How to fix global warming with cold fusion

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Abstract

Cold fusion can eliminate the threat of global warming two ways:

1. Cold fusion does not produce carbon dioxide so if it replaces other sources of energy carbon emissions would stop.
2. Cold fusion can enhance the removal of carbon from the atmosphere by reforestation.

Large scale reforestation projects have been proposed to remove carbon from the atmosphere and sequester it in trees. Cold fusion technology would greatly enhance such projects, increasing the amount of carbon by a factor of ten and reducing the cost of the project by a large factor. Cold fusion can be used to stop the natural boom and bust cycle of forest carbon, by burying charcoal made from deadwood underground. In effect this would speed up the formation of coal by a factor of a million. Conventional energy sources cannot do this.

Introduction

Cold fusion is not a chemical reaction. It is not any form of combustion. Like nuclear fission or plasma fusion, it adds no carbon dioxide to the atmosphere. So, if all energy were produced with cold fusion, carbon dioxide would stop increasing. However, the carbon dioxide already in the atmosphere would remain, possibly for centuries, unless we take active steps to remove it.

Many biologists, forestry experts and climatologists have advocated sequestering carbon by growing more trees. That is, by reforesting parts of North America, Europe and China that have lost forest in the last 300 years. This would be a megaproject in which trillions of trees are planted, in millions of square kilometers. Cold fusion would enhance this project. It would make the project far cheaper and faster, and it would remove ~10 times more carbon per square kilometer than the projects that have been proposed.

Engineering basis for these claims

Cold fusion researchers may feel that the predictions in this paper have no engineering basis, and they are mere speculation. I believe data from the most successful experiments justify these predictions. To use cold fusion for nearly all applications you need six things:

1. Sufficiently high power density.
2. High Carnot efficiency.
3. High energy density.

4. Perfect safety with no tritium, or at least no tritium leaks.
5. Reasonably low cost materials and manufacturing.
6. Control over the reaction.

High power density and Carnot efficiency are needed to make reasonably compact devices. If power density is low, a cold fusion generator would be too large for direct use, like a solar panel array. An array can power an electric car, but it is far too large to fit on the roof of the car.

One of the most successful experiments on record was performed by Roulette, Roulette and Pons. [1] Their tests produced 17 to 100 W, for up to 70 days continuously, in boiling cells. Experiment 3 produced 294 MJ from 3.6 g of palladium. This is comparable to the power density of a nuclear fission core fuel pellet (Table 1). A fission reactor core by itself is compact. The reactor as a whole needs a great deal of shielding, so it is not compact. If the core were safe without shielding, it would be compact enough for nearly any application.

A fission reactor runs at 300°C, giving Carnot efficiency of around 30%. The experiment by Roulette *et al.* was in unpressurized cells so the temperature was 100°C. It could easily be pressurized to 300°C or more, so it could also achieve 30% efficiency with most types of heat engines.

Table 1. Cold fusion cathodes from the best experiments compared to fission reactor fuel pellets

	Volume	Operating temperature	Power density by volume	Power density by area
Cold fusion cathode	0.3 cm^3	100°C	300 W/cm^3	16 W/cm^2
Fission reactor fuel pellet	1.0 cm^3	300°C	180 W/cm^3	32 W/cm^2

Cold fusion devices do not produce dangerous radiation. A few have produced tritium. Perhaps this can be prevented. If not, tritium is safely contained in today's wristwatches and hallway exit signs. Since a cold fusion cell will be tightly sealed tritium can probably be contained in them.

High energy density is assured. With Pd-D cold fusion, the ratio of energy to helium is 24 MeV, the same as one path in plasma fusion.

Materials in most cells are abundant and manufacturing processes should not be particularly expensive.

Complete control over the reaction obviously has not been achieved. I believe that with enough research funding it will be. This is shown by the history of other inventions such as internal combustion engines, transistors, masers and lasers. The initial laboratory prototypes took years to produce, and they were unreliable. The first maser prototype took three years to make. [2] Today we manufacture millions of these devices, and they are so reliable you can bet your life on them. As you do whenever you fly on an airplane.

How to remove carbon dioxide with cold fusion

With cold fusion we would stop adding carbon dioxide to the atmosphere. We can also remove the carbon we have already added. We put it back underground where it came from. We do this by growing billions of trees. When they are old, we cut them down and bury them underground in abandoned coal mines.

