COMMON SENSE

TO COMBAT

CLIMATE CHANGE

ADDRESSED TO THE

INHABITANTS

OF

A M E R I C A

(AND THE WORLD)

ON THE FOLLOWING INTERESTING SUBJECTS:

I. **Of the Worldwide Scope of CO_2 Emissions and the Requirement to Markedly Reduce Them**

II. **Of Which Methodologies Will Bring About the Necessary Reductions and Which Will Not**

III. **Of a Reasoned Guide to a Practical Plan to be Utilized by Policymakers**

IV. **Thoughts and Miscellaneous Reflections**

Written by Martin G. Lagina, PE

With apologies to Thomas Paine and with nowhere near the quality of the prose.

April 22, 2021

Earth Day

PREFACE

For many years, the issue of CO_2 loading of the atmosphere by human activities and the possibility of concomitant climate change have become significant worldwide. How badly human induced climate change will affect the ecosystems of the planet and humanity itself is uncertain. Qualified scientists have differing opinions. However, some scientific predictions are extremely disturbing. What *is* certain is that there is sufficient scientific evidence to have caused governments worldwide to make efforts to reduce CO_2 emissions.

This paper takes no position as to whether or not the consequences of human induced climate change merit drastic reductions in CO_2 emissions. Governments and populations are convinced we need to do so. Therefore, one of the key assumptions of this paper is that said reductions should in fact be made. However, if drastically reducing CO_2 emissions worldwide is the goal, current policies and initiatives will not get us there. This paper sets forth what *will* work and what *will not* work.

Simply put, if we are going to do this, let’s do it right.

The entire FLEET must be converted to run on a new fuel.

Winston Churchill

Early 1900’s

“The entire WORLD must be converted to run on a new fuel”

The author and 7,800,000,000 other people

April 22, 2021

Earth Day

Attaining a Meaningful Reduction in Worldwide CO_2 Emissions:

<u>"THE VIEW FROM 100,000 FEET" SUMMARY FOR POLICYMAKERS:</u>

1. The SCALE of the CO_2 problem is enormous.

2. The remedy must be at sufficient SCALE.

3. Policymakers need to continually test all their initiatives against two <u>common sense</u> questions:

   a) **Will our policies enhance the technologies that can produce carbon free renewable energy at lower cost and better efficiency?**
   b) **Will our policies promote the <u>utilization</u> of renewable energy <u>at the required scale</u> to drastically reduce CO_2 emissions?**

4. To date, the answer to the first question is an emphatic "YES". State RPS standards and Federal Tax Policy have made renewable carbon free energy cheap and efficient and are still doing so.

   To date, the answer to the second question is (unfortunately) "NO".

5. This paper presents THE PLAN that will work at sufficient scale.

<u>"THE VIEW FROM 50,000 FEET" SUMMARY FOR POLICYMAKERS</u>:

1. Electrification, electric vehicles, batteries, etc. will not fix the CO_2 issue at the scale required.

2. Green Hydrogen production on a massive scale <u>WILL</u> definitely fix the CO_2 problem on a world-wide basis.

3. Policymakers should not prioritize development of the electricity grid and electric vehicles, batteries, etc.

4. Most resources – incentives, subsidies, etc. of all types should be implemented on a massive scale to produce and utilize Green Hydrogen.

HYDROGEN BASICS:

Currently, there is a large (but not nearly large enough!) market for hydrogen used in many industrial processes. The great benefit of using hydrogen as a fuel is that when burns it produces only pure water.

Unfortunately, the vast majority of hydrogen is currently produced by "stripping" the hydrogen molecules from a methane molecule.* Currently, hydrogen is produced by utilizing natural gas. CO_2 is the byproduct of this process and it is virtually the same (actually, worse) as if the gas was simply burned. This is called Grey Hydrogen. Utilizing hydrogen produced in this manner does nothing to solve the climate issue.

There are two other significant ways of producing hydrogen:

Blue Hydrogen is produced as set forth above, but the CO_2 byproduct is sequestered in the process. Blue hydrogen is therefore almost carbon free. Unfortunately, there are severe limitations to the whole concept of sequestering CO_2 (see infra). Blue hydrogen therefore can play a role but it's not the answer.

Green Hydrogen is produced by electrolysis, utilizing electricity from a non-CO_2 emitting source. These sources are primarily solar, wind, and potentially nuclear.** The specific process utilizes electricity to split a water molecule (H_2O) into H_2 and O_2. The H_2 produced can then be burned in a plethora of different processes with the only byproduct being clean water.

GREEN HYDROGEN is the answer to the whole CO_2 issue.

*The process is called *steam reformation*.

**Hydrogen produced from nuclear power has been called "Pink Hydrogen". Nuclear power could indeed be a major source of carbon free hydrogen. For purposes of this paper, any carbon free source of electricity to make hydrogen is considered Green. Otherwise, we'd also need separate colors for things such as tidal power, wave power, geothermal, etc.

<u>EXECUTIVE SUMMARY:</u>

Intensive efforts have been underway during at least the past 20 years to substantially reduce worldwide CO_2 emissions. To date, those initiatives, although well intended, costly, and diverse, have not made a meaningful impact on CO_2 emissions. Enlightened policies like the various State's RPS standards have been instrumental in causing renewable technologies to become feasible and inexpensive, which was the required first step*. To actually reduce CO_2 emissions, however, those technologies must now be refocused on the correct economic sectors. Current projections (even with marked increases in previous efforts) show that initiatives to focus renewable technologies on the grid are highly unlikely to create the desired outcome. The way to create substantive CO_2 emission reductions can only be achieved by:

- Large scale, <u>rapid</u> deployment of technology or technologies applicable to <u>all</u> of the sectors that generate CO_2 emissions.
- The technology implemented must be of such nature that countries <u>worldwide</u> are likely to adopt it because it is in their self-interest to do so.
- There must be no significant barriers to wide-spread adoption (i.e. regulatory issues, access to existing infrastructure, barriers to entry, lack of sufficient siting, etc.)
- The technology must be economically viable, meaning that it is affordable for everyday people.

CONCLUSION: Overall, it is concluded that large-scale, rapid implementation of Green Hydrogen production would meet all of the criteria. It is further concluded that large scale electrification 100% powered by renewables (using the electrical grid for electric cars, etc.) would be: impractical, insufficient, incapable of being done in the time required, and actually create a ***<u>national security risk</u>***.

*The author's company has built and operated five utility scale wind farms in Michigan. It was Michigan's RPS that enabled these and other wind farms. Most importantly, Michigan's RPS drove the price of wind generated electricity down by more than 60%.

OTHER CONCLUSIONS:

1. The grid (and electrification) in the United States cannot provide sufficient amounts of carbon free energy nor utilize it in the correct economic sectors within the time frame required to create a meaningful reduction in CO_2 emissions.
2. The grid in the rest of the world is even less likely to accomplish meaningful CO_2 reductions.
3. The United States resource for the production of renewable, usable energy is magnitudes greater if it can be utilized WITHOUT SIGNIFICANT ACCESS TO THE GRID.
4. The world renewable resource is even more massive if it can be utilized without requiring any significant access to a "grid". For example, developing countries in Africa have an enormous resource that can be tapped expeditiously. There are only two main requirements: cheap carbon free energy and an adequate source of water. Both are found in abundance in Africa.
5. The technology to produce Green Hydrogen by electrolysis is available right now. The cost of production will be competitive with existing liquid fossil fuels such as gasoline, with appropriate incentive.
6. Widespread manufacture of Green Hydrogen (either completely off the grid or minimally tied to the grid) can dramatically reduce CO_2 emissions from ALL sectors. It can also happen much more quickly than grid-based solutions.
7. Companies (in particular, oil companies) that would otherwise oppose a transition to a carbon free economy can help implement the Green Hydrogen economy quickly and enthusiastically.

RECOMMENDATIONS:

FIRST 15 YEARS: THE PLAN-PHASE I*: *Reduce US and Worldwide CO_2 emissions by 50% as rapidly as possible.

THE PLAN-PHASE I is simple and can be fully implemented in less than 15 years.

