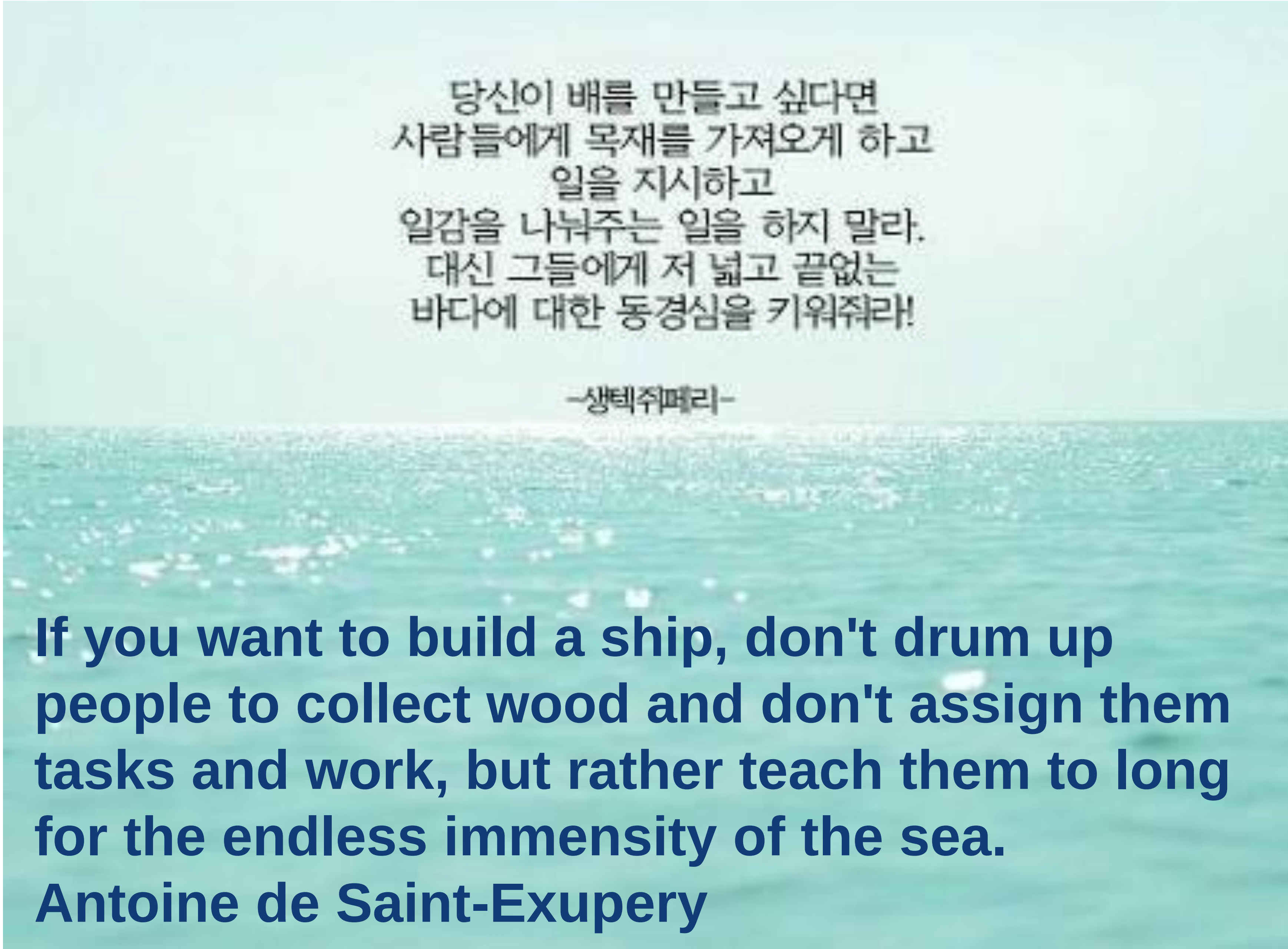
Introduction to Chemical Engineering



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

≡ Forbes

The College Degrees With The Highest Starting Salaries In 2016

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

Forbes

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

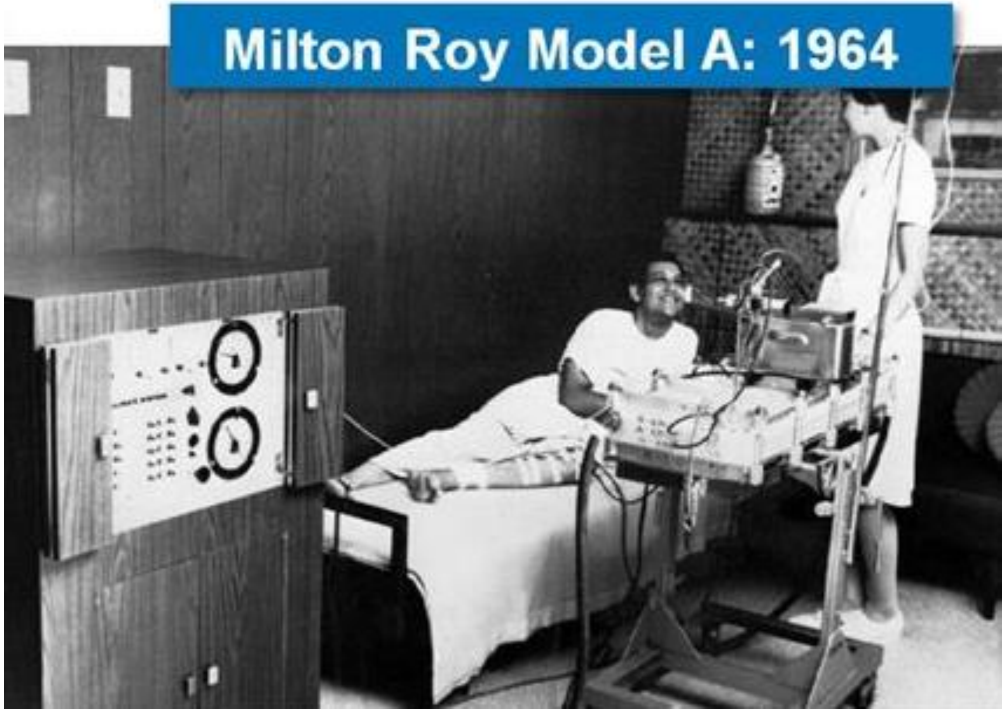
- Chemical engineers have made rich and varied contributions to many biomedical advancements in an effort to
  - Modernize disease diagnosis and treatment options
  - Improve the safety and efficacy of drug-delivery mechanisms
  - Achieve better therapeutic outcomes

