New Jersey Center for Teaching and Learning

Progressive Science Initiative

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AP BIOLOGY

Big Idea 3
Part D

February 2013

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Big Idea 3:

Living systems store, retrieve, transmit and respond to information essential to life processes.

Big Idea 3: Part D

Click on the topic to go to that section

Biotechnology

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Biotechnology is an Industry

In recent years, many businesses have taken advantage of the knowledge gained by biologists. The molecular machinery of cells has been utilized to produce thousands of new products.

just a few examples
of biotech companies

Biotechnology is an Industry

Since the beginning of this millennium the amount of revenue in the industry as a whole has more than doubled every five years. In 2012 this industry's total yearly revenue was valued at more than $400,000,000,000 (four hundred billion).

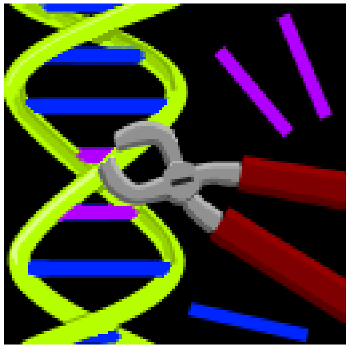
Biotechnology is an Industry

Currently there are more than 300 health care products dervived from the technology of biotech. Many of these treat previously untreatable diseases.

More than 14,000,000 farmers worldwide use biotech agriculture to increase food yield and reduce the impact of farming on the environment.

Definition of Genetic Engineering

The group of applied techniques of genetics used to cut up and join together DNA from one or more species of organism



Examples of Genetic Engineering

Golden rice is produced through genetic engineering to have more vitamins than natural rice to provide better nutrition. This product is used to better the nutrition of areas where food is scarce.

Genes from other plants have been spliced into its genome. Vitamin A, C and Beta-Carotene are among the added nutrients.

Examples of Genetic Engineering

A gene found naturally in fish has been spliced into these tomatoes. Now they can survive light frost, meaning a longer growing season and more yield per acre for farmers.

They have also been given a gene that makes a protein that repels bugs so farmers do not have to spray them with pesticides

Examples of Genetic Engineering

The genetically engineered fish in the background, produced by a company called AquaBounty, grows three times bigger in half the time as the natural version in the foreground.

This happens because of an added gene originally found in wild eel that produces a natural growth hormone and speeds the growth of the salmon.

Using DNA as Manufacturing

There are many individual technologies that can use DNA as a tool to make useful products. The rest of this section will focus on the techniques that use DNA as a technology.

1 Which of the following would be considered a product of genetic engineering?

- A A chemical used to lower cholesterol in humans
- B A chemical used to disperse an oil spill
- C A bacteria made to break down the toxic components of an oil spill
- D A heart transplant

Recombinant DNA

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Recombinant DNA

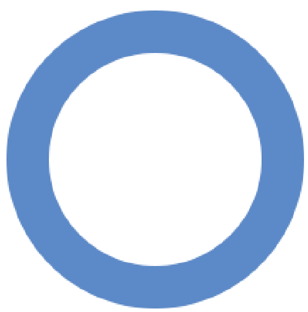
One of the first procedures to use DNA to successfully make a product that could be used for medical purposes was recombinant DNA technology.

In this procedure genes from one organism are spliced into the genome of another. Since all organisms use the same genetic code the cells that contained the recombined DNA will produce the protein encoded by the new gene.

Recombinant DNA

This multistep process uses a combination of technologies that mimic biological processes in the laboratory to ultimately make useful proteins.

As a case study to understand the process we will look at the history of **treating diabetes with insulin**.



The blue circle is the global symbol for diabetes, introduced by the International Diabetes Federation. The aim is to give diabetes a common identity and to raise awareness of the diabetes epidemic.

Diabetes

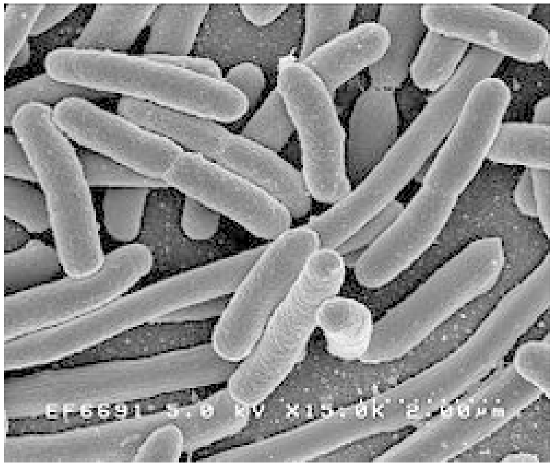
Untreated, diabetes causes many problems. Most severe is damage to the kidneys resulting from the increased solute of the blood for extended periods.

Early Treatment of Diabetes

At first doctors treated by injecting bovine insulin harvested from cows blood. This had some effect but the protein is not exactly the same as the human insulin protein. The symptoms would eventually overcome the patient.

Early Treatment of Diabetes

In the late 1970s scientists started to look for a way to make human insulin in a laboratory. Their efforts produced the first product ever made using genes from multiple organisms.



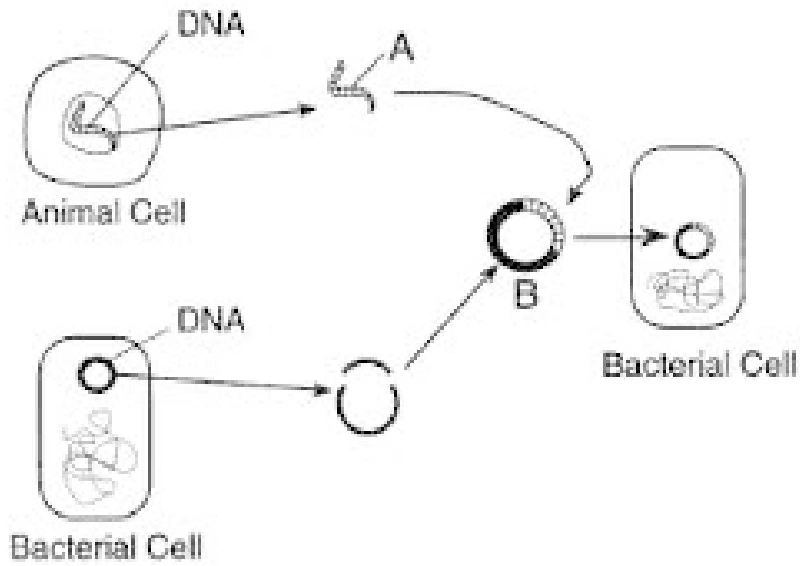
They recombined fragments of DNA from humans with the bacterial chromosome of *E. coli.* The new bacteria was then able to produce human insulin.