1) Eliminate CO_2 emissions from the entire transportation sector via production and distribution of Green Hydrogen.
2) Mandate the reduction of the current level of CO_2 emissions in the United States caused by the generation of electricity by 50%. This can be readily and quickly accomplished by a combination of:
    a. Replacing coal plants with Combined Cycle natural gas plants.
    b. Carbon capture and sequestration from coal plants.
    c. Adding additional solar and/or wind generation facilities to the existing grid. (But not so many as to make grid additions too difficult or expensive within the required time frame.)
    d. Additional electricity generation from new nuclear power plants. Ideally, these new plants could produce electricity *and* "Pink" Hydrogen.

    Market forces would dictate which mixture of methods would be used. Mandating or even incentivizing the grid to reduce CO_2 emissions by more than 50% is not wise nor practical at this point (see infra).

3) Reduce industry CO_2 emissions by 25% utilizing Green Hydrogen.
4) Reduce all other CO_2 emissions sectors by 25% utilizing Green Hydrogen.

General Recommendations:

A. The large-scale production of Green Hydrogen should be incentivized and implemented as rapidly as possible.
B. Large scale distribution and transportation networks and retail outlets for Green Hydrogen should be incentivized and implemented as rapidly as possible.
C. All other feasible CO_2 reduction initiatives (including electrification of vehicles, etc.) should proceed, BUT, in the aggregate such initiatives should be less than the allocation to A) and B) above.

Specific Recommendations:

A. Mandate that all Hydrogen be Green or Blue within four years (see infra).
B. Mandate that all generators of electricity reduce the current average CO_2 emissions of .9 lbs./kw-hr to .45 lbs. of CO_2 per kw-hr by 2035. This can be implemented via an existing "Cap and Trade" system that utilities already use for "capacity".
C. Re-direct the majority of resources of all kinds from electricity "fueling" stations to Green Hydrogen fueling stations.

FOLLOWING YEARS: THE PLAN-PHASE II: Further reduce CO_2 emissions to become virtually carbon free.

The second part of The Plan is simply to allow Green Hydrogen to replace all fossil fuels. After the implementation of THE PLAN-PHASE I, this will happen with minimal government assistance just as each superior fuel in the past gradually replaces the inferior one. Within 30-35 years, the US and the world could be 80-90% carbon free.

I. Summary of the extent of the problem.

The atmospheric loading with CO_2 from human activities is enormous. The world emits approximately 33,000,000,000 tons of CO_2 yearly, of which approximately 5,000,000,000 tons comes from the United States alone. This paper will not attempt to address the question of how dire the consequences of said emissions will be. That question is left to others. This analysis is based on finding a solution assuming just four items:

1) CO_2 loading of the atmosphere IS a very significant problem which will lead to unacceptable climate change.

2) The problem requires a timely solution (10 years best - within 20 years: mandatory).

3) Since the US is only 15% of the problem, the solution must be implemented worldwide.

4) The enormous SCALE of the problem needs to be constantly in mind when discussing and implementing solutions.

II. Summary of initiatives to date.

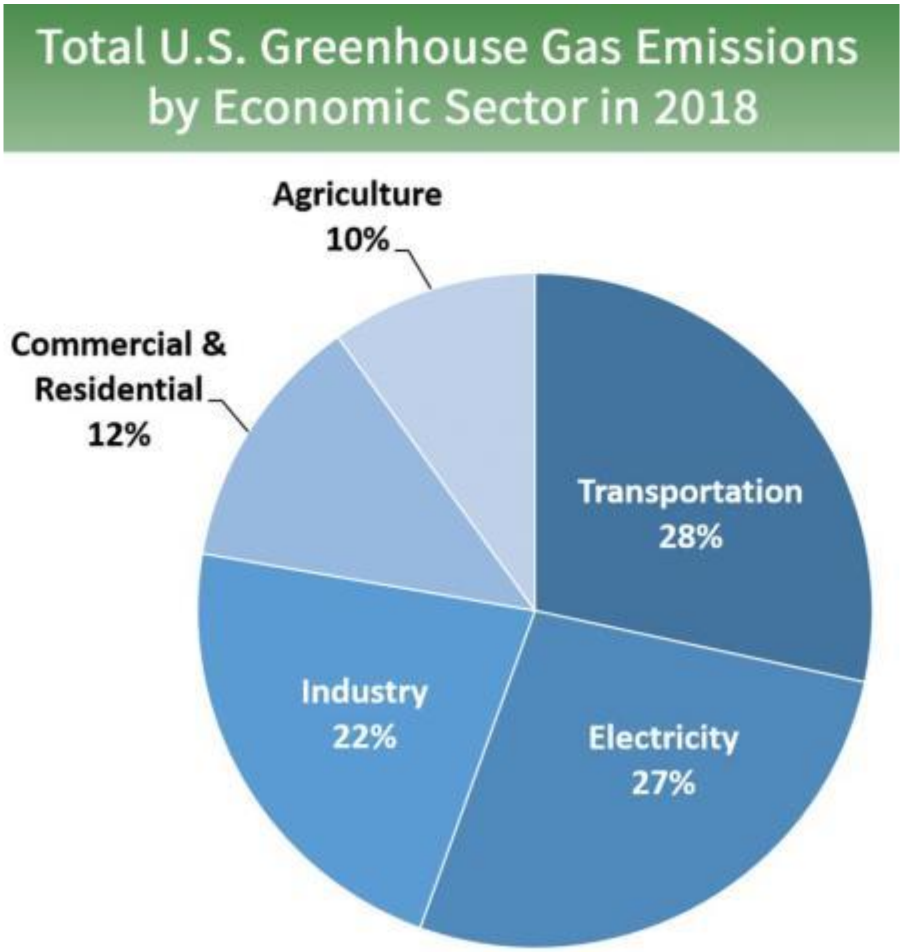
Efforts have been ongoing across the globe to diminish CO_2 emissions. Efforts have probably been most extensive in North America and Europe. Initiatives are underway in other parts of the world as well: in Asia, significantly China, India, Japan and Australia. In fact, almost all countries on the planet are cognizant of the problem with CO_2 emissions and are making their own efforts to lessen them. These initiatives have been ongoing for quite some time and have certainly been intensifying in the last 20 years or so. Rapid advancements in many types of renewable technologies have been made. In particular, the cost of wind generated electricity and solar generated electricity have dropped significantly.

So..... how are we doing?

Abysmally.

It is true that the United States, for instance, has reduced CO_2 emissions by about 30% since 2005. However, in what has to be one of the most ironic events in environmental history, almost all of the United States emissions reductions have been due to dramatic increases in (and at the inexpensive cost of) natural gas production. This has allowed utilities to shift away from coal thereby emitting significantly less CO_2. The irony is that the twin technologies of horizontal drilling and hydraulic fracturing drove the increase in natural gas production and drove the costs way down. These two technologies are probably the most intense focus of environmentalists in the past 15 years or so. The environmental movement has aggressively campaigned to stop these technologies. It is an "inconvenient truth" that the only very substantial reduction in US CO_2 emissions to date is because of horizontal drilling and hydraulic fracturing! The new renewables (wind and solar) have scarcely made a dent in CO_2 emissions, and the reductions have been almost completely limited to the electricity generation sector. That alone is a fatal flaw towards creating a significant reduction in CO_2 emissions. It is the author's opinion that natural gas production should continue but be gradually phased out (which will happen in THE PLAN-PHASE II). Methane leaks from existing wells and methodologies can and should be minimized because methane is also a greenhouse gas.