Growing trees to sequester carbon is not a new idea. Biologists, forestry experts and climatologists have recommended this in many project proposals (Table 2). In this paper, I describe how to enhance these projects with cold fusion. Cold fusion would make carbon removal far cheaper, faster, and 10 times more effective per square kilometer.

Table 2.Recent examples of proposals to sequester carbon with reforestation.

Reforest Action, Contribute to the Global Carbon Neutrality . . . by Funding the creation and preservation of Forests, https://www.reforestaction.com/en/contribution-climate, 19 million trees planted
University of Aukland, Can reforestation help reverse the extinction crisis? https://www.thebigq.org/2019/06/12/can-reforestation-help-reverse-the-extinction-crisis
Congressional Research Service, U.S. Tree Planting for Carbon Sequestration, https://sgp.fas.org/crs/misc/R40562.pdf
Forest Service, U.S. Department of Agriculture, Planting trees to mitigate climate change: Policy incentives could lead to increased carbon sequestration, https://www.fs.usda.gov/treesearch/pubs/61873
YOUNG TREES ARE BETTER! World Resources Institute, Young Forests Capture Carbon Quicker than Previously Thought, https://www.wri.org/insights/young-forests-capture-carbon-quicker-previously-thought
NO! OLD TREES ARE BETTER! Pacific Forest Trust, E&E: Old trees store more carbon, more quickly, than younger trees, https://www.pacificforest.org/ee-old-trees-store-more-carbon-more-quickly-than-younger-trees/ Most other sources say that younger trees store more carbon per year. See also Figure 1 caption.
100 YEARS TO STORE 10 YEARS OF EMISSIONS (I say 100 years to sequester all anthropogenic emissions) Frontiers in Forest and Global Change, Forests and Decarbonization – Roles of Natural and Planted Forests, https://www.frontiersin.org/articles/10.3389/ffgc.2020.00058/ The authors do not consider growing field crop indoors; irrigating deserts; or burying deadwood anaerobically in abandoned coal mines, OR cold fusion.

Carbon sequestration project outline

The project would begin by expanding forests with two technologies that are not related to cold fusion: indoor farms, and “cultured meat” grown from animal cells. These two greatly reduce the amount of land devoted to agriculture.

Indoor farms are already common in many parts of the world. They take up much less space than outdoor farms, and they use less water, no pesticides, and in some climates, less energy. The

Netherlands is a small country, yet it is now the second largest agricultural exporter by value, after the United States, because they grow huge quantities of food indoors. One-third of the fresh tomatoes sold in the U.S. are grown indoors. [3, 4] Cold fusion would enhance indoor farms (Ref. [5], p. 130).

Cultured meat is still under development. This is not plant-based imitation meat such as the Impossible Burger. It is actual meat, grown *in vitro* from animal cells. If this pans out, it will reduce the land devoted to agriculture, because 80% of land is used for livestock production. [1]

The land no longer used for agriculture can be used for living space, but much of it should be returned to nature. It should be reforested, partially restoring the North American ecosystem to the way it was before European colonization. Forests should also be expanded in Europe, especially in places such as Scotland, where hills are now barren that were forested in the 18th century. [2]

Cold fusion can help do this in a cost effective manner. It can do much more. Over the last 3,000 years, people expanded the Sahara and Gobi deserts by over-farming. This can be reversed with cold fusion powered desalination plants, and tap-root irrigation, which uses less water than conventional techniques. We could build roughly as many desalination plants as there are automobile assembly plants now. In fifty years, we could convert 3.5 million square kilometers of desert into verdant land, the way it was before human civilization. This is about a third of the Sahara and Gobi. It is also about a third of the land area of the United States. We would plant trees on the new land. After about fifty years the desalination plants would wear out, but we would not need to build many new ones because once the forests are established, natural rainfall increases. Reforestation of desert areas with minimal irrigation has been done successfully in Israel. Over the last 60 years, Israel has greatly increased forested land in arid and desert areas. The 3,000 hectare Yatir Forest in the Negev Desert is a good example.

The desert areas would become more livable for humans and other species. The population would increase. Towns and cities would be built, increasing land values. I do not think the land will be needed for agriculture because I assume indoor farming will be superior. But if outdoor farming continues, the new verdant land will greatly increase worldwide production of food.

This is a grand reforestation megaproject to reduce carbon in the atmosphere. With cold fusion, it is larger and more ambitious than anything proposed by the experts. The tree planting and forestry management part of the project is also hundreds of times cheaper. Bringing the deserts back to life would be expensive, but it would produce ancillary benefits worth trillions of dollars.

