True Sustainability
With
Low Embodied Energy

WHITE PAPER

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INTRODUCTION

Embodied energy is the energy required to produce or make the things humans use or rely on. Sustainability is essentially what human civilization is actively pursuing at this time on a global scale, with Climate Change prevention and mitigation the primary goal. Accumulating Green House Gas (GHG) emissions, particularly CO_2 from human activity, is the leading cause of Climate Change. Efforts to build up the infrastructure for a sustainable future aimed to reduce the emissions will involve a grand accounting of emissions, from manufacturing and power generation to usage and consumption energy and to other GHG emitting activities. This white paper, intended to generally inform on the subject of embodied energy in the transition to renewables, will address such accounting.

Sustainability is the ability to sustain life and future generations of life without diminishing the natural capital upon which all life depends. In essence, it means living on income rather than savings and respecting the natural cycles on earth – thermal, hydrological, carbon, and so on.

True sustainability assures that the approach to obtaining sustainability does not itself lead to non-sustainability.

True sustainability with low embodied energy is a challenge, as the recurring remnant embodied energy works up against the GHG/CO_2 budget in the longer term, as well as cumulatively forming a bow wave of GHG/CO_2 emissions in the buildup of the low carbon infrastructure in the shorter term. We will see that staying within the carbon budget is more difficult than dealing with a surge in carbon emissions early in the transition to renewable energy.

EMBODIED ENERGY

The path toward 100% renewable energy will inevitably face the challenge of providing an alternative to the fossil fuels sourcing of the production, process, and high heat energy needed to make things. Ultimately relying on Carbon Capture technology leaves us reliant on non-renewable fossil fuels, which is not true sustainability. To deal with the availability and intermittency issues of renewable energy we will have lots of energy storage (at Utility Scale and/or widespread Distributed Generation), which means higher embodied energy and more CO_2 emissions. We do not grow solar and wind power toward 100% renewable energy without a lot of energy storage, where evolution and even breakthroughs need to happen. Will the renewable Hydrogen Age arrive in time?

The intermittency of solar and wind power means intermittent over capacity (where supply exceeds the demand), as well as intermittent non-availability (when the sun does not shine and the wind does not blow). An impractical solution involves behavioral change, that is, live with it and adjust consumption habits. A practical solution involves scaling up of the existing state of the art (SOTA), while embarking on Research & Development to reduce embodied energy and to advance the state of the art, especially in the areas of energy storage and reliability, but also in Carbon Capture and Nuclear power – our backup plan in light of our persistent embodied energy, high heat challenges.

Embodied energy (aka Invested Energy) is inescapable, as it accompanies the buildup and maintenance of renewable energy infrastructure and large scale electrification of the economy, done so to prevent further Climate Change and to transition away from nonrenewable fossil fuels. It is all about GHG emissions, especially CO_2. We can discuss emissions baselines, targets, and annual reductions, but the CO_2 Budget metric (of about 900 Gigatons, or billion tons) is perhaps the most important. As of 2016, globally we had about 900 Gigatons of CO_2 emissions left before worsening Climate Change and passing Tipping Points (of irreversible, accelerating Climate Change).

Embodied energy is a three part problem:

- A CO_2 Bow Wave from initial infrastructure buildup (constituting embodied energy)
- Breakthroughs and technology advances over the next decades that reduce operational energy CO_2 emissions at the cost of higher embodied energy, a second Bow Wave of sorts when those breakthroughs are built up (commercialized)
- Remnant embodied energy to maintain the lower operational energy infrastructure in the face of an exhausted CO_2 Budget, amounting to billions of tons CO_2 emissions per year (a fraction of the projected 51Bt/y in 2050) when the remaining CO_2 Budget has dropped to zero.

The somewhat politically charged goal of global Zero Net Carbon by 2050 is not practical, as it largely depends on technology, know-how, and breakthroughs not even developed, yet. Global zero net carbon by 2100 is a more practical scenario. The 2050 goal essentially ignores the embodied energy issue. The 2100 goal provides time to resolve the embodied energy issue. We do not want the Perfect (Zero Net Carbon) be the enemy of the Good (highly reduced CO_2 emissions).

Approach to CO2 Emission Reduction Calculations

The two prongs of the approach to calculating CO_2 emission reductions reflect the fundamental nature of the categories of emissions.

The Top / Down Prong identifies reductions by added infrastructure and products and has 6 main development areas: Solar PV, Wind, EVs, Efficiency, Energy Storage, and Buildings. The focus is on consumers and products, with calculations based on direct assessments and analysis.

The Bottom / Up Prong identifies reductions by modifications of existing infrastructure, especially in manufacturing and production of material, which are energy intensive (not immediately amenable to the diffuse less intensive renewable energy). The focus is on suppliers and providers, with calculations based on historical data.

Aviation, though extensive in our modern world, is basically a non-essential activity and, thus, could be scaled down. Renewable fuels and electric propulsion are already in development and show promise, as progress has already been demonstrated. Agriculture can also look at renewable fuels to power its operation and to organics to help replace the use of fertilizers. Forests provide a sink for carbon, but tropical deforestation contributes about 1/5 of global GHGH emissions. Forests are not so much a technology issue, as they are socio-political – we choose to allow their overuse and destruction. We could choose less consumption of forest resources, and we can choose to manage sustainable forests.

Forestry, agriculture, and aviation will follow another path to Zero Net Carbon, and will somewhat depend on the progress in the other categories (two prongs). This third prong (or path) is beyond the scope of this white paper, as the solutions and implementations go beyond technology, facing revolutionary change politically and socially.

The two prong approach to calculating CO2 emission reductions is illustrated in the following figure.

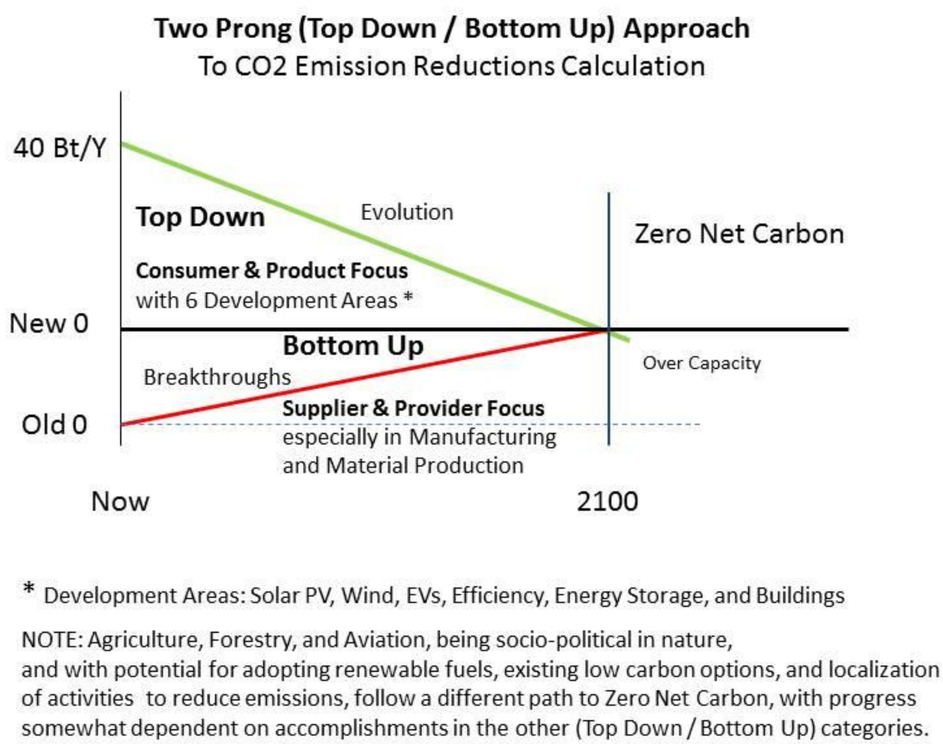


Figure 1

THE PRACTICAL SCENARIO

The practical scenario for achieving ongoing CO2 emissions reductions recognizes the technological realities and limits of today to achieve significant reductions by 2050, with Solar at 30% of electricity generation and Wind at fully developed optimal sites…Solar grows to 15 times and Wind to 4 times current capacity in the United States and similarly elsewhere.

Categories (Energy –related)	Invested Energy (U.S.) CO2 Levelized	Invested Energy (U.S.) thru 2050 CO2 released, tons	U.S. CO2 Reductions through 2050	Global CO2 Reductions through 2050
Solar PV	195 Mt/y	5.85 B	(522Mt/y) 15.7 B	62.8 B
Wind	30 Mt/y	900 M	(490Mt/y) 14.7 B	58.8 B
Electric Vehicles	169 Mt/y	5.07 B	(501Mt/y) 15 B	60 B
Efficiency	236 Mt/y	7.08 B	(507Mt/y) 15.2 B	60.8 B
Energy Storage	16 Mt/y	480 M	0	0
Buildings (1M/Y)	8 Mt/y	240 M	(35Mt/y) 1.0 B	4 B
TOTALS	**654 Mt/y**	**19.6 Bt total (78 Bt Global)**	**61.6 Bt (U.S.)**	**246 Bt (Global)**

Table 1

There are two major groups of emissions, Energy and Non-Energy sources. Non-Energy would include Agriculture, Forestry, and Waste/Wastewater, or in total about 1/3 of emissions, outside the scope of this white paper. Energy sources would include electricity generation, transportation (using fossil fuels), industry, and buildings, or in total about 2/3 of emissions. [Leontis]

The efficiency category is most interesting. With a reasonable assumption that across all sectors there is a feasible reduction of energy consumption (thus CO2 reductions) of 20%, the returns continue on past the 2021 to 2050 timeframe. Reducing energy consumption is akin to producing Negawatts, or negative watts. Be efficient now and save into the indefinite future. Efficiency is the investment that keeps returning, the gift that keeps on giving. The investment (invested energy) is not insignificant, as energy-saving equipment, machinery, resources, and appliances across all sectors are replaced.

