Climate Lab

Video Scripts

Video #1: Introducing The Climate Lab

Introduction

Hi, my name is Glenn Weinreb, and today we're announcing a new YouTube channel called "The Climate Lab"

We're a group of alumni from MIT who are interested in setting up a **laboratory**
that **prevents** runaway climate change.

More specifically, this lab would conduct R&D,
to the extent required,
to prevent the activation, of climate tipping points.

These are critical thresholds in Earth's systems that,
once crossed, trigger abrupt changes.

The first to go would probably be North Pole sea ice.

It is roughly 2 meters thick, and once it melts,
sunlight would be absorbed by water,
instead of being reflected by sea ice.

And, according to scientists, this would increase the average global temperature by 0.6 degrees Celsius.

And that's just the beginning.
Over the next 100 years, we can expect to see several meters of sea level rise.

Runaway Climate Change

<u>**After**</u> the first tipping point activates,
others are likely to follow, **like a chain of falling dominoes**.

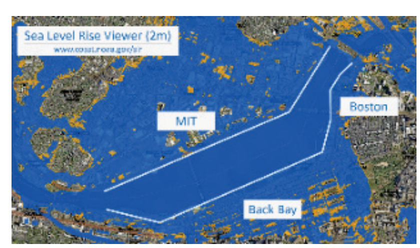
This is sometimes
referred to as *runaway climate change*, and yes, it could be bad.

Think: less food production,
mass migration, and
widespread disruption.

We believe, a surge of R&D, in key areas,
can help prevent this, and in our videos, we'll explain how.

For us, this hits close to home. Much of the MIT campus is built on landfill, which means it would be the first to go.

This shows what 2 meters of additional water would do. Obviously, this would be bad.



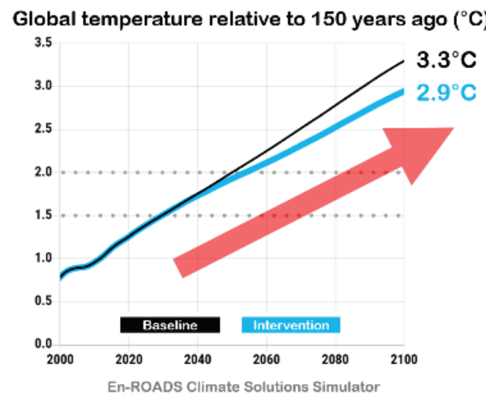
Is Decarbonization Helpful?

Thirty years ago, scientists suggested we can solve the climate problem by
replacing coal, oil and natural gas with green energy.

However, it seems like
we have progressed, beyond the point, where this will solve the problem.

To get a better sense of this, we can use the MIT climate solutions simulator,
to see what would happen, if a global tax caused, the cost of fossil fuel, to **double**.

According to the software, this would reduce the average global temperature anomaly,
at the end of this century, from 3.3 degrees Celsius, to 2.9.



And, we would still get, runaway climate change.

These temperatures refer to the increase,
from pre-industrial times, 150 years ago.

Okay, what about adding a worldwide, 200-dollar-per-ton,
tax on carbon dioxide, to roughly **quadruple** the cost of fossil fuel.

Would that help?

Nope. We still get runaway climate change.

Okay, so what does this mean?

In a nutshell, this means fixing climate, is more complicated,
than reducing carbon dioxide.

Furthermore, typical energy policies promoted by Conservatives,
and typical energy policies promoted by Liberals,
are **both too small,**
to influence tipping points,
in either direction.

In other words, Liberals are not helping, and Conservatives are not hurting.

All of this is another way of saying
mother-nature is **larger**
than your typical government policy.

The Journalism Problem

Part of the problem is journalists report on existing climate initiatives,
without quantifying their impact on the planet.

For example, a news story might cover a new solar farm and suggest it will help
bears, penguins, rice farmers, and people late for work.

But leave out the fact that even
if the **world** built these up to the level where they supply **all electricity** when sunny,
it would have little impact on tipping points.

There are several techniques for quantifying the impact of so-called climate remedies,
one of which is to use a climate simulator.

However, **few** journalists are familiar with these techniques,
and this has led to a **distorted view** of the **problem**, and **the solution**.

Actively Cooling the Planet

To prevent runaway climate change, we probably need to
reflect approximately 1% of sunlight back into outer space,
to cool the planet, and offset global warming.

In theory, this could be done with
airplanes that spray reflective gasses, into the upper atmosphere.

To get a sense of what 1% looks like, we placed a white bar in this image, and then made it 10% transparent, followed by 1%. As one can see, 1% is barely visible to the naked eye.

It would cost little money to conduct reflectivity **experiments** and look for harm.

For example, an experimental spray plane could inject material into the upper atmosphere,
and a monitor plane could visit the site once a day, for several weeks.

Multiple parameters could be measured by flying above the material,
below the material, and through the material.

~~Reflecting Sunlight is not Popular~~

Reflecting sunlight is not popular;
however, as the climate crisis worsens,
our society will be pushed in this direction —
in addition to, reducing carbon dioxide.

This raises important questions.
Can we reflect sunlight without causing harm?
How much would this cost?
Can we run small-scale tests, in a limited part of the sky, to measure side effects?

We'll explore these questions, as we
compare reflecting sunlight,
with **not reflecting sunlight**.

Unfortunately, we may also have a timing problem
—by the time we act, it could be too late.

We'll talk about that too.

Energy Economics

Currently, the world spends
approximately 4 trillion dollars, on fossil fuel, each year.

This includes 2.5 trillion for oil, 1 trillion for coal, and a half trillion for natural gas.

If we switched over,
this money instead would be used to produce green energy.

Or, more precisely,
it would pay down the mortgage on
facilities that produce green energy.

These are big numbers.

And we'll look at the economic forces that would be needed to push this forward.

According to basic principles of economics,
there's only one way to decarbonize worldwide,
within a reasonable amount of time.

Lab Goal - Statement

And that is to do R&D, to the extent required, to drive down the cost of 24/7 green energy, to below that of fossil fuel.

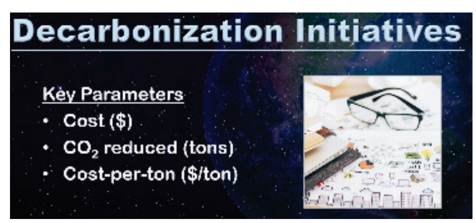
Lab Goal - SLIDE

Do R&D to the extent required, to drive down the cost of 24/7 green energy, to below that of fossil fuel.

This is not being done; however, it could be done.

And this would cost little, relative to costs typically associated with climate.

An Engineered Approach to Climate



Each decarbonization initiative can be summarized with **three** key parameters:
the cost to society,
the amount of carbon dioxide reduced ~~in units of tons,~~
and the cost per ton.

In theory,
economists can estimate these for each decarbonization initiative,
and identify the lowest-cost approach.

But in practice, this is rarely done. Yet why not? Why is our society inept at tackling climate?

Is it possible, our fundamental approach, to this problem, is flawed?

And if so, what might be a better approach? If we instead

pursued an **engineered approach**,
where the lowest cost solution is favored,
what might that look like?

In later videos, we'll do a deep dive, on what it means to tackle climate, **at lowest-cost.**

Climate Plan

A **plan** that decarbonizes over several decades would involve both speed and scale.

It would **not** look at building **one** nuclear fission reactor,
and instead would support building thousands.

Also, it would **not** look at building
one experimental fusion reactor 10 years from now,
and instead would support achieving economic fusion within several years,
given a **very large** R&D budget.

No one has ever presented a plan that solves the entire climate problem, let alone at the lowest cost.

But in theory, a website could generate a plan, based on criteria specified by the website user.

This website does not exist; however, it could be built.

A Surge of R&D in Key Areas

President Biden issued
93 billion dollars in climate-related,
loan guarantees, during the last few months, of his presidency.

This level of funding is probably needed to solve the entire climate problem
with additional R&D.

However, it would need to be focused on the right areas, and managed responsibly.

We'll look at how this might be done.

Politics is not the Problem

Let's take a break from climate, and look at politics.

Nations are dominated politically by large industries
that employ**millions of people**.

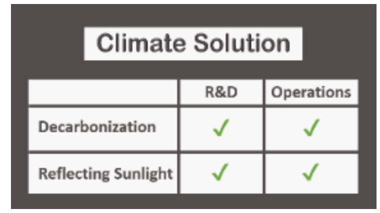
Examples are, the fossil fuel industry, labor unions, auto makers, and factories.

Climate, in comparison, employs
few people, and is therefore politically weak.

In a sense, large industries are political gorillas,
while climate is the small monkey.

But surprisingly, this is not a problem.

That might sound strange,
but it can be explained.



Preventing runaway climate change, for real,
primarily involves two activities **at large scales**.

One is Decarbonization, and the other is Reflecting Sunlight.

For each activity, there are two phases, R&D **and** Operations.

Political opponents **cannot block** R&D,
since it can be funded by a handful of environment-friendly governments, **and** foundations.

Also, political opponents cannot block Decarbonization Operations,
if the green option, costs less than, the carbon option.

And, political opponents are not likely to block Reflecting Sunlight,
since runaway climate change, would be bad for business.Also, for very little money, researchers can **calculate** how to avoid tipping points, at the lowest cost to society.

Wake Smith's excellent paper, is an example of this.

All of this suggests,
a path forward exists, **and** it is not blocked by politics.

Also, if we get the
right assignments to scientists and engineers,
practically everyone else can relax,
while a relatively small group of people, **handle this.**

Do We Need a New Laboratory?

Unfortunately, our society does not have a plan to solve the climate problem.

It does not evaluate the cost and impact of decarbonization initiatives.

It does not have a mechanism that favors the lowest-cost approach.

And no one feels responsible for solving the entire problem.

Perhaps the last point is the most relevant.

Can we make someone — or some organization — responsible for fixing this? And if so, what might that look like?

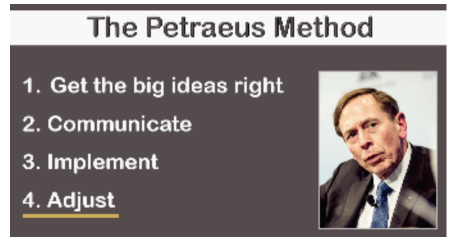
We've developed a business plan for an organization that could do this. This plan is open-source, which means it can be shared, edited, and used freely. To see it, click on the link, in the description below {BP}.

The Petraeus Method

Retired General David Petraeus is considered to be one of the most effective military thinkers of our time.

He has held top positions within the U.S. military,
in addition to leading the Central Intelligence Agency.

He advocates a four step process,
when solving complex problems.



Step #1 is to figure out the big ideas, and get them right.

Step #2 is to communicate those ideas.

Step #3 is to implement.

And Step #4 is to adjust as needed.

Our Strategy

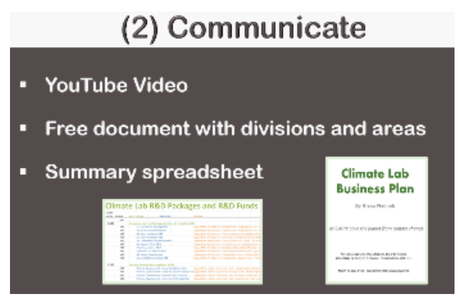
It is our intent, to apply The Petraeus Method, to climate.

Step #1 -- Big Ideas

The big ideas are:

- Drive down the cost of green energy with R&D.
- Figure out how to reflect sunlight with R&D.
- Develop a website that calculates what needs to be done, and when, to achieve an objective.
- And conduct decarbonization and reflectivity operations, at reasonable cost.

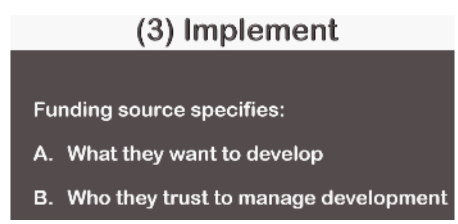
Step #2 -- Communicate



With communications, we have:

- Videos at this YouTube channel.
- A free document that describes 8 divisions within a proposed laboratory, each with about 7 focus areas.
- And a free summary spreadsheet that helps people figure out what they want to do, within each division.

Step #3 -- Implementation



To implement,
we need wealthy individuals to specify:
A, what they want to develop,
and B, who they trust to oversee development.

For example, someone might choose to put X dollars into area Y,
Z dollars into area P,
and have organization so-and-so oversee the development.

So that's it.

That's our strategy.

MIT Needs to Do Better

MIT teaches scientists, and engineers,
how to solve problems.

But when it comes to climate, they need to do better.

They need to focus less on the trees,
and more on the forest.

More specifically, they need to identify the R&D that can solve the entire problem — to the extent needed — to prevent runaway climate change.

Our lab business plan is one example of how this could be done.

Calling on MIT Alumni Worldwide

A lab that solves the entire climate problem would involve
tens of thousands of scientists and engineers.

Many MIT alumni have experience running large organizations,
and are therefore well suited to help set this up.

Calling on MIT Alumni Worldwide - Statement

For this reason, we're calling on MIT alumni worldwide, to help us.
The situation is dire, yet not impossible

And in future videos, we'll look at how this might be done.

Okay, that's it for me, and I'll talk to you all, real soon.

music fades out -- 5 seconds

Video #2: Tackling Climate with More R&D

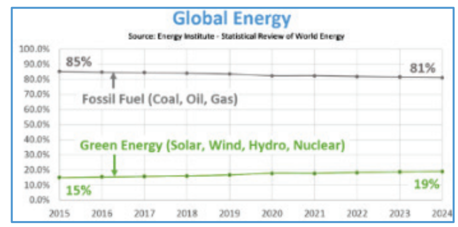
Hi, my name is Glenn Weinreb, and today we're going to look at how a
{SLOW} surge in R&D,
could potentially {SLOW} **solve**,
the {SLOW} carbon dioxide emissions problem.

But what might we develop, that is not already being worked on?

We'll look at that.

But first, let's review the problem.

The Prisoner's Dilemma Problem



In some cases, the green option costs less than the carbon option, and switching over is easy.

While in other cases, the green option costs more,
and switching over is less popular,
especially at large scales.

In these cases, the additional cost of the green product, is referred to as the "green premium."

And, unfortunately, consumers tend to **avoid** this so-called premium.

This is because they do not benefit from
{SLOW} reducing theirown emissions.

They are {VERY SLOW} too small.

Instead, harm comes from the {SLOW} **collective emissions**
of our planet's {SLOW} eight billion people.

For this reason, {SLOW} **each person**, wants {SLOW} **everybody else**, to reduce.

Economists refer to this as a "prisoner's dilemma problem."

And, according to economic theory, our fundamental strategy,
of using social pressure, to solve the climate problem, will not work.

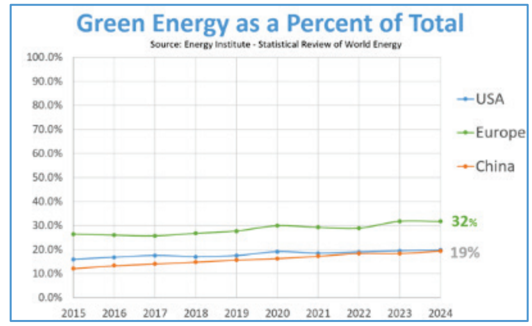
All of this might seem strange,
however, we can see evidence of it, in real data.

The History of Decarbonization

Globally, the share of total energy that doesn't emit carbon dioxide,
has only increased from 15%, to 19%, over the last decade.

This is all energy, not just electricity.

And this is the entire world, not just one nation.



At this pace, reaching full decarbonization,
would take about 200 years.

Far too long, to solve the climate problem.

We can also look at the U.S., Europe, and China.

The U.S. is on track to decarbonize over 200 years,
Europe over 125 years,
and China over 100 years.

It is worth noting,
decarbonization during conservative administrations is similar to that of
liberal administrations, even though liberals focus more on climate.

This is because **key** energy policies were similar, and market forces changed little.

For example, they both had a 30% subsidy on building solar farms,
and they both had natural gas, costing
less than coal.

In other words, policy **differences,** between liberals and conservatives, tend to be **small**,
relative to {SLOW} the size of the problem {View Earth}.

Tackling Climate in Lowest-Cost Order

Lawmakers sometimes ask, "Why spend 200 dollars to reduce carbon dioxide emissions by one ton,
when we can do it, for 20?"

For this reason, they often favor decarbonizing, in lowest-cost order.

In other words, easiest first, followed by, the more difficult.

Roughly one-third of carbon dioxide comes from electrical power generation,
roughly one-third from industrial processes that make chemicals & materials,
and roughly one-third from transportation.

Electrical power is the easiest to decarbonize,
followed by chemicals,
followed by transportation.

Electrical power, is currently being decarbonized,
by building solar farms, and wind farms.

However, industrial processes and transportation, has seen little decarbonization, relative to total.

Again, nations tend to tackle climate, in lowest-cost order.

And they often do it **slowly**, in part, due to The Prisoner's Dilemma.

In other words, it is in a nation's best financial interests,
to minimize costs,
while putting on a show,
and encouraging others, to act.

And, for the most part, this is what happens.

The Climate Solution

There is a field of study called *Energy Economics*,
and it examines our society's behavior with energy.

If you want to learn more about it, consider reading *The New Map,* by Yergin.

There are basic principles within this field,
and if you accept them,
and if you want to solve the Prisoner's Dilemma problem,
there's only one solution.

And that is to drive **down** the cost of 24/7 green energy,
so that it's cheaper,
than carbon-based energy.

And in theory, more R&D can make this happen.

Fortunately, this would cost little, relative to the cost of brute-force decarbonization,
and relative to the cost of climate harm.

However, this R&D would need to produce results quickly.

Which means it would need to focus on key areas,
with **known technologies**,
and favorable **cost models**.

And this applies to the 3 big areas, {tick fingers}
which are, again, electrical power,
the making of chemicals and materials,
and transportation.

Let's run through an example, to get a better sense of this.

Cheap Green Electrical Power

Let's say we want to
quickly decarbonize electrical power,
with low-cost nuclear fission reactors.

It typically take decades to commercialize reactors that are still in development.

Therefore,
we would need to COPY an existing design,

that is **currently operating** commercially,
and then build many.

The safest reactor in the world, is HTR-PM.

It does not melt-down, when not cooled.
And its reactor vessel and heat exchanger cost little.

Instead, most of the cost, comes from, site construction.

And, {SLOW} for little money, we could do rough designs, of custom machines, that automate that construction.

In other words, for small money,
we should be able to identify how to produce 24/7 green electrical power,
at a cost less than carbon-based power.

Okay, so why has this not been done?

The problem is, engineers typically build one nuclear reactor at a time,
instead of building many, low-cost reactors.

And a laboratory tasked with solving the entire climate problem,
would focus on doing the R&D that support many.

Cheap Green Chemicals & Materials

Ok, so that's electrical power.

Now let's look at making chemicals, and materials.

We want to do this {tick fingers} without emitting carbon dioxide,
and we want to do it for less money,
than the carbon-based approach.

This can probably be done by using heat, directly from, a cost-reduced nuclear reactor.

More specifically, we could pump steam, molten salt, or molten lead
through pipes, from a nuclear reactor, to a nearby, industrial processes.

To further reduce costs,
a new transportation system could be developed that transports
platforms of chemical processing equipment from factory, to site.

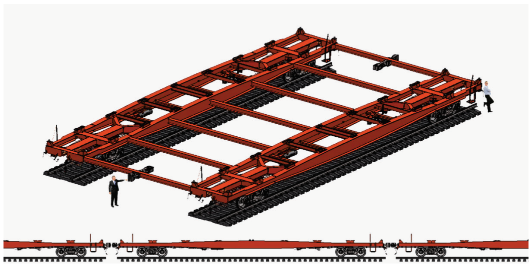
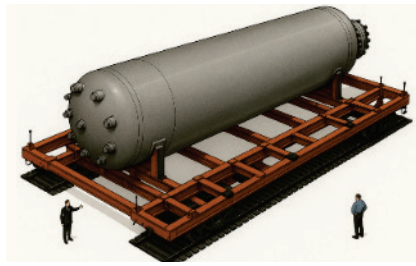
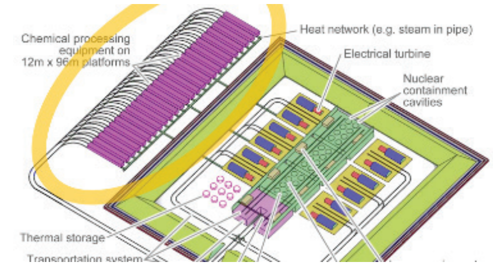
For example, we could develop a double-rail system, that moves
large and heavy loads, over land and water.

Also, multiple railcars, could move large platforms of industrial processing equipment,
and place them side-by-side, near a nuclear reactor.

Typically, 66% of the energy produced by nuclear power, is lost to the environment as unused heat.
However, this could potentially be used by nearby industrial processes, to further reduce costs.

Developing the standards that define how this fits together, plug-and-play,
would cost little, compared to costs
typically associated with nuclear power.

We'll talk more about this, in future videos.

Cheap Green Cars

Okay, now let's look at cars.

We want cars that,
do not emit carbon dioxide,
cost less than gas cars,
and are, as convenient as, gas cars.

Are we currently doing this, with electric vehicles?

Nope.

They are not convenient.

Okay, so how might we do better?

Currently, proprietary batteries are built into EVs,
and charged periodically.

Alternatively, EVs could use a standard **plug-in battery**,
where all cars use the same form,
and swap with a fresh battery in several minutes.

Car owners would pay for electricity consumed, and for wear on the battery.

And they'd pay less, when using lower-cost batteries.

Today, mechanical and electrical standards define batteries,
and allow us to power many products, at a low cost.

In theory, this could also be done with EVs.

In other words, a standardized battery, similar to the Tesla EV battery,
could be used by multiple manufacturers.

And batteries, sitting in swap stations, could charge at any time, over multiple days.

This would reduce costs for multiple reasons. {tick fingers}

- One, batteries could charge at night when electricity is cheap.
- Two, batteries could charge when solar farms and
wind farms are producing power.
- Three, batteries could charge slowly, and avoid expensive fast-charging hardware.
- And four, competition between battery manufacturers, would drive down costs.

In other words, we could get favorable costs, and favorable convenience.

Which is what we need to go green with cars.

Okay, so why has this not been done?

This problem is, lawmakers delegate to auto companies,
and auto companies focus on their own financial interests, not {SLOW} **fixing the planet**.

To move this forward, someone would need to support
the development of {SLOW} **standards** that
define how this fits together mechanically, electrically and with communications.

More specifically, climate money would probably need to build this up to the point of
working prototypes, and give the designs away for free.

We'll talk more about this in later videos.

Building Automation & Control

To fully automate buildings, we would need to put a microprocessor into every device,
and then connect them together with reliable communication.

Devices would include light switches, light sockets, HVAC equipment, appliances,
dampers in ducts, fans, occupancy sensors, temperature sensors, etc.

This could save money, improve comfort, and cut energy use in many ways.

For example, it could help control each room's temperature,
and move heat from one room to another.

In theory, a new lab could develop the standards that define how this fits together — plug-and-play.

