DR. KEITH: THANKS VERY MUCH. THANKS, ROB.
YOU MAY BE FORGIVEN IN LISTENING TO THIS TALK -- AND I WON'T SPEAK ABOUT THE NEXT ONE -- IN
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THINKING THAT THEY HAVE SOMEHOW LET THE LUNATICS OUT OF THE ASYLUM. AND I REALLY DO URGE YOU, JUST FOLLOWING UP ON WHAT ROB SAID, TO TRY AND HOLD YOUR SKEPTICISM A LITTLE BIT.
YOUR SKEPTICISM IS THE RIGHT REACTION. IT IS THE REACTION CERTAINLY I HAD AND MANY OTHER PEOPLE HAVE THINKING ABOUT THIS TOPIC; BUT I THINK THAT TIME HAS COME, AND I WILL ARGUE AT THE END OF IT TO GO BEYOND THE KIND OF KNEE-JERK SKEPTICISM AND ACTUALLY THINK ABOUT WHAT WE SHOULD DO IN THE WAY OF THINKING SERIOUSLY ABOUT THIS PROBLEM AND SEARCHING.
SO I WANT TO TALK TO YOU ABOUT GEOENGINEERING. ROB AND I HAVE HAD ACTUALLY SOME OF THE MOST HEATED DEBATES OR EVEN ARGUMENTS THAT I'VE EVER HAD IN THE TEN OR MORE YEARS I'VE KNOWN HIM ON THIS TOPIC JUST RECENTLY IN A MEETING THAT DAN SCHRAG AND I HELD AT HARVARD. AND I THINK THE FACT THAT WE HAD SUCH A HEATED DEBATE IS ENDEMIC TO THIS PROBLEM. THIS TOPIC I'M ABOUT TO TELL YOU ABOUT DOES BRING OUT A LOT OF EMOTION, AND IT SHOULD. BUT I JUST URGE YOU NOT TO HAVE THE KIND OF INSTANT REACTION THIS IS ALL NUTTY, BECAUSE, IN FACT, WE HAVE GOTTEN OURSELVES INTO A REAL FIX, AND WE SHOULD THINK HARD ABOUT THROWING ANY OPTION AUTOMATICALLY OFF THE TABLE.
SO THIS IS A SIMPLE SCHEMATIC OF WHAT THE
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CLIMATE PROBLEM IS. THERE'S DIFFERENT VERSIONS OF THIS, BUT THIS IS A SIMPLE ONE.
AND THIS IS THE STANDARD WORDS THAT HAVE BEEN USED FOR A LONG TIME ABOUT HOW WE MIGHT GO ABOUT SOLVING THIS PROBLEM. AND OF COURSE, YOU KNOWN ABOUT THE FIRST AND LAST ONE. YOU KNOW ABOUT ADAPTATION AND MITIGATION. AND YOU PROBABLY KNOW LESS ABOUT GEOENGINEERING, AND THAT'S THE TOPIC OF MY TALK.
NORMALLY, WHEN I START TALKS LIKE THIS, I START BY TRYING TO SHOW PEOPLE BOTH HOW SERIOUS THE CLIMATE PROBLEM IS AND HOW LITTLE WE'RE DOING TO ACTUALLY TACKLE IT. HERE I FEEL THAT'S BEEN DONE WONDERFULLY BY THE TALKS WE HEARD YESTERDAY AND BEFORE.
I WILL JUST REMIND YOU OF, I GUESS, TWO NUMBERS, MAYBE THREE. THE 8.4 GIGATONS A YEAR IS AN EXTRAORDINARY INCREASE IN GLOBAL EMISSIONS THAT WE'VE HAD DESPITE ALL OF THE TALK ABOUT REDUCING EMISSIONS, ALL OF US EXPERTS FLYING AROUND TO CONFERENCES AND TALKING. IT'S NOT CLEAR THE ACTUAL IMPACT OF ALL THAT WE HAVE DONE IS MEASURABLE OTHER THAN IN THE CONSUMPTION OF JET FUEL. LET'S BE HONEST HERE. WE'VE MADE EXTRAORDINARILY LITTLE PROGRESS IN ACTUALLY PUTTING THE BRAKES ON THIS VERY, VERY HIGH . . . SYSTEM OF THE GLOBAL ENERGY SYSTEM.
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SECONDLY, THE EXTRAORDINARY FACE OF LOSING

ARCTIC SEA ICE THAT'S FASTER THAN WE PREDICTED WITH ANY MODELS A FEW YEARS AGO REALLY SHOULD GIVE US PAUSE ABOUT THE NONLINEARITIES AND THE SURPRISES THAT MAY BE AWAITING FOR US.

AND I GUESS THE THIRD ONE IS JUST THE LENGTH OF TIME WE'VE KNOWN ABOUT THIS PROBLEM. OBVIOUSLY, THIS MEETING CELEBRATES THE 50 YEARS OF MEASURING CO2 ACCURATELY IN THE ATMOSPHERE. WE'VE KNOW ABOUT THIS PROBLEM FOR A LONG TIME. AT SOME POINT IN THIS TALK, I'LL SHOW YOU A SLIDE FROM THE REPORT THAT ARRIVED ON PRESIDENT JOHNSON'S DESK WHEN I WAS TWO YEARS OLD, WHICH ESSENTIALLY HAD ALL THE CORRECT SCIENCE ABOUT THIS PROBLEM AND SAID THE RIGHT THINGS. IT'S BEEN A LONG TIME SINCE THEN, AND WE HAVE DONE VERY, VERY LITTLE ABOUT THAT.

SO THAT'S THE SORT OF SCARING-YOU TALK. NOW I'M GOING TO TALK ABOUT WHAT WE MIGHT DO. THE SIMPLEST AND DUMBEST THING WE COULD DO IS SIMPLY TO PUT A LOT OF SULFATES IN THE STRATOSPHERE. AND WE KNOW FOR SURE THAT THAT WILL WORK. BE CAREFUL HERE. WHAT "WORK" MEANS, REDUCE THE TEMPERATURE OF THE GLOBE. "WORK" DOESN'T MEAN A HAPPY ENDING. "WORK" DOESN'T MEAN THERE WON'T BE SIDE EFFECTS. OF COURSE, THERE WILL BE OZONE LOSS, ET CETERA. "WORK" SIMPLY

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MEANS IT COOLS THE PLANET DOWN FAST.