The practical scenario for achieving ongoing CO2 emissions reductions (to Net Zero Carbon) by 2100 involves adding more solar PV, wind capacity, and energy storage and is summarized as follows:

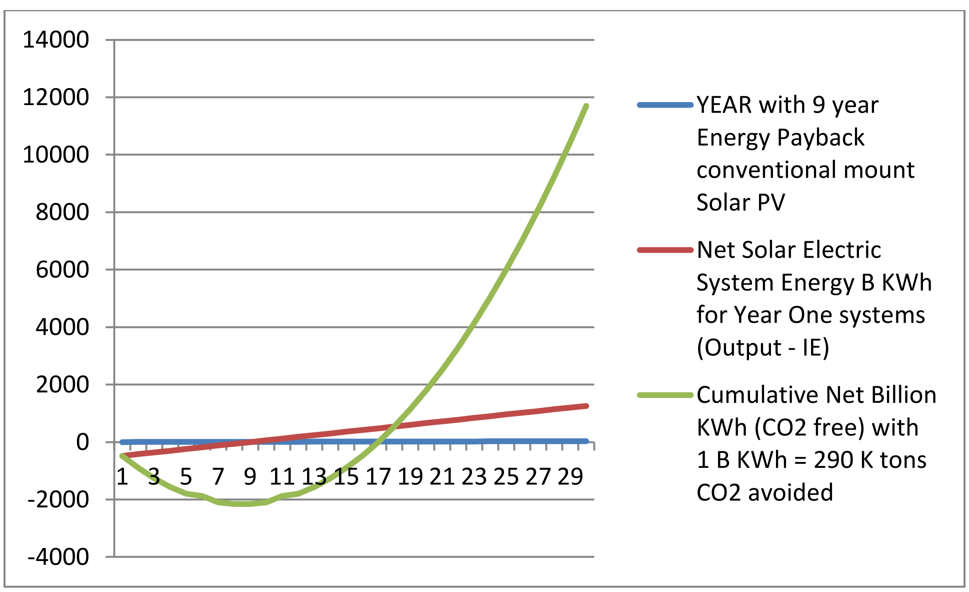
Note: In 2019, global emissions reported at 40 Bt/Y CO2, equivalent.

Categories (Energy –related)	Invested Energy (U.S.) CO2 Levelized (2050+)	Invested Energy (U.S.) thru 2100 tons	U.S. CO2 Reductions through 2100	Global CO2 Reductions through 2100
Solar PV	195 Mt/y (390)	25.5 B	(1562 Mt/y) 93.8 B	375 B
Wind	30 Mt/y (60)	3.9 B	(1273 Mt/y) 78.1 B	312 B
Electric Vehicles	169 Mt/y (169)	13.6 B	(1.03) Bt/y51.5 B	206 B
Efficiency	236 Mt/y (0)	7.1 B	(1.13 Bt/y) 56.5 B	226 B
Energy Storage	16 Mt/y (51)	3.1 B	0	0
Buildings (1M/Y)	8 Mt/Y (8)	0.6 B	(70Mt/y) 3.5 B	14 B
TOTALS	**654 Mt/y (678)**	**54 Bt total U.S. (216 Bt Global)**	**283 Bt (U.S.)**	**1133 Bt (Global)**

Table 2

The transition to Electric Vehicles will produce good net reductions in CO_2. An average passenger EV has an IE (assumed similar to that of ICEVs) of 11 tons of CO_2 emissions, while annually reducing almost 3 tons of CO_2 over an ICEV. If the entire 1.6 B ICE Vehicles in the world were EVs, we would be expending about 1 B tons of CO_2 per year to save/reduce/avoid about 4 B tons of CO_2 annually. But, ramping up car production and use for Developing Countries still means a temporary bow wave of net CO_2 emissions, thus, a pressure on the CO_2 Budget.

The practical scenario will have achieved a 100% renewable clean electric grid by 2100, along with expanded electrifications of transportation and other sectors, but, will have used up the 900 Bt CO_2 Budget. There remains the reference 1990 level of energy consumption…mainly the heavy industries producing machinery, ships, structural steel, cement, and automobiles. To contend with this (Bottom/Up) part of the challenge, the approach to manufacturing and such will have changed. We would certainly want fewer cars on the road – they require 11 tons of CO_2 emissions on average to make, while still releasing net CO_2 (of about ½ ton per year) when operating (prior to 2050). 2021's 1.6B cars would emit a total of 17.6 B tons of CO_2 if fully replaced (with either ICEV or EVs). With a 15 year useful service life, the embodied energy represents annualized emissions of 1.1 Bt CO_2 per year, not easily sourced from the electric grid, thus, the need for continued fossil fuel burning and Carbon Capture. Annualized Invested Energy from the new infrastructure buildup (of renewable energy generation, energy-saving non-generation, and Electric Vehicles) totals about 4 Bt CO_2 per year.



CO2-free KWh from Solar PV in U.S.

Note: In 2020, U.S. annual electricity production was 4,009 B KWh [expected to rise to 5,700 B by 2050]
Annualized Solar PV KWh production from added PV in 2021-2050 is 11,700/30 = 390 B KWh/Y (10%)
Solar PV KWh production from added PV by 2050 is 1500 B watts x 1.2 KWh/W/Y = 1800 B KWh/Y (30%)

Figure 2

In summary, from 2021 to 2100 (80 years), globally we have released about 216 B tons of CO_2 to build the infrastructure that reduces, saves, or avoids 1133 B tons of CO_2, as follows:

12,000 GW Solar PV 55% of grid capacity (enough solar panels to cover half of Texas)
1,800 GW Wind 45% of grid capacity
1.6 B Electric Vehicles
20% Demand Reduction via Efficiency across all sectors
10 B KWh (7 B KWh Utility Scale plus 3 B KWh Distributed Generation) Energy Storage
100% Residential & Commercial Energy Storage (10 KWh each, then to 20 KWh by 2100)
20% Lower Operating Energy in most or all Buildings
Hydropower 10% of grid capacity as a Backup
Nuclear power 10% of grid capacity (lower due to attrition, partial re-buildup)
Coal and NG powered electricity generation 10% of grid capacity as a Backup
Carbon Capture TBD
Renewable Hydrogen TBD
Concentrated Solar Thermal TBD

The practical scenario acknowledges the achievement of a 100% renewable energy electric grid in 2100, requiring recurring IE (after 2100) causing the release of 1 to 10 B tons of CO_2 per year, and the exhaustion of the (900 Bt) CO_2 Budget by 2050, necessitating measures to either Capture Carbon, use Hydrogen (sourced from RE), or develop concentrated solar thermal - all with cost and technology risk implications. The CO_2 Budget Gap is a real challenge, and if only the current state of the art is used to get us to 100% clean/RE electricity in 2100 (as the practical scenario does), then we either live with upwards of a 500 B tons of extra CO_2 and the climate that follows, or we develop new technology and new methods to reduce the Gap. Maybe, we reduce consumption (not likely without an economic downturn).

Groundrules & Assumptions

Some key groundrules and assumptions to note in the practical scenario:

1) Energy demand is assumed flat between 2050 and 2100 (mainly due to efficiency measures, economic reality, and policies), with increased demand met with CO_2-free supply.
2) The quantity of automobiles ceases to increase. There may be more cars and there may be fewer driven miles. Note, there are currently about 1.6 B vehicles in the world. The transition to EVs is complete before 2100. The Invested Energy of EVs is assumed the same as that of Internal Combustion Engine vehicles.
3) An aggressive Electrification "of everything" is pursued to the greatest extent possible, but it is reality that high heat processes are still powered by fossil fuels directly.
4) Hydropower capacity is assumed to remain flat (w.r.t. production capacity). Hydro can act as a backup source by 2100 and in the meantime serve as a risk mitigation "cushion", falling short on CO_2 goals can be negated by stepping up the existing hydro power.

5) Nuclear power is assumed to fall off by natural attrition, as plants reach the end of their Service Life times. Nuclear will serve as a backup to renewable energy sources. Of note, the very real contributions of hydro and nuclear power now to reducing CO2 emissions will assume a backup or contingency role in the future. Nuclear will need breakthroughs before again growing in capacity.
6) There will be a significant contingency of coal and natural gas powered electricity plants in 2050 – 2100, serving as backup.
7) In the 2020 – 2050 interval efficiency measures are assumed across all sectors, resulting in a 20% energy demand reduction. These are simply economically beneficial investments that have been happening for decades already, now with a special incentive to combat Climate Change.
8) Energy storage can be embodied energy intensive and significant R&D effort is assumed in 2050 – 2100, service life times of 10 years through 2050 expanding to 20 years through 2100.
9) Reliability (service life) improvements will play a positive role in reducing GHG emissions, but it is not credited in this analysis, thus serving a risk mitigation role.

BASIC REALITIES

The practical scenario for GHG reductions and a clean energy future recognizes two basic realities:

GHG emissions globally in 2021 are at 40 B tons CO2 (equivalent) per year.

The Paris Agreement, established at (Conference Of Parties) COP 21 in 2015-2016 and organizing commitments by member countries to document releases and reduce emissions, allows for a GHG Peak to occur in the near future, estimated to be around 2025 – 2030 and achieve Zero Net Carbon by 2100, or 0 Bt CO2 per year. That is, most reductions occur after 2050.

