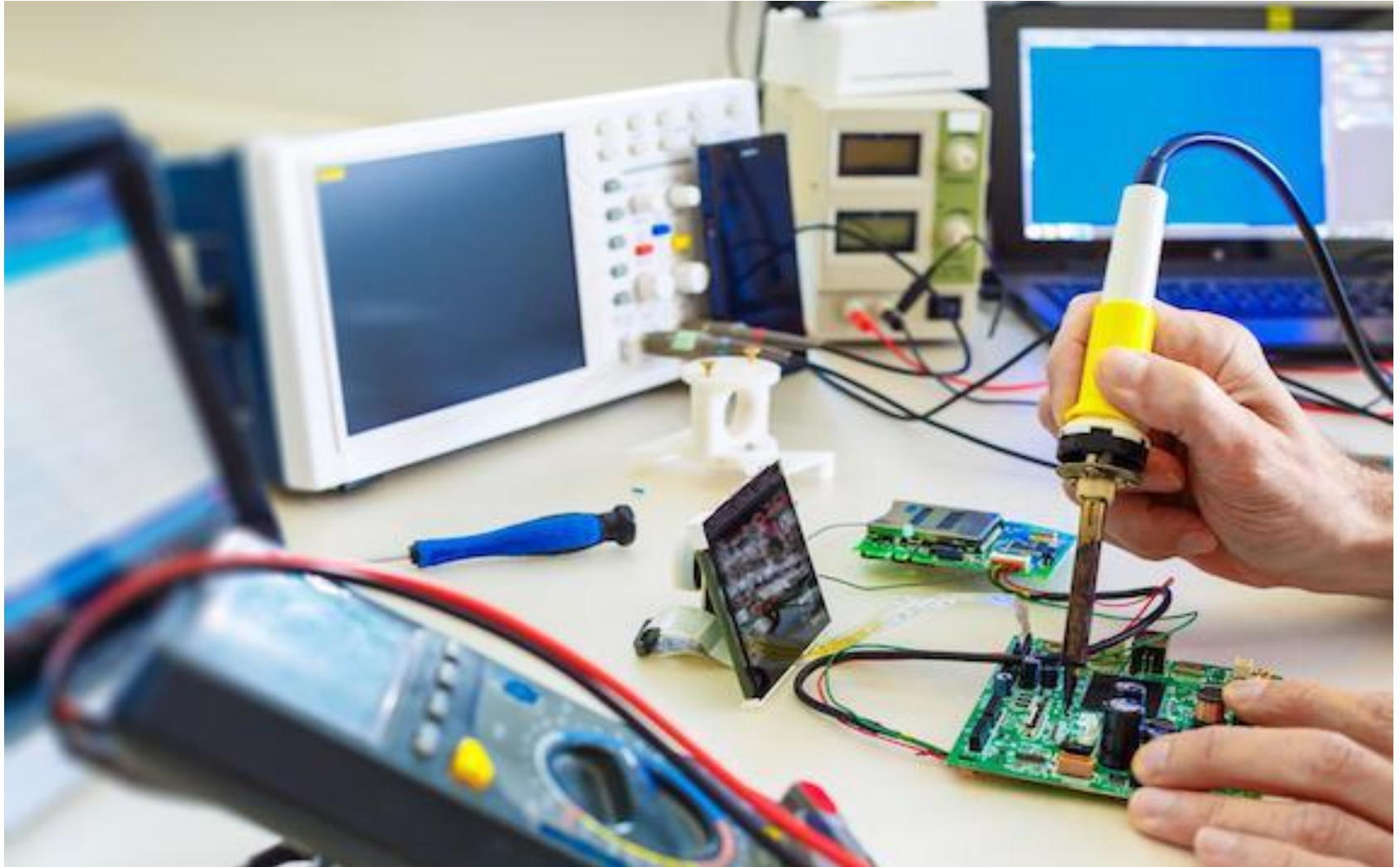
# Drug Delivery



# Drug Delivery

- With the help of chemical engineers
  - directly to the desired location within the body
  - release drug on demand.
- Advantages
  - Reduce or delay premature degradation of a drug in the body
  - Maximize the ability of a drug without affecting healthy tissue and organs
  - Minimize the total amount of the drug
  - Reduce potential side effects