Achievements in Advancing Biomedicine

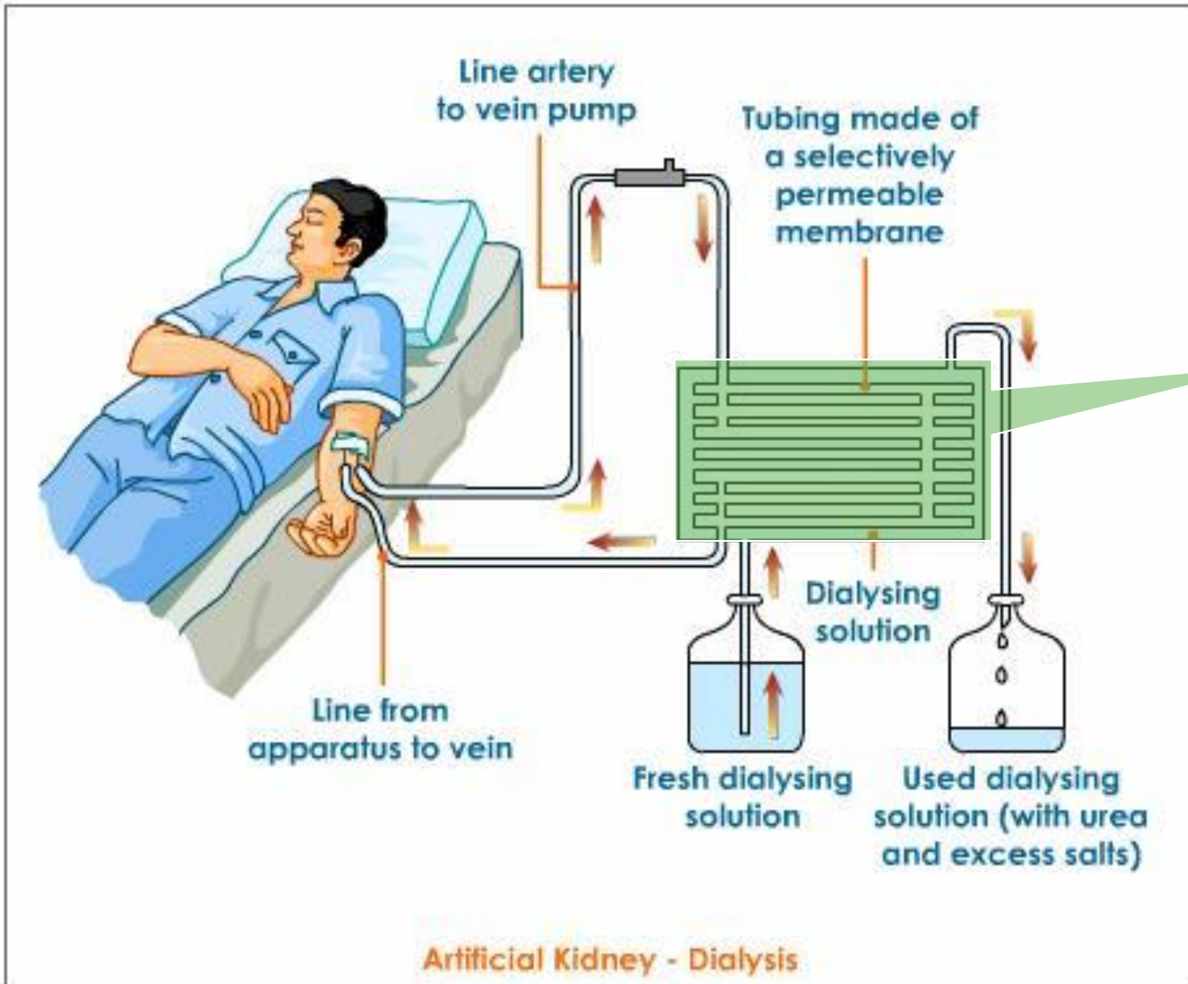
- Kidney Dialysis (artificial kidney)
- Treating Diabetes
- Tissue Engineering
- Drug Delivery