Fusion Moonshot

Currently, scientists are exploring
how to generate energy with a hot plasma inside a donut-shaped chamber.

This is referred to as "fusion," and some scientists believe it will not be commercially available for another 20 years.

However, a multi-billion-dollar R&D initiative,
overseen by the world's top fusion scientists, could potentially speed this up.

In 1961,
President Kennedy stated he wanted a man on the moon, by the end of the decade.

In response, a program was set up, and funded.

In theory, a government or foundation leader could do the same with, nuclear fusion.

For example, they could state they want to generate electricity with fusion,
at a cost less than natural gas based electricity,
and they want this done,
within a handful of years.

Engineers would then focus on a published design, that achieves this objective.

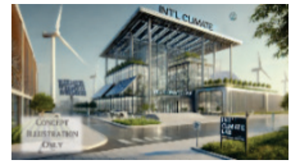
It turns out, such a thing exists {Reference: Volpe 2024 paper},
and we'll do a deep dive on what this means,
in later videos.

In closing, much can be done with additional R&D, in key areas.

And, for each of these areas, it costs little money, to assess technical and economic feasibility.

Okay, that's it for me, and I'll talk to you all, real soon.

Video #3: The Climate Lab Strategy



Hi, my name is Glenn Weinreb,
and today we're going to explore how a
new R&D laboratory could potentially tackle,
the climate problem.

{SLOW} Our planet's temperature, is currently accelerating upward.

{SLOW} This suggests, past R&D efforts have been insufficient.

{SLOW} So what might we do differently?

{SLOW} We'll look at that.

But first, let's do a quick review, of typical methods, for handling R&D.

Big R&D

Universities typically focus on professors-sized projects.

While **companies** typically focus on projects that
provide a return on investment,
within a reasonable amount of time.

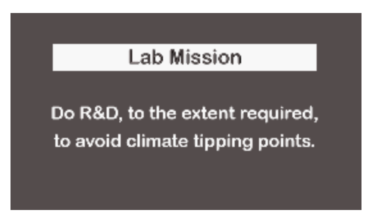
But there's another type that is often overlooked.

This is what Bill Gates refers to as "Big R&D."

These are large-scale projects, that exceed the capabilities of a university, or a company.

Examples include
The Manhattan Project during World War II, and
the U.S. program that landed a man on the moon.

Each started with a goal, broke the problem down into parts, and pushed forward.

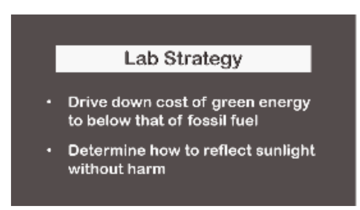


And each involved multiple teams, and multiple organizations.

In theory, the same could be done, for climate.

Lab Mission - Statement

More specifically, a new laboratory , could do R&D,
to the extent required,
to prevent runaway climate change.



To achieve this objective, the lab could

Lab Strategy - Statement

Drive down the cost of 24/7 green energy, to below that of fossil fuel,
and determine how to reflect sunlight, at reasonable cost, and without harm.

Lab Mission - SLIDE

Do R&D, to the extent required, to prevent runaway climate change.

Lab Strategy - SLIDE

- Drive down the cost of 24/7 green energy to below that of fossil fuel.
- Determine how to reflect sunlight at reasonable cost and without harm.

Big R&D is often avoided by Companies, due to excessive risk.

It is often avoided by Universities, due to a reliance on professor-sized projects.

And it is often avoided by Governments, unless they are under extreme pressure.

In theory, these barriers can be overcome with a unique organizational structure,
that coordinates multiple foundations, universities, and funding sources.

Yet how might this be organized?

And what would it take to get it started?

Let's take a closer look.

Spending Money Wisely

Big R&D might sound expensive; however, feasibility can often be verified with relatively little money.

More specifically, one typically spends small money before medium money,
and medium money before big money,
and only advances if technically and economically feasible.

Small typically involves developing rough designs, building cost models, and writing proposals.

This is sometimes referred to as "Phase One R&D."

Medium typically entails, detailed engineering, and prototype development.

While Big typically involves setting up factories, and supporting large volumes.

Sources of Funding

There are two main sources of R&D funding: Climate Money and Investment Money.

Climate Money hopes to save the planet from climate change,
whereas Investment Money hopes to make more money.

Each has constraints.

For example,
Investment Money avoids projects that are too complex, too risky, or lack consumer demand.

While Climate Money often requires results to be shared openly,
to maximize climate benefit, per dollar spent.

Open sharing brings reals advantages.

It maximizes use of developed technology.

It encourages peer review.

It promotes development of interconnection standards.

It reduces exaggerated claims.

And it lessens dependency on researchers and institutions.

Typical sources of Climate Money include governments, foundations, and individual donors.

While Investment Money typically comes from companies and investment funds.

Companies and universities, often prioritize their own financial interests, over climate interests.

For example, they often avoid sharing information, since it can interfere with
securing patents,
developing proprietary products, and
attracting further investment.

The Climate Lab

The public is tired of hearing about climate.

For the most part, they have 3 simple questions:

- One, how much does it cost to fix this?
- Two, **who** fix this?
- And three, what are they going to do about it?

In theory, a business plan, for a new lab,
can help answer these questions.

Lab Suggestion - Statement

For this reason, we encourage Foundations, Governments, and Universities to
task several people,
with writing an R&D plan,
that prevents runaway climate change.

Lab Suggestion - SLIDE

Task several people with developing an R&D plan that prevents runaway climate change.

For an example of this, click on the link, in the Description below.

Okay, so why is it helpful, for existing organizations, to write this kind of plan?

We can estimate the cost of decarbonization, and climate harm,
and see it's in the range of trillions of dollars.

Therefore, in theory, it's reasonable, to spend additional billions on R&D, to save trillions.

If additional R&D, cost 100 billion dollars over 10 years, for example.
And 500 hundred thousand dollars was spent on each technical person annually,
then this would support 20,000 scientists and engineers.

This goes beyond what one organization could handle.

Therefore, money would need to flow toward many organizations.

And writing a plan, helps them get a sense of what is needed, and how to attract money.

The idea of 20 thousand people might seem overwhelming.

But keep in mind,
one can get started with rough designs, cost modeling, and proposal writing --
for small money.

Climate Leadership

The climate problem is difficult to discuss for several reasons.

One, it's upsetting.

Two, it's difficult to comprehend significant changes to our planet.

And three, many people still believe decarbonization is viable,
in part, due to decarbonization news reports that appear, almost daily.

Also, a path forward does exist, and in theory,
a lab could help **explain** this to the public.

This YouTube channel, is an example, of how this might be done.

The Fog of Climate

As evidence of a changing planet increases,
support for reflecting sunlight, and decarbonization, also increases.

However, if and when **support** becomes sufficient,
it’s not clear,
we’ll have enough time to act
— at the scale needed
— to avoid climate tipping points.

In other words, we might have, a timing problem.

Also, if and when support **is** sufficient,
it’s not clear that people with money,
know what to do with it.

For example, the last US administration spent hundreds of billions of dollars, on climate
— yet these efforts had little impact, on tipping points.

Ok, so how might we spend money differently?

Well, with reflecting sunlight,
we can put lots of money in the hands of top climate people.

And with decarbonization,
we can focus on large R&D initiatives,
that involve known technologies,
and favorable cost models.

We'll discuss this further, in later videos.

Okay, that's it for me, and I'll talk to you all, real soon.

Video #4: What is Our Climate Plan?

Hi, my name is Glenn Weinreb, and today we're going to examine the following question:

Lab Question

{SLOW} What is our society's plan, to prevent runaway climate change?

{SLOW} Or, more specifically,
what is our plan to prevent the activation of climate tipping points?

{SLOW} After the first falls over, others are likely to follow, like dominos.

{SLOW} So we want to know what it takes to prevent the first, from tipping over.

{SLOW} We'll look at this.

But first, let's review {SLOW} past decarbonization efforts.

U.S. Electrical Power Decarbonization

Over the last decade,
the United States reduced carbon dioxide emissions
by building wind farms, solar farms, hydro-electric dams, and nuclear power plants.

{SLOW} But what impact did this have?

Let's look at some data.

Between 2016 and 2019, conservatives were in control of the U.S. government,
and carbon dioxide, from U.S. electrical power, decreased 11%.

And, several years later, liberals were in control,
and decarbonization was similar.

But liberals spent additional hundreds of billions of dollars on climate.

So why do we see a similar outcome?

To answer this question, {SLOW} we need to look at what drives decarbonization.

In the United States, electrical power decarbonization is primarily driven by three things.

{SLOW} One, state decarbonization requirements.
{SLOW} Two, federal subsidies on building solar farms, and wind farms.
{SLOW} And three, natural gas, costs less, than coal.

These 3 things changed little over the last 8 years,
and this is why decarbonization was somewhat consistent.

Okay, what
about the hundreds of billions of dollars spent on climate?

What did that do?

Well, apparently, not much.

As noted in previous videos, the impact of policy is rarely quantified, by anybody,
and this typically leads to wasted time, and wasted money.

Increase U.S. Solar Construction 5-Fold?

Okay, let's forget the past, and focus on the future.

Let's say someone is nervous about climate, and they want to increase {SLOW}
the annual construction,
{SLOW} of solar farms, {SLOW} in the U.S., {SLOW} by a factor of 5.

And let's assume we do this with
{SLOW} a federal law, that requires power companies, to buy more solar power,
{SLOW} and pass additional costs,
or savings, onto customers.

Okay, so how much would a 5-fold increase {SLOW} in U.S. solar construction, {SLOW} help the planet?

When building solar farms,
one eventually gets to the point,
{SLOW} where they produce enough electricity,
to satisfy {SLOW} **all customers**,
when sunny.

{SLOW} If one builds further,
electricity is simply discarded because supply is exceeding demand.

This is referred to as "solar saturation," and at this point, solar construction stops.

In other words,
there is a limit, to how much carbon dioxide you can reduce, by building solar farms.

The same applies, to wind farms.

Okay, so back to our original question.

What would happen, if the United States increased solar farm construction 5-fold?

The answer is, the U.S. would get to solar saturation **5-times sooner**.

Solar Saturation in the U.S.

Okay, so what impact would U.S. solar saturation
have on global carbon dioxide emissions?

Well, let's quantify.

The sun burns bright about 6 hours, out of every 24,
which means we can get roughly 25% of our electricity from solar power.

And, roughly one-third of carbon dioxide emissions are from electrical power.

And, roughly one-sixth of global carbon dioxide emissions, are from the United States.

Therefore, building U.S. solar farms, until saturation,
would **decrease** global carbon dioxide emissions,
by approximately 1.5%.

$1.5\% = {}^{1}/_{4} \times {}^{1}/_{3} \times {}^{1}/_{6}$

Okay, so what impact would this have on the planet?

Unfortunately, it would be **negligible**, since 1.5% is a small number.

But how do we quantify the impact this has on global warming?

The best method, is the MIT climate solutions simulator.

Within this software, one can add an $8 per ton tax on carbon dioxide, to decrease emissions by roughly 1.5%.

And, according to the simulator, this would lower the average global temperature, at the end of the century, by zero POINT zero-three (0.03) degrees Celsius.

And, we still get, runaway climate change.

Increasing solar construction 5-fold might **seem** terrific.

However it would do little to help the problem.

It's worth noting,
nations that spend heavily on climate,
typically have little impact on tipping points.

Furthermore, energy policies promoted by conservatives, **<u>and</u>**
energy policies promoted by liberals,
are both **too small** to
influence tipping points, in either direction.

Put differently, {SLOW} planet Earth is **big**, and
{SLOW} government policy, relatively speaking, is typically small.

What is Our Plan?

Okay, so let's go back to our original question.

{SLOW} What is a plan that prevents runaway climate change?

Surprisingly, this has never been presented.

Yet, theoretically, any university, government or foundation could create a plan.

So why don't we see these?

One problem is the disconnect between national behavior, and global outcome.

For example, the U.S. could decarbonize to zero carbon dioxide emissions, over 30 years,
while the rest of the world continues with business as usual;
and the U.S. effort would have a negligible impact on the planet.

So if you want a U.S. plan that prevents runaway climate change, it's not clear what that is.

And, according to the math, we need to do more than
just reduce {SLOW} global carbon dioxide emissions.

Plan Creation Website

Okay, so how do we resolve this conundrum?

The best we can do,
{SLOW} is build a **website,**
{SLOW} that creates a national climate plan,
{SLOW} based on requirements,
{SLOW} specified by the website user.

This would allow policymakers, researchers, and concerned citizens, to get a better sense of how this works.

For details, click on the link, in the description below {website reference}.

Sunlight Reflectivity Plan

Okay, so how might this website deal with reflecting sunlight?

In theory, {SLOW} the user could select a climate model,
{SLOW} and specify how many more years,
{SLOW} they expect the world,
{SLOW} to continue, emitting carbon dioxide.

The climate model, would then estimate, changes to the planet, over the coming decades,
and determine whether or not tipping points are expected to activate.

If activation **is predicted**, the climate model could estimate
{SLOW} how much sunlight,
would need to be reflected,
back into outer space,
to block the first tipping point.

A typical number might be 1%, of sunlight.

This website could also compare, reflecting sunlight, with **not reflecting sunlight.**

Decarbonization Plan

A comprehensive climate plan would include both a reflectivity plan, and a decarbonization plan.

The decarbonize plan would also be based on {SLOW} requirements specified by the website user.

For example, a user might want {SLOW} to decarbonize a nation over 30 years, in lowest cost order, without taxes, {SLOW} without subsidies, {SLOW} and with additional costs, {SLOW} passed onto consumers.

Each decarbonization {SLOW} **initiative** can be summarized with {SLOW} three key parameters. These are the cost to society, the amount of carbon dioxide reduced, and cost per ton.

In theory, energy economists can estimate these parameters for each proposed decarbonization initiative, and this can help determine, {SLOW} how to decarbonize, at the lowest cost.

Will discuss this more, in later videos.

National Climate Plan

Ultimately, a national climate plan would have 3 components.

The first would refer to actions taken by the nation,
{SLOW} the second would refer to actions assumed, to be done, by other nations,
{SLOW} and the third would estimate changes to the planet.

{SLOW} And yes, there is a disconnect between what a nation does, and global outcome.

For this reason, some nations
might put on a show of concern,
while minimizing climate costs,
and encourages others to act.

You might not like this, but this is how the **world works**.

So what can be done? {SLOW}

Well, if the green option costs less, consumers will buy it, to save money.

And well managed R&D can, in theory, reduce the cost of green products.

In other words, consider moving brute-force decarbonization money, to R&D.

Policy Making Tools

{SLOW} ~~In conclusion,~~ the climate problem is **large**,
{SLOW} and so far, our society's response, has been **small**.

In summary, {SLOW} national leaders need policy-making tools, {SLOW} that can help them understand options, costs, and global impact.

Lab Goal - Statement

{SLOW} For this reason, it is our intent to develop a website,
{SLOW} that creates national climate plans,
{SLOW} based on requirements, specified by the website user.

We'll talk more about this in future videos.

Okay, that's it for me, and I'll talk to you all, real soon.

Lab Goal - SLIDE

Develop a website that creates national climate plans based on requirements specified by the website user.

Video #5: What does a Climate Plan Look Like?

Hi, my name is Glenn Weinreb, and today we're going to explore what a national climate plan might actually look like.

A *plan* is essentially a list of actions designed to achieve a specific **goal**.

In the case of climate, a reasonable **goal**, is to prevent runaway climate change.

Reaching this **goal** requires two major efforts. One is decarbonization, and the other is reflecting sunlight back into outer space.

Each of these efforts primarily involves two areas. One is **R&D**, and the other is **Operations**.

So, when talking about costs, we're looking at four categories.

Climate Plan Budget

These categories can be laid out in a four-row budget table, an example of which is displayed here.

		Year 1	Year 2	Year 3	...	Year 10	...	Year 20	...	Year 30
Decarbonization	R&D	$8	$8	$8	...	$8	...	$8	...	$8
	Operations	$10	$20	$32	...	$142	...	$445	...	$727
Reflecting Sunlight	R&D	$5	$5	$5	...	$5	...	$5	...	$5
	Operations				...	$27	...	$27	...	$27
TOTAL		$22	$33	$45	...	$182	...	$485	...	$767

In this table, years are shown in columns.

And values, are in units, of dollars cost, per American, per year.

As one can see, the first two rows cover decarbonization, while the last two rows, focus on reflecting sunlight.

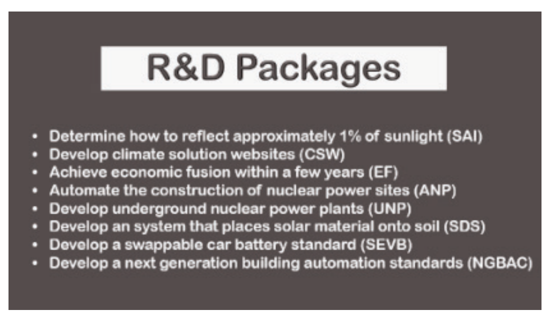
In this example, the **left side** shows the early years, while the **right side** shows the later years.

If decarbonization is done in the lowest-cost order, the early years would be relatively easy.

And, with additional R&D, in theory, the later years, could be easy too.

Additional R&D

Additional R&D can be broken down into multiple categories, where each is referred to as an "R&D Package".



For example, one R&D package might focus on nuclear fission, while another focuses on geothermal.

Each R&D package can further be divided into focus areas, where each area, is supported by an R&D fund.

Shown here is an example list of R&D packages.

And, shown here, is an example list of R&D **Funds**, inside of, one R&D **Package**.

Within a climate plan, an R&D Budget Table can show the cost of each R&D Package, over time.

And a budget table for each R&D Package, can show the cost of each R&D Fund, over time.

Our lab business plan suggests eight R&D packages, with roughly seven R&D funds in each {BP}.

This document is open-source, which means anyone can edit for free,
and define their own packages, and funds.

Also, a funding source can focus on any of these, at any level,
and have any organization, within reason, manage the development.

R&D that solves the entire climate problem would be too much for one organization to handle.

Lab Goal - Statement

Therefore, we need to develop a system, that coordinates
multiple universities, foundations and governments to do R&D,
to the extent required,
to prevent runaway climate change.

Lab Goal - SLIDE

Develop a system that coordinates multiple universities, foundations and governments to do R&D, to the extent required, to prevent runaway climate change.

We'll discuss this more in later videos.

Decarbonization Operations

In some cases, the green option costs less than the carbon-based option; while in other cases, the green option, costs more.

When the green option costs less, decarbonization is easy, and it moves forward in a natural manner.

However, when the green option costs more, government intervention is often needed.

R&D Package: Automate the construction of nuclear power sites (ANP)

- R&D Fund: Nuclear Power Automated Construction R&D
- R&D Fund: Automated Thermal Storage Construction R&D
- R&D Fund: Chemical Processing Platform Design
- R&D Fund: Chemical Processing Platform Factory Design
- R&D Fund: Chemical Processing Site Design
- R&D Fund: Chemical Processing Platform Standards Development
- R&D Fund: Chemical Processing Platform Transportation R&D
- R&D Fund: Double-Rail Transportation R&D
- R&D Fund: Double-Rail Concrete Processing R&D

This includes subsidies, taxes, and/or requirements.

Unfortunately, we rarely see this at large scales due to multiple factors, as discussed in previous videos.

From a plan's perspective, Decarbonization Operations can be broken down into multiple areas. These include electrical power, transportation, and industrial processing. And these can be broken down further into multiple categories, where costs are estimated for each.

Also, each of these category can be broken down into cases where the green option costs less,
and where it cost more, and government intervention, is needed.

Reflecting Sunlight

A plan that prevents runaway climate change would need to support R&D
that determines how to reflect sunlight at reasonable cost, and without harm.

This would cost little, relative to other climate costs.

Sunlight involves the entire planet, not just one nation.

Therefore, a national climate plan, would need to specify what share of global total,
is covered by that nation.

For example, if total operations is 30 billion dollars per year,
and the U.S. paid half, then the U.S. would pay 15 billion annually.

And this would show up in the Reflecting Sunlight Operations row, of the Summary Budget Table.

Problem Size

To understand the challenge we face, it helps to look at the size of the problem.

We already know how much energy the world consumes each year.

And we also know how much energy a single large facility — like Hoover Dam — can produce annually.

To get a sense of problem size, we can divide these two numbers to calculate how many Hoover Dam equivalents, would be needed, to replace global energy.

The math works out to roughly 17,000 Hoover Dams equivalents.

That's how much construction, would be needed, worldwide, spread over several decades.

Currently, green energy construction activity does not come close to this.

So the question is: How do we handle, a problem, of this size?

It is possible, perhaps probable, the only solution is additional R&D,
to the extent required,
to drive down the cost of 24/7 green energy,
to below that of fossil fuel.

Yet if this cost-reduction did occur, what might happen next?

To get a better sense of this, let's look at an example case.

China's 2024 Solar Construction Spree

In 2024, China faced a coal shortage that drove up the price of coal-based electricity.

At one point, it costs roughly twice as much, as electricity, from solar farms.

To reduce coal demand, lower coal prices, and save money, the Chinese built an astonishing 280 gigawatts of solar power, in one year.

For perspective, 1 watt of nuclear power produces the same amount of electricity as 4 watts of solar power.

This is because solar is good for roughly 6 hours a day, while nuclear supports 24.

Therefore, electricity production, from 280 gigawatts of solar, is similar to that of 70 gigawatts of nuclear.

Now, compare that to the United States, which built only 3 gigawatts of nuclear power, over the last 30 years.

In other words, China built 25-times more nuclear power equivalents **in one year**,
than what the U.S. did, over 30 years.

China's solar construction spree shows us that **speed and scale are possible**
— even likely
— when green energy costs less than carbon-based energy.

And a surge of R&D, in key areas, could theoretically make this happen.

Key areas includes nuclear fission, nuclear fusion, geothermal, and solar.

Political Strategy

One might be discouraged by the
fact that many lawmakers are not willing
to spend much **money** on climate.

However, one can argue, this is **not a problem**.

This is because many of the things we typically do for climate are either too small to matter.

Or, they are not cost-effective, and therefore not helpful, or not scalable.

Instead, we need to put relatively little money, in key areas.

In other words, -do more, for less.

And a plan generation website, that estimates outcome,
given plan,
would help identify these areas,
and help {slow} **waste less money**.

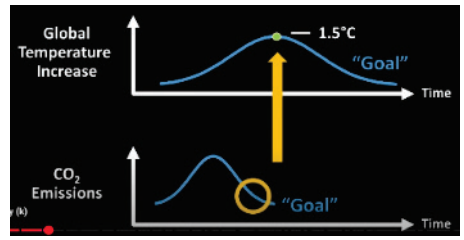
Okay, that's it for me, and I'll talk to you all, real soon.

Video #6: The Climate Acceleration Problem

Hi, my name is Glenn Weinreb, and today we're going to look at why,
the climate problem,
seems to be **accelerating**.

But before we begin, let's do a quick review of past decarbonization efforts.

The Failure of Decarbonization



A few decades ago,
scientists warned
the world must avoid warming
more than 1.5 degrees Celsius
above pre-industrial levels,
or "bad things" will happen.