Here's why renewables haven't done much:

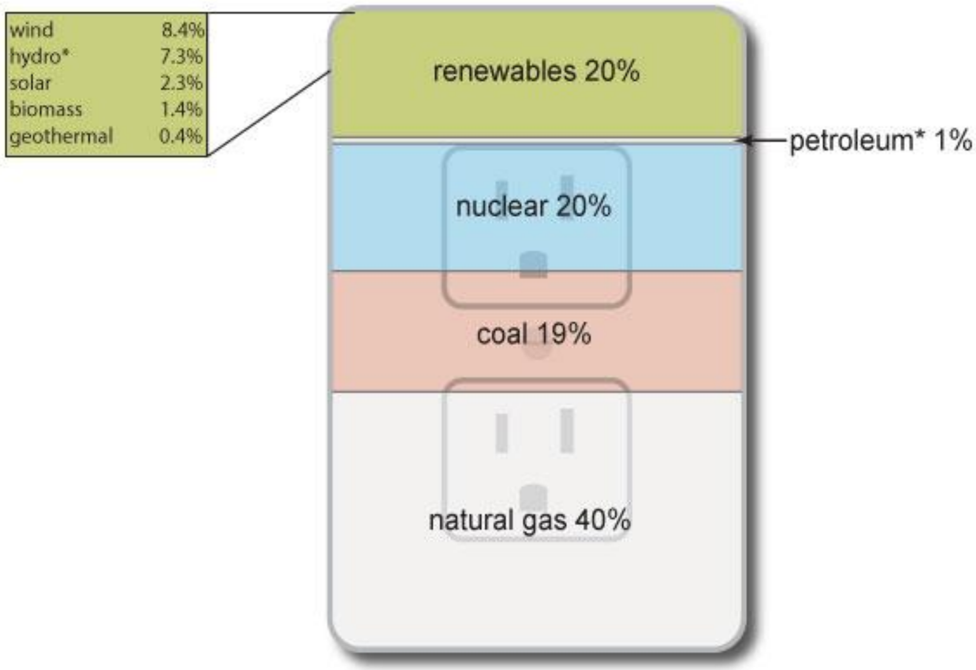


This is a pie chart of the sources of greenhouse gas emissions in the United States by economic sector in 2018. Electricity generation (which is the only sector which has had any meaningful CO_2 reduction) only comprises 27% of the problem. And of that 27% (as can be seen from the next chart) only 17% comes from renewables. And OF THAT 17%, only about 1/2 comes from true recently implemented renewables, that being solar and wind.* So, despite intense efforts for decades, we have eliminated CO_2 emissions from 27% of 17% of 50% of the problem. About 2% of the problem in total. The data will not be analyzed here, but with the exception of Europe, the rest of the world has done even worse.

*The balance consists of hydro power from dams that have existed for many years and biomass, etc.

Sources of U.S. electricity generation, 2020

Total = 4.12 trillion kilowatthours



Note: Electricity generation from utility-scale generators. * Hydro is conventional hydroelectric; petroleum includes petroleum liquids and petroleum coke, other gases, hydroelectric pumped storage, and other sources.
Source: U.S. Energy Information Administration, *Electric Power Monthly*, February 2021, preliminary data

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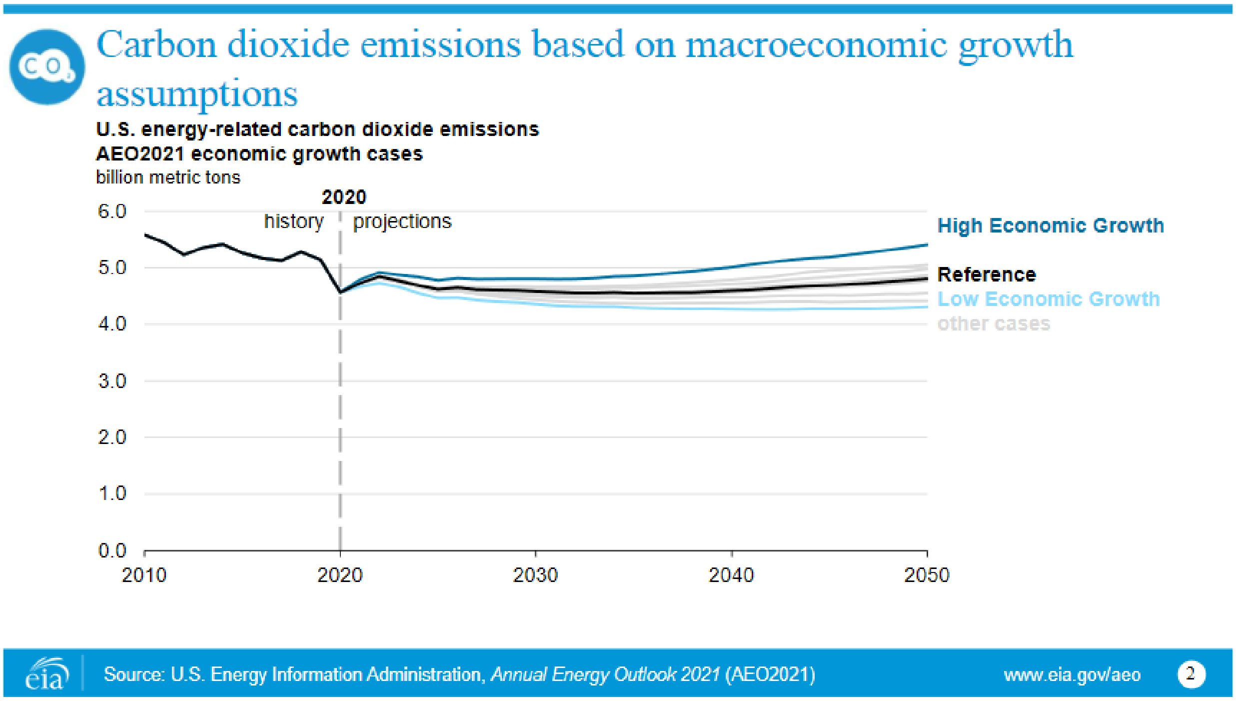
III. **Projections based on intensifying current initiatives**.

But surely with the advances in technology we're headed in the right direction…

Actually, no.

Below is a graph projecting United States CO_2 emissions through the year 2050. It appears that the most significant driver of CO_2 emissions is…… Economic growth. This curve is also abysmal. We get a small reduction depending on the economic scenario through 2030 and then head right back up.



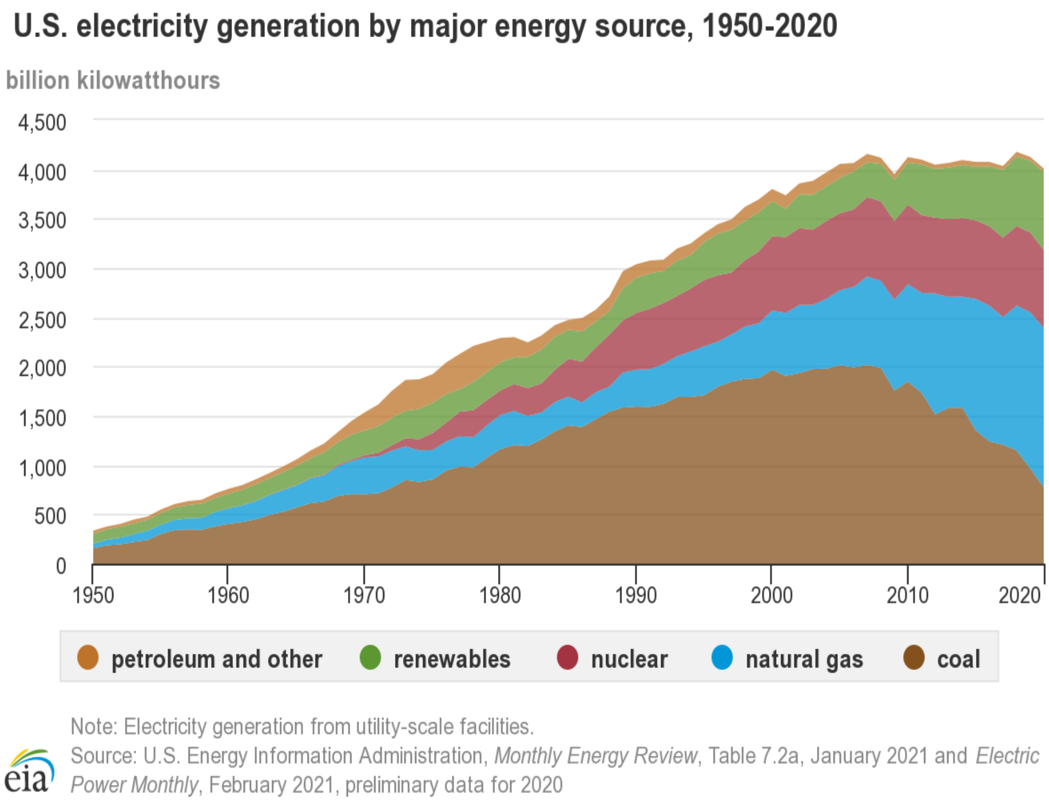
IV. Problems with what are viewed as most likely beneficial technologies.

