Global Zero Emissions Climate Action Plan

By Dr. Hari Lamba

Proposed in Book
"Brighter Climate Futures – A Global Energy, Climate & Ecosystem Transformation," Regent Press, Berkeley, California, USA, September 2020
www.brighterclimatefutures.com, Image: Courtesy NASA,

Chapter 2

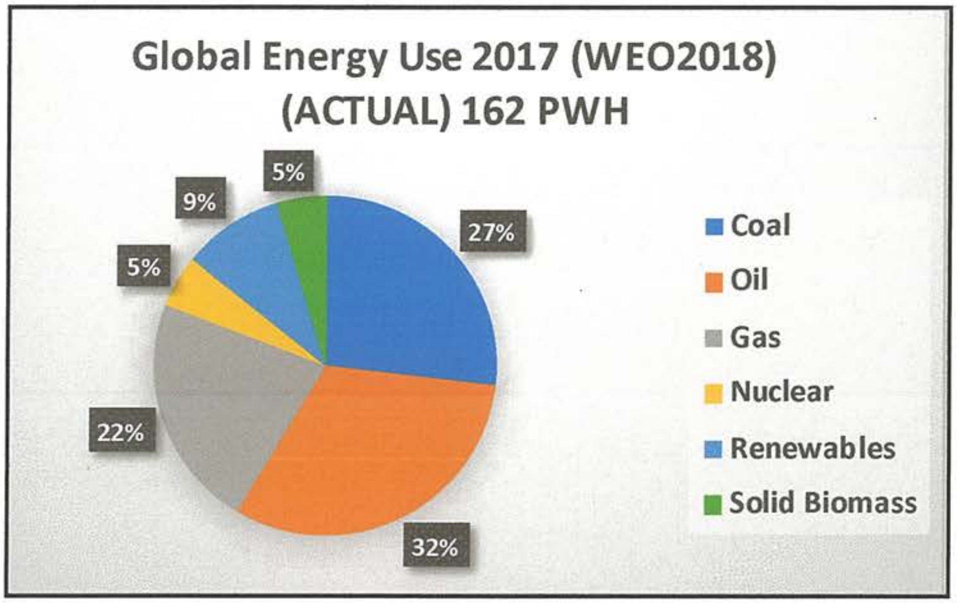
The Global Energy and Climate Plan

For the world, we first take a look at current energy use and that projected for the coming years by the International Energy Agency (IEA) in its World Energy Outlook 2018 Report (Hereafter referred to as WEO2018). [3]

Pie charts: In the following pages, we will present pie charts that show quantitatively in percentages the amount of each energy source used. The title at the top shows the total energy used (equal to 100%).

CURRENT ENERGY USE (AS OF 2017)

So where is the world as of 2017? The latest data available from the International Energy Agency (IEA) from its World Energy Outlook 2018 report (WEO2018) shows a very high reliance on fossil fuels that has been growing recently. In 2017, the world supplied 13,972 Mtoe (million tons of oil equivalent – that means all energy sources converted the same heat energy as metric ton of oil or petroleum) or 162 PWH (petawatt hours, in electrical energy units – One PWH is 1,000,000,000 MWH – megawatt hours). The actual energy consumed is less than this, as some part of this was expended in getting the energy to the end user. Anyway, the following pie chart shows where we were in 2017, causing global carbon dioxide emissions of 32.6 giga tons (or 32.6 billion metric tons, where one metric ton is 1,000 kilograms or 2,200 pounds).

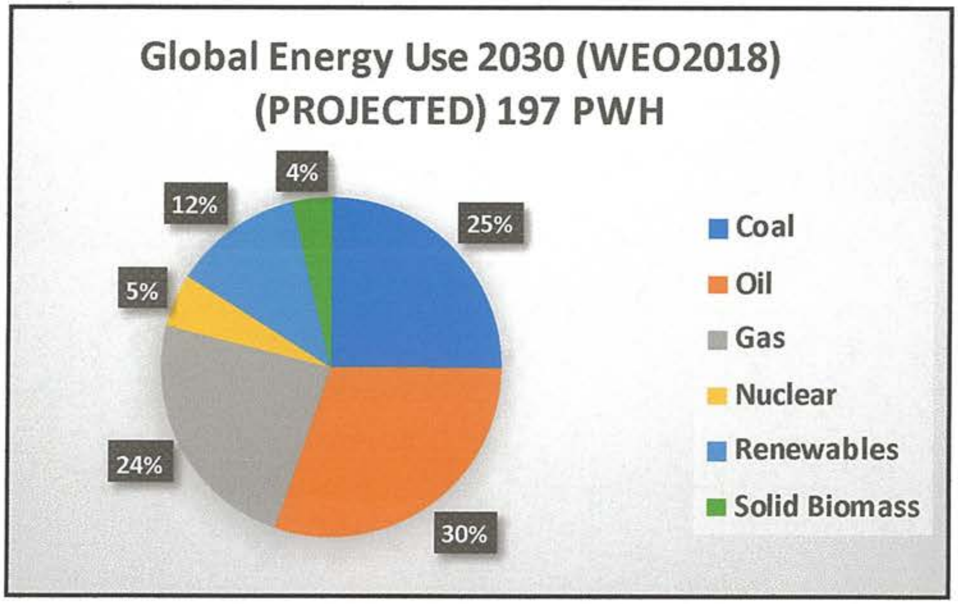


Energy Actually Consumed by World in 2017

Pie chart showing the Energy (including electricity) that the whole world used in 2017. Renewables include hydro, bioenergy, solar and wind. Fossil fuels are clearly still dominating, supplying about 81% of the world's energy. Coal use is still high. The total is 162 PWH (peta watt hours). To calculate energy value for any energy source, simply multiply total with the percentage (For example, coal use is 162 x 0.27 = 43.74 PWH).

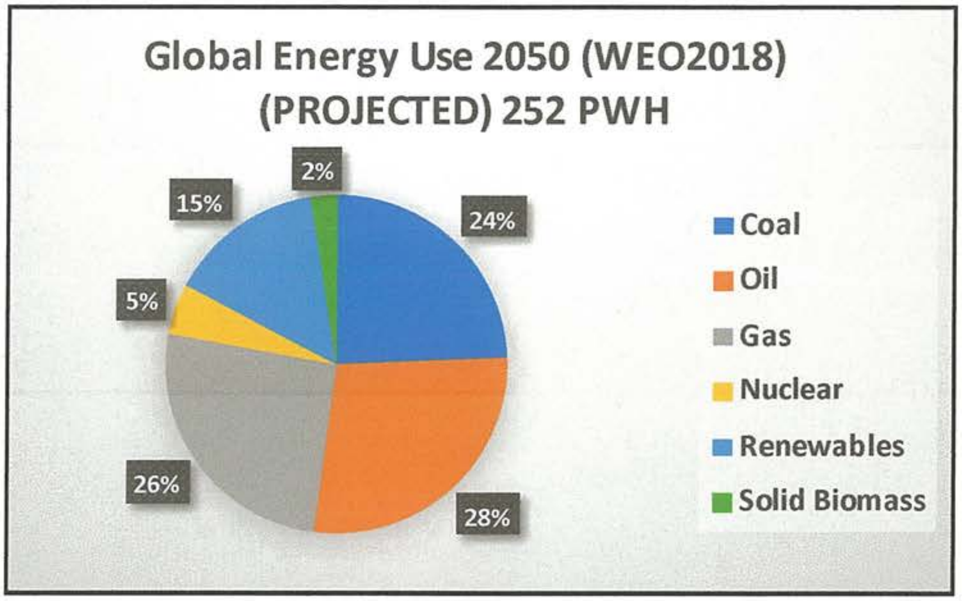
ENERGY USE PROJECTED TO 2030 and 2050 IF CURRENT POLICIES CONTINUE

The World Energy Outlook 2018 Report from the international Energy Agency (IEA) projects the energy use by the world in 2025 and 2040. From this, the energy use for the years 2030 and 2050 are calculated by linearly interpolating and extrapolating (drawing a straight line on graph and picking points for these years) for these years from the 2025 and 2040 year data. This gives us what the "Projected" energy use will be for these years, which is the best information that we have from an international organization that specializes in this activity. But these projections are estimates by them assuming that the current policies by all the nations will continue. So here are what we can expect if nothing changes and we continue doing what we are doing now for 2030 and 2050.



Global Energy Use Projected for 2030
from WEO2018 Projection

Pie chart showing the Energy (including electricity) that the whole world is projected to use in 2030 if we continue current policies. Energy use is projected to grow from 162 PWH to 197 PWH, and renewable energies that include hydro, bioenergy, solar and wind, increase a little, but fossil fuels still dominate at 79%.



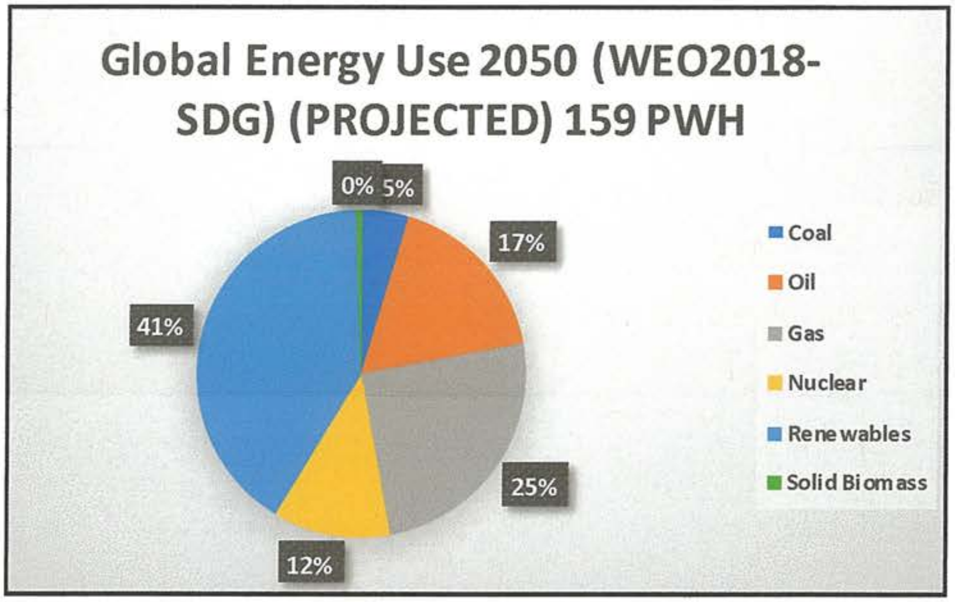
Global Energy Use Projected for 2050 from WEO2018 Projection – Current Policies

Pie chart showing the Energy (including electricity) that the whole world is projected to use in 2050 if we continue current policies. Energy use is projected to grow from 162 PWH to 252 PWH, about a 55% growth (most in developing economies), but fossil fuels still dominate at 78%. Meanwhile, the carbon dioxide emissions continue to grow from 32.6 giga tons (giga is 1,000 million) in 2017 to projected (extrapolated) emissions 47 Gt by 2050.

The International Energy Agency looks at another case which it calls the Sustainable Development Goals (SDG) case which goes to the maximum it considers practical in terms of reducing fossil fuel use and increasing production of energy by renewables (including hydro, wind, solar and bio energy), but not including biomass.

The best case projected by the WEO2018 Report of the IEA still shows fossil fuels contributing 47% of the total, and carbon dioxide emissions less than 17 Gt (giga tons) of carbon dioxide. Note that the energy use projected here (158 PWH) is less than that in 2017 (162 PWH) – so total energy use is down.

Before the Plan is presented, it is fair to describe the other scenarios and "plans" that have been put forward or proposed by others.



Global Energy Use Projected for 2050 from WEO2018 projection – SDG Case

Pie chart showing the SDS energy scenario that is described by WEO 2018, while halving the role for coal, still continues to show a great reliance on all the fossil fuels (coal, oil and natural gas), and with a doubling of the role of renewable energy from the current policies level of 37 PWH (petawatt hours or billion MWH) to 65 PWH by 2050 (extrapolated). However, it still shows that fossil fuels would provide 60% of the total energy and the carbon dioxide emissions would still be at a level of 17.6 giga tons in 2040 – an unacceptable level, that will not meet the goals of keeping the global average temperature increase below 1.5 degrees Celsius (2.7 degrees Fahrenheit), compared to the pre-industrial level.

Other Global Plans and Comparisons

World Energy Outlook 2018 – International Energy Agency (IEA)

The quantitative energy information shown above is taken from the World Energy Outlook 2018 (WEO2018) Report provided by the International Energy Agency (IEA). [2] The WEO2018 report also highlights what it calls a Sustainable Development Scenario (SDS) that is based on trying to meet the requirements of the UN Sustainable

Development Goals (SDGs) that try to tackle Climate Change, provide universal energy access and reduce the effects of air pollution. For the first time ever, the number of people without any electricity worldwide fell below 1 billion people and India electrified all its villages. But many hundreds of millions in sub-Saharan Africa still remain without electricity.

On the plus side, if the world adopted the Sustainable Development Scenario (SDS), there would be much increase in access to electricity and clean cooking fuels, and a big reduction in air pollution. Energy efficiency also much a greater role to play and SDS emphasizes investments in it. Another plus is that the SDS shows a big decrease in the water demands and use by thermal power plants because of the increased use of renewable energy.The proportion of energy use as electricity would be projected to rise from 19% in 2017 to about 28% in 2040. But the energy related carbon dioxide (CO2) emissions would only fall to net zero by 2070.

International Renewable Energy Agency – IRENA – Road Map to 2050

The International Renewable Energy Agency is an intergovernmental agency that exists to promote and assist nations in their transition to renewable energy of all kinds. According to them, renewable energy as a part of Total Final Energy Consumption, according to their ReMap plan is projected to grow from about 15% in 2015 to about 65% of the total by 2050, and is estimated to create about 11 million additional jobs. The carbon dioxide emissions reductions would be achieved 41% by renewable energy, 11% by switching to electrification and about 40% by enhanced energy efficiency. In their ReMap case, there is significant emphasis on bioenergy, especially for use in the aviation and shipping areas. Because of energy efficiency, the Total Primary Energy Supply (TPES) is projected to stay at the 2015 level of 500 EJ/year (500 Exa Joules are equal to 11,942 Mtoe, million tons of oil equivalent or 138.9 PWH – Peta Watt Hours, Exa = 10E18). But the ReMap plan still projects carbon dioxide emissions of about 9.7 GigaTons by 2050 and aims for a 2 degree Celsius temperature rise.[4]

The WWS Plan Proposed by the Solutions Project Led by Mark Jacobson

The Wind, Water and Solar (WWS) plan proposed by the Solutions Project is the most comprehensive plan that is out there to date. Although other renewable technologies are considered, most of the expansion proposed is in wind, hydro and solar PV power. The project has proposed plans for 139 countries, that calls for electrification of all energy sectors (transportation, heating/cooling, industry, agriculture/forestry/fishing) with technologies that are already available, and providing this power and energy with the three WWS energies. The plan claims to meet the carbon emissions reductions to keep the global average temperature rise below 1.5 degrees Celsius, avoid millions of deaths due to air pollution, create about 24 million net new jobs (added jobs created minus those lost in fossil fuel activities), reduce power requirements by about 40% due to higher efficiency (less energy lost in extracting, processing, storage, transporting, etc. of fossil fuels, and less heat energy lost in electricity production), and meet the world power and energy requirements by 2050.

As stated, for energy production and use, the three main technologies that are relied on are wind, hydro and solar, and it is shown that the land areas needed for these are only about 1.5 million square kilometers, out of a total land area of about 120 million square kilometers of the 139 nations. It presents the numbers mainly in terms of the power or Watts (MW or TW) needed rather than in energy or watt hours (kilo, mega or tera, KWH, MWH, or TWH). The total new WWS power added as per the plan is estimated to be 50 terawatts (or TW – 50 million megawatts or MW). The plan estimates that the total power demand of about 12 TW in 2012, which would be totally replaced by 12 TW of WWS energies by 2050, and about 8 TW would be saved as compared to Business as Usual (BAU) scenario through avoidance of energy losses in combustion (of fossil fuels), improvements in end user efficiency, and avoidance of energy lost in fossil fuel extraction, processing and distribution. [5]

The total power to be added of about 50 terawatts (or TW – 50 million megawatts or MW) would need a total investment of about $125 trillion (about $2.5 million/MW), compared with a Business as Usual (mainly fossil fuel investment) needed of about $2.7 million per MW, or about $3.5 trillion investment per year. This is of the order of magnitude of other plans discussed above. Plus, the WWS renewable energy based plan has zero fuel costs (the fuel is free), as compared with a significant fuel cost for fossil fuels (in the Business as Usual Scenario.

The Drawdown Plan

The book *Drawdown* presents a most detailed descriptions of most of the solution areas to Climate Change, and for each area, for the quantitative level proposed, the reductions in carbon dioxide emissions, the net cost and the net savings of each of those. For each of the major categories of energy, food, women and girls, buildings and cities, and materials, it presents excellent descriptions of all the categories and their sections. It also provides a ranking of all the different activities, so as to provide some idea as to the relative importance to be given to each area. At the end of the book the eighty areas are ranked, and top fifteen are highlighted. In its Optimum Scenario it emphasizes 100% renewable energy by 2050, and emphasizes that this is without biomass, landfill methane, nuclear and waste-to-energy. All of the above is very commendable and the book is a great resource. [6]

However, it ignores the big elephant in the room – fossil fuels. It does not even look at the prospect of eliminating or even reducing the use of coal, oil and natural gas. It does not even mention the need to ***replace*** fossil fuels with renewable energy – although the assumption may be that these are to be replaced by alternatives. **Also, the book does not present a plan on what is to be done when, by who and by which means, how the transition will be financed, what is to be done for fossil fuels and the nations that produce them, what is to be done for the mobile fuels and mobile needs (which need transportable fuel with zero carbon emissions), how the world will cooperate, and how the poorer nations will be able to afford or be helped to do what they need to do without blowing the global carbon budget.** Nonetheless, the book is a very good reference book if one wants to look at what a particular activity is about, and if it is done, what the carbon dioxide emissions reductions are, and what the costs and savings would be.

