A journey of a thousand miles…

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September 2020

1. Introduction

A journey of a thousand Chinese miles starts beneath one's feet.

– Literal translation of proverb by Lao Tzu

Today's small steps are important, even in a journey of a million miles by all of the countries in the world. That is where we are with our battle to reverse climate change.

Some of the really big steps we are taking today in this journey include:

- Very low greenhouse gas Electric Generation
- Electric vehicles
- Low-greenhouse gas (GHG) industrial processes
- Putting a real price on GHG emissions
- Training our workers for the above jobs of the future
- Negative Emissions Technologies

I recently posted a two-part paper on these big jobs. This is linked below.

https://energycentral.com/c/ec/tough-love-%E2%80%93-part-1

https://energycentral.com/c/ec/tough-love-%E2%80%93-part-2

But as I was writing the above linked paper, I kept running into much smaller steps we can take in the near-term future that will help carry us into the future, and as Lau Tzu's (translated) words above say, these too are important.

This paper is about low carbon fuels, emergency generation, green / blue hydrogen and development vs. deployment.

2. Low GHG Fuels

It may be necessary to temporarily to accept a lesser evil, but one must never label a necessary evil as good.

— Margaret Mead

Yes Margaret, I am not accepting any of the solutions described in the subsections below as more than temporary, but they are definitely less evil than today's acts. As with many things, as we create this lesser evil today, we should be looking for the future good.

2.1. Natural Gas & LNG

Natural gas (even geologically derived natural gas, a.k.a. methane) is a relatively clean fuel, and low in GHG compared to many alternatives. Burning natural gas for energy results in fewer emissions of nearly all types of air pollutants including carbon dioxide (CO_2) than burning coal or petroleum products to produce an equal amount of energy. *About 117 pounds of carbon dioxide are produced per million British thermal units* (MMBtu of heat produced) *equivalent of natural gas compared with more than 200 pounds of CO_2 per MMBtu of coal and more than 160 pounds per MMBtu of distillate fuel oil.*[1]

Further good news is that once a process uses natural gas, it can be converted to biologically-derived methane (biomethane) with no additional effort. Theoretically the biomass used to create biomethane (through anaerobic fermentation) consumes as much CO_2 from the atmosphere as the biomethane does when you burn it, but in reality you need to look at the whole process of creating, transporting and burning the biomethane and measure process GHG-efficiency to determine the real CO_2 payback.

The bad news is that there is the potential for natural gas leakage into the atmosphere. *Methane is an important greenhouse gas with a global warming potential of 34 compared to CO_2 (potential of 1) over a 100-year period, and 72 over a 20-year period.*[2] *As methane rises into the air, it reacts with the hydroxyl radical to create water vapor and carbon dioxide. The mean lifespan of methane in the atmosphere was estimated at 9.6 years as of 2001; however, increasing emissions of methane over time reduce the concentration of the hydroxyl radical in the atmosphere. With less OH˚ to react with, the lifespan of methane could also increase, resulting in greater concentrations of atmospheric methane.*[3]

I believe, all things considered, it is probably an improvement (reduction in GHG) to convert processes fueled by diesel or coal to natural gas, but only as an interim step, and also after careful evaluation of the specific process in question, including the economics. Although initially conversion to biomethane may not significantly reduce GHG vs. using geologically derived natural gas, I believe further development of biomethane production and transportation processes will reduce GHG. Also reduction of anthropogenic (human caused) methane leakage should be a high priority as long as methane (bio- or geologic-) is used.

2.2. Bio-Diesel Fuel

Another way to deal with existing diesel infrastructure is to use bio-diesel fuel. Per the source referenced here, [4] *Biodiesel is a form of diesel fuel derived from plants or animals and consisting of long-chain fatty acid esters. It is typically made by chemically reacting lipids such as animal fat (tallow), soybean oil, or some other vegetable oil with an alcohol, producing a methyl, ethyl or propyl ester. … bio-diesel is a drop-in biofuel, meaning it is compatible with existing diesel engines and distribution infrastructure. Biodiesel can be used alone or blended with petro-diesel in any proportions…*