The Intergovernmental Panel on Climate Change (IPCC), formed in 1988, is the United Nations body for assessing the science related to Climate Change. The IPCC periodically releases assessments that determine the state of knowledge on Climate Change, including where there is agreement in the scientific community. The IPCC looks at various scenarios reflecting the different possible temperature rises in the future, from the desired limit of 1.5 degrees C (since pre-Industrial Age), up to 4.8 degrees C (amounting to a doubling of pre-Industrial Age CO2).

Swedish scientist Svante Arrhenius considered in the 1890's what would happen if we doubled the amount of carbon dioxide in the atmosphere, stating that the average temperature of the earth would rise 5 degrees Celsius. One hundred years later we are seeing that scenario play out, with the near future temperature rise scenarios shown in the figure below. With no climate policies in place, we are heading to a 4.8 degree Celsius rise. The best we can hope for is a 1.5 degree Celsius rise, which would involve humanity going to Net Zero Carbon.

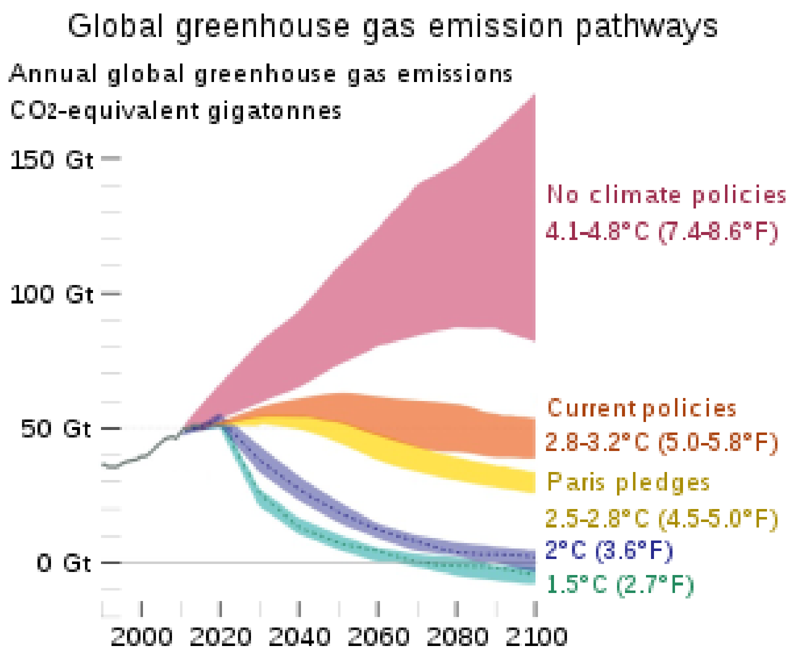


Figure 3

In his book "How to Avoid a Climate Disaster", Bill Gates breaks down 2020 GHG emissions into 5 categories by % and establishes the goal to be Nero Net Carbon by 2050:

Making Things	31%	12.4 Bt/Y re 2019
Plugging In	27%	10.8
Growing Things	19%	7.6
Moving Around	16%	6.4
Keeping Cool/Warm	7%	2.8

Innovation and breakthroughs will be required to meet the 2050 target, what might be called the best case scenario (called the Breakthrough Scenario herein). Gates pushes for electrification of just about everything (transportation, home heating and cooling, manufacturing processes, etc.). Without breakthroughs, growth in Nuclear power would be needed to get to Zero Net Carbon by 2050. Gates recognizes the ultimate challenge in zeroing out carbon in Making Things and relies on yet to be fully developed and scaled up Carbon Capture, alluding to Invested Energy (IE), the energy to Make Things, now mainly dependent on burning fossil fuels. As of 2021, there are no operating Carbon Capture systems due to the exorbitant cost.

The Paris Agreement stresses the importance of (Developed Countries like the U.S. and China) helping Developing and Poor Countries toward low carbon economies, through financing and technology transfer. But, how do High Carbon countries do this helping? Chemistry Professor Neocles Leontis of Bowling Green State University (BGSU) in Ohio has noted a CO2 Budget of 900 B tons of CO2 to limit temperature rise and avoid worsening Climate Change. Using only current state of the art (and not relying on new breakthroughs) and acknowledging the current 40 Bt/Y, one can see a CO2 Budget Gap emerging before 2050. Invested energy emissions are a significant and persistent portion of the CO2 Budget. Residual IE is the energy required to maintain the renewable energy infrastructure planned through the century. Buildup IE is the energy required to build the infrastructure, giving us the so-called Bow Wave of CO2 emissions.

The practical scenario leaves us with about 1 Bt/Y for IE(RE) and 1 Bt/Y for IE(EVs) through 2050. The IE(Non-RE) is the toughest to predict or levelize – if ½ of the Making Things CO2 Budget (of 12.4 Bt/Y) were eliminated by evolutionary technology, planning, and policy, then there would remain an IE(Non-RE/EVs) of 6 Bt/Y. We are looking at a total of 8 Bt/Y of Residual IE by 2100, down from a projected peak of 51 Bt/Y from all sources. Accounting for residual emissions for Growing Things and Moving Around (as for heavy equipment, airplane operation, trains, and trucks), and unless Energy Storage, Carbon Capture, Hydrogen, and Nuclear power are advanced significantly, even more Bt/Y will exist. Likely, at least 10 Bt/Y of CO2 will remain in 2100, a 21st Century CO2 Budget Gap of over 500 B tons of CO2.

Meeting the CO2 Budget in time to achieve Zero Net Carbon (and maintaining thereafter), and staving off worse Climate Change, must involve minimizing the IE used to build the clean energy infrastructure.

In the decades ahead, Making Things will increasingly be the major GHG contributor [in 2100]:

Making Things	90%	8 Bt/Y
Plugging In	0%	
Growing Things	5%	1 Bt/Y
Moving Around	5%	1 Bt/Y
Keeping Cool/Warm	0%	

LOW EMBODIED ENERGY SYSTEMS

Innovation to reduce the embodied energy (invested energy, IE) of renewable energy systems should be addressing the 1 Bt/Y of CO2 emissions. The Tensioned Cable System (TCS) for mounting solar panels (first produced and installed for the University of Findlay in Ohio) is low embodied energy and reduces energy payback of conventionally ground mounted solar electric systems from 9 years to 6 years. If the 3000 GW of Solar PV (in the U.S. by 2080) capacity modeled in the practical scenario were TCS mounted, then about 70 Mt/Y of CO2 emissions could be eliminated in the U.S., or about 280 Mt/Y globally – that is ¼ of the residual IE(RE). With less impact to land, the TCS also has lower Disposal Energy, as there is less mined material and less concrete to repurpose, resulting in lower Disposal Cost. Such technology exists now and can reduce system installed cost.

The economics of low embodied energy systems are favorable, even without anti-carbon policies or carbon disincentives such as Carbon Taxes. Material-intensive, high embodied energy systems, are costlier (to account for extraction and processing), and will become more costly as demand increases during the infrastructure build up and as fossil fuel production decreases past Peak.

Absent are metal post, beams, stringers, and concrete

TCS G1 in September 2020 (installed June 2012)

Figure 4

The practical place to implement low IE RE is in Developing Countries, where the Paris Agreement intends to develop low carbon economies. The high carbon U.S. is rapidly developing large utility-scale solar farms, which can operate well in its highly developed electrical transmission and distribution system. What about Developing and Poor Countries lacking such infrastructure? Smaller scale, low impact, versatile solar electric systems would be appropriate and affordable.

The cost of material-intensive products correlates to their embodied energy. Implicitly and generally, lower embodied energy products mean lower cost.

In summary, the case for low embodied energy renewable energy systems rests on these main points:

- Helps preserve the limited CO2 Budget for preventing worse Climate Change, especially in the longer term.
- Helps relieve the CO2 Bow Wave concurrent with large, fast buildup of renewable energy and energy efficient systems, thus, helping to prevent arrival of Climate Tipping Points, where accelerating Climate Change could happen irreversibly.
- Tends to lower costs of renewable energy and energy efficient systems.
- Reduces the development risk otherwise associated with the pursuit of breakthroughs, while the natural pursuit of doing more with less leads to time-proven positive results.

ECONOMICS

The industrial age has prospered with the availability and low cost of energy – coal, oil, and natural gas. Not without some investment (in exploration technology, extraction equipment, transportation and distribution systems, etc.). There are enough fossil fuels left to serve us a few more generations. But, we are spending our (solar) energy savings, and quite rapidly, despite billions of earth's inhabitants in poverty. Sustainability will require a transition to our (solar) energy income and will require technology and global cooperation (and tens of trillions of dollars in investment). True sustainability will require scientific truth, transparency, global perspective, and an appreciation for the long term.

The Paris Agreement prescribes financial help and technology transfer to Developing and poor countries, hopefully not to take the Western (Developed) world's path to prosperity, but to create a low carbon economy that provides the basics to survive and thrive. Of course, Climate Change is set to hit the Developing and poor countries worse, with sea-level rise (flooding), drought, etc. affecting them to the point of inducing mass migrations. Developed countries, such as the U.S., face a lot of challenges handling immigration.

The U.S. and other Developed countries have high carbon economies. To date, the Industrial Age has caused the emission of about 2000 Gigatons of CO2. Scientists claim that a budget of about 1000 Gigatons remains before worsening Climate Change, which will bring about catastrophic damages and big hits to the economy. Interestingly, Europe achieves each unit of GDP with a quarter less energy than the U.S. If a gallon of gas costs $3 in the U.S., it costs over $6 in Europe. Architect, inventor, and design science advocate R. Buckminster Fuller recognized the geologic value of gasoline at about $1M per gallon. Forty years ago Bucky Fuller suggested that it was cheaper to pay people to stay home, to avoid the gas guzzling trips to work, which did not necessarily contribute to the productive economy, though part of the consumptive economy. Bucky also had the foretelling suggestion that we build a global transmission system, so that the sunlit day side could power the dark night side, without large scale energy storage.

