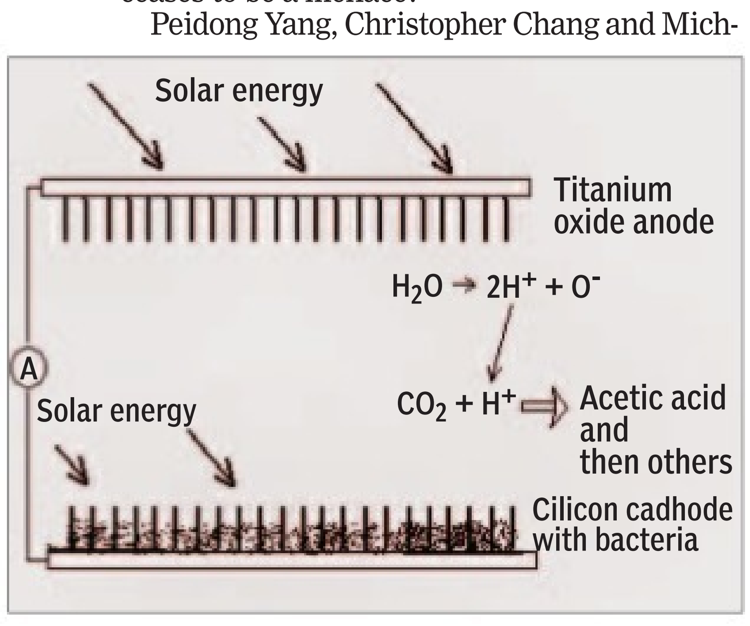
Road to artificial photosynthesis

IMITATING NATURE'S TRICK MAY CHECK THE EARTH'S GREATEST POLLUTANT AS SOON AS IT IS PRODUCED, WRITES

S ANANTHANARAYANAN

All life on earth owes its existence to the oxygen in the atmosphere and our planet causes life to thrive, thanks to carbon dioxide in the atmosphere being in check. Both these qualities of the earth come courtesy plants and organisms that use the sun's energy to turn CO_2 into food and oxygen. But humankind is producing more CO_2 than can be taken care of and the build-up is disturbing the planet's balance. Locking up all the CO_2, so that it does not get out there may not be viable. Can we create machines that convert CO_2 like plants or bacteria do so that it ceases to be a menace?

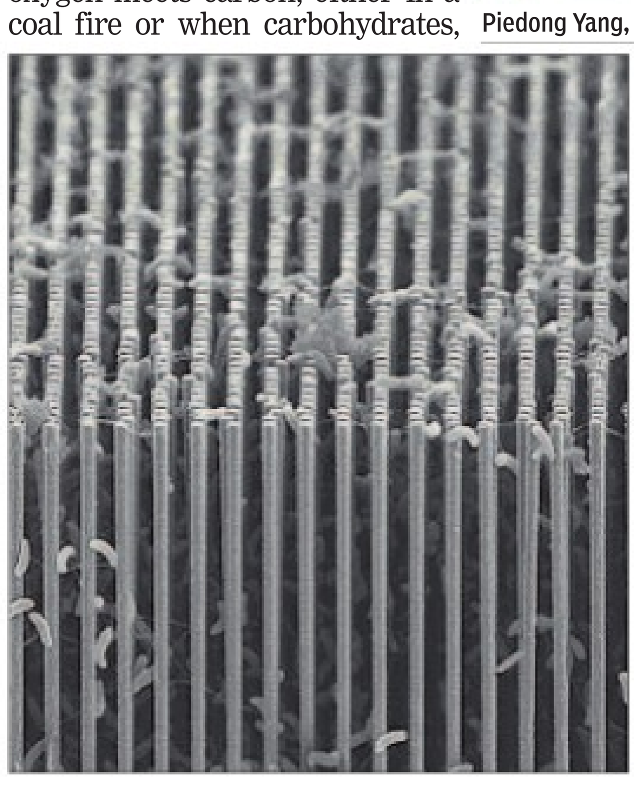
Peidong Yang, Christopher Chang and Michelle Chang, working with Chong Liu, Joseph Gallagher, Kelsey Sakimoto and Eva Nichols, at the US Department of Energy's Lawrence Berkeley National Laboratory and the University of California at Berkeley report in the journal *Nano Letters* that they have found a way to do just that — a device consisting of nanowires and bacteria that mimics the process of photosynthesis, by which plants use the energy in sunlight to synthesise carbohydrates from carbon dioxide and water.