# Chemical Engineers are Developing Electronics



# Chemical Engineers are Developing Electronics

- Chemical engineers contributed to the invention of **semiconductor chips**.
  - from children's toys to phones, automobiles, medical sensors, and communications satellites
- Chemical engineers are routinely involved with
  - Development of **advanced semiconductor materials**
  - Manufacturing **processes** required to produce them

**(Inorganic Materials & Process)**

# Semiconductor

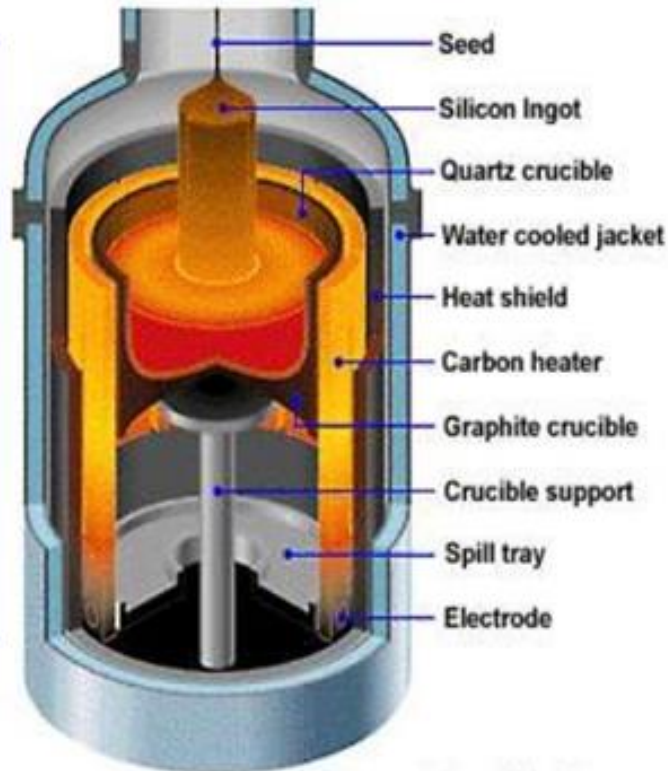
- Silicon → Semiconductor chip
  - requires the multidisciplinary expertise of chemical engineers
  - From sand to silicon  
<https://www.youtube.com/watch?v=Q5paWn7bFg4>
- Silicon ingot
  - The successful growth of silicon ingots requires an understanding of fluid mechanics, heat and mass transfer, and crystallization.

# Semiconductor

## ■ Silicon ingot (서랄스키 방법)

### Wafer growth – Czochralski Method (Cz)

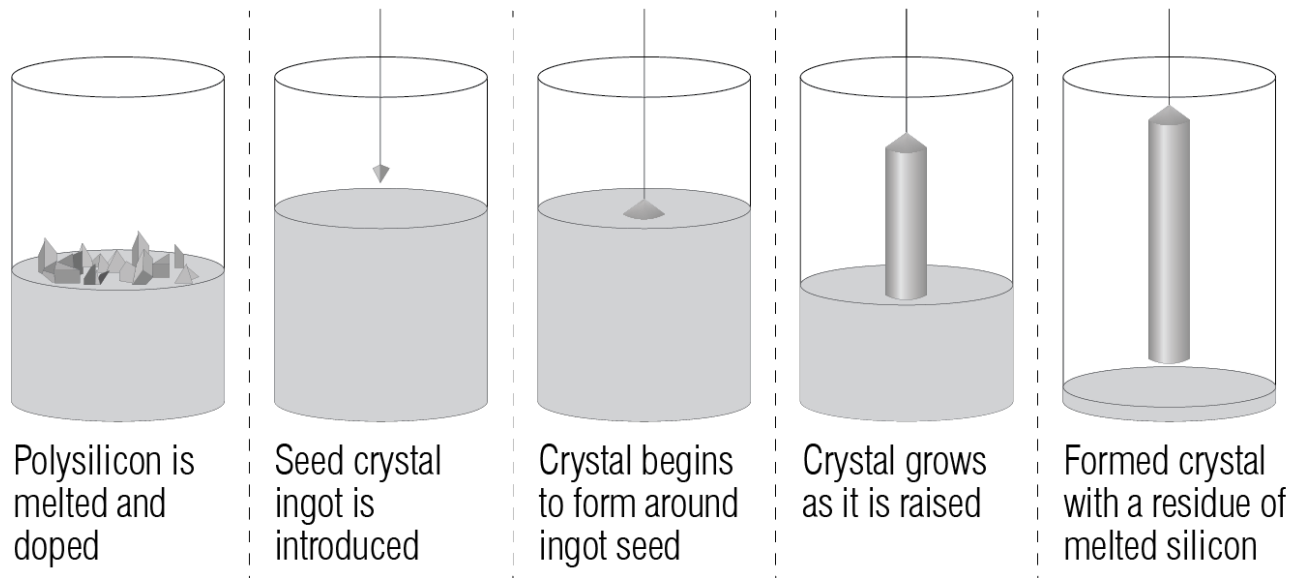
- From the high purity poly-Si, single crystal silicon is required,
- The Cz process is the most common for large wafer diameter production.
- Pull rate, melt temperature and rotation rate are all important control parameters.