The practical scenario, essentially in line with the Paris Agreement, may allow us to reach a 100% renewable energy Electric Grid and a Zero Net Carbon economy, but it will also consume the equivalent of about 40 years of fossil fuels at current annual levels, plus the 20% premium (8 years) for building the new infrastructure – more than the CO2 Budget established in 2016. As we learn to more efficiently utilize fossil fuel energy, an ironic paradox emerges – Jevon's Paradox, identified at the start of the Coal Age – the more efficiently we use a limited resource, the more of that limited resource we will use. Efficiency steps up demand, and demand induces greater supply, and supplied demand consumes the limited resource, be it coal, oil, or natural gas.

Before going forward with technology, reliability, and efficiency in a big way in the decades ahead, we start with a global plan – the Paris Agreement. Countries are differentiated, allowed to propose their own GHG reduction strategies, commit to targets, and generally support the Developing Countries with the goal to mitigate Climate Change impacts. Global emissions of the main GHG (CO2) are yet to peak, followed by a sustained decline. Accompanying the government run public/private partnership to fight Climate Change is a lot of investment – 100's of billions of dollars by the public, yet trillions by private investors with a profit motive. Some of the technology will be commoditized and put into the public domain, but much will be initially owned by private interests. A study out of Switzerland predicts a 15% drop in economic activity by mid-century [2050] due to effects of Climate Change, in effect trillions of dollars “lost”, but relatively small to the overall size of the economy and investment in clean energy and sustainable practices.

Given any progressive technology, reliability and efficiency improvements historically have followed, such as in Solar PV panels (from years to decades in Service Life) or in cars (from 100 to 300 thousand miles and from 15 to 35 mpg). We will rely on such improvements in the decades and century ahead. Jevon’s Paradox and Capitalism’s emphasis on consumption will be huge challenges to overcome, as profits get conflated with progress on the path to sustainability, low carbon, and avoidance of a climate disaster. Indeed, investments should pay off, but certain investments carry more than just potential financial reward: Hydrogen, Carbon Capture, and next generation Nuclear power can move us to Zero Net Carbon emissions, a precondition of True Sustainability.

Before geologic discoveries of large deposits of coal (and oil), and efficient ways to extract or use it, costs were high and production low. Efficiency became the key. Efficient boilers and machines to get more work with less coal stepped up the demand and consumption of coal. A similar phenomenon occurs with embodied energy and renewables (solar and wind) – as we use less energy in making the infrastructure, we see demand (for low embodied energy products and systems) going up, as acquisition costs (leveraged by the lower embodied energy) go down. This paradox of sorts can induce transition to solar in the midst of economic stress and high material costs, of which we clearly face in the future.

Energy consumption in the U.S. (and the World) means that 2/3 of the energy consumed is “rejected”. Rejected Energy is another name for waste. When fossil fuels are wasted, a whole lot of unnecessary CO2 emissions result. Efficiency improvements would not only reduce energy costs, but provide for a proportionately greater reduction in CO2 emissions.

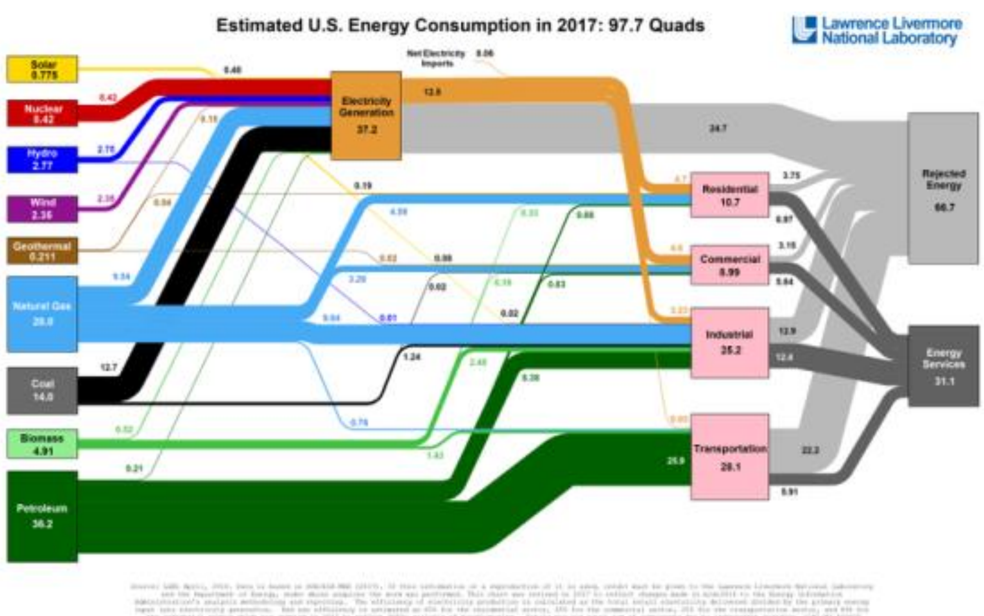


Figure 5

THE FUTURE

Humanity in the recent decades of the Industrial Age is grappling with the concept, meaning, and practicality of sustainability. Climate change is the antagonist in the sustainability story. Fossil fuels, the doomed protagonist of the Industrial Age, find company with emerging renewable energy, green living, organics, and clean technology. There is no clear frontrunner for the new protagonist, though we have a hunch it is renewable energy from solar and wind. Investments in solar and wind have solid returns, both in energy and dollars. Electric vehicles (EVs) will find their value in reducing GHG emissions compared with the replaced internal combustions engine vehicles (ICEVs). There is a tendency to focus on operational or end use consumption of energy and accompanying emissions. The ongoing electrification of our economy and lives will leave Making Things the clear leader in GHG emissions. Embodied energy (from Making Things) will be an increasing hurdle to achieving Zero Net Carbon (and, thus, True Sustainability) without busting the CO2 Budget (for avoiding worse Climate Change). The process energy for Making Things is not naturally occurring. Solar and wind energy is diffuse and low intensity, while process energy is concentrated and high intensity. Carbon Capture and continued fossil fuel use is not a long term sustainable solution.

We can establish goals and policies, identify trends in technology, make investments in renewable energy and such, but predicting the future state of energy and emissions is a multiple scenario process.

Three basic scenarios arise:

A) Do Nothing Scenario – Business As Usual; serves as a reference Baseline
B) Practical Scenario – Relies on current State Of The Art, evolution in technology, ramping up
C) Breakthrough Scenario – R&D actively pursues breakthroughs; high risk; expects Carbon Capture

An understanding of Climate Change – as in the science and modeling – is necessary to assess the impacts of these three scenarios. It is important that we know our CO2 (emission) Budget to stave off worsening Climate Change, particularly warming. There are currently at least 15 phenomena in nature that are at risk of runaway behavior, worsening Climate Change, such as polar ice melting, carbon sink forests diminishing, and ocean circulation changes. As of 2016, 900 Billion tons of CO2 was the Budget before we pass Tripping Points. None of the three scenarios get us to Zero Net Carbon by 2050, which would have reliably assured a Stable Climate. The progressive scenarios (Practical and Breakthrough) leave us with a CO2 Gap by 2050. Indeed, assuming that breakthroughs do happen as hoped, then there is a chance to reach Zero Net Carbon by 2050, albeit not practical or probable.

The Paris Agreement from COP 21 still acknowledges continued rising CO2 emissions into the 2020's and does not foreseeably achieve Zero Net Carbon until 2100. We do not yet fully know the countries' reduction strategies near term. Rapid reductions now are not the game plan, tending to dis-incentivize the pursuit of low embodied energy.

One thing for sure, as annual reductions increase over time, the Invested Energy (IE) needed to build up and maintain the clean energy and clean living infrastructure, and the associated emissions, will be increasingly significant, as it chips away at the CO2 Budget and contributes to the CO2 Budget Gap. The Practical Scenario returns 1133 B tons of reductions on an investment of 216 B tons (of IE), for a net reduction of 917 B tons of CO2. Even if Net Carbon was near zero by 2050, emissions (including the 3 or 4 Billion tons per year for IE in the Energy related category) accumulate over time and eventually blow the CO2 Budget.

The dilemma of embodied energy (invested energy for the infrastructure to fight Climate Change) is in the near term somewhat mitigated by following the old adage of the early environmental movement: REDUCE, REUSE, and RECYCLE, and mostly in that order. In the long term, recycling will be essential, and low embodied energy infrastructure is inherently easier and less costly to recycle. Implement low embodied energy now to reduce the CO2 Bow Wave, to prepare for recycling in the future, and to reduce hurdles to achieving Zero Net Carbon.

To transition the world's 1.6B cars and commercial vehicles to EVs, at the current production rate of 78M vehicles per year worldwide (with 90M recently), will require a minimum of 1 B tons per year of IE related emissions, achieving a net reduction in CO2 emissions only after 10 years, assuming a driven 12,000 miles per year per vehicle and assuming a fully EV dedicated production. The automaker GM does not have plans to solely produce EVs until 2035, seemingly to allow attrition to rid the world of ICEVs by about 2050, the target year for having solved Climate Change and perhaps having gone Zero Net Carbon. We see a CO2 Bow Wave in the intervening years. Recall, an EV's CO2 payback (similar to an energy payback, similar to a financial payback) is about 5 or 6 years, and we do not see an initial net reduction until cumulative savings exceeds the cumulative embodied energy (in an ongoing EV production scenario), or until 2 times that period (10 or 12 years).