They implied we are to crest at 1.5 degrees,
and then drop back down.

Instead, we breached 1.5 in 2023, and we are not cresting.

Instead, we are warming rapidly.

To actually bring temperatures down, carbon dioxide **emissions** would need to be
near zero, at the time of cresting.

Instead, **emissions** are at record highs —and still rising.

Reaching zero emissions takes decades.

Therefore, to be at zero today, the world would have had to initiate decarbonization at least 30 years ago.

In other words,
our society failed to decarbonize,
starting several decades ago.

Put in simpler terms,
to solve the climate problem with decarbonization,
we would have had have done **this**,
instead of **that**.

The Tipping Point Problem

Now that 1.5 has been breached,
we need to deal with **climate tipping points**.

These are critical thresholds in Earth's systems that,
once crossed, trigger abrupt changes.

Like a row of dominoes,
the toppling of one tipping point,
can unleash a cascade of effects, accelerating the pace of climate change,
beyond our control.

This is sometimes referred to as *runaway climate change* and it could lead to
rising seas,
less food production,
mass migration, etc.

Tipping points are triggered by higher global temperatures, as shown in this table.

Therefore, more warming, puts us at risk of tipping point activation.

The Acceleration Problem

Now that many different systems are in motion,
carbon dioxide is no longer our biggest problem.

Instead, our biggest problem is **accelerating changes**.

Acceleration is when the rate of change increases over time.

Unfortunately, we see this with ocean currents,
thawing permafrost,
sea ice,
and global warming itself.

This is **observed** with actual measurements, **so we know it's real**.

Due to acceleration,
the next 30 years will see significantly more change,
than the previous 30 years.

And a rapidly changing planet
is a bad planet, since it means we have less time to adjust.

The 0.3°C Jump

Here's an example of acceleration.

In 2022, the average global temperature,
was about 1.2 degrees Celsius above pre-industrial levels.

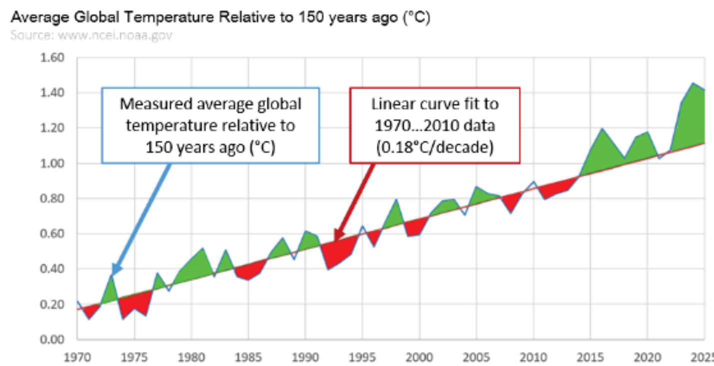
Two years later, in 2024, it hit 1.5 degrees.

So it jumped 0.3 degrees, in 2 years.

For comparison, from 1970 to 2010,
the long-term warming rate was 0.18 degrees per decade.

Therefore, a 0.3 degree increase, over several years, is unusual, **and concerning.**

Is This Noise?



Okay, is this random noise?

Or, are we **outside of noise**?

Let's look at the data.

The blue plot shown here is the average global temperature, relative to, 150 years ago.

And the red line is a linear curve fit between 1970 and 2010.

As one can see, deviations above, and below the red line are similar, during the 1970 to 2010 era.

In other words, before 2010, we see noise of similar size on top of constant rate warming.

But after 2010, **deviations** above the red line, seem larger.

This suggests global warming is accelerating, and not due to noise.

Why Accelerate?

The recent acceleration was **not** forecasted by **climate models**,
which suggests ***their*** understanding,
of the planet,
is incomplete.

This, by itself, is a profound concept.

It means scientists do not know **when** truly bad things will occur.

Which means we cannot calculate what needs to be done, and when, to avert disaster.

Not knowing what is going on is referred to as "climate **uncertainty**",
and it will be discussed further in videos 7 and 8.

Okay, back to the issue of global warming **acceleration**.

Why is this happening?

Top climate scientist, James Hansen believes thisis **in-part** due to **less** sulfur-based air pollution, and **in-part** due to an underestimate of Earth's sensitivity to carbon dioxide.

Sunlight reflects off sulfur-based air pollution, and back into outer space,
offsetting warming, with cooling.

Therefore, reducing sulfur in fuel, to reduce pollution, causes more warming.

And we know sulfur reduction occurred over the last 10 years, especially in fuel, used by ships.

So, ironically, as we've reduced sulfur-based pollution,
to clean the air we breathe,
we've also sped up, global warming.

Yea, I know it's crazy.

Prepare to Panic

Some scientists believe global warming is accelerating—
and that climate tipping points may arrive sooner than expected.

If they're right, this will probably be confirmed, by the wider scientific community,
within the next few years.

If and when that happens, urgency among world leaders will surge.

The problem is, many decarbonization efforts are either ineffective, or not cost-effective.

Therefore, expanding them, is not likely to have a significant impact.

This suggests we need to **identify** cost-effective solutions **today**,
so that when we panic **tomorrow**,
we don't run out of **money**,
before making significant **progress**.

Fortunately, preparing to panic is relatively inexpensive since it only involves
developing policy making tools,
decreasing the cost of green energy with R&D,
and determining how to reflect sunlight without harm.

We'll talk more about these items in future videos.

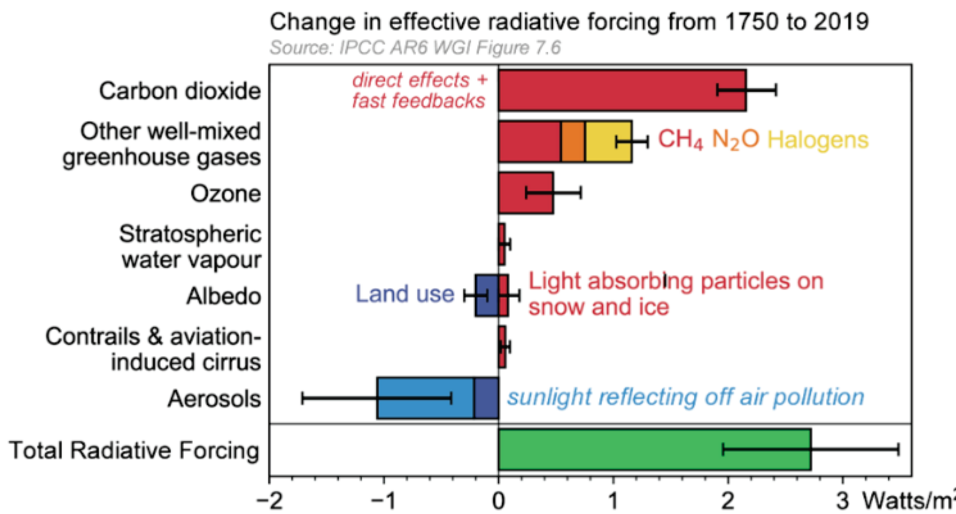
Okay, that's it for me, and I'll talk to you all, real soon.

Video #7: The Science of Global Warming

Hi, my name is Glenn Weinreb,
and today we're going to examine the science of global warming.

The main organization that studies this is called the IPCC, and they publish summary reports,
every few years.

The centerpiece of their most recent report is shown here.



It breaks global warming down into individual components called "radiative forcing's".

Some of which make the planet warmer,
while others,
make it colder.

Together, they combine, to produce a net effect, which is shown with a green bar.

In a sense, the red bars are like blankets that wrap around the planet,
where the thickness of each blanket, is proportional to the length of each bar.

This is not exactly what's happening, but close enough.

1% of Sunlight

The horizontal axis refers to the amount of **additional** heat,
that hits each square meter, of Earth's surface, on average, over a year.

{SLOW} This additional heat, warms the planet, and increases, the average global temperature.

For reference, the total incoming energy from the Sun, is about 340 watts per square meter.

Hundreds of years ago, this was **balanced** by an **equal** amount of outgoing heat radiation.

Put differently, the amount of warming, was the same, as the amount of cooling,
and the Earth's climate was stable

Today, however, an extra 2.8 watts per square meter, is warming, the planet.

That's about 1% of sunlight, since 2.8, divided by 340, is roughly 1%.

Therefore, in theory, roughly 1% of sunlight,
could be reflected back into space,
to offset the additional warming,
and {SLOW} prevent runaway climate change.

To get a sense of what 1% looks like, we placed a white bar in this image, and then made it 10% transparent, followed by 1%.

As one can see, 1% is barely visible, to the naked eye.

Fast Changes Due to CO_2

Sunlight warms the planet's **surface** after passing through carbon dioxide in atmosphere.

The planet then emits infrared heat radiation back into outer space.

Carbon dioxide in atmosphere absorbs the *outgoing* infrared radiation **more** than it absorbs the *incoming* visible light.

And this causes the planet, to become warmer.

Also, additional warming is caused by fast side-effects that unfold over days to months.

An example is water vapor in atmosphere. More heat causes more vapor, which traps more heat.

So the top bar refers to more absorption of heat due to carbon dioxide,
plus fast side-effects due to greater temperatures.

The length of this bar is determined by a formula.

Now I know many people would rather
visit the dentist than work with calculations, so we'll keep this quick.

The details of this formula are not important,
other than to say, more carbon dioxide, means more warming.

CO_2 forcing = 5.35 x ln (ppm/280) (Hansen uses 5.65, IPCC uses 5.35)

CO_2 forcing for 425 ppm = 5.35 x ln (425/280) = 2.23 W/m^2

~~Okay, we're done. {GSW Wave hands}~~

Slow Changes Due to CO_2

The previous formula refers to warming that occurs quickly, due to additional carbon dioxide.

Also, there are things that occur slowly, {SLOW} due to higher global temperatures.

These are called {SLOW} slow climate feedbacks and some of them take decades, or even centuries, to unfold.

An example is melting sea ice.

Elevated temperatures, from initial warming, cause sea ice to melt, which leads to more sunlight being absorbed by ocean water, which leads to more warming.

It can take many years for this to occur, due to the thermal inertia of ocean water.

Therefore, melting sea ice is considered to be a {SLOW} **slow feedback**.

Other slow feedbacks include the release of greenhouses gases from thawing permafrost;
and the darkening of clouds over decades.

With slow feedbacks, roughly one-third of additional warming occurs within the first five years,
another third over the next 100 years,
and the final third over the following 1,000 years.

This delayed response means the full effect of today's carbon dioxide will not be felt for many generations.

Also, this implies a significant amount of future warming is already "locked in" {SLOW} due to past emissions.

This is one reason why the MIT climate solution simulator is so gloomy.

Earth Climate Sensitivity (ECS)

Hundreds of years ago, atmospheric carbon dioxide levels were about 280 parts per million.

Today, they're around 425, and they're projected to reach 560, by the year 2075.

In other words, roughly 50 years from now, the concentration of carbon dioxide in atmosphere is expected to be twice that of pre-industrialized levels.

If we double the concentration of carbon dioxide, and hold it steady,
then after a 1000 years,
slow climate feedbacks will eventually stabilize,
and the average global temperature will settle on a new value.

The amount of eventual temperature increase, after doubling carbon dioxide,
is referred to as the Earth climate sensitivity constant, or "ECS."

Some scientists believe ECS is 3 degrees Celsius,
whereas others think it is closer to 5.

A higher value would be bad, since it would mean tipping points {SLOW} will activate sooner.

Outgoing Heat Radiation

There's an additional component that we need to discuss.

It's outgoing heat radiation,
that cools the planet,
and offsets the Radiative Forcing's.

We asked AI to illustrate this, and here's what it came up with.

Okay, not bad for a computer.

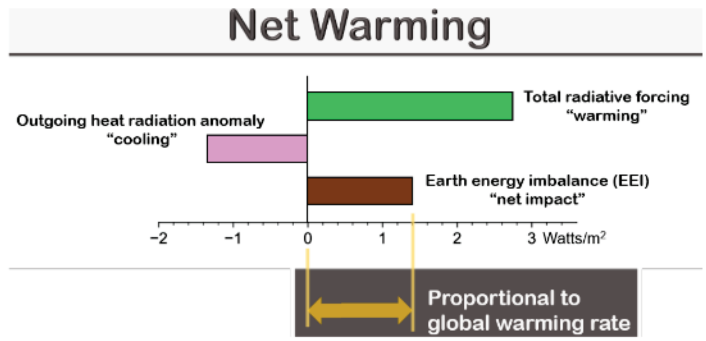
Outgoing heat radiation is roughly proportional to the average temperature of the planet,
and inversely proportional to the Earth climate sensitivity constant.

Outgoing Heat Radiation Anomaly (W/m^2)
= Current Temperature x 3.71 / ECS

Outgoing Heat Radiation Anomaly (W/m^2) for 1.5°C temperature and 4.5°C ECS
= 1.23 W/m^2 = 1.5°C x 3.71 / 4.5°C

Global Warming Rate (°C/decade)

Earth's temperature is mostly controlled by two energy flows:
One that warms the planet,
and one that cools it.



These offset each other to produce net warming, or net cooling.

This net effect is referred to as the earth energy **im**balance,
and it's roughly proportional
to the global warming rate.

The global warming rate is currently at 0.30 degrees Celsius per decade.

Earth's Set Point Temperature

There's a feedback mechanism,
built into the planet,
that causes it to eventually settle on an "equilibrium temperature",
which is sometimes referred to as the set point temperature.

The set point is determined by the concentration of carbon dioxide in atmosphere,
as shown by this formula.

In summary,
the set point **increases,**
when the concentration of carbon dioxide **increases**.

Set point temperature anomaly (°C) = ECS x $\log_2$ (ppm/280)

If we subtract the current temperature from the set point,
we get warming, that has not yet been, realized.

Not yet realized temp increase (°C) = Set point temperature (°C) – Current average global temperature (°C)

As noted previously, it takes about a 1000 years, for warming to stabilize,
after adding carbon dioxide.

Therefore, we can calculate how much additional warming would occur,
if we pegged the concentration of carbon dioxide at its current level.

According to one estimate,
the amount of unrealized warming is currently 1.2 degrees Celsius.

Thermostat 101

To understand Earth's climate, it helps to think about the household thermostat.

This device works with two key variables.

One is temperature, and the other is energy flow.

Temperature is often represented in units of degrees Celsius,
while energy flow is often represented in units of Watts.

The energy flows can be broken into two primary components.

One is external and somewhat constant,
while the other is variable and maintains the temperature of a system.

In a house,
the external energy flow comes from the outdoors through the walls,
while the variable energy flow comes from the heating and air conditioning system.

After these two combine, a net energy flows into, or out of, the system.

If energy flows in, the system gets warmer; and if energy flows out, the system gets colder.

If the energy that flows in, matches the energy that flow out, then the net energy flow is zero, and the temperature remains constant.

It follows that the net energy is roughly proportional to the warming rate,
which is the change in temperature over a period of time.

In the case of the planet,
the net energy is like the earth energy **im**balance,
the outdoor energy is like the radiative forcing's,
and the HVAC system is like the Earth's outgoing heat radiation.

Earth's Thermostat

If we take the earth energy **im**balance equation, and substitute in other formulas, we get an equation that describes Earth's thermostat.

Earth energy imbalance "warming" (W/m^2)
= Total radiative forcing (W/m^2)
– Outgoing heat radiation anomaly (W/m^2)

Earth energy imbalance "warming" (W/m^2)
= 5.35 x ln (ppm / 280)
– CurrentTemp x 3.71/ECS_{22}

The details are not important, other than to say, if the current global temperature is less than the set point, energy flows in, and warms the planet.

To get a better sense of this, we can look at an example scenario that begins 150 years ago,
before global warming.

At this time, the earth energy **im**balance, which refers to warming,
is zero, and the first term equals the second term.

Now let's assume the concentration of carbon dioxide in atmosphere increases by 10 parts per million.

The temperature has not yet changed,
but we now have some energy **im**balance,
which means energy flows in,
and causes the temperature to increase.

Warming occurs until the set point is reached,
at which time,
the first term would equal the second term,
and warming would stop.

This equation is another way of saying the concentration of carbon dioxide,
in atmosphere, sets the average global temperature,
in a manner similar to that done with a home thermostat.

The impact of this tiny molecule, on our planet,-might seem crazy, but this is how it works.

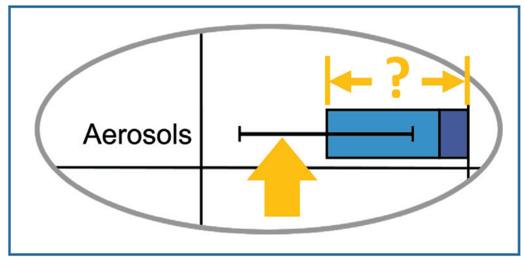
Okay, that's it for me, and I'll talk to you all, real soon.

Video #8: The Uncertainty of Climate Change [#8]

Hi, my name is Glenn Weinreb,
and today we're going to look at things that climate scientists are not sure about, by their own admission.

This is referred to as uncertainty, and it's bad.

It's bad because we would like to know when disaster will occur,
so we can assemble a list of things we need to do,
between now and then,
to prevent it.



This video is a continuation of our previous video,
and therefore assumes,
the viewer is familiar with,
basic principles of climate science.

Air Pollution Uncertainty

We begin by focusing on sunlight that reflects off air pollution,
and back into outer space.

As noted previously, this offsets global warming, with cooling.

This is illustrated here,
with the length of the blue bar being proportional to the magnitude of air pollution cooling.

Notice the error bar on the blue bar.

This means scientists do not know if the value of this parameter is small, or large.

Its value is **unknown** because it has never been measured.

Only estimated.

In science, this is called a *"free variable."*

This uncertainty might seem like a minor detail; however, it is of profound importance.

It means scientists cannot calculate, with certainty, when very bad things will happen.

And this makes it difficult for national leaders to give climate more priority.

Now let's look at the size of this error bar.

As noted in our previous video, the red bar indicates the amount of warming due to 150 years' worth of carbon dioxide emissions. This is not one years' worth of carbon dioxide. This is roughly proportional to the accumulated carbon dioxide in atmosphere, since the year 1875.

Now, let's compare this to the size of the cooling error bar.

The magnitude of air pollution cooling uncertainty is about the same as what we get from 100 years worth of carbon dioxide emissions. .

In other words, the degree to which scientists do not understand global warming,
based on their own admission, is enormous.

Earth Climate Sensitivity (ECS) Uncertainty

As noted in our last video, the amount of eventual temperature increase, after doubling carbon dioxide, is referred to as the Earth climate sensitivity **constant**, or "ECS."

ECS is essentially a way to quantify the size of **slow** climate feedbacks, such as melting ice sheets and long-term cloud changes.

Some scientists estimate ECS at around 3 degrees Celsius, while others think it could be closer to 5 degrees.

A higher ECS means the planet is more sensitive to carbon dioxide —and that climate tipping points will activate sooner.

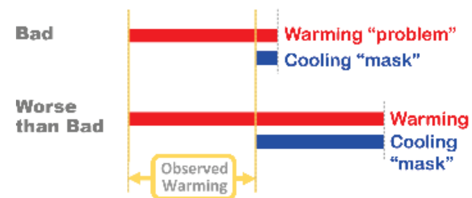
Put simply: some scientists think the climate problem is *bad*, whereas others believe it's *worse than bad*.

The Climate Mask

So, why do scientists disagree about ECS?

What is the source of their uncertainty?

Much of the confusion comes from not knowing the size of the blue cooing bar.



If we knew exactly how much cooling is caused by air pollution reflecting off sunlight, we'd have a clearer picture of how much warming is being **hidden** with cooling— and therefore a better understanding of the overall climate problem.

Think of the cooling as a mask of unknown size, that partly hides the true extent of global warming.

If the mask is small, the problem is only slightly larger than what we see.

Alternatively, if the mask is large, the problem is much larger than what we see.

Two Climate Scenarios

	"Worse than Bad"	"Bad"
Air pollution cooling	More	Less
Tipping point activation	Sooner	Later
0.3°C global temperature jump	Explained	Not understood
Earth Climate Sensitivity (ECS)	~5°C	~3°C

There is evidence, the climate problem, is worse, than previously considered.

The Air Pollution Climate Problem

As we just discussed, the climate mask refers to cooling
caused by sunlight reflecting off air pollution, and back into outer space.

Unfortunately, this presents us with an additional problem.

If we stop emitting carbon dioxide,
the air pollution would go away, along with its cooling effect.

In other words, the green bar would lengthen by the size of the blue bar,
which the IPCC currently estimates at 1 watt per square meter.

Subsequently, the total radiative forcing would increase by 1 watt per square meter,
and the earth energy imbalance would increase roughly 50%.

This imbalance is roughly proportional to the global warming rate,
therefore the warming rate would increase from 0.3 to .45 degrees per decade

Carbon dioxide in atmosphere lingers for hundreds of years.

Therefore, if we stopped emissions 100% tomorrow, the cooling from pollution would vanish quickly,
yet the top red bar would shrink very slowly.

Therefore,
the warming rate would surge,
and the planet's temperature would continue to increase for many decades.

Long story short, reducing carbon dioxide is complicated.

Is Direct Air Capture Economically Feasible?

What about removing carbon dioxide from atmosphere, to reduce the size of the top red bar?

Would that help?

Let's examine this mathematically.

It cost roughly 1000 dollars to extract 1 ton of carbon dioxide from atmosphere,
and we have thousands of gigatons of additional carbon dioxide in atmosphere.

Subsequently, for a trillion dollars,
we could reduce the length of the top red bar by 0.1%,
or one part per 1000.

Obviously, this is prohibitively expensive.

Therefore, national leaders would be more include to reflect sunlight back into atmosphere,
at an annual cost in the tens of billions of dollars range.

The Measurement of the Century

Okay, let's summarize.

The warming rate has increased from 0.18 to 0.3 degrees per decade.

It seems the earth is more sensitive to carbon dioxide than previously considered.

And we are at risk of North Pole sea ice collapse,
which will cause the average global temperature to increase by 0.6 degree Celsius.

Okay, so what is an intermediate step that would help us deal with this?

Well, for less than several million dollars,
we could design experiments that measure how much sunlight reflects off air pollution.

This would enable use to put together a list of gadgets that are needed to conduct those experiments.

These might cost ten's of millions of dollars and several years to develop.

After that, we could conduct experiments.

This would help us understand what will happen and when, with more certainty.

And this would help national leaders set priorities involving climate.

For this reason, one might consider this to be **the measurement of the century.**

Lab Goal - Statement

In summary, we need to design experiments that measure how much sunlight reflects off air pollution,
and develop gadgets that support those experiments.

For details, click on the link, in the description below {Example Aerosol Experiment}.

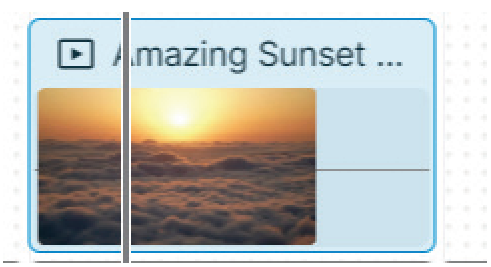
Okay, that's it for me, and I'll talk to you all, real soon.