1) The grid:
The grid, in a word, is a NIGHTMARE. The author's company has placed numerous renewable projects into production and into the grid. The process is cumbersome, extremely time-consuming and extremely inefficient. The electrical grid is more of an obstacle to large scale renewable energy than it is a benefactor of same.

Why is this?

The grid does not really exist in any meaningful sense as an entity. The grid is actually a hodgepodge of thousands of interconnected businesses, many of which are a monopoly or near-monopoly, and they are all motivated to protect their own turf. Each of the monopolies or quasi monopolies get an above market utility rate of return by justifying expenditures – they earn money by spending money. They are, of course, happily awaiting instructions to build massive grid additions THAT WILL NOT FIX THE CO_2 PROBLEM and they will get paid anyway – at above market rates.* To make things worse, the entire thing is overseen by numerous state and federal agencies, some of which are in conflict with each other. As of this writing it takes approximately three or more years from concept to connection to the grid - IF all studies during the three years show that the grid is capable of transmitting the proposed new electricity generation. Most often, the studies indicate that extensive, time-consuming upgrades to the grid are required before the project can go on-line. As renewables become more prevalent on the grid the money and time needed to upgrade the system become astronomical. It is beyond the scope of this paper to discuss how maddening and inefficient this is, but there is something even worse about the grid:
Despite intense and extensive efforts for at least the last 10 years the grid is not even close to being "green". The following chart sets out where we are at with the "greening of the grid".

*Take a look at an electricity bill: probably about 1/3 is for the actual electricity; 2/3 is for all the poles, wires, meters and overhead, etc. This will get much worse to the consumer with massive grid additions.



Fossil fuels still provide well over 50% of the energy for electricity generation. Two more things make the grid even less likely to be the entity which will meaningfully reduce greenhouse gases:

a) The "low hanging fruit" renewable penetration in the grid has already been accomplished. In plain English, the easy renewables have already been added. Further penetration by renewables is going to be more and more difficult without either a reasonable fossil fuel component or a breakthrough (a major breakthrough) in storage technology. It is inarguable that the grid, above all else, must be reliable. Recent events in Texas underscore the importance of reliability. It is again beyond the scope of this paper to discount the possibilities of battery storage to provide the requisite reliability. Suffice it to say that batteries on a scale significant enough to make the grid 100% renewable are not currently practical.

b) The inherent problems in the existing grid are a substantial barrier to the concept of electrification being able to reduce CO_2 emissions. But it is worse than that. Massive upgrades to the grid are required for electricity transportation and distribution and storage. If the grid is to be utilized as many have proposed with full-scale vehicle electrification alone, the infrastructure requirements are enormous.* Worse, even if we accomplish that goal, the result is a paltry and inadequate reduction in CO_2 emissions. Given all these things, it does not seem at all feasible for the grid to do nearly enough (at this point and into the future) to reduce CO_2 emissions. The problem is just too big.

*The grid would need to produce and transport about 2.5x as much electricity as it currently does PLUS replace the ±60% portion currently produced by fossil fuels, all with renewables and still somehow retain ***reliability***.

So… what do we do with the grid:

The grid, because of its complexities in both ownership and operations, cannot be powered entirely by renewables within any sort of reasonable time frame. A 100% renewable grid should be the LAST STEP in a carbon free economy. It is not economically nor technically feasible for the foreseeable future. It is currently not the correct goal. In recent years, the grid has greened up mainly by replacing coal with natural gas. Combined cycle natural gas plants are by far the most efficient and the lowest carbon emitters in the fossil fuel electricity generation sector.* Many have been built, many more are planned. This should continue, while a MUCH greater reduction in CO_2 emissions by replacing liquid hydrocarbons with Green Hydrogen could occur much more quickly.

A 100% renewable grid is not a prudent goal at this point. A much better, highly attainable goal is a 50% reduction in CO_2 emissions. Currently the "grid" in total emits about .92 lbs./kw-hr of CO_2. A simple mandate of no more than .45 lbs. of CO_2 per kw-hr for all generators of electricity within 10-15 years is VERY attainable. One thing the grid does have is basically a "Cap and Trade" system already in place. It is called "capacity" but the same system could immediately be used for the CO_2 reduction mandate. Grid emissions can be cut in half by market forces and without resort to unproven and massively expensive battery technologies. It can happen quickly and economically and most importantly, with grid reliability intact.

The required huge reductions in CO_2 emissions need to come from other sectors.

Government incentives and expenditures should <u>not</u> be used at scale to make the grid greener and increase electrification. It is a waste of time and money. The grid will get gradually greener by a very simple and entirely workable mandate (as set out above) and to some extent by itself** and that will help, but it is not the answer. Let us look closely at why this is so.

*Combined Cycle Gas (CCG) plants have the highest thermal efficiency of all fossil fuel electricity generation plants and the lowest CO_2 emissions. Many have been built in recent years and have 20+ year lives. They provide grid reliability without the need for batteries that would otherwise be necessary on a truly massive and unprecedented scale. Eventually CCG plants will be phased out too, as Green Hydrogen replaces all fuel. For now they should stay because bigger CO_2 reductions can be obtained elsewhere.

**See Thought Experiment #1 "The Tesla Effect"

2) Electric vehicles

So… What about electric vehicles? Could they be the answer to substantially reducing CO_2 emissions? The short answer is: NO.

At the present, use of electric vehicles is only shifting the point of CO_2 production to the source of the electricity; at least as to about 60%. While that is helpful, let's look at the overall impact and the overall possible impact of expanding the number of electric vehicles.

First it must be noted that the term "electric vehicles" as used today is generally meant to be passenger electric vehicles. Other vehicles such as trains, long-haul trucks, airplanes and ships are not included; nor are they likely to be in the foreseeable future. This is because of the substantial energy density they require which would be extremely difficult to provide with batteries.

Therefore, we are only considering passenger electric vehicles for the foreseeable future. Recall that the percentage of CO_2 emissions caused by the transportation sector is 28%.

The passenger vehicle share of that 28% is about half (14%). The sad fact is that if the United States could replace all passenger vehicles tomorrow with electric vehicles, by simple arithmetic we would reduce CO_2 emissions by about 7%! (because of the fact that over 50% of electricity from the grid is produced by burning fossil fuels). This is frankly worse than abysmal, because we are a long, long way (and trillions of dollars) from 100% electrically driven passenger vehicles which would give us a mere 7% reduction in CO_2 emissions! And we are a long, long, long way (and more trillions of dollars) from a 100% renewable grid. Even if the grid could get to 75% renewable (or otherwise carbon free) and all passenger vehicles are electric, the overall reduction from current emissions would be a dismal 10.5%.

And it's even worse than that. Analysis #1 shows a calculation of how bad the situation is with passenger electric vehicles right now. A conventional internal combustion driven or hybrid passenger vehicle that could get about 65 miles per gallon has CO_2 emissions equivalent to that of a 100% electric vehicle! What has often been disregarded by proponents of electric cars is that the situation is (again) even worse for cold climates. There are less CO_2 emissions from an Internal Combustion Engine car during the winter that gets 40 miles per gallon or better than a fully electric vehicle! At present in (say) northern Michigan, (in the winter) less CO_2 would be emitted by driving an efficient conventional Internal Combustion Engine car than a Tesla. And then… there is the enormous refueling problem and *national security issues*. See Analysis #2 Hydrogen Refueling vs. Electricity Charging.

None of this is designed to say that we should not continue as a society on the path of electrifying passenger vehicles. That effort is helping and will be part of the mix but we must look at the actual numbers as to the benefit, and the numbers say we should focus the bulk of our efforts elsewhere.

The strides that have been made in electric vehicles by companies like Tesla are very admirable but they have to be tested in the unyielding crucible of science. If drastic reductions in CO_2 emissions are the goal, the old adage "you just can't get there from here" applies.

Finally, expansion of the grid has its own problems with greenhouse gases. Big upgrades to the grid will require lots of things called "switchgear". This switchgear utilizes a gas called Sulfur Hexaflouride (SF_6) which has over 23,000 times (2.3 million %) the greenhouse gas effect as CO_2 does.

The current amount of SF_6 in the atmosphere is tiny (parts/trillion) but it is increasing at an accelerated rate which will continue to accelerate with massive grid additions.