The combined Bow Wave from all CO2 reduction measures represents a temporary uptick of several billion tons of CO2 in a 10 year or longer period, coinciding with the near term increases in CO2 emissions from infrastructure buildup. Net reductions occur only after 2 times the Energy Payback period (*where payback is typically 1 to 2 years for large-scale wind, 6 to 9 years for solar, 5 to 6 years for EVs, 5 years for efficiency improvements, and never for energy storage*). The Invested Energy (IE) situation with energy storage, especially upon large scale up, is uncertain. Use of storage in solar PV systems would push energy payback past 10 years. In aggregate, we do not see net reductions until after 2030. Will this reality impact our reaching climate Tipping Points? The answer is TBD.

Qualitatively, if Invested Energy (IE) is high, then we risk exceeding our CO2 Budget before achieving Zero Net Carbon. If a clean (renewable) energy buildup is intense and rapid, then reaching climate Tipping Points is still probable, on account of the CO2 Bow Wave. At a minimum, pursuing low Invested Energy infrastructure means lower rates of fossil fuel consumption, less costly recycling, lower risk of Climate Change worsening, and lower cost risk in the future, when energy and material costs are likely higher. Identifying the advantages of lower IE will justify incentivizing the development of IE-reducing technology, such as structural alternatives (to steel, aluminum, concrete, and glass), design with less material, hydrogen, concentrated solar thermal, and even Carbon Capture. As well, lower IE products, systems, and processes will be more easily transferred to Developing Countries, as fewer industrial plants, infrastructure, and processes would be needed.

CONCLUSIONS

There may be a conclusion to a study, an article, or a white paper, but there is no conclusion to the sustainability story. True sustainability is technically impossible if we are consuming the resources that now sustain us. Climate Change is the blaring red flag that tells us we are using up our limited resources. We would have reached the Embodied Energy challenge whether we experienced (human induced) Climate Change or not. At least we are acknowledging Climate Change and are making plans to fix, or rather, to mitigate it. But, what about actually resolving it?

The translation to a clean energy economy, largely with renewable energy, seems destined to be led by the free market system, with low cost and high profit the operative principles. Climate Change represents an added (emerging) cost to the market equation. The lure of free solar energy and the promise of technology is the market's answer to the greatest Incurred Cost imaginable, Climate Change. But, is this a setup to the greatest Paradox of our time? That we may be designing more efficient means of consuming even more of the limited resources we call fossil fuels?

Low embodied energy (i.e., low invested energy in Making Things) is a logical pursuit in our transition from quantity limited fossil fuels to renewable fuels, electricity, and materials. It is logical to incentivize the pursuit of low embodied energy in our free market economy. Certified Low Embodied Energy may one day coexist with Certified Organic, Low Sugar, Fat Free, and Gluten Free in the lexicon of the market. The first order, material-based Invested Energy estimating approach herein would need to be more rigorous and inclusive of all invested energy sources, such as machining, transportation, and installation energy. Encouraging is the fact that these secondary embodied energy demands can be supplied by the new clean energy infrastructure. Material production stands as the main challenge in achieving low embodied energy and advancing toward true sustainability.

Despite identification and planning for Climate Change (Global Warming) going back decades, the past decade has seen at least a 15% increase in global GHG emissions, attributable to population induced demand growth and perhaps to the renewable energy build up already in progress. The buildup (of Solar PV, Wind, and Electric Vehicles) has only just begun, with the bow wave of associated CO2 emissions coming in the next decade. We can only hope to begin the sustained decline in CO2 emissions by 2030.

The CO2 Bow Wave, though seemingly lost in the current rise of global emissions, is foretelling of the challenge ahead, that is, the needed revolution in the approach to Making Things. Globally, we are prioritizing the reductions in end use emissions (with EVs), and expanding emission-free electric generation, while not emphasizing lower embodied energy. It is not profitable, yet, to find alternatives to coal and natural gas for Making Things. So, it seems, we are putting off the most difficult, yet critical, of the emission reduction targets. The high court in Germany recently found that legislation to mandate lower emissions was unconstitutional – because it placed an unfair burden on future generations, while relieving the current leaders of having to more rapidly lower emissions. How fair the rest of the world is doing in planning for emissions reductions is yet to be seen.

Incentivizing low embodied energy now can be relatively less expensive than dealing with worse Climate Change mid-century, as we are already facing trillions of dollars in losses to the economy in the decades ahead due to Climate Change. The new (Buildup) Invested Energy portion of the CO2 Budget going forward, at about 200 Bt of CO2, is too large to ignore. The old legacy Invested Energy of the current manufacturing-focused Industrial Complex (with emissions on the order of 10 Bt/y of CO2) is also too large to ignore.

There is a proposal under debate in the U.S. Congress for a vast infrastructure plan, to include renewable energy and electric vehicles and the promise of many new Green Jobs. Meanwhile, China leads the world in renewable energy (producing Solar PV panels, building solar farms, and installing wind turbines), while continuing to build new coal-fired electric plants and developing "super mines" for coal. China's stated goal is Zero Net Carbon by 2060, seemingly inconsistent with their actions, but certainly after emitting tens of billions of tons of CO2 (chipping away at the CO2 Budget).

The U.S. has virtually stopped building new coal plants and regularly retires old coal plants. The push for renewables and Zero Net Carbon is essentially a large construction project, producing perhaps a few million jobs, far less than the demand for tens of millions of jobs by unemployed college students, coal-miners, retail workers, auto mechanics, general laborers, and so on. The math does not add up.

What global leaders appear to be working on is sustaining economic systems rather than living systems. Paris Agreement commitments are nationally-scoped, industrial-sized, technology-intensive goals seemingly void of a genuine sustainability context. Nations are at war, with a challenge to beat Climate Change, but void of smaller scale, cultural and personal supported local economies that have existed sustainably for centuries already. Void of low and non-technology solutions and know how. Void of the goal to consume less. Void of the notion to do more with less.

The goal of doing more with less can cost less. The Tensioned Cable System for mounting Solar PV panels (G1 or all metal G1M) costs less than conventional mounting, reduces Invested Energy CO2 emissions, creates semi-skilled jobs, and is amenable for broad use in Developing Countries. To appreciate the magnitude of costs, the Practical Scenario addressed herein for the U.S. will cost about $4.5 - 6T through 2050, still less than the cost of the Cold War ($6T in 1980 dollars), which went a long way to preserving the fossil fuel-dependent economy of the post WWII years.

The significance of Invested Energy and associated CO2 emissions grows over time. Ultimately, we face releasing 4 Bt of CO2 per year to maintain the 100% renewable energy/clean Electric Grid and perhaps 6 Bt of CO2 per year to Make Things. The last 20% of annual reductions are faced at a time (mid-century and beyond) of Climate Tipping Points – including sea level rise, carbon sink forest loss, and ocean circulation changes. The real deal will be finding new ways to produce material without burning fossil fuels and doing it sooner rather than later.

Ignoring or putting off the Invested Energy of building up the new renewable energy (and more broadly the sustainable) infrastructure is to put off resolving the currently large CO2 Budget for Making Things with no apparent or easy alternative to fossil fuels. A focus on end use energy/CO2 reductions, without a concerted effort on the upfront invested energy/CO2 emissions, is a veiled abrogation of our collective responsibilities and deferment of a heavy burden onto future generations. We may have a looming constitutional crisis on our hands if we move out with climate change legislation subtly shifting burdens to the future. Let us develop a Design Science of Doing More with Less and direct investment and effort into reducing Invested Energy (embodied energy), which will ultimately optimize and economize the global plan for reducing GHG emissions.

[The remaining pages relate to reference material and computations that form the basis of findings in the previous pages. The computations are simple and reasonable, basically estimates. Emissions and embodied energy accounting is complex. The goal for the white paper is presentation of a big picture view with sound premises about important aspects of the Climate Change, with reasonable numbers relatively accurate enough for general assessments (of embodied energy and associated CO2 emissions). A rigorous assessment is beyond the means of most, but would still be a good path to take, as by professional scientists, researchers, investigative journalists or others.]

CALCULATIONS (regarding Invested Energy)

Top down CO2 emissions reductions from added infrastructure in 6 main development areas are calculated based on build up rates. Build up rates are estimated based on CO2 reduction targets and EIA projections and the associated expected performance of the added infrastructure. Invested Energy and associated CO2 emissions, based mainly on material content and quantity, for the U.S. through 2050 and 2100 are calculated first, then global IE and CO2 emissions are calculated based on their current relative size. Global energy consumption and CO2 emissions are roughly 4 to 1, global to U.S., as China grows.

Energy Required To Produce Material [source: www.lowtechmagazine.com]

Wood from standing timber	0.830-1.950 KWh/kg (3-7 MJ)
Steel from recycled steel	1.665-4.170 KWh/kg
Aluminum from recycled Al	3.15-4.75 KWh/kg
Iron from Iron Ore	5.55-6.95 KWh/kg
Glass from sand, et cetera	5.0-9.7 KWh/kg
Steel from Iron	5.55-13.9 KWh/kg
Paper from standing timber	6.95-13.9 KWh/kg
Plastics from crude oil	17.2-31.95 KWh/kg
Copper from Sulfide ore	16.6-34.7 KWh/kg
Aluminum from mix w/ 20% recycled	60.8 KWh/kg
Silicon from silica	63.9-65.3 KWh/kg
Nickel from ore concentrate	63.6-75.0 KWh/kg
Aluminum from bauxite	63-95 KWh/kg
Titanium from ore concentrate	250-261 KWh/kg
Electronic grade Silicon Si	2,108-2,154 KWh/kg

Note: 1 Megajoule = 277.77 Watthour (Wh)
1 KWh = 3,412 BTU

Per the World Coal Association, approximately 200 Kg of coal is needed to produce 1 ton of cement.
Per Columbia University, 1 ton cement needs 4.7 MBTU of energy.
Per the US EPA (via concrete CO2 fact sheet from NRMCA Publication No. 2PCO2 June 2008),
1984-2425 lbs of CO2 released per 2205 lbs of Portland cement (50-60% calcination, 40-50% burning).
The U.S. cement industry accounts for 1.5% of U.S. CO2 emissions.
Concrete is 90% non-cement by weight. 170-500 lbs CO2 per 1 square yard of concrete.

