ENERGY SUSTAINABILITY: A CRITICAL NEED FOR SUSTAINABLE DEVELOPMENT

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ONTARIO CENTRE FOR ENGINEERING AND PUBLIC POLICY

ENERGY SUSTAINABILITY is increasingly becoming an imperative, regionally and globally, given the pervasive use of energy resources and their impacts on the environment. Energy is directly linked to the broader concept of sustainability, since energy resources, whether carbon based or renewable, are obtained from the environment, wastes from energy processes are typically released to the environment, and the services provided by energy often support good living standards, social stability and cultural and social development. Energy sustainability is more comprehensive than simply sustainable energy sources, as it involves sustainable energy use in the overall energy system, which includes technologies for harnessing energy sources, converting them to useful energy forms, and energy transport, storage and utilization. Given the close ties between energy and sustainability, energy sustainability is being increasingly recognized as a critical aspect of sustainable development.

Sustainable development is increasingly sought and has been defined in many ways. The United Nations World Commission on Environment and Development in 1987 defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Overall, sustainability is often considered to have three distinct components, in each of which energy factors: environmental, economic and social. Achieving a balance among these factors is challenging, since they often imply different directions; for example, economic sustainability may be achieved at the expense of environmental and social sustainability. No widely accepted definition exists for energy sustainability, but I contend that energy sustainability involves providing energy services in a sustainable manner, which in turn necessitates that energy services be provided for all people in ways that, now and in the future, are sufficient to provide basic necessities, affordable, not detrimental to the environment, and acceptable to communities and people.

KEY FACTORS FOR ENERGY SUSTAINABILITY

I have previously put forward several distinct components to the manner in which energy resources can be used sustainably in society, each of which is a requirement for energy sustainability:

1. **Harness sustainable energy sources.** Requirements for energy services need to be satisfied and sustainable energy sources need to supply them. This is particularly challenging since use of energy resources increases with increasing population and living standards, especially as developing countries become more industrialized and affluent. Many non-renewable and renewable energy sources exist. Fossil fuels are non-renewable, as are other sources like uranium, although nuclear fuel lifetimes ultimately depend on the development of advanced nuclear technologies like breeder reactors. Renewable energy includes solar radiation incident on the Earth, and energy forms that result from that radiation (e.g. hydraulic, wind, biomass, ocean thermal, and hot and ambient geothermal energy), as well as energy from such other natural forces as gravitation and the rotation of the Earth (e.g. tidal and wave energy). Non-fossil fuel energy options reduce or eliminate greenhouse gas emissions and thus often facilitate sustainable energy solutions, although some, like biomass, can lead to net emissions if not managed carefully.
2. **Utilize sustainable energy carriers.** The use of sustainable energy carriers usually implies the conversion of sustainable energy sources into appropriate energy carriers. The range of energy carriers is diverse. Material energy carriers include secondary chemical fuels, ranging from such conventional ones as oil products (e.g. gasoline, diesel fuel, naphtha), coal products (e.g. coke) and synthetic gaseous fuels (e.g. coal gasification products) to non-conventional chemical fuels like hydrogen, methanol and ammonia. Thermal energy can be either heat (or a heated medium such as hot air, steam and exhaust gases) or cold (or a cooled medium such as cold brine and ice), and can be transported via district energy systems. Hydrogen energy systems are considered particularly important as they facilitate the use of non-fossil

fuels by allowing them to be converted to two main classes of energy carriers: hydrogen and electricity. A key part of a hydrogen economy is hydrogen production, which can make use of sustainable or non-sustainable resources. Energy carriers in general are an important consideration in energy sustainability because conventional and non-fossil fuel energy options are not sufficient for avoiding environmental issues such as climate change, in that they are not necessarily readily useable in their natural forms. Conversion systems are often needed to render non-fossil fuel energy more conveniently useable.

