A Plan to Save the Planet

By Glenn Weinreb

Documentary Film Script

(DRAFT VERSION)

1. Cast

- Host — Someone like Lex Fridman, podcaster

- Prof-Climate — Professor of Climate Science
- Prof-Econ — Professor of Economics
- Prof-Mba — Professor of Business
- Prof-PoliSci — Professor of Political Science
- Prof-Chem — Professor of Chemistry
- Prof-Phy — Professor of Physics

- Prof-Fusion — Professor of Plasma Physics (fusion)
- Prof-Fission — Professor of Nuclear Engineering (fission)
- Prof-ChemEng — Professor of Chemical Engineering
- Prof-Indust — Professor of Industrial Engineering
- Prof-Trans — Professor of Transportation

2. SCENE: Introduction

{Scene: Black Background}

TITLE: A Plan to Save the Planet

What would you do if you knew how to save the planet from climate change?

Lex?: As some of you might know, I am a podcaster that has featured notable guests such as Elon Musk and Jeff Bezos(?).

An interesting question for me personally is "Can a podcaster save the planet from climate change? And if, how might he do it?" Well, this film is my initial attempt to achieve that goal. I love this planet, and want our future to be bright, yet not too bright.

There are basically three types of climate films. Type I examines the problem. Type II looks at what we are doing about it. And Type III looks at what we would need to do to solve the entire problem at the lowest cost to society. No one has ever created a Type III film, possibly because the size of the problem, and the size of the solution, are difficult to comprehend. It is my goal to present the first Type III climate film, and do so in the most humane, and responsible way possible.

Many people are tired of hearing about climate change. For the most part, they have one simple question, "How much does it cost to fix this?" We will provide an estimate shortly.

But first, let's review the problem.

3. Act I - The Climate Problem

{Scene: Professors sitting in an arc, on a stage, in a dimly lit auditorium, Host is at podium}

Introduction

Host at podium: I want to thank everyone for joining us. Today, we're going to talk about the climate problem, and the solution. And we're going to get the unvarnished truth from top university professors. The good news is there is a reasonable path forward that costs little, relative to the size of our economy. The bad news is we are not on that path.

We are here with professors {introduce people on stage}. {Host sits down out of view}

Act I: The Climate Problem

Prof-Climate: Several decades ago, climate scientists stated we need to avoid a 1.5 degree Celsius temperature increase relative to 150 years ago. This implies we are to crest at 1.5 degrees, and then drop back down. Instead, we breached 1.5 degrees in 2023, and we are not cresting. Instead, we are warming rapidly {global temperature increase graphs shows cresting "goal" and "actual"}.

Prof-Chem: Also, carbon dioxide emissions would need to be close to zero at the point of cresting, to cause global temperatures to decrease. Instead, actual emissions are at their highest level, and are increasing {CO_2 emissions graphs shows hitting zero "goal", and "actual"}.

In other words, our society failed to transition to a green economy.

Prof-Chem: It's even worse than that. We never were going to succeed.

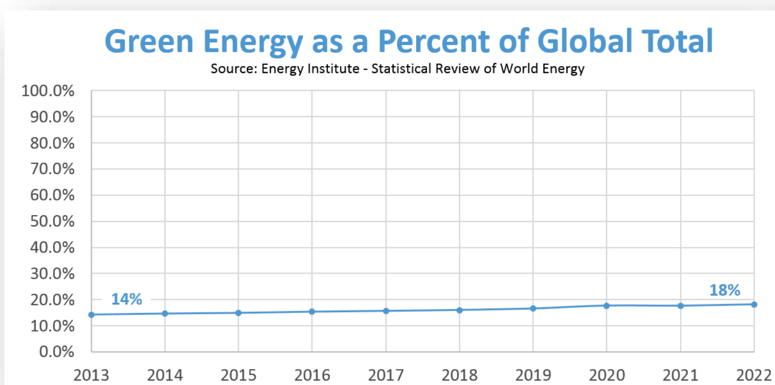
Prof-Econ: To understand why, we must look at this through the lens of economics.

The Prisoner's Dilemma Problem

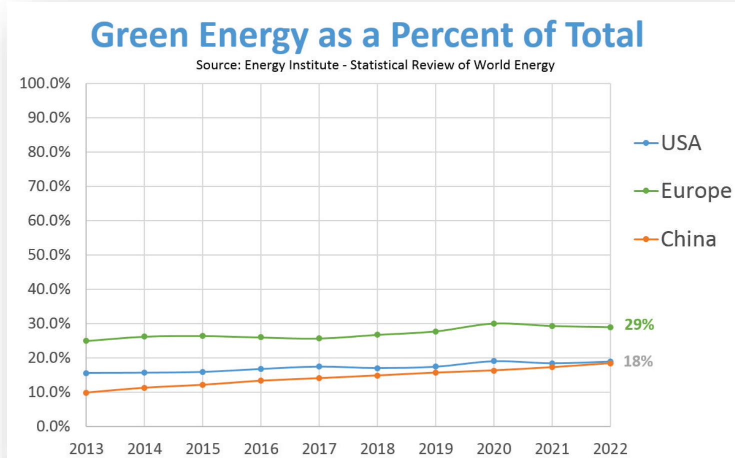
Prof-Mba: Harm comes from carbon dioxide emitted by eight billion people. One person's own carbon dioxide is too small to be relevant. Therefore, each person does not benefit if they reduce their own emissions. Instead, each person wants the other eight billion people to reduce.

Prof-Econ: In economics, this is referred to as a "prisoner's dilemma problem", and according to economic theory, our fundamental strategy of using social pressure to solve the climate problem was wrong from the start.

Put differently, social pressure to decarbonize has little impact. One can see this in a graph that shows the percentage of global energy that does not emit carbon dioxide.



This is all energy, not just electricity. And this is the entire world, not just one nation. As one can see, this has only increased from 14% to 18% over the past decade. At this pace, achieving full decarbonization would take approximately 200 years—far too long to solve the climate problem {graph}



Prof-Econ: We can also look at the U.S., Europe, and China. The U.S. is on track to decarbonize over 250 years, Europe over 175 years, and China over 100 years {graph}.

World:	205	= 10 * ((100%-18.2%) / (18.2%-14.2%))
USA:	245	= 10 * ((100%-18.9%) / (18.9%-15.6%))
Europe:	177	= 10 * ((100%-28.9%) / (28.9%-24.9%))
China:	94	= 10 * ((100%-18.4%) / (18.4%-9.8%))

These graphs tell us social pressure has not, and will not, solve the climate problem.

Decarbonization Law

Prof-Mba: The only way to transition to a green economy, over several decades, is to enact laws that require decarbonization.

Prof-Econ: The problem is, we would have had to enact these laws 30 years ago, to get to zero emissions today, to cause global temperatures to crest at 1.5, and drop back down.

Prof-Mba: Put differently, to solve the climate problem with carbon dioxide reduction, we would have had to enact decarbonization laws 30 years ago, which we did not do.

Runaway Climate Change

Now that 1.5 has been breached, carbon dioxide is no longer our biggest problem.

Instead, our biggest problem is runaway climate change.

Runaway climate change, once considered a fringe theory, is now a sobering possibility that demands our attention. It paints a picture of a world in constant turmoil, ravaged by extreme weather, rising sea levels, and widespread ecological collapse. It is a world where the very foundations of our civilization are shaken.

Tipping Points

At the heart of runaway climate change lies the concept of tipping points. These are critical thresholds in the Earth's systems that, once crossed, trigger abrupt and irreversible 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.

Prof-Climate: Unfortunately, we are currently observing acceleration in thawing permafrost, ocean current reduction, melting sea ice, and global warming itself {show 4 graphs}.

Prof-Chem: Acceleration is observed with actual measurements, so we know it is real.

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

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

Plans A, B and C

Prof-Climate: Unfortunately, we are past the point where reducing carbon dioxide emissions will fix this.

Prof-Phy: The acceleration problem is too great.

Prof-Mba: Ok, if carbon dioxide reduction was Plan A, what is Plan B?

Prof-PoliSci: You're not going to like Plan B {wagging finger at audience}.

Prof-Climate: Plan B is we change the atmosphere slightly, to reflect more sunlight back into outer space. This would cool the planet slightly, and stop acceleration.

Prof-Mba: What happens if we don't do Plan B? What is Plan C?

Prof-PoliSci: You're not going to like Plan C either {wagging finger at audience}.

Prof-Chem: Plan C is we take climate change on the chin, and experience dramatic changes over the next 30 years.

Prof-Mba: This would involve food shortages, mass migration, etc. And dealing with this is costly.

Prof-PoliSci: Do we have other options?

Prof-Climate: Yes. However, they are prohibitively expensive. So no, we don't have other options.

Prof-Mba: In summary, Plan A will no longer fix this; and we are now looking at Plans B and C, neither of which are popular.

Prof-Climate: Also, plan B requires billions of dollars of R&D over the next ten years, which we are currently not doing.

Two Challenges

Prof-Econ: Our society is facing two massive undertakings. One is carbon dioxide emissions reduction, and the other is reflecting sunlight.

Prof-Mba: Reducing carbon dioxide emissions would be done by each nation.

Prof-Phy: And reflecting sunlight would be done by multiple nations, since it involves the entire planet, not just sunlight above one nation.

Prof-Mba: In other words, each nation needs a decarbonization plan, and all nations together need a global climate plan that involves reflecting sunlight.

Prof-Econ: A plan would specify what needs to be done each year, the cost, and new laws that would drive it forward.

Prof-PoliSci: Currently, plans do not exist. However, a website that creates plans could be developed. We'll talk more about this in our film.

{For details, see www.APlanToSaveThePlanet.org/website}

New Climate Laboratory

Prof-Mba: All of this might seem complicated.

Prof-PoliSci: And overwhelming.

Prof-Econ: This begs the question, "Can we have someone take care of this?" I mean, all of this.

Prof-Mba: Currently, no one feels responsible for solving the entire problem.

Prof-Econ: And that is part of the problem.

Prof-Climate: In theory, a new laboratory could be set up to tackle the climate problem.

Prof-Econ: Transitioning to a green economy is likely to cost 100 trillion dollars globally over several decades. Therefore, spending something like 100 billion on a new lab, to save trillions, is reasonable.

Prof-Mba: Let's run some numbers to get a better sense of this.

Prof-Econ: If 100 billion dollars was spent over 5 years, it would cost 20 billion each year. And if 500,000 dollars was spent per technical person, this would employ 40,000 scientists and engineers.

Prof-Phy: This goes way beyond what one university could handle. Therefore, money would need to flow toward many organizations.

Prof-Mba: An example mission statement might be, "Save the planet from climate change, at the lowest cost to society."

Prof-Chem: In theory, faculty at universities, could help set this up.

Yet what might a new lab do to save us from climate change?

We'll talk more about this shortly.

{For details, see www.APlanToSaveThePlanet.org/cs12, and see example lab business plan}

An Engineered Approach to Climate

In summary, our current climate strategy is flawed in multiple ways:

* One, a plan to block runaway climate change does not exist.
* Two, national decarbonization laws have been missing for 30 years.
* And three, there is no mechanism that causes us to favor the lowest-cost approach.

All of this might sound terrible, and it is. However, it can be fixed using basic principles of science, engineering, and economics.

We'll explain this further as we explore a plan to save the planet from climate change.

4. Act II - Reflecting Sunlight without Harm

{Scene: Professors sitting in an arc, on a stage, in a dimly lit auditorium, Host is at podium}

Introduction

Host at podium: We're now going to talk about Plan B, which involves reflecting sunlight back into outer space.

This is a new field, and therefore requires research. The question for scientists is, “How can we reflect approximately 1% of sunlight back into outer space, at a reasonable cost, without causing harm?”

Prof-Phy: We are 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 explore this further.

Sulfur 101

Prof-Chem: 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.

Prof-Mba: 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 (SO_2) are emitted globally into the atmosphere each year.

Sulfur Cools the Planet

Prof-Chem: After SO_2 gas is emitted into the atmosphere, it typically combines with water (H_2O) and oxygen (O_2) 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.

Prof-Phy: 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.

Prof-Climate: A notable example is the 1991 volcanic eruption of Mount Pinatubo, which released SO_2 gas into the atmosphere, leading to a global temperature *decrease* of approximately 0.4°C.

High Altitude Sulfur is Cooler

Prof-Chem: 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.

Prof-Phy: 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.

Prof-PoliSci The latter point is important, since sulfur is harmful, as noted previously.