SO LET ME NOW GET INTO THIS A LITTLE BIT. WE KNOW THIS, OBVIOUSLY, FROM THE PINATUBO EXPERIENCE, PINATUBO PUT SOME 30 OR SO ROUND NUMBERS OF PETAGRAMS OF SULFUR IN THE ATMOSPHERE. WE HAVE SOME IDEA OF WHAT THE IMPACTS OF THAT WERE. WE KNOW THAT YOU GET VERY RAPID COOLING AFTER THESE EVENTS. THAT IS, OF COURSE, BECAUSE THIS IS TACKLING RADIATIVE FORCING DIRECTLY, NOT CO2 EMISSIONS. CO2 EMISSIONS, OF COURSE, AT THE BEGINNING OF THOSE CO2 EMISSIONS, OVER TIME THAT MATTERS. SO IF YOU GET YOURSELF INTO A FIX AND YOU WANT TO SOLVE THIS PROBLEM BY CUTTING EMISSIONS, YOU'RE IN TROUBLE, BECAUSE OF THIS LONG INTEGRAL OF EMISSIONS OVER TIME.

BUT IF YOU DO SOMETHING THAT ACTS ON RADIATIVE FORCING, YOU GET A VERY QUICK OUTCOME, FOR BETTER OR WORSE. BUT THAT, I THINK, IS FAIR TO SAY IS A FACT.

SO IT'S OBVIOUS THAT IF YOU PUT SULFATES IN THE STRATOSPHERE, IT WILL DO SOMETHING. NOW I WANT TO GIVE YOU A SENSE OF WHAT THE NUMBERS ARE AND SOME SENSE OF WHAT CLIMATE MODELS SAY MIGHT HAPPEN. AND THEN I WILL TALK YOU ABOUT SMARTER THINGS THAT WE MIGHT DO, ABOUT IMPLICATIONS OF ALL OF THIS, AND THE WAY YOU MIGHT GO ABOUT THINKING ABOUT IT ETHICALLY,

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MORALLY, ET CETERA.

SO, FIRST OF ALL, SOME PLAIN OL' ENGINEERING NUMBERS. ROUGHLY, ONE OR TWO, THEREABOUTS, TERAGRAMS OF SULFUR, MEGATONS OF SULFUR, WHATEVER, SAME NUMBER; ONE OR TWO MEGATONS OF SULFUR A YEAR INJECTED INTO THE STRATOSPHERE IS ROUGHLY

ENOUGH TO COMPENSATE, NET AVERAGE RADIATIVE FORCING TERMS, NOT IN ALL WAYS WE MIGHT CARE ABOUT TO THE EFFECT OF DOUBLING CO2 IN THE ATMOSPHERE. THAT IS NOT THAT MUCH SULFUR COMPARED TO THE CURRENT GLOBAL SULFUR EMISSIONS. IT'S A COUPLE PERCENT OF CURRENT GLOBAL EMISSIONS. OF COURSE, THOSE ARE FALLING QUICKLY AS WE REGULATE SULFUR EMISSIONS BETTER FROM COAL-FIRED POWER PLANTS.

ANOTHER WAY OF THINKING ABOUT IT, I'M A PHYSICIST, AND I LIKE TO THINK ABOUT DIMENSIONS RATIOS, IS THAT ROUGHLY IT'S THAT 1 TO 300,000 EFFECT, SO 1, 2, OR 3 GRAMS OF SULFUR IN THE STRATOSPHERE OFFSET SOMETHING LIKE ONE TON OF CO2 MIXED EVENLY IN THE ATMOSPHERE. AGAIN, I'M NOT CLAIMING ANY PERFECTION IN OFFSET. I'M ONLY TALKING ABOUT CRUDE OFFSETS IN RADIATIVE FORCING.

HOW MUCH DOES THAT COST? WE DON'T KNOW. WE HAVEN'T DONE ANY REAL ENGINEERING.

IN THE NATIONAL ACADEMY STUDY IN THE EARLY

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'90S, PEOPLE LOOKED AT A BUNCH OF WAYS YOU MIGHT PUT SULFUR IN THE STRATOSPHERE. THE CHEAPEST WAY THEY FOUND AT THAT TIME KIND OF MAKES YOU BELLY-LAUGH, AND IT SHOULD. IT IS VERY KIND OF STRANGE. IT'S FIRING NAVAL RIFLES UP INTO THE STRATOSPHERE. IT TURNS OUT THAT THOSE SHELLS COST ABOUT 20,000 BUCKS. AND YOU CAN DO THE MATH. YOU GET SOMETHING LIKE $30 MILLION A YEAR, AND THAT IS EXTRAORDINARILY CHEAP.

SCOTT BARRETT, ONE OF THE LEADING ECONOMISTS WHO WORKS ON CLIMATE CHANGE, IN GENERAL, AND CLIMATE POLICY, HAS WRITTEN A PAPER CALLING THIS "THE INCREDIBLE ECONOMICS OF GEOENGINEERING." IT'S JUST SO CHEAP. THAT DOESN'T MEAN WE SHOULD DO IT. WHAT IT MEANS IS THAT COST IS NOT THE METRIC THAT MATTERS HERE.

IN FACT, I'M GOING TO SHOW YOU A BUNCH OF OTHER WAYS WE MIGHT DO THIS THAT MIGHT BE MUCH CHEAPER. BUT THE POINT IS NOT AT THIS POINT THE COST. I THINK WHAT I'M SAYING IS THAT THERE IS SOME THRESHOLD BELOW WHICH COST ISN'T THE ISSUE. SO WHETHER OR NOT WE IMPLEMENT GEOENGINEERING, I THINK IT HAS TO DO WITH RISK TRADE-OFFS, WITH THE QUESTIONS OF POLITICAL CONTROL, CONTROL OF THE PLANETARY THERMOSTAT, WITH THE WAYS IN WHICH IT WON'T WORK, BUT IT DOESN'T MOSTLY HAVE TO DO WITH COST. IT IS, IN A

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SENSE, TOO CHEAP. IT JUST DOESN'T DO ALL THE THINGS THAT YOU MIGHT WANT TO DO, AND IT GETS US INTO VARIOUS MORE SERIOUS PROBLEMS, PERHAPS.