Production Energy	Aluminum	270 GJ/t	Aggregates	0.25 GJ/t
	Stainless Steel	90	Concrete	1.4
	Steel	30	Bricks	2
	Glass	20	Timber	2
	P. cement	5	Reinforced Concrete	2.5

Physical Data

Density	Water	1.000 Kg/m3 = 62.4 lbs/cf
	Cement	150 lbs/cf typical
	Gravel, loose, dry	95 lbs/cf
	Gravel, w/ sand	120 lbs/cf
	Steel	7,750-8,050 kg/m3 [484-503 lb/cf]
	Aluminum	2800 kg/m3
	Stainless Steel	7,861 kg/m3

Other Data

2014 Total installed electricity generation Capacity in U.S. = 1,068.4 GW (up 8.4 GW from 2013)
2018 Total installed electricity generation Capacity in U.S. = 1,220 GW (up from 2014)
2020 Total U.S. electricity generation = 4,009 B KWh
2018 U.S. energy consumption = 101 Quads (101x10^12 BTU/Y)
2020 U.S. installed Solar PV Capacity = approximately 100 GW
2020 Total installed wind electricity generation Capacity in U.S. = 107.4 GW (up 10% annually/2010)
2020 Total annual U.S. electricity generation from wind = 338 B KWh (8.4% of total U.S. generation)
2019 Global wind capacity = 651 GW (up 15% annually/2009)

Pounds CO2 emitted per MBTU of Fuel	Coal (Anthracite)	228.6
[Google]	Coal (Sub-bituminous)	214.3
	Diesel Fuel/Heat Oil	161.3
	Gasoline w/out ethanol	157.2
	Propane	139.0
	Natural Gas	117.0

Carbon Dioxide Emission Coefficient by Fuel
[American Geosciences Institute]

Propane	12.70 lbs CO2 / Gallon	139.05 / MBTU
Coal (all types)	4,631.5 / Short Ton (2000 lbs)	210.20
Natural Gas	117.1 / Thousand CF	117.00
Gasoline	19.6 / Gallon	157.20
Jet Fuel	21.1 / Gallon	156.30
Municipal Solid Waste	5,771 / Short Ton	91.90

TCS G1 (Ground Mount) Embodied Energy Analysis

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re G1 EMBODIED ENERGY ANALYSIS

WBS re G1-Z (6PAN)

WORK BREAKDOWN STRUCTURE		(DN 1873) kWh/kg PRODUCTION ENERGY	MATERIAL	EST. WEIGHT	(kg)	kWh PRODUCTION ENERGY
STANCHIONS	n=3	0	WOOD	100 lbs	= 45	∅
THRUST PLATES	n=8	20	SS	40	18	360
CABLES / CROSS-TIES	n=8	20	SS	50	24	480
CLAMPS / HANGERS	n=16	80	ALUMINUM	20	9	720
EARTH ANCHORS	n=4	15	STEEL	30	14	210
PIER BLOCKS	n=6	1/2	CONCRETE	120	50	25
FASTENERS	Various	20	SS	10	5	100
FASTENERS – MISC. (SPACERS)		25	NYLON	1 (lb)	1/2	15
MS HW (Rod/Flat)		80	ALUMINUM	1 (lb)	1/2	40
						1950 kWh

200 kg cont => 1 ton cement; 1 ton 100 kg conc => 1 lb; 22 lbs 13,000 BTU's/lb Cement ÷ 3500 BTU/kWh; ~1 kWh/lb Cement; ~ 1/2 kWh/kg Cement

G1-Z: PV/OC, PV/OC, PV/OC, PV/OC; PS, PG, PG; EZ, EA; ES, MS, ES; EA, EZ — by Electricity

× Efficiency FACTOR
Ex. Electricity from NG
1 kWh needs 2.5 kWh NG
@ 40% Utility Plant Efficiency
NG direct ≈ 80%
=> 1.2
1.2 – 2.5
Say 1.5
ALSO, PLANT ENERGY
TRANSPO ENERGY
COMPOSITE ≈ ×2

4,000 kWh
TO MAKE (1) G1-Z 6 PV
2.7 kW – 3.6 kW] n=2
Say 3 kW (of SOLAR)

(OR) 1.33 kWh / Capacity WATT re MOUNT (TCS)

PV, per NREL, has ENERGY PAYBACK OF 3 YEARS
1 W → 1.2 kWh/Y PRODUCES] 3.6 kWh
→ 3.6 kWh/W

The System as Installed → 5 kWh/WATT Nameplate → 4 YEARS ENERGY PAYBACK

✳ COMPARE TO CONVENTIONAL MOUNT

(A) POURED POST (Large-Scale) v. (B) CONCRETE FOOTERS / BALLAST (Small to Large Scale)

1800 W

	kWh/kg			kg	
UNI-RAC 6PV RACK	80	ALUMINUM	50 lbs	22	1760
CLAMPS	80	ALUMINUM	20	9	720
CONCRETE 6 FOOTER ANCHORS 1/2 yds (3x Efficiency)	1/2	CONCRETE	1200	500	250
FASTENERS	20	SS	1	1/2	10
RE-BAR / MESH	15	STEEL	90	42	630
				*TBV	3370 kWh

(G) 150 lbs per CF are; Water = 62.4 lbs/CF

made w/ electricity
IF NG, THEN 40% efficient
× Efficiency Factor
Say 2.25
ALSO, PLANT & TRANSPO ENERGY
COMPOSITE ≈ × 2.5

8425 kWh
TO MAKE US-6PV mounting 1800 W
CONVENTIONAL 4.68 kWh / Capacity WATT re MOUNT
~~3.6 kWh/W re PV~~

The System as Installed → 8.25 kWh/WATT Nameplate → 7 YEARS ENERGY PAYBACK

Approach and Considerations for Calculating Infrastructure Build Up CO_2 Numbers

Considerations

Service Lifetimes (assumed 30 years for Solar PV and Wind)
Invested Energy (per Watt, capacity)
Production (Emission Free)
Timeframes 2021 – 2050 (30 years) and 2050 – 2100 (50 years)
Build Up linearly over Timeframe
Costs in 2020 year dollars
Physical constants
Conversion data from public available sources
Capacity (of Build Up) to meet established goals with practical assumptions (Ex., 30% solar electricity)
Capacity is maintained (with replacements), incurring ongoing invested energy

1 KWh = 3412 BTU
Gasoline when burned releases 157.20 lbs CO_2/MBTU without ethanol (19.60 lbs/gallon)
CO_2 Avoided depends on power plant fuel (electricity)

Coal (Anthracite)	228.6 lbs emitted per MBTU
Natural Gas	117.0 lbs emitted per MBTU

(A composite of sorts averages the two values for 170 lbs CO_2 emitted per MBTU)

Assumed mix for U.S. Electricity emits 170 lbs CO_2 per MBTU
Assumed ration of US to Global GHG emissions is 1:4 (based on energy consumption as of 2005)

Service Lifetimes

Solar PV	30 years
Wind	30 years (up from 20)
Electric Vehicles	15 years
Efficiency Upgrades	> 30 years
Energy Storage	10 years (expected to improve)
Buildings (Efficiency)	90 years

Build Up Goals / Targets

Solar PV in U.S. to have 30% Solar Electricity by 2050: 1500 GW [100% by 2100: 3000 GW]
Wind power in U.S. from 107.4 GW to 425 GW by 2050, additional growth thereafter
EVs replace the world's 1.6 B vehicles about 15 years (depends on manufacturer plans)
Efficiency measure reduce energy consumption 20% across all sectors (affecting 2/3 of emissions)
Buildings (1 M in U.S.) replaced/built per year and saves 20% in energy
China's emissions are rapidly rising, especially as China assumes manufacturing formerly done in U.S.
Global Build Up assumed to be 4 times that of U.S.

Solar PV Build Up CO2 Numbers

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DN2582A
DN2570.3

re SOLAR PV BUILDUP CO2 NUMBERS

IN U.S.

ADD 50GW/Y → PRODUCING 60B kWh/Y

PV → GROUND MOUNT HAS 9 YEAR ENERGY PAYBACK

INVESTED ENERGY = 60B kWh/Y × 9[Y] = 540B kWh

540B kWh/Y × 3,412 BTU/kWh ÷ 1,000,000 BTU/MBTU

× (170 lbs CO_2/MBTU) ÷ 2000 lbs/TONS → s/b 80%

× 1.25

U.S. IE_{PV} = ~~156 M~~ TON/Y ÷ 80% (.80) — assumes 100% EFFICIENCY in MANUFACTURING, ie, direct heating → 213 lbs CO_2/MBTU

195M

AT 30 YEARS, BUILDING 60B kWh/Y CAPACITY [50 GW/Y SOLAR]

CUMULATIVE NET kWh's = 11,700 B kWh

÷30Y

↳ LEVERIZED ANNUAL = 390 B kWh/Y

= 292.B lbs CO_2 AVOIDED

= 146M TONS CO_2/Y AVOIDED

NOTE: Negative NET kWhs UNTIL 18 YEARS OUT

∴ NO NET CO2 EMISSION REDUCTIONS UNTIL 18 YEARS

THEN, INCREASING 18-30 YEARS OUT

THEN, STEADY DECREASE 30-60 YEARS OUT; ∅ @ 60Y

WHAT IS HAPPENING AT 30 YEARS, then YEARLY AFTERWARDS?