Early Treatment of Diabetes

The result was a new product called Humulin. The first human hormone to ever be produced by another organism.

Recombinant DNA Technology

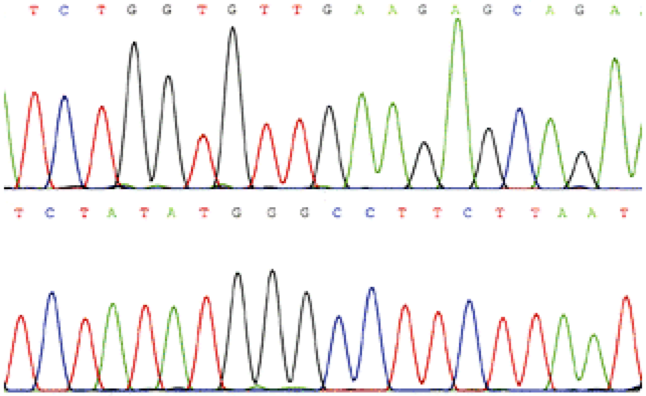
DNA pieces can be recombined to make unique, man made sequences. There are 7 main steps. As you go through the next slides make notes on the 7 steps. You will use them to complete an activity at the end of the section.



Recombinant DNA Technology

Step 1: Find the piece of DNA in the genome, the gene of interest.

Today this step is done by computers atached to robotic DNA sequencers that fragment, analyze and find a gene based on user input.



Recombinant DNA Technology

Step 2: "Cut" the gene of interest from the genome

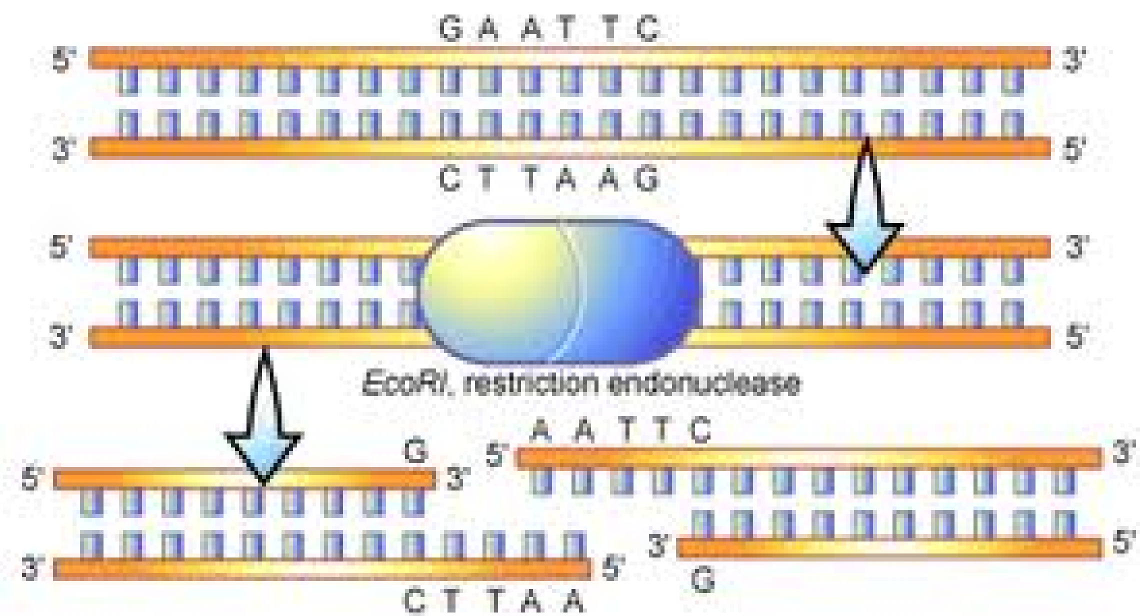
Genetic engineering was made possible by the discovery of a class of enzymes called **restriction enzymes**. In nature these enzymes are used by bacteria as weapons against invading viruses.

They look for specific sequences in pieces of DNA and cut them.

For example: EcoRI is a restriction enzyme that makes a staggered cut when it reads the sequence GAATTC

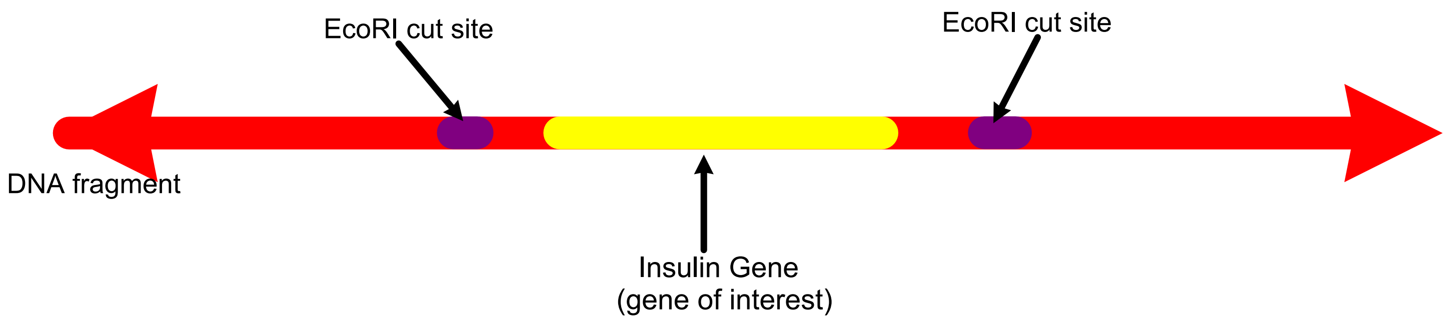
Recombinant DNA Technology

For example: EcoRI is a restriction enzyme that makes a staggered cut when it reads the sequence GAATTC. The staggered ends are called **sticky ends** because they leave a few unpaired nucleotides that will easily stick to another piece of DNA with the same sticky end.