Multiple Candidates

Prof-Climate: Sulfur-based materials are not the only substances with reflective properties. For instance, calcium carbonate, commonly known as chalk, exhibits similar capabilities.

Prof-Chem: Further research is needed to understand the benefits and drawbacks of each candidate material.

How Much Does this Cost?

Prof-Econ: To justify the expense, we would need to compare the cost of cooling the planet, with the cost of not cooling the planet.

Prof-Mba: 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 $27 per American per year (50% x $18B / 330M).

Atmospheric Reflectivity R&D

Prof-Climate: 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.

Prof-Phy: 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.

Prof-Chem: And, as noted previously, we have a timing problem. To avoid runaway climate change, our society would need to spend significantly more money on atmospheric reflectivity R&D.

Prof-Climate: In summary, Plan B does exist. However, it is not popular, and is therefore mostly being ignored. This is in-part due to our denial that Plan A failed due to undersized decarbonization efforts.

In conclusion, it is reasonable to support Plan B with extensive research and development.

AI Generated Text: Reflecting Sunlight

Reflecting Sunlight *(InVideo Test3 video, Chapter?, "The Ultimate Climate Change Solution: Plan B and Beyond")*
Having explored the limitations of carbon dioxide reduction, we now turn to Plan B -- reflecting sunlight back into space. This concept, solar radiation management, may seem like science fiction, but it is grounded in scientific principles. The Earth's atmosphere already reflects sunlight, a phenomenon known as albedo. By enhancing this reflectivity, we can reduce solar energy absorption. Sulfur, often considered a pollutant, may hold the key to mitigating climate change. Sulfur dioxide forms sulfate aerosols, tiny particles that reflect sunlight back into space.

Engineering the Atmosphere *(InVideo Test3 video, Chapter?, "The Ultimate Climate Change Solution: Plan B and Beyond")*
The concept of intentionally manipulating the Earth's atmosphere to counteract climate change raises complex technical, ethical, and governance challenges. However, the urgency of the climate crisis compels us to explore all viable options, even those that may initially seem outlandish or controversial. Engineering the atmosphere to reflect sunlight is not a simple endeavor; it requires a deep understanding of atmospheric chemistry, climate modeling, and the potential risks and benefits involved. One proposed method involves injecting sulfur dioxide into the stratosphere, the second layer of the Earth's atmosphere. At this altitude, sulfate aerosols can persist for several years, maximizing their reflective effect. Delivery mechanisms could range from modified aircraft to specialized balloons designed for high-altitude release. The amount of sulfur dioxide required to achieve a desired cooling effect is relatively small compared to the massive scale of the Earth's atmosphere.

Costs and Benefits *(InVideo Test3 video, Chapter?, "The Ultimate Climate Change Solution: Plan B and Beyond")*
Evaluating the feasibility of solar radiation management requires a careful assessment of both its costs and potential benefits. On the cost side, initial estimates suggest that large-scale deployment of sulfur-based solar radiation management could be surprisingly affordable, potentially costing a few billion dollars per year. This relatively low cost, compared to the trillions of dollars at stake due to climate change impacts, makes it an attractive option for governments seeking to mitigate climate risks without breaking the bank. However, the economic costs are only one piece of the puzzle. The potential benefits of solar radiation management, while significant, are not without their own set of complexities. By reflecting sunlight back into space, we could potentially slow down or even reverse global warming, protecting vulnerable ecosystems, reducing the frequency and intensity of extreme weather events, and mitigating the risks of sea level rise.

A Race against Time *(InVideo Test3 video, Chapter?, "The Ultimate Climate Change Solution: Plan B and Beyond")*

Given the uncertainties and potential risks associated with solar radiation management, it is essential to proceed with caution and prioritize research and development before embarking on any large-scale deployment. We need to deepen our understanding of atmospheric processes, refine climate models, and develop robust monitoring and control systems to minimize the risks and maximize the potential benefits of this technology. R&D efforts should focus on several key areas. First, we need to improve our understanding of the long-term impacts of sulfate aerosols on the atmosphere, including their effects on ozone depletion, precipitation patterns, and cloud formation. This will require both laboratory experiments and field studies to observe the behavior of aerosols in real-world conditions.

5. Act III - Runaway Climate Change

{Scene: Professors sitting in an arc, on a stage, in a dimly lit auditorium, Host is at podium}

Introduction

Host at podium: We will now talk about Plan C, which is runaway climate change.

In review, Plan A, which is decarbonization, failed. We know this because we breeched the 1.5 degree threshold in 2023, with a rapid warming rate, and high carbon dioxide emissions.

We still have Plan B, which is reflecting sunlight. However, it is being ignored.

Subsequently, we are headed toward Plan C, which involves significant changes to our planet over the next few decades.

This is difficult to discuss for several reasons.

- One, it is upsetting.
- Two, it is difficult to comprehend significant changes to our planet.
- And three, many people still believe plan A is viable, in part, due to decarbonization news reports that appear almost daily.

In spite of these difficulties, we will press forward.

We will begin with a review of tipping points {host sits down out of view}.

Tipping Points

Prof-Climate: Tipping points are additional sources of global warming that *add* to global warming already being done by carbon dioxide.

Prof-Chem: An example is North Pole sea ice. It is one to two meters thick, and when it melts, sunlight is absorbed by sea water, instead of being reflected by sea ice—and this causes the temperature of the planet to increase.

Prof-Phy: There are approximately 5 million square kilometers of sea ice around the North Pole.

Prof-Climate: This is about half the size of the U.S. If this were to melt, the average global temperature would increase by 0.6°C, and this would *add* to the 1.5°C of global warming already done by 150 years of carbon dioxide and methane emissions.

Prof-Econ: In other words, global warming would *accelerate*, due to this tipping point, and other factors.

Thawing Permafrost

Prof-Chem: Thawing permafrost is another tipping point. It releases methane, a greenhouse gas, which also causes the planet's temperature to increase.

Prof-Climate: Unfortunately, more heat causes more permafrost to melt in a self-reinforcing cycle, and this also causes global warming to *accelerate*.

Tipping Points are like Dominos

Prof-Climate: There are approximately a dozen tipping points that are capable of increasing the average global temperature. They do this *after* being activated, and they are activated by heat. In other words, tipping points activate each other, and are therefore like *dominos*.

An Insane Sequence of Events

Prof-Phy: One of the first dominos to tip will probably be North Pole sea ice. After this melts, the Artic region will become warmer, and this will cause snow and ice on Greenland to melt.

Prof-Climate: Unfortunately, this will dump fresh water into the Atlantic Ocean, which will reduce ocean currents {AMOC is expected to collapse in 15 to 40 years}.

Prof-Chem: These currents move heat from the equator to Europe, and a loss of this flux will make the former warmer, and the latter colder.

Prof-Mba: Ultimately, this will lead to less food production, mass migration, etc.

Prof-Climate: As noted previously, a quickly changing planet is a bad planet, and Plan C is a quickly changing planet.

{All of this might sound terrible, and it is. Also, a reasonable path forward does exist. } {We will explore this path in our next video.} {, which we will now review.}

AI Generated Text: Tipping Points

Tipping Points *(InVideo Test1 Video, "Plan C: Runaway Climate Change Explained")*

Tipping points are not abstract concepts; they are real and present dangers. Consider the Arctic sea ice, a vast expanse of frozen ocean that plays a crucial role in regulating global temperatures. As the planet warms, this ice is melting at an alarming rate. The loss of Arctic sea ice is not just a symptom of climate change; it's a driver of further warming. The bright white ice reflects sunlight back into space, helping to cool the planet. As it melts, it exposes the darker ocean beneath, which absorbs more heat, creating a vicious cycle of warming and melting. Another critical tipping point lies in the thawing permafrost, a layer of permanently frozen ground found in high-latitude regions. This frozen earth holds vast amounts of trapped methane, a potent greenhouse gas. As the permafrost thaws, it releases this methane into the atmosphere, further accelerating global warming. These are just two examples of the many tipping points that exist within the Earth's climate system. Others include the collapse of the Amazon rainforest, the disruption of ocean currents, and the melting of the Greenland ice sheet. Each of these tipping points represents a point of no return, a threshold beyond which the consequences of climate change become irreversible.

Tipping Points *(InVideo Test3 video, Chapter15, "The Ultimate Climate Change Solution: Plan B and Beyond")*

Tipping points are critical thresholds in the Earth's climate system that, once crossed, can trigger irreversible and potentially catastrophic changes. These tipping points act like dominoes, each one capable of setting off a chain reaction that amplifies the effects of global warming. Imagine the vast ice sheet covering Greenland, a frozen behemoth holding enough water to raise global sea levels by several meters. As temperatures rise, the rate of ice melt accelerates, pouring freshwater into the North Atlantic. This influx of freshwater disrupts ocean currents, altering heat distribution patterns and potentially triggering a cascade of climate impacts far beyond Greenland's shores.

Sea Ice *(InVideo Test3 video, Chapter16, "The Ultimate Climate Change Solution: Plan B and Beyond")*

The Arctic, often described as the canary in the coal mine for climate change, is warming at an alarming rate, twice as fast as the global average. This rapid warming is having profound effects on the region's delicate ecosystem and is a stark warning of the global consequences of unchecked climate change. The most visible impact of Arctic warming is the shrinking of sea ice, which has declined dramatically in both extent and thickness over the past few decades. This loss of sea ice has far-reaching consequences. Sea ice acts as a giant reflector, bouncing sunlight back into space and helping to regulate global temperatures. As sea ice melts, the darker ocean absorbs more solar radiation, further amplifying warming in a positive feedback loop. This phenomenon, known as Arctic amplification, is contributing to rising sea levels, altering weather patterns, and disrupting marine ecosystems.

6. Act IV - The Climate Solution

{Scene: Professors sitting in an arc, on a stage, in a dimly lit auditorium, Host is at podium}

Introduction

Host at podium: We will now look at how to solve the entire climate problem at the lowest cost to society. This is not being done, yet could be done.

We will begin by exploring the concept of decarbonization plan {host sits down out of view}.

Decarbonization Plan

Prof-Econ: Lawmakers are not inclined to support major changes to their economy without a detailed plan. This does not exist, yet could be developed.

Prof-Mba: A detailed plan would be a list of decarbonization initiatives to be implemented each year, over the next few decades. For each initiative, the following would be estimated: cost ($), tons of carbon dioxide reduced (tCO_2), and the cost per ton of carbon dioxide reduced ($/$tCO_2$).

Prof-Econ: Government-employed energy economists are capable of estimating these values, and are somewhat trusted by lawmakers. Therefore, they would probably be needed to help formulate a climate plan. However, they will only act if commissioned by lawmakers, and driven by a guiding principle.

{See inVideo Test3 video Chapter 19 for text describing decarbonization plan}

Grand Climate Bargain

Prof-PoliSci: To achieve majority support, the guiding principle would need to meet the satisfaction of both liberals and conservatives who are concerned about climate. Survey data indicates 67% of Americans are concerned about climate change, suggesting bipartisan support is achievable. Based on statements made by lawmakers on both sides, the following guiding principle would probably receive support.

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

Prof-Econ: 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 decarbonization rate, and fraudulent offsets. Requirements, on the other hand, do not have these problems.

Lowest Cost Order

Prof-PoliSci: Many lawmakers ask, “Why spend $200 to reduce emissions by one ton of carbon dioxide when we can do it for $20?” This implies they want to decarbonize in lowest-cost order. For example, tackle $20-per-ton initiatives first, followed by $25-per-ton.

Plan Development

Prof-Mba: A 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 {website reference}.

Prof-PoliSci: 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.

Prof-Econ: 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.

{See inVideo Test3 video Chapter 20 for text describing grand climate bargain}

Let Capitalism Fix This

Prof-Mba: For the most part, government needs to *require* transitioning to a green economy. For example, power companies could be required to decarbonize the grid by 2035. Builders of solar farms and wind farms would then compete with each other, and drive down costs.

How Much Would This Cost a U.S. Homeowner?

Prof-Econ: Let's calculate the additional cost of a green grid for the typical U.S. homeowner.

Prof-Chem: On most home electric bills, electricity consumption is specified in units of kilowatt-hours. For example, operating a vacuum cleaner for an hour uses approximately 1 kilowatt-hour of electricity.

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

Prof-Econ: Green electricity, which is produced without emitting carbon dioxide, typically costs 1 to 2 cents more per kilowatt-hour than non-green electricity. Currently, 40% of U.S. electricity is green; therefore 60% needs to be decarbonized. If this were done over 12 years, then 5% would be decarbonized each year. According to the math, 5% of 10,000 at an additional 2 cents 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.