Photosynthesis could be regarded as the ideal in conversion systems, where the raw material, carbon dioxide and water, is dismantled into components and reassembled as carbohydrates and free oxygen, directly using photons of light as the energy source. There are no undesired by-products, no heat, no electricity. And around the centres of photosynthesis a framework has evolved for the most efficient collection of light.

We can readily see that carbon combining with oxygen, which happens when things burn, a case of *oxidation*, and this releases heat. Photosynthesis is the opposite, where carbon in carbon dioxide is, in effect, separated from oxygen through a reaction called *reduction*, and which consumes energy. The reduction is carried out adding hydrogen to CO_2 to form carbohydrates, and in photosynthesis as carried out by plants and bacteria, the hydrogen comes from splitting water molecules into hydrogen and oxygen. In the water molecule, hydrogen atoms give up their electrons to oxygen atoms, to form a stable structure. When water is split by the action of photons, oxygen atoms get together as oxygen molecules and electrons and energy become available to "fix" CO_2 as carbohydrates.

The effect of photosynthesis is thus to store the energy of photons, partly in carbohydrates and partly in free oxygen. It is this energy that is given up when free oxygen meets carbon, either in a coal fire or when carbohydrates, like glucose, fuel the action within the bodies of living things.



Electron microscope nanowire.

The actual photon capture and splitting of water molecules is carried out in plants mainly by the pigment called *chlorophyll*. Each chlorophyll molecule captures one photon and loses an electron, which moves through a chain of other chemical agents as a form of energy currency. And while this action proceeds, the chlorophyll molecule regains its lost electron from water molecules to release oxygen, which is, in fact, is a "waste" product of the process. Along with this process of using the photon energy is the system for the most efficient capture and use of the photons themselves. In plant cells, the chlorophyll molecules are distributed over folded membranes that contain structures called *chloroplasts*. A cell can have 10 to 100 chloroplasts and leaf tissue can have 450,000-800,000 chloroplasts in every square millimetre. And within the cells, the light-sensitive molecules are arranged in a complex like an antenna and act together to capture photons with quantum mechanical efficiency.

Piedong Yang, Christopher Chang and Michelle Chang.

Artificial photosynthesis

The arrangement of the Berkley group mimics nature's method by using a mesh of nanowires made of silicon and titanium oxide to act as the photon capture and electron source, and microbes that speed up the reduction of CO_2 to useful organic chemicals. When photons strike the silicon surface, loosely bound electrons are ejected and used to feed the bacterium *Sporomusa ovata*, which readily accepts electrons directly from the surrounding environment and uses these to reduce carbon dioxide. The ejection of electrons is matched by a generation of "holes" or the "lack of electrons" in the titanium oxide, which acts on water to generate hydrogen and release oxygen.

The use of nanowires ensures the high surface area for efficient light gathering. The "artificial forest" of nanowires "is similar to the chloroplasts in green plants", says Peidong Yang, a chemist with Berkeley Lab's Materials Sciences Division. Many bacteria are anaerobic, and oxygen sensitive, but embedded within the nanowire mesh they are able to work in an oxygen-free environment, such as of flue gases.

In the "proof of principle" trial by the Berkley group, however, the bacterium *S. ovata* was able to act under aerobic conditions, which is 21 per cent oxygen, with good electrical efficiency stability. "S. ovata is a great carbon dioxide catalyst as it makes acetate, a versatile chemical intermediate that can be used to manufacture a diverse array of useful chemicals," says Michelle Chang, synthetic biologist and one of the corresponding authors of the paper. "We were able to uniformly populate our nanowire array with S. ovata using buffered brackish water with trace vitamins as the only organic component."

The trials, which represent an alliance between material science and biology, manage to create the key elements of the nanowire light-capturing mechanism and the CO_2 conversion by catalytic activity of the bacteria. The arrangement has been able to convert solar energy with an efficiency of 0.38 per cent continuously for 200 hours under simulated sunlight. This is about the same as the efficiency of a natural leaf.

"We are currently working on our second generation system which has a solar-to-chemical conversion efficiency of three per cent," Yang says. "Once we can reach a conversion efficiency of 10 per cent in a cost effective manner, the technology should be commercially viable." Once the CO_2 has been converted to acetate, or other form, genetic engineered e.coli can be employed to generate specific chemical products. During the trials, the performance of conversion was 26 per cent for butanol, a fuel comparable to gasoline, 25 per cent for a precursor to an anti-malaria drug, and 52 per cent for PHB, the renewable and biodegradable plastic. Artificial photosynthesis, thus, has the potential of treating large CO_2 output of facilities like power plants by using only water and sunlight to produce chemicals — a doubly green chemical industry!

