A 'Fusion' of Thoughts

The Calgary Herald published the following letter to the Editor on Tuesday 27 Dec 2022 from Daryl O'dowd, Industrial Meteorologist, strongly hinting of skepticism about Fusion Energy. In view of the recent Fusion Energy news release, his letter prompted thought about nuclear fusion and how people can view it as a disruptor in the power generation world. While it does appear a bit sarcastic, he makes points that could run counter to more reasonable or conventional views of the technology presented to the world. Following, in view of the letter, is a summary of information from a variety of sources in attempt to show that all that is "nuclear" or "electric" is not always bad.

> **Merits and flaws of energy sources**
> Re: Innovation suggests the fusion age is near, Dec. 27
> While heartened by fusion advances, success may simply open another Pandora's box of climate change challenges. Widely available and cheap energy — historically oil and gas, and maybe soon fusion — will be snapped up, used and overused. The key waste of our Industrial Revolution machines — and humans themselves — is heat. Cheap energy will let us have more light bulbs, water heaters, electric cars and smelters.
> Imagine Rankin Inlet having a year-round outdoor swimming pool thanks to cheap local fusion. All of that extra heat has to go somewhere, and instead of the sun warming us from above through CO2 and the greenhouse effect, we'll be cooking ourselves from below.
> Be careful what we wish for. Mr. Fusion may not be the answer.
> Daryl O'dowd, industrial meteorologist, Calgary

Upon first reading of this letter, it looked entirely satirical as his words imply fusion is still a distant technology, but fusion research has been going on since the mid 1940s, so it is not "new". The processes have changed as researchers learned more about the technology and although there is work to do yet, the world will see more innovation in this field as we strive to provide a stable and clean source of energy in the form of electrical power.

The Reality

There is about 25 kg of tritium available in the world today and not being an abundant natural material, most of it is made in Canada by extraction from 19 deuterium cooled CANDU nuclear reactors. Only trace amounts of tritium exist in the high atmosphere from Cosmic Radiation bombardment of nitrogen, and it is essentially not retrievable. Having a half life of 12.33 years means that if it is to be used as a fuel, it must be continuously created to ensure supply. The CANDU reactors each produce about 0.5 kg/yr (0.2 kg of tritium/yr/GW) and half of them are scheduled for retirement by 2030 since many of them are at least fifty years old or more. There are an additional 10 CANDU units in other countries but tritium supply from them is not guaranteed. The US military has access to a limited supply of Tritium made available from two nuclear reactors in Florida where lithium control rods have been used to replace the boron rods. The lithium rods are removed to extract tritium produced in the reaction and they are eventually replaced. Further innovation in coming years can help mitigate the need for larger quantities of tritium, a rare but required material. The engineering details to support fusion reactors are monumental. From an economic viewpoint, tritium sells for USD $30,000 per gram whereas deuterium, the other necessary material for fusion sells for USD $13 per gram as it is so plentiful in seawater which contains about one molecule of deuterium for every 5,000 atoms.

In 1984, the JET (Joint European Torus) project was designed to study fusion in conditions approaching those needed for a power plant. Since tritium is so rare, having a means to further create it in breeder reactors is a benefit. In the absence of additional tritium production, the world supply of tritium will continue to decline as additional fusion reactors are built (China, South Korea, USA, etc.). The EU has a planned successor to ITER, called 'DEMO', meant to be a working plant perhaps 50% larger than ITER and delivering 500 MW of electricity to the grid. These reactors are expected to burn about 1% of the tritium injected into them although much larger volumes are needed to initiate the reaction. Most of the tritium will be removed in operation and fed back into the reactor, but it is important to have designs that require small(er) amounts of tritium in total. Various reactor designs will use tritium differently and may not require as much as earlier research models. Some designs may include neutron multipliers, a material that incorporates lithium and beryllium or lead for example in 'blankets' that line the walls of the reactor. High energy neutrons from the fusion reaction can split Lithium into Helium and tritium in metal wall lined reactors. The ITER project (meaning "the way" in Latin) does not plan to use a lithium blanket or interior lithium wall liner which allows more free neutrons to be produced. Although demand for lithium for EV battery production is high, lithium is relatively plentiful.