5% = (60%/12)
$10 = (5% x 10,000 x $0.02)

Int'l Climate R&D Agreement

Prof-PoliSci: Nations meet annually at COP conferences to supposedly agree on how to tackle climate change. However, in many cases, little is achieved. This is partly due to conference attendees' lack of authority to create laws. So what is an intermediate step, short of real decarbonization, that nations might agree to? One possibility is for nations to commit to spending 0.01% of their annual GDP on additional climate R&D. In the U.S., this would equate annually to about $2.7 billion, or $8 per American.

Prof-Phy: Nations would need to agree on what constitutes "*additional* climate R&D." These would be things that are *not* currently being pursued, and have the potential for significant impact {example list}.

Global Climate Strategy

Prof-Climate: In theory, a national leader could ask government scientists to calculate how much sunlight needs to be reflected to block cascading tipping points, and identify how to do this at lowest cost, without harm.

Prof-Mba: Currently, a global climate plan does not exist; however, with a little prodding from leadership, it could be developed.

How Much Does it Cost to Fix This?

Prof-Mba: Resolving climate change involves three basic questions:

- How can we solve the entire climate problem at the lowest cost to society?
- What actions would this entail?
- How much would this cost?

Prof-Econ: An estimate is provided here.

	Year 1	Year 2	Year 3	…	Year 10	…	Year 20	…	Year 30
Planet Cooling R&D	$5	$5	$5	…	$5	…	$5	…	$5
Planet Cooling Op.				…	$27	…	$27	…	$27
Green Premium	$10	$20	$32	…	$142	…	$445	…	$727
More R&D	$8	$8	$8	…	$8	…	$8	…	$8
TOTAL	$22	$33	$45	…	$182	…	$485	…	$767

Prof-Econ: All numbers are in units of dollars cost per American, per year. Europeans would see similar numbers. These costs would show up as an increase in the cost of goods and services, in addition to government spending.

Prof-Chem: This table divides costs into three areas: reflecting sunlight or "planet cooling", the additional cost of green products known as the "green premium", and additional R&D. It is assumed decarbonization occurs at a constant rate, over 30 years, with initial decarbonization costs starting at $20-per-ton of carbon dioxide reduced, and increasing to $80-per-ton.

Prof-Phy: To calculate the additional cost of green products per American during Year 1, one can divide total annual carbon dioxide emissions by 30 years, multiply by $20-per-ton, and divide by the U.S. population. The math works out to $10 ((4.8B / 30yrs) x $20-per-ton / 330M).

Prof-Mba: The left side of the table examines costs for Years 1, 2, and 3; while the right side looks at Years 10, 20, and 30. One might think of these as the "early years" and the "later years." The early years are relatively easy, since decarbonization costs are proportional to the amount of carbon dioxide reduced, and initially this would be small {reference video}.

Tolerance of Costs

Prof-PoliSci: As evidence of climate harm continues to grow, the public's willingness to bear decarbonization costs is likely to increase. To address climate change, we need costs to stay below tolerance-of-costs as we go through time.

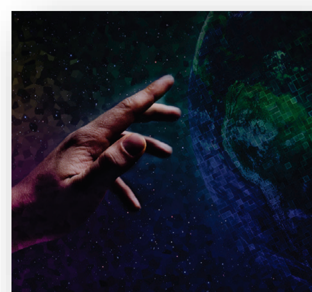
Prof-Mba: For example, we need the public to accept approximately $35 per American per year, during the early years, when people are moderately concerned about climate. And accept hundreds of dollars per American per year, during the later years, when people are more nervous.

The Early Years

Prof-Econ: 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. This would cost roughly $20-per-ton of carbon dioxide reduced.

Prof-Phy: During this initial period, billions of dollars could be spent on R&D for commercial fusion and improved fission. Either of these might be needed for times when the sun does not shine, and the wind does not blow.

Reflecting Sunlight



Prof-PoliSci: Currently, people do not want to touch the atmosphere. However, this will probably change as climate observations provide evidence that touching is easier than not touching.

Prof-Phy: Therefore, a reasonable strategy is to conduct reflectivity R&D while public opinion evolves, followed by small-scale pilot projects, and ultimately large-scale implementations.

Prepare to Panic

Prof-Climate: At some point, climate observations will probably cause our society to panic.

Prof-Econ: When and if this occurs, we need to be prepared with a lowest-cost approach. Otherwise, we are at risk of running out of money before making significant progress.

Prof-Mba: Fortunately, preparing to panic is relatively inexpensive since it only involves plan development, more R&D, and small-scale operations.

We'll talk more about this as we explore a plan to save the planet from climate change.

7. ACT V - Real Decarbonization

{Scene: Podcast host at table with professor of Chemical Engineering (Prof-ChemEng)}

Host: Transitioning from fossil fuel to a green economy is a daunting task. Yet how might we do this, for real?

We'll explore this with our guest {introduce guest}.

Prof-ChemEng: Glad to be here.

Problem Size

Host: How big is our carbon dioxide problem?

Prof-ChemEng: We know how much energy is consumed worldwide each year, and we know how much is produced by a large facility such as Hoover Dam. To get a sense of the problem size, we can divide these two numbers to calculate how many Hoover Dam equivalents, we would need, to replace global energy. The math works out to approximately 17,000 Hoover Dams.

Host: You are referring to all energy, not just electricity.

Prof-ChemEng: Yes.

Requirement Law

Host: How might our society cope with this large problem size?

Prof-ChemEng: There is only one way to deal with this, and that is new laws that require decarbonization.

Host: What is an example *requirement* law?

Prof-ChemEng: In 1970, the United States passed the Clean Air Act. This required producers of electricity and chemicals to emit less air pollution. To comply, they filtered more, and passed additional costs onto consumers. All operators were subject to the same requirements. Therefore, no one gained an unfair advantage.

Host: Problem solved?

Prof-ChemEng: Yes.

Host: So new requirement laws could potentially reduce carbon dioxide emissions to zero?

Prof-ChemEng: Yes.

Getting to Zero CO_2 Emissions

Host: Let's run through the numbers to get a better sense of this.

Prof-ChemEng: Ok. The US is one-seventh of total carbon dioxide emissions. This means the US could decarbonize to zero, while the rest of the world continues to emit carbon dioxide, and burn up the planet.

Host: You mean we need many nations to decarbonize.

Prof-ChemEng: That's right. Let's assume all nations decarbonize over 30 years at a constant rate. In other words, they reduce carbon dioxide emissions 1/30th each year, for 30 years, to get to zero, 30 years from now.

Host: Ok.

Prof-ChemEng: And let's assume this applies to all nations, not just the United States.

Host: Ok.

Prof-ChemEng: And let's assume decarbonization occurs in lowest cost order, since political support goes down, when decarbonization cost goes up. In other words, easiest first.

Host: Ok.

Prof-ChemEng: Roughly one-third of carbon dioxide emissions are from electrical power generation, one-third from material and chemical fabrication, and one-third from transportation.

Host: Ok.

Prof-ChemEng: The easiest is electrical power and some transportation. Therefore, a nation could focus on these, and ignore the more difficult areas, during the early.

Host: As long as emissions decrease 1/30th each year, the nation is on track.

Prof-ChemEng: Yes, and evidence of climate change increases each year, therefore one can tackle the more difficult areas later, when people are more nervous, and willing to spend more money.

The Easy Years

Host: What is an example law that would decarbonize electrical power generation?

Prof-ChemEng: Power companies could be required to decarbonize the grid.

Host: How much construction would be needed?

Prof-ChemEng: 40% of US electricity is already green. Therefore, 60% needs to be decarbonized. If you want to reduce carbon dioxide emissions 1/30th each year in lowest cost order, you might decarbonize 5% of electricity each year, for 12 years, or something like that.

Host: How does this compare with what we are already doing?

Prof-ChemEng: During the first 5 years, solar farm construction might be 5-times higher than what we are currently doing.

Host: What would it take to push this forward?

Prof-ChemEng: You would need to meet the satisfaction of three groups. These are Power Company engineers, conservative lawmakers concerned about climate, and bankers who invest in green projects.

Host: What are their requirements?

Prof-ChemEng: Conservative lawmakers are looking for a detailed plan that power company engineers verify as feasible.

Host: Correct me if I'm wrong, yet government can hire power engineers as consultants, and task them with suggesting a decarbonization law that drops emissions $1/30^{th}$ each year, along with an implementation plan. And have it reviewed and reworked until power companies considered it feasible.

Prof-ChemEng: Absolutely.

Host: How might one locate responsible engineers?

Prof-ChemEng: Former CEO's of power companies who are concerned about climate would be a good place to start. They built the grid, and are therefore familiar with how it works.

Host: Is it better to have a law that requires power companies to decarbonize 60% over 12 years? Or a law that requires power companies to decarbonize 25% over 5 years, with additional laws passed later?

Prof-ChemEng: It is much easier to develop a plan that decarbonizes 25% of electricity, than 60%.

Host: Why is this?

Prof-ChemEng: You need to make sure everything fits together, and we know how to do that with the easiest 25%.

Host: What would this entail?

Prof-ChemEng: You can easily get about 25% of your electricity from solar farms; however, going further with solar is less easy.

Host: Why is this?

Prof-ChemEng: The sun burns bright about 6 hours every 24, which is about 25% of the time. If you build more solar farms, you end up discarding electricity. Discarding some is ok. However, discarding a lot is costly. So building out solar to 25% is easy, however, going further with solar is difficult.

Host: We're talking about creating a plan that decarbonizes 25% over 5 years, which matches the sunshine limitation.

Prof-ChemEng: That's right. You can also switch coal based power plants over to natural gas, to drop carbon dioxide emissions 2-fold per unit energy.

Host: Why does it decrease?

Prof-ChemEng: This has to do with the molecules inside the fuel.

Host: So you're talking about sizing the construction of solar farms, and sizing the switching of coal to gas, to support $1/30^{th}$ per year decarbonization.

Prof-ChemEng: For the most part, that's it.

Host: What about wind farms, hydroelectric dams and nuclear power plants?

Prof-ChemEng: You can do some of that. However, many regions do not have high winds. Many regions are not suitable for building a dam. And many regions are not fond of nuclear power.

Host: Ok. What do we do when a cloud passes over a solar farm?

Prof-ChemEng: They need to be paired with fossil fuel based power plants that can increase their output power quickly. Many natural gas based power plants are agile enough to do this. However, many coal based power plants have long ramp-up times.

Host: Does this mean solar farms need to be physically near agile fossil fuel based power plants?

Prof-ChemEng: That's sometimes done. Or you can place them near large power lines that feed metropolitan areas.

Solar Regulators

Host: Is it easy to get land for new power wires?

Prof-ChemEng: In some cases, yes. And in other cases, no.

Host: How might this be resolved?

Prof-ChemEng: It would be helpful if there was a government office that had the authority to demand right of way for new power wires. Also, it would be helpful if they had the authority to amend agreements to buy electrical power.

Host: Let's assume we are looking for support from both liberal and conservative lawmakers. Don't conservative lawmakers resist adding regulation?

Prof-ChemEng: Yes and no. You would need to structure it in a way that met their satisfaction.

Host: What might this entail?

Prof-ChemEng: If additional regulation only applied to generating green energy on designated parcels of land, and these were accepted by local leaders, then federal support would be easy to obtain.

Host: You're talking about Green Energy Production Zones, which add regulation, in return for jobs.

Prof-ChemEng: That's right. Economically depressed regions often accept more regulation in return for economic activity. You don't need to build solar farms where they are not wanted.

Host: So the federal government defines the regulations, and then local leaders sign up for the program, to get jobs.

Prof-ChemEng: That's right.

Solar Bankers

Host: What about bankers that invest in these projects? What do they want?

Prof-ChemEng: Solar farms are built with borrowed money, and electricity revenue pays down the mortgage. Bankers just want to be repaid.

Host: So the solar farms need to hold together for the duration of the loan.

Prof-ChemEng: Yes. However, builders of solar farms need to compete with each other, and are under pressure to cheapen out, to quote lower electricity prices.

Host: Is the bank at risk of a cheap solar farm falling apart before the loan is repaid?

Prof-ChemEng: Yes. And in theory, this could occur witting, or unwittingly.

Host: You mean sometimes the owner knows their stuff is junk and doesn't care, and other times they don't know what they are doing.

Prof-ChemEng: That's correct. And in theory, an owner can sell the entire entity soon after construction, before it falls apart, and blame problems on the new owner.

Host: How might this be resolved?