Recombinant DNA Technology

If the sequence of the gene of interest, say the insulin gene, is known and the sequences in the surrounding DNA are known, then restriction enzyme cut sites that are on opposite sides of the gene can be utilized to cut the gene out.

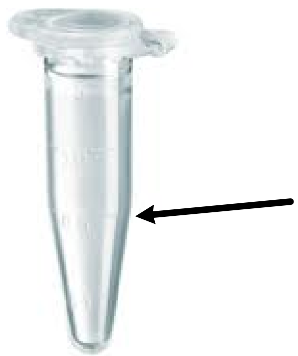


Recombinant DNA Technology

Step 3: Isolate the gene of interest

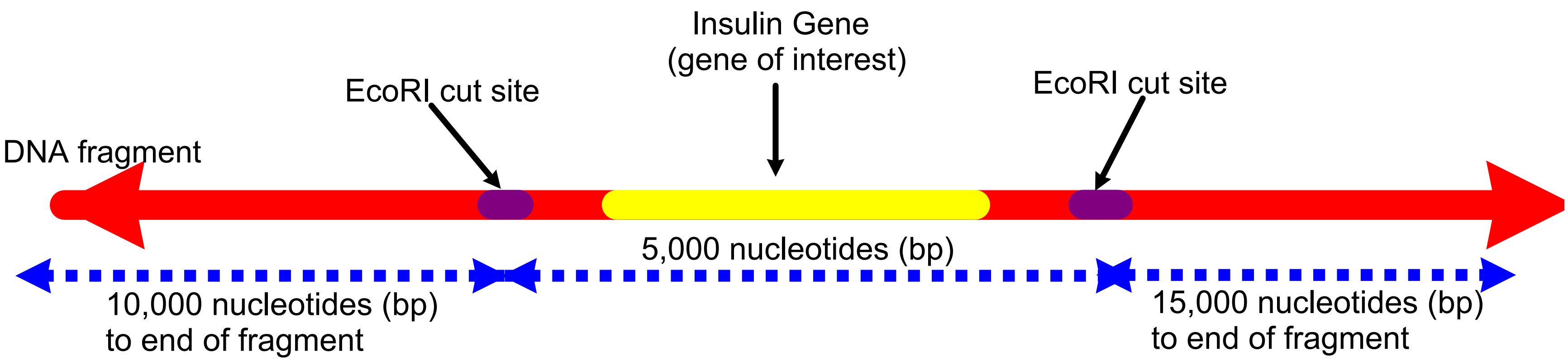
Restriction enzymes mixed with DNA is called a **digest** because the enzymes breaks down the fragments of DNA into many smaller pieces.

It is important to remember that we are working with molecules. We cannot simply "grab" the piece of DNA we want. We must separate the unique pieces of DNA in the digest and select the fragment we want.



Recombinant DNA Technology

If we look at the insulin gene again we can see that the sequence between the two EcoRI cut sites has a unique length.



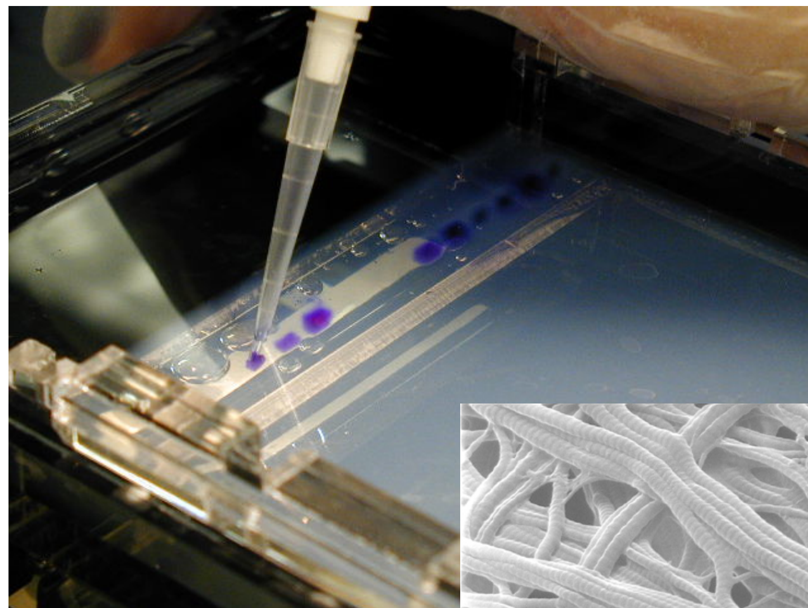
So in this digest there are DNA fragments that are 5k,10k, and 15k nucleotides long. The gene of interest here is the 5k piece.

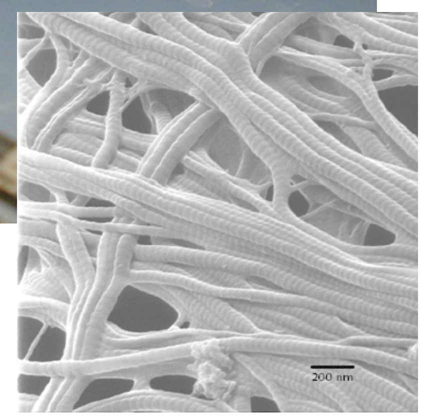
Recombinant DNA Technology

Gel Electrophoresis is one way to separate DNA fragments based on length.

The digest is loaded by pipet into a gel, that resembles Jello. The gel is a network of fibers called collagen.

Small pieces of DNA can move through the gel quicker than the longer pieces that get tangled in the collagen fibers.