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A NEW CONCEPT

TAPAN KUMAR MAITRA EXPLAINS THE REGULATION OF GENE EXPRESSION

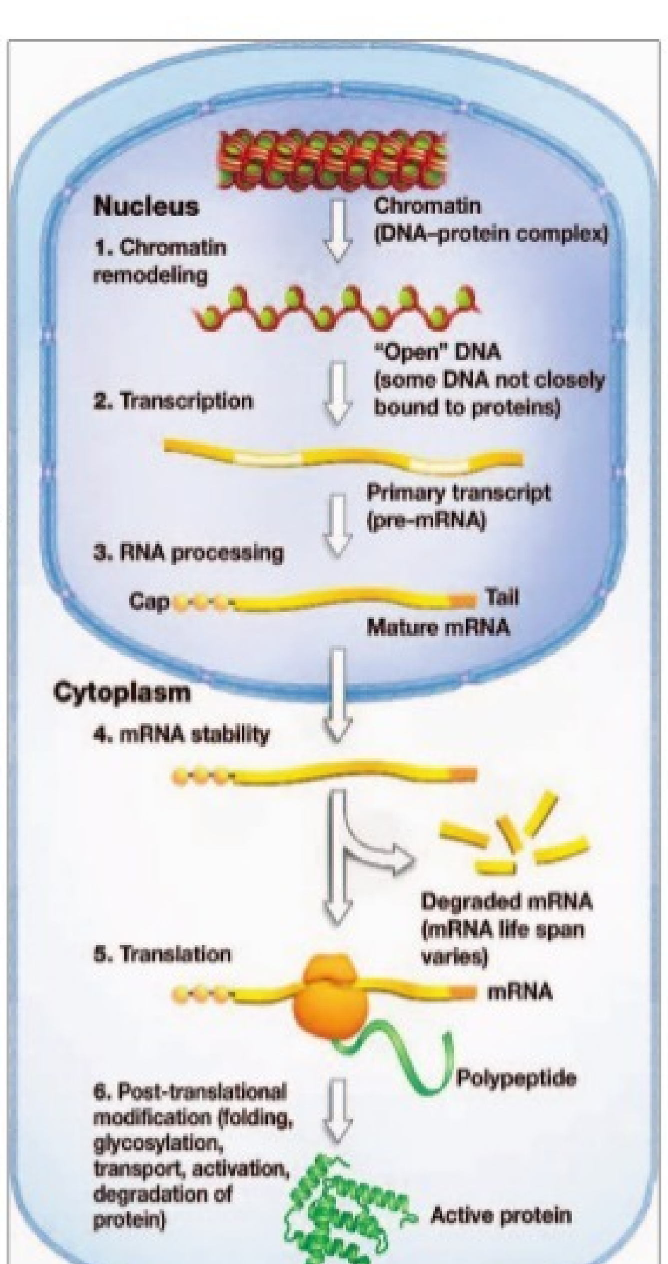
Since most genes are not expressed all the time we need to understand — in addition to knowing how genetic information is expressed in cells — how that expression is regulated. In prokaryotes, coordinately regulated genes are often clustered into operons and most regulation is effected at the level of transcription. Operons are turned on and off in response to cellular needs. In general, operons that encode enzymes of catabolic pathways are inducible; their transcription is specifically activated by the presence of substrates. Operons that encode anabolic enzymes, on the other hand, are subject to repression; transcription is specifically turned off in the presence of the end-product. Both types of regulation are carried out by allosteric repressor proteins that exert negative control by binding to the operator and preventing transcription of the associated genes.

Some operons coding for catabolic enzymes also have DNA control sites that respond to positive control by the cAMP receptor protein (CRP). This mechanism allows the operon to be shut down in the presence of glucose, ensuring preferential utilisation of that sugar. The effect of glucose is mediated by cAMP, the allosteric effector of CRP. Some operons that encode anabolic enzymes, such as those for amino acid biosynthesis, contain a leader sequence that can attenuate transcription when the corresponding amino acid is available.