Prof-ChemEng: It would be helpful if a government office of engineers was tasked with producing a list of requirements for builders of solar farms, which ensure they hold together.

Host: Might this be similar to building codes?

Prof-ChemEng: Yes.

Host: Building codes ensure buildings last a long time, to protect owners and lenders. Without these codes, builders could win contracts with lower bids, due to lower costs, due to less quality.

Prof-ChemEng: That's correct. Solar farms have the same kind of risk. And reporting of technical failures could be required at green energy production zones, to help engineers develop requirements.

Host: So we're talking about trading jobs at these zones, for more regulation, to improve reporting, to improve requirements, to reduce risk to banks, to reduce decarbonization costs.

Prof-ChemEng: That's right. And requirement documents could be shared with other nations, to help them not waste money.

Host: Might fossil fuel companies disrupt these zones?

Prof-ChemEng: They tend to have little power in regions that do not produce fossil fuel. So no, I would not expect that to be a problem. However, a federal law that requires decarbonization would result in a fight between lawmakers concerned about climate, and lawmakers concerned about fossil fuel revenue.

Plan First

Host: What might be a good strategy for those concerned about climate?

Prof-ChemEng: I would develop three plans before fighting anyone.

- The first would be is a detailed decarbonization plan that reduces carbon dioxide emissions $1/30^{th}$ each year for 5 years. This would rely heavily on solar farms, and be developed by power company engineers. New laws would require power companies to decarbonize, and pass additional costs onto consumers.
- The second plan would be a 30-year decarbonization plan that is not required by law, yet instead guides R&D and investment.
- And the third plan would block runaway climate change, at the lowest cost, without harm. This would involve reflecting sunlight back into outer space.

Host: Might oil companies disrupt the development of such plans?

Prof-ChemEng: You need to be more concerned with the people behind you, than in front.

Host: What do you mean?

The Tail Wagging the Dog

Prof-ChemEng: There are a tremendous number of so-called climate people that are involved in high cost-per-ton activity. If you decarbonize in lowest cost order, their jobs would go away, by definition.

Host: So climate people are more likely to disrupt plan development, than oil people.

Prof-ChemEng: Decarbonizing in lowest cost order threatens many so-called climate jobs; and many lawmakers only support decarbonizing in lowest cost order.

Host: You're referring to a catch-22.

Prof-ChemEng: Climate people who are dependent on wasteful spending have produced a mountain of materials that support their programs, and this has resulted in confusion.

Host: This sounds like a case of the tail wagging the dog, where climate people are the tail, and national leaders who want to solve the entire problem at the lowest cost are the dog.

Prof-ChemEng: That's right.

Host: How might the dog gain control over the tail?

Prof-ChemEng: In theory, national leaders could declare they want independent people to score each climate initiative for cost-per-ton of carbon dioxide reduced, and declare they want independent people to develop the three plans I mentioned.

Host: In a sense, the climate problem involves three groups of people. Those who want to solve the entire problem at the lowest cost to society. Those with oil interests. And those who are dependent on wasteful climate spending.

Prof-ChemEng: That's right. And in a sense, the last group is the most dangerous since national leaders often rely on them to solve the problem.

Host: So they are like the fox in the chicken coop, in sheep's clothing.

Prof-ChemEng: Kind of like that.

Climate Costs

Host: How much money might it cost to develop your three plans?

Prof-ChemEng: Plans for large nations might cost 100 million dollars total.

Host: That's small relative to other costs.

Prof-ChemEng: That's correct. Additional R&D might cost 1000 times more than plan development. And decarbonization itself might cost 1000 times more than R&D. So plan development costs little.

Host: What kind of numbers are we talking about?

Prof-ChemEng: Globally we might be looking at 100 million dollars over several years for plan development, 100 billion dollars over 5 to 10 years for additional R&D, and 100 trillion dollars over 30 years to pay for new green infrastructure.

International Climate Strategy

Host: If one nation wants to decarbonize other nations, they could potentially develop tools that identify how others can decarbonize at the lowest cost.

Prof-ChemEng: That's correct. A nation's own carbon dioxide is too small to do them harm. Therefore it is in each nation's best interest to help others identify how to decarbonize at the lowest cost.

Host: Also, technology developed with R&D can be given away to others, for free, to help others decarbonize.

Prof-ChemEng: That's right. If you want to get others to decarbonize, it is easier to pay for their plan development and for their R&D, than to pay for their actual decarbonization.

Host: Attendees at COP conferences seem to spend most of their time talking about how to transfer money from wealth nations to poor nations, to decarbonize.

Prof-ChemEng: This makes no sense. There is no benefit to reducing emissions in Africa at $200 per ton of carbon dioxide reduced, when you can do it for 10-times less in Kansas. In both cases, the molecules swirl around the planet.

Host: Why is decarbonization cost high when a wealthy nation gives money to a developing nation?

Prof-ChemEng: You have overhead costs of international relations people, government people in the developing nation, and fewer requirements that ensure solar farms hold together.

Host: What do you think should be done about the COP conferences?

Prof-ChemEng: I would shut them down and replace them with a one page agreement.

Host: What might you place on that page?

Prof-ChemEng:

- One, nations agree to have unbiased people develop the three plans I mentioned.
- Two, each nation agrees to consider decarbonization laws that reduce emissions 1/30th each year, in lowest cost order, for a handful of years.
- And three, R&D is increased to further reduce decarbonization costs, and developed technology is given away for free, to help others decarbonize.

Decarbonization Plan

Host: What might a decarbonization plan look like?

Prof-ChemEng: There are initiatives that reduce carbon dioxide emissions, and for each, you have a cost to society, a number of tons of carbon dioxide reduced, and cost per ton.

For each year going forward, you would have a table that summarizes initiatives that reduce carbon dioxide. Initiatives would appear in the rows, while those three parameters appear in the columns.

At the bottom of each table you would have the total number of tons of carbon dioxide reduced, total cost to society, and average cost per ton.

You want to see total tons reduced match your 1/30th number. And you want to see the average cost per ton increase with each subsequent year.

Host: So a 30-year decarbonization plan would have 30 tables for 30 years going forward.

Prof-ChemEng: Exactly.

Host: And an example initiative would be a law that requires power companies to decarbonize 5% of electricity each year for 5 years.

Prof-ChemEng: That's right.

Host: And you only need to pass decarbonization laws that cover the next few years, not all 30 years.

Prof-ChemEng: Correct. Tables for the later years are estimates, and provide guidance for how to spend R&D money.

Host: And you do R&D during the earlier years, to reduce the cost of decarbonization during the later years.

Prof-ChemEng: Exactly.

Host: Has anyone ever produced such tables?

Prof-ChemEng: No. A real decarbonization plan has never been produced. Also, nations do not quantify the cost and impact of existing decarbonization initiatives. And they do not have a mechanism that favors the lowest cost approach.

Climate Website

Host: Policy options influence would decarbonization plans. For example, a nation would need to decide how heavily to rely on nuclear fission power. Would it be helpful to have a website produce a plan after the website user specifies policy options?

Prof-ChemEng: That would be fantastic.

Host: So a wealthy person with tens of millions of dollars could potentially develop a plan generation website, to help move this forward.

Prof-ChemEng: Yes. However, they would need to hire the right people if they wanted plans that are trusted by lawmakers

Host: What kind of people?

Prof-ChemEng: I would consider former CEO's of power companies, top climate scientists, and top energy economists that are not dependent on wasteful spending.

Green Economics

Host: Ok. Let's talk about 17,000 Hoover Dam equivalents. This seems expensive.

Prof-ChemEng: Yes and no. We're talking about doing green stuff, *instead* of carbon stuff, worldwide, over 30 years.

Host: What does green stuff include?

Prof-ChemEng: For the most part, this involves building solar farms, building wind farms, building hydroelectric dams, building nuclear fission reactors, and possibly building fusion reactors {ticks off 5 items on fingers}.

Host: And what is carbon stuff?

Prof-ChemEng: That's exploration, extraction, refining, transportation, and storage of fossil fuel.

Host: And fossil fuel is oil, coal and natural gas.

Prof-ChemEng: That's right. If we decarbonize, consumers pay the cost difference between the green stuff, and the carbon stuff.

Host: I see.

Prof-ChemEng: And a website that generates a decarbonization plan would detail these additional costs, given policies specified by the website user.

Residential Solar

Host: If we decarbonize in lowest cost order, what initiatives might be downsized due to wasteful spending?

Prof-ChemEng: From an economics perspective, solar panels on homes are a disaster. Their cost-per-ton of carbon dioxide reduced is about 5 times higher than that of solar farms.

Host: Why is this?

Prof-ChemEng: This is due to overhead costs at each house. When you place 15 solar panels on a house, you need quotes, mechanical design, electrical design, city approval, installation, and inspection. This is repeated for each house, and it costs money.

At a solar farm, you don't incur overhead costs every 15 solar panels.

Host: It seems no one cares if someone else wastes their own money.

Prof-ChemEng: That's part of the problem. The problem size is so large, the world will run out of money if decarbonization is not tackled at the lowest cost.

Replace Not Block

Host: Climate activist seem to want to disrupt fossil fuel production by restricting pipelines, or not issuing drilling permits. Do you consider this wise?

Prof-ChemEng: No. It's a bad way to decarbonize. If you block fossil fuel and increase its price, then the additional cost spreads out over all consumers, and this is very expensive. It cost much less if you replace fossil fuel, instead of blocking it.

Host: How is fossil fuel typically replaced?

Prof-ChemEng: If you build a solar farm, less coal or natural gas is consumed. And the additional cost to the consumer is only the additional cost of the green product. This is the lowest cost way to decarbonize.

Host: So we need to replace fossil fuel, not block fossil fuel.

Prof-ChemEng: Exactly.

Economic Efficiency

Host: Do you favor taxes on fossil fuel?

Prof-ChemEng: That's not the lowest cost way to decarbonize either. Companies will pass the additional cost of the tax onto their customers, and not reduce carbon dioxide. Economists refer to this as inefficiency. Requirements are 100% efficient, while taxes are not. Keep in mind, political support goes down, when unnecessary costs to consumers goes up.

Host: So no new taxes.

Prof-ChemEng: Correct, and you do not need government subsidies either. They add to the deficit. Taxes and subsidies, at large scales, are often not politically feasible.

Energy Workers

Host: How might decarbonization effect workers?

Prof-ChemEng: Green stuff typically costs more than carbon stuff; therefore, the total number of workers would probably increase. However, if a region does not participate in green energy production, their total energy jobs might decrease.

Host: What about states that are active in both green, and non-green energy production?

Prof-ChemEng: Their workers can move from one to the other, in the event one area goes down, and the other up.

Host: So if a worker loses their job, they can drive their truck down the street to a new employer.

Prof-ChemEng: That's right. Texas is a prime sample. They produce oil and natural gas. And they also produce more wind power than any other state. And they are the second largest producer of solar power, relative to other states.

Host: They consider themselves an energy state, not just a fossil fuel state.

Prof-ChemEng: That's right.

Host: Also, politically, Texans are more conservative.

Prof-ChemEng: Yes. However, they are not thinking about politics. They diversify to keep the economy moving, in the event one area goes down, and the other up.

Host: Are Texans concerned about climate change?

Prof-ChemEng: That's a separate issue. But yes, they are very concerned. Texas does not need more heat, they don't need drier soil, and they don't need larger storms along their coast.

Host: It seems we have three separate issues. The first is political conservatism. The second is concern over climate change. And the third is diversification for economic reasons.

Prof-ChemEng: That's right, and last one seems to have the most impact, since it hits people in the wallet.

Energy Investments

Host: Correct me if I wrong, yet managers of capital also diversify.

Prof-ChemEng: Yes. However, green investments over the last decade have underperformed due to low demand for green things.

Host: I suspect this would change when and if government requires decarbonization.

Prof-ChemEng: Yes. However, investors don't know when that might occur.

Host: So they need to figure out timing.

Prof-ChemEng: Yes, and that's difficult to do.

Corporations

Host: How do corporations fit into the climate picture?

Prof-ChemEng: Social pressure pushes on companies to reduce carbon dioxide emissions. These leaves them with two options. They can either decarbonize for real, at great cost. Or they can appear to decarbonize, at low cost.

Host: If a publically traded company spends more money on decarbonization, their profit will decrease, and this will cause their stock price to decrease.

Prof-ChemEng: Yes, and the CEO's is tasked with increasing the stock price.

Host: So you are saying it's their job to put on a show that makes it look like they are concerned about the planet, while minimizing costs.

Prof-ChemEng: Yes, that's how capitalism works.