Getting to Carbon Neutral for California

The US state of California has set itself the goal of being carbon neutral by 2045 – meaning that after it achieves a reduction of 60% in fossil fuel emissions earlier, it is willing to look at options to offset its remaining carbon emissions with any means that absorb carbon. From the 2020 goal of 431 MtCO2e (million metric tons of carbon dioxide), which it has already met and meets the Kyoto target of reducing its emissions to 1990 levels, the emissions goal for 2030 is 260 MtCO2, and that for 2050 is 86 MtCO2 (80% reduction). So, a number of people at the Lawrence Livermore National Laboratory (LLNL) in the San Francisco area, have put forward a study titled, *Getting to Neutral – Options for Negative Carbon Emissions in California*, January 2020. In order for California to reach its goal of being carbon neutral by 2045, the study is proposing three options that it says can achieve 125 MtCO2 of negative emissions (or net carbon dioxide absorption). [7]

The three options are carbon absorption by natural and working lands (25 MtCO2 absorption), convert waste biomass to fuel and store the CO2 (84 MtCO2 absorption), and direct CO2 air capture and storage (16 MtCO2 absorption). While the natural and working lands option (forests, wetlands and agriculture) is guaranteed to work but quantitative absorptions are uncertain, it is not recommending a large amount of reforestation or afforestation. The waste biomass option mean collecting all or most of California's waste biomass and combusting it to generate energy and then absorbing the carbon dioxide. The major proposal (that both the second and third options need) is to collect and pipe large amounts of carbon dioxide gas to underground storage sites and store it there permanently, with each year adding to the total. This proposal is similar to what has been proposed in Europe as BECCS (Bio Energy Carbon Capture and Storage), which is described in a later chapter on the European Union. The important point here to make is that aside from small projects, there has been no large scale demonstration that Carbon Capture and Storage works, what it costs and the consumption needed to do it, and whether long term storage of carbon dioxide gas underground will work. Will the gas stay there, or will it leak?

Substantial Suggestions by Climate Reality
– Al Gore

Both as US senator and as Vice-President, and later as private citizen, Al Gore highlighted the problem of Climate Change, and went around the world, providing information and promoting action. His leadership contributed significantly to the definition and the agreement that led to the Kyoto Protocol in 1997 at Kyoto, Japan. It was a disappointment to him that the two nations that did not ratify the Kyoto Protocol were the US and Australia. For his efforts, he received the Nobel Peace Prize is 2007, along with the IPCC (Intergovernmental Panel on Climate Change). His most well-known 2006 book *An Inconvenient Truth* highlighted the problem of Climate Change and indicated significant solutions. In the latter part of his book he defined solutions in terms of renewable energy (biomass, wind, solar, hydro and geothermal), electric and fuel cell vehicles, increased end use energy efficiency, and personal actions to conserve. Since then, he founded the Climate Reality Project, the aim of which was to provide information and promote action on Climate Change. The Climate Reality Project has been very good for mobilization, training and leadership development, and has been responsible for developing many people who have taken up local leadership in many areas. (https://www.climaterealityproject.org).[8]

Substantial Suggestions by 350.org
– Bill McKibben

Bill McKibben is a well-known author who has written extensively on Climate Change. His books, articles and speeches on nature and Climate Change have been very influential in inspiring a whole range of people globally. The organization, 350.org was formed by a number of university students in the US in 2007, with the leadership of Bill McKibben. From 2008 to 2010, 350.org organized worldwide demonstrations in over 180 nations, linked organizations globally, provided information, and applied pressure worldwide. The organization states that we need to reduce the concentration of carbon dioxide (CO2) in the atmosphere from the current level of over 400 ppm (parts per million) to below 350 ppm, which many scientists say is needed to escape the worst consequences of Climate Change – hence the name 350.org. They helped organize the People's Climate March on September 21, 2014, which occurred at 2,000 places around the world. Inspired by Greta Thunberg, 350.org was one of the leading organizations that organized the Global Climate Strike on September 20-27, 2019, that was the largest climate related mobilization, in which about 7.6 million people participated in about 185 nations. They have organized thousands of volunteers in over 188 nations, and have formed alliances with over 300 organizations globally. They strongly advocate the replacement of fossil fuels with renewable energy and are very active globally. (https://350.org).[9]

We now present the Plan described in this book.

THE PROPOSED GLOBAL ENERGY AND EMISSIONS PLAN

This chapter lays out a time bound plan for the world to achieve the energy transition and the carbon emissions reductions in the time frame set forth in goals in Chapter 1. The principle areas for which the plan will be proposed are: electricity production, energy production, energy efficiency, transportation, buildings/homes, industry, agriculture, forestry, fisheries, tourism, shipping and aviation. Rather than electricity production being just enough to substitute for fossil fuels, the renewable energy sector plan will be shown to grow to meet increased electricity demands of a growing economy, after accounting for significant energy efficiency improvements. More detailed proposed plans for the larger carbon emitting economies, the USA, Europe, China, and India and others will be described in a following chapter. Also in following chapters we describe the ecosystem aspects of the Plan – forests, coastal ecosystems and agriculture – the carbon sinks that are treated as a bonus and act as an insurance, and so that the life supporting systems of the planet are enhanced. These account for only 3-5% of energy use, and only about 5% of carbon dioxide emissions.

As shown below, while we are not proposing that all of the world's energy be produced by solar energy, there is little doubt that ALL of the world's energy CAN be produced by solar energy, and the main issue that would remain is what to do when the sun is not shining. While the plan shows how other renewable energy sources, like wind energy, can also grow significantly, the main plan calls for a multi-dimensional energy strategy that relies heavily on solar PV (photo-voltaic) to generate electricity. There is little doubt that solar, wind, geothermal and hydro (mainly – supplemented by some nuclear in the short term), can produce all of the electricity we now consume, as well as the increase in electric energy demand till 2050, with some increase in energy efficiency that leads to a slight reduction in demand and also reduced GHG (greenhouse gas) emissions.

What the current Plan calls for is a massive increase in electrification of most other currently non-electric energy uses, some reliance on battery storage, but a big increase in electricity production, mainly with solar, to generate storage fuels like hydrogen, ammonia, methyl cyclohexane, and aluminum. The big electrification and generation of storage fuels can be done by about a three-fold increase in electricity production, mainly from solar, and the storage fuels can be transported by pipelines, tankers, trains or trucks to wherever needed. Every large solar electricity plant would generate an excess of a *storage fuel* as well as charge a battery storage system – one that would provide level or increased electric output by either batteries or storage fuel powered generators, whenever there is cloud cover or when the sun goes down, or the wind is not blowing. So let's begin with a quantitative reality check for solar energy.

The proposed plan is shown in the pie charts below for the years 2030 and 2050. Essentially, by 2030 fossil fuels begin significant reductions but still stay at about 53% of the total energy use (down from the current 79% as of the 2017 data), but solar PV and efficiency start kicking in significantly. However, by 2050, coal is gone and a small remaining use of oil and natural gas remain, so that fossil fuels are only 3% of the total energy use, and solar PV and efficiency energy use reductions have grown in a big way. In both cases, if energy efficiency can be counted as a quantitative benefit (which it is), then the total energy use as per the Plan proposed in this book is the same as that projected by the International Energy Agency (IEA) for energy use growth based on current policies (252 PWH).

First let us put things in perspective in regard to solar energy and world's energy consumption.

SOLAR ENERGY FACT CHECK

World Total Energy Consumption in 2017 (WEO 2018 Report – IEA)

- ❑ 13,972 Mtoe (Millions of Metric Tons of Oil Equivalent).
- ❑ 162,494 TWH (Terrawatt Hours, 1 TWH = 1,000,000 MWH) = 162.5 PWH (Petawatt Hours).
- ❑ **All fossil fuels only use an average of about 40% of their share (efficiency). The rest is wasted (coal: 35%, oil: 38%, and natural gas: 45%).**

Area Needed to Make This Energy with solar PV (Photo-Voltaic)

- ❑ MW – Megawatts, MWH –megawatt hours (or 1,000 KWH or kilowatt hours – shows up on your electric bill).
- ❑ 1 MW of POWER produced for 1 hour gives 1 MWH of energy
- ❑ 1MW solar panels typically generate 2,000 MWH of energy in a whole year.
- ❑ So 162,494TWH/2,000 – Needs 81.25TW, or 81,250,000 MW capacity size.
- ❑ So, 81,250,000 MW worth of solar PV panels could generate ALL of the world's energy for the year 2017.
- ❑ Typical utility scale solar PV system, 1 MW needs 0.0154 square kilometers area.
- ❑ So solar panels of 81,250,000 MW size need **1.25 million square kilometers.**
- ❑ At 40% efficiency, 162.5 PWH of fossil fuel energy only generates 0.40 x 162.5 PWH worth of electric energy (65 PWH), which only needs 32,500,000 MW.
- ❑ Which in turn only needs **0.5 million square kilometers.**
- ❑ Even if the numbers are off a little bit, that's about what we need
- ❑ The total land area of the world is **148.9 million square kilometers (58 million square miles).**

SUMMARY

- ❑ **WE ONLY NEED 0.3% TO 0.8% LAND AREA TO MAKE *ALL* OF THE WORLD'S ENERGY WITH SOLAR ENERGY. Even if solar panels only generate half the energy, the point is that the land area needed is very small.**

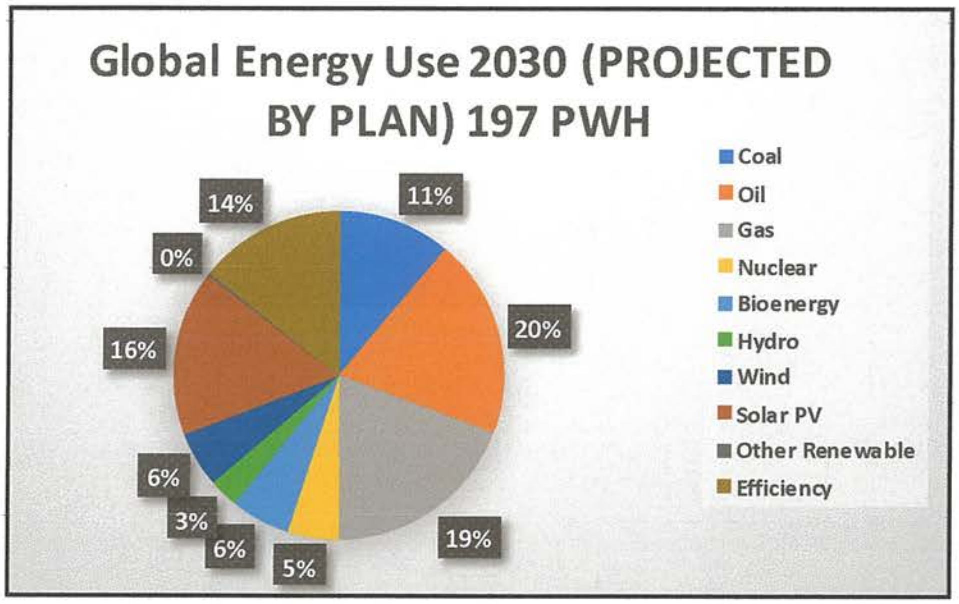
With this as background, the following Plan is proposed for the world.

THE PROPOSED GLOBAL PLAN

As shown below, while we are not proposing that all of the world's energy be produced by solar energy, there is little doubt that ALL of the world's energy CAN be produced by solar energy, and the main issue that would remain is what to do when the sun is not shining. While the plan shows how other renewable energy sources, like wind energy, can also grow significantly, the main plan calls for a multi-dimensional energy strategy that relies heavily on solar PV (photo-voltaic) to generate electricity. There is little doubt that solar, wind, geothermal and hydro (mainly – supplemented by some nuclear in the short term), can produce all of the electricity we now consume, as well as the increase in electric energy demand till 2050, with some increase in energy efficiency that leads to a slight reduction in demand and also very little GHG emissions.

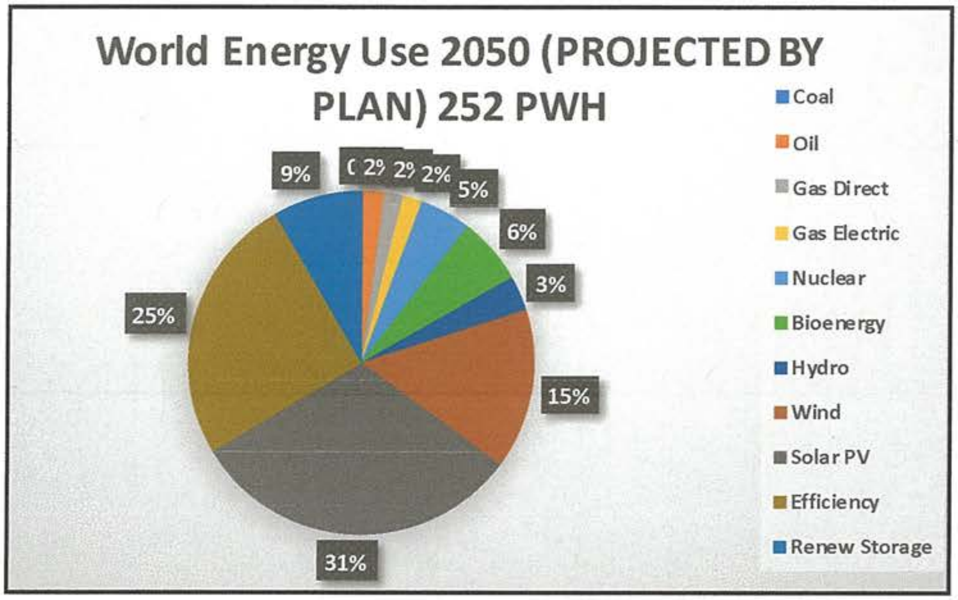
What the Plan calls for is a massive increase in electrification of most other currently non-electric energy uses, some reliance on battery storage, but a big increase in electricity production, mainly with solar, to generate non-carbon storage fuels like hydrogen, ammonia, and others to be produced, which when burnt do not lead to the release of carbon dioxide, and which are described later in this chapter. The big electrification and generation of storage fuels can be done by about a three-fold increase in electricity production, mainly from Solar, and the storage fuels can be transported by pipelines, tankers, trains or trucks to wherever needed. Every large solar electricity plant would generate an excess of a storage fuel as well as charge a battery storage system – one that would provide level or increased electric output by either batteries or storage fuel powered generators, whenever there is cloud cover or when the sun goes down, or the wind is not blowing.

The proposed plan is shown in the pie charts below for the years 2030 and 2050. Essentially, fossil fuels begin significant reductions by still stay at about 53% of the total energy use (down from the current 79% as of the 2017 data), but solar PV and efficiency start kick in significantly by 2030. However, by 2050, coal is totally gone and a small remaining use of oil and natural gas remain, so that fossil fuels are only 5% of the total energy use, and 5% or less of greenhouse gas emissions, and solar PV and energy efficiency energy use reductions have grown in a big way. In both cases, if energy efficiency can be counted as a quantitative benefit (which it is), then the total energy use as per the Plan proposed in this book is the same as that projected by the International Energy Agency (IEA) for energy use growth based on current policies. For the Plan between 2030 and 2050, it is proposed that there is a big increase in the "green" production and use of non-carbon storage fuels. The Plan only allows 5% carbon dioxide emissions from fossil fuels, and relies on carbon sink ecosystems to absorb only this amount of emissions, and if they absorb more, that will be considered a bonus.



Global Energy Use Projected for 2050 by Proposed Plan

Pie chart showing the new Energy Plan proposed in this book (including electricity) for the year 2030 that the whole world will use if it adopts this plan. Fossil fuels are down to 53% of the total use compared to the 79% of total projected above by WEO2018 if we continue current policies.



Global Energy Use Projected for 2050 by Proposed Plan

Pie chart showing the new energy plan proposed in this book (including electricity) for the year 2050 that the whole world will use if it adopts this plan. Fossil fuels are down to 5% of the total use (essentially gone) compared to the other projected use of 78% of total if we continue current policies, as projected above (WEO2018) – with fossil fuel based greenhouse gas emissions correspondingly down. There is a massive expansion of renewable energy (mainly wind, but solar in a big way). This plan relies quite a bit on energy efficiency efforts that use less energy to accomplish the same use. Also shown is Renew Storage, or the production of storage fuels (Fuels like hydrogen and ammonia produced with renewable energy) as 9% of the total. If energy efficiency targets are not met then they can be met through expansion of solar PV and storage fuels.

The above Plan energy projections were calculated in the following way:

1. Fossil fuels were totally replaced by other energy sources – mainly wind and solar as per below.
2. Nuclear energy growth was assumed to be about the same as projected by WEO2018 (International Energy Agency).
3. Hydro-electric energy was assumed to be about the same as projected by WEO2018.
4. Bioenergy was assumed to about the same as projected by WEO2018.

5. Wind Energy Projection was much higher that WEO2018, and about equal to that projected by the Jacobsen plan.
6. A number of others have suggested that a 25% goal for global energy efficiency is realistic, considering how the European Union and California have been doing.
7. Then, based on the fact check for solar energy, the rest is all solar PV energy, although other solar technologies like Concentrated Solar Power (CSP) can certainly substitute for it. Solar PV energy is about twice that proposed by the Jacobsen plan for the combined utility scale and roof top solar. This includes direct solar charging of vehicles. Renew Storage at 9% for 2050 is considered a realistic goal if the world steps up to the Research and Development tasks needed for producing storage fuels using solar PV and other renewable energies, and their end user technologies.The energy dense and mobile non-carbon fuels replace gasoline (petrol) and diesel.

We now look in greater detail at all the different parts of the Plan.

SOLAR PV POWER PLANTS ALREADY IN OPERATION WORLDWIDE

- For comparison, most nuclear reactors are of 200 MW size (usually in sets of 5).
- As of Jan 2020, there were about 62 solar PV Power Plants larger than 200 MW – Wikipedia.
- About 27 of these were already operational in the US – the largest number in any nation.
- Besides having the largest plant (2,050 MW at Pavagada), India already had 7 power plants larger than 500 MW – total 9 larger than 200 MW.
- China had 6 power plants larger than 500 MW, and total 10 larger than 200 MW.
- The main issue with solar PV is that it only produces power when the sun is shining.
- We look at how we overcome this below.