Artificial Kidney

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

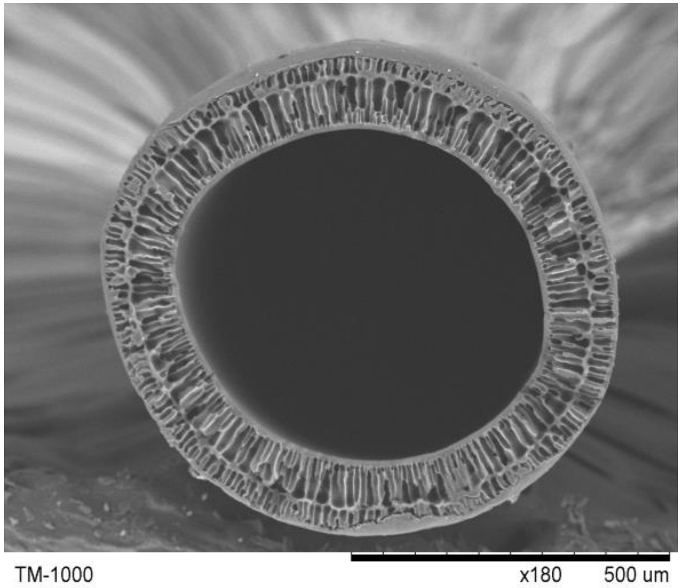


Artificial Kidney

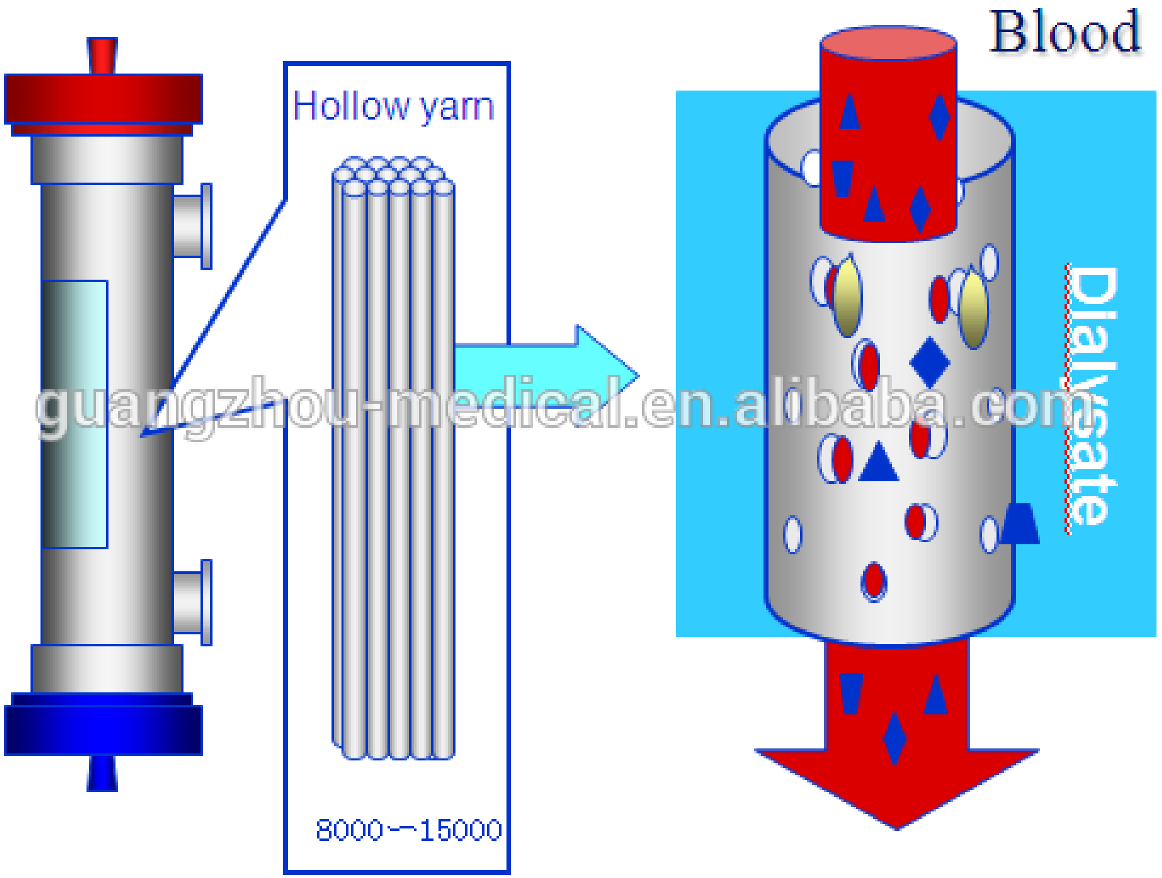


Artificial Kidney - Dialysis

Artificial Kidney



Artificial Kidney



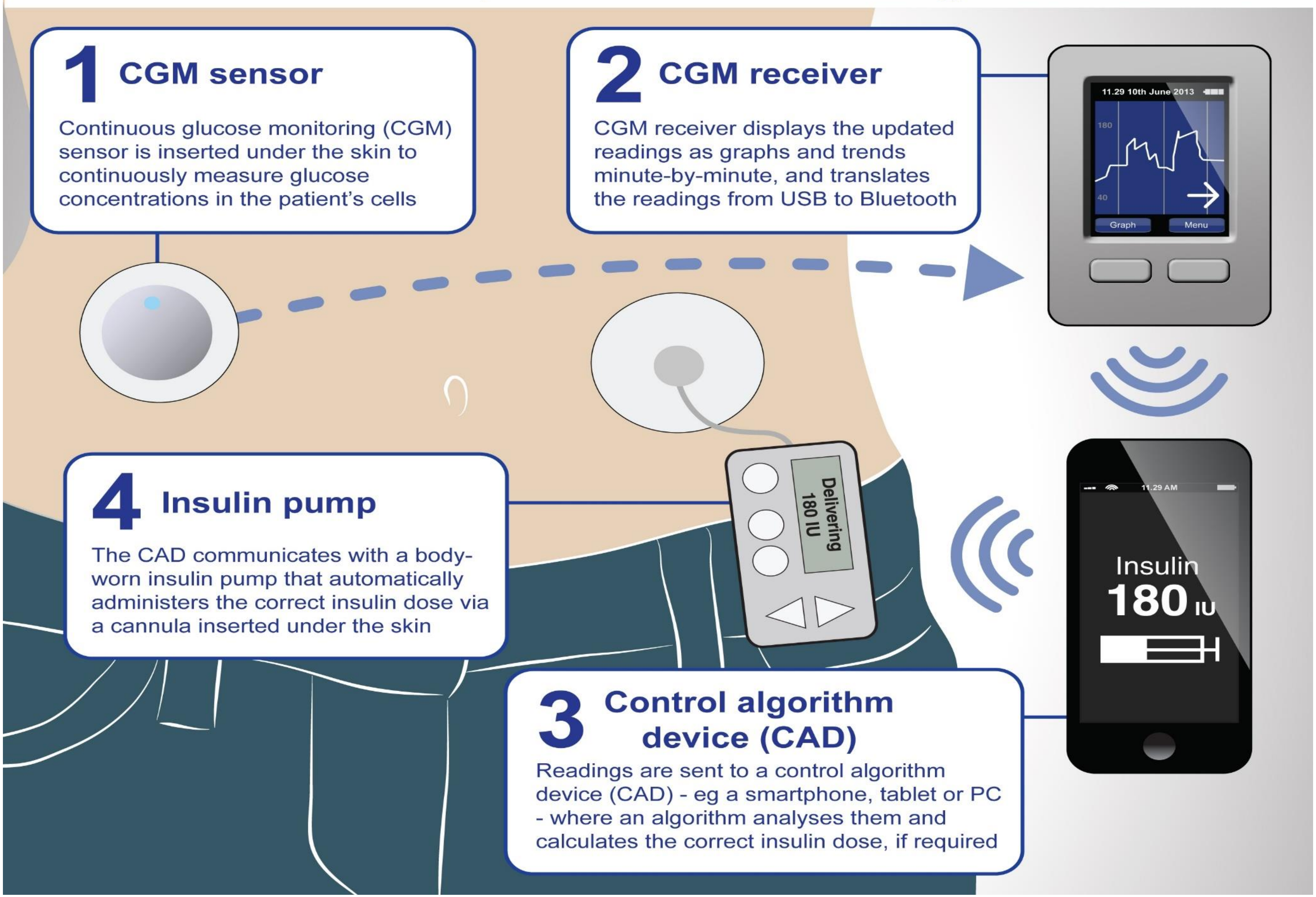
Artificial Kidney

- 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

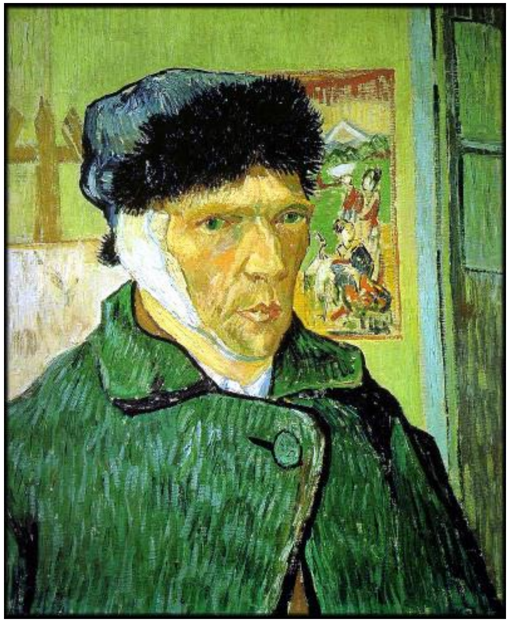
- Combined efforts of chemical engineers, physicians, and biomedical researchers
- Glucose level monitoring (Biosensor)
  - Microanalytical techniques (small blood samples)
  - Continuous monitors implanted beneath the skin
  - Use of implanted microchips to control insulin addition
- Insulin Injection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

