The Honorable Daniel S. Goldin

NASA Administrator

Keynote Address to Bio '99

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Thank you for being here today. Thank you to Jim Albaugh for your kind introduction.

Right away, I would like to salute Carl Feldbaum for his leadership as President of BIO, and I want to recognize Jean Mills and everyone on her team who worked so hard to organize this meeting.

It is an honor to be invited and to participate in this important gathering of our nation's bio-tech industry leaders. We, NASA and the biotechnology industry, have a great opportunity here to not only continue, but accelerate and expand our strategic alliances.

Just as physicists have done over the last 50 years. Empowered with the tools of atom smashing, the best and brightest scientists around the world peeled the onion of the nucleus and described the fabric of the Universe. It has allowed us to reach back to a hundredth of a millionth of microsecond after the Big Bang.

The 21st century, the beginning of the next millennium, will be the time of biology, and more to the point — biotechnology. Most people, and I even include many of the technologically savvy, don't understand that we are entering a biological revolution. Most people tend to see biology in a stovepipe -- in other words they don't see biology's connection beyond biology. They don't understand its implications and the potential to dramatically change electronics, computational devices (both hardware and software), sensors, instruments, control systems, multifunctional materials as building blocks for intelligent biologically-inspired and hybridized systems.

Now join me for a moment as I take you on one of many possible paths into the future.

The year is 2030. You still can't get good airline food and Stars Wars Part 20 has just been released. Talk about great special effects – you can even <u>feel</u> the heat from the explosions and smell the Wookies. But what has captured the public's imagination is the launch of NASA's first interstellar probe. Schoolchildren named it *Yoda*. This probe may give us new clues to new life forms on planets in other solar systems and communicate its findings back to Earth.

It took NASA's dedication to using the fundamentals of biology, bioinformatics and biomimetics to build this incredible machine. Let me tell you about this machine. It doesn't look anything like the spacecraft of 1999. The Coke can-sized spacecraft will reach and land on a passing asteroid two years after is launch from Earth.

Aboard the asteroid, the spacecraft will use its DNA-based biomimetic system as a blueprint to evolve, adapt and grow into a more complex exploring and thinking system. It will ride the asteroid like a parasite until it transforms itself into its next evolvable state – an intelligent interstellar probe. It will use the asteroid's native resources to accomplish its first phase of the mission. This may mean using the asteroid's iron, carbon and other materials to build its structure, nervous system, and communications. This reconfigurable hybrid system can adapt form and function to deal with changes and unanticipated problems. It will leave its host carrier and accelerate to a good fraction of the speed of light out to the stars and other solar systems.

As much as I would like to keep talking about this incredible future, the American taxpayers seem to prefer a NASA Administrator based in a nearer reality.

While the *Yoda* mission may be far out, we at NASA are already working toward the goal of building systems that mimic biologically based processes.

Here are few examples of where we are today:

We are working with a major U.S. auto company to embed adaptable neural network chips into car engines. It reacts and adapts to optimize the engine performance in your car as it ages and changes.

Aboard an experimental NASA F-15 fighter neural networks, through adaptive learning, can rapidly react to catastrophic failures of critical flight control components, such as partial lose of a wing or damaged to control surfaces or hydraulics. These are just a couple of examples.

This is where we are today. We hope that five or ten years from now we will carry these evolvable biologically-inspired systems to the next level. They should operate closer to the way the brain functions and assimilate and process information into knowledge and intelligence. No longer will the systems be pure data collectors and data processors. The new systems will have smart sensors and intelligent instruments that can gather, process, think and react.

Think of the implications on transportation, manufacturing, entertainment, and the exploding information and communications sectors.

This is exactly where we want to be.

Think about what is the most highly compact, energy efficient system to store and process information.

Computers operate in a binary, on-off, switch system and are based on a silicon semiconductor material system. As we push the processing time faster and faster, the power demands rapidly increase. The fastest computer we have today processes about a trillion operations per second and needs a megawatt of power. Now, compare that to the human brain. It processes one million times faster and requires only watts of power -- that's where we need to be in computing. If we can't send a power cord to the International Space Station, we're certainly not going to be able to plug-in an interstellar probe.