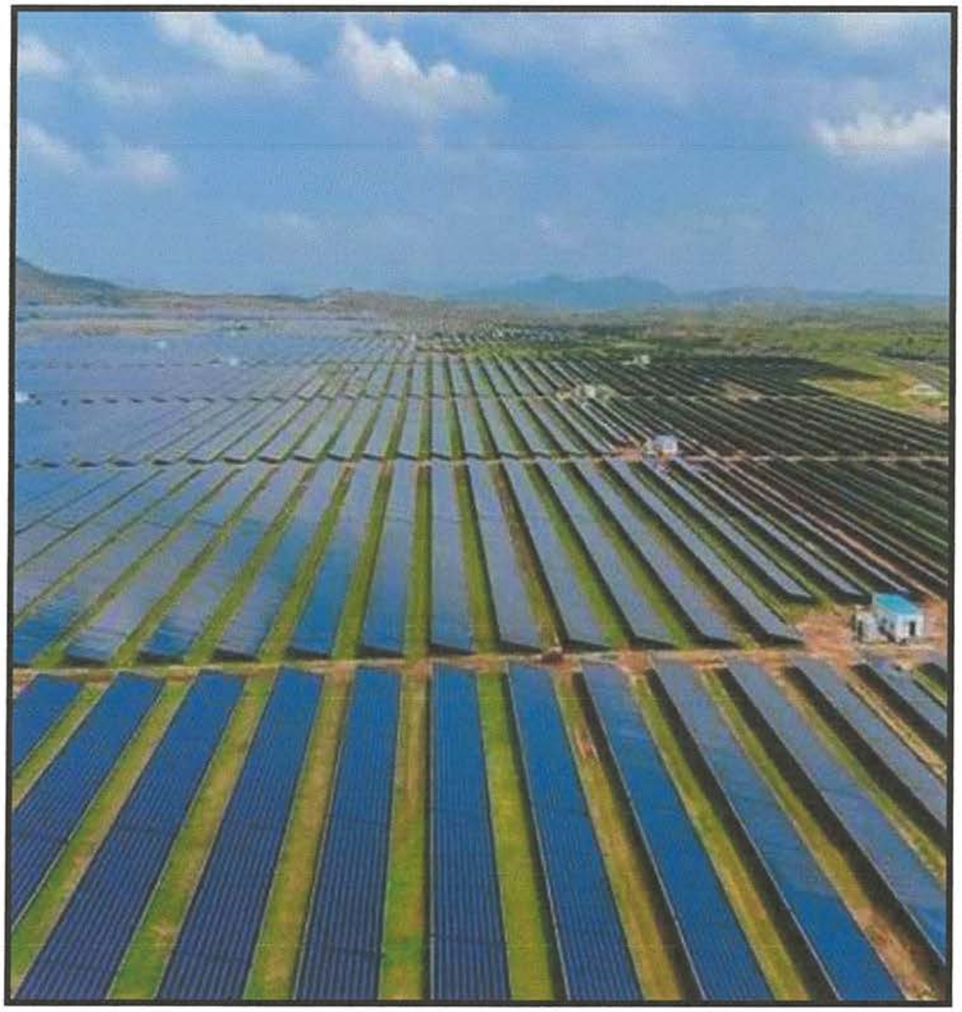
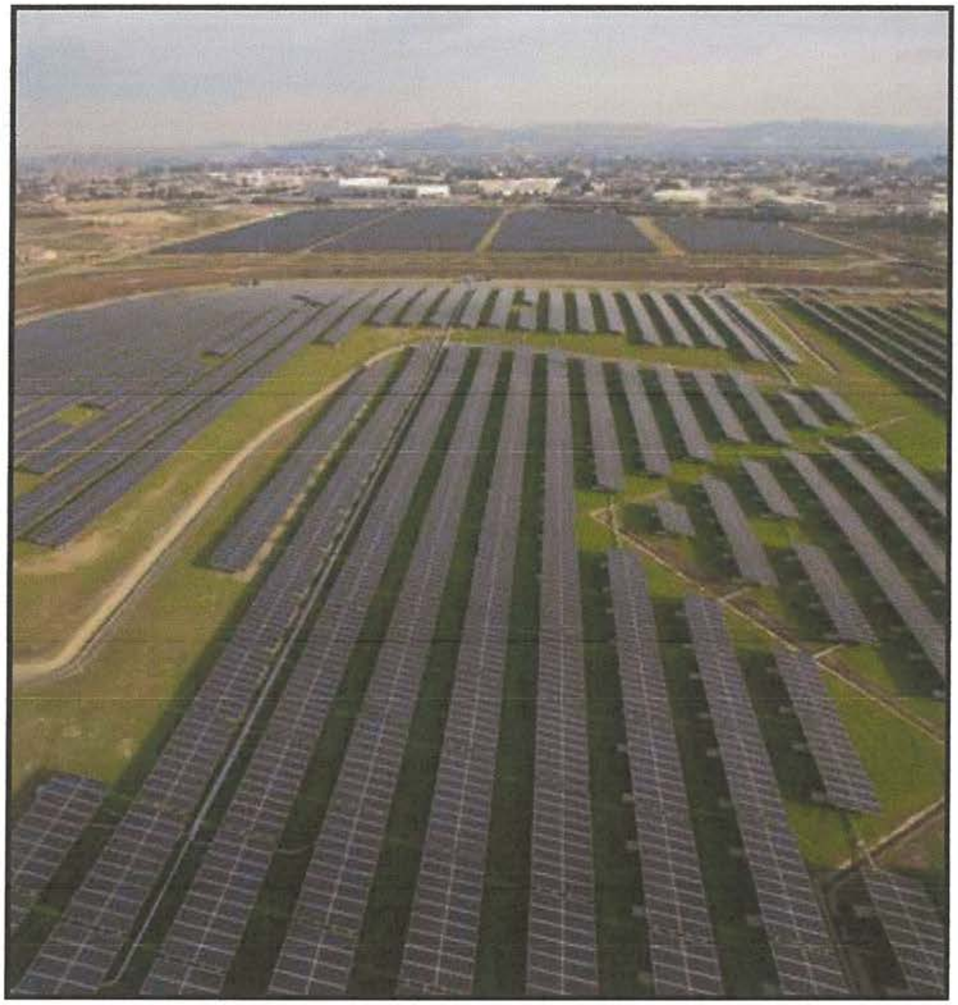


Image Credit: LA Times

Example of the largest solar PV power plant as of January 2020.

As of early 2020, the largest solar PV power plant was the 2,050 MW (megawatt) power plant in the state of Karnataka in India. This is the Pavagada Solar Park that is located in the middle of the peninsular area of India in a dry region. Completed at the end of 2019, this project cost $2.1 billion to build, which amounts to a system cost of about $1.02 per watt, one of the lowest costs in the world, at a location that has a very high solar insolation (high average hours of sunlight per day). Shown here is a photo of this power plant.



Courtesy MCE

An example of a smaller scale Utility type solar PV plant in the city of Richmond, California is shown here.

This is their Solar one project consisting of 10.5 MW (megawatt) solar PV panels. MCE (Marin Clean Energy) is California's first Community Choice Aggregation (CCA) not-for-profit organization operating in the San Francisco, California area that supplies renewable energy. More on CCAs later in the book.

TRANSITIONING OUT OF FOSSIL FUELS

NOTE: For each million BTU (British Thermal Units) of heat energy, fossil fuels emit the following amounts of carbon dioxide (CO2) on the average (US Energy Information Administration):

Coal (Average of Different Types):
210 Pounds, Lb. (or 95 Kilograms, Kg)

Oil (Gasoline or Diesel):
160 Pounds, Lb. (or 73 Kilograms, Kg)

Natural Gas:
117 Pounds, Lb. (or 53 Kilograms, Kg)

The biggest problem with coal power plants is with their massive carbon emissions. Airborne toxins and pollutants released include mercury, lead, sulfur dioxide, nitrogen oxides, particulates (smoke), and heavy metals. These cause health problems like breathing problems, brain damage, heart problems, cancer, neurological disorders and premature death. In the US, coal use leads to 100 million tons of ash waste every year that pollutes all the waterways.

Plan for Transitioning Out of Coal

1. All existing coal fired power plants globally be REPLACED by Utility Scale solar PV plus battery systems. In the short term, for evening and nights, electricity can come from other locations (nuclear, hydro or natural gas power plants), or small natural gas power plants that turn on only at night.
2. Construction of all new coal power plants be halted, and those planned, be canceled.
3. All planned coal investments be diverted into solar PV + battery power plants,
4. The solar PV stations produce an excess of storage fuels during the day, which are then used to generate the electricity at night.
5. Coal uses in industry be electrified or fueled by storage fuels, all made with renewable energy

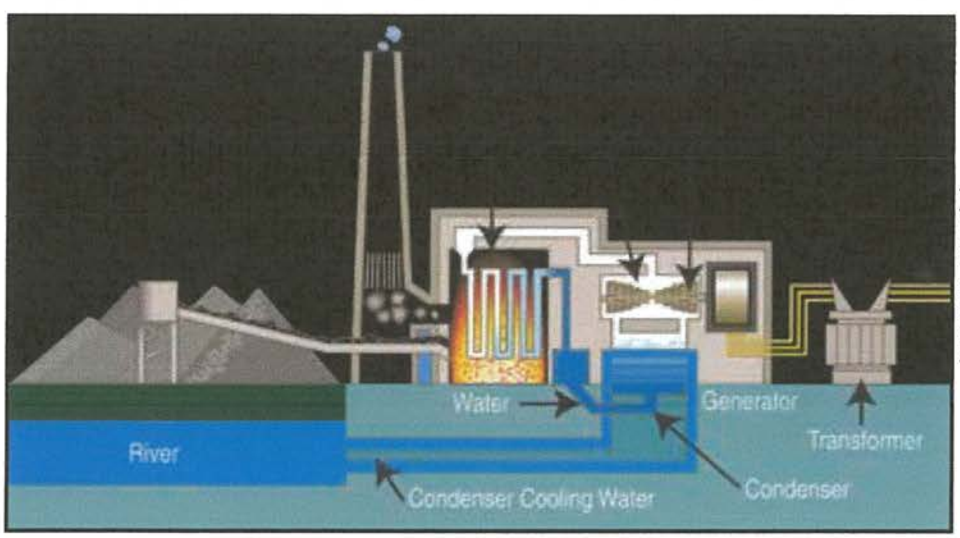
Plan for Transitioning Out of Oil

1. Where oil is used for energy or heat, the same strategy will be used as for coal above.
2. However, since oil or petroleum is the main fuel for transportation, the Plan proposes solar-electric highways and roads, and railways (see following pages)
3. Shipping will need to switch totally to storage fuels and have total plug in capability in ports – so their engines shut off.
4. Aviation needs a separate strategy – as there is little attention being paid to it

Plan for Transitioning Out of Natural Gas

1. For electric power production, natural gas use should expand slowly till about 2035, in order to support the solar PV plus battery power plants proposed above.
2. After 2035, storage fuels (like hydrogen and ammonia) that are produced at solar PV power plants (or other renewable sources) will completely replace natural gas for peak electric power production.
3. All other uses for natural gas – homes, buildings, industry, and transportation to be replaced by electric uses, or by use of "storage fuels," all with high energy efficiency.

For reference, it is useful to describe how a coal fired plant operates that generates electricity. The illustration below helps understand this. Basically, coal is mined far away in a coal mine that is either underground or is a strip mine that uses large drag shovels to



(By tennessee Valley Authority – tva.com, Commons Archive, Public Domain). https://commons.wikimedia.org/w/index.php?curid=24393916)

How A Coal Fired Power Plant Works

dig up hill or mountain sides. It is then shipped by rail (by very heavy and large trains in open hopper cars) or to a sea port and then by ship to the power plant. Although there is some dust control on the way, there is often a significant amount of coal dust that blows away from rail cars and finds its way into the air of communities that live along the rail lines. The coal is then stored in open piles at the plant site, often for many weeks, before it is loaded into the plant. All of this causes bad health effects on the communities and people that live along the way.

There is usually a river or a large lake near the plant from which water is taken, and the coal enters a furnace where the coal is burned together with incoming air, and the water is boiled and converted into superheated steam. The steam then enters the steam turbine, which is then powered by the steam to rotate at a fairly high speed, which then rotates a large electric power generator that converts the mechanical energy of rotation into electrical energy using the electrical wires and magnets inside it (designed to output an electric current). The electrical current is then fed to a large transformer that converts it into high voltage electrical energy that is then fed into the transmission line. After powering the steam turbine, the steam condenses back into water which is usually at a higher temperature than the intake water, which is then fed back into the lake or river (this is called thermal pollution). Besides the air pollutants that are emitted by the furnace into the air going up the smoke stack, there is a solid ash that remains. So-called clean coal power plants scrub the exhaust air so as to try and reduce the air pollution and the ash has to be disposed properly otherwise it pollutes the surrounding water and soil. The air exhaust consists of high levels of carbon dioxide, nitrous oxide, smoke particles and toxic pollutants.

GLOBAL COAL USE

World coal production grew from 3,255 million tons of coal equivalent (Mtce) in the year 2000, to about 5,360 Mtce by 2017 (WEO 2018 Report). From the years 2000 to 2017, China increased its production and consumption of coal from 955 Mtce to 2,753 Mtce, a really huge increase. So, in spite of the bad effects of the burning of coal on climate, there seems to have been no let-up in the growth

of coal use. As shown in the pie charts above, coal use was about 27% of total world energy use in 2017, and if current policies of governments continue, even by 2030 and 2050, the coal use will still be 25% of a larger number. Coal used for electric power generation is at 40% of world electric energy production. Even with a "Sustainable Development Scenario" or SDS, the WEO 2018 report projects that the world's coal consumption will still be about 2,282 Mtce (million tons of coal equivalent), which is still too high. Although it is normally used for base load type operation, so that the power plant is run at a high and constant level, more recent coal plants can be run more flexibly where power output can be varied as needed by the load, or demand by consumers.

Coal use is continuing to grow globally. The four biggest exporters are Australia, Indonesia, Russia and the US (which, in 2018, produced about 686 million metric tons and exported about 102 million metric tons). Coal use is causing massive air pollution in China and India, with some residents describing this as "gas chambers". China based its entire expansion and progress from 2000 to 2020 on coal. India plans to do the same by using its domestic reserves. **Clearly, the biggest challenge globally is to head off the increased use of coal, and convince all of the nations of the world to transition out of coal to renewable energy.**

PROPOSED PLAN FOR COAL

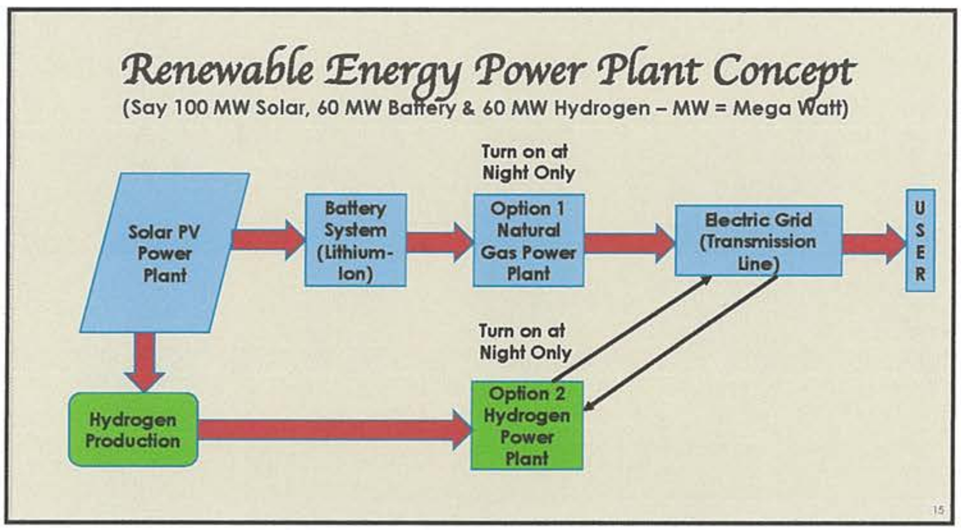
REPLACE ALL COAL USES BY RENEWABLE ENERGY AND REDUCE COAL USE TO ZERO BY 2050

SOLAR PV POWER PLANTS – THE TOTAL ENERGY SOLUTION

Solar PV Combined + Battery System + Storage Fuels

Small, medium and large utility scale solar PV plants will be established throughout the world (except of course in nations such as Iceland that already have met all of their needs with other renewable energy). When the sun is shining there will be three loads that would be supplied: (1) Direct supply for electricity for immediate use through transmission lines; (2) The charging of a local battery system that would provide short term smoothing and backup; and (3) the production of a storage fuels such as hydrogen or ammonia (fuels that can store renewable energy), for reuse at the plant and for excess production and supply to the rest of the economy. When clouds come over, the battery system would kick in immediately to make sure the supply is smooth. If the sun stops shining for a longer period of time, in the early stages of the plan, a generator such as one based on natural gas would start up and kick in to provide electricity during that time and at night. At the later stage of the plan, when the storage fuel technology is well developed and storage fuel is being produced and stored during the day, the storage fuel generator would provide electricity when the sun is not shining or at night. When this happens, the natural gas generator would be retired and be no longer needed.

The accompanying block diagram shows how such a concept would work.



Solar PV Plus Battery Power Plant

A US National Renewable Energy Laboratory (NREL) report shows that solar PV plus battery power plant systems at the same location have become practical and cost effective.[10]

SUMMARY

The new solar PV plants, from smaller community ones to larger state and regional utility scale plants would supply currently needed electricity, and the added electricity for battery charging and the production of storage fuels. The total electric capacity of all the new renewable energy power plants (in terms of power and energy) will be anywhere from two to five times the current electrical capacity, in order to meet the needs of the total electrification of the whole global economy.

LOCATIONS

To minimize the size and expense of the transmission grid (covered in following pages), it is best that the solar PV power plants be located near the end users and end user communities. In this way, the transmission line lengths will be much shorter. All solar-electric charging stations for vehicles will have the solar and battery systems located as close to the station as possible. Similarly, the solar PV based storage fuel production stations will be as close to the end user locations as possible. Solar PV plus battery power plants that REPLACE coal fired power plants will be located very near the original plant so as to use the same transmission lines.

CAISO, the California Independent System Operator of the state of California, USA, coined the term "DUCK CURVE" to point out the problem created for non-renewable power sources when solar PV was added at mid-day in a big way.

The customer demand over a 24 hour period is shown schematically below. (This is not actual data, but the shapes of the curves represent what happens). Then, mid-day as solar energy kicks in, the other energy sources (currently non-renewable energy sources – mainly natural gas power plants in California), have to ramp down very fast. Then, towards evening as the sun sets, these same sources have to ramp up fast. This is all in addition to what happens early morning and late at night as energy demand from customers fall.