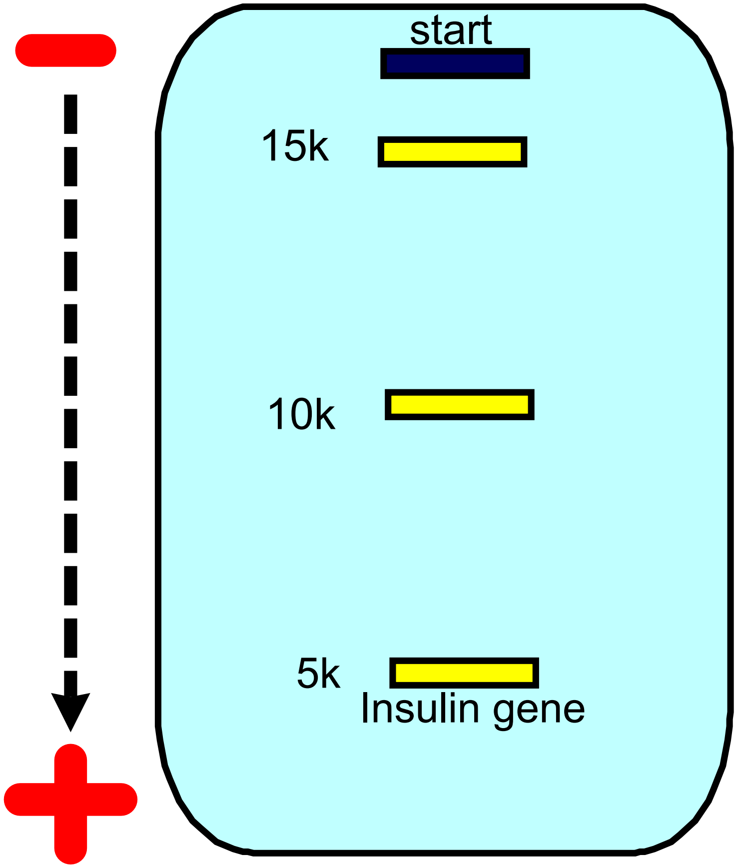


Recombinant DNA Technology

DNA has a slightly negative charge.

An electrical current is passed through the gel and the DNA fragments move to the positive charge. Small fragments move faster, larger fragments are slowed down by the matrix.

The result is that the small pieces can travel farther than the larger ones. The DNA is separated by size in what is know as a **banding pattern.**



Recombinant DNA Technology

Gel Electrophoresis virtual lab by the University of Utah

The Gel Lab

Recombinant DNA Technology

Step 4: Make more of the gene of interest (amplification)

Once the gene of interest is isolated in the gel, the band that contains the gene can be cut from the gel, but this is a very small sample. More DNA must be made in order to be able to work with it in the lab.

Recombinant DNA Technology

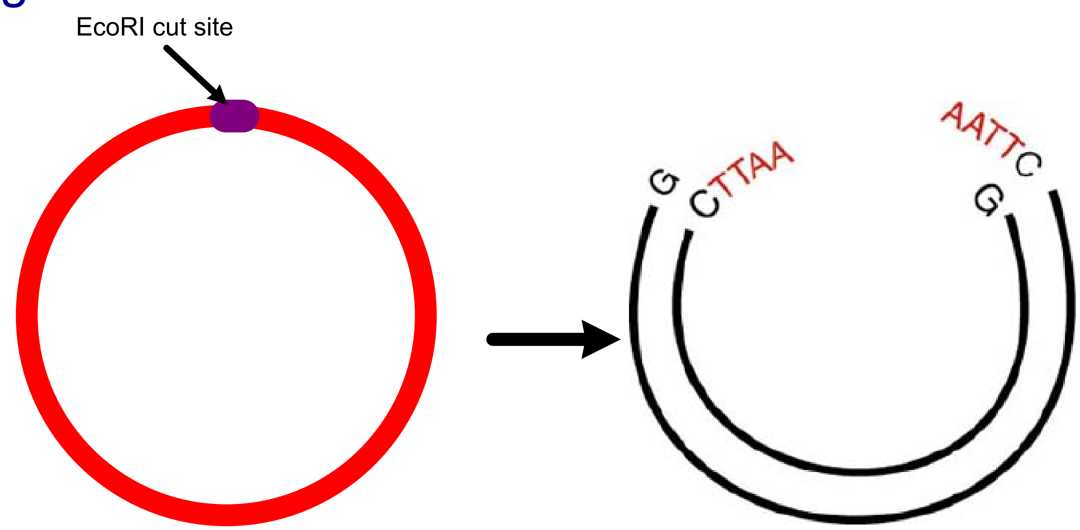
PCR (Polymerase Chain Reaction) is utilized to amplify DNA. This reaction is carried out by a special machine that utilizes repeating cycles of heat, DNA polymerase and free nucleotides to build copies of the DNA fragment.

This technology enables small amounts of DNA to be turned into large amounts.

Recombinant DNA Technology

Step 5: "Paste" the gene of interest into the host's DNA

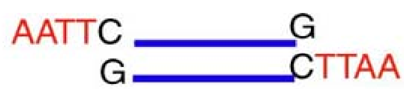
Sticking to the insulin example, the technique utilized to get the insulin gene into the *E. Coli* bacteria involved using a plasmid, the small circular pieces of DNA that bacteria use to trade pieces of genetic information.



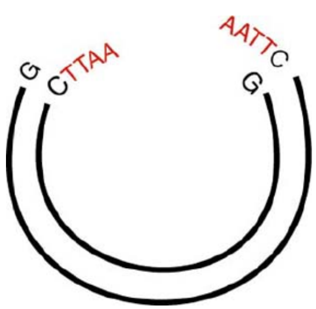
A plasmid with an EcoRI cut site is "digested" using the same restriction enzyme that was used to cut out the insulin gene.

Recombinant DNA Technology

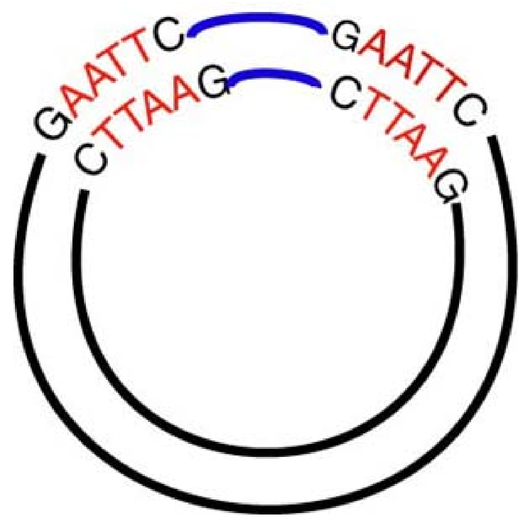
Mix the cut plasmid with the gene of interest to create a recombinant DNA plasmid that contains a human insulin gene



Insulin gene with sticky ends



Plasmid with sticky ends



Recombinant DNA Plasmid

Recombinant DNA Technology

Step 6: Put the recombined piece of DNA into the host organism

Now that the gene of interest is in a plasmid, it can be mixed with bacterial cells and be taken up into the bacterial chromosome.