Cz crystal pulling furnace

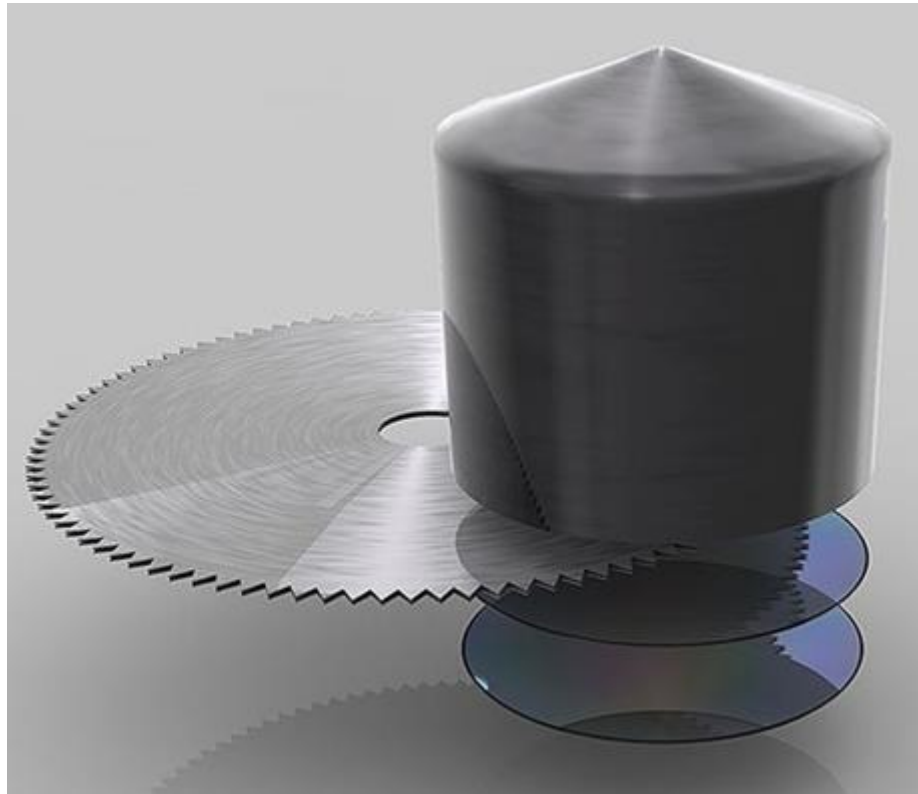
# Semiconductor

- Silicon ingot



# Semiconductor

- Silicon ingot → Wafers



# Semiconductor

- Silicon ingot → Wafer → Integrated circuit
- The highly polished wafers next undergo a successive series of process steps.
- Each step involves the deposit of a complex layer of either a conductor, a semiconductor, or an insulating material.
- These materials deposited in many layers produce the transistors, resistors, and capacitors that ultimately make up an integrated circuit.