Cold fusion would enhance this megaproject in ways that would remove at least 10 times more carbon per square kilometer than the experts think is possible. Here is why. The new trees in North America, the Sahara and the Gobi deserts would capture vast amounts of carbon dioxide as they grow. But experts point to two problems. First, when the trees mature into a climax

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[1] https://ourworldindata.org/agricultural-land-by-global-diets

[2] Trees for Life, Deforestation https://treesforlife.org.uk/into-the-forest/habitats-and-ecology/human-impacts/deforestation/

forest, they largely stop capturing carbon dioxide, according to most experts. (Some dispute this, as noted in Table 2 and the caption for Figure 1.) Second, when there is a forest fire, or when the trees die and decompose, much of the carbon dioxide returns to the atmosphere. This is called the natural boom & bust cycle of forest carbon (Figure 2).

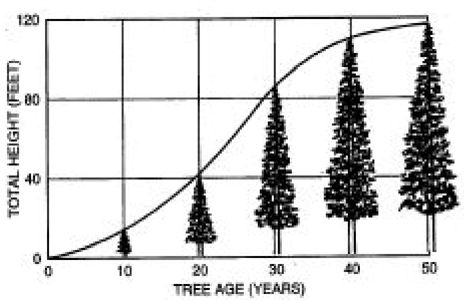

Figure 1. Tree growth patterns. Culmination in mean annual growth occurs after 40 to 50 years. Some experts think old growth forests continue to sequester carbon. "[W]hether carbon accumulation continues or peaks when net additional wood growth is minimal (in "old-growth" forests) is disputed." Ref. [6]

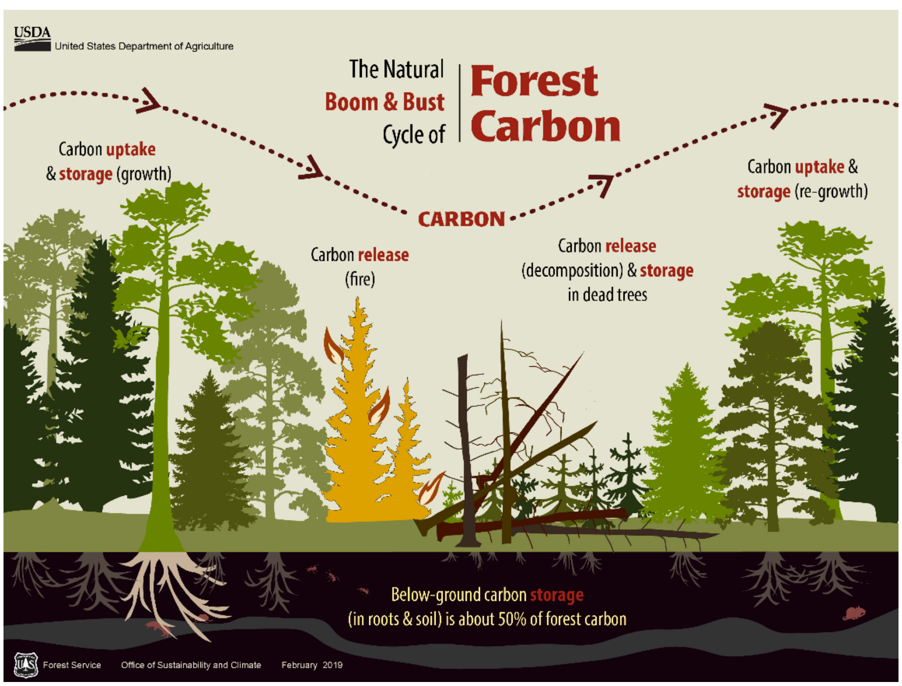

Figure 2. The natural boom & bust cycle of forest carbon. U.S. Forestry Service.

We need to stop this cycle before the carbon release phase (Figure 3).