THERE ARE A LOT OF OTHER WAYS YOU MIGHT DO IT THAT ARE MORE CLEVER THAN THESE NAVAL GUNS. THE MOST CLEVER ONE, I THINK, THAT HAS BEEN THOUGHT OF IN THE LAST FEW YEARS IS ESSENTIALLY A PIPE OR TUBE THAT WOULD GO UP IN THE STRATOSPHERE WITH A TETHERED BALLOON. AND BECAUSE THE BALLOON IS ATTACHED TO THE TUBE, YOU HAVE A CONTINUOUS FLOW THROUGH IT. YOU MIGHT GET VERY, VERY LOW COSTS FOR MOVING LARGE

QUANTITIES OF MATERIALS IN THE STRATOSPHERE.
BUT I'LL COME BACK TO THIS AGAIN AND AGAIN IN THE TALK: NO SERIOUS ENGINEERING HAS BEEN DONE. ONE OF THE THINGS ABOUT THE GEOENGINEERING WORLD, THERE IS A LOT OF TALK IN THE BLOGOSPHERE AND LOTS OF ATTENTION NOW AND ESSENTIALLY NO REAL RESEARCH. AND I'M GOING TO COME AND ARGUE AT THE END, THAT THAT IS A DANGEROUS AND UNSTABLE SITUATION, AND WE OUGHT TO THINK ABOUT DOING SOME REAL RESEARCH.
SO A QUESTION YOU MIGHT ASK YOURSELF IF YOU HAVE AN ATMOSPHERIC SCIENCE BACKGROUND IS, YES, OKAY, I ADMIT THAT WE CAN COMPENSATE THE GLOBAL AVERAGE RADIATIVE FORCING, BUT THAT'S NOT GOING TO MAKE THE CLIMATE THE SAME, BECAUSE THE RADIATIVE FORCING

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VARIES GREATLY IN LATITUDE AND SEASON FROM CO2 THAN IT WOULD FROM PUTTING SOMETHING LIKE SHIELDS IN OUTER SPACE OR SULFATES IN THE STRATOSPHERE, SO I MIGHT EXPECT QUITE A DIFFERENT CLIMATE, EVEN IF I ADJUST THE RADIATIVE FORCINGS. THE POINT IS, IF I HAVE SOME KNOB TO TURN THE SUN UP AND DOWN, IF I GOT WITH CO2, I CAN CERTAINLY ADJUST THAT KNOB SO I BRING THE GLOBALLY AVERAGE SURFACE TEMPERATURE BACK TO WHAT IT WAS BEFORE. BUT THERE IS NO REASON TO THINK THAT THE CLIMATE SHOULD LOOK PARTICULARLY LIKE IT DID BEFORE BECAUSE IT IS QUITE A DIFFERENT FORCING.
IN FACT, WHEN I HEARD ONE OF THE TALKS THAT GOT ME INTERESTED IN THIS TOPIC AGAIN IN THE LATE '90S FROM LOWELL WOOD AT LAWRENCE LIVERMORE AT THE TIME, WHO WAS SINGING THE PRAISES OF GEOENGINEERING, ESSENTIALLY SAYING WE SHOULD DO THIS AND NOT WORRY TOO MUCH ABOUT ANYTHING ELSE, I AND KEN CALDEIRA AND SEVERAL OTHERS IN THE BACK OF THE ROOM STOOD UP AND SAID, "THIS WON'T WORK. YOU DON'T KNOW ANYTHING ABOUT ENGINEERING SCIENCE. LET'S LOOK AT THESE COMPARISONS." AND WE GAVE THIS ARGUMENT ABOUT DIFFERENT SEASONAL LATITUDINAL FORCINGS.
KEN WENT HOME AND ACTUALLY RAN CLIMATE MODELS AND GOT A SURPRISING ANSWER. THE SURPRISING ANSWER IS THAT AT LEAST FROM THOSE EARLY MODEL

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EXPERIMENTS -- AND I'LL SHOW YOU SOME LATER ONES -- THE COMPENSATION IS EXTRAORDINARILY GOOD. SO THIS DOESN'T PROVE IT WILL BE SO IN REALTY, BUT WE HAVE NOW RUN EXPERIMENTS WITH QUITE A SWEEP OF MODERN ATMOSPHERIC MODELS, QUITE A FEW DIFFERENT EXPERIMENTS; AND THE RESULTS SEEM TO BE THAT YOU GET REMARKABLY GOOD COMPENSATION, NOT JUST IN TEMPERATURE, BUT IN PRECIP AND A BUNCH OF OTHER THINGS YOU MIGHT CARE ABOUT.
SO THIS SLIDE ON THE TOP IS THE SLIDE YOU'VE ALL SEEN LOTS AND LOTS OF TIMES. IT'S ONE PARTICULAR MODEL'S VERSION OF WHAT HAPPENS TO GLOBALLY AVERAGE SURFACE TEMPERATURE IF YOU DOUBLE CO2.
THE SLIDE ON THE BOTTOM IS THE SAME THING. THOSE ARE 1.8 PERCENT REDUCTION IN SOLAR INTENSITY.

THOSE EARLY EXPERIMENTS DIDN'T ATTEMPT TO ACTUALLY SIMULATE ANY PARTICLES IN THE ATMOSPHERE; THEY JUST REDUCED THE SUNLIGHT. AND THE COMPENSATION'S REALLY GOOD. AND IT'S TRUE WHEN YOU LOOK AT THE STATS, IT'S TRUE FOR ALL SORTS OF ACTUALLY QUITE INTERESTING PIECES OF ATMOSPHERIC PHYSICS UNDER THAT RESULT.

MORE RECENTLY THERE HAS BEEN MORE SERIOUS EFFORTS SPURRED ON BY THE NEW ATTENTION OF THIS, PHIL

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RASH (PHONETIC) AT . . . POST-DOC, HE HAS WORKED ON STRATOSPHERIC TRANSPORT AND SULFUR AND VARIOUS OTHER THINGS. AND PAUL CRUTZEN ENCOURAGED HIM TO ACTUALLY WORK ON THIS PROBLEM. FOR THOSE OF YOU IN THE MODELING WORLD, THIS GIVES YOU SOME DETAILS AND A LOT OF EXPERIMENTS, BUT SUFFICE IT TO SAY THIS IS ABOUT AS-GOOD-AS-IT-GETS, STATE-OF-THE-ART ATMOSPHERIC MODEL. THEY DID A LOT OF THINGS RIGHT IN TERMS OF THE PROCESSES IN THAT MODEL. AND IN THIS CASE, THEY ACTUALLY ARE INJECTING SULFUR AND THEY HAVE AN ATMOSPHERIC -- AN UPPER ATMOSPHERIC SULFUR CYCLE IN THE MODEL, AND THIS LOWER PLOT HERE SHOWS YOU THE DISTRIBUTION OF SULFUR IN THE STRATOSPHERE THAT'S DOING THE FORCING. AND NOW I'LL SHOW YOU TWO PLOTS ON THE RESPONSE. SO, BASICALLY, THE RESULTS ARE THE SAME. YOU CAN GET REMARKABLY GOOD COMPENSATION.

IN THIS CASE, PHIL DIDN'T SPEND THE COMPUTER TIME TO ACTUALLY DIAL IT IN EXACTLY AS KEN DID, SO THE UPPER AND LOWER GRAPHS DIFFER IN HAVING 1 OR 2 TERAGRAMS A YEAR OF SULFUR INJECTED; AND ONE OF THEM SLIGHTLY UNDERCOMPENSATES FOR DOUBLING CO2, AND THE OTHER ONE OVERCOMPENSATES FOR DOUBLING CO2 AS IT COOLS THE PLANET DOWN A LITTLE BIT.

