FOREWORD

Breaking free of our collective addiction to fossil fuels is of paramount importance, not only because greenhouse gas emissions are pushing the planet to the brink of climate catastrophe, but also because fossil-fuel based energy sources deployed in rural areas of low- and middle-income countries transfer local cash out of the region. Further development of fossil fuel resources works to ensure that the huge energy wealth inequity present in the world prevails.

Amongst the United Nations' goals for global sustainable development is Goal #7: Affordable and Clean Energy. This goal focuses specifically on ensuring access to affordable, reliable, sustainable and modern energy for all. Yet today one billion people have no electricity and two billion rely on open fires for cooking and heating. Many more people have only enough electricity to light one or two bulbs for a few hours a day and perhaps charge a cell phone, but nothing more. Communities impacted by unreliable and intermittent supplies of electricity in insufficient quantities are held back in attaining other United Nations sustainability goals including no poverty, zero hunger, good health and well-being, and clean water and sanitation. This is no small problem, as electrification of rural areas of low- and middle-income countries where poverty, hunger and disease are disproportionately present without vastly increasing fossil fuel consumption and greenhouse gas emissions is one of the greatest challenges of this century.

Heat energy is produced in Earth by radioactive decay of unstable elements, and populations in areas with high geothermal gradients like Iceland can tap into this supply of plentiful sustainable energy. Vast amounts of energy are tied up in unstable atomic nuclei and this energy can be liberated and harnessed by nuclear reactions in which mass is converted to energy according to Einstein's theory of special relativity. The tremendous amounts of liberated heat can be used to do useful work, including generating easily transported and stored electricity, or in propulsion systems. There is sufficient fuel for these reactors to be viewed as sustainable for thousands of years. To do this currently, massive and expensive facilities must be constructed, and are mostly out of reach for low- and middle-income countries. It is essential that high-income countries continue to develop nuclear power as an alternative to fossil fuels, as many experts argue this is the only way to significantly reduce greenhouse gas emissions on a time-scale that will perhaps change the severity of climate change. Development of small modular nuclear reactors that are cheaper to produce in larger numbers and deployable where needed is also an essential

component of the energy mix of the foreseeable future.

Much of the alternative energy that humanity can utilize without the expense of building nuclear power plants was produced by nuclear reactions in the Sun. Solar radiation striking photovoltaic cells here on Earth produces electricity and concentrating solar facilities store heat for electricity generation even when there is no sunlight. Life gathers solar energy and stores it in chemical bonds by photosynthesis that can produce biofuels, the hydrologic cycle moves water from the oceans to the mountains where it flows back again and can provide hydroelectric power, and weather patterns produce atmospheric pressure differences manifested in wind that can drive turbines. If we are satisfied with harvesting energy from solar radiation that is currently reaching Earth, or that has arrived only relatively recently (and is stored in the hydrologic cycle or biofuels, for example), the energy is sustainable until the Sun burns out. But when we go after solar energy that has been stored in chemical bonds for millions of years, sustainability is lost because fossil fuels are in limited supply and burning them causes irreversible damage to the environment.

Plants have been using photosynthesis to collect energy arriving as solar radiation in the form of chemical bonds for hundreds of millions of years. These bonds are in compounds built from carbon that plants harvested from the atmosphere, also over many millions of years. Geologic processes sometimes convert plants through application of time, pressure, and heat into fossil fuels such as coal, oil, and natural gas. We have been dependent on these warehouses full of ancient solar energy for far too long.

Burning fossil fuels provided the energy to propel the Industrial Revolution and still is the source of the lion's share of energy consumed in the world. China, United States, India, Russia, and Japan are the five countries that consume the most energy (in order of decreasing consumption). The breakdown worldwide of primary energy consumption by source is 34% oil, 27% coal, 24% natural gas, 7% hydro, 4% nuclear, and 4% other (including wind and solar). Eighty-five percent of energy consumed in 2018 was produced by combustion of fossil fuels. Doing this combines carbon and oxygen and liberates relatively modest amounts of energy stored in chemical bonds millions of years ago. It also releases vast quantities of carbon dioxide gas (and various other combustion products) into the atmosphere. Accumulation of these greenhouse gases in the atmosphere has upset Earth's energy balance because they absorb energy radiated from the planet as if they were a warm blanket. We are now entering the unchartered territory of anthropogenically-driven climate change that is directly attributable to combustion of fossil fuels, and many scientists predict the outcome will be

catastrophic.

The inaugural volume of JET kicks off with a focus on Alternative Energy. In other words, energy alternatives to combustion of fossil fuels. Alternatives to the primitive processes of combusting fossil fuels and exhausting gases to the atmosphere. Alternatives that not only are deployable in high-income nations, but also for the most energy-marginalized people of low- and middle-income countries.

Although barriers to wide-scale deployment of alternative energy sources include technical challenges, society's self-imposed hurdles are even more problematic. These include policies favoring the fossil fuel industry through regulations, incentives, and subsidies. They include the common approach of using expensive and difficult-to-maintain imported equipment and fuels to install unsustainable energy systems in low- and middle-income countries. The energy systems themselves are unsustainable because of cost and technical requirements, even if the energy source is sustainable (i.e. microhydro, solar, etc.). It is essential to develop training and production centers in the low- and middle-income countries to achieve sustainability of local energy production. Other hurdles include the unwillingness to impose a greater cost on consumption of greenhouse emitting energy sources, such as a carbon tax and the prohibitive cost of new nuclear power plants due in part to regulatory barriers and society's inability of solving the technically manageable but politically toxic issue of permanent management of nuclear waste.

There is still much work to do to ensure access to affordable, reliable, sustainable, and modern energy for all. Yet I believe we have made substantial progress in gaining a global understanding that by using alternative energy sources, we will be able to curb global warming and preserve Earth's resources. The hurdle of economic gain and political acceptance still remains a challenge. At the Center for Sustainable Energy at Notre Dame (ND Energy), we engage with faculty and associated researchers on these very issues and work to advance new technologies and energy systems in the hope of addressing these challenges and helping to attain the United Nations' goal for affordable and clean energy. I am encouraged that the inaugural volume of the Notre Dame Journal on Emerging Technologies will do more to further this discussion.

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