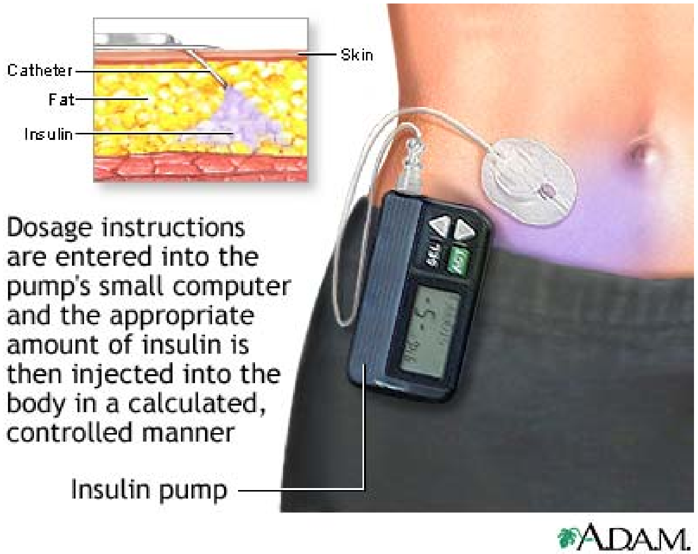
Remember, all living things use the universal genetic code. The bacterial cells will read the newly acquired gene, transcribe it into mRNA and its ribosomes will translate the mRNA into a protein.

The bacterial cells will reproduce and express the gene. Each time a recombinant bacterial cell divides by binary fission it will make a new copy of the gene.

Recombinant DNA Technology

Step 7: Collect the protein product

The protein can be extracted from bacterial cultures using various techniques. It can then be delivered to the patient.



Currently there is no cure for diabetes, but with advancements in insulin therapy patients can now avoid many of the life threatening complication.

DNA Technology: Group Problem

You and a small group of your classmates have identified a gene in gorillas that codes for a protein that has been found to slow the progression of cancer in humans. It would be far too expensive to harvest this protein from gorillas, so a biotech company has asked you to come up with a procedure to cheaply make the protein.

If your team makes the best procedure you will be given a grant of $10,000,000 to make the product. Work with your table group for the next 10 to15 minutes to **come up with a step by step plan** to make this product as cheaply as possible.

Other DNA Technologies

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Other Biotech Procedures

There are many individual technologies that are classified as the tools required for biotechnology. These are a few examples.

Gene Therapy
Cloning
Stem Cell Manipulation

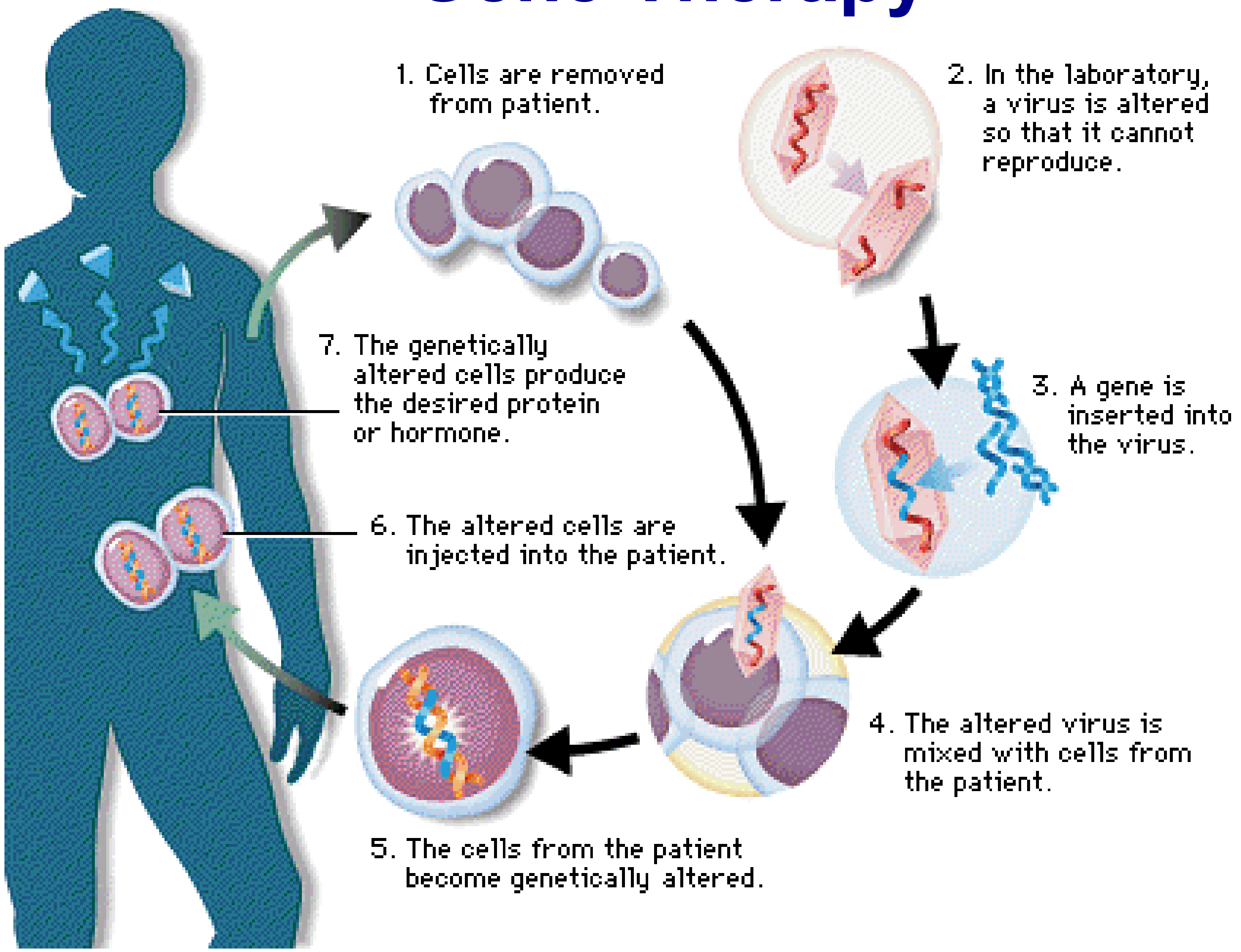
Future uses of DNA Recombination

Gene therapy is the hopeful future of Recombinant DNA

Instead of getting bacteria to make the needed protein,it would be better to give a patient's cells the gene so they could make their own insulin. This would eliminate the need for injections or blood monitoring.