THERE IS ALSO SOME REALLY INTERESTING LITTLE PIECES OF PERHAPS REAL PHYSICS THAT CAME OUT

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OF HERE THAT GIVES US SOME HINT ABOUT THE WAY THINGS MIGHT NOT WORK OUT THE WAY WE EXPECT. SO THIS SHOWS YOU YEARS OF SIMULATION ON THE BOTTOM AXIS, AND IT'S JUST GLOBAL AVERAGE SURFACE TEMPERATURE ON THE Y AXIS; AND THE CURVES WHICH YOU SEE HERE LIKE THIS ARE WHAT HAPPENS WHEN YOU DOUBLE CO2 INSTANTLY. THE CURVES LIKE THIS ARE WHAT HAPPENS WHEN YOU PUT THE GEOENGINEERING SULFATE IN. AND THIS AMOUNT IS BIGGER THAN THIS AMOUNT OF TEMPERATURE CHANGE. YOU MIGHT EXPECT IF YOU DID BOTH, YOU'D GET NET COOLING, BUT YOU DON'T. WHEN YOU DO BOTH, YOU, IN FACT, STILL GET SOME NET WARMING.

WHAT HAPPENED? THE ANSWER IS THAT IN THE TWO-TIMES CO2 WORLD, THE STATOSPHERIC LIFETIME OF SULFUR IS SHORTER BECAUSE OF MORE OVERTURNING; AND SO, IN FACT, THERE'S SOME FEEDBACK BETWEEN THE TWO PROCESSES, AND THAT'S MAYBE A HINT OF OTHER FEEDBACKS YOU'D FIND IF YOU DID THIS MORE CAREFULLY. SO THAT, IN FACT, YOU FIND THAT IT TAKES MORE SULFUR THAN YOU WOULD EXPECT TO GET THE EFFECT BECAUSE THE SULFUR LIFETIME IN THE STRATOSPHERE HAS FALLEN DUE TO THE

CHANGE IN MERIONAL TEMPERATURES . . . CHANGE IN HEATING RATES.

THIS IS THAT SLIDE THAT I MENTIONED THAT I WOULD SHOW YOU, THE SLIDE OF THE REPORT THAT ARRIVED

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ON PRESIDENT JOHNSON'S DESK IN '65. FOR ALL OF YOU WHO WORK ON CLIMATE CHANGE, I FIND IT'S WORTH GOING BACK AND READING SOME OF THE OLD REPORTS. BECAUSE IN A WAY IT'S STUNNING BOTH HOW MUCH WE KNOW MORE SCIENTIFICALLY, BUT HOW MUCH THEY KNEW BACK THEN IN THE MID '60S. THEY REALLY KNEW A LOT WHEN THESE FIRST REPORTS WERE WRITTEN. IF YOU LOOK AT THE TEXT HERE, IF YOU CAN READ IT, OR I CAN GIVE YOU A COPY OF THE REPORT IF YOU'D LIKE, YOU'LL SEE A LOT OF THE THINGS THAT WE NOW SAY WERE ALL SAID THEN. PEOPLE KNEW PRETTY WELL THAT THE DOUBLING OR TRIPLING OF CO2 IN THE ATMOSPHERE WOULD HAVE A REALLY BIG EFFECT, AND THEY HAD A PRETTY GOOD IDEA ABOUT WHAT THE IMPACTS WOULD BE. AND IN MANY WAYS, THESE FACTS ARE MORE OR LESS LIKE WHAT WE SAY NOW. THE IPCC REPORTS ARE JUST A GREAT DEAL THICKER.

I'M NOT CLAIMING WE HAVEN'T LEARNED A LOT. BUT IT IS IMPORTANT TO SAY WE KNEW ENOUGH IN 1965 TO KNOW THAT WE HAD A REAL PROBLEM ON OUR HANDS WITH THE DOUBLING OR TRIPLING OF CO2 IN THE ATMOSPHERE.

SO IT'S INTERESTING THAT WHEN YOU READ THAT REPORT, YOU GET ALL OF THE SORT OF SAME SCIENCE WE HAVE ROUGHLY, OBVIOUSLY WITHOUT AS MUCH DETAIL OR KNOWLEDGE, BUT THE STUNNING THING IS, WHEN YOU READ THAT REPORT, THE ONLY SUGGESTED SOLUTION TO THE

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PROBLEM IS GEOENGINEERING. AND WHAT THAT TELLS YOU IS THAT OUR THINKING ABOUT THIS, WHAT WE DO ABOUT THE PROBLEM HAS CHANGED MUCH MORE RADICALLY AND MUCH MORE QUICKLY. IT'S BEEN MUCH MORE LABILE THAN OUR THINKING OF THE UNDERLYING SCIENCE. AND THAT'S TRUE EVEN IF YOU GO BACK TO IRENAEUS DAY, ANOTHER 50 YEARS-PLUS BEFORE THAT.

SO THIS IS AN OLD TOPIC. THAT'S MY FIRST LESSON. YOU MAY THINK IT'S A NEW TOPIC. IT'S AN OLD TOPIC. BUT IT'S A TOPIC THAT WE'VE TALKED ABOUT IN ALL THE MAJOR SCIENTIFIC REPORTS DEALING WITH CLIMATE CHANGE FROM THAT DATE. SO IF YOU LOOK AT THE NATIONAL ACADEMY REPORT OF 1977 ON ENERGY AND CLIMATE, IT HAS A SERIOUS AND THOUGHTFUL SECTION DEALING WITH THIS; SAME OF THAT 1982 REPORT, ET CETERA, ET CETERA. BECAUSE THEN AS CLIMATE CHANGE BECAME A HIGH-PROFILE TOPIC IN THE LAST DECADE AND A OR HALF OR SO, IT BECAME POLITICALLY IMPOSSIBLE, POLITICALLY INCORRECT, IF I MAY SAY SO, TO TALK ABOUT THIS TOPIC, AND SO WE DIDN'T. SO THERE'S BEEN ESSENTIALLY NO RESEARCH AND NO DISCUSSION OF IT IN POLITE SOCIETY SINCE THEN.

TO SOME EXTENT THAT SILENCE WAS BROKEN WHEN PAUL CRUTZEN PUBLISHED THIS LITTLE ESSAY ON CLIMATIC CHANGE THAT SAID, HEY FOLKS, WE SHOULD RETHINK THIS.

