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Science as an Insurance Policy to the Risks of Climate Change

Keynote by Steven Chu at the Opening of the 67th Lindau Nobel Laureate Meeting

Delivered by William E. Moerner (see video)

Dear Students, Guests, and Participants of this year's Lindau Nobel Laureate Meeting,

I am sorry not to be there to be with you. My wife tripped and fell in Amsterdam two nights ago, fractured her knee just below her artificial knee and is now in a full leg cast. We are returning home.

I want to speak about "Science as an Insurance Policy to the Risks of Climate Change."

Alfred Nobel wished to award the Nobel Prize to those that "conferred the greatest benefit to mankind." In the past several hundred years, science discoveries have led to several revolutions in agriculture, medicine, communications and energy.

We live in magical times. With the flick of a finger, the power of 5 horses flow out of a wire in our homes to clean our floors. We go to the local market under the pull of hundreds of horses and fly across continents with the power of *a hundred thousand* horses. Our homes are warm in the winter, cool in the summer and lit at night.

The ability to synthesize ammonia from nitrogen and hydrogen was invented by Fritz Haber and Carl Bosch. With this discovery nitrogen based fertilizers avoided mass starvation, and a world of 2 billion people could be fed. The Green Revolution pioneered by Norman Borlaug led to a 5-fold increase grain production per acre in many parts of the developing world. His contributions made it possible to feed a world population that grew from 3 billion people in 1960 to 7.5 billion today. Fritz Haber, Carl Bosch and Norman Borlaug were all awarded Nobel Prizes for their enormous scientific contributions to the benefit of mankind.

What has made these miracles possible is our ability to find and exploit abundant sources of energy with ever increasing dexterity. Sadly, we have discovered that these benefits have come with unintended consequences. The discovery of those collateral effects is also an extraordinary scientific discovery. The discovery is this: for the first time in human history, science is showing that human greenhouse gas emissions are changing the Earth's climate. We are also predicting how future emissions will affect the world one hundred years from today.

Climate change is not new. The Earth went through six ice ages in the past 600,000 years. However, recent measurements show that carbon dioxide and other greenhouse gases have risen dramatically in the last century. Carbon dioxide levels and equivalent GHGs are now 45% higher than they were a century ago. Including all greenhouse gases, we are currently at 490 parts per million carbon dioxide equivalent. 550 parts per million of CO_2 is a 100% increase atmospheric carbon dioxide.

By examining the ratio of the carbon isotope ^{14}C to ^{12}C, we know the increase in carbon dioxide and methane has diluted the $^{14}C/^{12}C$ ratio. Since ^{14}C has a half-life of 5,700 years, that means the added atmospheric carbon had to have been sequestered from the biosphere for many ^{14}C decay times. The decline in the $^{14}C/^{12}C$ ratio agrees with an accounting of human GHG emissions minus the known absorption of CO_2 from land and the oceans. This finding is considered the "gold standard" confirmation that the increase in CO_2 we are now observing is due to the burning of fossil fuels.

Three quarters of human greenhouse gas emissions have occurred since 1950, and since that time, the Earth has warmed up by 1 degree Celsius. The Arctic and Antarctic polar ice caps and the glaciers in Greenland and Antarctica are melting much faster than was predicted 10 years ago. The increasing heat waves, torrential rains, encroaching seas and moving desert boundaries are other ominous warning signs of climate change.

Even if we stopped all greenhouse gas emissions, the full extent of the damage we have already done will not be seen for 100 years. Why? The deep oceans are very cold, and it will take a long time to warm then up. The new equilibrium temperature will not be seen for at least one century.

From the geological record of the last warm period (129,000 – 116,000 years ago), the Earth was only 1 degree C warmer than today. During that time, the sea level was 6–9 meters higher. This is a matter of history, not a computer simulation. We used to believe that it would take millennia for the sea to rise to these heights, but recent satellite data suggests that a greater than one meter sea level rise is possible by the end of this century, and a 4–5 meter rise by 2200.

A changing climate does not respect national boundaries. There is a real danger that rising seas or collapsing agriculture due to heat and drought will lead to massive climate-induced migrations. History has repeatedly shown that the inability of people to feed themselves can lead to unrest and civil wars. The 4.5 million Syrian refugees and additional millions of Africans pouring out of their home countries are an early warning of what may happen in the coming decades and centuries. 800 million people live within 10 meters of sea level.