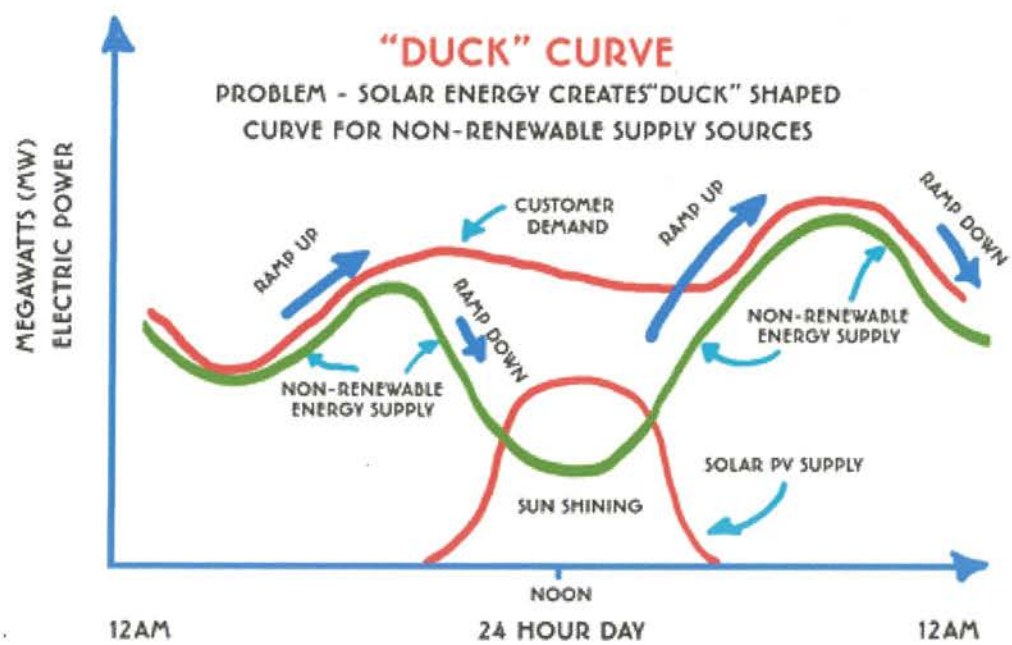


Illustration of the 'Duck" Curve

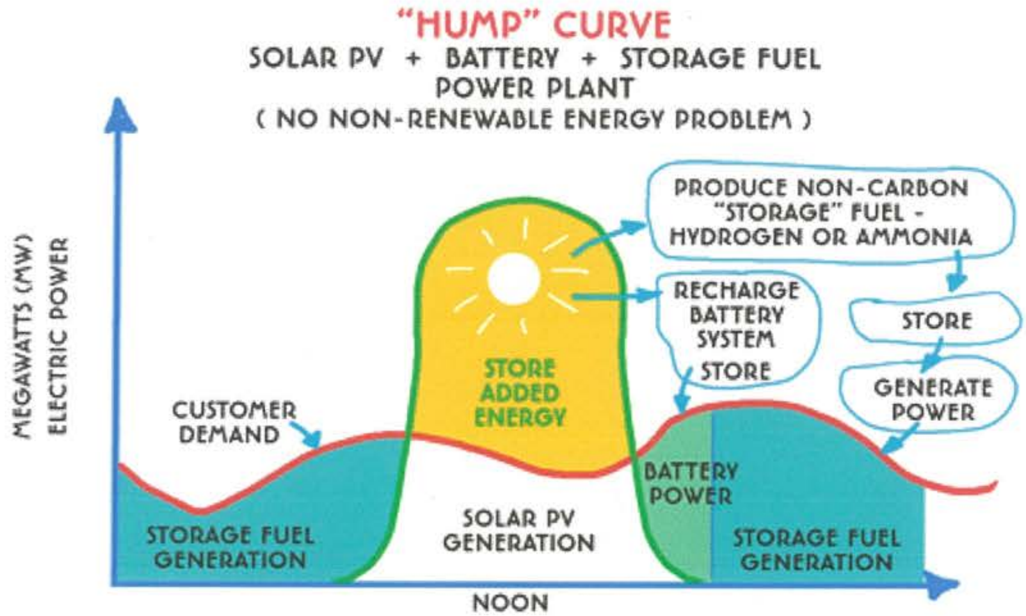


Illustration of the "Hump" Curve to overcome the variability of solar energy,

The "HUMP CURVE" proposed by the Plan completely overcomes the problem if solar PV is the only source of electric energy. The solar PV plus battery plus "storage fuel" power plant is sized such that when solar PV power is being generated, it is enough to not only meet the mid-day demand, but it fully charges the on-site battery system, and produces adequate quantities of a non-carbon storage fuel, which is stored for evening and night use. Then, as solar PV power and energy are going down as the sun is setting, the battery system cuts in and meets the late afternoon increased power demand. Then, after the battery system has discharged to a defined level that is good for battery level, the storage fuel electric power generator (gas turbine or fuel cell) kicks in and produces power and energy for the rest of the evening, night and early morning, till the sun rises again.

Other major storage sources can also play a role here in providing the power – compressed air, water pumped storage, molten salts at CSP (Concentrated Solar Power that use heat to generate power, but can also melt the salt) or other storage methods. For storage fuels, the maximum amount that might need to be produced in advance and stored would be, say 6-7 days' worth, in case there were a number of overcast or days with less sunshine. Also, before storage fuel green production and use is fully developed, natural gas power plants can be used from evening to early morning, or electricity can be imported by the grid from elsewhere (hydro, geothermal or wind).

The issues with high levels of solar energy that occur in the US in states such as California, do not occur in the middle of the United States which are more dependent on wind energy. Wind energy tends to be steadier and can blow at all times, so that it creates more of a flat curve during the day. Some have called it the "ALLIGATOR" curve that actually is closer to consumer demand most of the day, and only causes a small hump during the day when nearby solar PV power kicks in (utility scale or roof top solar). **So, it is important to encourage wind and geothermal energy that can provide power when the sun is not shining, and energy from hydro-electric power plants can also add to this.** There are other good ways of managing the issues and that is by demand side management, or reducing the demand on the user side by various means.

Other Strategies on the Demand Side

Energy Efficiency has been covered elsewhere in this book. Besides a customer buying and retrofitting the most efficient appliances and cooking units in the house or commercial building, the government organization that controls the utility companies must REQUIRE the company to be continuously reducing demand, so that (as often happens in the US), utilities offer rebates to customers when they install high furnaces and air conditioners that exceed a certain level of efficiency. The author got such rebates when he lived in the Chicago area when he replaced his old 90% efficiency natural gas furnace and electrically powered 12 SEER air conditioner with a 97% efficiency furnace and a 16 SEER (Seasonal Energy Efficiency Ratio) air conditioner. In this way, he went from being an energy inefficient customer to being a very energy efficient customer and both his electric and natural gas bills went down significantly. There are many other ways in which users can reduce their energy use by getting audits conducted by a professional energy auditor.

Demand Side Management is a "Smart Grid" Approach that is another way that can reduce the demand and hence overcome some of the disadvantages of the "DUCK" curve. Utilities, in order to ensure that they do not run out of power when demand is high (like on a very hot day when everyone turns on their air-conditioners), usually have been using "peaker plants", or generators that just turn on only for the few hours that power demand is high. These tend to be very expensive and also tend to be more polluting. One simple example of demand side management is if the utility installs a remotely operated receiver controller on the air conditioning units and then cycles the power between customers (turning off each customer's air conditioner for, say, no longer than an hour), **so that all the air-conditioners in an area are not operating at the same time.** Another way is for the utility to subsidize a battery system for the customer (say a hotel or large store), so that when demand is high, the battery system provides the added power, and the utility does not need to charge extra for higher than normal demand (in the US they call this a "demand charge"). With these strategies the need for a "peaker plant" is eliminated.

Consider the following advantages of solar energy over coal

1. No energy needed in mining – no pollution and destruction at mining sites.
2. No energy needed for transportation – no pollution transporting the fuel.
3. No water pollution at the power plant – no heat emitted to air and water.
4. No fuel cost at the power plant –THE FUEL IS FREE!
5. No toxic and other air pollution at plant site – no toxic ash to dispose off.
6. No actions needed at any site – once solar panels and power plant is installed, it produces electric power when the sun is shining – automatically!
7. The main disadvantage is that it stops producing when the sun goes down – but as shown above, solar energy can be stored in batteries or other mediums and used later for a properly sized solar system.
8. The cost of solar has been going down steadily and in most nations the installation and operating cost of a solar PV power plant is lower than a coal-fired power plant (more on that later).

Minimizing the Environmental Impacts of Solar PV Power Plants

It is totally true that once solar PV power stations are installed, there are no added carbon dioxide or other greenhouse gas emissions. However, there is strong need that every effort be made to minimize the impact on the global environment. Most solar panels use the metal silicon and trace amounts of other metals, but the production involves toxic and poisonous chemicals which must be handled properly and disposed of in a safe manner. Then, there needs to be a strong emphasis on recycling the materials if solar panels get damaged or at the end of their life – hopefully into the next generation of higher efficiency solar panels. Thin film solar sheets though involve a number of other chemicals like gallium arsenide, copper-indium-gallium-diselenide and cadmium telluride. These also need to be handled and disposed of properly, and being scarce metals, recycled. Next, it is important that the life cycle emissions of the silicon solar panels be minimized through the use of renewable energy in all stages of their manufacture, transport, installation and final recycling. Current estimates of the life cycle emissions of solar panels are 0.017-0.18 pounds of carbon dioxide equivalent per kilo-watt hour (KWH) – compared with 1.4–3.6 lbs of CO2e/KWH for coal.[11] It takes no more than 2–4 years of solar energy production to fully recover the energy consumed in their production.

Then for solar PV plants there are issues of land use, land costs, water use, and the environmental impact on local species of plants and animals. Water use is very little, but may be significant in dusty areas which require that the solar panels be washed frequently. Land use and land costs are important, and should fully take care of and respect local community rights. Further, adjustments need to be made in the design of these projects so that the need of local animal species be taken care of – possibly with gaps in the solar arrays having wetlands or grass areas. As the small to large solar PV projects are implemented, the need to do these in environmentally friendly ways is very important.

EXAMPLES OF RENEWABLE ENERGY REPLACING FOSSIL FUEL POWER PLANTS

Replacing Coal Power Plant in Utah with Natural Gas and Then Hydrogen by 2045

The Los Angeles municipal utility (LADWP – Los Angeles Department of Water and Power) plans to replace a large 1,800 MW (megawatt) Utah coal fired power plant (see accompanying photo Intermountain Power Project), from which it imports electricity, to a natural gas power plant by 2025, and then replace that with a totally green hydrogen power plant by 2045. The hydrogen will be produced using renewable energy available in the region (solar, wind, and geothermal). The power plant is interconnected on the grid to 370 MW (megawatt) wind, with added power to be available from wind, solar PV and geothermal. The power plant is going to be the first power plant that uses renewable energy to produce hydrogen (green hydrogen) through electrolysis, by which water (chemically H2O) is split up into hydrogen (H2) and oxygen (O2) using electricity. [12]

The plant will produce hydrogen and then store the gas in underground caverns that are available, in a quantity adequate enough for a year's generation of electricity. The three technologies needed for the 840 MW (megawatt) project are making hydrogen from renewable energy using electrolysis (in adequate quantities and at an acceptable cost), storing the hydrogen, and then using the hydrogen to produce electricity. Initially, when the 840 MW natural gas plant is established in 2025 (when the coal plant ceases operation), hydrogen will be capable of making 30% of the electricity when mixed with natural gas. Both electrolysis to produce hydrogen from renewable energy (production of the storage fuel) and modifying the Gas Turbine to burn on 100% hydrogen (End-user technology) are technologies that need RDD&D (Research, Development, Demonstration and Deployment), an issue that will be taken up in regard to storage fuels in pages that follow.

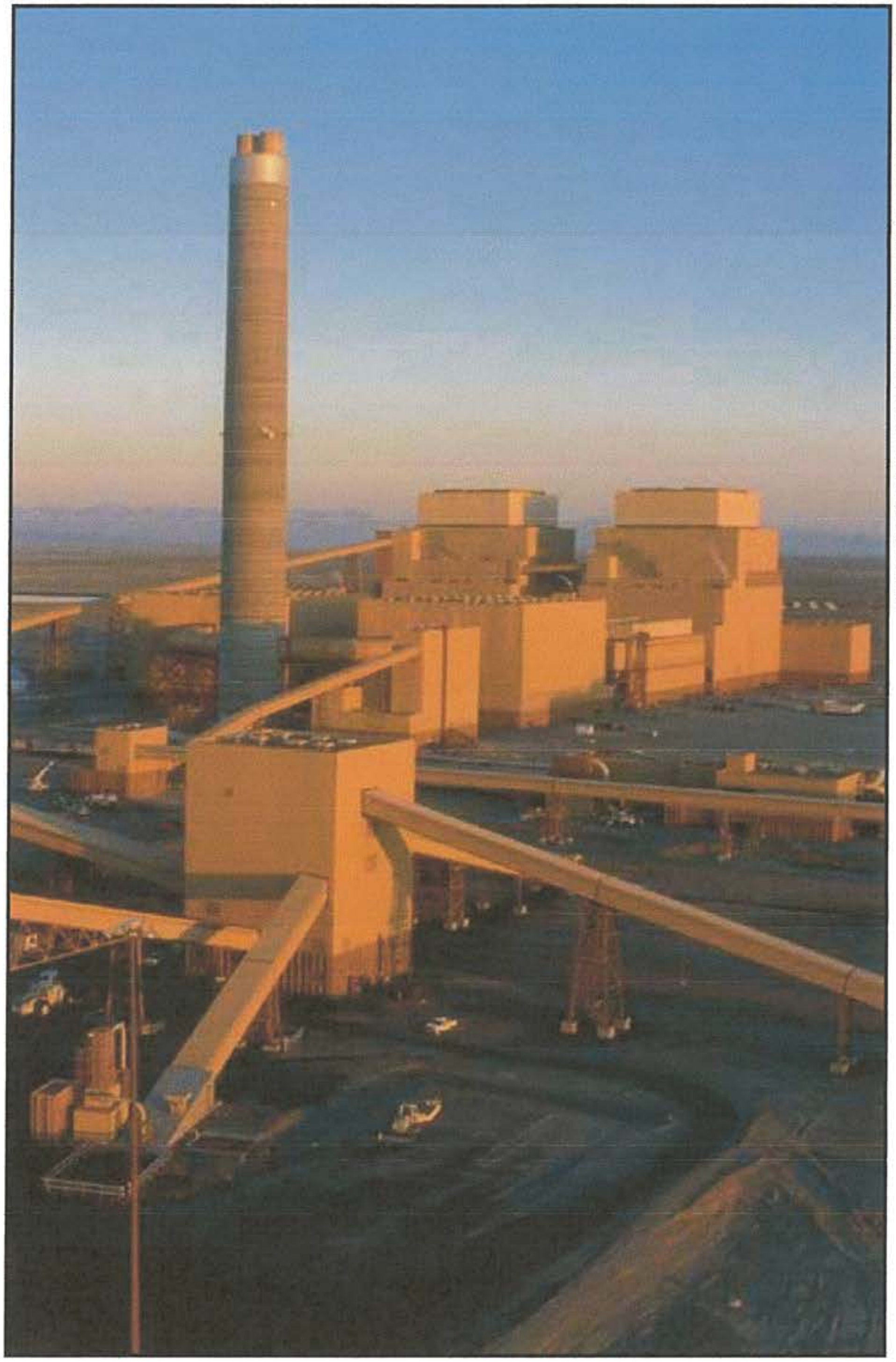


Photo Courtesy of the Los Angeles Department of Water and Power (LADWP)

Existing 1,800 Megawatt Coal Power Plant in Utah.

Replacing Fossil Fuel Power Plants With Solar PV Plus Battery Power Plants

Possible Natural Gas Power Plant In S. California to be Replaced with Battery System — Study Indicated it Can Be Replaced With A Solar PV Plus Battery System

Southern California Edison (the local Gas and Electric Utility Company) had proposed a 262 MW (megawatt) Natural Gas Peaker Plant at Puente for the area around the coastal city of Oxnard, California. Earlier, a battery system when proposed had been estimated to cost three times as much, but it turned out that these estimates were outdated. Instead, it is being substituted by a large battery system (although a solar plus battery power plant that will meet the same electricity needs as the natural gas power plant). Targeted for completion by December 2020, a company called Strata Solar will build and own a 100 MW (megawatt) lithium-ion battery system with a four hour energy capacity (hence 400 MWh – megawatt hour, or 100 MW for four hours) at Oxnard, California. **Since the year 2000, whenever California needed additional electrical energy or wanted to enhance grid reliability, it simply installed new natural gas power plants. This was going to happen again in 2013, and state energy regulators were ready to approve a 262 MW natural gas power plant at Puente, California.**

An independent study conducted by the Clean Coalition showed that a combination of solar PV and battery energy storage system would meet the same needs as the Puente power plant, and be more cost effective. The study demonstrated that a power plant consisting of 120 MW solar PV and a 75 MW battery storage system (of about 225 MWH energy capacity) would meet the whole requirement. If the solar PV power plant was ground mounted, the total cost would be $267 million (as of 2017), and if mounted overhead on poles (built environment) would cost $370 million. This was compared with a Puente gas power plant cost of $299 million, with an added cost of $16 million for natural gas infrastructure. A slightly larger system would also meet the needs posed by another nearby Peaker Plant at Ellwood, California. [13]

Other Major Renewable Energies

While solar PV has the distinct advantage that it is available everywhere and can be located near the ultimate user (hence minimizing transmission costs), there are other major renewable energies.

Wind Energy

Large onshore horizontal axis wind turbines (or wind mills that look like propellers) have increased many fold in recent years. In many places around the world, these can be seen as propellers on top of tall towers or varying height. In the US, there are many wind "farms" in the Midwest of the country and in Texas. IRENA in their GET 2018 Report (International Renewable Energy Agency) reported that worldwide in 2017 there was 167 GW (gigawatts) of renewable power added in 2017, of which 94 GW was solar PV and 47 GW was wind energy. In 2018 they reported that there was 109 GW of solar PV added and 51 GW of wind power added (more than the electric power addition from non-renewables). From 2017 to 2018 the cost of electrical energy from wind and solar had gone down from 6 and 10 US cents per KWH (kilowatt hour) to about 2-3 US cents per KWH. IRENA is projecting big increases in wind energy electric power generation capacity, so that it is projected by them to grow from about 411 GW (gigawatts) to 5,445 GW by the year 2050.[14]

In the Global Plan that is shown for 2050 in the pie chart before in this chapter, the world would about 38,000 TWH (terawatt hours) of wind energy (or about 38,000,000 gigawatt hours). Because this number is based on a replacement for fossil fuels (that are only about 40% efficient or about 60% energy is wasted), the world would only need 15,200 TWH of energy to replace the 38,000 TWH of fossil fuels, unless the world uses the difference to produce non-carbon storage fuels. So for the wind power needed to generate 15,200 TWH of energy, would be about 7,000 GW – about 30% higher than projected by IRENA above. However, if more wind energy is added to produce storage fuels like hydrogen and ammonia (which then have their efficiency losses as well), then the world may need even more wind energy. As for all renewable energies, wind mills need to be designed so that birds can see them and are not killed by flying into them. One way is for the speeds of these large blades to be reduced – for some designs the full capacity speed is 17 RPM (17 revolutions per minute – which means each blade rotates 17 times in each minute), which is a slow enough speed for birds to see them.