The only true cure for certain types of diabetes would be to alter the genetics of the pancreatic cells responsible for making insulin.

Gene Therapy



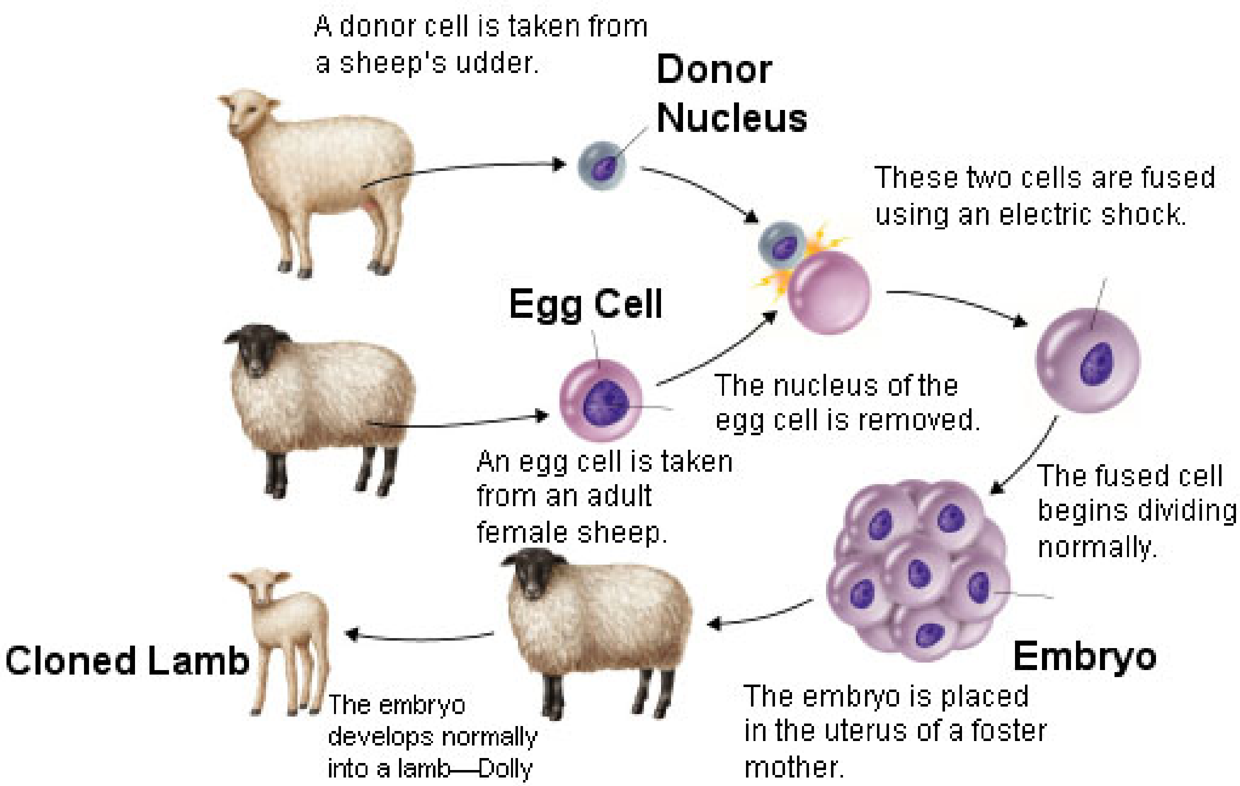
Cloning

Cloning refers to processes used to create copies of DNA fragments, cells, or organisms. Scientists have been cloning animals for many years. In 1952, the first animal, a tadpole, was cloned.

Dolly, the first mammal cloned from the cell of an adult animal, was a sheep. Researchers have cloned a number of large and small animals including sheep, goats, cows, mice, pigs, cats, rabbits, and a bison.

All these clones were created using **nuclear transfer technology**.

Nuclear Transfer Cloning



Nuclear Transfer Video

Stem Cells

Stem cells are biological cells found in all multicellular organisms, that can divide through mitosis and differentiate into diverse specialized cell types.

Types of Stem Cells

In mammals, there are two types of stem cells:

Embryonic stem cells that are isolated from the inner cell mass of blastocysts. In a developing embryo, stem cells can differentiate into all specialized cells.

Adult stem cells act as a repair system for the body. They maintain the constant turnover of regenerative organs, such as blood, skin, or intestinal tissues.