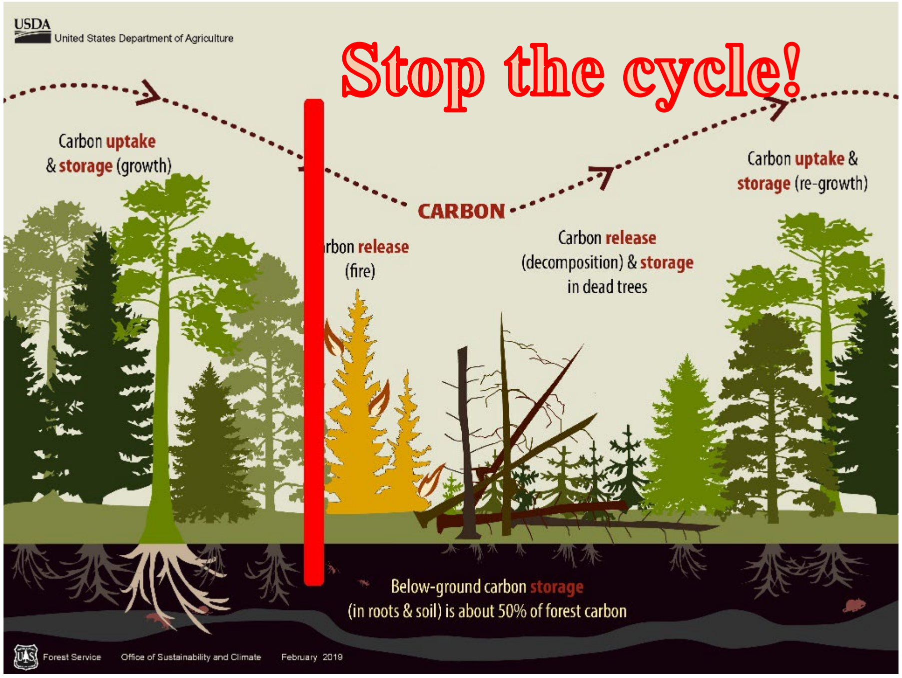

Figure 3. Interrupting the natural boom & bust cycle of forest carbon before the carbon release phase.

To interrupt the cycle, we harvest the deadwood (fallen trees and branches). The deadwood should be cut into chips, which are then baked into charcoal with cold fusion. The charcoal is taken to abandoned open-pit coal mines and buried underground, in anaerobic conditions. In other words, these pits would become reverse coal mines. We now dig up coal from a few mines, and send it to 230 power plants scattered around the country. With this project, we would collect solid carbon from many locations around the country, ship it to the mines, and put it back underground. In effect, this is speeding up the natural formation of underground coal by a factor of a million.

The wood is cut into chips to make it easier to transport. It is made into charcoal because charcoal has less mass to transport and bury, and it is less likely to rot.

If this project were done with fossil fuel, the baking and transport of the chips would add far more carbon dioxide to the atmosphere than the project removes. This is easily estimated from the caloric content of wood, 20 MJ/kg (about as much as 435 g of gasoline). Chipping 1 kg of wood, baking it into charcoal, transporting it to North Dakota, and burying it would take far more than 20 MJ. If this project were done with wind, solar and other renewable energy, it would cost vast amounts of money. It is only technically feasible and economically possible with cold fusion.

After about a century of burying carbon underground, we would sequester roughly as much carbon as we have added to the atmosphere since the beginning of the industrial revolution. (Figure 4). The cumulative total is 1,710 billion tons. [3] Suppose we put carbon back underground

[3] The totals from this graph equal approximately 1,540 billion tons. A more precise estimate of 1,710 billion was derived from a spreadsheet at https://ourworldindata.org/co2-emissions.

at the rate we emitted it in 1966, 15 billion tons. [4] In 114 years, we would bury the excess carbon.

Charcoal is 60% to 80% carbon, so we need to bury about 21 billion tons of charcoal per year to sequester 15 billion tons of carbon. Worldwide coal extraction was 7.9 billion tons in 2019. [7] So, we put the carbon back at about 2.6 times the rate we now mine coal.

Wood is approximately 50% carbon, so we need to chip 30 billion tons of deadwood a year. This goal cannot be met without new forests in irrigated deserts. If the deserts are not irrigated, the project will take about 200 years.

Worldwide production of lumber is approximately 1.3 billion tons per year (2.2 billion m^3). So, we increase forestry by a factor of 23.

Removing excessive deadwood improves the health of the forest overall, and reduces severe forest fires. Not all deadwood should be removed. Rotting wood is essential to the ecology, but there is too much in many forests today. Removing deadwood need not be done often. This would disrupt fauna and bother people living nearby. Deadwood could be removed every 10 years or so, in a cleanup that lasts a few days to a week.