The future advancements in computational systems can only be achieved by developing hybrid systems that mimic biological processes and result in systems that combine new concepts based not only in silicon but biochemical (DNA and protein based), quantum and optoelectronics. Not only could a DNA-based hybrid system be faster, but it could also be a billion times more energy efficient.

How will we usher in this exciting new age? By coupling NASA's space- and ground-based research platforms with the best simulation and modeling programs and your vision and entrepreneurial spirit.

It is that spirit that has led to the success of your industry so far. Today, the bio-tech industry, being driven by improvements in information systems and communications, generates $13.4

billion in annual sales. That's an increase of 17% over the previous year. Every one of you should be proud of your role in this dynamic growth.

But compare that $13.4 billion to the pharmaceutical industry's $322 billion, the U.S. Gross Domestic Product (GDP) of nearly $8.1 trillion, or the Gross World Product of approximately $33.7 trillion, and you can begin to see the possibilities for expansion in your sector. Just imagine how your companies would grow if you could increase your industry's market share to just one percent of GDP – the numbers are big!

I want to share some ideas of how we get on this pathway of the biologically-inspired revolution.

Today, healthcare- and agricultural-based biotechnology are the core of what you do. Exciting things are happening in those arenas and they enhance our lives. Protein crystal growth, tissue culturing and plant transgenics come to mind immediately, but there are many other examples. This work has immense implications for improving our lives on Earth and for sending astronauts beyond Earth.

We at NASA plan to be a part of that revolution. To carry out NASA's future missions we are working on systems that attempt to mimic the processes found in the biological world. When we send probes to space, like *Yoda*, our interstellar probe in 2030, we try to give them life-like qualities. We want them to be robust, self-reliant, adaptable -- even evolvable – and to heal when they are damaged. We want them to have complete self-awareness, to respond to circumstances as they find them. They shouldn't walk off a cliff simply because someone in mission control sent it forward 10 paces, or miss looking at a strange bluish liquid because we pointed it toward a rock.

We want to put "colonies" of robots on planets and have them thrive, not merely survive. The collective herd, if you will, of robots will exceed the capability of each individual element. We want them to be as mobile as four-legged animals and manipulate objects with the dexterity of the human hand. We want them to explore – and have attributes of curiosity and decision-making.

So far, we have been limited to silicon microchips, aerospace materials and designs that tend to emulate their biological counterpart. This is simply not good enough. In the future we want our systems to **<u>be</u>** biologically-based not just **<u>act</u>** somewhat life-like.

We also want to exploit biology to build life support systems for our astronauts that minimize re-supply. And like *Yoda*, we want to convert materials we find on other planets to useful materials. The atmosphere of Mars is 95% carbon-dioxide – the perfect raw material for plants to make oxygen. If we introduce plant-like systems to the Martian atmosphere, will they be able to create enough oxygen to sustain life? We want to answer this provocative question. In 2001 we will send a biochemical factory probe to Mars to conduct the first *in situ* test of converting carbon dioxide into oxygen.

NASA wants to provide the leadership for the development of bio-technology, as it relates to our missions in space and ultimately to Earth. As you know, we have had great success with bio-technology on the Space Shuttle. But months – even years – of preparation leading to less than two weeks in orbit is not very useful to help develop a new industry.

The international space station represents a major advance in available space and facilities with essentially unlimited research time on orbit. However, we see this as only a pathfinder for true commercial use of space. We envision commercially viable facilities, owned, operated and dedicated to industry and we see bio-technology as one of the core industries. Before that occurs, we are planning to devote 30 percent of on-orbit resources on the International Space Station to commercial ventures and if demand requires we are willing to go up to 50 percent or more as new industry sectors express interest and opportunities occur. The structure is already visible in the night sky. When fully assembled it will be as large as a football field and have the pressurized volume of two jumbo jets and four times the electrical power of the Mir space station. NASA hopes to create innovative partnerships with the bio-technology industry and help reduce the barriers of space access. The goal is to help mitigate risk and quantify the payoff of revolutionary products. We are building the ISS right now . . . and in three years we'll begin research and in five years the platform will be fully functional.

NASA has three initial, major research areas that not only will address critical needs for space travel but directly address products on Earth relevant to the bio-tech industry.