Artificial pancreas *at a glance*



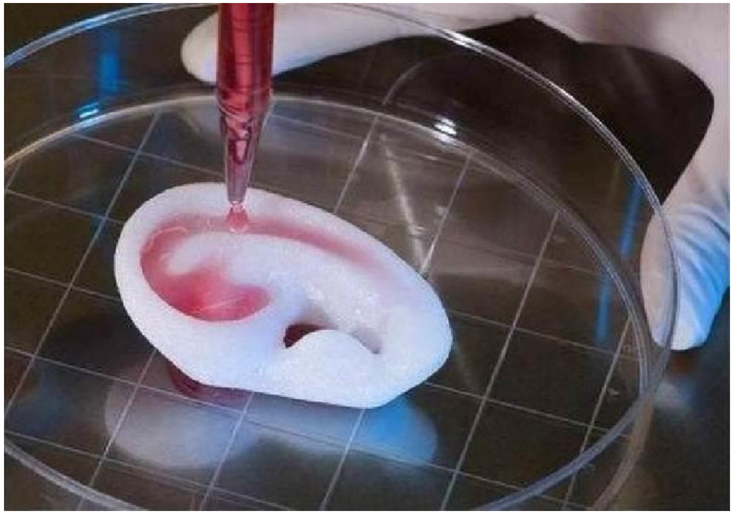
Tissue Engineering

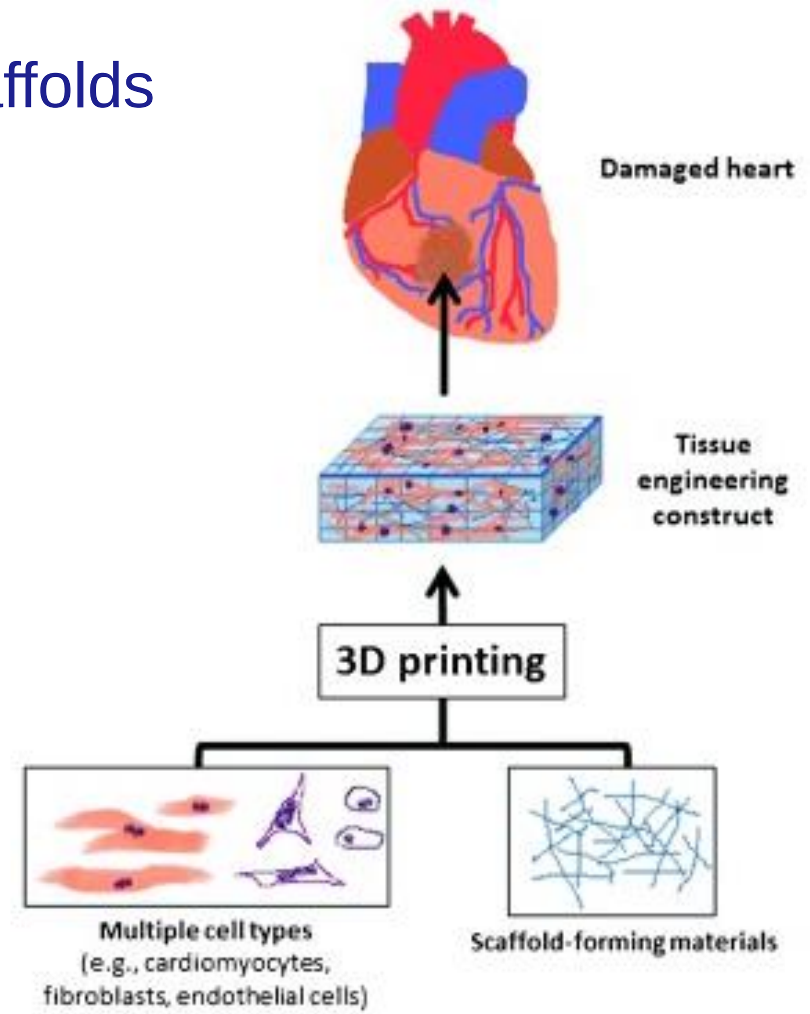
- To repair or replace damaged or diseased organs and tissues
- Use of living cells as building materials