3) Carbon capture and storage at the source

Carbon capture at the source (meaning the point where combustion occurs) followed by permanent sequestration has a superficial appeal. If this technology could be perfected and deployed wherever fossil fuels are burned, our problems with climate change would be over. As is the case with most of the potential solutions discussed in this paper, this concept has a role to play. However, it is fraught with difficulties that will make it literally impossible to cause the CO_2 emissions reductions we need.

The author is very familiar with the most likely technology to be utilized for the sequestration of CO_2. The most practical method of permanently storing CO_2 is in underground reservoirs. The author has over 40 years experience in such underground reservoirs. The natural gas industry, in particular, has utilized depleted oil and gas fields for storage of natural gas and the technology is well understood. The technology developed for storage of natural gas could be utilized to store CO_2 in underground reservoirs. Unfortunately, the best storage reservoirs are already currently being utilized. In addition, it is the scale of the problem and the geographically diversified points where this technology would have to be deployed that make it virtually impossible as a meaningful solution. The underground reservoirs needed must be particularly safe for long-term storage. This is actually more rare than one might imagine. In addition, the geology that would accommodate CO_2 sequestration is not coincidental with all the areas where CO_2 is being generated. In fact, this technology (if it were feasible and economical) would likely only impact electricity generation because of the potential centralized nature of that generation. But that's our old friend the grid again and the grid is gradually being decarbonized with other methods and will never be the sole answer. Sequestration of CO_2 is wholly impractical for all the other sources of emissions. The story is actually worse than that because there are enormous safety issues, corrosion issues etc. with this technology.

The author is not as experienced with the technology involved with the first part required: the capture of CO_2 at the source. Enough is known about the technology to know that it is very expensive and complex. The problems with just the sequestration portion are enough to make this a non-meaningful contributor to the climate change issue. Policymakers should utilize limited resources on this.

4) Carbon recapture from the atmosphere

The only thing that will ever be captured from this concept is the imagination.

The idea of cleaning up our mess by having giant scrubbers that filter all the air of the atmosphere sounds great.

It is also ridiculous.

This concept is so impractical, that it's hard to know where to begin. For openers, the reason we burn carbon is because it is an exothermic reaction when combined with oxygen. If we're actually going to undo that reaction the first and second laws of thermodynamics tell us that we have to put more energy *in* than we get *out* from all of that combustion in the first place.

Just *that* is ridiculous.

If instead we are contemplating removing the CO_2 molecules, then it's not quite as ridiculous; but nearly so. The amount of horsepower and facilities that would be required to move sufficient quantities of our atmosphere through some sort of scrubbing device would be gigantic - even if the device itself was practical and economical, which is itself very unlikely. If the reader of this paper comes away with only one idea and said reader is a policymaker of any sort, please do not allocate any resources towards this "scrubbing of the atmosphere" concept. Mr. Elon Musk has offered a $100 Million prize for this which is surely going to be the safest bet ever made because he is never going to have to pay out – it isn't going to happen.

Finally, to put the final nail in the coffin of this crazy idea, it is really a bit of human hubris to try and outdo nature in this regard. The best scrubbing devices that will ever exist already exist nearly everywhere.

Here's a picture of one:

Here's a picture of another:

Properly handled, natural systems will gradually clean up the atmosphere if we quit dumping CO_2 into it. Trees and plants and Earth's vast oceans over the eons have constantly sequestered CO_2 methodically and consistently. They continue to do so.

These natural systems will never be beaten by any of our technologies and they will do their job if we just quit overloading the system. Perhaps the worst thing about pursuing this "clean it up later" concept is that if the general population thinks this will eventually work, why bother to stop burning fossil fuels? Policymakers should avoid this bad idea entirely.

V. Current economics of Green Hydrogen production utilizing readily available off-the-shelf technology in comparison to the costs of other fuels that need to be replaced.

<u>Current cost comparison of Green Hydrogen to liquid hydrocarbon fuels: (gasoline and/or diesel)</u>:

Green Hydrogen can be produced and delivered to "gas station equivalent points" at a cost of about $10/kg or less using "OFF THE SHELF" technology with some incentives from the government, such as those bestowed on electric cars. This cost will continue to decline. See Analysis #3.

A kilogram of hydrogen contains roughly the same amount of energy as a gallon of gasoline, but when utilized in a fuel cell to propel a vehicle it is about 2.5 times as efficient. This simply means that Green Hydrogen produced today with today's technology delivered to the point where it can be injected into a vehicle is approximately on par with $4 for a gallon of gasoline. Most importantly, it can be used for passenger vehicles AND small trucks AND long-haul large trucks AND ships AND trains and most significantly in <u>airplanes</u>. The cost needs to be reduced even further, of course, and can and will be with the right policies. It can and will get as cheap as gasoline if THE PLAN is implemented.

<u>Current cost comparison of Green Hydrogen to natural gas</u>:

When comparing Green Hydrogen to natural gas, hydrogen does not currently fare as well. Green Hydrogen contains only a fraction the energy content of an equivalent amount of natural gas based on today's costs. This will undoubtedly improve markedly as technology develops. One very positive note is that Green Hydrogen can be injected directly into existing natural gas pipeline networks at a concentration of 10% to 30% with very minor changes to the system. Green Hydrogen will eventually replace natural gas, but using hydrogen in fuel cells to power vehicles is the best place to utilize it now. Use of hydrogen to produce motion is about 2.5x as efficient as burning gasoline.

Notes on water requirements:

There are really only two things necessary to make Green Hydrogen: a clean source of electricity (on a massive scale for this to work) and an adequate supply of water. What follows is a calculation of water required, but it must be noted immediately that the water is only "borrowed". The H_2O molecule is first split then put back together when used as a fuel. The water is not consumed at all, but is moved from one point to another geographically.

Water is necessary to produce Green Hydrogen in the amount of about 4 gallons/kgH_2. This could be a significant amount of water in the very driest areas of the world. However, it would not be an issue in most of the US because the amount utilized is much less than that used by other energy sources. (cooling water for thermal electricity, for instance).

Proper use of the available fuels coupled with prudent incentives (including Green Hydrogen of course) could cut US and worldwide CO_2 emissions by more than 50% in a very short period of time (10–15 years). Within 30 years, worldwide CO_2 emissions could drop 80% or more.

VI. How to put Green Hydrogen to work very quickly (the proverbial chicken/egg problem).

So how do we do this?

The obvious question is: "If Green Hydrogen can be used in all sectors to stop CO_2 emissions, why hasn't full-scale implementation already begun?"

Until very recently there were two answers to that question. Prior to the dramatic reduction in the cost of renewable electricity to generate Green Hydrogen, it was simply far too expensive. In our capitalist economy, that was enough to stop the effort. However, that is no longer the case due to the very recent drastic reductions in the cost of renewables. The cost of producing Green Hydrogen can be competitive with liquid hydrocarbon fuels right now.

The second barrier has historically been the proverbial chicken/egg problem. Companies are reluctant to produce Green Hydrogen at large scale because the infrastructure is not in place to move the product to market and sell it at retail. This is also where policy efforts would come in to play. Rather than incredibly expensive and ineffective expenditures on the grid and subsidized electric cars, incentives should be established to help with liquefying, transporting and distributing perfectly clean burning Green Hydrogen. These incentives in particular should foster the development of fueling stations nationwide rather than electric outlets that won't solve the problem. Incentives to develop the first "at scale" solar and or wind dedicated hydrogen producing plants would also be very helpful. The technology needs to be implemented and capital is always difficult to raise for new technologies. These plants should be on the scale of at least 100 MW or greater. They should be established most importantly with no or minimal reliance on the grid.

One very specific method to jumpstart the Green Hydrogen economy would be simply to mandate that all hydrogen be either blue or green within four years and that a significant proportion come from "off the grid" projects. This one, very simple policy would jumpstart the market in a very significant manner, giving the manufacturing process the chance to begin at scale while the infrastructure to liquefy and deliver is being established.

The incentives required for scaling up the production of Green Hydrogen are much less than those required to get to a 100% renewable grid – and a 100% renewable grid will not fix the problem anyway.