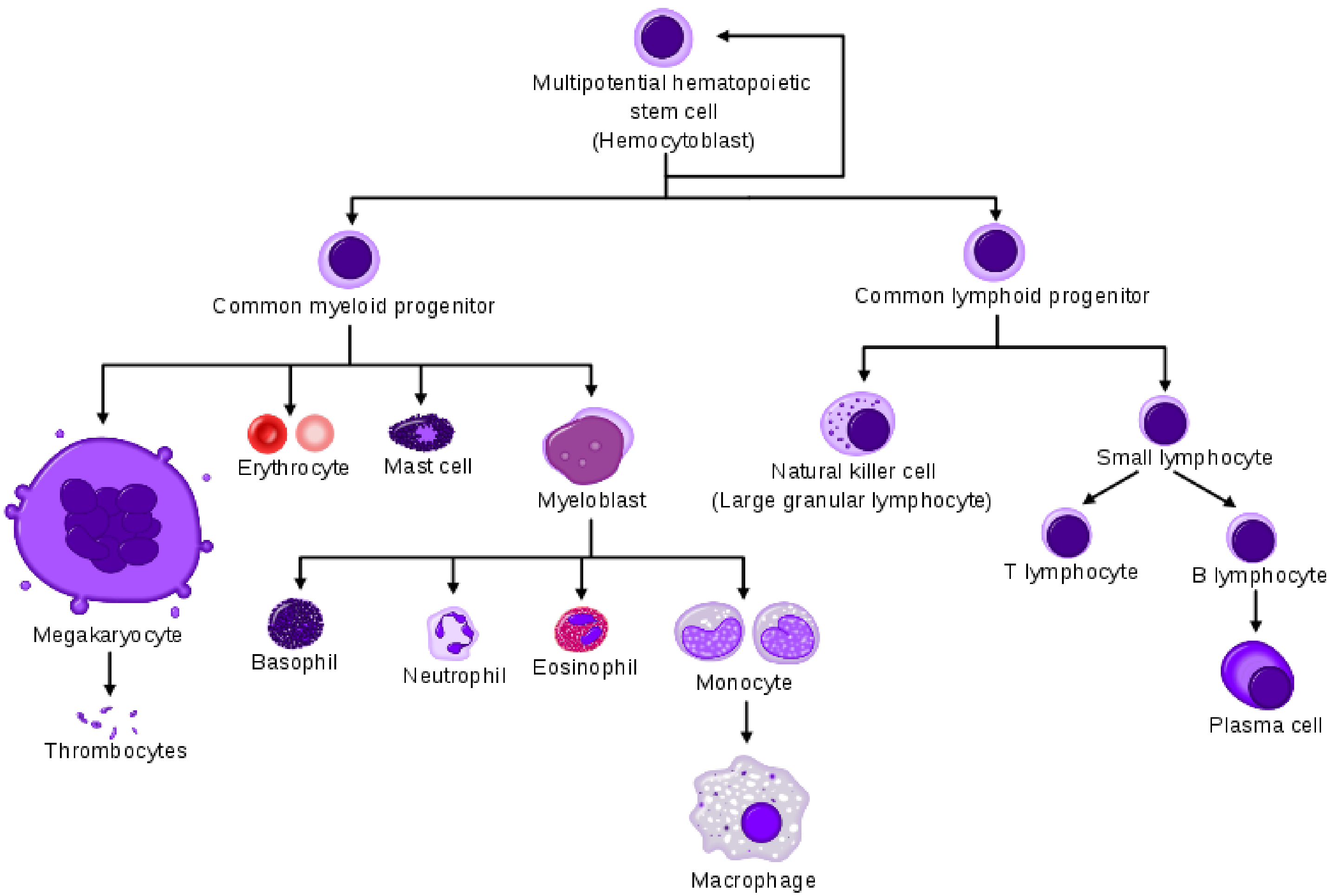
Stem Cell Potency

Embryonic stem cells are **totipotent**. They can differentiate into any cell type that is present in the organism.

Adult stem cells are **pluripotent**. They can differentiate into some, but not all, of the cells present in the adult organism.

Adult Stem Cell

An example of adult stem cells would be bone marrow cells (known as hematopoietic cells) that can produce many types of blood cells.



Stem Cell Technologies

Presently, embryonic stem cells have been used primarily for research. Potential for technologies exist, but currently no product has been produced.

Adult stem cells have been used as cancer treatments and to produce new organs for regenerative medicine.

Uses for Adult Stem Cells

A trachea (windpipe) that was "grown" from harvested adult stem cells.

It was used to replace a woman's damaged windpipe. Because the stem cells were her own, there was no chance for rejection by her immune system.

2 Which of the following best represents possible cloning products?

- A a sheep
- B a gene for insulin, a sheep
- C a bone marrow cell, a gene for insulin, a sheep
- D oil, a bone marrow cell, a gene for insulin, a sheep

3 In nuclear transfer, after an egg cell is denucleated, what is put into the egg?

- A mitochondria
- B a somatic cell nucleus
- C another egg's nucleus
- D a sperm cell

4 Which of the following is totipotent?

- A embryonic stem cells
- B adult stem cells

5 Which of the following is found in a blastocyst?

- A embryonic stem cells
- B adult stem cells

6 Which of the following was used to produce a trachea manufactured in a lab?

- A Adult Stem Cells
- B Embryonic Stem Cells

GMO

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Genetically Modified Organisms

A genetically modified organism (GMO) is an organism whose genetic material has been altered using genetic engineering techniques. Any living organism that possesses a novel combination of genetic material obtained through the use of modern biotechnology.

GMOs are the source of genetically modified foods, and are also widely used in scientific research and to produce goods other than food.

Genetically Modified Foods

GM foods are derived from genetically modified crops. Humans have genetically modified food organisms since the beginning of agriculture by **selective breeding.**

GM foods takes this a step further because they are produced by sharing genes from other species (not possible with selective breeding), greatly enhancing the possibilities for alterations of a crop.

Genetically Modified Foods

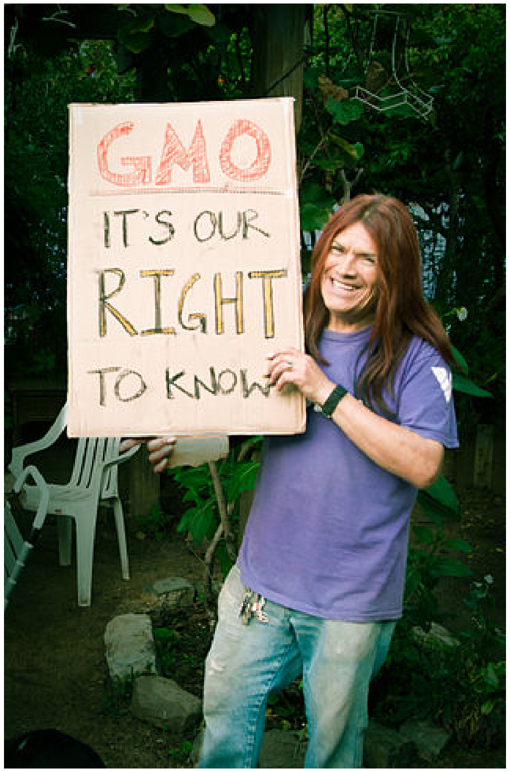
The GM foods controversy is a dispute over the advantages and disadvantages of food derived from GMOs.

There is broad scientific consensus that food on the market derived from GM crops pose no greater risk than conventional food. No reports of ill effects have been documented in the human population from GM food.

Genetically Modified Foods

Opponents of GM foods believe not enough research has been done to rule out possible negative effects. Their concerns include:

Risk of side effects from eating GM food
GM food labeling
Government regulation
The effect of GM crops on the environment
The role of GM crops in feeding the growing world population



Genetically Modified Foods

Most genetic alterations are to increase the food yield of a crop or to protect the food from some known detrimental environmental factor.