Host: They often claim their net emissions are zero. How do they justify this?

Prof-ChemEng: They pay organizations several dollars for a document that says their money reduced emissions by one ton of carbon dioxide. These are referred to as “carbon offsets”.

Host: Are they legitimate?

Prof-ChemEng: In many cases, they are fraudulent. For example, if a carbon offset program blocks tree farmers from harvesting trees on one parcel of land, and the trees are instead harvested elsewhere, then carbon dioxide emissions do not change.

Host: So you are saying that if a CEO has to choose between real decarbonization and less profit, and fake decarbonization and more profit, it is their job to select the latter.

Prof-ChemEng: That's correct.

Control Points

Host: It seems like there are lots of gimmicks that supposedly help with climate. However, many are not effective, or not cost effective.

Prof-Chem: There are only a few control points within our economy that can decrease carbon dioxide at large scales and low costs.

Host: So we only need to focus on these, and let everyone else go about their business.

Prof-Chem: That's right. The clean air act of 1970 is an example. It required refineries to filter sulfur out of fuel. We did not push on every corporation, and every building owner to reduce air pollution. Instead, we pushed on a few refinery engineers.

Host: So you are saying our fundamental approach to tackling the climate problem has been wrong from the start.

Prof-ChemEng: That's right. We've been pushing on everyone with social pressure. At best, they put on a show, while minimizing costs, and encouraging others to act. We need to do the opposite, and only push on a few people.

Host: We have an entire industry that makes money by selling climate.

Prof-ChemEng: That's correct, and this has led to confusion, in part because it implies the problem is being handled, which it is not.

Host: Who is more disruptive in solving the problem? The oil people, or the people who are supposedly solving the problem?

Prof-ChemEng: I'm more concerned about the latter.

Host: And you believe we need to develop plans that solve the entire problem at the lowest cost to society.

Prof-ChemEng: That's right.

Host: Seems reasonable.

Prof-ChemEng: I want to thank you for meeting with us.

Prof-ChemEng: My pleasure.

{For details, see Chapter 4 Planet Dashboard in Climate Lab business plan, and see Dashboard website}

8. ACT VI - Improved Nuclear Fission

{Scene: Podcast host at table with Professor of Nuclear Engineering (Prof-Fission)}

Host: Nuclear fission is the traditional form of nuclear power, and it is unpopular due to four main concerns: meltdown risk, nuclear waste, nuclear bomb proliferation risk, and high cost. In theory, more R&D could *improve* these areas, to the extent required by the public.

We will explore this concept with our guest {introduce guest}.

Prof-Fission: Glad to be here.

Improving Meltdown Risk

Host: The public is worried about nuclear fission reactors melting down. How might we resolve this, to the satisfaction of the public?

Prof-Fission: This is easy. Some nuclear fuels do not melt, when not cooled. This is due to additives to the nuclear fuel that cause energy production to decrease, when fuel temperature exceeds normal operation. This is referred to as "negative temperature coefficient fuel".

Also, some fuels reactive with air, water or metal. These are less safe.

If you are looking for safety, consider fuels that do not melt when not cooled, and are not reactive with air, water or metal.

Safe Fission Reactor

Host: What is an example of a commercially operating reactor with these features?

Prof-Fission: The Chinese are ahead of everyone with nuclear reactor design, and construction. They have something called HTR-PM, which is probably the safest commercially operating reactor in the world. Its fuel has the previously mentioned characteristics.

Host: Does this additional safety cost money, relative to traditional less-safe nuclear reactors.

Prof-Fission: Yes. More safety, cost more money.

Host: What might this additional safety do to the typical US homeowner's electric bill?

Prof-Fission: If the home got 30% of its electricity from safer nuclear, this additional safety might cost $30 (?) per year {30% x 10,000kWh/house x $0.01/kWh}.

Reducing Bomb Risk and Waste

Host: What about nuclear bomb proliferation risk, and nuclear waste? What might we do, to improve these, to the satisfaction of the public?

Prof-Fission: For an additional $10 (?) per US home per year, we could do additional processing, to reduce waste {30% x 10,000kWh/house x $0.003/kWh}.

Also, if we worked with thorium fuel, instead of uranium fuel, we could reduce waste, and also reduce nuclear bomb risk.

Host: How much would it cost to develop machines that support thorium fuel?

Prof-Fission: This might cost $10 (?) billion dollars.

Standardized Design

Host: The US built three fission reactors over the last 25 years. They were expensive, and took forever to complete. How might we do better?

Prof-Fission: If one wants to build reactors quickly, they probably need to start with an existing commercially operating reactor, and then copy.

Host: You would need to do this in a way that meets the satisfaction of the public.

Prof-Fission: Yes, and they would want an extra safe design, such as HTR-PM.

Host: How do you drive down cost?

Prof-Fission: In theory, someone could spend money to standardize this design.

Host: Explain.

Prof-Fission: This would entail setting it up so that responsible parties could use the design at a reasonable price.

Host: So they would copy.

Prof-Fission: Yes, but before they copy, the design would be improved to meet the satisfaction of US and European regulators, and then it be certified.

Host: Would you need to build one?

Prof-Fission: Yes, you would need to build it, and then test it to make sure it operates as expected.

Host: And then others can copy, at a relatively low cost.

Prof-Fission: Yes.

Host: How much might it cost to do this?

Prof-Fission: A bank loan could cover some of this, since electricity revenue can pay a mortgage. However, one might need several billion dollars to pay for improvements, certification in the US and Europe, and several cost reduction initiatives.

Improved Nuclear Fission - $20B Climate R&D Fund

Host: Let's assume 20 billion dollars are available to improve nuclear fission power, to the extent required by the American public.

Prof-Fission: Ok.

Host: And let's assume you're in charge.

Prof-Fission: Ok.

Host: How might you proceed?

National Fission Strategy

Prof-Fission: I would start by proposing a national fission strategy, summarized as follows:

- One, we work with nuclear fuels that do not melt when not cooled.
- Two, we work with nuclear fuels that do not react with air, water or metal.
- Three, we develop machines that support thorium fuel production.
- Four, we develop machines that reprocess nuclear waste.
- And five, we set it up so that responsible parties can build a safe standardized reactor quickly, and at a low cost.

Development Strategy

Host: How might you get this started?

Prof-Fission: I would have top fission people put together a list of things that need to be developed, to support a national fission strategy.

Host: And then that would be reviewed by potential funding sources, and improved to meet their satisfaction.

Prof-Fission: That's right. They would need to approve of the suggested fission strategy, and suggested development strategy.

Detailed Proposals

Host: Let's assume you get these approved. Then what?

Prof-Fission: Then top scientists and engineers would write detailed proposals that explain how to develop the things on the list.

Host: What would be in these proposals?

Prof-Fission: They would include things like:

- Rough designs.
- Design models, which are spreadsheets that calculate a variety of parameters.
- And, cost models, which are spreadsheets that add up costs.

Host: And they would need to reference where they got their numbers.

Prof-Fission: That's right.

Proposal Writing Fund

Host: How much would it cost to develop these proposals?

Prof-Fission: There is a wide range of possibilities, since more detail, costs more money.

Host: What if we want detail?

Prof-Fission: If one budgets 10 million dollars, and money is not wasted, then one could get materials with a level of detail that matches the 10 million number.

Host: Who might pay for this?

Prof-Fission: You would need an individual who thinks big to push this forward.

Host: Who thinks big?

Prof-Fission: Many billionaires think big, since they have done big things previously.

Host. So, how might a billionaire get this started?

Prof-Fission: They might set up a proposal writing fund at a foundation.

Host: With large projects, one typically spends small money before medium money, and medium money before big money.

Prof-Fission: That's right.

Host: And the 10 million is small money.

Prof-Fission: That's right. More money would need to follow.

Host: And this would come from foundations and or governments.

Prof-Fission: That's right.

Host: Some people might not consider 10 million dollars to be small.

Prof-Fission: That's correct. However, if you are looking at solving the entire climate problem, you need to think big, since the problem size is big.

Great People are Scarce

Host: Is it possible to develop the needed gadgets quickly, without wasting money?

Prof-Fission: To do that, you need good people. And, unfortunately, they are often busy. Therefore, moving fast, without waste, is not easy.

Host: Correct me if I'm wrong, but you can hire someone to do something, and if they are productive, get them more work.

Prof-Fission: Yes. However, you will only get so much out of the so-called labor market. You need to do the best you can, given what is available to you.

Host: It seems like there are many challenges here.

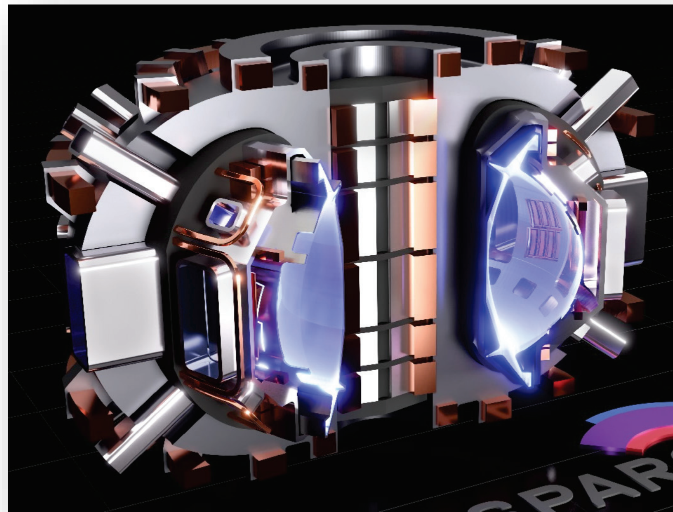
Prof-Fission: Oh yes.

{For details, see Chapter 9 Fission in Climate Lab business plan}

9. ACT VII - Commercial Nuclear Fusion

{Scene: Podcast host at table with Professor of Plasma Physics (Prof-Fusion)}

Host: Currently, scientists are exploring how to generate energy with a hot plasma inside a donut-shaped structure. This is referred as "Tokamak fusion," and some scientists believe it will not be commercially available for another 20 years. However, a billion-dollar sized R&D initiative, overseen by the world's top scientists, could potentially accelerate development.



We are here to today with {introduce guest}.

Prof-Fusion: Thank you for inviting me.

Fusion Moonshot

Host: How might the US accelerate fusion development?

Prof-Fusion: 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 power. For example, they could state that commercial fusion must be operational within several years, and put money behind it.

Commercial Fusion

Host: Exactly what is "Commercial fusion?"

Prof-Fusion: This refers to generating electricity with fusion at a cost comparable to electricity made with natural gas or coal. This requires the fusion reactor to run for long durations, without failure, and at a low cost.

Commercial Fusion within Several Years

Host: - Is it possible to achieve commercial fusion within several years?

- If so, how might you do it, given lots of money?

- How much would this cost?

{For details, see Chapter 8 Fusion in Climate Lab business plan}

10. ACT VIII - Materials and Chemicals

{Scene: Podcast host at table with Professor of Industrial Engineering (Prof-Indust)}

Host: Approximately one-third of carbon dioxide emissions are from making materials and chemicals, and today we're going to look at how we might do this without emitting carbon dioxide.

We are honored to have with us {introduce guest}.

Welcome.

Prof-Indust: Glad to be here.

Host: What does our society make?

Prof-Indust: Well, we make materials, such as metals, plastics, ceramics, glass, and cement.

And we make chemicals, such as fuels, food ingredients, and household chemicals.

Primary Chemicals

Host: What are the main chemicals?

Prof-Indust: The four big are ammonia, ethylene, methanol, and chlorine.

Each of these consumes about 1% of global energy when made.

Host: I see. So together, they constitute 4% of global energy (ref).

Prof-Indust: That right.

Host: How are they used?

Prof-Indust: They are used to make fertilizer and plastics, among other things.

Host: I know chlorine is used in bleach.

Prof-Indust: That's right. Also, 57% of PVC plastic, by weight, is composed of chlorine.

Host: So the white plastic pipes in my kitchen are mostly chlorine?

Prof-Indust: In a weird sort of way, yes.

Liquids and gases are often used to make solids.

Primary Metals

Host: What about making aluminum metal. Does that consume a lot of energy?

Prof-Indust: It consumes about 3% of global energy.

Host: What about steel production?

Prof-Indust: That's about 7%.

Host: So the four big chemicals and two big metals are about 14% of total.

Prof-Indust: Yes.

Green Heat

Host: How does making chemicals and materials emit carbon dioxide gas into the atmosphere?