Effectively, the Green Hydrogen economy is at the same correlative place as the Oil and Gas industry was in its infancy. Oil and gas became the dominant fuel because it was relatively cheap, abundant and spectacularly useful. It is the author's firm belief that with modest jumpstarting the similarly nearly perfect fuel that is Green Hydrogen will take over the fuel economy via the same factors.

In terms of time, this transition to a "climate perfect" fuel can occur far, far more rapidly than 100% renewable electrification. Furthermore, it is far more effective, will ultimately be cheaper, can be rapidly adopted worldwide, and can unite otherwise competing vested interests in a common goal.

VII. Quantifying the resources required to cut US and worldwide emissions by 50%.

Is there enough energy from solar and wind and potentially nuclear generated electricity to provide sufficient amounts of Green Hydrogen to drastically reduce CO_2 emissions?

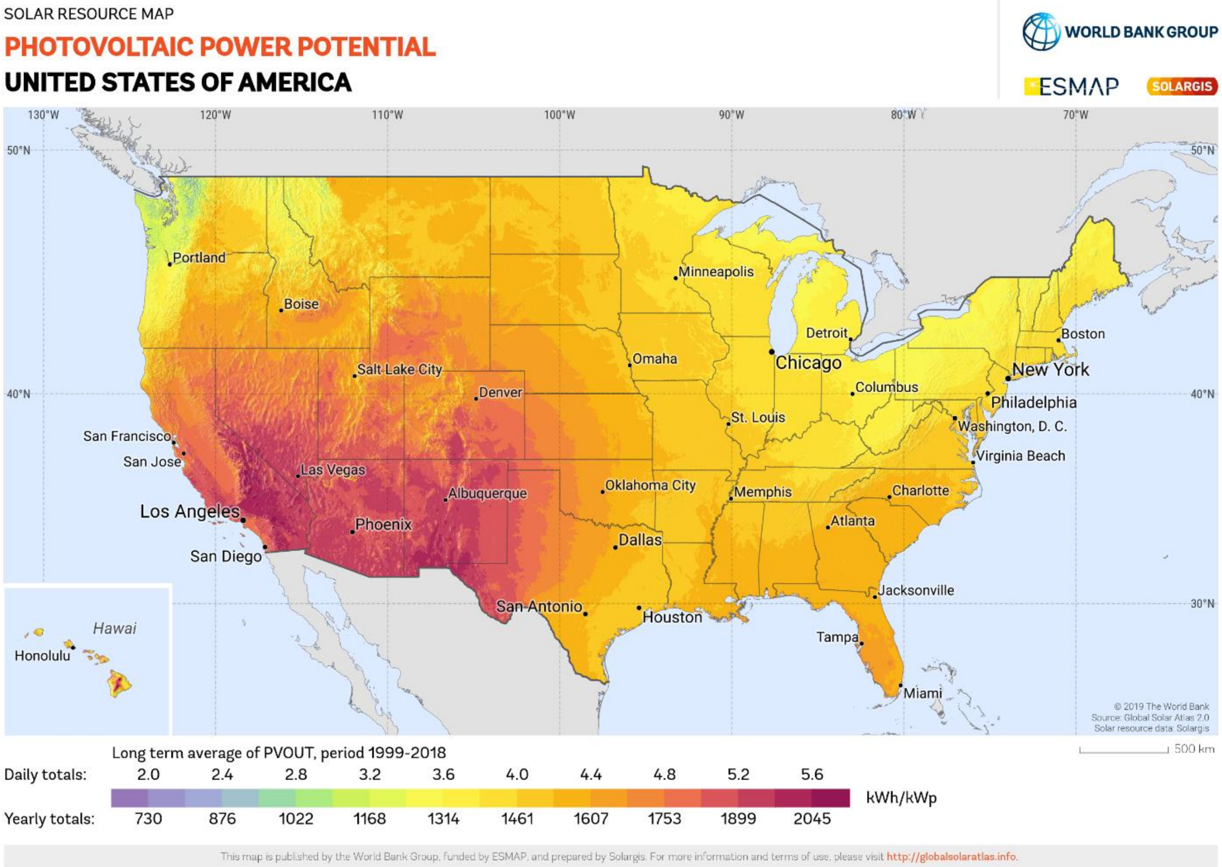
Analysis #4 answers the question: the answer is "YES".

Remember, THE PLAN is to reduce the transportation sector CO_2 emissions to effectively zero, (quite possible with Green Hydrogen - effectively *im*possible with electricity); reduce the electricity generation sector CO_2 emissions to 50% of what they are now; and each of industry, commercial, residential and agricultural sectors CO_2 emissions get cut by 25%. The effect would be (round numbers) to reduce US CO_2 emissions by more than 50% overall.

All these goals are eminently "doable" within less than 20 years with sufficient Green Hydrogen.

How much land would we need if this ALL came from Green Hydrogen generated from solar?

The answer is approximately 35,000,000 acres, which is equivalent to about 55,000 mi.^{2}. This sounds like a lot of land and indeed it is. However, to put it in perspective, there are approximately 3,000,000 mi.^{2} (land, not including water) in the United States lower 48. Therefore, about 1.9% of the land area would need to be covered with solar panels producing Green Hydrogen. This map of the US shows the extent of the resource.



The resource is ENORMOUS, particularly in the Southwest. For putting everything in perspective, the US Federal Government alone owns approximately 1,000,000 mi.^{2}. The 55,000 mi.^{2} area represents about just 5.5%. As another comparison, this is roughly the area of paved roads already in existence in the US.

A couple of points here:

It does not all need to come from solar. The 35,000,000 acres required is if all of our Green Hydrogen is produced only by solar energy. Any combination of solar, onshore wind, offshore wind, and nuclear power could be utilized. Solar panels covering much less than one percent of the lower 48 together with onshore wind and offshore wind with perhaps some component of nuclear generated electricity will do the trick quite nicely. Offshore wind, by itself, could easily provide much of the necessary electricity to make Green Hydrogen and is obviously ideal from the standpoint of aesthetics and water requirements. See Thought Experiment #2 the "Gulf of Mexico".

IN CONCLUSION, these efforts would cause US CO_2 emissions to drop more than 50%.

If we are serious about the CO_2 problem this is what we must do. This is the scale required. And one key point is that there is no way a present or future grid and electrification of vehicles (and everything else we can think of) could carry this sort of scale.

This could be done free of the enormous complexities of focusing too much on the electrical grid, it could be done virtually anywhere.

Best of all, the rest of the world has even more resources than the United States to accomplish this.

VIII. The potential role of the Oil & Gas industry

So, we know what we need to do; who is going to do it? Well, what industry do we know has the knowledge to handle flammable gases? Has the knowledge to transport flammable gases? Has the ability to meter flammable gases? And, has the ability to liquefy and transport flammable gases?

Lots of companies can and will, but…. The existing Oil and Gas industry already does all these things. Furthermore, it is a huge industry with many high-paying jobs. Switching over to Green Hydrogen as a fuel to replace gasoline and diesel fuel is a monumental task. The Oil and Gas industry can be part of the overall massive effort. The best part is that the Oil and Gas industry fears the transition away from the product they have produced for over 100 years. If policymakers make it clear that Green Hydrogen is the new fuel and manufacturing it, transporting it and selling it is properly incentivized, the Oil and Gas industry will be converted from a potential foe of decarbonization to an enthusiastic ally. To further elaborate on jobs, electricity generated from solar and wind farms creates many high paying jobs during the installation process. The truth is that long-term high paying jobs are markedly reduced during the much longer production period if the electricity goes to the grid. In contrast, producing and marketing hydrogen as a fuel will create a similar amount of high paying jobs during the construction phase, but most importantly, a large majority of those jobs will remain as Green Hydrogen takes over as the fuel of the future.