The other option for wind energy is to site the wind mills in the sea (**offshore**). This is projected to be about 10% of all wind energy but is a higher cost. Another option for smaller scale generation is to have **vertical axis wind turbines**, which look like the rotating vents on top of buildings. Some of these are like Darius Rotors. These wind generators are much smaller (usually less than 100 kilowatts), and can be located in urban areas, ground mounted on poles or mounted on the roofs of buildings. Coastal areas, where the wind blows often at the ground level are also well suited for these small vertical axis wind turbines, which can be a good supplement to small solar PV electric units on homes or buildings.

Plan for Wind Energy: Besides maxing out for wind (the maximum in terms of worldwide wind potential) in terms of quantity, since wind energy is generated most of the 24 hour period although at varying speeds, it is recommended that it be used in combination with solar PV. In this case, wind will provide a base load (or a nearly constant amount of electricity as is provided today by nuclear, coal and natural gas power plants), and the solar PV power plant still designed to provide the "Hump" energy for battery and producing storage fuels.

Geothermal Energy

Our Planet Earth was a molten ball when it formed about 4.6 billion years ago as a part of the formation of our solar system. Since then, as the surface of the planet cooled, it formed the crust on which we live, the atmosphere we breathe, and the oceans that give us water.

Geothermal energy is that which taps into the subsurface heat in the Earth's interior. To tap geothermal energy one need only go up to small depths where hot rocks are available, and sometimes near the surface as evidenced by surface hot water geysers as can be seen at the Yellowstone National Park in the US.

Geothermal based electric power generation may be simply tapping into a reservoir of subsurface hot water or steam that is ported to the surface to run a turbine and generate electricity, or it may involve injecting water which then gets heated and is ported to the surface. Even if not enough to generate electricity, the hot water may be used to heat buildings or for other uses. Near the surface, the constant temperature of the ground from 3 to 50 meters (10 to 160 feet), can be used by **geothermal ground source heat pumps,** in which an environmentally friendly liquid like polypropylene glycol flows through pipes buried horizontally or vertically to about 50 meter (165 feet) depths. The geothermal ground source heat pump works a little like a refrigerator in exchanging heat energy. When it is winter, it extracts heat from the ground and blows it into the house, and when it is a hot summer it dumps heat down there and cools the house. Heating and cooling costs can be reduced by as much as 75% with the use of this in homes or buildings. However, both geothermal for power generation and for ground source heat pumps have higher up-front costs, but the long term savings are definitely there. Another issue is that if rock cracking techniques are used, this can lead to mild earthquakes.

In 2013 about 11,700 MW (megawatts) of utility scale geothermal power plants were in operation worldwide, and there were plans to double this capacity. These produced about 68 billion KWH (kilowatt hours) of electricity, and produced about 25% of the electricity generated in Iceland and El Salvador. With about 3,300 MW capacity, the US leads the world with the state of California having 80% of this, so that geothermal produced about 7% of the state's electric energy. The US also has thousands of homes and buildings that use geothermal ground source heat pumps. [15]

Plan for Geothermal: For power generation, wherever ground resources are available, Plan calls for the use of geothermal to provide a base-load as the power is available 24 hours of the day. It is recommended that this be used in combination with solar PV, where the "Hump" generation by solar power be used to charge batteries and produce storage fuels, although geothermal can be used for the latter too.

Concentrated Solar Power

Concentrated Solar Power (CSP) is basically some type of reflecting mirrors concentrating the heat segment of solar light to either a trough (horizontal) or a tower (vertical), by moving with the sun during the day, in order to heat a medium that then is used to create steam, which runs a steam turbine, that is tied to a generator that produces electricity. Sunlight consists of a full spectrum of light, from ultra-violet to visible (which splits up into a rainbow, which we see) to infra-red. Concentrated solar power uses the Direct Normal Irradiation (DNI) that is found in tropical or desert regions, and solar PV uses Global Horizontal Irradiation (GHI), which is found everywhere. CSP also has an option whereby it can melt a salt or a synthetic oil during the day, which can be insulated and be available for heat or generating electricity when the sun goes down. Like geothermal, CSP can then be a "dispatchable" form of energy as it can also help overcome the disadvantage of a "DUCK" curve in late afternoon or evening when demand peaks.

As of 2018, the world had 5,400 MW (megawatts) of power being generated from CSP, with Spain leading with 2,300 MW, the US next with about 1,700 MW, and South Africa, Morocco, China and India each having a power of more than 200 MW. [Wikipedia]

Plan for Concentrated Solar Power (CSP): Plan proposes a greater use of CSP when used with its option for producing a molten salt or a synthetic oil even while it is generating electricity during the day for the customer. The molten salt or oil can then be used after the sun goes down in order to produce electricity from the evening through the night. In this way, the CSP station can complement a nearby solar PV plus battery station and performs the same function as geothermal and storage fuels can locally. For desert or similar regions it has the advantage over geothermal that it can be located anywhere where sunlight is available.

Solar Thermal for Other Uses

Solar hot water and space heating: Heating hot water by using the sun has been done for ages. If one just places a black water tank in the sun, the water in it will heat up, just as your skin heats up in the sun. Solar hot water heating in its simplest form can simply be a number of copper tubes attached to copper sheets (as copper conducts heat better than most other metals), painting them black and placing them in a box with a glass case. If the water in it is connected to a hot water tank, that also has water in it, as the water in the glass case (let us call it solar hot water panel) gets heated, it rises and the cooler water in the pipes flows to enter the glass case. The heated water in the pipes heats the water in the water tank, which can then be used. This is simple convective flow – hot water rises as it becomes lighter, and cold water falls. Simple hot water heating panels can be made very easily with a few tools and hardware. In this way, the heat component of solar energy can be used to preheat the water in a tank.

However, on a commercial scale, when one hires a contractor to install a system, the options available are many, as there can be a system with an electric pump to circulate the heated water, the liquid in the panel can be another environmentally friendly liquid that heats the hot water tank, and the tubes can be evacuated tubes (just like a thermos bottle), that reduces heat loss in a cold climate. As with all renewable energy hardware, all commercially sold hit water panels are tested for heat efficiency and other requirements. The biggest fact about solar hot water heating panels is that they usually cost less than solar PV electric panels, and with the amount of energy they provide, one gets one's money back sooner in energy cost savings.

On a wider level, concentrated solar power has been covered above, but solar thermal systems can be used for water heating, space heating (ventilation systems), as part of furnaces for heating homes and buildings, for solar cooking and even for cooling. The reason this is covered here is because these methods can be employed by individuals on a wide scale. Solar hot water heating systems for homes and buildings have been increasing throughout the world and the Plan calls for their widespread adaptation, as they can save on electrical and other energy used for the same purpose.

Rooftop or On-site solar PV

Lamba System: The author has used rooftop solar PV to generate some of his own electricity, wherever he has lived over the last 35 years. His previous house in the Chicago area had installed a 1kW (kilowatt) pole mounted grid tied solar system in 2003 that was fixed at an angle of about 40 degrees to the horizontal and facing south, that produced a significant amount of electrical energy over more than a decade. This kind of system uses a grid tied inverter that converts the DC volts (direct current that only varies with the solar electricity generated) electrical energy from the solar PV panels to 120 Volt AC (alternating current that changes in a waveform that varies at

60 Hertz or cycles per second – which is used by all households and buildings in North America). After moving to California, the author has gotten a larger 3.5 kilowatt (KW) solar PV system directly on his south facing angular asphalt shingle roof that generates more than his annual electricity than he consumes – because as per this book, he plans to electrify all the natural gas units in his house and buy a battery electric car, which will need to be charged. In the winter, the sun trajectory in the sky is low so the electricity production per month is less at a low of about 250 KWH (kilowatt hour or electricity units), and a high of about 600 KWH (kilowatt hour) in summer, when the sun is high and there are more hours that the sun shines on the panel. For a year (May 2019 – April 2020), his home solar PV panel system produced 5.25 MWH (megawatt hours of energy) – each kilowatt produced 1,500 KWH (or 1.5 MWH) of energy for the year. The author paid about $8,500 for the system, for which in the US there was a 30% federal tax credit for solar PV, so the system cost him about $5,000 – this unit cost was $2.4 per watt or a $1.4 per watt after the tax credit, and his electric bill has gone to zero, except for a transmission charge, so he does not have to be concerned with any future electricity cost increases.

Worldwide the total growth of solar PV power grew from 178 GW (gigawatts) in 2014 to 512 GW in 2018 (with about 180 GW of that being large or utility scale systems described elsewhere) with projected growth to about 770 GW in 2020. This growth has been exponential, meaning that the growth of added electrical capacity has been faster and faster each year. The six leading nations in 2018 with solar PV were China (175 GW), European Union (115 GW), USA (62 GW), Japan (55 GW), Germany (46 GW), India (27 GW), and Italy (20 GW). Rooftop solar has grown fast also, but faster in commercial and municipal sectors than in the residential sector. Still, even by 2024 IEA projects that there will be an added 100 million homes that will have solar PV installed. [2]

Plan for Rooftop and Distributed Solar

Plan calls for the requirement that all commercial and industrial buildings be net zero electricity buildings in that they produce as much electrical energy through solar PV as they consume annually, and that all new residential buildings (apartments or homes) also be net zero in electrical terms. All communities should plan to generate as much of their electricity through solar PV as they can locally, near their communities, by small scale solar PV plus battery plants, so that transmission costs are decreased, especially as they electrify. All of these should be tied to the electric grid so that they feed back excess energy and draw energy when producing less. The Plan for solar PV that is presented earlier in the pie chart for the world includes Utility Scale Systems, Concentrated Solar Power and rooftop/ distributed solar.

We now turn to the proposed Plan for storage fuels.

NON-CARBON FUELS NEEDED THAT ARE PRODUCED BY RENEWABLE ENERGY

The world needs a way of storing renewable energy in portable, storable, energy dense fuels that are zero carbon and whose burning or use do not cause carbon emissions. This is essential to decarbonizing ALL sectors of the economy. As the next section shows, it will not be possible to electrify everything – so for all of those uses we will need fuels in which we can STORE renewable energy. This Plan refers to these fuels as ***storage fuels.*** The two fuels that are very good candidates are hydrogen (H2) and ammonia (NH3), both of which are currently used commercially in relatively large quantities but are both made using fossil fuels and hence involving large greenhouse gas (mainly carbon dioxide) emissions.

Hydrogen is one of the lightest gases available, and it is actually everywhere as it is part of the water molecule (H2O – as two atoms of hydrogen and one atom of oxygen). Hydrogen gas (which consists of two atoms of hydrogen) is mostly made by the steam methane reforming of natural gas (which contains methane) at a high temperature, with the byproduct unfortunately containing carbon dioxide. However, to make commercial hydrogen the world actually uses natural gas, oil, coal and electrolysis in the proportion of 48%, 30%, 14% and 4% respectively. As of 2017, the world hydrogen market was about $115 billion, and in early 2019, the world was using 70 million tons of hydrogen annually for industrial processes (such as oil refining), the production of ammonia (to be discussed next), and methanol (a lower cousin of traditional alcohol or ethanol). So, the world knows how to handle and use hydrogen.

For information, it should be noted that hydrogen can be used in its gaseous form or at a very low temperature can be liquefied and stored in special insulated containers. As a gas, hydrogen has a high energy density by weight (about three times the energy content than gasoline of the same weight), but its energy density by volume is only quarter that of gasoline – so a much greater volume (or size of cylinder) is required for the same energy. However, hydrogen, when used to fuel an Otto-cycle internal combustion engine has a maximum efficiency of about 38%, about 8% higher than for gasoline in the internal combustion engine used in cars. A fuel cell and electric motor combination is 2 to 3 times more efficient than an internal combustion engine, that wastes most of the energy as heat in the exhaust.

As of 2015, it is known that by current electrolysis processes (in an electric cell that splits water, or hydrogen oxide, into hydrogen and oxygen), it takes about 50 KWH of electrical energy to produce 1 kilogram (Kg, or 2.2 pounds) of hydrogen gas. If the price of electricity is $0.06 per KWH, the price of hydrogen would be $3/Kg. This is about double the current price of $1.20-$1.50 per Kg for hydrogen. If the cost of electricity from solar or wind Energy could be less than about $0.03/KWH, it would be economical to produce this by electrolysis. If one considers the cost of carbon dioxide emissions by current production process, it will tilt it in favor of producing "Green" hydrogen using electrolysis that is powered by solar or wind energy. Pure hydrogen is currently used to provide the fuel for fuel cell cars, and for some other vehicles in small quantities today. Hydrogen is much safer than gasoline or natural gas as it is much lighter than air and shoots up when released and is gone. Gasoline vapor and natural gas are about the same weight as air so hang around and can cause explosions. Hydrogen in enclosed spaces can lead to an explosion if there is a spark. However, the world has learned how to use hydrogen safely, and it now has begun to be used in fuel-cell cars.

Plan for hydrogen

- Most hydrogen (H2) gas is produced today by Steam Methane Reforming that usually uses natural gas, but produces a lot of greenhouse gases too.
- Today, hydrogen is mainly used in refining petroleum, treating metals, producing fertilizer (via ammonia) and processing foods.

- ❑ As of 2017, about 70 million metric tons of hydrogen was used globally, and because its production used fossil fuels, it resulted in carbon dioxide emissions of about 830 million metric tons (more than the total emissions of Germany).
- ❑ Electrolysis is a method by which an electric current is used to split water (H2O) into hydrogen (H2) gas and oxygen (O2) gas. Currently, hydrogen produced by this method is more expensive, but research is under way to reduce the expense. The main challenge is electrodes that last.
- ❑ Hydrogen is produced, stored and used today in large quantities – the world knows how to safely handle and use it today.
- ❑ A photograph that follows shows one the first Stations in California that supplies Green Hydrogen.
- ❑ The Plan is calling for RDD&D (Research Development, Demonstration and Deployment) for producing Green Hydrogen, or hydrogen made with solar PV electricity or other renewable energy – see schematic that follows
- ❑ There are some significant demonstration projects under way to use electrolyzers of a few megawatts to produce significant quantities of hydrogen. If these projects are successful, they can be scaled up commercially.
- ❑ The use of hydrogen in cars and buses has already begun, and along with electric vehicles needs to be expanded to jointly cover all vehicles. The combination of solar powered electric charging stations and hydrogen refueling stations will need to replace most of the gas stations of today. Hydrogen will also power other forms of transportation like ships.
- ❑ In electric generation, hydrogen will be produced with solar PV energy during the day and, together with larger battery systems, produce electricity from evening to early morning, so the full cycle is all renewable energy – although energy during those times when the sun is not shining can also be provided by other renewable energies like wind, geothermal and hydro.

Ammonia (NH3, which has one atom of nitrogen and three atoms of hydrogen) has also been described in the Global Plan in Chapter 2. It is produced currently first by producing hydrogen using Steam Methane Reforming (SMR) which emits carbon dioxide, and then combining the hydrogen with nitrogen from the air (which is about 78% of the air we breathe), using the Haber-Bosch process. In 2016, the world produced and handled about 175 million tons of ammonia, most of which was used as fertilizer for agriculture. Ammonia has the advantages over hydrogen in that it is easier to handle because it doesn't require high pressure (which saves money). It has twice the amount of energy per unit of volume than hydrogen, it can be stored more easily in a smaller volume, it has a distinctive smell making it easier to detect (hydrogen is odorless), and it doesn't embrittle steels like hydrogen thus making the job of designing storage tanks easier. The main safety aspect that needs special handling is the toxicity of ammonia to human respiration. Plus ammonia is already handled, stored, transported and used in large quantities – about 175 million tons worldwide in 2015. In 2012, the US produced about 8.73 million tons of ammonia and imported some for its own use.

Plan for Ammonia

- ❑ Ammonia (NH3) gas is an alternative to hydrogen and a close relative of it.
- ❑ As of 2016, the world used 175 Million Metric tons of it, mostly as fertilizer for agriculture.
- ❑ Ammonia is made by taking nitrogen from the air and combining it with hydrogen using the Haber-Bosch process to produce anhydrous (dry) ammonia
- ❑ The infrastructure (storage, pipelines, and transport, etc.) already exist in a big way for it.
- ❑ Ammonia has its own distinctive properties – it is easier to store and transport than hydrogen.
- ❑ Again, the Plan is calling for RDD&D at both ends – that of making ammonia by Green methods, using Renewable Energy and for end-user technologies by which ammonia can be used as a fuel in fuel cells, internal combustion engines and gas turbines.
- ❑ Because of its toxicity to humans for respiratory purposes, ammonia needs special attention in regard to its safety, so that humans are not significantly exposed to it. Strict safety procedures are to be enforced wherever it is used, especially when humans and animals are in close proximity to where it is stored and used.

Ammonia has a very distinctive pungent smell that is easy to recognize. Its advantages are that it can be liquefied easily (much easier than for hydrogen). Because of its physical properties it can stored in an inexpensive pressure vessel. Then, since ammonia has a large percent of hydrogen (17.65%), its density per unit of volume in the liquid form is about 45% higher than hydrogen, so more of it can be stored in a given volume. Lastly, it can be decomposed over a catalyst to produce hydrogen and nitrogen (that is not a greenhouse gas).