Construction is currently underway on the ITER Tokomak scientific installation in Saint Paul-lez-Durance, France. The Tokomak unit will be a test site for tritium-breeding, but this still does not produce large amounts of tritium that will be needed in future years. The ITER Tokamak fusion reactor itself, now nearing completion of construction, is expected to consume about one kilogram of tritium each year. The reactor, once operational in 2035, after a ten year 'ramp-up' following first plasma in 2025, is expected to product 500 MW of fusion power from 50 MW of input heating power. This is a ten times multiplier (or 'Q' factor) and is a target rate for the system. The ITER Tokomak system, planned to operate at 150 million degrees Celsius, will be an ideal test site for the many other aspects of nuclear fusion as well as refinement of operational processes needed before units like it could be used to produce commercial electrical power.

Many other fusion test sites such as the recent "NIF" announcement at the US National Ignition Facility located at the Lawrence Livermore National Laboratory in California, have taken a different approach to the toroidal plasma approach. Laser ignition of fuel pellets and other techniques are equally promising. Some sites and plan to use hydrogen and boron instead of tritium although this approach would require operational temperatures very much greater than that required for tritium fusion reactors.

Energy Use

Fusion energy will not be on our doorstep tomorrow but will take well into the latter part of the century to be pervasive enough to be considered in the same way we view electrical power from any other source available to us today. We can't drop everything and look towards fusion as the panacea to our global power needs, but it will become a major player as we move close to the end of the century.

Electricity, the energy from a fusion plant, is no different than that produced by any other means except the process produces no GHGs and places no danger of radiation on humanity. It requires distribution infrastructure as does power from Solar, Wind, Hydro, Biomass, Geothermal, Gas, Coal, Gas, Nuclear (fission) plants & SMRs, Hydrogen production, etc. The land use required by solar, and wind is large and such generation facilities are generally located away from populated areas. This means the electrical distribution network must be expanded to include the capability to bring the electrical energy produced to where it will be used. Some forms of energy are ideal for addressing not only power generation but for addressing the needs of localized heating for steelmaking, cement making, glass, and other heat-intense (>500 C) processes. Admittedly, electric arc furnaces have been used for years in steelmaking. Electric resistance heating is used for aluminum smelting and electricity is in common use for other high temperature material processing. In today's primarily industrial demand for energy, about half the energy requirements needed by those processes that do not require heat more than 400 C, can be supplied from electricity alone or in a hybrid combination with another non-electrical source. Metallurgical and ceramic processes require high heat that can not be directly provided by electrical sources although much of these have possible options to address their energy needs. The heat from fusion reactors for example, like that from existing fission reactors, would be used to generate steam to drive turbines that would produce electricity and not be considered as a 'local' high heat source for such industries.

Delivery

As noted, nuclear fusion generation plants can be located 'within' or near the social infrastructure without the stigma that other forms of energy generation installations have. This is all good but the implementation over time of nuclear fusion sites will take several decades before any reasonable augmentation or replacement of current day installed power sources and those being implemented and planned can be considered even in the most industrialized countries.

The use of 'mobile' energy for transportation poses many conditions on energy from electricity alone, including the use of batteries, hydrogen cells, etc. Current day use of fossil fuel products to power aircraft, shipping vessels, etc. is well served by high energy density fuels (e.g., selected fossil fuels) that can be transported and used at site. Hydrogen cell powered locomotives are being tested (and used) as the 'fuel' can be easily transported and used in transportation.

Some parts of the world may not have even the minimum climate to support the accelerated implementation of solar and wind power we see today. This raises interesting questions as many of these countries may be ideal candidates for fusion energy but not for solar or wind.