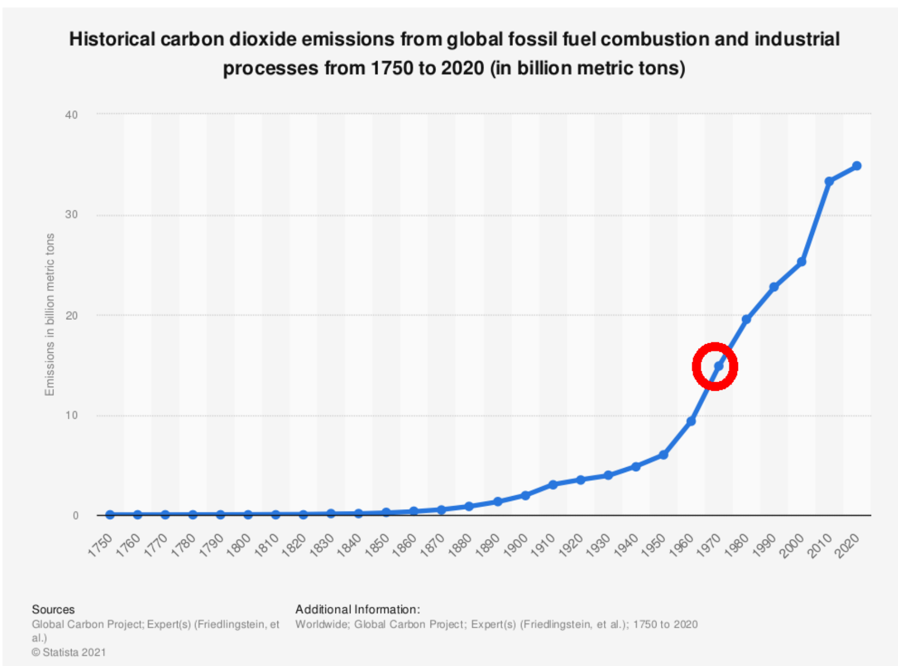

Figure 4. Graph of carbon dioxide emissions since 1750.

To make 30 billion tons of wood chips, I think it would be best to use small, flying, cold fusion powered robots, the size of woodpeckers. Woodpeckers and insects demolish millions of fallen trees without much disruption.

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[4] Carbon in the atmosphere comes from coal, oil and natural gas, but we would put it all back as coal, so we end up burying more coal than we originally mined.

A flying robot the size of a woodpecker may seem implausible, or risible. It may seem that such a small machine would take far too long to demolish an entire tree. However, large numbers of these machines working in coordinated groups could do this in a reasonable amount of time. Figure 5 shows a pileated woodpecker making a hole. Holes are rectangular. The larger ones are 10 cm × 14 cm, perhaps 4 cm deep: around ~500 ml. The birds can make 2 or 3 holes a day, roughly ~1 L. The birds weigh 300 g, and their metabolism is ~1.4 W (28.31 kcal/24 hour). [8] Larger 1 kg flying robots, with 140 W of thermoelectric power, and cutting blades that make 53 L of wood chips per day should be possible. They would be a combination of a flying drone, a cell phone, and a Dremel cutting tool. A tree service company would use about 20 of them to demolish a 15 m pine tree in one day. [5] You would need a fleet of 3.1 billion of them to remove 30 billion tons of wood per year. 3.1 billion may seem like a large number, but it is not. If the robots last 10 years, we need to manufacture 310 million per year. Compare this to the number of cell phones we make, 1.3 billion per year.

Figure 5. Pileated woodpecker making a feeding hole. https://ebird.org/species/pilwoo

The robots can be made quieter than today's drones and cutting tools by using electroactive polymers (EAP). They would also be longer lasting, requiring less maintenance and replacement parts. An EAP resembles an artificial muscle. It contracts when electricity is passed through it. An EAP-powered flying drone would have flapping wings, rather than the propellors used in today's drones. Small, flapping wing drones are more complicated than propeller aircraft, but the engineering problems are being solved and such machines will be perfected soon. Wings are much quieter than propellers because they move slower, pushing a larger volume of air with each stroke. This is why a hawk can fly low and silently across a field to snatch a squirrel off the

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[5] This estimate is based on various sources. 15 m is a 50-foot tree 12 inches in diameter. It produces 0.27 Cords of firewood, which is 0.93 m^3. The tree also has many small branches and leaves, but these are easily cut up.

ground. I have seen hawks do this. One flew just over my head and landed on a fence a meter away from me before I noticed it.