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HE SAID MUCH OF WHAT'S BEEN SAID BEFORE. HE DID A VERY NICE JOB OF SAYING IT. HE HAD SOME PARTICULAR IDEAS OF HOW, FOR EXAMPLE, STRATOSPHERIC WARMING MIGHT COMPENSATE FOR THE OZONE LOSS PROBLEM BECAUSE IT'S NOT JUST REACTIVE SURFACE AREA THAT MATTERS BUT ALSO TEMPERATURE. BUT IT WASN'T REALLY WHAT HE SAID THAT MATTERED; IT WAS WHO SAID IT. OBVIOUSLY, HE'D WON THE NOBEL PRIZE FOR WORK ON OZONE CHEMISTRY. SO PEOPLE TOOK HIS COMMENTS ON THAT SERIOUSLY. AND THERE WAS A HUGE FEAST OF PRESS ABOUT THAT ARTICLE THAT KIND OF GOT THIS BACK INTO THE PUBLIC DOMAIN, FOR BETTER OR FOR WORSE; AND THAT'S WHERE WE STAND NOW, WHERE THE BLOGOSPHERE IS FULL WITH THIS. THERE'S ALL SORTS OF TALK ABOUT IT, AND THERE IS ESSENTIALLY NO RESEARCH ON WHAT THE IMPACTS MIGHT BE OR HOW YOU WOULD BE SMARTER THAN SULFATES.

SO I'M NOW GOING TO TELL YOU A LITTLE BIT ABOUT HOW YOU MIGHT BE SMARTER THAN SULFATES. A PARTICULAR IDEA OF MY OWN THAT MIGHT OR MIGHT NOT BE USEFUL, BUT I THINK THAT THAT IDEA POINTS TO THE FACT THAT THERE ARE A LOT OF IDEAS OUT THERE; AND AS SOON AS WE GET CREATIVE, SMART PEOPLE ACTUALLY LOOKING AT THIS, WE'LL FIND THERE IS A LOT MORE IDEAS THAN JUST PUTTING SULFATES IN THE STRATOSPHERE.

SO, ACTUALLY, THE FIRST OF THOSE AREN'T MY

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OWN. THEIR IDEAS THAT LOWELL WOOD AND EDWARD KELLER AND OTHERS THOUGHT ABOUT A DECADE AND A HALF AGO. THEY REALLY JUST PUT THEIR PHYSICISTS' THINKING CAPS ON AND THOUGHT ABOUT ALL THE WAYS WE MIGHT DESIGN SCATTERING SYSTEMS. AND THERE ARE A LOT OF WAYS YOU MIGHT DESIGN SCATTERING SYSTEMS THAT ARE DIFFERENT FROM JUST STRATOSPHERIC SULFATES. I'M NOT GOING TO SAY VERY MUCH IN DETAIL EXCEPT THAT SOME OF THESE HAVE ENORMOUSLY LOWER MASS THAN SULFATES. SO YOU'D HAVE TO PUT MUCH LESS MATERIAL INTO THE ATMOSPHERE. THOUGH, OF COURSE, THEY ALSO COST MORE. AND SOME OF THEM MIGHT HAVE QUITE DIFFERENT IMPACTS ON THE PHOTOCHEMISTRY AND CHEMISTRY OF THE UPPER ATMOSPHERE.

WHAT YOU GET BASICALLY WITH ALL OF THESE IDEAS IS MUCH LOWER MASS AND SPECTRAL SELECTIVITY. YOU DON'T HAVE TO DO THIS ACROSS THE WHOLE SOLAR SPECTRUM. YOU COULD BE SMARTER THAN THAT.

LET'S SAY YOU WANTED TO COOL THE PLANET DOWN BUT NOT SLOW DOWN PHOTOSYNTHESIS. IN PRINCIPLE, THIS IS POSSIBLE. HOW EXPENSIVE, I CAN'T TELL YOU. WE HAVEN'T DONE THE RESEARCH. BUT THERE'S NO DOUBT THAT YOU COULD DESIGN SCATTERING SYSTEMS THAT SCATTERED IN AREAS OF SPECTRUM THAT AREN'T USED BY PHOTOSYNTHESIS.

NOW I WILL TELL YOU A LITTLE BIT MORE ABOUT

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A PARTICULAR WAY YOU MIGHT GO ABOUT DOING THIS. SO I WAS LITERALLY LYING IN BED THINKING ABOUT THIS ONE NIGHT, AND I THOUGHT ABOUT THESE LITTLE ROTATING KIDS' TOYS YOU'VE SEEN, AND I WONDERED IF THE SAME PHYSICS THAT WORKS ON THOSE COULD BE USED TO SUSPEND

THE PARTICLES IN THE UPPER ATMOSPHERE BECAUSE I MIGHT NOT WANT THE PARTICLES TO FALL OUT AS QUICKLY AS THEY DO NATURALLY. AND I STARTED TO CALCULATE THIS FROM FIRST PRINCIPLES, AND THAT WAS HARD, I GOT STUCK; AND THEN I WENT TO GOOGLE AND I FOUND THAT THERE ARE AN ENORMOUS NUMBER OF PAPERS ABOUT THIS TOPIC ALREADY PUBLISHED.

THE PHYSICS WHICH I WILL DESCRIBE TO YOU IN A MINUTE IS CALLED PHOTOPHORESIS. AND IT TURNS OUT THAT THERE IS ALL SORTS OF PAPERS ABOUT PHOTOPHORESIS IN INTERSTELLAR DISKS AND EVEN IN THE UPPER ATMOSPHERE. SO THIS PAPER I HAVE HERE POINTS OUT THAT IT MAY BE THAT FINE SULFUR, FINE CARBONACEOUS AEROSOLS ARE ALREADY LOFTED TO THE MESOSPHERE BY THE ACTION OF THESE FORCES I'LL DESCRIBE TO YOU IN THE CURRENT ATMOSPHERE. AND SO WHAT I'M TALKING ABOUT BASICALLY IS JUST ENGINEERING NOTES.

SO WHAT'S THE FORCE? IT'S THE FOLLOWING IDEA: LET'S SAY I HAVE SUNLIGHT HEATING UP SOME PARTICLE, AND ONE SIDE OF IT, THE SIDE FACING THE

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SUN, PERHAPS GETS WARMER AND THE OTHER SIDE IS COOLER, AND THIS PARTICLE IS IN AN AREA OF THE ATMOSPHERE WHICH A MEAN-FREE PATH THE DISTANCES THAT MOLECULES GO WITHOUT HITTING OTHER MOLECULES IS LONG COMPARED TO THE SIZE OF THE PARTICLE. PARTICLES THAT BOUNCE OFF THE WARM CYCLE COME OFF FASTER THAN PARTICLES THAT BOUNCE OFF THE COOL SIDE. SO THERE WILL BE A NET FORCE AWAY FROM THE SUN. THAT'S THIS BASIC PHOTOPHORETIC EFFECT. THAT'S THE FLOW OF LOGIC HERE.