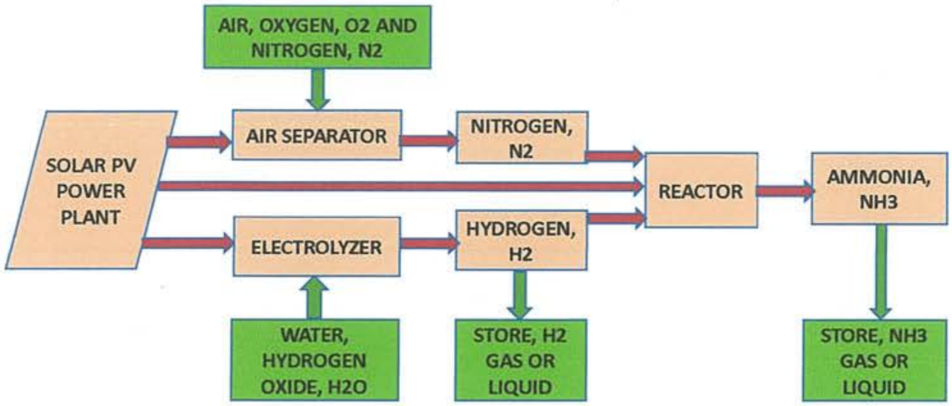
Other advantages of ammonia are that it is an excellent storage fuel (for storing renewable energy). It can power an internal combustion engine (like gasoline for cars), although this technology is still under development. It can power an alkaline fuel cell, or be cracked to provide hydrogen that can power a non-alkaline fuel cell. Ammonia's storage, transportation and distribution are much cheaper than hydrogen, and its use in an engine or fuel cell would not produce carbon dioxide. Also, since it carries more hydrogen per volume, it is better in terms of on-board storage in cars, is easier to crack than other hydrocarbon fuels, and no greenhouse gases are emitted.

The special character of ammonia does require attention for onboard storage in vehicles. It expands with rise in temperature, has a high tendency to react with water, reacts with some container materials and has a high toxicity of the vapor when released to air. Proton exchange membrane (PEM) fuel cells used for hydrogen cannot tolerate ammonia, so it needs to be effectively filtered if it is cracked to hydrogen. Storage tanks need attention to these aspects of ammonia. Ammonia is currently transported by pipelines, sea tankers, railcars and trucks. The US currently has about 5,000 Km (kilometers) or about 3,000 miles of pipeline for it. For large scale storage for the energy purpose of this Plan, ammonia has the lowest cost and space needed for long term storage times (100 – 10,000 hours).

One promising technology is the Proton Exchange Membrane (PEM) technology that converts water to hydrogen at one electrode and then takes hydrogen and combines it with nitrogen at another electrode to produce ammonia. Although Japan and Australia are very active, there are significant activities in Europe and in the US for producing ammonia by Green methods (using only renewable electric power and no fossil fuels and no carbon emissions).

The Flow Chart above shows how hydrogen and ammonia can be produced anywhere where there is solar energy. The Plan calls for

PRODUCING GREEN HYDROGEN & AMMONIA
From Solar Energy



RDD&D (Research, Development, Demonstration and Deployment) for all aspects of the above.

The US state of California has developed about 40 retail hydrogen refueling stations, and one is located near Honolulu, Hawaii. These have been opened by a company to serve Toyota Mirai car drivers who lease their fuel cell vehicle cars through Toyota. Most of these refueling stations are located near the Los Angeles area, but others are spread throughout the state. As of the time of the writing of this book (early 2020), there are about another 24 hydrogen stations that are at various stages of permit, planning, construction and commissioning. Other car manufacturers that have developed fuel cell vehicles are Honda (2018 Clarity Fuel Cell) and Hyundai (2019 Nexo) – the latter offers 5 passenger seating and a 380 mile (612 kilometer) range. Hyundai says that it plans to build 500,000 fuel cell vehicles powered by hydrogen by 2030. The former Governor of California, Jerry Brown, had signed executive orders that that set targets of 200 hydrogen refueling stations by 2025 and 5 million zero emission (electric or fuel cell) vehicles by 2030.

The main challenge of hydrogen fuel is that they need to ALL be green, or use renewable energy sources to produce the fuel. The photo to the right shows a 100% green or renewable hydrogen station installed in 2019 in the city of San Francisco, that was developed by Shell and funded by the California Energy Commission (CEC). This is open 24 hours a day, has a capacity of 513 kilograms (about 1,130 pounds), has two refueling nozzles that supply hydrogen gas under pressure, to fill the vehicle tanks. The government of California

Photo by Author.

A 100% green hydrogen refueling station in San Francisco, California.

requires that at least 33% of the hydrogen fuel supplied at each station comes from green sources, and that a station that supplies at least 40 % green hydrogen qualifies for its Low Carbon Fuel Standard ZEV (Zero Emission Vehicle) Infrastructure credit. **[California Fuel Cell Partnership – Cafcp.org]**

Electrification of The Whole Global Economy

SOLAR-ELECTRIC HIGHWAYS – EXAMPLE OF THE USA

VARIATIONS OF THIS TO BE APPLIED GLOBALLY

- The Entire US Highway Transportation system can be electrified by solar PV powered electric charging stations throughout its entire highway and road network.
- Indirect electrification will be by fuels that are produced by solar energy, and then stored for later use – we call these storage fuels – more on these in next few pages.
- These vehicles will use either fuel cells (like the hydrogen fueled vehicles of today), or have internal combustion engines (like those used in vehicles today).
- Calculation for the US based on its energy use on roads and highways in 2017 **(US Energy Information Agency).**
- The US used 27 Quads (quadrillion BTUs) or 7,930 billion KWH of energy.
- Information from the US Energy Information Agency Report.
- On the average, vehicles consume this energy with only 40% efficiency.
- About 60% is wasted and leaves out of the muffler.
- So, for Electric Energy, we only need 3,172 billion KWH (40% of 7,930).
- For most latitudes of the US, this energy needs 2,115,000 MW (megawatt) of power. Each MW of *power* annually assumed to give 1,500 MWH (megawatt hours) of *energy*.
- **If Charging Stations are 10 MW is size we need 211,500 of these.**
- **At 0.015 square kilometers per MW, this needs 0.15 sq. Km. or 38 acres area.**

- ❑ Each Solar-Electric charging station can also store and sell storage fuels, produced on-site or transported from some other location.
- ❑ Each Station can also have an on-site unit that produces one or more storage fuels using solar PV energy using the same solar panels.
- ❑ These storage fuels can either be hydrogen or ammonia.
- ❑ Since the US has 47,000 miles of Interstate Highways, one station each 20 miles means 2,350 of these stations on the Highways alone.
- ❑ The photo on the next page shows a Solar Powered Electric Charging Station.
- ❑ Or the solar panels could be elevated construction along the center strip of the highway.
- ❑ See the page after next for a Concept of such a Solar-Electric Charging, including "storage fuel" on-site production as an option.
- ❑ Over a period of 30 years (2021-2050), these Solar-Electric Charging Stations can replace the 111,000 "Gas" Stations currently in the US (for gasoline and diesel).

SOLAR-ELECTRIC ELECTRIC VEHICLE CHARGING STATION

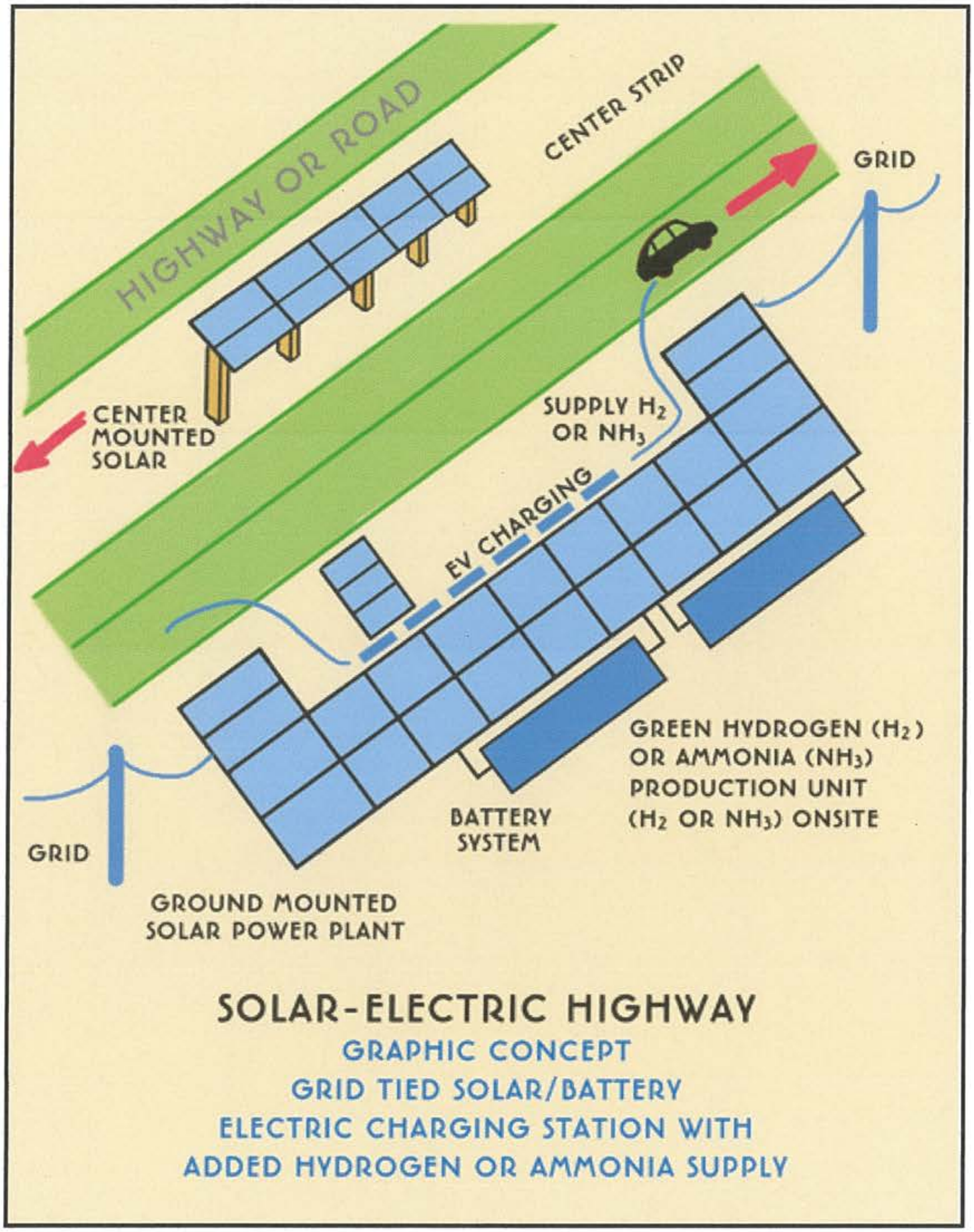
In April 2019, Marin Clean Energy (MCE), a local non-profit organization in California, that was established for Community Choice Aggregation (CCA* – see next page) completed a solar PV Powered Electric Charging Station in cooperation with a company called American Solar Corporation, that is of 80 kW (kilowatt) capacity that powers 10 Level 2 Electric Vehicle (EV) Charging Stations next door to its office in San Rafael, California (a level 2 charging station takes a few hours to fully charge a nearly fully discharged batters system on a car). The station will generate about 120,000 kWh (kilowatt hour) of electric energy per year and power the 10 EV charging stations. When the sun is shining, the solar energy directly charges the battery electric vehicles, and at other times will receive power from MCE's other California's renewable energy sources (mainly wind and solar). If there is excess solar energy, it will flow back into the grid and be used to offset the energy use of its nearby office building. MCE contributed funds to make required infrastructure upgrades, and received some financial support from local area California governmental organizations. The effort complimented MCE's Electric Vehicle Program where it has funded and supported 644 charging ports at mainly multifamily dwelling and workplace locations in their service area.

***Community Choice Aggregation or CCA**, is a method that is being used in California and other states of the US. These are covered in more detail in the California Plan, but here is a summary. A CCA is a not-for-profit organization that provides an alternative to investor owned utilities, where the CCA provides alternative renewable energy supply, but the utility still handles transmission, metering and billing. Marin Clean Energy is the first of about 19 Community Choice Aggregation organizations in California, and it began service in 2010 with the aim of providing stable electricity rates to customers and reducing greenhouse gas emissions.

CONCEPT OF GLOBAL SOLAR-ELECTRIC TRANSPORTATION SYSTEM

HIGHWAYS AND ROADWAYS

- ❑ The Global Plan proposes direct electrification of the world's highways and roadways.
- ❑ The Plan proposes solar-electric highways and roadways. So the plan here is to have solar panel systems with raised structures covering highways, or where the space along the highways is available, ground mounted solar systems.
- ❑ See the concept on the next page of such a Solar-Electric Charging Station.
- ❑ As is proposed elsewhere for power plants, the solar system will be accompanied by battery backup system, so there is power at times other than when the sun is shining.
- ❑ At each location, there will be electric vehicle charging stations, so battery electric vehicles can be charged, some directly from solar panels, and later directly from the battery system.
- ❑ At other times (like at night), the solar charging station can be on the transmission grid and powered by electric power from elsewhere.
- ❑ If the solar-electric charging station is stand-alone (not tied to the grid or connected to the utility), then its battery system will need to be much larger and be capable of charging vehicles when the sun is not shining.



This is the concept of a solar-electric charging and refuelling station.

RAIL TRANSPORTATION SYSTEMS

Similarly, light rail, bus systems and all railways will develop supporting systems for pure electric, battery and storage fuel use. Although the cost of adding pure electrification of mass transit type systems (such as electric trams) is high, wherever these make sense, these should be developed or expanded. For battery light rail vehicles, solar PV charging stations will be developed that charge these vehicles throughout the day, and at night from stationary batteries that have been charged. All rail vehicles, especially diesel-electric locomotives will be converted to hybrid battery electric and storage fuel turbine based engines. End-use engines, fuel cells and turbines that use storage fuels will need the RDD&D (Research, Development, Demonstration & Deployment) so that these achieve widespread use. The use of diesel fuel in railway locomotives and other types of light rail systems will be phased out after the whole system is electrified, or converted to storage fuel-based vehicles.

STORAGE FUEL OPTION FOR HIGHWAYS, ROADWAYS AND OTHER MODES

The storage fuel can be hydrogen that is produced and consumed quickly on-site, or ammonia, that is produced and stored and consumed over longer periods. The size of the storage fuel production unit can vary depending on local demand. The storage fuel production unit will only need water that is split to provide the hydrogen, and nitrogen that is drawn from the air – both resources that are available everywhere. Since these fuels can be produced locally, they do not need to be transported over large distances.

Electrification of Buildings and Homes

A significant number of homes and buildings globally use propane, fuel oil and natural gas for heating and other appliances (water heaters, clothes dryers, and cooking appliances). Parts of the developed world have piped natural gas, while many other parts of the world use gas cylinders for cooking (which is a big improvement over cooking with wood or coal).

So, here is the Plan for the Electrification of Homes Buildings

1. **Require that all new structures of all kinds have no fossil fuel options (natural gas, fuel oil or propane), and that they be fully electrified**, have battery electric vehicle charging stations, have solar panels, and they meet mandated energy efficiency standards that are technically feasible. This has been done by the city of Berkeley California in 2019. (Berkeley's all-electric building ordinance requires that starting Jan 1, 2020, all new buildings be built all electric – no gas hook-ups – covers new houses, apartments and commercial buildings.)
2. **Change all laws and regulations, and building and energy codes** in order to make it easier for any retrofits of existing structures to switch to the all-electric modes.
3. For each nation to engage in a nation-wide program that is a combination of incentives, rebates, tax credits, and education in regard to the all-electric technologies needed. This should include the encouragement for solar thermal panels, solar ovens for cooking and electric heat pumps.
4. Starting 2035, the Plan proposes a mandatory electrification, helping users financially and physically to retrofit their homes and buildings, for electrification.
5. **Electrification Technologies:** Air conditioning is generally electric powered the world over. However wherever natural gas is used in homes and buildings, these need to be converted to electric powered units. So natural gas furnaces need be converted to electric heat pumps, and gas cooking stoves to electric (direct or induction) stoves – induction heating is where a frequency is used to heat steel cooking utensils. Also all other appliances like clothes dryers need to be converted to electric dryers.
6. **What Governments Need to Do:** It is important that the costs of new and retrofitted electric units be comparable with natural gas units, otherwise incentives or rebates must be offered by utilities or governments (or tax credits) to make it easier for home owners and building owners to electrify their homes. At the same time, training programs need to be put in place to educate owners and technicians of contractors on how to install new electric units, or retrofit

older natural gas units. Further, central governments need to put in place industrialization strategies for the volume production of these units.

Electrification of Industry

This is an area that is technically very challenging but needs to be addressed. There are several end-use electrical technologies that are already growth areas that can grow more. These are cryogenics, direct arc melting, induction heating, resistance heating and melting, ultraviolet curing and infrared processing and many other electric technologies.

The Plan for the direct use of Renewables and the electrification of Industry are as follows:

1. The expansion of known technologies and methods for electrification must be made universal. All industries will need to switch to these if they can use them. For this, all the encouragement, incentives and standards will be needed.
2. Locally, all of industry will maximize the use of renewable energy (mainly solar PV) to produce electricity for ALL of their electric needs (existing and expanded).

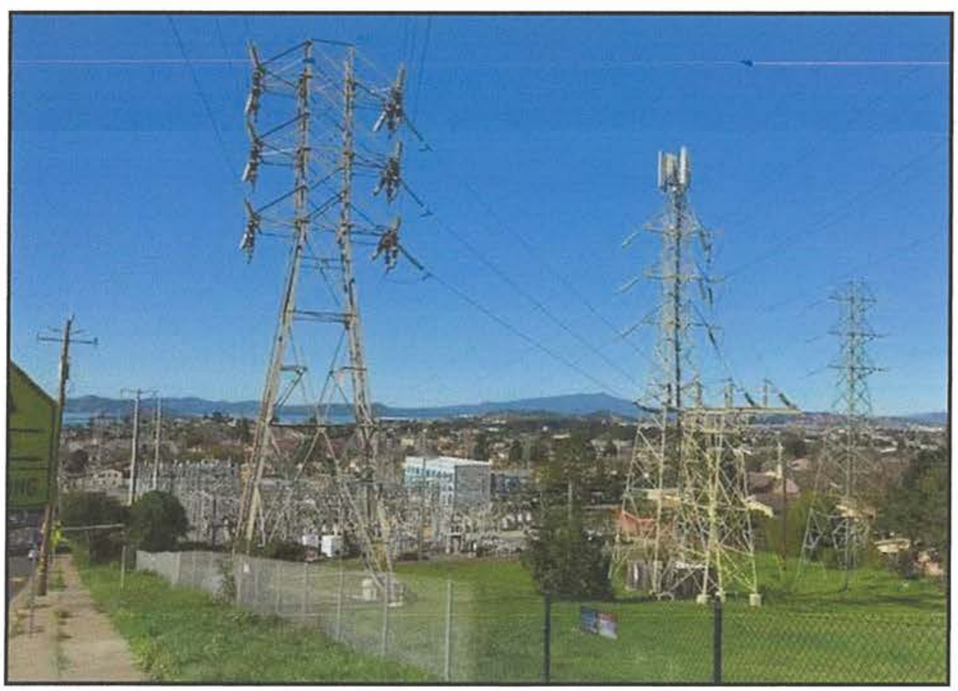


Photo by Author

Electric transmission lines bringing electric energy into the East Bay of San Francisco over the hills.