An EAP cutting blade might pinch, like an insect taking a bite out of wood. This should be quieter than a rapidly spinning circular blade.

Why use miniature flying robots? Why not make human sized chainsaws and woodchippers like the ones we have now, only powered by cold fusion? There are several good reasons to make them smaller: They can fly up into the tree, rather than climbing. If they fall out of the tree, they cause no damage. They would be quieter than chainsaws. They would not need logging roads. They could fly into wilderness areas in California to remove deadwood without roads and without disturbing the environment. This would reduce wildfires. They do not need human operators, so they would be much cheaper and safer. [6] Climbing trees and cutting with chainsaws is dangerous work.

If these are such good reasons, why don't we make small gasoline or battery-powered robots now? Because they would not be practical. You would have to refuel or recharge them a dozen times a day. They could not fly into the California wilderness; they would run out of fuel. Cold fusion machines run for years on a drop of fuel, so they do not need fuel tanks, and they can be any size. You pick the best size for the application, rather than being hemmed in by the limitations of the technology.

When you think about future cold fusion technology, you should rethink the size of machines. Think small. Cold fusion robotic machines do not have to be made on a human scale, the way chainsaws are. Rethink everything. The scale, the methods, the economics should all be considered anew.

This global warming reversal project would be a continental-scale megaproject. But so is the flow of coal from under the ground to coal-fired generators today. We hardly notice that. This project is no more complicated than today's forestry and coal mining. The project as a whole, including bringing the deserts back to life, would be the most profitable enterprise in history. For a trivial cost we would create trillions of dollars in wealth.

I estimate the reforestation in North America and Europe would cost roughly 100 times less than the experts do, because the work will be done by cold fusion robots. I also estimate it can remove all of the carbon in 100 years, whereas most experts say it can only remove 10 years' worth of emissions (Table 2). They are pessimistic mainly because of the boom and bust cycle. A climate researcher wrote an op-ed in the New York Times on June 4, 2022 titled, "Let's Not Pretend Planting Trees Is a Permanent Climate Solution." [9] The gist of it was that because of the boom and bust cycle, carbon in trees eventually returns to the atmosphere:

> Trees can quickly and cost-effectively remove carbon from the atmosphere today. But when companies rely on them to offset their emissions, they risk merely hitting the climate

[6] The early models would need a human forester to direct them to the tree that should be cut.

“snooze” button, kicking the can to future generations who will have to deal with those emissions. . . .

That is true. [7] But with cold fusion we would stop the cycle. This author did not consider the possibility of burying the carbon in abandoned coal mines. He never thought of irrigating deserts to produce 5 million square kilometers of new forest. Or having miniature robots do the work. He did not think of these things because he has never heard of cold fusion. He did not imagine these things because without cold fusion *they are unimaginable*.

When modern electric lights began replacing inefficient incandescent lights in the late 20th century, they reduced both energy costs and equipment costs, because they last much longer. One expert said: “this is not a free lunch; it is a lunch you are paid to eat.” [10] That should be the motto of cold fusion.

APPENDIX A. Cost of project

Here is a rough estimate of the cost of the project in 2020 dollars. This covers the cost of cutting chips, baking them into charcoal, transporting them to abandoned mines, and burying them. It does not cover the cost of growing new forests in deserts. Reforesting temperate climate trees costs little or nothing. Since 1900, in New England many small farms were abandoned. Tree coverage increased from 50% to 80% with no effort by human beings. [11]

Assume the project can be completed in about 100 years. (As noted above, this would require new forests reclaimed from deserts. Otherwise it will take 200 years.) It will start slowly as new trees grow. It will not reach peak activity until the first generation of planted trees begins to die out, around 50 to 80 years after they are planted. Cutting trees before they mature would be defeat the purpose. There will be plenty of time to ramp up this project and improve the technology. When the project peaks, roughly 15 billion metric tons of carbon will be buried per year. 30 billion tons of deadwood will be collected, which is used to make 21 billion tons of charcoal, which contains 15 billion tons of carbon.

The project has two steps:

Step 1. Cutting chips and making charcoal

Cutting up the deadwood will be done by robots. Human labor costs will be low. The main cost is for 310 million robots per year. I estimate they will cost roughly $500 each, $155 billion total (Appendix B).