Leader sequences in mRNAs may also contain riboswitches that bind to small molecules, thereby altering hairpin loop configurations that in turn influence either the termination of transcription or the initiation of translation.

Regulation is more complicated in eukaryotes because of the size and organisational complexity of the eukaryotic genome, as well as the intricate nature of development and cell differentiation in multi-cellular organisms. As a general rule, the cells of a multi-cellular organism contain the same set of genes, although events such as DNA amplification, deletion, rearrangement and methylation can introduce alterations. Activation of individual genes most likely involves a selective decondensation of chromatin. This structural change can be seen microscopically in the giant polytene chromosomes of insect salivary glands, but it is probably a general phenomenon.

Once uncoiled, the DNA is more accessible to RNA polymerases and to the protein factors required for transcriptional initiation. In eukaryotes as well as prokaryotes, transcription initiation is perhaps the most important control point in gene expression. The initiation of gene transcription is controlled by the binding of regulatory transcription factors to various types of DNA control sequences. Especially important among these are DNA response elements, which allow nonadjacent genes to be regulated in a coordinated fashion. For example, hormone response elements coordinate the expression of genes activated by specific hormones and the heat-shock response element coordinates the expression of genes activated by elevated temperatures and other stresses.



In addition to transcriptional regulation, cells possess numerous mechanisms for controlling gene expression at the post-transcriptional level. In eukaryotes, where post-transcriptional controls are especially well developed, these mechanisms include the ability to generate multiple mRNAs from the same gene using alternative splicing; general, as well as mRNA-specific, mechanisms to regulate translation and mRNA degradation; and post-translational modulation of protein structure, activity and degradation.

While the interaction of regulatory proteins with specific DNA and RNA sequences plays a central role in many of these mechanisms for controlling gene expression, it has recently become apparent that certain classes of short RNA molecules (siRNAs and microRNAs) can also regulate the expression of specific genes through a process known as RNA interference. By binding to complementary sequences in specific messenger RNAs (or in some cases DNA), these short RNAs silence the translation and/or transcription of individual genes.

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The greener alternative

NUCLEAR POWER DISCOUNTS THE USE OF FOSSIL FUELS AND NEW TECHNOLOGY ADOPTED BY AREVA OF FRANCE ~ WHICH IS COLLABORATING WITH INDIA ~ WILL HOPEFULLY RESULT IN ENERGY THAT IS CLEAN, SAFE AND ECO-FRIENDLY, SAYS PARTHASARATHI CHAKRABORTY

The power derived from nuclear reactor plants involves an intricate process but the recent technology adopted by Areva of France eliminates many obstacles and ensures environmental safety and its cooperation with India will help pave the way to producing nuclear energy that is clean, safe and eco-friendly. The next generation atomic power plant is likely to be very different from the present one, with America's GE and Westing House and Areva claiming that the new reactors will be simpler and safer, with maintenance proving no serious problem.

Nuclear power isn't a new phenomenon in India given that we have reactors in Tarapur, Kalpakkam and Rajasthan. The fuel required is enriched uranium, which is gotten from Nuclear Supplier Groups that include Australia and Canada. Enriching uranium increases the proportion of atoms that can split by the fission process to release energy, usually producing heat that is used to produce electricity. All uranium atoms are not identical and the ore consists of about 99.3 per cent of U-238, 0.7 per cent of U-235 and about less than 0.01 per cent of U-234. These different uranium isotopes contain 92 protons their nucleus but U-238 contains 146 neutrons, U-235 atoms contain 143 neutrons and U-234 atoms contain only 142 neutrons. The total number of protons plus neutrons gives the *atomic mass* of each isotope — that is, 238, 235 or 234, respectively.

The fuel has to have a higher concentration of U-235 — enriched uranium that exists in the natural ore. This is absolutely necessary, because U-235 is "fissionable", which means it is capable of starting a nuclear reaction. Usually the amount of the U-235 isotope is enriched from 0.7 per cent of the mass to about five per cent and commercially enriched uranium is produced by a *gaseous diffusion* process.

In a reactor, a speedy neutron energised by a cyclotron machine strikes the U-235 atom and the fission process starts. More neutrons are generated and the *chain reaction*, as it is called, can be controlled in a reactor to provide useful energy. At the end of the reaction, uranium is eventually converted into plutonium and during the entire fission process the reactor is covered with a wall of heavy concrete or steel to prevent the escape of radioactive rays into the atmosphere. This, then, is simplified version of a Fast Breeder Reactor and there are also Heavy Water Reactors and Pressurised and Advanced Light Water Reactors.