First, we have to optimize basic food production for growing on plot sizes that are square yards in size not square acres in scale. We need very high yield under limited energy resources. The implications for agriculture and designer plant characteristics that resist disease, require minimal resources, minimal energy input to achieve high yield.

Second, we will be going into potentially highly dangerous and unknown toxic environments. To protect our astronauts we will need to be able to synthesize and tailor counteracting drugs. These drugs must be producible in very short time frame and their effect must be immediate. Imagine the possibilities on drug development and production.

And third, we cannot take blood and tissue banks on our journey far beyond Earth's orbit when astronauts are gone for several years. This requires the ability to create regenerative and repairable blood and tissue supplies. Already, NASA has flown the first three-dimensional tissue culture reactor – we call it the Bioreactor.

Although this system will operate on Earth, we have found that the absence of gravity and sedimentation result in larger, more complex three-dimensional cultures in a much shorter time period in space. Think of the potential for understanding tissue growth and application of drugs on these tissues.

During this incubator period, NASA will continue working to reduce launch costs and increase reliability. A few decades from now when space-based bio-technology facilities could dwarf the space station, the cost of getting there will be a few hundred dollars per pound -- not the ten thousand it costs today -- and commercial shuttles may run daily. I know Jim Albaugh and Boeing are working on this right now.

In addition to providing outstanding facilities in space, NASA is leading the way in ground-based astrobiology.

Just yesterday, I was at NASA's Ames Research Center to kick off the new Astrobiology Institute located there. We named Dr. Baruch Blumberg as the Institute's first director -- a Nobel Laureate, honored for his work in identifying the hepatitis B virus, and president of the Fox Chase Cancer Institute in Philadelphia.

The major goal of the Astrobiology Institute is to answer three age-old questions:

- How does life begin and evolve?

- Does life exist elsewhere in the universe?

- And, what is the possible destiny of life on Earth and beyond?

To answer these simple, yet elusive questions, we will require new computing and communication capability and observation tools.

To peer beyond our solar system, possibly as far as the edge of the Universe, we will need diverse and complex observation systems. Through robots, robotic colonies and humans integrated with robotic systems and by using revolutionary telescopes we will gather information to detect life-processes beyond Earth.

We will start by building our understanding of basic life processes here on Earth. We know that life exists in harsh, extreme environments – in places that you wouldn't expect life to survive, like volcanic vents at the ocean floor. With this new understanding we may be able to capture and develop the universal fingerprints of life processes.

At this virtual Institute the finest minds in the world, using the best computer models and simulation will couple their theories with observations in the lab, on Earth, in our solar system and, yes, maybe even beyond.

Astrobiologists will continue to explore these extreme environments on Earth, and we will build simulation chambers that model the conditions of early Earth, present day Mars, the moons of the outer planets and the predicted ecosystem on planets around other stars.

The bio-tech industry has an important role in this Institute. You could utilize this facility, either directly by providing on-site researchers, or off-site through virtual collaboration with the Institute and its world-renown members. Either way, you stand to gain increased access to the best and brightest in government, academia, and the rest of the private sector.

This meeting comes at an important time, because it is time for NASA and the bio-tech industry to develop and expand some common goals. I believe that bio-technology will be the hallmark of the 21st century. It will lead the new technological revolution, and you are uniquely positioned to reap the benefits.

The rapid development of the silicon era led to the rapid growth of companies like Intel. And the upcoming revolution in the bio-technology era will propel other companies to unprecedented growth and expansion.

We are setting out on an exciting and daunting odyssey, and we don't know what the final results will be. Because we invest in high-risk, high-payoff research we are confident that it will return benefits that are out of this world. We will have successes and we will have failures, but we ultimately reach our goal. It may not happen tomorrow, or even next year, but our grandchildren will be thankful for the work you did today to bring extraordinary discoveries tomorrow. And the NASA developed tools that took *Yoda* light years away will also bring biologically-inspired products that will dramatically improve the quality of life on Earth.

One thing I am sure of, though, is that T.S. Eliot was right when he said: "Only those who will risk going too far can possibly find out how far one can go."

At NASA, we can't wait. Thank you.