# Chemical Engineers are Enhancing Food Production



# Chemical Engineers are Enhancing Food Production

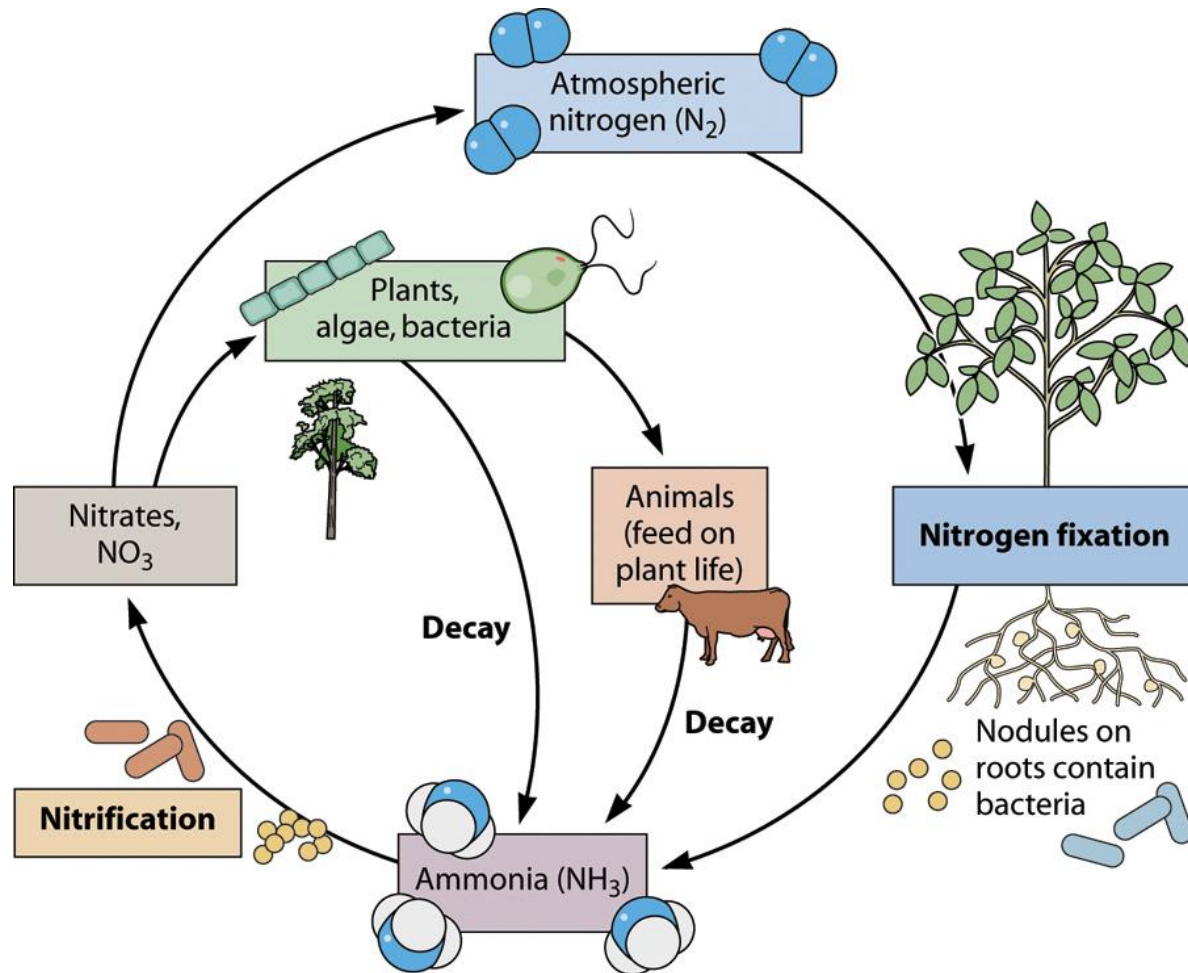
## Chemical Engineers' Contribution

- The discovery of fertilizers, pesticides, and herbicides
- Innovations in food processing and packaging that help improve taste, appearance, and nutritional value while increasing safety, convenience, and shelf life
- New sterilization techniques that protect food against spoilage and people against food-borne illnesses.