Lab Goal - SLIDE

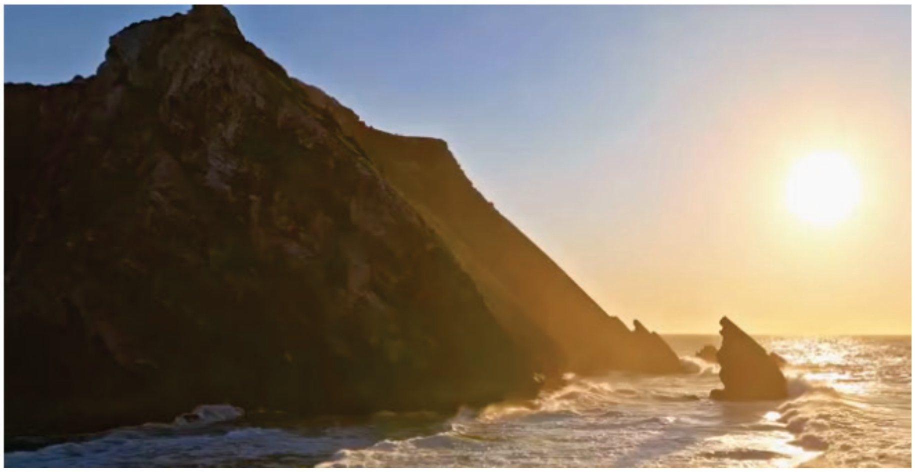
Design experiments that measure how much sunlight reflects off air pollution, and develop supporting gadgets.

Suggested Video

Amazing Sunset Over the Clouds



Aerial view of the cliffs of the famous Cabo da Roca are washed by the huge waves



Nature Park Tre Cime: Stunning Italian Alps. Aerial FPV drone flights at sunset

Nature Park Tre Cime: Stunning Italian Alps. Aerial FPV drone flights at sunset.

Industrial plant engineers discussing ways to refine designs for increased energy output

Industrial plant engineers discussing ways to refine designs for increased energy output. Factory employees i

Video #9: Is Decarbonization Helpful?

Hi, my name is Glenn Weinreb, and today we're going to look at the connection between decarbonization, and global outcome, or lack thereof.

This topic is rarely discussed, even though it is of profound importance.

The MIT Climate Solutions Simulator

One of the best tools available for understanding how climate policy affects global outcomes is the MIT Climate Solutions Simulator.

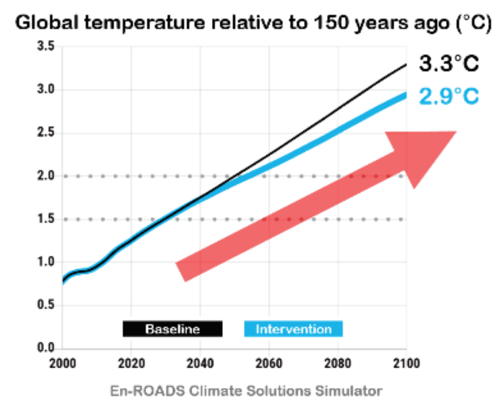
It's a free web-based tool called En-ROADS, and anyone can access it online.

Okay, let's run a scenario.

Let's see what would happen if a global tax caused the cost of fossil fuel to **double**.

How might this effect the planet?

According to the software, this would reduce the average global temperature, at the end of this century, from 3.3 degrees Celsius, to 2.9 degrees, and we would still get runaway climate change.



These numbers refer to the increase in temperature from pre-industrial times, 150 years ago.

Okay, let's try something else.

Let's add a $200 per ton global tax on carbon dioxide, to roughly quadruple the cost of fossil fuel.

Perhaps this would avert runaway climate change?

Nope.

This does decrease additional carbon dioxide from 200 ppm to 50 ppm, which is helpful.

But warming already in the pipeline, due to past emissions, remains a problem.

And other greenhouse gases, such as methane, continue to add to the challenge.

Okay, perhaps the software is buggy? Let's do a quick check to make sure it's ok.

The simulator shows that a 2.5-degree rise by the end of the century is about 30% less than without the intervention. And if we plot cumulative carbon dioxide emissions over time, we see a similar reduction.

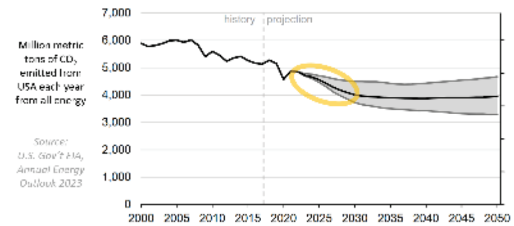
So, the simulator appears to be working correctly.

Within the En-ROADS software, we are working with a default earth climate sensitivity of 3. But there's evidence it's closer to 4.5. If that's true, the average global temperature at the end of the century could be roughly 1 degree higher than what we see in these graphs.

Yikes.

United States Decarbonization Now, let’s focus on the United States, and see how its decarbonization efforts affect global outcomes.

The United States emits roughly 5 billion tons of carbon dioxide each year, and U.S. government economists expect this to fall by approximately 1 billion tons over the next decade. Most of this reduction would come from building more solar farms, building more wind farms, and from natural gas replacing coal.



So, what impact would a 1-billion-ton annual reduction actually have on the planet?

Using the MIT simulator, we find that a 75-billion-ton reduction in global emissions over 75 years would lower the average global temperature at the end of the century by just 0.04 degrees Celsius.

This is a 1% temperature decrease, and we can do a quick check to see this is similar
to the decrease in total cumulative carbon dioxide emissions.

In other words, the United States’ current decarbonization efforts, while well-intentioned, will do little to stop runaway climate change.

10-Point Climate Summary

We’ve been bombarded with messaging that says
we just need to build a solar farm.

However, the situation is more complicated than a solar farm.

Part of the problem is journalists report on existing climate initiatives,
yet **rarely quantify impact.**

For example, they might cover a new wind farm, but leave out the fact that even if we built wind farms to global saturation, it would do little to stop runaway climate change.

Unfortunately, a lack of comprehensive reporting, has led to a distorted view of the problem, and the solution.

To really understand the climate challenge, we can break it down into 10 key concepts: .

1. Tipping points are critical thresholds in Earth’s systems that, once crossed, trigger abrupt changes.
2. The first tipping point to activate will
probably be North Pole sea ice.
After it melts, the average global temperature is expected to jump about 0.6 degrees Celsius.
This is due to
sunlight being absorbed by sea water,
instead of being reflected by ice.
3. After this, more tipping points are expected to activate, like a row of dominos.

4. Tipping points are generally triggered once global temperatures rise more than 1.5°C above pre-industrial levels — and we are currently at that 1.5 level.
5. We define runaway climate change as the activation of these tipping points. Once they kick in, they will be difficult to stop.
6. One can use a simulator to see existing climate initiatives have close to no impact on the problem.
7. A plan to solve the problem has never been produced, even though it is easy to **calculate** how to prevent runaway climate change, at the lowest cost to society.
8. It cost less to resolve climate change with R&D, than with brute-force decarbonization.
9. In theory, airplanes can spray reflective gases into the upper atmosphere, to reflect about 1% of sunlight back into outer space, to prevent runaway climate change.
   However, the public is weary of such measures.
10. And lastly, people are upset, and
    this is likely to intensify in the coming decades.

Okay, so what should we do?

It turns out, much can be done.

We'll discuss this further in future videos.

Okay, that's it for me, and I'll talk to you all, real soon.

Video #10: Grand Climate Bargain

Hi, my name is Glenn Weinreb, and today we're going to explore how
liberals and conservatives who are
concerned about climate might find common ground.

Before we begin, let's review the issue of costs.

Decarbonizing in Lowest-Cost Order

There are many initiatives that reduce carbon dioxide emissions.

Each has a cost to society, and an amount of carbon dioxide that is reduced. One can divide these two numbers to calculate the cost to reduce emissions by one metric ton of carbon dioxide.

One can think of this as "cost" and "decarbonization impact."

Lawmaker often ask "Why spend $200 to reduce carbon dioxide emissions by one ton, when we can do it for $20?"

This suggests they favor decarbonizing in lowest-cost order, if at all.

For example, initiatives costing $10 per ton would be addressed first,
followed by initiatives costing $12 per ton, and so forth, and so on.

A Beautiful Decarbonization

We define a "Beautiful Decarbonization" as
one where costs to society are negligible throughout the entire decarbonization period.

In other words, decarbonization occurs in lowest cost order,
and R&D is successful at keeping green energy costs, below fossil fuel costs, as one goes through time.

In theory, a new R&D laboratory could be tasked with performing a beautiful decarbonization.

For details on what this might look like, click on the link, in the description below {BP}.

Decarbonization Plan

Lawmakers are unlikely to support major changes to their economy, without a detailed decarbonization plan. This does not exist, yet could be developed.

A detailed plan would be a list of decarbonization initiatives that are to be implemented each year, over the next few decades.

Government-employed energy economists are capable of estimating the cost and impact of decarbonization initiatives, and they are somewhat trusted by lawmakers. Therefore, they would probably be needed to help formulate a plan. However, they will only act if commissioned by lawmakers, and driven by a guiding principle.

Grand Climate Bargain

To achieve majority support, a guiding principle would need to
meet the satisfaction of both liberals and conservatives who are concerned about climate.

Surveys show 67% of Americans are concerned about climate change,
suggesting bipartisan support in the U.S. is achievable.

Based on statements made by lawmakers on both sides,
the following guiding principle might receive majority support.

Decarbonize over 30 years,
in lowest cost order,
without taxes,
without subsidies,
and with additional costs passed onto consumers.

Taxes and subsidies do not have broad political support at large scales due to several issues.

These include deficit spending,
economic efficiency,
sensitivity to fuel price,
control over the pace of decarbonization,
and fraudulent offsets.

Requirements, on the other hand, avoid these problems.

If decarbonization does not have majority support, lawmakers might consider the
following kind of guiding principle.

Do R&D to the extent required,
to drive down the cost of 24/7 green energy to below that of fossil fuel, and
to determine the lowest cost way to reflect roughly 1% of sunlight without harm.

Or lawmakers might want something more broad, such as

Do R&D to the extent required,
to prevent runaway climate change.

As noted previously, after lawmakers agree on a principle,
government economists and engineers can be tasked with
developing an implementation plan.

Conservatives are stronger politically if they have something for climate voters,
and a massive R&D effort,
coupled with a "we do more for climate, for less money" message,
might help them eek out another 1 to 2 percent of political support.

For this reason, a grand climate bargain, of some kind, might be politically feasible.

Plan Development

A national climate plan would be influenced by policy options.

In theory, government economists could be tasked with building a website that generates a climate plan,
after the website user specifies policy options.

For details on what this might look like, click on the link, in the description below .

Many conservatives are fond of green energy.

However, they typically require
a lowest-cost approach, while liberals are often less demanding.

Texas, a conservative state, produces more wind power than any other U.S. state,
suggesting conservatives are comfortable with green energy at large scales.

Many climate initiatives are not effective, or not cost-efficient.

This is because people sell climate to make money,
and the impact of their efforts are rarely quantified.

This is why government energy economists are needed to evaluate initiatives,
and help craft a climate plan.

Being Less Annoying

Economists that craft a plan could be instructed to
annoy as few people as possible.

For example, electricity **consumers** do not need to be bothered.

These include homes, commercial buildings, companies and factories.

Instead, power companies could be required to decarbonize electrical power at a specific rate,
with customers paying for what they receive.

In other words, there are only a few control points within an economy, that need attention.

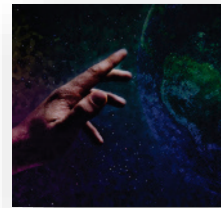
The Early Years

A reasonable strategy during the early years is to focus on lowest-cost decarbonization and more R&D.

During the first five years, many nations could reduce carbon dioxide emissions by approximately 1/30th each year by building solar farms and wind farms at a high rate. This would cost less than $20-per-ton of carbon dioxide reduced.

During this initial period, billions of dollars could be spent on R&D for commercial fusion, improved fission, and next generation geothermal. These might be needed
for times when the sun does not shine,
and when the wind does not blow.

Reflecting Sunlight



Currently, most voters do not want to touch the atmosphere.

However, this will probably change as climate observations provide evidence that touching is easier
than not touching.

Therefore, a reasonable strategy
is to conduct reflectivity R&D, while public opinion evolves.

This includes conducting experiments in the atmosphere, with airplanes.

The Tail Wagging the Dog Problem

In a sense, the climate problem involves three groups of people.
One, those who want to solve the climate problem, at the lowest cost to society.
Two, those with fossil fuel interests.
And three, those who are dependent on wasteful climate spending.

As one might imagine, decarbonizing in lowest-cost order threatens many climate jobs;
and lawmakers often favor decarbonizing in lowest-cost order.

This can lead to a "tail wagging the dog" problem,
where people dependent on wasteful spending are the tail,
and a leader who favors the lowest-cost solution
is the dog.

So how might the dog, gain control, over the tail?

Lab Suggestion - Statement

In theory, a national leader can declare they want independent government economists and engineers,
to develop a climate plan,
based on a guiding principle,
agreed to,
by lawmakers.

Our society's current approach to the climate problem is not working;
therefore, it's reasonable to consider alternatives.

An example would be to trust government economists and engineers to help craft a plan.

Okay, that's it for me, and I'll talk to you all, real soon.

Lab Suggestion - SLIDE

Task independent government economists and engineers with developing a climate plan based on a guiding principle agreed to by lawmakers.

Video #11: National Energy Strategy

Hi, my name is Glenn Weinreb, and today we're going to look at how one might formulate a national energy strategy that addresses climate change, **and** garners broad political support.

Much of this was covered previously. Yet it was long ago. So some redundancy is ok. I should consider deleting this video.

The Prisoner's Dilemma Problem

Climate harm comes from the combined carbon dioxide emissions of our planet's eight billion people. One person's own emissions are too small to matter; therefore, no one benefits from reducing their own emissions. Instead, everyone hopes the other eight billion people will cut theirs. Economists call this a "prisoner's dilemma."

And according to economic theory, our fundamental strategy of using social pressure to solve the climate problem, will not work.

The Saturation Problem

In many regions today, the cost of electricity from a solar farm or wind farm is less than the fossil fuel it replaces. In other words, green costs less than carbon. However, if one continues to build solar and wind farms, they eventually reach "saturation," which entails green supply exceeding electricity demand. At this point, electricity is discarded and construction stops. To decarbonize further, we need reliable clean power sources that work when the sun doesn't shine and the wind doesn't blow—such as nuclear, geothermal, or solar and wind with large-scale battery storage. These options, however, come at a higher cost.

30-Year Decarbonization

In theory, a region could steadily reduce carbon dioxide emissions by approximately $1/30^{th}$ per year, over 30 years, in lowest-cost order. Under this approach, power companies could be required to size solar and wind farm construction to meet each year's emission-reduction target. At first, costs would be modest, since solar and wind now compete with fossil fuels. But after five to seven years, saturation would occur, and decarbonization costs would increase. Moreover, if prisoner's dilemma holds true, few would decarbonize further.

In other words, if you believe prisoner's dilemma, and you believe U.S. government estimates for future green energy costs, then roughly 20% of global carbon dioxide is likely to be decarbonized, yet not more.

The Case for More R&D

If this is the case, a *surge* in R&D would be needed to reduce the cost of persistent green energy beyond current projections. This would help prepare for the day when solar and wind power saturate. The cost of this additional R&D would be small compared to the 4 trillion dollars spent globally each year on fossil fuel, and compared to the cost of climate harm.

National Energy Strategy

Nations are concerned about energy security, energy economics, and climate change.

Energy security involves reducing dependence on other nations who might withhold energy to gain influence.

Energy economics involves reducing energy costs to strengthen competitiveness.

And climate involves reducing carbon dioxide emissions.

Doing More for Less

Out of these three, climate typically receives the lowest priority, in part because regions do not benefit by decarbonizing, as noted previously.

Still, public concern about climate change is high. This means political support is often strong for solutions that deliver meaningful results at a reasonable cost.

The good news is that much can be achieved without significant spending.

Lab Suggestion - Statement

This includes
building solar farms at a faster rate,
expanding wind power at a faster pace,
spending more money on targeted R&D,
and developing policy making tools.

Also, money can be saved by downsizing ineffective climate programs.

In other words, it is possible to do more for climate, for less money.

Okay, that's it for me, and I'll talk to you all, real soon.

Lab Suggestion - SLIDE

- Build solar farms at faster rate
- Expand wind power at faster pace
- Spend more money on targeted R&D
- Develop policy making tools
- Downsize ineffective climate initiatives

Video #12: Electrical Power Decarbonization

Hi, my name is Glenn Weinreb, and today we're going to look at how one might decarbonize electrical power, the easiest, laziest, and simplest way possible.

Electrical Power Fundamentals

Before we dive in, let’s take a moment to review the basics of electrical power.

And to make this easy to follow, we will focus on one house in the United States.

On most home electric bills, electricity use is measured in kilowatt-hours.

For example, when a guy vacuums for his wife, for an hour, he's consuming approximately one kilowatt-hour of electricity.

The typical U.S. home consumes 10,000 kilowatt-hours each year, at 14 cents per kilowatt-hour, for a total cost of 1,400 dollars per year.

This is retail cost and it covers electricity generation and distribution.

Generation refers to making electricity at the power plant, while distribution refers to the network of power wires between generation plants and consumers.

Typically, 7 cents per kilowatt-hour goes to generation, and 7 cents to distribution.

Residential Decarbonization Costs

Green electricity, which is produced without emitting carbon dioxide, sometimes cost 2 pennies more per kilowatt-hour than electricity from fossil fuels. This is without subsidies, and without taxes.

Currently, roughly 40% of U.S. electricity is green. This means we still need to decarbonize the remaining 60%.

If we spread this transition evenly over 12 years, that’s about 5% per year.

According to the math, 5% of 10,000 at an additional 2 penny is $10 per year.

Therefore, the additional cost per household would be $10 in the first year, $20 in the second year, $30 in the third year, and so on.

So, while the costs grow gradually, they start out surprisingly low — just $10 per year in the beginning.

Residential Solar Power

Electricity from solar panels installed on a **house** typically costs about three times more than electricity from a **solar farm**.

Why the difference?

It comes down to overhead.

At the household level,
each installation involves marketing costs,
mechanical and electrical design,
city permits,
installation, and final inspection.

Alternatively, at a solar farm,
you don't incur these costs every 15 solar panels.

In other words,
it cost much less to decarbonize by building solar farms,
than to place solar panels on unique structures.

Perhaps a more interesting question is why is this rarely discussed?

Examining this question goes beyond the scope of this video.

But in summary, the cost and impact of climate initiatives is rarely quantified,
and this leads to wasted time, and wasted money.

Companies

Okay, let's forget homes and look at companies.

We often encourage them to reduce their carbon dioxide emissions.

But in practice, they face two choices.

They can either decarbonize for real, at high cost.
Or they can appear to decarbonize, at less cost.

For publicly traded companies,
spending more on climate action usually means lower profit, which can push stock prices down.

However, CEO's are expected to do the opposite.

They are expected to increase profit, and increase stock price.

So many respond with token climate efforts designed to look good,
while keeping costs low.

One common approach is buying carbon offsets. In theory, these pay for projects that reduce emissions.

But in many cases, they do not deliver as promised.

For example, if an offset
blocks tree farmers from harvesting on one parcel of land,
and trees are instead harvested elsewhere,
there’s no benefit.

Ultimately, many CEOs need to select either
more decarbonization and less profit,
****or**** less decarbonization and more profit.

Too often, they choose the latter option —
in part because their decarbonization claims are **rarely verified**.

The Power Company

It turns out, there is no reason to **bother** companies **or** homeowners.

Instead, we can let the power company handle the bulk of decarbonization, especially during the early years.

So the key question becomes, what can power companies do to fight climate change?

Well, let's take a closer look.

Solar Farms and Wind Farms

Some regions are more sunny,
while others are more windy.

As one might imagine, it cost less to generate electricity with a solar farm in a sunny region,
and it cost less to generate electricity with a wind farm in a windy region.

Yet by how much?

This table shows the wholesale cost of electricity from solar farms built in the year 2025, and projected costs for the year 2033. These costs are estimated by the U.S. government's National Renewable Energy Laboratory.

The units shown here are megawatt hours,
which are 1000-larger than kilowatt-hours.

Wind energy tells a similar story.

It's often windy at higher altitudes, so windmills are technically feasible in many areas. But because of audio noise and other concerns, they can't be placed too close to people.

That's why wind farms are typically set up in remote areas. For example, windmills for U.S. east coast cities are likely to reside 200 miles inland.

Fossil Fuel Costs

Now, let's compare this with fossil fuels.

This table shows the wholesale cost of fossil fuel, plus the variable cost of generating electricity with it.

Fuel + VC ($/MWh)	Fuel+VC (¢/kWh)	% of US Electricity	Type of Power Plant
$25	2.5¢	38%	Natural Gas Combined Cycle
$32	3.2¢	8%	Natural Gas Steam Turbine
$39	3.9¢	4%	Natural Gas Combustion Turbine
$43	4.3¢	14%	Coal

When we replace fossil-fuel based electricity with solar or wind, this is the money we save.

In other words, the cost to decarbonize,
is the cost of the green electricity,
minus a red value shown here.

30-Year Projections

So, how might these costs change over the next 30 years?

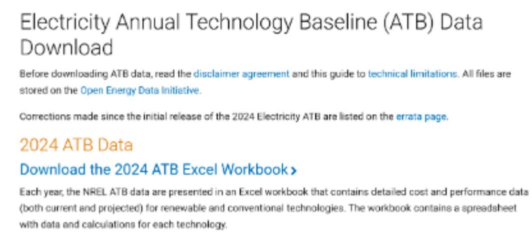
The United States government provides estimates, as shown here.

In summary, solar and wind are expected to be somewhat competitive with fossil fuel.

However, the more reliable forms of green energy — such as those available 24/7 — are projected to remain more expensive for decades to come.

Lowest-Cost Order

This data can be download from a U.S. government website for free, and one can use this to predict what would happen if power decarbonization occurred in lowest-cost order.


Electricity Annual Technology Baseline (ATB) Data Download

Before downloading ATB data, read the disclaimer agreement and this guide to technical limitations. All files are stored on the Open Energy Data Initiative.

Corrections made since the initial release of the 2024 Electricity ATB are listed on the errata page.

2024 ATB Data

Download the 2024 ATB Excel Workbook ›

Each year, the NREL ATB data are presented in an Excel workbook that contains detailed cost and performance data (both current and projected) for renewable and conventional technologies. The workbook contains a spreadsheet with data and calculations for each technology.

We did this, and one can get a free copy of our analysis by clicking on the link, in the description below.

We looked at reducing U.S. carbon dioxide emissions 1/30th per year, over 30 years, to get to zero emissions, 30 years from now. And we looked at doing this in **lowest-cost order**.

We found decarbonization costs would be close to zero for the first 5 to 7 years, and then go up.

In other words, decarbonization would be easy at first, and then less easy.

And, in theory, with **additional R&D**, we could make later years easy too.