We are at a point in history which is analogous to two situations as follows:

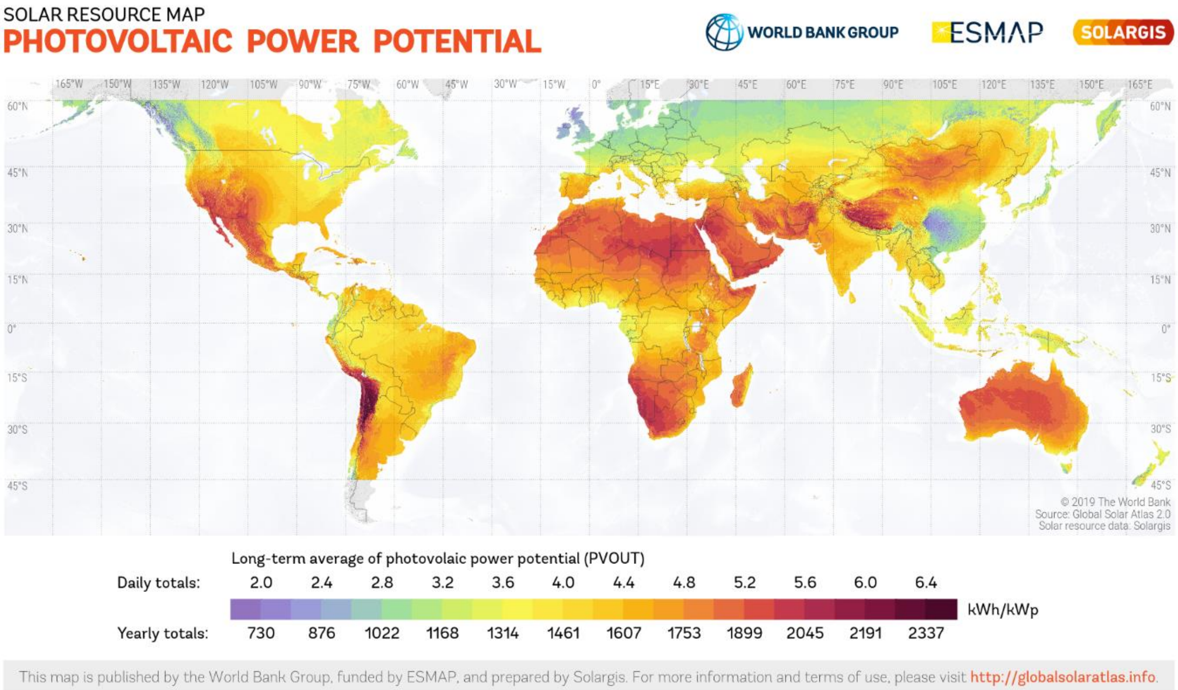
1) The point in time during the early 1900's when then First Lord of the Admiralty, Winston Churchill converted the British fleet from coal to oil. This was not without controversy because Britain had a lot of coal and zero oil at the time. But it was the right new fuel and the right thing to do at that time.

2) We are also at a crossroads similar in time to when Tesla and Westinghouse were proponents of alternating current and the acclaimed Inventor, Thomas Edison, was a proponent of direct current. Edison was wrong then and Tesla was correct. This time, this Tesla is not correct in advocating a complete transition to battery electric vehicles and overlooking the many advantages of fuel cell driven Green Hydrogen vehicles.

It has become ***common sense*** to embrace full-scale adaptation and utilization of Green Hydrogen as the new fuel of the future. We, the people of this planet need to implement this expeditiously and massively or we might just as well start moving to higher latitudes and higher ground now.

IX. The World

This is really the best part. The CO_2 emissions issue is not a United States problem; it is not a European Union problem; it is a worldwide problem. If the rest of the world does not embrace the solution, again we might just as well head for high ground now. But here's the good news: Here is a diagram depicting the worldwide solar resource. It has been demonstrated that the United States (and North America) has magnitudes more solar resources than it needs; but the US resources are dwarfed by the resources of other countries and continents. Look at Africa. Its resource is enormous and it has an abundance of water. It is perhaps not an overstatement to observe that a worldwide switch to Green Hydrogen as a fuel could make Africa a very wealthy continent. Africa could supply not only its own needs but all of Europe as well. And there are plenty of solar resources in Asia and South America, too. Australia's resource is probably 100 times what it needs. If developed countries lead the way the rest of the world will follow.



COMMON SENSE dictates: "Let's get to work on this"

ANALYSIS #1

Are EVs Electric Vehicles) really "green"?
Answer: Somewhat, but not enough to matter.

Here is why:
The US grid (even after all renewables plus nuclear) emits about .92 lbs (418 grams) of CO_2/kw-hr. EV's electricity usage varies, but a good (realistic, real-world) number is between 2-4 miles per kw-hr.

Using 3 miles per kw-hr as a generous average an all-electric car emits 418/3 = 140 gms CO_2/mile. (Not including life cycle emissions associated with battery manufacture, etc.) A 2020 Toyota Prius, emits about 200 gms/mile. So, at least currently, an all-electric car emits a full 70% of CO_2 as does an efficient gasoline powered car. In fact, the mileage needed for a gasoline vehicle to have the equivalent emissions of CO_2 as a <u>fully</u> electric car is as follows:

- All electric car @ 3 miles/kw-hr = 140 gms/mile
- Burning 1 gallon of gasoline produces 19.6 lbs. of CO_2 = 454 x 19.6 = 8,896 gms CO_2
- 8,896 gms/gallon ÷ 140gms/mile = 63 miles/gallon

- *If a car gets 65 miles/gallon it is currently emitting <u>less</u> CO_2 than a fully electric car getting 3 miles/kw-hr!*

When life cycle CO_2 emissions are factored in EVs look even worse.

AND… in Northern climates, for cold weather driving it is much worse. Various sources cite a 50% reduction in EV range in cold conditions because of battery issues and vehicle heating requirements. This would double an EV's CO_2 emissions to 280 gms/mile. This means that for much of the US in the winter, the "all-electric" vehicle is responsible for 40% <u>more</u> CO_2 emissions than a highly efficient gasoline vehicle!

Even a modestly efficient (38 miles/gallon) conventional Internal Combustion Engine vehicle only emits about 240 gms/mile – still better than a cold weather EV.

A final note: A fuel cell powered by Green Hydrogen vehicles would not have the "winter problem". Fuel cells give off adequate heat as a byproduct of making electricity to power the vehicle. EVs do not. Heat is basically "free" in a fuel cell powered vehicle. Fuel cells are NOT "fool cells".

ANALYSIS #2
Hydrogen Refueling vs. Electricity Charging:

The Basics: Hydrogen powered vehicles can be fueled right now in about the same time it takes to fuel with gasoline or diesel. In stark contrast, THE VERY BEST estimate for future chargers is at least 20 minutes or more to "fill the electric tank". Is this acceptable to the American driving public? Very doubtful. It boggles the mind to picture the situation at electric fueling stations when EVs are the dominant vehicle (or worse the only available vehicle). Why on earth would policymakers want to subsidize thousands of electricity charging stations that will never be acceptable at scale. Contrast this with the Toyota Mirai hydrogen vehicle available right now - 400 mile range; 5 minute fill-up time! Green Hydrogen fueling stations are a "hands down" winner on this issue.

ANALYSIS #3
Current costs to produce Green Hydrogen:

The fuel cost of producing Green Hydrogen is, first of all, tied to the cost of electricity. The electricity is utilized to split the water molecule (H_2O) into H_2 + O_2 (Hydrogen + Oxygen). Later the hydrogen is simply "burned" as fuel and recombined to make H_2O (water) again. The electricity currently required is about 55 kw-hr per kg H_2. Electricity from solar panels can be profitable in the Southwest of the US @ 3.5₵/kw-hr or less, 5₵ or less in the rest of the USA. Therefore, based on electricity from solar at 4.5₵/kw-hr, the fuel cost of one kg of Green Hydrogen is .045₵ x 55 = approximately \$2.5. The actual device that takes electricity and water in and produces Hydrogen (and Oxygen) is called an electrolyzer. The cost of the electrolyzer itself and balance of plant must be amortized over time and this fact adds some complexity.

For a solar only facility, the electrolyzer would only run ± 30% of the time. This is not a good scenario. An electrolyzer connected to a solar/wind project could run at more like 50%. With an on-site nuclear facility, the electrolyzer could run at 90%+. Electrolyzer prices are falling, but for now this is one good place for government incentives (low cost loans to amortize electrolyzers, for instance). At any rate, assuming worst case numbers: the cost of a 1 MW electrolyzer is approximately \$1,200,000. Balance of Plant is estimated to be \$800,000, which equals a total estimated cost of \$2,000,000/MW. Using a 20-year amortization of the plant at 8% requires about \$200,000/year, yearly production is calculated to be approximately 50,000 kg, meaning a plant amortization cost of about \$4/kg. Adding 10% for operating costs brings the total manufacturing costs to (\$2.5 + \$4) x 1.1 = \$7.15/kg. Liquification and transport* will add at least 40% more bringing the total cost to \$7.15 x 1.4 = ± \$10/kg delivered. The \$10 price calculated is based on solar only and is conservative.