Prof-Indust: Making things often requires heat, and heat is typically produced by burning coal or natural gas. We sometimes refer to this as "process heat". And when we burn fossil fuel, the exhaust contains carbon dioxide. To decarbonize, we need "green heat", which is heat made without emitting carbon dioxide.

Host: What are some of the considerations when making green heat?

Prof-Indust: The main thing is factories will favor the lowest cost approach, to minimize expenses and maximize profit.

Host: So what costs the least?

Prof-Indust: This would depend on the existing equipment.

- In some cases, this would be green electricity.
- In others, it would be heat direct from a nuclear fission reactor. Or possibly a fusion reactor, if that becomes a reality.
- And in other cases, the lowest cost approach would be to make hydrogen gas with heat from a nuclear reactor, pipe the hydrogen to a different location, and burn it.

Green Heat Demand

Host: Are many companies looking to buy green heat?

Prof-Indust: No. There is no reason why anyone would pay additional money to reduce carbon dioxide emissions.

Host: What about being a good citizen?

Prof-Indust: Climate activists think that encouraging so called good citizenry will do something. The world does not work that way. Companies need to keep costs down to be competitive.

Host: What if government required all competitors to reduce carbon dioxide?

Prof-Indust: They would comply, and pass additional costs onto consumers. However, such laws do not exist. Consequently, there is close to no demand for green heat.

Host: Let's assume evidence of climate harm increases, and decarbonization laws appear within 10 years. And let's assume they require decarbonization in lowest cost order, over 30 years. How might this change the demand for green heat?

Prof-Indust: It costs less to decarbonize electrical power generation, than process heat.

- Therefore, during the first 5 to 10 years, electrical power would be decarbonized by building solar farms and wind farms.
- And after that, process heat would need to step up.

Host: Is there anything we can do now, to reduce the cost of process heat decarbonization?

Prof-Indust: Yes. Many things can be done to prepare for the day, when green heat is in demand.

Co-locating Nuclear Reactors and Industrial Processes

Host: Let's talk about using heat directly from a nuclear reactor.

Prof-Indust: Co-locating nuclear reactors and industrial processes is currently not being done. However, in a green new world, this might change, due to lower costs.

Host: Where might this appear first?

Prof-Indust: China does more with nuclear than anyone. Therefore, I'd put my money on China.

Moving Heat

Host: How does one move heat from one place to another?

Prof-Indust: You can move heat hundreds of meters by pushing hot steam, molten salt, or molten lead through a pipe.

Host: Doesn't salt cause metal to corrode?

Prof-Indust: Stainless steel holds up fairly well. However, you might need to replace pipes every 10 years. Fortunately, this costs little.

Host: Is it difficult to insulate pipes?

Prof-Indust: If you place one pipe inside another pipe, you can pump the air out in-between, and reduce heat loss through air. Also, you can wrap a pipe in multiple layers of foil and thin plastic, to shield heat radiation. Pipes tend to be the easy part.

Host: Does one need to worry about molten salt, or molten metal, solidifying in a pipe?

Prof-Indust: When powering down, molten liquids are pumped into storage tanks.

And heaters inside these tanks either maintain the liquid state, or they re-melt if material solidifies.

Host: Sort of like a pot of tomato sauce simmering on the stove.

Prof-Indust: Kind of like that.

Heat Decarbonization Considerations

Host: In some cases, industrial facilities have been built and paid for, and are not looking to be relocated next to a nuclear reactor.

Prof-Indust: Yes. In those cases, when getting energy from a nuclear reactor, you can either make electricity, transmit it on power wires, and heat with electricity.

Or, you can use a chemical process to split water (H_2O) into pure hydrogen gas (H_2), and oxygen gas (O_2), and pipe the gas to another location, to be burned in a furnace.

Host: Which of these two methods costs less?

Prof- Indust: The electricity generation process is approximately 40% efficient, while a hydrogen/oxygen generation process is more like 80% efficient.

Host: Ok, so when working with a nuclear reactor, the lowest cost method is direct heat from the reactor, followed by piped hydrogen gas, followed by electricity.

Prof-Indust: Yes and no. There are other considerations.

Host: Such as?

Prof-Indust: You need to look at temperature. Those four big chemicals, aluminum and water splitting can be supported directly by a 1000°C high temperature nuclear reactor. However, steel and other metals need higher temperatures. For those, you would need either electricity, or the hydrogen/oxygen gas mixture.

Host: What other considerations are there?

Prof-Indust: If existing equipment currently gets heat from electricity, it might not have room to add a gas furnace. Alternatively, if it currently gets heat from natural gas, it might not have room to add electrical heating elements.

Host: And if switching over to hydrogen gas, you would need a pipe under the road, outside your building, carrying hydrogen.

Prof-Indust: Yes, and if switching to green electricity, you would need the supporting power transmission wires.

Host: Is it easy to get land for wires?

Prof-Indust: Sometimes yes, and sometimes no.

Host: So space around existing processing equipment, and space between facilities and energy sources, influences how engineers might decarbonize, if required to do so.

Prof-Indust: That's right.

Green Electricity

Host: Let's talk about green electricity. What are the primary sources?

Prof-Indust: The big four are solar farms, wind farms, hydroelectric dams and nuclear power {cs10}.


Solar Farms


Wind Farms


Hydroelectric Dams


Nuclear Power

Host: What considerations might be made when working with these?

Prof-Indust: Cost and coverage.

- New nuclear reactors in the US and Europe are expensive, whereas in China, they are reasonably priced. However, this might change in the future.
- Solar and wind power tends to be low cost; however, these are intermittent, and industrial processes are looking for 24x7 coverage.

- Dams provide 24x7 coverage; however, many countries are running out of places to put a new dam.

Host: Nuclear power in China is low cost, and is accepted by their people. Does this mean China is likely to be competitive in a green new world?

Prof-Indust: Very.

Water Splitting Machines

Host: Is it correct that 10's of a percent of our global energy needs could be satisfied by having a nuclear reactor split water into hydrogen gas and oxygen gas?

Prof-Indust: Yes, that's correct. This could be done with a process called "sulfur-iodine". I'll spare you the details.

Host: Can you tell us the short version?

Prof-Indust: Sure. A water molecule is two hydrogen atoms and one oxygen atom (H_2O). If we split this into pure hydrogen gas (H_2), and pure oxygen gas (O_2), we can burn these gases to create heat. Water splitting can be done with a chemical process that is driven by electricity, and heat from a nuclear reactor. This process is 80% efficient, which means 20% of the original energy is lost by heating up the atmosphere around the machine. Ultimately, you can burn the hydrogen and oxygen gases, at a different location, and get back 80% of your original heat.

Host: What is the status of such machines?

Prof-Indust: Since demand is low for green heat, they are not being sold commercially. However, small prototypes are running in the laboratory.

Host: What can we do to reduce cost, accelerate development, and increase the number of companies selling water splitting machines driven by heat?

Green Heat Testing Laboratory

Prof-Indust: It would be helpful to have a building near a nuclear reactor that tests machines that use heat from the reactor. This would help develop water splitting machines. Pipes would carry heat into the test facility, and other pipes would carry hydrogen and oxygen gas out.

Host: Where might the outgoing gas go?

Prof-Indust: It would probably be pipped to a nearby industrial zone, where it would be burned to create heat. Consumers would need to be able to switch to another heat source, if the hydrogen was not flowing well.

Host: What kind of tests might be performed?

Prof-Indust: Engineers would want to run commercial grade machines for long durations, and at maximum power. And if they failed, they would want to see why, and then improve. Each machine might need to be revised several times before it became a viable commercial product. And this might take several years.

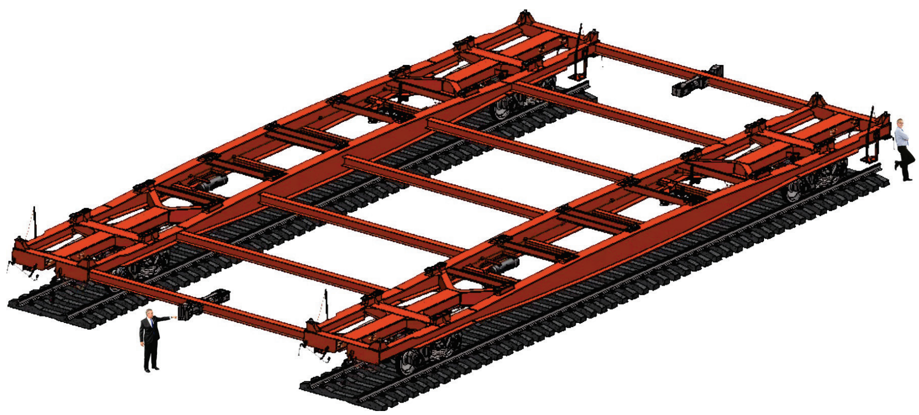
Host: What is the difference between commercial grade machines, and experimental machines?

Prof-Indust: Commercial run for long durations, without failure, and at low cost; while experimental do not. Going from one to the other is sometimes not so easy.

Host: I often see news reports for a so-called "great" new gadget, and later, the new gadget disappears. What is happening?

Prof-Indust: A company that introduces a new product rarely mentions limitations or obstacles. These include things like longevity, durability, and maintenance costs. In many cases, obstacles are not mentioned since the covering journalist has no way to identify them. Ultimately, the public ends up with a distorted view.

Next Generation Super-Sized Transportation



Host: Let's talk about processing equipment that makes chemicals and materials without emitting carbon dioxide.

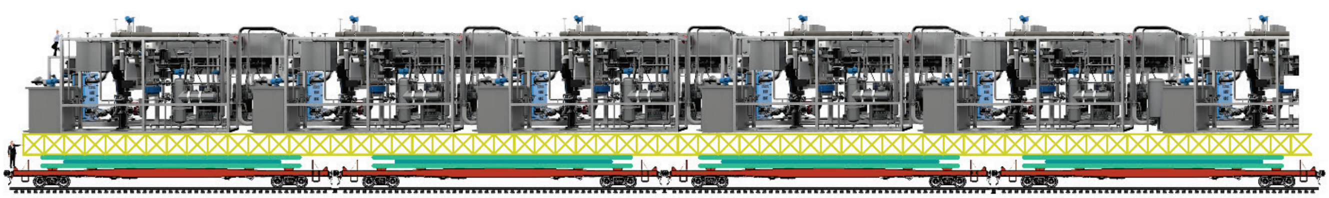
Prof-Indust: Ok.

Host: What can be done to drive down its' cost?

Prof-Indust: If you build an industrial facility in the field, it cost much more than building it at a shipyard, or in a factory. However, it is difficult to transport large platforms of equipment. It would be helpful to have a next generation transportation system that moves large batches of industrial processing equipment. .

Host: How large?

Prof-Indust: If you place two rails 12 meters apart, and you have railcars 12 x 24 meters in size, then 4 railcars could move a platform that is 12 x 100 meters in size.

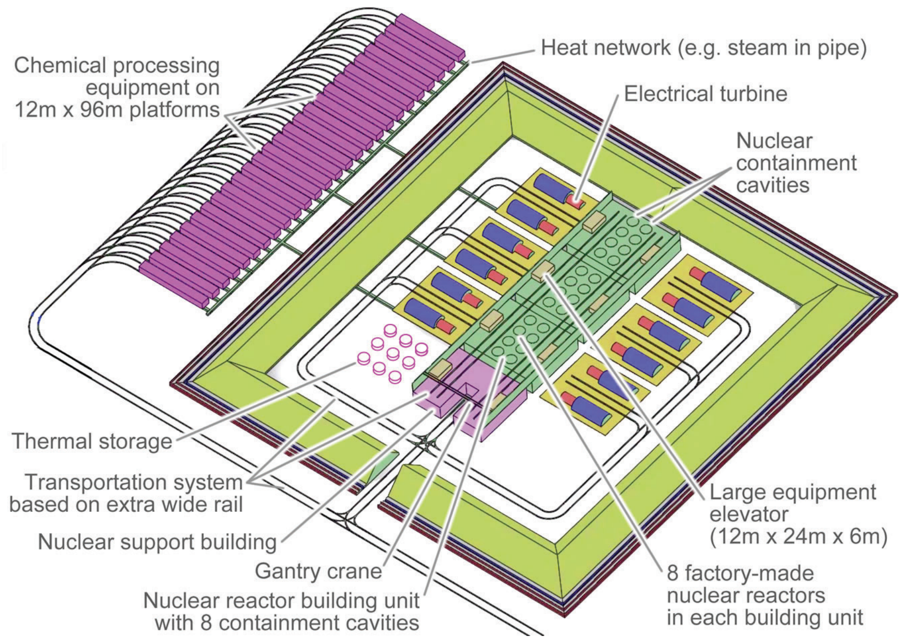


Host: You are talking about rolling the platform on double rail from factory to water, moving the platform to a ship, traveling via ship, moving the platform back to land, and then rolling to site.