IT TURNS OUT THAT THAT EFFECT IS IMPORTANT IN INTERSTELLAR DISKS BUT PROBABLY NOT MUCH IN THE ATMOSPHERE. THE ONE THAT MATTERS IN THE ATMOSPHERE IS A LITTLE MORE COMPLICATED TO EXPLAIN. IT HAS THE SAME BASIC IDEA. LET'S SAY I HAVE A PARTICLE THAT'S WARMER THAN THE SURROUNDING AIR, WHICH IS GOING TO BE TRUE FOR MOST PARTICLES IN THE UPPER ATMOSPHERE, IT TURNS OUT. AND IT TURNS OUT THAT THE PROBABILITY OF THERMALLY EQUILIBRATING, A FEELING THE WARMTH OF THE SURFACE IF YOU'RE A GAS MOLECULE BOUNCING OFF A SURFACE, THAT PROBABILITY IS NOT ONE, IT DEPENDS ON THE KIND OF GAS MOLECULE YOU ARE ON THE SURFACE THAT YOU'RE BOUNCING INTO. AND YOU CAN CHOOSE SURFACES WITH DIFFERENT -- THESE ARE CALLED THERMAL ACCOMMODATION COEFFICIENTS. AND IF YOU HAVE A

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PARTICLE WHICH IS ASYMMETRIC WITH GRAVITY, SO THAT IT ALWAYS WANTS TO FLOAT FACING DOWN AND YOU HAVE IN THE BOTTOM HALF THE MORE -- MORE -- HAVE A HIGHER THERMAL ACCOMMODATION COEFFICIENT, THEN THERE IS A NET FORCE UP. THAT'S THE LOGIC I HAVE THERE.

AND THIS IS THIS PHOTOPHORETIC LEVITATION THAT MAY ACT EVEN TODAY IN THE REAL ATMOSPHERE. BUT YOU CAN BE SMARTER THAN NATURE IS.

THIS IS A CONCEPTUAL DESIGN THAT I HAVE STARTED TO THINK ABOUT THAT WOULD ACTUALLY GET YOU

ESSENTIALLY A LOFTED THIN PARTICLE THAT WOULD BE LOFTED EITHER INTO THE UPPER STRATOSPHERE, OR EVEN UP TO THE MESOSPHERE, AND THESE PARTICLES COULD BE ORIENTED, NOT JUST BY GRAVITY, BUT BY ELECTROGRAMATIC FIELDS, IT TURNS OUT. AND I HAVE NOT JUST TOTALLY WAVED MY ARMS. WE'VE ACTUALLY PUT NUMBERS IN FOR COMMON MATERIALS AND TRIED TO UNDERSTAND HOW THEY MIGHT WORK. AND THERE'S SEVERAL THINGS THAT THESE PARTICLES -- I WON'T GO INTO MUCH MORE DETAIL ABOUT THEM -- MIGHT BUY FOR YOU.

I REALIZE I'M GOING A LITTLE SLOW, SO I'LL SKIP THROUGH SOME OF THIS EXCEPT TO SAY THAT THIS SHOWS YOU PARTICLES WITH DIFFERENT INFRARED AND VISIBLE BAND EMISSIVITIES, AND THIS SHOWS YOU THE NET LOFTING FORCE. SO A PARTICLE, A NET LOFTING FORCE OF

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ONE, IS JUST NEITHER BEING LOFTED NOR FALLING. PARTICLES BELOW THAT ARE BEING DRIVEN DOWN. AND SO YOU COULD BASICALLY TRAP PARTICLES NEAR THE STRATOPAUSE OR NEAR THE MESOPAUSE. SO IF YOU WANT, THE POINT IS YOU CAN GET THEM OUT OF THE OZONE LAYER. SO IF YOU'RE WORRIED ABOUT THE IMPACTS THAT WE KNOW ABOUT OF STRATOSPHERIC CHEMISTRY DUE TO REACTIVE SURFACE AREA, YOU COULD LOFT THESE PARTICLES OUT OF THE STRATOSPHERE AND GET AROUND THAT PROBLEM.

SO WHAT ARE THE POTENTIAL BENEFITS OF THIS? LONG ATMOSPHERIC LIFETIMES. PARTICLES ABOVE THE STRATOSPHERE HAVE LESS OZONE IMPACT, WE THINK. THERE MAY BE SOME OTHER PROBLEM WE HAVEN'T THOUGHT ABOUT YET. THAT'S THE POINT OF DOING RESEARCH. I'M NOT CLAIMING WE HAVE THIS ALL WORKED OUT.

FINALLY, IT TURNS OUT -- AND I'M NOT GOING TO GO INTO DETAIL HERE -- BUT THERE IS A TRICK YOU CAN USE WITH THESE LEVITATED PARTICLES THAT MAKES THEM MIGRATE TOWARDS THE POLES. IT'S NOT THE MAGNETIC EFFECT DIRECTLY, BUT IT IS A LITTLE TORQUE FROM MAGNETIC EFFECT THAT ALLOWS YOU TO DO THAT, AND SO YOU COULD HAVE NOW A WAY TO DESIGN PARTICLES THAT WOULD TARGET THE POLAR REGIONS THAT WOULD BASICALLY REDUCE INSULATION OF THE SOLAR REGIONS, IN A SENSE COMPENSATING FOR THE ICE/ALBEDO FEEDBACK PROBLEM THAT

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IS DRIVING THE UNDERLYING WARMING AT THE POLES, WHICH IS HAPPENING BECAUSE WE'RE LOSING THIS SNOW COVER. SO YOU COULD IMAGINE IN A SENSE, YOU COULD LOOK AT THIS AS A STRATOSPHERIC SNOW COVER REPLACEMENT. BUT, OBVIOUSLY, IT WON'T BE THE SAME THING.

WHAT IS THE POINT OF ALL THIS? NOW I'M GOING TO STEP BACK TO THE LAST PART OF THE TALK WHERE I TALK ABOUT IMPLICATIONS FOR A MINUTE.