However, the actual real-world price will probably (for the first plants) be higher still. There will likely be cost overruns for the initial plants. This is why incentives will be necessary. As the industry matures, incentives will not be needed, and the delivered price should drop. This price is also for a non-grid-connected facility. Costs would actually be less for a grid-connected facility because this would enable 24-hour run time to amortize the plant. For THE PLAN to work, however, Green Hydrogen must be made on a large scale with minimal help from the grid.

*These numbers are uncertain and part of the implementation problem.

ANALYSIS #4
What is it going to take to reduce CO_2 emissions by over 50% in less than 20 years:
IF ALL REDUCTIONS COME FROM SOLAR ENERGY?

By Sector:

ELECTRICITY GENERATION:
THE PLAN-PHASE I: Cut emissions by 50% within 10-15 years:

- Currently there are approximately 1,530 Megatons of CO_2 emissions:
    - 950 Megatons from coal
    - 560 Megatons from natural gas
    - 20 Megatons from other petroleum products
- Need 765 Megaton reductions
- For estimation, replace all Coal with Natural Gas: CO_2 reduction = 475 Megatons
- Deficit: 765-475 = 290 Megatons

The remaining deficit is filled by renewables replacing Natural Gas and the other Petroleum liquids:

- 290 Megatons = 2200 x 290 x 1,000,000 = 638 x 10^9 lbs.
- Each kw-hr causes .9 lbs CO_2 if generated by Natural gas (average)

Therefore, 638 x 10^9/.9 = 709,900,000,000 kw-hr needed to be generated by renewables instead of Natural Gas or other Petroleum.

A one acre solar farm (based on 6 acres per 1000 kw) produces 1/6 x 8760 hours x .25 x 1000 = 365,000 kw-hr/acre

The number of acres required = 709,900,000,000 kw-hr/365,000 kw-hr/acre = approximately 2,000,000 acres.

TRANSPORTATION:
THE PLAN-PHASE II: Eliminate virtually all CO_2 emissions by replacing gasoline and diesel with Green H_2 and utilize fuel cells in vehicles of all sorts.

- Current usage is approximately 28 “Quads”*
- Current thermal efficiency – heat to motion by combustion is approximately 25%
- Fuel cell efficiency to motion is approximately 70%
- Therefore, 28 x 25/70 = 10 Quads H_2 required

1 kg Hydrogen contains 114,000 BTU

Therefore, 10 x 10^{15} ÷ 114,000 = 87.7 x 10^9 kg H_2

It takes 55 kw-hr to make 1 kg H_2 by electrolysis

Estimate: it takes 40% more to liquefy and transport the H_2
(Assume 20% can be used without liquification and transport, e.g. Utilized where produced)

*A “Quad” is a quadrillion BTUs: 1,000,000,000,000,000

Then .8 x 55 x 1.4 x 87.7 x 10^9 = 5.4 x 10^{12} kw-hr
+ .2 x 55 x 1 x 87.7 x 10^9 = .9 x 10^{12} kw-hr
6.3 x 10^{12} kw-hr

The number of acres required = 6.3 x 10^{12} kw-hr /365,000 kw-hr/acre = approximately 17,000,000 million acres required.

REMAINING SECTORS: (INDUSTRY, RESIDENTIAL/COMMERCIAL AND RESIDENTIAL)

THE PLAN: Reduce CO_2 emissions by 25% within 10-20 years

- Quads required: approximately 10
- 10 x 10^{15} Quads / 114,000 = 87.7 x 10^9 kg H_2

- 50% via pipeline
- 50% requiring liquification and transport

Then .5 x 55 x 87.7 x 10^9 = 2.4 x 10^{12}
+ .5 x 55 x 1.4 x 87.7 x 10^9 = 3.4 x 10^{12}
5.8 x 10^{12}

The number of acres required = 5.8 x 10^{12} kw-hr /365,000 kw-hr/acre = approximately 15.8 million acres

TOTAL ACRES REQUIRED FOR THE PLAN:

Electricity Generation Sector	2,000,000
Transportation Sector	17,200,000
Remaining Sectors	15,800,000
Total Acres	35,000,000

= Approximately 55,000 square miles

BUT ONLY IF ALL OF THE ELECTRICITY COMES FROM SOLAR

- State of the art solar tracking devices could greatly reduce the land requirements.
- Onshore and offshore wind could carry 25-50% of the load.
- State of the art nuclear plants could reduce land requirements even further.

Thought Experiment #1: "The Tesla Effect"

There is information to be gleaned from what the author calls "The Tesla Effect". And that information is extremely positive. In the author's opinion, the only rational explanation for the irrational value of the company Tesla, is that the population of the United States, in general, is aware of the CO_2 problem and WANTS to do something about it. They support the admirable efforts of Tesla to reduce CO_2 emissions via the manufacture and sale of electric cars. That same "Tesla Effect" is influencing decision makers of virtually all corporations. Millions of people want action to avert climate change. That single factor is why the grid will gradually become greener than mandated. People will and are demanding it. CEOs know they must comply. Unfortunately, much of what has been done to date is not meaningfully successful. Once the much better strategy of Green Hydrogen as a fuel is implemented on a large enough scale, the same millions of people will embrace that too. In the meantime, policymakers must get this started.

Thought Experiment #2: Gulf of Mexico:

Recently NREL released a study on the potential magnitude of offshore wind installations in US waters. The potential was enormous. Just focusing on the Gulf of Mexico, however, reveals a few things that need to be put into perspective. The study showed that the potential of the area in the Gulf of Mexico currently utilized by drilling and production platforms for oil and gas is on the order of 500 Gigawatts. The study went on to conclude that the existing platforms and infrastructure could be utilized for wind generated electricity. The study further concluded that the amount of electricity that could be generated would be far in excess of that being utilized by the entire Southeast United States. But the thought experiment goes like this:

How long would it take the very complicated and Byzantine grid to be improved such that it could handle such a massive amount of newly generated electricity? In the opinion of this author the amount of time it would take is "almost forever" if at all. In marked contrast, the amount of wind generated electricity that could immediately be used to produce Green Hydrogen by electrolysis could be put in place very expeditiously (certainly less than fifteen years) and all of this would take place in basically the backyard of the Oil and Gas industry. In fact, the oil and gas companies certainly would be a large part of the implementation. It has been the author's experience that properly motivated oil and gas companies can accomplish things amazingly quickly- and massive things at that. Just that wind resource in the Gulf of Mexico, with existing infrastructure, could produce enough Green Hydrogen to reduce CO_2 emissions from the entire transportation sector by a very significant percentage.

Thought Experiment #3: National Security and A 100% Renewable Grid

Say we have reached our goal: As implausible and expensive as it was, all US transportation is with EVs and the grid is powered 100% by renewables with giant batteries for reliability. However, those batteries will not provide power for more than a few days. Great… except… the grid is already today a worrisome target for terrorism. The threat would be magnitudes worse if grid outages could paralyze transportation for more than just a few days. And what about natural disasters? When the power goes out can no-one evacuate from a hurricane?

Should we have giant batteries at each "fueling" station as a back up to charge the millions of batteries that are in the cars? And these batteries would be in addition to the giant batteries we need for short term reliability on a 100% renewable grid - THREE complete sets of batteries???

This is ridiculous AND is a genuine national security issue.

Green Hydrogen refueling stations would be a much better investment.

About the Author

The author, Martin G. Lagina has 40+ years of experience in the production and sale of energy. He has extensive experience in conventional oil and gas production. He is a past Chairman of the Michigan Oil and Gas Association. In addition, he has approximately 15 years of experience in building and operating utility scale solar and wind farms. He holds a Bachelor of Science in Mechanical Engineering from Michigan Technological University and is a registered Professional Engineer in the state of Michigan. He is also a graduate of the University of Michigan law school and member of the State Bar Association.

He is on reality TV too, and for that he apologizes.