Scaffold & 3D Printing

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





D.J. Richards et al, Israel Journal of Chemistry, 53, 805, 2013

Tissue Engineering

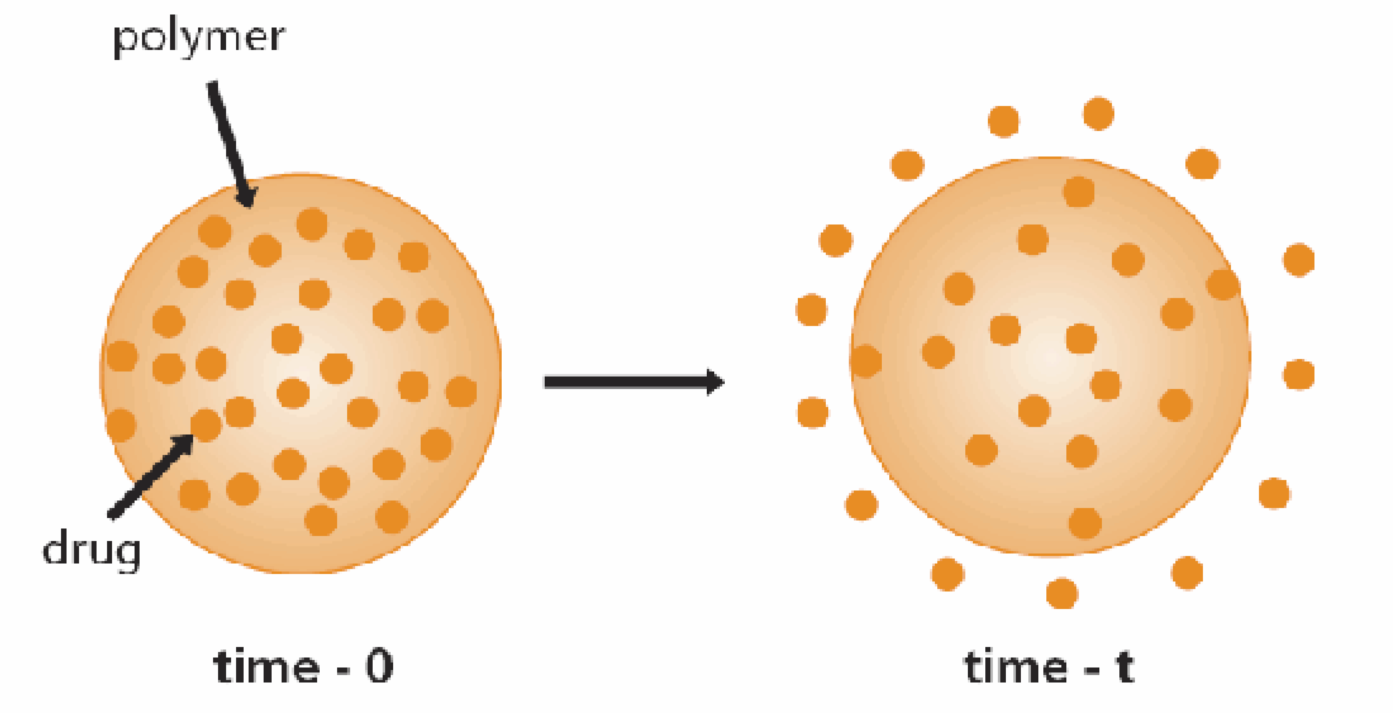
- Transplantation cells for specific biochemical functions
  - improving pancreas, liver, or bladder functions
- Replacement tissues
  - artificial skin, bones, cartilage, blood vessels, tendons, and ligaments
- Stem cells
  - able to regenerate functional human tissues.

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.

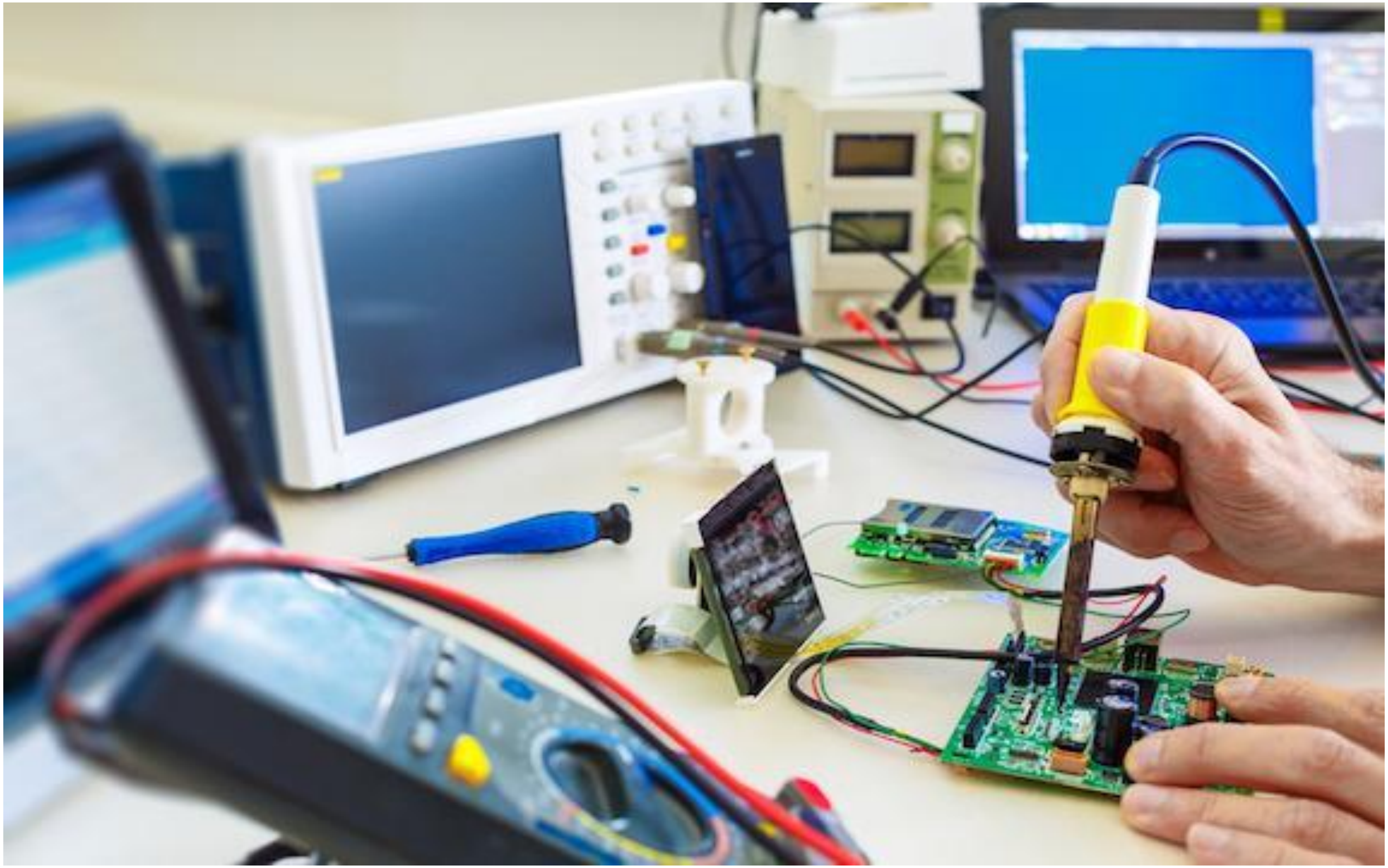
Drug Delivery



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

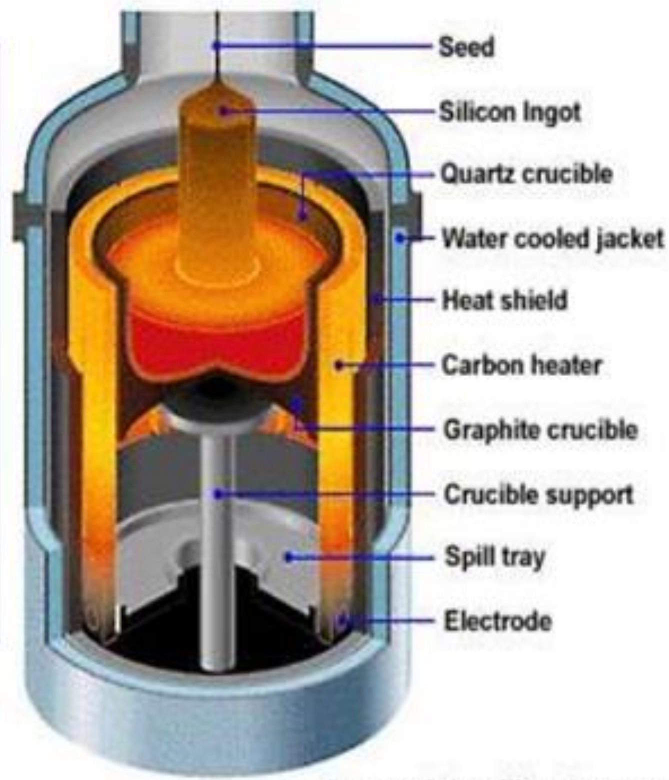
- Silicon ingot
  - The successful growth of silicon ingots requires an understanding of fluid mechanics, heat and mass transfer, and crystallization.