We also face the specter of non-linear "tipping points" that may cause more severe changes. An example of a tipping point is the thawing of the permafrost. The permafrost contains immense amounts of frozen organic matter that have been accumulating for millennia. If the soil melts, microbes will spring to life and cause this debris to rot. The difference in biological activity below freezing and above freezing is something we are very familiar with. Frozen food remains edible for a very long time in the freezer, but once thawed, spoils quickly. How much methane and carbon dioxide might be released from the rotting permafrost? Even if only a small fraction of the carbon is released, it could be greater than all the greenhouse gases we have released to date. Once started, a runaway effect could begin.

There are numerous people and politicians who enjoy the benefits of scientific discovery, but do not accept the compelling scientific evidence and overwhelming scientific consensus that humans are changing our climate. There are others who admit the climate is changing, but the change is due to natural causes. Hence, they conclude there is nothing we can do about these changes. Others argue that the government should not spend money until we are certain of the predicted consequences of climate change.

The Earth climate system is extremely complex and there are considerable uncertainties in predicting future risks. However, the uncertainty does not lie in whether we are causing climate change, but in predicting with precision the consequences of our actions. With each passing year, measurements tell us that the climate system is far more sensitive than we thought only a decade ago. Given these findings, it is prudent risk management to take significant steps to mitigate the worst risks of climate change. We buy fire insurance even though we don't expect that there is even a 1% chance of our home to burn down. Climate scientists believe the probability of adverse climate change is considerably higher than 50%.

We also need to confront a moral issue. Deeply rooted in all cultures is the notion of generational responsibility. Parents work hard so that their children will have a better life, but are we willing to invest our money to protect the grandchildren of people we will never know? One of the cruelest ironies of climate change is that the ones who will be hurt the most are the most innocent: the world's poorest and those yet to be born.

When individuals risk their health by smoking, the consequences are borne by the smoker. Climate change introduces intergenerational risks. The risks are not bourn by the smoker, but by the children and grandchildren throughout the world. A world not willing to spend even 0.5% of its GDP is the moral equivalent of saying, "I enjoy smoking, but my doctor tells me that there is considerable risk to the grandchildren of the world if I continue to smoke. I don't believe her because she can't tell me precisely who will die from my smoking. Why should I sacrifice my pleasure based on her speculation that it will affect people half way around the world I will never know?"

What can science and technology do to help us mitigate and adapt to climate change? We need abundant, clean and inexpensive energy sources to power and feed the world. The population is projected by the U.N. to grow to 9.8 billion by 2050 and 11.2 billion by 2100. In short, we will need another industrial revolution, another agriculture revolution, and a water resource revolution.

Tremendous progress has been made in carbon-free energy sources such as wind and solar energy. Today, long term power purchase agreements of solar energy (signed contracts to purchase solar energy

at an agreed upon price for 20 or more years) have decreased to one third of its price in 2012. In many places in the world, solar power is becoming competitive with fossil energy. The cost of on-shore wind power has also declined and is approaching parity with fossil energy. Great progress is being made in reducing the cost of off-shore wind energy. I foresee at least 20 more years of declining costs for these forms of renewable energy.

Despite this progress, we need additional technical advances. Why? As we transition to greater than 50% intermittent renewable energy, the full cost of renewable energy includes energy storage, enhanced long-distance transmission lines, and a more sophisticated distribution system to manage two-way energy flows, and stand-by power.

We also need to de-carbonize our transportation system. The adoption of electric vehicles (EVs) for personal transportation has begun. However, before EVs become the mainstream consumer choice, the cost must become competitive with internal combustion automobiles. The manufacturing cost of batteries for electric vehicles have declined to one sixth of the price in 2007, and by 2019, the projected cost is one tenth the cost in 2007. Perhaps in 6–10 years, further technical improvements can reduce the size and weight of today's batteries by three at no additional cost. With these advances, EVs will become the low-cost option.