This cost of this step may be substantially reduced by ancillary profits. Urban tree services and municipal sanitation departments might pay the project to take chipped wood, yard trimmings, and other organic waste to reduce the need for landfills. Many landowners will pay to

[7] True as far as it goes, but excessively pessimistic. If we planted mainly oak trees, which are the dominant species in North America, we would press the snooze button for 300 years, the lifespan of many oaks. Surely this would give our descendants time to find a more permanent solution.

have deadwood removed. This improves the quality of the forest. Forests in National and State parks have most of the deadwood removed.

Charcoal making machines will process 30 billion tons of chips. A unit costing $240,000 processes 4.5 tons per hour. (https://www.alibaba.com/product-detail/Price-Charcoal-Making-Machine-Factory-Price_1600120544661.html) Assuming it lasts 5 years and operates 12 hours a day, that comes to 21,900 hours and 98,550 tons. With cold fusion the operating cost would be zero. Excluding labor and maintenance costs it comes to $2.44/ton. To process 30 billion tons of wood costs $73 billion. I assume that decades from now these machines will be robotic, with little or no human labor needed.

The 30 billion tons of chips convert to 21 billion tons of charcoal. Most of the lost weight is in water, which is released and causes no environmental harm. A small amount of volatile gas vents from the wood. It is burned, and causes no harm.

These machines process wood chips, sawdust, coffee grounds, rice husks, straw, peanut shells, and other organic materials, converting them all into charcoal. The 21 billion tons of charcoal does not all have to come from trees.

This phase of the project comes to $228 billion per year, worldwide.

Step 2. Transporting charcoal and burying it in abandoned coal mines

The following estimate is based on the cost of mining and shipping coal from the U.S. Energy Information Agency (EIA.gov). [12] U.S. data is shown in short tons (2000 lb). 21 billion metric tons equals 23 billion short tons.

The cost of coal ranges from $14.43 to $98.68, depending on the quality of the coal. The lowest grade of coal, subbituminous, costs $14.43 to mine, and $7.26 to deliver, $21.69 total. Presumably, that is close to the lowest amount you can charge and still cover the cost of digging up and shipping 1 short ton of coal. Presumably, going the other direction, shipping and then burying 1 short ton of charcoal, would cost about the same. So, 23 billion short tons would cost $499 billion worldwide, with today's technology.

This cost will be greatly reduced in 80 years by robots and by cold fusion. In the U.S. coal industry, labor is 41% of costs, and energy is 12%. [13] I predict that nearly all physical labor will be eliminated in 80 years, replaced by robots, which will be far cheaper than humans. Cold fusion will eliminate the cost of energy. So, costs of mining will be reduced by 53%, bringing the total down to $234 billion. (Shipping will also be cheaper with cold fusion, but we will not account for that.)

For steps 1 and 2 the total is $462 billion. To put that in perspective, worldwide soft drink sales are $330 billion. [8] So, for a little more than we spend on fizzy drinks, we can reverse global warming and improve the quality of forests.

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[8] https://www.statista.com/outlook/cmo/non-alcoholic-drinks/soft-drinks/carbonated-soft-drinks/worldwide

Appendix B. Estimate of how much wood a robot could cut

Assume the flying robots would resemble today's 1 kg commercial class drones. The Autel EVO II model is a popular example. Specifications include: [9]

Takeoff weight 1150 g
Maximum takeoff weight 1999 g
Wheelbase 397 mm including the propeller arms
Maximum hovering time 35 minutes
Battery energy 82 Wh
Battery weight 365 g

82 Wh expended in 35 minutes comes to 140 W. This is in line with other estimates that drones can lift 4 to 8 g/W; 8 g/W for the larger, more efficient models.

Assume the cutting robots will also weigh 1 kg and have 140 W mechanical power. I assume the drone will fly with 140 W of power, attach to the tree with a clamp or drill, and then shift all 140 W to operate the cutting blades. Future thermoelectric devices should be ~25% efficient, so this will require 560 W of heat. A 140 W cold fusion thermoelectric generator should weigh no more than the 82 Wh battery in this drone. Instead of lasting 35 minutes it would last for many years.

I assume it would not be safe to have robots weigh more than 1 or 2 kg. Even if larger ones are possible, above 2 kg the price increases proportional to the weight, so there would be no advantage to making them as large as a chainsaw (5 to 11 kg with fuel).