3. **Increase efficiency.** High efficiency allows the greatest benefits to be attained from energy options and reduces environmental intrusions, thus aiding sustainability efforts. Efficiency improvements also include energy conservation, fuel substitution, improved energy management, better matching of energy carriers and demands, and more efficient use of energy quality. Many efficiency improvements are best considered with exergy, a measure of energy quality or usefulness that stems from the second law of thermodynamics. Exergy analysis can reveal by how much it is possible to design more efficient systems by reducing inefficiencies and, via its links to economics, environment and ecology, greatly assists sustainability efforts.
4. **Reduce environmental impact.** Numerous environmental impacts associated with energy processes are of concern and must be addressed in efforts to attain energy sustainability, including climate change, atmospheric ozone depletion, acidification of ground and water, abiotic resource depletion due to the extraction of non-renewable raw materials, and ecotoxicity. Climate change is viewed by many as the most urgent environmental impact facing humanity. Mitigating climate change requires non-fossil fuel energy options, in that they avoid or greatly reduce emissions of greenhouse gases, particularly carbon dioxide, which is an inherent product of the combustion of any carbon-containing fuel. An Earth-sun-space energy balance (see Fig. 1) indicates that most of the energy entering the Earth's atmosphere with solar radiation eventually exits back to space as heat. Global warming disrupts this balance, causing the mean temperature of the Earth to increase. Non-fossil fuel energy sources can provide a foundation for the supply of sustainable energy services, which are a requisite for energy sustainability and sustainable development. To comprehensively address energy-related environmental impacts, the entire life cycle of a product or process must be considered (see Fig. 2).
5. **Address related socio-economic factors.** Many socio-economic sustainability factors relate to energy, and consequently need to be considered in approaches to energy sustainability. These factors often are linked to the previously described sustainability approaches, for example, harnessing sustainable energy sources must account for economics, global stability and geographic and intergenerational equity to maintain a sustainability focus. Some energy-related, socio-economic sustainability factors include social acceptability, economic affordability, equity, lifestyle, land use and aesthetics. All societies need to be able to access energy resources, regardless of geographic location, to achieve energy sustainability, and future generations also must be able to access energy resources. The use of land for energy-related activities must be balanced with other needs, such as agriculture and recreation. Modifying lifestyles and tempering desires that are energy driven can contribute to energy sustainability, although this is difficult given the continually increasing aspirations of people. Community involvement is also important, and a culture of sustainability can evolve when a consultative and collaborative approach is consistently followed.

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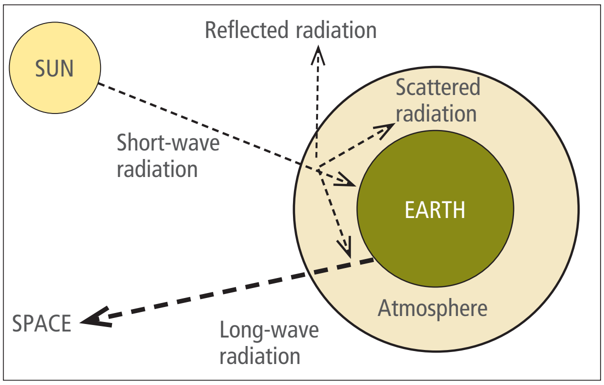
Fig. 1. Energy balance between the Earth, the sun and outer space



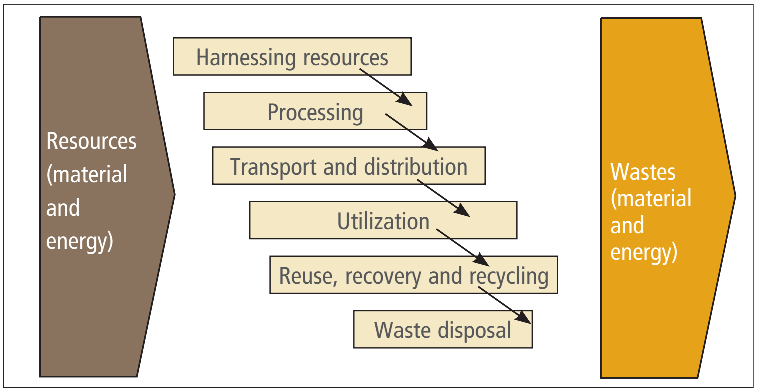


Fig. 2. Life-cycle assessment of a product or process, highlighting steps in life cycle