Semiconductor

- Silicon ingot (서랄스키 방법)

Wafer growth – Czochralski Method (Cz)

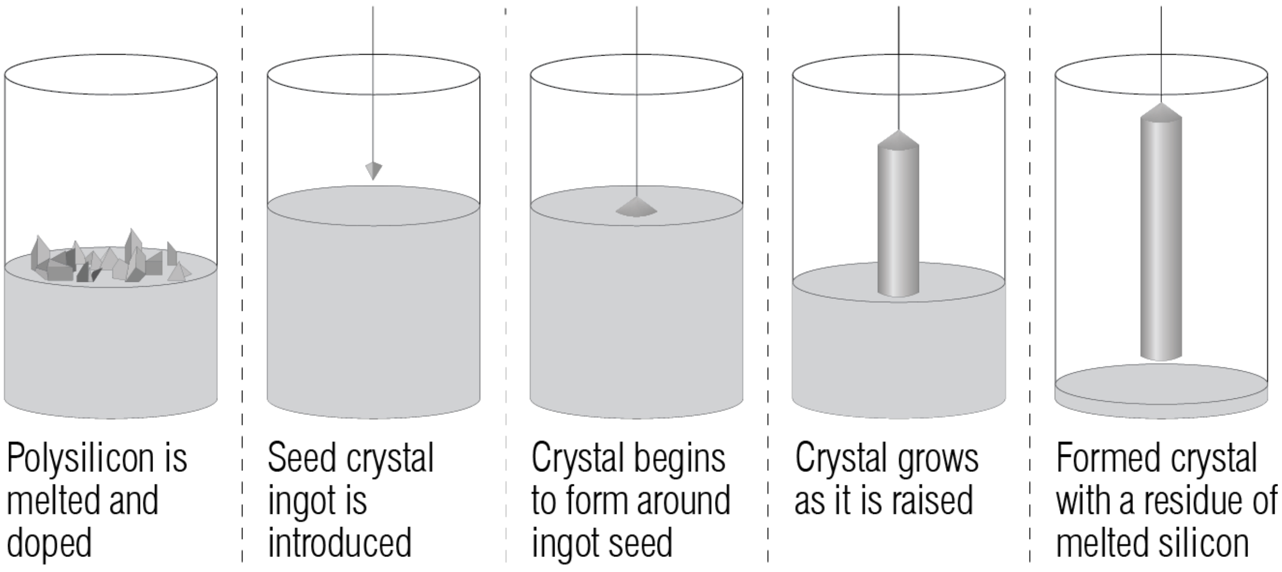
-From the high purity poly-Si, single crystal silicon is required,
-The Cz process is the most common for large wafer diameter production.
- Pull rate, melt temperature and rotation rate are all important control parameters.