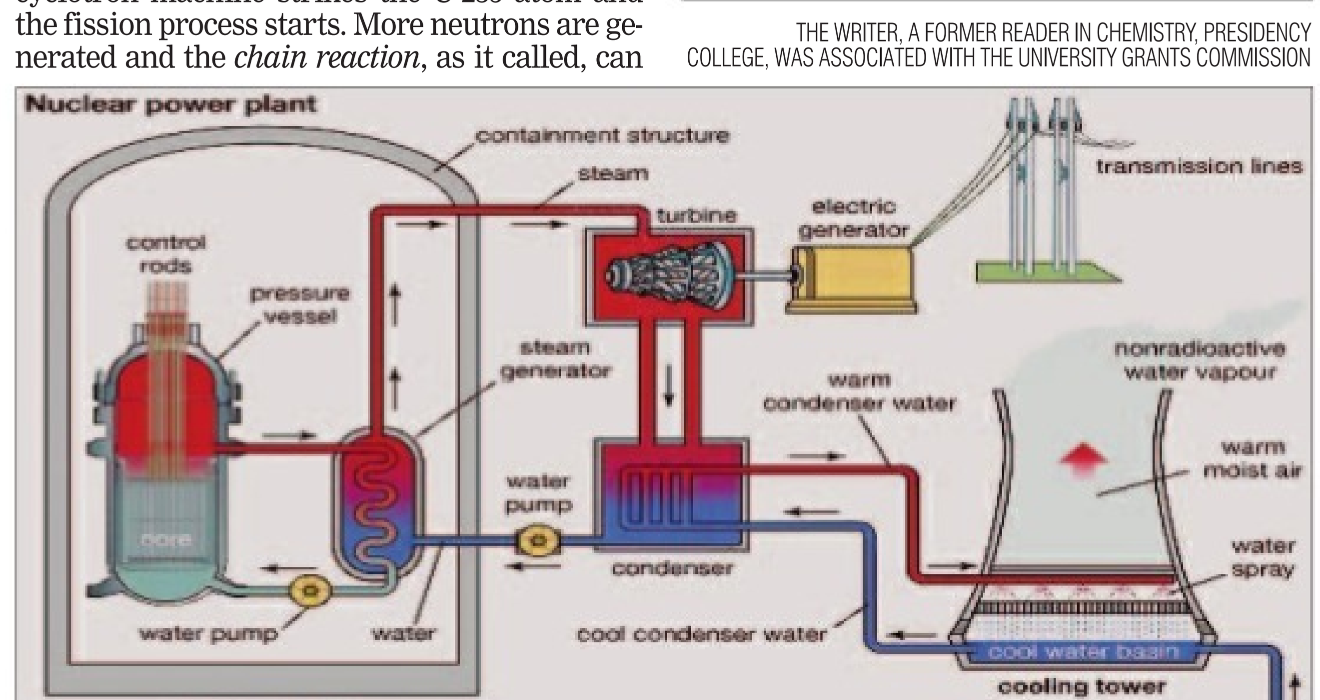
Technocrats say the nuclear energy revival scenario in India is destined to occur within decades. Electricity from atomic power plants will provide carbon-free clean energy and renowned environmentalists are now offering moral support as well. There is also every possibility that the automobile industry will get a boost by switching over from oil to electricity to a large extent.

Nuclear power plants are enormously expensive to build, but once installed they are very cheap to run. Moreover, nuclear fuel discounts the use of fossil fuels and embraces a cogent green environment, which translates into an honest attempt to save the planet.

It bears recall that in 1986 nuclear power generation across the world suffered a massive setback following an accident at a reactor in Chernobyl of the erstwhile Soviet Union, now Ukraine. The disaster (around 4,000 eventual deaths were reported) spread radioactive emission across Europe and the nuclear industry lost momentum. In 1979, an accident occurred at Three Mile Island in Pennsylvania and last year the leakage of radioactive material from a reactor was reported in Japan because of an earthquake.

Hopefully, the collaboration with Areva will involve no risk associated with the disposal of nuclear waste. Most countries store waste underground in watertight, airtight containers but it would be prudent to review radioactive waste management from time to time as also an assessment of proper environmental impact.