Prof-Indust: Yes, that's right.

Host: What would be needed to set this up?

Standards Development



Prof-Indust: This would involve multiple companies, and they would need to agree on how everything fit together mechanically, electrically and with communications.

Documents that define interconnections are sometimes referred to as "standards documents". And, before you have a standard, you need to design the system, build prototypes, and get it working.

Host: How much time might this take?

Prof-Indust: This could take 3 to 10 years.

Host: How much might this cost?

Prof-Indust: This could cost billions of dollars, given the many different components that are needed. However, in the end, you would probably end up with a method to decarbonize industrial processes quickly, and at a low cost.

Host: Is it easy for companies to agree on how things fit together?

Prof-Indust: They often have one primary requirement. They don't want someone else to control the interconnection technology, and charge any amount to use it. In other words, they prefer developed prototypes be based on free and open technology, as opposed to a proprietary system owned by a competitor.

Host: So who might pay to develop the prototypes?

Prof-Indust: This might be a foundation or government looking to save the planet from climate change.

Host: In a sense, they make their money by avoiding the harm of climate change.

Prof-Indust: Something like that.

5,000 Nuclear Reactors

Host: Let's talk about nuclear reactors. How many do we need to replace coal, oil and natural gas?

Prof-Indust: How much coal, oil and natural gas are we talking about?

Host: Let's say all of it.

Prof-Indust: Ok. If each reactor is 1 gigawatt, you might need to build 5,000 reactors worldwide over 30 years (1e9GW x 24hrs/day x 365days/yr / 1e12TWh/yr = 8.8 TWh/yr; 56,000TWh/yr / 8.8TWh/yr = 6,300 reactors).

Host: It seems like it takes forever to build just one reactor, and in many places, they are expensive.

Automated Construction

Prof-Indust: Yes, that's why we should consider automating construction.

Host: Explain.

Prof-Indust: In theory, supersize transportation could help to deliver, mix and dispense concrete; among other things.

Host: How much might it cost to set this up, to the point of working prototypes?

Prof-Indust: You are looking at billions of dollars.

Host: Who might pay for this?

Climate Money vs Investment Money

Prof-Indust: There are two types of R&D money. Climate Money and Investment Money. Climate Money is trying to save the planet from climate change by reducing carbon dioxide emissions. Whereas Investment Money is trying to make more money.

Each of these has constraints. For example, Investment Money will not participate if too complicated, too risky, or consumer demand is lacking. And Climate Money might require engineers to share their work with others, for free, to maximize utilization of developed material.

Host: Where does this money come from?

Prof-Indust: Governments and foundations are sources of Climate Money. While companies and investment funds are sources of Investment Money.

Financial Interests

Host: What about the financials interests of companies and universities?

Prof-Indust: They often prioritize their own financial interests, over climate interests. For example, they typically do not share developed materials unless required to do so. This is because transparency often detracts from: (a) filing patents, (b) developing proprietary products, and (c) raising money for projects.

Climate Interests

Host: If many organizations are focused on their own financial interests, how might sources of climate money encourage recipients to focus on climate interests?

Prof-Indust: They might require developed materials be placed onto the internet, open source. This maximizes the utilization of developed technology worldwide, maximizes candid review, maximizes the development of interconnection standards, and minimizes inaccurate claims.

Host: Do researchers mind open-source requirements?

Prof-Indust: Some researchers prefer open, others do not.

Production Follows Demand

Host: There is a basic principle in economics that says production follows demand.

Prof-Indust: Yes, it implies the following sequence of events.

- One. Accelerating changes to our planet will eventually cause the public to panic.
- Two. This will lead to new laws that require decarbonization.
- Three. This will increase the numbers of customers wanting to buy green things.
- And four. This will cause investors to pay for production equipment that makes green things. This is your hydrogen pipe networks, water splitting machines, etc.

Host: Is it possible to create demand for green things, at large scales, before new laws require decarbonization?

Prof-Indust: No. Economics does not work that way, due to basic principles "production follows demand" and "prisoner's dilemma." The later principle says people do not buy things unless they benefit.

Host: It seems like our society's strategy for tackling the climate problem has been wrong from the start.

Prof-Indust: Yes. The world has been confused about climate, in part because people like me have not done enough, to explain this clearly.

Host: How do you feel about this?

Prof-Indust: I should have done this interview a long time ago.

Host: I appreciate your taking the time to speak openly.

Next Generation Green Energy Production Site

Host: Let's assume we are building 5,000 fission or fusion reactors. We are attaching them to platforms of equipment that make chemicals, including hydrogen. We are transporting platforms using a next generation system. We are automating the construction of these platforms, and we are automating site construction.

Prof-Indust: You're talking about a next generation green energy production site, and focusing on the entire fleet, as opposed to one site at a time.

Host: That's correct. Here's my question. Let's ignore the 5,000 reactors for a moment. How much money would it cost to develop all this stuff, and how long would it take?

Prof-Indust: You are looking at 10 to 30 billion R&D dollars, and 5 to 10 years of development time.

Host: If we are 10 years away from having demand for green heat at large scales, then starting R&D now seems reasonable.

Development Fund

Host: Let's assume we hand you a check for 30 billion dollars after we finish this recording. What might you do with it?

Prof-Indust: Are we going to Vegas?

Host: No. You're building a fleet of 5,000 green energy production sites.

Prof-Indust: I see.

Development Strategy

Host: What would you do first?

Prof-Indust: I would start by making a large pot of coffee. And then I would sit down at my kitchen table, with my laptop, and type out a list of things that need to be developed. For example, with supersized transportation, we need railcars, support ships, and machines that move railcars between ships and shore. And we need to develop interconnections standards so that different companies can make components that fit together.

Host: What about factories that build platforms of equipment using industrial robots?

Prof-Indust: We need that too. I would set up a transparent factory in a shipyard to do this. They are good at handling metal at a low cost. This includes buying, bending, cutting, welding, etc.

Host: Why do you refer to this as a "transparent factory?"

Prof-Indust: This is when you give all materials away for free, so that others can easily copy. You want to save the planet from climate change, right?

Host: Yes please.

Prof-Indust: So the 30 billion is developing technology and giving it to the world for free, to help them build the 5000 sites. I'm not doing that. I'm only building a few. Then others can copy, and not pay for the R&D, since I'm picking that up. This enables the world to decarbonize quickly, and at a low cost.

Host. Right. Ok. How would you handle the different development projects?

Prof-Indust: Each would have several phases. These include rough design, detailed design, building prototypes, testing prototypes, review, and improvement.

Host: How might you find good engineers?

Prof-Indust: In many cases, you don't know what kind of quantity or quality you're going to get when you hire someone. Sometimes the person you supposedly hired, gets someone else to do the work, who is less skilled. To reduce risk of underperformance, multiple teams are typically hired to do a rough design, and then one or two are selected for more work.

Host: A weeding out process, if you will.

Prof-Indust: Yes.

Host: Then what?

Prof-Indust: I would then need to find people to work on the list of things that need to be developed.

Host: And they in turn would make a large pot of coffee, and sit down at their kitchen tables, and get to work.

Prof-Indust: Yes. The development process would propagate.

Host: What would you have these people do?

Prof-Indust: It would depend on the amount of money I had. I could spend almost any amount. More money gets you more R&D.

Host: So we're looking at developing a free and open, next generation, green energy processing site, funded by climate money, to prepare for the day, when decarbonization is required by law.

Prof-Indust: That's right.

Host: Ok. After you get the first one running, we'll celebrate in Vegas.

Prof-Indust: Fantastic. But, don't tell my wife about this.

Host: Vegas or your 30 billion dollar assignment?

Prof-Indust: Both {both laugh, add humanistic element to conversation}.

11. ACT IX - Transportation

{Scene: Podcast host at table with Professor of Transportation (Prof-Trans)}

Host: Approximately one-third of carbon dioxide emissions are from transportation. This includes cars, trains, ships and planes.

For each method of decarbonization, we can calculate the cost to reduce emissions by one ton of carbon dioxide. And many lawmakers are not supportive of measures that costs *more* than $40 per ton of carbon dioxide reduced. Especially at large scales. However, many lawmakers do support less costly activity. Yet what are these with transportation? That's what we're going to talk about today.

We're honored to have with us {introduce guest}.

Welcome.

Prof-Trans: Glad to be here.

Green Electricity

Host: What areas of transportation are easy to decarbonize? The low hanging fruit, if you will.

Prof-Trans: If you have a train that is *already* powered by electricity, you can build a solar farm, or wind farm, and feed green electricity into the train, instead of carbon based electricity. This is easy to do, since the electrical power infrastructure, in the field, is already in place.

Host: How much might this cost, per ton of carbon dioxide reduced?

Prof-Trans: This typically runs $20 per ton.

Host: So anything that already uses electricity is easy to decarbonize.

Prof-Trans: That's right.

Automobile Economics

Host: What about cars? What can we do that's easy?

Prof-Trans: If the total cost of the electric car is less than the total cost of the gas car, then the electric car owner will be paid to decarbonize.

Host: And the cost per ton of carbon dioxide reduced becomes negative.

Prof-Trans: That's right.

Host: I take it total cost refers to the cost of the car, plus the cost of the fuel.

Prof-Trans: Correct.

- With gas cars, this is the cost of the car, plus the cost of gasoline.
- And with electric cars, this is the cost of the car, plus the cost of the replacement battery, plus the cost of the electricity.

EV vs. Gas Cost Comparison

Host: Let's look at some numbers to get a better sense of this.

Prof-Trans: Ok. The Toyota Camry Hybrid gas car is one of the biggest sellers in the US. It averages 50 miles per gallon city plus highway, and it typically travels 200,000 miles over its lifetime. One can do some math to estimate lifetime gas cost of 13,000 dollars ($3.20/gallon x 200e3miles/50mpg), given the current US price of $3.20 per gallon. If we add this to the 30,000 dollar car cost, we get 43,000 dollar total lifetime cost.

Host: Ok. How does this compare to a low end Tesla?

Prof-Trans: A Model 3 or Y after rebates typically costs 38,000 dollars. A replacement battery typically costs 15,000 dollars, and residential electricity for 200,000 miles typically costs 9,000 dollars (200e3miles x ($0.14/kWh / 3)). We add these up and get 62,000 dollars total lifetime cost (38+15+9).

Host: Ok, so the electric costs 19,000 dollars more than the gas car.

Prof-Trans: That's right, and this is why more Americans are not rushing out to buy EV's.

Half the Car for Half the Money

Host: How might we make EV's more competitive?

Prof-Trans: Two things.

- One. If we reduce range two-to-one, for example, then battery costs decrease two-to-one.
- And two, if a car is not capable of fast charging, then battery longevity increases. And if we can get 200,000 miles out of a battery, instead of 100,000, then battery costs decrease another two-fold.

Host: So an EV that cannot fast charge, and only has a 150 mile range, would cost less.

Prof-Trans: That's right.

Host: How much less?

Prof-Trans: Well, if it takes two 15,000 dollar tesla batteries to get 200,000 miles, then your total battery cost is 30,000 dollars. If you decrease the range two-fold, and go to slow charging only, then you can decrease your battery cost 4-fold, and reduce the 30,000 dollars to 7,000 dollars.

Host: So you drop your 62,000 dollar total cost by 23,000 dollars, and get that down to 39,000 dollars.

Prof-Trans: That's right. And 39,000 is 4,000 less than the 43,000 dollar gas car.

Host: I see. The electric is now costing less than the gas car.

Prof-Trans: Exactly.

1 ½ Car Family

Host: Who might buy a car such as this?

Prof-Trans: A guy who drives 10 miles to work each day might have his wife and kids take the gas car, while he uses a cheap electric to get to work.

Host: You're talking about a one-and-a-half car family.

Prof-Trans: That's right. This is a sub-market, and if you're looking at decarbonizing cars in lowest cost order, this would probably come first.

Host: What percentage of US car buyers might consider a cheap electric?

Prof-Trans: Perhaps 15% (?). Right now, approximately 8% of US cars sold are EV's, and if you increased this to 23%, that would be a decent step forward.

Host: Why don't we see more cheap EV's on the road?

Prof-Trans: Automakers have an average selling price per customer. If this number decreases, revenue decreases, and stock price goes down.

Host: Ouch.