The speed of recharging EVs is also essential for wide-scale adoption. Most people are not wealthy enough to own garages. Today's fast-charging stations can add 140 miles in 20 minutes, but we need to decrease the charging time to ~5 minutes. I not only believe this is possible, I am working with a colleague at Stanford University to turn the dream into a reality. We are also developing a method of economically extracting lithium from sea water, thereby increasing the world supply of lithium 10,000-fold. With lithium-sulfur batteries that we and the others are working towards, we hope to revolutionize personal transportation. Clean alternatives to liquid hydrocarbon fuels are also needed for airplanes and other forms of long-distance transportation.

There are numerous other technology developments needed before clean energy becomes the low-cost option for all our energy needs. Science is part of the solution, but we also need stable, long-term

policies to fund visionary research and development. Policies are also need to guide the private sector investments needed to turn discovery and invention into wide-scale deployment.

Key members of the current U.S. Administration doubt the scientific evidence of climate change. The proposed Presidential federal budget calls for stopping federal support of climate research including the cancelation of future satellite missions to monitor climate change. Perhaps they believe if we don't measure changes in the climate, it is not happening.

The President's proposed budget also calls for a drastic reduction of funding designed to lower the cost of clean energy and the capture of carbon from power, cement and steel. For example, their proposed budget calls for the elimination of the innovative new research program: ARPA-E which stands for Advanced Research Projects Agency – Energy. As Secretary of Energy, I was privileged to turn the recommendation into reality in 2009 as part of President Obama's administration. This program enjoyed strong bipartisan support in Congress, and I hope the bipartisan Congressional support of ARPA-E will continue.

Regardless of what members of Congress may think of the risks of climate change, the science and technology supported by this program are laying the foundations of technologies that will add to the economic competitiveness and prosperity of the United States and the world. The funding decisions have led to an average of 10-fold more private sector investments to APRPA-E awardees.

Even if the federal government is no longer showing leadership in combating climate change, my home state of California has been a leader in energy efficiency, environmental sustainability and clean energy since 1973. California is the 6th largest economy in the world, behind only the U.S., China, Japan, Germany and the United Kingdom. California passed a state bill that establishes targets to increase renewable electricity use to 50 percent by 2030 and double the energy efficiency savings in electricity and natural gas end uses by 2030. Many other states in the U.S. have renewable portfolio standards that comprise about 85% of the U.S. economy.

I close my remarks by asking the young students gathering this week at the Lindau Nobel Laureate Meeting to consider joining the effort to

combat climate change. Now more than ever, we need talented young scientists and engineers to create the innovations needed for a prosperous and sustainable future. We also need young economists and political scientists to work with the technologists to create better policy options, and future business leaders that will make sustainability an integral part of their business.

I hope the Lindau Opening Ceremony will show you the photograph of "Earthrise" taken on Christmas Eve, 1968 during the Apollo 8 mission. As the capsule completed its final orbit around the moon, the capsule was turned to earthward. Astronaut Bill Anders, who took this picture, said: "We have come all this way to explore the moon and the most important thing is we have discovered the Earth." Since that time, we have discovered that we are changing the climate of our home. From this vantage point, we see a beautiful blue Earth rising above a bleak grey lunar landscape. The blackness of the surrounding space is a stark reminder that there is nowhere else we can go.

There is also an iconic image taken by Voyager 1 in 1990. As the spacecraft began to leave our solar system, the astronomer Carl Sagan convinced the NASA engineers to turn Voyager for one last, homeward look. In this picture, Earth appears as a pale blue dot of light, one tenth of the area of a single pixel, and embedded in a rainbow of scattered light.

Here is a condensed version of what Sagan said about this picture.

"Look again at that dot. That's here. That's home. That's us. On it, everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives.... on a mote of dust suspended in a sunbeam.

"Our planet is a lonely speck... in all this vastness, there is no hint that help will come from elsewhere to save us from ourselves. The Earth is the only world known so far to harbor life. There is nowhere else, at least soon, to which our species could migrate... Like it or not, for the moment the Earth is where we make our stand.

"...there is perhaps no better demonstration of the folly of human conceits than this distant image of our tiny world. To me, it underscores our responsibility to deal kindlier with one another, and to preserve and cherish the pale blue dot, the only home we've ever known."

To this message, I add an ancient Native American saying about how we should care for our planet: “Treat the Earth well: it was not given to you by your parents, it was loaned to you by your children.”

I thank you for your attention, and I hope you, the young Lindau scientists, will be moved to use your considerable talents to help enrich and save the world.

Steven Chu