# Fertilizers

- Fritz Haber, a chemist, engineered a process to synthesize ammonia through a reaction between hydrogen and nitrogen in 1908 .
- Nobel Prize in Chemistry in 1918
- Haber-Bosch process
  - Working with Carl Bosch, an industrial chemist, Haber designed and scaled up a successful process for cost-effective commercial-scale production of ammonia for use in nitrogen fertilizers.

# Nitrogen Cycle



# Nitrogen Cycle

## ■ Nitrogen fixation

- Nitrogen-fixing bacteria
  - Nitrogenase:  $\text{N}_2 + 6\text{H}_2 \rightarrow 2\text{NH}_3$
  - High energy consuming: 15 ~ 20 molecules of ATP
- Symbiosis between nitrogen-fixing bacteria and plant
  - Formation of nodules in plant roots
  - Mutual benefits (glucose vs. nitrogen source) : mutualism

## ■ Chemically synthesized nitrogen fertilizer

- Use high E to break  $\text{N}_2$



# Pesticides and Herbicides

- Chemical engineers have been instrumental in discovering and synthesizing many chemical compounds that function as pesticides to kill bugs and as herbicides to kill weeds.
- Chemical engineers also design the industrial processes necessary to produce these compounds on a commercial scale.

# Herbicides

- Glyphosate
  - the primary ingredient in Monsanto's popular herbicide **Roundup**.
- It works by inhibiting a specific growth enzyme in plants. When applied to crops, glyphosate is rapidly metabolized by weeds.
- Roundup Ready crops
  - Crops genetically modified to be resistant to Roundup
  - Soy, Corn, Canola, Alfalfa, Cotton, Sorghum  
Wheat (under development)
  - Referred to as "terminator seeds"

# Pesticides

- Chemical pesticides
- Biological pesticides
  - Bt (*Bacillus thuringiensis*) toxin
  - No need to spray synthetic pesticides
  - Not harmful to human and other animals
  - Not kill beneficial insects
  - Traditional pesticides are typically applied only to the leaf and stem (not to the root or inside plant tissues)

# Bt Crops



- Bt corn
- Bt potato
- Bt cotton
- Bt soybean

Non-Bt cotton vs. Bt Cotton

# Better Foods

- Taste and Look
  - Improving food flavors and textures,
  - Adding nutritional value
  - Perfecting the appearance of foods
- Packaging
  - Modern packaging developed by chemical engineers
- Convenience
  - Fast and easy, delicious and nutritious
  - Fast-cooking foods
  - Frozen foods

# Chemical Engineers are Generating Energy



# Chemical Engineers are Generating Energy

## Chemical Engineers' Contribution

- Traditional, nonrenewable fossil-fuel sources
  - coal, petroleum, natural gas, propane
- Renewable fuels derived from
  - Biomass feedstocks
  - Solar power
  - Wind

# Traditional Refining

- Chemical separation and conversion processes to turn crude oil into
  - Gasoline, Diesel and jet fuel, Kerosene, Lubricating oils, Numerous other end products
- Chemical Conversion Processes
  - Thermal cracking
  - Distillation
  - Fluid catalytic cracking
  - Hydrocracking
  - Powerforming

# Biofuels & Biorefinery

- Convert renewable biomaterials into electricity and transportation fuels, and valuable chemicals
- Biomass is plant material
  - Fast-growing trees and grasses, grains, corn, sugar cane, wood scrap, even woody leaves and stalks and garbage
  - Sun-dependent renewable feedstock