Cz crystal pulling furnace

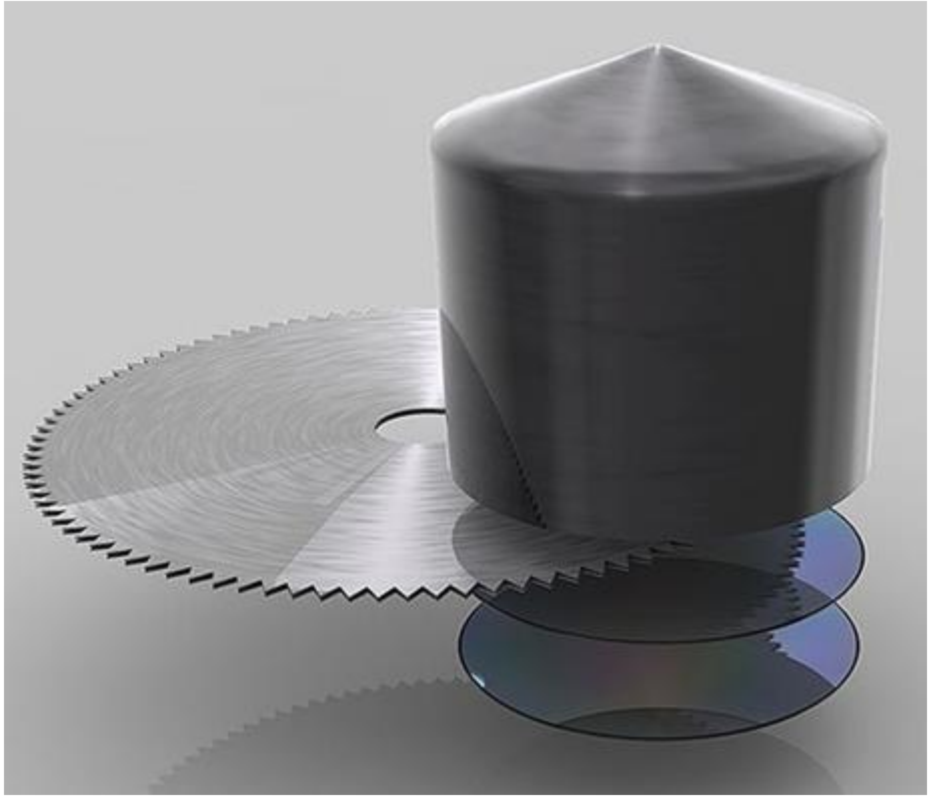
Semiconductor

- 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

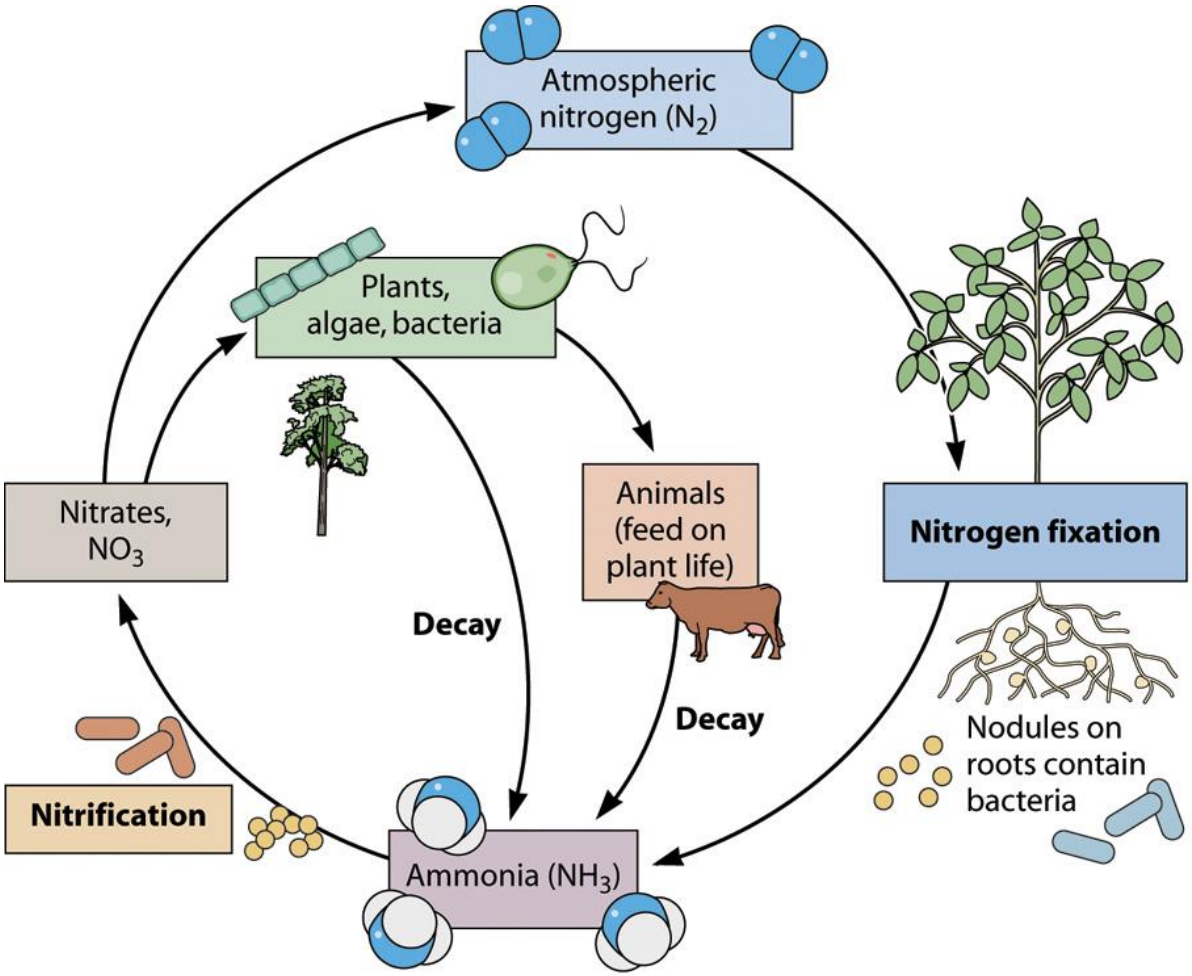
Chemical Engineers' Contribution

- 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: $N_2 + 6H_2 \rightarrow 2\ NH_3$
    - 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 N2

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

Non-Bt cotton vs. Bt Cotton

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

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

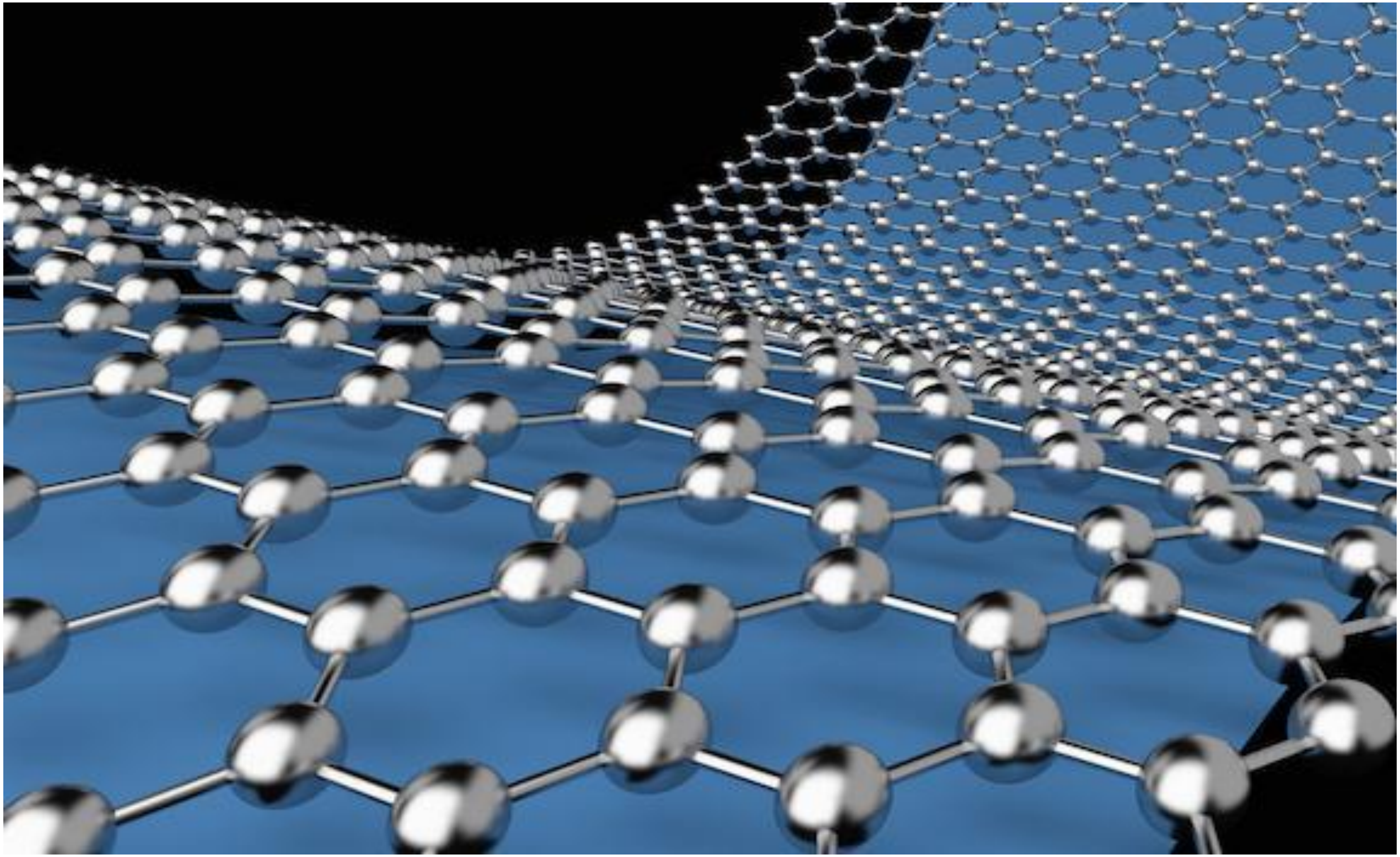
- Convert renewable biomaterials into electricity and transportation fuels, and valuable chemicals