3. Produce storage fuels on-site – Governments need to help industries and companies with RDD&D on producing green storage fuels on site (or purchasing from elsewhere).
4. Develop end-use technologies that will enable them to substitute coal, oil and natural gas use with the use of either direct electric or the use of storage fuels.
5. The industrial sector will be invested in terms of all of the RDD&D (Research, Development, Demonstration and Deployment) needed for establishing new methods and technologies or improving on existing ones, or furthering either electrification or the use of storage fuels.
6. Improve the energy efficiency and material recycling and re-use efficiency of all industry.
7. Clean manufacturing should mean not only one that supports industrialization for renewable energy but also conversion of ALL existing industry to clean renewable energy and elimination of toxic and hazardous materials.

THE NEEDED EXPANSION AND UPGRADE OF THE GLOBAL ELECTRIC TRANSMISSION SYSTEM

THE ELECTRIC GRID – ENHANCEMENT OF THE SIZE AND SMARTNESS

The Plan calls for a total overhaul and modernization of the entire global electric power system. Electric power needs the supply of storage fuels, renewable energy power generation, transmission and distribution. Plus, modernizing the whole system will need smart and flexible grids that can make the system more efficient (conduct operations with less energy used), a flexible strategy to account for the variability of renewable energy (which only makes electricity when the sun shines or the wind blows, as the case may be), and begin to take account of the strategy of battery storage, as well as the production, storage, transport and use of storage fuels (to regenerate electricity).

Expansion and Enhancement of the Electric Grid

- ❑ Fossil Fuel to Renewable Energy Conversion: As per above, all fossil fuel based electricity generation will be converted to a combination of solar PV (or other renewable energy) plus battery system plus natural gas or storage fuels. If the storage fuels are produced and then used on-site to produce electricity, then no added expansion of transmission lines will be needed.
- ❑ Electrification: To the maximum attention possible, as per the previous section, the global economy will be electrified. For direct electric supply, this will mean a 3 to 5 times expansion of electrical energy and power.
- ❑ **Transmission Grid Expansion:**
  - ❑ Option 1: If the new added renewable energy generation facility is located close to the usage center, or if there is more roof top solar, then only a local increase in the size of the transmission system (together with an interconnection point) will be necessary. This will minimize the cost of the transmission system upgrades and is preferred. Also, this will lead to greater energy democracy in that local entities can own and control these production units.
  - ❑ Option 2: There is an expansion of local community micro-grids that are capable of operating independently (with combined solar PV and battery system), so these can disconnect and operate independently even if the larger grid fails.
  - ❑ Option 3: If the added renewable energy electric power stations are far from the user locations, then a major expansion of the electric transmission system will be needed. This will need greater attention given to grid size, reliability and safety.
  - ❑ All measures will be taken to enhance the smartness of the grid, both in order to manage the variability nature of renewable energy, and also to better manage the supply and demand sides of electric power, so that the use is more efficient and peak power problems are avoided. Smart grid as most people understand it today is where it may have something like automatic turn on

and turn off capability of people's air conditioners, so that on a very hot day, when everyone wants to use air conditioners continuously, the utility company can rotate the turning on and off of air conditioners remotely, so that peak power does not go too high (which currently means turning on added generators to meet peak power – these are called ***peaker power*** plants).

As the overall plan indicates above, the electricity production and the accompanying transmission lines will need to grow 3 to 5 times to meet the needs of added electrification through renewable energy.

The Global Plan for expanding the global electric transmission grid is described on the previous page. Whenever one considers an electrical energy system, there is the generator, the spur transmission (that gets the electricity to the main or bulk transmission line), the Point of Interconnection (POI), that interconnects the spur to the bulk transmission line, and the main or bulk transmission line that carries electric energy far away. "Brownfield" sites are those where an existing power plant is simply being replaced. In such Brownfield cases, where say an existing coal, oil or natural gas generating station is being replaced by a solar PV plus battery generating station, one can use the existing transmission line if enough land is available locally for the solar PV plant. **Hence, in most cases where fossil fuel power plants are being replaced by renewable energy power plants (Brownfield Sites), little or no expansion of the spur transmission grid may be required. However, for grids to work reliably and be resilient, the whole transmission system globally needs to be modernized and upgraded.**

This chapter has covered mainly the energy aspects of the Global Plan. With the almost total replacement of fossil fuels, the high levels of pollution involved with them will be gone, and the carbon dioxide emissions from these will be nearly eliminated. The direct greenhouse gas emissions aspects are dealt with in a later chapter.

Plan for Bioenergy

Bioenergy mainly consists of the generation of electric power by the burning of fuels that are biological in origin. If it relies on crops then these must be grown on non-agricultural land. The increasing use of good farmland to produce ethanol is not a good or sustainable model. Other sources of bioenergy include the use of biomethane fuel from sewage treatment, manure treatment and landfills – either to combust directly or to convert to a fuel like hydrogen. The quantitative Plan is as it appears in the WEO2018 report.

We now turn to what is needed for make our global transportation systems green.

REDUCING THE CARBON FOOTPRINT OF TRANSPORTATION – INCLUDING AVIATION, SHIPPING AND TOURISM

Besides near total electrification, the electric and low carbon modes would be substituted for high carbon modes of transportation: So, mass transit, pedways and bikeways would replace much car traffic, for distances less than say 500 miles (or 800 kilometers) airline traffic would be replaced by high speed rail, and diesel trucks would be replaced by electric, battery-electric and storage fuel trucks.

Shipping – Transitioning Out of Fossil Fuels

When we talk of expanding world trade, all of that leads to more and more goods being shipped by sea and some by air. For goods to be made in one country and shipped all over the world takes a lot of ship travel (and some cargo by air), and as more of that has happened, the carbon emissions from shipping have increased. The more that goods need to be transported over longer distances, the more carbon emissions there are. Until recently, as shipping occurs between nations and did not count in the greenhouse gas emissions of nations, this had escaped attention. It is now important to make sure that we pay attention to this as these ships are emitting carbon dioxide in the ports and in all over their travels over the seas.

For shipping of goods, materials and fuels between nations, there are many ways in which the carbon footprint can be reduced. As a follow-up to the Paris Agreement, one of the committees of the International Maritime Organization (IMO) organized a meeting at which five options were considered: (1) Slow steaming the ships so they travel slowly and avoid unnecessary travel; (2) Improving design of ships like improvements in hull and propeller design, and waste heat recovery; (3) The use of renewable energy like wind power and kite systems; (4) The use of batteries to store excess energy, and the use of shoreside electrical power (powered by solar PV or wind) in ports; and (5) Switch to lower carbon fuels. Also, one of the immediate actions recommended was to begin reducing the use of high sulfur fuel oil that was giving high levels of pollution.

This Book proposes a plan for Shipping as follows:

1. Elimination of the use of high sulfur fuel oil and replacement with low sulfur fuels to begin with.
2. The use of sails and renewable energy kite systems, combined with solar PV technologies to provide energy and propulsion. Flettner Rotors and Kites are two wind based technologies that can considerably cut energy use.
3. The use of hybrid battery and electrical propulsion systems (batteries and motors) to reduce fuel consumption, much like used in cars today.
4. This should be combined with complete switch to electrical power from shoreside when in ports, with all that power being provided by renewable energy (solar PV and wind).
5. Replace all fuel oils and fossil fuels with storage fuels like hydrogen and ammonia, with these fuels being produced onshore using renewable energy (solar, wind and hydro). Ammonia as a fuel would be ideal with liquid ammonia being carried on board, and the use of a combination of internal combustion engine and fuel cell technologies would provide power. This area does need a significant amount of research and development, and hence needs investments in RDD&D. Projects are underway to develop compression ignition engines for ships that burn ammonia.

Research and development of ammonia as shipping fuel and the development of engines that burn ammonia is proceeding well and should be globally supported. The advisable strategy will be to begin with the small measures such as use of electrical power only in ports, and shutting down of engines, and the switch away from high sulfur fuel oil. However, all of the other activities need RDD&D (Research, Development, Demonstration and Deployment), so that the research, demonstration, economics, technologies, equipment, supply of storage fuels, etc. will be worked out in cooperation with the International Maritime Organization (IMO).

Aviation – Transitioning Out of Fossil Fuels

Aviation represents a really big challenge and needs to be tackled effectively. In response to the Paris Agreement, the International Civil Aviation Organization (ICAO) organized a scheme called the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) that aims at reducing the emissions from the expansion in civil aviation from 2019-2035. CORSIA calls for increasing the fuel efficiency of aircraft, new technologies to select more efficient flightpaths and reduce delays, using lower carbon fuels (mainly bio-fuels), and investing in emissions offsets. Of the 73 nations that agreed to initially participate, implementing what they agreed to will cover about 77% of the projected increase in emissions from 2019 to 2035 (Ref: ICAO). There is NO talk of even beginning to address the greenhouse gas emissions that are already being emitted annually. Clearly, a bolder action plan is needed as aviation is a big contributor to greenhouse gas emissions.

The Book Plan for Aviation

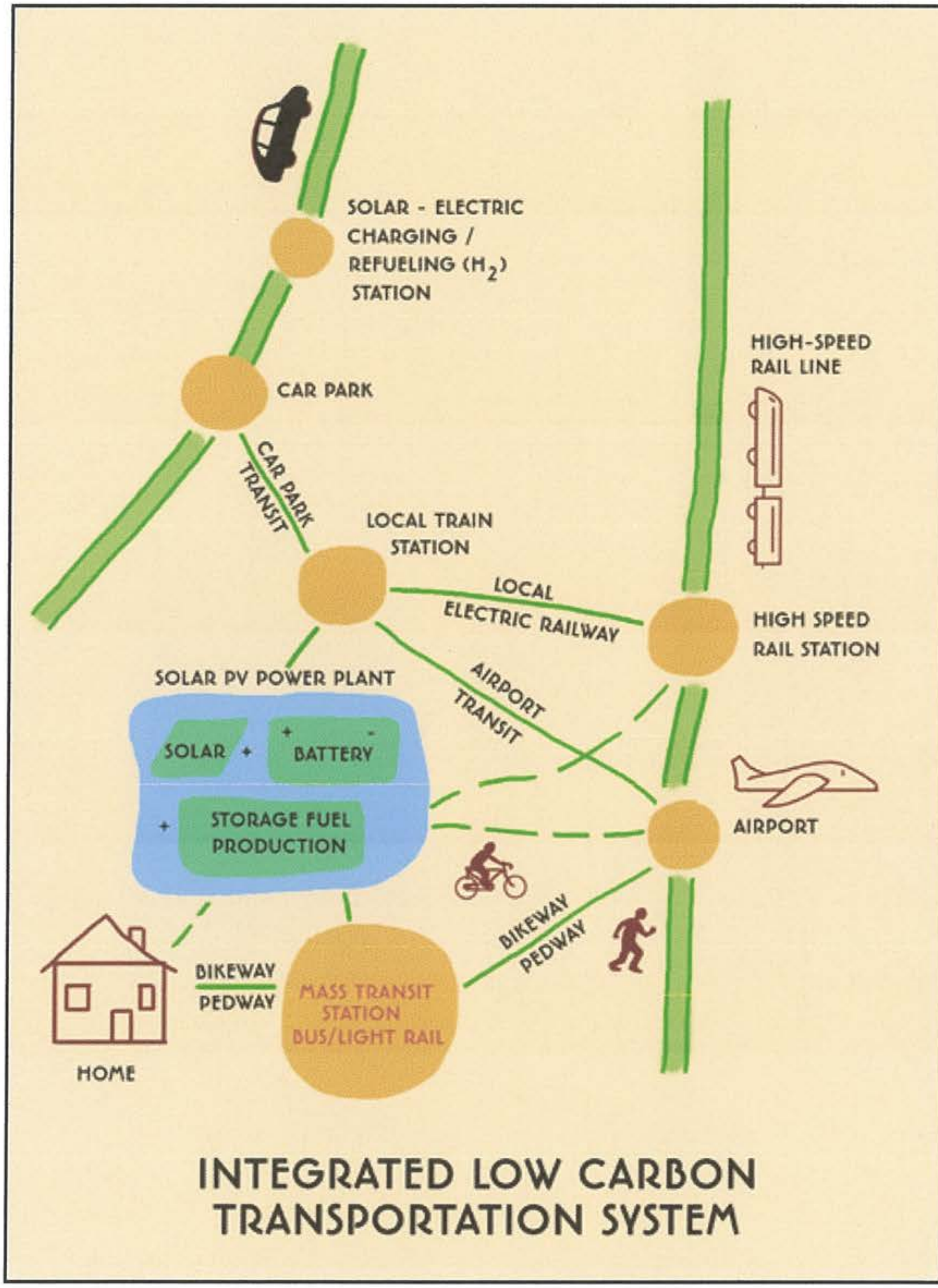
- For ALL areas connected by land, for travel distances less than 200 miles, air travel should be replaced by electrified light rail and medium speed passenger rail powered by solar PV energy, supplemented by battery backup and storage fuels.
- For ALL areas connected by land on the same continents, travel should be switched to electric powered high speed rail supplied mainly by solar PV energy, supplemented by battery backup and storage fuels. For the Americas, this means connecting all the way from the northern tip of North America to the southern tip of South America, one each along the eastern and western shores. For Eurasia, this means high speed rail powered from the western end of Europe, all the way through Russia (for one route), another through China, and another through India and South-east Asia, all the way to Vietnam. Another route will be all the way around Australia.
- High speed stations will be linked to and integrated with medium speed rail, light rail, bus transit, bike and pedestrian travel.
- Aviation will be used only for cross ocean and cross water

travel over long distances, using the above strategy as per CORSIA for ALL aviation emissions. Bio-fuels can only be produced from non-agricultural land and there must be no net deforestation.

- Rather than going to the final destination by air, the air travel will be organized so that the flight ends at the extreme ends of the medium and high speed rail network, and travel from there is by other rail, mass transit and autos either electric or fueled by storage fuels.
- An RDD&D program is needed to develop aircraft engines using storage fuels like ammonia. In the short term, these technologies can use mixed fuels that combine with jet fuel, until technologies are developed that use only storage fuels. Because of the long lead times, laboratory research on this must begin soon.
- Bio-fuels are being developed for jet engines, but care should be taken to ensure that these fuels come from biological sources that do not use fossil fuels.

DEVELOP AN INTERNATIONAL INTEGRATED LOW CARBON TRANSPORTATION SYSTEM

For the people of the world to continue to have a reasonable level of mobility, a transportation plan is proposed for the whole world that will integrate all the modes of low or zero carbon transportation, so that one can travel from one end to the other with little or no carbon emissions! That means starting with pedestrian, bike travel, electrified vehicles, light rail, buses and storage fuel autos, linking with major travel hubs or stations for rail and, only as needed, air travel. Then again, at the other end of a rail terminal or an airport, there will be direct links with all the other zero carbon transportation modes, all powered by solar PV, batteries and storage fuels. Here is a concept for such a system.


SOLAR - ELECTRIC CHARGING / REFUELING (H_2) STATION
HIGH-SPEED RAIL LINE
CAR PARK
CAR PARK TRANSIT
LOCAL TRAIN STATION
LOCAL ELECTRIC RAILWAY
HIGH SPEED RAIL STATION
SOLAR PV POWER PLANT
AIRPORT TRANSIT
SOLAR + BATTERY
+ STORAGE FUEL PRODUCTION
AIRPORT
BIKEWAY PEDWAY
BIKEWAY PEDWAY
MASS TRANSIT STATION BUS/LIGHT RAIL
HOME
INTEGRATED LOW CARBON TRANSPORTATION SYSTEM

CONCEPT OF A LINKED AND INTEGRATED LOW CARBON TRANSPORTATION SYSTEM

This system will enable people to go on a bikeway (or human powered transportation with or without added battery electric power) or pedway (sidewalk of walkway) to a local mass transit station that links to a bus line or a light rail line. This in turn links with a local train station, an airport, a high speed rail station and a car park. The highway or roadway on which battery electric and storage fuel vehicles run has a solar-electric plus battery plus storage fuel refueling station. The whole system is powered by a solar PV plus battery plus storage fuel power plant. This will enable a person to leave the home and go from one system to the other and do all of that safely and emitting very little carbon, with maximum capability of elderly and disabled people to travel on it. Depending on the distances involved, bikeways and pedways can be maximized so that people are able to access all the hubs and park their bikes or trikes there, as needed. The aviation system which uses jet fuel or biofuels can then concentrate on long haul and cross-continental flights. ALL new cities or developments that are established anywhere in the world can begin with this system, making it very easy to implement.

REDUCING THE CARBON FOOTPRINT OF TOURISM

Enjoying nature, architecture, history and fun destinations, and getting away from a severe winter or hot weather are part of the global enjoyment of tourism. People who are rich, and even those of the middle class enjoy getting away for a vacation or for travel to the beautiful places of the world. Even environmental organizations encourage their members to go and enjoy nature. The problem is that all that travel and all of the activities at the destinations lead to a lot of greenhouse gas emissions that are damaging the very beautiful places that they (and we) are visiting. I visited Alaska on a cruise and all but two of the glaciers are fast melting. I visited Leh, Ladakh at the western end of the Himalayas in India, and later the same year the area was devastated by massive rains and mudslides during the monsoon season. I visited the garden isle Kawaii of Hawaii, but it was struck later that year with massive rains, mudslides and isolation of people. Many of the beautiful areas of Europe are being devastated by heavy floods and now heat waves, the like of which they have never known. **Our tourist destinations are fast deteriorating because of Climate Change and may not be worth visiting in the not too distant future.**

A recent study (*The Carbon Footprint of Global Tourism,* Nature – nature Climate Change) looked at the entire carbon footprint of tourism from travel to and within destinations (air and land travel) and all of the other aspects like food, accommodation, fuel, and shopping, and all of the activities that occur in other places in support of tourism. It showed that global tourism expenditures grew from US $2.5 trillion in 2009 to about US $4.7 trillion in 2013, with the greenhouse gas (GHG) footprint increasing from 3.9 to 4.5 Gt-COe (giga tons of carbon dioxide equivalent), or about 8% of all GHG emissions! The US ranks the highest in emissions, followed by China, Germany and India. [16]

So how does one go about making tourism a zero emissions activity? Recognizing that greenhouse emissions are a problem, the United Nations World Tourism Organization (which otherwise promotes increases in tourism), proposed two strategies – to encourage tourists to go to locations closer to home and use more public transportation and less aviation, and to provide incentives for operators to improve their energy and carbon efficiency. Neither of these strategies appear to be working. So here is the Plan.