U.S. Government CO_2 Projections

Now, let's look at carbon dioxide emissions across the entire U.S. energy system — not just electricity.

This chart shows a U.S. government projection of carbon dioxide emissions, from the U.S., over the next 30 years.

Over the last 20 years, U.S. annual emissions fell by about 1.2 billion tons.

But surprisingly, most of this decline had little to do with renewable energy, or government policy.

Instead, about 80% of the drop came from natural gas costing less than coal.

Due to internal molecules, natural gas produces half as much carbon dioxide per unit energy; therefore switching over reduces carbon dioxide.

So that was the past. What about the future?

Well, economists expect additional decarbonization over the next decade, primarily driven by 3 things.

One, low cost solar farms.
Two, low cost wind farms.
and Three natural gas costs less than coal.

But each of these has limits.

Solar and wind can’t be built beyond saturation,
and there’s only a limited number of coal plants left to replace.

Once these limits are reached, decarbonization will slow —
and, in the government’s projection, it basically stops.

Okay, so now what?

Well, additional R&D, **beyond what the U.S. government currently expects**,
could potentially change this.

We’ll discuss this more, in future videos.

Okay, that's it for me, and I'll talk to you all, real soon.

Video #13: Decarbonization Politics

Hi, my name is Glenn Weinreb, and today we're going to look at the political considerations related to reducing carbon dioxide emissions.

Before we dive in, let's first examine some common obstacles to decarbonization.

The Competition Problem

Companies need to compete with other companies,
and regions need to compete with other regions.

Because of this, they are often reluctant to take on additional costs that could make them less competitive—especially when their own emissions are tiny compared to global total.

Those who believe in basic economic principles
view the Competition Problem as a serious barrier to decarbonization.

The Hi-Jack Problem

To make matters more complicated, policymakers often face what's known as a hi-jack.

This is when a different political group takes control of an issue to advance their own interests.

For example, the U.S. Inflation Reduction Act
required builders of solar farms
to buy U.S.-made solar panels, to qualify for subsidies.

While this created jobs, it also raised the cost of solar electricity—
ironically leading to higher carbon dioxide emissions.

This policy came at a time when U.S. unemployment was at 4%, which is full employment.

Adding jobs under such conditions can lead to labor shortages and rising wages,
which is **great** for workers.

As one can imagine, blue collar labor is a **massive** voting bloc.
And if you can win their support, **you** can become President of the United States.

This why **both** conservative presidents, and liberal presidents prioritized **protectionism** over **climate**.

This is another way of saying **labor** is politically **strong**,
while **climate** is **weak**.

And history tells us, the strong often take from the weak.

And labor, hijacking climate, is just another example of this.

Engineering Review

Another consideration is proposed decarbonization initiatives are often reviewed by engineers who are responsible for their implementation.

Here's an example.

Let's say one proposal requires power companies to decarbonize 50% of carbon-based electricity over 7 years, and another requires them to decarbonize 100% of electricity over 14 years.

Power company engineers are likely to verify the first proposal as feasible, but not the second.

This is because the first involves
building solar farms,
and wind farms,
up to the point of saturation, and engineers know how to do that.

As noted previously, saturation is when solar farms or wind farms are built up until they produce enough electricity, to satisfy **all** customers.

Beyond this point, excess electricity is discarded, and construction halts.

In other words, it is easier pass new requirement laws every few years for well-understood activity; than to push for more complexity, over longer timeframes.

Government Intervention

In some cases, the green option costs <u>less</u> than the carbon-based option; while in other cases, the green option costs more.

When the green option costs less, decarbonization tends to happen naturally and easily.

But when the green option is more expensive, we rarely see decarbonization at large scales.

In theory, R&D can be conducted to drive the cost of the green option below that of the carbon-based one.

However, if this does not happen, governments have three main tools to intervene.

These include subsidies, taxes, and requirements.

Economic Efficiency

The cost difference between the green option and the carbon-based option is sometimes called the physical decarbonization cost. This refers to actual production costs—without taxes or subsidies.

In a competitive market, the *price* of a product is typically about 8% higher than its production cost, on average. However, prices can rise further due to things like taxes or supply constraints.

When evaluating a decarbonization initiative, one can calculate the *cost to society* by adding together the price difference between the green and carbon-based options, plus government spending on subsidies.

Economic efficiency is then defined as the ratio of the physical decarbonization cost to the total cost to society.

If there's 100% economic efficiency, it means society is paying exactly the physical cost—no more.

Otherwise, if consumers pay more than what they have to, then it is considered an economic **<u>in</u>**efficiency.

It’s important to note, political support often **declines** as economic efficiency **drops**.

In other words, if you're aiming for broad political support, consider solutions that achieve close to 100% economic efficiency.

Okay, so let's look at examples of **in**efficiency.

Taxes

When companies are forced to pay a carbon-related tax, they often pass this additional cost onto their customers, while not reducing carbon dioxide.

In other words, for each dollar spent on physical decarbonization, more a dollar may be added to the price of goods and services.

This is an example of an economic **inefficiency**.

Subsidies

Governments occasionally influence behavior by paying a portion of a product's cost.

This is known as a subsidy.

However, in many cases, behavior does not change.

In other words, in many cases, the cost to society increases, while behavior does not.

This is another example of an economic **inefficiency**.

Decarbonizing via Requirements

To reduce carbon dioxide with **100% economic efficiency**,
governments can enact laws that require decarbonization.

This can be done **without** subsidies, **without** taxes,
and with additional costs passed directly to customers.

Ultimately, the costs incurred by society are close to the physical decarbonization costs.

This is roughly 100% economic efficiency,
which is the same as decarbonizing at the lowest cost to society.

An example is the United States Clean Air Act in 1972
which required power companies, and refineries, to emit less air pollution.

To comply, they filtered more,
and passed additional costs onto consumers.

Requirements like these can be instituted without bothering citizens, companies, cities and states.

This is good, since they often wiggle out of obligations,
and fighting each one burns political capital.

In short, the easiest way to decarbonize, is to
add requirements to key areas of an economy,

bother as few people as possible, and
aim for **100% economic efficiency**.

Production Follows Demand

A basic principle of economics is **"production follows demand.**"

This is another way of saying that suppliers, make the amount of product, wanted by customers.

For example,
global oil suppliers currently produce, 35 billion barrels per year,
since this is roughly what is needed.

They don't produce 45 billion barrels, and they don't produce 25. Production follows demand.

If one tries to block oil production by limiting drilling permits,
or restricting pipelines,
then an oil shortage ensues, and oil price increases.

The additional cost, due to the shortage, is paid by every oil customer, and this creates a massive decarbonization **<u>in</u>efficiency**.

Instead, decarbonization cost to society is much less when fossil fuel is **replaced** by green energy.

For example,
when a solar farm is built,
less fossil fuel is consumed,
and customers see little additional costs, if any.

In other words, we need to replace fossil fuel, not block.

At first glance, these might seem similar;
however, from an economic and political perspective, they are very different.

Furthermore, complaining about the oil industry is not helpful,
since, again, **production follows demand**.

Trust Energy Economists

There are multiple factors to consider when designing a decarbonization strategy.

These include economic efficiency, defending against hi-jack, passing engineering review, and dealing with individuals who depend on inefficient climate programs.

So, how might one resolve these?

Lab Suggestion - Statement

Consider tasking independent energy economists with identifying how to decarbonize
in the lowest-cost order, over 30 years, with 100% economic efficiency.

Energy economists are an important part of the solution—
especially when national leaders want to tackle the problem at the lowest cost to society.

Okay, that's it for me, and I'll talk to you all, real soon.

Lab Suggestion - SLIDE

Task independent energy economists with identifying how to decarbonize in lowest-cost order, over 30 years, with 100% economic efficiency.

Video #14: Reflecting Sunlight

Hi, my name is Glenn Weinreb, and today we're going to explore how to prevent runaway climate change by reflecting sunlight back into outer space.

This is a new field, and it requires research. The key question for scientists is,
"How can we reflect approximately 1% of sunlight,
back into outer space,
at a reasonable cost,
and without causing harm?"

We're already reflecting sunlight, since it reflects off man-made air pollution.

More specifically, it reflects off of sulfur.

It's possible this is a key element in solving the climate problem.

Let's take a closer look.

Sulfur 101

Sulfur is an element on the periodic table, and it is present in
large amounts within coal
and oil.

Therefore, it is typically
emitted into the atmosphere when these fuels are burned.

Sulfur is harmful to people, plants, and oceans.

Consequently, governments often require that some sulfur
be filtered out before or after combustion.

However, even with some filtration, approximately 70 million tons of sulfur dioxide gas are
emitted globally into the atmosphere each year.

Sulfur Cools the Planet

After sulfur dioxide gas is emitted into the atmosphere, it typically combines with water and oxygen to form H_2SO_4. This nucleates, which means it converts to tiny physical particles. Water sticks to these particles, and causes them to grow into physical water droplets.

These droplets are so small and sparsely distributed that they are often imperceptible to the naked eye.

Droplets containing sulfur typically reflect more sunlight than those without.

Therefore, more sulfur causes more sunlight to reflect back into outer space, instead of being absorbed by the planet. In effect, sulfur cools the planet.

A notable example is the 1991 volcanic eruption of Mount Pinatubo, which released sulfur dioxide gas into the atmosphere. This caused the average global temperature to decrease approximately 0.4 degrees Celsius for several months.

High Altitude Sulfur is Cooler

As mentioned previously, sulfur is present in coal and oil, and is released during combustion. In theory, we can filter more of it out before combustion,
transport the harvested sulfur to
an airplane, and emit it at a high altitude,
instead of at ground level.

High-altitude sulfur stays aloft for one to two years,
while ground-level sulfur typically stays aloft for only several days.

Therefore, changing the emission site reduces the planet's temperature, without increasing total sulfur emissions.

The latter point is important, since sulfur is harmful, as noted previously.

Multiple Candidates

Sulfur-based materials are not the only substances with reflective properties. For instance,
calcium carbonate, commonly known as chalk, exhibits similar capabilities.

Further research is needed to understand the benefits and drawbacks of each candidate material.

How Much Does this Cost?

To justify the expense, we would need to compare the cost of cooling the planet,
with the cost of not cooling the planet.

One study suggests large-scale planet cooling would cost approximately $18 billion a year.

For comparison, the total value of
New York City property is $1,400 billion,
and this is just one coastal city that would be lost to sea level rise.

If the U.S. paid half, planet cooling would amount to
about $30 dollars per American per year (50% x $18B / 330M).

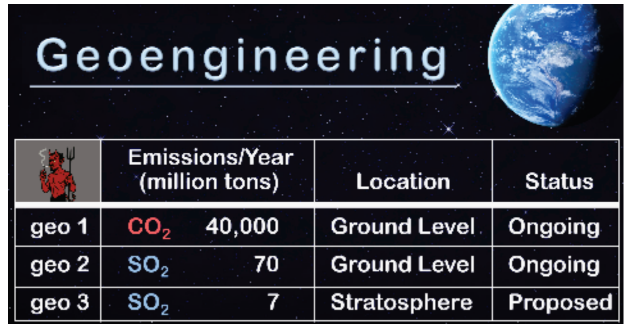
For details, see Wake Smith's 2024 paper.

Three Geoengineering Projects

Geoengineering involves injecting material into the atmosphere, either intentionally,
or as a side-effect of another activity.

An example is the 40 billion tons of carbon dioxide,
and 70 million tons of sulfur dioxide, that are emitted into the atmosphere, each year,
due to burning fossil fuel.

Also, roughly 7 million tons of sulfur dioxide are **considered** for injection, each year, into the upper atmosphere, to prevent runaway climate change.



	Emissions/Year (million tons)		Location	Status
geo 1	CO_2	40,000	Ground Level	Ongoing
geo 2	SO_2	70	Ground Level	Ongoing
geo 3	SO_2	7	Stratosphere	Proposed

Let's compare these 3 geoengineering activities.

To make this easier to follow, we will refer to them as "Geo1", "Geo2", and "Geo3".

In review, Geo1 and Geo2 are ongoing operations, while Geo3 is under consideration.

Geo1 and Geo2 are mostly ground level operations,
while Geo3 would target the upper atmosphere with airplanes.

Geo1 warms the planet, while Geo2 and Geo3 do cooling.

Geo3 involves 6,000 times less material than Geo1, by weight. However, Geo3 has a large cooling effect, per gram of material, in part due to its long hover time, as noted previously.

Each geoengineering activity can be characterized with multiple parameters that are quantified by scientists.

They do this with scientific models,
laboratory experiments,
and field experiments.

Lab experiments typically involve measuring properties of gasses,
within chambers, inside a laboratory.

An example parameter is increased acidity. We know how much acidity is caused by each gram of material, and we know how many grams of material are emitted each year.

From this, we see Geo2 contributes 10 times more acidity than Geo3,
and Geo1 contributes roughly 100 times more than Geo2.

{Reference: }

{Reference: https://chatgpt.com/c/68941787-f5c0-8332-94b0-f02170e6c942}We can also look at size by weight. Geo1 is enormous. To get a sense of this, we can look at what happens when an A380 airplane flies from New York to Tokyo.

This one flight injects roughly 1 million pounds, or 500 metric tons, of carbon dioxide, into the atmosphere.

This is about the same weight as 500 small cars.

To get a sense of this, we can view 140 parked cars,
which is roughly one-third of 500.

And this is just one flight, from one airplane.

For reference, there are roughly 28,000 commercial airplanes worldwide, and airplanes are responsible for approximately 3% of total carbon dioxide emissions.

In other words, Geo1 is massive.

In comparison, Geo3 is tiny.

However, for the most part , the public does not like it,
even though it could potentially be helpful.

This is likely to change,
as the risk of runaway climate change becomes more evident.

Atmospheric Reflectivity R&D

Increasing the reflectivity of the atmosphere is a new field and there are many things we don't know. We don't know what to inject, when, where, and how. And we don't have an accurate assessment of costs and adverse side effects. To resolve unknowns, we need R&D.

This includes developing
better instrumentation for measuring atmospheric reflectivity,
developing equipment that injects small amounts of material for field experiments,
and developing equipment that injects large amounts of material for full-scale operations.

Blocking the First Tipping Point

This needs to be reworked. AI might help. It was written fast and needs serious rework. (????)The first tipping point to activate is probably North Pole sea ice.

After this melts, sunlight will be absorbed by water, instead of being reflected by ice.

To get a sense of what this will do, one can hold up their hand to the sun, and feel the warmth.

This is the amount of additional heat we would get,
times the surface area of North Pole sea ice.

This is not tiny.

It is 5 million square kilometers, which is half the surface area of the United States.

Loosing this reflector would increase the average global temperature by 0.6 degrees Celsius.

This would trigger other tipping points, and lead to mayhem.

This would be bad; therefore, we would like to avoid this from happening,
and one can calculate what this entails.

The Timing Problem

At this time, public support for reflecting sunlight is low.

This is in part, due to a lack of understanding, of what would happen,
if sunlight is **not reflected**.

Unfortunately, by the time public support does become sufficient,
it could be too late.

In other words, we might have **a timing problem.**

Reflecting Sunlight R&D

What to do?

Lab Goal - Statement

It is our intent to determine how to reflect approximately 1% of sunlight back into outer space,
at a reasonable cost,
and without causing harm.

For details, click on the link, in the description below .

Okay, that's it for me, and I'll talk to you all, real soon.

Lab Goal - SLIDE

Determine how to reflect approximately 1% of sunlight back into outer space, at a reasonable cost, and without causing harm.

Video #15: Can Air Pollution Save Our Planet?

Hi, my name is Glenn Weinreb, and today we're going to look at how air pollution could potentially save our planet.

We can solve the carbon dioxide problem by replacing fossil fuel with green energy.

However, this alone probably will not solve the tipping point's problem.

We seem to be approaching these critical thresholds too quickly.

Therefore, we probably need to reflect approximately 1% of sunlight back into outer space, to cool the planet.

Stratospheric Aerosol Injection (SAI)

There are several ways to do this, one of which is called "stratospheric aerosol injection", or SAI for short.

This involves spraying reflective gases, or liquids, into the upper atmosphere, using airplanes.

The lower atmosphere is called the troposphere, while the layer above is known as the stratosphere. At the equator, the boundary between these two layers is at a 20 kilometer altitude, whereas near the North and South Poles, this boundary is lower, at approximately 12 kilometers.

High Altitude Airplanes

Existing aircraft can reach the upper atmosphere over the Polar Regions, making it possible to cool these regions using SAI.

However, cooling the entire planet would require injection to occur near the equator, at altitudes around 20 kilometers. We currently do not have large airplanes that fly to this height; however, they could be developed.

In summary, we can cool the Polar Regions with existing aircraft, yet would need to develop new aircraft to cool the entire planet.

Sulfur Dioxide (SO_2)

One possible injection material is sulfur dioxide gas. Sulfur occurs naturally in coal and oil, and is therefore emitted into atmosphere upon combustion.

In principle, it could be extracted before combustion, moved to an airplane, and emitted into the stratosphere instead of being emitted at ground level.

Stratospheric sulfur stays aloft for one to two years, while sulfur emitted at low altitudes typically stays aloft for only hours to days. Therefore, shifting the emissions site reduces the temperature of the planet, while *not* increasing total sulfur emissions.

Sulfur Cools the Planet

Sulfur injected into the upper atmosphere follows a different path than sulfur injected into the lower atmosphere.

Sulfur in the *Upper* Atmosphere

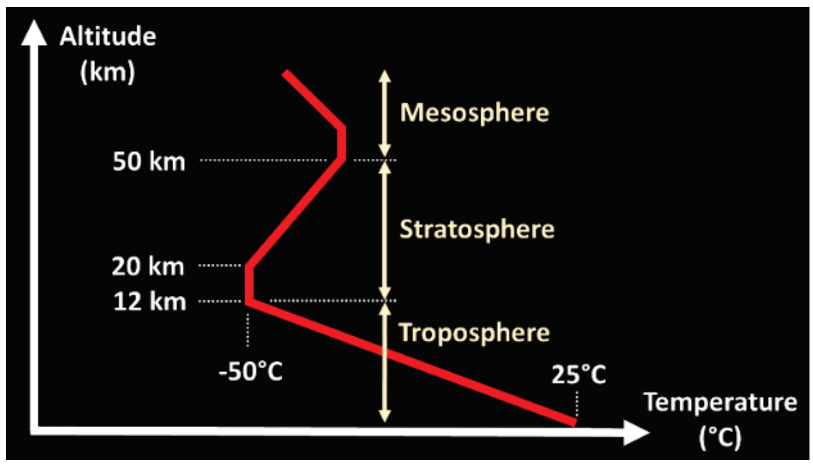
Sulfur in the upper atmosphere is rare; however, it is made possible via volcanic eruptions and SAI. When sulfur dioxide gas enters the stratosphere, it chemically reacts with water and oxygen to form liquid H_2SO_4. This combines with water to produce tiny droplets that are typically composed of 50% H_2SO_4 and 50% water. These droplets last for month to years, while reflecting sunlight back into outer space.

Sulfur in the *Lower* Atmosphere

Significant quantities of sulfur are already present in the lower atmosphere, primarily due to fossil fuel combustion. However, this sulfur typically remains airborne for only hours to days because of rainfall and gravitational settling. In humid conditions, tiny sulfuric droplets grow into cloud droplets consisting of more than 99% of water. Clouds with sulfur reflect more sunlight than clouds without, and therefore offset global warming, with cooling.

Atmospheric Temperature Gradient

Air temperature varies with altitude in unobvious ways, as shown in this graph.



Altitude values in this illustration reflect the atmosphere near the equator. In contrast, these values are approximately 40% less when near the North Pole or South Pole.

As one can see, the atmosphere is relatively warm at ground level, and gets colder as one goes up. However, this reverses after one enters the stratosphere, since ozone in this region absorbs solar radiation, and causes temperatures to become warmer as one goes higher. In other words, there is a layer of relatively cold air in the lower portion of the stratosphere, and a layer of warmer air above it.

Also, warm air rises, which means material injected in the lower stratosphere will go up, and not quickly fall to Earth due to gravity. Therefore, one gram of sulfur injected into the upper atmosphere will cool the planet more than one gram injected at ground level.

Three Physical Areas of Operation

Increasing the reflectivity of the atmosphere involves three physical areas of operation. These are polar research, cooling the Polar Regions, and cooling the entire planet.

Polar **research** involves a spray plane that injects material into the upper atmosphere, and a monitor plane that visits the site once a day for several weeks to (ref). The monitor plane would measure several parameters by flying below the material, above the material, and through the material.

Cooling the poles involves approximately one-hundred Boeing 777 airplanes that inject material close to the North and South Poles, to block tipping points associated with those regions (ref).

And cooling the entire planet involves approximately one-hundred large custom made, high-altitude aircraft that inject material near the equator, to cool the entire planet (ref1, ref2).

Sunlight Reflectivity Strategy

A reasonable strategy is to first operate at a level that is one ten-thousandths of full scale operations, followed by one-thousandth, followed by one-hundredth, and so-forth, and so-on.

$^1/_{10,000}$ ▷ $^1/_{1,000}$ ▷ $^1/_{100}$ ▷ $^1/_{10}$ ▷ $^1/_3$ ▷ $^2/_3$ ▷ 1

Obviously, our society would only advance, if no harm, was detected.

Sunlight Reflectivity Risks

Reflecting sunlight does involve risks.

Two that stand out are site security risk, and undercapitalization risk.

Site security risk involves protecting reflectivity operations from physical attack. This is important, since, in theory, any "grumpy" national leader could key the coordinates of reflectivity infrastructure into a missile guidance system, and press a button.

There are multiple reasons why they might do this, one of which is they perceive it as harmful.

This is a complex topic, since there could be some harm, yet it would need to be weighed against the harm of no action.

And harm on both sides of this coin can vary in both time and place.

Again, this is a complex topic, and it could lead to fighting.

Another risk is undercapitalization. This involves financial support being less than what is needed. For example, several years from now, a panicked national leader, could push reflectivity forward, at large scales; before scientists had measured the side-effects, at small scales.

Sunlight Reflectivity Laboratory

To minimize risks, exhaustive field testing would be needed to evaluate different candidate materials, in different locations, with different sets of monitoring instruments.

Such experiments have **not** been conducted, even though they are of profound importance.

To perform experiments,
scientists need airplanes that inject different candidate materials,
and they need airplanes that monitor the injected material, over days to weeks.

For details, click on the link, in the description below {sunlight reflectivity chapter}.

Lab Goal - Statement

It is our intent, to develop gadgets, which support **sunlight reflectivity**, field experiments

Okay, that's it for me, and I'll talk to you all, real soon.

Lab Goal - SLIDE

Develop gadgets that support sunlight reflectivity field experiments.

Video #16: Tackling Climate with Nuclear Fission Power

Hi, my name is Glenn Weinreb, and today we're going to look at how to tackle the climate problem with nuclear fission power.

Our society currently builds several nuclear reactors at a time,
and this has close to no impact on climate change.

Instead, to have a measurable impact, we would need to build thousands.

Nuclear Cost Reduction

In theory, this could be driven forward by reducing the cost of extra-safe reactors that don't melt down, when not cooled.

It turns out, this is easy to do, as we will explain in this video.