THE POINT OF ALL THIS IS THAT OUR LEVERAGE OVER THE NATURAL WORLD INCREASES WITH SCIENCE AND TECHNOLOGY, AND THAT HAPPENS WHETHER OR NOT THE SCIENCE TECHNOLOGY IS SPECIFICALLY DESIGNED TO ENGINEER THE PLANET. THAT'S IMPORTANT TO SAY. EVEN IF WE -- I THINK WE SHOULD NOW HAVE A RESEARCH PROGRAM ON THIS TOPIC. BUT EVEN IF WE HAD NO

RESEARCH PROGRAM ON THIS TOPIC, THE IMPROVEMENTS IN SCIENTIFIC KNOWLEDGE OF THE ATMOSPHERE AND IN OUR ABILITY TO FABRICATE SMALL THINGS, IN THIS CASE, WILL GO ON UNABATED OVER THE CENTURY ANYWAY, AND EFFECTIVELY OUR LEVERAGE OVER THE PLANET GETS LARGER AND LARGER AND LARGER. WE NEED TO THINK ABOUT THE IMPLICATIONS OF LEVERAGE, HOW WE USE IT, WHEN WE SHOULD, WHEN WE SHOULD NOT.

SO LET ME START DOWN THE ROAD OF TALKING ABOUT HOW TO THINK ABOUT THIS. I'M NOT CLAIMING I

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HAVE ALL THE ANSWERS, BUT I'M GIVING YOU SOME OF THE WAYS THAT I AND OTHERS ARE NOW THINKING ABOUT THIS. SO ONE POSSIBLE WAY TO THINK ABOUT GEOENGINEERING IS THAT YOU USE IT INSTEAD OF CUTTING EMISSIONS. SO UNDER THIS SCENARIO, YOU LET THE CO2 CONCENTRATIONS IN THE ATMOSPHERE TREND UP, AND YOU JUST TREND UP THE AMOUNT OF SULFATES OR FANCY PARTICLES IN THE ATMOSPHERE SO THAT THE GLOBAL SURFACE TEMPERATURE STAYS THE SAME OR AT SOME DESIRED LEVEL.

I THINK THAT'S NUTTY, REALLY NUTTY. I JUST CAN'T CONCEIVE OF ANYBODY WHO THINKS THAT THIS IS A SENSIBLE PLAN. AND IN GENERAL, I THINK THE PEOPLE, SMALL NUMBERS OF US WORKING ON THIS TOPIC, DON'T THINK THIS IS SENSIBLE. TO JUST SAY ONE THING, YOU'RE ESSENTIALLY WALKING FARTHER AND FARTHER AND FARTHER AWAY FROM THE EQUILIBRIUM STATE AND INTO MORE AND MORE DANGEROUS TERRITORY IF YOU DO THIS. OBVIOUSLY, PROBLEMS OF OCEAN ACIDIFICATION ARE NOT SOLVED BY GEOENGINEERING, BUT THERE ARE A WHOLE BUNCH OF OTHER REASONS WHY THIS IS A PARTICULARLY DANGEROUS PATH.

BUT THERE ARE OTHER WAYS TO THINK ABOUT IT. THE NEXT WAY IS TO THINK ABOUT THE FOLLOWING: LET'S SAY THAT WE THINK OF GEOENGINEERING AS A WAY TO DEAL WITH THE WORST CONSEQUENCES OF THE EMISSIONS PEAK.

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SO LET'S SAY THAT WE WORK AS HARD AS WE CAN WITH CO2 CAPTURE AND STORAGE AND SOLAR POWER AND EFFICIENCY AND ALL THE DIFFERENT THINGS WE DO; AND THEN FINALLY IN SOME DATE, MAYBE 2074, WE FIND THAT WE'VE REACHED THE PEAK OF ATMOSPHERIC CONCENTRATIONS OF CO2, AND WE HAVE GRAND CELEBRATIONS ALL AROUND THE WORLD, CHEERING AND SPEECHES FROM PRESIDENTS; BUT WE FIND THAT, IN FACT, WE'RE STILL LOSING GREENLAND AT AN UNACCEPTABLE PACE AND THE IMPLICATIONS OF THAT CONCENTRATION IN THE ATMOSPHERE ARE UNACCEPTABLE TO US.

WE MIGHT THEN SAY THAT WE WANT TO DO GEOENGINEERING FOR A LIMITED PERIOD DURING THE TIME OF THE PEAK CONCENTRATIONS; NOT INSTEAD OF MITIGATION, BUT AS WELL AS MITIGATION, TO REDUCE THE IMPACTS. I THINK THAT'S A MUCH MORE CREDIBLE WAY TO THINK ABOUT IT. BUT THERE'S SEVERAL CATCHES. HERE'S ONE: KNOWLEDGE THAT GEOENGINEERING IS POSSIBLE, JUST THE KNOWLEDGE OF IT, MAKES THE CLIMATE IMPACTS LOOK LESS FEARSOME. IN THE LANGUAGE OF ECONOMISTS, PART

OF WHAT'S SCARY ABOUT CLIMATE CHANGE IS THE FAT TAILS, THE HIGH IMPACT, LOW PROBABILITY OUTCOMES FROM CLIMATE CHANGE ARE A LOT OF WHAT GETS US UP IN THE MORNING AND MAKES US WANT TO SOLVE THIS PROBLEM. BUT TO THE EXTENT THAT GEOENGINEERING REDUCES THE WORST

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OF THOSE OUTCOMES BECAUSE WE KNOW THAT IF WE FIND OURSELVES IN THAT STATE, WE'RE GOING TO TRY TO GEOENGINEER, IT MAY MEAN A WEAKER COMMITMENT TO CUTTING EMISSIONS NOW, AND I THINK THIS IS THE UNDERLYING REASON THAT MOST PEOPLE QUITE REASONABLY THINK THAT WE SHOULDN'T TALK ABOUT THIS TOPIC, BECAUSE THE FEAR IS THAT IF WE TALK ABOUT IT, THE PUBLIC WILL ASSUME THEY DON'T HAVE TO WORK AS HARD AT CUTTING EMISSIONS NOW. THAT'S A FEAR I VERY MUCH SHARE. I'VE THOUGHT ABOUT THIS TOPIC ON AND OFF FOR 15 YEARS OR SO, AND FOR A LOT OF THOSE 15 YEARS, I'VE SAID WE SHOULD JUST NOT TALK ABOUT IT FOR THIS REASON, BUT I NO LONGER THINK THAT.

THE SECOND ISSUE IS A SORT OF A SLIPPERY-SLOPE ISSUE, AND IT'S THE FOLLOWING: I THINK IT'S SAID BEST BY THIS NATIONAL ACADEMY REPORT IN THE EARLY '80S THAT SAYS: INTEREST IN CO2 MAY GENERATE OR REINFORCE A LASTING INTEREST IN NATIONAL OR INTERNATIONAL MEANS OF CLIMATE AND WEATHER MODIFICATION. ONCE GENERATED, THAT INTEREST MAY FLOURISH INDEPENDENT OF WHAT'S DONE ABOUT CO2.