# Biofuels

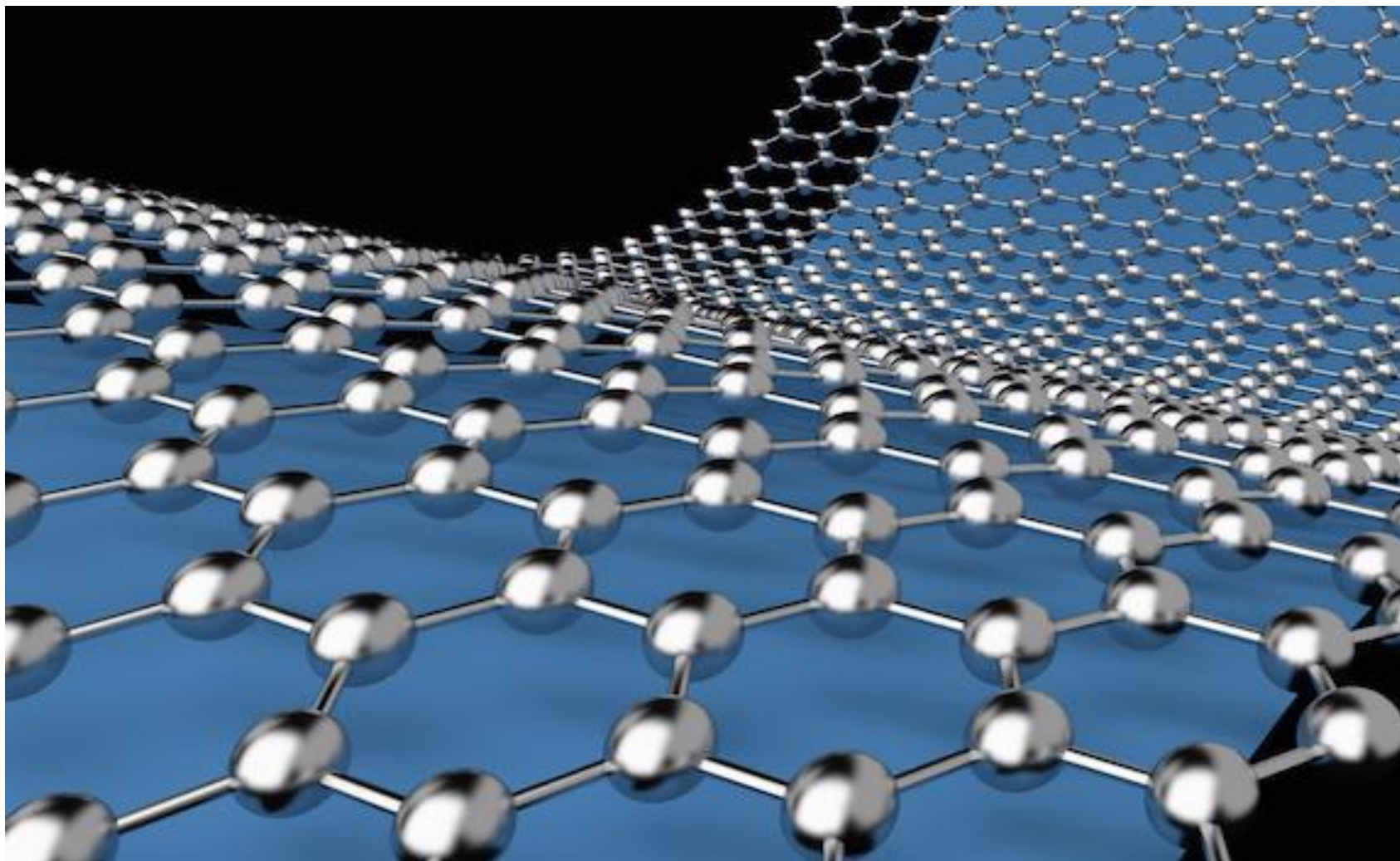
- **Bioethanol**

- Made by fermenting biomass rich in carbohydrates (starches and sugars)
- Gasoline-like alcohol

- **Biodiesel**

- Made from vegetable oils, animal fat, and even recycled cooking grease
- Functional alternative to conventional diesel

# Chemical Engineers are Improving Materials



# Chemical Engineers are Improving Materials

- By manipulating and exploiting the properties, chemical engineers develop and fabricate new end products.
  - Electrical properties
  - Thermal properties
  - Magnetic properties
  - Strength
  - Flexibility or rigidity
  - Resistance to damage.

# Plastics

- It was only about 100 years ago that the first true plastic to be commercialized, Bakelite, was invented.
- Composed of long, chain-like molecules produced in a process called polymerization  
(Polymer)
  - Broad resistance to chemicals
  - Functional thermal and electrical insulation
  - Light weight with varying degrees of strength
  - Processing flexibility.

# Uses of Plastics

- Everyday uses
  - children's toys, beverage bottles, clothing, and carpeting and packaging materials
- More esoteric uses
  - industrial machine components, automotive parts, biomedical implants, and medical instruments.

