Conclusions

A central purpose of the NICE Future initiative and its Flexible Nuclear Campaign is to pool international experience on nuclear energy flexibility and share this experience with the broader CEM community. Through collaboration, we can help realize the enormous potential of a wide range of low-emission energy sources. The Campaign also represents a call for ambitious action to overcome barriers to the widespread use of flexible nuclear technologies. Throughout this report, prominent research laboratories, industry, and international organizations have shared their experiences and research results associated with flexible nuclear energy. Several conclusions can be drawn from this body of technical work.

Nuclear energy can work in harmony with renewables to expand the use of clean energy sources. As the percentage of VRE in electricity systems increases, nuclear flexibility is often cited as a way to provide a backstop for weather-related impacts on VRE generation, with wind and solar energy commonly referenced. Indeed, chapters in this report showed that flexible nuclear energy can allow for increased penetration of wind and solar in the electricity system. Nuclear energy can also provide a reliable source of clean energy in regions of the world where other clean energy sources might not be available or are seasonal (as is sometimes the case for hydroelectricity). Additionally, other energy sectors, such as transportation and industry, can reduce emissions through use of hydrogen produced by nuclear energy. As demonstrated in this report, countries that choose to implement nuclear energy can increase the feasibility of other clean energy sources as well.

Nuclear energy is operating flexibly today in some forms, and innovation can lead to more pathways for nuclear flexibility. As demonstrated by operating experience, some nuclear power plants can and do operate flexibly to support variations in daily and seasonal demand. Many established research programs indicate even greater opportunities for nuclear energy to provide both operational and product flexibility to enable more clean energy use. Building on this experience, both current fleet and future advanced reactors have a large role to play in the future of nuclear flexibility.

Integrated energy systems that connect nuclear energy to multiple energy products present novel opportunities for nuclear flexibility and enhanced system value. Nuclear energy has always been a capital-intensive investment compared to many other energy sources. At the same time, nuclear systems provide more value to both the plant owners and society by producing reliable, affordable, low-emissions energy (equivalent to renewables) at very high capacity factors throughout their operational life. Commercial nuclear reactors have primarily been used for electricity production, but there are many proven and innovative applications that could utilize both thermal and electrical energy from nuclear reactors. Nuclear-generated thermal and electrical energy can be used to produce primary or secondary products that are valuable to society. Integrated energy systems seek to couple the production of nonelectric products to the reactor to increase overall operational efficiency and the opportunity for nuclear energy to serve multiple energy demands beyond just electricity. These technologies have the potential to use nuclear energy more fully and efficiently, and thus maximize revenue streams and associated capital investments.

Nuclear energy can safely operate flexibly based on an established body of international knowledge. To facilitate broader application of flexible nuclear operation, the nuclear community could amplify the body of operational experience that demonstrates that flexible operations are safe based upon research and industry experiences. That experience and additional research on flexible nuclear energy can be translated into national-level licensing frameworks that support nuclear plants to operate flexibly. International organizations and national governments could demonstrate and communicate the safety of flexible nuclear energy to their regulatory authorities through collaboration with countries which already operate nuclear systems in this manner.

While this study fills some technical data gaps, more work needs to be done to incorporate nuclear flexibility into existing nuclear research, development, demonstration programs, and energy planning processes. The contributing organizations have engaged in extensive and world-renowned research on the topics of nuclear safety, efficiency, reliability, sustainability, economics, and proliferation resistance. However, flexibility is becoming an increasingly valuable asset for nuclear generators, and more could be done to ensure flexibility of these systems in meeting a wide range of energy needs and providing benefits to society. Traditional fields of material science, reactor physics, and thermal hydraulics would benefit from incorporating nuclear flexibility concepts into their research. The same is true of energy planners in their modeling, analytical, and planning processes.

Cost-effective energy storage would benefit all generation technologies, especially nuclear energy. There are multiple ways to curtail or reduce the output of all generation sources. Geothermal plants can ramp down, solar PV can be curtailed through electronic control systems, and nuclear energy can reduce its core thermal output. However, for technologies with higher capital costs and low operating costs, like nuclear energy, energy storage allows generation assets to run at full output and use the coupled storage component as the source of flexibility. Utilizing power generation technologies at full capacity lowers the overall levelized cost of energy and increases the efficiency of energy systems. Different timescales for energy services require different storage technologies. Electrochemical batteries are economical on the order of seconds to hours, thermal energy storage is economical on the order of hours to days, and chemical storage (such as hydrogen) can be economical on the order of days to months. Although all energy storage systems have the opportunity to help energy generation technologies provide greater flexibility and efficiency. The NICE Future initiative looks forward to partnering with other CEM work streams on the subject of energy storage, recognizing that energy storage benefits all generating technologies.

No two energy systems, countries, or economies are the same, and analysis for flexible nuclear energy should be tailored to each jurisdiction. The work summarized in this report includes perspectives and experiences from many countries and international organizations. Each energy system will require tailored analysis as it relates to flexible nuclear energy. From technology, economic, and public acceptance perspectives, each country has unique values and variables. Hence, there is no universal methodology that can calculate the value of flexible nuclear energy throughout the world. There are, however, lessons from each analysis that can be transferred or adapted to other energy systems. This report shares some of the analyses, methodologies, and lessons learned from previous work to provide countries with a background on steps they can take to understand the value of flexible nuclear energy in their own economies. Through its collection of authors and contributors, this report provides a broad range of technical and economic expertise that other CEM members can use as they consider their own clean energy transitions.