THE WRITER, A FORMER READER IN CHEMISTRY, PRESIDENCY COLLEGE, WAS ASSOCIATED WITH THE UNIVERSITY GRANTS COMMISSION



PLUS POINTS

Human hibernation

Since time immemorial, humans have often wished they could curl up and sleep away the cold winter days like their furry friends, but that dream could one day become a reality with scientists

Astronauts could be kept asleep for days or even weeks.

investigating new ways for astronauts to hibernate in space.

According to Leopold Summerer, head of the advanced concepts team at the European Space Agency, research could put "some science fiction into the realm of science reality" within our lifetimes. Trials are now being conducted to see whether there is a way to keep astronauts in a sleeplike state for days or weeks using temperature without any ill effects, something that may be required for deep space travel.

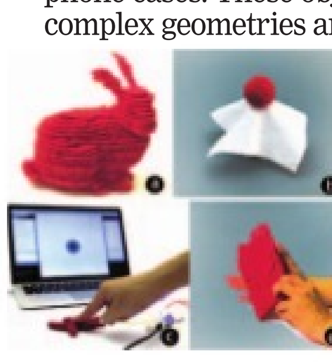
Summerer told the *Washington Post*, "It doesn't mean we will have hibernating astronauts anytime soon, but we are learning from nature how to understand some of the things that happen to animals during hibernation, such as preventing bone loss or preventing muscle loss. This is already something that would be a great benefit for long-distance space flight."

In recent years, the National Aeronautics and Space Administration has invested millions of dollars in studying the effects of long-term effects of living in space. Last year, it announced a study involving two identical twins to see how space affected the body. Scott Kelly has been on the International Space Station for an entire year, twice the duration of a normal stay on the facility, while his 50-year-old identical twin brother Mark remains on the ground. Both will be subject to 10 separate investigations monitoring everything from how their digestive tract to how their genes change due to a year spent in space.

CAROLINE MORTIMER/THE INDEPENDENT

3D soft toys

A team from Disney Research and Carnegie Mellon University has devised a 3D printer that layers together laser-cut sheets of fabric to form soft, squeezable objects such as bunnies, doll clothing and phone cases. These objects can have complex geometries and incorporate circuitry that makes them interactive.



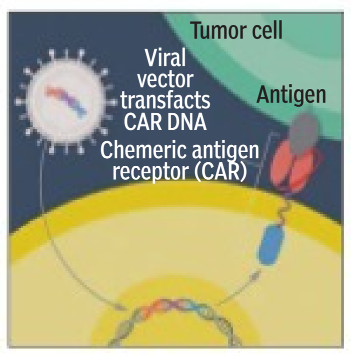
The new fabric printer is similar to laminated object manufacturing, which takes sheets of paper or metal that have each been cut into a 2D shape and then bonds them together to form a 3D object. "Today's 3D printers can easily create custom metal, plastic, and rubber objects," said Jim McCann, associate research scientist at Disney Research, Pittsburgh. "But soft fabric objects, like plush toys, are still fabricated by hand. Layered fabric printing is one possible method to automate the production of this class of objects," he added.

The team demonstrated this technique to create a two-inch bunny. The process took about two-and-half hours. During the process, the laser cut a rectangular piece out of the fabric roll and then cut the layer's desired 2D shape within that rectangle. Once the process was complete, the surrounding support fabric was torn away by hand to reveal the 3D object.

The layered-fabric printer was unveiled at the Association for Computing Machinery's annual Conference in Seoul that will end on 23 April.

Car T-Cell race

Last December, scientists at Juno Therapeutics reported at the American Society of Hematology meeting that in an ongoing Phase 1 trial its Chimeric Antigen Receptor T-cell therapy, JCAR015, put 24 of 27 adults with refractive Acute Lymphoblastic Leukemia into remission, with six patients remaining disease-free for more than a year. This disease is extremely hard to treat and progresses rapidly when it becomes refractory; most patients die within a few months. "This response rate is unprecedented for patients who had stopped responding to all other treatments," said Michel Sadelain, a founding director of Memorial Sloan Kettering's Center for Cell Engineering and a co-founder of Juno.



Founded just a year earlier, the Seattle-based company now has four CD19-targeting Car T-cell therapies in trials. The premise is simple: extract a patient's T cells from blood and train them to recognise and kill cancer by modifying them with a viral vector to express an artificial, or chimeric, receptor specific for a particular cancer-associated antigen — in this case, CD19, an antigen expressed in B-cell–related blood cancers — then reinfuse the cells back into the patient.