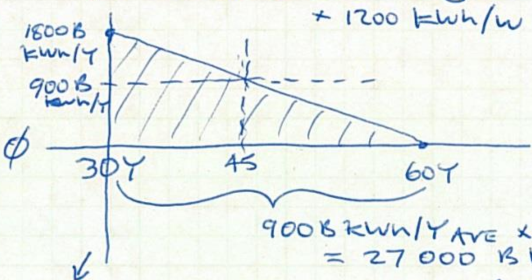
1500 GW [1500 B W] CAPACITY [DIMINISHING BY 50BW/Y AFTER]

× 1200 kWh/W = 1800 B kWh/Y

−60B kWh 1st Y

−60B kWh 2nd Y etc.

−1800 B kWh/Y



∅ PRODUCTION @ 60Y UNLESS REBUILD 50 GW/Y at 30 Years & beyond

900B kWh/Y AVE × 30Y

= 27 000 B kWh TOTAL (over 2nd 30 Years)

× 3412 BTU/kWh × 1 MBTU / 1,000,000 BTU × 170 lbsCO_2/MBTU — assumes 100% efficiency @ Utility... s/b 50%

= 15.6 T lbs CO2 = 7.8 B TONS CO_2 REDUCED

÷ 2000 lbs/TON

÷ 30Y

s/b 340 lbs CO2

50 ×2

~~261 M~~ TONS CO_2/Y

522 M AVOIDED/REDUCED Levelized

→ DIMINISHES YEARLY THEREAFTER...

1800 B kWh @ Year 30

× 3412 BTU/kWh

× 1 MBTU / 1,000,000 BTU

× 170 lbs/MBTU — s/b 340 re 50% Efficiency

= 1.044 T lbs CO_2 REDUCED

50 ×2

÷ 2000 lbs/TON

PV

= ~~522 M~~ TONS CO_2

in U.S. 1.04B REDUCED/AVOIDED in Year 30 [2050]

{2% of 51B TONS/Y GOAL

* COST? 1500 BW × $1.50/W ave = 2.25T DOLLARS

$2.25T PV TO BUILD UP FOR 2% REDUCTIONS

SPENT 2021-2050

FROM 2050-2080 WILL RECYCLING BE AFFORDABLE/DOABLE?

Wind Power Build Up CO2 Numbers

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DN 2568
DN 2572

re WIND POWER BUILD UP CO2 NUMBERS

IN U.S.

2020 WIND CAPACITY = 107.4 GW (EXISTING) → expect to grow to 4x by 2050 or 1.35T kWh

338 B kWh PRODUCED IN 2020

3.15 kWh / W capacity / Y

1E → Payback (2 YRS) (of 30 Y Service Life)

× 3.15 kWh/W

BUILD UP @ 10 GW / Year

× 6.3 kWh/W ← 1E Wind 6.3 kWh/W

63 B kWh / Y

× 3,412 BTU/kWh × 1 MBTU / 1,000,000 BTU × 170 lbs CO_2/MBTU

÷ 80% (efficiency)

÷ 2000 lbs/TON

U.S. 1E WIND = 22.8 M TONS / Y BUILD UP NEW + Replace EXISTING @ 3.3 GW / Y (on top of 10 GW/Y) = 7.5 MT/Y

= 30 M TONS / Y

CO2 EMISSIONS REDUCTIONS

✓ IN Year 30 Capacity in U.S. @ 425 GW producing 338 B × 4 kWh/Y = 1.35 T kWh/Y

1.35 T kWh / Y

× 3,412 BTU/kWh × 1 MBTU / 1,000,000 BTU × 170 lbs CO_2/MBTU

÷ 50% (efficiency)

÷ 2000 lbs/TON

= 783 M TONS CO_2/Y (2050) and thereafter ~ Replaced

DIMINISHES THEREAFTER, UNLESS REPLACED — REDUCED/AVOIDED IN 2050 (per year)

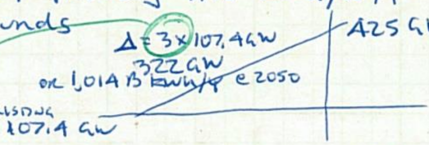
↳ 13.3 GW/Y ≡ 30 MT/Y CO_2

LEVELIZED 2021-2050
3.15 kWh/W/Y → 430 GW
338 B kWh (2021) → 1,354 B kWh (2050)
846 B kWh/Y
Ave
× 3412
÷ 1M
× 170
÷ .5
490 M TON/Y LEVELIZED 2021-2050

V. PV SOLAR 1.04 B T/Y @ 2050

ADD 10 GW/Y producing 3.15 kWh/W/Y

and it compounds



1,014 B kWh/Y @ 2050 means ½ × 1,014 B kWh/Y on AVERAGE

or 507 B kWh/Y

× 3412 BTU/kWh × 1 MBTU / 1,000,000 BTU × 170 lbs CO_2/MBTU

÷ 50% (efficiency)

÷ 2,000 lbs/TON

= 294 M TONS CO_2 / Y Average 2021-2050

392 M REDUCED/AVOIDED Levelized

✱ COST?

20 year SL now → 30 years

ON AVERAGE, ½ of 1.35 T kWh / Y IS ACHIEVED OVER 30 Y PERIOD (due to RAMP UP / BUILD UP & ATTRITION over 30 more Years)

× 30 Years

~ 20 T kWh @ $0.04/kWh LCC WIND POWER

IN U.S. = $800 B TO BUILD UP (UNTIL 2050) WIND

EV Build Up CO2 Numbers

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DN 2567.2
DN 2569
DN 2573

re EV BUILD UP CO_2 NUMBERS

IN U.S.
~ 350 M ICE Vehicles

Per ISERUNDSCHMIDT (BONN, GERMANY)

30,000 KWh Embodied Energy
× 3,412 BTU / KWh
÷ 1,000,000 BTU / MBTU
× 220 lbs CO_2 / MBTU
÷ 2000 lbs / TON
= 11.2 TONS CO_2 / Vehicle
× 15 M BUILT / Year, est.

[NOTE, Globally ~ 1.6 B ICEV]

IE_{EV} = 168.9 M TONS CO_2 / Y

EV OPERATIONAL ENERGY ANALYSIS
(U.S.) 15 M / Y PRODUCED
× 30 Y
450 M EV's → 12,000 Miles / Y

DN 2562A

@ 100 mpge [ICEV @ 35 mpg]
120 gallons equivalent / Y
× 100 K BTU / gallon
12 MBTU / Y × 170 lbs CO_2 / MBTU ÷ 50% efficiency

∴ (1) EV → 2 TONS CO_2 / Y
Releases from Operating Energy
IF BY 2050 30% Solar 10% Wind 10% Nuclear
THEN (1) EV releases 1 TON CO_2 / Y ... i.e, NOT Ø

EV: 11.2 TONS CO_2 / EV TO MAKE
Similar to ICEV
2 TONS CO_2 / EV / Y TO DRIVE

V. ICEV → 12,000 miles @ 35 mpg
= 342 gallons / Year
× 100 K BTU / gallon
34.2 M BTU / Y
× 157.20 lbs / CO_2 / MBTU
or (× 19.60 lbs CO_2 / GALLON)

ICEV: 3.3 TONS CO_2 / Y ← 6,703 lbs CO_2 / Y
AVOIDED IF ICEV IS REPLACED BY EV...

(1) EV SAVES 3.3 − 2 = 1.3 TONS CO_2 / Y if current ELECTRICITY MIX (fossil fuels)
SAVES up to 3.3 TONS CO_2 / Y w/ 100% RE ELECTRICITY

by 2050 ~50% RE
SAVES 2.3 TONS CO_2 / Y
× 450 M EVs TBV
1,035 M TONS CO_2 / Y — 585 M TONS / Y 4 0% RE — 1.485 B TONS / Y w/ 100% RE

CO_2 REDUCTIONS
= (1.03 B TONS CO_2 / Y IN 2050) [Pre-2050 ≈ ½ BT / Y]

COST? Premium Price will likely fall from \$5K–10K TO \$1K to Ø
Say \$1K in next 30 Y
250 M – 450 M EVs
→ (\$250 B TOTAL) U.S.

GLOBALLY, CO_2 REDUCTIONS = U.S. × 4 est.
4 B TONS CO_2 / Y @ 50% RE Electricity
OR 2 BT / Y w/ 0% RE
OR 6 BT / Y w/ 100% RE

Efficiency Build Up CO2 Numbers

CONFIDENTIAL TCSAMS | OES | 2588.4 5/25/21 TAC

DN 2574

re EFFICIENCY BUILD UP CO_2 NUMBERS

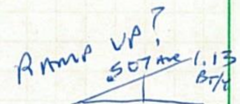
Per EIA (2019, U.S.) consumed 100 QUADS (10^{12}) [BTU/Y]
↳ 100,165,395,000,000,000 BTUs/Year

Say you reduced overall consumption by 20%
ACROSS ALL SECTORS [TO GREATEST EXTENT]

DN 2564 GLOBALLY ≈
- MAKING THINGS 31%
- PLUGGING IN 27%
- GROWING THINGS 19% → Other Path to Ø
- MOVING AROUND 16% → TO EV's
- KEEP COOL/WARM 7%

2/3 of 20% amenable to efficiency improvements

20 QUADS/Y
↓
20,000,000,000 MBTU/Y
× 2/3 [see above]
× 170 lbs CO_2/MBTU
÷ 2000 lbs/TON



EFFICIENCY CO_2 REDUCTIONS 1.13 B TONS/Y

IE? ~~Ø~~ Ø [replacing equipment, etc. takes Energy & CO_2]
machinery, HVAC, Electric Motors, Furnaces ...