Papaya has been genetically modified to resist the ringspot virus. 'SunUp' is a transgenic papaya that has an added gene that protects it from the virus. In the early 1990s, Hawaii's papaya industry was facing disaster because of the virus. The engineered papaya saved the industry.

7 Do you think it was right to save the papaya industry in Hawaii with a GM food?

- ❍ Yes
- ❍ No

8 Would you eat a SunUp Papaya?

- Yes
- No

9 If you found out your favorite food was genetically modified, would you still eat it?

- Yes
- No

10 Should all GM foods be labeled in the supermarket?

- Yes
- No

Synthetic Biology

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Synthetic Biology: The Future of Biotechnology

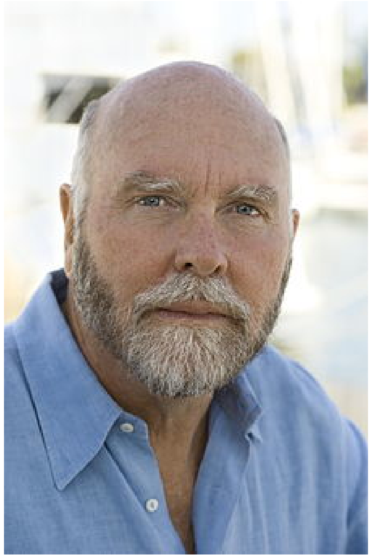
In a recent New York Times article, Drew Endey, a founder of a synthetic biology competition at M.I.T. called iGEM, was quoted:

"Synthetic biologists imagine nature as a manufacturing platform: all living things are just crates of genetic cogs; we should be able to spill all those cogs out on the floor and rig them into whatever new machinery we want.

If you want to build a bookcase, you can find a nice tree, chop it down, mill it, sand the wood and hammer in some nails. Or, you could program the DNA in the tree so that it grows *into* a bookshelf."

Synthetic Biology: The Future of Biotechnology

The J. Craig Venter Institute is the leading facility for synthetic biology. In 2010 the scientists at the institute successfully created a completely man made genome and made a new bacterium, one that could not have been created by nature.



John Craig Venter

Synthetic biologists see life as computers:
The cells and organisms are hardware, powerful machines capable of carrying out complex function.

The genes are the software that tell the hardware what to do. This software can be updated, replaced and added to with new software.

Creating Synthetic Life

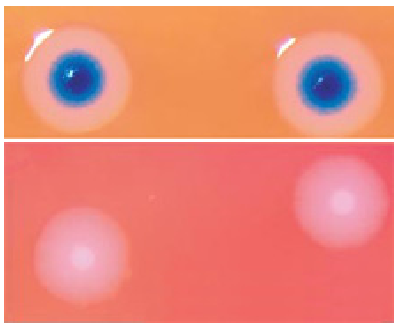
To create synthetic life, a bacterial cell had its genome removed in the same way that would be done in the nuclear transfer technique for cloning.

A synthetic genome was produced by using the recombinant DNA techniques talked about earlier. They stitched together short pieces of known sequences into an entire genome.

The new genome was inserted into the bacteria. Just like a computer with new operating system, the cell booted up and ran the new "program".

Synthetic Metabolism

The cell produces all new protein products and uses a different form of metabolism that was programmed by the scientists. One feature of the new code was a gene that coded for a blue protein pigment so they could visually confirm the cell was reading the new genetic code.



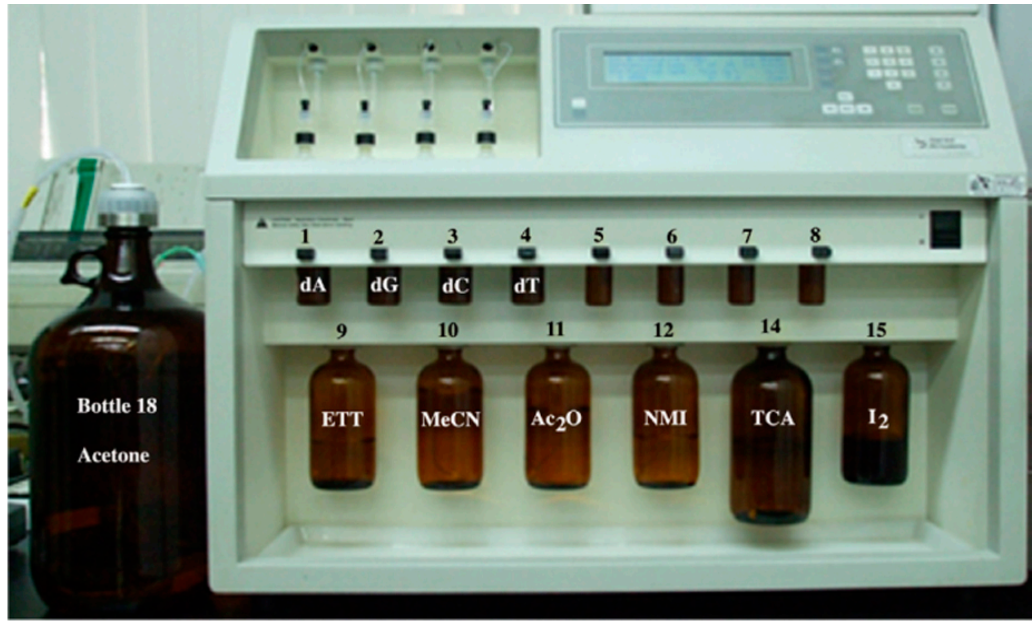
Synthetic genome expressed

Before synthetic genome

The hope for this technology is that scientists can create bacterial cells that produce medicines and fuels and can also absorb pollutants like green house gases and petroleum products.

Synthetic DNA

A DNA synthesizer is capable of making unique, man-made DNA sequences.



In other words, it is no longer necessary to find a gene in nature. Scientist can make any protein product they can think of by making new genes.

The Ethics of Biotechnology

These new technologies have allowed humans to manipulate nature and evolution in an unprecedented way. With this ability comes a need to examine how we will use it and define our responsibilities

Paul Wolpe is the Chief of Bioethics at NASA. He presents a quick tour of new technologies and questions what we will do with them on TED.com.

It's Time to Question Bioengineering Video