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[1] U.S. Energy Information Administration, "Natural gas explained", https://www.eia.gov/energyexplained/natural-gas/natural-gas-and-the-environment.php
[2] Wikipedia article on Methane, https://en.wikipedia.org/wiki/Methane
[3] Wikipedia article on Atmospheric Methane, https://en.wikipedia.org/wiki/Atmospheric_methane
[4] Wikipedia article on "Biodiesel", https://en.wikipedia.org/wiki/Biodiesel

According to the reference at the end of this paragraph, biodiesel from soy oil results, on average, in a 57% reduction in greenhouse gases compared to petroleum diesel, and biodiesel produced from waste grease results in an 86% reduction. [5]

Given adequate supplies, using biodiesel in lieu of diesel is an easy conversion. Especially if we understand that this is only a temporary solution. California has a program to help boost this adaption, and an earlier post on this is described and linked below.

Low Carbon Fuel Standard & Low Emissions Provisions: This post reviews California's Low Carbon Fuel Standard (LCFS), the Zero Emissions Fuel Infrastructure (part of LCFS) and California's Advanced Clean Cars Program.

https://energycentral.com/c/cp/low-carbon-fuel-standard-low-emissions-provisions

2.3. Other Biologically-derived Fuels

There are a wide range of fuels that can be biologically derived. These include ethanol, biomethane, biomass (directly burned), Alcohol to Jet Synthetic Paraffinic Kerosene (bio-based jet fuel) and biopropane. In the future many more of these lower GHG alternatives will be available for fuel and feedstock, and as long as we use these cost-effectively and always look beyond these for lower-still GHG alternatives, these are reasonable *lesser evils*.

3. Emergency Generation

The first thing we do, lets kill all the diesels

- A paraphrase of Shakespeare, Henry VI, Part 2 Act 4, Scene 2

If you will note, we are not discussing vehicular deceased engines here (one of the big steps), but instead those that are widely used for several forms of emergency electric generation. Diesels have been used for this function for well over a century, and today they are reliable and efficient.

They are also a pain in the butt. Of course there are their various emissions, including those of the gas type (like GHG), particulates, and noise. Then there is managing their fuel. Older diesels can only be used for emergency backup plus limited testing in many states.

For utility-scale natural gas fueled generators (mostly combined cycle in my state), when they need to respond to an outage, they need to use emergency generation for black-start power. Yes, large generators need electric power to start.

[5] U, S. EPA's Renewable Fuel Standards Program Regulatory Impact Analysis, February 2010, section 2.6, starting on Pg. 468. Note that this is not an easy document to find or use, but a very useful one that is packed with information. Go through the link below, and then follow the instructions below that. https://www.epa.gov/renewable-fuel-standard-program/renewable-fuel-standard-rfs2-final-rule-additional-resources Scroll down to **Peer Review of Lifecycle Analysis** heading, and under that "Final Regulatory Impact Analysis (PDF)" and click on that. It will bring the document up in the EPA's reader, which really sucks, so download a PDF (right side of reader pane) and use Acrobat or Acrobat Reader.

There are many other facility-types that use back-up diesel generation: data centers, hospitals, military bases and any facility that hosts processes that cannot withstand a power outage.

So, after we have axed all of the emergency generation diesels, what do we replace them with?

Really a baby step is to replace them with natural gas fueled back-up generators. Although these do not have many of the issues that diesel generators do, they do have one that diesels don't. They are relatively small (compared to diesels). The largest natural gas fueled generators can produce power in the low hundreds of kW per gen set. The largest diesel gen sets are over 2 MW. Thus you will need more gen sets for high-load applications. Diesels are probably also more reliable, although this is less of a consideration for emergency backup power than for applications with longer run-times. A positive attribute of the natural gas fueled generators is that they can be used for fill-in power (in addition to backup power) as they have very low emissions. Of course they can also be run using biomethane.

Moving on to the "good" (very low GHG backup generation), although there are other alternatives, this will likely be one of the options below, depending on logistics:

Photovoltaic (PV) Arrays plus a battery energy storage system (BESS): This is currently being used for peaking capacity for utilities, and the only real difference is that the BESS will need to store enough energy to support emergency load through a winter evening plus mitigate minimum daytime solar output for several days.