# Environmentally focused bio-based plastics

- Produced from such renewable raw materials as corn, soybeans, and other agricultural and forest crops
- “Greener” plastics
  - not only help reduce society’s reliance on fossil fuels
  - but are also more biodegradable

# Computer Chips

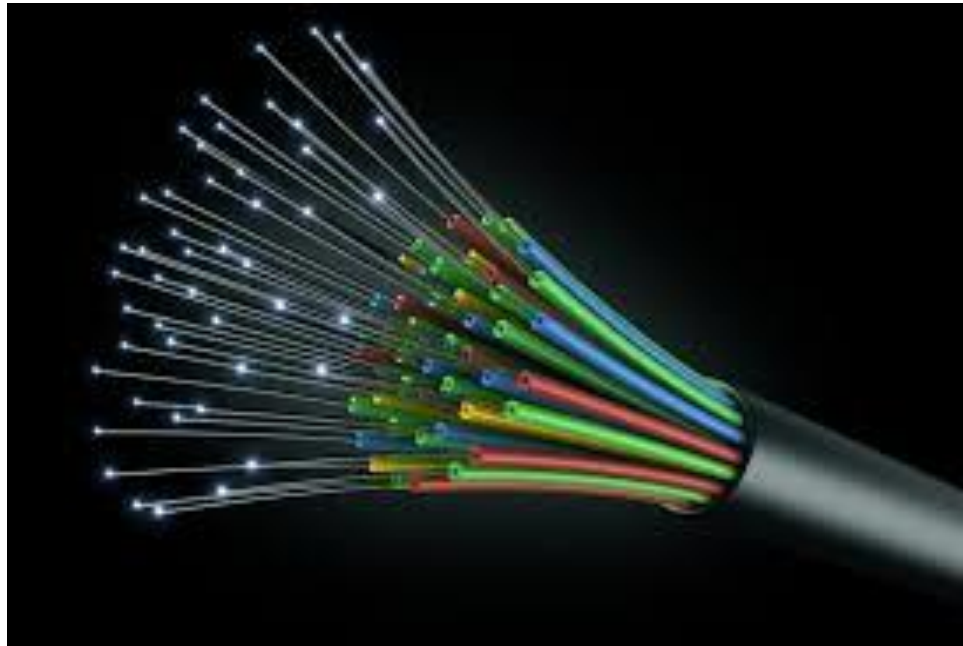
- Electronic devices become smaller, faster, smarter, and cheaper.
- Semiconductor chips
  - provide the backbone for modern computing systems.
  - complex microelectronic circuits composed of a base material with electrical conductivity greater than an insulator but less than a conductor.
  - The typical base material is silicon, although germanium is also used.

# Chemical Engineering for Computer Chips

- **Kinetics** and **thermodynamics** in the crystallization of silicon wafers;
- **Polymer science** in the development of patterned photoresist coatings;
- **Heat transfer** to maintain desired temperatures and manage heat buildup during the chip-making process
- **Mass transfer** to improve etching of complex semiconductor-chip patterns and the plating of electronic microchannels.

