Exploring Drivers and Concepts for International Research Collaboration Towards a More Sustainable Nuclear Energy Future

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Outline

The background context

The global energy situation
  • Climate change
  • Energy supply and infrastructure

Longer-term nuclear energy opportunities
  • Current situation and challenges
  • Long-term potential for nuclear energy
  • Research towards long-term opportunities

International university research collaboration
Background Context - Nuclear Energy Sector Challenges

- Recent experience with new build projects
- Push for renewable energy
- Challenges for operating NPP Units
- Phase-outs, decommissions & retirements
- Energy sector changes and trends ($/kWh)
Global Climate Change... A Serious Problem

- Increase in temperature anomaly from 1980 to 2000.
- Climate map showing potential changes from 2030 to 2039.
- Projected impact of climate change on agricultural yields.
- Climate Change Vulnerability Index 2013 showing most at risk cities.

* A key output in climate change – carbon emissions – can also help agriculture by enhancing photosynthesis in many important crops such as wheat, rice, and soybeans. The science, however, is far from certain on the benefits of carbon fertilization. This map represents the case of beneficial carbon fertilization processes.

Source: Qin W., 2007, Global Warming and Agriculture.
Global Challenge of Sustainable Development...
Estimated Energy Investment
Global Electricity Production

Figure 3: World electricity production by source 2018 (source: International Energy Agency)
Recent Trend in Relative Costs of Energy
Growth in Energy Demand

Electricity consumption in advanced and developing economies

Figure 13. Electricity consumption in advanced and developing economies

IEA (2019). All rights reserved

*Electricity demand is flat-lining in advanced economies, largely due to gains in energy efficiency.*
Construction Costs of New Build Nuclear

Figure 9. Projected overnight construction cost of nuclear power capacity and recent United States and Western European experience


Construction costs of new nuclear power plants in the United States and Western Europe have turned out to be much higher than projected.
Long-term Energy Picture....

- Global demand (urbanization)
- Renewable focus
- Mix of energy sources
- Integrated micro-grids
- Increasing role of energy storage
- Share of fossil & nuclear diminishing

Future Energy Picture
Home Energy Station
The Home Energy Station generates hydrogen from natural gas and is designed to provide heat and electricity for the home and to supply fuel for a hydrogen-powered fuel cell electric vehicle.

Panasonic “Ene-Farm” home fuel cell

Emerging Fuel Cell Energy Systems
uCHP Market
(e.g. BLUEGEN System from Solid Power Co.)

- micro CHP system (combined heat & power)
- based on fuel cell technology
- system supplies 13,000 kWh

Home Battery Storage Systems

Panasonic 11.4 kWh EverVolt System
Boeing's reversible solid oxide fuel cell

Tesla - SolarCity grid-level energy storage arrays
The Future: Distributed Smart Grids

Fig. 1. The IEEE’s version of the Smart Grid involves distributed generation, information networks, and system coordination, a drastic change from the existing utility configurations.
Country Example - USA

In 2018 the U.S. Federal Energy Regulatory Commission (FERC) issued a landmark order (Order 841) mandating that Regional Transmission Organizations (RTO’s) and Independent System Operators (ISO’s) adopt new participation models for energy storage that require storage be able to participate in all markets and services for which it is technically capable regardless of location.

This important ruling and the ability to monetize energy storage systems by selling energy into markets is considered key to making many energy storage projects financially viable particularly at commercial and industrial facilities.

Source: Dynapower - https://www.dynapower.com/energy-storage-applications/
US and Global Energy Storage Market Growth

Battery storage investment, 2014-2021E

Grid-scale battery storage

Behind-the-meter battery storage

Billion USD (2019)

Solid State Battery Technology

• Solid-state batteries use both solid electrodes and electrolytes. They serve to be a potential alternative to conventional lithium-ion batteries, which use liquid or polymer electrolytes.

• Solid-state batteries are an emerging trend for next-generation traction batteries, as they offer high performance and safety at low cost. Additionally, they have low flammability, higher electrochemical stability, higher potential cathodes, and higher energy density as compared to liquid electrolyte batteries.

Source: FutureBridge - https://www.futurebridge.com/blog/solid-state-batteries/
Relative Energy R&D Spending

Spending on energy R&D by globally listed companies, by sector of activity

- Nuclear
- Batteries, hydrogen and energy storage
- Renewables
- Thermal power and combustion equipment
- Electricity generation, supply and networks
- Oil and gas
- Automotive
- Other

Billion USD (2019)

Promising future applications of hybrid NPP designs

...and other longer-term applications
High Temp Steam Reforming of Biomass or Plastics for H Production (ref. A. Marzo, 2017)

Figure 1.3. Schematic representation of the main processes involved in a lignocellulosic thermochemical bio-refinery.
Example of Large Scale Coal Gasification – The (Failed) Kemper Project

supposed to cost $2.4 billion, but costs ballooned by 212.5% to $7.5 billion

• 582-MW plant designed to convert the second-lowest grade of coal lignite into a natural gas-like synthesis gas to fuel its electricity-generating turbines
• Two gasifiers turned the high-moisture lignite into 1750°C syngas
• Environmental promise was its carbon capture system
(Source: Miss. Ctr for Public Policy)
High Temp Steam Electrolysis (HTSE) & Thermo-chemical Hydrogen Production, Coal Gasification

Today’s Light Water Reactors (LWRs) vs. future HT Reactors (HTRs)