Prof-Trans: Therefore, they are not interested in selling less car.

Host: How might we change their minds?

Prof-Trans: There are several techniques.

Host: Such as?

Prof-Trans: You have things like automaker requirements, tax credits, and making it easier for new car companies to get started with this kind of car.

Fast Charging is Not Easy

Host: Automakers talk about fast charging in 30 minutes. However, in practice, it is often larger. Why is this?

Prof-Trans: One typically needs 80 homes worth of power to do that, and hardware that supports this is expensive. For this reason, fast charging equipment is often undersized, to save money.

Host: So fast charging is technically difficult, and therefore expensive.

Prof-Trans: That's right.

Host: It seems automakers are trying to mimic gas cars, with decent range and fast refueling. However, this is not a natural fit with EV's.

Prof-Trans: Right. Less range and slow charging is easier. The low hanging fruit of decarbonization, if you will.

Swappable EV Battery

Host: What else might we do to decarbonize cars, at a low cost?

Prof-Trans: In theory, a system could be set up that supports electric vehicle battery swapping, in addition to typical charging.

Host: How might that work?

Prof-Trans: Multiple EV car manufacturers would share a common fleet of batteries, and swap stations.

And drivers would be charged for battery rental, swap station service, and electricity.

Swap Costs Less

Host: Does this reduce costs?

Prof-Trans: Batteries sitting in swap stations could charge anytime over a 48 hour period. This would reduce costs for several reasons.

Host: Such as?

Prof-Trans:

- One, they could charge at night when electricity is cheap.
- Two, they could charge when solar farms and wind farms are producing power.
- Three, they could charge slowly, and avoid expensive fast-charging hardware.
- Four, they could be placed near large power cables at shopping malls, and get electricity at the commercial rate, which is 30% less than residential.
- And five, drivers could swap-in *inexpensive* low-range batteries that are not capable of fast charging, and slowly charge at home. Battery rental costs would be less with low cost batteries.

Host: Also, manufacturers of cars, batteries and swap hardware would compete, and drive down costs.

Prof-Trans: That's right.

Host: And range anxiety would go away since swap is fast.

Prof-Trans: Correct.

Swap Standards Development

Host: What would it take to get swap started?

Prof-Trans: Someone would need to develop standards that define how the various components connect together electrically, mechanically and with communications.

Host: Who might pay for this?

Prof-Trans: A government or foundation looking to save the planet from climate change.

Host: How much might this cost?

Prof-Trans: Perhaps 100 (?) million dollars.

Host: This is small potatoes relative to the amount of money spent on transportation.

Prof-Trans: Yup.

{Reference: *Do We Need Swappable Standardized EV Batteries?*, EE Times, July 4, 2024}

Ammonia Powered Ships and Trains

Host: What about ships and freight trains?

Prof-Trans: They burn liquid fuels, and the exhaust contains carbon dioxide.

Host: Right. How might we reduce these emissions?

Prof-Trans: If you make hydrogen gas with heat from a nuclear reactor, and add nitrogen, you can make liquid ammonia. And this can be feed into a fuel cell, on a ship or train, to make electricity, to power electric motors.

Host: Is this currently being done?

Prof-Trans: No. But it could be done.

Ammonia vs Gas Cost Comparison

Host: Walk me through the cost calculations.

Prof-Trans: We know the cost of electricity from a nuclear reactor in china, and can therefore calculate the cost per unit heat before making the electricity. We can divide this by the efficiency of making ammonia using heat and electricity from a nuclear reactor. And divide that by the efficiency of making electricity with a fuel cell in the field.

Host: So this is an estimate of the cost to turn wheels or propellers with green ammonia.

Prof-Trans: That's right. Also, we can divide the cost per unit energy of diesel fuel, by the efficiency of a diesel engine, to estimate that cost.

Host: How does green ammonia compare with traditional carbon based fuels?

Prof-Trans: Long story short, the costs are similar.

Ammonia is Toxic

Host: What are some of the considerations when working with ammonia?

Prof-Trans: Well, for one, it's toxic.

Host: How toxic?

Prof-Trans: If an open bucket of ammonia was sitting on your kitchen floor, and you sat next to it, you would not feel well.

Today's Ammonia

Host: Ammonia is used in fertilizer, which means we are already dealing with it.

Prof-Trans: Yes. We produce, transport, and store large amounts of the stuff every day.

Host: How is it transported?

Prof-Trans: It is moved in tanks, on ships and freight trains.

Host: So it's already at railyards and ports.

Prof-Trans: Yup.

Ammonia Refueling Stations

Host: How might we refuel a train or ship with ammonia?

Prof-Trans: A hose would attach, and the station would pump ammonia while monitoring for leaks.

Host: What would they do if a leak was detected?

Prof-Trans: Automated procedures would need to be in place, to handle every contingency.

Multiple Chemicals In and Out

Host: What else might we consider when working with ammonia?

Prof-Trans: Ammonia fuel cells are more complicated than you put ammonia in, and get electricity out.

Host: How so?

Prof-Trans: You also need to filter pollutants out of the exhaust. And this means you need to feed in additional chemicals, and dispose of waste chemicals.

Host: So refueling stations would have multiple nozzles, one for each chemical.

Prof-Trans: That's right.

Ammonia Refueling Standards Development

Host: Multiple companies would need to make gadgets that handle those chemicals. And the gadgets would need to fit together mechanically, electrically, etc. How might we coordinate multiple companies in multiple industries?

Prof-Trans: We would need standardized methods for refueling, filtering exhaust, monitoring, and responding to fault conditions.

Host: So someone would need to build prototypes, get them working, and have multiple companies agree on how things fit together.

Prof-Trans: That's right.

Host: Could this be done quickly?

Prof-Trans: No, this might take 3 to 10 years. Gadgets would need to be developed, tested, and improved. This takes time. Also, if a train with 100 railcars can't move due to a squirrel chewing on a rubber gasket, then money would be lost.

Host: So the system would need to be fault tolerant.

Prof-Trans: Right.

Host: Is anyone developing such standards?

Prof-Trans: Nope.

Host: Why not?

Prof-Trans: Decarbonization is not required by law; therefore, people have no reason to bother with this.

Host: Why doesn't climate money pay people to develop the needed standards, to prepare for the day when decarbonization is required?

Prof-Trans: That would require forward thinking at a foundation or government, and this is rare.

Host: If a well-funded laboratory was tasked with saving the planet from climate change, might it support ammonia based transportation standards development?

Prof-Trans: Definitely. Standards development costs very little, relative to other decarbonization costs.

Host: I want to thank you for visiting with us.

Prof-Trans: The pleasure is mine.

12. Background Material

- AI's Solution to the Climate Problem
- Climate Solution Videos
- Climate Solution Articles
- Open-Source Business Plan for New Climate R&D Lab
- Open-Source Proposal to Build Policy Making Tools
- The 2024 state of the climate report: Perilous times on planet Earth

13. Filmora

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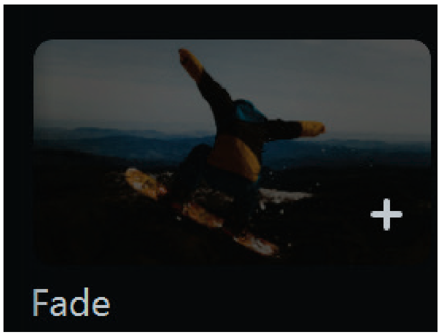
Transition: "Fade"

Set duration to 0.04 (4 frames), not 0.16 (16 frames) since 16 causes to much flash between scenes.



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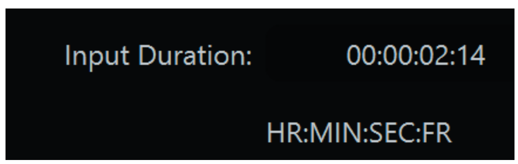
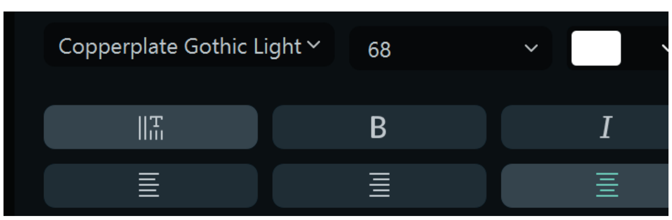
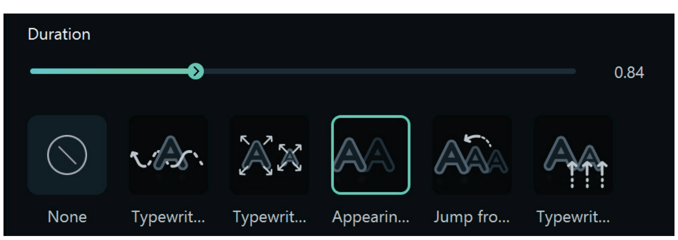
Chapter Break: Text "Glow Title 1"







Msg to ChatGPT

Here is a script for a documentary film. It has 2 people chatting. I would like you to convert this to one person who is the narrator who says the same thing with the same text, yet from one person narrating instead of two people having a conversation. Here is the script:

14. Not Used Material

Meeting the Satisfaction of Conservatives

~~Host: Liberals might accept a law that requires power companies to decarbonize 25% of electricity over 5 years. However, conservatives concerned about climate are more particular. How might this be structured to meet their satisfaction?~~

~~Prof-ChemEng: They are looking for a decarbonization plan that decarbonizes over several decades, in lowest cost order, without taxes and without subsidies.~~

~~They are looking for a global plan that blocks runaway climate change, at lowest cost, without harm.~~

~~They are looking for cost numbers.~~

~~And they want government engineers to review calculations, and improve accuracy.~~

The Fog of Climate

~~Host: Are you confident gov't can enact decarbonization laws in a competent manner?~~

~~Prof-ChemEng: No.~~

~~Host: Why not?~~

~~Prof-ChemEng: People in companies lie to make money, and people in government lie to raise money for their projects. This leads to confusion. A fog of climate, if you will. And this leads to ineffective policies, which leads to wasted money, and wasted time.~~

~~Host: Are you referring to sellers of green things lying, or sellers of carbon things lying, to derail sellers of green things?~~

~~Prof-ChemEng: Both.~~

~~Host: Lying for money has probably been done for thousands of years.~~

~~Prof-ChemEng: Probably.~~

~~Host: Is lying a big problem?~~

~~Prof-ChemEng: It can be debilitating.~~

Etc.

~~Prof-ChemEng: Your 5 year law would push the power companies to commission the building of solar farms, and pass additional costs onto consumers. You can calculate solar farm construction based on that mandate. It might be 5 times more than what is currently being done.~~

~~Host: You also need to burn fossil fuel to get electricity when the sun goes down.~~

~~Prof-ChemEng: Correct. Solar farms need to be paired with fossil fuel plants that can increase power output quickly, for when a cloud passes overhead. Many coal-fired power plants cannot do this. Therefore, power companies with coal plants might replace them with natural gas plants which emit less carbon dioxide and are capable of adjusting output more rapidly. And power companies with natural gas plants might pair them with new solar farms.~~

~~Host: Can we trust power company engineers to figure this out?~~

~~Prof-ChemEng: Definitely. They understand the options, and the costs of each.~~

~~Host: We're talking about a law that requires 5% of be decarbonized each year for 5 years. Why not make it 5% a year for 10 years?~~

~~Prof-ChemEng: Lawmakers might want a detailed implementation plan, and getting that for 25% of electrical power is a lot easier than 50%. And during the first five years, significant amounts of money could be spent on R&D, to prepare for the second block of 25%.~~

~~Also, lawmakers would want a plan that is reviewed by people responsible for implementation, and decarbonizing 25% of electricity is easier for them to understand. The sun burns bright about 6 hours out of 24, which is 25%. In other words, power company engineers can lean heavily on solar to decarbonize 25% of electrical power, and they know how to build solar farms.~~

~~Host: How many years would it take to get to 100% green electricity in the US if 5% is decarbonized each year?~~

~~Prof-ChemEng: 60% needs to be decarbonized, so that would require 12 years if 5% were switched over each year.~~

Host: Why?

Prof-Chem: National leaders rely on them to fix the climate problem. However, they are too close to wasteful spending to be effective.

Plan First

Host: Changes to our planet are accelerating, and at some point, the public will probably panic. And when they do, they will want to throw a lot of money at the problem.

Prof-ChemEng: Yes, and when that occurs, we need to have good plans in place. Otherwise, we will waste money, and achieve little.

Host: In engineering school, students are always taught to begin with plan.

Prof-ChemEng: Plan first, implement second.