Fuel-cells (using green hydrogen qualifies as "good", see the next section): This may not be as far in the future as you think. Microsoft is already experimenting with this in one of their data centers.[6]

For the first time, Microsoft has successfully powered a row of data center servers using hydrogen fuel cells for 48 hours, a milestone the company is marking because of its potential to reduce reliance on fossil-fuel consuming generators…

Although Microsoft uses diesel generators as back-up power for data centers on average less than once a year, and only when the grid fails, the company sees other applications for hydrogen fuel cells down the road…

The estimated costs to produce hydrogen fuel cells has fallen 75% since 2018, according to Microsoft. If the trend continues, the company predicts hydrogen fuel cells will be price-competitive with diesel generators.

Microgrid: A microgrid for a facility uses multiple sources of generation plus BESS to provide low power cost and high power availability. Another advantage is that the facility owner can use gradual deployment to maintain current capabilities (like diesel generation), while adding more efficient power generation (like from photovoltaic arrays). This allows a gradual learning curve to help the owner evolve the facility power infrastructure to the most efficient configuration while increasing resiliency. Also note that PV plus BESS is on the development path for a microgrid.

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[6] Monica Nickelsburg, GeekWire, "Microsoft makes hydrogen fuel cell breakthrough in quest to power data centers with renewable energy", July 27, 2020, https://www.geekwire.com/2020/microsoft-makes-hydrogen-fuel-cell-breakthrough-quest-power-data-centers-renewable-energy/

4. Green / Blue Hydrogen & How to Move & Store It

In a post a few weeks ago, I wrote the text below. Since it's reasonably short, I am repeating it rather than sending you to that post.

Ammonia (NH_3) is a potential future hydrogen carrier. However producing ammonia does have a down-side. The most popular industrial process, the Haber-Bosch process, is extremely energy-intensive. This process is shown below:

$$N_2 + 3\ H_2 \rightarrow 2\ NH_3 \quad \Delta H^\circ \text{ (change in enthalpy) is -91.8 kJ/mol}$$

The Haber–Bosch process is a reaction between hydrogen and nitrogen at an elevated temperature (840 °F) and high pressure (1,500 psi). The reaction, which happens in a special pressure vessel, disrupts the conditions required for the reaction, so it must be continually cycled, making it more expensive.[7]

Reasons that ammonia is being considered as a hydrogen carrier include: (1) it has a higher volumetric efficiency than other carriers (even liquid hydrogen), (2) cracking it to liberate the hydrogen does not produce undesirable byproducts (like GHG), (3) the cost of renewable energy has become the least expensive energy and its price continues to decrease (making the cost of making and cracking ammonia less expensive) and (4) under some conditions ammonia can be directly combusted (thus used in combustion turbines) or used in fuel cells, with only water vapor and nitrogen as byproducts.

Since it's an element, other than different isotopes (which we are not considering here), hydrogen is hydrogen is hydrogen. However there are considerations of how it's produced including any undesirable byproducts (read: GHG). A large majority of hydrogen used in industrial processes (like making ammonia) is produced by reforming natural gas, but this produces CO_2 (I've seen this referred to as gray hydrogen). The common term for hydrogen produced by electrolysis (no GHG) powered by renewable electricity (very low GHG) is green hydrogen. Hydrogen produced by reforming natural gas with CO_2 capture and sequestration is commonly called blue hydrogen.

So the lesser evil is using gray hydrogen, and the path to good includes blue hydrogen, green hydrogen and possibly ammonia as a transport / storage method.

5. Development vs. Deployment

A major step forward for any new or improved product requires a development process. Near the end of this process are the pilots, where initial products are deployed into their markets for final testing and fine-tuning. Pilots are important, but they do not need to be economically efficient. When products are actually deployed en masse into the market-place they do need to be economically efficient. This is not a tutorial on product management, so I will leave it at that.

One other thing. When a product has societal benefits government may choose to support a product through one of several mechanisms. This was done very effectively with renewable electric generation and electric vehicles through tax credits and other subsidies. Other mechanisms having the same effects are mandates (like renewable portfolio standards).

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[7] Wikipedia article on Ammonia, https://en.wikipedia.org/wiki/Ammonia