Not feasible with LWR NPP designs!
High Temp Steam (HTS) Conversion of Conventional Fossil Fuels and Hydrocarbons to Hydrogen and Syngas

Hydrocarbon Resources

- Coal
- Peat
- NG
- Oil
- Heavy Oil
- Solid Waste
- Organic Waste
- Bio-mass
- PFAS
- Plastics
- Shale

HTS Reforming Conversion Process

High Temperature Steam

Nuclear Steam Supply

Sustainable Hybrid Nuclear

Hydrogen, Syngas (i.e. hydrogen carrier products)

PFAS = Per- and Poly-fluoroalkyl Substances
Opportunities for Energy Conversion

- Conventional Fossil Fuels
- High Temperature Steam
- Future Hybrid Nuclear
- HTS Reforming Conversion Process
- Hydrogen, Syngas or other products

- ✗ Hydrocarbon Emitting
Other Hybrid Nuclear Applications

- Space systems
- Ship propulsion
- Large scale desalination (irrigation, fresh water supply, thorium extraction)
- Direct HT electrolysis for H production
- Ammonia production
- District heating applications
- Waste conversion to clean energy
  - Industrial and agricultural waste
  - Municipal solid waste
  - Simultaneous recovery of heavy and precious metals
- Mining
- Carbon capture technology and systems
Towards a More Sustainable Nuclear Energy Future

- Near-closed fuel cycle
- Options for thorium fuel cycle
- Options to “burn-up” spent fuel
- Options to “burn-up” plutonium
- Options to Produce Isotopes
- Inherently Safe Designs
- Sustainable Economic Lifecycle
- Factory Built & Modular
- Hybrid Designs for HTS Apps
- Proliferation Resistant Design
- International Design Certification
- International Regulatory Oversight

Sustainable Nuclear Energy Options
Significant more R&D Investment needed!
Opportunities from emerging technology ("disruptive and transformational technologies")

- Modernization tech
- Digitalization tech
- Wireless mobile tech
- Plant Info Models, digital twins
- AI, ML, AA, APR
- Simulation, visualization
- Engineering tools
- Simulation-based design
- Robotics and drones
- AM and material science
- Advanced sensing/scan tech
Recent SMR Developments in Canada

1. The Government of Canada, together with partners from across the country, launched:
   – A Canadian Roadmap for Small Modular Reactors (November 2018)
   – Canada’s SMR Action Plan (December 2020)

2. Global First Power (GFP) and Ontario Power Generation to construct a 5 MWe “Micro Modular Reactor” (MMR) at CNL (July 2019)

3. Ontario Power Generation plans to build a GE Hitachi SMR at the Darlington (December 2021)

4. NB Power is working with both ARC Canada and Moltex to advance their respective SMR technologies for use in New Brunswick
Fostering Interest in Research on Possibilities for the Future of Nuclear Energy....

• Universities can play a vital role (short, medium and long term research)
  — Concepts, components, materials, methods...
• Need for selling a vision of what nuclear energy could be
• Attracting bright young minds to challenging research questions
• Exploring industry partnerships in university research
• Achieving the goal of “net zero” by 2050
The Appeal of Altruistic and Egalitarian SDG Goals

- Ensure access to affordable, reliable, sustainable energy
- Ensure availability and sustainable management of water resources and sanitation
- Promote inclusive and sustainable economic growth, full employment and high quality employment
- Taking action to combat climate change and its impacts
- Contribute to responsible environmental management of waste
- Contribute to efficient re-use of natural resources
- Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
Towards an International university research collaboration framework for sustainable nuclear energy

- Shared Vision of Future
- Social Acceptance
- Industry Participation
- Tangible Outcomes
- Developing a Viable Path Forward
- Investment in Research
- Political and Gov’t Support
Possible strategic research partners to focus on "more sustainable nuclear energy"...
Fostering International University Research Collaboration

- Dialogue on Vision/Principles of Long-term Sustainable Nuclear
- Dialogue on Collaboration Framework Elements
- Dialogue with new partners (big oil, environmentalists)
- Groundwork for GFF policy, funding, agreements

Advancing nuclear energy towards long-term sustainability goals
Interest in research addressing the social license considerations...

- Advancing nuclear energy towards a “near closed” fuel cycle
- Providing solutions for existing waste inventory
- Elimination of Pt inventory
- Addressing non-proliferation and security (e.g. safeguards by design)
- Economic production of medical isotopes
- Inherently safe designs (e.g. accident tolerant fuels, passive safety systems etc.)
- More sustainable nuclear technology (life-cycle economics, ease of servicing, fueling, refurbishment and decommissioning)
- Technology accessible to developing countries (localization)
IAEA Can Help to Facilitate

• Support and facilitate university research collaboration framework development
  – Nuclear Education Networks

• Fostering leadership and direction in university research related to:
  – Safety, security, safe-guards issues
  – Strengthening university research (e.g. Coordinated Research Projects) related to future challenges related to:
    • Nuclear economics, financing, construction, liability framework...
    • International licensing and design certification
    • Operational oversight and technical support
    • Design authority and lifecycle knowledge management
    • Design and validation tools and platforms
  – Formation of new research collaborations, etc.
  – Linkages to existing international nuclear energy research forums
Ramping up: Involve National Labs, Industry and Supplier Partners, International Research Forums
IAEA International Collaboration Center at Ontario Tech University

University Network of Excellence in Nuclear Engineering (UNENE)

Brilliant Energy Institute at Ontario Tech University (hybrid energy research)
Thank You!

DISCUSSION AND QUESTIONS?