Proposed Plan to Reduce Emissions from Tourism to very Low Levels

1. The strategies proposed above for road transport and aviation must be adopted for tourist travel – low carbon, electric (energized by renewable energy) and high efficiency.
2. Laws and agreements have to be adopted that minimize aviation travel, requiring that travel distances be minimized and that all travel within nations be by low or zero carbon means. So, travel to Europe should be such as to travel by air only to the closest destination, and that all travel on land areas be by high speed rail, bus, and light rail, or zero carbon highway modes.
3. All local travel within tourist cities must be by electric vehicles, storage fuel vehicles, and all cities of the world must encourage all local travel to be by pedestrian, bike or bus

means. Walking and small electric vehicles, bikes, trikes and quad bikes should become the norm.

4. All food, materials and fuel must be local – locally grown food, locally produced energy (solar PV, wind, geothermal or hydro), and all accommodations must be totally turned into net zero energy establishments. Exotic food from far away locations must be discouraged by all means possible – luxury seafood, beef and meat from distant locations, or gourmet foods from other parts of the globe, must be shamed out of existence.
5. All cruise ships must be converted or replaced by ships that use the plan described in shipping, and must convert to use of storage fuels produced by use of solar PV energy.
6. All island nations that are distant tourist locations must be helped locally to be net zero energy nations, through use of solar PV and wind energy, through water harvesting, and making themselves into nations where only biking, walking or horse/animal buggies are allowed – taxi or hotel electric cars providing transport of people and goods as needed. That this can be a great deal of fun is demonstrated by the Mackinac Island in Michigan USA, where all cars are banned and one reaches there only by ferry. Travel by low carbon cruise ships to these distant island destinations, or by ferry if some mainland is close by, should be encouraged.
7. All tourist travel within nations, or within land masses not separated by sea or water, will be converted to a low carbon mode and aviation travel discouraged through taxes, and incentives for low carbon options – with high and medium speed rail invested in for all land travel.

INVESTMENTS IN ENERGY EFFICIENCY – DOING MORE WITH LESS

The whole economy would become much more efficient through deliberate efforts to increase energy efficiency in energy production and distribution, in homes, in buildings, in transportation and in agriculture, meaning that the same tasks should use much less energy. How do we do this? First let us look at the plans that are already out there that propose energy efficiency improvements.

The International Energy Agency (IEA), as per their WEO2018 report showed that the four areas of the economy where energy efficiency enhancements have already been done from 2000 to 2017 are in transport, industry, residential buildings and services buildings (business, municipal and organizational). Global energy efficiency policies because of extending existing energy efficiency standards to added products led to increases in the coverage of products from about 15% in the year 2000 to about 30-40% in 2017. In its Efficient World Scenario (EWS) the report projects the following energy efficiency improvements: (1) Transport: Road vehicles can use 40% less fuel per passenger mile or per vehicle-kilometers traveled in 2040 than today, and with hybridization and logistics improvements road freight would use 46% less energy per metric ton-kilometer; (2) In Industry, the energy needed to produce per ton of steel, and per unit of pulp and paper would decrease by about 25% mainly due to increased recycling rates and improved energy efficiency – with most of that coming from improvements in electric motors and use of heat pumps; and (3) In residential buildings, each unit of area would consume 26% less energy in 2040 than today, and in non-residential buildings 37% less than today. Their Sustainable Development Scenario (SDS), if adopted by governments would give even larger reductions in energy use.

In 2017, the world spent US $236 billion on energy efficiency, and if current policies are continued, the world will spend $300 billion per year in the 2018-2025 period, increasing to about $500 billion in the 2026-2040 period, with most of this being in the European Union, followed by the US, China and India. California has done an admirable job with energy efficiency also. In their Sustainable Development Scenario (SDS – highest efficiency, WEO2018), the world would need to invest about $500 billion per year in the 2018-2025 period, increasing to about $800 billion in the 2026-2040 period. As can be seen, the increased spending above what is already being planned is not much. As per IRENA (the International Renewable Energy Association) report GET 2018, according to their REMap case, a 40% reduction in carbon dioxide emissions can be achieved by 2050 compared with 2015 through energy efficiency base reductions in energy use.

Energy Savings and Greenhouse Gas Reductions by Switch in Meat Eating and Related Agriculture

There is also a great deal of evidence that overall energy consumption and greenhouse gas emissions will be reduced by a reduction in the production and consumption of meat. Agriculture causes about 25% of all greenhouse gas emissions and about 80% of that comes from animal agriculture. Transitioning to a more plant based or vegan diet is estimated to reduce food related greenhouse gas emissions by about 70%. In terms of land use, about 70% of agricultural land supports livestock farming, and this uses about 30% of all the land of planet Earth.

Livestock farming also generates about 37% of all human related emissions of methane that has 23 times more global warming potential than carbon dioxide. Also, the activities related to livestock farming generate about 64% of ammonia emissions which contribute to acid rain and acidification of ecosystems. Animal agriculture has also contributed the most to tropical deforestation, where 70% of previously forested tropical land has been converted to pastures, and 20% of all pastures have been degraded by livestock overgrazing, compaction and erosion. Switching from a red meat and dairy diet to eating poultry, fish and vegetarian diet has a big effect on reductions in related energy use and greenhouse gas emissions.

Someone who has spoken about this issue is Sailesh Rao who has argued for a switch from meat eating to veganism and the positive effect this will have on Climate Change, although he does take up more fundamental issues regarding our civilization. [17]

Plan for Energy Efficiency – More with Less

This Plan calls for energy efficiency growth or reduction in energy use to be about 14% of energy use by 2030 and about 25% by 2050 of the increased total energy levels. This would save the energy that would normally be consumed by end users, and hence reduce the need for this energy to be supplied. Hence, the same functions would be performed and the same benefits obtained but with less energy.

1. **Mandatory for Anything New:** All new buildings, cars, vehicles, industrial processes, and other activities from now on

must be the highest efficiency that is available at the time. Technologies, research, development, deployment, government energy regulations and company strategies must be aligned to make sure this happens! Any person, company, builder, developer, or organization must be required to meet high mandatory efficiency standards. All nations of the world should provide the incentives, investments and regulations to make sure this happens. From now on, the world cannot afford anything that is energy inefficient!

2. **Minimizing Transmission Losses:** To do this, the renewable energy production must be close to the building or industry – preferably on the property.
3. **Transportation:** All vehicles sold after 2020 must have higher and higher energy efficiency standards. A significant transition of all fossil fuel vehicles initially to plug-in hybridization (meaning smaller fossil fuel engine and larger than normal hybrid battery system). This will mean a more than doubling of fuel efficiency. This needs to be done for ALL vehicles. The second and third stages would be total electrification and the use of storage fuels. Inefficient and fossil fuel vehicles must be mothballed, scrapped, and recycled in a phased manner.
4. **Industry:** Electrification combined with the implementation of energy efficient methods of production that would reduce the energy requirements of all industry – metals, pulp paper, products and cement. This would lead to decreases in energy use of about 25%. All new industrial plants must be required to be net-zero or produce as much energy (by renewables) as they consume.
5. **Buildings and Homes:** Energy audits and total retrofits of residences and buildings will be implemented for existing structures, combined with mandatory high efficiency standards for all new homes, apartment buildings and services buildings. These will include heating ventilation and air conditioning (HVAC – more efficient heating and cooling units), lighting, better insulation, total electrification and use of more efficient appliances. The whole sector would use about 30% less energy by 2050 than today.
6. **New or Modified Cities and Habitats:** All cities must be

designed to be highly efficient, and low carbon, minimizing travel distances, maximizing transit, maximizing areas where people only walk, or bike or use larger human driven or small electric vehicles. First, the scope for stress free walking must be the highest priority, followed by human, electric and solar powered small vehicles. These will then be linked with bus and light rail mass transit stations, and parking lots for larger vehicles. **The concept of small eco-cities is presented in a later chapter.**

7. **The investments needed per year are projected to be about $1,100 billion per year for all three sectors, but this includes the money needed to electrify all three sectors.** This is higher than the $300-500 billion that is currently planned and $500-800 billion per year projected by the International Energy Association in their Sustainable Development Scenario.
8. **Global Reduction in Eating of Red Meat and Dairy Products:** the Plan proposes a phased reduction in the eating of red meat and dairy products of up to 50% globally, which will add to the energy savings of about 10% of total use and greenhouse gas emissions reductions of about 10% also. This will also enable a massive reforestation of the Earth, that will greatly add to the carbon sink capacity of forests, and help revive biodiversity and plant and animal species.

REDUCING THE CARBON FOOTPRINT OF THE GLOBAL MILITARY

Finally, the militaries of the world also need to switch their operations to low carbon modes as Climate Change is already adversely affecting even their operations. This is true of all nations, and so it is in their interest to include military operations in their Climate Change solutions, **otherwise, besides adversely affecting their military operations, after the devastation of Climate Change, their nations may not be worth defending!** Again, each nation needs to come up with zero and low carbon operational modes, so that most of their ongoing military operations (transport, exercises, weapon systems, training, energy use in bases and by troops, etc.) are converted from high carbon fossil fuels to zero or low carbon modes.

In 2018, the world military expenditures rose to $1.82 trillion, about 76% higher than that in 1998. The top spending nations were: US ($649 billion), China ($250 billion), Saudi Arabia ($67.6 billion), India ($66.5 billion), France $63 billion), Russia ($61.4 billion) and the UK ($50 billion) (Figures from the Stockholm International Peace Research Institute). [18] In 2019 the US budget is about $700 billion and in 2020 it is projected to be more than $700 billion. The greenhouse gas emissions of the militaries of these nations are very significant, but seldom come up for scrutiny or discussion. **In 1997, it was requested that military emissions not be covered, and hence they were left out of the Kyoto Protocol. These have also been left out of the Paris Agreement discussions and accounting. But if the Climate Change problem is to be solved, the greenhouse gas emissions by the world's militaries also need to be significantly reduced.**

Also, Climate Change is damaging the locations, efforts and bases of the militaries. The Boston Institute of Brown University has documented its bad effect on the US military (*Pentagon Fuel Use, Climate Change & the Costs of War*, Boston University, June 2019). In 2014, the US Department of Defense (DOD) issued a "Climate Change Adaptation Roadmap" that stressed the importance of adapting to Climate Change. In 2018, DOD reported that the US was already suffering from Climate Change effects in terms of recurrent flooding (53 installations), drought (43 installations), wildfires (36 installations) and desertification (6 installations), and that the effects would worsen over the next 20 years if Climate Change was not solved. The US navy has expressed concerns about the effect of melting permafrost (in the Arctic area – this must be affecting Russian bases as well), and rising sea levels and coastal storms, that can have a bad effect on base infrastructures. The Norfolk Naval Base, Norfolk, Virginia and the Keesler Air Force Base have been badly affected by flooding.

As per the Watson Institute Report the US fuel use had been steadily declining, but was about 1,000 Trillion BTUs (British Thermal Units) for about the last 20 years, and among organizations, the organization that is the single largest user of petroleum is the military. Its fighting vehicles consume fuel at a very high rate, with its 60,000 Humvees consuming about 4-6 miles per gallon of diesel. After a spike during the Afghanistan and Iraq wars, the greenhouse gas emissions have been about 60 million tons per year of CO2e (carbon dioxide equivalent), which was more than the emissions of the Scandinavian nations of Finland, Sweden and Denmark, who emitted about 30-50 million metric tons each per year. Meanwhile, the US military industry emitted about 150 million tons of CO2e per year during its manufacturing operations. [19]

With the US economy and the US military so heavily dependent on oil for its functioning, it has focused its military capabilities a lot in terms of maintaining an assured supply globally and especially to its operational areas. Since domestic US and Canadian petroleum production has increased recently, the vulnerability of US economy to disruptions of oil supply from the middle east has decreased. However, supply lines to its military bases and operations around the world are very vulnerable to attack and disruption. Although the US military has installed solar PV at most of its installations, renewable energy is still only 1% of its total energy use. There is much scope for both the US and the other global militaries to reduce their consumption of fossil fuels. Hence the following plan is recommended for the global military.

Proposed Plan to Reduce Fossil Fuel Use of the Global Military to Very Low Levels

1. Convert all of its vehicles for transport or fighting to the hybrid battery-electric mode, with much smaller engines. Convert the rest to be battery electric vehicles, with solar PV powered charging stations located at all suitable locations.
2. Establish solar PV battery backup plants to power all of its installations for direct energy supply. Initially use backup at nights with natural gas plants, and convert to storage fuel generators as soon as these become available.
3. Establish solar PV plants to produce large quantities of storage fuels like ammonia and transport these to its locations for use by mobile vehicles, or by electric generation plants nearby.
4. Power all of its industry with solar PV plants that are backed up by battery systems.
5. Develop non-carbon storage fuels for its jet aircraft that currently produce such large amounts of greenhouse gas emissions, and develop jet engine designs that maximize the use of these fuels.

The global energy transformation that has been proposed in this chapter covers all aspects of fossil fuel use and how we can transition out of these fuels to the solar and renewable energy age. It is the only way we will be *sure* that carbon emissions from fossil fuels (which are 87% of all emissions) are down far enough to cool our planet. We have to cover everything and leave no stone unturned in order to succeed.

NOTES / REFERENCES

[1] "Storms of My Grandchildren – the Truth about the Coming Climate Catastrophe and Our Last Chance to Save Humanity," James Hansen, Bloomsbury Press, 2009.

[2] IPCC 2018: Summary for Policy Makers In, "Global Warming of 1.5 Degrees C: An IPCC Special Report on the Impacts of Global Warming of 1.5 Degrees C above pre-industrial levels and related global greenhouse gas emissions pathways, in the context of strengthening the global response to the threat of Climate Change, and efforts to eradicate poverty," V. Masson-Delmotte, et al, World Meteorological Organization, Geneva, Switzerland, 32 pp, October, 2018, Intergovernmental Panel on Climate Change. https://www.ipcc.ch/sr15/chapter/spm/.

[3] "World Energy Outlook – 2018," or WEO2018, published by the International Energy Agency, 2019. www.iea.org/weo.

[4] "Global Energy Transformation – Roadmap to 2050," IRENA (2019), International Renewable Energy Association, Abu Dhabi, 2019, www.irena.org

[5] The Solutions Project, https://thesolutionsproject.org

[6] "Drawdown – The Most Comprehensive Plan Ever Proposed to Reverse Global Warming," Edited by Paul Hawken, Penguin Books, 2017.

[7] "Getting to Neutral – Options for Negative Carbon Emissions in California," January, 2020, Lawrence Livermore National Laboratory, LLNL-TR-796100, www.gs.llnl.gov/content/assets/docs/energy/Getting_to_Neutral.pdf

[8] "An Inconvenient Truth – The Planetary Emergency of Global Warming and What We Can do About It," Al Gore, Rodale Books, 2006.

[9] "Fight Global Warming Now – The Handbook for Taking Action in Your Community," Bill McKibben, Holt Paperback, 2007.

[10] Fu, Ran, Timothy Remo, and Robert Margolis, 2018. 2018 Utility-Scale-Photovoltaics-Plus-Energy Storage System Costs Benchmark. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-71714. https://www.nrel.gov/docs/fy19osti/71714.pdf

[11] IPCC, 2011: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared for Working Group III of the Intergovernmental Panel on Climate Change [O. Edenhofer, et al], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1075 pp. (Chapter 7 &9).

[12] "Green hydrogen and the Intermountain Power Project", Presented by the Los Angeles Department of Water and Power (LADWP), Los Angeles, California, USA, 2019. https://www.cpuc.ca.gov/uploadedFiles/CPUC_Website/Content/Utilities_and_Industries/Energy/Energy_Programs/Gas/Natural_Gas_Market/Nov13LADWP.pdf

[13] "Cost and Engineering Study of Puente Power Project Cost Effective PV Solar and Storage Capacity," Dr. Doug Karpa, August 2017, Study for the Clean Coalition. www.cleancoalition.org

[14] "Global Energy Transformation – Roadmap to 2050," International Renewable Energy Agency, IRENA, GET 2018 Report, Abu Dhabi, 2018. www.irena.org/publications.

[15] "How Geothermal Energy Works," December 2014, Union of Concerned Scientists (UCS).https://www.ucsusa.org/resources/how-geothermal-energy-works.

[16] "The Carbon Footprint of Global Tourism", Article in Nature, Climate Change, June 2018, Volume 8, pp. 522-528. www.nature.com/naturecliamtechange.

[17] "Carbon Dharma – The Occupation of Butterflies", Sailesh Rao, A Climate Healers Publication, 2011-2016, www.climatehealers.org.

[18] "World Military Expenditure Grows to $1.8 Trillion in 2018," Stockholm International Peace Research Institute, SIPRI, Press Release, April, 29, 2019. https://www.sipri.org/media/press-release/2019/world-military-expenditure-grows-18-trillion-2018

[19] "Pentagon Fuel Use, Climate Change, and the Costs of War," Neta C. Crawford, Watson Institute, Brown University, June 12, 2019.

[20] "The Global Carbon Budget 1959-2011", Le Quere, C., et al, Earth System Science Data Discussions 5, No. 2, (2012): 1107-1157.

[21] The Bonn Challenge on Forests, Managed by the International Union for the Conservation of Nature, https://www.iucn.org/theme/forests/our-work/forest-landscape-restoration/bonn-challenge.

[22] A Story of Large Commitments yet Limited Progress. New York Declaration on Forests Five-Year Assessment Report." Climate Focus (coordinator and editor). www.forestdeclaration.org

[23] "The Global Tree Restoration Potential," Article, Jean-Francois Bastin, et al, Science Magazine, Volume 365, Issue 6448, pp. 76-79, July 5, 2019. Authors from Crowther lab. https://science.sciencemag.org/content/365/6448/76/tab-pdf.