The advent of **Electric Vehicles**, let alone the front and back end environmental concerns, will place an additional load on electrical grids. Battery technology improvement will help but further enhancements will be needed to reduce the energy demand envisioned by more of these vehicles on the road. The existing grid in the typical residential neighbourhood is not capable of supporting an EV in every driveway. This problem would need to be addressed on a national basis as well, regardless of how many charging stations private enterprise plans to install or is installing today across the country. This applies to most industrial nations where large expanse geography is common and perhaps not so much an issue within smaller area countries.

Geopolitical concerns also have a potential impact on power sources in general, but this has always been of concern, more so in some parts of the world than others. This concern will not change much as fusion power matures and expands but fusion generation power plants could more easily be built in more places. An envisioned need for security at fusion plants would be no different than that for fission energy plants except we could consider more fusion energy plants and therefore a need for more security.

Economic considerations will play a large role but, while electrical distribution networks costs can become lower with the installation of multiple fusion plants in future decades, there are other potential costs. As fusion plants are built in years to come, the technology they use will be of importance with respect to their cost of operation. Tritium, as a major fuel, would be more costly unless it was more easily produced. The CANDU reactors mentioned above will be phased out as they age and today provide at least some amount of tritium.

In addition to a move to a more 'electrified' world, a large part of the currently installed base of gas & oil heating systems, in-building wiring, infrastructure wiring, etc. will need to be replaced of time.

Public Education will be an important part of the fusion energy program. Some political and ideological views to innovation, strengthened by an unclear or incorrect understanding of the technology can present an unnecessary barrier to progress. The NIMBY (Not In My Back Yard) theme could play a big part in moving forward with fusion energy that will benefit even the naysayers in society. There needs to be a concerted effort made to counter sources of misinformation so more support of initiatives designed to provide cleaner energy can be promoted.

The **rest of the world** where prosperity and investment are not so prevalent could benefit from clean energy but the participation cost if considering fusion energy might be too high a price to pay. We must do more work on the non-nuclear energy sources and find ways to create those energy producing systems that do not contribute to ecological pollution. Both efforts need to be conducted in parallel as the more industrialized nations are the ones that can solve these problems and they can help the less affluent parts of the world enjoy a more satisfying life. **Political strife**, although not a part of the solution, is a large part of the problem in many countries of the world and cannot be seen as an impediment to progress.

The move forward, in recent notes from Eric Newell, is best done by a more controlled transition from oil & gas to the 'appropriate' energy sources for the future. The migration or conversion to cleaner fuels (e.g., LNG in the near term) from the use of coal-fired power generation facilities is something that should accelerate. This is one way we can reduce the GHGs we now put into the atmosphere while we continue moving forward with fusion and while we plan a more rational approach to the use of other power generation systems such as wind and solar. The continued use of fossil fuels in the near term will be needed as the transition to cleaner energy accelerates. Ongoing research can have a large positive impact on the slow transition from coal-fired electricity production by providing cleaner ways to operate. This will be necessary as the overall clean technology makes further inroads in the world.

Again, as Eric Newell noted, a step change from coal-fired power generation to renewable energy is not reasonable in addition to it being a gross misuse of resources, both financial and material. Hydrogen fuel will help the need for mobile energy but could play a key role in furthering the need for the current ancillary products to those that we burn for energy. We need a **Passive Disruption** approach over the coming decades where we would make certain changes sooner than others, to ensure a future secured with cleaner energy.

As a final comment, we are already witnessing the reversal of premature decisions such as Germany's restarting coal generation plants and removing wind turbines to allow access to more coal. The assumed replacement of nuclear plants with energy generated from wind and solar, including smaller contributory sources, without the obvious thought of a backup source of energy, is also not well planned. The perceived blind ideological moves that we know we will need to redo or reverse in the future should be re-evaluated on scientific and economic viewpoints. The "two steps forward, one step back" approach needs to be more unidirectional. A scientific approach makes things work but this often is found to conflict with political decisions or those based upon ideology alone. If we can develop a plan to make things better, we can arrive at the cleaner future we all want sooner than otherwise possible.