Costs can be reduced through measures such as building standardized reactors, relying heavily on factory-made subassemblies, and developing a new transportation system that moves large subassemblies from factories to power plant sites.

The nuclear reactor vessel and internal gadgetry account for only 2% of total nuclear site costs. The majority of expenses arise from excavation, concrete pouring, and rebar installation. And these costs could be reduced by developing equipment that automates site construction.

Design One, Build Many

Engaging in a lengthy nuclear reactor design and certification process is unnecessary. Instead, one can copy an existing design.

China's HTR-PM is a reasonable candidate since it is probably the safest commercially operating nuclear fission reactor in the world. In particular, it does not melt down if not cooled; its fuel and coolant do not react with air or water; and its helium gas coolant is not radioactive. In the event coolant is lost, the core radiates heat outward to the metal containment vessel, which then radiates heat to the concrete containment chamber, which conducts heat to bedrock.

This reactor took 20 years to develop and repeating this process is not necessary.

Nuclear Waste

Nuclear waste can also be reduced by spending more money. For example, allocating approximately 10% of the wholesale electricity cost to advanced waste processing could significantly decrease both the volume and the longevity of nuclear waste.

The Nuclear Leader is China

China has constructed many nuclear reactors over recent decades, gaining expertise that allows them to build at relatively low costs. Conversely, the United States and Europe have been less active, resulting in less proficiency and higher costs. However, this lack of experience is not permanent. If nuclear power was used to solve the carbon dioxide problem, more construction would result in more proficiency and lower costs. Also, if construction was automated, this would naturally occur first in regions that are comfortable with nuclear power, and eventually spread to nations who are less comfortable.

Decarbonization Problem Size

Large nuclear power facilities typically host between three and six reactors, with each reactor commonly producing approximately one billion watts of electricity. Given that an average U.S. household consumes about 1,000 watts, a single reactor can supply electricity to roughly one million homes.

We know how much energy is consumed worldwide each year, and we know how much is produced by a large 1 gigawatt nuclear reactor. To get a sense of decarbonization problem size, we can divide these two numbers to calculate how many 1 gigawatt reactors would be needed to replace global energy. The math works out to about 9,000 gigawatts of nuclear power. This refers to *all* energy, not just electricity.

The Nuclear Solution

If, for example, nuclear power were used to decarbonize 50% of global energy over the next 30 years, approximately 150 gigawatts of nuclear power would be constructed worldwide each year (50% × 9,000 GW_e ÷ 30 years). This would entail building 41 gigawatts per year in China, 23 gigawatts per year in the U.S., and 19 gigawatts per year in Europe. And this would involve increasing annual construction 6-fold in China, 150-fold in the U.S., and 100-fold in Europe.

Nuclear Economics

The cost of new nuclear reactors in China is currently around $2 per watt of capacity ($2/W). For example, a nuclear reactor site in China with 3 gigawatts costs 6 billion dollars to build.

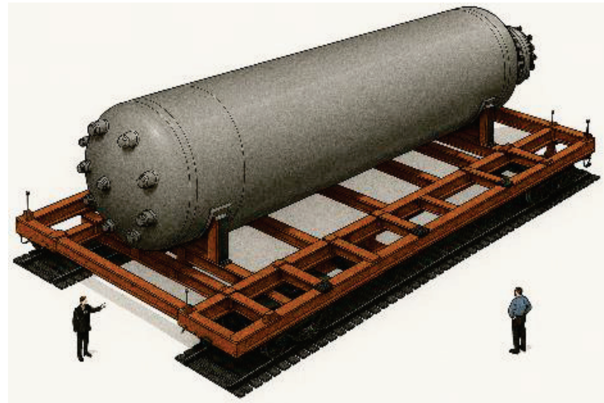
Nuclear power in the U.S. and Europe are much more expensive; however, they would likely approach Chinese levels if construction volumes were similarly high.

If global nuclear construction were scaled up to 150 gigawatts per year, then cost-reduction due to automated construction could potentially offset the additional cost of higher quality. In other words, the $2-per-watt cost could potentially continue, with 150 gigawatts of annual construction costing $300B per year.

We can compare this with the annual cost of half of fossil fuel. Present global fossil fuel spending is around 4,000 billion dollars per year. This includes 2,500 billion for oil, 1,000 billion for coal, and 500 billion for natural gas. While nuclear reactors are not a direct replacement, we see that $300B per year for new nuclear reactors, is less than $2,000 billion per year for half of fossil fuel.

For more details, click on the link in the description below.

New Transportation System



In theory, a new transportation system could be developed to move large and heavy loads over land and water, to better connect factories to nuclear power sites. For example, a 12 meter wide by 24 meter long railcar on double-rails could potentially transport: (a) large nuclear reactor components, (b) bins of concrete, (c) concrete forms, (d) rebar subassemblies, and (e) large automated construction equipment.

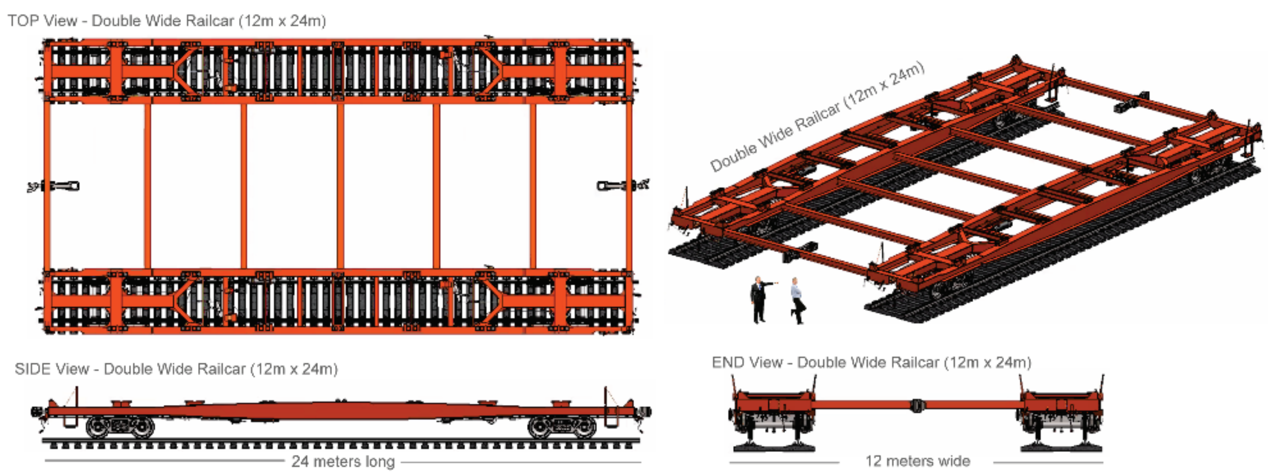


Figure 5.1: Double-width railcar. Concept illustration by G. Weinreb.

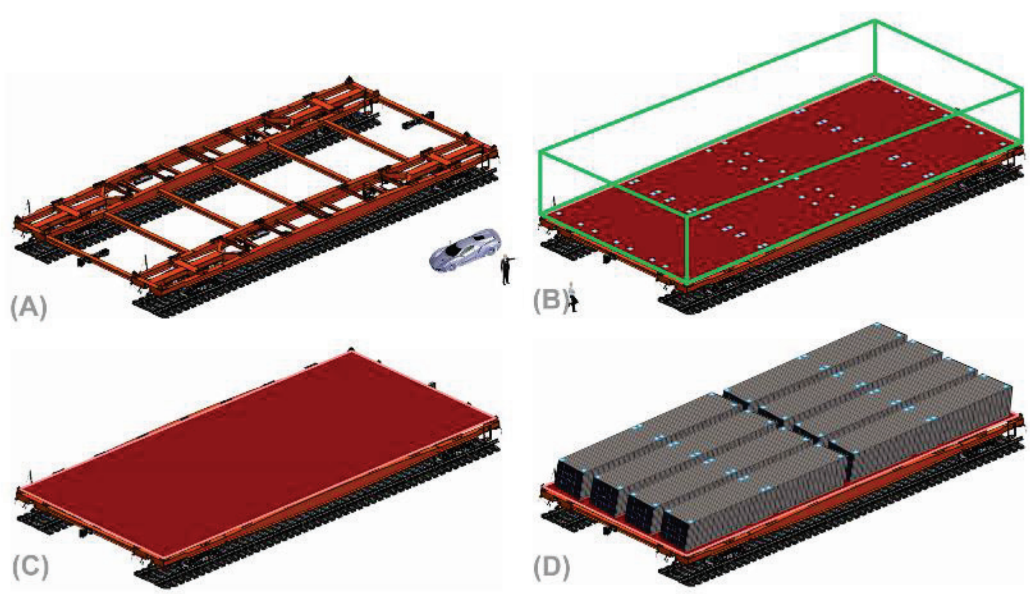


Figure 5.2: A large railcar could be adapted to support: (A) base frame, (B) large container, (C) flat working surface, and (D) multiple shipping containers.

Chemical Processing Platforms

Large platforms of chemical processing equipment could theoretically be co-located with nuclear power plants, and powered by heat transported through pipes carrying steam or molten salt. For instance, platforms measuring 12 meters wide by 96 meters long could be transported via double-rail and positioned side-by-side near the reactor.

Site-wide efficiency could be maximized by capturing unused heat and redirecting it to generate electricity, produce chemicals, or increase the temperature of thermal storage.

In theory, platforms of chemical processing equipment could support the production of common chemicals, including hydrogen gas, and liquid ammonia.

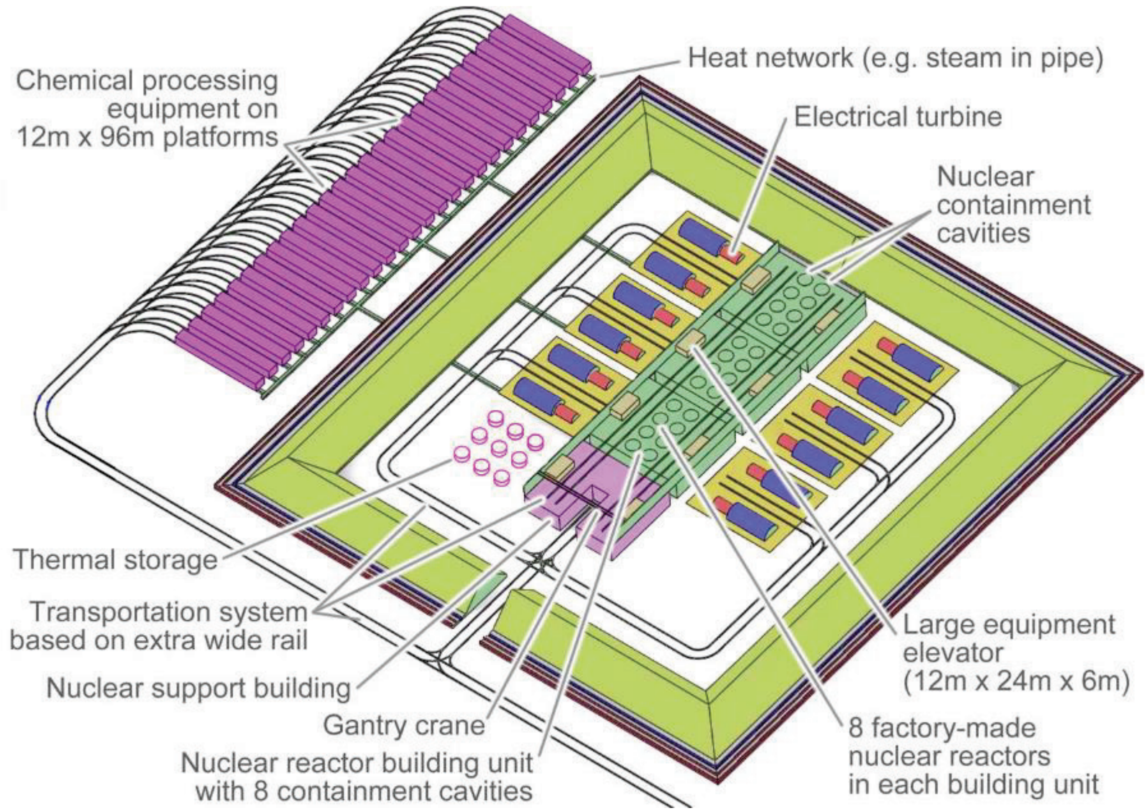


Figure 5.3: Nuclear reactors co-located with multiple platforms of chemical processing equipment. Concept illustration by G. Weinreb.

Chemical Processing Yard

Chemical processing platforms could potentially be positioned side-by-side, as shown here. In this illustration, platforms are shown in green, pipes carrying heat from the nuclear reactors are shown in blue, underground tunnels that support pipes in between platforms are shown in light violet, and underground tunnels that support moving material into and out of the chemical processing platforms are shown in light purple.

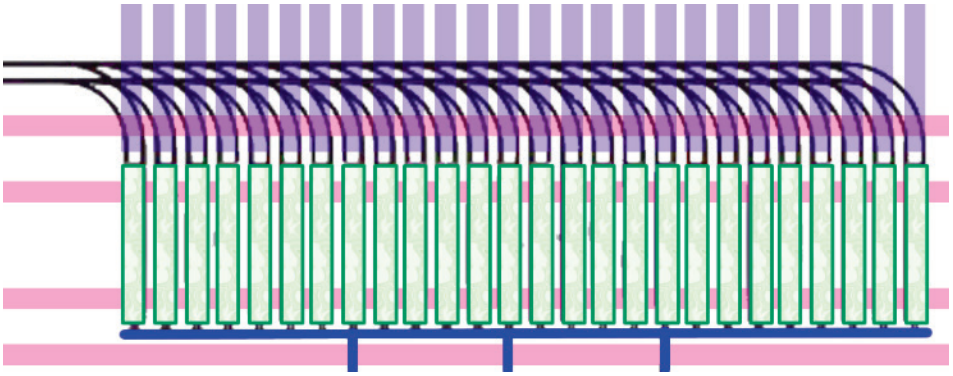
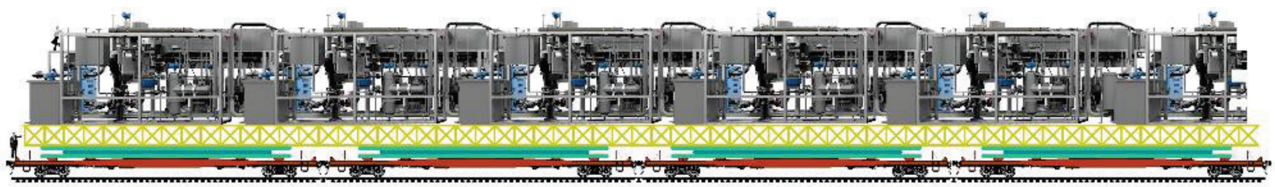


Figure 5.4: Chemical processing yard consists of processing platforms side-by-side.

Platform Transporter

In theory, equipment could be developed that moves 12 meter by 96 meter platforms across land via double-rail, and across water via specially built ships. To prevent bending when traveling over hills or around curves, these platforms could be mounted on a ridged truss supported by jacks between the truss and railcars, as illustrated here.



Thermal Storage

When electricity demand is low, nuclear reactors can increase the temperature of a hot liquid in a thermal storage tank; and when electricity demand is high, the stored energy can be used to make electricity. In other words, to minimize costs, thermal storage can bridge the gap between fluctuating demand and constant supply. Also, thermal storage can minimize waste heat by consuming it when available at a temperature higher than the storage temperature. In theory, R&D could reduce thermal storage costs by supporting the development of equipment that automates their construction.

Speed and Scale

As noted in previous videos, solving the carbon dioxide problem requires both Speed and Scale.

Speed is not working with an experimental reactor that takes 20 years to commercialize;
and instead is copying an operating unit that has already completed the certification process.

And Scale is not building several reactors,
and is instead building thousands.

Our society is not doing Speed or Scale with green energy; however, in theory, this could change.

Yet what might cause this transformation?

To get a better sense of this, let's take a break from nuclear power, and look at solar.

Or, more specifically, let's look at solar farm construction, in China, during 2024.

China's 2024 Solar Construction Spree {see video #5}

A coal shortage during that year increased the cost of coal-based electricity to the point where it was roughly twice the cost of solar farm electricity.

To reduce coal demand, reduce coal price, and save money,
the Chinese built 280 gigawatts of solar power in 2024.

For reference, this is approximately 10-times more solar power, built in the U.S., in a typical year.

Each nuclear watt is worth about 4 solar watts. This is due to the fact that the sun burns bright roughly 6 hours out of every 24.

Therefore, building 280 gigawatts of solar is like building 70 gigawatts of nuclear power.

In comparison, the U.S. built 3 gigawatts of nuclear power, over the last 30 years.

China's nuclear construction cost-per-watt is approximately 4 times more than their solar construction cost-per-watt. Therefore, the money they put into solar construction could have theoretically gone into nuclear construction, and yielded a similar amount of electricity.

However, solar can be built faster than nuclear. This is why they favored solar.

In both cases, money for construction can be borrowed, and repaid with electricity sales.

It is worth noting China's solar construction spree has little to do with climate change.

Instead, they did this primarily to save money.

This is basic energy economics,
and if you want to better understand why nations do what they do,
consider reading "The New Map" by Yergin.

Okay, back to Speed and Scale.

With green energy, we can get Speed by copying commercially operating nuclear reactors,
and we can get Scale by driving down costs with automated construction.

Lab Goal - Statement

It is our intent to develop custom machines that automate the construction of, extra-safe, nuclear power-based green energy production sites.

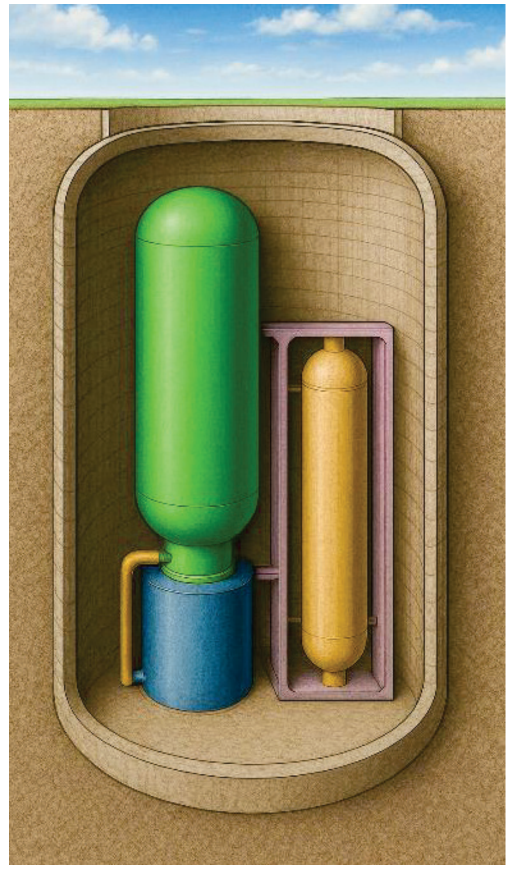
For details, click on the link in the description below .

Okay, that's it for me, and I'll talk to you all, real soon.

Lab Goal - SLIDE

Develop custom machines that automate the construction of, extra-safe, nuclear power-based green energy production sites.

Video #17: Extra-Safe Low-Cost Nuclear Power



Hi, my name is Glenn Weinreb, and today we're going to look at how to significantly reduce the cost of nuclear fission power.

Rethinking Nuclear Fission

Nuclear power plants typically require significant amounts of concrete and rebar, in part because they need to withstand attack from missiles and airplanes.

In principle, these costs could be reduced by placing the reactor vessel underground, inside a concrete-lined chamber, surrounded by bedrock.

Achieving this affordably would probably require the development of specialized machines that automate excavation, installation of concrete lining, and assembly of reactor components.

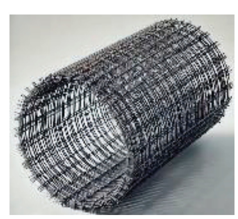
The Case for Going to Ground

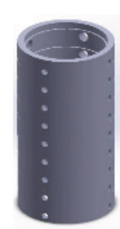
It typically cost more to build underground. However, this might not hold true for gas-cooled nuclear fission reactors that are built with custom machines.

Traditional reactors are cooled with pressurized water; however, several advanced designs instead use helium gas. Gas carries less heat per unit volume compared to water, and therefore gas-cooled reactors are physically larger than their water-cooled counterparts. Consequently, their nuclear fuel is more spread out, which helps them not melt, when not cooled.

More specifically, in the event coolant is lost in a gas-cooled reactor, decay heat is moved via radiation to concrete chamber walls, to bedrock, without melting. Alternately, water-cooled reactors are dependent on external systems that must be protected against attack, significantly driving up costs. ~~(For details, see this video)~~

Automated Excavation and Concrete Installation





A cost-effective underground approach would involve developing specialized machinery that excavates in bedrock, and installs a concrete lining.

Rebar and formwork assemblies could be prefabricated within a factory, transported to the site, lowered into the excavated cavity, and then filled with wet concrete.

Concrete Example

Concrete Strategy

Excavation

There are two primary methods for excavating bedrock: blasting and mechanical excavation. Blasting uses explosives to fracture rock , while mechanical excavation uses machinery to cut and remove material in a controlled manner .

Costs can vary significantly, reaching up to approximately $250 per cubic meter of rock. However, based on our calculations, this would cost less than 2% of total site costs.

For a copy of these calculations, click on the link in the description below .

Excavation Support

Custom machines are needed to break bedrock, remove debris, install a concrete lining, and install nuclear components.

This would probably require a gantry-like crane system that lowers custom machines into an excavation, an example of which is shown here. In this illustration, the cylinder-shaped excavation is depicted in blue, and a custom machine being lowered into the excavation is shown in orange.

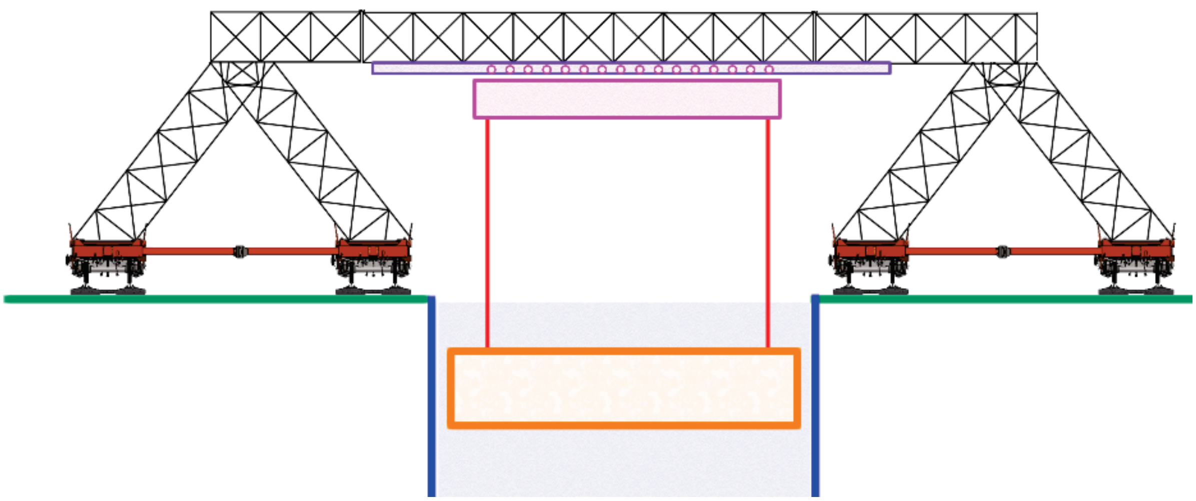


Figure 6.1: Gantry-like crane supports excavation.