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A POSSIBLE PATHWAY TO ENERGY SUSTAINABILITY

A possible pathway to energy sustainability is described based on a utility-scale application of cogeneration, which is the simultaneous production of thermal and electrical energy, typically using significantly less energy resources than required to produce the same thermal and electrical products in separate processes. Approximately 25 per cent to 50 per cent of the heat from a thermal power plant is converted to electricity, with the remainder rejected as waste to the environment. Cogeneration systems are similar to thermal power plants, but some of the generated heat is delivered as a product in such forms as steam or hot water, usually with a sacrifice in electricity production. In steam turbine-based cogeneration, overall cogeneration efficiencies, based on both the electrical and thermal energy products, of over 80 per cent can be achieved.

Several heat demands can normally be satisfied through cogeneration: residential, commercial and institutional processes (e.g. space and water heating), which require large quantities of heat at relatively low temperatures, and industrial processes (e.g. chemical; petrochemical and metal processing; fertilizer and cement production; manufacturing and construction; and pulp and paper processing), which require heat at a wide range of temperatures for processes like drying, heating and boiling.

ILLUSTRATION OF A PATHWAY

An examination of two penetration scenarios for utility-scale cogeneration in Ontario yields several important provincial and utility-sector results (see Table 1). For the region, electricity consumption decreases by between 5 per cent for low penetration of utility-based cogeneration and 30 per cent for high penetration, thereby permitting regional electrical generation to decrease correspondingly, and emissions of carbon dioxide to decrease by 4 per cent to 15 per cent, demonstrating that utility-based cogeneration can contribute significantly to mitigating climate change. For the electrical-utility sector, utility-based cogeneration permits reductions of 20 per cent to 40 per cent in coal use and coal-related emissions, 7 per cent to 35 per cent in uranium use and related emissions, and 20 per cent to 40 per cent in carbon dioxide emissions. Although based on a past version of the province's utility system, the results are qualitatively applicable today and suggest that electrical utility-based cogeneration in a region could be beneficial, confirming that cogeneration can contribute to sustainability by improving efficiency and thereby reducing environmental impact. The benefits could be enhanced if trigeneration, an expanded form of cogeneration in which electricity, heat and cold are simultaneously produced, were implemented using absorption chillers for space cooling.

Degree of cogeneration penetration	Regional parameters		Electrical-utility sector parameters		
	Electricity consumption	CO_2 emissions	Coal use	Uranium use	CO_2 emissions
Low	5	4	20	7	20
High	30	15	40	35	40

Table 1. Percentage reductions in key parameters for Ontario and its electrical-utility sector with cogeneration

POTENTIAL CONTRIBUTIONS TO ENERGY SUSTAINABILITY OF THE PATHWAY CONSIDERED

Some of the contributions of the pathway considered to energy sustainability, in terms of the factors described herein, follow:

- Sustainable energy sources–cogeneration allows for the use of sustainable energy sources and enhances energy-resource flexibility;
- Sustainable energy carriers–cogeneration produces heat and electricity, appropriate energy carriers for the corresponding energy demands, enhancing energy sustainability;
- Efficiency–cogeneration greatly improves the efficiency with which energy resources are used and energy services are provided, allowing electricity and thermal energy to be produced with 10 per cent to 40 per cent less energy resources than would be required via separate processes;
- Environmental impact–cogeneration reduces resource use and environmental emissions, thereby enhancing energy sustainability; and
- Socio-economic acceptability–cogeneration assists in attaining sustainability by enhancing many socio-economic factors, for example, economic competitiveness and improved affordability of energy services, and environmental stewardship.

SUMMARY

Key factors for achieving energy sustainability are described and a possible pathway to energy sustainability, which can contribute to facilitating a broader societal shift toward overall sustainability, is illustrated. The discussions are applicable in Ontario and beyond, given local, regional and global concerns over energy use, its environmental impact, its importance in economic development and living standards. An engineering perspective is often taken in part because of its importance in energy sustainability and also to be practical. Although not comprehensive, this approach is intended to support movement toward energy sustainability. Σ

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