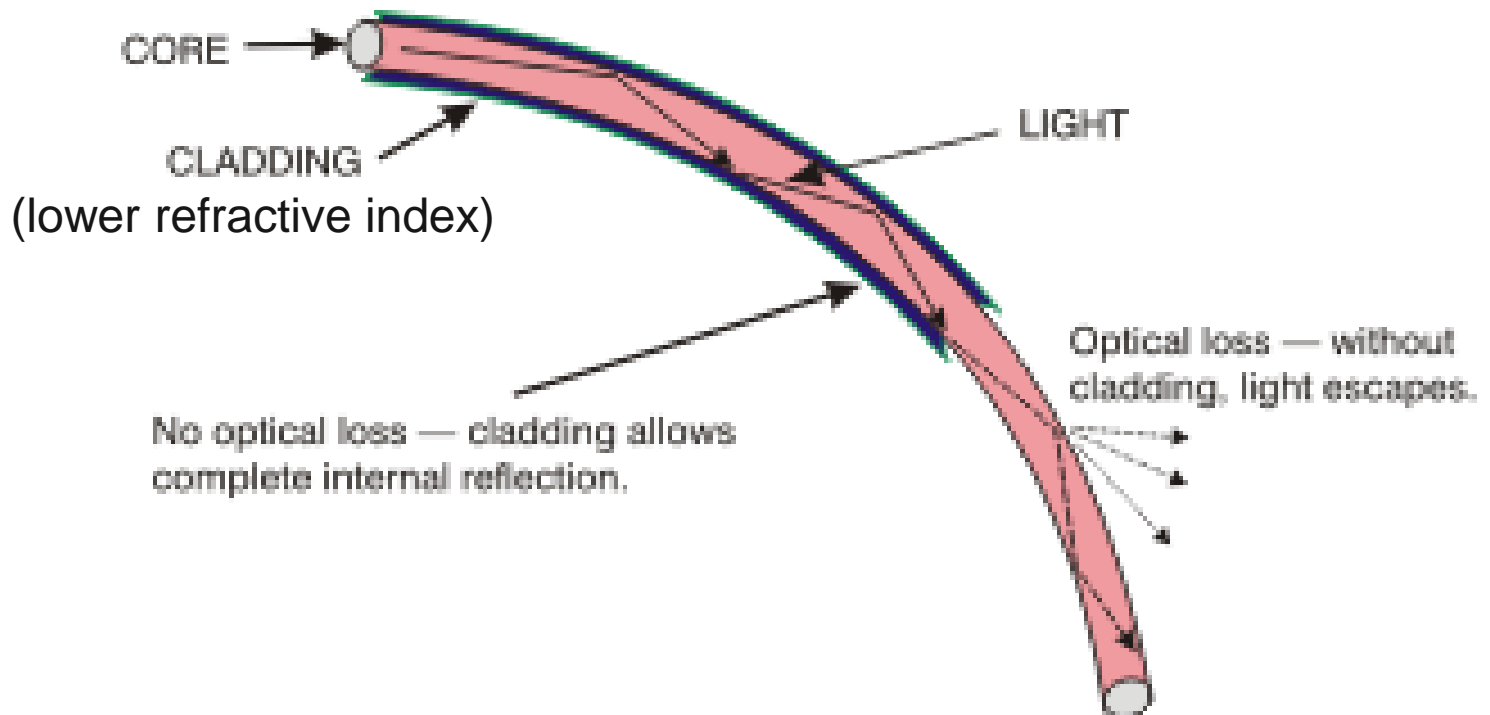
# Telecommunications

- Fiber-optic cables
  - Bundles of long, thin glass fibers, each narrower than a human hair



# Fiber-optic cables

- Total internal reflection (100% of the light is reflected off the walls of the fiber, so no light is lost)



# Fiber-optic cables

- Thin glass fibers are very brittle and fracture easily.
- Modified chemical vapor deposition (MCVD)
  - Chemical engineers invented a process that coats the drawn glass fibers with a specialized polymer.
- This coating
  - maintains the optical properties needed to guide light and data through the fibers
  - prevents the fibers from fracturing, no matter how severely they are bent.

# Biomaterials

- Chemical engineers focus their efforts on the discovery and optimization of biocompatible materials.
  - Nontoxic,
  - Well tolerated, and
  - Damage and degradation resistant.

# Biomaterials

- Biocompatible materials used inside the body
  - Vascular grafts (specialized polyester)
    - used to repair or reinforce existing veins and arteries
  - Stents (specialized stainless-steel alloys)
    - used to facilitate drainage and reinforce weak arterial tissue
  - Spinal, cardiovascular, and ophthalmic implant devices
    - made from a variety of specialized polymers, ceramics, and metals
  - Artificial knees and hips
    - fabricated from combinations of biocompatible polymers and surgical titanium

# Chemical Engineers are Saving the Environment



# Chemical Engineers are Saving the Environment

- Chemical engineers develop advanced technologies, monitoring devices, modeling techniques, and operating strategies that
  - Reduce the volume and toxicity of pollutants allowed to enter the air, waterways, and soil;
  - Significantly reduce the negative environmental impact of industrial facilities, power plants, and transportation vehicles; and
  - Allow greater reuse of post-consumer and post-industrial waste streams.