I THINK THIS IS PROBABLY A FAIR AND REAL STATEMENT ABOUT THE WAY HUMANS INTERACT WITH THE NATURAL WORLD; THAT PART OF THE WAY WE WORK OUR WAY OUT OF THIS PROBLEM IS GOING TO BE BY REFORMING OUR

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ENERGY SYSTEM, BUT PART OF IT IS GOING TO BE BY WORKING OUR WAY INTO A KIND OF CLIMATE AND WEATHER CONTROL. BUT THIS IS NOT A CONTROL THAT HAS EASY OUTCOMES POLITICALLY.

TO CLOSE, HERE'S A FEW KIND OF QUESTIONS AND OPINIONS. FIRST OF ALL, OPINIONS. AND EVEN SIX MONTHS AGO IF I HAD GIVEN THIS TALK, I WOULD HAVE LISTED THIS AS A QUESTION; BUT NOW, FOR ME, ANYWAY, IT IS MY OPINION ABOUT WHAT WE SHOULD DO. WE NEED A RESEARCH PROGRAM. WE'RE IN A VERY DANGEROUS STATE NOW WHERE, AS I'VE SAID BEFORE IN THIS TALK, WHERE WE HAVE THE REAL POSSIBILITY THAT THIS CAN BE DONE AND DONE CHEAPLY, BUT ESSENTIALLY NO RESEARCH ON HOW YOU DO IT, ON WHAT THE IMPACTS ARE, ON THE SOCIAL SCIENCE SIDE OF THIS, HOW YOU WOULD CONTROL IT, WHETHER YOU NEED A TREATY, ET CETERA. AND WE HAVE A LOT OF TALK OUT THERE IN THE WORLD, AND THAT'S VERY DANGEROUS. IN A WAY, THE WORST POSSIBILITY WITH GEOENGINEERING IS IF WE THINK WE CAN DO IT AND THEN WE FIND THAT FOR SOME REASON WE REALLY CAN'T. SO IF WE THINK WE CAN DO IT AND DO LESS THAN WE SHOULD HAVE TO CUT EMISSIONS AND THEN WE FIND WE CAN'T, THAT'S THE WORST CASE.

SO I THINK WE NEED RESEARCH ON AT LEAST THREE TOPICS: ON THE IMPACTS OF THESE GEOENGINEERING

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THINGS, AND THAT'S THE COMMUNITY I'M TALKING TO HERE, THAT'S THE SCIENCE COMMUNITY. THIS IS STILL ABOUT SCIENCE. I'M NOT -- I DON'T THINK ANYBODY IS PROPOSING THAT WE SHOULD DO THIS NOW. BUT IT'S ABOUT IMPACTS, METHODS, AND IMPLICATIONS. IMPACTS, WHAT IT DOES, HOW WE DO IT, AND WHAT THE IMPLICATIONS ARE. IT NEEDS TO BE INTERNATIONAL, AND WE DON'T NEED VERY MUCH MONEY TO MAKE HUGE PROGRESS BECAUSE HARDLY ANYTHING HAS BEEN SPENT. SO THE SECOND COMMENT IS THE ONE THAT I'VE MADE LOTS OF TIMES, IT'S OBVIOUS.

A THIRD COMMENT THAT WE HAVE TO BE HONEST ABOUT IS THAT THE SCIENCE COMMUNITY SHOULD EXPECT TO LOSE CONTROL ON THIS TOPIC. WE MAY HAVE OUR OWN OPINIONS ABOUT HOW THIS SHOULD BE USED, BUT WE HAVE TO BE HONEST ABOUT THE FACT THAT ONCE THIS IS OUT IN THE WORLD, IT MAY NOT BE USED THE WAY WE THINK, BUT WE HAVE TO USE WHATEVER LEVERAGE WE CAN TO INFLUENCE THE WAY IT IS USED.

SOME QUESTIONS: THE OBVIOUS ONE IS HOW WE AVOID THIS TRADE-OFF BETWEEN MITIGATION AND GEOENGINEERING BECAUSE THERE IS A TRADE-OFF, AND IT'S A TRADE-OFF WE SEE IN ALL SORTS OF REAL-WORLD SURROUNDINGS. SO WHEN WE INVENT SEAT BELTS, WE DON'T SAVE AS MANY LIVES AS WE THINK BECAUSE PEOPLE DRIVE FASTER WITHOUT SEAT BELTS THAN THEY DO WITH THEM.

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THIS IS JUST A FACT OF HUMAN BEHAVIOR AT LOTS OF SCALES.

FINALLY, DO WE NEED A TREATY? TOM SCHELLING, WHO HAS WORKED ON THESE TOPICS, A NOBEL PRIZE WINNER, AN ECONOMIST, WORKED ON THESE TOPICS SINCE THE LATE '70S, HAS SAID THAT GEOENGINEERING IS THE OPPOSITE OF ABATEMENT. WITH ABATEMENT, THE PROBLEM IS HOW YOU GET EVERY COUNTRY TO COMPLY. WITH GEOENGINEERING, IT MAY BE SO CHEAP THAT THE PROBLEM IS HOW TO CONTROL SOME COUNTRY THAT DECIDES THEY JUST WANT TO DO THIS. YOU KNOW, WE MAY BE THINKING THE U.S. IS GOING TO DO THIS, BUT PERHAPS IT IS BANGLADESH IN 2030 WHO JUST FEELS THESE IMPACTS ARE UNACCEPTABLE AND IS TIRED WITH ENDLESS DEBATES ABOUT MORALITY AND JUST WANTS TO COOL THE PLANET DOWN.

THIS IS AN ARTICLE I WROTE BACK IN '92, AND IT SAID THIS -- AND I THINK THIS IS STILL WHAT I THINK -- "CURRENT DISCUSSIONS OF GEOENGINEERING ARE UNSYSTEMATIC AND TAKE INSUFFICIENT ACCOUNT OF PRIOR RESULTS. THE POSSIBILITY OF UNPLEASANT SURPRISE IN THE CLIMATE SYSTEM JUSTIFIES A MORE COHERENT, THOUGH NOT LARGE, RESEARCH PROGRAM. IN ORDER TO DEFINE OPTIONS, WE NEED TO MAKE REASONABLE CHOICES. A RATIONAL ALLOCATION OF RESEARCH PRIORITIES DICTATES THAT SOME RESOURCES BE SPENT ON THIS TOPIC UNLESS YOU

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ASSIGN ZERO PROBABILITY TO NASTY OUTCOMES."

THAT'S IT. I WAS GOING TO TALK ABOUT SOME PEOPLE, BUT I WILL LEAVE IT AT THAT SINCE I'M OVER MY TIME.

THANK YOU.