Probably, the upper limit of performance of the drones would be the temperature of the waste heat. They cannot be so hot they might injure a person, or ignite leaves at 800°C. A reviewer described the body of the EVO II drone as being about the size of "an adult's shoe." The top would have ~300 cm^2 of surface area. The surface would be covered with metal screen, with the thermoelectric generator cooling fan blowing air through it. This would resemble a small resistance electric room heater, which produces 823 W with a 156 cm^2 screen. The metal screen is too hot to touch, but not so hot that it might injure a person or start a fire. It is much cooler than a conventional chain saw exhaust pipe. Based on this, power higher than 140 W might be possible.

Wood chippers use 0.5 L of Diesel fuel per ton of wood chips, which is 49 J/g (primary energy from fuel to cut 1 g of wood), or 21 J/g mechanical energy. [14] A manufacturer reports a line of 6 wood chippers ranging from 6 to 50 tons of chips per hour, consuming 54 J/g to 38 J/g.[10]

Smaller cutting tools are less efficient. I used a variable speed jigsaw (Black & Decker JS600) to cut a two-by-four board into simulated wood chips. I measured watts, maximum watts,

[9] https://shop.autelrobotics.com/pages/evo-ii-specification
[10] High efficiency Diesel/electric drum wood chipper, Jinan Shanghangda Machinery Co., Ltd., https://www.timberwolfcorp.com/enc-13024-1400-600-Large-Hot-Selling-High-Efficiency-Diesel-Electric-Engine-Drum-Wood-Chipper-with-Capacity-15-20t-H-and-Power-250kw/

and kilowatt hours with a meter (KUMAN Power Meter KW47). The power was approximately 280 W when cutting, 342 W maximum. I cut until the meter reached 0.010 kWh (36,000 J), removing 237 g of wood, including 38 wood chips averaging 4.7 g each, and sawdust. This comes to 152 J/g. With a 25% efficient thermoelectric device it would be 608 J/g primary energy, considerably more than the primary energy of the Diesel wood chippers.

Assuming the 140 W robot cutting blades are as efficient as the jigsaw, at 140 W mechanical power, they would cut 1 g of wood in 1.08 s. In an 8-hour day of continuous cutting, that comes to 26.5 kg. In one year of 8-hour days it comes to 9.7 tons. I assume the robots will work 12 hours a day, but 4 hours will be spent in transport to the job location, positioning in the tree, and moving to new positions as the tree is cut. The robots might be able to work autonomously, 24 hours a day, with low light illumination, which would increase output. 30 billion tons of wood divided by 9.7 tons per robot equals 3.1 billion robots. Assuming they last 10 years, 310 million will be manufactured each year.

An Autel EVO II drone costs $5,000, including the controller. It is a flexible machine designed to be operated by people for a variety of applications. I expect future wood cutting drones of this size will be far cheaper, costing about $500. They will be cheaper because they will be single use, with one ground-based master computer controlling the entire swarm, and they will be mass produced in far greater numbers than today's drones.

Appendix C. Estimate of how much land would be needed

This project calls for 15 billion tons of carbon to be removed and buried during the peak years of the project, when new forests are growing at the fastest rate. It would take about 114 years to remove the excess carbon from the atmosphere.

Various sources claim that a growing forest sequesters 1 to 3 tons of carbon per year per hectare. An International Monetary Fund policy guide says, ". . . the annual sequestration rate for a typical New England forest is 0.5 tonnes per hectare per year, a southern pine plantation is 1 tonne, and a moist tropical forest could be as high as 11 tonnes." [15] So, this project would take at least 5 billion hectares of forest.

Total forest area on earth is now 4 billion hectares, down from 6 billion at the end of the last ice age, 10,000 years ago. [16] Let us assume that with desalination we will reverse desertification caused by humans. Let us assume that with reforestation and indoor agriculture, we can increase forests back up to 5 billion hectares.

Fifteen billion tons is probably close to the upper limit of wood that can be grown per year worldwide. We would not need to bury all of this wood. We can use as much for conventional purposes as we like, such as lumber or paper pulp. As long as we do not end up burning the lumber or the paper, the carbon from it will be sequestered. However much wood is left over after the demand for lumber and paper is met, we can bury in abandoned mines.

If we do not reverse desertification, there will be less overall reforestation, and the new forest will be less productive. In that scenario, ~7 billion tons of carbon might be sequestered, and the project would take ~200 years, instead of ~114 years. This would probably ameliorate the problem. Decades into the project, the amount of carbon dioxide would already be significantly reduced, and catastrophic global warming would be averted.

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