5 YEAR ENERGY PAYBACK TYPICAL

IE → 20 Quads/Y × 5Y [÷ 30Y] ⇒ CO_2
× 2/3
× 170 lbs/MBTU ÷ 1M ÷ 2000 ÷ 80% Efficiency

$IE_{Efficiency}$ = 354 M TONS/Y [over 30 years]
↳ 10.6 B TON TOTAL/30Y
× 2/3 (see above)
= 236 M TON/Y

COST ... based on energy cost of production (manufacturing)
1 KWh ≈ 3412 BTUs ⇒ $0.05/KWh

3-5 YEAR ENERGY PAYBACK TYPICAL
20-30 YEAR SERVICE LIFE
20 QUADS/Y SAVED ... .20 × 100,165,395,000,000,000 BTU/Y
÷ 3,412 BTU/KWh
5.87 T KWh/Y
× $0.05/KWh Energy
× 1.5 Manu. Factor
$ 440 B Manu. Cost re Efficiency

Energy Storage Build Up CO2 Numbers

CONFIDENTIAL TCSPMS | OES | 5/28/21 JAC 2588.5

DN 25703A
DN 2580
DN 1873

re ENERGY STORAGE BUILD UP CO_2 NUMBERS

ESTIMATION APPROACH

- ASSUME CAPACITY (POWER) × ½ HOUR (ENERGY)
  BASED ROUGHLY ON WHEATSBOROUGH SOLAR IN GROTON TWP, OHIO (WHERE PLAN IS FOR 50 MWh STORAGE w/ A 125 MW FARM)
- ASSESS EMBODIED ENERGY FOR 1 kWh, THEN SCALE UP (LEAD ACID ×1, Then LITHIUM OR Other ×½ TBD)

Example: LEAD ACID BATTERY 6V ×220 Ah ≈ 1 kWh ≈ Copper 16.6–34.7 kWh/kg, Say 25 kWh/kg

↳ 40 lbs LEAD ÷ 2.2 lbs/kg = 17.5 kg × 25 kWh/kg
+ 5 lbs PLASTIC ÷ 2.2 lbs/kg = 2.5 kg × 25 kWh/kg
→ 17.2–31.95 kWh/kg, Say 25 kWh/kg

20 kg × 25 kWh/kg

Per BCI (and per Matt KATFORD) Lead Batteries 150 kWh / 1 kWh v. REASONABLE Lithium 450 kWh / 1 kWh

(½ WEIGHT → Same Capacity as Lead-Acid)

$IE_{\text{Lithium Battery}}$ = 250 kWh ← $IE_{\text{Lead Acid Battery}}$ = 500 kWh/kWh STORAGE

ENERGY STORAGE … Utility Scale v. DG @ Homes, etc.

	by 2050 1500 GW CAPACITY = 1500M kW × ½ H per kW Capacity	100 M sites w/ 10 kWh STORAGE
	0.75 B kWh POTENTIAL	v. 1 B kWh POTENTIAL
	× 250 kWh/kWh STORAGE	× 250 kWh/kWh STORAGE
	187.5 B kWh	250 B kWh
s/b ÷ 80% re EFFICIENCY (UTILITY) or (Plant re Heating, etc.)	÷.80 × 3412 BTU/kWh ÷ 1,000,000 BTU/mBTU × 170 lbs CO_2/mBTU ÷ 2000 lbs/TON	÷.80 × 3412 BTU/kWh ÷ 1,000,000 BTU/mBTU × 170 lbs CO_2/mBTU ÷ 2000 lbs/TON

IE_{ES} = ~~54.4M~~ 68M TONS CO_2 + ~~72.5M~~ 90.6M TONS CO_2 for 100 M SITES

= ~~127M~~ 159M TONS CO_2 every 10 YEARS TBV

Assume 10 YEAR SERVICE LIFE

IE_{ES} ⇒ ~~13M~~ 16M TONS CO_2/Y thru 2050 / through 2050 in U.S.

IE_{ES} for 2050–2100? → DOUBLE THE SOLAR PV CAPACITY

WIND ES? TBD

ADD 1500 GW w/ 4 H STORAGE and 100 M DG SITES @ 20 kWh

~~54.4M~~ 68 × 8 = ~~435M~~ 544M TONS + ~~145M~~ 181M TONS / 10 YEARS TBV s/b Longer… 20 Years?

~~725M~~ ~~580M~~ TONS ÷ 20 Years / ~~29M~~ 36M TONS/Y

So, 2020–2050 ~~13M~~ 15M T/Y CO_2
2050–2100 ~~29M~~ 36M T/Y + ~~13M~~ 15M T/Y = ~~42M~~ 51M T/Y CO_2 } in U.S. — on SCALE w/ G1 IE SAVINGS!!

GLOBALLY (×4) → ~~52M~~ 60M T/Y through 2050 = $IE_{ES\,2050}$
~~168M~~ 204M T/Y 2050–2100 = $IE_{ES\,2100}$

COST → 0.75B + 1B kWh = 1.75B kWh STORAGE × \$100/kWh = \$175B / 10 Years × 3 (≈30 Years) = \$525B through 2050

Efficient Buildings Build Up CO2 Numbers

CONFIDENTIAL TCSPMS OES 5/28/21 JAC 2588.6

DN 2575

re EFFICIENT BUILDINGS BUILD UP CO_2 NUMBERS

90 YEAR LIFE CYCLE (Residence)

100M+ HOMES IN U.S.

DN2567.1 Per Study: 30% to 40% of Life Cycle Energy Consumption = IE

20,000 kWh/Y/Home, Typical ... REPLACE 1%/Year ≈ 1M/Y

16,000 kWh/Y × 90Y ↙ w/ 20% REDUCTION IN ENERGY USE

80% of 20,000 kWh/Y] NEW REDUCED USE

= 16,000 kWh/Y

× 90 Y Service Life — For Life Cycle purposes?

× 30% [APPROX. IE]

432,000 kWh /HOME

? { IE = 30% [IE + OE]

(.7) IE = (.3)(1,440,000 kWh)

~~= 432,000 kWh~~

IE = 617,143 kWh }

× 1 M BLDGS/Y

432 B kWh / ~~Y~~ STEP. [IE]

× 3412 BTU/kWh ÷ 1,000,000 BTU/MBTU × 170 lbs CO_2/MBTU ÷ 80% efficiency

÷ 2000 lbs/TON

157 M TONS / ~~YEAR~~ STEP. (156.6m) = $IE_{NEW\ BLDGS}$ (Replaced) — At end of Lifetime

∴ DO NOT JUST REPLACE... DO WHEN NEEDED.

BUILDINGS/HOMES ALREADY BEING BUILT - NEW OR REPLACE @ END OF LIFE ~ NOT A GOOD RETURN

... Anytime CAN ALSO UPGRADE EXISTING BUILDINGS ← UPGRADE × 5%

~ 5 YEAR ENERGY PAYBACK & 90+Y LIFETIME (not always possible/feasible economically)

$IE_{EFF.\ UPGRADE}$ ≈ 8 M TONS / ~~Y~~ STEP. — GOOD RETURN

SAVED CO_2?

20% × 20,000 kWh/Y

× 1 M "COMPOUNDED"

→ 4 B kWh 1st Year

8 B kWh 2nd Year

⋮ etc

360 B kWh 90th Year

Average ≈ ½ → 180 B kWh/Y → × 3412 BTU/kWh ÷ 1,000,000 BTU/MBTU × 170 lbs CO_2/MBTU

÷ 2000 lbs/TON ÷ 50% Efficiency (Utility) ↳ assuming Electric HVAC

104.4 M TONS/Y CO_2 SAVED LEVELIZED across 90 Years

@ 30 Years (2050), 30 M HOMES/BLDGS

each SAVING 4,000 kWh/Y × ⅓ ↳ 35 M TONS/Y after 30 Years LEVELIZED 2050

120 B kWh/Y = 2050

× 3412 BTU/kWh ÷ 1,000,000 BTU/MBTU × 170 lbs CO_2/MBTU ÷ 50% Utility Efficiency

↳ 35 × 2 = 70 MT/Y @ 2050

÷ 2000 lbs/TON

69.6 M TONS/Y = 2050 CO_2 REDUCED/AVOIDED re EFFICIENT BUILDINGS

COST

ASSUME 5% PREMIUM PRICE ON HOMES @ $250k ave

→ $7.5k/UPGRADE × 30 M BLDGS by 2050 ≈ ($230B)

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REFERENCES

Gates, Bill, 2021. How To Avoid A Climate Disaster. Alfred A. Knopf, New York.
Fuller, R. Buckminster, 1981. Critical Path. St. Martins Press.
Fuller, R. Buckminster, 1969. Operating Manual For Spaceship Earth. Southern Illinois University Press.

NREL (Boulder, CO) re PV panel energy payback [National Renewable Energy Lab]
COP 21 = 21st Conference Of Parties, aka The Paris Climate Conference
UNFCCC (website) (Bonn Germany) – United Nations Framework Convention on Climate Change
Iserundschmidt (Bonn German) re What's that – Embodied Energy? [video]
G.E.O. [Big Solar] conference, BGSU, 8/25/2016; ref. Professor Neocles Leontis, Chemistry, BGSU
Institution of Civil Engineering re embodied energy
Global Energy Project re Assessments of COP 21, re Tipping Points
Wikipedia re Definitions, background on topics, etc.
International Energy Agency re 7 Principles to guide implementation of Net Zero

www.olympicenergysystems.com
www.eia.gov re Energy Outlook 2020 (and 2021)
www.investopedia.com
www.seia.org
www.350.org
www.carbonvisuals.com
www.realclimate.org
www.e360.yale.edu
www.mnre.gov.in
www.americangeosciencesinstitute.org re energy required to produce material
www.lowtechmagazine.com re energy required to produce material
www.researchgate.net re wind turbines