Custom machines would perform several key functions: (a) excavation support, including breaking and removing bedrock; (b) concrete lining installation, such as placing rebar cages and pouring wet concrete; and (c) installation of subassemblies. These machines would operate within the excavation under the control of the gantry crane system, enabling precise placement and sequencing of tasks.

Gantry-Like Crane

In theory, a truss mounted on two synchronized railcars could span the excavation and implement a crane system. A trolley could move along the truss to enable Y-axis movement, railcars could provide motion along the X-axis, and motorized hoists could provide Z-axis vertical positioning.

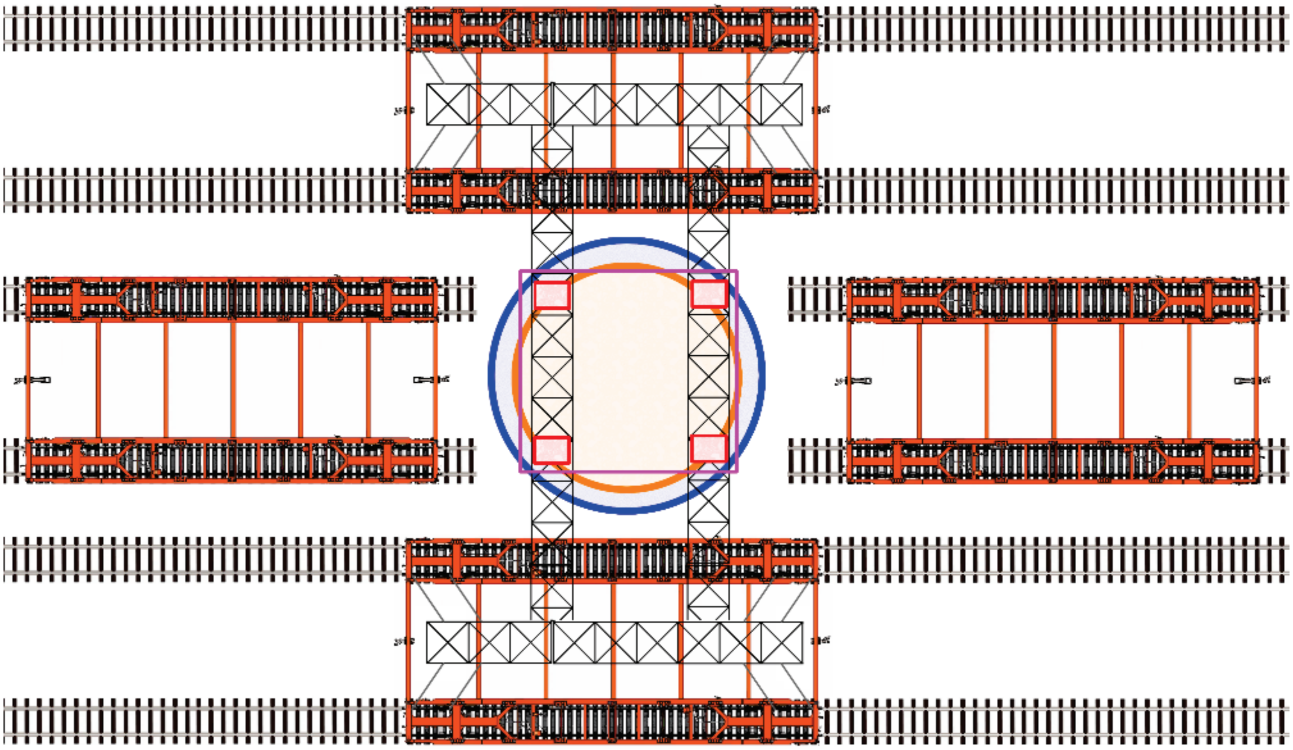


Figure 6.2: Top view of excavation.

In the above concept, additional railcars support material handling and machine exchange. For example, a rock removal machine could be retrieved from one support car, lowered into the excavation, and used to transport material via conveyor to a bin on another support railcar.

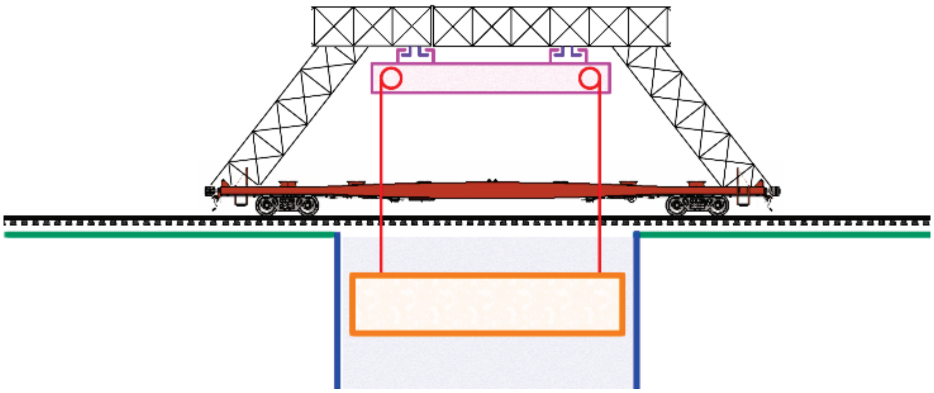
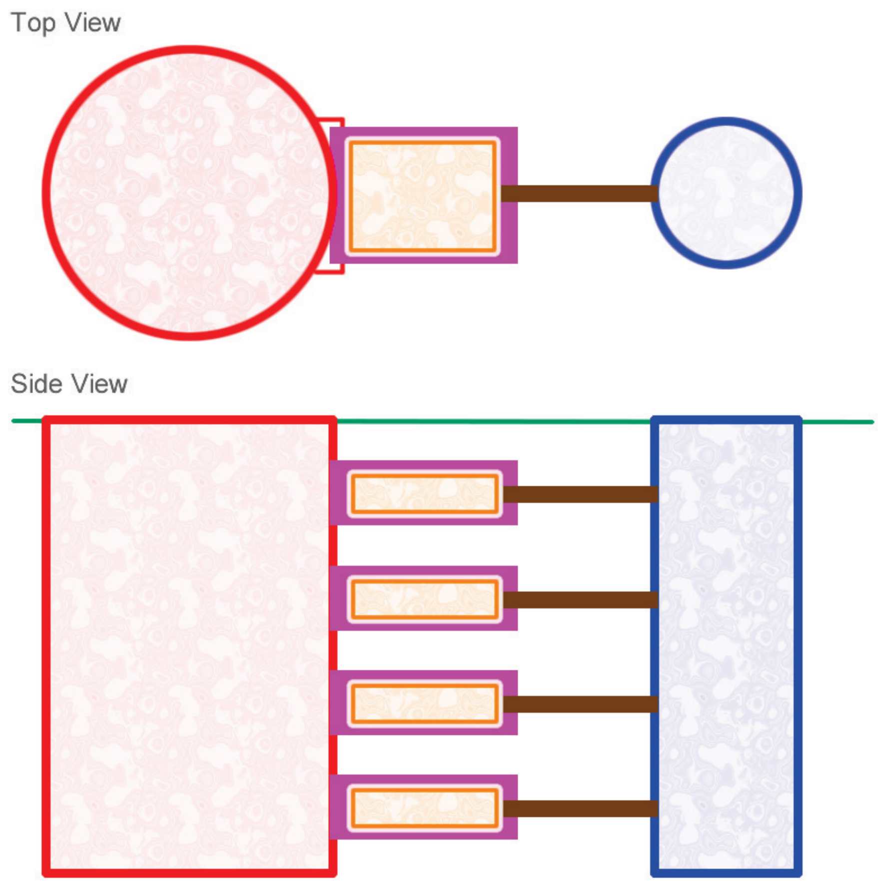


Figure 6.3: Side view of gantry-crane.

Nuclear Containment

The primary functions of the containment structure are to withstand attacks and to contain radiation under pressure, in the event of system failure. To hold pressure, a dome-shaped seal could be bolted to the top; and to protect against attack, a retractable concrete block could be placed above it.

Support Equipment



Nuclear reactors require various support systems, including pumps, electrical power generators, monitoring instruments, control systems, and nuclear fuel storage. In theory, these could be housed in a separate "equipment excavation," while reactor vessels and heat exchangers are kept in "power excavations."

Support systems could be preassembled within factory-made metal enclosures that are transported to the site, lowered into the equipment excavation, and slid into pre-positioned concrete boxes.

This is illustrated here with power excavations shown in blue, equipment excavations shown in red, concrete boxes shown in violet, metal equipment boxes shown in orange, and connecting tunnels shown in brown.

In theory, a custom machine could excavate rectangular chambers in the side of the equipment excavation. A second machine could install factory-made concrete boxes to prevent bedrock collapse. A third machine could pump wet concrete between bedrock and concrete boxes to affix in place. And a forth machine could install metal equipment boxes.

Site Design

To reduce costs, multiple power excavations could be positioned around a single central equipment excavation, as shown below.

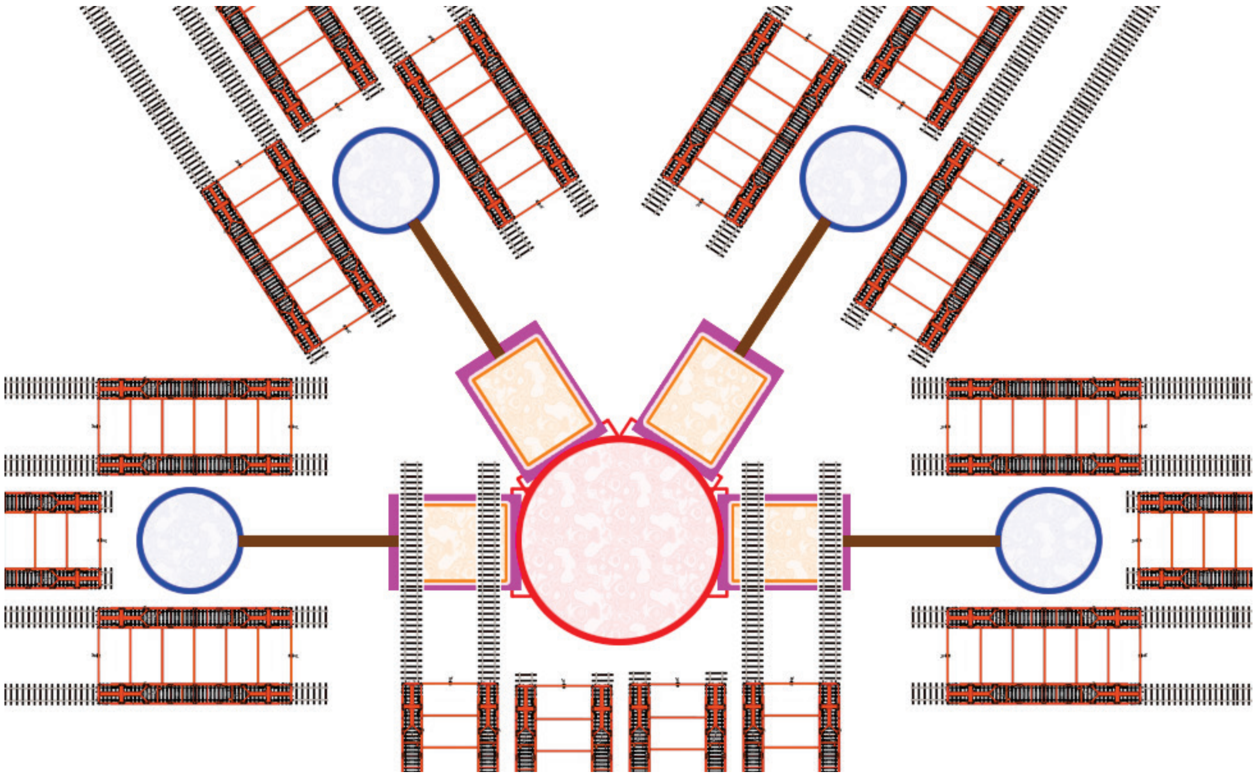
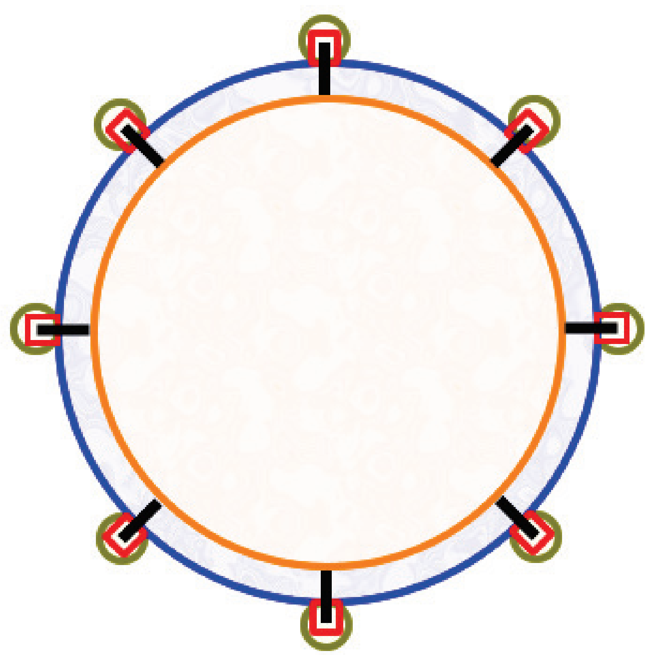


Figure 6.4: Top view of nuclear power system. Concept illustration by G. Weinreb.

A preliminary estimate finds this approach would consume 9-times less concrete-per-unit-electricity than Vogtle 4, and 26-times less concrete-per-unit-electricity than Hinkley C. In other words, less concrete is needed when mission-critical infrastructure is kept close to gas-cooled reactors.

Excavation Alignment



Excavation might begin by drilling multiple 1 meter diameter pilot holes outside the excavation, as shown here. Rails could be installed in these holes to guide custom machines that break rock and remove rock. Wheels on the machines could slide within the rails to ensure alignment. In this illustration, the excavated cylinder is shown in blue, pilot holes are shown in gold, rails are shown in red, wheels are shown in black, and the custom machine is shown in orange.

Precision Excavation

Traditional excavation methods are often imprecise, while a surface accurate to 1 centimeter might be preferred. Therefore, crude excavation methods might be used to remove bulk material, followed by more precise methods. For example, a custom machine with a rotating cutting head could be used to refine the excavated surface to a higher precision, as shown here. In this illustration, a custom machine is shown in orange, a rotating assembly in green, a bearing in yellow, and cutting heads in red.

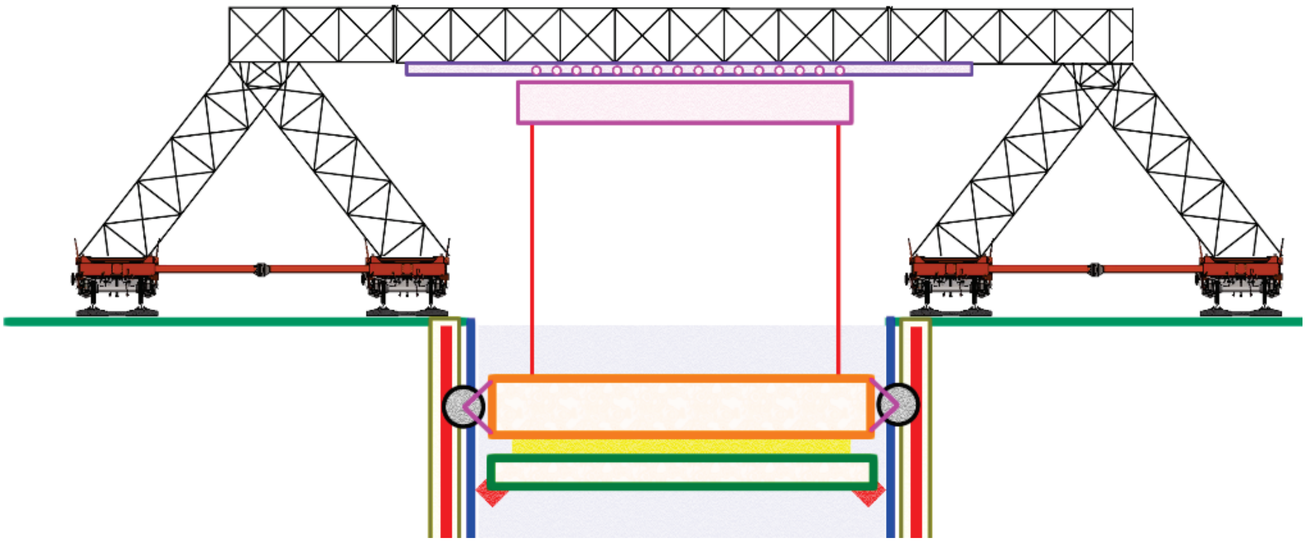


Figure 6.5: Side view of precision excavation machine.

Heat from nuclear reactors creates steam, which presses on fan turbine blades, which produces electricity. The electrical turbine could be located either above ground, or below ground within the equipment excavation. In theory, custom machines could support both methods.

How Much Does this Cost?

Okay, so how much does this nuclear stuff cost,
and what cost is needed, to beat, fossil fuel?

Beating fossil fuel would require a nuclear site cost of
less than 2 dollars per watt of electrical power generated.

And the three main components described in this video, are estimated,
as costing 10 pennies per watt, or 5% of the total budget for cost parity.

The three main components are excavation, concrete, and reactor pressure vessel.

Additionally, the cost to develop custom machines would probably be small,
relative to typical nuclear costs.

In other words, if we put R&D money in the right places,
we should be able to get 24x7 green energy,
at a cost less than fossil fuel.

For details, click on the link, in the description below.

Lab Goal - Statement

It is our intent to develop machines, that

excavate,
install concrete linings,
install concrete boxes,
install equipment boxes, and
install nuclear reactor components.

For details, click on the link in the description below .

Okay, that's it for me, and I'll talk to you all, real soon.

Lab Goal - SLIDE

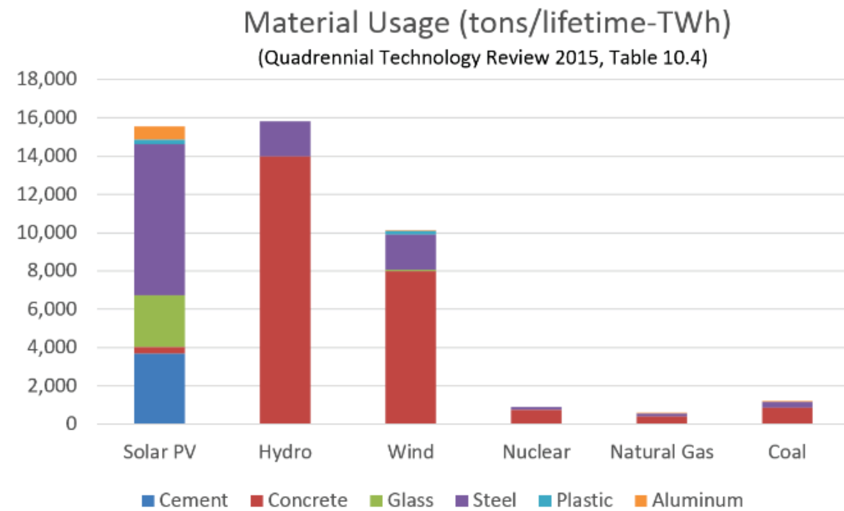
Develop machines that excavate, install concrete linings, install concrete boxes, install equipment boxes, and install nuclear reactor components.

Video #18: Solar Material Rolled onto Land

Hi, my name is Glenn Weinreb, and today we're going to look at how to potentially reduce the cost of solar power.

The Materials Problem

This graph shows how much material is used by the traditional methods of generating electricity. Materials primarily include steel, concrete, and glass. PV solar farms use as much material as hydroelectric dams in terms of weight per unit of lifetime electricity generated. This is a lot, and we would like to reduce, to reduce the cost of solar, and to reduce CO_2 emitted when making materials.



Silicon solar cells are typically covered with 3.2mm thick tempered glass to protect against hailstones and wind. Wind applies tremendous force. For example, 160kph wind presses 125 kilograms- per-square-meter against a surface. In other words, protecting silicon for 30 years requires significant amounts of material.

Solar Material Rolled Directly onto Land

Solar farms typically mount silicon solar cells 1.5meters above ground. Alternatively, one might unroll flexible thin-film approximately 2mm thick solar material directly onto soil in a manner similar to unrolling a 2 meter by 100 meter carpet onto a surface. Prior to installation, the land would be shaped with earth-moving equipment under computer control.

Initially, this might seem like a bad idea. However, there are good reasons for going to ground, such as significantly less material usage. Engineers could explore various techniques for overcoming challenges such as soil erosion, upward pressure due to wind, and keeping solar material clean.

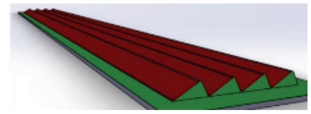
Traditional photovoltaic solar farms use aluminum and glass to resist wind loads. Alternatively, direct-to-soil would use soil for rigidity and use thin-film conversion material instead of silicon solar cells.

Thin-film is typically rollable, resistant to hailstones, and does not need 3.2mm thick protective flat tempered glass. It also has less conversion efficiency and more efficiency degradation per year, which means one needs more land for the same energy output. However, if one has an infinite supply of land, they might focus on cost-per-watt as opposed to cost-per-square meter of land.

The above-ground layer might be similar to flat flexible plastic with an embedded steel wire mesh. To hold in place, installation machinery might install a parallel layer of material underground, perhaps 50 centimeters or 20 inches below the top above-ground layer. The above-ground layer might connect to the underground anchoring layer via metal links.

Let's look at several concept illustrations to get a better sense of this.

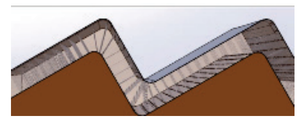
Pic-1



Multiple rows of flexible solar material could be placed directly onto soil, as shown here . In this concept illustration, each bed consists of 4 rows, and each row is 2 meters wide, by 100 meters long.

If rain touches dirt, it will move over time. Therefore, to keep it in place, it is completely covered with a 2 millimeter thick blanket of solar material. We refer to this as the "above-ground" layer.

Pic-2



To keep the above-ground layer from moving over time; it is held in place with metal links that connect it to a below-ground wire-mess anchoring-layer. Soil between the two layers holds the anchoring layer in place.

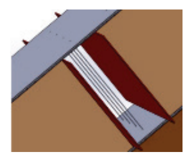
Pic-3

Metal links are installed by a machine, and are used to connect the two layers.

Pic-4

The below-ground anchoring layer consists of a wire mesh that is installed by a machine that is similar to farm equipment that manages soil.