- 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

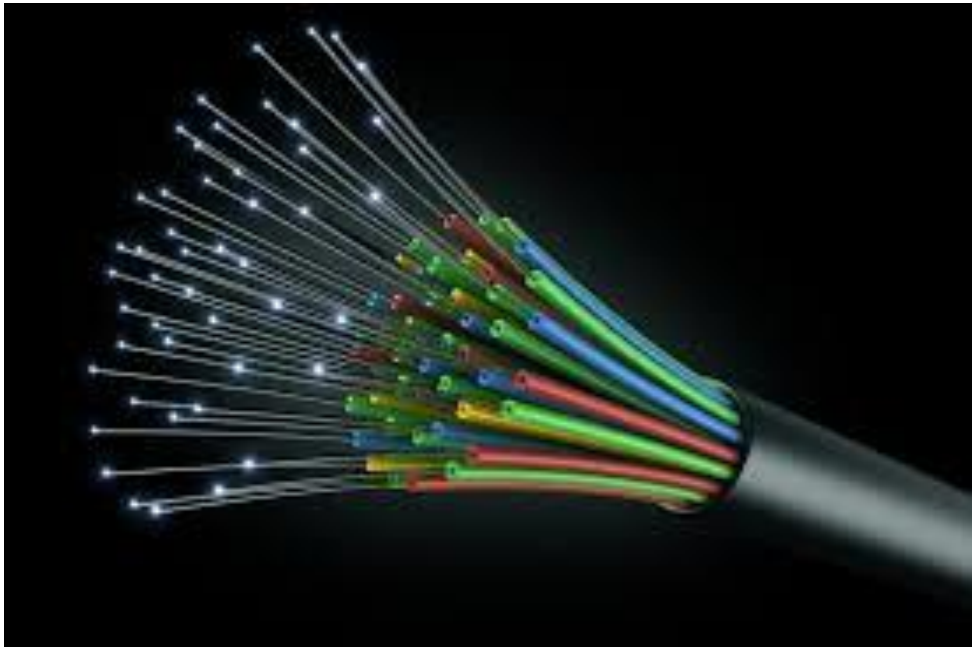
- Electronic devices become smaller, faster, smarter, and cheaper.
- Semiconductor chips
  - provide the backbone for modern computing systems.
  - complex microelectronic circuits composed of a base material with electrical conductivity greater than an insulator but less than a conductor.
  - The typical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

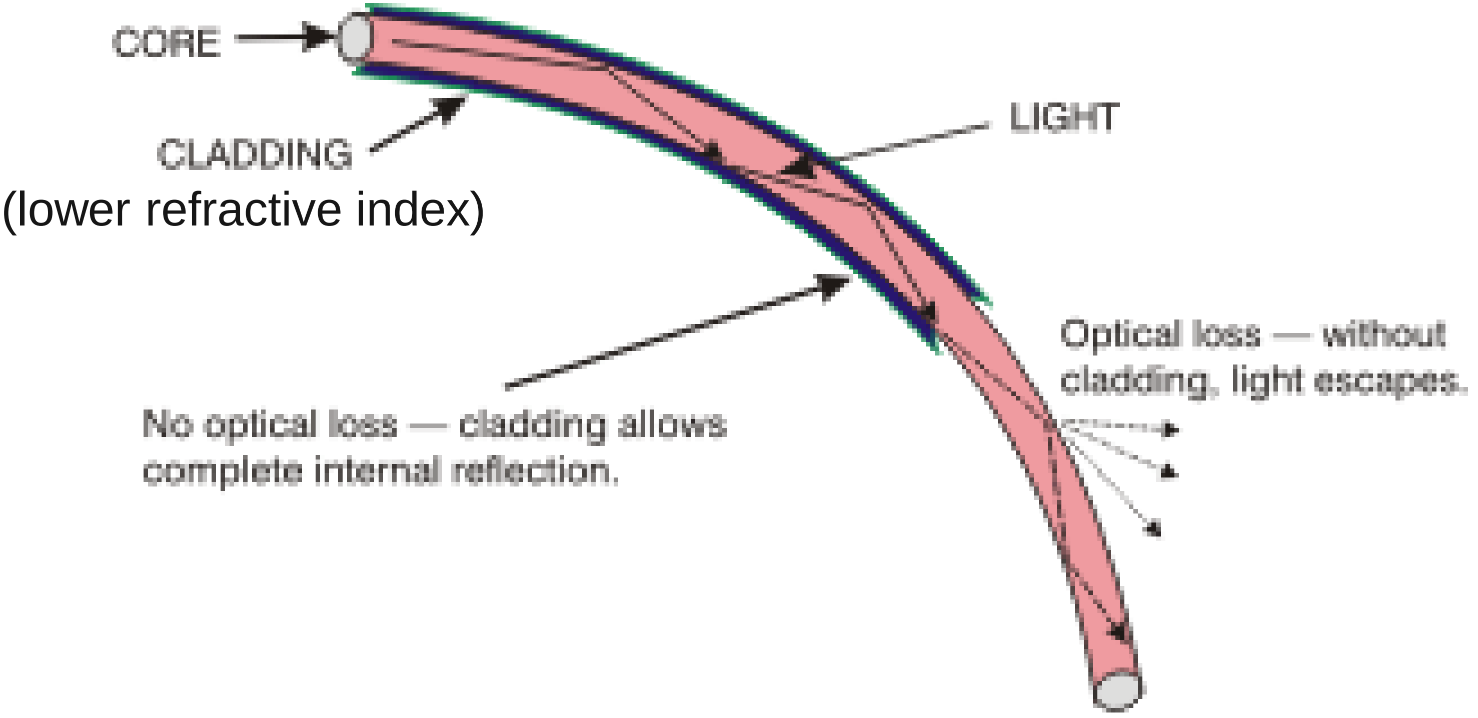
Telecommunications

- 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.