Pic-5



This installation machine would unrolls both layers, places soil in between, and connects them together via metal links. It might use retaining plates, shown here in red, to control soil between the top layer and bottom layer, while a mechanism between the plates installs vertical metal links.

Some regions would be more feasible than others. For example, deserts with 3 centimeters of rain per month, and dense soil, might be most suitable. Engineers would need multiple-decade simulations and wind tunnel testing to ensure that soil movement due to wind and rain is acceptable.

Thin-Film Plastic vs Silicon Solar Cells

Traditional solar farms use sheets of glass, and metal frames, to protect delicate silicon-based solar cells . And, over the last 20 years, costs have been driven down with mass production.

Alternatively, thin-film solar material, mounted on rolls of plastic, is currently expensive, due to small production volumes.

However, it would be more competitive, if mass produced via roll-to-roll processing .

Custom Machines

Placing thin-film solar material directly onto soil requires the development of custom machines that
manage the material in the field,
and fabricate the material in a factory.

Special purpose built machines in the field would
shape the land,
install the material, and
clean the material.

Some of these might look similar to existing equipment, shown here.

Figure 7.2. Earth-moving vehicles and agricultural sprinkler system.

Lab Goal - Statement

It is our intent to develop custom machines that support solar material rolled directly onto land.

For details, click on the link in the description below .

Okay, that's it for me, and I'll talk to you all, real soon.

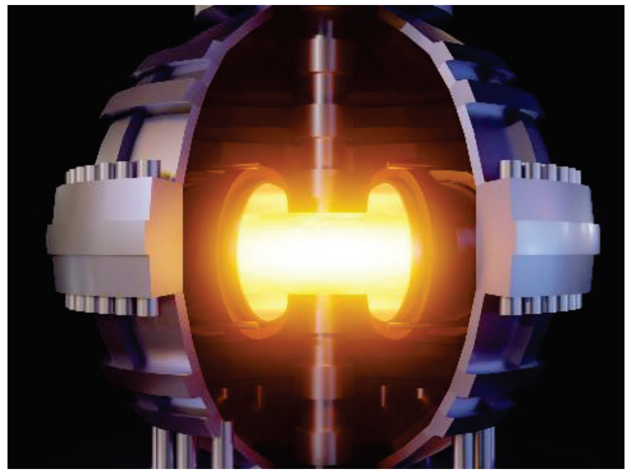
Lab Goal - SLIDE

Develop custom machines that support solar material rolled directly onto land.

Video #19: The Quest for Economic Fusion

Hi, my name is Glenn Weinreb, and today we're going to look at what it would take to accelerate the development of fusion energy.

Fission vs Fusion



There are primarily two types of nuclear power: fission and fusion.

Fission is the traditional form, that generates electricity with uranium fuel. However, this is not popular due to meltdown risk, nuclear waste, nuclear bomb proliferation risk, and cost.

Fusion, on the other hand, does not have these issues; however, it is still in development. Typical fusion systems maintain a hot plasma within a donut-shaped reactor, as illustrated here.

The Case for Economic Fusion

To solve the carbon dioxide problem with fusion, it would need to generate electricity
at a cost below that of fossil fuel.

This is referred to as "economic fusion,"
and it entails continuous operation, without failure.

If green energy were cheaper than fossil fuel, nations would have a powerful incentive to decarbonize, to save money, to remain competitive, to keep voters employed.

In other words, cheaper green energy could potentially solve the carbon dioxide problem.

However, to fend off climate tipping points with fusion,
it would need to be operational within a handful of years,
and then thousands of machines would need to be built over a relatively short period of time.

Achieving economic fusion over a handful of years
would require funding that goes beyond current levels.

The world currently spends 4 trillion dollars a year on fossil fuel,
and harm from climate change is expected to reach trillions of dollars annually.

Therefore, it's reasonable to spend additional billions on fusion,
in an effort to save trillions.

Fusion Moonshot

In 1961,
President Kennedy stated he wanted a man on the moon, by the end of the decade.

In response, a program was set up, and funded.

In theory, a similar approach could be applied to economic fusion.

But how might this be done, without wasting money? Let's explore.

Bumpy Costs Less

The tokamak and the stellarator are two fusion designs that could potentially produce large amounts of electricity in the near future.

The tokamak features a donut-like shape,
while the stellarator is more bumpy.

According to cost models, electricity from a stellarator costs less than that from a tokamak;
and is therefore likely to be favored.

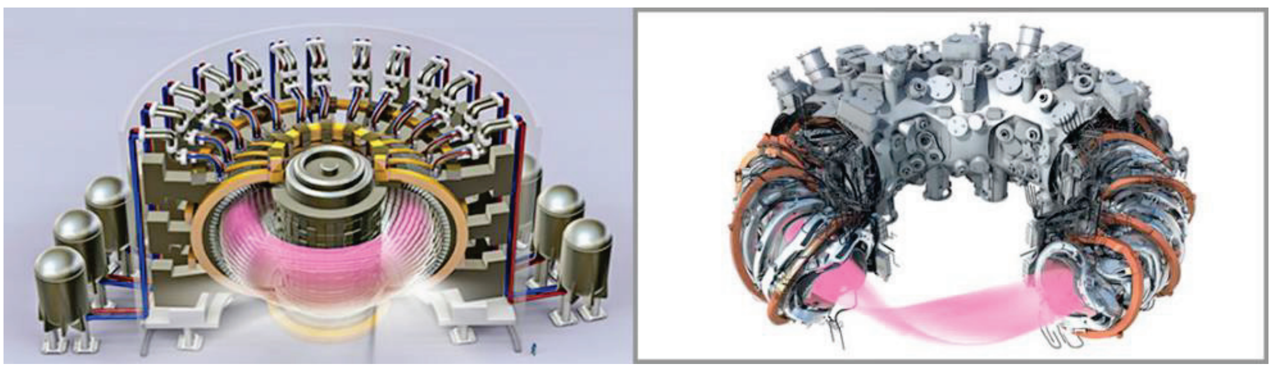


Figure 4.1: Tokamak (left) and stellarator (right).

To produce electricity cost-effectively,
the energy output from the plasma must exceed the energy input,
and the electrical power generated by the site must surpass that consumed by the site.

This requires powerful magnets and adequate plasma confinement,
both of which are reasonably well understood by scientists.

Heat Removal

The hot plasma inside the donut shaped chamber
radiates heat outward,
and causes the internal surface of the chamber to get hot.

This heat needs to be moved outward,
to create steam,
to press on fan turbine blades,
to produce electricity.

The easiest way to do this is to pump molten metal, toward the hot plasma, and then outward.

There are two ways to do this.

One involves having liquid metal flow in front of the chamber internal surface plate,
and the other involves flowing liquid *behind* the plate.

Liquid Metal Wall

Flowing liquid in front of the metal plate is referred to as "liquid metal wall."

This is illustrated here, with liquid shown in red.

To get this to work, magnets and currents push the liquid outward, toward a metal plate, while flowing liquid,
removes heat.

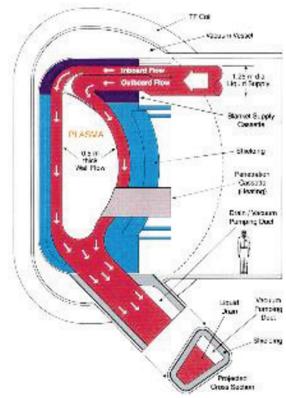


Figure 4.2: Plasma radiates against liquid wall (red), held in place against metal plate (blue) by electrical currents and by magnet fields. Ref: 2001 paper by Dr. Mohamed Abdou.

Internal Cooling System

The alternative cooling method is to expose a 2mm thick metal plate to the plasma radiation, and cool it by flowing molten liquid along its back surface, within channels.

However, radiation from the plasma eventually damages the metal plate,
requiring replacement every one to five years.

Frequent replacement necessitates disassembly,
which is expensive.

Therefore, it is more cost-effective to protect the metal plate with a flowing liquid metal wall, and only assemble the machine *once* during its lifetime.

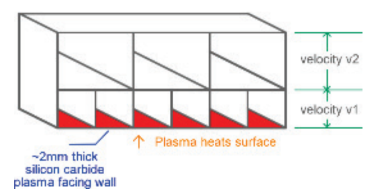


Figure 4.4: Liquid flows in channels behind metal plate (red) and removes heat.

In other words, liquid metal wall costs less.

However, it is a new technology, and more experiments are needed to verify feasibility.

3D Magnet Printing

Stellarators require irregularly shaped magnets to confine plasma, and these magnets are expensive to fabricate using traditional methods. However, in theory, they could be made by placing alternating layers of superconductor and “insulator” onto a rotating tube via an additive process such as ion deposition. For example, one might place five irregular shaped magnets onto each of 12 tubes, and place a large magnet at the end of each tube—as illustrated here.

This could potentially reduce costs;
however, this is also a new technology,
and needs to be verified with experiments.

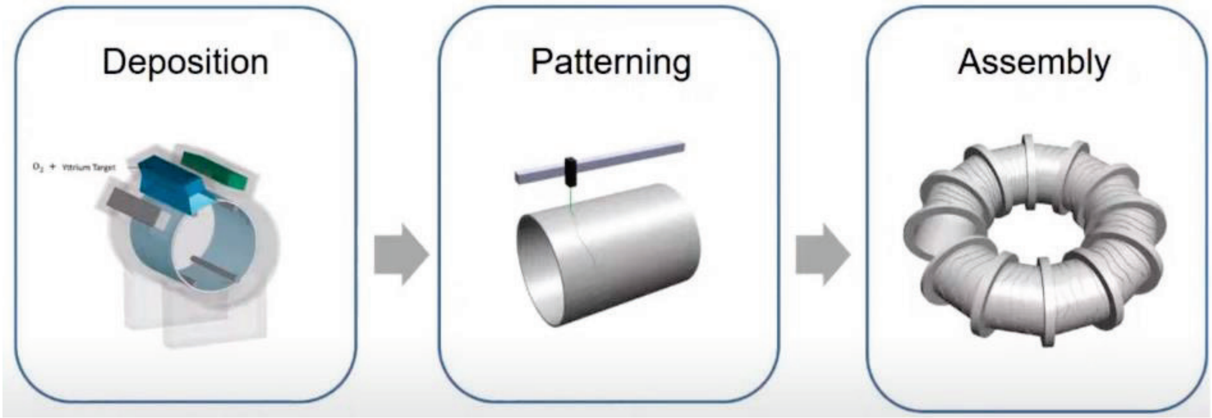


Figure 4.5: 3D magnet printing. Courtesy Renaissance Fusion.

Economic Fusion Design Published in 2024!!!

In theory, researchers can design a fusion machine entirely on paper, and calculate the cost to generate electricity.

This has been done, and a design that achieves economic fusion was published in 2024 .

It uses liquid metal wall, and 3D printed magnets, to reduce costs.

Current Fusion Efforts Will Not Solve the CO_2 Problem

The U.S. government currently allocates $800 million dollars annually to basic fusion research.

This is spread out among different technologies, instead of focusing on one design.

Therefore, it is not likely to achieve economic fusion any time soon.

The leading fusion company is Commonwealth Fusion Systems.

They hope to build a fusion machine in the 2030s that generates electricity. However, it would be paid for by investors, and therefore generate expensive electricity.

In the best case, this company is not expecting to generate competitively priced electricity before 2040.

In other words, both government and corporate efforts are not designed to fend off climate tipping points.

That would require moving faster, and at a higher funding level.

More Money for Fusion

Lab Goal - Statement

It is our intent to develop a fusion reactor that produces electricity at a cost less than fossil fuel based electricity.

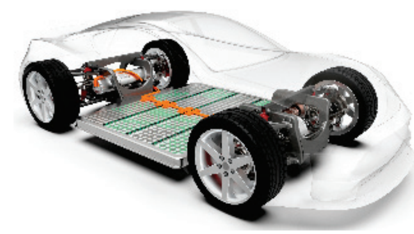
For details, click on the link, in the description below .

Okay, that's it for me, and I'll talk to you all, real soon.

Lab Goal - SLIDE

Develop a fusion reactor that produces electricity at a cost less than fossil fuel based electricity.

Video #20: Swappable EV Car Battery



Hi, my name is Glenn Weinreb, and today we're going to look at how a swappable EV battery standard could help decarbonize cars .

The Fast Charging Problem

In the past, what did you see while glancing at fast charging stations? Did you see cars charging? In many cases, charging stations are underutilized.

The equipment cost-per-charge is determined by the equipment cost, divided by the number of charges.

Therefore, the cost-per-charge is high when the number of charges is low.

This causes fast charging to typically cost three times more than slow charging at home.

This, along with charging inconvenience, causes EV owners to rarely fast charge.

The High Power Problem

The greatest challenge with fast charging cannot be seen. It is electrical power. The typical 50 kilowatt-hour EV battery consumes 100 kilowatts of power when charging in 30 minutes. This is the same amount of power drawn by 80 U.S. homes on average. In other words, supporting large amounts of power is expensive, especially if the hardware is underutilized.

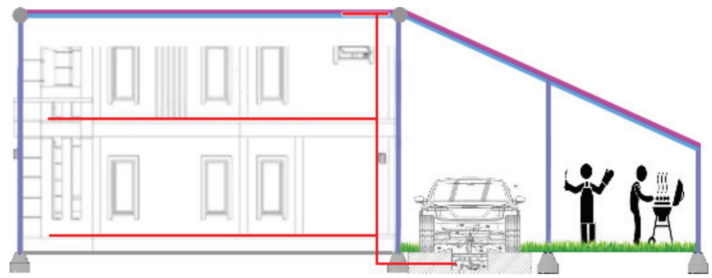
Fast charging hardware that converts grid AC power to battery DC power is very expensive. And this gear is often undersized, to reduce cost. This leads to longer charging times, especially when multiple cars are charging at the same time. And this leads to more range anxiety since drivers often do not know how long it will take to charge, since it depends on who else is charging.

Swappable Standardized EV Battery

There is one way to resolve all these problems. It is a standardized plug-in swappable EV battery. Currently, the world has mechanical and electrical standards that define batteries, and these enable us to power many products at a low cost.

In theory, one could have a standardized car battery that looks similar to the Tesla EV battery, yet is used by multiple manufacturers. The standard would define the mechanics ~~(e.g., height, length, and width)~~, electrical connections, and communication between battery, car and swap station. ~~This is not a new idea. For a video that discusses this, click here.~~

Currently, proprietary batteries are built into EVs and are charged periodically. Alternatively, one could have a standard plug-in battery, wherein all cars use the same form, and swap with a fresh battery in several minutes. Car owners would pay for electricity consumed and wear on the battery; and would pay less when using lower-cost batteries.



Also, homes could install swap chambers in their driveway with multiple batteries, as illustrated here. These could be charged by solar during the day, power the house at night, and swap with cars as needed.

Swap Costs Less

Batteries that only slow-charge, cost 2 to 3 times less per mile, than batteries that can fast-charge.

Put a little differently, batteries that are designed to never fast-charge, last longer and cost less.

Therefore, those who drive less than 150 miles or 250 kilometers per day,
and never fast-charge,
could swap in a small slow-charge-only battery, and save money.

Alternatively, for long trips, they could swap in an expensive high-range fast-charge battery;
or swap more often.

Also batteries sitting in swap stations could charge slowly over multiple days. This would reduce costs by drawing cheap power at 3am, and avoiding expensive fast-charging hardware.

Regional Differences

Regions that import significant amounts of oil, such as China and Europe, would probably lead the way with standardized swappable batteries, since EVs reduce dependence on foreign oil. In contrast, the U.S. produces oil, and is therefore less interested in EVs. However, as adoption increased in regions fond of EVs, economies of scale would drive down costs,
eventually making swap more attractive,
to regions less supportive of EVs.

Standards Development

Cars with swappable batteries already exists.

For example, a company in China called Nio makes hundreds of thousands of EV's annually with swappable batteries. However, their technology is propriety, and we instead are looking at multiple manufacturers that share the same fleet of batteries and swap stations.

This requires standards that define
how batteries mechanically and electrically attach to cars and swap stations,
how batteries communicate with cars, and
how cars communicate with swap stations.

Automakers would not be inclined to invest in a swappable system controlled by a competitor. Therefore, a neutral entity would need to oversee the design, prototype and testing of related gadgets. And to encourage widespread adoption, developed technology would need to be disseminated freely.

Lab Goal - Statement

It is our intent to develop free and open swappable EV battery standards.

For details, click on the link, in the description below .

Okay, that's it for me, and I'll talk to you all, real soon.

Lab Goal - SLIDE

Develop free and open swappable EV battery standards.

Video #21: Next Generation Building Automation

Hi, my name is Glenn Weinreb, and today we're going to look at how a next generation,
building automation system,
could potentially reduce cost, reduce carbon dioxide emissions, and increase comfort.

For example, automation could help control the temperature of each room,
and help move heat from one room to another.

A Chip in Every Device

To fully automate buildings, we would need to place a microprocessor chip in every device, and connect all devices with reliable communication.

Devices include things like light switches, light sockets, HVAC equipment, appliances, motorized dampers in ducts, fans in ducts, occupancy sensors, temperature sensors, and fire detectors.

To facilitate global acceptance, and ensure bug-free operation,
the same free and open,
operating system software,
would need to be installed on all devices.

This is easy to do, since these already exist, they are relatively simple, and they are free.

Reliable Communication

When one flips a physical wall light switch, the communication between the switch and the ceiling bulb is operational ≥ 99.999% of the time. This is commonly referred to as 'five nines'. This gets little attention, yet is important. Occupants typically do not tolerate less reliability from building infrastructure. It's worth noting that wireless and power-line communication are significantly less reliable, with failure rates on the order of roughly 1%.

To ensure high reliability, a communications data wire would need to be added to power cables {picture}, inside building walls . Fortunately, it would cost little to add this to new buildings.

Light and Heavy Devices

To reduce costs, devices could be divided into two categories: 'Light' and 'Heavy'.

'Light' might consume less than 20 watts and include bulbs, switches, sensors, and small motors;
while 'Heavy' supports 110 or 220 volt ac outlets, HVAC equipment, and appliances.

From a cabling perspective,
'Light' might be supported by 48 volts DC power and one communications data wire;
while 'Heavy' is supported by 110/220 volts AC power, and two data wires.

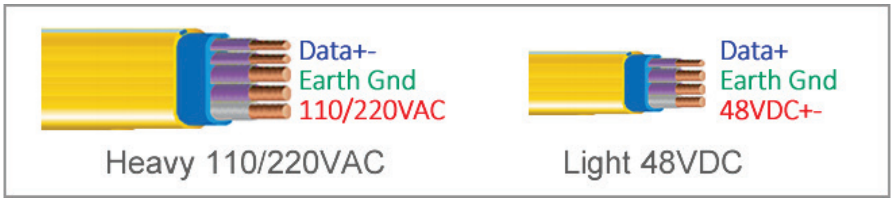


Figure 9.1: In theory, buildings could be supported by two power/data networks, one for large loads, and one for small.

Most devices in a building are 'Light' and could use lower voltages and lower power to save money via multiple techniques.

These include smaller cables, less conduit, fewer safety requirements,
and less expensive power supplies.

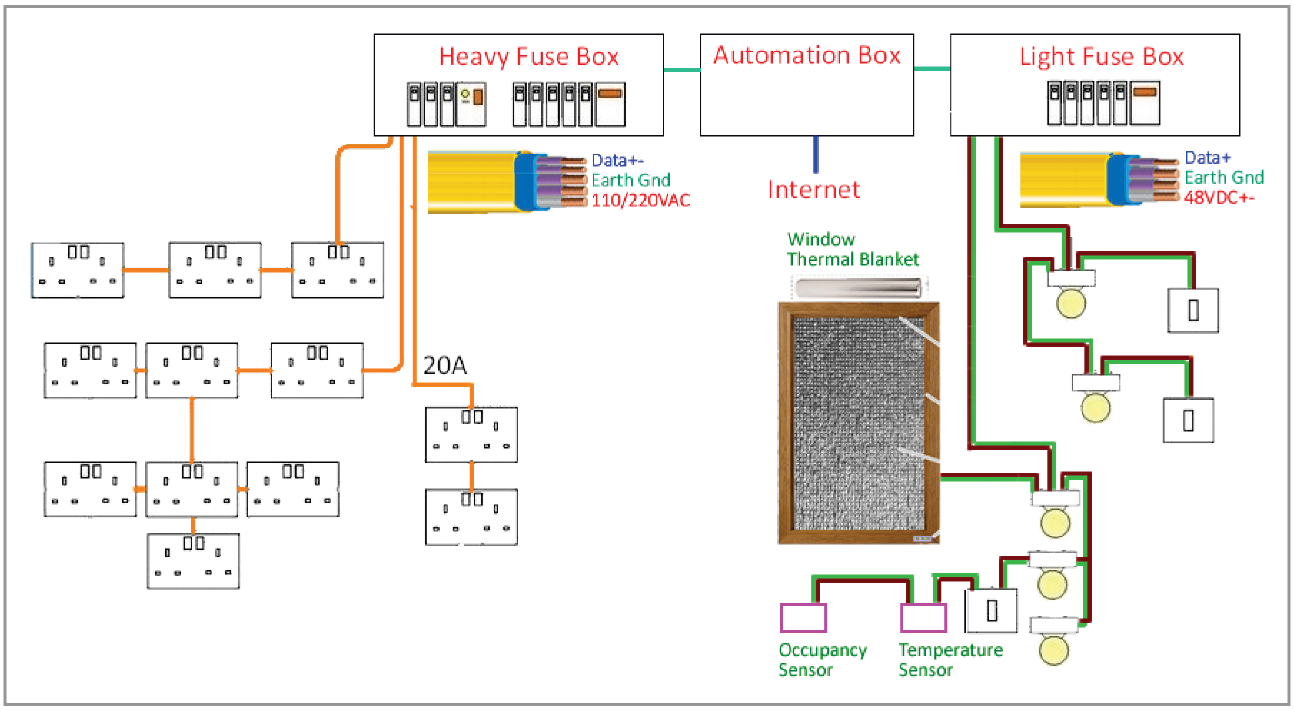


Figure 9.2: In theory, a data wire could be added to power cables in newly constructed buildings to enable reliable device communication.

Plug-and-Play Standards

To support plug-and-play operation, standards would need to define how devices connect electrically, mechanically, and with data communications.

Before these are proposed, components would need to be designed, prototyped, tested, debugged, and improved. This might cost tens of millions of dollars given the size of the system.

So who might fund this initiative, and how might it be structured to meet the satisfaction of the various participants?

Nations resist being controlled by external entities, and therefore might require new standards be based on free and open technology.

Companies cannot afford to give their money to their competitors, and governments rarely provide leadership.

Therefore, a foundation looking to save the planet from climate change might be required. The Gates Foundation is uniquely suited since Bill has experience developing networks, devices, operating systems standards, and automated buildings.

Standards Development

Lab Goal - Statement

It is our intent to develop free and open, next generation, building automation and control standards.

For details, click on the link, in the description below .

Okay, that's it for me, and I'll talk to you all, real soon.

Lab Goal - SLIDE

Develop free and open next generation building automation and control standards.